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ESTABLISHING BOUNDARIES BETWEEN NORMAL, CHANGED, AND DEGRADED AREAS

The previous three papers have dealt with the development of the Infaunal Index, the determination of what constitutes natural conditions, and an extensive survey of the bottom in bays and off headlands. They are mainly factual statements of scientific findings; few conclusions are drawn that are not readily evident from the data presented. The papers show the feeding response of small benthic animals, but they do not relate those responses to the question that many people ask: "What areas of sea bottom off southern California have been biologically degraded (polluted) by municipal wastes?" This paper will use the information in the preceding papers as a foundation to answer that question, reorganizing the data in such a way that our logic for establishing boundaries between "normal," changed," and "degraded" marine communities is evident to the reader. Specifically, we will propose criteria for determining which of these three conditions exists; we will then apply the criteria to our data to determine the sizes of bottom areas affected at each of the major municipal wastewater discharge sites.

Based on a careful analysis of the large amount of data collected in this series of studies, the authors believe that an Infaunal Index number larger than 60 indicates that conditions of the bottom are "normal," numbers between 30 and 60 indicate "change," and numbers below 30 indicate "degradation." Changed bottom areas occupy about 168 sq km, or 4.6 percent, of the 3,640-sq-km mainland coastal shelf of southern California between 20 and 200 meters; the degraded areas occupy about 12 sq km. No area is devoid of marine life.

BACKGROUND

The reader is assumed to be familiar, at least in a general way, with the Infaunal Index methods and the extensive surveys described in the previous papers. As stated in those

papers, the control data used for comparative purposes are considered to be reliable in water depths of between 20 and 200 meters in the open coastal waters of southern California. This paper has that same qualification. However, the principles presented here probably can be applied to any area of the world, provided a sufficient data base exists.

The information previously presented is summarized here in a somewhat different form so that the logic of selecting boundaries between normal, changed, and degraded areas can be readily followed. These boundaries are based primarily on the effects of an unusual food supply on animal communities, and not on the distribution or effects of toxicants. The effects of toxicants seem to be insignificant in the "normal" areas; perhaps they are important in "degraded" areas. However, they were not considered in developing the logic presented here, and they do not affect the resulting boundaries.

Much of this discussion requires agreement on the definitions of such words as community, pollution, normal, degraded, and changed; we will clarify those at the onset:

- A marine community is "collectively all the organisms inhabiting a common environment, interacting with each other and with their inanimate surroundings" (Pennak 1964). With respect to southern California benthic communities, Jones (1969) concluded that "benthic marine associations are not discrete assemblages of organisms bound together by the biological interactions of their component species or determined by precise limits of the environment. They are, rather, roughly definable units with fairly recognizable geographic limits consisting of organisms that have similar reactions to their total environment, the physical and biological factors taken together."
- Pollution is a "damaging excess." The GESAMP (United Nations Group of Experts on Special Aspects of Marine Pollution) further defines marine pollution as the "introduction of substances into the marine environment that result in harm to living resources." This group emphasized the concept of harm as a necessary element in pollution and noted that change should not be equated with damage (Cole 1976).
- Normal means "within reasonable natural variation"--in this case, populated by a community of organisms with feeding strategies similar to those used by animals in control areas.
- Degraded areas are "less desirable," both to man and to certain marine organisms. The degraded areas off southern California could be said to be polluted in the sense that the original benthic infaunal communities have been damaged because of the great changes caused by an excess of organic matter--and possibly by

toxic substances. However, as far as we can tell, both the present communities and the individuals in them are healthy. They are simply new communities of specialized animals that are "out-competed" elsewhere but do well in this unusual environment.

- The area defined here as changed is inhabited by benthic animals that feed on suspended material as well as off the sediment surface. Where adjacent communities overlap in this fashion, many of the organism of each type are present. This type of area is known to ecologists as an "ecotone." There is no implication of damage, and it is quite common for both the number of species and the population density in such an area to be greater than in the regions flanking it (Odum 1971).

We began to develop the logic presented here by examining the data from the survey described in the preceding paper (see Bascom, this report); we were looking for abrupt changes in characteristics of the infauna or sediments with decreasing Infaunal Index value. Specifically, we considered the number of species, the number of individuals, and the biomass of the infauna and the amount of organic material in the bottom (Figure 1). It was somewhat surprising to find that all measurements were increasing or only slightly changed relative to controls as Infaunal Index values dropped from 100 to 60.

Number of species had increased as Infaunal Index values fell from 80 to 60; however, it began to decline when Index numbers dropped below 60. This gave us a suggestion about how to set the first boundary: Any region where all characteristics were equal to or greater than those in control areas could be considered normal. Thus an Infaunal Index value of 60 marks the boundary between "normal" and "changed."

As Index values fell below 60, the number of species steadily declined, but biomass and number of individuals continued to rise. Finally, these began to drop as the Index numbers dropped below 30; this seemed to be the logical boundary between "changed" and "degraded" areas.

THE RANGE OF CHANGES IN BOTTOM CONDITIONS

In the surveys described in previous papers, we found Infaunal Index values for the southern California shelf that ranged from 0 to 100, but values below 60 were almost always associated with areas of waste discharge. Table 1 is divided by horizontal lines into six sections; these were used to evaluate bottom conditions as related to ranges of Infaunal Index values. In each interval, the values and

ranges are given for number of species per sample, number of individuals, biomass (grams per square meter), sediment BOD (5-day biochemical oxygen demand), and volatile solids. The arrangement of the data from top to bottom roughly parallels the changes observed as one moves from a control area toward a large outfall.

