DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-24

AQUATIC DISPOSAL FIELD INVESTIGATIONS DUWAMISH WATERWAY DISPOSAL SITE PUGET SOUND, WASHINGTON

APPENDIX G: BENTHIC COMMUNITY STRUCTURAL CHANGES RESULTING FROM DREDGED MATERIAL DISPOSAL ELLIOTT BAY DISPOSAL SITE

by

C. Rex Bingham

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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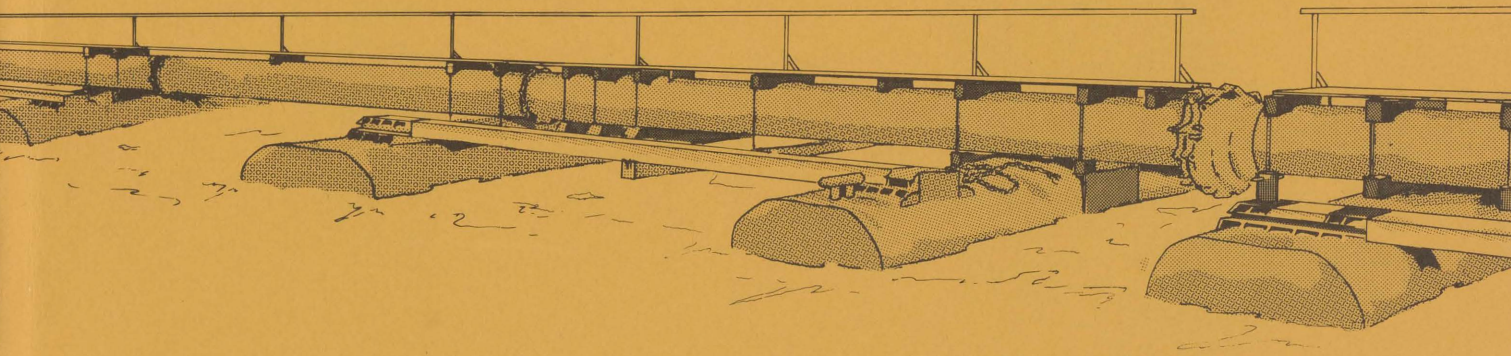

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under DMRP Work Unit No. 1A10B

AQUATIC DISPOSAL FIELD INVESTIGATIONS
DUWAMISH WATERWAY DISPOSAL SITE
PUGET SOUND, WASHINGTON

Appendix A: Effects of Dredged Material Disposal on Demersal Fish and Shellfish in Elliott Bay, Seattle, Washington

Appendix B: Role of Disposal of PCB-Contaminated Sediment in the Accumulation of PCB's by Marine Animals

Appendix C: Effects of Dredged Material Disposal on the Concentration of Mercury and Chromium in Several Species of Marine Animals

Appendix D: Chemical and Physical Analyses of Water and Sediment in Relation to Disposal of Dredged Material in Elliott Bay

Appendix E: Release and Distribution of Polychlorinated Biphenyls Induced by Open-Water Dredge Disposal Activities

Appendix F: Recolonization of Benthic Macrofauna over a Deep-Water Disposal Site

Appendix G: Benthic Community Structural Changes Resulting from Dredged Material Disposal, Elliott Bay Disposal Site

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESYR

15 September 1978

SUBJECT: Transmittal of Technical Report D-77-24 (Appendix G)

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of several research efforts (Work Units) undertaken as part of Task 1A, Aquatic Disposal Field Investigations, of the Corps of Engineers' Dredged Material Research Program. Task 1A is a part of the Environmental Impacts and Criteria Development Project (EICDP), which has as a general objective determination of the magnitude and extent of effects of dredged material disposal on organisms and the quality of surrounding water, and the rate, diversity, and extent disposal sites are recolonized by benthic flora and fauna. The study reported herein was an integral part of a series of research contracts jointly developed to achieve the EICDP general objective at the Duwamish Waterway Disposal Site, one of five sites located in several geographical regions of the United States. Consequently, this report presents results and interpretations of but one of several closely interrelated efforts and should be used only in conjunction with and consideration of the other related reports for this site.

2. This report, Appendix G: Benthic Community Structural Changes Resulting from Dredged Material Disposal, Elliott Bay Disposal Site, is supplementary to Appendix F: Recolonization of Benthic Macrofauna over a Deep-Water Disposal Site, one of seven appendices published relative to the Waterways Experiment Station Technical Report D-77-24, entitled: Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington. The titles of the seven appendices are listed on the inside front cover of this report. The main report will provide additional results, interpretations, and conclusions not found in the individual appendices and will provide a comprehensive summary and synthesis overview of the entire project.

3. The purpose of this study, conducted as Work Unit 1A10B, was to determine the effect of open-water disposal of Duwamish Waterway dredged material upon the relatively deep-water macrobenthic community of the Elliott Bay disposal site. Macrobenthic organisms were collected from the disposal site and two adjacent reference sites, once prior to disposal and five times at spaced intervals for nine months after disposal.

The organisms were collected, identified, enumerated, and weighed by Shoreline Community College, Seattle, Washington, Messrs. John C. Serwold and Robert A. Harman, principal investigators. This report provides results from additional analyses performed on several parameters in the data supplied by Serwold and Harman.

4. A conclusion of this report, based on the evidence presented, is that the negative impact of dredged material disposal upon relatively deep, low- to medium-current-energy macrobenthic communities is confined to the actual dump site and primarily to the disposal mound. It appears that insofar as the benthic community is concerned, delimited areas of similar nature to the Duwamish River-Elliott Bay disposal site can be disposed upon with sediments similar to those used in the study and have the detrimental effect upon the benthos confined to the immediate area.

5. The results of this study are particularly important in determining placement of dredged material for open-water disposal. Referenced studies, as well as those summarized in this report, will aid in determining the optimum disposal conditions and site selection for either the dispersion of the material from the dump site or for its retention within the confines of the site, whichever is preferred for maximum environmental protection at a given site.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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Benthic community changes resulting from the open-water disposal of 114,350 m^3 of Duwamish River dredged material at the Elliott Bay, Puget Sound, deep-water (approximately 60 m) experimental disposal site, 7 February 1976 to 6 March 1976, were investigated. Analyses were performed on macrofaunal density, species composition, biomass, biomass/individual, frequency of occurrence, and species diversity, at several taxonomic levels for one predisposal sampling and five postdisposal samplings at 10 days, and 1, 3, 6 and 9 months

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20. ABSTRACT (Continued).

after disposal. These analyses were performed on data from stratified (central, side, and corner) disposal site stations and two (east and west) reference sites. Taxonomic levels investigated were total benthic macrofauna, macrofaunal groups (gastropods, pelecypods, errantian worms, sedentarian worms, and miscellaneous species), and individual species.

Total macrofaunal densities at the disposal site showed large decreases 10 days after disposal that were unmatched by decreases at the reference sites. Disposal site total macrofaunal density gradually increased thereafter through 6 months after disposal, then decreased slightly at 9 months after disposal. The most abrupt increase occurred at 3 months. Disposal site marcofaunal densities never returned to their predisposal level nor to concurrent levels at the reference sites.

Total number of species showed large decreases at 10 days and 1 month after disposal, a considerable increase at 3 months, and a leveling off for the remainder of the study. Number of species at the reference sites remained relatively stable throughout the study. Total biomass and frequency of occurrence reacted somewhat similar to density.

Species diversity indices decreased at 10 days and 1 month after disposal at the disposal site and increased thereafter for the remainder of the study. At 9 months the disposal site species diversity index exceeded both its predisposal value and concurrent values at the reference sites.

Comparison of corner, side, and central disposal site stations and the two reference sites showed that the effects of dredged material disposal upon the previously discussed parameters were graded within the disposal site with central stations receiving the greatest negative impact. Side stations received a less negative effect while corner stations showed little effect. Both graphical and statistical analyses showed that there are certain species within each group, except gastropoda, which suffered little or recovered rapidly from the dredged material disposal while others suffered greatly and either failed to recover or recovered slowly.

Most individual species showed seasonal trends (both graphically and statistically) at the reference sites and the corner disposal site stations, indicating that rate of benthic macrofaunal recovery from dredged material disposal may be affected by seasonal parameters. Therefore, timing of dredged material disposal on similar sites may be important in reducing the severity of impact on the benthic macrofauna.

SUMMARY

This research was conducted to provide the U. S. Army Corps of Engineers with objective information concerning the effects of open-water disposal of dredged material upon deep-water macrobenthic communities and the rate and degree of recovery of these communities once disposal has ceased.

Benthic community changes resulting from disposal of 114,350 m^3 of Duwamish River dredged material at the Elliott Bay, Puget Sound, disposal site, 7 February 1976 to 6 March 1976, were investigated at several taxonomic levels with density (abundance) and biomass as basic structural units. Indicative community parameters investigated were: numbers of individuals per sample replicate (density), species composition, biomass per replicate, biomass per individual, species diversity indices, and frequency of occurrence of individual species. For these parameters comparisons of reference sites with disposal site were accomplished for one predisposal sampling period and five postdisposal sampling periods spaced at intervals of 10 days, 1 month, 3 months, 6 months, and 9 months postdisposal.

Statistical comparisons involving grouped disposal site station means and reference sites station means for densities, biomass, and biomass per individual over time were accomplished using 12 dominant species.

Spatial differences in the effect of dredged material disposal within the disposal site were investigated by segregating the station data of the 16-station disposal site grid into four corner, eight side, and four central stations and comparing mean species composition, density, biomass, and diversity indices from these groups of stations along with means for the reference sites.

There were graded effects of dredged material disposal upon benthic macrofauna of the disposal site. These effects correlated with areal distribution of the disposal site sampling stations relative to the disposal material mound. Large decreases in number of species, mean density, biomass, and diversity of benthic macrofauna were observed at

the four stations containing the actual disposal mound relative to predisposal and concurrent reference sites values. Diversity recovered in 3 months after disposal but other parameters failed to recover fully, relative to predisposal and concurrent reference sites values, during the study. It is, therefore, concluded that there was a detrimental effect from dredged material disposal upon the central disposal site stations of the Elliott Bay disposal site.

Disposal site stations adjacent to the disposal mound received smaller amounts of dredged material. There were large decreases in number of species, mean density, and biomass of the benthic macrofauna relative to predisposal and reference sites values though not to the extent of those at central disposal site stations. These parameters failed to recover relative to predisposal and concurrent reference sites values although they were progressed ahead of the central stations. Diversity displayed a general increase at the side stations throughout the study. It is concluded that there was a detrimental effect from dredged material disposal upon the side stations of the disposal site but that the intensity of this effect was less than that at the central stations.

The corner disposal site stations, covered with less than 0.5 m of dredged material, had slight decreases in number of species, mean density, and biomass of benthic macrofauna relative to predisposal and reference sites values. However, these values quickly recovered to predisposal levels and by 6 months postdisposal they exceeded predisposal values. Diversity remained stable for 1 month after disposal, then increased during the remainder of the study.

Decreases in number of species, mean densities, and biomasses showed an apparent correlation with depth of burial of benthic macrofauna at the Elliot Bay disposal site. Disposal of dredged material consisting of clay, silt, and fine sand apparently has a large detrimental effect upon benthic macrofauna when burial exceeds 0.5-m depths.

The increase in densities 3 months after disposal indicates no long-lasting detrimental chemical effects upon the benthic macrofauna of the Elliott Bay disposal site. It is therefore concluded that the detrimental effects upon the benthic macrofauna resulted from deep burial and suffocation.

The postdisposal period of study was too short for most of the species to show increases by reproduction. No species are known to survive deep burial for two weeks and migrate vertically thereafter. Biomass per individual failed to indicate recolonization primarily by developing larvae. The order in which stations showed signs of recovery was corner, side, and central, consecutively. Recovery by developing larvae "only" should have shown simultaneously at all stations since overlying waters can be assumed to contain equal larval numbers and since similar type sediments covered all stations. Recolonizing worms peaked after seasonal peaking at the reference sites. These facts lead to the conclusion that repopulation was by horizontal migration.

Increases in number of species, mean density, and biomass at corner disposal site stations above predisposal and concurrent reference sites values lead to the conclusion that benthic macrofauna of peripheral areas around a disposal site may benefit from the disposal of dredged material consisting of clay, silt, and fine sand. The foregoing facts also lead to the conclusion that the effects of the 1976 dredged material disposal upon the benthic macrofauna of the Elliott Bay disposal site were confined to the immediate disposal site area. This conclusion may be generalized for similar dredged materials disposal at low-current-energy sites.

Freshly disposed dredged material lacks an oxidized layer underlying the interface with overlying water and is slow to develop such a layer to more than a few millimeters in the absence of low oxygen tolerant, burrowing benthic infauna. If such macrofauna are not originally present near the disposed material, recolonization is delayed until these species arrive. Once such species are well established, reworking of the sediment increases the thickness of the oxygenated layer to several centimeters depth. This allows species requiring more oxygen to colonize the area. It is therefore concluded that early colonizers must be present in considerable quantities for rapid recolonization to proceed in a successional manner.

Individual species density variation at reference sites and corner disposal site stations indicated seasonally high and low populations. Therefore, rate of recovery of a similar disposal site may depend somewhat upon time of disposal. It is suggested that, since repopulation appears to be via horizontal migration, migration might occur most rapidly during high densities at surrounding areas. Such densities appeared in Puget Sound from June until September for most of the various species. Therefore, it is suggested that to achieve most rapid benthic recolonization, dredged materials might best be disposed immediately preceding and during the early stages of high density benthic macrofaunal populations. If a 3-month period is required to complete dredging operations, then May, June, and July would appear best for the Puget Sound area. However, May and June might be best if a 2-month period will suffice.

PREFACE

Shoreline Community College, Seattle, Washington, was subcontracted through the Northwest Fisheries Center, National Marine Fisheries Service (NMFS), to provide a macrobenthic invertebrate study at the U. S. Army Engineers experimental open-water dredged material disposal site in Elliott Bay, Mouth of the Duwamish River, Seattle, Washington. The study was a part of the U. S. Army Engineers' comprehensive Dredged Material Research Program (DMRP), which was sponsored by the Office, Chief of Engineers, and was authorized by Congress in the 1970 River and Harbor Act. The DMRP was assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the Environmental Laboratory (EL), previously the Environmental Effects Laboratory. The NMFS, by interagency agreement, was assigned the biological portion of the study, conducted from November 1975 to December 1976.

The study was planned and managed by personnel from the Environmental Resources Division of the EL and these personnel elected to conduct additional analyses upon the field and laboratory macrobenthic data collected and classified by Shoreline Community College. This report documents the analyses performed by the EL personnel upon the raw data supplied them by Messrs. John C. Serwold and Robert A. Harman, principal investigators for Shoreline Community College.

Statistical analyses of dominant species were performed by Mr. Dale Magoun and staff. All other analyses were performed by Mr. Rex Bingham, with the aid of technician Ms. Barbara Bell Adams. Ms. Adams and Ms. Susan Turner, technicians, assisted with graphical construction. Drs. Richard Peddicord, Carlos H. Pennington, Harold L. Schramm, and Henry E. Tatem provided valuable review comments during the report writing stage. Mr. Jeffrey H. Johnson, now with the U. S. Fish and Wildlife Service, Denver, Colorado, was Project Manager during most of this study and provided valuable assistance during the early stages of preparation of this report.

The study was under the direct supervision of Dr. Robert M. Engler, Manager, Environmental Impacts and Criteria Development Project, and under the general supervision of Dr. John Harrison, Chief, EL.

Directors of WES during the conduct of the study and preparation of the report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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APPENDIX G: BENTHIC COMMUNITY STRUCTURAL CHANGES RESULTING FROM DREDGED MATERIAL DISPOSAL, ELLIOTT BAY DISPOSAL SITE

PART I: LITERATURE REVIEW

1. In the absence of information particular to deep-marine (50-60 m) open-water disposal sites the contents of this review include studies fundamental to any marine environment. Though no previous estuarine deep open-water dredged material disposals have been monitored for benthic macrofaunal changes, a number of studies have been performed on shallow marine and/or estuarine sites and some show certain phenomena that might be expected to occur similarly in deep sites.

2. Physical, chemical, and biological parameters interact to produce the existing environmental condition at any point in time. Alterations in any one of these parameters produce a necessary readjustment in the others, usually in such a manner as to moderate the alteration.

Some Effects of Environmental Perturbations

3. Benthic macrofauna exhibited a decline in variety of species attributed primarily to deep burial during a freshwater dredged material disposal study at Ashtabula, Ohio.[1] Following the initial decline in number of species and abundance there was an increase in number of species as a function of time.

4. Species diversity indices of benthic macrofauna may increase though densities decrease at areas exposed to direct disposal of dredged material.[2] Early colonizing species of mud bottoms are small deposit-feeding organisms adapted to unstable conditions.[3] They prepare the habitat for further colonizers by reworking the sediments. This reworking produces a deeper oxidized layer of sediment capable of

supporting other organisms.[4] It also changes the grain-size distribution to a more favorable condition for organisms less tolerant to the fine soft clays and silts.[5] Tube-building polychaete worms help to stabilize the loose sediment, thus preparing it for colonization by macrofauna less tolerant to uncompacted silts and clays.[4,5]

Effects of Macrofauna on Conditions of Existence

5. Deposit feeders change the grain-size distribution grain shapes and spatial segregation of grain sizes.[4] Deposit-feeding infauna are especially important in increasing the depth of the redox potential discontinuity level, sediment water content, and dissolved oxygen content of the interstitial water.[5] Thus, this "reworking" prepares habitat for further colonization and may well serve as a control in benthic succession.

Sequence of Colonization

6. Early colonizers are small tube-dwelling, deposit-feeding organisms adapted to unstable conditions.[3] Benthic climax species are large, mobile nondeposit-feeding organisms that are poor colonizers but good competitors with low mortality.[3] Intermediate successional steps and organism relationships are likely to be small deposit-feeding bivalves and small suspension feeders.[3]

7. One of the striking features of soft-bottom organisms is their generally small size compared with invertebrates living on hard sand.[4] Large, dense organisms are apparently unable to adapt to the poor support provided by the soft bottom or to ingestion of large quantities of fine particles or both. This is particularly true of organisms that live at, or near, the interface.[4]

Oxygen Procurement and the Redox Discontinuity Zone

8. One of the basic phenomena associated with mud seafloors is low oxygen content. This problem must be adequately dealt with by

macrofauna that colonize such habitats. The problem has been dealt with in different ways, e.g., absorption through the body wall, blood pigmentation, air bubbles, reduced metabolism, irrigation of burrows, etc. Most invertebrate groups occupying low-oxygen marine basins are not affected by reduced oxygen until values reach concentrations less than 1 ml/l, and those forms which persist in low concentrations are small infaunal species.[4]

Aspects of Several Unique Studies

9. Several recent unique studies illuminate certain aspects of macrobenthic community changes associated with dredged material disposal.

10. A significant decrease of benthic infauna occurred at both the dredging site and disposal site immediately after a small maintenance dredging operation in Coos Bay, Oregon.[6] The infauna readjusted to predredging conditions within 28 days in the dredged area. At the disposal site, the infauna recovered to predisposal conditions in two weeks postdisposal. The authors suggest that an area subject to maintenance dredging is also subjected to frequent disturbance from ship movement. Therefore, the infauna are well adapted to such disturbances and maintenance dredging in such environments is a relatively normal event that should not produce catastrophic effects.

11. A study of the effects of dredging and disposal for marsh island development, Windmill Point, James River, Virginia, found that the dominant species were highly opportunistic, thus allowing quick recovery from perturbations.[7] Long-term changes were associated with areas of gross sediment alteration, such as at the fill material excavation sites, dike perimeter, and the confined area of fill within the dikes.

12. Laboratory studies testing the effects of dredged material depth on the vertical migration of benthic macrofauna demonstrated that the majority of Atlantic Coast organisms tested were able to move upward through 32 cm of dredged material if it was similar to their natural substrate.[8]

Life Span, Seasonal, and Depth Factors as Related to Macrobenthic Communities

13. Seasonal variations in numbers and standing crop of organisms with short life spans and high reproductive capacities are usually great as compared with those of organisms with longer life span and lower reproductive potential. Two obvious fundamental physical changes that occur seasonally and initiate chemical and biological changes are temperature and light. Decreases in magnitude of these two changes most certainly decrease the magnitude of associated chemical changes and probably, either directly or indirectly, the biological changes. Temperature and light changes are moderated with increasing water column depth, in general becoming smaller as depth increases. No significant seasonal variations in abundance of benthic organisms in Puget Sound were found during a study conducted in 1963-1964.[9] It was suggested, however, that seasonal abundance changes should follow seasonal spatfall and that detection of such might require a finer sieve mesh than that which was used (1 mm).

14. Though sediment type was considered to be the overwhelming dominant environmental parameter in Puget Sound, the low degree of similarity of one station to all others was considered to be in part due to a function of depth.[9]

Macrobenthos-Substrate Relations

15. Distribution and density of macrofauna are without doubt greatly influenced by substrate type. In Puget Sound the greatest number of species existed at stations with mixed substrate and the lowest number where the substrate was a fairly uniform mud.[9] The proportion of crustaceans and polychaetes in Puget Sound increased toward sand and/or coarser bottom types while that of the lamellibranchs decreased heavily towards these coarser bottom types. There was a gradual increase in number of species of polychaetes from soft to hard bottom. The opposite trend was revealed for the lamellibranchs while crustaceans and echinoderms showed no significant trend in relation to sediment type. The

distribution and density of the epifauna were found to be dependent upon the more or less scattered distribution of rocks and wooden debris on the relatively uniform substrate.

Diversity and Synecological Evaluation Methods

16. It has long been recognized that certain communities of plants and/or animals were more diverse than others but a concise means for comparing these communities has been slow in coming. The concept of an index of diversity has arisen and within the past thirty years many indices of diversity have been proposed, a few receiving rather wide but differing degrees of acceptance and use. Notable among these indices have been Margalef's, Simpson's, and Shannon's (known as the Shannon-Weaver index). The Shannon-Weaver index has been most popular primarily because it is supposedly based on "information theory" adopted from literal coding and popularized by Margalef. Margalef cautions that in succession, an increase in number of species initially increases the complexity and thus the diversity; however, information will cease to flow as succession progresses. Opposing forces favor increased diversity during earlier stages of succession and decreased diversity during climax or near-climax stages.[10]

17. It has been postulated that communities having high diversity and low components of organization are not biologically stable.[11] Communities possessing high diversity as well as high levels of organization were suggested to be biologically stabilized with respect to current physical circumstances. Johnson states that when comparing diversities, it is important that the faunas of the area under considertion be potentially the same.[12]

18. One problem associated with the use of diversity indices for comparison of different communities has been that the indices are to some extent dependent upon sample size and there has been no standardization of sample size in the scientific community. Sanders conducted a comparative study of within-habitat diversity using data collected from soft-bottom marine and estuarine environments of a number of

differing regions and proposed a procedure, "the rarefaction method," to allow comparison of samples of differing sizes.[13] Fager, however, found that the relation between rarefaction predictions and sampling results was highly dependent on the distribution of individuals among species.[14] For sample sizes of 20 to nearly 1,000, the rarefaction method predicted more species than would be found in actual sampling.

19. Hurlbert suggests that species diversity has become a meaningless concept and that the term should be abandoned, and ecologists take a more critical approach to species-number relations and rely less on theoretic information and other analogies.[15] He suggests that if the term is to retain any usefulness its meaning should be restricted to at least a function of the number of species present and the evenness with which the individuals are distributed among these species.

20. Grassle and Sanders state that much controversy relating to the concept of diversity and what it implies can be resolved by realizing that an increase of within-habitat diversity is achieved by two entirely different and unrelated pathways.[16] They differentiate the resulting diversities as follows: short-term nonequilibrium or transient diversity induced by a low level or unpredictable physical or biological perturbation, and a long-term or evolutionary diversity - the product of past biological interactions in physically benign and predictable environments.

21. According to Odum, "graphic analyses have two advantages over indices: (1) sampling bias is reduced, and (2) no specific mathematical relationship is assumed."[17] Variety of species and their relative abundance are by no means the only things involved in community diversity. Arrangement patterns and programmed activities also contribute to community function and stability.

PART II: METHODS

22. Community structural changes of benthic macrofauna were investigated following dredged material disposal upon the community. Structural changes occurring after disposal were referenced to the concurrent changes at two reference sites and to disposal site community structure prior to disposal.

23. A dredged material disposal site, 365.6 m on a side and composed of a 4 × 4 sampling grid of 16 stations each 91.4 m on a side (Figure 1), was selected for study. Two reference sites (Figure 1) were chosen for comparative evaluations. (See Duwamish Evaluative Summary for background).

24. Sampling was accomplished with a 0.1-m^2 Van Veen grab. Three replicate grabs per station for 16 stations (total of 48 replicates) represented the disposal site sampling effort per sampling period. Three replicates per station for four stations (total of 12 replicates) represented the reference sites sampling effort per sampling period. Volume of the contents of each grab was estimated, using a large graduated flask, then washed through a 1-mm sieve. Contents remaining on the sieve were returned to the laboratory for separation and identification. Residue volume was estimated and wood, plant fiber, and rock were separated and their volumes estimated. Volumes of fines (<1 mm diameter) were determined by subtracting the estimated volumes of residue from the estimated volumes of the grab sample. Macrofauna were separated, identified, and their wet weights determined. For details, see Duwamish Appendix F.

25. Data of the above-mentioned collections and identifications were received at the Waterways Experiment Station and served as the basis for this report.

26. Dredged material effects upon benthic macrofaunal structure were investigated by first comparing mean data of species composition, density, biomass, frequency of occurrence, and species diversity among sites for one predisposal sampling and five postdisposal samplings at intervals of 10 days, 1 month, 3 months, 6 months, and 9 months.

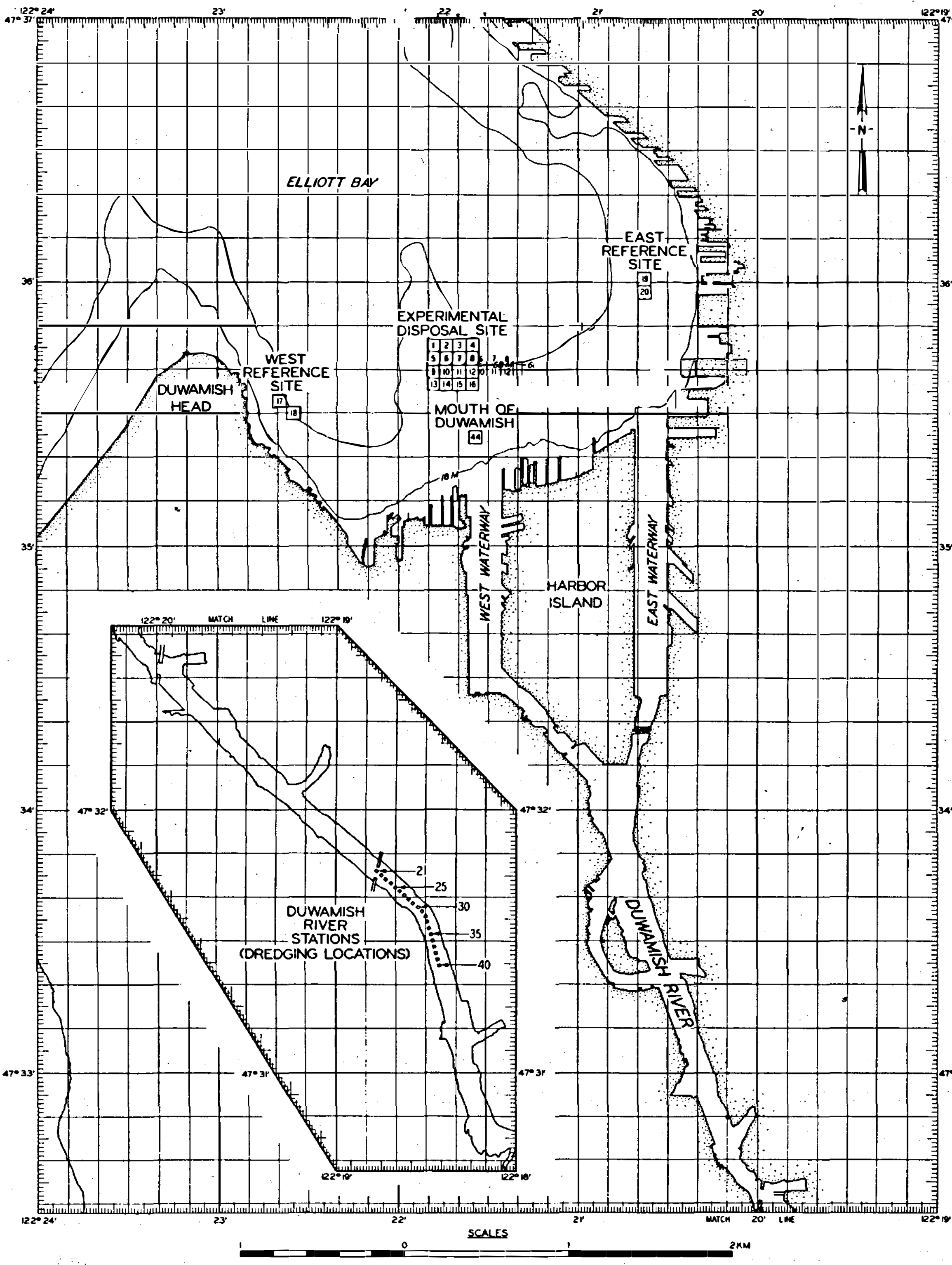

Figure 1. Locations of dredging, disposal, and reference (control) sites. Dredging was accomplished in the vicinity of the river stations shown in the insert

27. The dredged material disposal site data were then grouped by four central, eight side, and four corner stations for the dual purpose of internal analysis and accounting for expected within-site variations due to areas of greater to lesser dredged material deposition impact upon benthic macrofauna. Central stations macrofauna were expected to receive the greatest impact due to their greater depth of burial. Side stations macrofauna were expected to receive an intermediate impact and corner stations were expected to be least affected due to their greater distance from the discharge locale.

28. Statistical and graphical analyses were performed on macrofaunal density, biomass, and biomass/individual. Graphical analyses were also performed on species composition, frequency of occurrence, and species diversity. Analyses were performed at several taxonomic levels for one predisposal sampling and five postdisposal samplings at intervals of 10 days, 1 month, 3 months, 6 months, and 9 months after disposal.

29. Statistical comparisons among grouped stations and reference sites over time were conducted using an unbalanced nested factorial analysis of variance with equal cell size. Since rare or infrequently occurring species introduce large variation into the analysis with lesser accompanying information, only the more dominant species were included in the statistical analysis.

30. Mean data of each sampling period for the previously mentioned parameters are displayed graphically within the text of this report.

PART III: ANALYSES AND RESULTS OF BIOLOGICAL STUDIES

Benthic Assemblages

Specific objectives of benthic study

31. The specific objectives of the biological studies were to determine the temporal and spatial effects of Duwamish River dredged material disposal on the macrofauna of a deep-water (60 m) site in Elliott Bay, Puget Sound, Washington.

Spatial and temporal changes in sampling depths

32. Predisposal benthic sampling depths and a bathymetric survey showed a general increase in water column depths from approximately 55 m at the southwest corner (Station 13) of the 4 × 4 sample grid to approximately 67 m at the northeast corner (Station 4). Depths increased from west to east and from south to north. The east reference site depths ranged from 46 to 64 m, with a mean depth of 55 m. The west reference site depths ranged from 46 to 68 m, with a mean depth of 53 m.

