Biology of the lobster in Massachusetts Bay

Massachusetts Water Resources Authority

Environmental Quality Department
Report ENQUAD 98-13

MASSACHUSETTS BAY OUTFALL MONITORING PROGRAM: TOXICS ISSUE REPORT ON BIOLOGY OF THE LOBSTER IN MASSACHUSETTS BAY

submitted to

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Attachment 1. Is There Reasonable Evidence to Suggest that the New Massachusetts Water Resources Authority Sewage Outfall May Have A Negative Impact on Lobsters?

1.0 INTRODUCTION

1.1 Background

The Massachusetts Water Resources Authority (MWRA) is responsible for the development of secondary sewage treatment facilities serving the greater metropolitan Boston area. For many years, primary-treated sewage was discharged directly to Boston Harbor from the treatment plants at Deer Island and Nut Island. A new outfall has been built offshore in Massachusetts Bay at a distance of 15 km from Deer Island and at a depth of 32 m. Secondary-treated effluent will be discharged from the new diffuser array beginning late in 1998.

The water and sediment quality of Massachusetts Bay and Cape Cod Bay, and, by extrapolation, the flora and fauna of the area, are not expected to be adversely impacted by the new discharge (EPA, 1988). However, in order to monitor any potential impacts from the new outfall, the MWRA developed an Effluent Outfall Monitoring Plan that describes the physical, chemical, and biological monitoring necessary to evaluate the response of the ecosystem to the new outfall (MWRA, 1991). Baseline monitoring has been conducted each year since 1992, providing a database against which future changes can be assessed.

The Outfall Monitoring Task Force (OMTF) is an independent oversight committee with members from federal and state agencies, as well as academic and private institutions. The OMTF convenes regularly to assess information resulting from the MWRA monitoring program and also considers relevant issues raised with regard to the program. In 1997, concerns were raised by public interest groups over the potential exposure of the commercially important American lobster, *Homarus americanus*, to planned MWRA effluent discharges to Massachusetts Bay. A Lobster Larvae Focus Group was therefore designated by the OTMF to address the issue of potential toxicity of the MWRA effluent to lobster larvae. This focus group met twice in 1997 and presented recommendations to the MWRA (see Section 1.2).

In January 1998, the MWRA authorized a special task within the framework of its ongoing monitoring program to review the biology of *Homarus americanus* in the Boston Harbor/Massachusetts Bay area and to evaluate the potential adverse risk posed by the future MWRA discharge to lobster populations in Massachusetts Bay. This report is intended to help the MWRA and the OTMF further evaluate the question:

> Is there any reason to expect that the discharge of secondary effluent from the Massachusetts Bay outfall will pose an appreciable threat to recruitment of lobster larvae and/or to the survival and growth of juvenile stages of lobster in Massachusetts Bay, with a potential to impact the fishery?

The risk evaluation presented in this report is qualitative in nature and focuses on two critical life history stages of the lobster: the planktonic larval forms and the newly settled benthic juveniles. This evaluation reviews the results of MWRA toxicity tests and considers the potential effects of toxics in the effluent on both larval and early benthic phase juvenile lobsters and also the effect of solids deposition on benthic habitat.

1.2 Lobster Larvae Focus Group: Concerns and Recommendations

The Lobster Larvae Focus Group (LLFG), chaired by Dr. Judith McDowell of the Woods Hole Oceanographic Institution, met twice, in July and October 1997, to consider several recommendations made by Dr. Joseph Ayers of Northeastern University regarding additional studies and/or testing that the MWRA be obligated to perform under its NPDES Permit requirements (see Section 4.1.1). These recommendations included the requirement to include lobster larvae and the primary prey of lobster larvae in routine acute and chronic toxicity testing.

The LLFG considered two basic issues: (1) whether lobster larvae should be used in toxicity testing, and (2) whether lobster larvae should be sampled at the new outfall. Specific items which were discussed included toxicity of the effluent; toxicity of the polymers that might be used to enhance settling; toxicity to resource species such as larval lobsters; the comparability of the standard test organism *Mysidopsis bahia* and larval lobsters; lobster recruitment, and the abundance of larval lobsters in Massachusetts Bay.

Discussion among LLFG members resulted in the recommendation that the MWRA should limit the use of polymers and should conduct toxicity tests prior to any use deemed necessary. However, given the difficulties in using lobster larvae for such tests, the results of toxicity tests using the standard suite of test species (including *M. bahia*) are appropriate to determine potential effects on additional species including the lobster.

The LLFG also recommended that the MWRA investigate the habitat value of the new outfall area. This recommendation reflects the opinion that in addition to any concern over the planktonic larval stages, the early benthic phases of the lobster should be considered as well.

1.3 Sections Added After Review of the Draft Report

During the OMTF review of the draft of this report, concerns were raised that toxicity from residual chlorine at the existing outfalls in Boston Harbor and at the future offshore outfall may have the potential to impact lobster. One of the recommendations made as a result of the March and April OMTF meetings was that the MWRA review the literature on chlorine toxicity to lobsters and evaluate the possible impacts from residual chlorine in MWRA effluent discharges upon egg-bearing female lobsters.

Drs. Kari L. Lavalli and Diane F. Cowan of the Lobster Conservancy, Orr's Island, Maine prepared an independent report for an OTMF focus group meeting held on April 22, 1998. Their report contained a detailed review of the literature on chlorine toxicity to lobsters and is included here as Attachment 1, with the permission of Dr. Jerry Schubel, Chair of the OTMF, and Drs. Lavalli and Cowan. In addition, Section 4.4 has been added to this report, providing additional chlorine-related information specific to Boston Harbor.

2.0 GENERAL BIOLOGY OF THE AMERICAN LOBSTER

2.1 General Life History

The American lobster *Homarus americanus* (Figure 1) has a complex life history that has been the subject of study for over 100 years (Herrick, 1895; Factor, 1995). The early life (6-8 weeks) of the newly released lobsters takes place in the plankton (water column), whereas the later stages (and majority) of life takes place on the bottom. Lobsters can live more than 30 years (Lawton and Lavalli, 1995). Traditionally, the life cycle has been divided into a series of developmental phases, each consisting of several stages. Various researchers have proposed different schemes to place these stages in a framework corresponding to larval, juvenile and adult phases (Herrick, 1895; Hudson, 1987; Barshaw and Bryant-Rich, 1988; Wahle and Steneck, 1991; Lawton and Lavalli, 1995). In spite of major research efforts beginning in the 1970s, most of these phases continue to be imperfectly understood, especially the planktonic portion and the first year of benthic life.

Figure 2 and Table 1 summarize the major life history stages (Factor, 1995). Fertilized eggs are carried on the pleopods of the female for 9-12 months, then released into the water column as prelarvae. Shortly after hatching, the prelarva molts into a Stage I larva. Successive molts result in Stage II and Stage III larvae. These stages are very similar in appearance, but are distinguished from each other by several external morphological features, primarily details of the thoracic appendages and telson. Successive stages also increase in size, with the adult lobster potentially reaching >200 mm in carapace length (CL; measured from the posterior edge of the eyestalk to the posterior edge of the carapace) and >9 kg in body weight.

Metamorphosis occurs with the molt from stage III into stage IV or postlarva, which begins to look like a miniature adult. This molt is accompanied by obvious external and internal anatomical changes, including the development of long whip-like appendages on the second antennae, as well as a shift in swimming function from the thoracic to the abdominal appendages. Stage IV postlarvae begin to exhibit behaviors which will result in the lobster settling to the bottom and taking up a benthic existence.

A series of juvenile stages begins with stage V. The recently-settled "shelter-restricted juvenile" remains confined to its burrow, feeding on planktonic organisms or on food found within the confines of the shelter. The "emergent juvenile" makes limited trips from the burrow, while the later "vagile juvenile" continues to use the shelter but makes longer, more wide-ranging excursions in search of food.

Adolescent lobsters are defined by having achieved physiological but not functional sexual maturity. These animals are mostly nocturnal and may participate in seasonal movements along with reproductive individuals. The adult phase begins with the onset of functional sexual maturity, which for males is the capability of mating with and inseminating a female. Females are clearly mature when they are seen to have external eggs, although individuals not carrying eggs may also be mature. Courtship is controlled primarily by the female, who will approach and enter a mating shelter set up by a dominant male; the two animals will share the shelter for one week or longer. A brief mating takes place usually within 30 minutes after the female molts; sperm can be stored for 3 years and used to fertilize several batches of eggs.

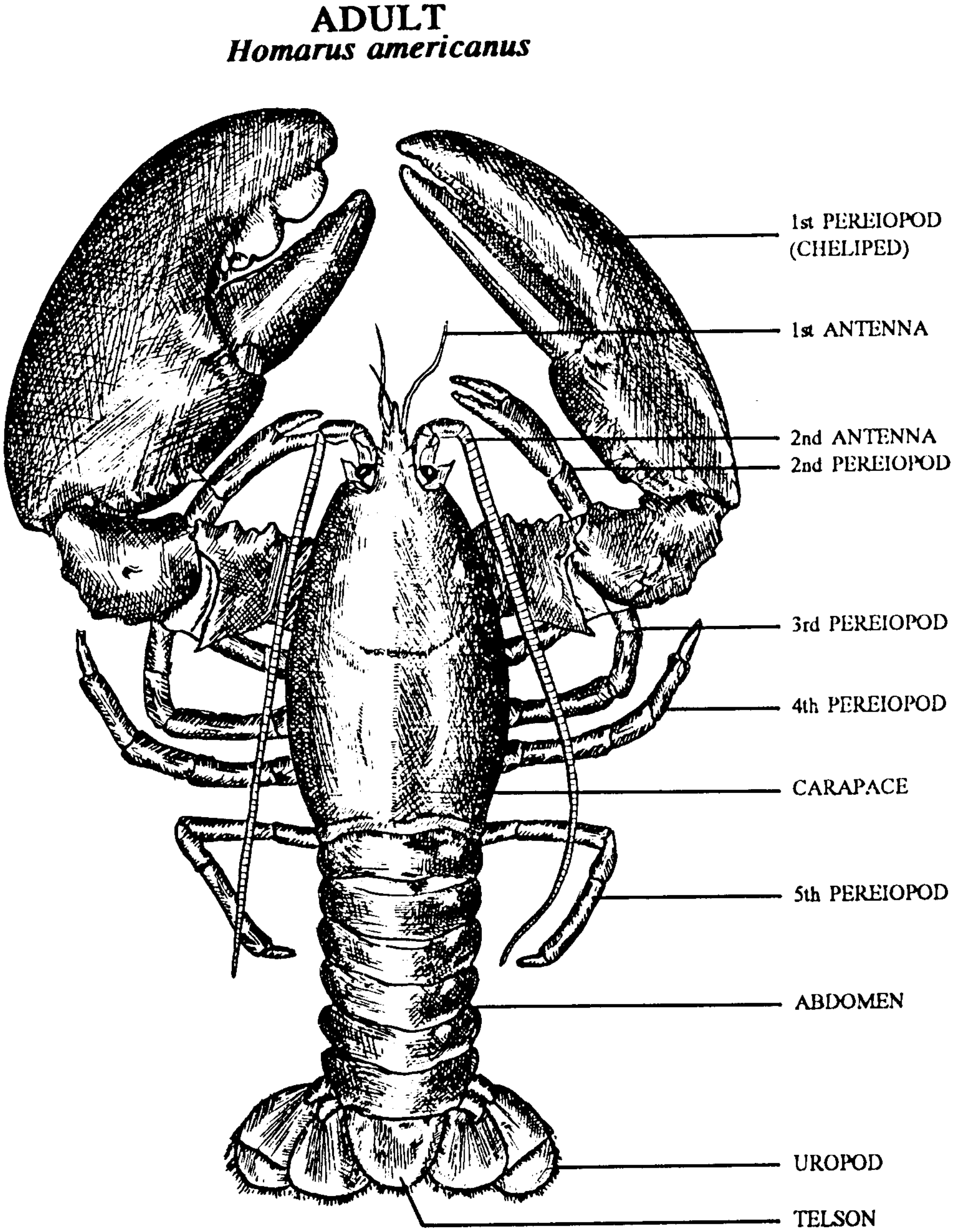


Figure 1. Dorsal view of adult lobster, *Homarus americanus*. (From Factor, 1995)

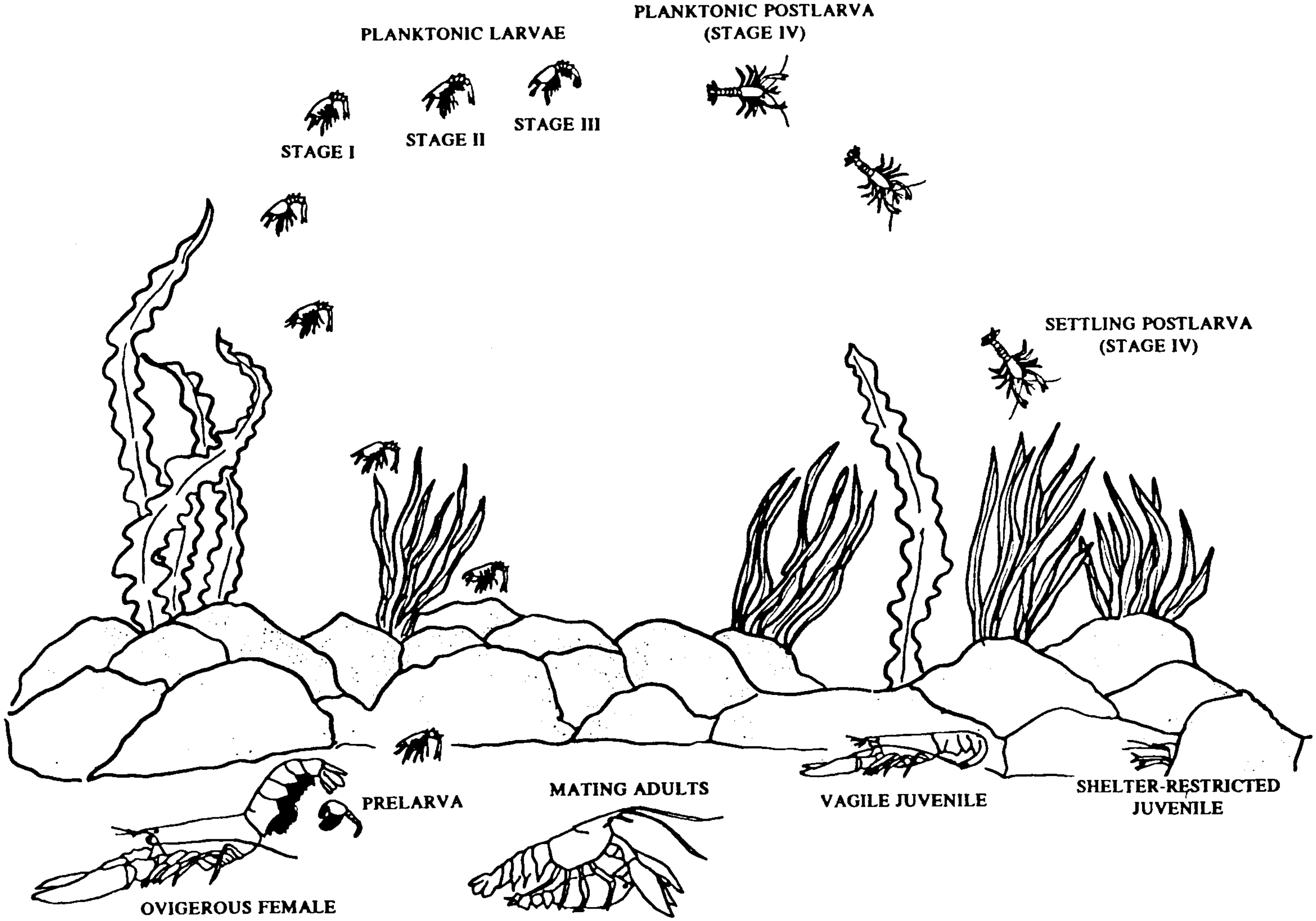


Figure 2. Diagrammatic summary of the life history stages of the lobster, Homarus americanus.
(From Factor, 1995)

Table 1. Life History Phases of *Homarus americanus*.
(Modified from Lawton and Lavalli, 1995)

Phase	Size (mm CL)	Foraging Mode	Activity Pattern
Larval Stages I-III	~2 - 4	Raptorial	Pelagic, migrates vertically
Postlarval Stage IV	~ 4 - 5	Raptorial/Suspension	Settles to bottom
Shelter-restricted juvenile	~4 - 14	Suspension; Browser within shelter; ambusher at shelter entrance	Recently settled, remains under cover, may have spatially complex shelters
Emergent juvenile	~15 - 25	Browser, ambusher	Mostly confined to shelter; limited movement outside shelter; 1 - several shelters
Vagile juvenile	~25 - ~40 (physiological maturity)	Ambusher, pursuer, searcher	Uses 1 - several shelters; more extensive movements outside
Adolescent	Physiological, not functional maturity (~ 50)	Pursuer, searcher	Active, Nocturnal, may participate in seasonal movements with reproductive individuals
Adult	Functional maturity (>50)	Pursuer, searcher	Active, Nocturnal, Seasonal reproductively mediated movement; direct fishing mortality

2.2 Larval Development and Larval Life

Release of larvae to the plankton follows a 9- to 12-month period of embryonic development, during which the eggs are carried on the abdomen of the female lobsters. The females may migrate to deeper waters in the winter in order to expose the eggs to the maximum temperature available during the winter months (Campbell 1986; Ennis, 1995). They then return to shallow water in the summer to hatch the eggs when surface temperatures are high, thereby minimizing the time needed for the pelagic larvae to develop to the benthic stage (Caddy, 1979; Hudon and Fradette, 1988; Ennis, 1995).

The first three stages after release are sometimes called mysid larvae and are considered to be equivalent to the zoeal stages of other decapod crustaceans. The stages differ from each other only slightly in terms of external anatomy. Stage I larvae (Figure 3) are about 8 mm long and have a segmented body which has functional appendages on the cephalic and thoracic but not the abdominal segments. The six pairs of exopodites located on the five thoracic pereiopods and on the third maxillipeds provide the primary swimming capability. This stage is also characterized by large eyes, a conspicuous rostral spine, dorsal spines on the abdominal segments, and a triangular telson. Stage II larvae are about 9 mm long, or only slightly larger than Stage I larvae. The chief characteristic that distinguishes the Stage II larva is the presence of four pairs of pleopods or swimmerets on the second through fifth abdominal segments (Figure 4). The chelae of the first pereiopods are also noticeably larger; these limbs will become the familiar great chelae. Stage III larvae are noticeably larger (ca. 11 mm) than the preceding stage. The tail fan of this stage has broadened with the addition of uropods held lateral to the telson; the abdominal pleopods (swimmerets) are larger and have developed hairs or setae; and the chelipeds (large claws) are noticeably larger (Figure 5).

Under favorable conditions, the first three molts occur in rapid succession, taking anywhere from 2-8 weeks (Figure 1 in Ennis, 1995). Temperature appears to be the most important factor affecting the growth and development of larval and postlarval lobsters (Ennis, 1995). Lower temperatures result in a longer duration between molts, with the accompanying requirement for additional food and the possibility of mortality due to predation. Larvae hatched early in the season, when surface temperatures are rising, have the shortest planktonic life and highest survival rates (Ennis, 1995). Tolerance to fluctuations in salinity varies with temperature. In laboratory studies in which the temperature was held at 15°-17.5°C, Templeman (1936) found that neither the time required to reach the postlarval stage nor the size attained by postlarvae were altered by variations in salinity from 21 to 32 ppt. However, survival was reduced by 20% (from 83% to 63%) at the lower end of the range, and was less than 10% at 19-20 ppt. Below 17 ppt, few larvae survived even to Stage II. Sastry and Vargo (1977) demonstrated that high temperatures (20-25°C) reduce larval tolerance to high salinity (35 ppt), but increase tolerance to low salinity (15 ppt). Tolerance to low salinity decreases during larval development: the lethal salinity for 50% of animals exposed for 24 hours increased from 14 ppt for stage I larvae just prior to molting to 17 ppt for postmolt postlarvae (Ennis, 1995).

Metamorphosis occurs with the molt to Stage IV, which is the postlarval stage. The abdominal exopodites which provided swimming power for the larval stages are greatly reduced, leaving essentially uniramous appendages on the thoracic segments (Figure 6). Swimming power is shifted to the abdominal segments, where the swimmerets have grown larger and more setose. The chelipeds are also much larger and extend forward rather than hang downward; additionally, the antennae and antennules are also much larger. Although the proportions are different, the lobster at this stage resembles a miniature adult.

STAGE I LARVA
Homarus americanus

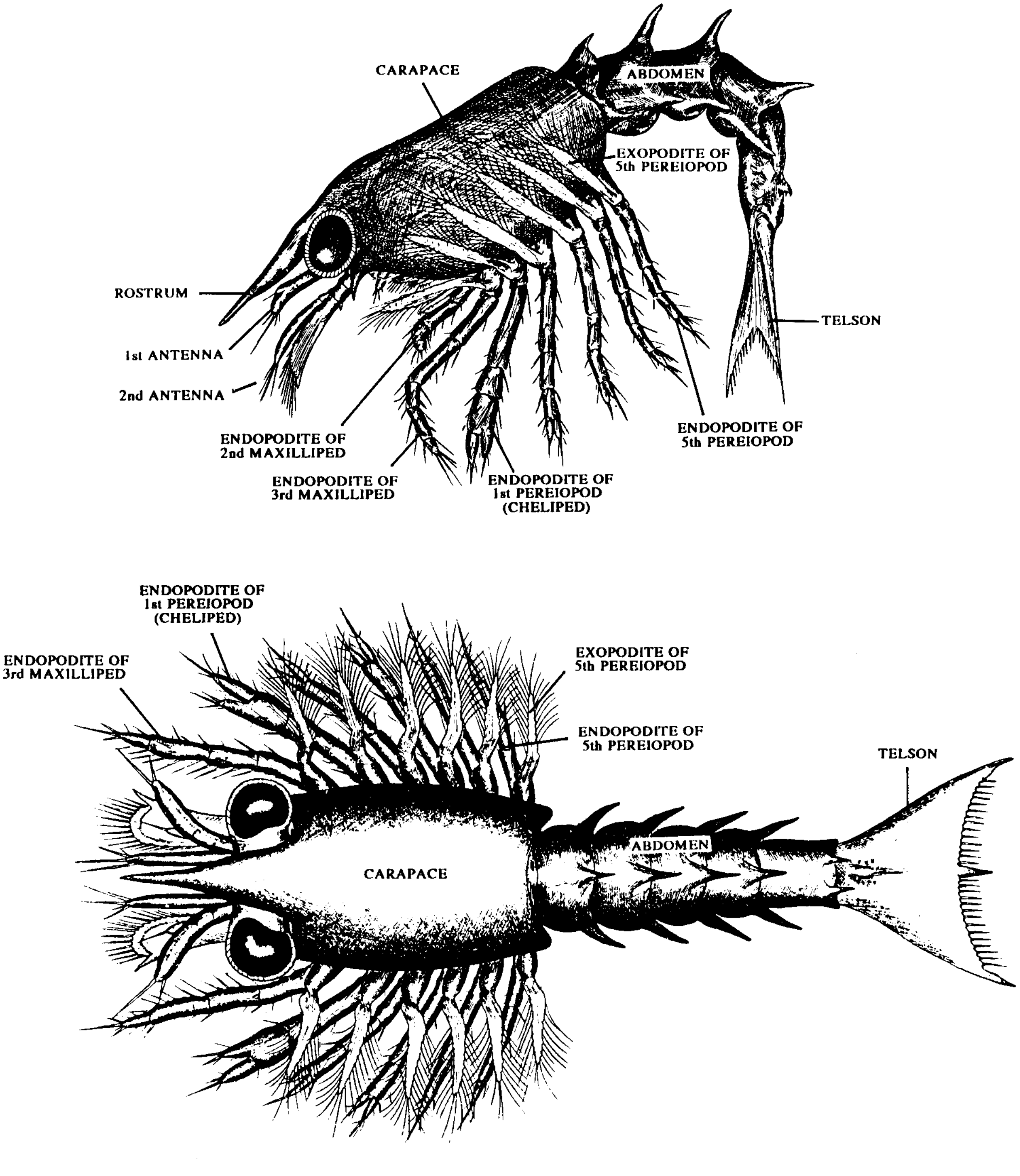


Figure 3. Lateral and dorsal views of Stage I larva of *Homarus americanus*. Total length of specimen is 8 mm, age 3 days. (From Factor, 1995)

STAGE II LARVA
Homarus americanus

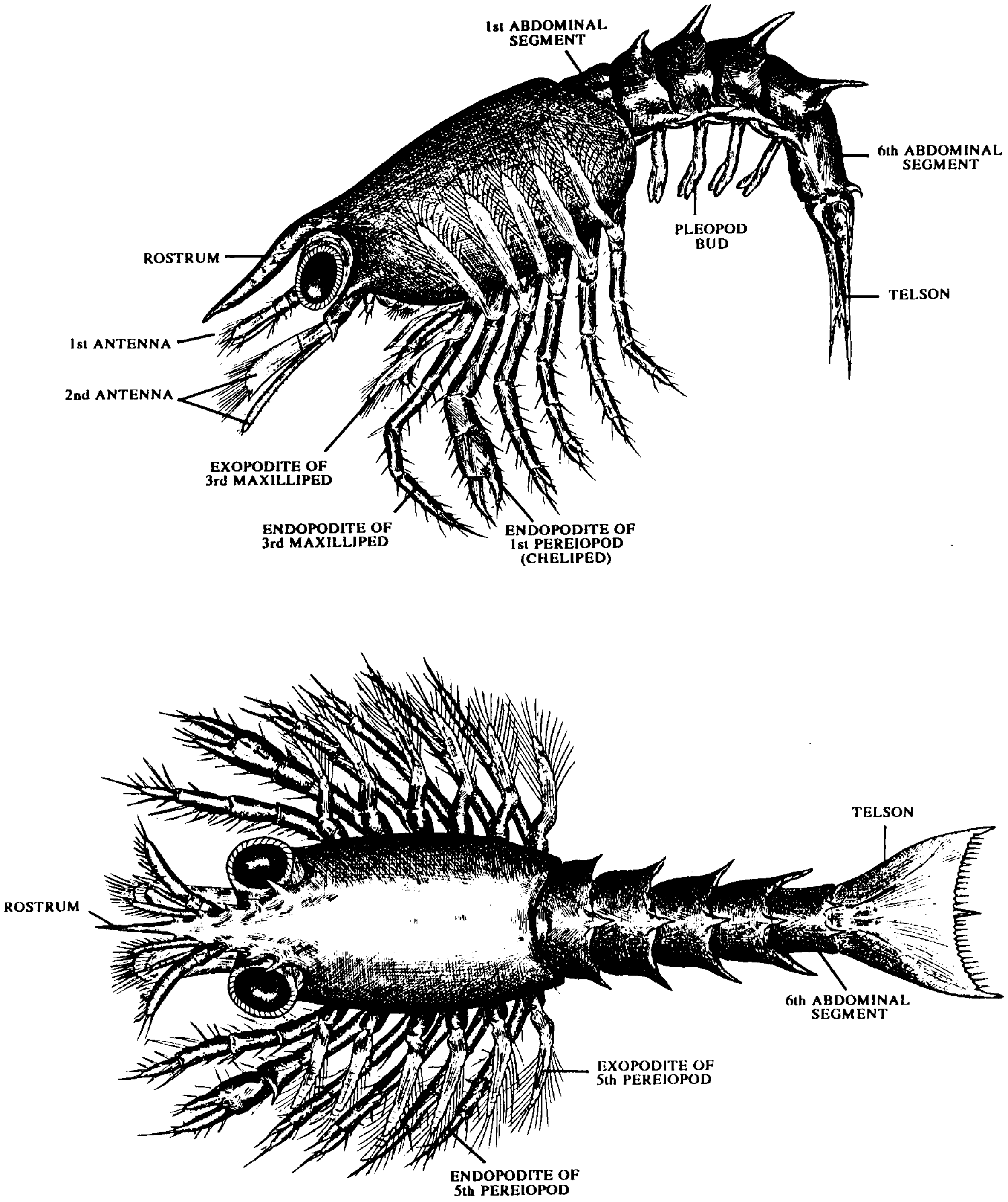


Figure 4. Lateral and dorsal views of Stage II larva of *Homarus americanus*. Total length of specimen is 9.5 mm, age 6 days (From Factor, 1995)