Background or control areas are characterized by In-

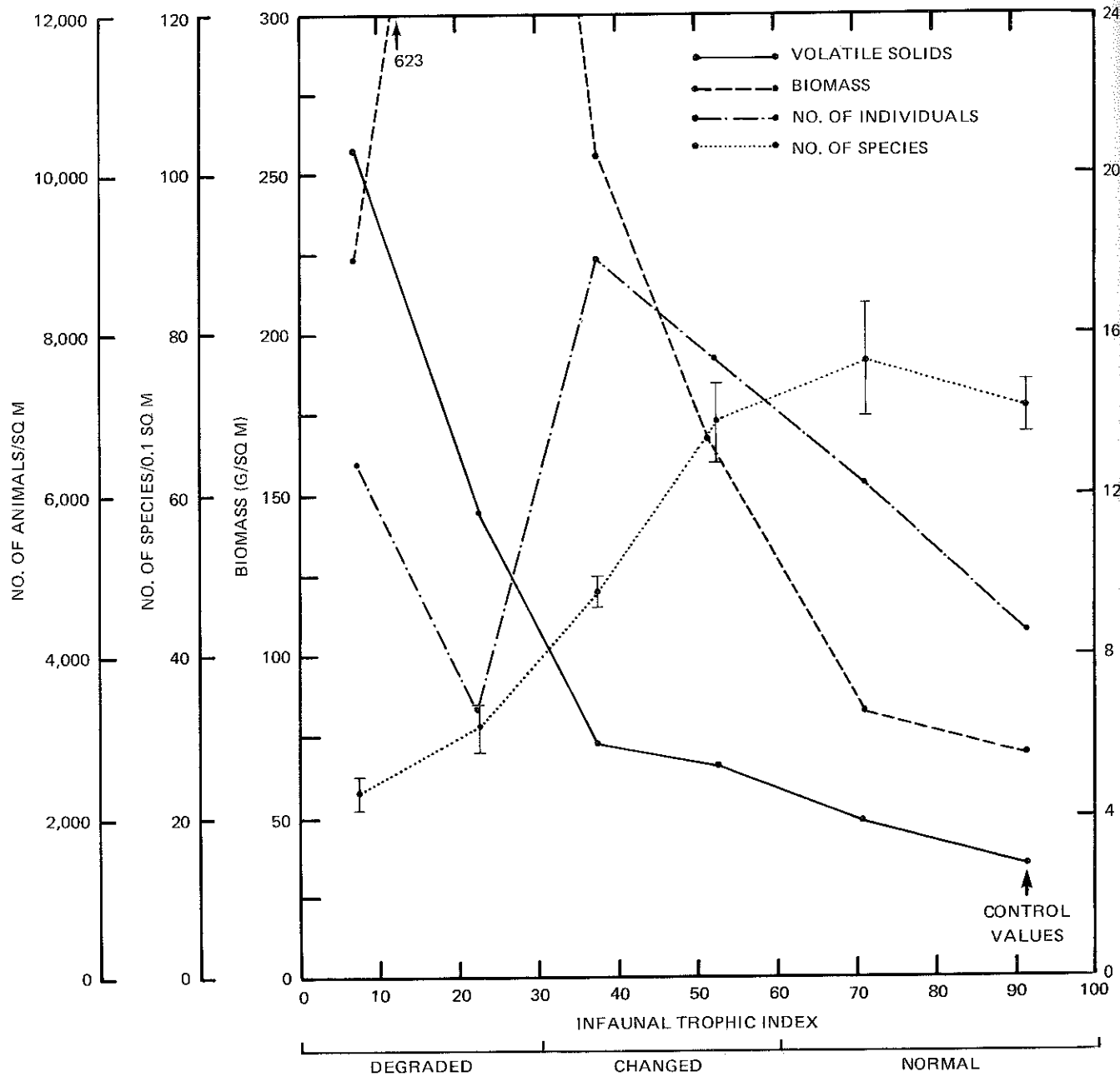

Figure 1. Variations in sediment and infaunal community parameters with change in Infaunal Index value. When Index values are above 60, all biological values are equal to or greater than control values; in the range of 30 to 60, number of species is lower than in control areas; below 30, the number of species is low, and the number of individuals is erratic.

faunal Index numbers ranging from 83 to 100, an average of 71 species per 0.1-sq-meter sample, and an average of 70 grams of biomass and 4,300 individuals per square meter. These data from our 60-meter control survey form our standard.

At Infaunal Index levels of 60 to 80, the number of species, biomass, abundance, BOD, and volatile solids all increase slightly. The benthic infauna remains dominated by suspension-feeding organisms (63 percent are Group I Infaunal Index species; Figure 2). Since all indicators are equal to or greater than controls, we have called all Infaunal Index numbers above 60 "normal."

Where Infaunal Index values range from 45 to 60, the infauna is dominated by surface-deposit-feeding invertebrates. As Index values decrease in this range, biomass and abundance continue to increase, but the number of species decreases slightly--there are only 69 species compared with 71 in control areas. BOD and volatile solids values have risen until they are about 50 percent greater than controls.