33. Two postdisposal bathymetric surveys (9-19 March and 21-23 April 1976) identify the disposal mound and show accompanying depth changes over the 4 × 4 disposal site grid. The surveys showed the center of the disposal mound in Station 10 approximately 30 m southwest of the disposal buoy anchored at the junction of the central stations (6, 7, 10, and 11). It measured approximately 2.7 m high at the center and was well defined with definitive contours extending well into adjoining Stations 6, 7, and 11 before blending with predisposal contour trends. Away from the defined mound, shifting of depth contour lines, without changing predisposal direction of the lines, indicated a general decrease in water column depth over all the disposal site. Corner stations, being farthest from the disposal mound, showed approximately a 0.5-m decrease in water column depth.

34. As implied above, the major impact of disposal materials

occurred over the central grid stations and the grid stations least impacted were the corner stations.

Spatial and temporal changes in sediment characteristics (percent composition)

35. Field measurement of sample volume using a graduated flask, and later laboratory measurement of residue volume and rock, wood, and plant fiber volumes allowed fairly accurate estimates of sediment percent composition.

36. There was no real difference in percent fines (<1 mm diameter) within sites or between sites over time. The vast majority of the sediment taken over all sites with the 0.1-m^2 Van Veen sampler was composed of fines (silt, clays, and fine sand). The lowest percent fines estimated was 84.6 percent taken at the east reference site during predisposal and the highest was 94.1 at the west reference 1 month after disposal. The disposal site percent fines ranged from 88.0 at 9 months after disposal to 89.5 one month after disposal.

37. Though considerable changes in rock, wood, and plant fiber occurred at the disposal site following the disposal of dredged materials, within-site changes failed to correlate with those of the benthic macrofauna. Rock, wood, and plant fiber were, therefore, discounted as a major contributor to the observed macrofaunal changes. Consequently, discussion of these changes is omitted for the sake of brevity.

38. Visual observations of disposal site samples prior to disposal showed a thin (1-3 cm) layer of greenish-brown mud over greenish-black mud sediment. Ten days after disposal most samples had little or no superficial layer, but when present the color was a brownish-rust over black. Three months after disposal a superficial layer 1/2 to 2 cm thick covered the black sediment and little change was noted thereafter. Both reference sites showed a layer of light green mud or muddy sand over a dark green mud or muddy sand.

39. Influence of the Duwamish River is a major consideration in interpreting the spatial and temporal changes in benthic macrofauna resulting from dredged material disposal at the Elliott Bay site. Located

on the river delta at the edge of its shelf, the site is subject to rapid sediment deposition from both suspended and bedload sediments as the delta continues its growth. On flood tide the Duwamish River plume is compressed into Elliott Bay and towards the mouth of the river.[18] This compression slows the velocity of the overlying riverine waters, thus allowing river-transported sediments to sink into the underlying more saline water where the net motion is back toward the mouth of the river and upstream therein. This upstream movement of the saline wedge was documented by the U. S. Geological Survey as referenced by Stephens, Thompson, and Runyon.[19] Mean suspended sediment load of the Green-Duwamish River system is 185,666.7 tons/year and highly variable as estimated by the U. S. Geological Survey over the time period 1964-1966.[20] Other measurements indicated that the bed load is proportional to stream flow and ranges from 20 to 40 percent of the suspended load. The above phenomena create a situation conducive to a rapid sedimentation rate over the Duwamish River Delta (disposal site location). While Duwamish currents serve as a source of rapid sedimentation, they also serve as a transport mechanism for riverine benthos immigration over the disposal site. Careful consideration must be given these factors for an adequate interpretation of the biological data associated with benthic recolonization of the disposal site. While transport of organisms over the site should aid in recolonization, the continued rapid sedimentation applies a physical stress which must be compensated for by recolonizing organisms, thus opposing rapid recolonization by many species of organisms.

40. Odum[17] broadly classifies ecosystem populations as being physically or biologically controlled and states that in all ecosystems there is a strong tendency for all populations to evolve through natural selection towards self-regulation. While predisposal sampling indicates to what degree the chosen site had evolved, there is no indication of the time required to reach this stage. Studies conducted in high-current-energy, shallow, rapid-sediment-dispersion areas have shown an almost immediate return to predisposal benthic norms;[6] however, such has not been demonstrated for low-current-energy, sediment-retainment

areas, such as the Duwamish site. Data from this study indicate that a longer recovery period may be necessary.

Spatial and Temporal Community Structure and Analyses

Species composition analyses

41. The total number of species of benthic organisms collected from each sampling site (disposal, west reference, and east reference sites) is shown in Figure 2 for comparison of changes in number of species. The reader is cautioned that site comparisons cannot be made on the basis of Figure 2, since sampling effort was comparable only among stations and not among sites. However, this does not prevent comparing changes among sites by means other than totals. All sites showed a decline in total number of species during March (10 days after disposal) but the decrease at the disposal site was proportionally greater than those at the reference sites. For an equitable means of detecting differences in changes in the number of species between the disposal and reference sites the percent changes from predisposal values to each remaining sampling period value for each site were computed. The mean percent change in numbers of species for the reference sites was then compared with the comparable percent change at the disposal site. Comparison was accomplished by finding the difference in percent change at the disposal site as opposed to that of the means of the reference sites. These differences (Table 1) are attributed to changes other than seasonal variations within the disposal site since the seasonal variation is accounted for by changes within the reference sites.

42. Reference sites samples indicated that under undisturbed conditions the greatest number of species occurred in Elliott Bay during June (3 months after disposal). Therefore, this is the time that the greatest number of species over the disposal site area would be expected if it had remained under natural conditions.

43. Table 1 shows the greatest nonseasonal variation from the expected number of species over the disposal site occurring three months after disposal. Though the greatest postdisposal number of

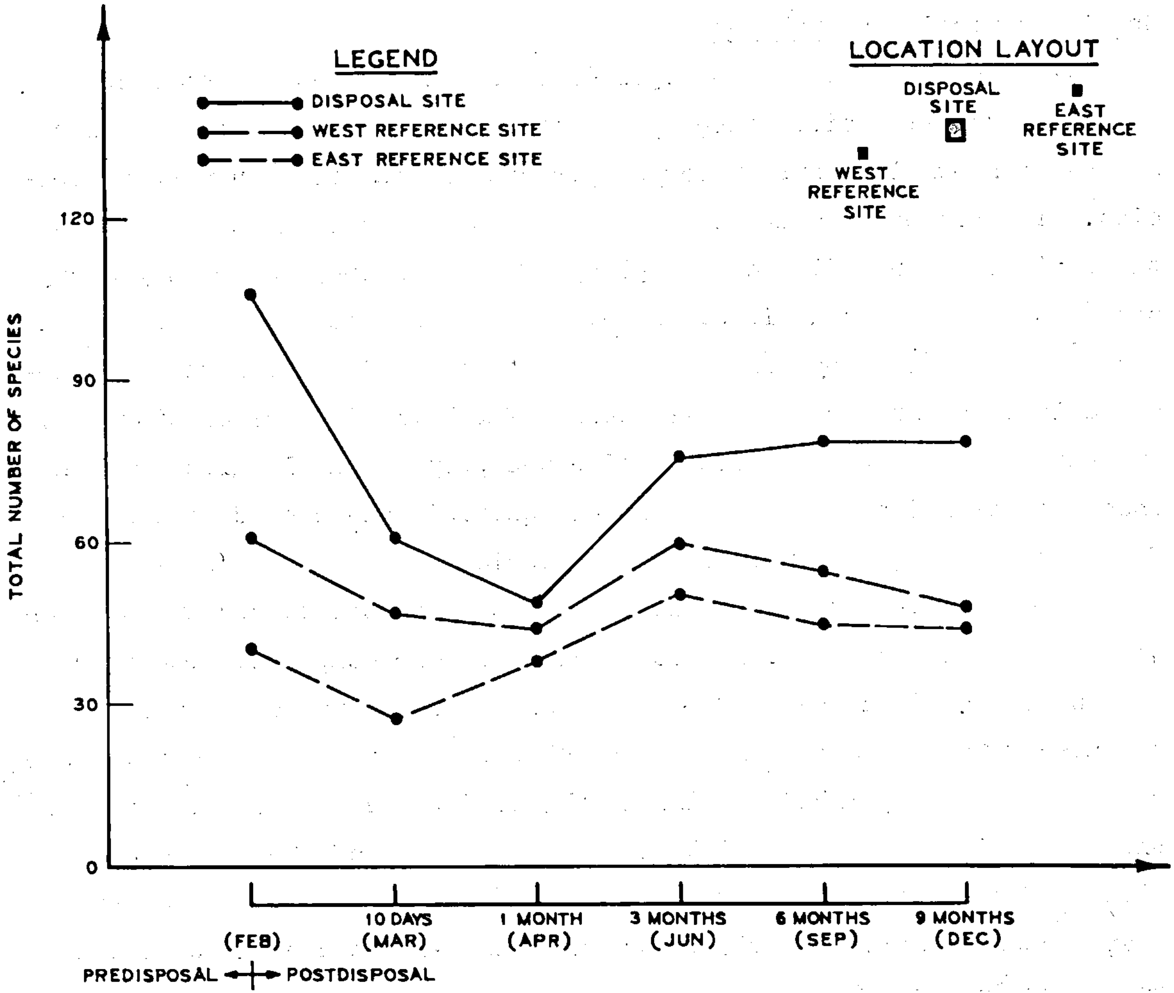

Figure 2. Total number of species of all groups

Table 1

Disposal and Reference Sites Percent Change in Number of Species

Time	Disposal Site Percent Changes	Seasonal Variation Mean Reference Sites Percent Changes	Disposal Site Percent Changes Minus Seasonal Variation Mean Reference Sites Percent Changes (Nonseasonal Disposal Site Percent Changes)
Predisposal	--	--	--
Postdisposal			
10 days (Mar)	- 42.0	- 27.0	- 15.0
1 mo (Apr)	- 54.0	- 16.5	- 37.5
3 mo (Jun)	- 28.0	+ 13.0	- 41.0
6 mo (Sep)	- 25.0	+ 2.0	- 27.0
9 mo (Dec)	- 25.0	- 5.0	- 20.0

species (79) at the disposal site occurred at six and nine months postdisposal, the greatest rate of increase occurred between one and three months after disposal. The number of species shown in June (76) was only three less than the maximum postdisposal number (Figure 2).

44. Total number of species at the reference sites (Figure 2) showed a trend whereby they decreased in the spring, increased to a maximum in June, and decreased thereafter. In contrast, the disposal site, having been impacted, reached a maximum number of species in September and remained steady in December. This trend might possibly have resulted from the recolonizing pressure (immigrating species) counterbalancing seasonal declines.

45. Tables 2, 3, and 4 show the number of species per group per sampling period and total number of species per sampling period for comparison of within-group species changes. Inspection of groups (Table 2) shows that failure of the disposal site to follow the autumn and winter seasonal decline noted for the reference sites was primarily due to large increases in number of species within the sedentarian worm group which peaked in September. Within the reference sites maximum numbers of sedentarian worm species also occurred in September (Tables 3 and 4), but their increases from June to September were not

Table 2

Number of Species/Group and Total Number of Species per Sampling Period at Elliott Bay Disposal Site

Time	No. Gastropod Species	No. Pelecypod Species	No. Errantian Worm Species	No. Sedentarian Worm Species	No. Misc Species	Total No. Species
Predisposal (Feb)	9	19	38	27	13	106
Postdisposal						
10 days (Mar)	6	11	21	17	6	61
1 mo (Apr)	6	8	15	16	4	49
3 mo (Jun)	4	13	27	19	13	76
6 mo (Sep)	5	17	23	27	7	79
9 mo (Dec)	6	14	19	26	14	79

Table 3

Number of Species/Group and Total Number of Species per Sampling Period at West Reference Site

Time	No. Gastropod Species	No. Pelecypod Species	No. Errantian Worm Species	No. Sedentarian Worm Species	No. Misc Species	Total No. Species
Predisposal (Feb)	4	15	20	13	9	61
Postdisposal						
10 days (Mar)	5	10	18	7	7	47
1 mo (Apr)	5	13	11	11	4	44
3 mo (Jun)	5	12	15	17	11	60
6 mo (Sep)	3	13	13	19	7	55
9 mo (Dec)	3	9	13	15	8	48

Table 4

Number of Species/Group and Total Number of Species per Sampling Period at East Reference Site

Time	No. Gastropod Species	No. Pelecypod Species	No. Errantian Worm Species	No. Sedentarian Worm Species	No. Misc Species	Total No. Species
Predisposal (Feb)	6	10	12	8	4	40
Postdisposal						
10 days (Mar)	3	8	9	3	4	27
1 mo (Apr)	4	12	12	7	3	38
3 mo (Jun)	6	12	15	12	6	51
6 mo (Sep)	3	9	13	16	4	45
9 mo (Dec)	4	13	10	14	3	44

sufficient to offset the declines within other groups. Total number of species at the disposal site remained constant in December due to a large influx of miscellaneous species plus recruitment of one gastropod species.

46. Errantian worms showed the highest total number of species (38) at the disposal site prior to disposal, followed by sedentarian worms with 27 species. These two groups dominated the richness of species composition followed by pelecypoda, miscellaneous species, and gastropoda in that order.

47. Except for miscellaneous species, which were erratic and showed no particular trends, sedentarian worms showed the greatest recovery in number of species with 26 occurring in December, this being only one less than the predisposal value. However, reference sites sedentarian worm numbers of species were greater than before disposal. A switch in rank of the two dominant groups during recovery placed sedentarian worms first and errantians second. Though the errantian worms showed a higher recovery by June they declined thereafter, while the sedentarians continued to increase, showing the same number of species in September as before disposal. This might seem to indicate complete recovery of sedentarian worms at the disposal site; however, at this time the reference sites showed that the number of species should be greater than before disposal.

48. The disposal impact on number of species was greatest over the central stations followed by side and corner stations in that order (Figure 3). The lowest number of species at the disposal site occurred in April, one month after disposal, and was followed by a general recovery through December when recovery appeared almost complete.

49. Analysis of numbers of species by groups (gastropod, pelecypod, errantian worms, sedentarian worms, and miscellaneous species) showed the same general trends as for total number of species except that the sedentarian worms indicate less clumping by species (more uniform oversite distributions) during September and December than before disposal. This is evident from the increased numbers of species per grouped station means during these months as compared to those for

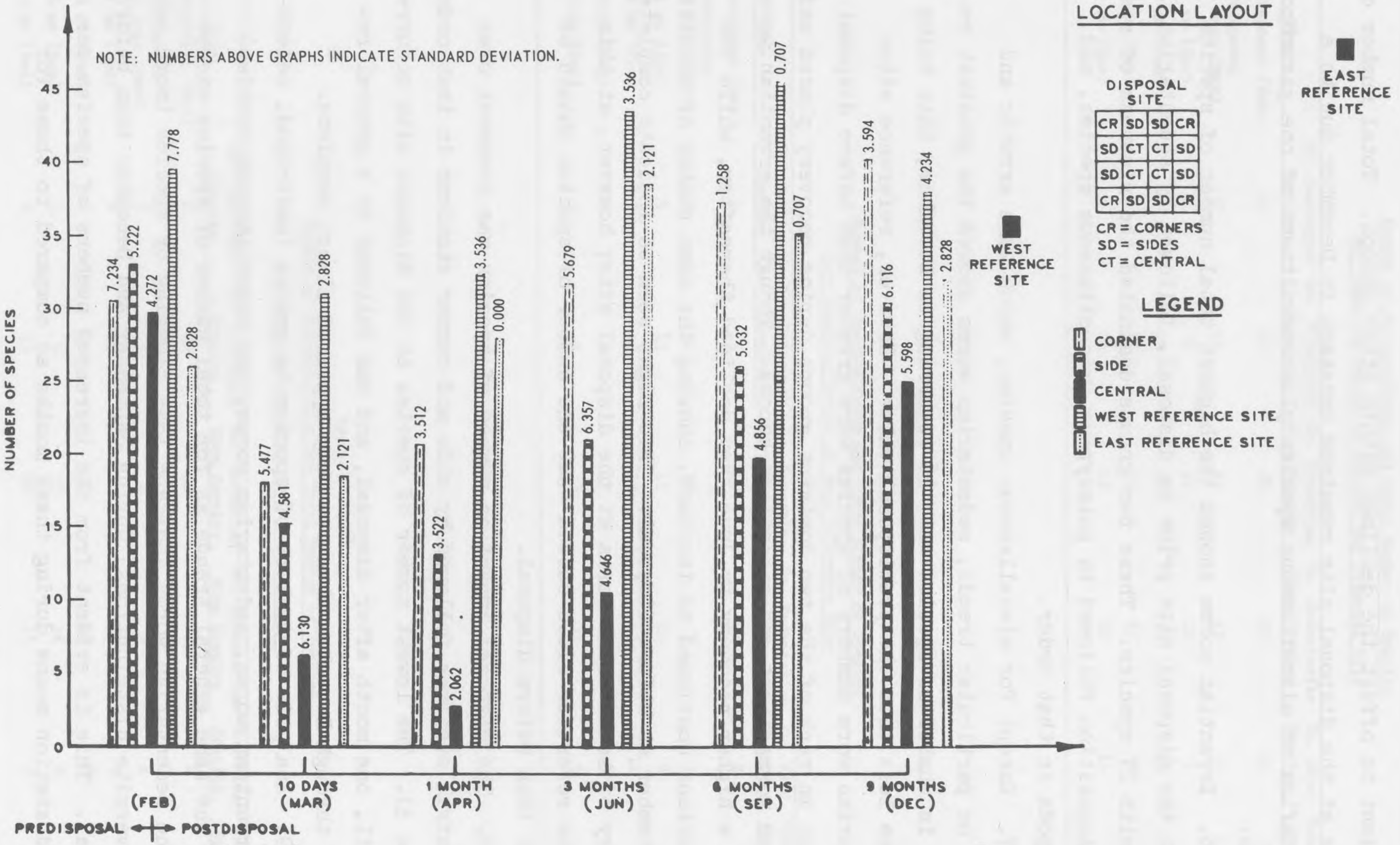

Figure 3. Mean number of species per sampling period for grouped stations

predisposal (Figure 4). Though the greatest numbers of species over the entire disposal site occurred at predisposal and in September and December, equally (Table 2) the greatest means per grouped stations occurred in December with the September means next highest (Figure 3). Reference site means per station were highest in September, declining slightly in December.

Density analysis

50. The mean densities in numbers of organisms per replicate (No./0.1 m^2) for each site and each sampling period are presented in Figure 5. The west reference site showed highest densities during all but the last (December) sampling period when the east reference site was slightly the higher. Prior to disposal, densities ranked highest to lowest were: west reference site, disposal site, and east reference site. After disposal, the east reference site and disposal site switched rank order and the disposal site remained the lowest in density throughout the remaining sampling periods.

51. All sites showed a decline in densities from February to March but the magnitude of the decline at the disposal site was 1.2 times that at the west reference site and 11.1 times that at the east reference site. As shown in Figure 5, the reference sites had a spring decrease in densities followed by a summer increase and an autumnal decline. However, the disposal site showed a summer density increase followed by a further increase in autumn and a slight decline in December. This continued density increase through September resulted from increases in sedentarian and errantian worms (Figure 6). Both these groups experienced their higher densities at the reference sites during June and September with sedentarians peaking in June and showing only slight declines in September (Figure 7), and with errantians peaking in September but being almost as high in numbers during June (Figure 8). At the disposal site sedentarian worm density more than doubled from June to September. This departure from the seasonal trends displayed by the reference sites is interpreted as resulting from recolonization pressures at the disposal site as indicated earlier herein in discussions of species composition. Errantian worm density at the disposal

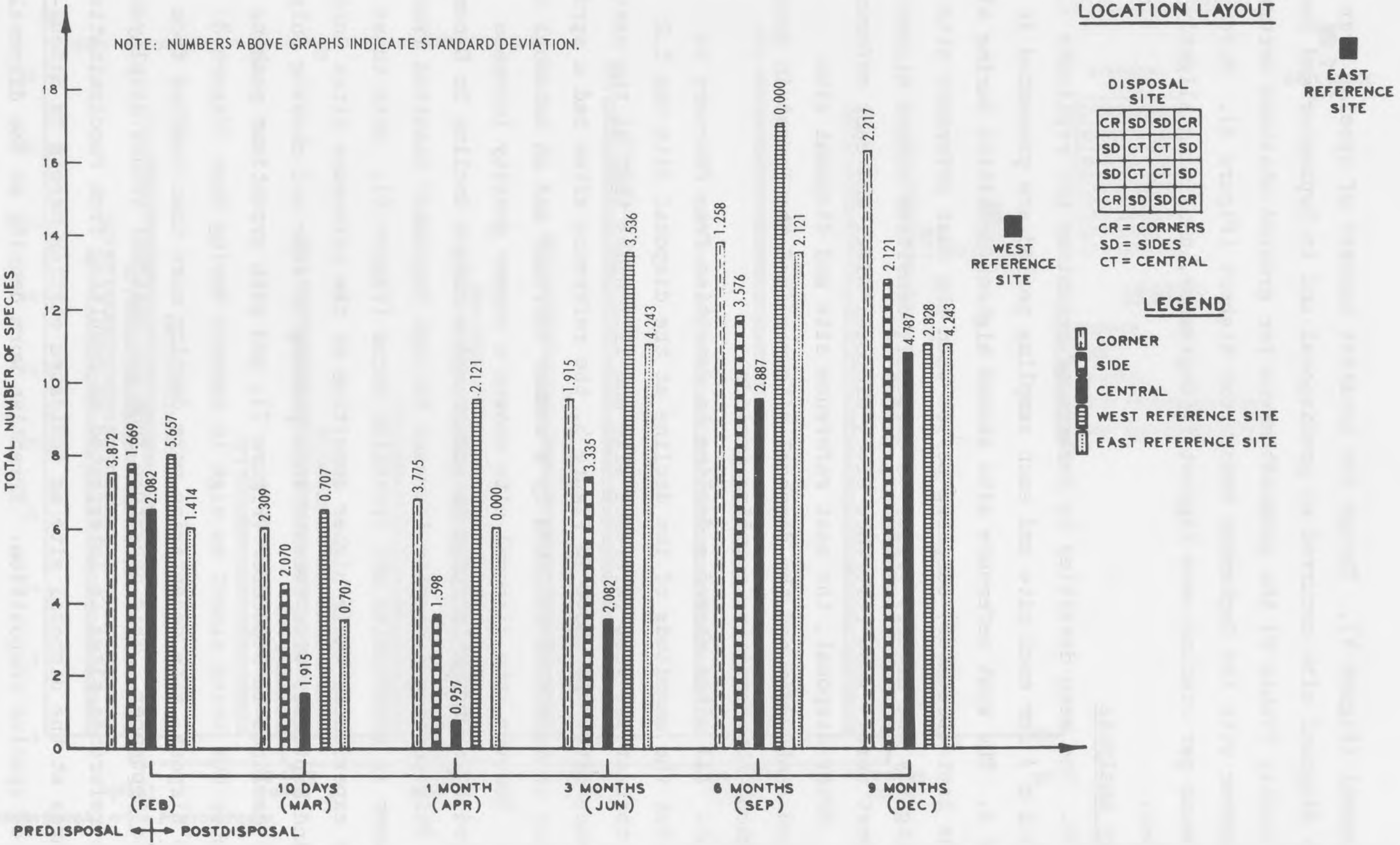

Figure 4. Total number of sedentarian species (means for grouped stations)

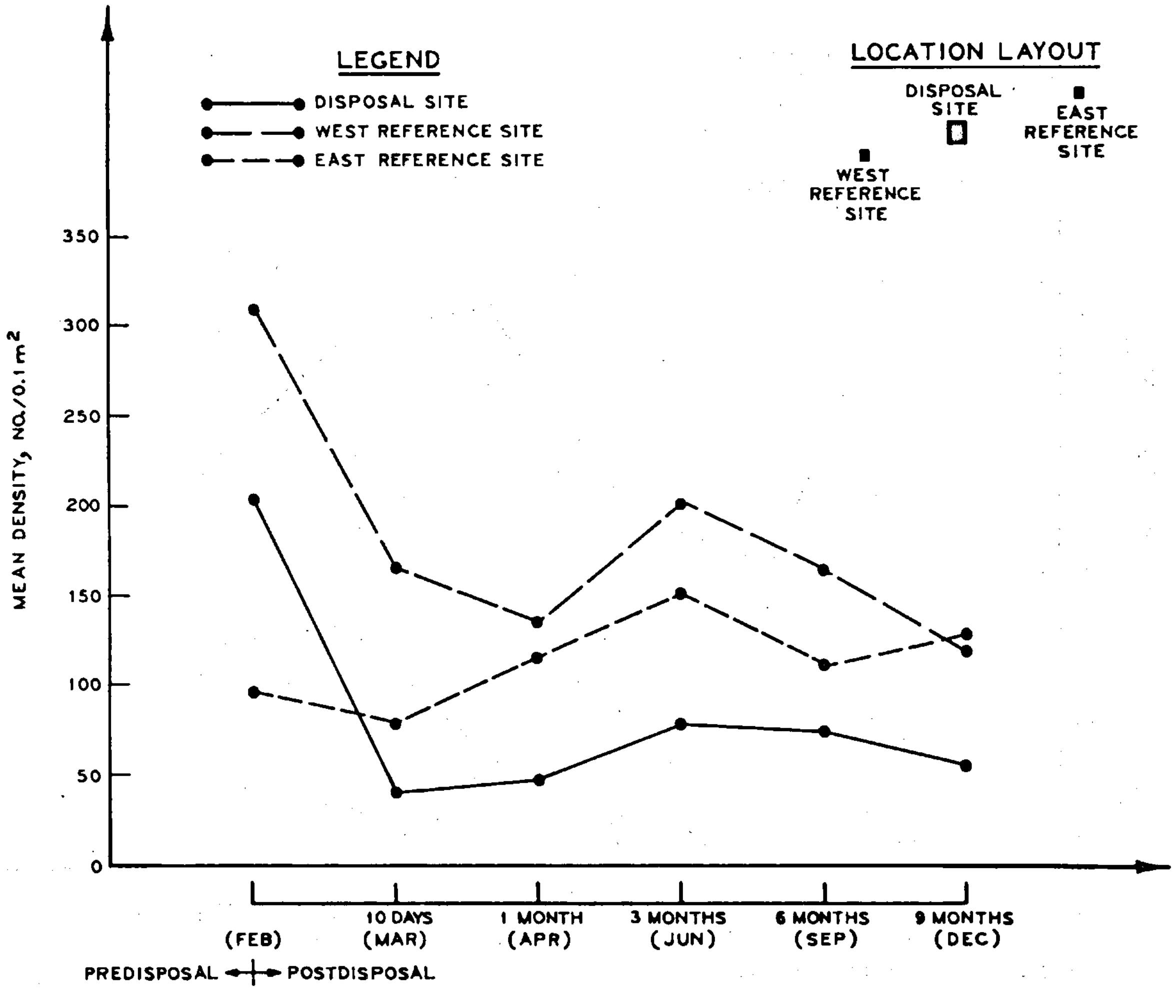

Figure 5. Mean densities (i.e. number of organisms per 0.1 m^2) for disposal site and east and west reference sites

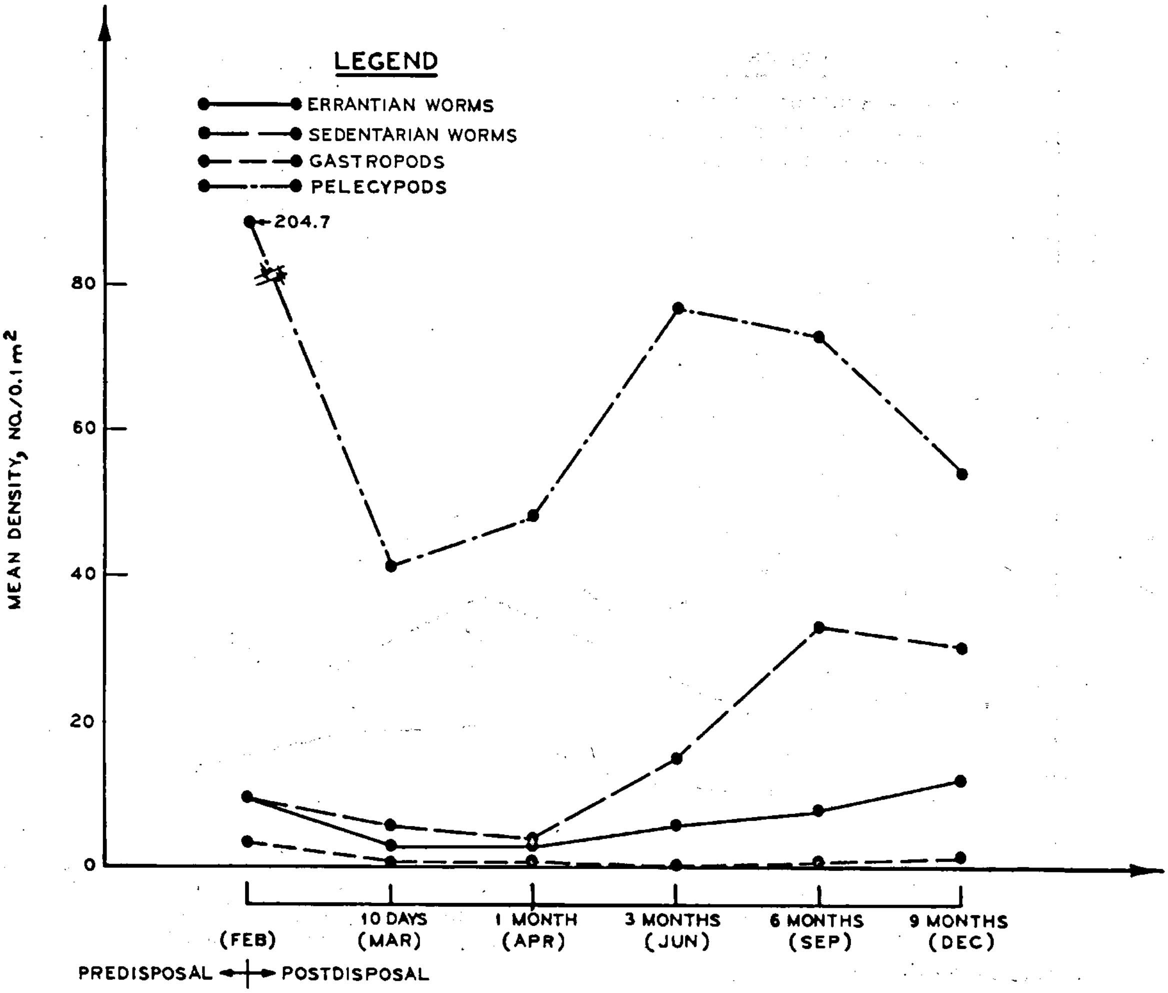

Figure 6. Mean densities (i.e. number of organisms per 0.1 m^2) of gastropods, pelecypods, errantian worms, and sedentarian worms at disposal site

