ABUNDANCE OF JUVENILE LOBSTERS AT THE NEW OUTFALL SITE: COMPARISONS WITH INSHORE ABUNDANCES AND DISCUSSION OF POTENTIAL OUTFALL IMPACTS ON LOBSTER POPULATIONS

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January 19, 1999

ENVIRONMENTAL QUALITY DEPARTMENT TECHNICAL REPORT 1998-14

Citation:

Lavalli KL, Kropp RK.1998. **Abundance of juvenile lobsters at the new outfall site: comparisons with inshore abundances and discussion of potential impacts on lobster populations.** Boston: Massachusetts Water Resources Authority. Report 1998-14. 26 p.

EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) was mandated by the Outfall Monitoring Task Force (OMTF) to design and execute a study in the cobble-boulder habitats of the new outfall nearfield region for determination of the density of early benthic phase lobsters ("EBPs", 5 to 40 mm carapace length (CL)), particularly that of new recruits ("young-of-the-year", <12 mm CL) and yearling lobsters (shelter-restricted, <20 mm CL). Both of these life history phases are thought to be relatively nonmobile, obligate shelter-dwellers. MWRA was also required to determine if the densities of these life history stages were comparable to that of nearby inshore habitats. This mandate resulted from serious concerns about the effects that the new outfall might have on juvenile lobsters and thus the future of the economically important lobster fishery. If densities of these relatively nonmobile life history phases were as high at the outfall as they were at inshore habitats, then it was recommended that MWRA consider further testing of effluent impacts on lobster juveniles.

MWRA responded to this mandate by proposing a survey plan that incorporated previous data on lobster density from hard bottom surveys and used a mathematical calculation to determine appropriate sample sizes for the collection of species occurring only rarely in a region. Both of these tactics were designed to maximize the chances of locating young-of-the-year and shelter-restricted lobsters at the outfall vicinity. In early September 1998, density sampling was undertaken by the foremost experts in airlifting for lobsters underwater at both the vicinity of the outfall and two nearby inshore stations. The data collected showed significantly lower densities of young-of-the-year and yearling lobsters as well as larger EBP lobsters at the outfall compared to the inshore sites. Measures of the proportion of non-zero observations (which is another measure of frequency) for each size class also showed significantly fewer non-zero observations at the outfall. Taken together, these data demonstrate that while the cobble habitat at the vicinity of the outfall is suitable for settlement, it does *not* represent a major settlement site and thus there is no indication that the outfall will have any appreciable impact on these life stages of the American lobster.

INTRODUCTION

The Massachusetts Water Resources Authority (MWRA) was mandated by the Outfall Monitoring Task Force (OMTF) to design and execute a study in the cobble-boulder habitats of the new outfall nearfield region to determine the density of early benthic phase lobsters (EBPs). MWRA was required to compare the densities of early benthic phase lobsters, specifically "shelter-restricted phase" lobsters (defined as ~4–14 mm carapace length or CL, called "young-of-the-year" or YOY), which are thought to be obligate shelter-dwellers, at the outfall with those found at inshore sites. This mandate resulted from serious concerns about the effects that the new outfall might have on settling lobsters as well as yearlings and older juveniles that appear to move only short distances. Since these lobsters represent the future of the economically important lobster fishing industry, determining their density at the outfall site would allow a better assessment of the potential impact of the discharged effluent.

Prior to discussing the behavior and ecology of juvenile lobsters, which would influence their potential exposure to the outfall, the terminology used for life history phases of this animal needs to be addressed. The current terminological schemes have been developed to deal with the confusing array of names applied in the literature to various sizes of juveniles that behave differently from other sizes. One scheme (Wahle and Steneck 1991), combines lobsters of various sizes that are located on the same habitats and display similar overall behavioral patterns in their range of movements—these are the "early benthic phase lobsters" or "EBPs" (~5 mm carapace length (CL) to between 20 and 40 mm CL). The upper and lower limits of this phase referred to the fact that there might be local differences in the use of shelter-providing habitats and movements, something which Cobb and Wahle (1994) recognized when they refined the definition of "early benthic phase lobsters" to those <20 mm CL. Lawton and Lavalli (1995) further subdivided the EBP scheme into behavioral phases: 1) the *shelter-restricted phase* (~4–14 mm CL) which remains sheltered and does not make any significant movements from its settlement site; 2) the *emergent juvenile phase* (~15–25 mm CL), which is still mostly confined to shelter, but will make limited movements in the vicinity of its shelter, and 3) the *vagile (mobile) juvenile* (>~25 and <40–50 mm CL) which makes more extensive movements and may routinely immigrate to other shelter-providing habitats (as seen by Roach 1983, Wahle and Incze 1997). Wahle and Incze's latest work (1997) confirms that lobsters >20-25 mm CL typically emigrate from region to region and do not necessarily display any site fidelity over long periods of time. Thus, while the original definition of EBP of a lobster ~5 to 40 mm CL may still be useful in terms of defining a population of lobsters found at a particular site, it no longer should be considered as defining lobsters who are the most cryptic and nonmobile. That particular definition should be reserved for "shelter-restricted" and "emergent" juveniles or the definition of Cobb and Wahle (1994) should be used to redefine EBPs as lobsters between ~5 and 20 mm CL. The OMTF's recommendations confusingly used both behavioral "phases" (shelter-restricted, emergent phase) and ecological groupings (EBPs), due to the interest in determining whether or not significant populations of both young-of-the-year (YOY) and first year lobsters (yearlings) were present at the outfall (which they termed "shelter-restricted"). YOY and yearling lobsters are not known to make significant movements away from their settlement sites and, thus, they would be the most likely lobster life history stages to suffer negative effects from chronic exposure to the new secondary-treated effluent at the new outfall site. Therefore, we often have combined these shelter-restricted/emergent phase lobsters as a YOY/yearling classification. However, the use of EBP in the OMTF's recommendations broadens the size class to either Cobb and Wahle's (1994) definition of <20 mm CL or to original scheme proposed by Wahle and Steneck (1991) of 5–40 mm CL. Because of this use of terms, we have used the following definitions throughout this report: 1) young-of-the-year (YOY)—settlement size (~4 mm CL) to 12 mm CL (sensu Wilson and Steneck, unpublished and Estrella, unpublished); 2) emergent phase or yearlings—from >12 mm to ~20 mm CL; 3) young-of-year/yearling (=EBP definition of Cobb and Wahle 1994)—settlement size (~4 mm CL) to ≤20 mm CL; and 4) EBPs—settlement size (~4 mm CL) to 40 mm CL (sensu Wahle and Steneck 1991). While we recognize that lobsters larger than ~20–25 mm CL are capable of emigrating from habitat patch to habitat patch and thus provide little information about settlement in the region, we do use the original definition of "early benthic phase lobsters" in most tables and for all analyses. This is done primarily to make our data comparable to data provided in published and unpublished reports where two classes are typically shown: YOY or lobsters ≤12 mm CL, and EBP or lobsters between 5 and 40 mm CL. These definitions are more thoroughly defined in Table 1 and should be referred to throughout this report.