STAGE III LARVA

Homarus americanus

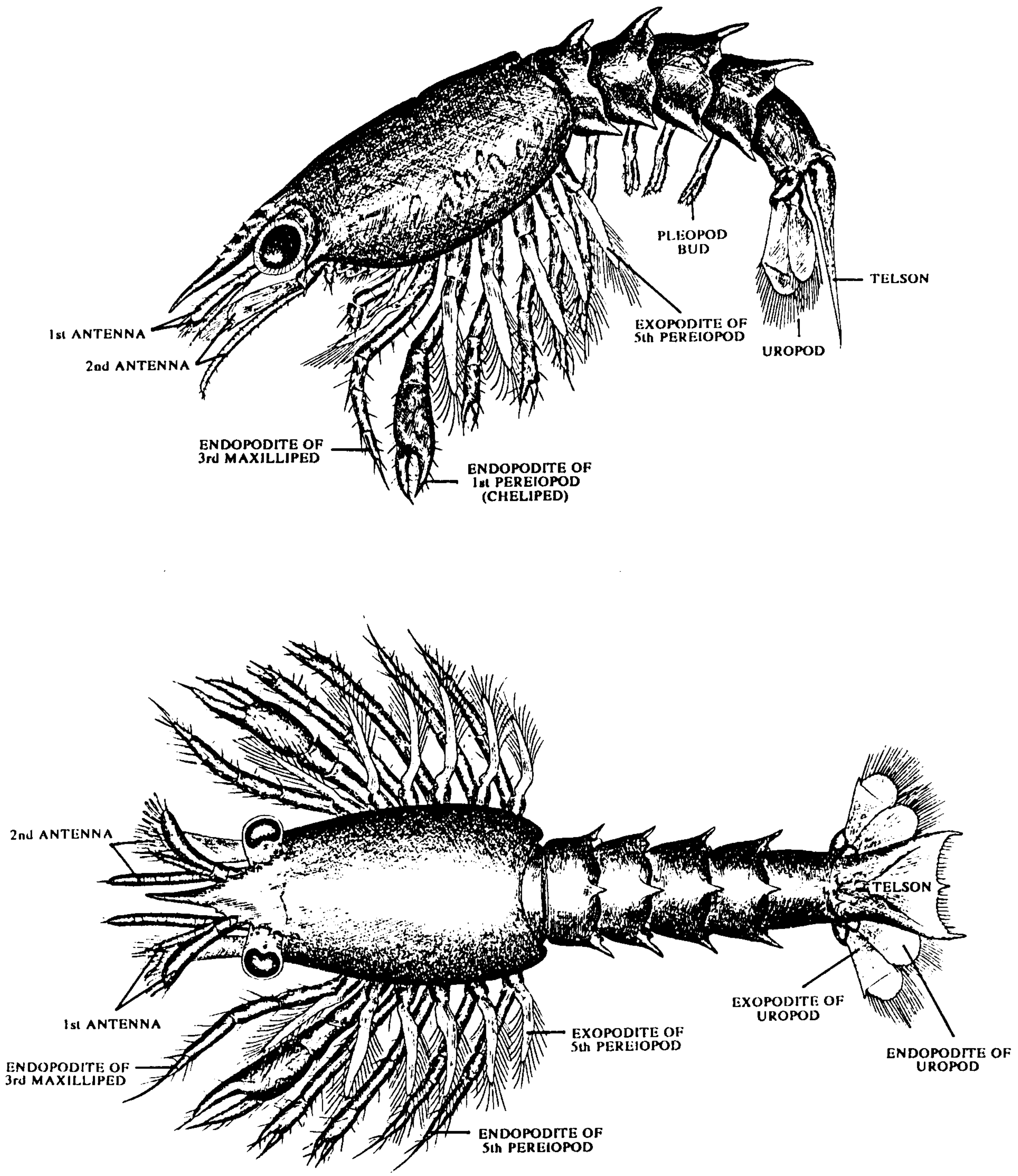
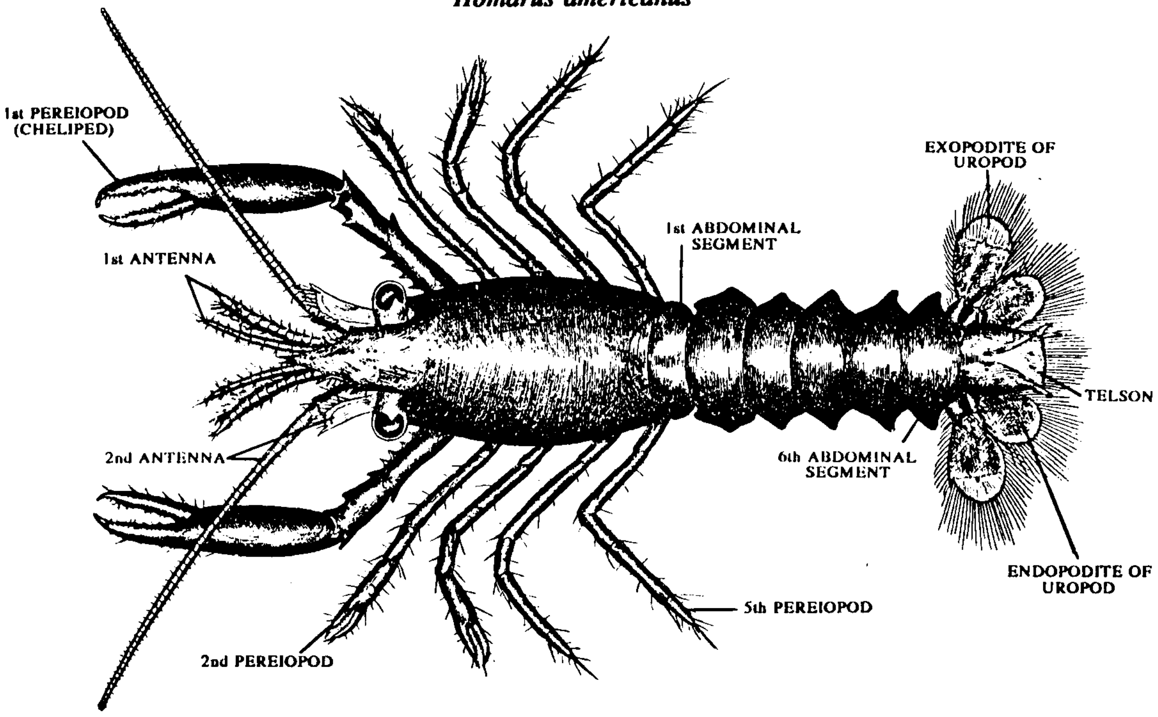


Figure 5. Lateral and dorsal views of Stage III larva of *Homarus americanus*. Total length of specimen is 11.5 mm, age 9 days. (From Factor, 1995)

POSTLARVA (STAGE IV)
Homarus americanus



JUVENILE (STAGE XIV)
Homarus americanus

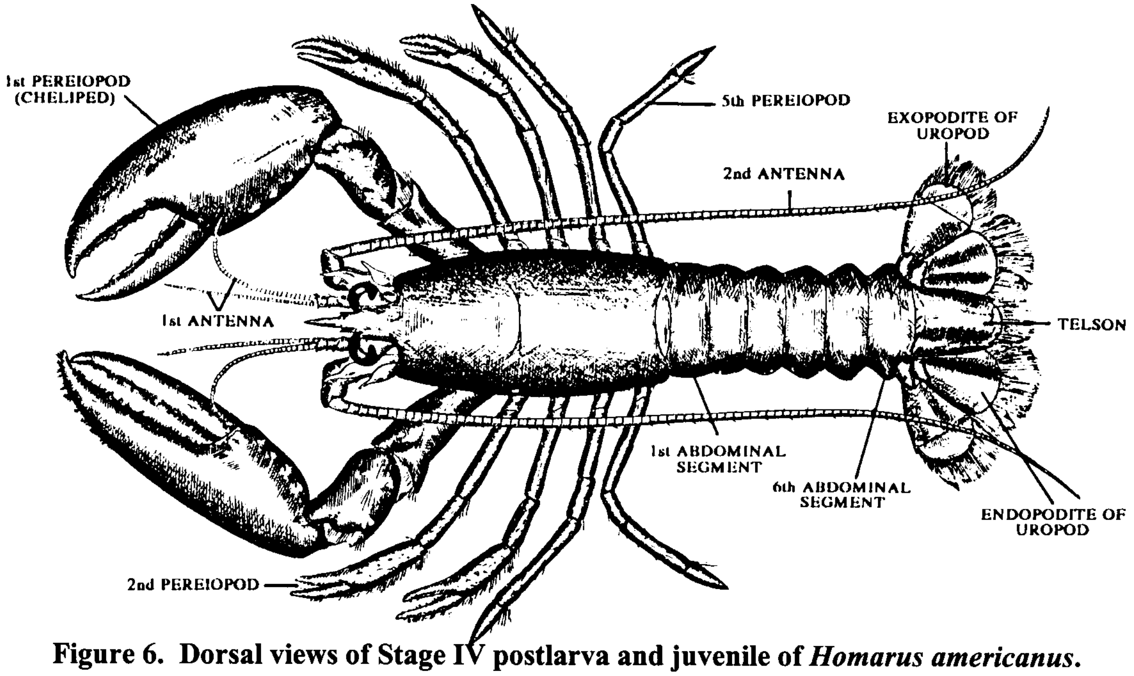


Figure 6. Dorsal views of Stage IV postlarva and juvenile of *Homarus americanus*. Length of postlarva is 14.8 mm, age 14 days. Juvenile is 65 mm, 14 months. (From Factor, 1995)

In addition to the changes in the external morphological characteristics described above, several complex modifications occur in the anatomy and physiology of the lobster during the progression through the larval stages. This development has been studied in some detail by various researchers (e.g., mouthparts and digestive system: Factor, 1978, 1981, 1995; Hinton and Corey, 1979; neuromuscular system: Lang *et al.*, 1977; King and Govind, 1980; Stephens and Govind, 1981; Costello *et al.*, 1981). One of the striking habits of the larvae is their incessant activity and apparently aimless swimming, a behavior noted immediately after hatching (Herrick, 1909, Ennis, 1995). Using the exopodites and bursts of tail flexes, movement can be directed with some degree of precision when necessary. However, the incessant activity apparently serves to bring the larva into contact with prey or other food items in the water column.

Larval and postlarval lobsters are opportunistic omnivores, feeding primarily on other planktonic zooplankton. Analysis of stomach contents of lobster larvae from areas along the east coast of North America revealed copepods, decapod larvae, fish eggs, chaetognaths, larvaceans, cladocerans, diatoms, filamentous algae and insect parts (Varma, 1977; Harding *et al.*, 1983; Juinio and Cobb, 1992; Ennis , 1995). Conversely, larval lobsters are eaten by pelagic and demersal fish species such as cunner, and probably by birds such as the herring gull and common tern (Ennis, 1995).

In coastal areas, larval and postlarval lobsters tend to be highly concentrated at or very near the surface of the water column, but exhibit a pattern of daily vertical movements controlled primarily by light. The highest concentrations of larvae at the surface occur during early daylight and late afternoon; the bright sunshine of mid-day tends to provoke a movement away from the surface, as does lack of light during the nighttime hours (Templeman, 1937, 1939; Templeman and Tibbo, 1945). The use of multicompartment sampling nets has demonstrated that these semidiurnal vertical movements are principally confined to the upper 2-3 m of the water column and that it is Stage I larvae that exhibit the greatest range of movement (Scarratt, 1973; Harding *et al.*, 1982; Hudon *et al.*, 1986). In offshore waters, however, larvae are found within the top 30 m of the water column (Harding *et al.*, 1987). As in coastal areas, it is the Stage I larvae that exhibit vertical movement: during the day the larvae are most abundant at 15- to 30-m depths, with very few at the surface; whereas at night most are at the surface or at 5- to 10 m, but very few are deeper (Harding *et al.*, 1987). Stage II and III larvae are taken over a broad depth range, with no indication of change in vertical distribution between day and night. In both coastal and offshore waters, postlarvae tend to remain highly concentrated near the surface.

The diurnal pattern of movement of Stage I larvae in offshore waters contrasts with the semidiurnal pattern seen in coastal waters; this difference implies that some environmental factor other than light levels, perhaps temperature or salinity, mediates the change in offshore waters (Harding *et al.*, 1987). In laboratory experiments, newly hatched larvae swam upward in high salinity seawater (31-32 ppt), but would typically not pass into an overlying freshwater layer. Those that did encounter the freshwater either became inactive and sank back down into the higher salinity water, or swam energetically downward (Scarratt and Raine, 1967). The vertical distribution of larvae can be affected by the salinity gradient in nearshore areas where extensive runoff or heavy rains might lower the surface salinity. A strong thermocline, regardless of depth, has been observed to restrict larvae to the warmer upper layer (Harding *et al.*, 1987).

2.3 Larval Settlement

The duration of the postlarval stage is approximately 11 days (at 22°C) and bottom-testing behavior begins within 2-6 days of the molt to this stage (Cobb *et al.*, 1989). Postlarvae apparently have considerable flexibility in responding to environmental conditions associated with choosing the time and place of settling (Lawton and Lavalli, 1995). In typical bottom-testing behavior, the postlarva will swim to the bottom with the body oriented vertically and the large claws held together. An alternate form of this behavior involves the postlarva sinking passively to the bottom while holding the claws apart and the mid-body arched downward. Ascents from the bottom usually involve directed, claws-together, vertical swimming. Dives to the bottom followed by ascents within 30 seconds ("touchdowns") and ascents from the bottom followed within 30 seconds by returns to the bottom ("liftoffs") are bottom-testing behaviors that become increasingly frequent after 2 days of postlarval life (Cobb *et al.*, 1989).

Selection of a settlement substrate, and therefore recruitment to the population, appears to be deliberate, not random (Ennis, 1995). Complex substrates which provide or can be manipulated to form burrows or shelters are highly preferred, at least in part for the protection afforded against predators such as fish and crabs. In laboratory studies, settlement can be delayed if suitable substrate is not available; however, as postlarvae age and if predator cues have been used to condition the water, they become less selective in choosing a shelter (Boudreau *et al.*, 1993). Studies by Cobb *et al.* (1983) in shallow Buzzards Bay and Narragansett Bay provide field data that support active habitat selection. Shelter-restricted and emergent juvenile phases are found principally among cobble, rocks on sand, and *Spartina alterniflora* peat reefs (Hudon, 1987; Able *et al.*, 1988; Wahle and Steneck, 1991). Substrate covered with macroalgae and with preformed crevices is strongly preferred by newly settled juveniles, but later stages (*i.e.*, adolescent and adult) are also found in areas where there is no algal cover (Lawton and Lavalli, 1995). Postlarvae are known to share shelters in the field as well as in the laboratory or to live in close but separate shelters (Cobb, 1971; Boudreau *et al.*, 1993, Lawton and Lavalli, 1995). Atema and Voigt (1995) report that lobsters do not leave their shelter system until they have reached approximately 25 mm carapace length; achieving this size may take up to 2 years. (Other researchers consider ≥15 mm CL to mark the emergent phase).

In spite of recent laboratory research on larval stage lobsters, Lawton and Lavalli (1995) point out that information on settlement cues in the field is generally lacking. Similarly, postlarval survival rates in marginal habitats, as well as the impact of predation and intra- and interspecific competition on the population structure are not well known.

2.4 Juvenile Life

Recently settled juveniles excavate burrows in which they remain until size and nutritional needs outweigh predator pressure outside the shelter. The shelter-restricted juvenile relies for food on items found within the burrow, including planktonic organisms brought in on water currents and benthic animals present on the floor of the shelter (see section 2.5.) Cunner and sculpin, crabs, shrimp, and other lobsters have been reported as predators on all stages of juvenile lobsters, although the significance of this predation pressure on population densities is not clear (Lawton and Lavalli, 1995).
Laboratory studies demonstrate that shelter-restricted juveniles are capable of predator-avoidance responses, including "freezing" and "retreating" behaviors (Johns and Mann, 1987) as well as a tail-flip reflex to escape danger (Lang *et al.*, 1977). As the lobster grows, the relative proportion of the abdomen to total body mass decreases, while at the same time the claws increase in size; in larger lobsters, the tail

flip is partially replaced by defensive claw displays (Lang *et al.*, 1977). Additional laboratory studies on shelter usage suggest that while the shelter-restricted juvenile may stay in the shelter 100% of the time, shelter usage is reduced to 50-80% of the time for emergent juveniles, and to 30-50% of the time for vagile juveniles, and that visual displays rather than increased shelter usage may occur in response to predator cues (Lavalli *et al.*, 1995).

As development proceeds, the juveniles begin to forage more widely, encountering a wider variety of habitats and exhibiting increasingly complex behaviors (Atema and Voigt, 1995). Laboratory studies suggest that beginning with the juvenile stage (Stage VII), lobsters compete for shelters and establish dominance hierarchies (Jacobson, 1977; Jacobson and Atema, 1977). Dominant lobsters control access to shelters and food; whereas the subordinates have greater exposure to predators while foraging longer for food. It is not clear if such hierarchies exist in the wild (Atema and Voigt, 1995), although growth rates in natural populations appear to be affected by the density of lobsters present on a particular substrate, with lower densities promoting greater overall growth increases of the population (Roach, 1983).

The nocturnal nature of the lobster is evidenced in behaviors observed in shallow water (Karnofsky *et al.*, 1989, *inter alia*). Lobsters generally emerge from their shelters about 1 hour after sunset, show great activity during the next 2 hours, after which they return to their own or a nearby shelter. Field and laboratory observations suggest that lobsters know their environments, as evidenced by their ability to immediately locate alternate shelters in the event of direct predator threat. Karnofsky *et al.* (1989) suggest that information about the environment gained during the foraging period is as important, if not more so, than food.

In nature, lobsters prefer close-fitting shelters where the height is less than the width (Cobb, 1971); the relationship of lobster size to shelter size is very close for shelter-restricted and emergent phase juveniles, but is more relaxed for vagile phase lobsters >30 mm CL. Shelter is more important for juvenile lobsters than for adult lobsters, except during periods of molting and mating (Lawton and Lavalli, 1995). Generally, only one shelter is used at a time, but during the time period directly preceding molting, individual lobsters may occupy as many as three shelters, perhaps to enlarge territory and enhance chances of survival during the vulnerable post-molt period (Karnofsky *et al.*, 1989; Atema and Voigt, 1995). Lobsters may occupy one shelter for as long as 9 months, including overwintering; others may move from shelter to shelter within the same general area or may be transient through an area (Karnofsky *et al.*, 1989; Ennis, 1980, 1984).

Direct observations of naturalistic aquaria and limited field observations indicate that dominant males can and do evict all others (Atema and Voigt, 1995). Larger lobsters generally evict smaller ones, except that larger females rarely evict smaller males. Males approach primarily male shelters, but females will approach shelters of both males and females equally (Karnofsky *et al.*, 1983). Conversely, nonmating lobsters may share shelters when one animal is much larger than the other, when one or both animals has missing claws, when shelter is rare, or when water temperature is low (Lawton and Lavalli, 1995).

2.5 Feeding

Prior to settlement, postlarval lobsters feed on a wide range of planktonic organisms, including copepods, diatoms, bacteria, crustacean remains, decapod larvae, amphipods, algae, fish eggs, gastropod larvae, echinoderms, polychaetes, molluscan larvae, and insects (or insect pieces) (Herrick, 1895, 1909; Williams, 1907; Templeman and Tibbo, 1945; Harding *et al.*, 1983; Gunn, 1987; Juinio and Cobb, 1992).

Information on the feeding behavior and choices of newly settled lobsters is available only from laboratory studies; no field data have been developed (Lawton and Lavalli, 1995). In the laboratory, postlarval lobsters survived on plankton derived from unfiltered seawater (Emmel, 1908) and on brine shrimp (D'Agostino, 1980). Other studies have shown that barnacle larvae, copepods, mysids, crab zoeae and unidentified planktonic organisms up to 1 mm in size are sufficient nutrition for both postlarvae and shelter-restricted juveniles (Daniel *et al.*, 1985; Barshaw, 1989; Lavalli, 1991). The small size of the claws of newly settled lobsters imposes a constraint on their feeding behavior and choices; the small claws are not capable of capturing and crushing the same molluscan prey that the adult lobster pursues. The combination of relatively ineffective small claws and vulnerability to predators when outside the shelter makes it likely that newly settled postlarvae feed on particles suspended in the water column and benthic items found within the shelters (Lawton and Lavalli, 1995).

The natural diet of emergent and vagile phase lobsters is better known than that of shelter-restricted juveniles. Plankton continue to be an important component of the diet, supplemented by the benthic polychaetes and amphipods found within the burrow. Juvenile lobster retain the capacity for suspension and raptorial feeding as seen in postlarvae (Lawton and Lavalli, 1995), but at some point, the nutritional requirements for growth and further development are no longer being met and the lobster begins foraging outside the shelter. The diet is fairly consistent for shelter-restricted, emergent and vagile phases, being dominated by mussels, lobsters, Atlantic rock crab, gastropods and ectoprocts (Hudon and Lamarche, 1989; Lawton and Lavalli, 1995). Lobsters begin feeding shortly after molting and mostly eat items high in calcium for remineralization of skeleton (Weiss, 1970, Scarratt, 1980). Seasonal variations in the diet may reflect availability of prey, lobster size, or nutritional need related to the molt cycle (Weiss, 1970; Scarratt, 1980; Leavitt *et al.*, 1979).

Stomach content analyses suggest that although the types of prey may be similar for lobsters in different stages from juvenile though adult, the relative proportions of these prey items is dependent on the size of the lobster. For example, smaller lobsters consume more hydroids, gastropods, polychaetes and brittle stars than do larger lobsters (Weiss, 1970). Plant material, including eelgrass and algae, is also a consistent component of the natural diet, suggesting that it is actively selected rather than incidental in the diet (Elner and Campbell, 1987). Earlier suggestions that lobsters are scavengers (Herrick, 1895, 1909), unspecialized feeders (Scarratt, 1980) or opportunistic carnivores (Squires, 1970; Miller *et al.*, 1971) no longer appear to be viable.

2.6 Movements and Migration of Juveniles and Adults

Three patterns of movement have been described for lobsters: *homing*, periodic, often daily, excursions from the shelter followed by a return to the same or a nearby shelter; *nomadism* (or *transient* behavior), the wandering of individuals over a large area without a defined start or end point; and *migration*, the movement of individuals or populations over considerable distances followed by a return to the original area (Hernnkind, 1980, Lawton and Lavalli, 1995).

Little information is available on the scale of movement of emergent and vagile juvenile lobsters (Lawton and Lavalli, 1995). It is most likely that movements of the vagile stage are restricted to homing, perhaps with a tendency to transient behavior when shelters must be exchanged in response to physical and feeding requirements. Emergent and vagile juveniles, as well as some adolescent lobsters are probably resident in specific shelters during the winter; there is little information to suggest that these stages migrate to shelters in deeper water during periods of low temperature (Lawton and Lavalli, 1995). Younger lobsters may move on a scale of several meters or less, while adolescent lobsters (i.e., >40-mm CL) may range up to 300 m (Cooper and Uzmann, 1977).

Adult lobster exhibit a wide range of movement patterns, perhaps related to seasonal temperature configurations. Understanding of the scale of movement of adults comes principally from mark-recapture studies, which have inherent biases (Lawton and Lavalli, 1995). Early studies carried out in inshore areas indicated that the majority of lobsters did not travel more than ca. 5 km (e.g., Templeman, 1935, 1940; Wilder, 1963; Cooper *et al.*, 1975; Krouse, 1980, Lawton et al., 1984). However, tagging studies on offshore lobsters indicated that as much as 40% of the population, primarily the larger, sexually mature individuals, annually migrate shoalward in the spring and summer and return offshore in the fall and winter (Cooper and Uzmann, 1971; Uzmann *et al.*, 1977; Fogarty *et al.*, 1980; Pezzack *et al.*, 1992). Studies on inshore populations on the ocean side of Cape Cod also demonstrated the presence of highly mobile lobsters, primarily large berried females (Estrella and Morrissey, 1997). Adult inshore females apparently move to deeper water earlier in the fall than do males (Campbell and Stasko, 1986; Robichaud and Campbell, 1991; Roddick and Miller, 1992). Seasonal migration of ovigerous females into deeper water in the fall and shallower water in the spring and summer is perhaps related to maximizing the temperature regime to which the eggs are exposed (Cooper and Uzmann, 1971).

There is also evidence for a strong homing mechanism, in which animals return to within a few km of their original starting point during a return migration or return from displacement (Lawton and Lavalli, 1995). In several instances, lobsters that were taken in offshore waters, then tagged and released in inshore areas, were recaptured near their original sites of capture (Saila and Flowers, 1968; Fogarty *et al.*, 1980; Pezzack and Duggan, 1986).

3.0 POPULATION DYNAMICS OF LOBSTERS IN MASSACHUSETTS BAY

The adult American lobster is found in a wide range of habitats along the continental shelf and upper slope of the northwestern Atlantic, from Cape Hatteras, North Carolina to the Straits of Belle Isle, Newfoundland and Labrador. The principal depth range is from the sublittoral fringe to 50 m, but lobster are fished to depths of 700 m on the edge of the continental shelf (Cooper and Uzmann, 1971; Lawton and Lavalli, 1995). The major inshore fisheries are found between Rhode Island and Newfoundland, with Massachusetts the second largest, producing about 28% of all U.S. landings (Estrella and Morrissey, 1997). The northern Gulf of Maine produces nearly half of all annual U.S. landings. The offshore fishery developed in the late 1960s with the introduction of deep-water trap fishing which replaced trawl fishing. Areas on Browns Bank, Georges Bank, Crowell Basin in the Gulf of Maine and many submarine canyons along the edge of the continental shelf are fished for lobster (Lawton and Lavalli, 1995).

Commercial lobster fishing began in the United States and Canada in the early 1800s, and landings have undergone significant fluctuations over the last two centuries (Figure 7). Changes in landings may reflect several factors in addition to changes in abundance. Declines in landings during the early 1900s possibly reflect depletion of easily accessible inshore stocks, with a recovery coming after the respite provided by two world wars and the Depression (Fogarty, 1995). Following World War II, increased demand and technological changes spurred changes in fishing strategy and efficiency, as well as an expansion of territory to previously inaccessible offshore areas. Landings increased steadily through the early 1990s, and several hypotheses have been proposed to explain these increases (Fogarty, 1995). Reduced interspecific competition with flatfish (Jeffries, 1994) or reduced predation levels due to depletion of Atlantic cod and other groundfish (Elner and Campbell, 1991; Pezzack, 1992) may have led to increased survival and recruitment. Favorable water temperatures have been cited as contributing to increased landings in parts of Atlantic Canada (Campbell *et al.*, 1991).

Declines in landings during the later half of the 1990s are as difficult to explain as the earlier increases. The population structure of both the inshore and offshore fishery has changed noticeably in terms of size and abundance. In the mid-1800s, the average market weight of lobsters in Massachusetts was reported to be 4 lb (1.8 kg), with 10- to 12-lb lobsters not uncommon (Gould, 1841). Today the mean size is approximately 0.75 kg, or less than half the early weight (Thomas, 1973; Cadrin and Estrella, 1993). Additionally, as much as 90% of the inshore Massachusetts catch may now be composed of new recruits, i.e., individuals meeting minimum size for the first time in the current fishing season (Estrella and Morrissey, 1997). Thus, overfishing may have reduced the available resource, but additional environmental factors have not been ruled out.