	Infaunal Index	Average No. of Species/ 0.1 sq m	Dominant Feeding Strategy of Infauna	% in Group I, II	% in Group III, IV	Average Biomass (g/sq m)	Average No. of Individuals/ sq m	Average BOD of Sediments (mg/dry kg)	% Volatile Solids in Sediments
CONTROL	100	71 ± 4 (n = 29)	Suspension Feeders	96	4	70 ± 5 (n = 29)	4,230 ± 240 (n = 29)	632 ± 38 (n = 29)	2.8 ± 1 (n = 29)
NORMAL	90								
	80								
	70	77 ± 7.2 (n = 23)		79	21	81.7 ± 9.7 (n = 18)	6,179 ± 720 (n = 23)	870 ± 123 (n = 18)	3.9 ± 0.7 (n = 37)
	60								
CHANGED	50	69 ± 5 (n = 30)	Surface Feeders	56	44	168 ± 47 (n = 30)	7,725 ± 1,886 (n = 30)	1,188 ± 174 (n = 10)	5.2 ± 1.3 (n = 23)
	40	48 ± 2 (n = 38)		21	79	254 ± 65 (n = 21)	8,935 ± 1,056 (n = 38)	2,421 ± 600 (n = 22)	5.8 ± 0.8 (n = 20)
	30								
DEGRADED	20	31 ± 2.4 (n = 12)	Subsurface Feeders	19	81	623 ± 160 (n = 12)	3,480 ± 763 (n = 12)	12,893 (n = 3)	11.6 ± 4.7 (n = 3)
	10	23 ± 2 (n = 25)		7	93	223 ± 71 (n = 25)	6,401 ± 1,005 (n = 25)	17,021 ± 2,038 (n = 9)	20.6 ± 2.7 (n = 9)
	0								

Table 1. Conditions in southern California marine sediment from 20 to 200 meters defined as "normal," "changed," or "degraded." Only Palos Verdes data were used for Infaunal Index values below 30, as these conditions are seldom seen elsewhere.

In areas where Infaunal Index values range from 30 to 45, biomass and abundance values are nearly double the controls. Surface-feeding clams tend to dominate the infaunal communities; presumably, this is in response to the increase in food supply that the high BOD and volatile solids values for these areas reflect. There is an increase in biomass and abundance, but the number of species is now significantly below the control value (48 compared to 71). This is the first substantial decrease in any of the values. As there seems to be no logical reason for concluding that animal communities are either improved or degraded when two of the indicators are up and one is down, we have called areas with Infaunal Index values of 30 to 60 "changed."

Index values below 30 are found only in regions close to large wastewater outfalls. As values drop below 30, the infauna becomes dominated by subsurface-deposit-feeding