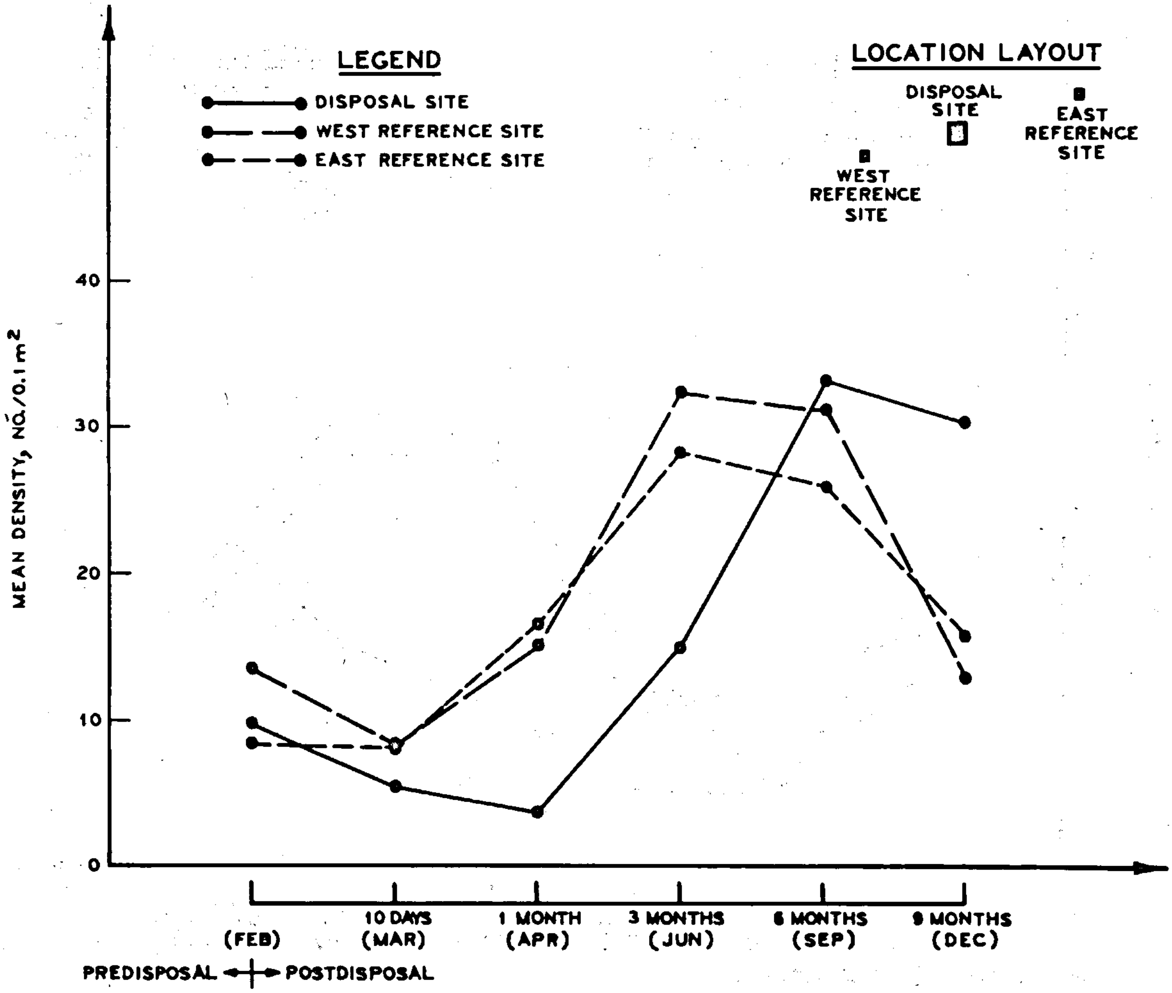

Figure 7. Mean densities (i.e. number of organisms per 0.1 m^2) of sedentarian worms at disposal site and east and west reference sites

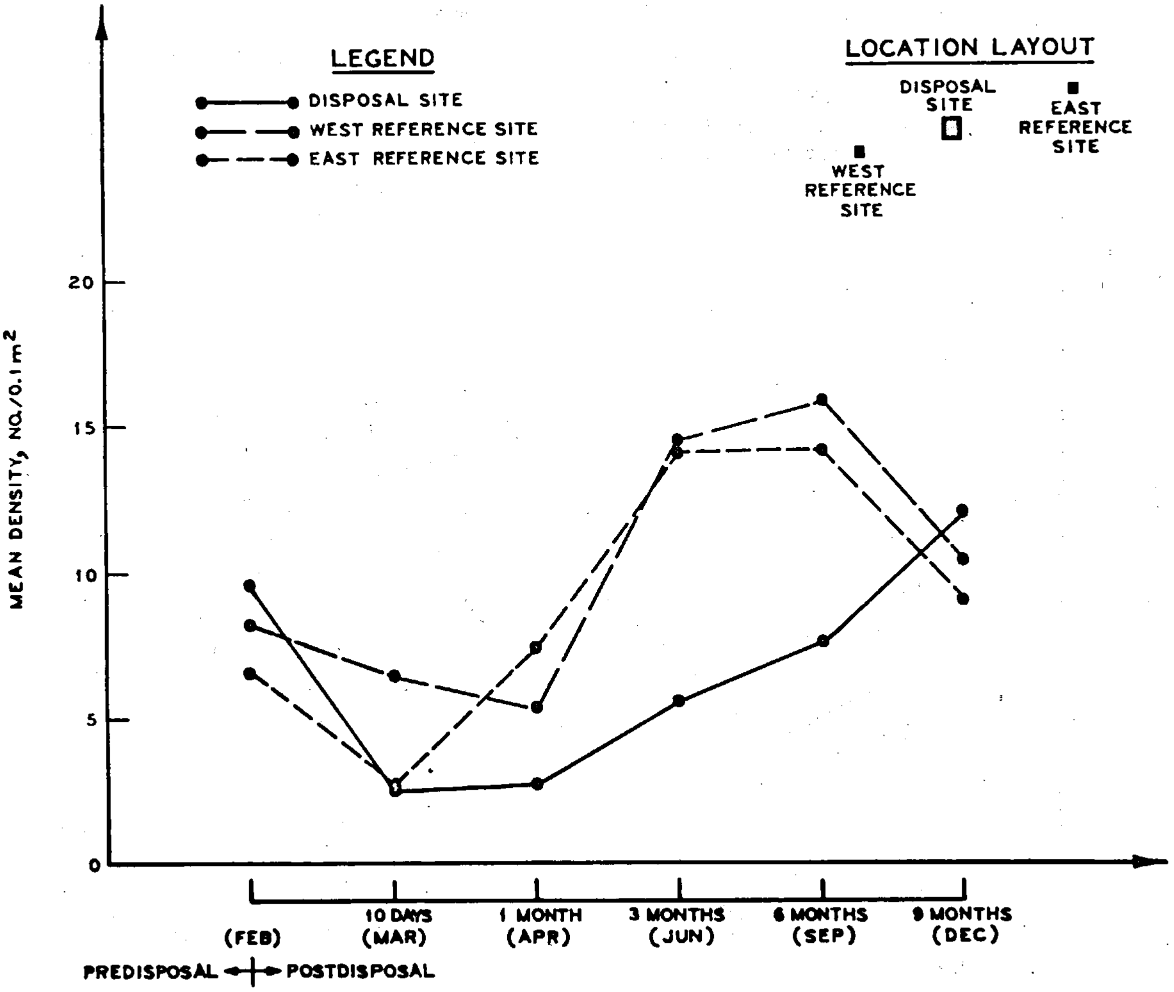

Figure 8. Mean densities (i.e. number of organisms per 0.1 m^2) of errantian worms at disposal site and east and west reference sites

site essentially paralleled those of the reference sites except for showing a sharp increase (60% increase in magnitude) from September to December in contrast to seasonal declines at the reference sites during the same period. This trend of sedentarians first showing rapid density increase followed, three months later, by a rapid increase in errantian worm density might be a reflection of benthic succession at the beginning state of transition from opportunistic species to predator species since predators dominated the errantians found and deposit feeders dominated the sedentarians. This hypothesis can be neither confirmed nor denied without further sampling and analysis.

52. When compared to reference sites densities over time, both sedentarian and errantian worm densities showed full recovery at the disposal site with sedentarians recovering by 6 months after disposal and appearing to have benefited at 9 months after. Errantian densities appear to have required 9 months for full recovery.

53. Pelecypoda, the overwhelmingly density-dominant group before disposal and dominant throughout the study, showed the sharpest density decrease immediately following disposal with the March disposal site density being only 20.5% of the predisposal density (Figure 6). This sharp decline was followed by a general seasonal density increase, peaking in June at 38% of its predisposal value and declining continuously thereafter to 27% of its predisposal value in December.

54. Figure 9 compares and/or contrasts pelecypod densities at the disposal site and the west and east reference sites over time. The west reference site showed the highest densities throughout the study until the last sampling period at which time the east reference site density was greatest. The predisposal value of the disposal site pelecypod density was 2.26 times that of the east reference site and 0.66 times that of the west reference site. Ten days after disposal pelecypod density at the disposal site was 0.52 times that at the east reference site and 0.25 times that at the west reference site. The disposal site pelecypod densities remained considerably less than those of each reference site throughout the remainder of the study, showing little or no signs of overall site recovery.

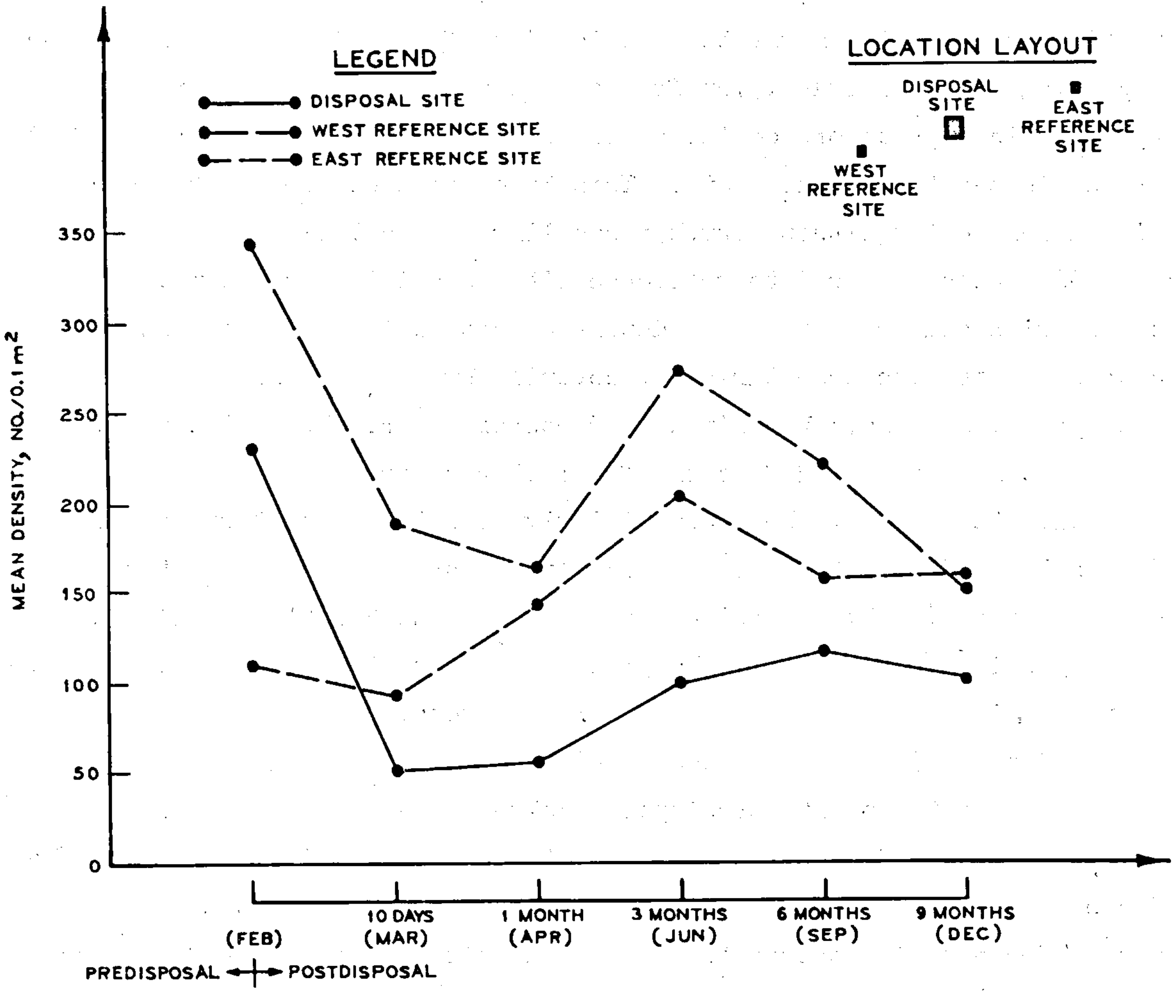

Figure 9. Mean densities (i.e. number of organisms per 0.1 m^2) of pelecypods at disposal site and east and west reference sites

55. Gastropod density (Figure 10), representing the lowest density of all groups, was reduced to 11.4% of its predisposal value in March, ten days after disposal. It reached its lowest value, 4.9% of its predisposal value, during June and thereafter increased to 36.4% of its predisposal value during the final sampling period in December.

56. When compared to the reference sites densities (Figure 10), at predisposal the gastropod density at the disposal site was 1.41 times greater than that at the east reference site and 0.40 times that at the west reference site, which showed density superiority throughout the study. At 10 days after disposal gastropod disposal site density was 0.64 times the east reference site value and 0.08 times the west reference site value. Disposal site gastropod density remained considerably lower than either reference site density until 9 months after disposal when it again exceeded the east reference value. Relative to the reference site densities the disposal site gastropod density appeared recovered at that time; however, the hypothesis cannot be verified without further sampling and analysis at some later time when seasonal increases at the reference sites occur and one can observe the further response at the disposal site.

57. Figure 11 displays the overall species mean densities at the four corner, eight side, and four central stations of the disposal site and the west and east reference site stations over the six sampling periods of the study.

58. All stations of the disposal site appear to have been impacted initially by the dredged material disposal. However, the corner stations, if impacted, recovered rapidly. When compared to the reference sites they showed full recovery 1 month after disposal whereas the side and central stations, though appearing to have been recovering at 6 months after disposal, showed no further improvement 3 months later. Corner stations appear to have benefited when compared to the reference sites before disposal and 9 months after disposal. Very obviously the central stations suffered the greatest overall species density impact.

59. Figures 12-16 show the density means of gastropods, pelecypods, errantian worms, sedentarian worms, and miscellaneous species for the

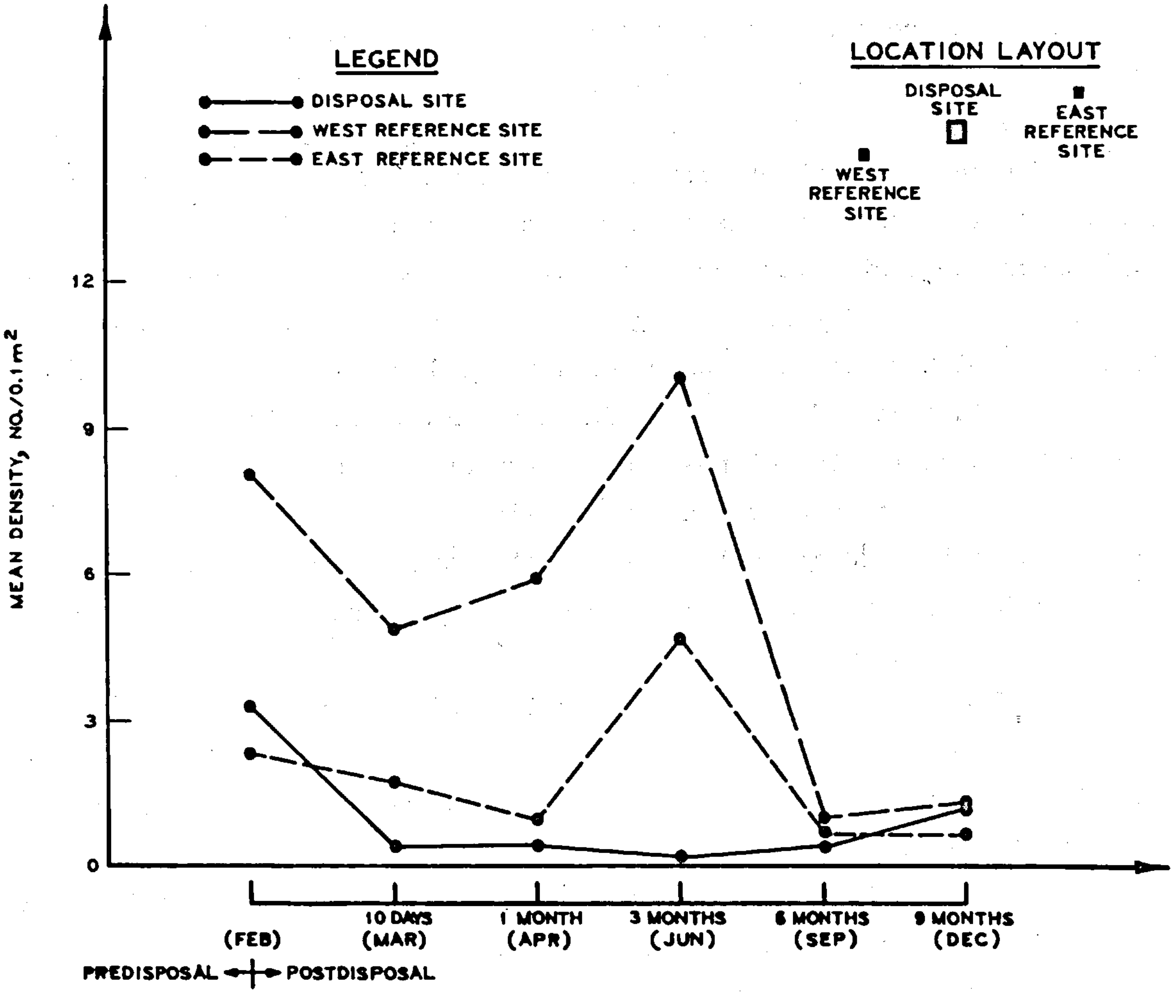

Figure 10. Mean densities (i.e. number of organisms per 0.1 m^2) of gastropods at disposal site and east and west reference sites

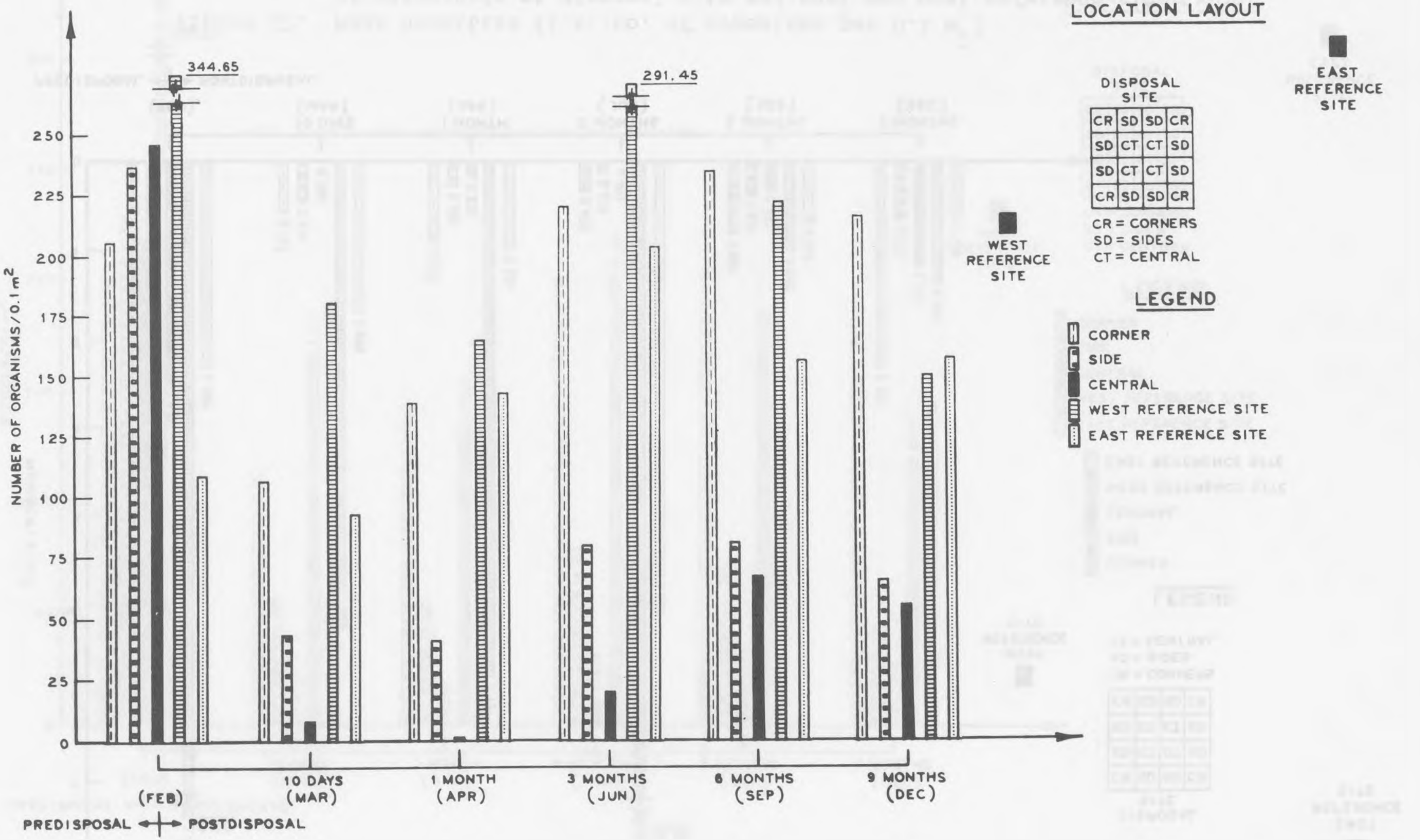

Figure 11. Overall species densities (i.e. number of organisms per 0.1 m^2) for grouped stations

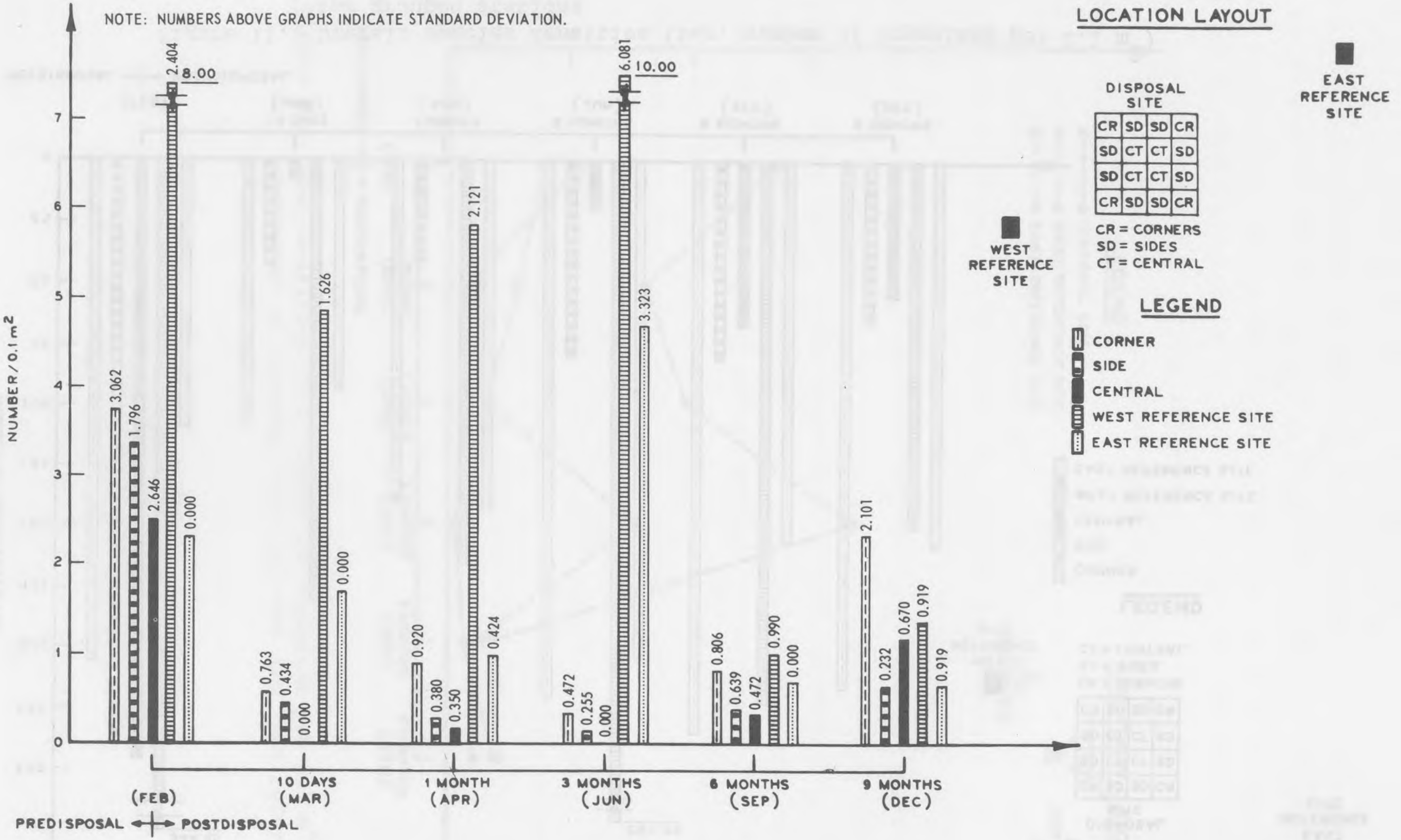

Figure 12. Mean densities (i.e. no. of organisms per 0.1 m^2) of gastropods at disposal site and east and west reference sites

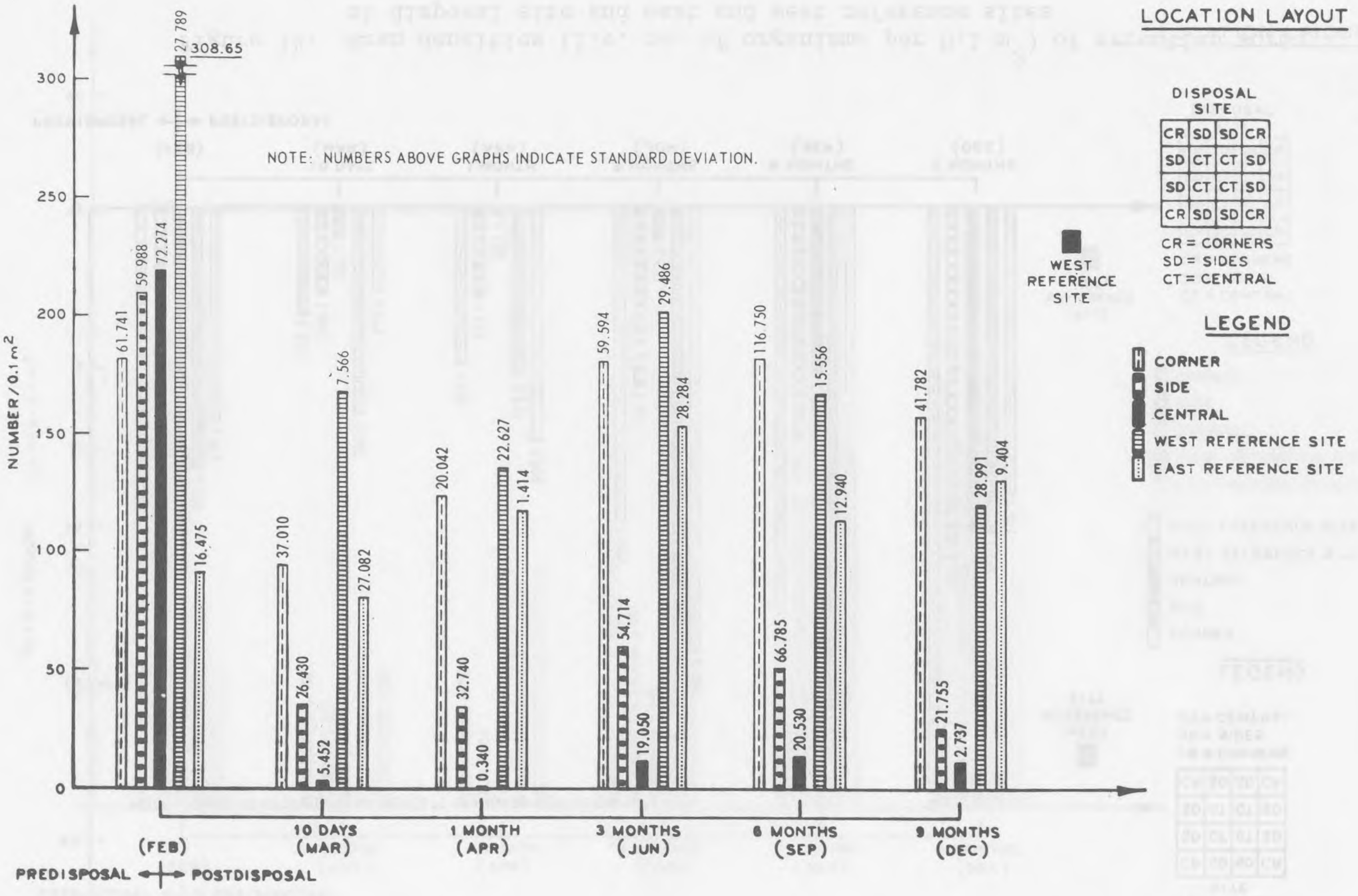

Figure 13. Mean densities (i.e. no. of organisms per 0.1 m^2) of pelecypods at disposal site and east and west reference sites

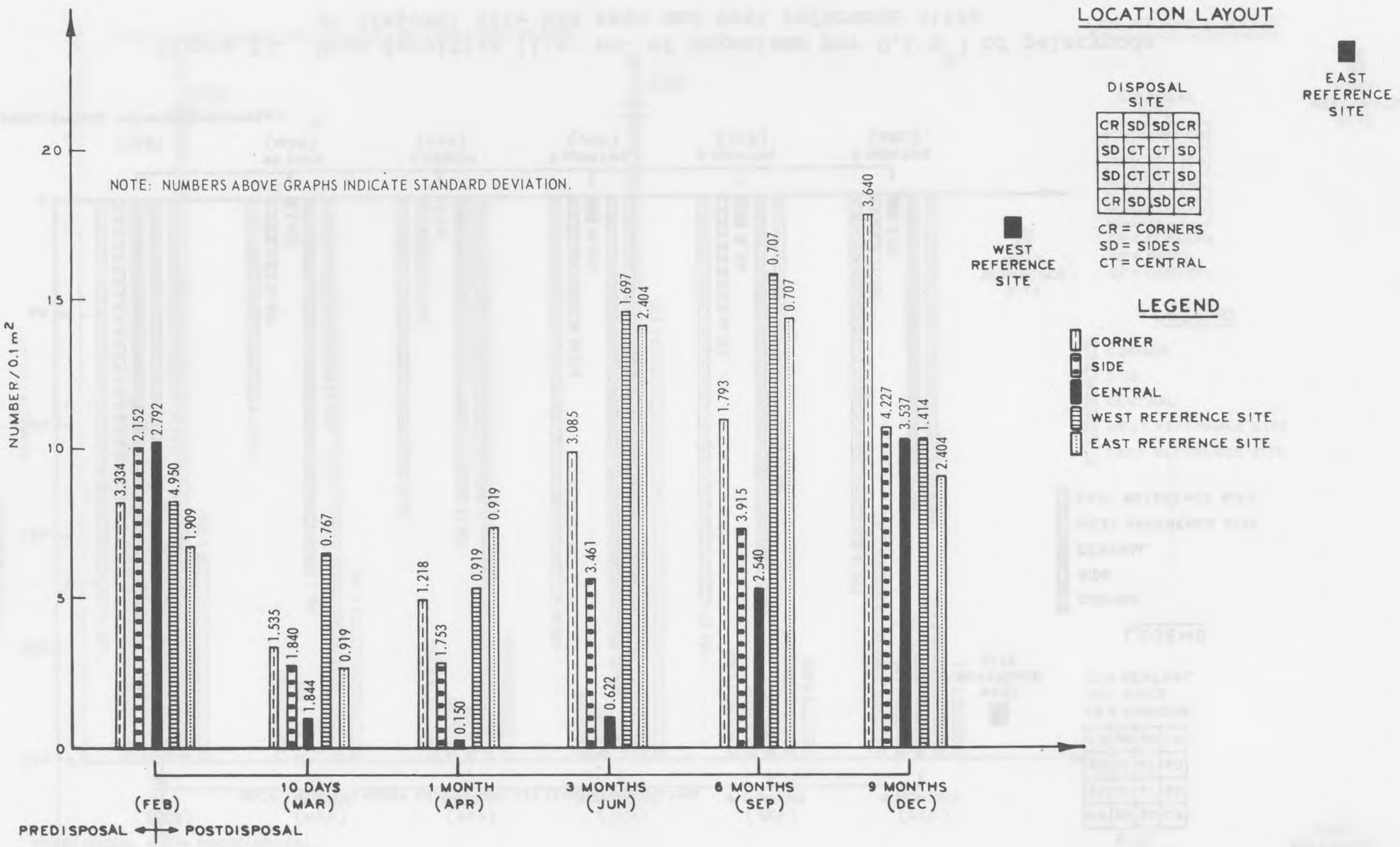

Figure 14. Mean densities (i.e. no. of organisms per 0.1 m^2) of errantian worms at disposal site and east and west reference sites