Our understanding of lobster behavior and ecology comes from both laboratory studies and field sampling. From previous neustonic sampling of larval lobsters, the following picture has emerged: in coastal waters the larval stages are confined to the upper 2-3 m of the water column (Templeman 1937, Sherman and Lewis 1967, Scarratt 1973). However, stage I larvae exhibit semidiurnal vertical migrations that are based on responses to light intensity that concentrate them at the surface in early morning and late afternoon/early evening and involve depth changes of several meters (Templeman and Tibbo 1945, Scarratt 1973, Harding *et al.* 1987). Some of these vertical movements may allow the larvae to use subsurface countercurrents to counteract surface currents that remove them from a certain location; however, their swimming ability is quite limited. Vertical temperature and salinity profiles, as well as the depth of the pycnocline (density profile), strongly influence the distribution of the larvae and restrict them to the upper layers of the water column. Larvae avoid swimming into low salinity waters, or will move from an area of low salinity by swimming elsewhere or by using countercurrents (Scarratt and Raine 1967).

After metamorphosing, the stage IV postlarvae undertake periodic excursions from the pelagic to the benthic realm to locate suitable habitat. Stage IV postlarvae are considered transitional forms, neither fully pelagic nor fully benthic (Cobb 1988, Charmantier 1989, Factor 1989). Like the larvae, they too are confined to the upper water layers (~0.5 m depth) until they are physiologically competent to settle (Harding *et al.* 1982, 1987, Fogarty and Lawton 1983, Hudon *et al.* 1986, Cobb *et al.* 1989). Competence to settle occurs at molt stage D_0 (Botero and Atema 1982, Cobb *et al.* 1989, Cobb and Wahle 1994), which is the beginning of the pre-molt phase (Sasaki 1984). Environmental cues that may influence settlement choices include, but are not be limited to, thermal gradients (Boudreau *et al.* 1992), changes in phototaxis (Hadley 1908, Botero and Atema 1982), chemical cues from benthic conspecifics and/or substrates (Hudon *et al.* 1986,

Table 1: Terminological definitions of lobster sizes.

Term	Definition
Larvae	Pelagic forms following hatching; have no contact with the benthic environment; ~2–4 mm CL
Postlarvae	Transitional form from the pelagic to benthic realm; initiates benthic settlement; ~4–5 mm CL
Early Benthic Phase (EBP)	An ecological grouping of lobsters 5–40 mm CL typically located together on the same types of habitats; their movements are limited (even at larger sizes) compared to expansive movements by adults
Young-of-the-Year (YOY) (aka "Shelter-Restricted")	Size range of lobsters from settlement (~4–5 mm CL) to ~12 mm CL; the upper size will vary according to the time at which the postlarva settles (e.g., a postlarva settling in July may reach a size of ~14–15 mm CL before overwintering; however, a postlarva settling in October may only reach a size of 10 mm CL); for comparisons with other data in Massachusetts, we define YOY as ≤12 mm CL, although others have defined it as ≤10 mm CL in Maine.
Yearling (aka end of "Shelter-restricted" + beginning of "Emergent Phase")	A benthic juvenile that passed through one overwintering period; size range between 12 mm CL and <20 mm CL; again this size range will vary depending on the size at which the lobster overwintered and its geographic location (which will affect how quickly the waters warm up in the spring/summer so that molting can resume).
YOY/Yearling (aka "Shelter-Restricted" + "Emergent Phase")	Equals EBP as redefined by Cobb and Wahle (1994); size from settlement to <20 mm CL; these lobsters have very limited movements away from their settlement sites
Vagile Juvenile	Lobsters >20 mm CL that have not yet attained physiological maturity; Cobb and Wahle (1994) and Wahle and Incze (1997) note that these lobsters have much greater movement patterns than previous size classes, although the movements are still not as wide-ranging as adults
Adolescent Phase	Lobsters that are physiologically but not functionally mature; ~50 mm CL; the attainment of both physiological and functional maturity may be dependent on geographic location; movement patterns are similar to adults.
Adult	Lobsters that are functionally mature; >50 mm CL in many locations although in some colder water regions, functional maturity may be delayed; are capable of wide-ranging movements.

Boudreau *et al.* 1993), and reactions to predator odors (Wahle 1992, Boudreau *et al.* 1993). Of these factors, a thermal gradient of 4–5°C appears to be a barrier to most postlarvae (70%), such that they will not typically swim from the warmer surface waters through the colder gradient and into the colder waters below the thermocline (Boudreau *et al.* 1992). Because of their thermal preferences, postlarvae are thought to exploit warmer, shallower, inshore waters where such gradients are absent (Wahle and Steneck 1991, Boudreau *et al.* 1992). This temperature avoidance behavior may also explain why sampling at cobble sites at Swan's Island in northern Maine revealed no recently settled juvenile lobsters even though the habitat was considered to be "prime" settling habitat, as well as their absence at other "prime" locations (Carl Wilson and Robert Steneck, University of Maine, unpublished data). The lack of EBPs in northern Maine led Wahle and Steneck (1991) to hypothesize that lower temperatures (<15°C) and thermal gradients may inhibit settlement, as was originally proposed by Huntsman (1923). In fact, Fogarty *et al.* (1983) noted that postlarval abundance in Block Island Sound was linked to surface water temperatures that increased above 17°C, such that greater numbers of postlarval lobsters were found in these warmer waters than elsewhere.