3.1 Catch Statistics

The lobster fishery is the most economically important commercial fishery in the Commonwealth of Massachusetts (Estrella and Glenn, 1996). The Department of Marine Fisheries oversees the issuance of permits to take lobster and, as part of the permit, requires the holder to file a detailed catch report annually. These data are then compiled, analyzed, and summarized according to statistical reporting areas (Figure 8). In 1996, 1598 coastal commercial, 551 offshore commercial, and 11, 148 student or recreational lobster permits were held (Pava *et al.*, 1997).

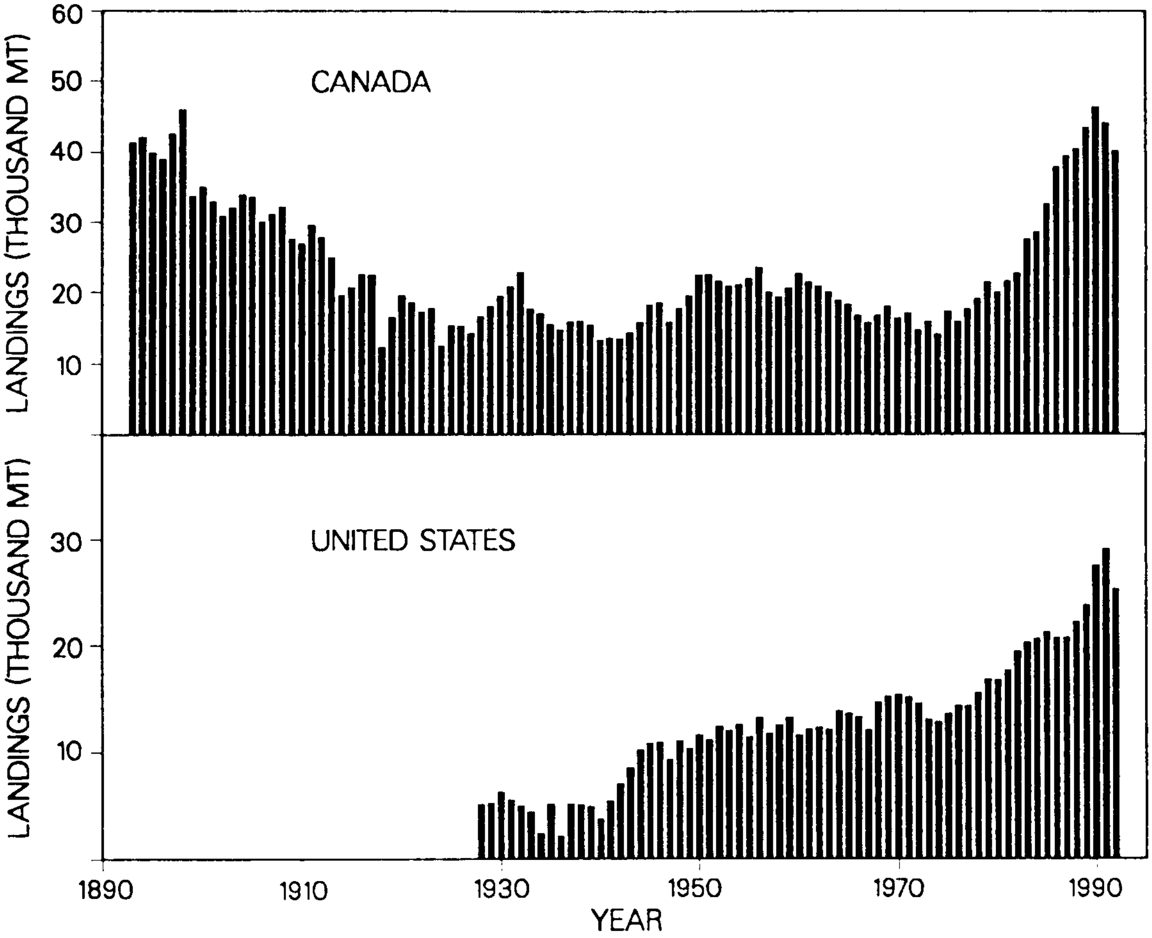
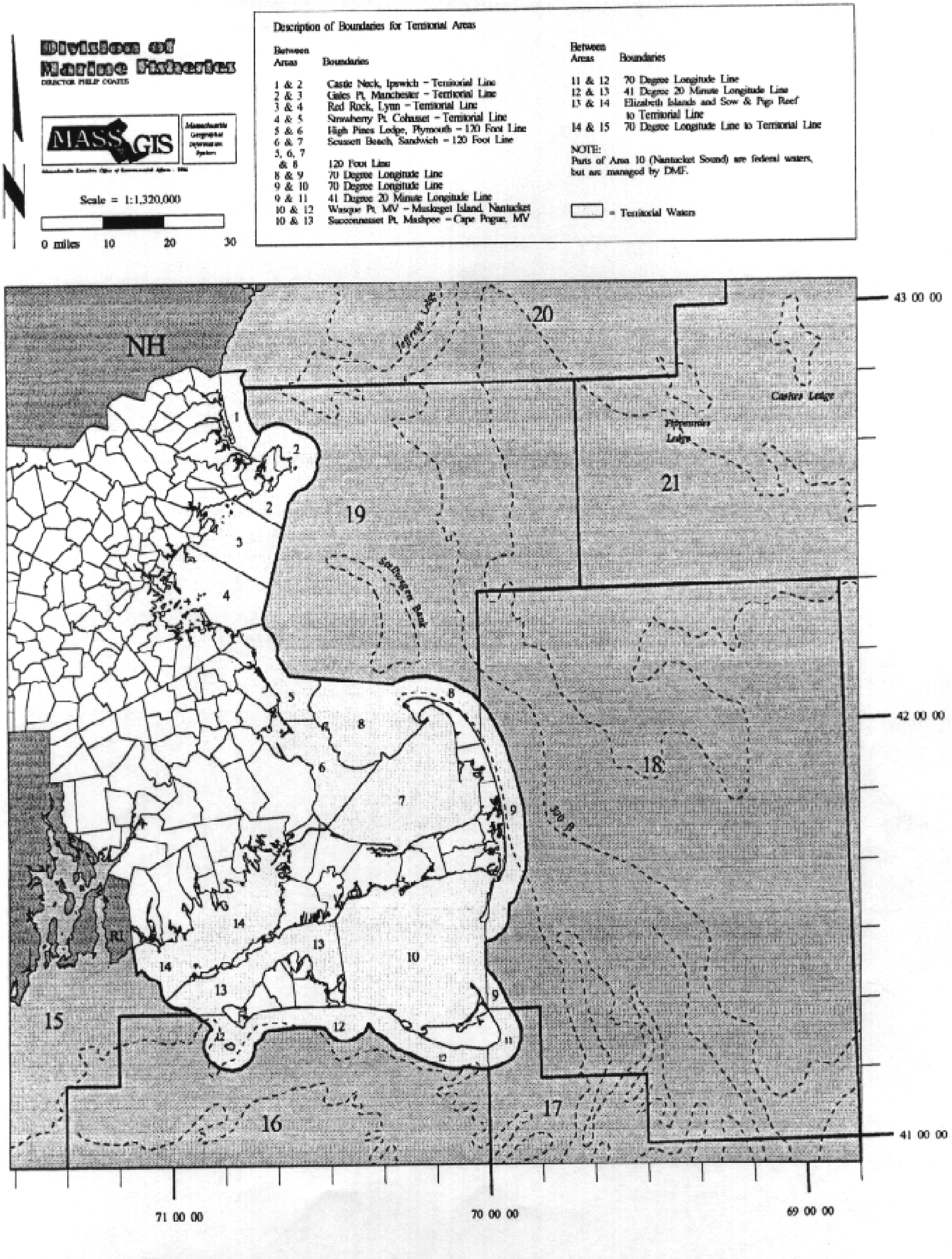


Figure 7. Lobster landings in metric tons (MT) in Canada and the United States. (From Fogarty, 1995)



Description of Boundaries for Territorial Areas

Between Areas	Boundaries
1 & 2	Castle Neck, Ipswich - Territorial Line
2 & 3	Gales Pt, Manchester - Territorial Line
3 & 4	Red Rock, Lynn - Territorial Line
4 & 5	Strawberry Pt. Cohasset - Territorial Line
5 & 6	High Pines Ledge, Plymouth - 120 Foot Line
6 & 7	Scusset Beach, Sandwich - 120 Foot Line
5, 6, 7 & 8	120 Foot Line
8 & 9	70 Degree Longitude Line
9 & 10	70 Degree Longitude Line
9 & 11	41 Degree 20 Minute Longitude Line
10 & 12	Wasque Pt. MV - Muskeget Island, Nantucket
10 & 13	Succonnesset Pt. Mashpee - Cape Pogue, MV
11 & 12	70 Degree Longitude Line
12 & 13	41 Degree 20 Minute Longitude Line
13 & 14	Elizabeth Islands and Sow & Pigs Reef to Territorial Line
14 & 15	70 Degree Longitude Line to Territorial Line

NOTE:
Parts of Area 10 (Nantucket Sound) are federal waters, but are managed by DMF.

▭ = Territorial Waters

Figure 8. Division of Marine Fisheries statistical reporting areas for Massachusetts lobster fishery. The Boston Harbor area is Area 4.

In 1996 (the last year for which summary statistics are available), 15,361,045 lbs of lobster were reported landed by commercial lobstermen in Massachusetts, a decrease of 3.7 percent from 1995 (Pava *et al.*, 1997). Based on an average price of $3.26 per pound, the 1996 commercial catch was valued at $50,077,078, a decrease of 1.9 percent from 1995. Recreational landings were about 2.2 % of the commercial catch, or 335,776 pounds (Pava *et al.*, 1997). The Port of Boston ranked fifth after Gloucester, Marshfield, Plymouth, and Sandwich) in terms of total pounds landed and fourth (after Gloucester, New Bedford, and Plymouth) in number of active fishermen.

Nearly 60 percent of the 1996 landings, or 9,109,902 lbs, were reported taken within territorial waters, that is, within 3 mi of the coast. Approximately 22% of this harvest (1,970,472 lbs) was taken from the Boston Harbor vicinity (Area 4 in Figure 8), which has historically produced the majority of Massachusetts lobster landings (Estrella, 1996). A trend towards increased landings in this area peaked in 1990, when Area 4 accounted for 43% of the state's landings. The 1995 landings were comparable to 1981 results and reflect a similar but less drastic decline in other, adjacent areas (Figure 9, Table 2). Total 1996 territorial landings decreased about 9.2 percent from 1995, with the Boston Harbor (Area 4) showing a decline of nearly 30 percent compared to the previous year (see Table 2). Lobstermen report that the greatest change in lobster abundance has occurred in Boston Harbor proper, west of a line drawn from Deer Island through Hull (Estrella, 1996).

3.2 Local Studies

Several state and federal agencies, as well as private industries, have performed studies in the Boston Harbor/Massachusetts Bay area in which an evaluation of the presence of *Homarus americanus* was a component. The Massachusetts Division of Marine Fisheries (DMF) has been a leader in this regard, having established a Coastal Lobster Investigations Project to study several parameters relevant to the ecological health of lobsters along the Massachusetts coastline. The MWRA, as part of its Secondary Treatment Facilities Plan (STFP) and the ongoing Outfall Monitoring Project, has conducted reconnaissance dives and camera studies in the area. The Boston Edison Company, in partial fulfillment of its NPDES requirements, has monitored the occurrence, distribution and relative abundance of lobster in the vicinity of its Pilgrim Nuclear Power Station in Plymouth, MA for nearly 25 years. The results of these studies complements information derived from the fisheries landings information.

3.2.1 Studies on Larval Lobster

Results of studies in the vicinity of the Pilgrim Nuclear Power Station indicate that during the period 1974-1977, larval lobster occurred in Cape Cod Bay as early as May 11 and as late as September 28 (Matthiessen, 1984). However, the majority of larvae were seen inshore during July and August and June through August across the entire Bay. The early appearance of larvae, when water temperatures were lower than the 20°C that was thought to be optimal for hatching, was surprising to the investigators.

Further sampling led to the conclusion that a significant percentage of the larval lobsters found in Cape Cod Bay in June 1976 may have come through the Cape Cod Canal. The source of these larvae could have been ovigerous females inhabiting the easterly section of the Canal, or even more remote populations in Buzzards Bay. Neuston tow data for the period 1974-79 compiled by Fogarty and Lawton (1983) revealed that Buzzard's Bay, the Cape Cod Canal, and Block Island Sound had substantially greater pelagic larval lobster densities than did Cape Cod Bay or locations on the Maine and New Hampshire coasts. It was not clear whether these larvae would be recruited to the local benthic

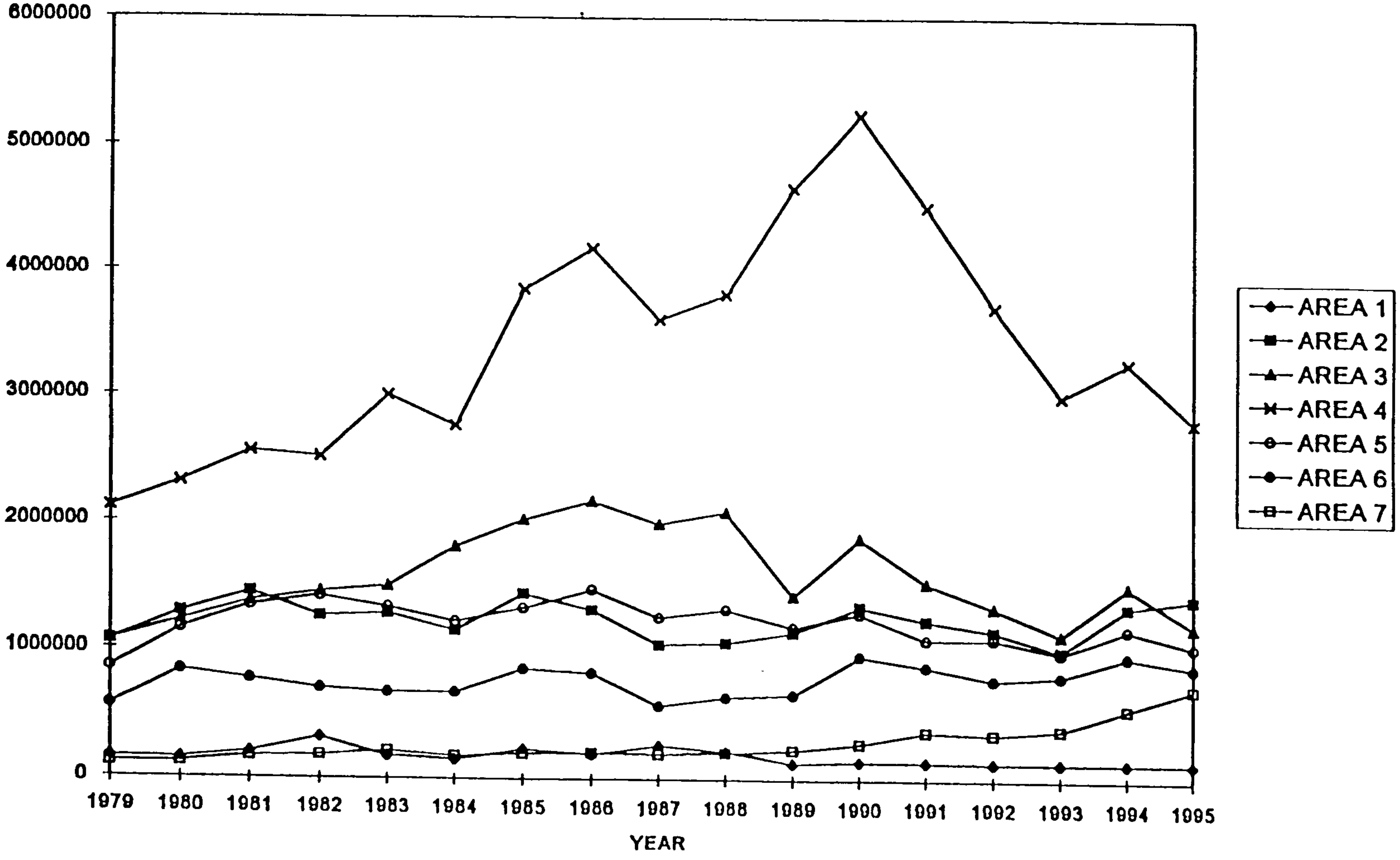


Figure 9. Massachusetts lobster landings by statistical area, 1979-1995. Boston Harbor is included in Area 4 (From Estrella, 1996)

Table 2. Selected Landing (Lbs.) Statistics for Massachusetts Lobster Fishery (from Pava *et al.*, 1996, 1997 and Estrella, 1996).

	1990	1991	1992	1993	1994	1995	1996
Inshore Landings	12,172,414	11,001,384	9,6588,545	9,124,412	10,498,3166	10,040,721	9,109,902
Outside 3 mi Landings		4,985,607	5,308,715	5,3011,452	5,676,503	5,908,641	6,251,143
Total MA Landings (Lbs.)		15,986,991	14,967,260	14,425,864	16,174,818	15,949,362	15,361,045
Boston Harbor Area 4	5,234,138					2,804,265	1,970,472
Area 4 as Percent of Inshore	43					28	22

populations or whether they would be carried past Provincetown and out of Cape Cod Bay before reaching the settling stage (Matthiessen, 1984).

3.2.2 Studies on Early Benthic Phase (EBP) Juvenile Lobster

Ongoing studies by the Massachusetts DMF Coastal Lobster Investigations Project represent the first monitoring program in Massachusetts for EBP lobsters (Estrella, in prep.). During late August to early September 1995-1997, suction sampling was used to collect data on EBP lobster density at 15 cobble bottom sites along the Massachusetts coast. EBP lobsters were found at only 1 of 4 stations inside Boston Harbor, but at both sites sampled outside the Harbor, resulting in significantly different mean densities inside and outside the Harbor. The low densities inside the Harbor appear to be at odds with the availability of suitable habitat and the size of the commercial fishery, suggesting that perhaps cobble substrate is not as significant a nursery habitat as has previously been thought. However, EBP lobster densities within and outside the Harbor were within the range observed at other coastal locations (i.e., Beverly/Salem, Cape Cod Bay, and Buzzard's Bay) sampled as part of this program (Estrella, in prep.).

3.2.3 Studies on the Abundance and Distribution of Emergent Juvenile and Adult Lobster

Lawton *et al.* (1984a) reported on the occurrence, distribution and relative abundance of lobster in the immediate vicinity of the Pilgrim Nuclear Power Station in Plymouth, MA. Tagging studies were performed from 1970 to 1975. The majority of lobsters (71%) returned in the study were recovered from their respective release areas, i.e., one of three nearshore ledges. The remaining 29% traveled parallel to the shore north towards Hull or east and south throughout Cape Cod Bay. Five percent were recovered at distances greater than 4.8 km from their release sites.

A catch sampling program was implemented from 1970-1976, spanning a preoperational and operational period of the power plant. Information gathered from observing the hauls of two local lobster fishermen indicated that there was no impact of the plant on the overall size composition of the lobster population, on the estimated time of onset of molt, or on the catch rate of legal-sized lobsters (Lawton et al., 1984b) Lobster trap-fishing studies have been carried out since 1986 (Lawton *et al.*, 1994). Again, lobster catch rates have not shown any trends that could be correlated with the thermal discharge from the power plant. However, a steadily increasing trend in the catch ratio of sublegal-sized to legal-sized lobster was observed from 1988 through 1992. This trend might reflect the increase in the legal size that was instituted in 1989, but was not accounted for by the trap design used in the study. Carapace lengths of the 6465 lobsters trapped in 1993 ranged from 35 to 130 mm, with an average CL of 74.5 mm.

The MWRA conducted two benthic reconnaissance cruises (November/December, 1986 and July, 1987) as part of its secondary treatment plant siting study (Battelle, 1987; Etter *et al.*, 1987). These cruises included the use of a Remotely Operated Vehicle (ROV) to take videotapes of the benthic environment. Analysis of the results included an evaluation of the presence of commercially important species, including the lobster *Homarus americanus*. The first cruise visited 27 sites in Massachusetts Bay and found lobster to be frequent at only one of the sites and present in low numbers at 13 additional sites (Figure 10). The second cruise visited 3 USGS stations and 35 sites along 7 transects located farther offshore than the stations visited in the first cruise; lobsters were seen along the majority of transects and were most numerous closer to shore (Figure 11).

In 1994-1997, as part of the Outfall Monitoring Program, the MWRA conducted video surveys of the hard-bottom area in the immediate vicinity of the new diffuser array (Coats and Campbell, 1994; Coats *et al*, 1995; Hilbig *et al.*, 1996; Blake *et al.*, 1997; Blake *et al.*, in prep.). During many of these surveys,

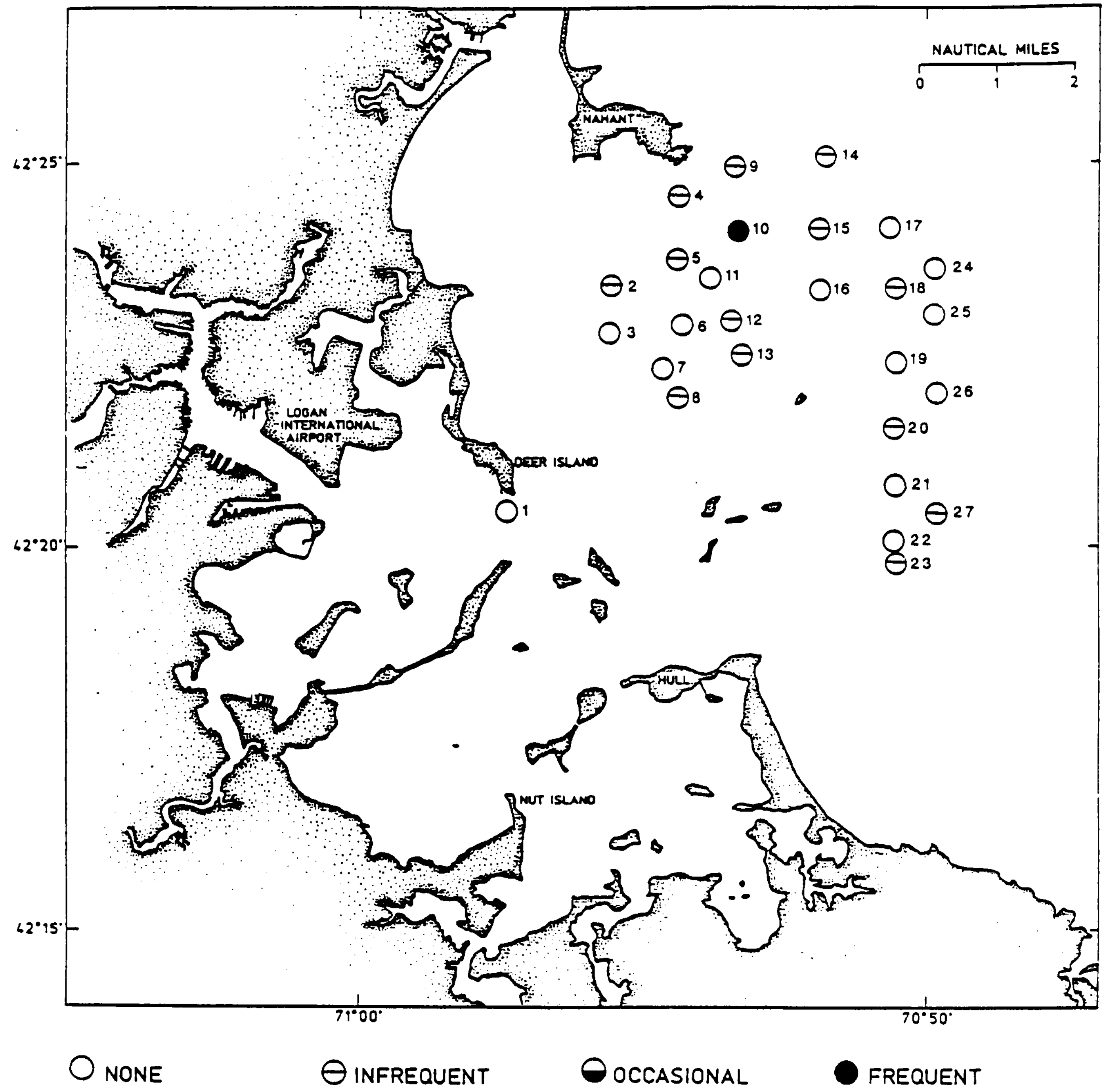


Figure 10. Distribution of lobsters as seen on videotapes during the MWRA benthic reconnaissance cruise in November/December 1986. (From Battelle, 1987)

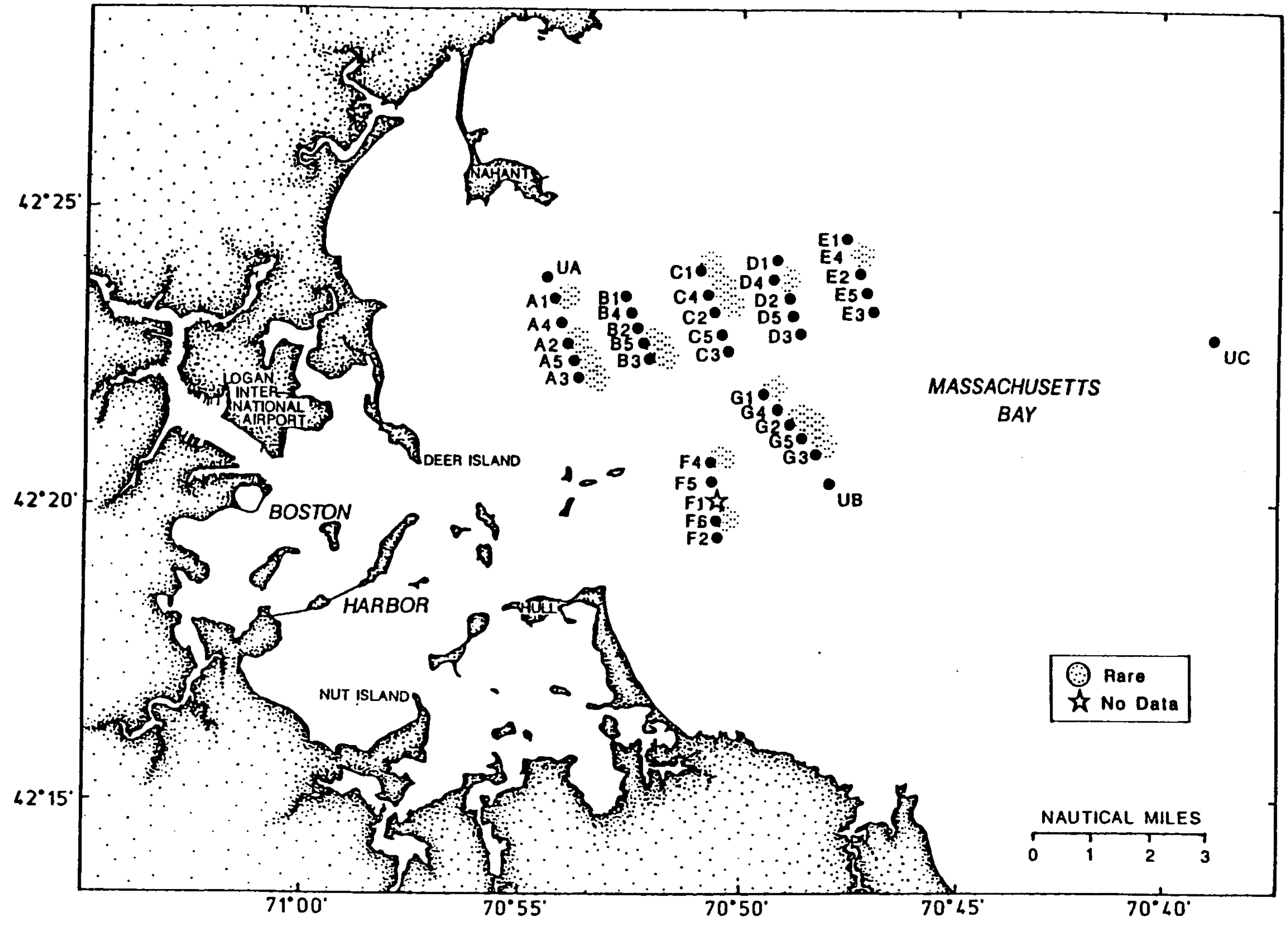


Figure 11. Distribution of lobsters as seen on videotapes during the MWRA benthic reconnaissance cruise in July 1987. Stations not plotted to scale. (From Etter *et al.*, 1987)

the camera equipment had to be hauled out in order to avoid the many lobster traplines that were set in the area, which is heavily fished by local lobstermen. The popularity of this area for lobster fishing was confirmed by Mr. Bernard Feeney, a local lobsterman, in his comments for the record at the OMTF meeting on March 30, 1998. Coats *et al.* (1995) ranked the lobster as the 14th most abundant organism identified from the videotapes taken on all transects, noting that there was no positive correlation of the abundance with either water depth or substrate size. This set of videotape was reviewed early in 1998 by Drs. Kari Lavalli and Roy Kropp (Battelle), confirming the presence of nearly 200 individuals along all transects (Keay, MWRA, pers. comm.).