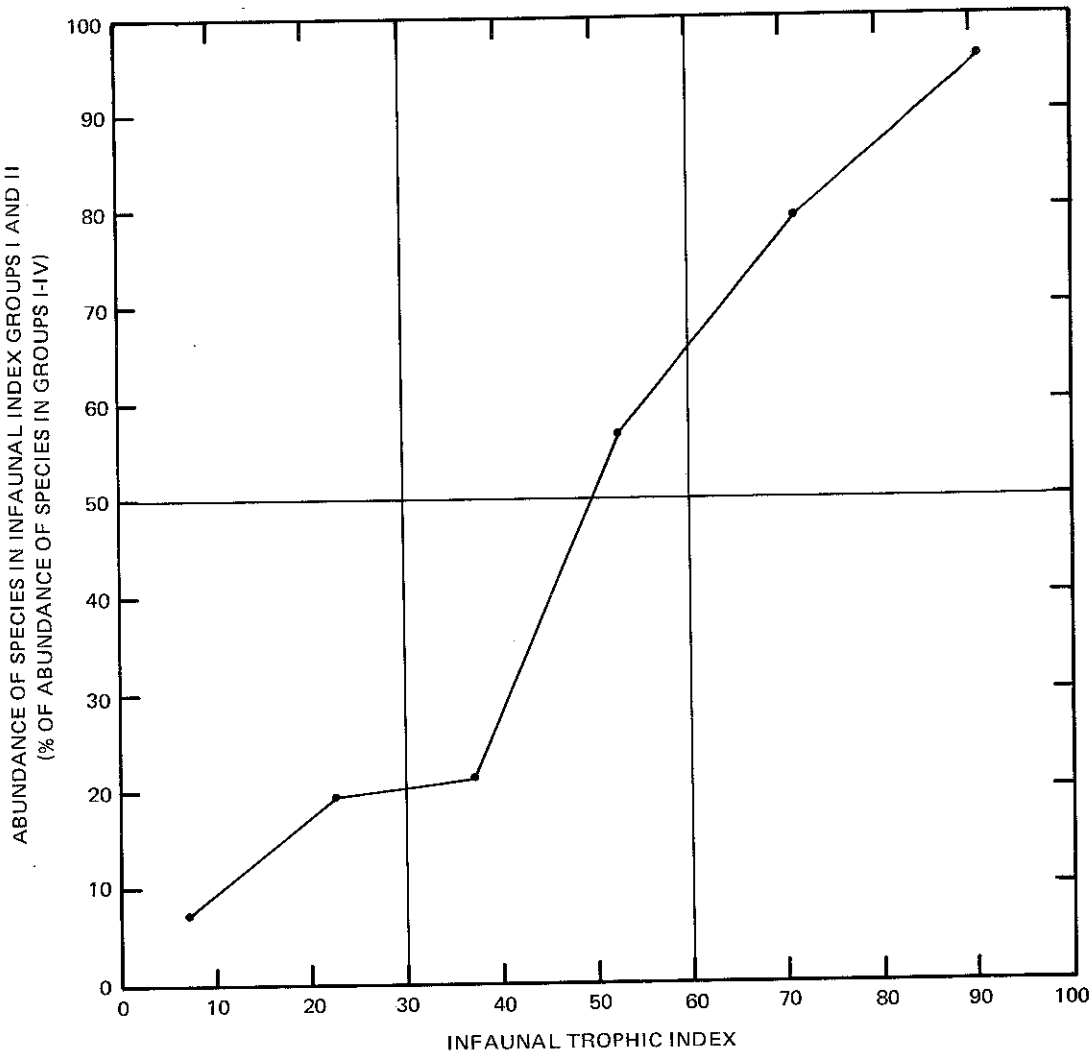

Figure 2. Increase in Infaunal Index values with increase in abundance of organisms in Groups I and II, which are primarily suspension-feeding species.

invertebrates. Biomass and abundance begin decreasing (although values for the former are still above controls), and the number of species is less than half that at control sites. BOD and volatile solids values continue to increase, the former becoming very high close to an outfall discharge point. Thus, an Infaunal Index value of 0 to 30 means that values for two of the three indicators are below controls. Areas with such Index numbers are "degraded."

SIZE OF AREA AFFECTED

The size, in square kilometers, of bottom areas characterized by "changed" and "degraded" infaunal communities was determined by drawing isolines around areas with Infaunal Index values of less than 60 and less than 30 on carefully prepared scale charts of the Los Angeles/Orange County and Point Loma/San Diego coastal regions. We then planimetered the surface area about each outfall occupied by "changed" infaunal communities and "degraded" communities. The areas we have identified (shown in Figures 3 through 6) are limited not only by the isolines but by the depth range of 20 to 200 meters. Off the Palos Verdes shelf and in the Santa Monica submarine canyon, there are additional areas of change and degradation not included in our figures.

Our data come from the stations whose positions are shown in the paper entitled "Life in the Bottom" (see Bascom, this report). The maps provide an overall picture of coastal conditions rather than a detailed look at the areas very close to the ends of the outfalls. Therefore, there may be small areas of change or degradation within a few meters of the discharge points--we have not sampled close enough to know. If so, these probably come within what has been defined by the U.S. Environmental Protection Agency as the "zone of initial dilution." These are small areas, but conditions there may be exceptions to our general statements.

As shown in Figure 7, there was a wide size range of bottom areas affected by the four major outfalls. No area off Point Loma is classified as "degraded," but the infauna in an area of about 4 sq km is "changed." Off Orange County, an area of about 10 sq km is "changed." The area in Santa Monica Bay that is "changed" by the Hyperion discharges occupies at least 48 sq km (limited by the 200-meter depth contour); within this area is a degraded area of about 3 sq km. The result of the Los Angeles County Sanitation Districts' discharge off Palos Verdes is that an area of at least 85 sq km is "changed;" about 9 sq km is "degraded."

Using data from a June 1977 survey of the coast off Oxnard, we were able to assess the effects of the fifth largest wastewater discharge into southern California