Finally, all sampling data thus far accumulated indicates that postlarvae settle primarily 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 at depths of 20 m in Gulf of Maine locations where there are high densities of YOY lobsters at 5 and 10 m depths, show an order of magnitude decrease in the numbers of YOY lobsters present (Wilson and Steneck, unpublished data, Table 2). 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 such as bare sediment and eelgrass in shallower depths (Wahle and Steneck 1991). It is possible that these differences in density with depth are related to thermal conditions—shallower waters presumably would be warmer in the summer and early fall months than deeper waters. Warmer benthic waters would promote faster growth rates of the settled young-of-the-year, which would, in turn, make them less vulnerable to predators (Wahle and Steneck 1992, Wahle 1992).

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 (Lavalli and Barshaw, 1986; Barshaw and Lavalli, 1988; Wahle and Steneck 1992). Featureless habitats (those lacking in significant relief or vegetation) represent the “worst” habitats. This does not necessarily mean, however, that lobsters only settle in cobble habitats nor does it mean that all cobble habitats represent prime settlement sites. Prior to detailed information on temporal and spatial patterns in postlarval supply, it was generally thought that only habitat quality shaped recruitment patterns (Incze and Wahle 1991). However, a 10-year times series linking postlarval supply with benthic recruitment (Wahle and Incze 1997) demonstrated that it is postlarval supply that influences benthic recruitment. Even where special “cobble emplacement plots” were placed to promote postlarval benthic recruitment, Wahle and Incze (1997) did not find settlement in areas where postlarval supply was low.

Thus, the picture that has emerged concerning lobster settlement is one driven by postlarval supply in the pelagic waters, followed by the strong influence of thermoclines to drive settlement shoreward into shallower, warmer waters where the postlarvae can grow rapidly before overwintering. However, this does not mean that postlarvae ONLY settle in shallow regions (as evidenced by their presence at depths of 20 m), but it strongly suggests that shallow waters support higher populations of YOY and shelter-restricted juveniles than deeper waters (see Figure 1).

Table 2. Densities of YOY or EBP lobsters in cobble habitats for given depths at various Maine locations. Data taken from Wahle and Steneck 1991; Incze and Wahle 1991; Wahle and Incze 1997; Wilson and Steneck (unpublished); Wahle (unpublished). [*=Lobsters ≤ 10 mm CL *a.k.a.* YOY; ‡‡ =Lobsters ≤ 12.5 mm CL *a.k.a.* YOY; §=All Lobsters Present; all other densities report refer to EBP lobsters, 5 to 40 mm CL.]

[Note: Table 2 and Figure 1 are not shown, as permissions to display unpublished data were obtained for hard copy only. Copies of the printed report can be obtained by contacting the MWRA Environmental Quality Department at (617)788-4700.]

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Figure 1. Mean density of YOY (<12 mm CL) lobsters sampled at various depths in Maine. Trend is for highest densities of YOY to be found at shallower depths.

Consistent with the mandate of the Outfall Monitoring Task Force, we designed and executed a benthic sampling survey to determine and compare densities of YOY and shelter-restricted juvenile lobsters at the outfall site and two inshore sites, previously identified as settlement areas. This report describes the outcome of this survey and interprets its results.

METHODS

Selection of Sites at the Outfall

We examined videotapes of transects from the September 16 and 17, 1994 Hard-Substrate Reconnaissance Survey S9404 (reported in Coats and Campbell 1994, Coats *et al.* 1995) that was designed to provide a semi-quantitative census of the seafloor bed and associated megafauna around the diffuser. The 1994 survey, which used a continuously running Phantom DS4 Remotely-Operated Vehicle (ROV) to observe benthic habitats, covered > 3 km of the seafloor from the diffuser caps themselves to distances up to 1200 m from the diffuser and at depths from 20 to 37 m. Six transects were traversed along the tops of the glacial drumlins and depositional lows; each transect was subdivided into 50-m subsections and comprised 19 to 44 subsections, depending on the length of the transect.

We examined videotapes and reports from the 1994 survey that recorded the numbers of lobsters seen along various transects (Coats and Campbell 1994, Coats *et al.* 1995). This examination permitted us to identify the cobble-boulder habitats most likely to harbor juvenile lobsters, and to identify the subsections of transects where these habitats lay. In other words, we selected the habitats in the vicinity of the outfall where juvenile lobsters (including recent settlers) were most likely to be found.

The best lobster habitats were typically sand substrates that had a cover of 26 to >75% of rocks (6 in to 3 ft in diameter) and boulders (3 to 9 ft in diameter) colonized by hydroids or covered with detritus. The best subsections identified typically had more than 75% of rocks and boulders and yet were still capable of being sampled by airlifts and quadrats (i.e., the boulders weren't of a size that would be impossible for divers to move). These habitats provide a structurally complex environment with rich food sources for lobsters. For each transect, we identified 3–4 subsections (each of which represents a 50-m segment of the transect). Our original plan (Lavalli and Kropp 1998) of having divers work linearly along three 50-m subsections was later modified to keep the divers in one location (i.e., one subsection), given the depths involved (>25 m). These depths represented a safety and time problem for the divers that necessitated expending as little time as possible in moving around the sites. Thus the divers worked in circles around downlines that were placed at specific locations at least 24 h prior to the actual dive.

We specifically chose Transect 6 because we noted smaller juveniles (vagile or adolescent phase lobsters) on the videotapes and because Coats and Campbell (1994) indicated that there were 56 lobsters present. Similarly, we saw many lobsters in Transects 1 and 2 and the 1994 report indicated that 40 and 47 lobsters were present, respectively. While lobsters were also present on Transects 3, 4, 5, they occurred in fewer numbers (16, 13, and 16, respectively). Again because of diving safety considerations, we ultimately had to replace Transect 2, most of which was deeper than safe-diving depths, with Transect 4. Thus, the sections chosen were Transect 6, Subsection 6; Transect 4, Subsection 9; and Transect 1, Subsection 4 (Figure 2). Each of these subsections was at least 1 km apart from the others.