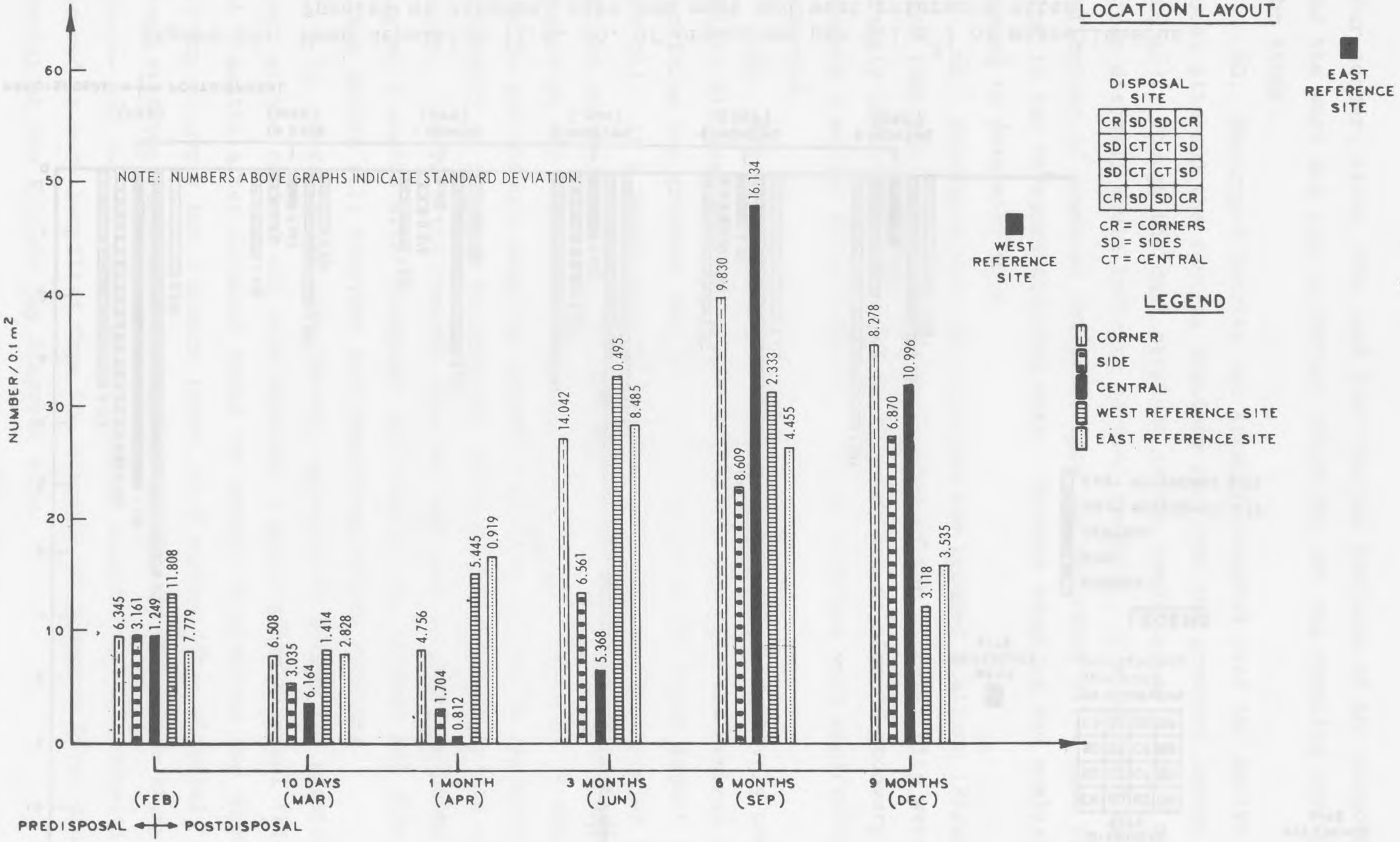

Figure 15. Mean densities (i.e. no. of organisms per 0.1 m^2) of sedentarian worms at disposal site and east and west reference sites

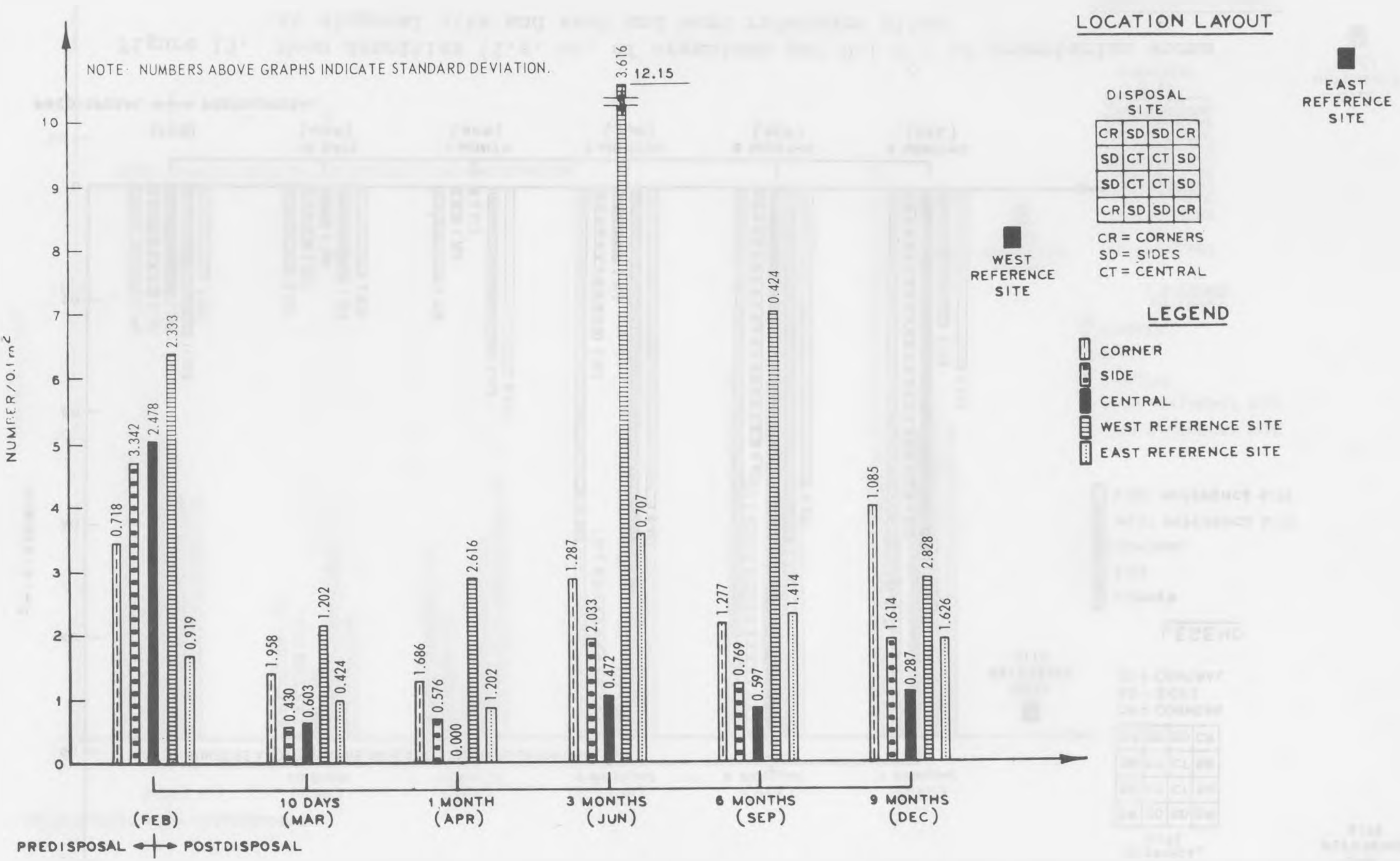

Figure 16. Mean densities (i.e. no. of organisms per 0.1 m^2) of miscellaneous species at disposal site and east and west reference sites

four corner, eight side, and four central stations of the disposal site and the west and east reference sites for the six sampling periods of the study.

60. Gastropod density was greatly impacted over the entire disposal site and the central stations received the greatest impact (Figure 12). Though the data obtained in the samplings at 6 and 9 months after disposal could indicate partial recovery, it also could be only a reflection of seasonal influence upon the reference sites that failed to show in the stressed disposal site. Further sampling and analysis are needed to determine this.

61. Pelecypod mean densities for the grouped stations (Figure 13) show that the central and side stations of the disposal site were greatly impacted by the dredged material and no sign of recovery was present 9 months after disposal. Corner stations were apparently not affected.

62. Errantian worms were apparently impacted negatively over the entire disposal site at 10 days after disposal with the central stations receiving the greatest and the corner stations the least impact (Figure 14). At 1 month after disposal there was a further density decline at the central stations, an increase at the corner stations, and no change at the eight side stations. All stations increased in density at the 3- and 6-month sampling periods but these increases appear to be primarily in response to seasonal increase as indicated by the reference sites. However, the central stations appeared to show beginning recovery at 6 months after disposal; at 9 months the central and side stations showed full recovery with benefited corner stations.

63. Sedentarian worm density appeared to suffer its greatest impact at the central and side stations 1 month after disposal (Figure 15). At 3 months after disposal these two groups of stations had shown little if any recovery but 3 months later, at 6 months after disposal, the central stations registered the highest density of the entire study. At the 6- and 9-month sampling periods the sedentarian worm densities appeared to have benefited from the disposal of Duwamish River dredged material at the Elliott Bay disposal site.

64. Though miscellaneous species is a catchall and fictitious grouping, we felt the need (for the sake of completeness) to present those species occurring infrequently but not covered in the previous groupings. Figure 16 displays densities of this group and, like the previous true groups, the miscellaneous species densities were adversely impacted at the side and central stations. Miscellaneous species at these stations did not recover during the entire study period whereas the corner stations appear to have been benefited at the 9-month postdisposal period.

Biomass analysis

65. The mean biomasses of all benthic organisms per 0.1 m^2 for the disposal site and the east and west reference sites are presented in Figure 17.

66. Biomass means at the disposal site were lower than those at the two reference sites for comparable sampling periods throughout the study. The temporal curve established for the disposal site biomass means (Figure 17) had the same general shape as that for density means (Figure 5). The greatest disposal site biomass mean was that determined before disposal (3.495 g/0.1 m^2) and the lowest was measured 10 days after disposal when it dropped to 25% of this value. At predisposal, biomass at the disposal site was approximately 94% that at the east reference site and 77% that at the west reference site. Ten days after disposal it had dropped to 57% that at the east reference site and 34% that at the west reference site. By 9 months after disposal it was 77% that at the east reference site and 90% that at the west reference site.

67. The west reference site biomass mean followed the same general trend as did its density mean except that the biomass showed an increase at 1 month after disposal. The east reference site showed its greatest biomass mean 1 month after disposal (April) and its greatest density mean 3 months after disposal (June). This phenomenon resulted from Axinopsida serricata, Nucula tenuis, and most of the dominant worms possessing a greater biomass per individual during April at the east reference site than they possessed in June at this site, which probably indicates a greater juvenile/adult ratio in June at this site. The east

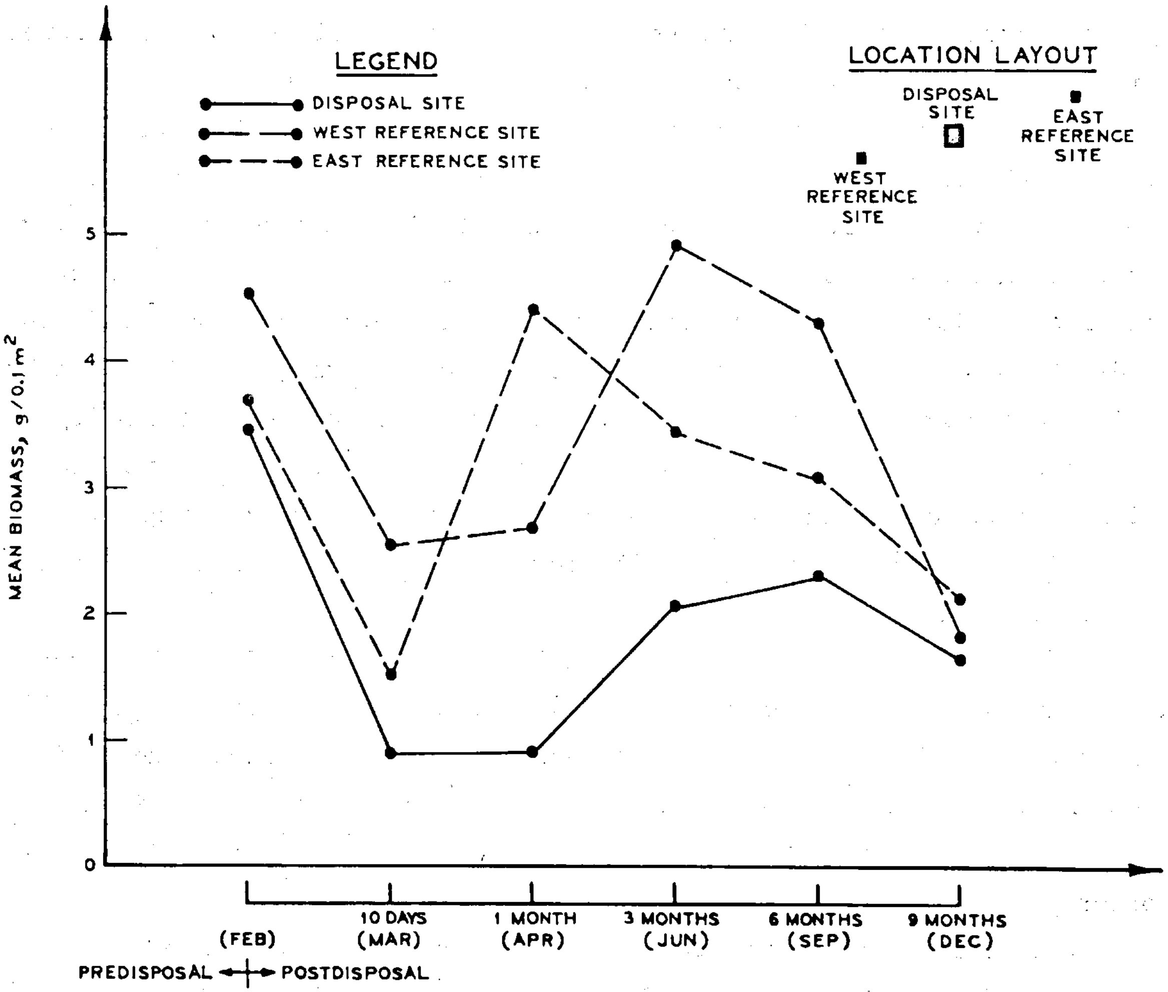

Figure 17. Mean biomasses of all species at the disposal site and east and west reference sites

reference site showed an increasing number of organisms per replicate beginning between mid-March and 6 April and continuing into mid-June, whereas the increase for the west reference site began in April and continued until mid-June (Figure 5). While earlier recruitment is indicated by increased numbers per replicate, the mass per organisms was greater during April than during March and greater at the east reference site than at the west reference site, which indicates either rapid growth of individuals at the east reference site or migration of larger individuals into this site. The west reference site showed an increase in biomass per replicate in April concurrent with a decrease in density, indicating a size growth of individuals for many of the more dominant species. Evidence from both the east and west reference sites tends to indicate a period of high food availability or embryo growth immediately prior to the April sampling period. The period of most rapid density increases at both east and west reference sites was preceded by rapid biomass increases. This could possibly result from embryonic growth but sufficient evidence is unavailable at this time to confirm a cause and effect relationship.

68. Examination of the individual groups (gastropoda, pelecypoda, errantian worms, and sedentarian worms) at the disposal site (Figure 18) shows pelecypoda dominating the biomass throughout the study except in September when sedentarian worms dominated. Sedentarian worm biomass was next in abundance followed by errantian worms and gastropoda in that order.

69. Pelecypoda showed the greatest decrease in biomass of all groups 10 days after disposal of the dredged material when it was approximately 18% of its predisposal value. In April the biomass was 23% of the predisposal value and in June it was as its highest postdisposal value. From that point it showed a continuous decline to approximately 27% of the predisposal value in December.

70. Sedentarian worm biomass decreased to 41% of its predisposal value 10 days after disposal and reached its lowest postdisposal value of 26% of the predisposal value 1 month after disposal. From that time, April, it increased to its highest in September at 1.45 times its

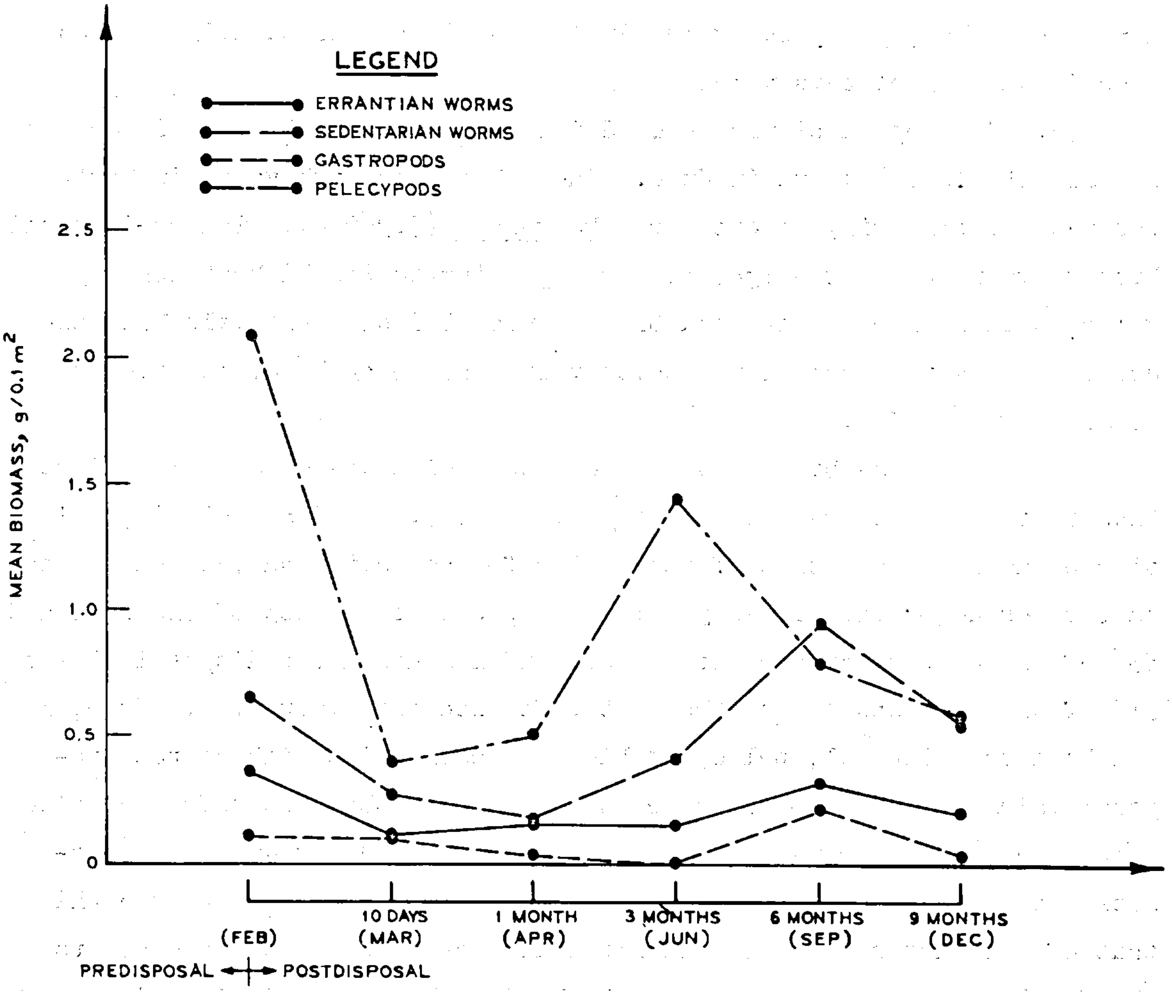

Figure 18. Mean biomasses of gastropods, pelecypods, errantian worms, and sedentarian worms at disposal site

predisposal value. In December it had decreased to 83% of its predisposal value.

71. Errantian worm biomass was at its highest value during the predisposal (February) sampling and decreased to its lowest value 10 days after disposal when it was 29% of the predisposal value. It most nearly approached the predisposal value during the September sampling period when it was 89% of this value.

72. Gastropoda biomass showed its highest overall value in September and its lowest value in June. The relatively high value in September was due primarily to one large Polynices (7.962 g). The predisposal biomass value was next highest, corresponding to its highest density value at this time. Gastropod biomass was at its lowest value in June corresponding to its lowest density value and being 7% of its predisposal biomass value.

73. Pelecypod biomass at the disposal site was at all times less than that at either reference site (Figure 19). Predisposal disposal site biomass was 60% that of the west reference site and 74% that of the east reference site. Ten days after disposal it was 20% of the west and 53% of the east reference site values and 1 month after disposal it was 31% of the west and 18% of the east reference site values. In June, 3 months after disposal, pelecypod biomass reached its highest postdisposal value at the disposal site and was 90% of the east reference site value and 44% of the west reference site value. After June, the biomasses of the west reference site and the disposal site decreased while that of the east reference site first increased and then decreased to the final values in December, at which time the disposal site biomass was 49% of the west reference site value and 66% of the east reference site value. The disposal site pelecypod biomass never returned to its predisposal norm.

74. Sedentarian worm biomass at the disposal site was greater than that of either reference site prior to dredged material disposal and was lower than that of either reference site for the three sampling periods immediately thereafter (Figure 20). In September and December it was between the reference site magnitudes with the west reference site

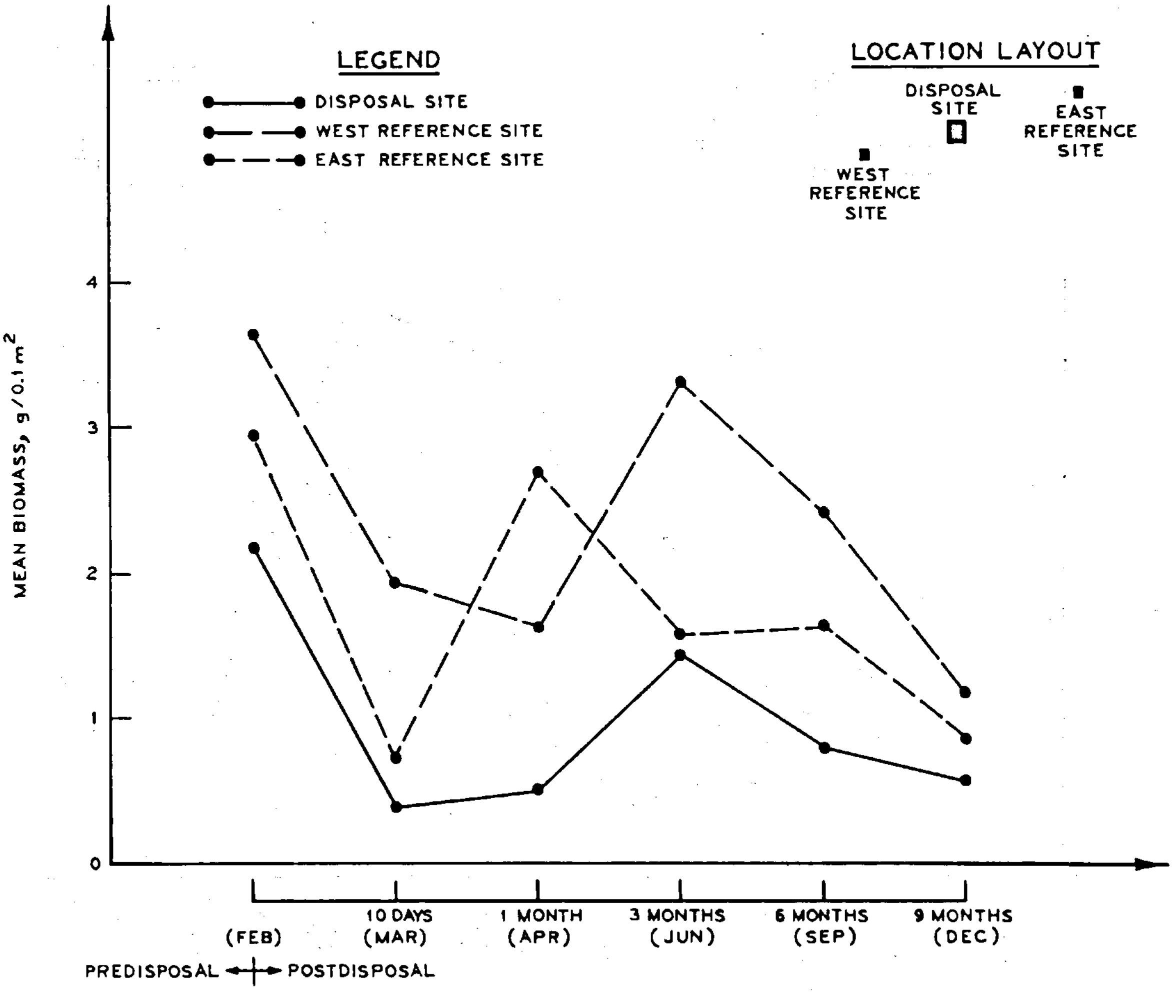

Figure 19. Mean biomasses of pelecypods at disposal site and east and west reference sites

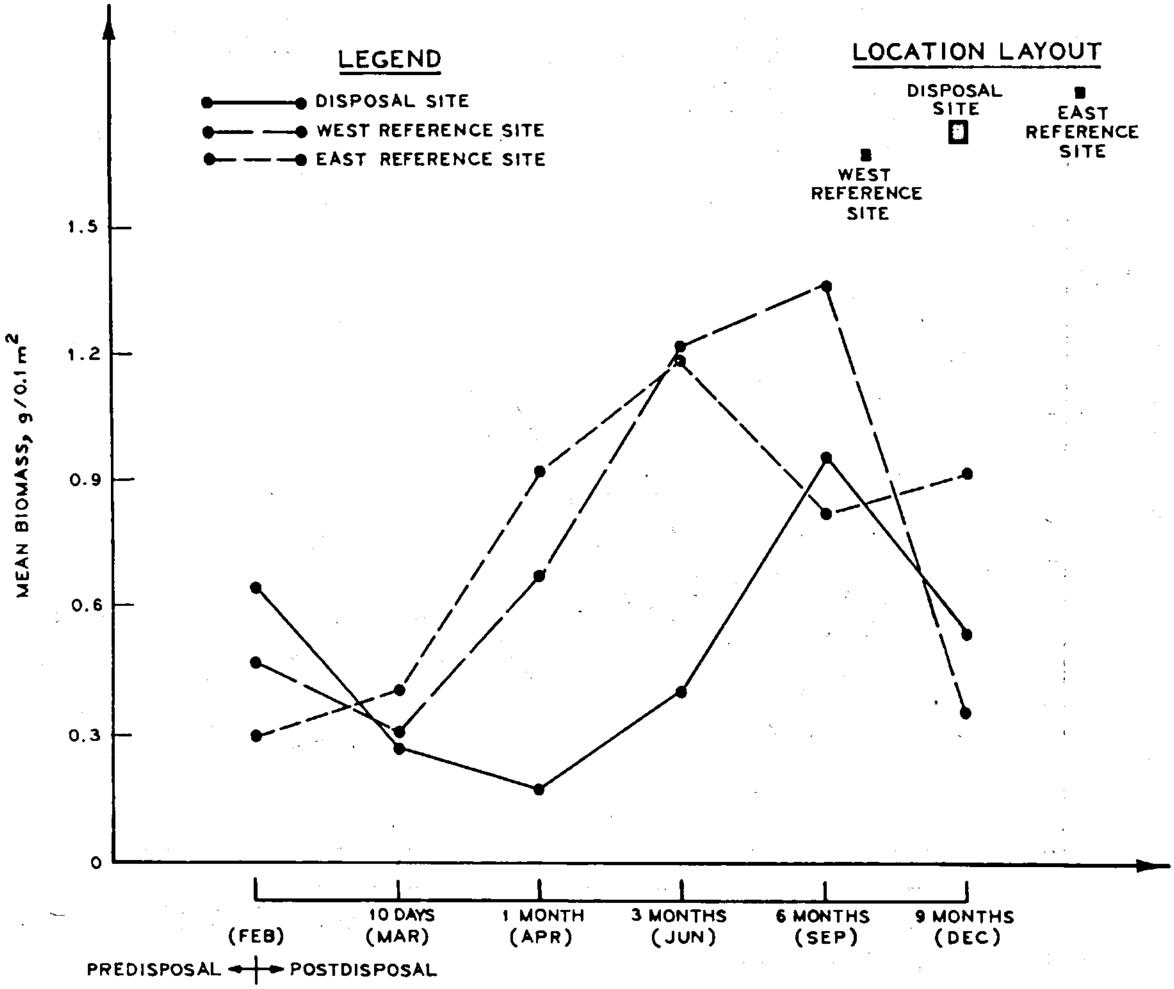

Figure 20. Mean biomasses of sedentarian worms at disposal site and east and west reference sites

being highest in September and the east reference site highest in December. At its lowest value the disposal site sedentarian worm biomass was 25% that of the west reference site and 18% that of the east reference site, this occurring in April. By September the disposal site value was 1.16 times the east reference site value and 0.70 times the west reference site value. Nine months after disposal the disposal site biomass was 1.50 times the west reference site value and 0.59 times the east reference site value. Though the disposal site biomass never occupied the same relative position at postdisposal that it had at predisposal, it was considered as fully recovered during the last two sampling periods.

