Impact of Dredged Sediment Disposal on Lobster and Crab Abundance and Movements at the Rockland Disposal Site

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13. ABSTRACT

A survey was conducted at the Rockland Disposal Site (RDS) in 2002 to assess the effect of late autumn dredged material disposal on seasonal lobster migration. A trap-based mark-recapture methodology was employed before and during a series of disposal events at RDS. Seventy-two traps were set in three areas: the disposal area and two control areas. Traps were pulled once a week over a period of seven weeks. Trapped lobsters were counted and tagged, and were then released at the same trap location. Crab abundance was also recorded.

Approximately 57,000 m^3 of dredged material was disposed at RDS over the course of the survey. Side-scan imagery collected before and after the autumn 2002 disposal revealed a new mound covering 7-18% of the disposal site. A decline in lobster catch rates was observed in both the disposal area traps and the adjacent control area traps, associated with a decline in local lobster abundance. Seasonal migration of lobsters out of Penobscot Bay was likely the reason for the decline, and no statistically significant impact of disposal on lobster movement was detected. The abundance of migrating lobsters in the area suggests that postponing disposal at RDS until after the autumn emigration period could minimize direct mortality impacts to lobsters in the area. Increased crab catch was observed in the disposal area relative to the control areas following the onset of disposal activity. Crab catches were highest at traps nearest the newly deposited sediment, possibly because of the rich source of food provided by the sediment deposition.

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EXECUTIVE SUMMARY

Penobscot Bay, Maine is one of the most productive lobster (*Homarus americanus*) fishing grounds in the species' range. The Bay is also host to the Rockland Disposal Site, a 0.25 nmi^2 area that periodically accepts dredged sediment from regional harbors. This study was conducted in response to fishing industry and state marine resources agency concerns that late-autumn dredged material disposal at the Rockland Disposal Site could negatively impact lobster migration.

We applied a trap-based mark-recapture methodology to assess the impact on local lobster catch, abundance and movements during a period of disposal beginning in late autumn 2002. We set 72 lobster traps in a geo-referenced, 1.7 by 0.9 km array over the disposal area. The array was divided into three equal areas: a treatment area, impacted by dredged material, flanked by two control areas. Sampling began on November 1, 2002 prior to onset of disposal on November 18, and continued until December 19. We counted lobsters and crabs (*Cancer irroratus*) in each trap haul, tagged all lobsters and released them at the same trap location.

From the onset of disposal to the end of our sampling there were 81 disposal events, totaling 57,105 m^3 of material. Pre- and post-disposal side-scan sonar surveys revealed a new mound of soft sediment covering 7-18% of the treatment area (44,170 - 108,881 m^2). Lobster catch rates declined over the full course of the study, and the decline at the impacted area largely paralleled those in the control areas. Preliminary mark-recapture analysis supports patterns observed in catch rates, reflecting a decline in abundance and not merely a decline in the propensity to enter traps.

No statistically significant impact of disposal on lobster abundance or movement was detected. Declines in the disposal area were more likely the result of the regular fall migration of lobsters out of the Bay than of dredged material disposal. Recapture of tagged lobsters outside the study area by harvesters reflects this seasonal pattern of lobster movements. However, the abundance of emigrating lobsters at the disposal site in mid-November suggests that direct impacts to lobsters may be minimized when disposal occurs after the autumn emigration period. The quantitative data collected by this study provides a basis by which to assess potential impacts for future projects.

In contrast, the overall catch of rock crabs (*Cancer irroratus*) increased dramatically in the treatment area relative to the control areas within a few weeks of the onset of disposal. Moreover, crab catches were highest at traps nearest the newly deposited sediment. Thus, while we did not detect an effect of disposal on lobsters, crabs aggregated around the disposal site possibly because it provided a richer source of food than the surrounding area.

1.0 INTRODUCTION

The disposal of dredged sediments from harbors and channels poses a potential hazard to benthic habitat, resident biota, and fisheries (Kester et al. 1983, Harvey et al. 1998, Grigalunas et al. 2001). Here we report the results of a short-term study to evaluate the impact of the disposal of dredged material on the local abundance, catch rates, and movements of lobsters (*Homarus americanus*) and crabs (*Cancer irroratus*) in the immediate area of the Rockland Disposal Site in Penobscot Bay, Maine.

Penobscot Bay is home to several industrial harbors, including Rockland, Belfast, Camden, and Searsport, all of which support deep-draft shipping traffic. Periodically these harbors are dredged to maintain shipping channels. Sediments from these and other harbors in the bay are disposed of at the Rockland Disposal Site, centrally located in the Bay in approximately 75 m of water.

Penobscot Bay is also one of the most productive lobster fishing grounds in New England (Steneck and Wilson 2001). The disposal site is located in an area of the bay that is actively fished during the warmer months – May through November. The impact of dredged material disposal on this valuable resource has not been measured. In response to concern expressed by harvesters, as well as the Maine Department of Marine Resources, the U.S. Army Corps of Engineers agreed to restrict disposal activities to the cooler months and to conduct an impact study on the effects of sediment disposal on lobster abundance and movements in the immediate area of the disposal site.

Prior surveys of the site have been conducted by the New England District (NAE) of the U.S. Army Corps of Engineers (SAIC 1989, 2000). These surveys characterized the bathymetry, substratum, and benthic biota of the site. Observations of lobsters were made during the latter survey, but were limited to video footage of a single individual and a number of possible lobster burrows. Therefore, the primary objective of this study was to evaluate the effects of depositing dredged sediments on seabed structure, lobster abundance, trap catch rates and movements in the defined study area around the disposal site. Reports from lobster harvesters of tagged lobsters outside the study area are included to further illustrate patterns of seasonal movement. Because the crab, *Cancer irroratus*, was such a prominent component of the catch, and is also commercially exploited to a limited extent, evaluating disposal impacts on these crabs became a secondary objective of the study. This study involved seabed mapping by side-scan sonar and spatially referenced trap-based mark-recapture sampling in a comparison of treatment and reference areas before and after the onset of sediment disposal.

2.0 METHODS

2.1 Study Area

The study was centered on the disposal grounds buoy (labeled DG) located at the Rockland Disposal Site at the mouth of Penobscot Bay, Maine (44° 07.160' N, 69° 00.102' W) approximately mid way between Rockland Harbor and North Haven Island (Figure 2-1). This area largely consists of a mix of sediments (mud, sand, gravel), both naturally occurring, as well as the remains of previous disposal events. Water depths at the site range from 65 to 75 m below mean low water, and the area is subject to north-south trending tidal currents. Between 1985 and 2001 there were 585 disposal events (= scow loads) amounting to 586,050 m^3 of material. Disposal activity during this study commenced on November 18, 2002 and continued beyond the time frame of the study. Between 18 November and 20 December 2002 there were 81 disposal events, totaling 57,105 m^3 of material.

The site is located in a common transit route with considerable shipping traffic. Although the area is also heavily fished for lobsters during the warm months, fishing activity was on the decline at the beginning of the study and little to no gear was present in the area by the end of the study.

Temperature was recorded 7.5 km south of the study area by a Gulf of Maine Ocean Observing System (GoMOOS) data buoy that monitors the water column between 0 and 50 m. Over the course of the study the water temperature at 50 m, nearest the depth of our study area, fell from 12 to 7 °C.

2.2 Experimental Design

2.2.1 Side-Scan Sonar Surveys

Side-scan sonar surveys of the experimental area were conducted on two occasions: once before and once after a period of disposal activity (14 November and 20 December 2002, respectively). The surveys utilized an EdgeTech DF1000 dual frequency digital side-scan sonar towfish coupled to a Triton-Elics International (TEI) topside processing unit by a double reinforced kevlar cable. Data were collected on both 100 and 500kHz at 200 m range. The 500-kHz data were discarded due to poor image quality resulting from towing depth. All data were acquired in TEI's Isis® Sonar v. 6.0 and survey navigation was logged through The Capn digital navigation software. Survey lines were oriented east-west and spaced 125-150 m apart to ensure 100% coverage. Survey lines extended at least 200 m beyond the area of interest to eliminate distortion associated with turns. Sea states for both surveys were less than 1.5 m.

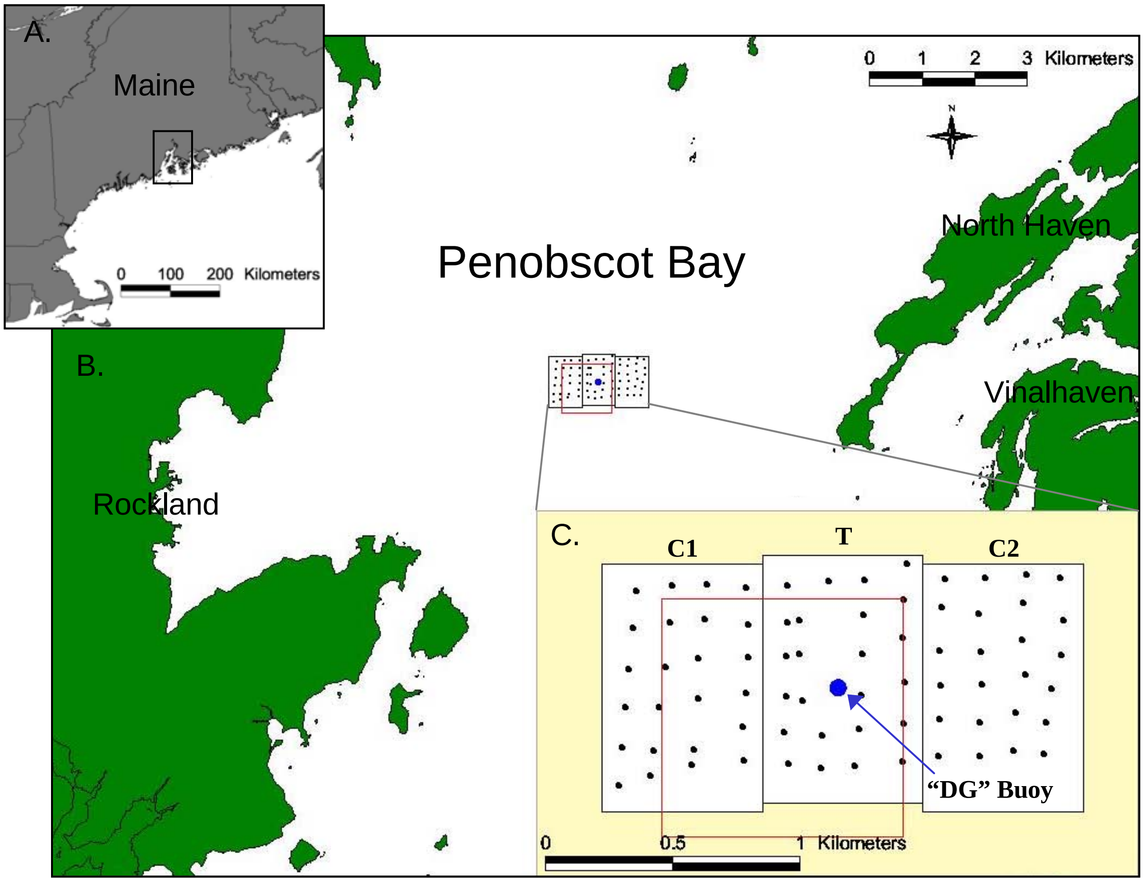


Figure 2-1. Location of study area within Rockland Disposal Site. a) Location of Penobscot Bay in Maine. (b) Location of Rockland Disposal Site (red box) and study area (black boxes) within Penobscot Bay. (c) Study area was centered on the disposal grounds buoy ("DG", blue dot), the designated location of disposal events during the study. A spatially referenced array of 72 lobster traps (black dots) was spread uniformly over three equal experimental areas: a treatment area (T), and two flanking control areas (C1, C2), less likely to be impacted given the north-south tidal flow.

