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THE ENVIRONMENTAL QUALITY OF SEDIMENTS IN A CONTAINED
DREDGED MATERIAL DISPOSAL FACILITY OF AN INDUSTRIALIZED
SEAPORT: OPEN CLEAN DISPOSAL ALTERNATIVES

By
Raymond W. Alden, Principal Investigator
Robert J. Young, Jr.
G. J. Hall
and
S. S. Jackman

Final Report
For the period ending October 1983

Prepared for the
Department of the Army
Norfolk District, Corps of Engineers
Fort Norfolk, 803 Front Street
Norfolk, Virginia 23510

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Submitted by the
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SEAPORT: OPEN OCEAN DISPOSAL ALTERNATIVES

By

Raymond W. Alden¹, Robert J. Young, Jr.,
G. J. Hall, and S. S. Jackman²

INTRODUCTION

The periodic dredging of navigational channels is vital to the maintenance of seaport systems. Unfortunately, the sediments from urban estuaries may be highly contaminated. Pollutants introduced directly or indirectly into the water of these ecosystems are generally partitioned into, and concentrated in the sediments. Therefore, a problem of major concern to port cities is how potentially toxic dredged materials can be disposed with the least possible ecological damage.

Onshore disposal, or landfill management, is not feasible in many seaport systems. In the urbanized setting of most seaports, land is generally at a premium and, therefore, economically unfeasible for use as a disposal site. Quite often the only open areas in the vicinity of a seaport are wetlands that should not be filled or impounded due to their ecological value. Therefore, a great deal of attention has been focused upon the possibility of open ocean disposal of dredged materials (Pequegnat et al., 1978).

The U. S. Environmental Protection Agency (EPA) and the U. S. Army Corps of Engineers (COE) are responsible for the permitting of ocean disposal operations in the United States. Specific criteria were developed

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(Federal Register, January 11, 1977) with an implementation manual (EPA/COE, 1978) for technical guidelines for evaluating the ecological effects of dredged materials. The guidelines describe a series of lethal bioassay and bioaccumulation experiments which are designed to evaluate the acute toxicity of sediments in order to minimize or prevent severe damage to open ocean ecosystems. Sediments which are shown by these tests to be unacceptable for ocean disposal generally are designated for placement in onshore or contained sites where the contaminants will cause the least possible environmental damage.

Therefore, one management strategy that would minimize the land use problem in seaports would involve open ocean disposal of all sediments for which the criteria are met and the operations are economically feasible, with unacceptable materials being placed in onshore or contained sites. For this strategy to work as a long term solution, sufficient land sites must be available for use as repositories of the unacceptable sediments.

One possible method for obtaining sufficient land for use as repositories for sediments which are unacceptable for ocean disposal would be to use active or abandoned onshore disposal sites. In order to most effectively use these sites over the long term, it may be necessary to evaluate how much of the sediments currently in the sites may be removed for ocean disposal to make room for contaminated sediments. Sediments disposed in contained or onshore sites often lose much of their initial toxicity due to physicochemical "weathering" processes (e.g. evaporation, leaching, diffusion, photochemical oxidation, numerous oxidation and reduction reactions in the sediments and at the sediment-air interface, etc.) and dilution with noncontaminated sediments. Therefore, much of the materials in these sites may be acceptable for ocean disposal. Of course, the feasibility of any rehandl-

ing/ocean disposal operations will depend upon the amount and distribution of acceptable materials in the sites, the projected land requirements for the repositories of unacceptable sediments, as well as economic and engineering practicalities of the project.