Selection of Inshore Site Locations for Comparison Sampling

To select suitable inshore sites for comparison to the outfall site, we used lobster density data collected by the Massachusetts Department of Marine Fisheries (MADMF). MADMF has sampled several Boston Harbor sites for lobsters, but they had only one year of data (Table 3) for comparison. Because the MADMF had several years of data for Beverly/Salem Harbor sites (Bakers and Coney Islands), we chose the two Beverly/Salem Harbor locations as the inshore reference sites (Figure 3) against which the densities of EBPs at the outfall site would be compared. The several years of data provided us with repeated measures and a better database with which to assess the possible variability in numbers seen at these sites. This longer-term database for the inshore sites allowed us to determine if densities found in this survey were representative of previous densities. It also allowed us to determine if 1998 was a typical settlement year, which then allowed us to determine if the numbers of YOY and shelter-restricted juveniles found at the outfall site represented what should be found during a typical settlement year. Without such comparative data, it would have been impossible to adequately assess the relevance of the densities found at the outfall.

[To view Figure 2, click on link below:]

Figure 2. Locations of sites in Massachusetts Bay sampled for EBP lobsters in September 1998.

Table 3. Densities of juvenile lobsters at Massachusetts cobble bed sites. Data from Wahle and Steneck 1991, MADMF unpublished, Lavalli unpublished, Wahle unpublished. (NOTE: * in 1998 Nahant data indicates that some lobsters reported may be larger than EBPs.)

Year	Density (#/m^2), EBPs	Density (#/m^2), YOY	Depth (m below MLW)	Location
1995 1997	0.889 ± 1.453 0.5 ± 0.904	0.444 ± 0.882 0.167 ± 0.577	6	Bakers Island Beverly/Salem
1995 1997	3.571 ± 2.243 0.5 ± 1.243	1.833 ± 1.586 0.167 ± 0.577	4.5–6	Coney Island Beverly/Salem
1995	0.75 ± 2.121	0.0 ± 0.0	6	Peach Point Beverly/Salem
1997	0.0 ± 0.0	0.0 ± 0.0	3–6	Castle Island Boston Harbor
1997	0.0 ± 0.0	0.0 ± 0.0	3.6–6	Long Island Boston Harbor
1997	0.333 ± 0.778	0.167 ± 0.577	3–4.5	Bumpkin Island Boston Harbor
1997	0.0 ± 0.0	0.0 ± 0.0	3–4.5	Grape Island Boston Harbor
1997	0.5 ± 1.243	0.167 ± 0.577	4.5–6	Point Allerton Boston Harbor
1997	0.333 ± 0.778	0.0 ± 0.0	4.5–6	Greater Brewster Island Boston Harbor
1989 1993 1994 1998	2.8 ± 3.3 1.889 ± 1.557 2.927 ± 1.675 2.17 ± 1.95*	 0.370 ± 0.699 0.195 ± 0.436 0.25 ± 0.62	3–5	Canoe Beach II, Nahant

Figure 3. **Locations of sites in Beverly/Salem Harbor sampled for EBP lobsters in September 1998. The SESD outfall also is shown.**

Determination of Sample Sizes

Sampling for lobsters has included hand sampling (Cobb 1971, Cooper *et al.* 1975, Bernstein and Campbell 1983; Hudon 1987, Bologna and Steneck 1993), suction pumping (Able *et al.* 1988), visual surveys (Cobb and Clancy 1998; Cobb *et al.* in press) and, most recently, suction sampling (Incze and Wahle 1991, Wahle and Steneck 1991, Wahle 1993, Incze *et al.* 1997, Wahle and Incze 1997, Cobb and Clancy 1998, Cobb *et al.* in press). While suction sampling seems to undersample lobster populations by about 20% (Cobb *et al.* in press), it currently is the most successful method for locating the smallest lobsters in a population. However, one should note that it collects more than just the smallest lobsters in a population because all larger lobsters (including adolescents and adults) are hand-collected by divers prior to airlifting.

Because little was known about what the densities of EBP lobsters were prior to the 1990's, determination of appropriate sample sizes has depended on repeated samples at the same site. Wahle and Steneck (1991) used a previous year's data to determine that the cumulative mean and variance of lobster densities stabilized at 10 0.25-m^2 quadrats; however, they chose to sample 16 quadrats as a conservative measure. To sample more than was necessary to stabilize the mean and variance, Incze and Wahle (1991) chose to obtain samples from 12 0.46-m^2 quadrats. Most subsequent researchers (Wahle 1993, Wahle and Incze 1997, Wilson and Steneck unpublished, Bruce Estrella unpublished) have followed their lead and used a sample size of 12 0.5-m^2 quadrats.

However, we used a more conservative approach because we suspected that EBP lobsters were "rare" at the outfall site. Green and Young (1993) provided a method for determining the sampling effort needed for a 0.95 chance of detecting a rare species via the equation $n = 3/m$ where n is the sample size and m is the mean density of the species. As another conservative measure, we used the average density of EBPs in Boston Harbor, which is lower (usually less than 0.2 per m^2, MADMF data, unpublished) than comparable northern cobble sites, to determine the appropriate sample size to detect rare lobsters. These densities gave us a sample size of 16 for a 1-m^2 quadrat. However, because we were using 0.5-m^2 quadrats (measuring 0.7075 m on a side) and due to time limitations placed on diving at depths >20 m, our sample size for each region needed a minimum of 32 quadrats (16 x 2). For the three chosen transect areas at the outfall we determined that 12 quadrats per transect were needed, giving a total of 36 quadrats at the outfall site (or 18 m^2 surveyed). To provide an equal sample size (36) for the inshore sites, 18 quadrats were required per inshore site (Bakers and Coney Islands). These sample sizes represent a greater effort than has been used previously to assess EBP lobster densities in Maine, Massachusetts, New Hampshire, and Rhode Island.