Post-processing was conducted with TEI Isis® Sonar v. 6.0 and DelphMap™. Imagery was slant and speed corrected with an appropriate layback applied. Gains were set based on a uniform muddy seafloor observed on the first survey. The gains were not changed while processing the second survey's data. All imagery was viewed in grayscale with soft sediments appearing as light shades and hard substrates as dark shades. Imagery was exported to GeoTif format for spatial analysis in geographic information software packages by ESRI.

These geo-referenced images were imported into ESRI's ArcView 3.2 GIS software to conduct a before-after comparison. First, the trap array and three study areas were overlaid as constant reference points. In addition, each of the three study areas was divided into six subsections and assigned a unique identifier so that corresponding sub sections in the before and after images could be enlarged (1: 2100) and compared visually. This comparison was a somewhat subjective analysis; nonetheless, criteria for noting substrate changes were established and followed. First, in corresponding before and after subsections, obvious differences in geometric features (anomalies) were noted. Second, the grain size composition of each subsection was classified into one of three categories: fine sediment, coarse gravel and boulder, and a mix of the two. Our interpretation of sediment types and alterations from side-scan images was verified by the Marine Geology Working Group at the University of Maine Department of Geological Sciences.

2.2.2 Trapping Protocol

To capture both the spatial and temporal effects of the dredged material disposal on lobster and crab catch rates, we employed a Before-After-Control-Impact (BACI) experimental design (e.g., Underwood 1991, 1992). We set 72 lobster traps in a 6 x 12 grid centered on the DG buoy and spread over a 0.9 x 1.7 km area (1.53 km^2, Figure 1-1). Traps were thus spaced approximately 180 m apart on the short axis and 155 m apart on the long axis. Three traps in one of the central columns were offset from this pattern by approximately 100 m to the west to avoid damage from tug and barge traffic moving in and out of the disposal site to unload dredged material. Each trap location was spatially referenced with differential GPS using a North Star 951 XD unit with an accuracy of ± 3 m. The array was arbitrarily divided into three equal areas: a treatment area (T) where disposal impacts were likely to occur, and two flanking control areas (C1, C2) where no disposal activity was planned.

We used standard commercial lobster traps (1.2 x 0.6 x 0.4 m) modified to prevent the escape of sub-legal lobsters (<83 mm carapace length). Traps were hauled and reset at the same locations on a bi-weekly and then weekly basis from 1 November 2002 until 19 December 2002. Traps were returned to within approximately 20 m of the original geo-referenced location. Some 18 traps were lost over the course of the study resulting in minor loss of data. In most cases traps were replaced by the next sampling occasion.

For each trap, all lobsters were measured (carapace length in mm) and sex was determined. The number of claws and legs and shell condition was recorded. In addition, because of the large volume of crabs (*Cancer irroratus*) in the catch, we began to record number of crabs per trap on the second sampling occasion. On two sampling dates the entire contents of haphazardly selected traps was measured to determine the size composition of crabs in the catch.

All trapped lobsters were tagged. Given the short time frame of this project, we chose not to use permanent tags that would be retained through the molt. We used two types of "Zip-tie" tags stamped with a unique identification number and phone number (Figure 2-2). Lobsters were tagged with two tags, one around each cheliped, so they could still be identified as a recapture in the event one claw was lost, thereby allowing an evaluation of tag loss rate. Lobsters missing one or both claws, therefore, were not tagged and are not included in the mark-recapture analysis. All lobsters and crabs were released at the same trap location at which they were caught. This combination of spatial referencing and marking lobsters allowed us to evaluate the spatial patterns of catches and lobster movements over time.

2.2.3 Statistical Analysis of Catch

In the analysis of catch rates we report catch-per-haul as the response variable, as opposed to catch-per-day (= catch per haul / soak time in days). We felt that to use the latter would involve an assumption of a linear relationship between catch and trap soak time that may not be valid, especially in cases where traps may fill to capacity, most likely with crabs in our case. In that case, catch rate in the days before the trap fills up can be underestimated. Statistical analysis using the two forms of catch rate, however, did not alter the major conclusions of the study regarding lobster catch.

We employed a single factor ANOVA to test the null hypothesis that the proportional change in catch of lobsters and crabs after the onset of disposal was no greater in the treatment area than in the adjacent control areas. We used proportional changes as the response variable in this case to standardize for pre-existing area-specific differences in absolute catch, which were less important to the assessment of disposal impacts. To determine proportional change in catch for each trap we subtracted the average catch per haul after the onset of disposal from the average pre-disposal catch; this difference was then calculated as a proportion of the pre-disposal average. Thus, if the average catch for a trap declined after disposal began, we would record a negative proportional change.

Figure 2-2. Lobster with two zip-tie "knuckle tags" bearing identification and phone numbers. Only two-claw lobsters were tagged.

Based on the footprint of newly disposed sediment, we further refined our analysis of catch impacts to the eight traps at the center of the treatment area that were most likely to be impacted, along with their counterparts in the two reference areas (C1, C2) to balance the comparison with the same number of traps per area. If the ANOVA resulted in a significant treatment effect (at $p < 0.05$), we employed an SNK post-hoc test to make pair-wise comparisons of proportional catch in the three experimental areas. Significance of the post hoc test was then set at $p < 0.01$.

2.2.4 Fine-scale Spatial Analysis of Catch

In ArcView 3.2 a d-base table of catch data for each trap was joined to the attribute table of a shape file containing the latitude and longitude positions of the traps that had been projected as UTM Zone 19N NAD 83. Using the Interpolate Grid function of the Spatial Analyst Extension, we could map the time series of distributions of lobster and crab catches over the study area. Missing values were distinguished from zeros in the analysis by interpolating among the nearest existing values.

2.2.5 Mark-Recapture Analysis of Lobster Population

<u>Modeling Approach</u>: The application of multiple mark-recapture methods provides a powerful means to estimate population size, gains, and losses in an open population as long as certain assumptions are satisfied (e.g., Lebreton et al. 1992). We assume that: (1) tagged individuals mix freely with the remaining population, (2) no tags are lost, (3) tagging does not alter survival or behavior in a way that would change an individual's capture probability relative to untagged individuals, and (4) individuals that leave the study area do not return. We evaluate the degree to which we satisfied these assumptions in the results.

The standard Jolly-Seber multiple mark-recapture approach to estimating population size from mark-recapture data is inefficient for this experiment, however, in that: (i) it cannot take explicit account of exchanges of lobsters between experimental plots; and (ii) it cannot be used to formulate experimental hypotheses appropriate to the 'BACI' design used here. Accordingly, a new approach to mark-recapture modeling was developed to include both these facilities. This is particularly important in the current case, given the paucity of the recapture data (only 34 out of 877 tagged lobsters were recaptured during the experiment, with eight observed movements between experimental plots).

The model was constructed in terms of capture probabilities p_i and probabilities of exchange between sites (plots) ϕ_{ij}. Catches at each site, C_i, are related to population size at the start of fishing by:

$$\begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} = \begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} \\ \phi_{21} & \phi_{22} & \phi_{23} \\ \phi_{31} & \phi_{32} & \phi_{33} \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \\ p_3 \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \end{bmatrix}.$$

Note that for $i=j, \phi_{ij}$ is simply the site fidelity of a lobster at site i. Using this equation as the basic building block for a mark-recapture model, the probability of any observed capture history can be expressed in terms of values of ϕ_{ij} and p_i. Capture histories specify not just occasions of release and recapture, but also sites. The capture histories are specified in an analogous way to that given in Lebreton et al. (1992). A likelihood for the data given particular values of ϕ_{ij} and p_i can be calculated by assuming that the observed frequencies of capture histories are drawn from a multinomial distribution. An iterative approach (quasi-Newton algorithm) is used to maximize this likelihood and thus obtain maximum likelihood estimates of ϕ_{ij} and p_i.

Population sizes at the start of each fishing occasion on each site are estimated by solution of the matrix equation for N_i using the observed catch numbers and the mark-recapture estimates of ϕ_{ij} and p_i. Accounting for the exchanges between sites, this is analogous to the standard Jolly-Seber method of population size estimation (e.g. Pollock et al. 1990).

Application of the model: The model was applied to the mark-recapture data assuming that the ϕ and p might vary between occasions as well as sites. Given the sparse data and large number of parameters for a full model of this type, a restricted time-dependent model was specified, whereby site and time effects on the exchange/fidelity (ϕ) and capture probabilities (p) are assumed to be additive rather than fully independent. This model is denoted ϕ_{s+t}, p_{s+t}. Simplifications of this model were also considered, down to a model of constant parameters over time and site (ϕ, p). The constant ϕ model needed to retain the distinction of exchanges between adjacent (e.g. Control 1 and Treatment) and non-adjacent sites (Control 1 and Control 2).

In addition to these time- and site-dependent models, specific experimental hypotheses were also specified. 'BACI' made a complete distinction between capture and movement processes before and after the first disposal event, with no other specification of time-dependence. 'BACI2' made the distinction only in terms of processes involving the Treatment plot.

All parameters were logistically transformed in the estimation procedure. Cumulative logistic transformations were applied to the ϕ parameters for each occasion, to ensure that summed transfer probabilities did not exceed 1 for any site. Since soak times and numbers of traps were not constant throughout the experiment, capture probabilities were scaled to trap days and movement (ϕ) parameters were scaled to intervals between trap haul occasions. The most parsimonious model for the data was selected by minimum value of Akaike's Information Criterion (AIC). The bias-corrected version of this criterion, AIC_c was used because of the small sample size (Burnham & Anderson 2002).

2.2.6 Recapture Reports from Lobstermen

Word of the tagging project was spread by local media with a request to lobster harvesters to report the date and location of tagged lobsters in their catch. The fact that fishing activity was on the decline during the course of the study tempered our expectations for a response. Nonetheless, the returns we did get during and after the field work contribute a larger scale view of lobster movements beyond the boundaries of our experimental trap grid. Clearly, any interpretation of lobster movements from harvester reports must take into account the fact that fishing effort is not uniform in time or space. We did not use these data in our analysis of disposal impacts, however.

3.0 RESULTS

3.1 Habitat Impacts

The side-scan sonar survey prior to the onset of disposal events revealed a preexisting heterogeneity and a number of prominent features on the sea bed. Previous disposal events may have contributed to the seabed structure we observed (Figure 3-1a). In general, sediments on the western side of the study area consisted of coarser material than those on the eastern side (Figure 3-1b). The mottled, high reflectance area directly west of the disposal buoy corresponded with the location of the prior disposal events. The more uniformly dark, high reflectance area directly below the buoy corresponds with the disposal locations during 2001. The difference in appearance between the two disposal mounds is likely due to differing grain size and degrees of reworking. Other prominent features included a large rock outcrop just inside the western border of the C1 area and a non-contiguous vein of undetermined high reflectance material trending North East/South West through the C2 area. All of these features, with the exception of the last, were also described in a previous disposal area monitoring report (SAIC 2001).

Examination of the post-disposal side-scan sonar images revealed an area of new low reflectance soft sediment roughly centered on the DG buoy that was not present in the pre-disposal images (Figure 3-2, 3-3). This feature corresponds with the locations of disposal events since the study began (Figure 3-3a). Combining the extent of the new mound of soft sediment with the known locations of most recent disposal events we delineated a conservative estimate of the impacted area that covers 7% (44,170 m^2) of the Treatment area (Figure 3-3c). A less conservative estimate of the outer limits of the impacted area incorporated more subtle differences in substrate between the pre- and post-disposal side-scan images. This outer limit of impacted area covered 18% (108,881 m^2) of the Treatment area. Determining the limited area of this impact area caused us to narrow our analysis to the most central traps in the treatment area most likely to be impacted (Figure 3-3a). This became the basis for conducting the secondary analysis of trap catch impacts in the more restricted area.