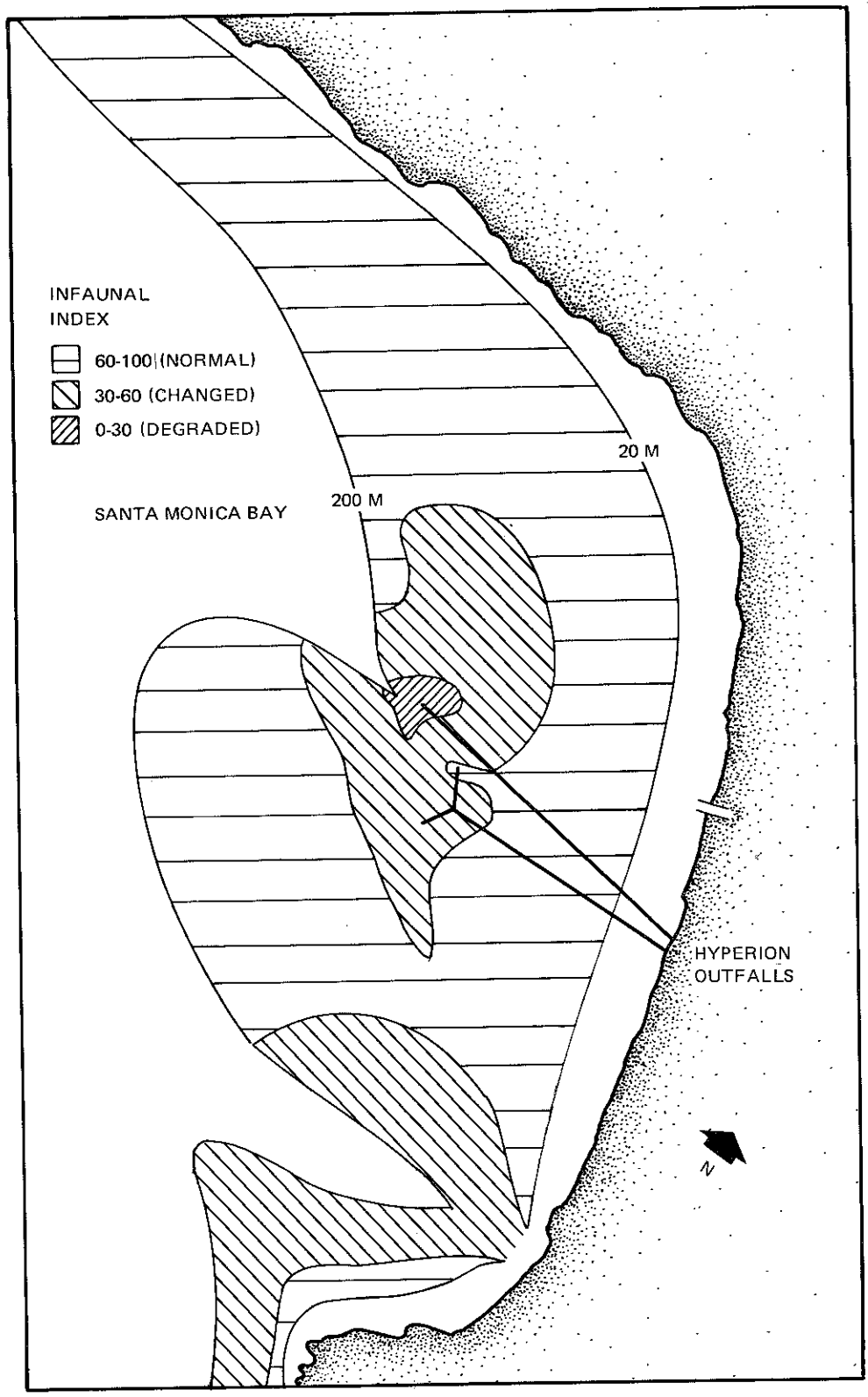

Figure 3. Location of "normal," "changed," and "degraded" areas in Santa Monica Bay, as defined by changes in Infaunal Index values.

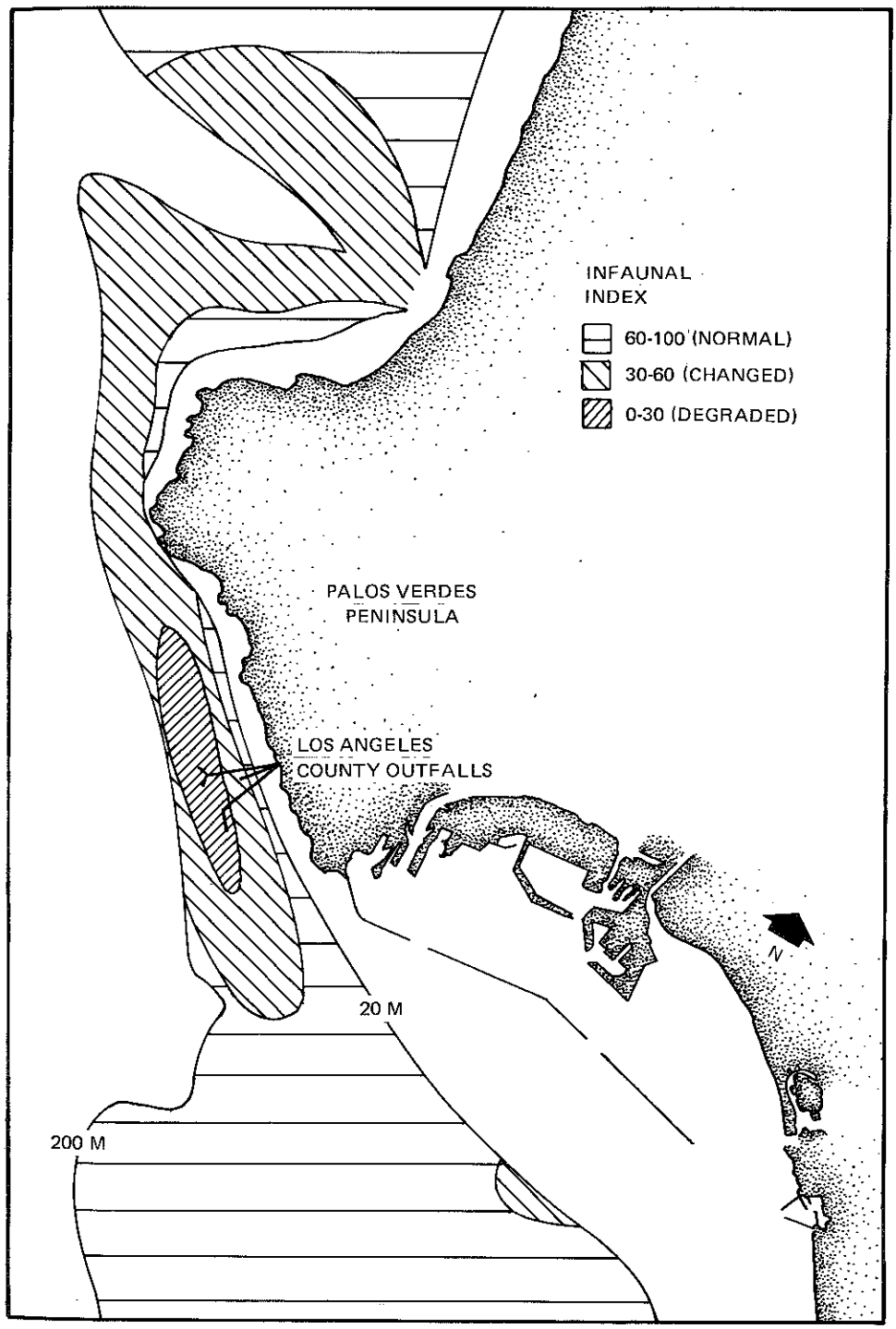

Figure 4. Location of "normal," "changed," and "degraded" areas off Palos Verdes, as defined by changes in Infaunal Index values.