4.0 RISK EVALUATION OF POTENTIAL IMPACTS OF MWRA OUTFALL TO LOBSTER

This risk evaluation is qualitative in nature and focuses on potential risk to two critical life stages of the lobster, namely the planktonic larval forms and the newly-settled or early benthic phase (EBP) juveniles. This evaluation considers the effect of toxics in the effluent to both larval and EBP lobsters and the effect of solids deposition on benthic habitat.

4.1 Current and Future MWRA Outfall Discharge Conditions

Currently, the MWRA effluent outfall discharges an average of 383 million gallons per day (mgd) of effluent containing numerous constituents which are potentially toxic to aquatic organisms in Boston Harbor. The effluent discharge contains metals and various organic compounds as well as wastewater treatment chemicals such as chlorine for disinfection. The minimum dilution is assumed to be 10:1, with the average dilution approximately 25:1. The effluent rises to the surface in Boston Harbor in the absence of significant water column stratification and exits the harbor in a surface plume to the south and east.

Beginning in late 1998, this effluent discharge will be diverted to a new outfall pipe which extends 15 km offshore into Massachusetts Bay where it will undergo dilution upon discharge from 55 diffusers located along the final 1 km of the outfall pipe. These diffusers will discharge effluent from ports located above the seafloor into water approximately 32 m deep. The proposed mixing zone for the outfall will extend approximately 60 m from the discharge point.

Minimum (worst case) dilution is assumed to occur in late summer when stratification is deepest, trapping the effluent plume to approximately 30 ft above the seabed. Theoretical worst-case minimum dilutions were determined by the EPA to be 49:1 for acute exposures and 68:1 for chronic exposures. In the event that a powerful storm disrupts stratification and the effluent plume reaches the surface, dilution is estimated to increase to a minimum of 100:1. From November to early March the water column remains unstratified and effluent will routinely reach the ocean surface. Minimum dilution during this period of time is estimated to be greater than 100:1.

In addition to increased dilution with discharge from the new outfall, the effluent will also receive a higher level of wastewater treatment. An upgraded primary wastewater treatment facility has been in operation for the Harbor discharge since 1995. The first battery of secondary treatment came on line in August 1997, with the second battery following in February 1998. The third battery is expected to be ready in early 2000. With three batteries available, 98.6% of the total annual flow will receive secondary treatment. With two batteries available, 81% of the flow will receive secondary treatment, with 99.9% expected to receive secondary treatment during the summer months when lobster larvae are released from the females and when dilutions are lower. Results from September and October 1997, when the secondary treatment was in place, were used to evaluate the potential water quality of the discharge.

4.1.1 MWRA Draft NPDES Discharge Permit Limits and Mixing Zone

Section 301 (b)(1)(c) of the Clean Water Act (CWA) specifies that effluent limitations be established for point source discharges where required to meet state or federal water quality standards for the designated use of the receiving water (class SA marine waters for Massachusetts Bay). The Commonwealth of Massachusetts has adopted the federal ambient water quality criteria (AWQC) for toxics control in class

SA waters in addition to developing narrative standards for conventional pollutants. Dilution of the effluent in the receiving water is taken into consideration in setting discharge permit limits to meet the AWQC where appropriate (40 CFR § 122.44 (d)(1)(I)).

In February 1998, U.S. EPA released a draft National Pollution Discharge Elimination System (NPDES) permit for the MWRA discharge to Massachusetts Bay. The draft discharge permit limits are based on the most restricted possible mixing zone, the zone of initial dilution (ZID). The ZID was determined by the EPA using results of EPA flow tank studies which simulated the projected discharge plumes. The extent of the hydraulic mixing (i.e., ZID) occurred approximately 60 m from the discharge. For parameters for which ambient concentrations already possibly exceed a water quality standard, the draft permit does not allow dilution calculations to be factored in for compliance. The only water quality criteria assumed to be exceeded in the ambient Massachusetts Bay waters is the Human Health Criteria for PCBs, as Aroclor mixtures. The draft permit will not allow detectable concentrations of these Aroclors in MWRA effluent. For all other parameters, the draft permit requires that water quality criteria be met at the boundary of the mixing zone, thus allowing the acute and chronic dilutions in the setting of any permit limits. Only chlorine residual has the potential to exceed the acute and chronic limits at the boundary, and, as a result, permit limits have been set (see Section 4.4).

In order to ensure that effluent concentrations do not increase to a level that may cause an exceedance of water quality standards, 12 contaminants will be monitored in the effluent. They are: aldrin, arsenic, chlordane, copper, cyanide, 4,4-DDT, dieldrin, heptachlor, heptachlor epoxide, hexachlorobenxene, mercury, and volatile organic compounds (VOCs).

In addition to mandating compliance with AWQC, the draft NPDES permit also insures that there will be no toxicity in the receiving waters by including limits for whole-effluent toxicity (i.e., no-effect concentrations (NOECs) for chronic tests, and LC50s for acute tests). On a monthly basis, the mysid shrimp (*Mysidopsis bahia*) will be used to test acute toxicity, the inland silversides (*Menidia beryllina*) will be used to test both acute and chronic toxicity, and the sea urchin (*Arbacia punctulata*) will be used to test chronic toxicity. The EPA's use of multiple species for toxicity testing is designed to provide at least one sensitive species to each of the several classes of chemical contaminants found in wastewater.

In addition to testing discharge effluent, any polymers to be used by MWRA in the secondary treatment of wastewater must be tested for potential toxicity to aquatic organisms. Prior to its use, each new polymer must be tested by MWRA or the manufacturer using standard EPA protocols. The same three species used in effluent monitoring will be used to evaluate potential polymer toxicity. The accepted toxicity requirements (e.g., NOEC) at the ZID boundary can not be exceeded with the use of any polymer.

4.1.2 Comparison of Mixing Zone Concentrations to AWQC

A comparison of the predicted concentration of discharge parameters at the edge of the ZID to applicable AWQC was conducted to evaluate potential toxic concerns. The AWQC were developed by U.S. EPA based on aquatic toxicity data for a minimum of eight families and, therefore, reflect toxicity to a spectrum of potentially exposed aquatic organisms. The AWQC represent "an estimate of the highest concentration of a substance in water which does not present a significant risk to the aquatic organisms in the water and their uses" (40 CFR Part 131). The AWQC correspond to a cumulative probability of 0.05 in toxicity to test organisms (i.e., protective of 95%). Thus, the AWQC are highly protective of aquatic organisms.

Table 3 presents average and maximum concentrations of several metals of potential concern and organic compounds in the Deer Island effluent sampled in September and October 1997 when approximately 75% of the effluent was receiving secondary treatment. Table 3 also contains the maximum concentration of these constituents in the receiving waters of Massachusetts Bay. The effluent concentrations were diluted by the available dilution at the boundary of the ZID under worst-case conditions (49:1 for acute toxicity and 68:1 for chronic toxicity) to reveal the expected worst-case conditions at the point of compliance. Ambient water concentrations of each constituent are incorporated into the calculation of the diluted concentrations.

Table 4 presents a comparison of the diluted concentrations derived from mixing of the effluent and receiving waters with the applicable AWQC. All of the constituents are in compliance with the AWQC even under these worst-case conditions. In fact, the majority are well within the required concentration limits. This analysis is additionally conservative in that (as discussed above) MWRA effluent concentrations of individual constituents have decreased in the last several years as a result of wastewater treatment installation and other factors and will continue to improve as the final battery of secondary treatment is brought online. Based on this comparison, effluent concentrations at the boundary of the ZID of the future outfall do not pose a potential risk to aquatic organisms including lobster. Further consideration of the sensitivity of the lobster relative to the protection afforded by compliance with AWQC is given below.

4.2 Consideration of AWQC and EPA-Mandated Toxicity Test Species as Protective of Lobster.

Tools intended to protect indigenous species in Massachusetts Bay are currently in place under regulatory oversight. The protection of commercial species such as the American lobster is one of the strongest concerns of these regulations.

4.2.1 Consideration of AWQC

While existing data suggest that all AWQC will be met within meters of the discharge, an assessment of the development of the AWQC was conducted to determine whether or not they are specifically protective of the American lobster. Although laboratory toxicity testing with lobsters is very difficult, several of the AWQC incorporated lobster toxicity data in the development of the criteria. Table 5 presents data from four of the AWQC development documents where toxicity tests involving lobster were used in the development of the acute marine criteria. This table presents the data used to develop the mean acute value and ranks the relative sensitivity of the saltwater organisms for each constituent based on toxicity test data. In each case, the lobster is less sensitive than the most sensitive (rank 1) saltwater organism. For these four constituents (i.e., cadmium, copper, zinc, and ammonia), the lobster is 2 to 20 times less sensitive than the most sensitive test organism. In addition, an examination of the criteria relative to the species mean toxicity levels reveals that the criteria are substantially lower than the lobster toxicity test concentrations. Thus, the AWQC are highly protective of the American lobster in addition to providing protection for other, more sensitive, aquatic organisms.

4.2.2 Consideration of EPA-Mandated Toxicity Test Species

In addition to analytical monitoring for compliance with permit limits and AWQC, the EPA-mandated toxicity testing on whole effluent will signal any potential toxicity risks to lobsters. Three test organisms will be used in the toxicity testing program, including the mysid shrimp (*Mysidopsis bahia*) which is considered to be very similar to stage I-III lobsters (see Section 2.2 for a discussion of lobster larval stages). The American lobster is a poor test species for laboratory testing. The larvae are very

Table 3. MWRA Effluent Discharge and Mixing Zone Concentrations

Parameter[a]	Average Effluent Concentration*	Maximum Effluent Concentration*	Ambient (Mass Bay) Maximum Conc.**	Diluted (68:1)[b] Avg. Effluent Conc.***	Diluted (49:1)[b] Max. Effluent Conc.***	Diluted (100:1)[b] Max. Effluent Conc.***
Metals (ug/L)						
Ag	1.35	2.42	NA	0.020	0.049	0.024
Cd	0.05	0.22	0.03	0.030	0.034	0.032
Cr	1.1	2.44	0.18	0.193	0.225	0.202
Cu	**29.79**	**48.63**	**0.3**	**0.727**	**1.267**	**0.779**
Mo	13.34	15.36	NA	0.196	0.313	0.154
Ni	4.65	5.25	1.6	1.644	1.673	1.636
Pb	5.26	7.52	0.19	0.263	0.337	0.263
Zn	30.02	36.33	0.57	0.997	1.285	0.924
Hg	**0.101**	**0.226**	**0.0014**	**0.003**	**0.006**	**0.004**
Organics (ng/L)						
Total PCB	11.52	20.4	0.27	0.433	0.673	0.469
Total DDT	**1.51**	**3.7**	**0.0053**	0.027	0.079	0.042
Total Chlordane	**0.98**	**1.8**	**0.019**	0.033	0.055	0.037
Total PAH	3090	6813	6.519	51.207	142.649	73.910

Notes:

Values in **bold** font represent data for effluent constituents to be monitored.

*Values reflect average and maximum effluent concentrations of twelve samples collected in September & October, 1997; Undetected values are treated as zero.

**Ambient metals concentrations from Battelle (1992) as cited in Battelle (1995). Ambient organics data collected by Shea, D. (Maury Hall, pers. comm., 1997).
Ambient concentrations of total DDT, total chlordane, and total PAH represent the mean of winter and summer concentrations in Massachusetts Bay ("B" buoy).
The ambient total PCB concentration represents the maximum of summer and winter surface water measurements in Massachusetts Bay (Station 2).

***Diluted concentrations estimated at the ZID (68:1 for chronic and 49:1 for acute) and in surface waters during unstratified periods (100:1 approximated minimum dilution);
Diluted concentrations incorporate ambient water concentrations in Mass Bay;

a - Concentrations presented represent total (dissolved + particulate) concentrations.

b - Effluent concentrations diluted with the maximum ambient water concentration except where noted.

Table 4. Comparison of Mixed MWRA Effluent with AWQC

Parameter[a]	Diluted (68:1) Avg. Effluent Conc.	Diluted (49:1) Max. Effluent Conc.	Diluted (100:1) Max. Effluent Conc.	Chronic AWQC	Acute AWQC	Criteria Notes	Ratio of 68:1 Diluted Avg. to Chronic AWQC	Ratio of 49:1 Diluted Max to Acute AWQC	Ratio of 100:1 Diluted Max to Acute AWQC
Metals (ug/L)									
Ag	0.020	0.049	0.024	0.92	2.3	proposed	0.022	0.021	0.011
Cd	0.030	0.034	0.032	9.3	43		0.003	0.0008	0.0007
Cr	0.193	0.225	0.202	50	1100	Cr VI	0.004	0.0002	0.0002
Cu	**0.727**	**1.267**	**0.779**	**NA**	**2.9**		**NA**	**0.437**	**0.268**
Mo	0.196	0.313	0.154	NA	NA		NA	NA	NA
Ni	1.644	1.673	1.636	8.3	75		0.198	0.022	0.022
Pb	0.263	0.337	0.263	8.5	220		0.031	0.002	0.001
Zn	0.997	1.285	0.924	86	95		0.012	0.014	0.010
Hg	**0.003**	**0.006**	**0.004**	**0.025**	**2.1**		**0.114**	**0.003**	**0.002**
Organics (ng/L)									
Total PCB	0.433	0.673	0.469	30	10000	Arochlor	0.014	0.00007	0.00005
Total DDT	**0.027**	**0.079**	**0.042**	**1**	**130**		**0.027**	**0.0006**	**0.0003**
Total Chlordane	**0.033**	**0.055**	**0.037**	**4**	**90**		**0.008**	**0.0006**	**0.0004**
Total PAH	51.207	142.649	73.910	NA	300000	LOEL	NA	0.0005	0.0002

Notes:

Values in **bold** font represent data for effluent constituents to be monitored.

Diluted concentrations are calculated in Table 3.

a - Concentrations presented represent total (dissolved + particulate) concentrations

AWQC - U.S. EPA Ambient Water Quality Criteria

NA - AWQC is not available

Criteria notes:

proposed - the marine chronic AWQC for Ag is a proposed value.

Cr VI - the AWQC presented is for the CR VI form of Cr.

Arochlor - the AWQC for PCBs is based on the toxicity of arochlor mixtures.

LOEL - the value presented is a lowest observed effect level (LOEL) for total PAH.

Table 5 Relative Toxicity Ranking of Test Organisms Used in AWQC Development

Cadmium[a] Saltwater acute AWQC = 43 µg/L			**Copper**[b] Saltwater acute AWQC = 2.9 µg/L			**Zinc**[c] Saltwater acute AWQC = 95 µg/L			**Ammonia**[d] Saltwater acute AWQC = 0.465 µg/L**		
Rank	Species	Mean Acute Value (µg/L)	Rank	Species	Mean Acute Value (µg/L)	Rank	Species	Mean Acute Value (µg/L)	Rank	Species	Mean Acute Value (µg/L)
1	Mysid *Mysidopsis bahia*	41.29	1	Blue mussel *Mytilus edulis*	5.8	1	Cabezon *Scorpaenichthys marmoratus*	191.4	1	Winter flounder *Pseudopleuronectes americanus*	0.492
2	**American lobster (larva)** ***Homarus americanus***	**78**	2	Summer flounder *Paralichthys dentatus*	13.93	2	Quahog clam *Mercenaria mercenaria*	195	2	Red drum *Sciaenops ocellatus*	0.545
3*	Copepod *Acartia* sp. (1)	156	3*	Oyster *Crassostrea* sp. (5)	14.92	3*	Oyster *Crassostrea* sp. (10)	247.5	3	Sargassum shrimp *Latreutes fucorum*	0.773
4	Polychaete worm *Capitella capitata*	200	4	Soft-shell clam *Mya arenaria*	39	**4**	**American lobster (larva & adult** ***Homarus americanus***	**380.5**	4	Prawn *Macrobrachius rosenbergii*	0.777
5*	Crab *Cancer* sp. (2)	248.5	5*	Copepod *Acartia* sp. (6)	39.97	5	Hermit crab *Pagurus longicarpus*	400	5	Planehead filefish *Monocanthus hispidus*	0.826
6	Sand shrimp *Crangon septemspinosa*	320	6	Dungeness crab *Cancer magister*	49	6	Striped bass *Morone saxatilis*	430	6*	Copepod *Eucalanus* sp. (15)	0.829
7	Copepod *Eurytemora affinis*	399.4	7*	Abalone *Haliotis* sp. (7)	65.6	7*	Mysid *Mysidopsis* sp. (11)	543.2	7*	Bass *Morone* sp. (16)	1.012
8	Hermit crab *Pagurus longicarpus*	645	**8**	**American lobster (larva & adult)** ***Homarus americanus***	**69.28**	8	Dungeness crab *Cancer magistar*	586.1	8	Mysid *Mysidopsis bahia*	1.021
9	Grass shrimp *Palaemonetes vulgaris*	760	9	Polychaete worm *Phyllodoce maculata*	120	9*	Copepod *Acartia* sp. (12)	665.9	9	Spot *Leiostomus xanthurus*	1.04
10	Atlantic silverside *Menidia menidia*	779.8	10	Winter flounder *Psuedopleuronectes americanus*	128.9	10	Green crab *Carcinus maenus*	1,000	10*	Silverside minnow *Menidia* sp. (17)	1.117
11*	Oyster *Crassostrea* sp. (3)	930.6	11*	Silverside minnow *Menidia* sp. (8)	137.8	11	Polychaete worm *Neanthes arenaceodentata*	1,273	11	Striped mullet *Mugil cephalus*	1.544
12	Bay scallop *Argopecten irradians*	1,480	12	Copepod *Psueudodiaptomus coronatus*	138	12	Polychaete worm *Ophryotrocha diadema*	1,400	12	Grass shrimp *Palaemonetes pugio*	1.651
13	Soft-shell clam *Mya arenaria*	1,672	13	Polychaete worm *Neanthes arenaceodentata*	150.6	13	Copepod *Nitrocra spinipes*	1,450	**13**	**American lobster (larva)** ***Homarus americanus***	**2.21**
14	Copepod *Pseudodiaptomus coronatus*	1,708	14*	Mysid *Mysidopsis* sp.(9)	159.8	14	Squid *Loligo opalescens*	>1,920	14	Sheepshead minnow *Cyprinodon variegatus*	2.737
15	Copepod *Nitocra spinipes*	1,800	15	Sheepshead minnow *Cyprinodon variegatus*	280	15	Polychaete worm *Capitella capitata*	2,439	15	Three-spined stickelback *Gasterosteus aculeatus*	2.932
16	Starfish *Asterias forbesi*	2,413	16	Polychaete worm *Nereis diversicolor*	363.8	16	Blue Mussel *Mytilus edulis*	3,934	16	Brackish water clam *Rangia cuneata*	3.08
17	Amphipod *Ampelisca abdita*	2,900	17	Florida pompano *Trachinotus carolinus*	411.7	17	Copepod *Eurytemora affinis*	4,074	17	Quahog clam *Mercenaria mercenaria*	5.36
18	Pink shrimp *Penaeus duorarum*	3,500	18	Copepod *Eurytemora affinis*	526	18*	Polychaete worm *Nereis* sp.(13)	8,856	18	Eastern Oyster *Crassostrea virginica*	19.102
19	Amphipod *Marinogammarus obtusatus*	3,500	19	Green crab *Carcinus maenus*	600	19*	Silverside *Menidia* sp. (14)	4,515			
20	Blue Mussel *Mytilus edulis*	3,934	20	Common rangia *Rangia cuneata*	7,694	20	Amphipod *Corophlum volutator*	4,683			
21	Green Crab *Carcinus maenus*	4,100				21	Soft-shell clam *Mya arenaria*	6,328			
22	Oyster drill *Urosalpinx cinerea*	6,600				22	Polychaete worm *Ctenodrilus worm*	7,100			
23	Blue Crab *Callinectes sapidus*	7,384				23	Winter flounder *Pseudopleuronectes americanus*	9,467			
24	Oligochaete worm *Limnodriloides verrucosus*	10,000				24	Mummichug *Fundulus heteroclitus*	36,630			
25	Sand worm *Nereis virens*	10,110				25	Spot *Leiostomus xanthurus*	38,000			
26	Polychaete worm *Neanthes arenaceodentata*	12,250				26	Starfish *Asterias forbesi*	39,000			
27	Winter flounder *Pseudopleuronectes americanus*	14,297				27	Mud Snail *Nassarilius obsoletus*	50,000			
28	Mud Snail *Nassarius obsoletus*	19,170				28	Clam *Macoma balthica*	320,400			
29	Fiddler Crab *Uca Pugilator*	21,240									
30	Oligochaete worm *Tubificoides gabriellae*	24,000									
31*	Mummichug *Fundulus s* p.(4)	32,590									
32	Sheepshead minnow *Cyprinodon variegatus*	50,000									
33	Oligochaete worm *Monopylephorus cuticalatus*	135,000									

Notes:

** - Ammonia AWQC temperature, pH, and salinity - dependent. Value shown is based on temperature range of 0-25 C, pH of 7.8 - 8.0, and a salinity of 25 ppt.

* Ranking based on toxicity testing with more than one species, and value is average of following species-specific test results:

(1) *A. tonsa* (168.9 µg/L) and *A. clausi* (144 µg/L)
(2) *C. irroratus* (250 µg/L) and *C. magister* (247 µg/L)
(3) *C. gigas* (227.9 µg/L) and *C. virginica* (3,800 µg/L)
(4) *F.heteroclitus* (50,570 µg/L) and *F. majalis* (21,000 µg/L)
(5) *C. gigas* (7.807 µg/L) and *C. virginica* (28.52 µg/L)
(6) *A. clausi* (52 µg/L) and *A. tonsa* (30.72 µg/L)
(7) *H. cracherodii* (50 µg/L) and *H. rufescens* (86.08 µg/L)
(8) *M. menidia* (135.6 µg/L) and *M. peninsulae* (140 µg/L)
(9) *M. bahia* (181 µg/L) and *M. bigelowi* (141 µg/L)
(10) *C. gigas* (233.3 µg/L) and *C. virginica* (262.5 µg/L)
(11) *M. bahia* (499 µg/L) and *M. bigelowi* (591.3 µg/L)
(12) *A. clausi* (1507 µg/L) and *A. tonsa* (294.2 µg/L)
(13) *N. diversicolor* (9,682 µg/L) and *N. virens* (8,100 µg/L)
(14) *M. menidia* (3,640 µg/L) and *M. peninsulae* (5,600 µg/L)
(15) *E. elongatus* (0.867 µg/L) and *E. pileatus* (0.793 µg/L)
(16) *M. saxatilis* (0.481 µg/L) and *M. americana* (2.13 µg/L)
(17) *M. beryllina* (1.317 µg/L) and *M. menidia* (1.050 µg/L)

References:
a - U.S. EPA, 1984a
b - U.S. EPA, 1984b
c - U.S. EPA, 1987
d - U.S. EPA, 1989

difficult to maintain in a laboratory setting, and control mortality often exceeds EPA protocol standards (<10% mortality for acute toxicity tests). The control mortality is an artifact of the sensitivity of lobster to a laboratory setting and is not indicative of the overall sensitivity of the lobster *in situ*.

As noted in Section 1.2, the Lobster Larvae Focus Group concluded that the EPA-mandated toxicity test species (particularly *M. bahia*) are suitable surrogate species for lobster larvae. Table 5 (discussed above) shows the relative toxicity of *M. bahia* and lobsters to several constituents where one or both were used for AWQC development. For cadmium and ammonia, the mysid is approximately twice as sensitive as the lobster. For zinc, lobsters are approximately 50% more sensitive, but they are sensitive at concentrations 10 times higher than what will be observed in the MWRA effluent (see Table 3). There are no comparable data for copper; however, the most sensitive species, the blue mussel *Mytilus edulis*, is currently used to measure bioaccumulation of contaminants in the effluent plume of Deer Island. Historically, little mortality has occurred in these mussels during the 60-day deployment period. Mussels will also be deployed in the plume of the offshore discharge to measure bioaccumulation. Any significant mortality in the caged mussels will serve to signal potential risks to other indigenous species, such as the lobster.

4.3 Potential for Exposure of Lobster Larvae to MWRA Effluent

As part of the risk evaluation, the potential exposure of lobster populations to the future MWRA outfall was assessed. As part of this assessment, the life history of the lobster in Massachusetts Bay was considered. The following sections summarize information presented in Section 2.0.

The American lobster is a benthic predator that inhabits bottom areas in coastal and oceanic waters of the Atlantic to depths of 720 m (primarily in areas with salinity >20 ppt). Mating typically occurs once every other year for individual females just after molting. Spawning adults are present in Massachusetts Bay and Boston Harbor between late March and October (NOAA, 1994). After hatching, lobsters undergo one prelarval and four pelagic larval stages before settling to the bottom to molt to benthic juvenile and adult stages. Planktonic lobster larvae occur in coastal New England waters between late May and early October with peak abundances in Massachusetts Bay in July and August (Fogarty and Lawton, 1983).

American lobsters, particularly the egg and larval lifestages, are sensitive to low salinity and temperature fluctuations and larval development is temperature dependent. For this reason, lobsters are not abundant in the estuarine mixed zone of Boston Harbor. However, adult and juvenile lobsters are abundant in the more saline part of Boston Harbor and in Massachusetts Bay. Larval lobsters are also described as seasonally common in these waters. Based on these factors, it was assumed that the larval and early benthic phase post-larval lobster are most likely to be potentially exposed to the MWRA outfall discharge effluent in Massachusetts Bay. The pelagic larvae and early benthic phase post-larvae are assumed to have the greatest sensitivity to contaminants and are therefore discussed below.