3.2 Catch Patterns

A total of 1,056 lobsters were caught over the seven-week study period. The mean carapace length was 83 mm (SD = 9 mm). Culls, lobsters missing one or both claws, increased from 7% to 19% of the catch over the course of the study. A total of 28,610 crabs were caught. The catch was entirely composed of *C. irroratus*, except for six green crabs (*Carcinus maenas*) that appeared late in the season and are believed to have originated from the disposal sediments. The mean *Cancer* crab carapace width was 108 mm (SD = 16).

The time series of lobster and crab catch reveal contrasting patterns (Figure 3-4). Crab catches were roughly ten fold higher than lobster catches. Lobster catch rates

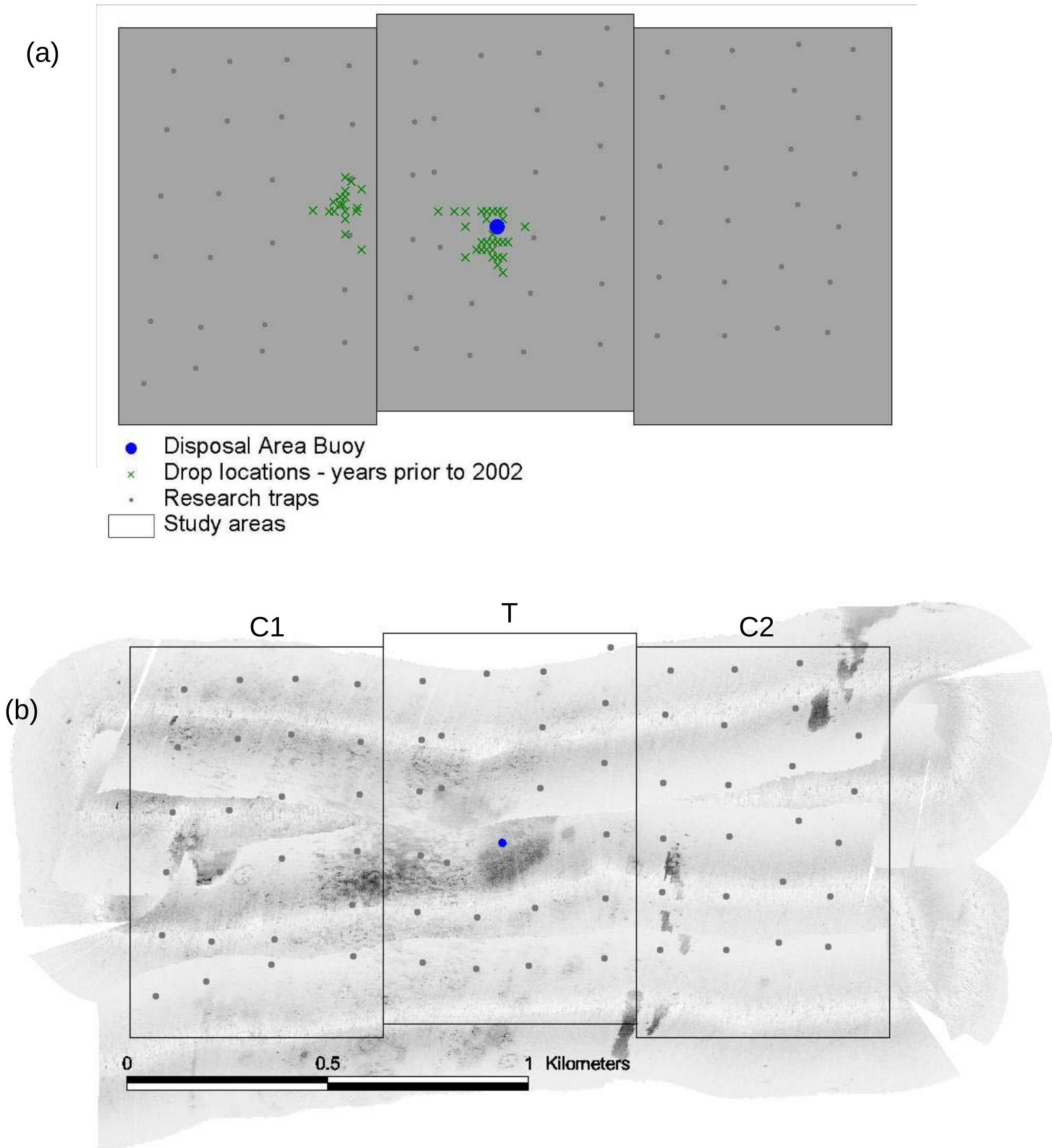
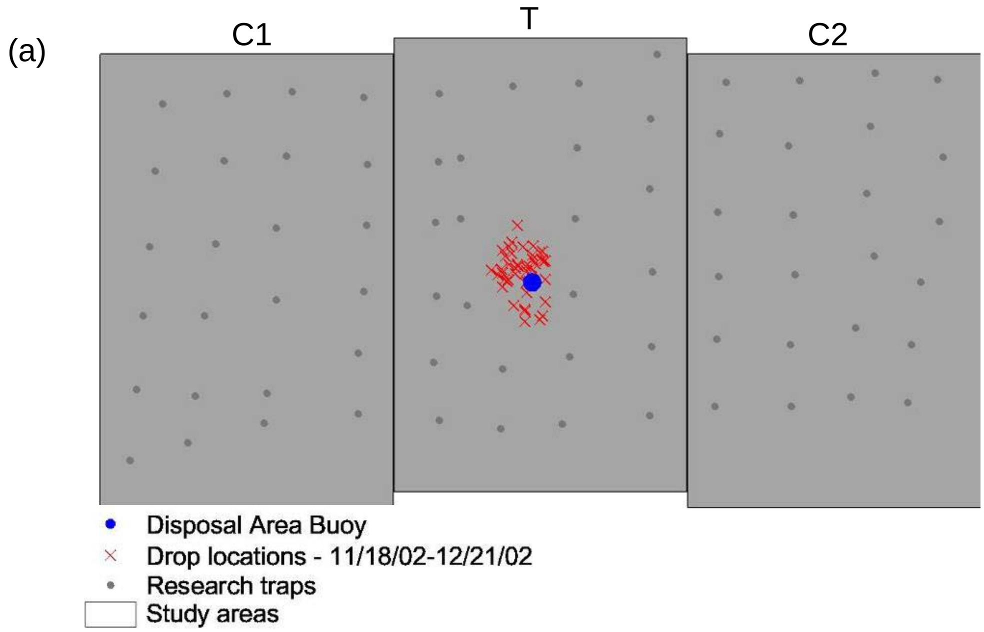


Figure 3-1. Study area with pre-survey disposal events and pre-survey side-scan sonar. (a) Study area with the location of disposal events between 1999-2001 for which GPS positions were taken (green x). Not shown are pre-1999 disposal events for which LORAN coordinates were taken that do not map accurately in ArcView. (b) Side-scan sonar survey of study area conducted on November 14, 2002 immediately prior to the onset of disposal events during this study.



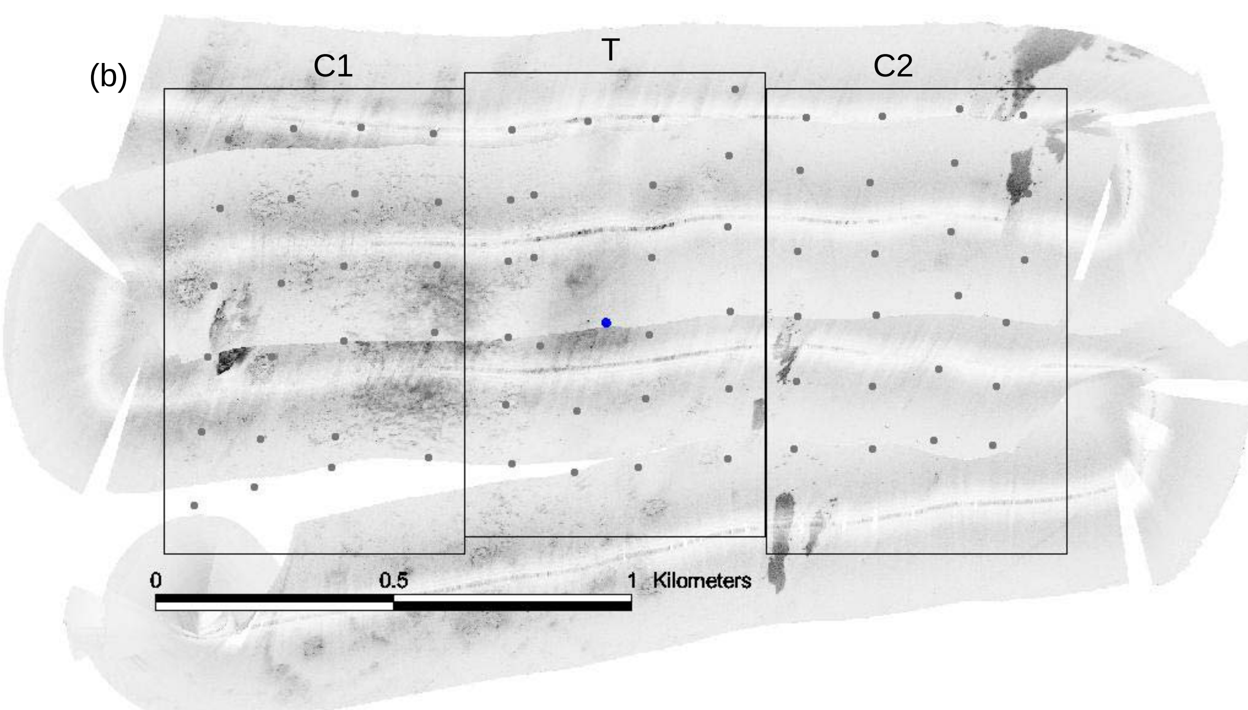


Figure 3-2. Study area with disposal locations and post-disposal side-scan sonar. (a) Study area indicating location of disposal events during this study between 18 November and 21 December 2002 (red x). (b) Side-scan sonar survey of study area conducted on December 20, 2002 after several weeks of disposal events.