75. Disposal site errantian worm biomass relative to reference site biomasses is displayed in Figure 21. Predisposal disposal site biomass for errantian worms was 2.40 times that of the east reference site and 3.54 times that of the west reference site. Ten days following dredged material disposal, it had decreased to the same value as that displayed by the east reference site for the same period and was 0.74 times the value of the west reference site at this time. Throughout the remainder of the study, disposal site biomass remained below the reference site biomass values. Though the disposal site errantian worm biomass never recovered to its predisposal relative value, it was 81% and 85% as great as those of the east and west reference sites, respectively, during December, indicating that recovery was in progress.

76. Due to the initial low biomass and density levels of gastropoda and also to the wide variation in biomass of different species and individuals within some species, we do not consider gastropod biomass variation a reliable criterion for this study. For this reason no graph or discussion comparable to those for the other groups is presented here for the gastropod group biomass and density analyses.

77. Since this study was designed to monitor community changes occurring over time at a particular disposal site and to delimit seasonal changes by monitoring adjacent undisturbed reference sites similarly and simultaneously, it is felt that diversity is a valid supplementary measure to use in following these temporal changes.

78. In order to complement and/or provide a check on other means

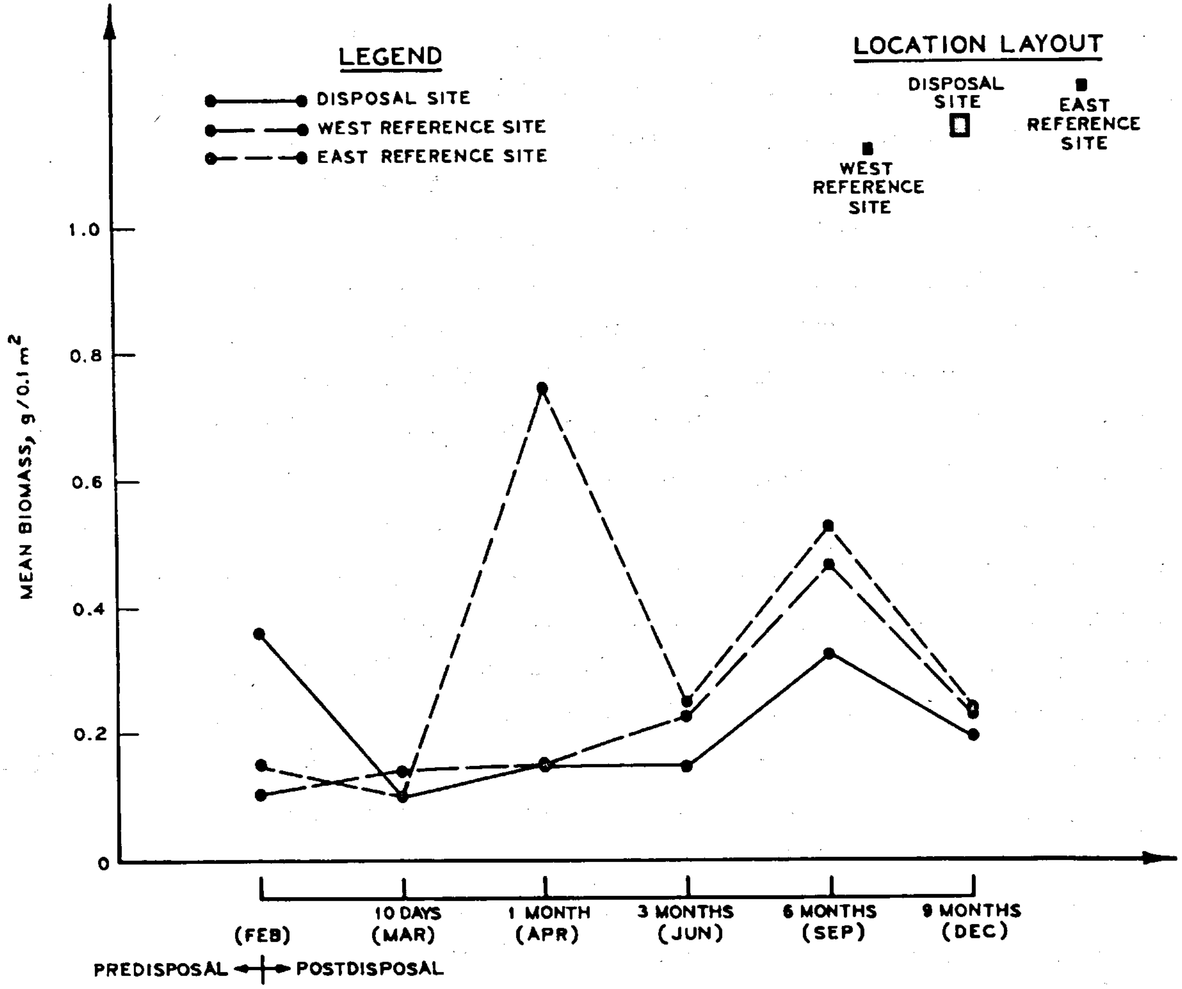

Figure 21. Mean biomasses of errantian worms at disposal site and east and west reference sites

of community analyses, Shannon-Weaver species diversity indices with log base 2 were calculated for each sample replicate for each sampling period. The station means and standard deviations for the three replicates per station were determined and recorded by numbered station. Further, for the purpose of comparison of the three groups of disposal site stations and the two reference sites per sampling period, means and standard deviations of each group and reference site were determined using the average of station means for each group and site per sampling period. Site means were determined in a similar manner.

79. Figure 22 shows the mean Shannon-Weaver diversity indices for each site at each sampling period. Comparison of these means among sites shows a considerably decreased disposal site mean 1 month after disposal, whereas the reference site indices had increased at this time. The remainder of the study showed continuously increasing diversity indices for the disposal site whereas those at the reference sites increased from March until September and decreased in December. Though the reference site indices are different for each site their trends are the same, both showing their lowest in March, steadily increasing to a peak in September, and declining in December. Though the disposal site mean index declined in March as did the reference sites indices, its lowest value occurred in April, 1 month after disposal. From this time until the study ended, the disposal site diversity indices showed improvement and, unlike the reference sites, showed its highest value in December.

80. In order to investigate diversity in a manner similar to that used in the density and biomass investigations, the mean diversities were determined together with their standard deviations for grouped stations. Figure 23 displays the mean diversities for corner, side, and central disposal site stations and the west and east reference site stations for the six sampling periods of the study.

81. Adverse effects of the dredged material disposal are seen to be confined to the central stations, Figure 23. Full recovery of the diversity means at these stations is apparent at the September sampling

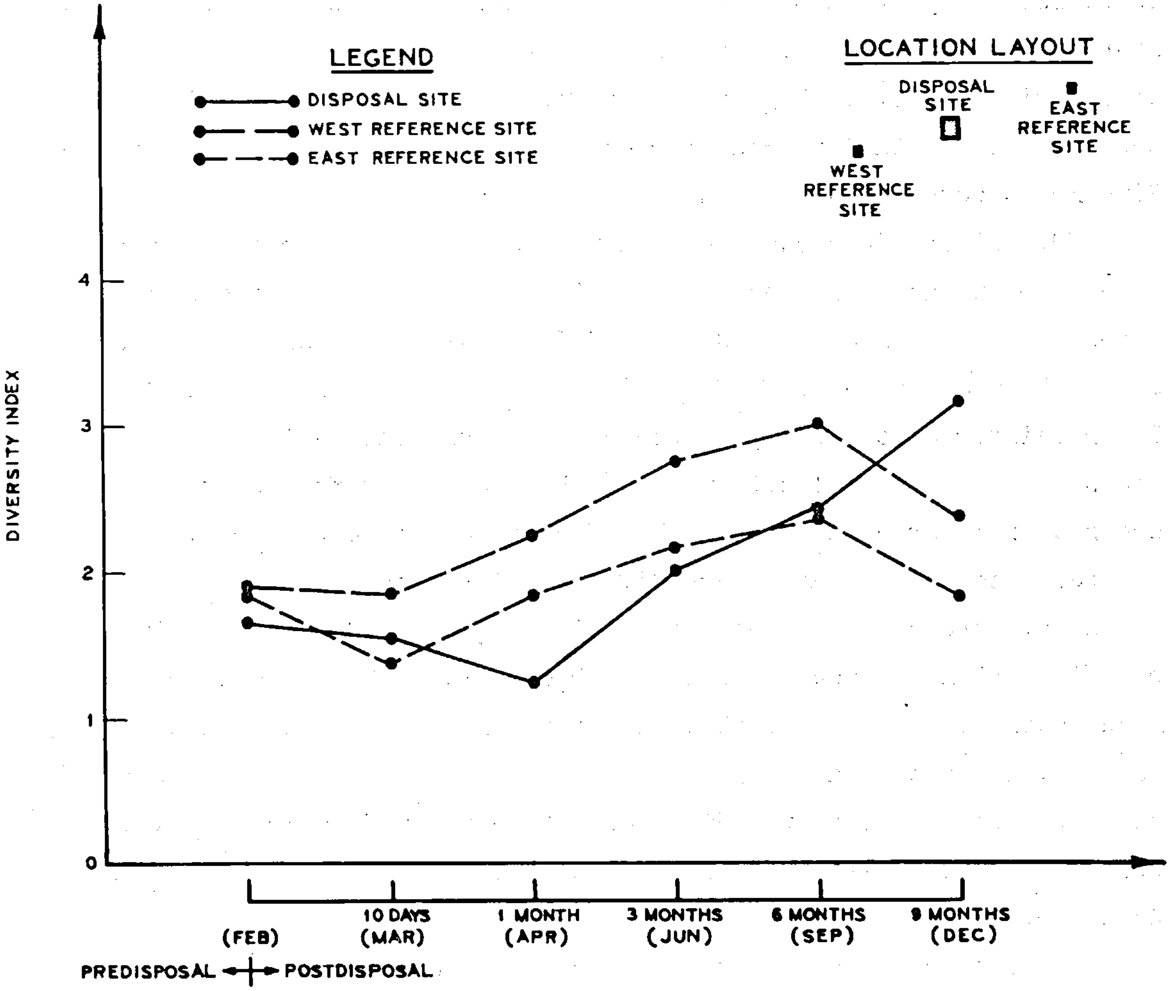

Figure 22. Shannon-Weaver diversity indices for disposal site and east and west reference sites

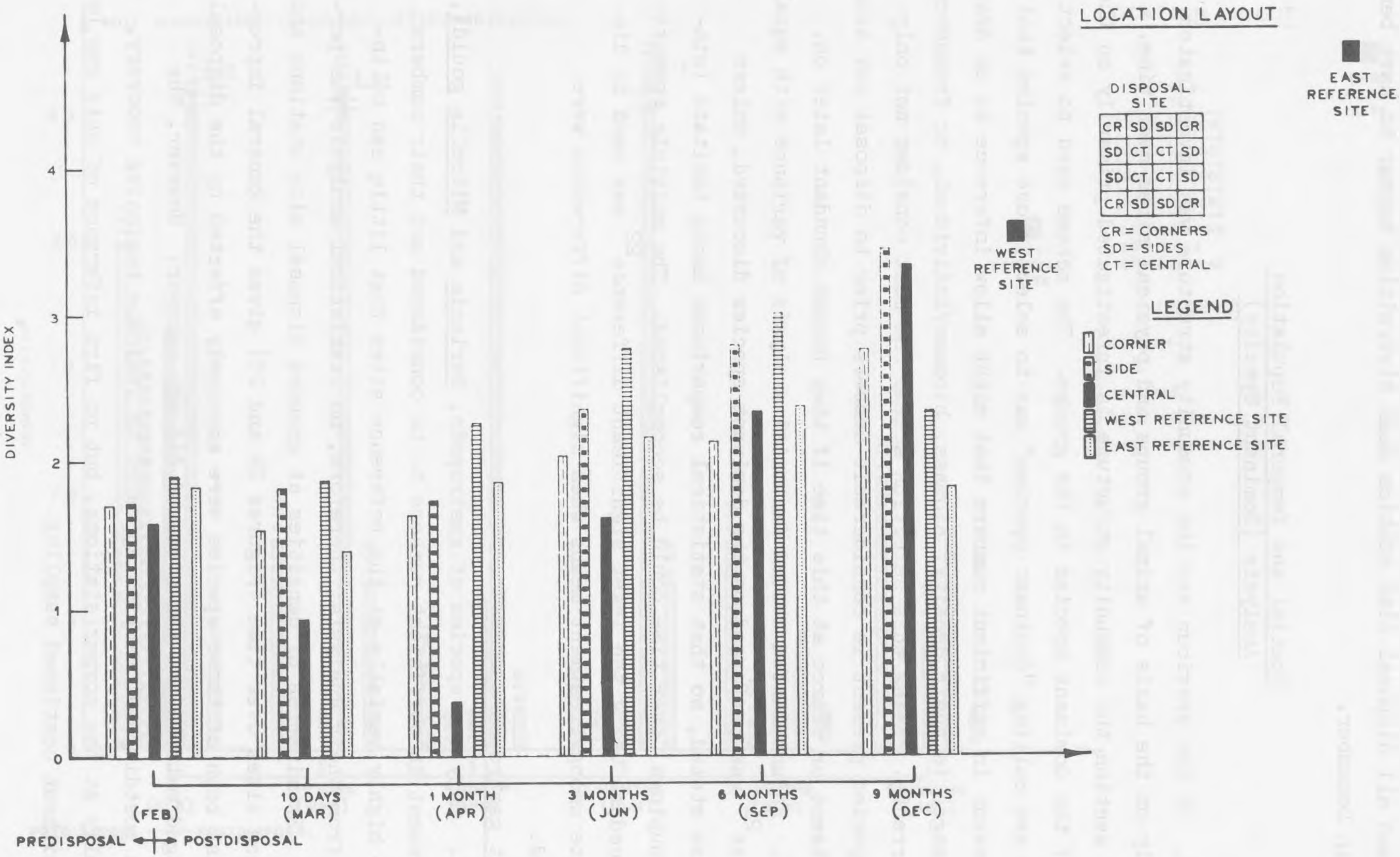

Figure 23. Mean Shannon-Weaver diversity (log base 2) indices for disposal site and east and west reference sites

period and all disposal site station mean diversities appear to have benefited in December.

Spatial and Temporal Population Analysis (Dominant Species)

82. In the previous section community structure was investigated primarily on the basis of animal groups and physical sites over time. In this section the community structure is investigated primarily on the basis of the dominant species in the groups. The scheme used to select what we are calling "dominant species" was to select those species that were present in sufficient numbers that might allow inference to be drawn from changes in their density, biomass, biomass/individual, or frequency of occurrence. Using this selection scheme one must consider not only those species present in considerable numbers prior to disposal but also those absent or scarce at this time if they become abundant later on.

83. An unbalanced nested factorial analysis of variance with equal cell size[21] was performed on the dominant species discussed, unless otherwise stated, so that statistical comparisons among habitats (station groupings) over time could be accomplished. The multiple comparison procedure using the least significant difference[22] was used to discriminate among treatment means when significant differences were observed.

Dominant gastropod species

84. Only two species of gastropods, Barleeia and Mitrella gouldi, were present in sufficient numbers to be considered and their numbers were so highly variable at the reference sites that little can be inferred from their analysis; therefore, no statistical analysis was performed. Examination of densities at grouped disposal site stations and reference sites over time (Figures 24 and 25) gives the general impression that both of these species were adversely affected by the disposal of dredged material at the site and did not recover. However, the 9-month postdisposal samples appeared to indicate beginning recovery, especially at the corner stations, but no firm inference of this can be drawn without continued sampling.

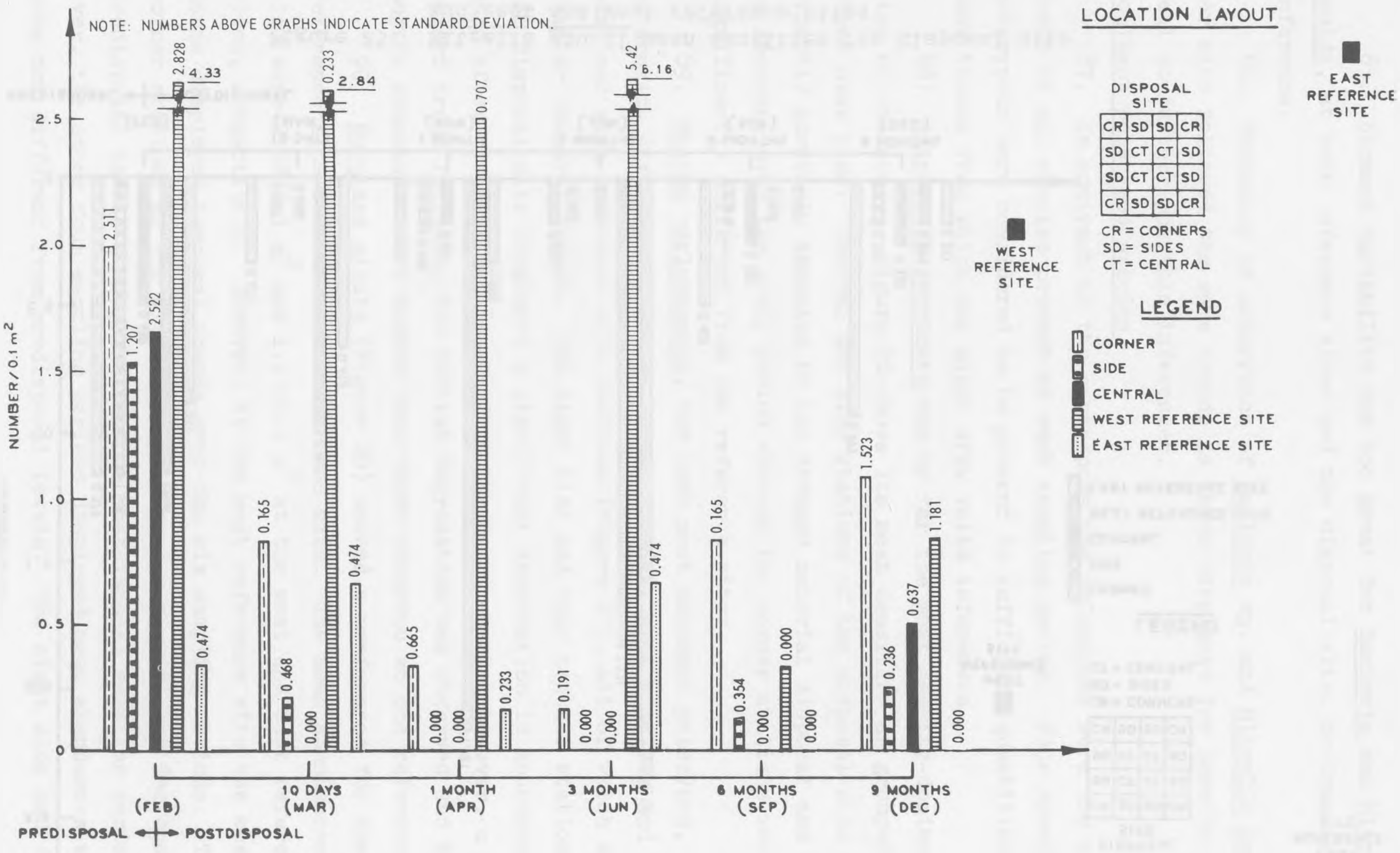

Figure 24. Barleeia mean densities for disposal site and east and west reference sites

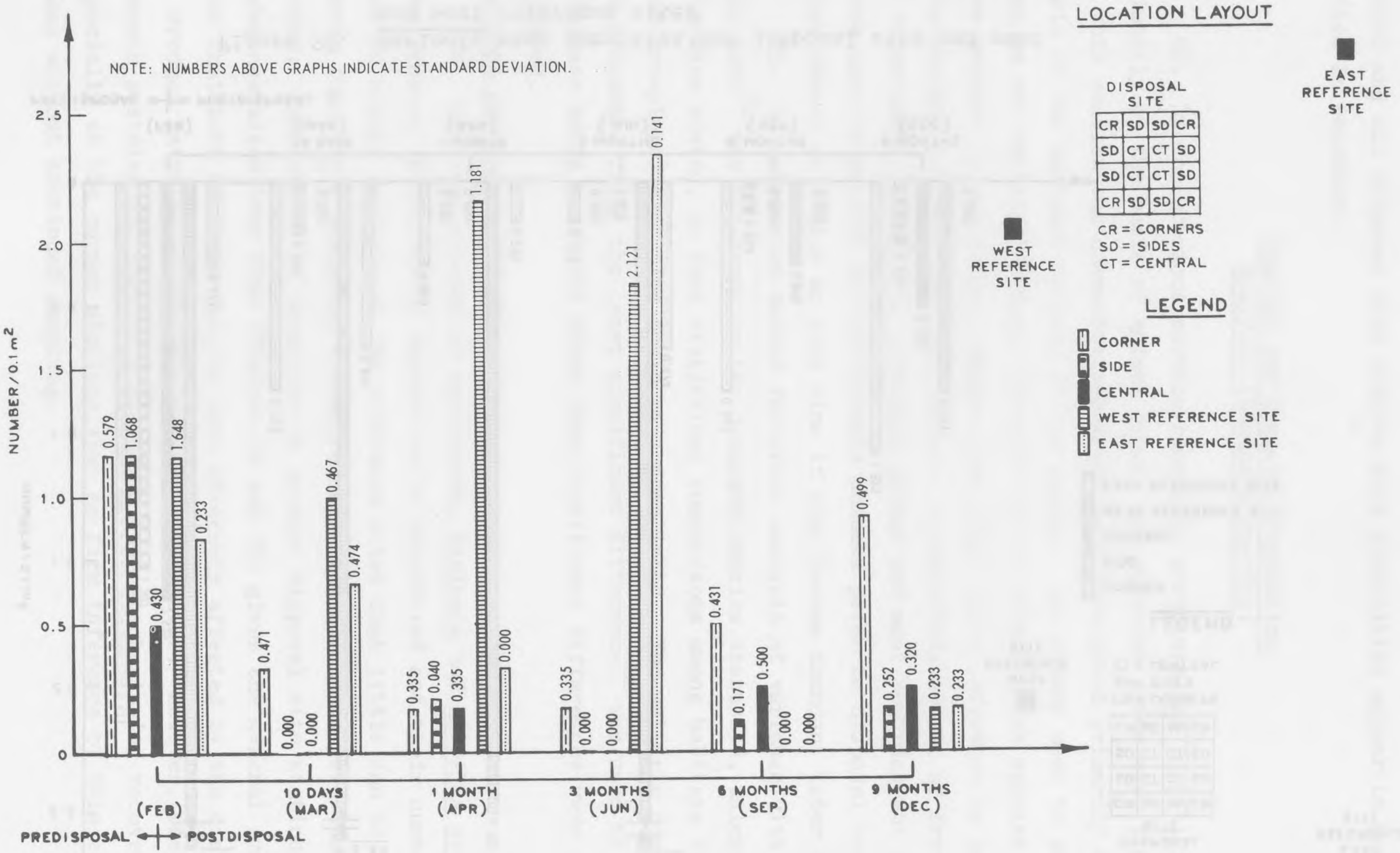

Figure 25. *Mitrella gouldi* mean densities for disposal site and east and west reference sites

85. Biomass variability was too great for Barleeia and Mitrella gouldi, at both reference sites and the disposal site, to draw any inference.

86. Frequency of occurrence of Barleeia sp. and Mitrella gouldi per site followed the same trends as those displayed for density and reveal no further possible inferences.

Dominant pelecypod species

87. In contrast to the gastropods the pelecypods were the most dominant of all species present at each sampling period. Four species of pelecypods were considered to be present in sufficient quantities to show trends from which one might draw valid inferences.

88. Axinopsida serricata was by far the most density-dominant species of the study. Figure 26 shows its mean densities at grouped stations over time. Central and side stations of the disposal site were promptly adversely impacted by the dredged material disposal and showed no recovery over the study period whereas the corner stations were not significantly different from the reference sites.

89. Macoma carlottensis, the next most abundant pelecypod, showed no density differences between corner disposal site stations and the east and west reference site stations (Figure 27), all of which showed similar temporal trends. The eight side and four central stations of the disposal site displayed a significant degradation in abundance 10 days after disposal and remained so through 6 months; however, a slight upward trend following the initial degradation was observed and by 9 months abundances were higher than those observed at the reference sites.

90. Nuculana minuta (Figure 28) showed a preference for the west reference site over the east reference site. The mean abundances over time were $9.28/0.1\ m^2$ and $1.17/0.1\ m^2$ at the west and east reference sites, respectively. However, at the west reference site the mean abundance displayed temporal trends over the six sampling periods. The four corner stations at the disposal site showed a significant decrease from predisposal levels during the 1-month postdisposal sampling period; however, the other four sampling periods displayed mean abundances which were not different from predisposal levels. The eight side and four

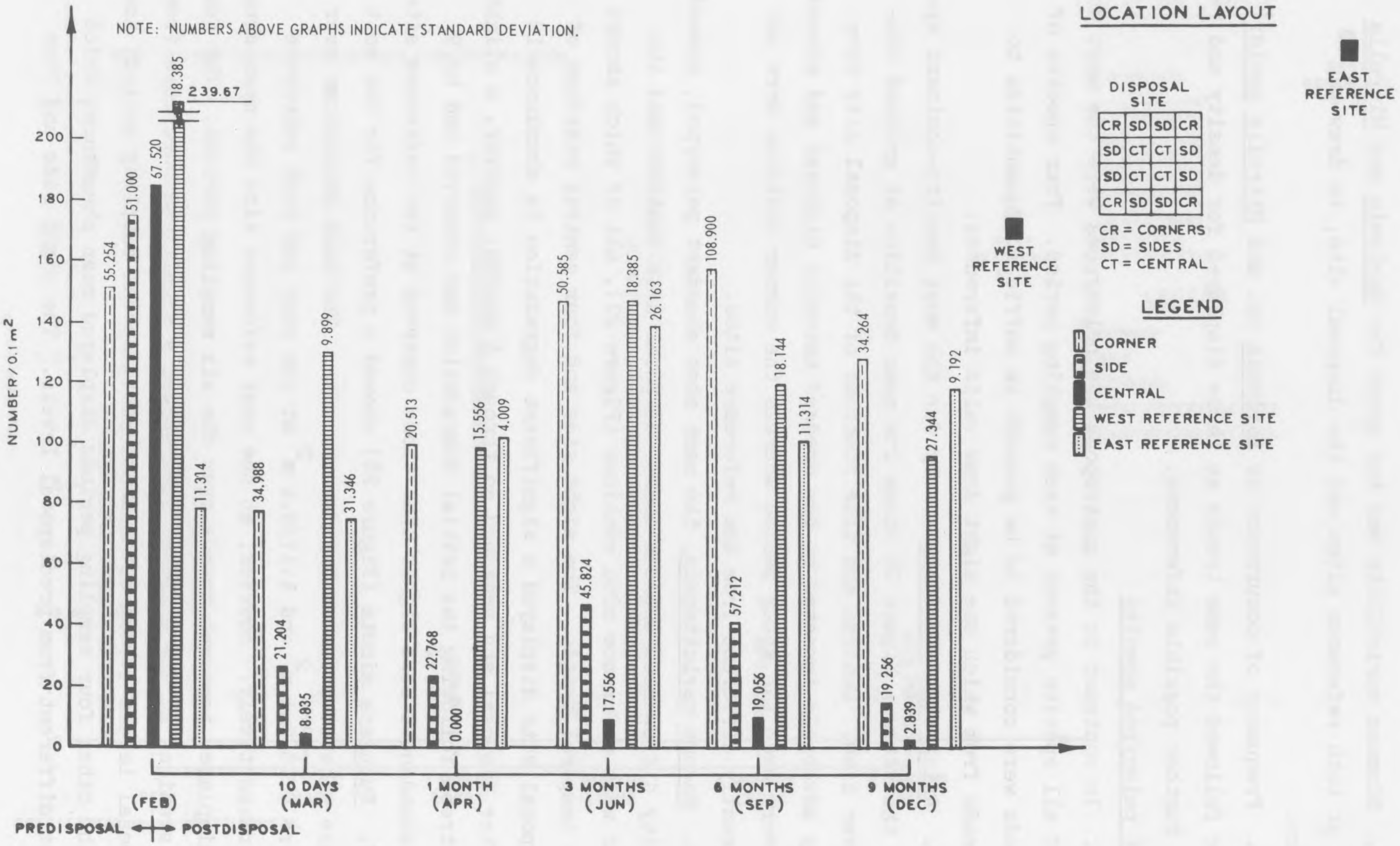

Figure 26. _Axinopsida serricata_ mean densities for disposal site and east and west reference sites

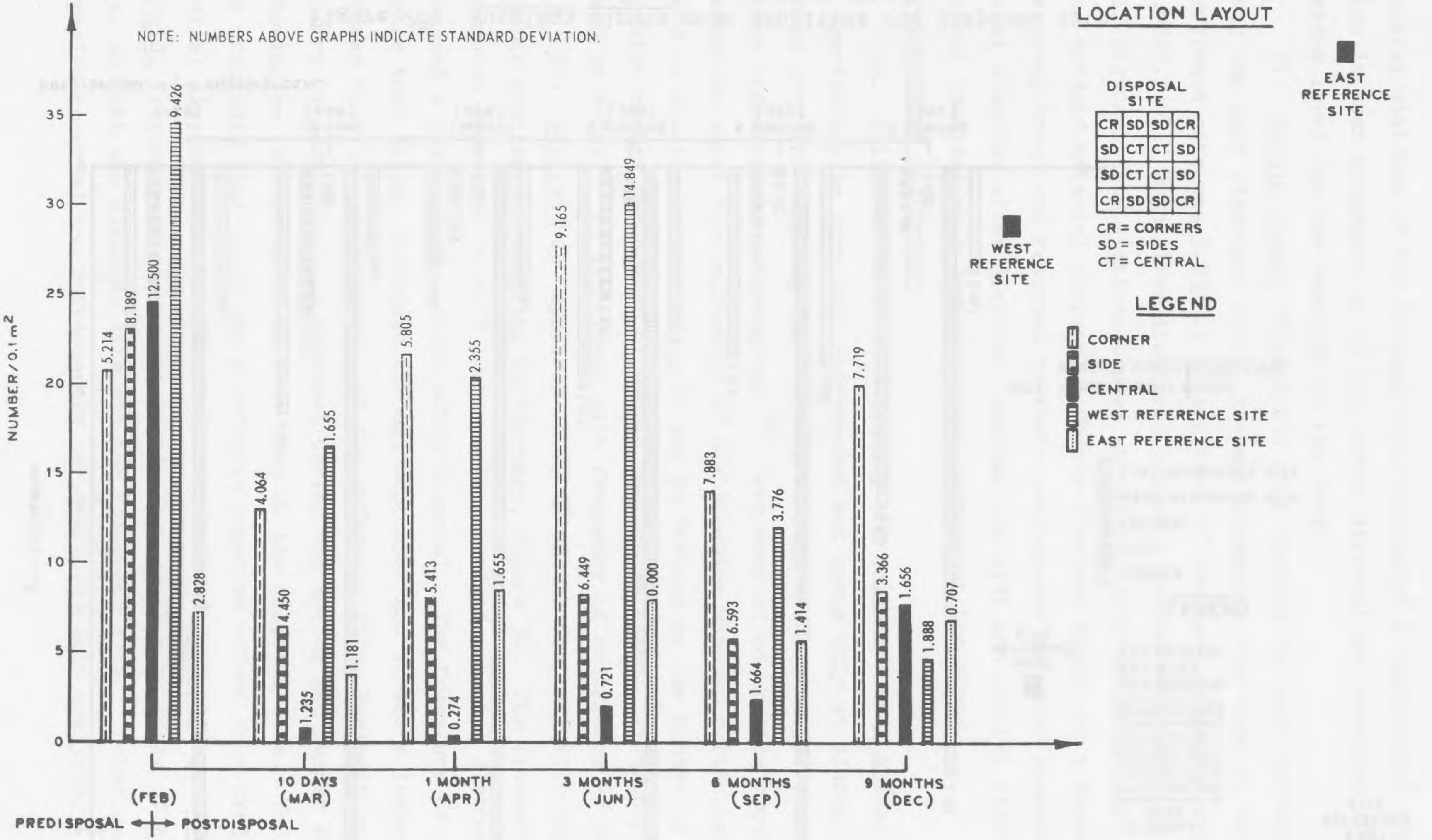

Figure 27. Macoma carlottensis mean densities for disposal site and east and west reference sites

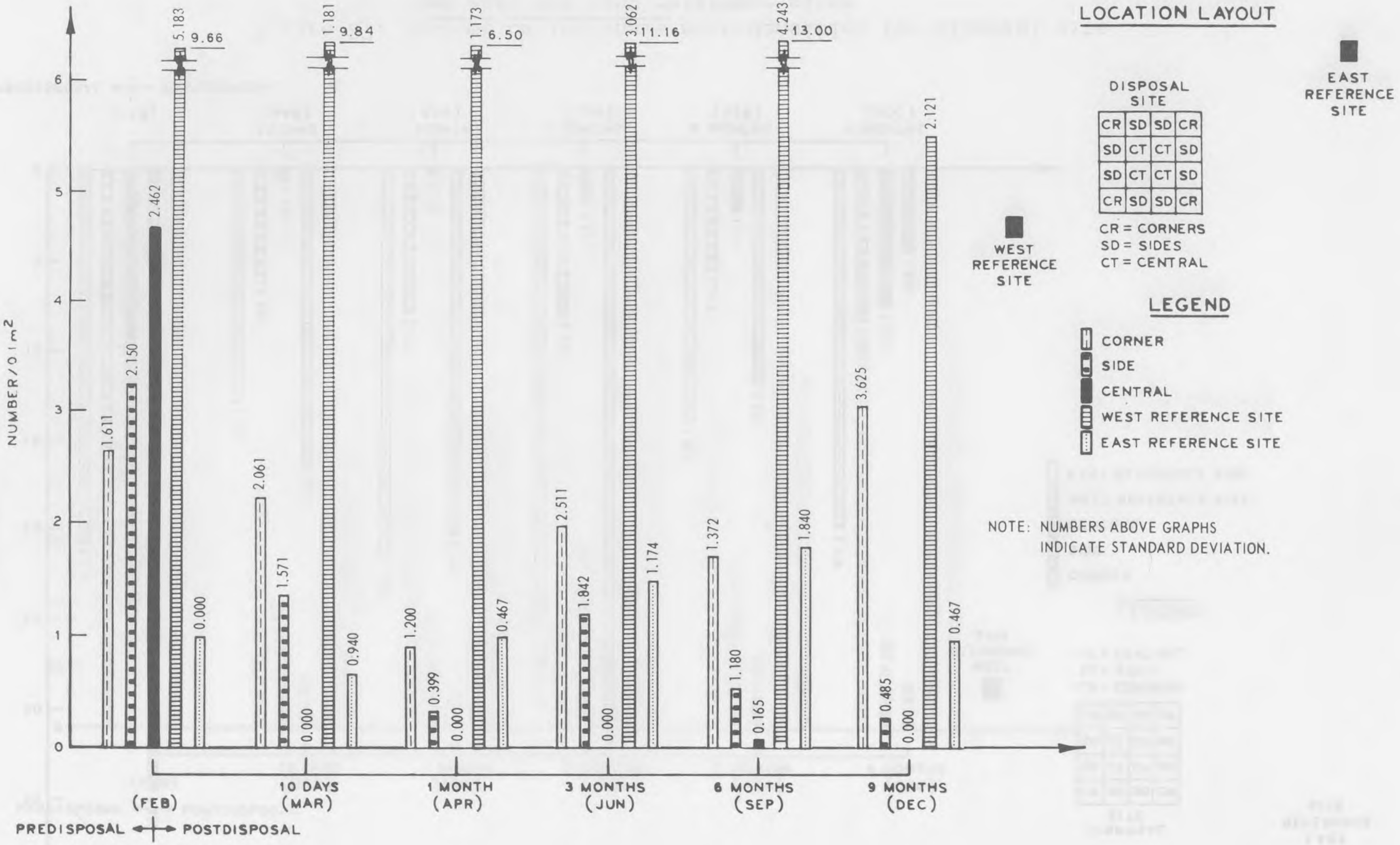

Figure 28. Nuculana minuta mean densities for disposal site and east and west reference sites

central stations of the disposal site displayed a significant degradation in mean abundance by 10 days after disposal and remained at this degraded level for the duration of the study.