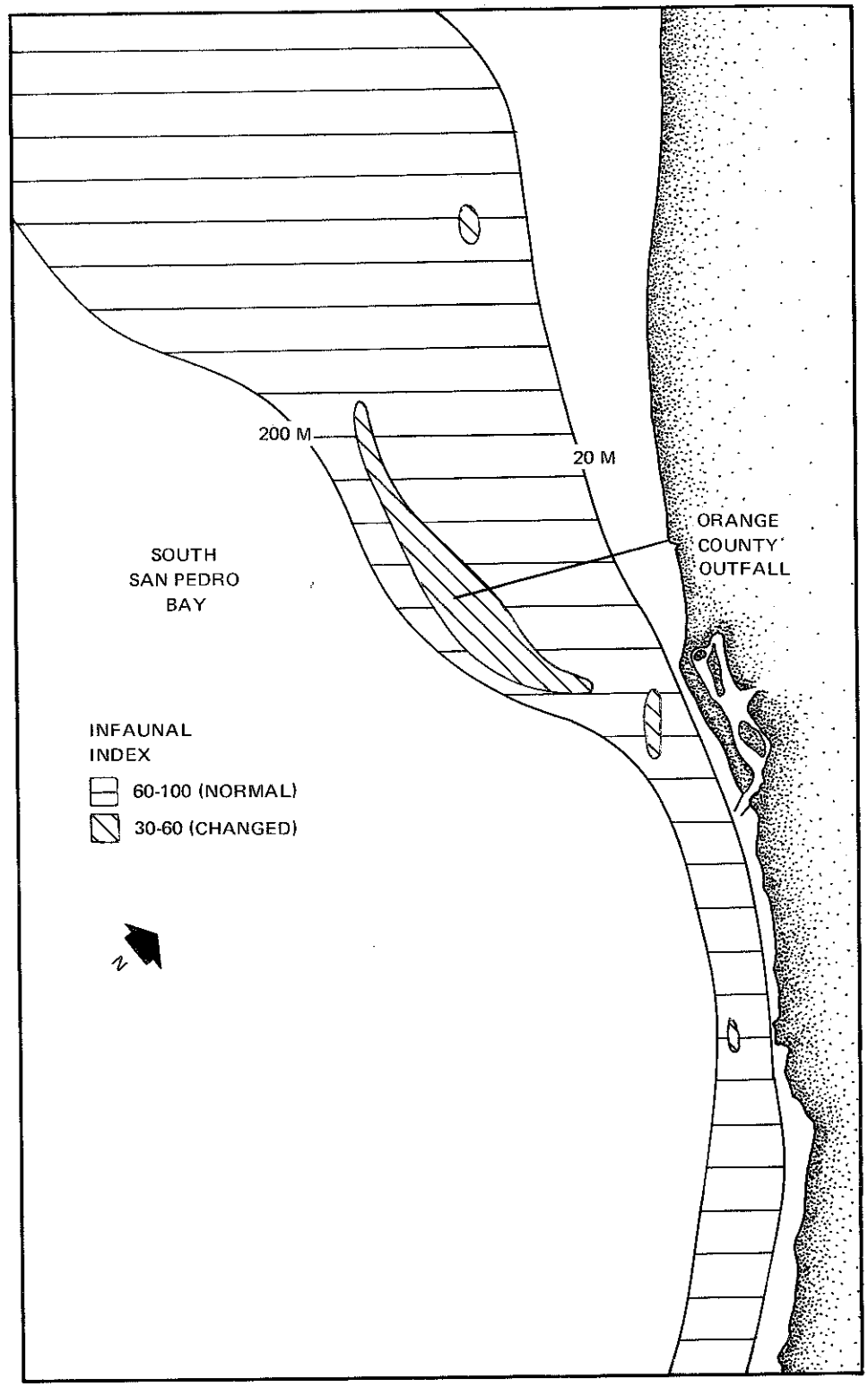

Figure 5. Location of "normal" and "changed" areas off Orange County, as defined by changes in Infaunal Index values. No area was found to be "degraded."

