IMPACT OF BEACH GRAVEL ENHANCEMENT ON EPIBENTHIC ZOOPLANKTON AT LINCOLN PARK, SEATTLE, WASHINGTON

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ABSTRACT

To evaluate the impact of a high intertidal beach filling on density of potential juvenile salmon prey, epibenthic zooplankton were quantitatively sampled monthly from March through June before, and a year and a half after, placement of fill. Control samples were collected simultaneously along transects in nearby areas not filled. Assessment of the impact of beach filling was made by comparing relative changes in density at the treatment beach to changes at control beaches. Post-project density of epibenthos declined more on the fill site than at the control for most taxa in most months. This loss was compounded by loss of intertidal area due to the fill changing the beach slope. In the lower intertidal zone seaward of the fill, post-project density of epibenthos increased more than at similar elevations in the control. However, this only occurred in certain months and for certain potential prey taxa. Therefore, a negative project impact cannot be ruled out based on this study.

ACKNOWLEDGEMENTS

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INTRODUCTION

In 1985 the City of Seattle applied to the Army Corps of Engineers, Seattle District, for repair of the seawall at Lincoln Park. Wave action over the years had been undermining the wall and threatening the park facilities. The Corps chose beach gravel enhancement to protect the park, instead of rebuilding the seawall. This consisted of placing gravelly fill in about three acres of the high intertidal zone of the beach, that is, the area between five and twelve feet above mean lower low water. Beach nourishment is expected to protect the existing seawall and park facilities from erosion for five to ten years. The Corps has described the timing, composition, and extent of filling in their Final Environmental Assessment (U.S. Army Corps of Engineers 1986).

The primary federal natural resource issue is the project's effect on the salmon that use the area, since restoring Pacific salmon and steelhead is one of the Fish and Wildlife Service's principal goals. Our agency expressed this concern in the Fish and Wildlife Coordination Report (Cooper 1986). Juvenile salmon migrating seaward from their rivers of origin during the spring and early summer feed in the nearshore areas of Puget Sound. Much of the nearshore prey for some species of salmon comes from the epibenthic zooplankton, the assemblage of crustacea produced on the surface of the bottom or within several centimeters above it. The specific issue is whether beach fill placement will change the stability and texture of the substrate in a way that reduces the density of those types of epibenthic zooplankton upon which juvenile salmon are known to feed.

The best way to answer this question was to assess the density of epibenthic zooplankton before and after beach nourishment. Toward this goal, we reviewed the literature on feeding ecology of juvenile salmon and conducted a pilot study to determine feasibility of plankton sampling at the site and to set appropriate sample sizes (Hiss and Boomer 1985). That study allowed us to design and propose a baseline evaluation (Hiss and Boomer 1987), which we carried out under contract with the Corps during the spring of 1988 (Hiss et al. 1988).

In 1990 we conducted a post-project evaluation for comparison to baseline data. The results of the combined baseline and post-project work are reported here. At the time the final baseline study design was approved, the natural resource agencies (Washington Departments of Fisheries and Wildlife and the National Marine Fisheries Service) also agreed with the Corps that a post-project evaluation should be repeated in some subsequent years if 1990 results were ambiguous.

The Corps completed their project as planned by placing three acres of river-run gravelly fill in the high intertidal zone along the seawall in the fall and winter of 1988-1989. According to our interpretation of the project design (Corps of Engineers 1986) combined with the 1985 beach survey (Thom and Hampel 1985), the fill cut the high intertidal area in half, from approximately 12,500 square meters down to 6,800 sq m. By the spring of 1990, the fill appeared as a narrow ledge of sand at the crest of the old seawall, dropping to a scarp and driftwood strand at the high tide line (+12 ft), and then an even slope of coarse gravel and small cobble down to the mean tidal level (+5 ft), or possibly a few feet lower.

The objective of this study was to determine the effect of placing gravelly fill over the formerly eroded beach adjacent to the Lincoln Park seawall, on the density of epibenthic zooplankton.

METHODS

Experimental Design

Definitions. The following terms have more specific meanings in this report than in the literature at large:

Area: geographical stretch of shoreline. There are three areas in the study: the beaches adjacent to Brace Point; Lincoln Park; and Lowman Park.

Control: absence of manipulation or lack of its anticipated effects. The control areas were chosen to be far enough to the north or south of Lincoln Park that no fill material would settle there. There were two control areas in this study, one just north of Lowman Park and the other just south of Brace Point. These were combined into the two control plots in this study, the upper intertidal control being a combination of the samples from the +6 and +8 elevations in the two areas, and the lower intertidal control being a combination of the samples from the -2, 0, +2, and +4 elevations in these two areas.

Transect: an imaginary line perpendicular to a landmark on the shore, along which samples were taken.

Elevation: vertical distance from the mean lower low water line.

Location: a specific elevation along a given transect, within limits of navigational error.

Plot: a set of samples receiving the same treatment or serving as control for that treatment. Samples from the same zone of each of the two control areas were considered to come from one plot for statistical analysis. Thus there were four plots in the study: The Lincoln Beach fill, the Lincoln Beach lower intertidal, the high intertidal control, and the lower intertidal control.

Zone: a specified range of intertidal elevations. We studied two zones: the upper intertidal, that is, from +8 to +5 feet above mean lower low water, and the lower intertidal, that is, from +5 ft down to -2 ft.

Replicate sample: the contents of one run of the epibenthic pump, at one of 8 or 16 systematically chosen unique locations within a plot in a given month.

Treatment: actual manipulation of a plot or anticipated changes at a plot. The two treatments were placement of fill at high intertidal elevations and proximity to fill in the lower intertidal.

The variables studied were the densities (number per 0.08 square meter sample) of potential prey taxa in the pre-project season, that is, spring of 1988, versus one year after the project, that is, in the spring of 1990. The same elevations were sampled before and after the filling, in both the upper and lower intertidal zones. Sampling in 1990 duplicated 1988 sampling as reported by Hiss et al. (1988), with one exception. In May and June of 1990, the number of replicate samples was doubled from 8 to 16 in each plot.

Size and Placement of Plots. We established two treatment plots for baseline and post-project sampling (Figure 1). One was to assess the direct effect of fill on the epibenthic zooplankton in the upper intertidal zone down to the designed toe of the fill, that is, from the seawall to +5 feet above mean lower low water. The other plot was established seaward to assess the effect of potential downslope movement of fill material on the intertidal area seaward of the fill, that is, tidal elevations +5 to -2. Two control areas were chosen because no single area was physically diverse enough to represent pre-project conditions at Lincoln Beach. Each control area contained a high and low intertidal zone similar to those at Lincoln Beach. The high and low intertidal zones of the two control areas were combined into two control plots for final analysis.

The size and location of the fill treatment plot corresponded with the area to be filled. This was the southwest-facing, three-acre segment of Lincoln Park Beach from the existing seawall down to an elevation of +5 feet.

The lower intertidal treatment plot was adjacent to the planned fill and extended from the toe of the fill at +5 feet down to the lower limit of the intertidal zone, which was about -2 feet. The same transects established for the fill extended into this plot.

The control areas were selected for similarity of substrate type, similar occurrence of freshwater seeps, similar exposure to prevailing winds, absence of obvious pollution sources, and presence of seawalls. The control areas were sampled with the same distribution of elevations and approximately the same spacing of transects as the treatment plots. One control area, containing four transects, was established just north of Lowman Park, approximately 3/4 mile north of the north end of the beach enhancement site (Figure 1). The other four control transects were established just south of Brace Point, approximately 1/2 mile to the south of the south end of Lincoln Park.

Replication. Eight replicate samples were taken from each of the four treatment plots each month. This number was one more than the minimum needed to fulfill our required sample replication, based on the pilot study (Hiss and Boomer 1985) data. We further explained our choice (Boomer 1989, Hiss 1989) in response to questions by Washington Department of Fisheries (Phinney 1989).

In all plots, approximate locations of replicates remained the same each month, relative to elevation along the transect, varying only with the ability to steady the boat in the same location.

The locations of replicate samples in the treatment plots were selected systematically from the grid system used by Thom and Hampel (1985) in their baseline study of algae and infauna. Thom sampled along eight evenly spaced transects perpendicular to the shore at elevations of +8 +6, +4, +2, 0, and -2 ft. Geographical points over which we sampled differed between 1988 and 1990 because in both years year we sampled at the same tidal elevations, at least some of which had moved outward from the seawall after the fill.

To represent the fill treatment plot, we ordinarily took eight replicates, one at every other point in Thom's gridwork for the +8 and +6 elevations (Figure 1). However, in May and June of 1990 we sampled every gridwork point in the fill plot, and every other point in the lower intertidal plot. These supplementary samples were taken because the relatively low numbers of organisms in the March and April samples allowed increased laboratory hours in the subsequent months without exceeding the limited funds specified by our contract.

To represent the lower intertidal treatment plot, that is, the zone seaward of the fill, we also took eight replicates, but we ordinarily used only every fourth point in Thom's gridwork for the +4, +2, 0, and -2 elevations, because there were four instead of two elevations to sample. In May and June of 1990 we sampled at every other point.

The locations of replicate samples in the control plots were established to subjectively duplicate baseline conditions at Lincoln Beach, and to give the same weight to each elevation and to both control areas. We set up a gridwork of four transects and six elevations at each of the two control beaches. For comparison to the fill treatment plot, we ordinarily took a replicate from each control area at two points in our gridwork at each of the +8 and +6 elevations. However, in May and June of 1990 we sampled at all points in our gridwork at each elevation in each control area.

For comparison to the lower intertidal treatment plot seaward of the fill, we took a replicate at one point in our control plot gridwork for each of the +4, +2, 0, and -2 elevations. However, in May and June of 1990, we sampled at two points in our gridwork at each elevation for each control area.