The present study represents an assessment of the environmental acceptability for ocean disposal of sediments in the Craney Island Facility in the Port of Hampton Roads Virginia. Although this facility is the largest contained disposal site in the world, it is rapidly approaching its capacity in its current configuration. Therefore, the present study was designed to evaluate and "map" the quality of sediments in Craney Island in the event that the rehandling/ocean disposal management strategy may be desired as a long term solution to the Port's dredged material disposal needs. The study not only involved tests recommended by the EPA/COE Implementation Manual (1978), but the development of sublethal toxicity tests and a multivariate statistical protocol for the evaluation of field and laboratory data as well). The general approach produces environmental information which may be invaluable to dredged material management experts in evaluating the rehandling/ocean disposal option since it provides quantitative maps of contamination patterns of sediment in the Facility. Should this management option prove to be feasible in terms of the engineering and economic considerations, managers may wish to remove only the least contaminated sediments in the Facility. On the other hand, it may be necessary to evaluate the cost-benefit relationship of rehandling sediments which are more contaminated (albeit still "acceptable") but more readily available for excavation.

The present study is a component of an on-going 5-year multidisciplinary investigation designed to determine the potential ecological effects of open ocean disposal of sediments from various areas within the Port. Re-

sults from portions of this program have been reported previously (Alden and Young, 1982; Alden et al., 1982).

METHODS AND MATERIALS

Study Area and Field Methods

The Craney Island Facility is a 1012 hectare confined disposal site which receives sediments from dredge sites from throughout the Port of Hampton Roads, Virginia (Figure 1a). The metropolitan area of Hampton Roads includes the cities of Norfolk, Virginia Beach, Chesapeake, Portsmouth, Newport News, and Hampton and represents one of the most highly industrialized coastal areas on the eastern seaboard of the United States, as well as the largest military port in the world. On the average, 4.1 million m³ of sediment are dredged from the navigation channels of the Port annually by the COE, approximately 60% of which is classified as mud, clay, and silt, taken primarily from the highly industrialized Hampton Roads Harbor/Elizabeth River complex; the remainder consisting of sand, gravel, and shell dredged mainly from channels in the Chesapeake Bay (Pequegnat et al., 1978). Most of the finer sediments from the Port are disposed in Craney Island, while the coarser materials from the access channels in the Bay are taken to Dam Neck, an interim nearshore ocean disposal site, or used for beach nourishment. The current configuration of the Craney Island Facility is expected to be filled to capacity through routine maintenance dredging and disposal operations within the next two decades. In addition, plans are currently being made to deepen the Port from the present 13.8 m depth to 17 m to accommodate new shipping industries utilizing larger, deep-draft vessels. Therefore, the filling of the Craney Island Facility may be greatly accelerated in the near future.

Details of the design, history, sources of dredged materials, and engineering characteristics of the Craney Island Facility may be found in a recent management study report produced by the Waterways Experiment Station of the COE (Palermo et al., 1981). To summarize some of the points pertinent to the present study, the Facility was constructed in the mid-1950's by impounding a shallow portion of the Hampton Roads Harbor with dikes to form a trapezoidal disposal area (Figure 1b). The average fill elevation of the Facility at this time is 4.57 m above mean low water (MLW), while the dikes are 5.49 m above MLW. Two interior dikes have been partially completed, separating the Facility into northern, central and southern subcontainments on the eastern portion and an open compartment on the western sector. Major points of dredged material inflow are indicated in Figure 1b, by the lettering system of Palermo et al., 1981. In general, material deposited directly by pipeline from various projects in the Hampton Roads Harbor and nearby naval installations are placed at point B; direct pump-out of hopper barges from the highly industrialized Southern Branch of the Elizabeth River and more distant naval facilities occurs at E; pump-out from a rehandling basin serving primarily small contractors is located at C; and points F and D are used sporadically for input of materials from Newport News and miscellaneous contracts. By far the greatest flow of dredged materials is from the eastern portion of the facility, with point B receiving 52%, point E receiving 30% and point C receiving 10% of the total volume projected for 1979-1992. The dredged material typically develops a sheet flow condition in moving from the eastern input sites towards the 4 outlet weirs located on the western dike. Typically, the western portion of the Facility is maintained as an area of ponding to maintain adequate water quality of effluent. Thus, coarser materials tend to be found around the periphery of the Facility,

near input points, and along dikes, while finer materials settle out towards the interior and western portions. The quality of sediment received at the facility ranges from clean, coarse material, which is excavated subsequently for commercial fill, to highly contaminated materials from the Southern Branch of the Elizabeth River, which has been shown to be quite toxic to bioassay test animals (Alden and Young, 1982).