4.3.1 Potential Exposure of Pelagic Larvae

As discussed in Section 2.0, pelagic larvae are found predominantly in the upper few meters of oceanic waters. The larvae are most likely to be exposed to surface waters near the outfall during the spring and summer months, between late May and early October. Highest densities are expected to occur in July and August when the waters around the outfall are well stratified, confining the effluent plume below the pycnocline, approximately 5 to 15 m below the surface (Figure 12). As stratification becomes more pronounced through the summer, the density boundary, and therefore the plume, is depressed further to

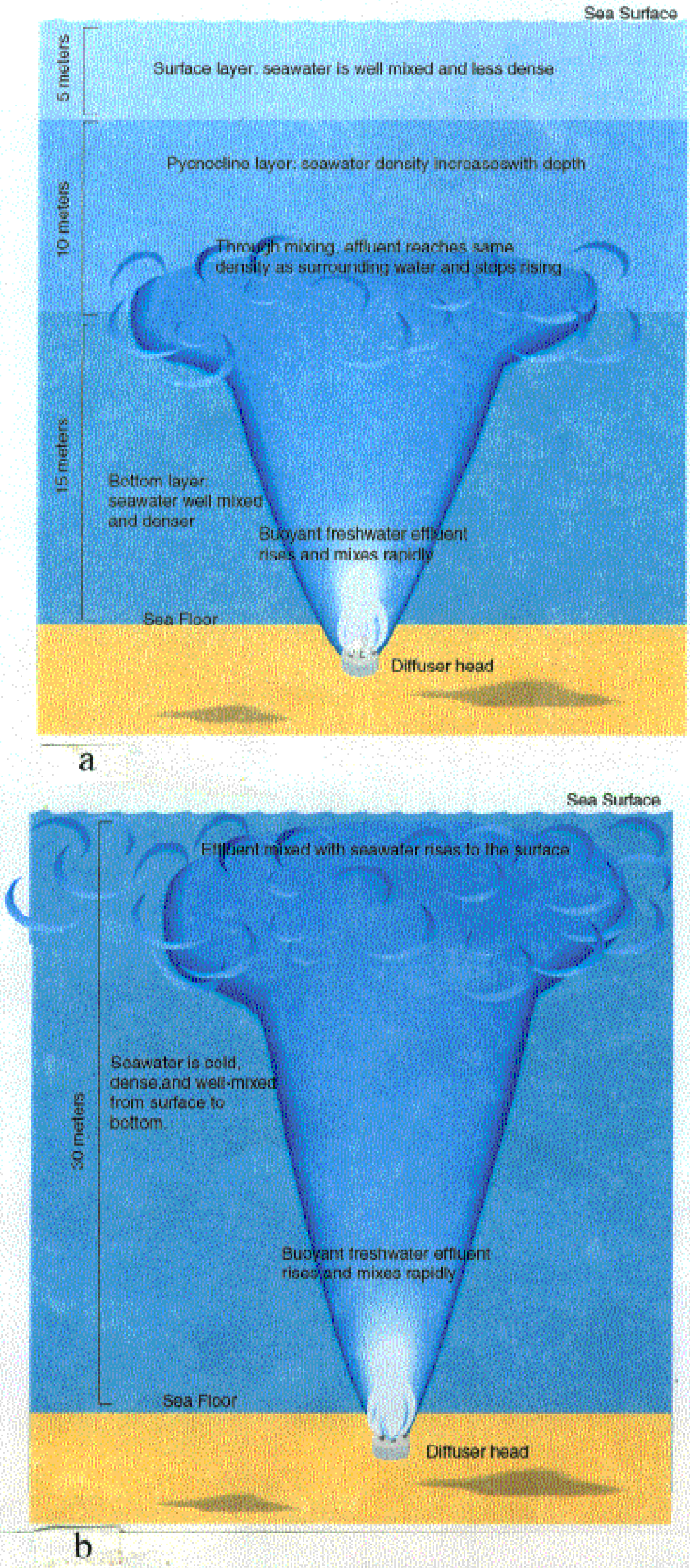


Figure 12. Seasonal depth profile of MWRA diffuser effluent.
(Fig. 12a: diluted effluent and seasonal stratification; Fig. 12b: diluted effluent under winter conditions)

approximately 20 m below the surface by August. Therefore, during this pelagic stage, lobster larvae are not likely to come into contact with the plume. In the unlikely event that the pycnocline is disrupted by a significant storm event during the period of stratification, the effluent potentially reaching the surface where lobster larvae may occur would be diluted at a minimum of 100:1, which is well below the protective acute and chronic AWQC levels.

During the transition from pelagic stage to benthic stage, the lobsters settle out of the water column towards the sediments. Although this may increase the potential for exposure, Dr. Kari Lavalli (Attachment 1) suggests that the settling larvae would be unlikely to traverse the naturally existing pycnocline in the vicinity of the discharge. It is more likely that they would travel or be carried inshore by winds or currents where the stratification is weaker. Here, they would settle to appropriate benthic habitat. Additionally, studies have indicated that lobster larvae may prefer to settle in waters shallower (i.e., < 20 m) than the site of the diffusers (approximately 32 m) (Attachment 1). Dr. Lavalli noted that little opportunity exists for this stage to be exposed to the effluent until it has been diluted to a ratio significantly higher (i.e., more dilute) than the worst-case scenarios used for compliance purposes.

4.3.2 Potential Exposure of Early Benthic Phase (EBP) Post-Larvae.

As part of the evaluation of potential impacts from the future outfall effluent discharge, the potential effect on EBP lobster populations was evaluated. This qualitative evaluation considered two potential impacts: the potential for toxics in dissolved phase to impact the benthic areas which contain potential preferred habitat for the lobsters, and the potential for the sediment deposition from the outfall to impact the habitat areas.

Evaluation of Impacts to EBP Lobster due to Effluent Toxics

As part of the evaluation of potential impacts on EBP lobsters, the potential impact of the effluent discharge on the preferred habitat was considered. The area in the immediate vicinity of the diffusers may not be preferred habitat for EBP lobsters. The depth of the diffusers (32 m) may exceed the depth at which larvae preferentially settle (Attachment 1). The contention that lobsters may not settle in waters deeper than 20 m is based on two hypotheses: (1) the lower temperatures noted in deeper waters in the summer may inhibit their growth, and (2) the settling larvae may be unable to traverse the pycnocline (see Attachment 1). There is also the distinct possibility that the settling larvae may be inhibited from coming to rest near the diffusers due to the currents caused by the discharge (see Attachment 1). However, for the purposes of this analysis, it was conservatively assumed that the possibility of EBP lobsters being found in the area of the diffusers is equal to the possibility of being found in all other areas.

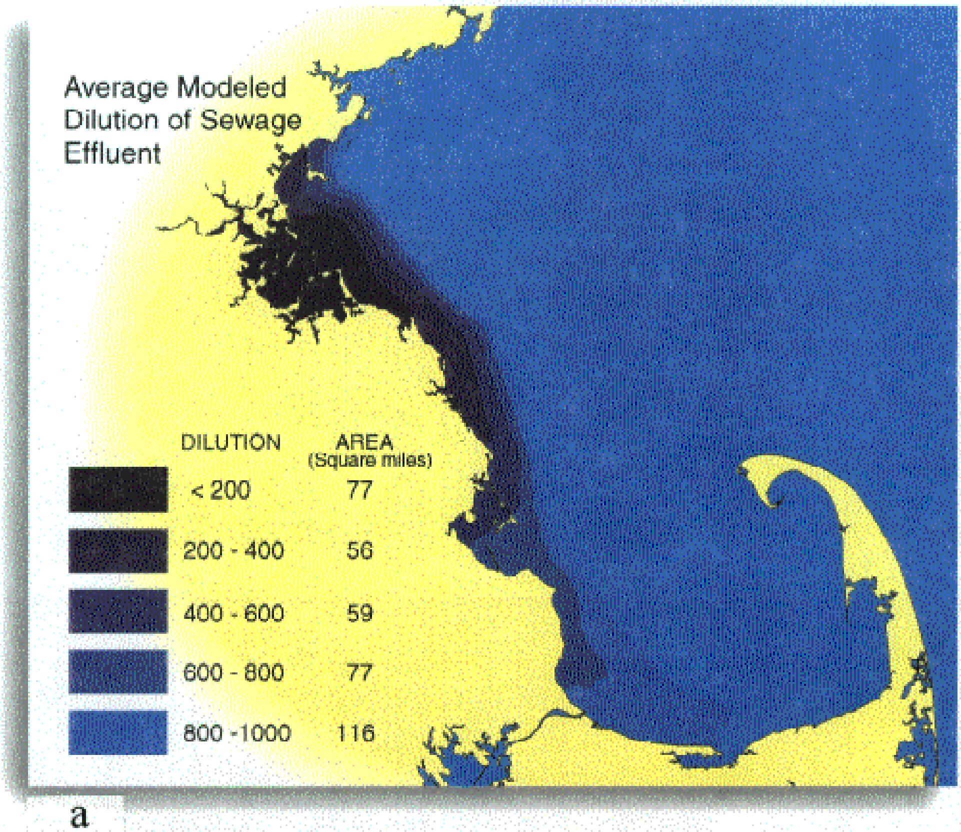
In contrast to the evaluation for lobster larvae, which considered the effects in the water column, this evaluation focused on the benthic habitat, particularly the hard-bottom cobble areas. As described in Section 2.0, EBP lobsters, also known as juveniles or shelter-restricted juveniles (Lawton and Lavalli, 1995) are the newly-settled post-larval lobsters which inhabit burrows or shelters in areas of suitable hard substrate. The availability of suitable shelters is considered a critical factor since the EBP lobsters are otherwise subject to high rates of predation. Hence, the potential spatial overlap of the effluent discharge and the hard-bottom areas is of particular importance since these areas are more likely to sustain higher populations of EBP lobsters. To evaluate the potential areal impact, the dilution isopleths for the current and future outfall effluent discharges were superimposed on areas of hard-bottom substrate.

The first step of this analysis was to delineate the areas of different degrees of dilution for the current and future outfall (Figure 13). The dilution isopleths represent linear bounds of equivalent mixing and were derived from the results of the HydroQual modeling of the current and future outfall discharges. The modeled isopleths are for winter surface water conditions when the summer pycnocline has dissipated. It should be noted that the modeled isopleths are predicted values but that dilutions >100:1 are unlikely to be detectable in the environment. Under the current outfall discharge conditions, the diluted outfall effluent moves to the southeast with considerable impingement of the shoreline and in-shore areas by the 200:1 and 400:1 isopleths. Following diversion of the sewage effluent to the future outfall, two changes are evident in the patterns of diluted effluent. The first is that the relative size of the areas affected by the outfall (as indicated by the dilution isopleths) is reduced in extent and distance. Further, the areas of lower dilution are restricted to deepwater areas near the discharge diffusers. For example, the 400:1 isopleth does not impinge upon the shoreline and in-shore habitats.

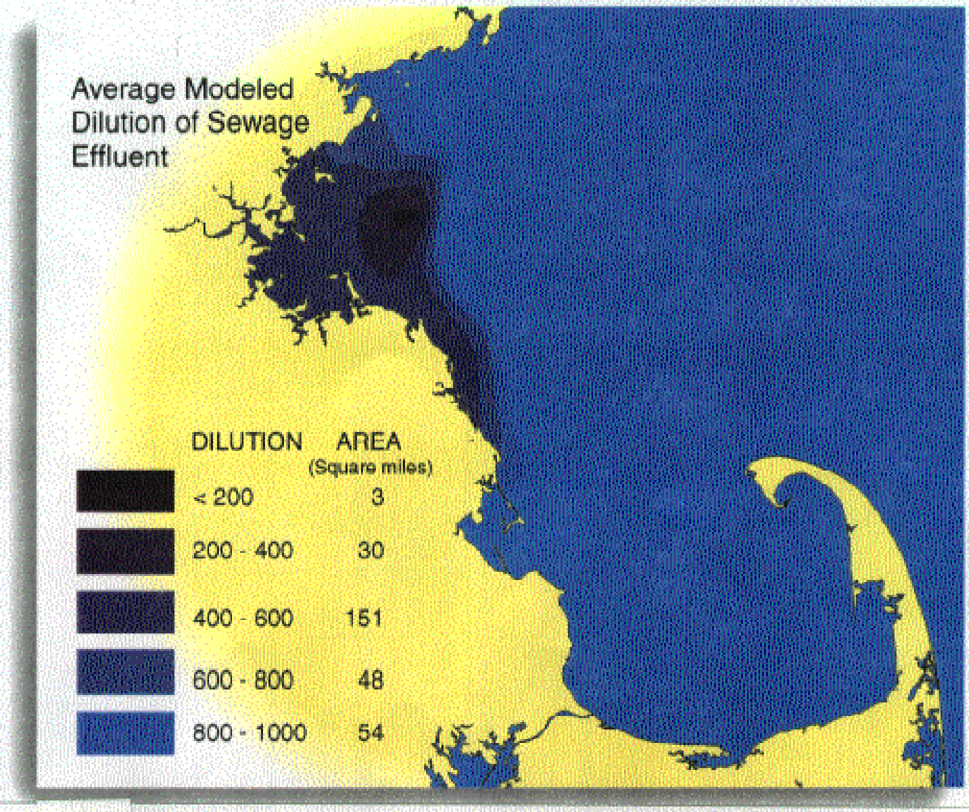
To complete this substrate impact analysis, areas of hard-bottom substrate were identified from the USGS mapping of erosional and sedimentation areas in Massachusetts Bay (Bothner *et al.*, 1992). Two types, designated as areas with (1) patterns with isolated reflections or (2) patterns of strong backscatter, are likely to be preferentially associated with hard-bottom substrate (H. Knebel, pers. comm.). The areas of isolated reflections are primarily outcrops of coarse glacial drift, containing substantial amounts of boulders and cobble. Sediments recovered from these areas are comprised of 84% gravel, 15% sand, and 1% mud on average (H. Knebel, pers. comm.). The areas of strong backscatter do not contain as much cobble material and the recoverable sediments are composed of 42% gravel, 53% sand, and 5% mud on average. Based on substrate compositions, it may be inferred that the areas of isolated reflections are more likely to provide better juvenile habitat due to substrate heterogeneity. However, both substrate types will provide preferred habitat for EBP lobsters relative to the depositional areas of mud and silt sediments. Therefore, both substrate types areas were considered for the substrate impact analysis.

Figures 14 and 15 impose the modeled dilution zones within the 400:1 isopleth for both the current and future discharges onto a map of the hard-bottom areas. A comparison of the area of potentially affected hard-bottom substrate areas within various dilution isopleths for the current and future discharges is given in Table 6. Significant reduction in areas potentially affected by the future outfall is evident. For example, the amount of hard-bottom substrate within the 200:1 isopleth is reduced by 94% from the current discharge conditions. In other words, the area of higher effluent concentrations under future discharge conditions is 1/20th of the existing conditions. Based on these results, it can be concluded that the diversion to the future outfall will greatly reduce the amount of hard-bottom substrate potentially affected by the discharge.

It should also be noted that the design of the diffusers will act to reduce the influence of the effluent on bottom life, since the discharge ports are 2.4 to 4.3 m above the seafloor. This elevated diffuser port design, coupled with the buoyancy of the freshwater effluent, will reduce the potential area of effluent influence on benthic life. Thus, the model isopleths (Figures 14 and 15), which represent surface water concentrations, will tend to overestimate the area affected. Finally, it should be recognized that the isopleths indicated in the figures do not correspond to areas of potential concern but are simply used to illustrate the relative magnitude of reduction. As described in Section 4.1.1, areas with significant dilution (i.e., >49:1)of the effluent pose no toxic threat to marine life due to reduction of toxics below AWQCs.


Existing Harbor Outfalls

a


New Bay Outfall

b

Figure 13. Predicted dilution of MWRA effluent.
(Fig 13a: existing conditions; Fig. 13b: future conditions with new outfall.)

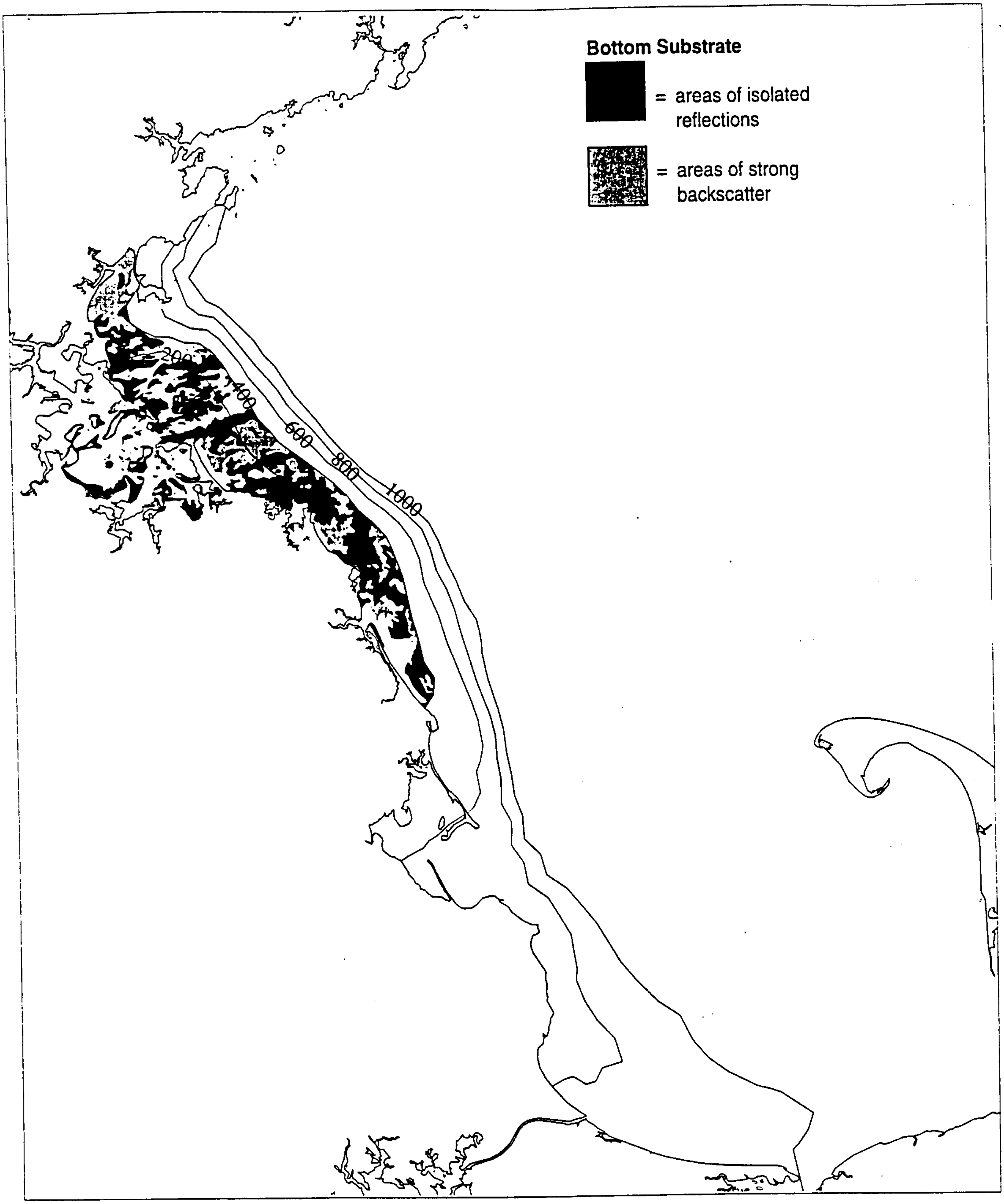


FIGURE 14

Hard-Bottom Substrate Types Contained Within 400:1 Dilution Isopleth Under Current Conditions

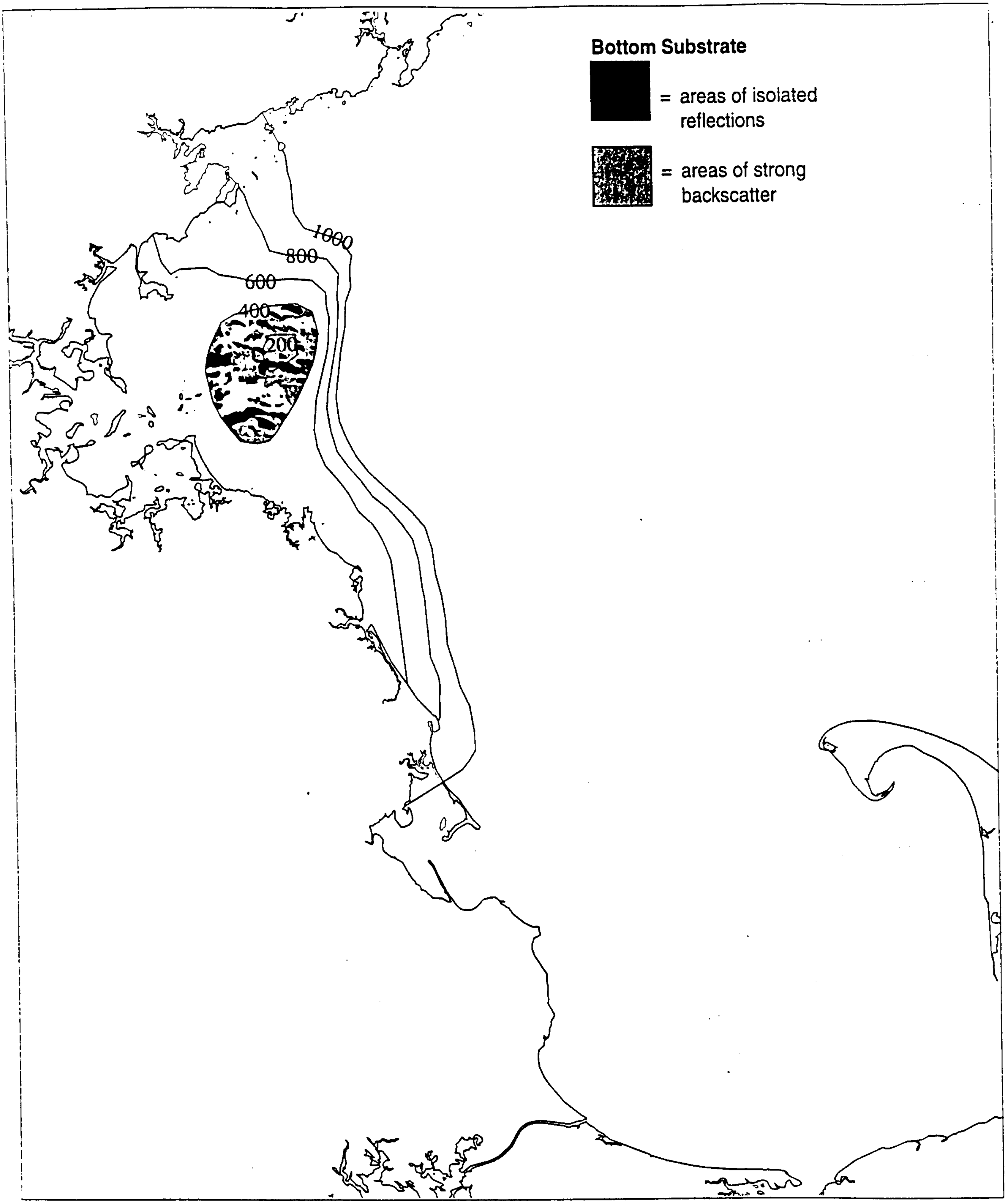


FIGURE 15
Hard-Bottom Substrate Types Contained Within 400:1 Dilution Isopleth Under New Bay Outfall

Table 6. Cobble/Hard-bottom Areas Affected by Current and Future MWRA Discharge

Dilution Isopleth	Area Affected by Current Discharge (km^2)			Area Affected by Future Discharge (km^2)			% Reduction of Total Area
	Areas of Isolated Reflection	Areas of Strong[1] Back Scatter	Total Area	Areas of Isolated Reflection	Areas of Strong[1] Back Scatter	Total Area	
< 200:1	68.5	15.6	84.1	2.0	3.30	5.30	94%
200-400:1	65.9	38.7	104.6	21.2	26.4	47.6	54%
≤ 400:1	134.4	54.3	188.7	23.2	29.7	52.9	72%

Notes:

[1] Areas identified in the USGS mapping of sediment depositional and erosional areas in Massachusetts Bay.

Evaluation of Impacts to EBP Lobster due to Effluent Deposition

As a further evaluation of potential impacts to EBP lobsters, the potential for sediment deposition arising from discharge effluent to adversely impact EBP lobster habitat was considered qualitatively. For this analysis, the immediate vicinity of the diffuser was considered, along with the patterns for predicted particulate organic carbon (POC) deposition derived from the HydroQual model.

Figure 16 depicts the benthic habitat in the immediate vicinity of the diffuser outfall, with hard-bottom areas indicated by shading. The area in the immediate vicinity of the diffuser is highly variable, with areas of mud or sand interspersed with high-relief hard-bottom areas. The edge of the ZID (approximately 60 m from the diffuser, as cited in Draft NPDES Permit Fact Sheet) also does not impinge on hard-bottom areas. Sediment deposition due to settling of POC near the outfall will likely be focused in nearby areas of lower relief, where erosional forces are weaker.

Inspection of the areas of predicted POC deposition from the HydroQual model (Figure 17) provides a somewhat similar result as the comparison of the effluent deposition described above. That is, the relative size of the area of high deposition (i.e., >1000 mg C/m^2) is much reduced and the location is shifted. There is very little POC deposition predicted near the outfall location under future conditions. Due to water movements in the Bay, the area of greatest deposition is closer to shore and likely to occur in sediment depositional areas. Taken together, consideration of the factors discussed above indicate that the future outfall is unlikely to pose a risk of adverse impact to benthic habitat due to sediment deposition. (Please note that the version of Figure 17 that was included in the draft version of this report contained a graphical error that was identified in review. Previously missing contours have been added to the Harbor discharge panel. See Hydroqual and Normandeau (1995) Figure 7-22.)

4.4 Chlorine Toxicity

As noted in Section 1.0, concerns were raised during review of this document that potential toxicity from the chlorine added (as sodium hypochlorite) as a disinfectant might have an adverse impact on various lifestages of the lobster. Particular concerns were raised by citizens groups and by commercial lobstermen that chronic exposure to low levels of chlorine might cause egg-bearing females to lose their eggs. Additionally, the recent decline in lobster landings in the vicinity of Boston Harbor has raised concerns that chlorine residual associated with effluent discharges has been impacting lobsters and will continue to do so once the discharge is moved to Massachusetts Bay. Suggestions have also been made that since the early 1990's, the vicinity of the near-shore Deer Island outfalls has become a near-sterile “desert” (e.g., *Boston Globe* , 1998). This section, added following technical review of the draft report, provides information relevant to these concerns. A review of technical literature on chlorine effects on lobsters is contained in Lavalli and Cowan (Attachment 1).

4.4.1 Results from Benthic Monitoring

MWRA's long-term soft-bottom benthic monitoring program in Boston Harbor includes several stations within a few hundred meters of the existing Deer Island and Nut Island effluent outfalls. In a series of technical reports (e.g., Kropp and Diaz, 1995; Hilbig *et al.*, 1996), dramatic improvements in benthic communities have been documented harborwide, including those stations in the vicinity of the discharges. These data provide no evidence for increased degradation since the early 1990's in the vicinity of the discharges. Additionally, video taken by divers in 1995 as part of an inspection during a repair to Deer Island Outfall 002 showed vigorous epifaunal and epiphitic growth (barnacles, attached seaweed, etc.) within meters of a break that spewed minimally diluted (estimated at 2:1) effluent.