Furthermore, the ratio of the area surveyed to the total area of cobble beds was also greater in this study. Previous work has characterized EBP lobster densities in individual cobble beds extending 13 km from Penobscot Bay to Damariscove Island on the basis of 16 0.25-m^2 quadrats (or 4 m^2) at each of 5 sampling locations (or 20 m^2 total area) (Wahle and Steneck, 1991). Similarly, EBP lobster densities were assessed in large areas in Narragansett Bay, Rhode Island (which is about 37 km long and covers 265 km^2) via the use of 12 0.46-m^2 quadrats (~5.52 m^2) at each of 6 sampling sites (or 33.12 m^2 total area). The 18 m^2 surveyed in this study assessed the density of EBP lobsters in a cobble bed extending ~5.3 km^2 (Coats *et al*. 1995). This larger sampling effort was based on the assumption that YOY lobsters at the outfall site were likely to be rare and represented the minimum number of quadrats needed to find the "rare" lobster. If, however, this assumption of rarity were false, then we would have expected to see a higher number of YOY lobsters present. Therefore, our sample size would have represented an oversampling effort compared to the efforts used to assess Maine and Rhode Island lobster populations.

Determination of Sampling Times in Mid- Versus Late Summer

Settlement of postlarvae typically occurs during the summer months of July, August, and September, but is variable from region to region. For example, postlarvae were no longer captured in neustonic sampling in Rhode Island by mid-August; in contrast, they were caught until mid-September in Maine (Incze and Wahle 1991, Incze *et al.* 1997, Wahle and Incze 1997). The task of the present survey was to determine if EBP lobsters were present in significant numbers at the outfall site compared to inshore sites and, more specifically, to determine if the nonmobile shelter-restricted (i.e., YOY) and emergent juveniles (i.e., previous year's benthic recruits) were present in significant densities; thus, we chose to conduct this survey in September. This decision was based on sampling in Nahant (by Lavalli), where the first indication of settlement-sized individuals (5.5 mm CL) was in late July but YOY were not common until after mid-August (Lavalli, unpublished data). Given that more northerly regions experience settlement approximately one month after southerly regions and that YOY (≤ 12 mm CL) are detectable through late October (Lavalli, unpublished data), a survey in September was most likely to occur after the peak of settlement of YOY.

Sampling Methods

Sampling involved multiple teams of two divers each and was carried out by the research teams of Drs. Robert Steneck (University of Maine, Walpole) and Richard Wahle (Bigelow Laboratory for Ocean Sciences)—the two leading experts on this type of sampling for EBP lobsters. During sampling one diver operated the airlift while the other carefully removed rocks and boulders. Prior to this sampling, all mobile megafauna was removed from the quadrat and placed into numbered bags—including larger lobsters that would not easily be captured by the suction of the airlift. Suction bags were replaced after completion of each quadrat and were also individually identified. These samples were taken at the locations listed in Table 4 on September 8th and 9th, 1998 (Figures 2, 3) where divers worked a radius around the baseline of a downline, haphazardly placing and sampling quadrats wherever feasible. Samples were examined for lobsters on board the R/V *Gulf Challenger* (University of New Hampshire). Lobster carapace length (CL) and crab carapace width (CW) were measured to the nearest 0.1 mm. A few representative samples were fixed in 10% formalin. Observers from Battelle, MWRA, and the New England Aquarium were present during the diving and sorting operations.

Table 4. Site characteristics for this survey. From Kropp 1998.

Location	Coordinates	Depth (below MLW)	Water Temperature (at bottom)	Substrate	Algae Types Present	Other Species Present
Outfall T6, S6	42°22.647' 70°46.318'	89 ft (~27 m)	40°F (~4°C)	Rocks 2 - >50 cm diameter	Coralline	Ophiuroids, small sea stars, decapod shrimp, one axiid shrimp, amphipods, polychaetes
Outfall T4, S9	42°22.976' 70°47.298'	80 ft (~24 m)	40°F (~4°C)	Rocks 2 - >50 cm diameter	Coralline	Ophiuroids, small sea stars, decapod shrimp, one axiid shrimp, amphipods, polychaetes
Outfall T1, S4	42°23.709' 70°48.280'	81-88 ft (~25–27 m)	37°F (~3°C)	Rocks 2–50 cm diameter	Coralline; Some Kelp	Ophiuroids, decapod shrimp, sea stars polychaetes, sea urchins, amphipods
Bakers Island	42°31.934' 70°46.993'	27 ft (~8 m)	Not taken	Rocks 2 – >50 cm diameter	Coralline; Urchin Grazed	Cancrid crabs *(Cancer irroratus, C. borealis*); green crabs (*Carcinus maenas*), snails (*L. littoralis*); mussels (*M. edulis*), nereid and/or nephtyid polychaetes
Coney Island	42°31.738' 70°50.326'	16 ft (~5 m)	60°F (~16°C)	Rocks 2–50 cm diameter	Kelp; Red Foliose Species	Cancrid crabs *(Cancer irroratus, C. borealis*); green crabs (*Carcinus maenas*), snails (*L. littoralis*); mussels (*M. edulis*), nereid and/or nephtyid polychaetes

Depths at the outfall site (~110 ft was assumed with a 10-ft tidal range) restrained the bottom time of the divers to a no-decompression limit of 25 minutes according to the AAUS Recommendations and Guidelines for Scientific NITROX diving at 32% oxygen. However, the dive plans filed by Drs. Wahle and Steneck called for an ascent to begin at 20 minutes or when the divers reached 900 psi air pressure in their tanks (whichever occurred first). Four dive teams were used to sample transect location T1-4 at the outfall site on Day 1; after a sufficient surface interval, the divers sampled the shallower sites at Bakers and Coney Islands with a no-decompression limit of 45 minutes (~45 ft was assumed here with a 10-ft tidal range). On Day 2, four teams again dove at transect location T6-6 at the outfall site for 20 minutes total bottom time and, after a sufficient surface interval, completed the final transect location T4-9 with a no-decompression limit of 18 minutes. Safety stops of 3 minutes at 20 ft were required for all outfall sites and spare tanks were placed at this depth in the event that any diver was close to running out of air.