91. Nucula tenuis (Figure 29) also favored the west reference site over the east reference site. Average abundance over time at the west reference site was 5.83/0.1 m^2 and that of the east reference site was 1.08/0.1 m^2. Both sites displayed temporal trends over sampling periods. All disposal site stations showed an initial degradation 10 days after the dredged material disposal. Corner stations displayed a decreased temporal trend and returned to their predisposal relative abundance level 6 months after disposal, whereas the side and central station abundances remained at a degraded level throughout the study.

Frequency of occurrence

92. A limitation of both density and dominance evaluations is that a species may be very well represented but occur only at places scattered over the sampling area (site), whereas the statistics suggest moderate representation throughout.[23] Frequency of occurrence provides information about the uniformity of distribution without particular reference to density (abundance). It may be defined as the number of times a species occurs per number of sample replicates taken. Frequency index, used by Seber,[24] is synonymous with frequency of occurrence as used here.

93. Barleeia sp. appeared in 55.3% of the disposal site samples during predisposal sampling in February, Figure 30. The frequency of occurrence decreased to 6.2% 10 days after dredged material disposal and reached a low of 2.1% 1 month after disposal. The frequency of occurrence then slowly increased through September and showed a large increase to 27.1% in December. At the reference sites Barleeia sp. frequency of occurrence was greatest during the spring and summer months, showing an inverse trend to that seen at the disposal site. Thus it can be concluded that there was a definite negative effect from dredged material disposal upon frequency of occurrence of Barleeia sp. Mitrella gouldi frequency of occurrence trends were similar to those of Barleeia sp. at both the disposal site and the reference sites. Other gastropod species occurred too infrequently to permit reliable analysis.

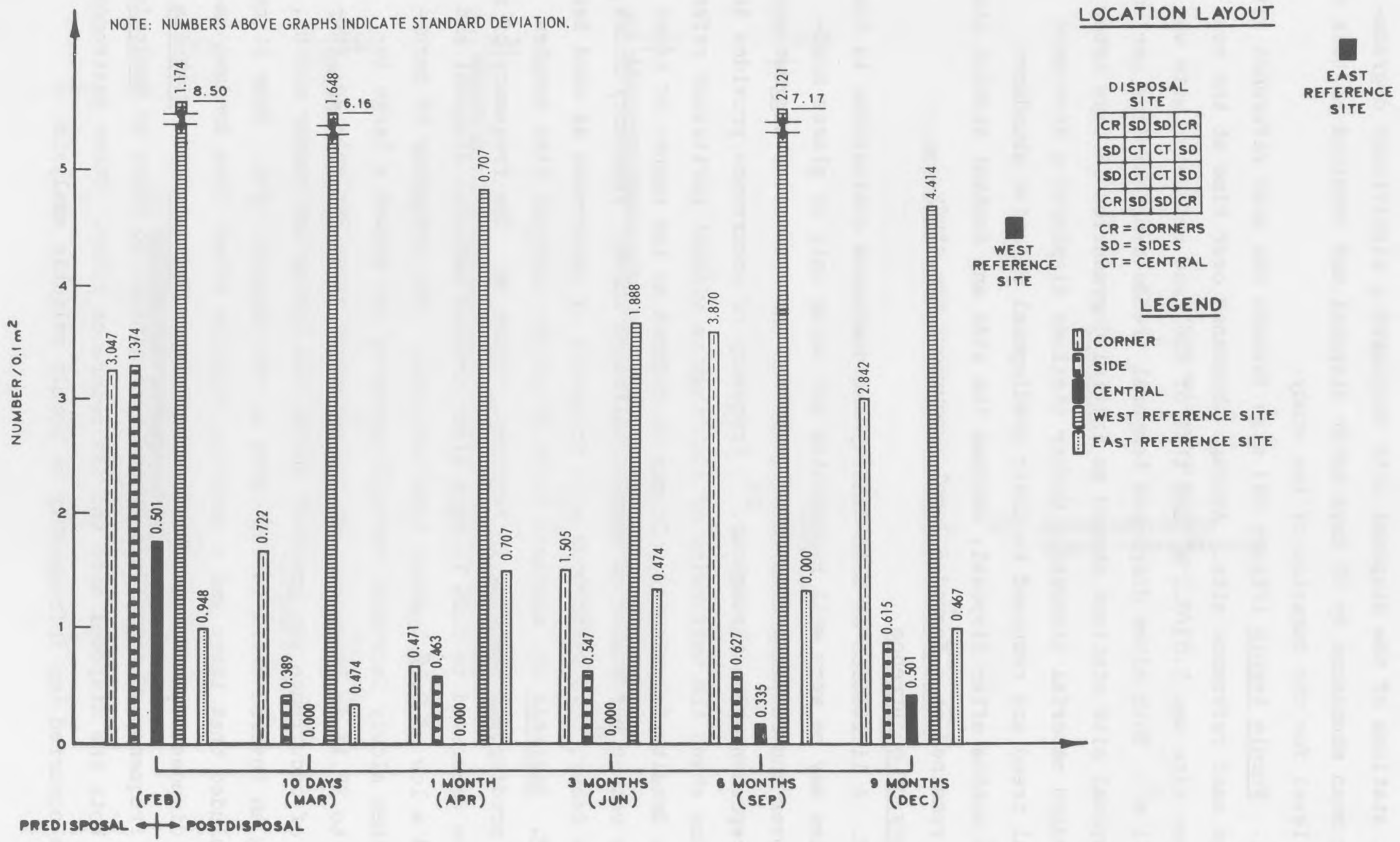

Figure 29. Nucula tenuis mean densities for disposal site and east and west reference sites

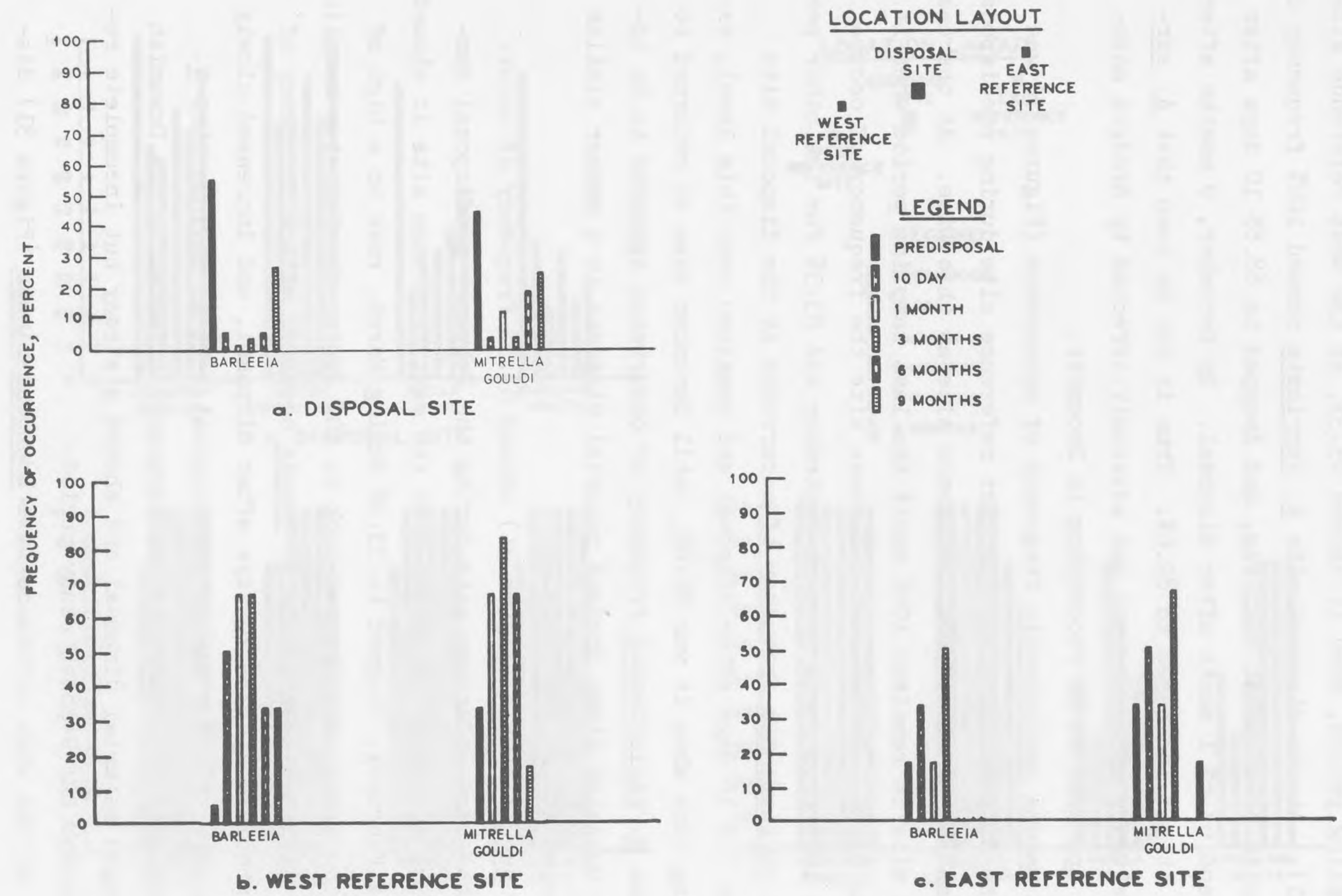

Figure 30. Frequency of occurrence of gastropoda at disposal site and east and west reference sites

94. Axinopsida serricata showed 100% frequency of occurrence over all sampling periods at the east reference site and over all but the February sampling period, when it showed 83.3%, at the west reference site (Figure 31). At the disposal site A. serricata showed 100% frequency of occurrence in predisposal sampling, and dropped to 68.8% 10 days after disposal and 64.6% 1 month after disposal. By December, 9 months after disposal, it had increased to 89.6%. Thus it can be seen that A. serricata frequency of occurrence was adversely affected by dredged material, but appeared to be recovering in December.

95. Macoma carlottensis frequency of occurrence (Figure 31) was 100% at the disposal site and the east reference site during predisposal sampling and 83.3% at the west reference site at this time. At the east reference site it remained 100% until the last sampling period when it dropped to 83.3%. At the west reference site the frequency of occurrence was 100% from April through September and 83.3% for the other periods. M. carlottensis frequency of occurrence at the disposal site dropped to 75% 10 days after disposal and remained near this level, except during June when it was 89.6%, until December when it returned to 100%. Thus M. carlottensis frequency of occurrence appeared to be affected by Duwamish River dredged material disposal in a manner similar to that noted for A. serricata.

96. Nucula tenuis (Figure 31) showed 83.3% frequency of occurrence at the west reference site during the February predisposal sampling period and 100% thereafter. At the east reference site it showed 50% during February, dropped to 33.3% during March, rose to a high of 83.3% during April, and dropped back to 50% during the last two sampling periods. At the disposal site N. tenuis occurred with a frequency of 85.1% at predisposal, 25% 10 days after disposal, and increased slowly but steadily to 56.2% 9 months postdisposal. It is obvious that N. tenuis frequency of occurrence was adversely affected by the Duwamish River dredged material disposal and showed a steady but incomplete recovery through the 9-month study period.

97. At the west reference site Nuculana minuta (Figure 31) displayed 83.3% frequency of occurrence during the predisposal sampling

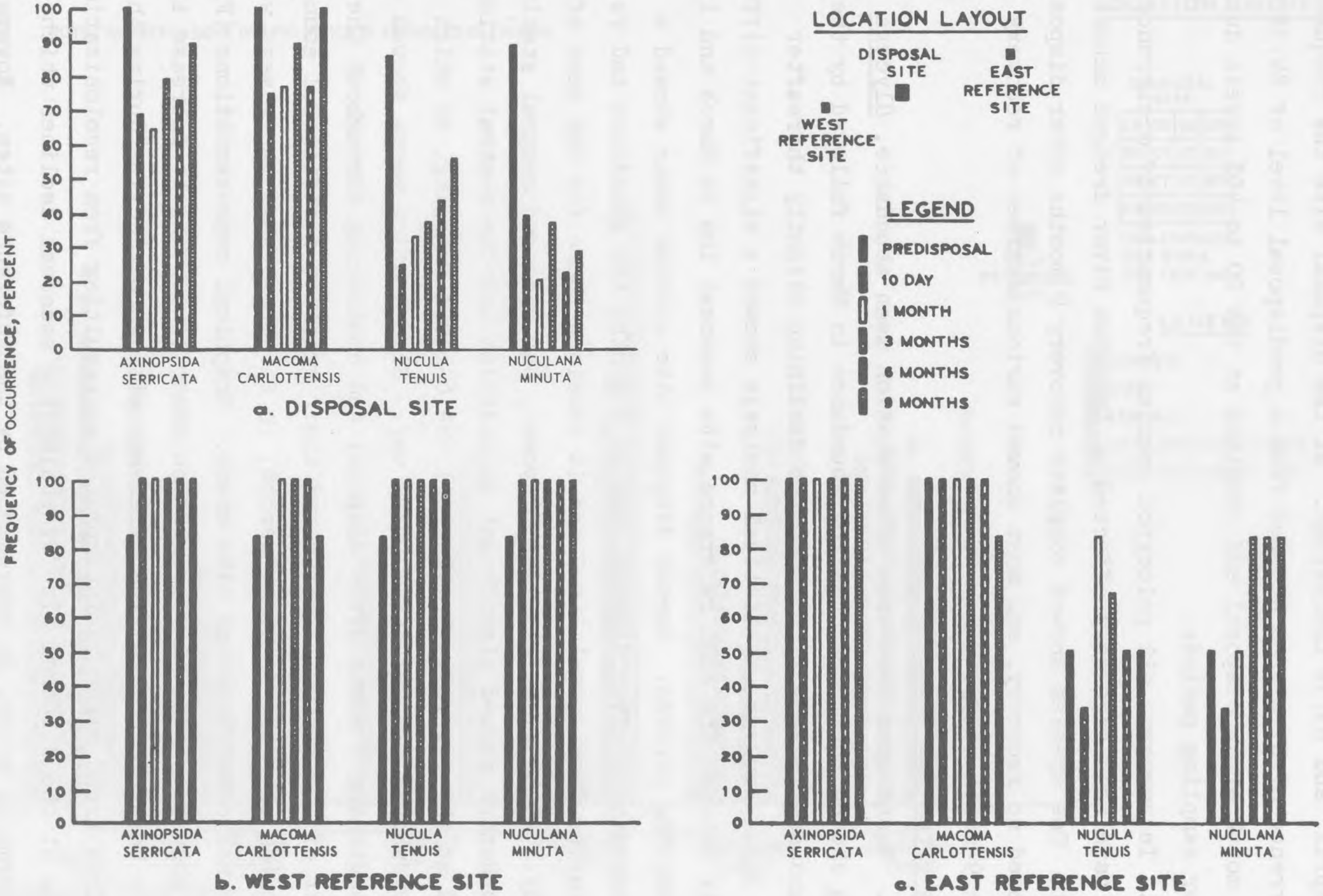

Figure 31. Frequency of occurrence of pelecypoda at disposal site and east and west reference sites

period and 100% thereafter. At the east reference site its frequency of occurrence was 50% during the predisposal sampling, 33.3% during March, 50% in April, and 83.3% thereafter. At the disposal site the frequency of occurrence of N. minuta dropped from a predisposal level of 89.3% to 20.8% 1 month after disposal and remained at the 20 to 40% levels during all other sampling periods.

98. In summary, all pelecypod species frequencies of occurrence appear to have been adversely affected by Duwamish River dredged material disposal. One species showed complete recovery 9 months after disposal, some showed no recovery, and most showed various degrees of recovery over the 9-month study.

Dominant errantian worms

99. Based upon reference sites station mean abundance, Glycera capitata showed their seasonal low abundance in March followed by their peak abundance in June with abundance declining slightly thereafter (Figure 32). However, statistical analysis showed a significant difference only between the east reference site seasonal low in March and its other sampling periods. Corner disposal site station means showed a small degradation after disposal but by 3 months the abundance had returned to its predisposal level and it remained there for the rest of the study. At 10 days following disposal, the side and central station mean abundances showed significant degradation and the central stations remained at this degraded level until the 6-month sampling, at which time they showed recovery well under way. Side station means showed recovery beginning 1 month after disposal and continuing throughout the remainder of the study. They showed their greatest postdisposal abundance during the last sampling period, in December, when their mean was greater than other disposal site means. Graphical representations (Figure 32) show all disposal site station means continuing to increase in abundance beyond June, whereas reference site means decline during this time. This trend might be interpreted as resulting from recolonization pressures at the disposal site overbalancing seasonal declines which should normally occur, as represented by the reference sites. However, since variation is too great to see seasonal fluctuations statistically,

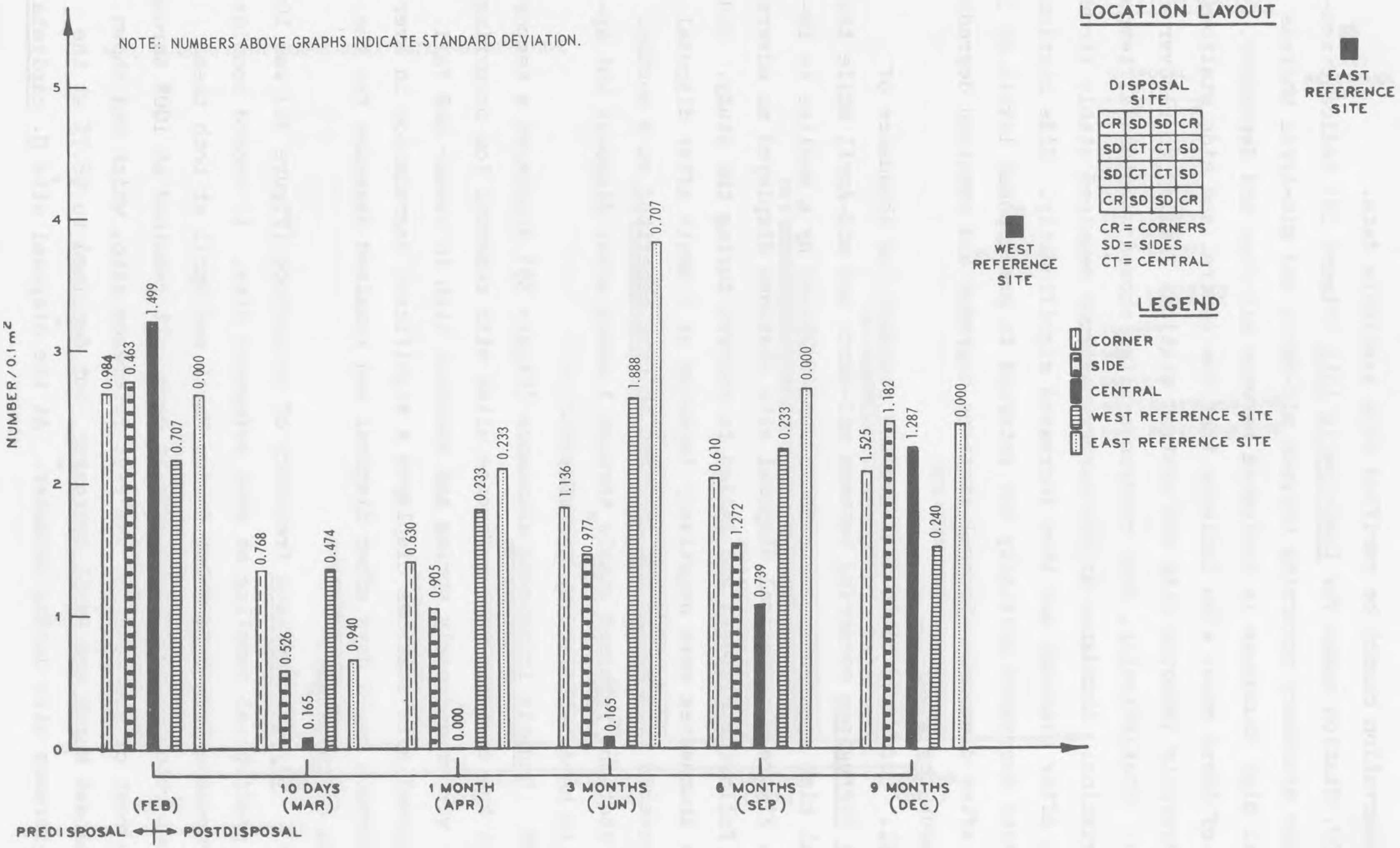

Figure 32. *Glycera capitata* mean densities for disposal site and east and west reference sites

this observation cannot be verified with available data.

100. Station means for *Lumbrineris luti* (Figure 33) indicate seasonal low abundance occurring between mid-March and mid-April whereas seasonal high abundance is indicated between mid-June and September. Graphs of these means also indicate that the central and side stations were adversely impacted with the central stations failing to recover completely. Statistically, both reference sites showed substantial temporal variation. Abundance at the corner stations remained stable through 1 month after disposal and then increased significantly. Side station abundances decreased initially but returned to predisposal levels by 3 months after disposal. Central stations degraded and remained degraded throughout the study.

101. Reference sites indicate the seasonal low abundance of *Nephtys ferruginea* occurring between mid-March and mid-April while the seasonal high apparently occurred in June followed by a decline to December, Figure 34. Central disposal site stations displayed an adverse impact following disposal and failed to recover during the study. Side station abundances were negatively impacted at 1 month after disposal but recovered by 3 months and appeared to have benefited at 9 months. Corner stations remained stable through 1 month after disposal but appeared to have benefited by December.

102. *Onuphis iridescens* abundance (Figure 35) displayed a temporal trend at the east and west reference sites with seasonal low occurring in late winter and early spring and seasonal high in summer and fall. All disposal site stations displayed a significant degradation in average abundance by 10 days after disposal and remained degraded for the duration of the study.

103. *Glycera capitata* frequency of occurrence (Figure 36) was 100% during predisposal sampling at each reference site. It showed considerable decreases from this value during March and April at both these sites but returned to 100% by June at each. It remained at 100% throughout the rest of the study at the east reference site, which had shown the greatest March and April decreases, but declined to 66.7% at the west reference site during December. At the disposal site *G. capitata*

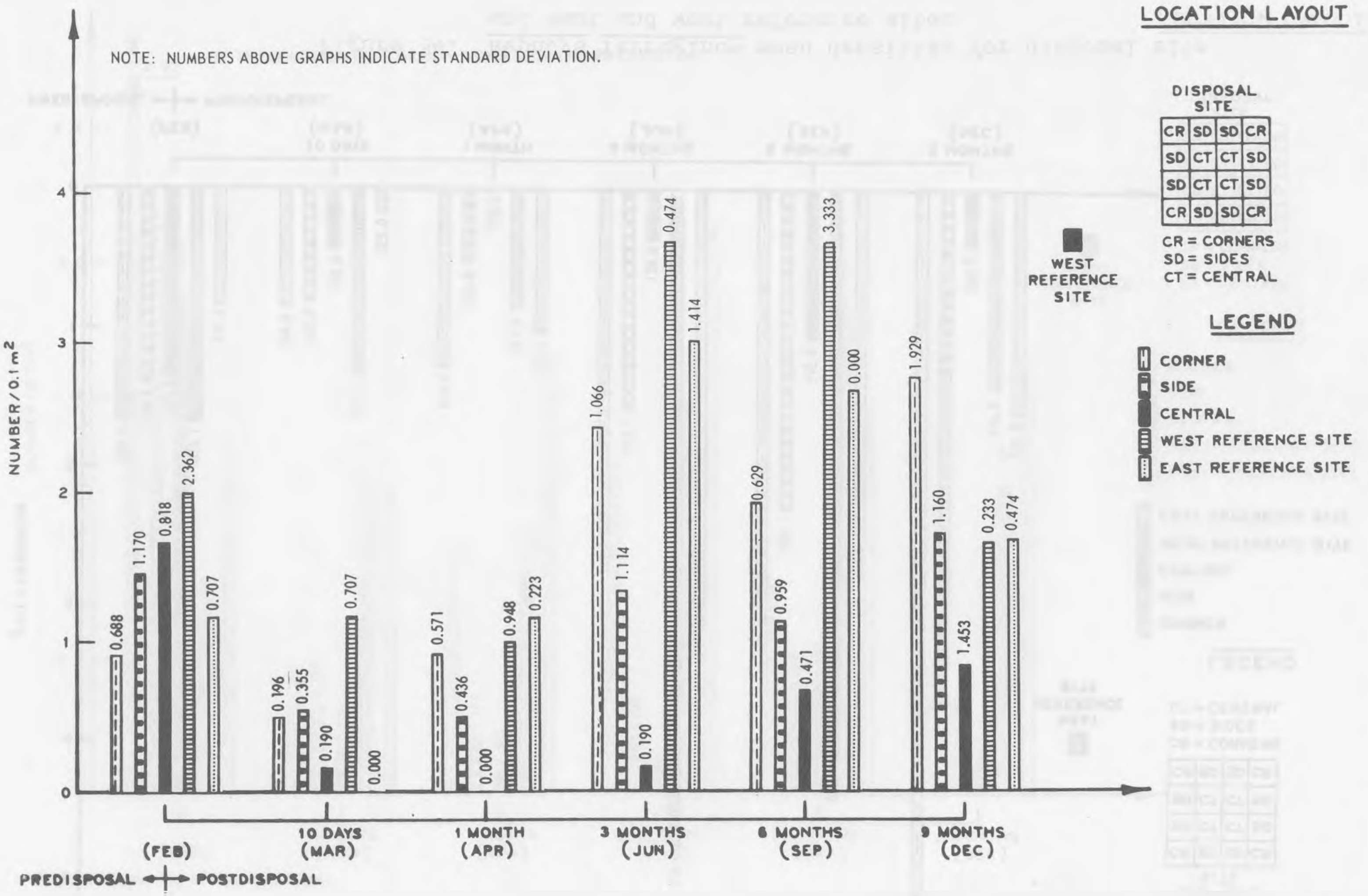

Figure 33. *Lumbrineris luti* mean densities for disposal site and east and west reference sites