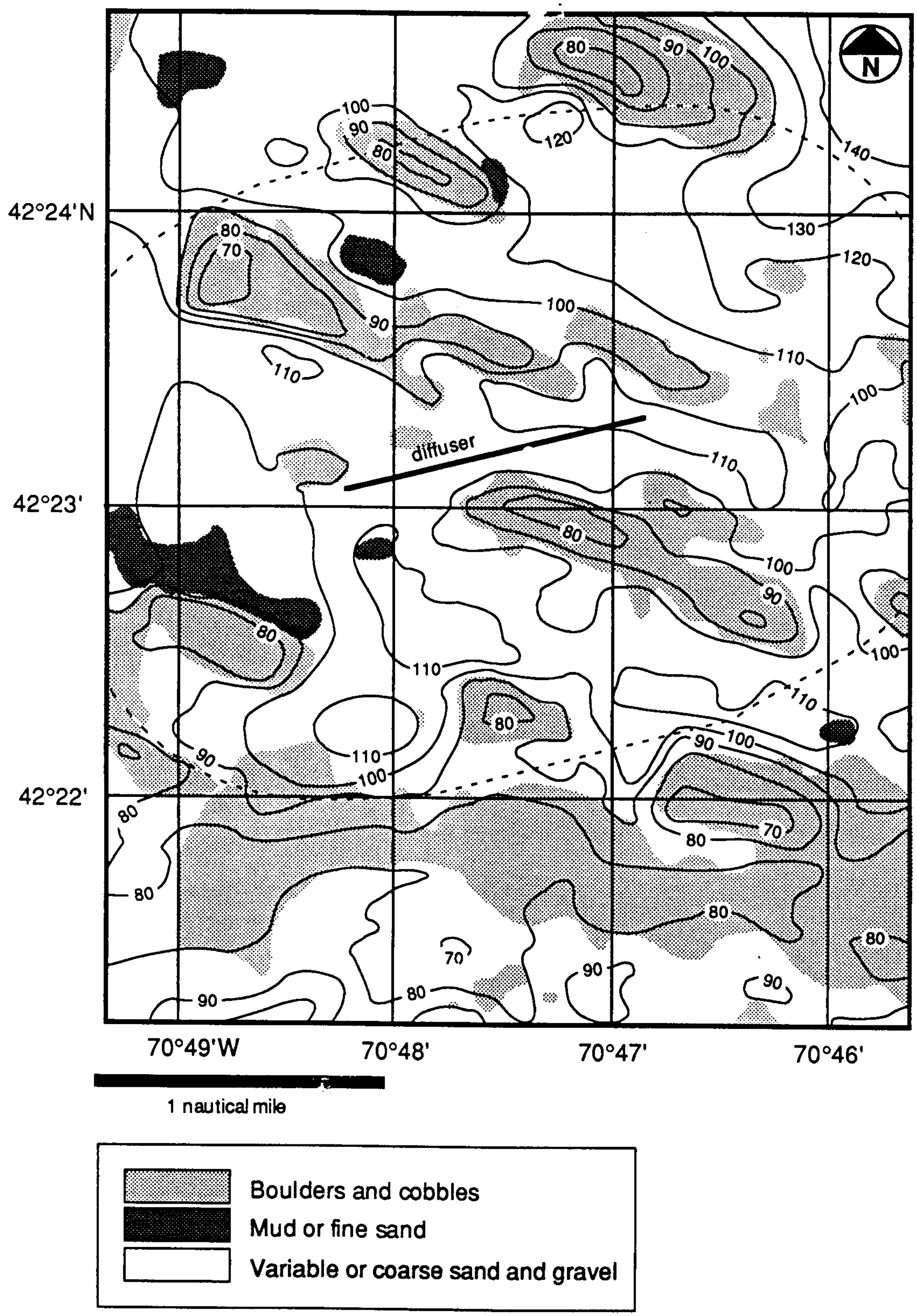


Figure 16. Benthic habitat in the area of the MWRA outfall diffuser. (From Bothner et al., 1992)

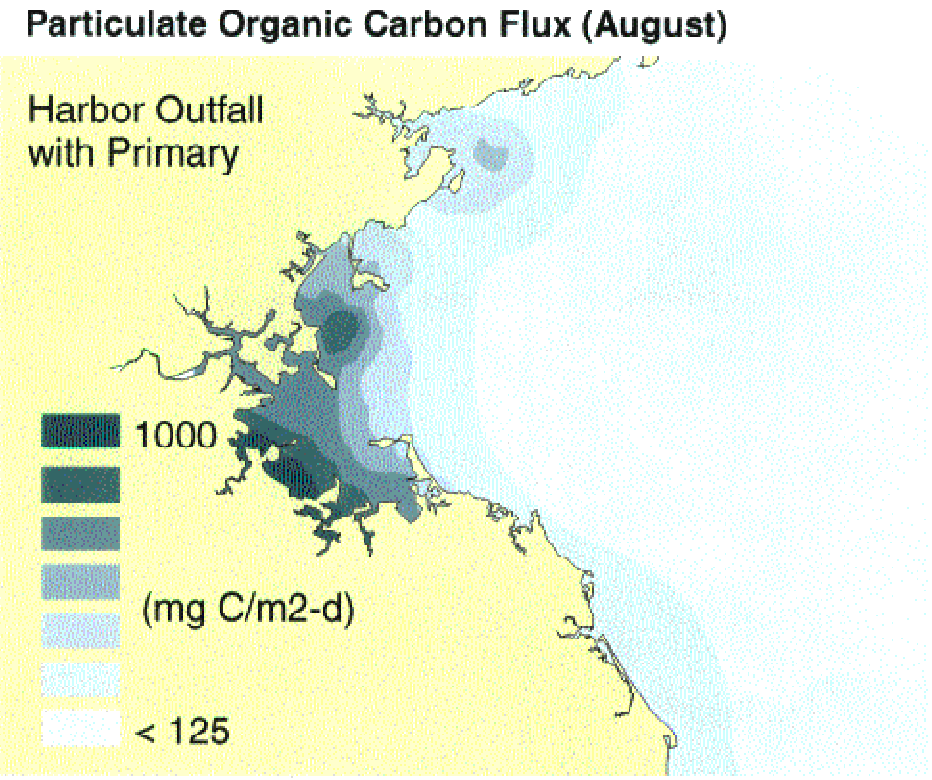

Particulate Organic Carbon Flux (August)

Figure 17a

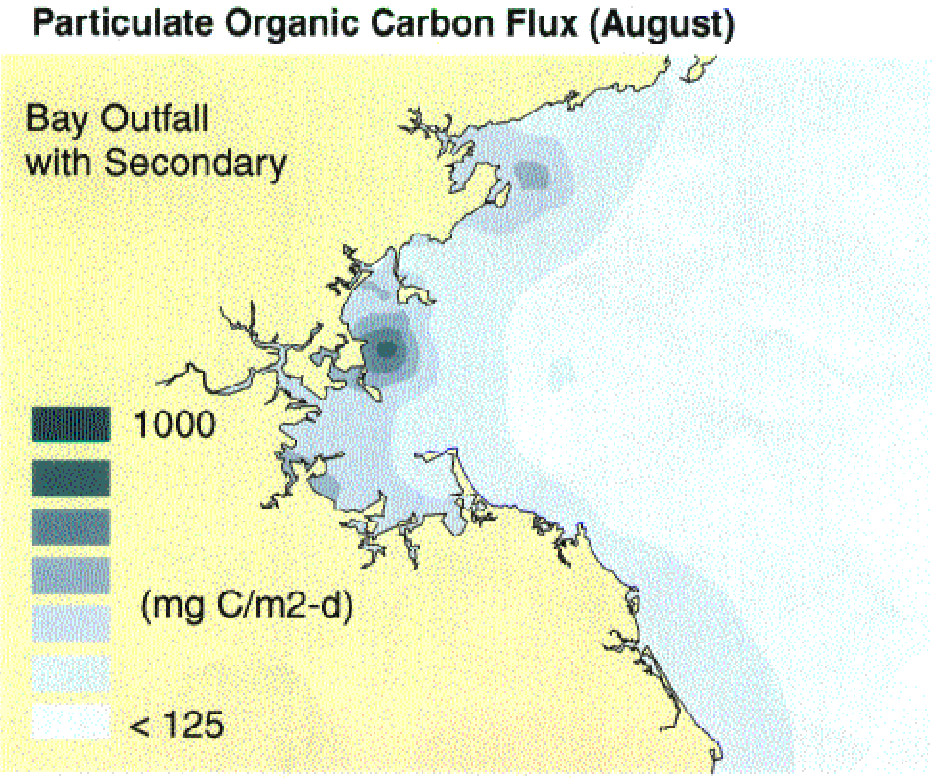

Particulate Organic Carbon Flux (August)

Figure 17b

FIGURE 17
Modeled Deposition of Particulate Organic Carbon
(Fig. 17a – existing conditions with primary treatment; Fig. 17b – future conditions with secondary treatment and new outfall).

4.4.2 Results from Caged Mussel Deployments

As part of its monitoring, MWRA deploys arrays of caged live blue mussels *Mytilus edulis* in the Zone of Initial Dilution (ZID) of the Deer Island outfall for a 60-day period in mid-summer each year. The purpose of the study is to measure the bioaccumulation of contaminants in the tissue of the mussels during deployments (e.g., Downey *et al.*, 1993; Mitchell *et al.*, 1996, 1997). The survival of the caged mussels is also recorded, as are the extent to which invertebrates and algae grow on the cages during deployment. Mean effluent dilution where the mussels are deployed is approximately 25:1. Since 1987, 60-day survival of the mussels deployed at Deer Island has always exceeded 90%, and is consistently greater than the survival of mussels deployed in the Inner Harbor (Figure 18). Similarly, the cages retrieved from Deer Island are consistently heavily biofouled, with heavy settlement by algae, hydroids, and crustaceans.

4.4.3 Chlorine Residual in Boston Harbor

The relative toxicity ranking of the saltwater species used to calculate the AWQC for chlorine is presented in Table 7. Data generated in tests with lobster larvae were not used for the calculation of the criteria, but were presented in the AWQC document. Lobster larvae were up to ten times less sensitive than the copepod *Acartia tonsa* (Table 8), which is the dominant copepod near the Deer Island discharge in Boston Harbor (Figure 19; Cibik *et al* ., 1998). Since *A. tonsa* , which is sensitive to residual chlorine, is found in high abundance near the Deer Island outfall, it follows that lobster larvae are likely not affected by any residual chlorine.

The greatest concern about toxicity of chlorine is the potential effect on the eggs of egg-bearing females. Some of these concerns over residual chlorine in effluent were triggered by analogy to an illegal practice reportedly used by a small number of dishonest lobstermen. Egg-bearing females, when caught, were reportedly dipped in bleach or a 50:50 solution of bleach and seawater in order to dissolve the cementin that binds eggs to the abdomen. The additional concern that this alleged practice raised was that long-term exposure to effluent with a chlorine residual in the low parts per million range (and rapidly diluted within the ZID to much less than 1 ppm) that has been discharged into the Harbor might somehow mimic the cementin-dissolving effects of an acute exposure to hypochlorite concentrations of >25,000 ppm (Chlorox® solution guarantees a minimum titer of 5.25% sodium hypochlorite, or 52,500 ppm). A comparison of these concentrations to the expected chlorine concentration in the ZID of the outfall indicate that such an analogy is without merit.

Little is available in the literature to document the effects of long-term exposure to low concentrations of residual chlorine on egg retention in female lobsters. However, monitoring by the Massachusetts Division of Marine Fisheries indicates that the percentage of egg-bearing females in the Harbor in 1996 was more than four-fold the percentage documented in the mid-1980's. During much of the same time, improvements in MWRA's chlorination facilities led to better effluent disinfection, and an increase in average residual chlorine (Figure 20). Increased removal of solids and BOD have recently allowed the reduction of the amount of chlorine required to achieve the same levels of bacterial "kill" in the effluent, allowing MWRA to reduce the amount of chlorine added per volume of effluent. These data document that there is no evidence for chronic exposure to diluted residual chlorine to have an adverse effect on egg retention in lobster from Boston Harbor.

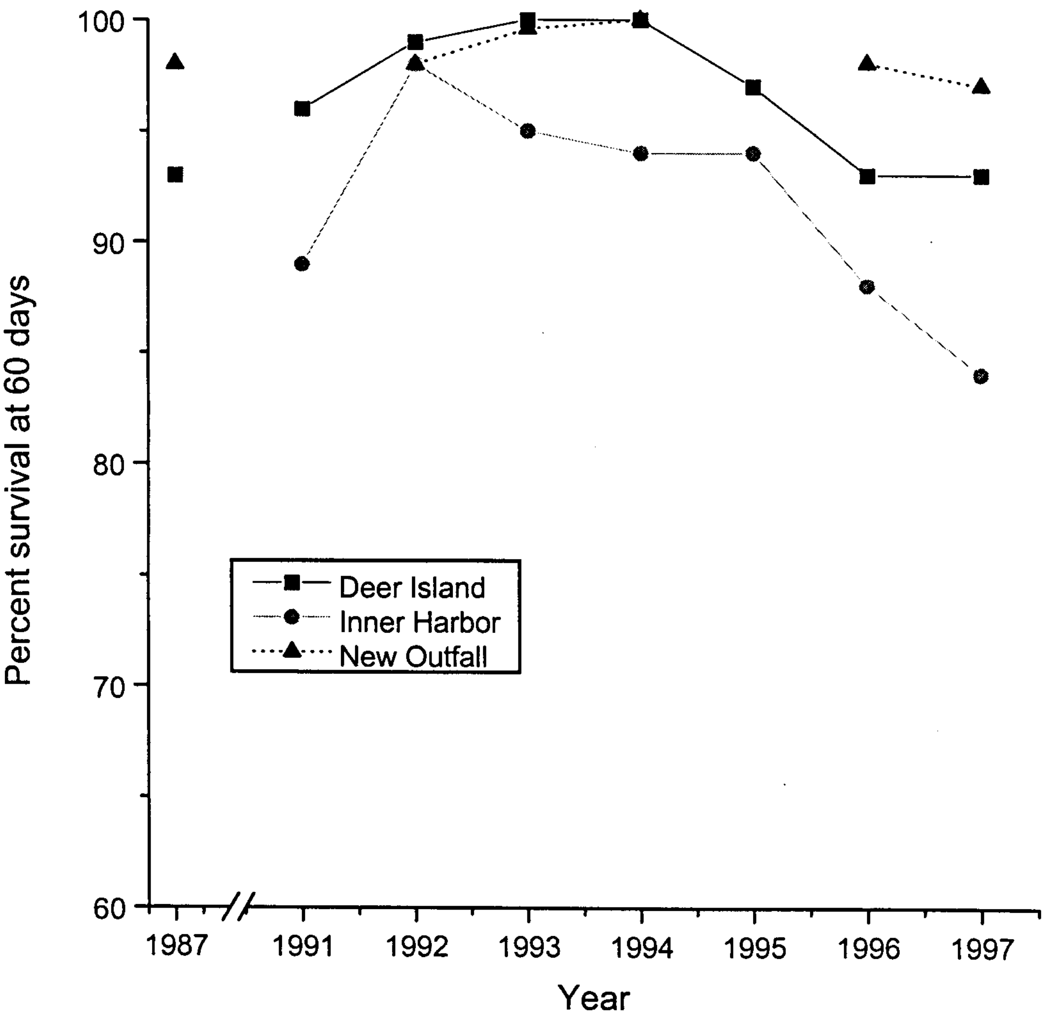


Figure 18. Survival of Deployed Blue Mussels.

Table 7. Relative Toxicity Ranking of Test Organisms Used in Saltwater Acute Chlorine AWQC development

Chlorine[a] Saltwater acute AWQC = 13 µg/L		
Rank	**Species**	**Mean Acute Value (µg/L)**
1	Eastern Oyster *Crassostrea virginica*	26
2	Copepod *Acartia tonsa*	29
3*	Silverside *Menidia* sp.	44.7
4	Coho Salmon *Oncorhynchus kisutch*	47.33
5	Pacific Herring *Clupea harengus paliasi*	65
6	Shiner Perch *Cymatogaster aggregate*	71
7	English Sole *Parophrys vetulus*	73
8	Naked Goby *Gobiosoma bosci*	80
9	Pacific Sand Lance *Ammodytes hexapterus*	82
10	Spot *Leiostomus xanthurus*	90
11*	Shrimp *Pandalus* sp.	131.5
12	Shrimp *Crangon nigricauda*	134
13	Amphipod *Anonyx* sp.	145
14	Hermit Crab *Pagurus longicarpus*	146.7
15	Mysid *Neomysis* sp.	162
16	Threespine Stickelback *Gasterosteus aculeatus*	167
17	Grass Shrimp *Palaemonetes pugio*	220
18	Northern Pipefish *Syngnathus tuscus*	270
19	Amphipod *Pontogenia* sp.	687
20	Blue Crab *Callinectes sapidus*	796.7
21*	Shore Crab *Hemigrapsus* sp.	1,418

a - U.S. EPA, 1984c

* Ranking based on toxicity testing with more than one species, and value is average of following species-specific test results:

(1) Two species, *H. nudus* and *H. oregonersis*, used in single toxicity test

(2) *P. danae* (192 µg/L) and *P. gonlurus* (90µg/L)

(3) *M. menidia* (37µg/L) and *M. penisulae* (54µg/L)

Table 8. Comparison of Other Data on the Effects of Chlorine on the Copepod (Acartia tonsa) and the American Lobster

Species	Duration	Effect	Result mg/L	Reference[a]
Copepod *Acartia tonsa*	24 hrs	LC50	<50	Roberts, et al. 1975
	48 hrs	LC50	<50	Roberts, et al. 1975
	48 hrs	LC50	29	Roberts and Gleeson, 1978
	30 min	LC50	820[b]	Capuzzo, 1979a
	30 min	LC50	320[c]	Capuzzo, 1979a
	30 min	LC50	860[b]	Capuzzo, 1979a
	30 min	LC50	320[c]	Capuzzo, 1979a
American Lobster (Larva) *Homarus americanus*	60 min	LC50	2900[b]	Goldman, et al. 1978
	60 min	LC50	300[c]	Goldman, et al. 1978
	60 min	LC50	3950[b]	Goldman, et al. 1978
	60 min	LC50	1300[c]	Goldman, et al. 1978

a - Full citation for specific study references may be found in USEPA, 1984c; Ambient Water Quality Criteria for Chlorine

b - Applied as free chlorine in test; measured as CPO

b - Applied as chloramine in test; measured as CPO

CPO = Chlorine Produced Oxidants; standard measure in saltwater for chlorine and basis of saltwater AWQC.

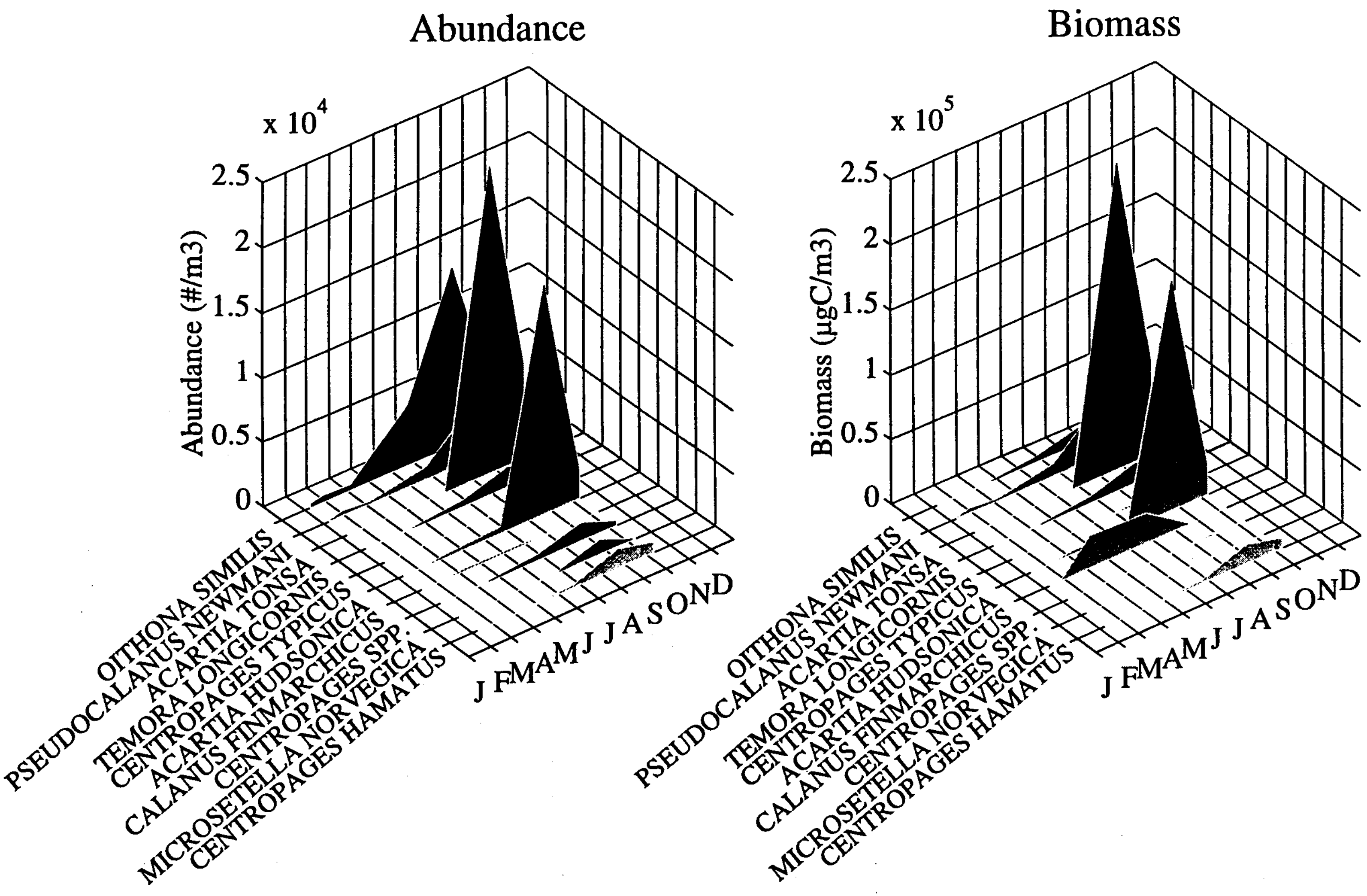


Figure 19. Relative Abundance of Copepod Species in Boston Harbor in 1996.

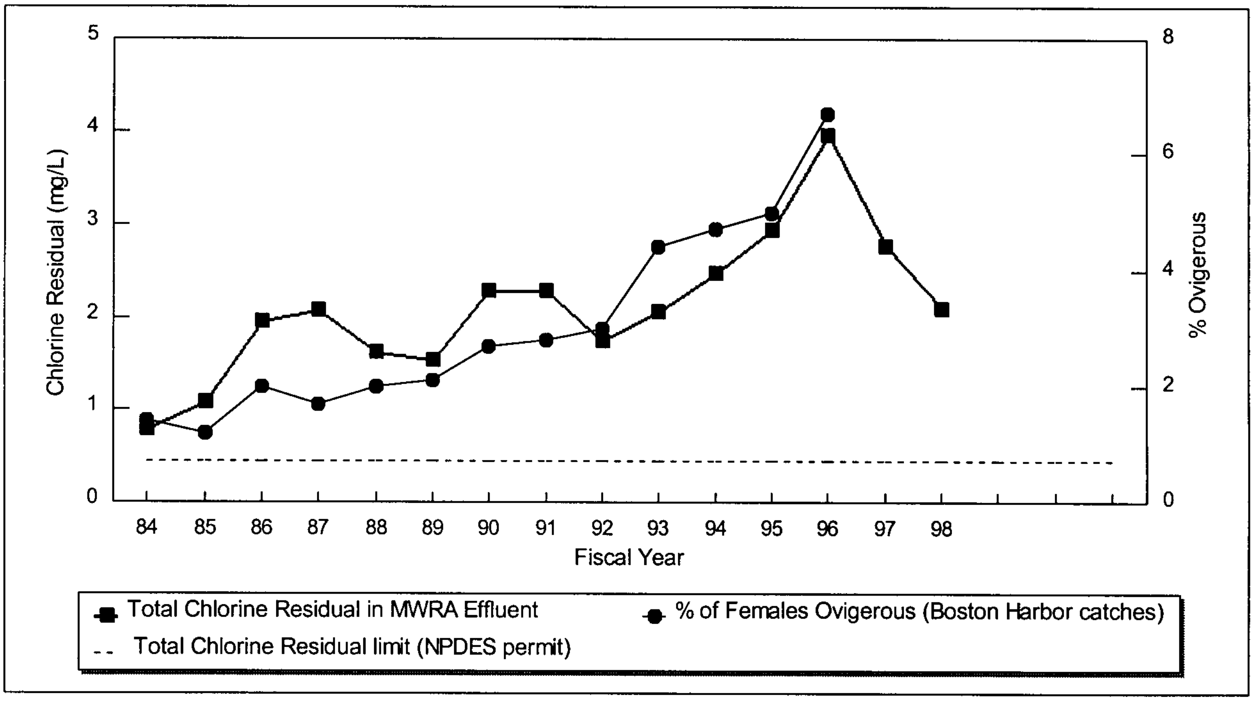


Figure 20. Comparison of chlorine levels in Deer Island effluent (source: MWRA NPDES reporting) and relative percentage of egg-bearing (ovigerous) female lobsters (source: DMF), 1984-present.

Currently, the MWRA does not have a chlorine limit. Upon discharge into Massachusetts Bay, MWRA effluent will be limited to a maximum of 0.631 mg/L. This will be measured from the effluent as it leaves the plant, and enters the effluent discharge pipe. The pipe is approximately 15 km long, and the effluent could take 2 to 7 hours to transit the pipe and be discharged into Massachusetts Bay. The residence time in the pipe, the chlorine demand of the effluent, and turbulence will all act to release chlorine from the effluent. The concentration of residual chlorine in the effluent will decrease. After the initial dilution, which will be complete 60 m from the discharge, the concentration of chlorine will be below water quality standards and will likely not be present at detectable levels.

During the summer, pelagic lobster larvae will be at the surface and thus separated by the pycnocline from any possible contact with chlorine. During the rest of the year, EBP lobsters and egg-bearing females will be on the seafloor and separated from the plume by the tendency for the plume to rise. Therefore, there is little possibility of exposure to effluent-related chlorine at levels which may be toxic to the lobsters.

5.0 SUMMARY AND CONCLUSIONS

The American lobster *Homarus americanus* is a commercially important species that represents a major fishery in Boston Harbor and Massachusetts Bay. It has a complex life cycle that includes multiple planktonic stages followed by a several juvenile stages, each with successively greater motility . The mature lobster is a nocturnal benthic predator that may migrate long distances, either in search of optimal temperatures for developing eggs or for food.

Public concern over the potential impact on the lobster of the secondary-treated effluent to be discharged to Massachusetts Bay prompted the present review of the biology of the lobster in this area. A risk evaluation of the potential impacts (both toxic and depositional) to lobster populations in Massachusetts Bay was conducted. This qualitative assessment of potential risks to critical lifestages (i.e., larval and early benthic phase (EBP) juvenile lobsters) from the MWRA outfall discharge resulted in the following conclusions:

- The draft NPDES permit sets conservative requirements for compliance and monitoring which provide adequate protection for aquatic organisms outside the ZID. The AWQC are all met within the ZID, most at the point of discharge.
- Comparison of available toxicity tests of marine organisms indicate that lobsters are not more sensitive than other species used to develop the AWQC. Thus, the AWQC are considered protective of larval lobsters.
- Exposure of larval lobsters to the MWRA effluent is likely to be very limited based on spatial and temporal factors, particularly the trapping of the effluent plume below the pycnocline during summer months when larval lobster presence in the surface water is greatest.
- Under a worst-case scenario where the summer stratification breaks down, dilution in surface water is predicted to be a minimum of approximately 100:1, which should be protective.
- Routine toxicity testing of the MWRA effluent with three test organisms, particularly the mysid shrimp, will be indicative of potential lobster toxicity.
- The habitat area for EBP juvenile lobsters potentially affected by the outfall will be significantly reduced from the previous discharge and shifted away from nearshore habitats.
- Exposure of the EBP juvenile lifestage to the plume is unlikely based on the life history of the lobster, diffuser design, and buoyancy of the plume.
- No impact is expected from residual chlorine in the effluent because after the initial dilution, which will be complete 60 m from the discharge, the concentration of chlorine will be below water quality standards and will likely not be present at detectable levels.