Data Analysis

The data obtained were highly non-normal and had all of the problems previously described in Cobb and Clancy (1998) and Cobb *et al.* (in press) papers on the impact of the North Cape oil spill on lobsters populations in Rhode Island. These problems included violations of the following assumptions: (1) Random sampling—violated because lobster distribution appears to be habitat-specific and habitats are not distributed randomly. We therefore sampled only in areas at the outfall and Bakers and Coney Islands that were most likely to support lobster populations, and that were identifiable via the Hard Bottom Survey (Coats and Campbell 1994, Coats *et al.* 1995) or from previous sampling by MADMF. Furthermore, quadrats were not placed randomly, but were placed haphazardly within cobble patches. Nevertheless, the haphazard placement was done without prior knowledge of where lobsters might be. (2) Normal distribution of data—violated because our distributions were dominated by zero density observations. Data transformations would not have improved this situation. (3) Homoscedasticity of variances—violated because F_{max} tests for homogeneity of variances found that the data were heterogeneous (F_{max} ratios for all sizes of lobsters = 14.4; for YOY = 9; one-tailed F_{max} (0.05, 2, 35) = 2.07). Thus, only certain types of nonparametric analyses could be carried out. These analyses consisted of log-likelihood ratio tests (G-tests) to compare the proportion of non-zero quadrats at the outfall sites versus the inshore sites and Kruskal-Wallis comparisons of the densities found at outfall versus inshore sites. We also compared the densities obtained between years at the inshore sites with a Kruskal-Wallis test to determine if densities for this survey were similar to previous densities found in these locations. When differences were found, we used a nonparametric multiple comparisons test (Zar 1984) to determine where those differences lay.

Results

Suction samples were collected at three outfall and two nearshore stations (Table 4) during this survey. Cobble beds at the outfall and inshore transects consisted of rocks ranging in size from 2 to >50 cm diameter. At the outfall transects, much of this cobble was colonized by coralline algae. In contrast, only at the inshore site of Bakers Island was the cobble colonized by coralline algae and there was evidence that urchins had been grazing this algae. Patches of mussel beds and several kelp plants were located at Outfall Transect 1. At Coney Island, cobble consisted of rocks and mussel patches with many kelp plants present. Sand and mud substrate, shell fragments, and red foliose algae (*Chondrus*, *Polysiphonia*, *Ceramium*) were also present.

Lobsters collected at Bakers Island ranged in size from 13.2 to 110 mm CL—these size ranges span yearling sizes to fishable adult sizes; however, adolescent phase lobsters were not detected. The male to female ratio was 1:1. Lobsters collected at Coney Island were smaller and ranged in size from 7.8 to 57.4 mm CL, representing post-settlement, YOY sizes to adolescent phase lobsters. All juvenile phases were present at Coney Island. The male to female ratio was 2:1. In contrast, only two lobsters were collected at the Outfall sites. Their sizes were 8.6 (post-settlement, YOY size) and 35 mm CL (vagile juvenile size). Table 5 provides the detailed data on the sampled lobsters.

Densities of all lobsters (All Sizes), EBP (<40 mm CL) lobsters, and YOY/Yearling (<20 mm CL) lobsters were significantly different between the inshore and outfall sites (Kruskal-Wallis, $p < 0.001$, $p < 0.0001$, and $p < 0.0001$, respectively for All, EBP, and YOY/Yearling size classes). Comparisons between the proportion of non-zero quadrats at the inshore stations versus the outfall site also revealed significant differences for All Sizes (G test, $p < 0.0001$), EBPs (G test, $p < 0.0001$), and YOY/Yearling lobsters (G test, $p < 0.005$) (see Tables 6, 7, and 8). Taken together, these results demonstrated that while benthic recruitment did occur at the outfall site and there was a population of YOY and larger juvenile lobsters present, the population density of both age classes was significantly less than that found at shallower, inshore sites with similar habitat.

Table 5. Characteristics of lobsters collected at the survey.

Site	Age Class	Size (mm CL)	Sex
Bakers Island	Yearling (Shelter-Restricted and Emergent Juvenile)	13.2 15.7 16	Undetermined Undetermined Male
	Vagile Juvenile	22.4 25.5 30 30.4 30.5	Female Male Not Recorded Female Female
	Adult	110	Male
Coney Island	YOY (Shelter-Restricted Juvenile)	7.8 9.3 9.9 10.8	Undetermined Undetermined Undetermined Undetermined
	Yearling (Shelter-Restricted and Emergent Juvenile)	13.3 19.7	Undetermined Male
	Vagile Juvenile	22.2 22.6 25.8 31.8 32.7 34.7 40.0	Male Male Female Male Male Female Male
	Adolescent	46.4 51.1 57.4	Female Female Male
Outfall Site	YOY (Shelter-Restricted Juvenile	8.6	Undetermined
	Vagile Juvenile	35	Male

Table 6. **Frequency of observed zero and non-zero density observations for all lobster sizes collected.**

Region	Number of Quadrats	Zero	Non-Zero	% Non-Zero
Outfall Site	36	34	2	5.56
Bakers Island	18	11	7	38.89
Coney Island	18	8	10	55.56
Total Inshore	36	19	17	47.22

Table 7. **Frequency of observed zero and non-zero density observations for EBP lobsters (5–40 mm CL) collected.**

Region	Number of Quadrats	Zero	Non-Zero	% Non-Zero
Outfall Site	36	34	2	5.56
Bakers Island	18	12	6	33.33
Coney Island	18	8	10	55.56
Total Inshore	36	20	16	44.44

Table 8. **Frequency of observed zero and non-zero density observations for YOY and shelter-restricted lobsters (< 20 mm CL) collected.**