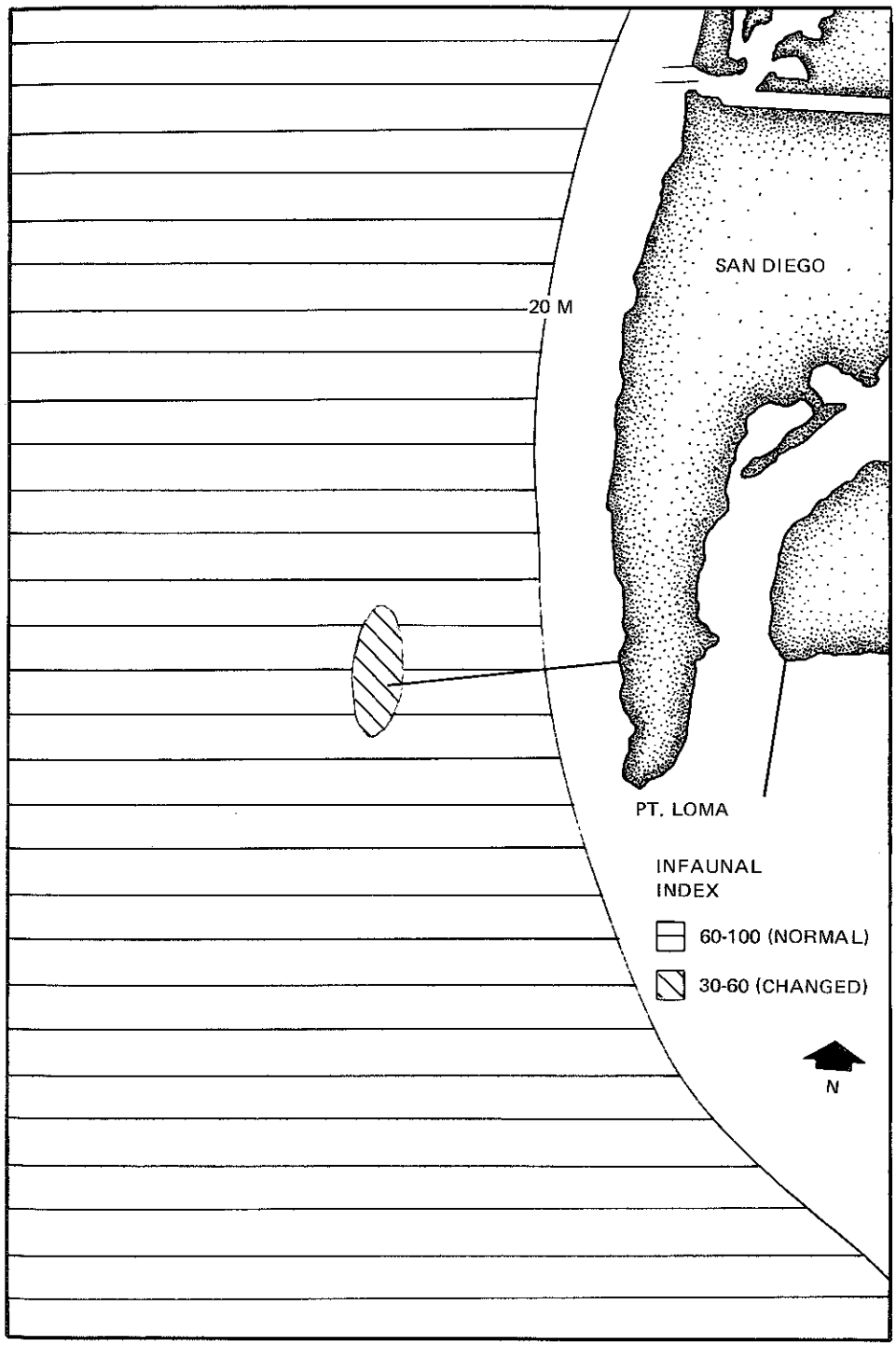

Figure 6. Location of "normal" and "changed" areas off San Diego, as defined by changes in Infaunal Index values. No area was found to be "degraded."

coastal waters. We found the area near the Ventura County Regional Sanitation Districts outfall, which terminates in 16-meter water depth, to be "normal;" conditions there are very similar to those in control areas.

Overall, we estimate that some 168 sq km, or 4.6 percent, of the 3,640-sq-km mainland shelf of southern California are "changed" as a result of deepwater sewage discharges. About 12 sq km of this area can be considered "degraded" on the basis of the criteria used here.

RELATION TO POLLUTANTS

Work is now in progress to relate toxicant levels in sediments to Infaunal Index values. The data in Table 1 and