The question posed in the Introduction of this report is restated here:

> Is there any reason to expect that the discharge of secondary effluent from the Massachusetts Bay outfall will pose an appreciable threat to recruitment of lobster larvae and/or to the survival and growth of juvenile stages of lobster in Massachusetts Bay, with a potential to impact the fishery?

Based on the weight-of-evidence of the findings presented in this report, it can be concluded that no significant potential risk is posed to the two most sensitive lobster lifestages, the pelagic larvae and the benthic juvenile, from the MWRA outfall. Thus, the potential for the MWRA outfall to adversely impact lobster populations and thereby the fishery in Massachusetts Bay due to effluent toxics or deposition is negligible.

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Attachment 1

Is There Reasonable Evidence to Suggest that the New Massachusetts Water Resources Authority Sewage Outfall May Have a Negative Impact on Lobsters?

THE LOBSTER CONSERVANCY

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August 11, 1998 (revised)

I appreciate having the opportunity to offer my opinions and bring my expertise and 14 years of experience studying the behavior and ecology of lobsters to bear on the tough decisions being made regarding the future of the new MWRA outfall in Boston Harbor. The opinions expressed herein are the author's, based on a compilation of scientific data available to her. The author has no current affiliation with MWRA, EPA, NMFS, Division of Marine Fisheries-Massachusetts, or the New England Aquarium. The author previously had a temporary position with NMFS as a research fishery biologist in charge of lobster collections off the NY Bight Region which was terminated at the beginning of 1995 at the conclusion of a lobster-pollutant study. No attempts have been made by the author to apply for any state or federal grants to conduct any of the research projects suggested herein, which could be considered a conflict of interest.

The following concerns have been raised by Dr. Joseph Ayers (of Northeastern University's Marine Science Center) in a memo to Jerry Schubel, Chair of the MWRA Outfall Monitoring Task Force (dated 9 June, 1997) and a letter to John DeVillars, Regional Administrator of EPA (dated 23 December 1997):

1) Lethal and sublethal effects of the new MWRA outfall on lobster larvae and their food sources--particularly with regard to toxic material discharged in the effluent--may result in larval malnutrition and/or death;

2) Lethal and sublethal effects of toxic material discharged via the MWRA outfall effluent on settling postlarvae and benthic young-of-the-year (YOY), as well as the larger, but relatively non-mobile juveniles, may result in recruitment failures to the lobster fishery in the years to come.

Dr. Ayers has proposed that the potential negative impacts of the new MWRA outfall be studied on early life history stages of lobster, namely, the larvae, postlarvae, and young-of-the-year (YOY). Based on a critical review of the literature, I will argue that many of the concerns raised by Dr. Ayers can be eliminated due to a large body of existing data. This report will: (1) summarize the results of studies that directly relate to the above-mentioned concerns, (2) point out where knowledge is lacking, and (3) present suggestions for further research. I will begin by attempting to establish the proper context for evaluating the concerns by (1) briefly summarizing what is known about early lobster life history, behavior, and ecology; and (2) discussing the validity of indicator species being used by MWRA. Then I will review the toxicity literature and discuss whether results have indicated a cause for concern at the site. Finally, I will offer some concluding remarks. This report is not meant to be a replacement for the ENSR Consulting and Engineering Report of 1 March 1998 (prepared by Mitchell et al. for the MWRA), entitled "Massachusetts Bay Outfall Monitoring Program: Toxics Issue Report on Biology of the Lobster in Massachusetts Bay"--instead it is meant as a supplement to that report.

I. LOBSTER BEHAVIOR: *What is the likelihood that lobsters will come into contact with the new MWRA outfall in Boston Harbor?*

Larvae: *(Note on terminology: Here I will refer to larvae by convention as pelagic stages I-III. Larvae do not settle or come into contact with the benthos at any time.)* Upon hatching, lobsters molt out of the pre-larval stage into the first larval stage. These animals are attracted to light and make their way to the upper couple of meters of the water column where they are transported predominantly inshore by wind-driven currents. Studies examining the position of larvae in the water column indicate strong differences depending on whether the larvae are found offshore (in deep ocean waters), or inshore (in shallower waters). Since Boston Harbor is inshore and the outfall pipe is in "relatively" shallow water (~100 ft or 28-32 meters), this discussion focuses only on larval behavior in shallow waters.

In coastal waters, larvae (stages II-III) and postlarvae are confined to the upper 2-3 m of the water column; however, stage I larvae exhibit semidiurnal vertical migrations that are based on light intensity--these movements concentrate them at the surface in early morning and late afternoon/early evening and involve depth changes of several meters (Harding et al., 1987; Scarratt, 1973; Templeman and Tibbo, 1945). Some of these vertical movements may allow the larvae to utilize subsurface countercurrents to counteract surface currents and remain near a certain location; such subcurrents are used by other decapod larvae. Vertical temperature and salinity profiles, as well as the depth of the thermocline, strongly influence the distribution of the larvae.

Larvae are repelled by freshwater so after a heavy rain, they will be repelled by the freshwater layer on top of the seawater. Similarly, they would be repelled by freshwater runoff in nearshore environments and the MWRA effluent *if* they were found at the outfall pipe or in its plume. Larvae actively avoid swimming toward seawater diluted to 21 ppt, but will readily swim into salinities ranging from 26.7 ppt to 32 ppt (Scarratt and Raine, 1967). They are not terribly strong swimmers and cannot fight against currents--which would be present at the site of the diffusers given that the effluent discharge rate out of individual diffuser ports is ~5.6-22.6 ft/sec or ~170-690 cm/sec (Ken Keay, MWRA, personal communication). Thus, their exposure to low salinities would be questionable, first due to the depth of the diffusers and the effluent and second due to their inability to swim towards the diffusers during emissions of effluents.

Thermoclines, particularly strong thermoclines (>5°C difference in upper vs. lower waters), restrict both larvae and postlarvae to the warmer upper layers. At the location of the outfall diffusers there is a strong thermocline at about a 5 m depth (MWRA, 1997) with a 5-10°C temperature stratification between surface and near-bottom waters. This thermocline is present roughly from May to late October (Ken Keay, MWRA, personal communication)--months which represent the time when larvae are typically present in the water column (see Fogarty, 1983 and papers cited therein). This thermocline indicates that the larvae, if present above the discharge, will be restricted to the upper waters away from effluent discharge. Furthermore, as the effluent is freshwater and will cause a lowering of salinity in the immediate vicinity, larvae *if* present at all at depth, will be repelled from the area.

The two main points concerning larvae are that (1) the depth of the outfall pipe (28-32 meters) does not coincide with the vertical depth to which larvae are typically found (surface waters, 1-3 meters), and (2) the presence of a sharp thermocline at 5 m depth further prohibits their likelihood of movement into the range of an effluent plume. Furthermore, given that the effluent's temperature will range from ~13°C to ~24°C at the location of the plant, and will cool over the 9.5 mile pipe (as heat is given up to the surrounding cooler bedrock through which the pipe travels), its temperature upon mixing will be reduced to a level that will prevent it from rising past the thermocline. Current estimates for the temperature of the mixed effluent, based on a turbulent mixing rate of 49:1, indicate that it will be between 8.3 to 12.25°C (Ken Keay, MWRA, personal communication). As the effluent plume rises, it will continue cooling and by the time it reaches the thermocline 15 meters above the benthos, it will not be any warmer than the ambient seawater. *Thus, the thermocline will prevent the effluent plume from reaching the upper water layers and it is unlikely that larval lobsters would ever come into direct contact with substances from the wastewater outfall.*

Postlarvae: *(Note on terminology: Here I will refer to postlarvae as the transitional stage between the pelagic and benthic realms--this is the settling stage and is not a larval stage. In contrast to postlarvae).* After three larval stages, lobsters molt into the postlarval stage (stage IV). At this stage, they look like miniature adults (except their claws are small) and they are strong swimmers. They begin to make excursions to the bottom to search for suitable habitat mid-way through stage IV, typically at molt stage D_0 (*NOTE: molt stages indicate whether the animal is postmolt-A&B, intermolt-C, or premolt-D*). The timing of these excursions varies, but typically occurs from August through October, although some postlarvae may settle as late as November and December (Cowan, unpublished data). During the transition from pelagic larva to benthic postlarva, the lobster is sensitive to temperature, current velocity, salinity and depth.

Postlarvae are strongly influenced by the presence of thermoclines--a difference of 5°C is all that is necessarily to significantly reduce the possibility that the postlarvae will continue their downward journey to the bottom (Boudreau et al., 1992). At the site of the outfall, there is a strong thermocline present at a 5 m depth representing 5-10°C of temperature stratification between surface and near-bottom waters from roughly May to late October (MWRA, 1997; Ken Keay, MWRA, personal communication). Thus, few, if any, postlarvae are expected to pass through this thermocline to examine the bottom habitat near the outfall. Furthermore, smaller juvenile lobsters (>16 mm CL) are sensitive to currents and tidal action. They can walk normally in current speeds of 5 cm/sec, but are impaired at currents of 10-15 cm/sec (this data on lobsters having difficulties in flow regimes is from a study on a sister species of lobster by Howard and Nunny, 1983). As the effluent discharge rate at the diffuser nozzles will be on the order of 170-690 cm/sec, currents well in excess of 5 cm/sec will be generated. The diffuser heads are designed to cause water to flow upwards and will thus create a current in the water column, which would make it fairly difficult for postlarvae to settle nearby. If any current reaches the substrate surface, it is also highly likely that postlarvae and small juveniles will have difficulty approaching the diffuser area. Thus they will not be found in this area.

Finally, all sampling data thus far accumulated indicates that postlarvae settle in *shallow* coastal bays--from the lower intertidal/shallow subtidal interface (Diane Cowan and Jay Krouse, unpublished data) to between 5-10 m in depth in the subtidal (Wahle and Steneck, 1991). Samples taken in Gulf of Maine locations that show high densities of young-of-the-year (YOY) at 5 and 10m depths, show an order of magnitude drop off in the numbers of YOY lobsters present at depths of 20 m (Carl Wilson and Robert Steneck, unpublished data). The densities of YOY at depth, when present at all, range from 0.3 to 0.1 lobsters/m^2, which are typical for poorer habitats (Wahle and Steneck, 1991). *Thus, it is highly likely that densities will be as low or lower for depths greater than 28 m.*

While postlarvae are capable of using a variety of habitats (ranging from cohesive mud to peat beds in salt marshes to eelgrass to boulders on shell hash--sometimes termed "cobble"), environments comprised of rocks and boulders represent the "safest" habitat against predation events. Featureless habitats (those lacking in structure or vegetation) represent the "worst" habitats. This does not necessarily mean, however, that lobsters only settle in "cobble" habitats. The habitat near the outfall diffuser pipes ranges from a sand-gravel bottom between submerged, relict glacial drumlins to a cobble habitat with some boulders some distance away. This habitat, while certainly suitable for postlarval settlement, would most likely not even be sampled by the postlarvae due to the thermocline present and the depth involved (>20 m). Furthermore, freshwater plumes would repel the postlarvae and flows out of the diffuser would prevent postlarvae from settling nearby. Additionally, no evidence to date indicates that this nearby cobble area would represent a "prime habitat for larval (sic) recruitment" prior to diffuser deployment (as stated by J. Ayers in his memo to Jerry Schubel dated 9 June 1997).

Wahle and Steneck (1991) have suggested that availability of shelter-providing habitats may limit postlarval recruitment to the benthos. *This is not to say, however, that all shelter-providing habitats represent recruitment habitats.* Evidence for resource- or recruitment-limitation has been conflicting. A previous article by Incze and Wahle (1991) suggested that habitat quality shaped recruitment patterns irrespective of postlarval supply. Their most recent study (Wahle and Incze, 1997), representing many more years of study, now favors the hypothesis that it is postlarval supply that drives benthic recruitment. Even where special "cobble emplacement plots" were placed so as to promote postlarval benthic recruitment, Wahle and Incze (1997) did not find settlement in areas where postlarval supply was low. Thus, the cobble habitat located near to the outfall pipe would only be a potential site for benthic recruitment if postlarvae of molt stage D_0 or greater (these are the "competent-to-settle" postlarvae) were present in the water column above, if they were inclined to pass through the thermocline present, and if they were inclined to swim for more than 20 m to reach the bottom below. Presence or absence of these postlarvae can easily be assessed via neuston nets towed outside a vessel's bow wake during settlement season from July through October (as per Wahle and Incze, 1997). Benthic suction sampling would allow the determination of whether postlarvae are currently settling in the area and whether they have previously settled. The finding of 15-25 mm CL juveniles in such a sample would strongly suggest that settlement had occurred in previous years.

The take-home message concerning postlarvae is that due to their behavior, they are unlikely to ever come into proximity to the new MWRA outfall pipes.

Adults: Of all the life history stages, free-ranging adult lobsters are the most likely to come into contact with the new outfall effluent because of their range of movements. The most relevant questions, therefore, concern the adult population--their distribution and range of movements in the outfall area and the effect that effluent compounds may have on them after long-term exposure. To date, we have very limited data of the kinds of movements adults make in any particular region and we do not know whether or not most coastal lobsters are residential or transient. Collecting such data would require tag and recapture studies. The most logical way to capture the lobsters is in commercial traps; however, the required coordinated cooperation between scientists and fishermen may be prohibitive because the study would be labor intensive for the fishermen and would take time away from fishing. Additionally, lobstermen have been loathe to provide location data since that would tell others where they are laying their traps; however, scientists could alleviate such fears by showing the lobstermen the kinds of movement maps that would be constructed from their location data (and these would not show points, only lines--from which it would be difficult, if not impossible, to determine exact locations). Whereas previous such studies have only had limited success, future studies could have greater success if the scientists and lobstermen took the time to discuss what would happen to the data collected and discussed results after they were collected and analyzed. Such studies have been successful in Canada and in Cape Cod waters (Estrella and Morrissey, 1997). Interestingly, Estrella and Morrissey found that ovigerous females moved significantly more than sublegal and legal-sized females without eggs. These movements will typically be offshore for females who have just extruded eggs and inshore for females preparing to hatch their eggs and molt (these movements maximize temperatures needed for egg development). *This movement pattern suggests that developing embryos would have limited exposure to the effluent because the majority of embryonic development would occur offshore, far from the outfall site and embryos, even if exposed to the discharge, would have limited exposure as the females moved offshore.* Furthermore, larger lobsters are also affected by current speed: Adolescent lobsters (50 mm CL) can walk normally in current speeds of 5 cm/sec, but their walking is impaired at 10-15 cm/sec and at 21-42 cm/sec, they can no longer gain purchase on the substrate and slip downstream (Howard and Nunny, 1983). As mentioned above, the effluent discharge rate at the diffuser nozzles will be on the order of 170-690 cm/sec and if this sets up currents on the substrate surface, it would discourage larger lobsters from venturing nearby.

Conclusion on how behavior of the lobsters will affect their exposure: Given that the larvae are restricted to the warmer upper water layers and exhibit behaviors that prevent them from staying in the presence of lower salinities and colder temperatures, it is highly unlikely that they will come into contact with the outfall discharge. Similarly, existing evidence indicates that postlarvae avoid passing through thermoclines with a temperature difference greater than 5°C and, while their tolerance to low salinities is higher than that of the larvae, postlarvae prefer salinities above 26 ppt (see Section III). Finally, all evidence to date indicates that regardless of whether a habitat is suitable for settlement, if postlarvae are not present at molt stage D_0 (the stage at which they are competent to settle in the benthic environment) in the overlying waters, benthic recruitment will not occur.

Dr. Ayers proposed benthic sampling via SCUBA and airlift techniques to determine whether or not benthic recruitment to the cobble habitat adjacent to the outfall occurs. Given the depths involved (~30 m), this kind of sampling would require the repeated use of NITROX diving over a long period of time to sample the necessary number of quadrats for an adequate sample (~four 0.5 m^2 quadrats could be sampled in the 40-50 min allowed for NITROX 36 mixtures at 27-30 m). This kind of sampling is not necessary given that the probability of benthic recruitment can be assessed via neustonic sampling for postlarvae of molt stage D_0 in the overlying waters from July through October. If no such postlarvae are found, there will be no benthic recruitment to this cobble habitat. Furthermore, neustonic sampling is more cost effective as it requires only boat time for the tows, while benthic sampling requires boat time, SCUBA costs, extra personnel costs--divers, and also exposes divers to potential hazards. However, if benthic sampling is conducted, it should be understood that the absence of lobsters in the size range of 5-25 mm CL would mean that no recruitment is occurring at the cobble site adjacent to the diffusers. Lobsters of a size 25-40 mm CL are known to immigrate from their settlement sites to other sites (Wahle and Incze, 1997), and if present at all should not be considered to have necessarily settled at this cobble site.

Dr. Ayers has also proposed chronic toxicity testing of caged early benthic lobsters at the cobble habitat adjacent to the outfall diffusers, control "clean" regions, and the present Deer Island outfall. He has proposed to do this using ten 1 m^2 wire trays enclosed with screening, and filled with cobble placed on the bottom. After several weeks of "seasoning", he has proposed to add 10 YOY lobsters and retrieve them 2 months later. This study is impractical for the following reasons:

1) *Fouling:* use of a sufficiently fine mesh size (to prevent escape of the lobsters) would mean that the cages will become fouled. If the fouling agents differ from site to site, how can one uncouple the different fauna (some of which might represent food) present from the survivability of the lobsters? There may also be temperature and tidal current differences at each site that will confound growth and survivorship data.

2) *Oxygen deprivation:* use of a sufficiently fine mesh size would also present boundary layer problems that could impede water flow and therefore oxygenation of the cage. Will divers be required to return to all sites on a weekly basis in order to remove the fouling? What kind of effects might this "disturbance" have on the YOY?

3) *Predators in cages:* during "seasoning" of the cages, some organisms may recruit to the cobble present in the cages (e.g. if their settling forms are very small, they will be able to enter through the mesh). Some of these organisms may represent potential predators, which might be large enough at the time of seeding to cause the YOY lobsters a problem. How does Dr. Ayers propose to deal with this potential problem?

4) *Densities within cages:* 10 YOY lobsters/m^2 represents the upper limit of density that has been observed in nature. Generally speaking, densities of YOY of the lobsters are far less and range from 1.2 to 5.7 individuals/m^2. Studies by Wahle and Incze (1997) indicate that seeded lobsters quickly stabilize their densities to those matching typical recruitment densities found in nature. If the seeded lobsters are prevented from doing this kind of stabilization due to caging, they may very likely cannibalize each other at times of molting.

5) *Lobster rearing:* all lobsters used in such a study must be siblings to minimize genetic differences that might affect growth and survival. Some pre-design would have to occur to raise a sufficient number of sibling lobsters (3 sites x 10 plots x 10 lobsters per plot = 300) to conduct this study. How large would these YOY of the year be? While it only takes 1 to 1.5 months to rear postlarvae in optimal temperature conditions, it takes some time to obtain large numbers of juveniles. The study Dr. Ayers is proposing is slotted for this summer. Given that no rearing effort has yet been made, I do not see how this experiment could be run in July 1998.

Even if all of the problems describe above were solved, this study is not necessary until we know whether or not competent postlarvae are present in the waters overlying the outfall area. The only studies warranted at this time are those determining the presence of competent postlarvae in water column above the outfall site and possibly those involving the movements of ovigerous females described below (under Section III. Toxicity Issues).

II. INDICATOR SPECIES USED BY MWRA: *Are the species currently used as indicator species relevant for lobsters?*

The MWRA uses several indicator organisms such as adult mysid shrimp, inland silversides, and sea urchins to monitor the effects of their effluent. These indicator species represent organisms inhabiting a vertical distribution from surface waters to the benthos. The EPA has also used calanoid (*Acartia* sp.) copepods for toxicity testing since they are extremely sensitive to various pollutants. Calanoid copepods represent *the major food* source for larval lobsters from all gut content studies conducted thus far. Benthic postlarvae and juveniles consume amphipods, decapods, echinoderms (sea urchins and brittlestars, primarily), polychaetes, copepods, hydrozoans, fish, juvenile mussels, as well as other incidental items. Given that the toxicity testing at MWRA includes a crustacean (mysid shrimp), an echinoderm (sea urchin), and a fish (silverside), and EPA testing has previously included copepods, the food items of lobsters are or have been well-represented. Furthermore, given that MWRA conducts monitoring for calanoid copepods, if the discharge produced compounds that negatively impacted copepods (and thus potentially the larvae, both indirectly and directly), their monitoring schedule would determine such an event. If any further items should be added to the testing scheme, we would suggest polychaete worms and mussels. However, since larvae are relegated to the upper 3 m of the water column in coastal regions and are subjected to surface wind currents that carry them away from their original hatching location and towards the shore (along with their food, who are also subjected to the same currents), the likelihood that larvae or their food sources would be trapped in the outfall area is incredibly small.

The situation is different, though, with postlarvae and YOY juveniles. These animals are not particularly vagile (they do not move far from their shelters) once they have taken up a benthic existence. However, their behavior, as described above, indicates that they too will not be impacted by the outfall area given that it is highly unlikely that they will be found there.

Conclusion: The current species used as bio-indicators are appropriate because they are much more sensititive to the compounds found in the effluent than are lobsters (Mitchell et al., 1998). They also provide the widest range of organisms found at different vertical depths. If any changes should be made at this time, we suggest that MWRA continue their monitoring of copepod presence and density, begin to use calanoid copepods (which are one of the more ecologically important herbivores in the water column) and add polychaete worms or mussels to the bio-indicator species list. Mussels are a main food resource for larger juvenile and adult lobsters and their byssal gland is extremely sensitive to continuous chlorination. A continuous dose of 0.25 ppm is sufficient to cause all exposed mussels to lose their holdfasts and open their shells. Higher doses delivered intermittantly cause loss of attachment, but not death (Clapp, 1947 as reported in Gentile et al., 1976). Given this reaction, MWRA should review their area surveys mentioned in Mitchell et al. (1998) and determine if mussels are present in sufficient density to warrant concern.

III. TOXICITY: *Based on the scientific literature and ecological context, is there evidence to suggest that effluent from the new outfall may negatively impact lobster?*

The wastewater effluent will contain various potentially toxic substances including chlorine and chloramine, other halogenated hydrocarbons, ions and heavy metals. Of these, only DDT's and PCB's pose a potential threat to lobsters because they bioaccumulate. The consequences of bioaccumulating these compounds are poorly understood for lobster. Other potentially toxic substances will apparently be present at sufficiently low concentrations that they should not pose a serious threat.

Chlorine & Chloramine: The toxicity of chlorine to marine organisms is dependent on the available form of chlorine, the temperature of the water (higher temperatures are required for toxic reactions), and time of exposure to the chlorinated waters. The available form of chlorine will depend on the concentrations of ammonia, bromide, organic matter, and other nitrogenous compounds. Generally there are several forms of free chlorine: hypochlorous acid (HOCl), hypochlorite ion (OCl^-), hypobromous acid (HOBr), hypobromous ion (OBr^-), and broamines (EPA, 1984). When nitrogen-containing compounds are present, chloramine (monochloramine and dichloramine) will be formed and it is the compound that has the greatest potential to cause toxic reactions (note that there is a ten-fold difference in the amount of free chlorine vs. chloramine needed to produce a toxic reaction in lobsters, with chloramine being far more toxic), although all of the compounds formed are toxic to aquatic organisms. Of course, in wastewater effluents, there is a high concentration of nitrogenous compounds; thus, chloramine will be formed, and this is why concerns have been raised about the effects on lobster larvae.

While chlorine and chloramine compounds can have serious lethal effects on stage I lobster larvae, they must be *in high concentration* (16.3 mg/liter for free chlorine and 2.02 mg/l for chloramine) *at elevated temperatures* (25-30°C). At lower temperatures (20°C), free chlorine resulted in ~20% mortality at levels ranging from 0.08 mg/l to 8 mg/l; mortality increased at 10 mg/l (Fig. 1). However, at 20°C chloramine had dramatic mortality effects at concentrations greater than 1 mg/l (Fig. 2). Thus, temperature and concentration work together to produce greater effects than either would on their own--they are synergistic. Part of this synergistic effect is due to the fact that higher temperatures are extremely stressful to larvae, as evidenced by the fact that a temperature of 30°C caused more than a 10% increase in mortality to control lobsters exposed to it for 30 minutes and more than a 20% increase in mortality to control lobsters exposed for 60 minutes (Capuzzo et al., 1976).

Lower concentrations of both compounds can also cause respiratory distress in larvae at a constant temperature of 25°C (Fig. 3). Exposure to free chlorine in concentrations of 5.0 mg/l results in a doubling of the respiratory rate of stage I larvae. Concentrations of 10 mg/l result in a significant decrease in the respiratory rate. However, at concentrations of 0.1 mg/l and 1.0 mg/l free chlorine, no respiratory distress is noted. Again, the effects of chloramine are more dramatic with concentrations of 0.05 mg/l and 0.5 mg/l causing initial increases in O_2 uptake, followed by significant decreases after 48 h and increased mortality (Capuzzo et al., 1976).