Field Sampling

The seasonal time interval for sampling corresponded to the expected entry of juvenile salmonids and ended when these fish were expected to have either left the intertidal zones or to have shifted to primarily neritic prey. Our literature review (Hiss and Boomer 1985) suggested this interval usually begins in late February and extends to mid-June. We sampled each plot four times over each sampling season, from March through June. Sampling dates in 1988, before the beach was filled, were March 4, 7, and 9; April 5 and 6; May 2 and 3; and June 13 and 14. Bad weather forced a two-week delay of the June sampling. We sampled again in 1990 after the fill had been in place for approximately a year and a half. The sampling dates were March 1 and 2, March 27 and 28, May 8 and 9, and June 6 and 8.

To collect samples, we anchored a 24-ft aluminum inboard work boat at each sampling location. Transects were defined as imaginary lines perpendicular to points on shore. At Lincoln Park we marked the transect heads used by Thom and Hampel (1985) by painting their numbers on the seawall. At the control areas we chose trees, flagpoles, or other immobile objects as reference points. We could usually position our boat within two boat lengths of the imaginary transect line. We maneuvered the boat to the appropriate elevations by sounding with a pole. The boat was anchored at a depth equal to the predicted tide minus the desired elevation. This method placed us within about 0.8 foot of the desired elevation.

Epibenthic zooplankton was collected with a suction apparatus covering 0.08 square meters of the bottom, as described in the pilot study (Hiss and Boomer 1985). Water from the sample was pumped through two nested sieves with opening sizes of 250 and 500 microns. The larger mesh was used to reduce clogging of the smaller mesh. Pumping continued until at least 100 liters, but no more than 500 liters had passed through the pump or until sand, algae, or debris began clogging the sieves. If the sieves clogged before 100 liters had been pumped, we discarded the sample and took another one within one meter of the original location. Contents of each sieve were transferred to 15% formalin in the field and preserved in 70% ethanol in the lab.

Laboratory Methods

Identification and sorting of organisms (Table 1) emphasized categories of epibenthic zooplankton of potential prey value to juvenile salmon in estuaries and nearshore marine areas of the Northwest (Hiss and Boomer 1985). Categories considered to be of secondary prey value were designated as "other genera" or "other families." A subcontractor provided a special key to facilitate sorting the zooplankton into these categories (Cordell 1988), trained our technicians, and verified identifications as needed. The final taxonomic level of identification depended on the condition of the invertebrates and their life history stage. All samples were archived in 70% ethanol after sorting and identification.

Raw data were recorded as counts of individuals by category for each sample. Data from fine and coarse sieve meshes were combined and analyzed together.

Relative prey value. For summarization and interpretation of statistical results, harpacticoids (code C1000) and gammarids (code C7000) were considered of higher prey value than other categories on the highest taxonomic level. Other categories were considered of secondary value either because of their low abundance relative to the above, in the case of Cumaceans (code C3000) or low utilization based on the literature, in the case of isopods (code C6000) and caprellids (code T8000). Harpacticoid genera specified in codes T1011, T1012, and T1021 of Table 1 were considered of higher prey value than other harpacticoid groups, (code T1090) based on the literature and personal communications (J. Cordell, Cordell and Associates, pers. comm.). The level of total harpacticoids (code C1000) is of intermediate prey value since it contains taxa of both relatively high and relatively low prey value. On the same basis, gammarid families specified in Table 1 (codes T7010 through T7119 were considered of higher prey value than other gammarid families (code T7990). The category of total gammarids (code C7000) is of intermediate prey value since it contains families from both levels of prey value.

Statistical Procedures

Preparation of data. A taxonomic level was deemed to contain enough organisms for statistical analysis when organisms of that level occurred in more than half the replicate samples taken in a given year, zone, beach, and month. Counts on the lowest taxonomic level were combined with counts in the level just above until this criterion was met. This not only prevented unproductive analysis of consistently scarce organisms, but also eliminated some of the non-normality which would have violated the requirements of parametric statistics. The data were then transformed by

$$Z = \log(10\ X + 1)$$

to further normalize the distribution, as suggested by Green (1989).

t-tests. We conducted pairs of t-tests for treatment and control plots; with one test to detect change in prey density in the treatment plot between 1988 and 1990, and the other test to detect change in the control plot between those two years. The statistics of interest were both alpha and beta. Alpha represented the likelihood of rejecting the hypothesis that the density of potential prey remained the same after the fill, and, in case we failed to reject that hypothesis, beta represented the likelihood that there was an actual change that the t-test was not powerful enough to detect.

Alpha, or the probability of Type I error, was calculated for all tests. The null hypothesis was rejected if alpha was less than 0.10. Beta, or the probability of Type II error, was calculated for all tests that did not yield a significant alpha. The necessity for calculating beta is forcefully presented in the recent literature (Conquest 1983, Peterman 1989). The formula given in Conquest and Ralph (1990:23) was solved for the t value for beta as:

tBeta =(ABS(Z90 - Z88)/SD9088)/SQRT(1/n90 + 1/n88) - tAlpha

where Z90 = mean of log-transformed counts per sample in 1990
Z88 = mean of log-transformed counts per sample in 1988
SD9088 = standard deviation of log-transformed counts from 1990 and 1988 samples combined
n90 = sample size in 1990
n88 = sample size in 1988
tAlpha = two-tailed t for Alpha = 0.10 at (n90 + n88 - 2) degrees of freedom

Beta values corresponding to one-tailed t values were located in a t-table (Rohlf and Sokal 1969) for n90 + n88 - 2 degrees of freedom and reported as being less than 0.45, 0.25, 0.20, 0.10, 0.05, or 0.01. A beta value over 0.20 was interpreted as a sample size too small (that is, a test not sufficiently powerful) to allow rejection of the hypothesis of equality of mean densities if there was truly inequality.

Interpretation of t-test results within one plot. There were five possible outcomes of change in density between 1988 and 1990 for a given prey taxon in either treatment or control plots:

(1) "+": a significant positive change, with alpha less than or equal to 0.10; (In this case beta is not relevant.)

(2) "+?": a questionable positive change, with an observed increase in mean density but alpha greater than 0.10 and beta greater than 0.20;

(3) "0": no change, with alpha greater than 0.10 and beta less than or equal to 0.20;

(4) "-?": a questionable negative change, with an observed decrease in mean density but alpha greater than 0.10 and beta greater than 0.20; and

(5) "-": a significant negative change, with alpha less than or equal to 0.10. (In this case beta is not relevant.)

Interpreting t-tests for treatment relative to control. To enable a conclusion about the two t-tests, one for the treatment plot and one for the control, we constructed a matrix (Table 2) listing all possible outcomes of each test and the interpretation of each combination of these. If the outcome at Lincoln Beach ranked closer to the top of the preceding list of possible outcomes than the outcome at the control plot (upper right portion of Table 2), the project was considered to positively affect the density of organisms at the treatment plot relative to the control plot, as measured by t-tests. If the two plots ranked equally (center diagonal of Table 2), there was no change relative to the control, and if the Lincoln outcome ranked lower (lower left portion of Table 2), then treatment had a negative effect relative to the control. Any effect was considered questionable if one of the two plots had a questionable outcome, based on high beta value.

RESULTS AND DISCUSSION

Upper Intertidal Impact

March. Overall, the project can be associated with a decline in epibenthic prey in March, relative to the control, although the results were mixed for the two principal groups of highest prey value. Total Harpacticoid copepods (prey code C1000) declined at the Lincoln Beach fill area relative to control areas (Table 3, Figure 2). In particular, Tisbe (T1021) and those taxa of secondary prey value (T1090) declined. On the other hand, total gammarid amphipods (C7000) increased relative to control areas, particularly in the case of Calliopiids (T7030). Hyalid gammarids (C7070) may have also increased. Total isopods (C6000) may have also declined, but our sample size was not large enough to detect a significant change. In any case, isopods should not be given as much weight as other taxa because, according to the literature, they usually did not greatly contribute to salmon prey locally (Hiss and Boomer 1985). (For this reason they are listed as prey of secondary value in the summary (Table 7) below).

April. Overall, the project had mixed effects on epibenthic prey in April, relative to the control, although the results were positive for the two principal groups of highest prey value. More harpacticoids (C1000) were captured in April than in March samples, exemplified by taxa of primary importance such as Tisbe species (T1021) (Table 4, Figure 3). The interpretation of change in harpacticoids of secondary prey value (T1090) is ambiguous. The t-tests showed a significant decline only in the treatment plot, but the alpha values for the treatment and control tests were not too far apart. Total gammarids (C7000) increased, as they had in March, but Hyalids (C7070) may have declined; however, this item was not very abundant relative to other gammarid taxa. Total isopods in the treatment (C6000) declined relative to the control, as they may have done in March as well.

May. Overall, the project had mixed effects on epibenthic prey in May, relative to the control. Total harpacticoids (C1000) declined after the fill, relative to control plots, in particular the Harpacticus uniremis group (T1011) and Tisbe species (T1021), as in April (Table 5, Figure 4). However, harpacticoids of secondary prey value (T1090) may have increased relative to control areas. Total gammarids (C7000) declined relative to controls, but the decline in treatment area was only slightly greater than that in the control areas. This taxon masks two very different trends: The fill appeared to have a positive effect on Calliopiid gammarids (T7030) and a negative effect on Hyalids (C7070). The same negative impact on Hyalids occurred in April. The effect of the project was inconsistent between isopod categories (T6010, T6090, and C6000).

June. Most epibenthic groups experienced significant or potential declines, relative to the control plots, including the harpacticoid taxa Tisbe species (T1021), harpacticoids of secondary value (T1090), and especially total harpacticoids (C1000) (Table 6, Figure 5). Total isopods (C6000) and all abundant taxa of amphipods, including total gammarids (C7000), Calliopiids (T7030) Hyalids (C7070), and caprellids (T8000).

Months combined. Overall, there was a decrease in epibenthos densities in the filled beach relative to the control (Table 7). This was felt mainly in the decline in harpacticoids; isopods also decreased relative to control, although the changes in gammarids were mixed. In general, it appears that the fill had less impact in April, when epibenthos (and plankton in general) were relatively scarce, than in March, May, and especially in June, when plankton was relatively abundant. The fill may have reduced the epibenthic carrying capacity so that "blooms" are not as large as they might otherwise be.