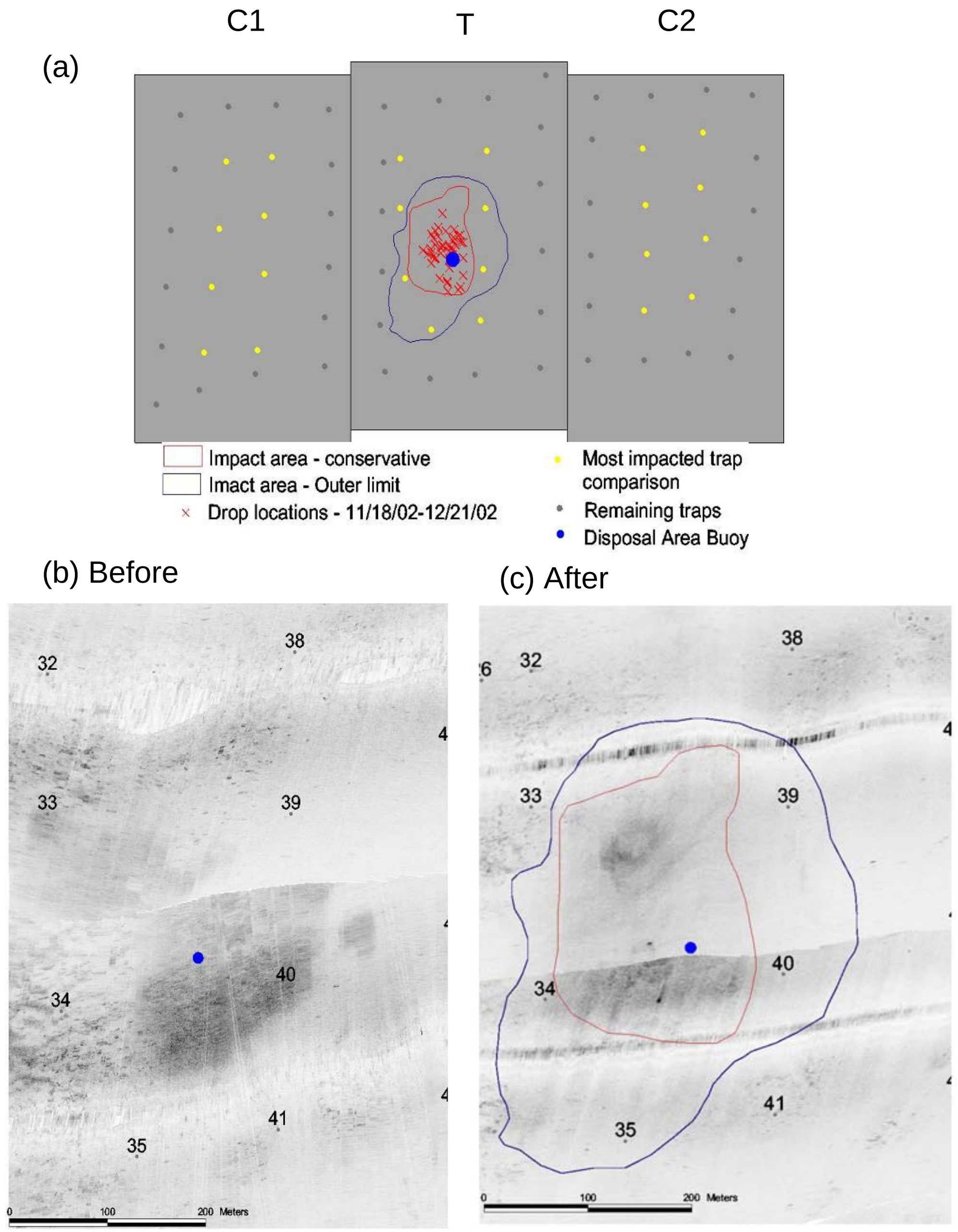
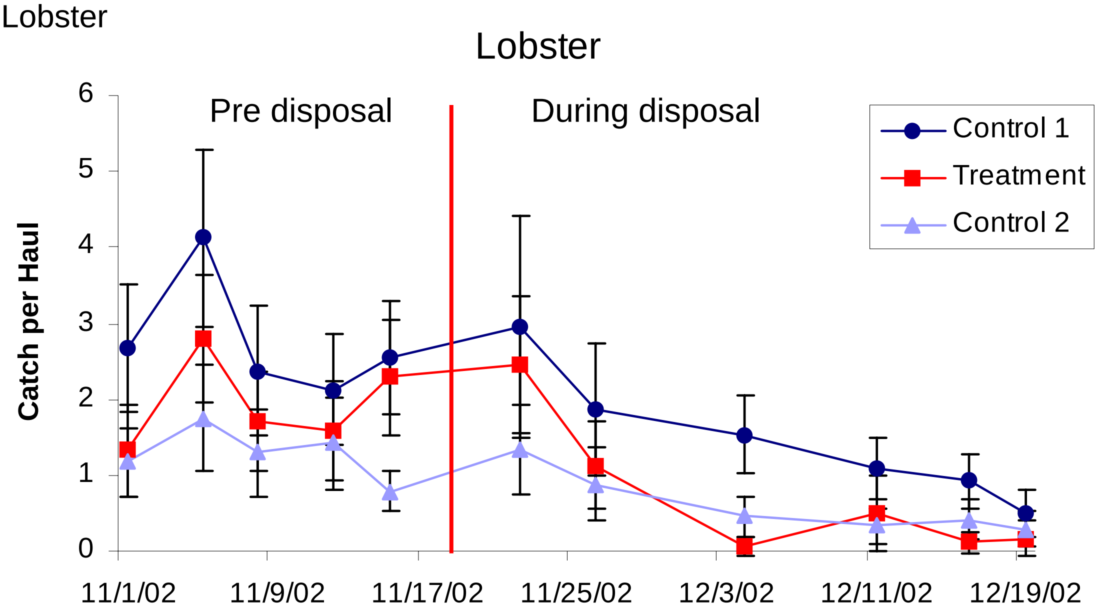


Figure 3-3. (a) Study area indicating interpreted areas of impact around the disposal events that occurred during this study. Initial statistical analysis of impacts on catch included all traps; secondary analysis compared the eight central traps within area T that were most likely to be impacted with their counterparts in areas C1 and C2 (yellow dots). Area within dashed line enlarged as side-scan sonar images taken before (b) and after (c) most recent disposal events. Area within red line is conservative estimate of impacted area; area within blue line includes more subtle substrate differences.

(a) Lobster



(b) Crab

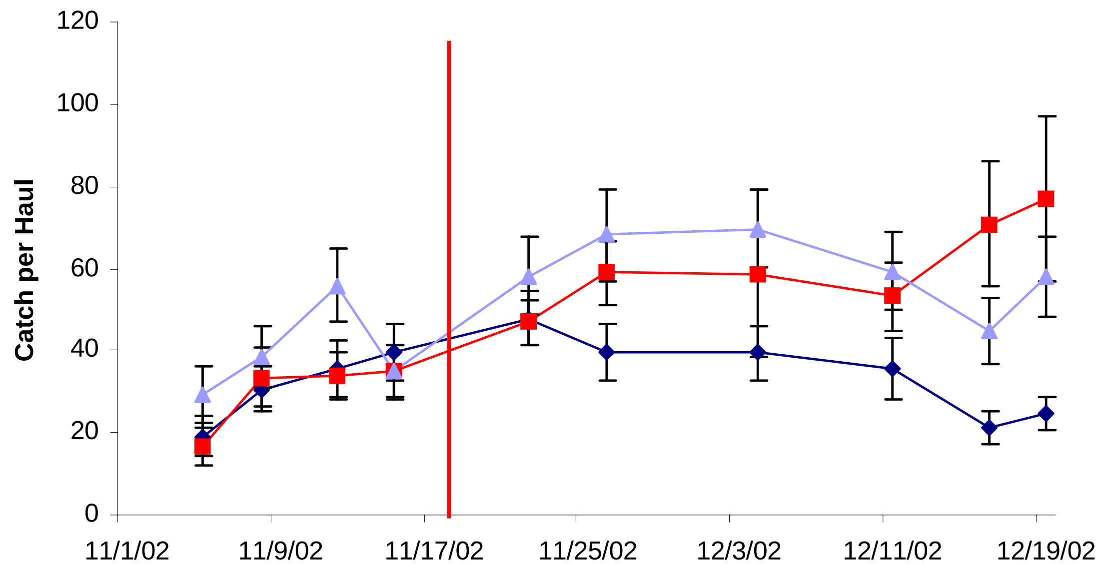


Figure 3-4. Time series of mean (±1SE) catch per trap haul of lobsters (a) and crabs (b) in each of the three study areas. Vertical line indicates date of onset of disposal events that continued almost daily for the remainder of the study.

tended to be higher in the western area (C1) with coarser substrate, whereas crab catch tended to be higher to the east (C2) in finer grained substrate. During the term of the study, lobster catch declined whereas the crab catch increased mostly in the Treatment area, less so in the C2 area, and remained nearly constant in C1.

Simplifying the analysis to a before-after comparison within each area bears out these trends more clearly (Figure 3-5, 3-6). For lobsters there was no significant difference in proportional change in catch among the three areas (Figure 3-6a, Table 3-1); in all three areas the catch declined by 36-42%. For crabs, in contrast, there was a significant 140% increase in catch in area T. The two control areas (C1, C2) only increased between 16 and 58 % and were not significantly different from each other (Figure 3-6a, Table 3-1).

Secondary analysis of the catch in the eight central traps of each area suggested more pronounced disposal impacts both for lobsters and crabs than the initial all-inclusive analysis (Figure 3-6b, Table 3-1). While proportional changes in the catch of the eight central traps of the control areas remained largely unchanged, changes in the Treatment area became even greater: for lobsters, the decline deepened from 36 to 75%; and for crabs, the increase expanded from 140 to 218%. From this more localized perspective, the treatment effect on lobster catch, while still not statistically significant, moved substantially in that direction (from $p = 0.95$ to 0.14; Table 3-1) despite the loss of statistical power resulting from a reduced sample size.

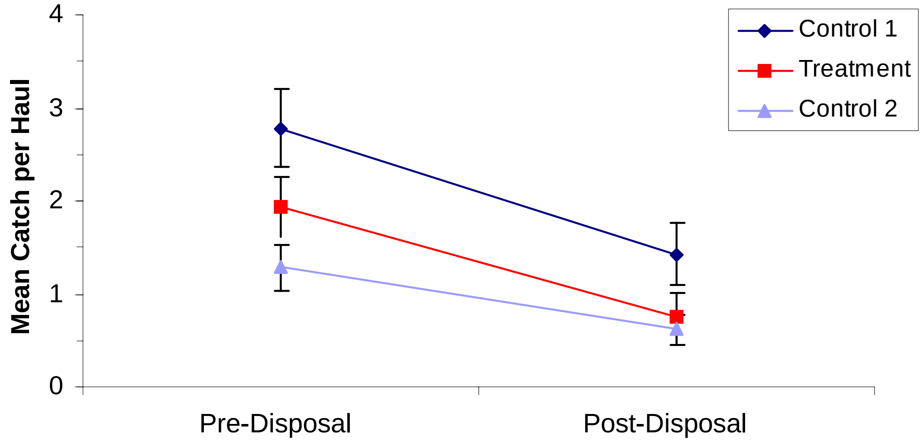
3.3 Fine-scale Spatial Patterns in Catch

Initial lobster catches were highest in the Control 1 area and concentrated in the area of the older of the two disposal mounds identified in the side-scan sonar analysis (Figure 3-7). Lobster catches diminished to a uniformly low level in all areas by early December. While crab catches throughout most of the study were highest in the Control 2 area, in the last three to four trapping occasions crab catches became increasingly concentrated at the location of the recently disposed material (Figure 3-8).

3.4 Mark-Recapture Analysis of Lobster Population

Of the 877 lobsters tagged, 34 (4%) were recaptured by traps within the experimental grid. All of the recaptures had both claws and tags intact. All recaptures were caught in traps within the study area; harvesters returned none. The assumptions of the mark-recapture analysis appear to have been satisfied. Tagged lobsters readily mixed with the population as demonstrated by movements among trap locations and exchange among study areas (Figure 3-9); none of the recaptures had lost a tag; nor do we have reason to believe that tags would affect lobster behavior or survival enough to alter the probability of capture from that of an untagged lobster. External tags are unobtrusive and benign, and have been widely used in prior crustacean tagging studies. It is more

(a) Lobster



(b) Crab

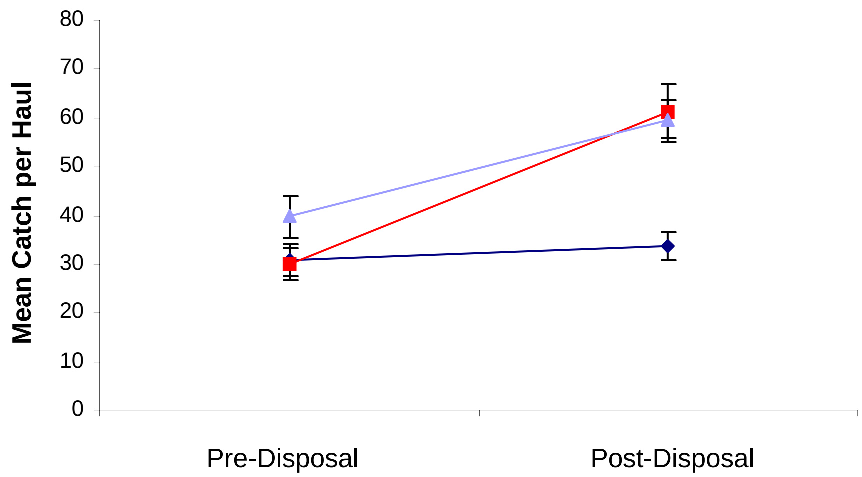
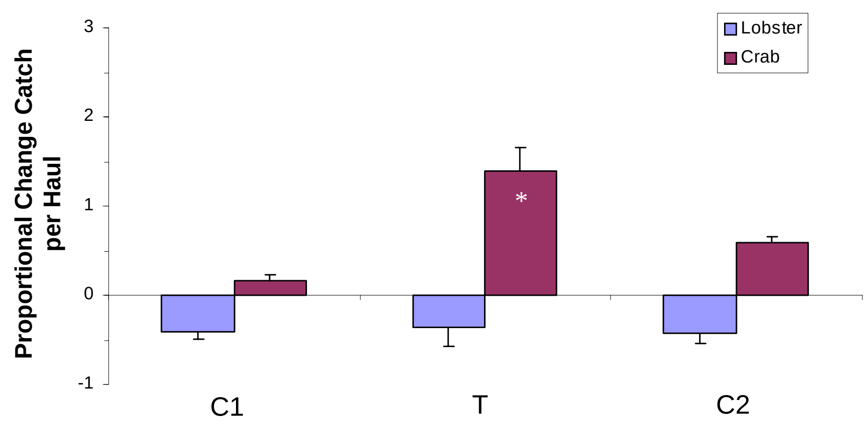


Figure 3-5. Pooled mean catch per haul (±1SE) of lobsters (a) and crabs (b) in each study area before and after the onset of disposal.