In approaching the assessment of sediment quality within the Facility, two a priori hypotheses were tested for each type of analysis: 1) the patterns of sediment quality are related to geographic location; and 2) the patterns of sediment quality are related to geographical characteristics. A stratified random sampling regime was employed to establish sampling sites. The a priori geographical hypothesis was that the northern (N), central (C), southern (S), and western (W) subcontainment areas had different patterns of sediment quality due to different sources of input and differential settling patterns of sediment particle sizes (particularly with respect to the ponding area W). The Facility was divided up in a grid of 100-hectare squares, with peripheral squares being split into sections as required by the trapezoidal shape of the Facility. The grid was divided into the four geographic regions, with the interior boundaries of the W region being roughly defined by the 4.25 m elevation contour (Figure 1b). This region was selected subjectively as representing the ponding area during the initial phases of the study in 1981. The only areas excluded from the grid were regions along the eastern and northern peripheries being used as active burrow pits.

A total of 55 potential collection sites were randomly allocated among the four regions according to their relative areas: region N represented 26%; C was 22%, S was 23%, and W was 29% of the total study area. An appro-

appropriate number of 100-hectare squares from each region were randomly selected employing a random number generator. A grid of thirty-six smaller squares was placed over each of the selected 100-hectare squares and one was selected randomly as the collection area. The exact positions of the sites within the small squares (e.g. center, corners, midpoint of sides) were likewise selected randomly.

The collection sites were located by standard surveying triangulation methods employing base points established along retaining dikes. This method was accurate to within 1 m for all sites. Although station locations were marked with poles where possible, the positions were relocated by the surveyors prior to each major study.

Field collections of sediments were accomplished through the use of a custom-made stainless steel hand corer designed to dig to 2 m in depth. All samples were taken in triplicate. Samples were placed in acid washed 18 L snap-top polyethylene containers and stored at 4°C until tested. Ultimately, a total of 42 collection sites were used during the three-year investigation at Craney Island.

Geological and Chemical Methods

Particle size analysis of the sediments was performed according to the sieve and pipette analysis of Folk (1974). Subsamples of each core were taken for analysis from the surface, 1 m and 2 m depth.

Sediment metals were analyzed by methods adapted from those used by the EPA Region III Laboratory. Briefly, 1-3 g sediment samples were mixed with 15 ml of concentrated, redistilled nitric acid and allowed to stand overnight. The samples were then heated in beakers covered with watch glasses at 110°C for 4 hours, and 5 ml of 30% hydrogen peroxide were added dropwise.

The samples were heated for an additional 1.5 hours. The watch glasses were removed and the digestate allowed to evaporate to 10 ml. The digestate was then diluted with 20 ml of deionized (DI) water, covered and heated to near boiling to dissolve all salts. The sample was filtered through acid washed 0.45 μ glass fiber filter paper and diluted to 100 ml in a volumetric flask.

Metals and nutrients in elutriate water samples were analyzed by methods described by EPA (1979) or by the American Public Health Association (APHA, 1979). Metals were determined by atomic absorption spectrometry (AAS) following MIBK/APDC preconcentration. Concentrations of ammonia and total Kjeldahl nitrogen were determined by micro-Kjeldahl modifications, steam distillation and nesslerization. Nitrates were determined by the Brucine method, while nitrites were analyzed by the sulfanilic acid method. Samples for total phosphate were digested by the persulfate method followed by phosphomolybdate blue color development.