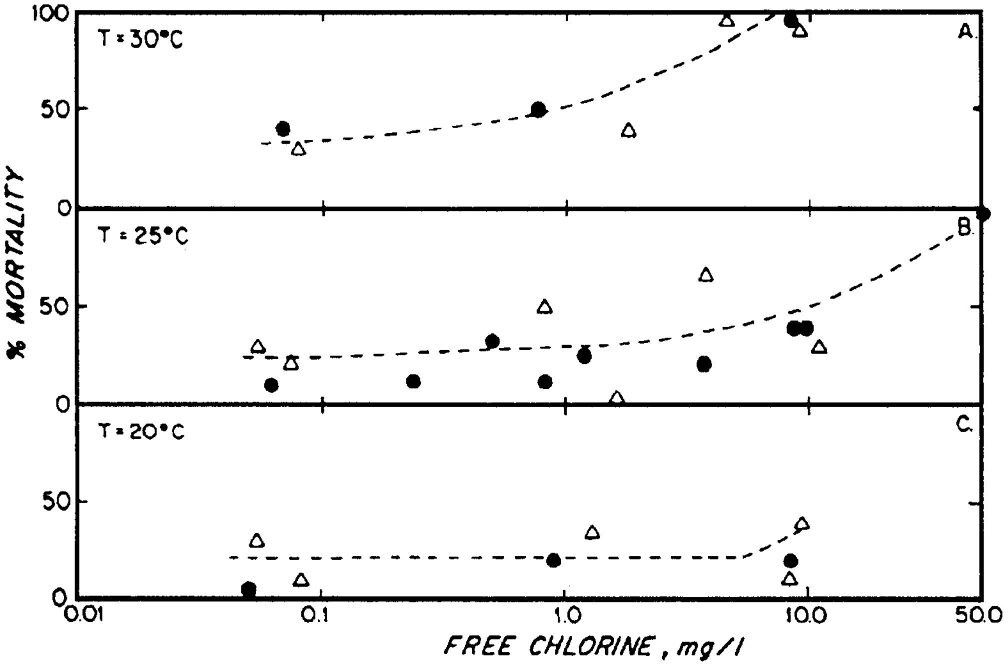

Figure 1: Percent mortality of stage I lobster larvae 48 h after exposure to applied free chlorine at 20°, 25°, and 30°; closed circles=30 minute exposure; open triangles=60 minute exposure. Control mortality was <10% at 20° and at 25°, 20% at 30° with a 30 minutes temperature exposure, and 30% at 30° with a 60 minute temperature exposure; ------ signifies trends in mortality observed. (Capuzzo et al. 1976)

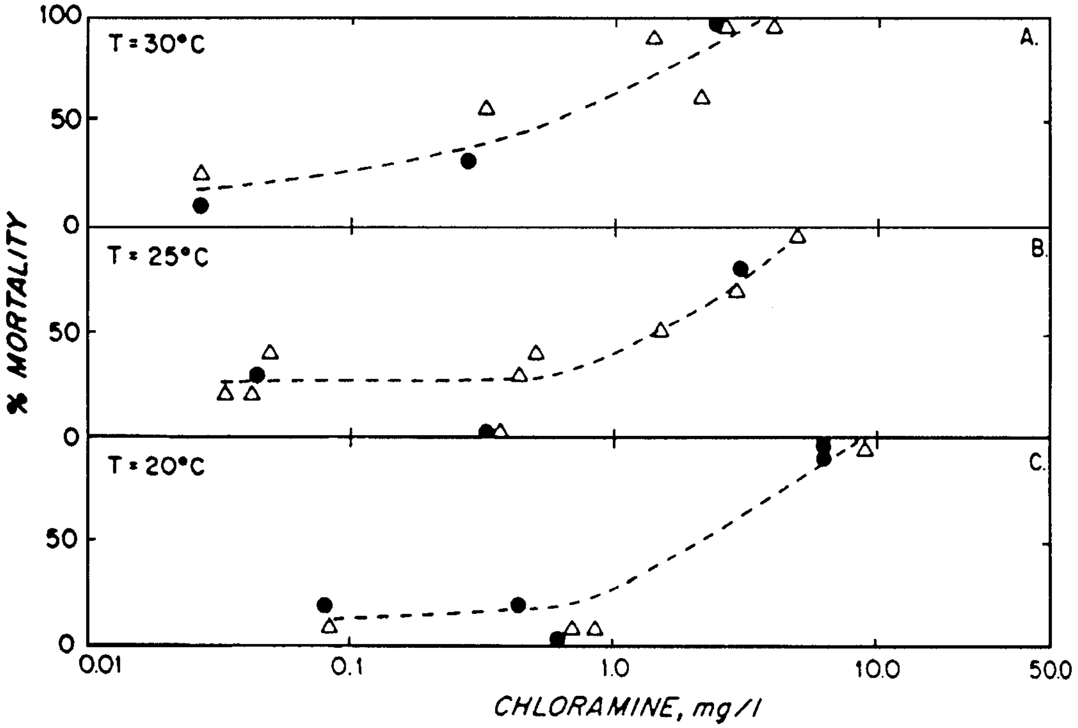

Figure 2: Percent mortality of stage I lobster larvae 48 h after exposure to applied chloramine at 20°, 25°, and 30°; closed circles=30 minutes exposure; open triangles=60 minutes exposure. Control mortality was <10% at 20° and 25°, 20% at 30° with a 30 minute exposure to the temperature, and 30% at 30° with a 60 minute exposure to the temperature; ------ signifies trends in mortality observed. (Capuzzo et al. 1976)

Exposure to both free chlorine and chloramine (at 1 mg/l) at 25°C can result in increased mortality (compared to control groups), but the mortality value is significantly less than the LC_{50} values of 16.3 mg/l free chlorine and 2.02 mg/l chloramine, and it stabilizes after 48 h of exposure to between 15-25%. However, these lower concentrations (1 mg/l) reduce the growth of the larvae as measured by both length and weight; this growth reduction is particularly noticeable in the molt from stage I to stage II (Figs. 4 & 5). For free chlorine exposed animals, no further growth rate reduction is noted for length in subsequent molts, but weights are reduced, implying that the intermolt interval may be longer for these larvae. For chloramine exposed animals, growth rate is reduced for each subsequent molt with postlarvae (stage IV) being considerably smaller and lighter than either control or free chlorine exposed animals. Furthermore, respiratory rates are reduced for exposed larvae and postlarvae compared to control animals. These sublethal effects indicate that long-lasting metabolic disturbances may result from acute exposure to chlorinated seawater, *but only at elevated temperatures* (25°C). At lower temperatures, these effects will not occur (Capuzzo, 1977).

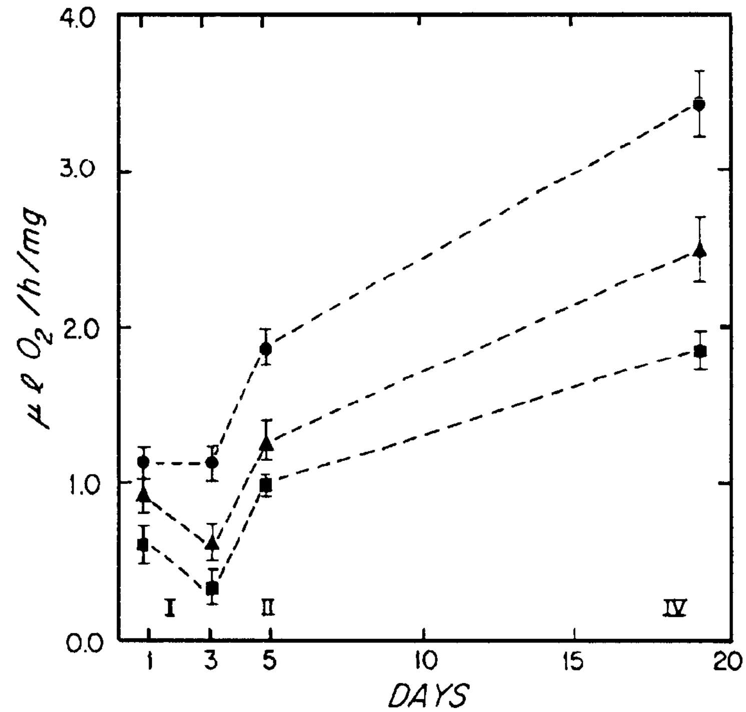

Figure 3: Standard respiration rate (µl O2/hr/mg dry weight) of larval lobsters, stages I-stage IV; circles=control organisms; triangles=chlorine exposed organisms; squares=chloramine exposed organisms; values are mean values from each group ± 1 standard error. (Capuzzo et al., 1976)

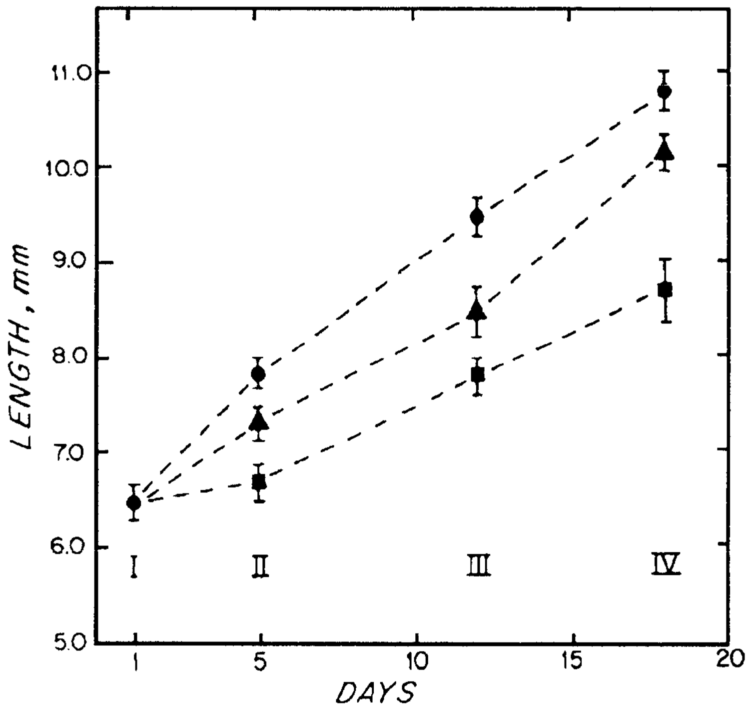

Figure 4: Length (mm) of larval lobsters, stage I-IV; circles=control organisms; triangles=chlorine exposed organisms; squares=chloramine exposed organisms; values are mean values from each group ± 1 standard error. (Capuzzo, 1977)

In summary, a toxic reaction to chloramine is *dependent* on temperature. If the temperature is 25-30°C, chloramine is very toxic even in very low concentrations (2 mg/l); if the temperature is 20°C, 1 mg/l chloramine is sufficient to cause respiratory distress and to affect growth, but a toxicity effect is not noted until the concentration of chloramine reaches 4.08 mg/l. At lower temperatures, a greater and greater concentration of chloramine will be required to cause a toxicity effect. It is highly unlikely that conditions potentially harmful to lobster larvae would arise because the new outfall pipe is located at a depth ranging from 28-32 meters, in an area where the bottom temperatures rarely exceeds 12°C and where mixing with warmer effluent waters will not result in waters warmer than 12.25°C.

Surface temperatures above the new outfall site may exceed 20°C and it is possible that larval lobsters could occur there if females release hatchlings nearby. However, there is a seasonal thermocline present which would most likely form an effective barrier to compounds within the effluent plume. Thus, those compounds would not be able to reach the upper layer waters where temperatures would be great enough for toxic effects to occur *assuming that NO dilution of original emitted concentrations took place between the bottom and the surface*--an event which is unlikely. Similarly, as the food of the pelagic larvae is also planktonic and concentrated at the water's surface, it too should not be affected by chlorine and chloramine compounds.

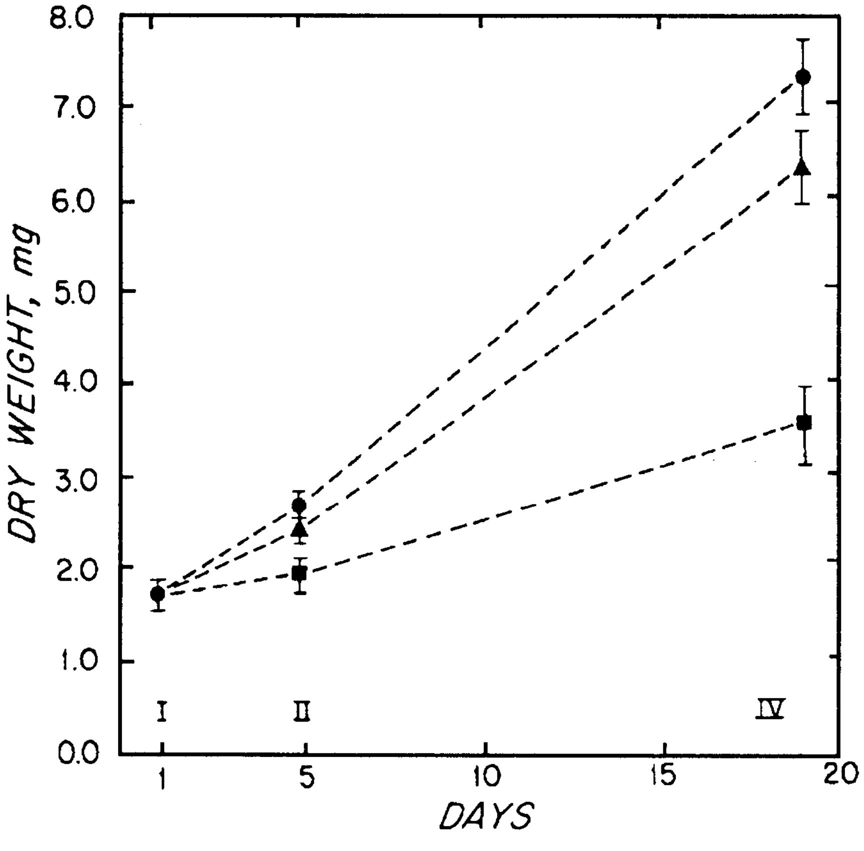

Figure 5: Dry weight (mg) of larval lobsters, stage I-IV; circles=control organisms; triangles=chlorine exposed organisms; squares=chloramine exposed organisms; values are mean values from each group ± 1 standard error. (Capuzzo, 1977)

The basic flaw of these above-mentioned tests is that they have been conducted with pulsed doses--the kinds typically used in power plants to eliminate fouling species. However, in the case of wastewater effluent, the dose of chlorine is not intermittant, but continuous. Thus the effects of short-term exposures will likely be underestimates of the potential effects during continuous exposure. However, these pulsed experiments provide us with baseline data that we can use to predict the effects of continuous doses. Currently, the chlorine concentrations found in wastewater effluents in Boston Harbor are ~ 2 mg/l before dilution with seawater occurs (Ken Keay, MWRA, personal communication). These are free chlorine concentrations, which if combined with high water temperatures and organic matter, could cause problems for lobster larvae and other marine organisms only *in the event of no dilution.* Unfortunately, this ongoing effluent discharge is not what is causing the current concern. It is the proposed new outfall pipe's effluent that is causing the concern--and the chlorine concentration for the new effluent has been set at 0.456-0.631 mg/l (upon dilution with seawater, it is expected to go no higher than 0.1 mg/l; Ken Keay, MWRA, personal communication). Clearly, these lower concentrations of free chlorine are far better than the present situation--there is far less chance that any toxic or sublethal effects will occur. Furthermore, according to EPA testing (EPA, 1984), the Atlantic silverside, calanoid copepod (*Acartia tonsa*), and the eastern oyster are three of the most sensitive genera to chlorine toxicity. MWRA currently uses the silverside as an indicator species and we have recommended above that they begin to use copepods. Additional information on the relative half-lives of these compounds in seawater and turbulent flow would help determine how likely they are to cause problems.

Other Halogenated Hydrocarbons: Effects of exposure to other halogenated hydrocarbons are summarized in Mercaldo-Allen and Kuropat (1994). Of particular concern is DDT retention in egg masses, since that may alter reproductive performance. Adult lobsters withstand sublethal acute exposures to organics such as DDT or PCB by sequestering the pesticides into their lipophilic tissues (hepatopancreas and egg masses). Egg masses retain more than 1% of a dose of 100 μg/l of DDT one month after an intravascular injection. If the dose is administered through ambient seawater or in food, residue concentrations are highest in eggs masses (1000 ng/g wet weight) and hepatopancreas (400 ng/g wet weight) one week later. The impact on developing embryos has not been studied thus far, so it is currently impossible to assess the effect that the MWRA effluent concentrations reported in Table 3 of Mitchell et al. (1998) will have given that they range between 1.51 to 3.7 ng/l. However, the effluent discharges of DDT are well below the levels used to determine residual concentrations and will be diluted upon exposure to the seawater. They may or may not represent a problem to developing embryos, but this would need to be determined in laboratory studies where embryonic development of chronically exposed females could best be assessed.

PCBs are also retained in egg masses and have a half life of 40 days. Lobsters can take up PCBs directly from the water via their gills and via trophic exchange by feeding on animals containing PCBs. Again, we know nothing of the effect of PCBs on developing lobster embryos. MWRA effluent concentrations will range from 11.52 to 20.4 ng/l for total PCBs. Whether this will represent a problem for lobsters cannot be determined without laboratory testing.

PAH LC_{50} concentrations have been determined for both larvae and adults. Creosote at a concentration of 0.02 μg/g is lethal after 96 hours for lobster larvae at 20°C (McLeese and Metcalfe, 1979). It is not known if this concentration is more or less or equally lethal at other temperatures. However, at 10°C, 1.76 μg/g of creosote administered to adult lobsters for 96 hours is lethal. At elevated temperatures, PAHs are known to accumulate in lobster tissues in greater concentrations and lobsters are capable of metabolizing and flushing these compounds out of their system if held in clean water (Uthe et al., 1984; James, 1989). The MWRA effluent concentrations will range from 3090 to 6813 ng/l of total PAHs, which would seem to represent no problem for the lobster larvae or the adults given the differences in concentration magnitudes.

Other Compounds (Ag, Cd, Cr, Cu, Mo, Ni, Pb, Zn, Hg, Fe, Se, Sn): According to Table 3 in Mitchell et al. (1998), all of these metals would be released in accordance with EPA ambient water quality criteria. Again the effects of these compounds are summarized in Mercaldo-Allen and Kuropat (1994). Cadmium, copper, and mercury effects have been assessed for stage I larvae (Johnson and Gentile, 1979) reared in temperatures of 20°C. A dose administered over 96 hours of 78 μg/l Cd results in 50% mortality, while that of 48 μg/l Cu results in 50% mortality and that of 20-33 µg/l Hg results in 50-73% mortality. Higher doses over shorter times, also result in considerable mortality: Twenty-four hour exposure to 1000 µg/l Cd results in 50% mortality while 48 hours of exposure results in 100% mortality. A dose of 330 µg/l of Cu results in 100% mortality after 24 hours, whereas dosages ranging from 100-330 µg/l of Hg result in 97-100% mortality. MWRA effluent levels of Cd range from 0.05-0.22 µg/l; those of Cu range from 29.79-48.63 µg/l; and those of Hg range from 0.101-0.226 µg/l, and will be released to the surrounding waters at temperatures under 20°C (concentrations taken from Table 3 of Mitchell et al., 1998). With the exception of copper, all of these concentrations are 80 to 350 times lower than the LC_{50} levels determined for 24, 48, and 96 hours and thus do not represent a problem for larval lobsters. Copper is of concern, however, given the behavior of the larvae (described above in Section I), we do not anticipate that they will come into contact with this metal.

The lethal and sublethal effects of silver, iron, nickel, lead, selenium, tin, and zinc have not been determined for larval lobsters. In juveniles and adults however, doses of 500 µg/g Zn can cause sluggish behavior. Again, Zn levels at the outfall will range from 30.02-36.33 µg/l (concentration taken from Table 3 of Mitchell et al., 1998), which is under the value at which juvenile and adult lobsters altered their behaviors.

Salinity: Larvae raised to the postlarval stage at various temperatures and salinities exhibit the following survival patterns: at 15-17°C in artificial light with a day:night cycle, survival rates are 83% at 30.9-31.8 ppt, 67% at 27.6-28.4 ppt, 58% at 21.8-22.5 ppt, and 8.3% at 19-19.8 ppt. Survival of the larvae from stage I to stage II and III is higher than that during the metamorphic molt into the postlarval stage. At 15-17.5°C in artificial light with a day:night cycle, survivals of animals passing through all three molts to the postlarval stage are 83% at 30.1-31.8 ppt, and 67% for both 26.3-27.2 ppt and 21.1 to 22.1 ppt. In the absence of light and at higher temperatures (17.5-20.2°C), survival ranges from 95% at 30.8-31.2 ppt to 85% for 25.4-25.9 ppt and 20.7-21.5 ppt (Templeman, 1936). Clearly decreases in salinity to 19-20 ppt can prove quite harmful to larvae exposed for a long duration (>20 days), but lethal limits are 13.6 ppt. However, given the fact that larvae will avoid swimming into low salinity waters or will remove themselves from them by swimming elsewhere (Scarratt and Raine, 1967), the low salinities at the immediate location of the effluent are not expected to cause a problem with the larvae.

In addition to the negative taxis of larvae towards lower salinities, non-reproductive female lobsters are also very selective about salinities and exhibit much higher levels of activities in response to them than do male lobsters. When given choices between moving into salinities of 20-25 ppt or 10-15 ppt, both males and females preferred to enter the higher salinities. Lobsters left their shelters but remained in their vicinity when salinities dropped to 18.4 ppt ± 1.42 (SE); when the salinity dropped to 12.62 ppt ± 1.59 (SE), they left the vicinity of their shelters altogether (Jury et al., 1994). Lethal salinities vary with temperature: as temperature increases above 20°C, tolerance for low salinity decreases to 16.4 ppt, whereas at lower temperatures (5°C), lethal salinity may be not be reached until 11 ppt (McLeese, 1956). While it is not understood why non-reproductive females would be more active than males in lower salinity (and would move away from it), it is suggested that this may be a physiological response having to do with potential reproductive events at a later date.

Conclusion: From all the available evidence, the current outfall is not expected to have any effect upon lobster larvae. Toxicity testing has already been conducted for both adult, juveniles, postlarvae, and larvae for a number of the metals, halogenated hydrocarbons, and other organic compounds (see Renee Mercaldo-Allen and Catherine Kuropat's 1994 NOAA Technical Memorandum NMFS-NE-105 for review) and, in the cases for which we have available data, the projected MWRA outfall emission concentrations are well below levels of concern. The EPA has developed ambient water quality criteria which require that toxic compounds be released in concentrations that will have only a 5% probability of toxicity to test organisms (as opposed to the 50% mortality or LC_{50}'s). This is conservative and prevents MWRA from releasing any compound in excess of these criteria. Thus lobster larvae will not be at risk. Furthermore, there is already a monitoring program underway for these compounds, given that MWRA must monitor their concentrations and keep to the ambient water quality criteria set by the EPA, or be found in violation of EPA standards. Given that the lobster's ranking in the toxicity testing varies depending on the compound tested (i.e., they are more sensitive to some things and less sensitive to others) and they are generally 2 to 20 times less sensitive than the most sensitive test organism, use of lobster as an indicator species is not warranted.

The only area which might present a concern is that involving the accumulation of PCBs and DDTs in egg masses and the subsequent effect these accumulations may have on developing embryos. To determine accumulation effects, we would need to know:

1) the movements and residence periods of ovigerous females in the area of the outfall;

2) if ovigerous females are found to be residential near the outfall, would they take up these compounds at greater rates than ovigerous females in outlying areas (such as Cape Cod or further up in the Gulf of Maine); and

3) the effect of dosage concentrations similar to those at the outfall on embryonic development (if any).

Movements and residence times of egg-bearing females could be determined by MADMF or NMFS agents tagging ovigerous females in the abdomen (with sphyrion tags) and recapturing them via the commercial fishery (again coordinated efforts would be required for this study to be successful, as previously discussed). This study would be best designed by MADMF officials and NMFS scientists to determine the appropriate number of ovigerous females to be tagged to provide the best possible recapture rate, since tag-recapture studies typically result in less than a 30% return rate (Estrella and Morrissey, 1997).

If a tag-recapture study indicates that females are indeed residential, then a study to determine bioaccumulation of DDTs and PCBs would be warranted. This study could be effected by MADMF or EPA agents collecting females within Boston Harbor and at some outlying area (matched for depth and temperature) and running comparative concentration analyses of egg masses.

Dose responses could be assessed by holding a large number ovigerous females at various concentrations of PCBs and DDTs (representative of those at the outfall) and determining chronic accumulation concentrations and effects on developing embryos (as compared to embryos of ovigerous females held in clean water). A facility that has the space, water quality, and resources to conduct this kind of study is the EPA Environmental Laboratory in Narragansett, RI or the Woods Hole Oceanographic Institution. Given that many sources other than the MWRA outfall contribute to the presence of DDTs and PCBs in our coastal waters, these kinds of studies could be viewed as a public service and would be within the purview of EPA.

IV. CONCLUDING COMMENTS:

Lobster behavior will largely determine whether or not various life history stages are present at the site of the new MWRA outfall. *If particular life history stages of the lobsters are not now and have never been at the site, then investigating the consequences of treatments at the site on those life stages would be a complete and utter waste of time.* Thus, determining the presence or absence of the various life stages of lobster at the outfall site is the most pressing matter. Depending on the behavior of the lobsters, the outfall may have some effect or none at all. However, the outfall may have other effects that would influence lobsters--for example, if it resulted in a reduction of food resources used by the lobsters, then this might be the reason that lobsters are found in lower abundance near outfalls. Food species could be affected by a number of things, but the three of greatest concern would be: freshwater effects (many animals cannot survive in reduced salinity or are repelled by it), flow effects, and toxicity effects. Freshwater and flow effects do not seem to have been studied thus far, but toxicity effects are already being assessed via EPA protocols and indicator species. Obviously, the kind of long-term studies that need to be pursued at outfall sites are ones that look at trophic food web changes as opposed to a single species, such as the lobster. Such data may already be available from current MWRA outfall monitoring programs and should be used to determine the likely changes in fauna at the new outfall site.

Although the recent *Boston Globe* article (from Thursday 16 April, 1998, page 1) suggested that lobsters were completely absent from the outfall areas in Lynn, Salem, Scituate, and Hull, landings in Massachusetts Bay indicated that they are not absent, but are reduced compared to the early 1990's level. The reduction in landings is likely due to a combination of changes in fauna (their food sources) and overfishing. Subsequent to improving the quality of their effluents by removing many organics, the cities of Lynn, Salem, Scituate, and Hull, have seen the fauna at the outfall sites return to the types seen before effluents were used (in other words it has been restored to historic types; Sebens, personal communication) and perhaps some of the food resources of lobsters (e.g., mussels) have been lost. If this were the case, you would not expect lobsters to be as concentrated in outfall areas (former hotspots for fishing) as in the past.

Bruce Estrella's 17 year time series shows that Massachusetts Bay areas sampled have the highest exploitation rates, highest fishing mortalities, lowest mean size of lobsters landed and lowest percentage of ovigerous females compared to adjacent areas of Cape Ann and Cape Cod Bay. Approximately 93% of the legal catch in inshore regions (Cape Ann south to Cape Cod and Buzzards Bays) consists of new recruits to the fishery (83-94 mm CL) (Estrella and Armstrong, 1994). Clearly the resource in this inshore region in Massachusetts is overexploited and this alone could result in reduced landings in Boston Harbor. It is difficult to tease apart the various factors that may affect landings; however, landings by county or region throughout the state could be individually plotted for the past decade to look for trends. If the trend is of decreased landings in counties or regions with and without outfall sites present, then this is a strong argument that overfishing, not outfall effluent, is causing the reduction in lobster numbers. Additional information that would be needed for a complete assessment of the trends would be number of traps fished per lobstermen per area and number of lobstermen fishing in a particular area.

In addition to the above-mentioned possibility for lobster disappearance in outfall sites (food source reduction, flow rates, freshwater repulsion, overfishing), the areas listed in the *Boston Globe* article of 16 April 1998: Lynn, Salem, Scituate, and Hull -- have experienced enormous coastal development over the last 20 years and those of us who sample for lobsters in coastal regions know the following: *the shallow coastal regions are THE nursery areas for lobsters.* If you damage these, you damage the future of the fishery because this is where the juveniles come from to enter the fishery. Every time you dredge, plow over, build around (causing siltation), etc. these areas, you are negatively impacting future generations of fished lobsters. Those of us working out in the field believe that this is the *single most important threat* to the future of the fishery. If lobstermen and the industry want to get up in arms about something, then coastal development is it. Unfortunately it is often easier to aim the blame at larger targets (like the governmental agencies such as MWRA, EPA, DMF, or NMFS), than it is to concentrate the blame on the thousands of developers and home owners who want to have houses with an ocean view and who don't care if they destroy coastal habitat to get that view.

Pollution is a serious issue and an emotional one--and it should be. We have, too often, treated our ocean waters as dumping grounds and as a result have seen increased incidences of public warnings about what we shouldn't eat and where we shouldn't swim. However, the issues surrounding the reasons for changes in lobster abundance and distribution in Massachusetts Bay are very complex (particularly those concerning settling postlarvae) and we don't yet have the picture in nonpolluted or polluted areas. As with any scientific study, this situation requires pinpointing the problems and fully researching the existent literature in order to avoid a wasteful duplication of effort. A careful review of the literature allows one to then ask the right questions, based on logical hypotheses about probable events. The current situation with regard to lobsters and the future MWRA outfall has not determined the correct questions due to a basic lack of knowledge of larval, postlarval, and YOY behavior. Some studies are warranted, but these should involve (1) determination of the presence (or absence) of larvae and competent-to-settle postlarvae in the waters overlying the outfall diffusers; (2) determination of ovigerous female movement patterns; and (3) assessment of chronic exposure to harmful organics on egg masses carried by females--if their movement patterns warrant it. Toxicity tests on larvae are not warranted, given that we have considerable information on their sensitivity to many compounds and given that other, more sensitive indicator species are being used for continued monitoring. Intensive diver surveys and cobble emplacement studies are also not warranted until it is determined that competent postlarvae are present for potential benthic recruitment. If diver surveys are undertaken in lieu of neustonic sampling, then agreement about what consitutes a "no threat" situation must be made beforehand (in other words, if the survey finds no lobsters present of sizes 5-25 mm CL, then there must be agreement that this is a sufficient test, rather than the result of inadequate sampling). Duplication of toxicity tests and repetitive benthic surveys at this time would be a waste of taxpayer funding. However, in the event that YOY lobsters are found near the outfall site, then further testing would be warranted.

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