(a) All Traps



(b) Central Traps

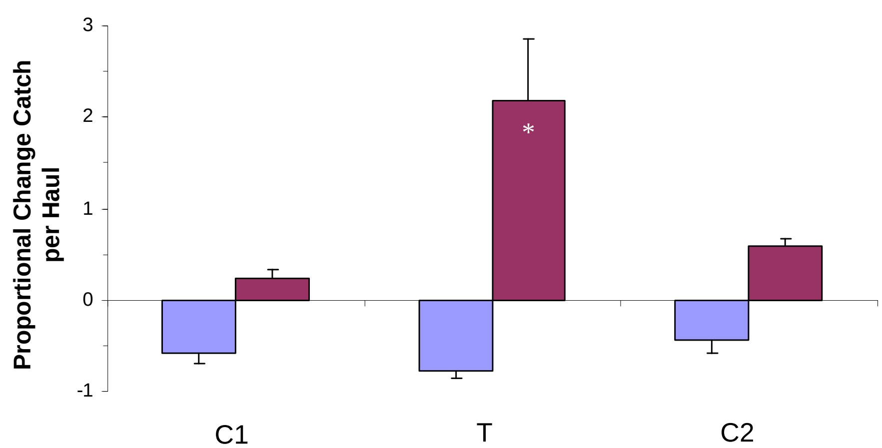


Figure 3-6. Proportional change in crab and lobster catch per haul (±1SE) for all traps (a) and for the central traps (b) within each study area. Results of statistical analysis in Table 1. Asterisk indicates statistically significant treatment as determined by ANOVA followed by post hoc pairwise comparisons (SNK tests, $p < 0.01$).

Table 3-1.

Single Factor ANOVA Results for Proportional Change in Lobster and Crab Catch per Haul for the Entire Trap Array and the Eight Central Traps

		F	df	p
Lobsters				
	All traps	0.048	2, 69	0.9536
	Central traps	2.188	2, 21	0.1370
Crabs				
	All traps	15.191	2, 69	0.0001
	Central traps	6,830	2, 21	0.0052

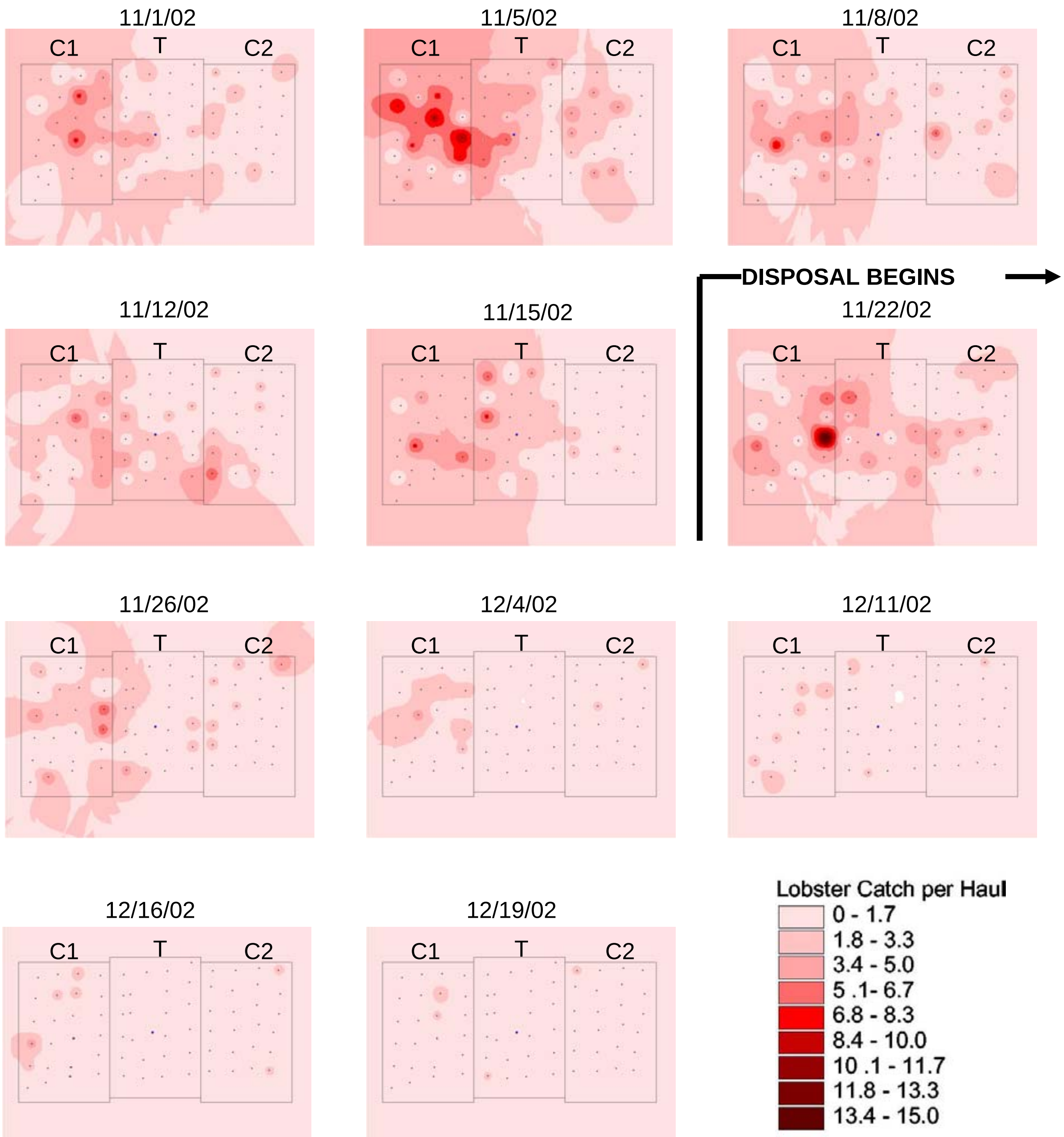


Figure 3-7. Time series of spatial patterns in lobster catch. Catch standardized to catch per haul. Soak times ranged from 3-8 days.

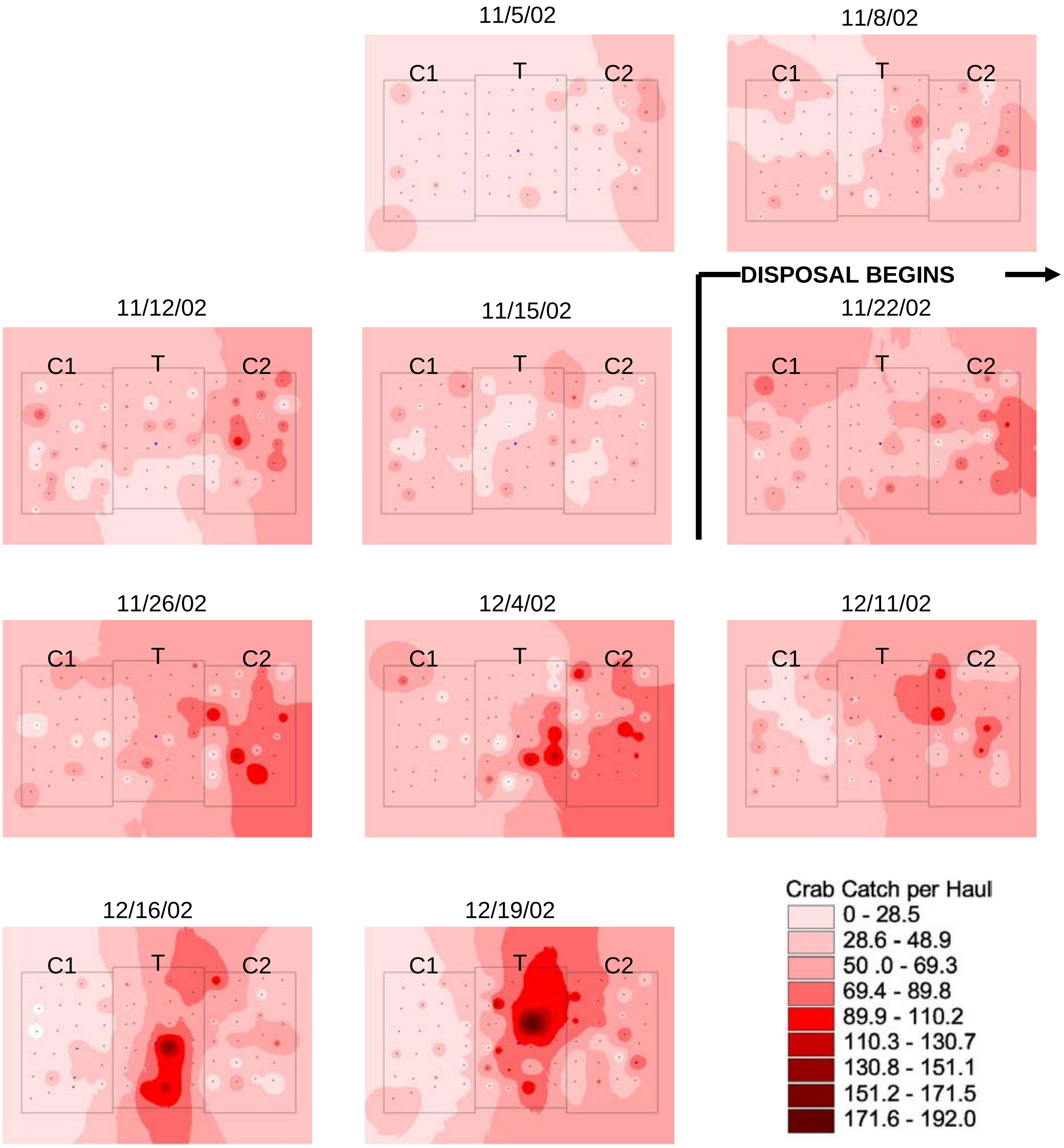


Figure 3-8. Time series of spatial patterns in crab catch. Catch standardized to catch per haul. Soak times ranged from 3-8 days. Note difference in catch scale compared to lobsters (Fig. 9).