Loss in epibenthos density must not be viewed as the only effect of the project on the standing crop of epibenthos. The actual area of the upper intertidal has also decreased due to filling. The rise in slope at a given geographical point will automatically reduce the area available for epibenthos in the high intertidal. To achieve no net loss, we would have to see a general increase in epibenthos density over baseline levels.

Our subjective observations raise the question whether the beach is still under the process of stabilization and recolonization (by micro-algae, barnacles, macro-algae, as one proceeds seaward), or whether the present condition represents an equilibrium. The beach still seems loose underfoot. Barnacles are not so dense at the toe of the fill as they seem to be at the same elevation at control sites.

Lower Intertidal Impact

March. Overall, the project impact in March was probably negative, although the effect on primary prey groups was mixed. The fill in the high intertidal did not appear to diminish total harpacticoids (C1000) in the lower intertidal in March, and may be associated with an increase in abundance of Tisbe species (T1021) (Table 8, Figure 6) relative to the control. Total gammarids (C7000) were judged to decline, but the decline in treatment was very close to that in the control, so the determination is by no means definitive. Subjectively, gammarids did not change relative to control areas. Total cumaceans (C3000) and total isopods (C6000) may have declined, but, if so, sample sizes were not large enough to detect a significant change.

April. The project impact in April was positive for virtually all prey groups. Most taxa increased relative to control areas (Table 9, Figure 7). Generally, declines in treatment area were less than in control areas. All harpacticoid taxa (C1000, T1011, T1012, T1021, and T1090) increased more than the control, significantly in all but the case of harpacticoids of secondary prey importance (T1090). Gammarids (T7030 and C7000) also shared in the increase at the treatment plot, although Hyalids (C7070) were a definite exception. Total cumaceans (C3000) may have increased. Total isopods (C6000) , including both Sphaeromatids (T6010) and other families (T6090), declined less than at control areas.

May. Overall, the project impact in May was probably negative, although the effect on primary prey groups was not noticeable. No significant change was noted for harpacticoids of any category (T1011 through C1000) (Table 10, Figure 8). Total gammarids (C7000) did not show an effect of the fill, except that Hyalids (C7070) may have declined, but power to test this was weak. Cumaceans (C3000) and isopods (C6000) of all categories were depressed at Lincoln beach whereas they increased at the control sites.

June. The project impact in June was positive for the primary prey groups, but with notable exceptions (Table 11, Figure 9). Total harpacticoids (C1000) may have increased relative to the control, and Zaus (T1012) and Tisbe species (T1021) significantly increased. However, harpacticoids of secondary value (T1090) may have decreased, and these made up a substantial part of the total. Gammarids present a mixed picture. While the total (C7000) potentially increased relative to control, and Hyalids (C7070) significantly increased, Calliopiids (T7030) significantly decreased. The effect on secondary prey groups was negative. Cumaceans (C3000) may have declined, and total isopods (C6000) significantly decreased.

Months combined. In summary, results for the lower intertidal were mixed (Table 7), although the impact on primary prey categories was usually positive. The observed increases in density of epibenthos relative to control in the lower intertidal was unexpected. Recent studies (Parametrix 1985, Schadt and Weitkamp 1985) indicated that the increase in unstable-appearing silt patches in the lower intertidal, where before there had been stable sand or hardpan, would discourage epibenthic colonization. However, the epibenthos in the Lincoln Park lower intertidal did not show such a negative effect.

The fill probably resulted in changes in epibenthos and benthic macrofauna and flora in the lower intertidal caused by sand sifting out of the fill due to wave action and currents. The lower intertidal substrate seemed more like loose silt and less like the hard sand found at control sites at these elevations. Our sampling in the 0 and -2 elevations was much more difficult in 1990 than in 1988 because sand clogged the sieves.

Validity of Statistical Analysis

We are aware that our experiments rely on pseudoreplication in the sense of Hurlbert (1984) because no replicate beach fills were interspersed with unaffected areas. This admittedly weakens the applicability of the Lincoln Beach conclusions to other potential beach fill sites. However, we contend that our experimental design does not violate the assumptions required for application of results to the Lincoln Beach fill area and the entire lower intertidal zone adjacent to it. The main issue is probably whether the sampling scheme represented the zones without bias by allowing each sample to be independent of the other samples. The great distance between transects within a plot (300 ft in the treatment and 50 to 200 ft in the control areas) assures that this assumption is met, so that our systematic samples are statistically equivalent to random samples.

The significance levels we set are more liberal than is customary in statistics. This is on the recommendation of Conquest and Ralph (1990) based on the high variability of biological field data and the philosophical priority a resource biologist gives to detecting differences, as opposed to equality, of populations potentially affected by a project.

We are also aware that a multivariate approach might have been able to make a statement about how the epibenthos behaved as an aggregate and would have also accounted for the experiment-wide error rate, which could be considerable when so many prey categories were analyzed. We did not take this approach because each major taxon was important in its own right, and cannot be readily weighted in value with respect to the others. For example, harpacticoids may be the essential prey of chum salmon in early spring regardless of the abundance of gammarids, and these may be especially important to coho and chinook later in the year. For this reason also, we did not analyze community diversity.

Total Project Impact

We conclude that, a year and a half after beach gravel enhancement, there was a noticeable reduction in epibenthos densities in the filled area (Table 7). While densities were decreased in the upper intertidal zone, there was also a loss of total habitat due to filling. Increases in epibenthos density in the lower intertidal may offset those losses somewhat but the extent of offset is unknown. At present one cannot rule out the possibility of a net negative impact on the total intertidal zone at Lincoln Park Beach. An additional year of sampling, ideally with sample sizes at least as large as in May and June of 1990, may help resolve this question. Another reason for repeated sampling is that many categories of epibenthos declined in the control plots in most post-project months; repeating the study improves the chance of finding control plot densities more similar to baseline conditions. This could make any project-related changes stand out more clearly than they did this year. Furthermore, the epibenthos may recover with time and future sampling could detect the recovery.

SUMMARY AND CONCLUSIONS

1. Placement of coarse river-run gravel fill in the high intertidal depressed the density of epibenthic zooplankton during the spring plankton bloom in May and June. This impact was compounded by the loss of approximately half the high intertidal habitat area itself due to the elevation and slope of the fill.

2. Sand, possibly sifting out of the fill, had formed a loose, patchy deposit on the lower intertidal. This was accompanied by sporadic increases in certain taxa in certain months, with a few definite exceptions.

4. The beach may still be stabilizing, in physical and biological terms, so the 1990 study may not represent a long-term project impact, if such exists.

5. Our work confirms other studies that have shown the lower intertidal is relatively more productive of epibenthos than the upper intertidal. Our insistence on filling only down to the 5-ft line, and no further seaward, is fully supported by this investigation.

RECOMMENDATIONS

1. Convene the interagency advisory committee to advise on the need for (1) further analysis of the existing epibenthic data and (2) another season of evaluation in the field.

2. Synthesize existing data on substrate texture and large fauna and flora to better interpret the project's impact on epibenthos in the lower intertidal.

3. Survey treatment and control plots to assign elevations to existing photographs along transects. Interpret photographs to assess substrate stability and maturity of macro-benthic community.

4. Restrict future beach fills elsewhere in the Seattle area to the high intertidal elevations, if they must be done at all.

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Table 1. Taxonomic sorting protocol for epibenthic zooplankton analysis at Lincoln Beach. Numbers refer to prey codes specific to this project. "C" indicates a taxon combined with lower taxonomic levels for data analysis. "T" indicates a taxon not combined with others in analysis.

- C1000. Adult Harpacticoids, not further identifiable, combined with:
    - T1011. *Harpacticus uniremis* group
    - T1012. *Zaus* spp.
    - T1021. Tisbidae: *Tisbe* spp.
    - T1090. Harpacticoid families, genera, or species of secondary prey value
- T2000. Mysidacea
- C3000. Cumacea, not further identifiable, combined with:
    - T3010. *Cumella vulgaris*
    - T3090. Cumacean genera less commonly reported as salmon prey
- T5000. Tanaidacea
- C6000. Isopoda, not further identifiable, combined with:
    - T6010. Sphaeromatidae
    - T6090. Isopod families less commonly reported as salmon prey
- C7000. Amphipoda: Gammaridea, not further identifiable, combined with:
    - T7010. Ampithoidae
    - T7020. Aoridae: *Aoroides* spp.
    - T7030. Calliopiidae
    - T7041. Corophiidae: *Corophium* spp.
    - C7050. Pontogeneiidae, not further identifiable, combined with:
        - T7051. *Pontogeneia* spp.
        - T7052. *Paramoera* spp.
        - T7059. Pontogeneiid genera less commonly reported as salmon prey
    - C7060. Anisogammaridae, not further identifiable, combined with:
        - T7061.*Anisogammarus pugettensis*
        - T7062.*Eogammarus* spp.
    - C7070. Hyalidae, not further identifiable, combined with:
        - T7071. *Allorchestes angusta*
        - T7072. *Hyale* spp.
    - C7080. Isaeidae, not further identifiable, combined with:
        - T7081. *Photis* spp.
        - T7089. Isaeid genera less commonly reported as salmon prey
    - C7090. Ischyroceridae, not further identifiable, combined with:
        - T7091. *Ischyrocerus* spp.
        - T7099. Ischyrocerid genera less commonly reported as salmon prey
    - T7100. Phoxocephalidae
    - C7110. Pleustidae, not further identifiable, combined with:
        - T7111. *Parapleustes pugettensis*
        - T7119. Pleustid genera less commonly reported as salmon prey
    - T7990. Gammaridean families of secondary prey value
- T8000. Amphipoda: Caprellidea
- C9000. Saltwater life stages of insects, not further identifiable, combined with:
    - C9010. Diptera, not further identifiable, combined with:
        - T9011. Chironomidae
        - T9012. Ephydridae
        - T9019. Dipteran families less commonly reported as salmon prey
    - T9090. Insect orders less commonly reported as salmon prey

Table 2. Determination of project impact from combination of t-test results from treatment and control plots. "0" = no significant change, "+" or "-" = Prey abundance changed over time, with probability of type I error less than 0.10. "?" = Change non-significant but probability of Type II error greater than 0.20.