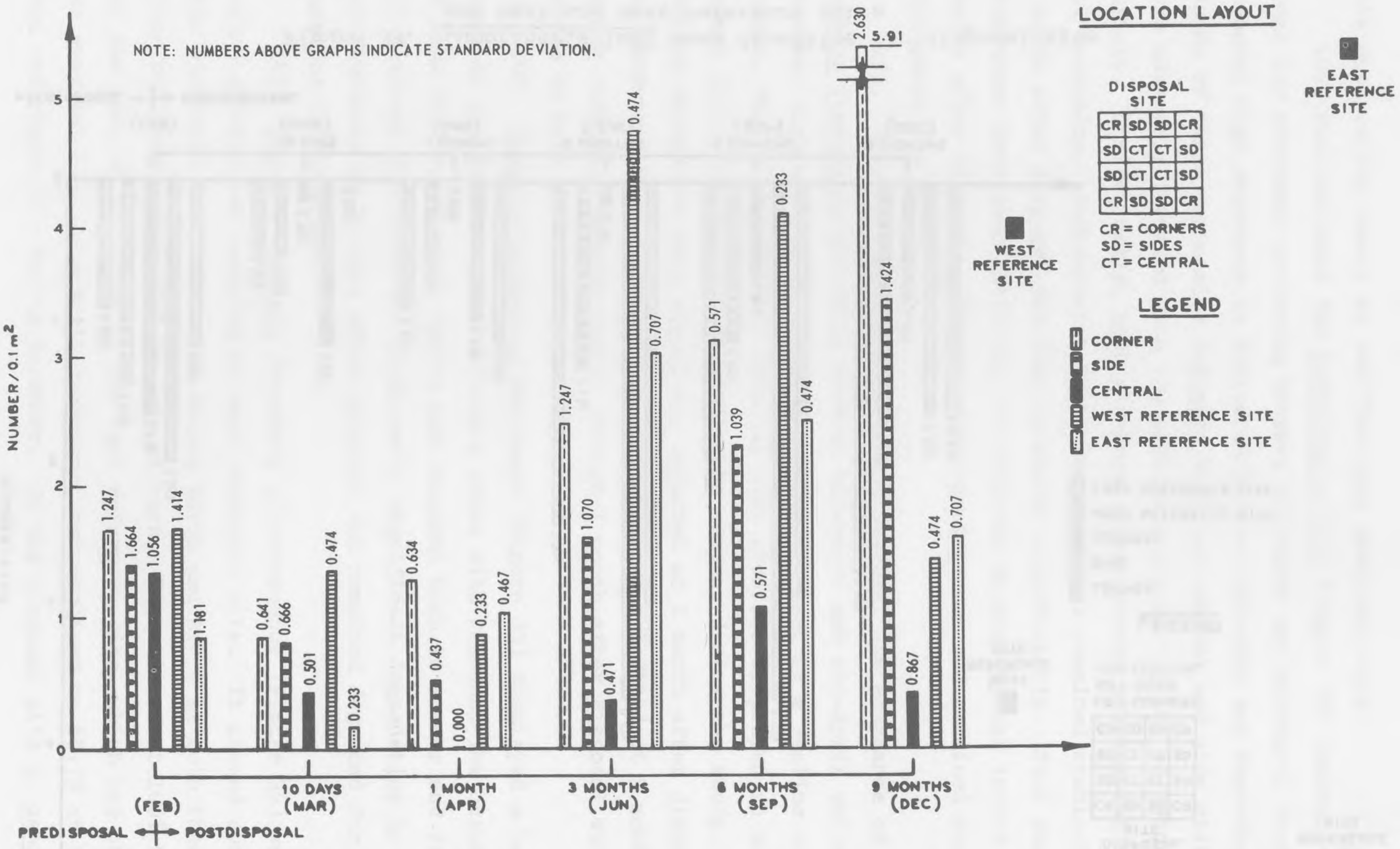

Figure 34. *Nephtys ferruginea* mean densities for disposal site and east and west reference sites

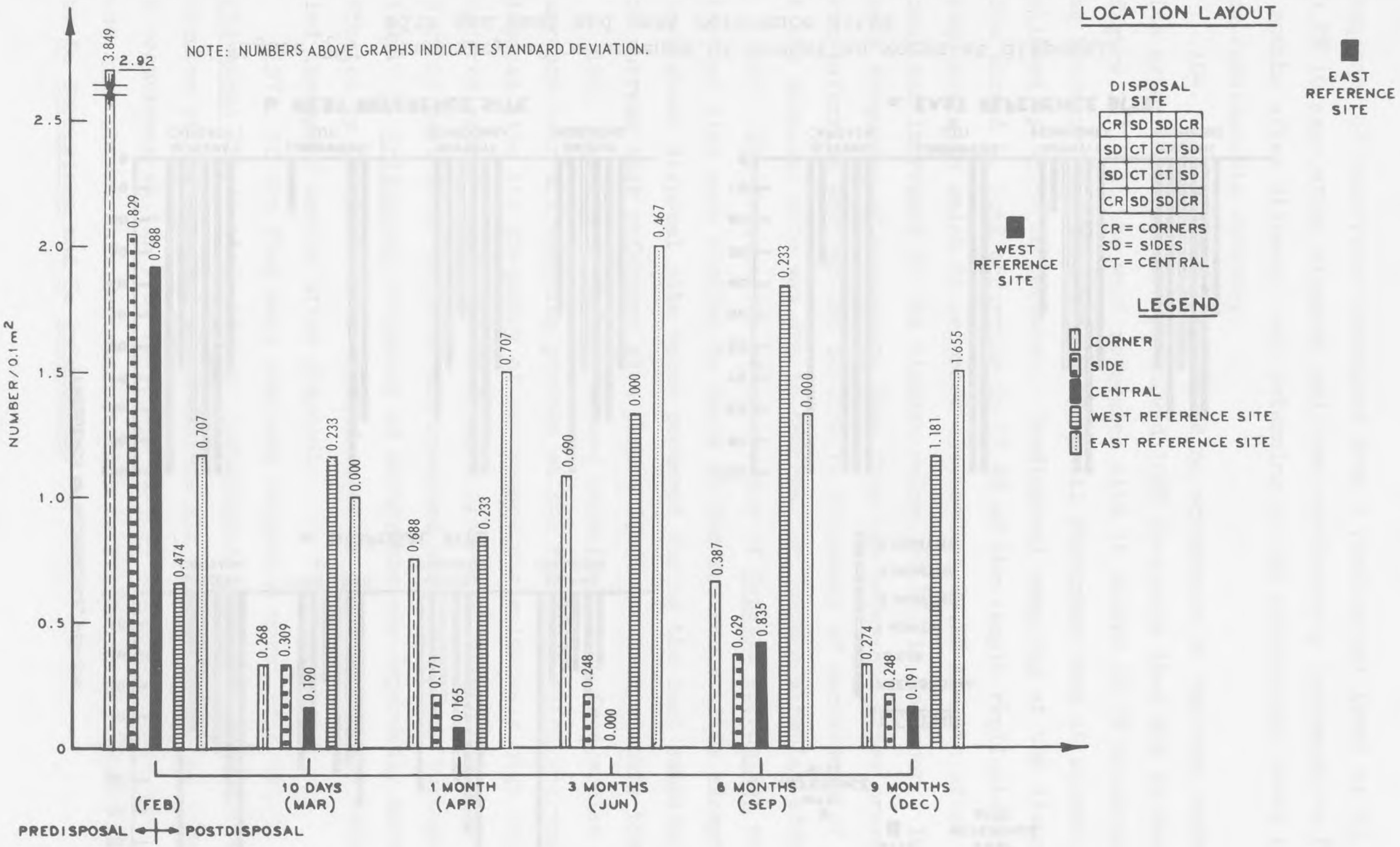

Figure 35. Onuphis iridescens mean densities for disposal site and east and west reference sites

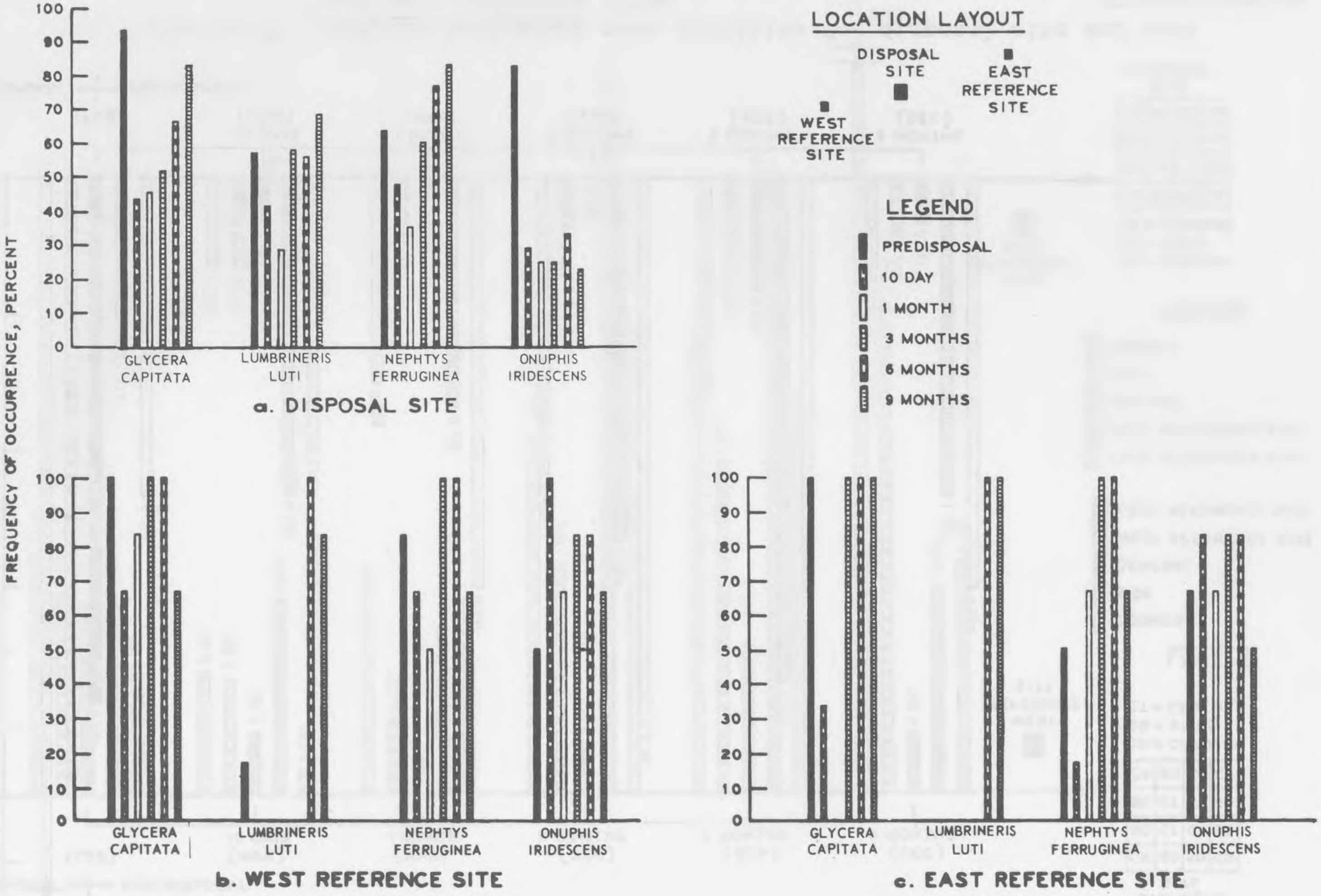

Figure 36. Frequency of occurrence of errantian worms at disposal site and east and west reference sites

frequency of occurrence decreased from a predisposal level of 93.6% to 43.8% 10 days after disposal and then continuously increased to 83.3% 9 months after disposal, not returning to its predisposal level but showing considerable recovery.

104. Lumbrineris luti showed no occurrence at the east reference site prior to September but showed 100% frequency then and in December (Figure 36). At the west reference site it showed 16.7% occurrence during February, and zero afterwards until September when it showed 100% followed by 83.3% in December. Predisposal sampling at the disposal site showed L. luti occurring in 57.4% of the sample replicates. The frequency with which it occurred declined to 29.2% 1 month after disposal and increased to its highest value, 68.8%, in December. Inadequate frequency of occurrence data from the reference sites prevents one from inferring whether the decline in frequency of occurrence of L. luti at the disposal site was due to seasonal or dredged material effects.

105. The frequencies of occurrence of Nephtys ferruginea at the disposal site were similar to those at the reference sites except that the highest disposal site value occurred during the last sampling period whereas each reference site showed 33.3% declines at this time.

106. Onuphis iridescens showed relatively high frequencies of occurrence over all sampling periods at the reference sites whereas at the disposal site its frequency of occurrence was relatively high only during predisposal sampling. It dropped from 82.9% before disposal to 29.2% 10 days after disposal and remained near this level through the study. O. iridescens frequency of occurrence was apparently adversely affected by Duwamish River dredged material disposal and the effect carried through 9 months after disposal.

107. Of the four more dominant errantian worms, all but O. iridescens showed their highest postdisposal frequency of occurrence in December at the disposal site, whereas all showed decreasing frequencies of occurrence at the west reference site at this time. The east reference site showed this December decline in frequency of occurrence only for N. ferruginea and O. iridescens.

Dominant sedentarian worms

108. Abundance. Figure 37 displays the mean sample replicate *Heteromastus filobranchus* densities averaged for the four corner, eight side, and four central disposal site stations, and the two stations each at the west and east reference sites. The statistical analysis showed that the corner station means and west and east reference site means displayed an upward trend during the first 3 months after disposal followed by a downward trend through 9 months after disposal. The mean abundances of these grouped stations were no different at 9 months after disposal than the levels observed prior to disposal.

109. The side and central station abundances of the disposal site displayed a downward trend through 1 month after disposal followed by an upward trend through 9 months after disposal and showed no difference at 9 months relative to the predisposal abundance levels. Thus the analysis indicates that *H. filobranchus* abundances at the central and side disposal site stations were adversely affected by the Duwamish River dredged material disposal but recovered completely by 9 months after disposal while the corner stations showed no disposal effect.

110. *Euclymene zonalis* mean densities for grouped stations and all sampling periods are displayed in Figure 38. The statistical analysis showed an upward postdisposal trend with maximum abundances occurring between 6 and 9 months after disposal for the corner stations and east and west reference site stations. This trend was not observed for the eight side and four central stations at the disposal site. These station densities showed an initial downward trend but returned to predisposal levels by 3 months after disposal. However, relative to concurrent reference site abundances, side and central station abundances showed an adverse impact 1 month after disposal, from which they did not recover during the study.

111. *Praxilella gracilis* mean abundance at grouped stations (Figure 39) displayed a temporal trend for the corner disposal site stations and the east and west reference site stations when subjected to the statistical analysis. The side and central disposal site station

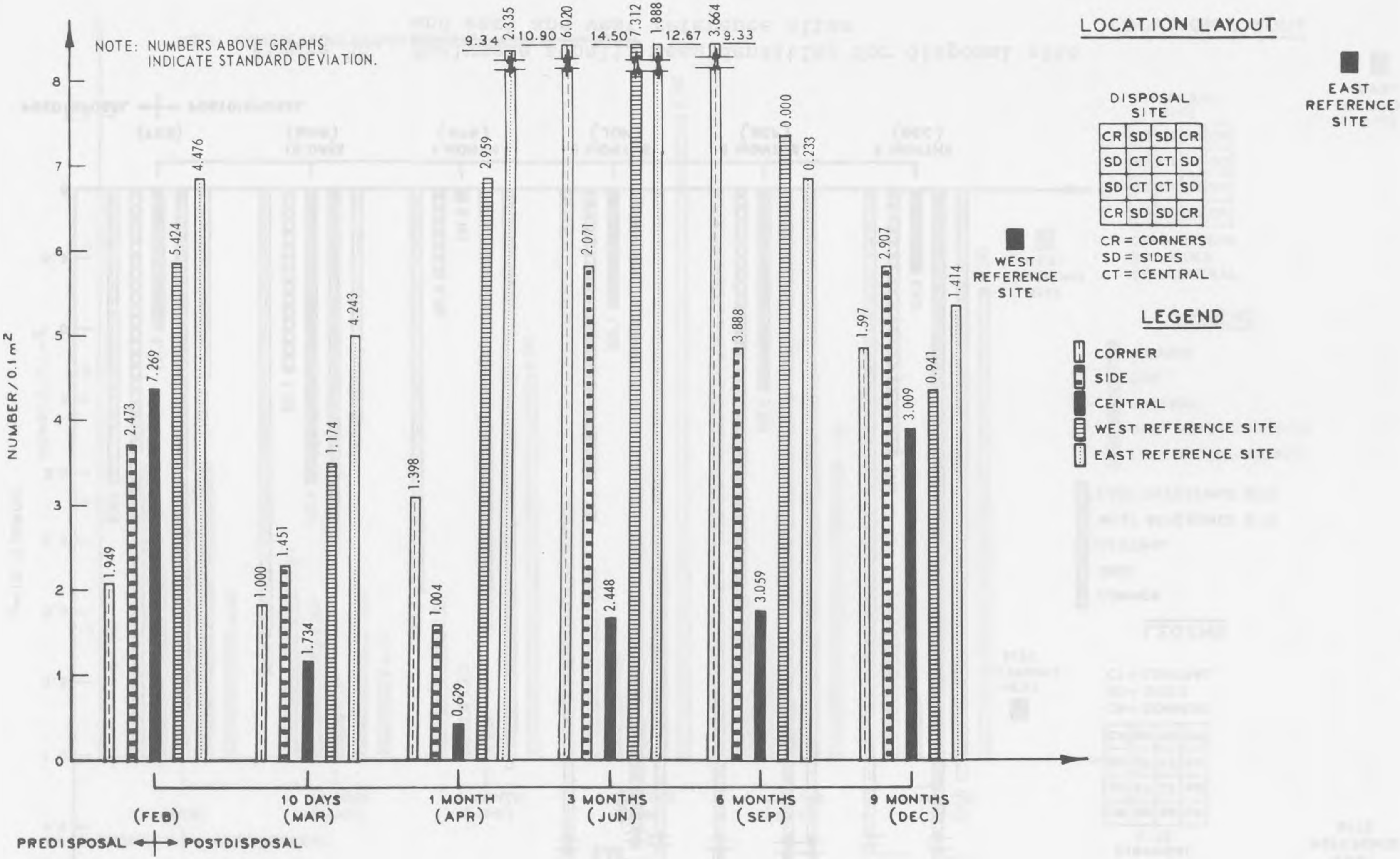

Figure 37. *Heteromastus filobranchus* mean densities for disposal site and east and west reference sites

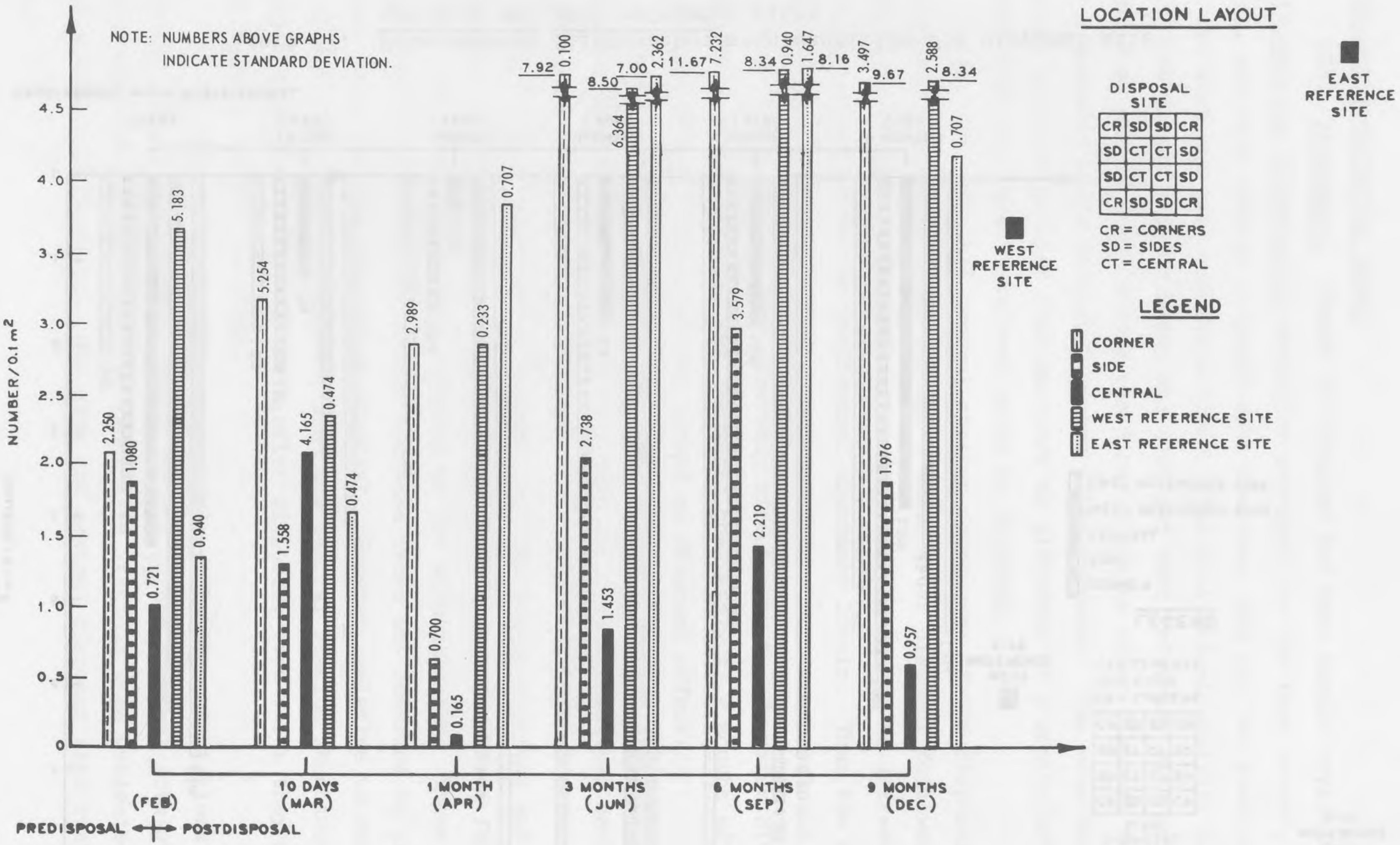

Figure 38. Euclymene zonalis mean densities for disposal site and east and west reference sites

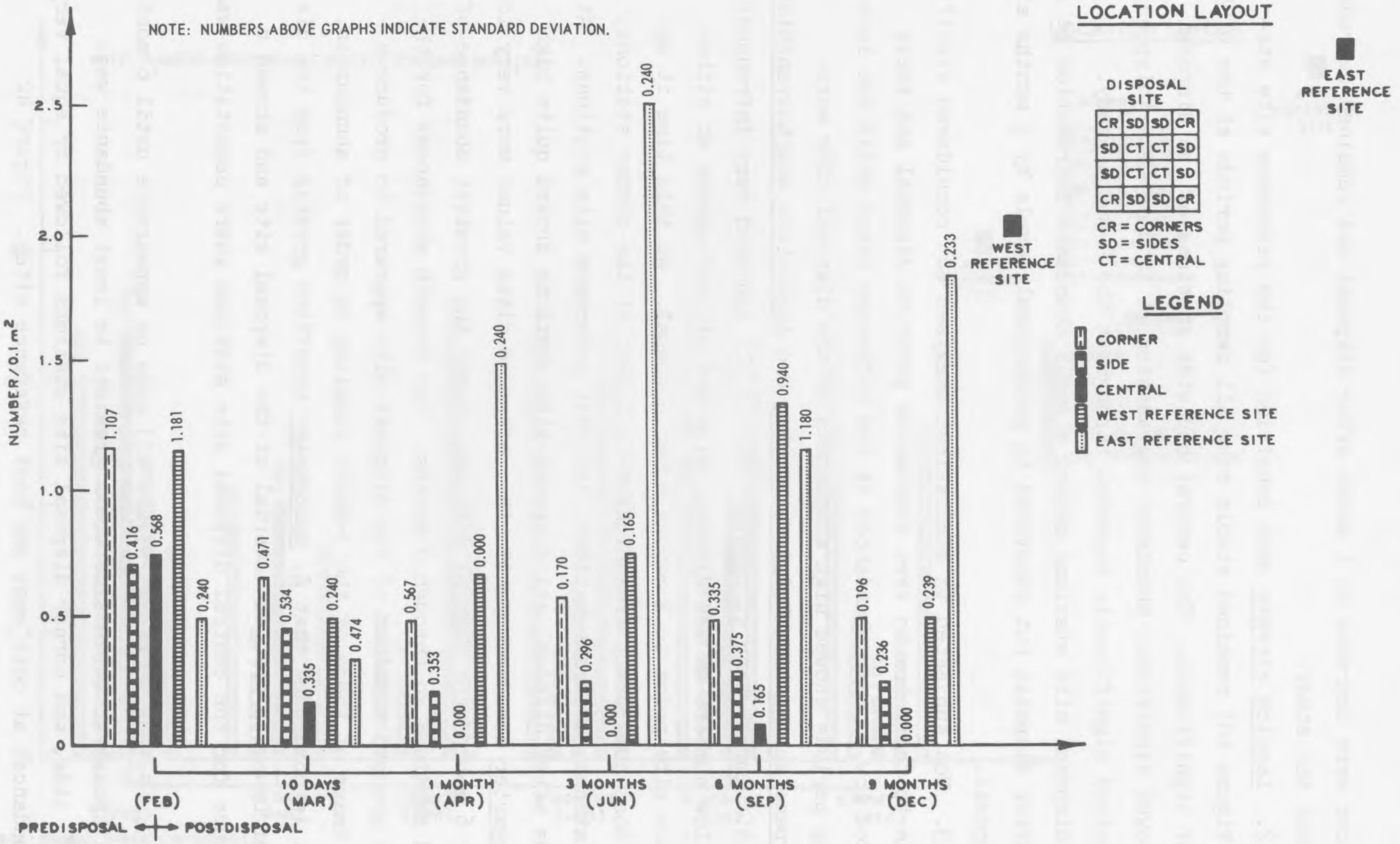

Figure 39. Praxilella gracilis mean densities for disposal site and east and west reference sites

abundances were degraded by 1 month after disposal and remained degraded throughout the study.

112. *Laonice cirrata* mean densities for the reference site stations (Figure 40) remained stable over all sampling periods at the 0.05 level of significance. The central and side stations of the disposal site showed significant abundance degradation at 10 days after disposal and remained significantly degraded throughout the 9-month study. Corner disposal site stations showed a small abundance degradation at 1 month after disposal but recovered to predisposal levels by 3 months after disposal.

113. Not subjected to statistical analyses but considered significant due to their low to zero abundances prior to disposal and their continued low to zero abundances at the reference sites while the later sampling periods showed high abundances at the disposal site were: *Ammotrypane aulogaster*, *Polydora uncata*, and *Amphicteis scaphobranchiata*.

114. *Ammotrypane aulogaster* (Figure 41) appeared very infrequently and in low numbers at the disposal site and did not appear at either reference site prior to 3 months after disposal. At this time it appeared most numerously from highest to lowest at the corner stations, side stations, central stations, and west reference site stations. At 6 months after disposal all disposal site stations showed quite high *A. aulogaster* abundances while the reference sites values were very low. Also by 6 months the central stations showed the greatest abundance of all and remained so through 9 months. The 9-month abundances for the various grouped stations of the disposal site appeared to produce a mirror image of those of the 3-month sampling in order of abundances. Thus it is concluded that *A. aulogaster* benefited greatly from the disposal of Duwamish dredged material at the disposal site and showed a preference for the central disposal site stations where competition was least.

115. *Polydora uncata* (Figure 42) made no appearance until 6 months after disposal at which time their greatest to least abundance was: central, side, and corner disposal site stations followed by equal very low abundances at both west and east reference sites. Figure 42

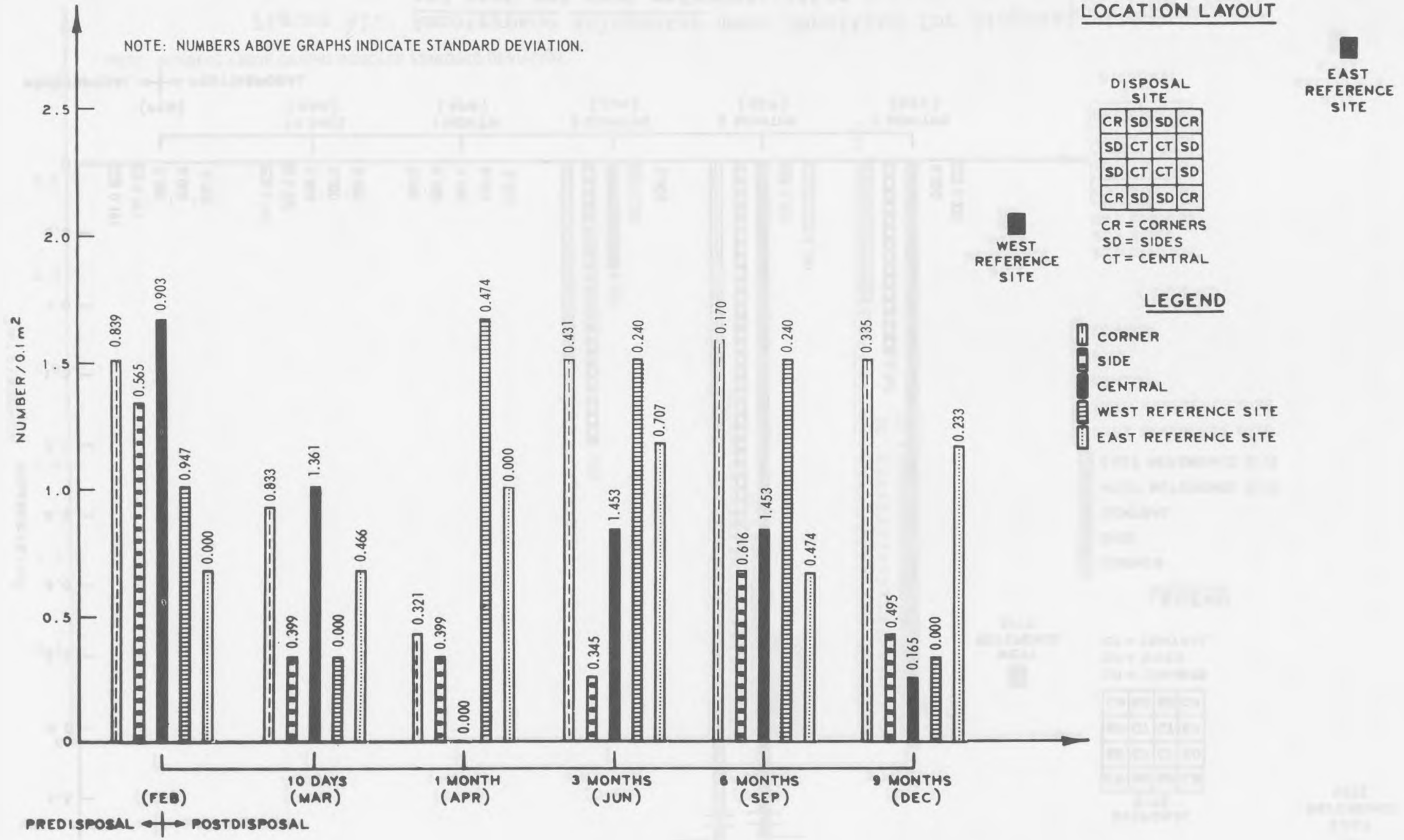

Figure 40. *Laonice cirrata* mean densities for disposal site and east and west reference sites