Region	Number of Quadrats	Zero	Non-Zero	% Non-Zero
Outfall Site	36	35	1	2.78
Bakers Island	18	15	3	16.67
Coney Island	18	12	6	33.33
Total Inshore	36	28	9	25

To determine whether the densities at the outfall and inshore sites represented a normal settlement year, we compared MADMF's (unpublished) data for 1995, 1997, and 1998 with this survey's data. Table 9 shows this comparison for mean densities per meter-square for both EBP and YOY lobsters. While densities were variable from year-to-year, there were no significant differences for any of the years at Bakers Island for YOY lobsters (Kruskal-Wallis, $0.25<p<0.5$) or EBP lobsters (Kruskal-Wallis, $0.25<p<0.5$). At Coney Island, however, significant differences were detected between the years for both YOY lobsters (Kruskal-Wallis, $p<0.001$) and EBP lobsters (Kruskal-Wallis, $0.005<p<0.01$). Because of these differences, a nonparametric multiple comparison test (Zar 1984) was used to determine exactly which years differed from each other. This test revealed no significant differences for YOY lobster densities between the MWRA 1998 data and the MADMF data for years 1995 ($0.05<p<0.1$), 1997 ($0.5<p$), and 1998 ($0.5<p$). Furthermore, there were no significant differences for EBP lobster densities between the MWRA 1998 data and the MADMF data for years 1995 ($0.2<p<0.5$), 1997 ($0.2<p<0.5$), and 1998 ($0.5<p$). However, the MADMF data differed for YOY lobsters between 1995 and 1997 ($0.01<p<0.02$) and 1995 and 1998 ($0.002<p<0.005$) and for EBP lobsters between 1995 and 1997 ($0.002<p<0.005$) with significantly greater densities found in 1995. Because the MWRA 1998 data collected at both Bakers and Coney Islands did not differ significantly from any of the previous years of sampling at the same sites, it strongly suggests that the numbers found there represent a "typical" settlement year. If these densities represent a typical year for these inshore sites, we also argue that it is most likely that the densities found at the outfall site are also representative of a "typical" settlement year.

Table 9. Comparison between years of mean densities (per m^2 ± SD) of EBP and YOY lobsters at Coney and Bakers Islands. 1995 and 1997 data from MADMF unpublished. NOTE: In this case, YOY is defined as <12 mm CL to make the survey data directly comparable to MADMF's data.

Site	Age Class	MADMF 1995	MADMF 1997	MADMF 1998	MWRA 1998
Bakers Island	YOY (< 12 mm CL)	0.444 ± 0.882	0.167 ± 0.577	0.167 ± 0.577	0.000 ± 0.000
	EBP (5–40 mm CL)	0.889 ± 1.453	0.5 ± 0.904	1.833 ± 1.992	0.888 ± 1.410
Coney Island	YOY (< 12 mm CL)	1.833 ± 1.586	0.167 ± 0.577	0.000 ± 0.000	0.444 ± 0.856
	EBP (5–40 mm CL)	3.571 ± 2.243	0.5 ± 1.243	1.333 ± 1.969	1.556 ± 1.756

DISCUSSION

In its letter to Secretary of Environmental Affairs, Trudy Coxe, dated 22 May 1998, the Outfall Monitoring Task Force recommended that MWRA conduct a "suction sampling survey in the vicinity of the future outfall site during the summer of 1998 to sample shelter-restricted early benthic phase juvenile (EBP) lobsters." The OMTF also recommended that the MWRA's proposed survey strategy be reviewed by their members prior to the study being conducted. MWRA complied with this recommendation and forwarded a copy of the proposed study plan (dated 22 June 1998) to the OMTF members and interested parties, prior to approving the contracting of Drs. Robert Steneck and Richard Wahle, the two foremost experts in this technique, to conduct the field sampling. Comments returned on the proposed study plan focused only on the dive protocol and diving safety at the depths of the outfall site. These concerns were addressed via conversations with Mr. Edward Maney, President of AAUS and Mr.

Vin Malkoski of MADMF and AAUS Scientific NITROX diving regulations were followed in the dive plan presented by Drs. Wahle and Steneck. Additional comments on the dive plan were received and considered in the final planning for the survey. The dive plan was approved by the dive safety officers, who were not survey participants, of the University of Maine and Bigelow Labs.

The OMTF further stated that "if a properly designed survey finds no significant numbers (i.e., lower abundances than in contiguous coastal areas) of EBP juveniles in the vicinity of the future outfall site, issues and concerns about outfall impacts on those life stages will be re-evaluated." The proposed survey plan was designed to maximize the chances of locating juvenile lobsters, particularly young-of-the-year, at the outfall vicinity. This was accomplished by first assuming that young-of-the-year would be rare and using the formula from Green and Young (1993) to determine the sampling effort needed to locate the rare lobster. In the event that our assumption of rarity was proven false (via the determination of high densities of young-of-the-year), then the sampling effort calculated from Green and Young (1993) would have been greater than that necessary to detect YOY lobsters in the vicinity of the outfall. Such was not the case. The fact that our sampling effort revealed the presence of young-of-the-year lobsters at the vicinity of the outfall indicates that the calculated sample size was sufficient for its stated purpose. Because the densities of these young-of-the-year lobsters were low, it also indicates that they are rare in the vicinity of the outfall—were this not the case, then we should have captured greater numbers in our samples.

The use of previous hard bottom survey data to select sites that were likely to be good habitat for lobsters also maximized the chance of sampling young-of-the-year and yearling lobsters, as did the awarding of the sampling contract to Drs. Robert Steneck and Richard Wahle who have been assessing EBP lobster densities via suction sampling since 1987. Nevertheless, and despite all efforts to maximize the chance of locating high densities of young-of-the-year and yearling lobsters, significantly fewer young-of-the year and yearling lobsters were found in the vicinity of the outfall. Furthermore, comparisons between all sizes of lobsters (mostly YOY, EBPs and adolescents) and EBPs found at the inshore and outfall sites also revealed significant differences, again with fewer lobsters of these age classes present in the outfall vicinity. Not only were the densities of juvenile lobsters lower in the vicinity of the outfall, but the proportion of zero quadrats to quadrats returning lobsters was also lower. Again, this measure of non-zero quadrats relates to the density of the lobsters present and provides additional evidence that EBP lobster densities in the vicinity of the outfall are significantly lower than those at nearby inshore habitats.