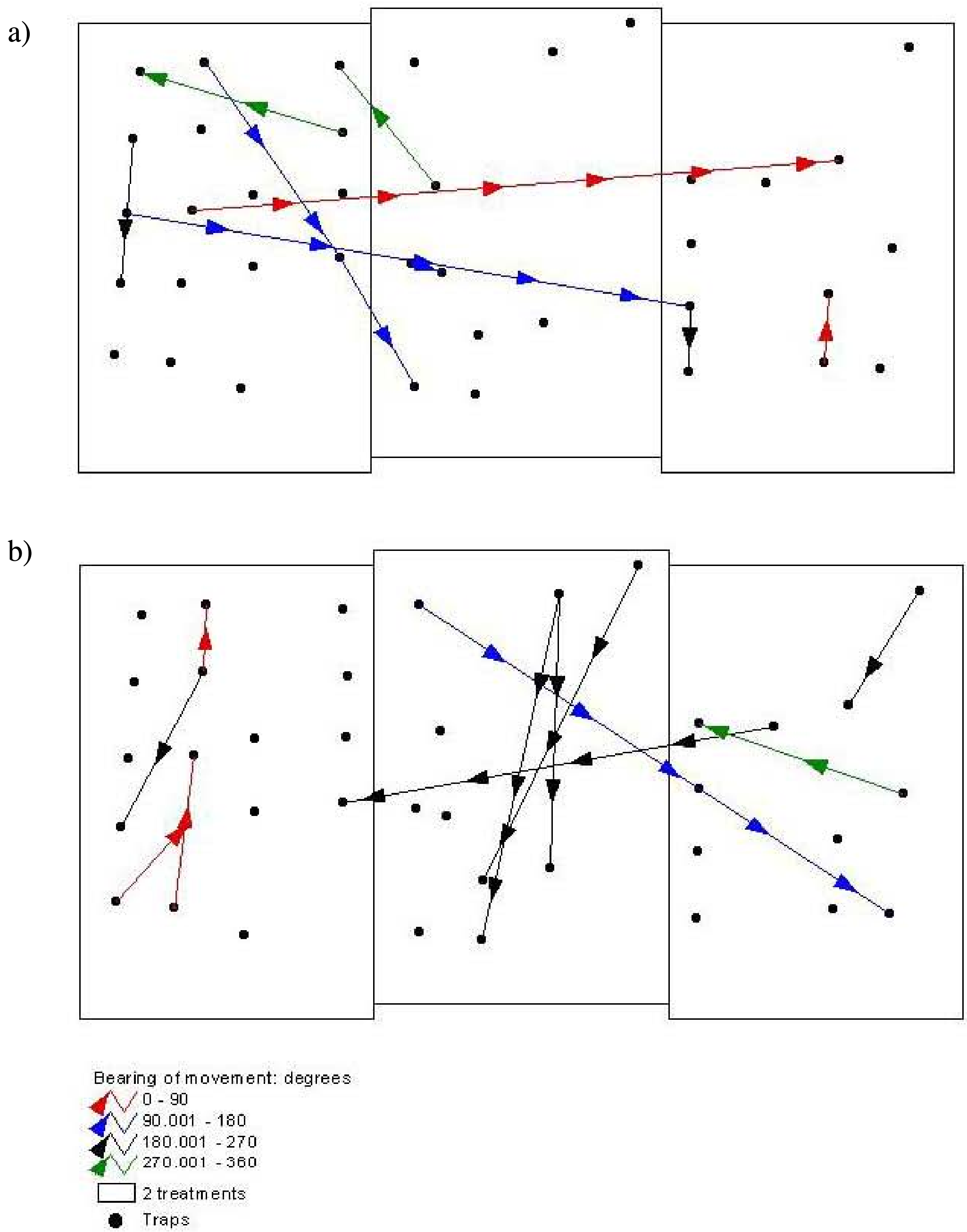


Figure 3-9. Movements of recaptured lobster within the study area. (a) Lobsters tagged and recaptured before disposal began (18 November, 2002). (b) Lobsters recaptured during disposal period.

difficult to determine if movements out of the area were permanent. However, because most lobsters were emigrating from the Bay it is not likely recaptured individuals would have left and returned to the site.

Satisfactory convergence was achieved for all mark-recapture models considered (Table 3-2). The model (ϕ, p) assuming constant exchange rates and constant capture probabilities best fit our recapture data (i.e., resulted in the minimum AIC_c model) (Table 3-2). The results of this model are summarized in terms of population size, gains and losses from each experimental plot in Figures 3-10 to 3-12. Note that confidence intervals are not available for these estimates, since population variance estimation has yet to be developed for this new model. However, it may safely be inferred that confidence intervals are likely to be very large. Declines in estimated population size through the experiment (Figure 3-10) are generally in line with declining catch rates (Figure 3-4). By these estimates large and roughly equal rates of emigration and immigration are estimated relative to movements among the three areas (Figures 3-11, 3-12). Most movements were occurring during the middle of the study period when the population was declining. These patterns are driven by changes in catch per unit effort rather than in movement or capture probabilities, since model ϕ, p implies a constant probability of capture of 3.6% per 100 trap days (2.0-6.3%, 95% CI) and a constant site fidelity of 82.8% per day (77.2-87.9%, 95% CI) throughout the experiment.

The 'BACI' models were rejected on the basis of AIC_c. However, for the sake of considering the experimental hypotheses, it is useful to examine the results of the best of these models, ϕ_{BACI}, p_{BACI}. Capture probability and site fidelity estimates are shown in Figures 3-13 and 3-14. Extremely wide confidence intervals are apparent for these estimates, and there are no consistent experimental effects apparent, either in terms of before/after or treatment/control comparisons.

The mark-recapture experiment did not detect any effect of dredged sediment disposal on lobster densities, movement rates or capture probabilities that were independent of other differences between sites or changes over time. However, given the low recapture rates, the statistical power of the experiment to detect such effects was very low.

3.5 Recapture Reports from Lobstermen

By the end of the 2002 fishing season only four lobsters had been reported by lobstermen, all in November, and all due south of the tagging area in deep water where some fishing activity continued into November (Figure 3-15). In the 8 to 14 days these lobsters were at large they moved a total southward distance of 5.8 and 6.8 km, at an average daily rate of 0.5 to 1.2 km.

Table 3-2.

Bias Adjusted Values of Akaike's Information Criterion (AIC_c) for Mark-Recapture Models Fitted to the Penobscot Bay Lobster Data. Darkened Cell Indicates Best Fit Model

		Movement Model (ϕ)					
		s + t	s	t	constant	BACI	BACI2
Capture Model (p)	s + t	459.6	459.2	461.6	454.3	460.6	459.4
	s	442.8	444.2	447.7	439.8	449.8	445.2
	t	452.2	456.6	461.5	452.7	477.1	460.0
	constant	445.6	441.6	446.2	438.2	464.6	444.7
	BACI	441.9	447.0	451.7	445.0	445.9	451.2
	BACI2	444.0	443.4	449.5	441.0	462.4	447.3

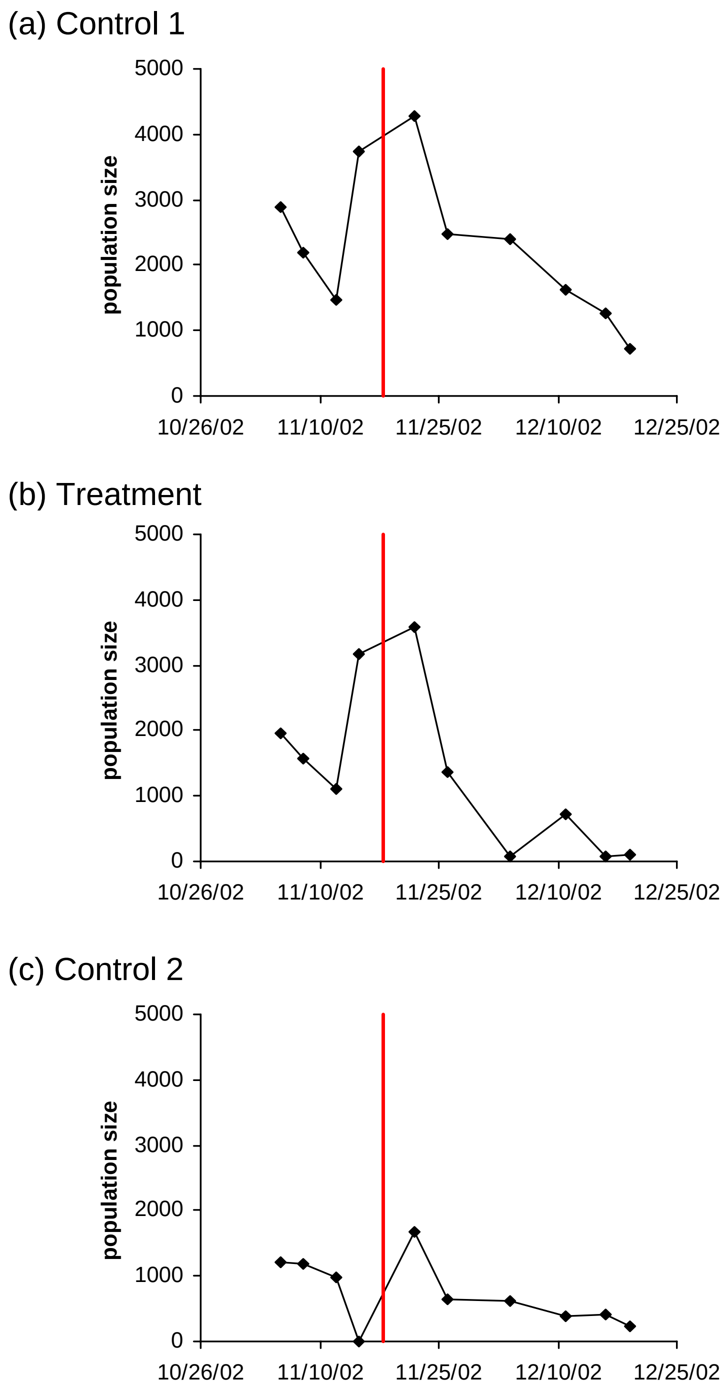


Figure 3-10. Population size estimates compared to catch rates of lobsters over time at the Control 1 (a), Treatment (b), and Control 2 (c) areas. Vertical line indicates date of onset of disposal events.