	Control Plots				
Lincoln Beach	+	+?	0	-?	-
+	None	Pos?	Pos	Pos	Pos
+?	Neg?	None	Pos?	Pos	Pos
0	Neg	Neg?	None	Pos?	Pos
-?	Neg	Neg	Neg?	None	Pos?
-	Neg	Neg	Neg	Neg?	None

Note: None = treatment had no detectable impact on epibenthos relative to control.
Pos = treatment had positive impact relative to control.
Neg = treatment had negative impact relative to control.
Pos? = treatment had either positive or no impact; questionable because of low power in one of plots.
Neg? = treatment had either negative or no impact; questionable because of low power in one of plots.

Table 3. Results for upper intertidal zone in March.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1021	0.63	0.17	0.33	0.34	-0.46	0.01	0.01	(d)	0.95	0.10
T1090	0.57	0.10	0.48	0.25	-0.47	-0.23	0.00		0.03	
C1000	0.88	0.23	0.68	0.61	-0.65	-0.07	0.00		0.63	0.20
C6000	0.76	0.39	0.90	1.08	-0.37	0.18	0.17	0.45	0.50	0.20
T7030	0.64	0.41	0.98	0.61	-0.23	-0.37	0.25	0.25	0.06	
C7070	0.32	0.42	0.35	0.17	0.10	-0.18	0.59	0.20	0.35	0.25
C7000	0.74	0.70	1.25	0.85	-0.04	-0.40	0.83	0.10	0.06	

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1021	-	0	Neg
T1090	-	-	None
C1000	-	0	Neg
C6000	-?	0	Neg?
T7030	-?	-	Pos?
C7070	0	-?	Pos?
C7000	0	-	Pos

(a) Counts per sample transformed to log (count + 1).
(b) Alpha and beta values are less than or equal to the given values.
(c) See Table 1 for definitions.
(d) Beta not given unless alpha is non-significant at 10% level.
(e) "+" or "-" = Density changed over time, with probability of type I error less than 0.10.
"+?" or "-?" = Change non-significant but probability of Type II error greater than 0.20.
"0" = No significant change.
(f) "Positive" = Lincoln Beach had more positive level of change than control.
"Negative" = Lincoln Beach had more negative level of change than control.
"?" = change at one beach was questionable due to low power of test.
"None" = Both beaches had same level of change.

Table 4. Results for upper intertidal zone in April.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1011	0.27	0.10	0.44	0.00	-0.17	-0.44	0.21	0.45	0.00	
T1021	0.82	0.23	1.35	0.44	-0.59	-0.91	0.54	0.20	0.00	
T1090	0.65	0.37	0.70	0.37	-0.28	-0.33	0.10		0.14	0.45
C1000	1.10	0.53	1.56	0.67	-0.57	-0.89	0.34	0.25	0.00	
C6000	0.89	0.27	0.63	0.36	-0.62	-0.27	0.01		0.45	0.99
T7030	0.97	0.91	1.49	0.96	-0.06	-0.53	0.95	0.10	0.00	
C7070	0.47	0.12	0.10	0.00	-0.35	-0.10	0.04		0.88	0.45
C7000	1.15	0.99	1.50	1.08	-0.16	-0.42	0.53	0.20	0.01	

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1011	-?	-	Pos?
T1021			
T1090	-	-?	Neg?
C1000	-?	-	Pos?
C6000	-	-?	Neg?
T7030	0	-	Pos
C7070	-	-?	Neg?
C7000	0	-	Pos

(a-f) Please see footnotes to Table 3.

Table 5. Results for upper intertidal zone in May.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1011	0.59	0.34	0.29	0.26	-0.25	-0.03	0.07		0.86	0.10
T1021	1.51	0.77	1.15	0.60	-0.74	-0.55	0.00		0.00	
T1090	0.89	0.69	1.24	0.95	-0.20	-0.29	0.28	0.45	0.10	
C1000	1.63	1.06	1.52	1.16	-0.57	-0.36	0.00		0.03	
T6010	1.48	0.34	0.69	0.56	-1.14	-0.13	0.00		0.48	0.20
T6090	0.13	0.36	0.19	0.30	0.23	0.11	0.04		0.31	0.20
C6000	1.50	0.58	0.74	0.68	-0.92	-0.06	0.00		0.73	0.10
T7030	1.53	1.29	1.34	0.89	-0.24	-0.45	0.21	0.45	0.02	
C7070	0.85	0.50	0.29	0.41	-0.35	0.12	0.06		0.52	0.20
C7000	1.72	1.34	1.38	1.02	-0.38	-0.36	0.04		0.05	

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1011	-	0	Neg
T1021	-	-	None
T1090	-?	-	Pos?
C1000	-	-	None
T6010	-	0	Neg
T6090	+	0	Pos
C6000	-	0	Neg
T7030	-?	-	Pos?
C7070	-	0	Neg
C7000	-	-	None

(a-f) Please see footnotes to Table 3.

Table 6. Results for upper intertidal zone in June.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1011	0.54	0.24	0.49	0.29	-0.30	-0.20	0.01		0.08	
T1012	0.62	0.17	0.38	0.12	-0.45	-0.26	0.00		0.05	
T1021	0.80	0.54	0.86	0.71	-0.26	-0.15	0.16	0.45	0.42	0.20
T1090	1.18	1.07	1.10	1.25	-0.11	0.15	0.37	0.20	0.27	0.25
C1000	1.45	1.19	1.39	1.41	-0.26	0.02	0.07		0.91	0.10
C6000	1.43	0.48	0.74	0.64	-0.95	-0.10	0.00		0.63	0.10
T7030	0.61	0.48	0.08	0.89	-0.13	0.81	0.40	0.20	0.00	
C7070	0.76	1.21	0.40	0.88	0.45	0.48	0.01		0.01	
C7000	1.06	1.30	0.76	1.26	0.24	0.50	0.12	0.45	0.00	
T8000	0.53	0.00	0.26	0.00	-0.53	-0.26	0.00		0.00	

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1011	-	-	None
T1012	-	-	None
T1021	-?	0	Neg?
T1090	0	+?	Neg?
C1000	-	0	Neg
C6000	-	0	Neg
T7030	0	+	Neg
C7070	+	+	None
C7000	+?	+	Neg?
T8000	-	-	None

(a-f) Please see footnotes to Table 3.

Table 7. Summary of effects of beach fill by month and prey code. Effects defined in Tables 2 and 3. Monthly results are summarized here from final column of Tables 4-7 and 9-12.

Prey	High intertidal					Low intertidal				
code(a)	Mar	Apr	May	Jun	Overall	Mar	Apr	May	Jun	Overall
Primary prey value										
C1000	Neg	Pos(b)	Mixed	Neg	Neg	Mixed	Pos	None	Pos(b)	Pos
C7000	Pos	Pos(b)	Mixed	Neg	Mixed	None	Pos	None	Pos(b)	Pos
Overall	Mixed	Pos	Mixed	Neg	Neg	Mixed	Pos	None	Pos	Pos
Secondary prey value										
C3000	NA	NA	NA	NA	NA	Neg	Pos	Neg	Neg	Neg
C6000	Neg	Neg	Neg(c)	Neg	Neg	Neg	Pos	Neg	Neg	Neg
T8000	NA	NA	NA	None	None	NA	NA	NA	None	None
All prey categories										
Overall	Neg	Mixed	Mixed	Neg	Neg	Neg	Pos	Neg	Pos	Mixed

(a) Defined in Table 1.
(b) Project negatively affected some lower taxonomic levels.
(c) Project positively affected some lower taxonomic levels.

Table 8. Results for lower intertidal zone in March.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1021	1.43	1.03	1.46	0.65	-0.40	-0.81	0.30	0.25	0.04	
T1090	1.02	0.84	1.25	1.03	-0.18	-0.22	0.65	0.20	0.59	0.20
C1000	1.61	1.25	1.84	1.24	-0.36	-0.60	0.38	0.25	0.15	0.45
C3000	0.67	0.44	1.00	0.83	-0.23	-0.17	0.43	0.45	0.54	0.20
C6000	1.02	1.17	0.90	1.21	0.15	0.31	0.50	0.20	0.15	0.45
T7030	1.35	0.92	1.06	0.76	-0.43	-0.30	0.16	0.45	0.33	0.45
C7070	0.80	0.53	0.48	0.20	-0.27	-0.28	0.17	0.45	0.15	0.99
C7000	1.65	1.12	1.56	1.04	-0.53	-0.52	0.04		0.04	

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1021	-?	-	Pos?
T1090	0	0	None
C1000	-?	-?	None
C3000	-?	0	Neg?
C6000	0	+?	Neg?
T7030	-?	-?	None
C7070	-?	-?	None
C7000	-	-	None

(a-f) Please see footnotes to Table 3.

Table 9. Results for lower intertidal zone in April.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1011	0.73	0.34	1.05	0.06	-0.39	-0.99	0.07		0.00	
T1012	0.67	0.62	1.59	0.47	-0.05	-1.12	0.87	0.10	0.00	
T1021	1.83	1.53	2.21	0.89	-0.30	-1.32	0.41	0.20	0.00	
T1090	1.53	1.37	1.74	1.25	-0.16	-0.49	0.72	0.10	0.29	0.45
C1000	2.07	1.83	2.50	1.55	-0.24	-0.95	0.55	0.20	0.02	
C3000	0.70	0.54	1.13	0.73	-0.16	-0.40	0.56	0.20	0.14	0.45
T6010	0.87	0.70	1.25	0.48	-0.17	-0.77	0.63	0.20	0.03	
T6090	0.46	0.10	0.74	0.08	-0.36	-0.66	0.05		0.00	
C6000	1.14	0.76	1.55	0.49	-0.38	-1.06	0.18	0.45	0.00	
T7030	1.32	1.37	1.88	1.06	0.05	-0.82	0.82	0.10	0.00	
C7070	0.62	0.19	0.46	0.10	-0.43	-0.36	0.02		0.04	
C7000	1.67	1.60	2.11	1.33	-0.07	-0.78	0.70	0.20	0.00	

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1011	-	-	None
T1012	0	-	Pos
T1021	0	-	Pos
T1090	0	-?	Pos?
C1000	0	-	Pos
C3000	0	-?	Pos?
T6010	0	-	Pos
T6090	-	-	None
C6000	-?	-	Pos?
T7030	0	-	Pos
C7070	-	-	None
C7000	0	-	Pos

(a-f) Please see footnotes to Table 3.