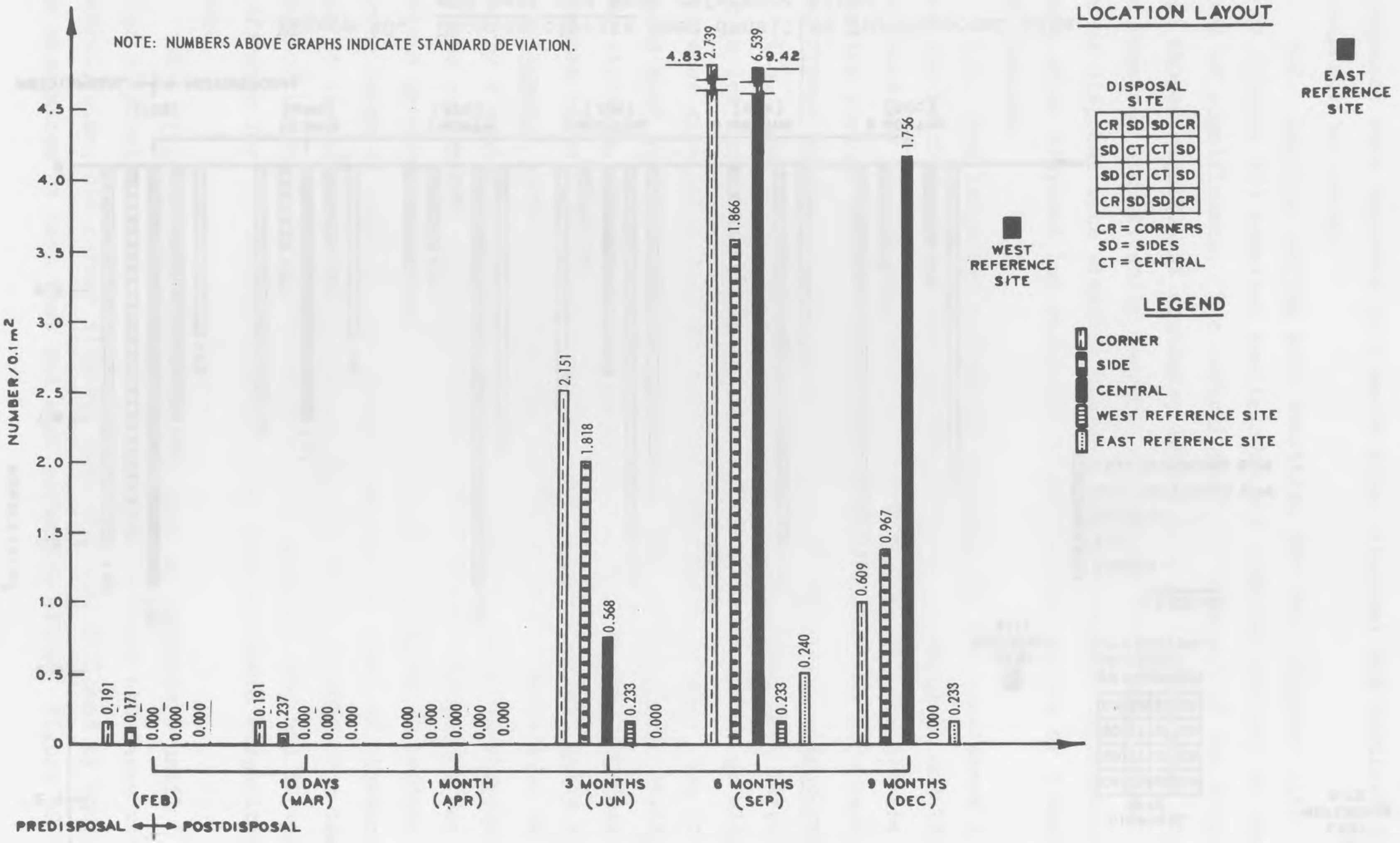

Figure 41. <u>Ammotrypane</u> <u>aulogaster</u> mean densities for disposal site and east and west reference sites

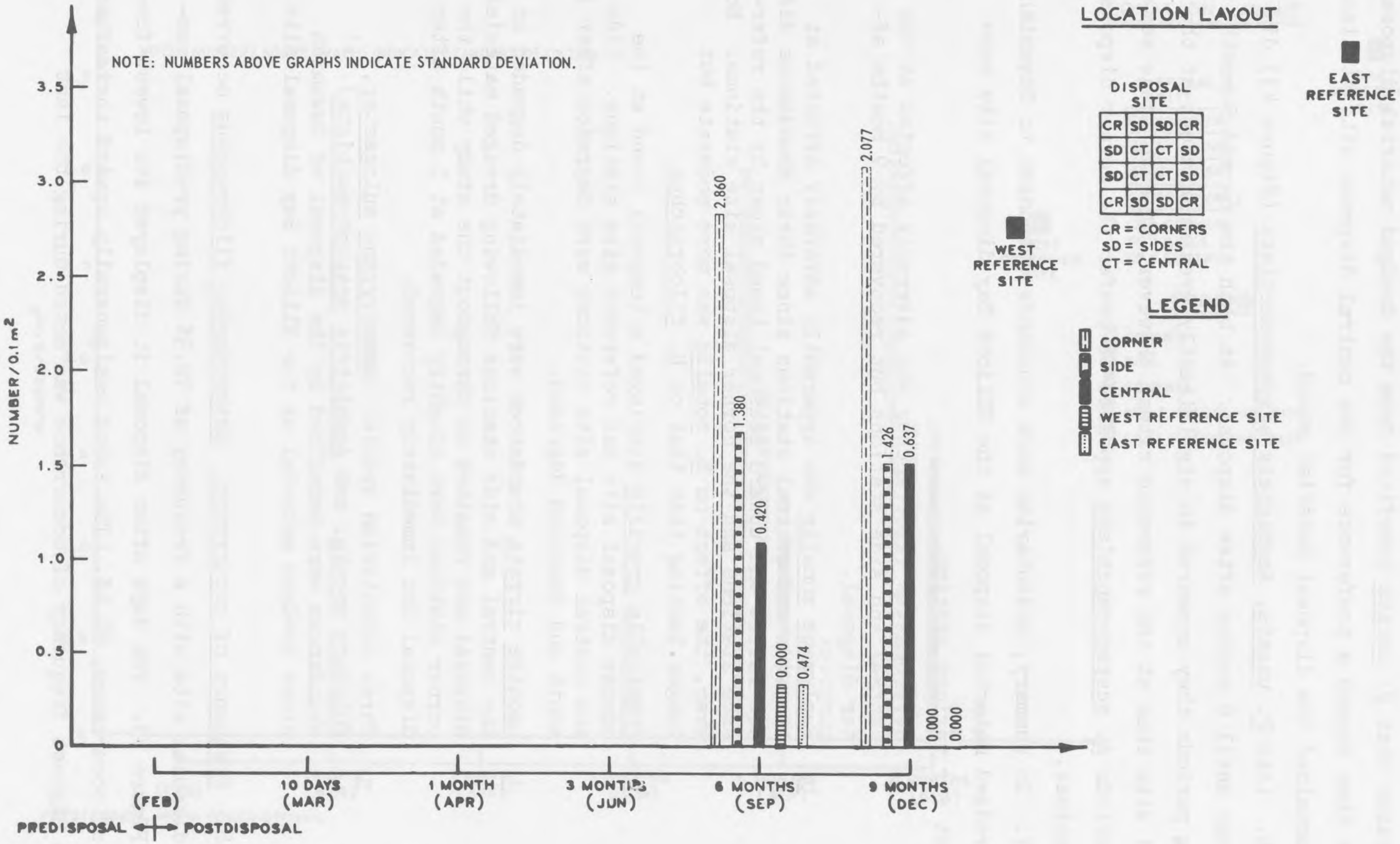

Figure 42. Polydora uncata mean densities for disposal site and east and west reference sites

demonstrates that P. uncata benefited from the dredged material disposal and that they showed a preference for the central disposal site stations, which contained the disposal material mound.

116. Like P. uncata, Amphicteis scaphobranchiata (Figure 43) did not appear until 6 months after disposal. At both the 6- and 9-month sampling periods they appeared in significantly greater numbers at the disposal site than at the reference sites. However, at both these sampling periods A. scaphobranchiata appeared to prefer the corner disposal site stations.

117. In summary, sedentarian worm abundance responses to Duwamish River dredged material disposal at the Elliott Bay disposal site were different for various species.

a. Heteromastus filobranchus was adversely affected at the central and side stations but recovered by 9 months after disposal.

b. Euclymene zonalis was apparently adversely affected at the side and central stations since their abundances did not follow the upward seasonal trend shown by the reference stations and the corner disposal site stations. However, the effect on E. zonalis was more moderate but longer.lasting than that on H. filobranchus.

c. Praxilella gracilis displayed a temporal trend at the corner disposal site and reference site stations. Side and central disposal site stations were degraded after 1 month and remained degraded.

d. Laonice cirrata abundances were immediately degraded at the central and side stations following dredged material disposal and remained so throughout the study while the corner stations were slightly degraded at 1 month after disposal but immediately recovered.

e. Three sedentarian species (Ammotrypane aulogaster, Polydora uncata, and Amphicteis scaphobranchiata) abundances were benefited by the disposal of Duwamish River dredged material at the Elliott Bay disposal site.

118. Frequency of occurrence. Heteromastus filobranchus occurred at the disposal site with a frequency of 72.3% during predisposal sampling, Figure 44. Ten days after disposal it displayed its lowest frequency of occurrence, 60.4%. The trend was generally upward thereafter and its highest frequency of occurrence was noted during the last

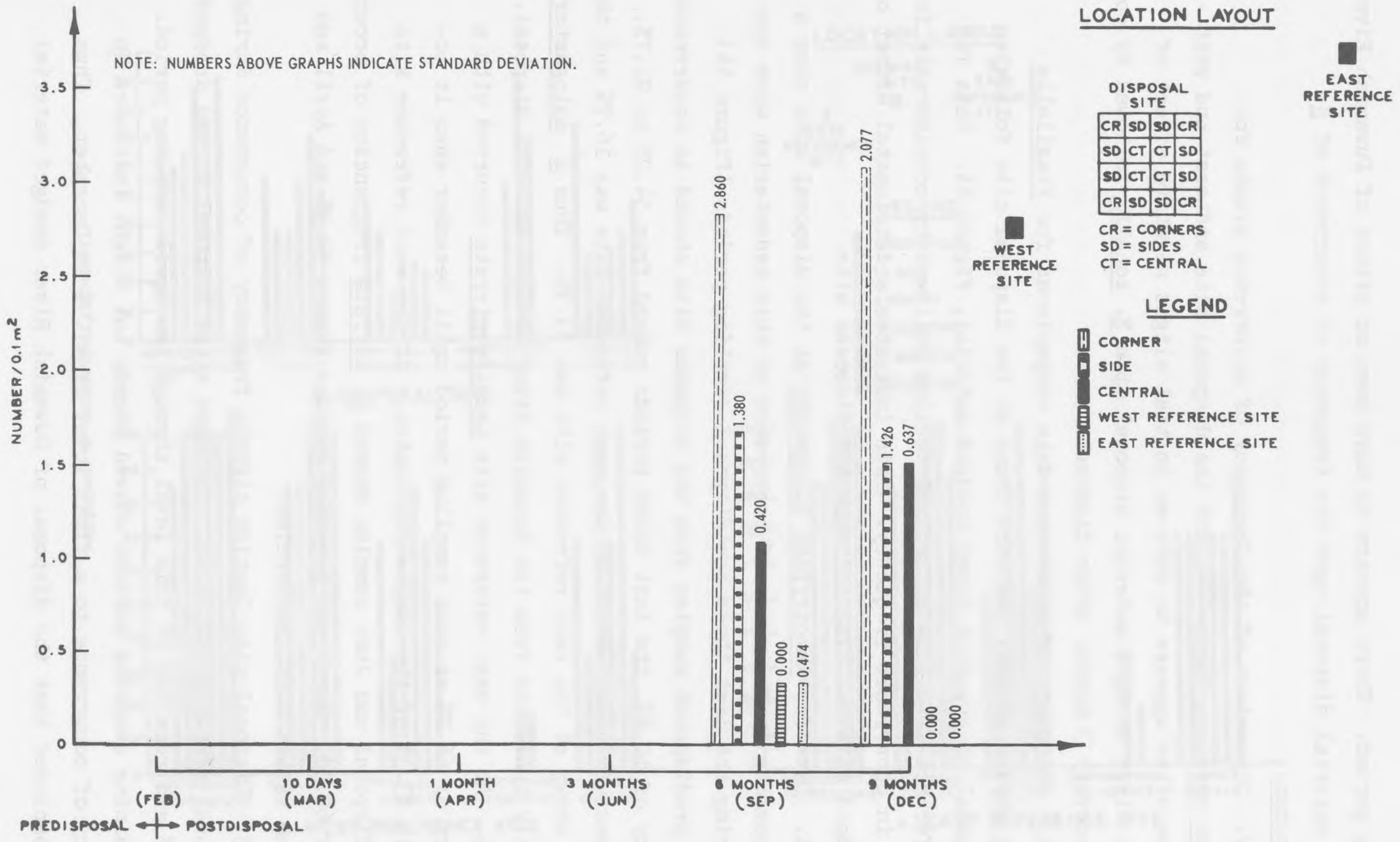

Figure 43. Amphicteis scaphobranchiata mean densities for disposal site and east and west reference sites

sampling period. There appears to have been no effect of Duwamish River dredged material disposal upon the frequency of occurrence of H. filobranchus.

119. Comparison of the frequency of occurrence graphs for Euclymene zonalis, Figure 44, for the disposal site and east and west reference sites appears to show an initial slight negative effect of Duwamish River dredged material disposal upon E. zonalis followed by complete recovery 3 months after disposal.

120. Frequency of occurrence data comparisons for Praxilella gracilis show a general downward trend at the disposal site following the disposal of Duwamish River dredged material, Figure 44. Data for each reference site show an initial decline followed by considerable increases in occurrence frequency. This indicates a detrimental effect of the dredged material disposal upon the disposal site.

121. Data for Ammotrypane aulogaster at the disposal site show a great increase in frequency of occurrence of this sedentarian worm species during the last three postdisposal sampling periods (Figure 44). Whereas predisposal samples form the disposal site showed an occurrence frequency of 10.6%, the last three periods ranged from 54.2% to 91.7%. The highest frequency shown at the west reference site was 16.7% and the highest shown at the east reference site was 33.3%. Thus A. aulogaster apparently benefited from the Duwamish River dredged material disposal.

122. At the east reference site Laonice cirrata occurred with a frequency of 66.7% at each sampling period until December when it occurred in 83.3% of the sample replicates. At the west reference site the predisposal and June samples showed L. cirrata frequencies of occurrence of 66.7%. March and December samples showed 33.3% and April and September showed 100% frequencies.

123. Disposal site Laonice cirrata frequency of occurrence during predisposal sampling was 74.4%. Ten days after disposal it had dropped to 29.2% and remained at this level through the April sampling period. The remaining sampling periods showed steady but slight increases in frequency of occurrence to a final level of 47.9% in December. Thus, it is concluded that the disposal of Duwamish River dredged material

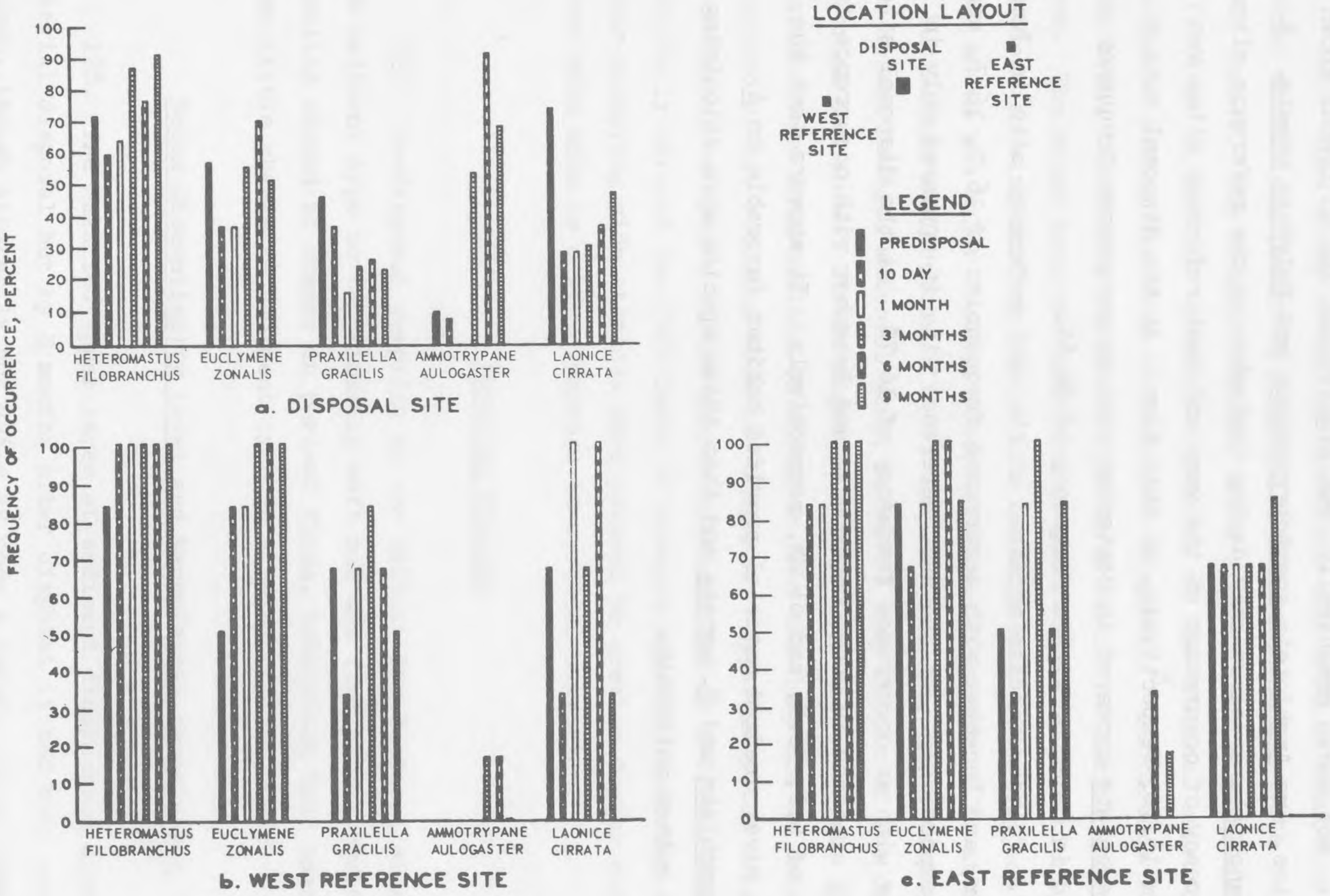

Figure 44. Frequency of occurrence of sedentarian worms at disposal site and east and west reference sites

had a negative effect upon the frequency of occurrence of L. cirrata and this effect lasted through at least 9 months.

124. Not shown graphically, but significant due to trends shown by the species, are Amphicteis scaphobranchiata and Polydora uncata. A. scaphobranchiata appeared only during September at the reference sites. Its frequency of occurrence at the west and east reference sites was 33.3% and 16.7%, respectively, at this time. At the disposal site A. scaphobranchiata appeared in September with an occurrence frequency of 58.3% and in December with a frequency of 64.6%.

125. Polydora uncata appeared at the east reference site in June, September, and December with occurrence frequencies of 16.7, 16.7, and 33.3%, respectively. At the west reference site it appeared only in September with an occurrence frequency of 16.7%. At the disposal site P. uncata appeared in June, September, and December with occurrence frequencies of 6.2, 70.8, and 81.2%, respectively. It appears that the Duwamish River dredged material provided habitat favorable to A. scaphobranchiata and P. uncata and that these species were colonizing the site rather uniformly.

PART IV: DISCUSSION OF RESULTS

126. This study showed an immediate and drastic reduction in macrofaunal densities, primarily limited to the area of immediate bulk material impact. The disposal mound, being greater than 2 m in depth, was sufficient to prevent vertical migration of the original macrofaunal inhabitants within the area of immediate disposal.[8] Macrofauna within this area, therefore, were destroyed as a result of burial and suffocation. The mound area was confined to the four central stations, those stations showing maximum impact upon macrofauna. Other studies have also shown the major dredged material disposal impact to be attributable to burial and suffocation.[1,2,6,7] Corner stations, being farthest from the actual dredged material dump, received very little of the dredged material and showed little negative effect from the disposal. Side stations were intermediate in distance from the dump and an intermediate negative effect resulted from the disposal. Apparently the original macrofaunal occupants of the corner stations had no difficulty migrating vertically through the thin layer of dredged material covering them. Those occupying side stations were covered to greater depths and thus fewer were able to achieve success in vertical migration.

Physical Changes

127. Predisposal sampling at the Elliott Bay disposal site showed the sediment type to be primarily soft mud and fine sand. Postdisposal sampling showed no change in percent fines, indicating that there had been little change in sediment type as a result of disposal.

Redox Discontinuity Level and Macrofaunal Association

128. The oxidized upper layer of sediment disappeared upon dredged material disposal but by 3 months after disposal it had been reestablished, though apparently not quite as deep a layer. Since reworking of mud bottom sediments by benthic macrofauna appears to be a requirement

for establishing and maintaining a deep redox discontinuity level in otherwise highly reduced mud bottoms,[4,5] it is likely that the lower densities of benthic macrofauna produced at the disposal site were unable to produce the necessary reworking to establish the oxidized layer until densities began to increase, approximately 3 months after disposal. The shallower layer of oxidized material appearing at 3 months after disposal and continuing through 9 months appears to correspond with the early colonization stage found by Rhoads, Allen, and Goldhaber at the New Haven dump site.[25] This stage consisted of shallow-burrowing surface-deposit feeders, suspension feeders, and meiofauna. The rapid recruitment shown in September appears similar to Stage II as indicated by the above authors and the overall leveling off of densities shown in December appears similar to their Stage III. However, the leveling off in this case resulted from continued increase in sedentarian worms counterbalanced by continuing decrease in pelecypoda and no increase in depth of the oxidized layer resulting from deep-burrowing infauna was noted. This, along with the facts that disposal site abundances never reached magnitudes as great as those of the reference sites and species composition never returned to predisposal levels, suggests that a longer recolonization period may be required for the deeper, quieter waters of the Elliott Bay site.

Recolonization, Succession Evidence

129. Rhoads[4] states that one of the striking features of soft-bottom organisms is their generally small size compared with invertebrates living on hard sand. The original macrofaunal community was dominated by small deposit-feeding, tube-building, filter-feeding and carnivorous worms, plus a sprinkling of larger miscellaneous species. Early recolonizing species were dominated by deposit-feeding worms. By September and December a goodly number of carnivorous and filter-feeding worms began to make their appearance though the deposit feeders continued to dominate. Pelecypoda continued to decline through December. The sequence of recolonization at the Elliott Bay disposal site appeared to

be progressing in a manner similar to that suggested by Rhoads[4] and Fisher and McCall;[3] however, the time period required for the occurrence of separate successional stages of dominance appears to be considerably longer in the deeper, quieter waters of the Elliott Bay site. From predisposal sampling, it appears that the climax stages indicated by Fisher and McCall will never occur at the Elliott Bay site but that succession will be arrested at the stage they indicated as intermediate, i.e. being dominated by small deposit-feeding and filter-feeding bivalves. Though not confirmed by counts at this time, Harman,* in conversation, conveyed information that a poststudy sampling at the disposal site is showing high numbers of very small Axinopsida serricata, which suggests that the site is progressing toward its predisposal community assemblage.

Diversity, Density Comparisons

130. Richardson, Carey, and Colgate[2] found that stations exposed to direct disposal of dredged material had significantly higher diversity and evenness values and lower macrofaunal density approximately 2 weeks after disposal when compared to unaffected stations. However, this study showed a decrease in diversity indices over the disposal site at 10 days and 1 month after disposal followed by increasing indices that became greater than that at each reference site only at 9 months postdisposal, Figure 22. Inspection of grouped station mean diversities, Figure 23, shows that the impact was primarily confined to the central stations, the disposal mound area.

Early Colonizers and Succession

131. Most previous recent recolonization studies have made much of the role of early colonizers, so-called opportunistic species,

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* Harman, Robert A., co-principal investigator of this project, Shoreline Community College, Seattle, Washington, 1977.

in reestablishing faunal densities and preparing sediments physically, chemically, and biologically for further successional colonization. Fisher and McCall[3] classified such species as small tube-dwelling, deposit-feeding organisms adapted to unstable conditions, being good colonizers, with high reproductive potential, high mortality, and poor competitors. These classifying criteria appear to serve quite well in explaining the rapid recolonization of shallow-water high-current-energy regimes such as the Coos Bay area[6] and the Windmill Point area[7] because sources are readily available for such animals. However, certain of the above criteria would appear to limit the rapid recovery of deeper marine sites since those sites are generally more stable and occupied by fauna that possess longer life spans, lower mortality, and lower reproductive capacity. Therefore, a source of fauna for rapid recolonization of deep marine sites might not be readily available from adjacent habitats. Such conditions would therefore necessarily prolong the time required for recolonization of such sites. An illustration of the case in point is borne out in this study. Two species, _Ammotrypane aulogaster_ and _Polydora uncata_, are apparently very poor competitors. _A. aulogaster_ appeared very infrequently and with extremely low densities prior to dredged material disposal (Figures 41 and 42) whereas by 6 months after disposal both frequency of occurrence and density were quite high, especially over the central stations where competition was low. Three months were required before _A. aulogaster_ began to appear in appreciable quantities after removal of competition. _Polydora uncata_ (Figure 42) showed similar results more dramatically since it did not appear at all at the site until 6 months after disposal when it showed very high density over the central disposal site stations and much lower densities over the side and corner stations. Apparently, due to their scarcity in the surrounding environment and/or less frequent reproductive and slower growth periods, these animals required a considerable time before colonizing.

Notes Concerning Dominant Species Within Groups

132. Gastropod densities were too low to place confidence in

analyses thereof. Within the pelecypod group only Macoma carlottensis showed solid evidence of recovery during the study.

133. Within the sedentarian worms Glycera capitata showed solid evidence of complete recovery of all within-site station groups by 9 months after disposal whereas Lumbrineris luti and Nephtys ferruginea showed complete recovery at side and corner disposal site stations but not at central stations. Onuphis iridescens failed to show recovery at any of the disposal site stations.

134. Heteromastus filobranchus density and biomass showed complete recovery at all station groups of the disposal site by the end of the study and appeared to benefit at all station groups. Euclymene zonalis density and biomass failed to recover at the central stations but benefited at corner stations. Praxilella gracilis density and biomass were degraded and failed to recover at the side and central disposal site stations. Laonice cirrata density and biomass were degraded and failed to recover at the side and central stations. Three sedentarian worm species, Ammotrypane aulogaster, Polydora uncata, and Amphicteis scaphobranchiata, density and biomass benefited from the dredged material disposal.

135. Within the errantian worms, Lumbrineris luti and Nephtys ferruginea densities and biomasses showed benefits at corner stations sufficient to offset losses at central and side stations.

136. Temporal effects were displayed for density, both statistically and graphically, by most dominant species, suggesting that seasonal parameters are operative at the sites studied. Seasonal effects may moderate rates of macrofaunal community recovery and thus may suggest a more or less opportune time for dredged material disposal in order to minimize detrimental effects upon macrofaunal communities of the Elliott Bay and similar disposal sites.

PART V: CONCLUSIONS

137. There were graded effects of dredged material disposal upon benthic macrofauna of the disposal site. These effects correlated with areal distribution of the disposal site sampling stations relative to the disposal material mound. Large decreases in number of species, mean density, biomass, and diversity of benthic macrofauna were observed at the four stations containing the actual disposal mound relative to predisposal and concurrent reference sites values. Diversity recovered in 3 months after disposal but other parameters failed to recover fully, relative to predisposal and concurrent reference sites values, during the study. It is, therefore, concluded that there was a detrimental effect from dredged material disposal upon the central disposal site stations of the Elliott Bay disposal site.

138. Disposal site stations adjacent to the disposal mound received smaller amounts of dredged material. There were large decreases in number of species, mean density, and biomass of the benthic macrofauna relative to predisposal and reference sites values though not to the extent of those at central disposal site stations. These parameters failed to recover relative to predisposal and concurrent reference sites values although they were progressed ahead of the central stations. Diversity displayed a general increase at the side stations throughout the study. It is concluded that there was a detrimental effect from dredged material disposal upon the side stations of the disposal site but that the intensity of this effect was less than that at the central stations.

139. The corner disposal site stations, covered with less than 0.5 m of dredged material, had slight decreases in number of species, mean density, and biomass of benthic macrofauna relative to predisposal and reference sites values. However, these values quickly recovered to predisposal levels and by 6 months postdisposal they exceeded predisposal values. Diversity remained stable for 1 month after disposal then increased during the remainder of the study.

140. Decreases in number of species, mean densities, and biomasses

showed an apparent correlation with depth of burial of benthic macrofauna at the Elliott Bay disposal site. Disposal of dredged material consisting of clay, silt, and fine sand apparently has a large detrimental effect upon benthic macrofauna when burial exceeds 0.5-m depths.

141. The increases in densities 3 months after disposal indicate no long-lasting detrimental chemical effects upon the benthic macrofauna of the Elliott Bay disposal site. It is therefore concluded that the detrimental effects upon the benthic macrofauna resulted from deep burial and suffocation.

142. The postdisposal period of study was too short for most of the species to show increases by reproduction. No species are known to survive deep burial for two weeks and migrate vertically thereafter. Biomass per individual failed to indicate recolonization primarily by developing larvae. The order in which stations showed signs of recovery was corner, side, and central, consecutively. Recovery by developing larvae "only" should have shown simultaneously at all stations since overlying waters can be assumed to contain equal larval numbers and since similar type sediments covered all stations. Recolonizing worms peaked after seasonal peaking at the reference sites. These facts lead to the conclusion that repopulation was by horizontal migration.

143. Increases in number of species, mean density, and biomass at corner disposal site stations above predisposal and concurrent reference sites values lead to the conclusion that benthic macrofauna of peripheral areas around a disposal site may benefit from the disposal of dredged material consisting of clay, silt, and fine sand. The foregoing facts also lead to the conclusion that the effects of the 1976 dredged material disposal upon the benthic macrofauna of the Elliott Bay disposal site were confined to the immediate disposal site area. This conclusion may be generalized for similar dredged materials disposal at low-current-energy sites.

144. Freshly disposed dredged material lacks an oxidized layer underlying the interface with overlying water and is slow to develop such a layer to more than a few millimeters in the absence of low oxygen tolerant, burrowing benthic infauna. If such macrofauna are

not originally present near the disposed material, then recolonization is delayed until these species arrive. Once such species are well established, reworking of the sediment increases the thickness of the oxygenated layer to several centimeters depth. This allows species requiring more oxygen to colonize the area. It is therefore concluded that early colonizers must be present in considerable quantities for rapid recolonization to proceed in a successional manner.

145. Individual species density variation at reference sites and corner disposal site stations indicated seasonally high and low populations. Therefore, rate of recovery of a similar disposal site may depend somewhat upon time of disposal. It is suggested that, since repopulation appears to be via horizontal migration, migration might occur most rapidly during high densities at surrounding areas. Such densities appeared in Puget Sound from June until September for most of the various species. Therefore, it is suggested that to achieve most rapid benthic recolonization, dredged materials might best be disposed immediately preceding and during the early stages of high-density benthic macrofaunal populations. If a 3-month period is required to complete dredging operations, then May, June, and July would appear best for the Puget Sound Area. However, May and June might be best if a 2-month period will suffice.

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Aquatic disposal field investigations, Duwamish Waterway disposal site, Puget Sound, Washington; Appendix G: Benthic community structural changes resulting from dredged material disposal, Elliott Bay disposal site / by C. Rex Bingham. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
103 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-24, Appendix G)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 1A10B.
References: p. 99-103.

1. Aquatic environment. 2. Benthic fauna. 3. Dredged material disposal. 4. Duwamish Waterway. 5. Elliott Bay. 6. Field investigations. 7. Open water disposal. 8. Waste disposal sites. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-24, Appendix G.
TA7.W34 no.D-77-24 Appendix G