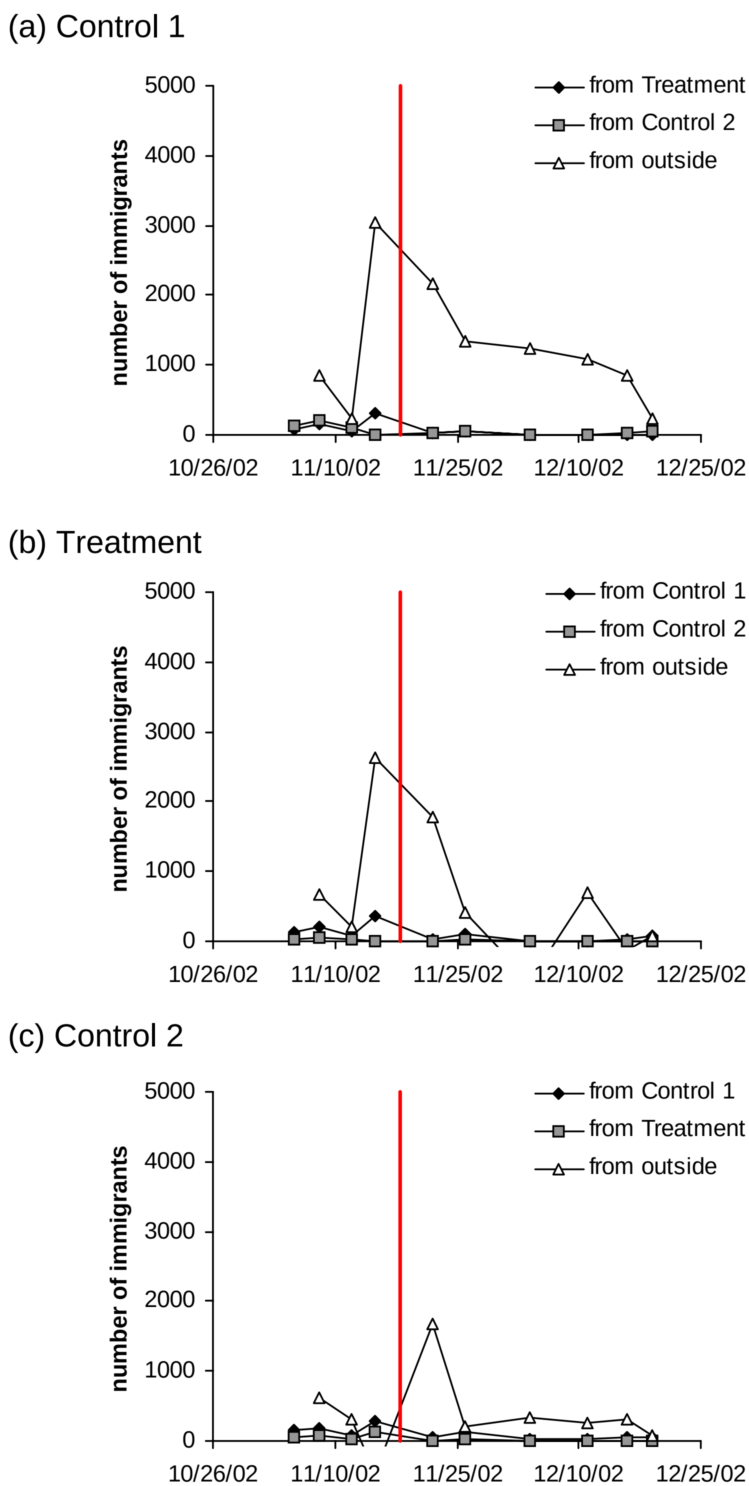


Figure 3-11. Estimates of immigration to the Control 1 (a), Treatment (b), and Control 2 (c) areas from the other experimental areas and beyond. Vertical line indicates date of onset of disposal events.

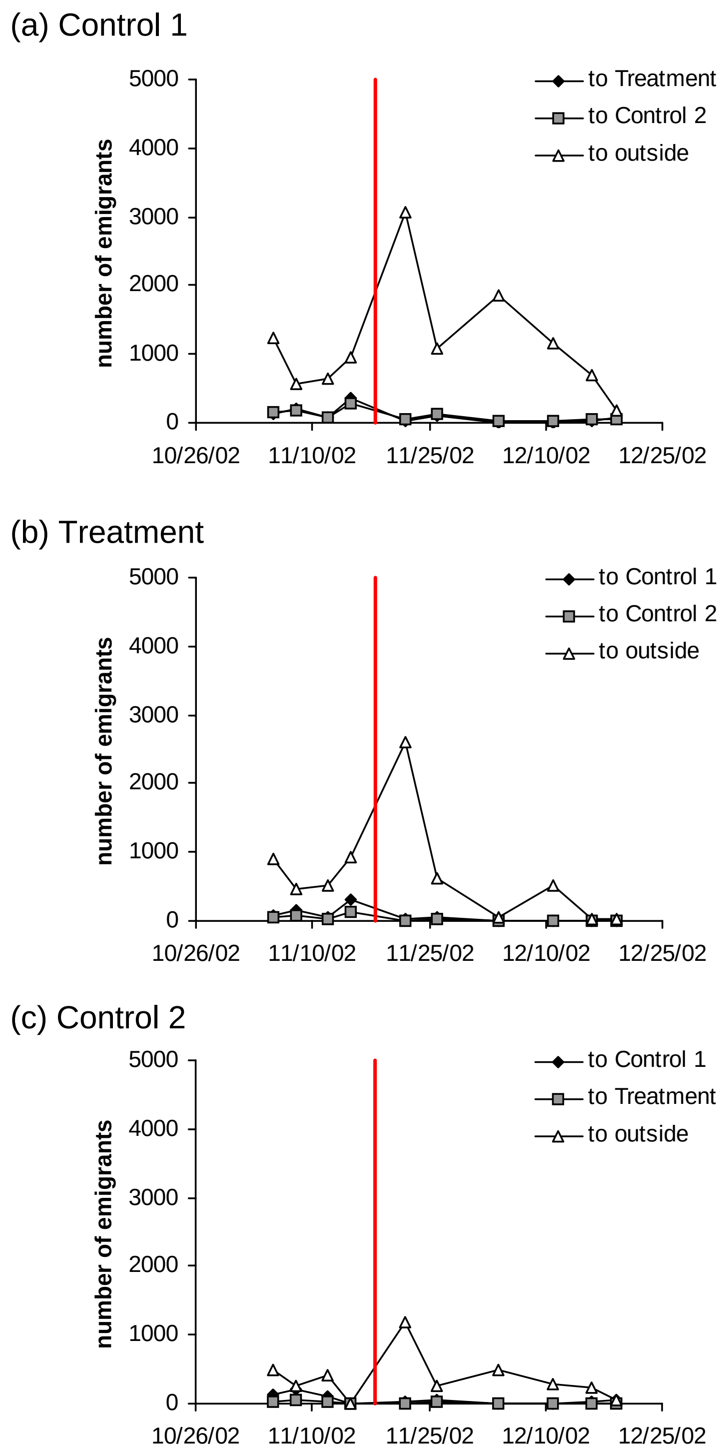


Figure 3-12. Estimates of emigration from each study area to the other experimental areas and beyond. Vertical line indicates date of onset of disposal events.

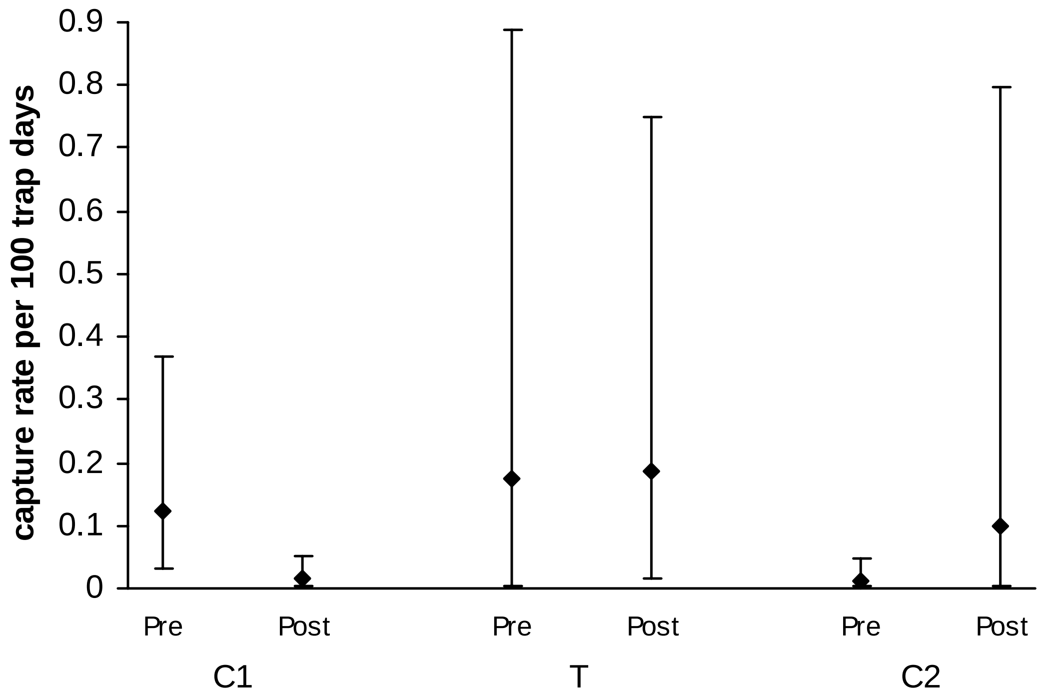


Figure 3-13. Before and after comparisons of mean capture probabilities (p ± 95% CI) for each experimental area.

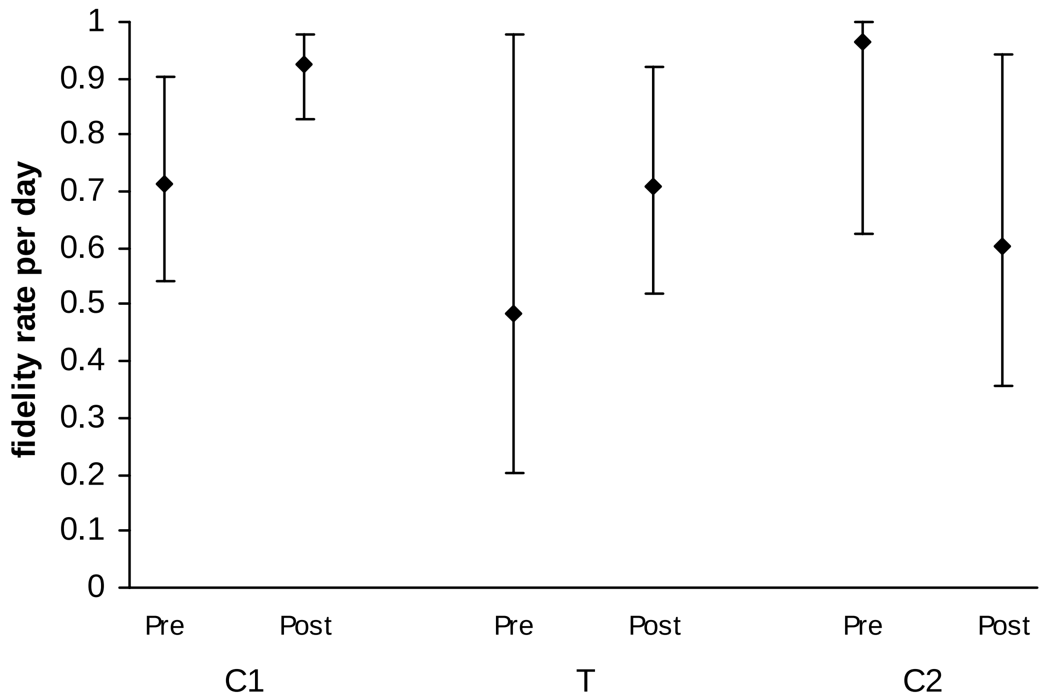


Figure 3-14. Before and after comparisons of mean site fidelities ($\phi \pm 95\%$ CI) for each experimental area.