Table 10. Results for lower intertidal zone in May.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1011	1.04	0.95	1.06	1.03	-0.09	-0.03	0.76	0.10	0.93	0.10
T1012	0.70	0.59	0.90	1.01	-0.11	0.11	0.77	0.10	0.76	0.10
T1021	1.96	1.43	1.61	1.30	-0.53	-0.31	0.14	0.45	0.40	0.20
T1090	1.67	1.68	1.90	2.00	0.01	0.10	0.95	0.10	0.72	0.10
C1000	2.27	2.01	2.20	2.24	-0.26	0.04	0.43	0.20	0.89	0.10
C3000	0.64	0.60	0.86	1.39	-0.04	0.53	0.90	0.10	0.10	
T6010	1.36	0.90	1.17	0.98	-0.46	-0.19	0.08		0.46	0.20
T6090	0.41	0.51	0.24	0.47	0.10	0.23	0.64	0.20	0.25	0.25
C6000	1.51	1.09	1.32	1.25	-0.42	-0.07	0.02		0.71	0.10
T7030	1.52	1.50	1.86	1.71	-0.02	-0.15	0.95	0.10	0.46	0.20
C7050	0.29	0.44	0.29	0.21	0.15	-0.08	0.39	0.20	0.66	0.20
C7070	1.00	0.85	0.43	0.75	-0.15	0.32	0.61	0.10	0.25	0.45
C7000	1.71	1.73	1.90	1.84	0.02	-0.06	0.90	0.10	0.75	0.10

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1011	0	0	None
T1012	0	0	None
T1021	-?	0	Neg?
T1090	0	0	None
C1000	0	0	None
C3000	0	+	Neg
T6010	-	0	Neg
T6090	0	+?	Neg?
C6000	-	0	Neg
T7030	0	0	None
C7050	0	0	None
C7070	0	+?	Neg?
C7000	0	0	None

(a-f) Please see footnotes to Table 3.

Table 11. Results for lower intertidal zone in June.

Prey code (c)	Count per sample (a)						t-tests, 1988 v. 1990 (b)			
	Treament		Control		Change 88-90		Treatment		Control	
	1988	1990	1988	1990	Treat.	Cont.	Alpha	Beta	Alpha	Beta
T1011	0.54	0.81	0.86	0.59	0.27	-0.27	0.23	0.45	0.24	0.25
T1012	1.02	0.66	1.20	0.60	-0.36	-0.60	0.19	0.45	0.04	
T1021	1.12	1.50	1.36	0.83	0.38	-0.53	0.18	0.45	0.07	
T1090	1.59	1.85	1.65	2.06	0.26	0.41	0.26	0.25	0.07	
C1000	1.87	2.11	2.00	2.14	0.24	0.14	0.30	0.25	0.56	0.20
C3000	0.46	0.22	0.89	1.11	-0.24	0.22	0.46	0.45	0.49	0.20
C6000	1.21	0.79	1.27	1.24	-0.42	-0.03	0.04		0.89	0.10
T7030	1.16	1.14	0.80	1.42	-0.02	0.62	0.95	0.10	0.01	
C7070	0.71	1.25	0.83	1.01	0.54	0.18	0.01		0.38	0.20
C7000	1.37	1.63	1.45	1.59	0.26	0.14	0.18	0.45	0.45	0.20
T8000	0.42	0.00	0.57	0.00	-0.42	-0.57	0.00		0.00	

Interpretation of t-tests

Prey code (d)	Treatment (e)	Control (e)	Beaches combined (f)
T1011	+?	-?	Pos
T1012	-?	-	Pos?
T1021	+?	-	Pos
T1090	+?	+	Neg?
C1000	+?	0	Pos?
C3000	-?	0	Neg?
C6000	-	0	Neg
T7030	0	+	Neg
C7070	+	0	Pos
C7000	+?	0	Pos?
T8000	-	-	None

(a-f) Please see footnotes to Table 3.

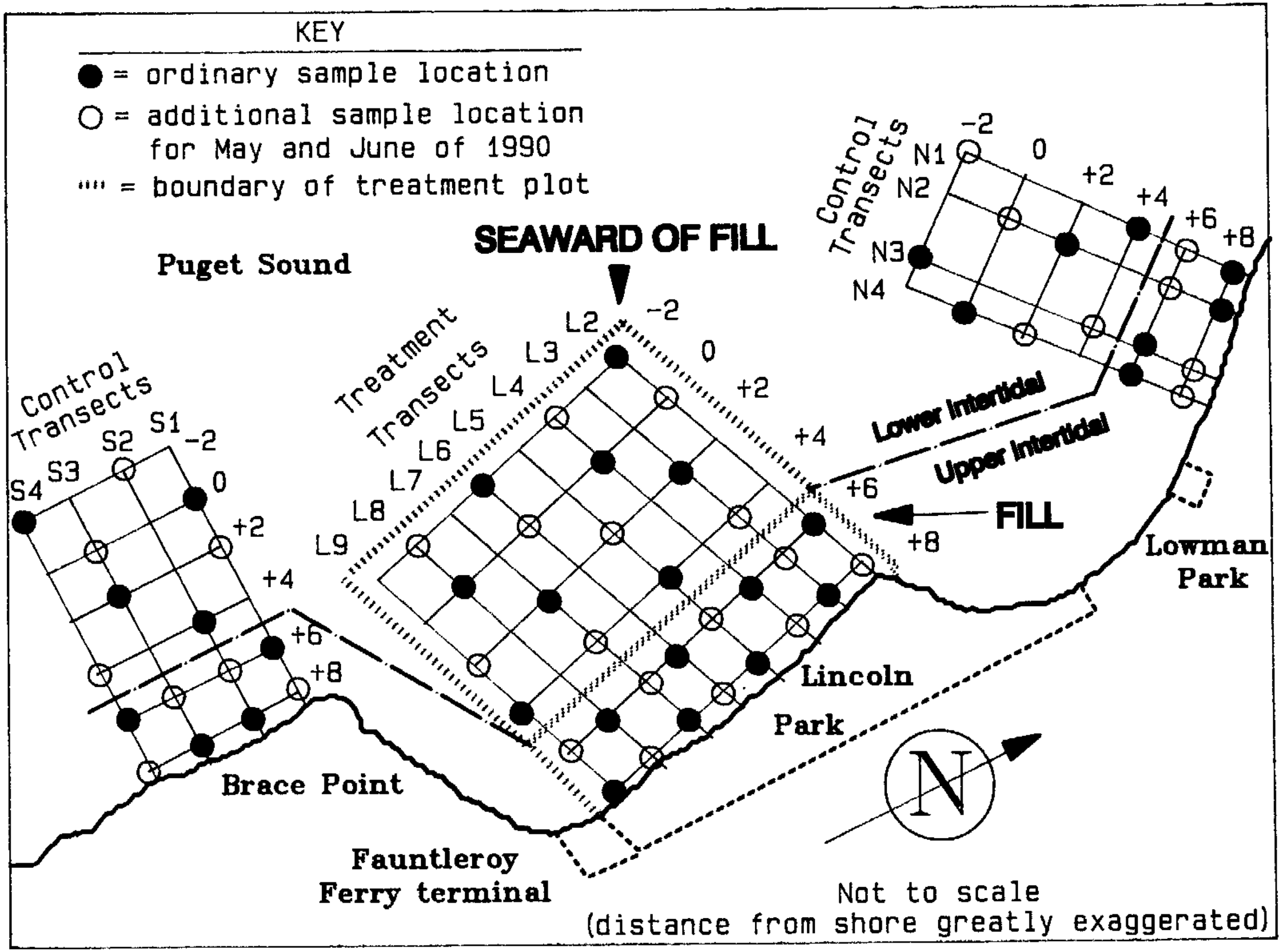

Figure 1. Lincoln Park Beach and control plots, with sampling locations. Numbers (-2 through +8) indicate elevation above mean lower low water.