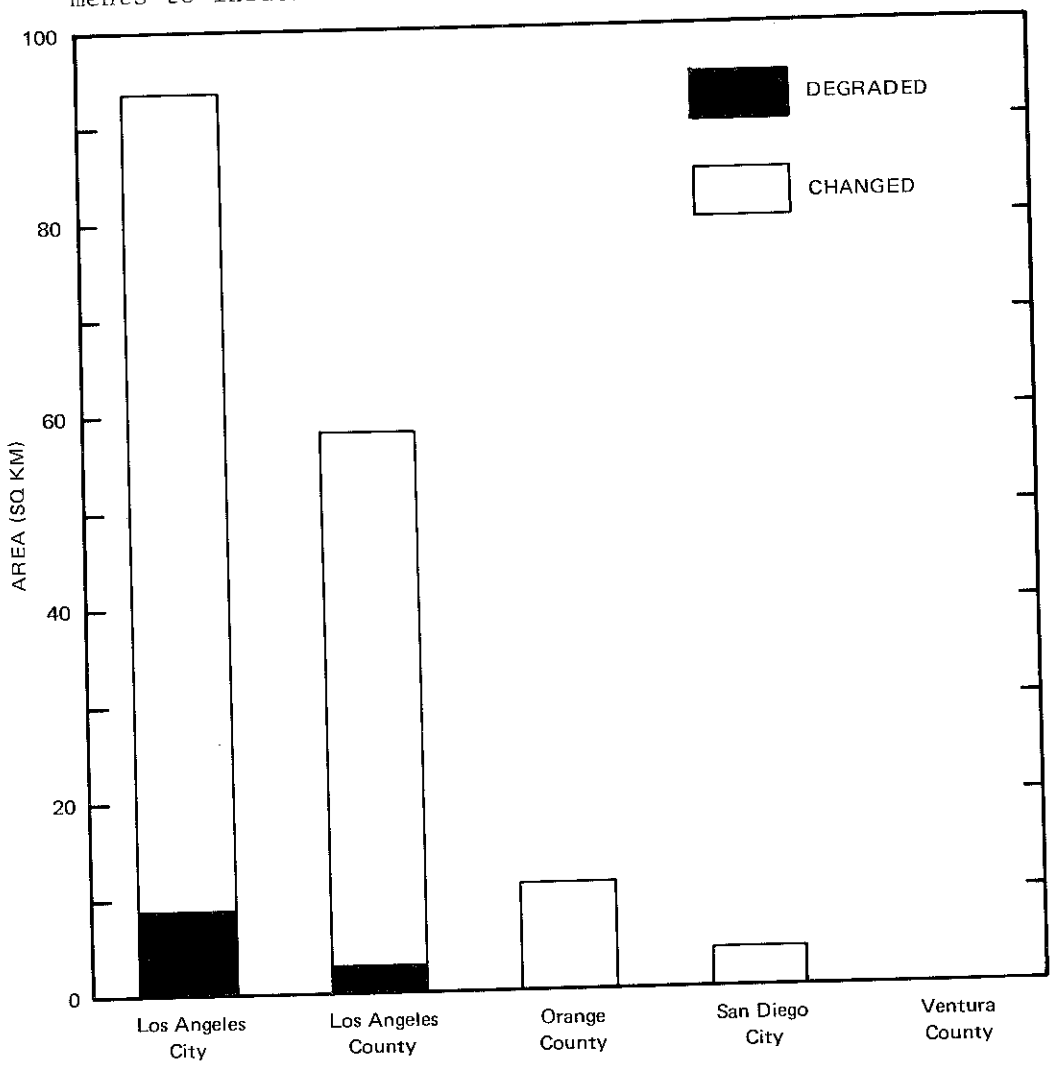

Figure 7. Areas near southern California's major municipal wastewater outfalls that are "changed" and "degraded." Note that there is no "changed" area near the Ventura outfall and no "degraded" areas near the Orange County and San Diego City outfalls, except perhaps within the zone of initial dilution. Changed and degraded areas off Los Angeles City and County outfalls are limited by the 200-meter depth contour.

the preceding discussion suggest that there is a relationship between excess BOD and biological changes. On the basis of the criteria used here, it appears that BOD can increase to about 25 percent above control levels, and volatile solids to a value of at least 4.0 percent, without causing substantial changes in the feeding structure of the infaunal communities.

We cannot say much about the effects of toxicants on the infauna, mainly because the Infaunal Index measures feeding alterations only. Except for the chlorinated hydrocarbons, it is not clear which substances have any effective toxicity. Measurements of trace metals in small benthic invertebrates indicate that exposure to contaminated sediments results in only slight increases in tissue levels of metals. We also know that, in larger filter-feeding invertebrates such as scallops, it is unusual to find body contamination of more than a few tenths of a part per million, and such an increase in body burden is not known to have any toxic effects.

Part of the problem in relating Infaunal Index values to levels of toxicants in the sediments is that very low Index measurements are mostly found off Palos Verdes, where there is a special suite of contaminants, which have been in the sediments for a long time. The region has a notable lack of microcrustaceans, and we think this may be related to the high DDT levels in the sediments. As no other area off southern California is similar, it is not possible to make a comparison.

Generally speaking, most of the possible pollutants correlate with each other; our measurements of increased volatile solids or BOD give a general indication of increases in other contaminants. Although we have inadequate supporting data on this point, it seems likely that when volatile solids, BOD, or other possible pollutants are less than twice the level at control sites, no major change in the feeding structure of infaunal communities will occur.

DISCUSSION

This paper deals broadly with the problems of identifying important changes in the community structure of benthic animals caused by changes in their food supply and distinguishing between changes that have ecological significance and those that do not.

We are attempting to provide useful and scientifically based answers to the questions: Which of the areas affected by wastewater discharge are worthy of public concern and expenditure, and which areas are so little affected that no action is required? Then an appropriate response to the effects of each outfall can be planned.

The initial problems were to find a scale of measurement (the Infaunal Index), a basis for comparison (the con-

trol survey), and the facts about the existing situation (the Bascom survey). We then tabulated the data and used the statistics to derive the logic explained in this paper. The words normal, changed, and degraded were carefully selected to be as descriptive and as noncontroversial as possible. These apply to the condition of the benthic infauna at the depths specified and with the restrictions noted. We ask the reader not to try to use these criteria for some other purpose.

In the future, we expect to complete work that will similarly specify the condition of trawl-caught creatures and rocky bottom biota and to extend the present work into shallower and deeper water.

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