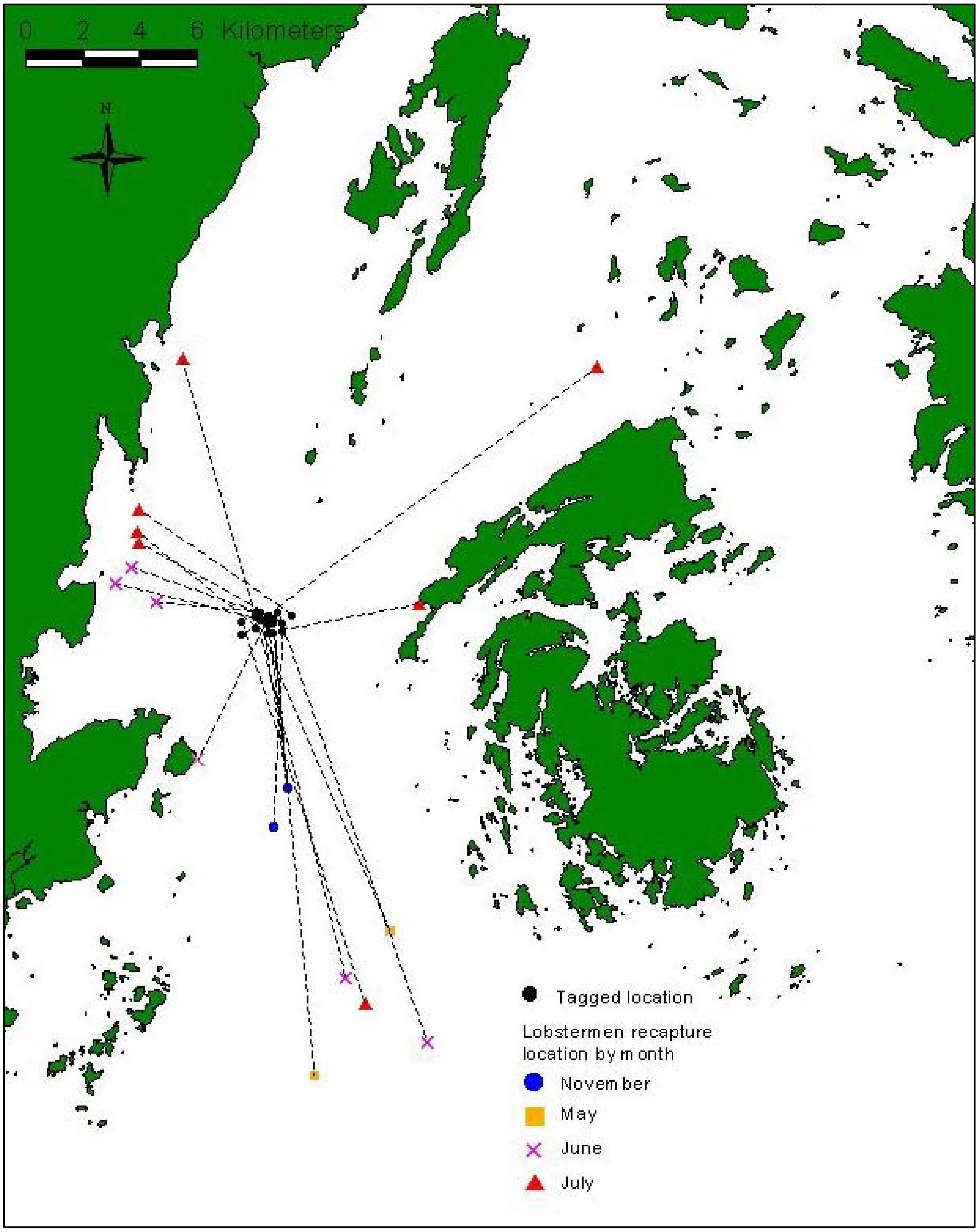


Figure 3-15. Locations of 19 recaptured lobsters reported to date by lobstermen relative to their original tagging location near the Rockland Disposal Site. Recaptures are color coded by date to illustrate seasonal pattern. Most recaptures have occurred since the onset of the 2003 fishing season. Of the four recaptures in November three were at the same location, so only two points are visible.

No tagged lobsters were reported again until May 2003 when fishing activity resumed, and reports have continued to come in every few days up to this writing (July; Figure 3-15). To date, 15 additional lobsters have been reported that tend to reflect a net movement into the Bay during the warm months. Two lobsters reported in May were both caught 12-15 km south of the disposal area, still in deep water. Of six lobsters reported in June, four had entered shallow water to the west of the study area, and two were in deep water to the south. Of the seven caught in July, only one was south of the site (14 km away) and the rest were spread over shallow areas well within the Bay, 5-15 km to the north, west and east of the study area.

4.0 DISCUSSION

Our pre-disposal side-scan sonar survey revealed seabed features consistent with an earlier survey of the site conducted in 2000 (SAIC 2001), some of which are the result of prior disposal. Conspicuous habitat impacts of the disposal events during this study were restricted to an area immediately around the disposal buoy where a low relief mound of fine sediments accumulated. Any more subtle substrate effects that may have existed over a larger area were not detectable from our side-scan sonar images.

Disposal impacts on lobsters were negligible during these disposal events most likely because sediment placement occurred at a time when lobsters were exiting the Bay on their annual outward migration. Relatively high lobster densities and catch rates tended to be associated with the coarser sediments of the study area. The behavioral preference for pre-existing shelter probably explains the differences in lobster densities and catch among the experimental areas (Lawton and Lavalli 1995). Population densities had become very low by the time disposal treatment had run its course. Except possibly in the immediate neighborhood of the disposed sediments, the decline in lobster numbers and catch in the treatment area were not significantly greater than in the two control areas. So few lobsters remained in the entire 1.5 km^2 study area - several hundred individuals – that the question of impacts to lobsters almost becomes moot.

By contrast, during the height of the summer fishing season four other locations in Penobscot Bay have been estimated by the same methods to harbor standing populations as high as 60,000 lobsters per km^2, and support catch rates averaging 10-30 lobster per trap (Wahle in prep). Our results, therefore, should not be taken to infer that sediment disposal would not impact lobsters during the warmer season when lobsters are more abundant in Penobscot Bay. Seasonal movements of lobsters are well documented through the species range (Munro and Therriault 1983, Campbell and Stasko 1986, Robichaud and Lawton 1997, Watson et al. 1999). The reports of tagged lobsters from lobstermen in this study are also consistent with a seasonal pattern of movement and activity. These movements tend to correlate with seasonal warming and cooling, and changes in turbulence and salinity in near-shore waters. It is therefore, not surprising to have observed high rates of emigration and immigration and dramatic net decline in lobster abundance in our study area.

Despite the relatively low recapture rates within the study area, the mark-recapture estimates are an important component of the assessment of disposal impacts on lobsters for two reasons. First, they provide the only estimate of population size where other methods, such as remote camera surveys, have not proven useful because of high turbidity (SAIC 2001). Second, the mark-recapture results dispel any doubt that the decline in catch rate was the result of a declining population, not merely a drop in the propensity of lobsters to trap. However, even these methods become impractical to estimate population dynamics when the absolute number of recaptured individuals becomes very small (e.g., Fitz and Wiegert 1992).

In this study only two-clawed lobsters were tagged. The mark-recapture method in this case therefore underestimates lobster abundance by the fraction missing claws. The magnitude of that correction is relatively small and does not affect the conclusions of the study. As for the reason the cull rate increased over the course of the study, we believe it is more likely the result of two clawed lobsters leaving the area than of heightened claw loss during the period. Claw loss typically occurs during the warm season as a consequence of the molting process, agonistic encounters, and fisherman handling. In the present study, however, no recaptured lobsters had lost claws. There was no evidence of molting; little to no commercial fishing was being done to aggravate claw loss; and lobster densities were low. It is possible that culls tend to remain longer in the area because they are less vagile than two clawed individuals.

Our assessment of disposal impacts on rock crabs was solely based on trap catches without tagging. Nonetheless, the positive treatment effects on catch rates were so strong that it is perhaps possible to make some inferences about the behavioral response of rock crabs to sediment deposition. The dramatic increase in catch rate in the immediate area of the disposed sediments suggests that crabs were attracted to it. This spike in crab catch at the disposal site falls on a background of generally increasing crab catch rates in the study area. It is possible that crabs were immigrating to the area during the period, but we cannot rule out the possibility that when lobsters were relatively abundant, they interfered with the crabs' access to traps, thereby giving the impression of lower densities. Some literature suggests competitive interactions between adult *H. americanus* and *Cancer* crabs (Richards and Cobb 1986, Hudon and Lamarche 1989). Without a more direct measure of abundance as we have for lobsters from the mark-recapture analysis, it is difficult to say whether changes in crab catch rate reflect real changes in abundance. Prior surveys of rock crabs in the Gulf of St. Lawrence indicate a seasonal movement into soft sediments in nearshore waters during the fall (Gendron and Cyr 1994). Our observations are consistent with that, but it is unlikely that the dramatic increase of crab catch at the disposal site proper can be explained by seasonal immigration or relaxed competition from lobsters alone. It is possible that, given its source, the disposed sediments contained a richer concentration of invertebrates and other organic material that could have attracted crabs (Germano 1994, SAIC 2001). Prior to the disposal events, the crab catch was somewhat higher in the eastern end of the study area and may reflect a tendency to associate with finer sediments.

A search of the literature indicates that placement of sediment, gravel and sludge on the seabed can have both negative and positive effects on lobster and rock crab distributions, depending on the quality of the material. Placement of cobbles and boulders in experimental reefs have had positive effects on local lobster densities via immigration and larval settlement (Wahle and Incze 1997, Castro et al. 2001). The discontinued disposal of fine sediments and sewage sludge at a site in the New York Bight was reported to have had little short-term impact on the distributions of several crab species, including *C. irroratus*, but favored the return of lobsters to the area (Pikanowski 1992).

These reports and our observations are generally consistent with prior work on the habitat preferences of the American lobster and rock crab. Although the two species broadly overlap in habitat use, lobsters tend to prefer to take shelter in coarse gravel and boulder substrates, especially at the time of larval settlement and during early benthic life. As lobsters grow, shelter fidelity relaxes, movements become wider ranging, and they become entrained in seasonal inshore-offshore movements, but continue to prefer pre-existing shelter throughout life (see review by Lawton and Lavalli 1995). The rock crab, by contrast, is less discriminating about the larval settlement habitat (Palma et al. 1998); it tends to concentrate in rocky habitats as a larger juvenile, and ranges widely as an adult (Hudon and Lamarche 1989, Gendron and Cyr 1994). Reports of movements are limited, but where it has been studied, adult rock crabs tend to migrate into shallow soft sediment during the fall where they bury themselves for the winter (Gendron and Cyr 1994).

Longer-term impacts were not addressed in this project, but may be important. Dredged sediments from harbors and channels can contain pollutants that are toxic to marine organisms over longer time scales than were addressed by this study (Swartz et al. 1981, Kester et al. 1983). Careful screening of these sediments prior to disposal, however, greatly minimizes risk to the biota (USACE 1992). On the other hand, the relatively rich biotic material in these sediments and the assemblage of fauna that invades it after deposition could enhance food availability (Germano 1994). These potential effects remain undetermined for lobsters and crabs that inhabit or pass through the Rockland Disposal Site.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The major findings of this study are summarized as follows:

- As interpreted from side-scan sonar imagery, habitat alteration that resulted from the disposal of fine-grained sediments were localized to the immediate neighborhood of the disposal grounds buoy. The affected area is estimated to be between 44,170 and 108,881 m^2.

- Statistically significant impacts of disposal on lobster trap catch, abundance, and movement were not detected as measured in a Before-After-Control-Impact study design that employed a spatially referenced trap grid and multiple mark-recapture methodology.

- Higher catch rates and population densities of lobsters were associated with the coarser sediments in the study area. By mark-recapture methods, the lobster population in the study area is estimated to have declined from several thousand to several hundred individuals over the course of the study. Declines at the impacted area largely paralleled those in the control areas and are more likely attributable to the late autumn emigration from the Bay than to the effects of sediment disposal. Emigration appeared unimpeded. Harvester reports of tagged lobsters are consistent with a seasonal pattern of lobster movement in and out of the Bay.

- Catch rates of the rock crab averaged about ten-fold higher than the lobster catch. Higher crab catches were associated with the finer sediments of the study area. There was a statistically significant increase in rock crab catch in the impacted area. Spatial analysis of the catch indicated that crabs became increasingly concentrated in the immediate area of the disposal footprint. Crabs were not marked, so population estimates were not available as they were for lobsters.

No statistically significant impact of disposal on lobster abundance or movement was detected. However, the abundance of emigrating lobsters at the disposal site in mid-November suggests that direct impacts to lobsters may be minimized when disposal occurs after the autumn emigration period. The quantitative data collected by this study provides a basis by which to assess potential impacts for future projects.

Because lobsters tend to associate with coarse, shelter-providing substrates, winter disposal of coarse-grained dredged sediments may even provide an opportunity to enhance lobster populations while minimizing direct impacts to individual lobsters.

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