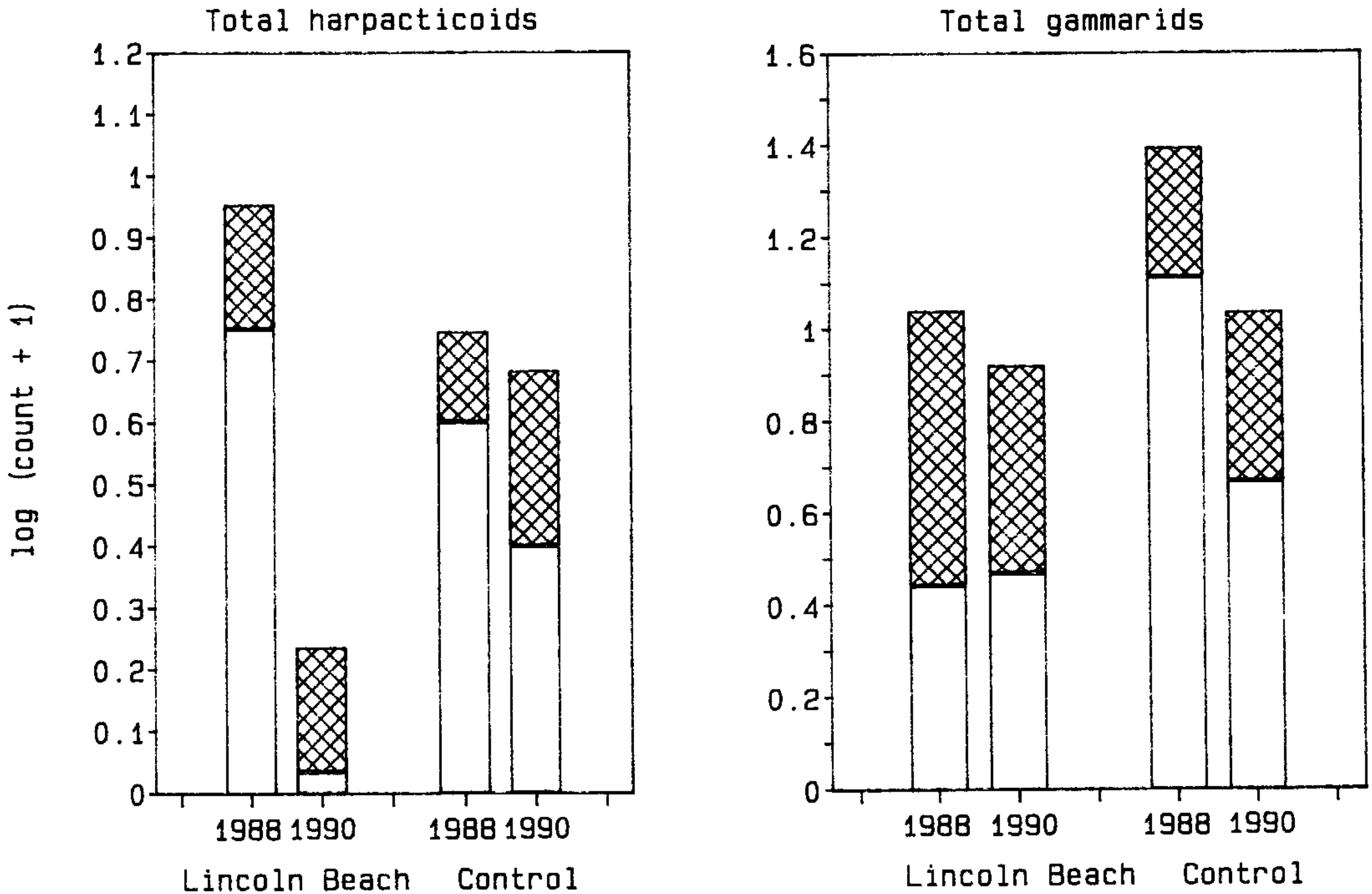

Figure 2. Ninety percent confidence limits (cross-hatched area) of mean epibenthos density per sample from high intertidal zone in March.

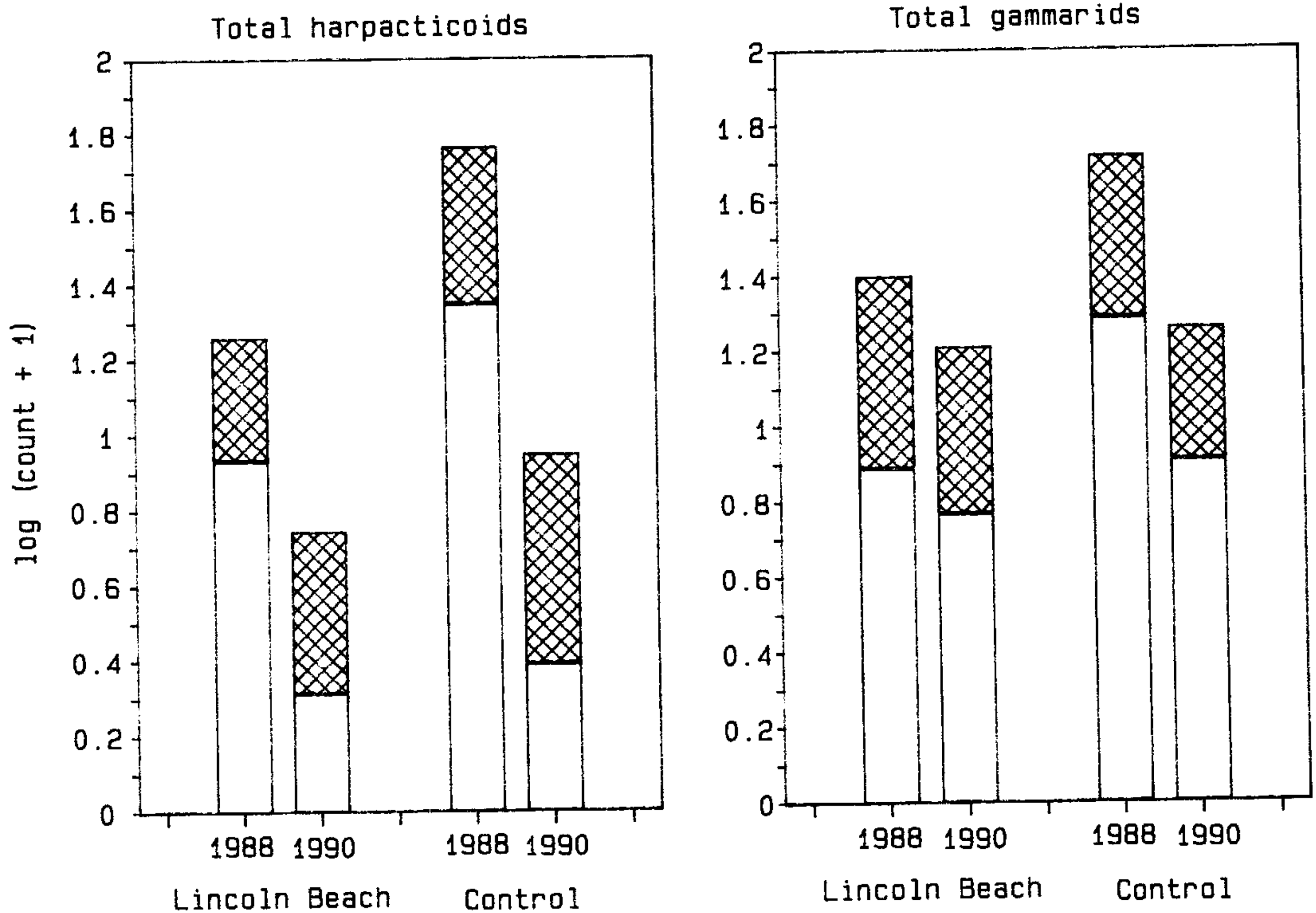

Figure 3. Ninety percent confidence limits (cross-hatched area) of mean epibenthos density per sample from high intertidal zone in April.

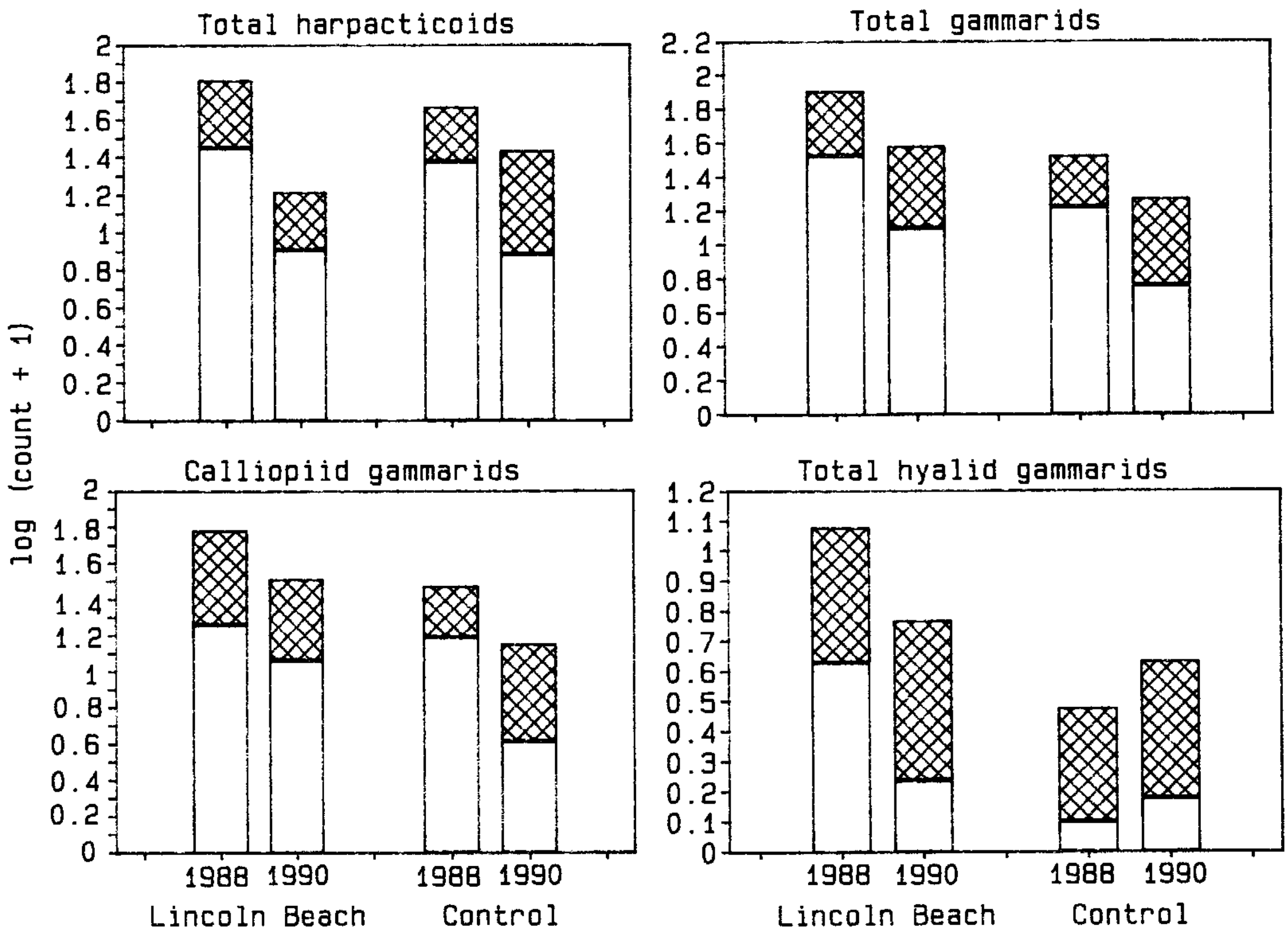

Figure 4. Ninety percent confidence intervals (cross-hatched area) of mean epibenthos density per sample from high intertidal zone in May.