Comparisons between previous years of sampling at the inshore sites revealed that the densities obtained by MWRA in 1998 were no different from those obtained by MADMF divers in 1995, 1997, and 1998. Thus, MWRA's 1998 densities appear to represent typical densities found at these locations. By extrapolation, if one accepts that MWRA's 1998 densities are representative of a typical year inshore, they probably are also representative of a typical year in the vicinity of the outfall.

These results agree with all of the previous data accumulated on the behavior and preferences of the settlement stage of the lobster and the subsequent early benthic juvenile phases (reviewed in

Lavalli and Cowan's 1998 report to the OMTF). Given the physical characteristics of the outfall site, where a strong seasonal thermocline and a halocline form a distinct pycnocline that would repel most postlarvae that are competent to settle (Boudreau *et al.* 1992) and where depths may exceed 30 m, it is of little surprise that densities of young-of-the-year and yearlings are lower. Furthermore, for postlarvae that do settle in this area, survival rates most likely would be low and growth rates severely retarded. MacKenzie (1988) showed that survival rates of postlarvae are reduced to <26% at 10°C compared to those raised at higher temperatures (12, 15, 18, and 22°C) where survival was >75%. This 10°C cut-off is warmer than the bottom water temperatures at the outfall measured in September 1998 that ranged from 3 to 4°C (Kropp 1998, Table 4) and in most of the previous five years for which data have been collected (Cibik *et al.* 1998). Also, postlarvae benefit by selecting a habitat where the thermal regime can support rapid growth, which makes them less vulnerable to predators (Wahle and Steneck 1992, Wahle 1992). Data from St. Andrews, New Brunswick, where temperatures do not exceed 13°C, show that postlarvae reach stage IV between late August and mid-October and grow rapidly to about 12–16 mm CL until temperatures drop to 5°C in December (Waddy *et al.* 1995). They then overwinter without growing and resume their molting pattern in the spring as temperatures rise. However, if the postlarvae settle in an area where temperatures are less than 5°C, their growth may be inhibited altogether or their grow-out time may be greatly extended. With juveniles and adults, molt induction is blocked at 5°C (Waddy *et al.* 1995). At present, there are no data to indicate whether this is also the case for early benthic phase juveniles, although there are data that show inhibition of molting of larvae from stage I to II (Templeman 1933). There is but one report of one YOY lobster molting at 0°C (Barshaw and Bryant-Rich 1988). In *Cancer irroratus*, larvae reared at 10°C have lower net growth efficiencies than siblings raised at elevated temperatures because they divert protein from tissue synthesis and use it in energy production (Johns 1981). Again, we have no data similar to this for lobster larvae or early benthic phase juveniles, but if such a process were occurring, this could severely impact the newly settled lobster's ability to outgrow its predators.

In contrast, shallow inshore populations of EBP lobsters benefit from the warmer temperatures there (e.g., September 1998 temperatures were 16°C at the inshore stations; Kropp 1998) and would presumably grow very rapidly attaining a much larger size than their outfall counterparts. Evidence from *in situ* predation studies indicate that lobsters >30 mm CL are significantly less vulnerable to inshore fishes than those between either 5–7 mm CL or 15–20 mm CL (Wahle and Steneck 1992). Thus, retardation of growth rates at low temperatures could prolong the vulnerable phase of EBP lobsters and would be predicted to result in a further dwindling of the population of early benthic phase lobsters at the outfall vicinity. Optimally, postlarval lobsters should settle where they can maximize the number of warm temperature days and thus their molting and growth rates prior to overwintering.

Densities of young-of-the-year at Maine sites at different depths (5, 10, and 20 m) decline with increasing depth (see Figure 1), as would be predicted from the behavior of the postlarvae. Unfortunately, long-term databases of densities at varying depths are not yet available for Massachusetts, but recent sampling efforts by Dr. Wahle at inshore (Nahant) and offshore (Stellwagen Bank) stations indicate that this trend exists because young-of-the-year lobsters were collected at inshore sites, but not at offshore sites (Wahle, personal communication).

Furthermore, sampling by Wahle in Boston Harbor also failed to detect young-of-the-year lobsters; similarly, samples collected by MADMF at various locations in Boston Harbor have only returned low densities compared to sites such as Beverly-Salem or Nahant's Canoe Beach. Without understanding the picture of current transport and postlarval supply to these areas, it is difficult to determine why inshore cobble beds vary in their ability to attract settling postlarval lobsters.

Taken together, the behavior of postlarval and early benthic phase lobsters, the thermal conditions present at the outfall, and the results of the present study all demonstrate that the outfall vicinity is not a significant site for settlement and probably contributes significantly fewer individuals per unit area to future larger-juvenile, adolescent, and adult populations than do nearby inshore sites that have greater densities. Thus, in accordance with the OMTF recommendation, the purported impacts of the outfall on young-of-the-year and early benthic phase lobsters thus should be re-evaluated.

ACKNOWLEDGEMENTS

We would like to acknowledge the extraordinary efforts put into the collection of this data by the scientific diving crews of Dr. Robert Steneck and Mr. Carl Wilson (University of Maine, Walpole, Maine) and Dr. Richard Wahle (Bigelow Laboratory for Ocean Sciences, Boothbay Harbor, Maine). We would also like to thank Drs. Wahle, Steneck, and Bruce Estrella (MADMF) for sharing their unpublished benthic sampling data to make the necessary comparisons with densities obtained in this survey and for their criticisms and comments on both the survey plan and the relevance of the data. Others who aided in the design of this study include Vin Malkoski, dive officer from MADMF; Dr. Doug Coats from Marine Research Specialists, Ventura, California; Edward Maney, President of AAUS. Dr. Jelle Atema from Boston University and Mr. Charles Vautrain from Duxbury High School allowed us the use of their SuperVHS VCRs.

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