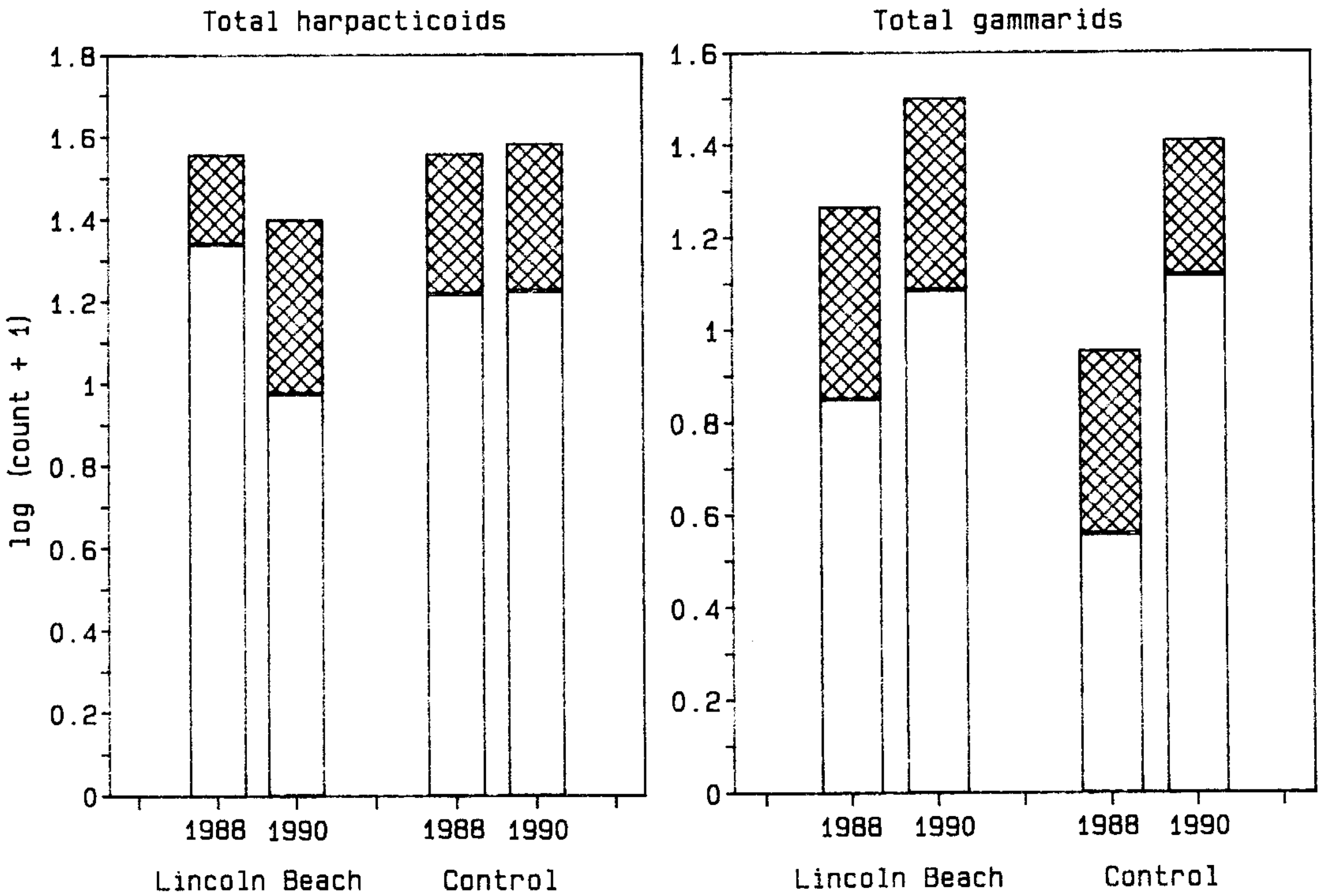

Figure 5. Ninety percent confidence intervals (cross-hatched area) of mean epibenthos density per sample from the high intertidal zone in June.

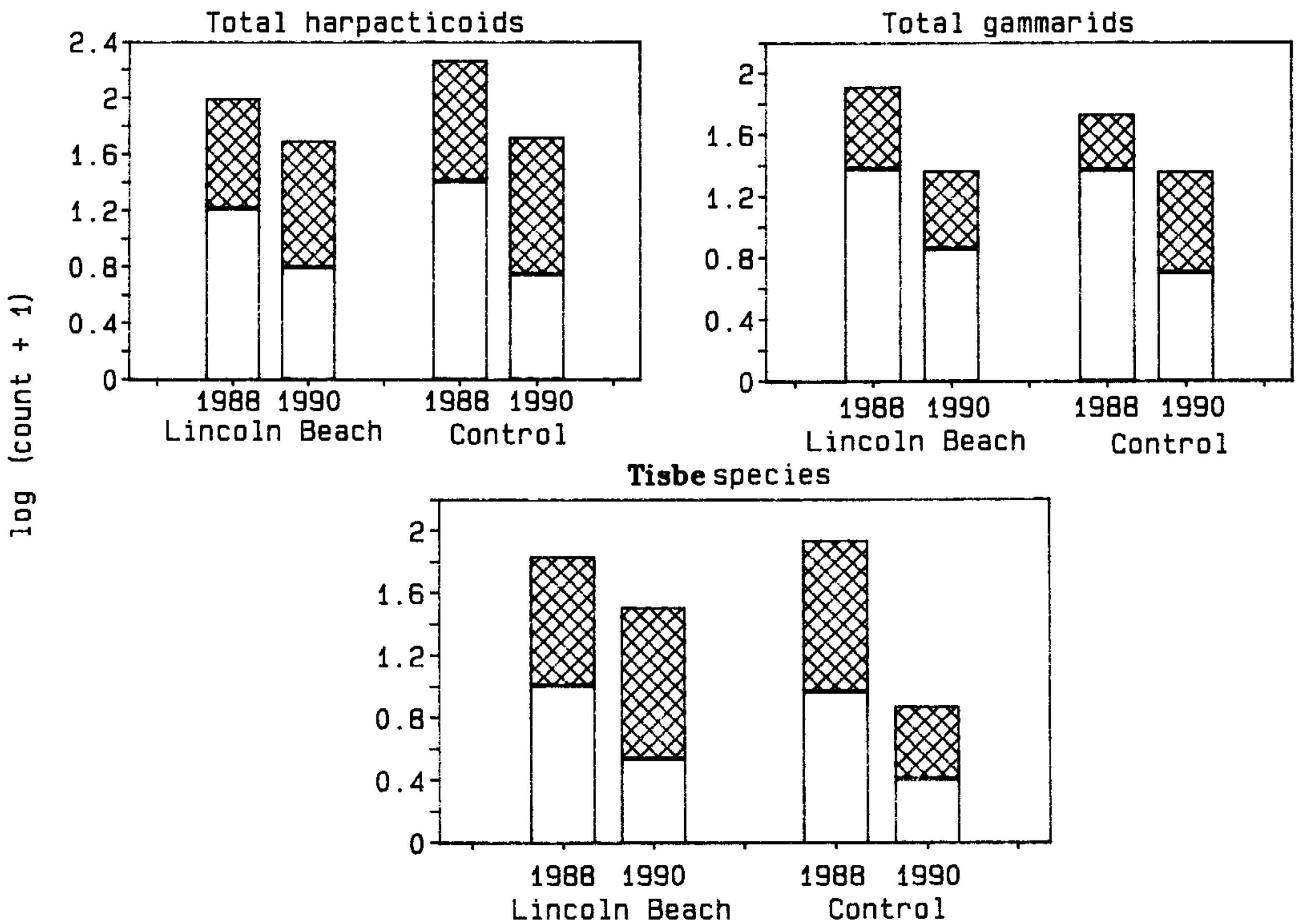

Figure 6. Ninety percent confidence intervals (cross-hatched area) of mean epibenthos density per sample from the low intertidal zone in March.

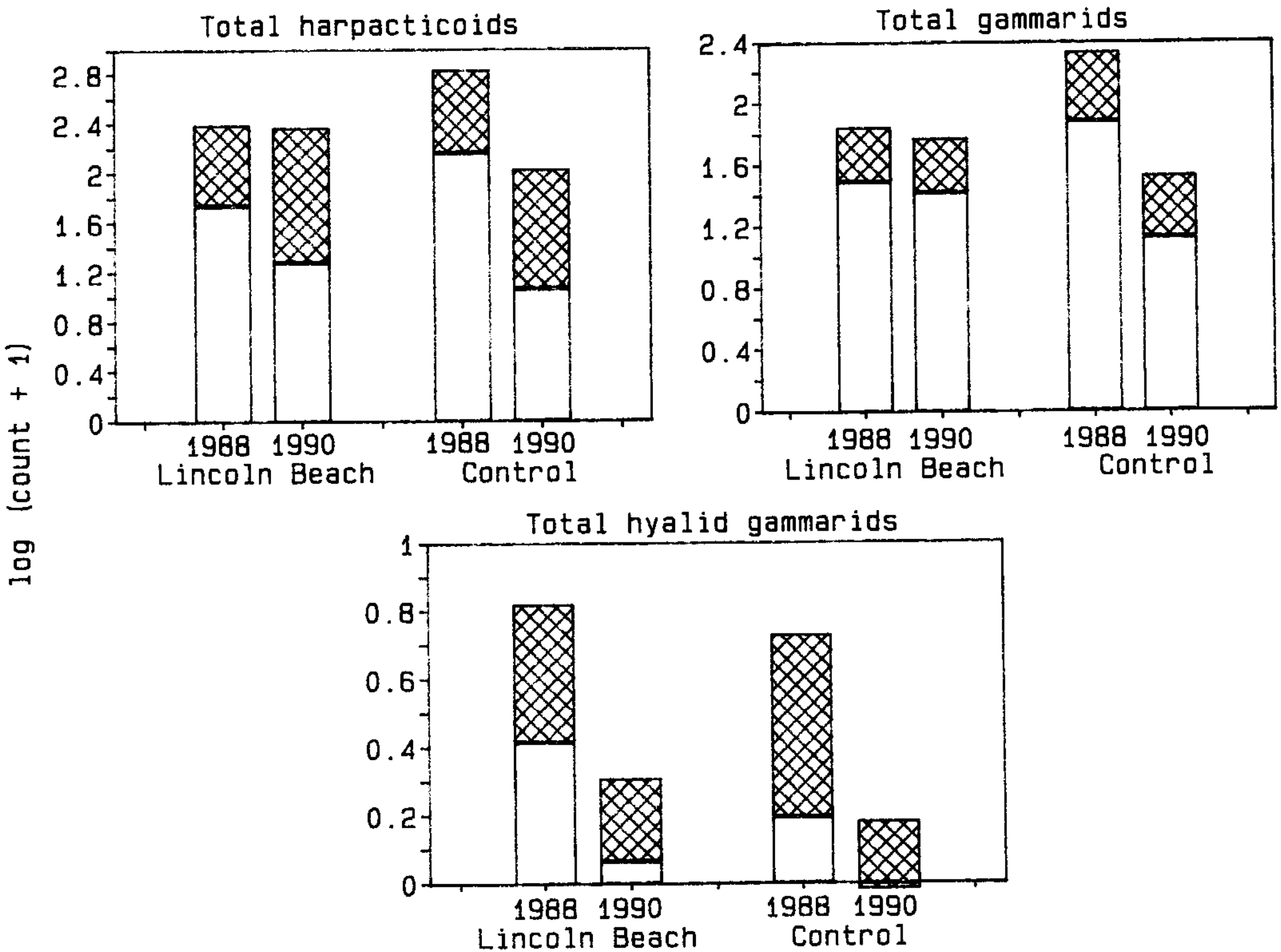

Figure 7. Ninety percent confidence intervals (cross-hatched area) of mean epibenthos density per sample form the low intertidal zone in April.

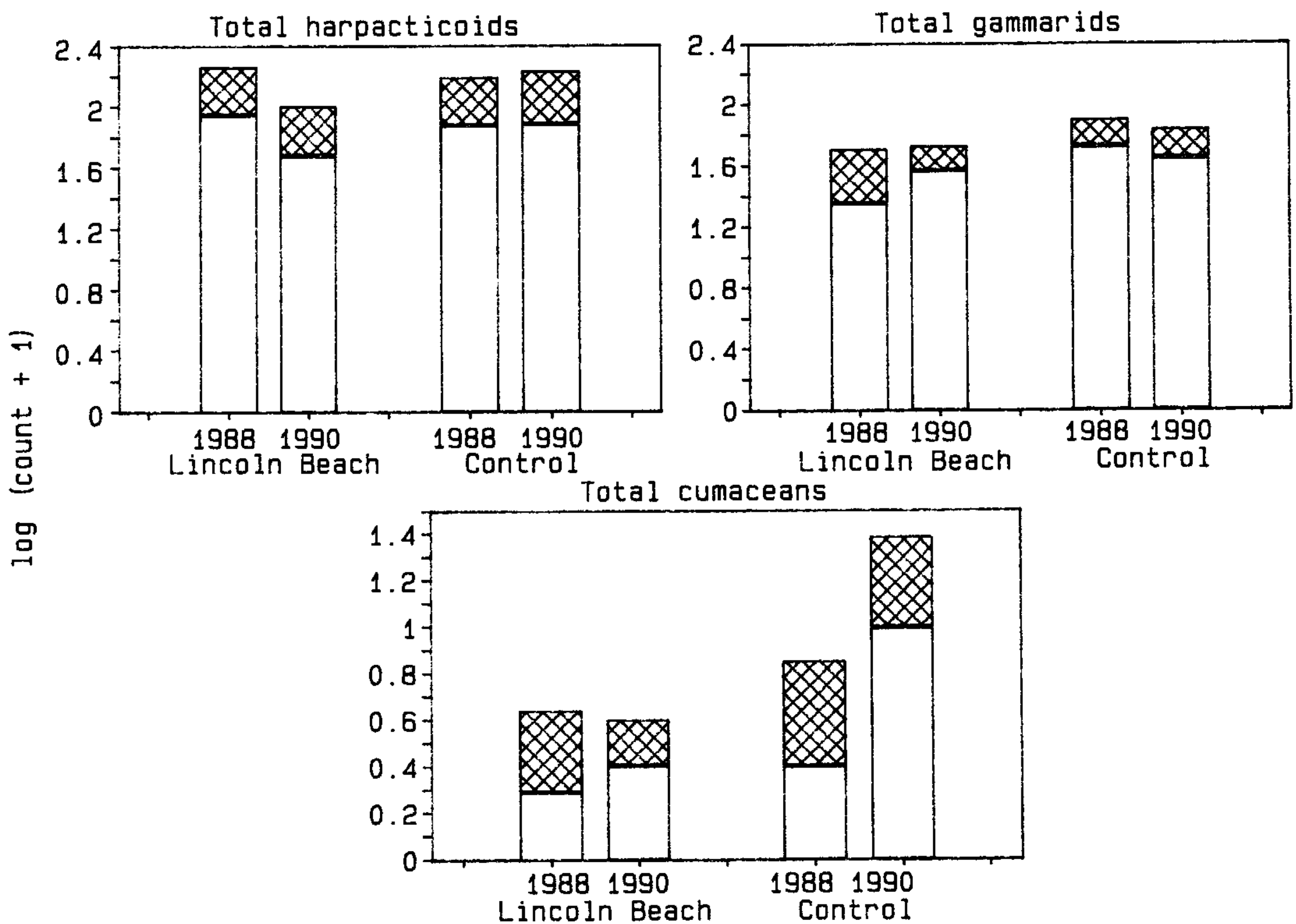

Figure 8. Ninety percent confidence intervals (cross-hatched area) of mean epibenthos density per sample from the low intertidal zone in May.

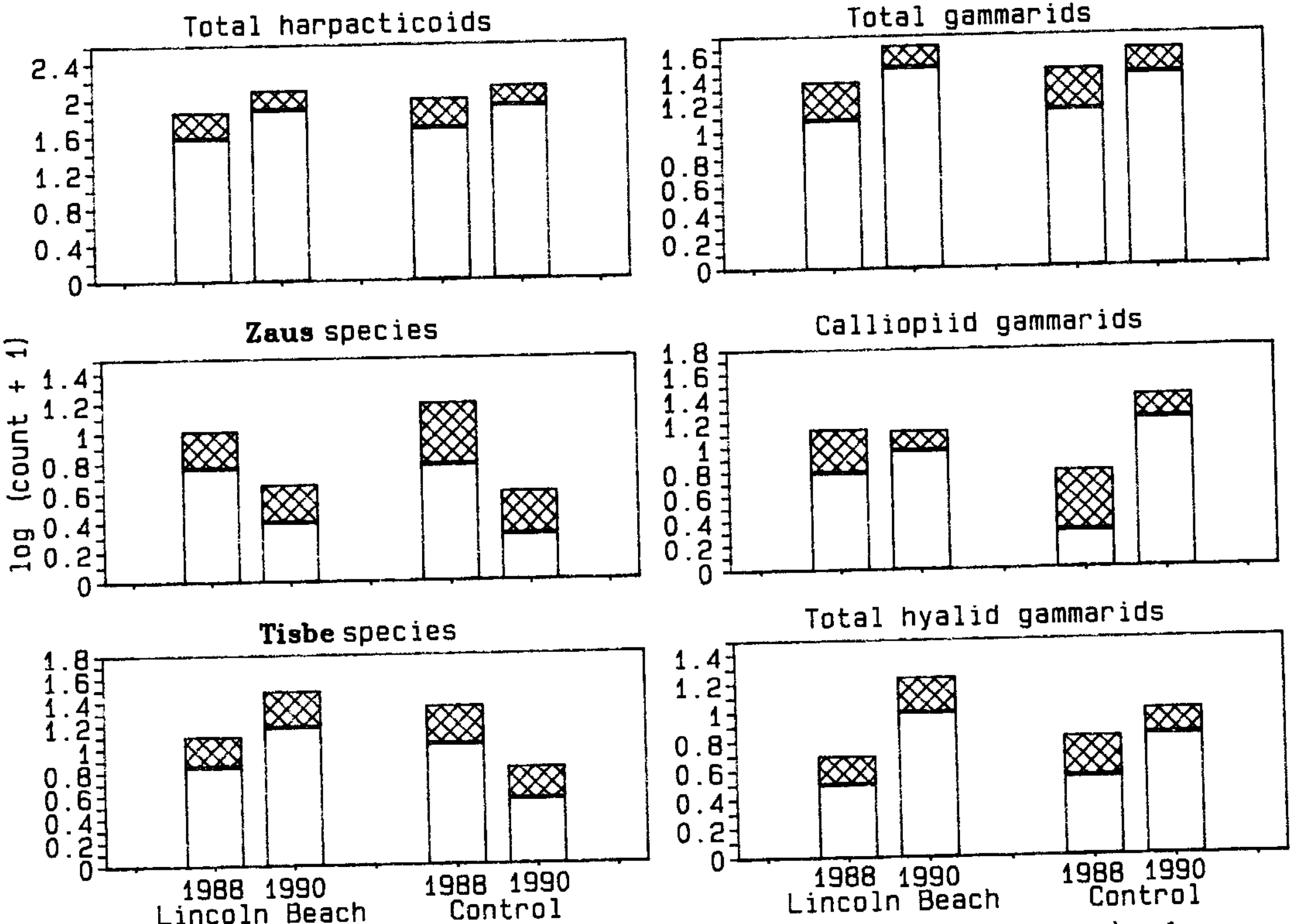

Figure 9. Ninety percent confidence intervals (cross-hatched area) of mean epibenthos density per sample from low intertidal zone in June.