Chlorinated hydrocarbons (CHC) were analyzed by a steam distillation extraction/cleanup method (Veith and Kiwas, 1977) followed by capillary gas chromatography (GC) with an electron capture detector (ECD). Elutriate water samples to be analyzed for polynuclear aromatic hydrocarbons (PNAH's) were filtered through 0.45 μ pre-extracted glass fiber filters and the filtrates and nonfilterable solid fractions were extracted separately. The liquid fractions were extracted with methods described by EPA (1982), while the filter paper and filtered sediments were extracted in a Soxhlet apparatus according to the method of Brown et al. (1980). The extracts from the two fractions were combined, cleaned up by the column chromatography method of Boehm (1980), and analyzed on a capillary gas chromatograph fitted with a Flame Ionization Detector (FID). All chromatographic data were processed on a microprocessor employing internal standards (mirex for CHC's; 1-1-Bina-

phthyl for PNAH's) and libraries of external standards of representative toxins. Selected samples containing compounds identified and quantified by capillary gas chromatography were analyzed by gas chromatograph/mass spectrometry (GC/MS) for confirmation purposes.

The method of analysis for metals in biological tissues were modified from that used by Region III EPA Laboratories. Biological tissue samples of 0.5-g dry weight were placed in micro-Kjeldahl flasks and allowed to stand overnight with 10 ml of concentrated, redistilled nitric acid (HNO_3). The digestates were boiled until approximately 3-5 ml remain. The flasks were cooled, and 3 ml of 30% hydrogen peroxide (H_2O_2) were added to each dropwise. The digestates were boiled to near dryness and, if residues remained, an additional 5 ml of HNO_3 and 3 ml of H_2O_2 were added for additional digestion. Following a cooling period, 5 ml of HNO_3 and 30 ml of DI H_2O were added and the flasks reheated to dissolve any salts. The digestates were then diluted to 100 μl with DI H_2O .

Organic toxins in tissues were analyzed according to methods recommended by EPA (EPA, 1980a for CHC's; EPA 1980b for PNAH's). The cleaned extracts were analyzed on capillary gas chromatograph systems fitted with ECD's or FID's, as appropriate, and data microprocessors. Representative samples were analyzed by GC/MS to confirm the identity of toxins.

Bioassay Methods

The methods employed in the lethal bioassay experiments on the suspended solid and solid fractions of the sediments were essentially those which have been described previously (EPA and COE, 1978; Alden and Young, 1982). There were only two basic modifications to the protocol. Only the 100% suspended solid elutriate concentration was tested in the 96-hour experi-

ments rather than an entire dilution series. Secondly, the mortalities in the 10 day solid phase tests were only recorded at the end of the experiment rather than daily. The grass shrimp Palaemonetes pugio was the test species in the 96-hour tests of the suspended solid fractions. The 10-day solid phase experiments employed P. pugio, the polychaete worm Nereis virens, the hard clam Mercenaria mercenaria, and the blue mussel Mytilus edulis as the test species.

In order to assess potential sublethal effects of exposure of organisms to sediment fractions, respiration and osmoregulation experiments were performed on a subpopulation of shrimp during the 96-hour suspended solids experiments. A custom-made flow-through respiration system (described in detail in an accompanying report) was used to obtain daily oxygen consumption ratings for groups of shrimp exposed to the elutriates pumped from the bioassay test banks. Pertinent data (e.g. upstream and downstream oxygen levels for chambers with and without organisms, flow rates, and final dry weight biomass) were entered into a computer program which produced respiration rates ($\mu\text{g O}_2 \text{g}^{-1} \text{hr}^{-1}$) corrected for the B.O.D. of elutriates moving through the chambers. Respiration chambers and B.O.D. chambers were established for each of the triplicate bioassay tanks for each site and ten shrimp were used in each chamber.

Following the 96-hour period, shrimp surviving exposure to elutriates were transferred to tanks containing artificial seawater at either a higher salinity (35 ppt) or a lower salinity (10 ppt) than the acclimation and test conditions (30 ppt). Following a 24 hour exposure period, the internal osmotic pressure of each shrimp was determined by cutting open the hemocoel in the region of the heart, saturating a small absorbent filter pad with body fluids, and measuring the osmolality on a vapor pressure osmometer.

Following each 10 day solid phase experiment, the surviving test organisms were placed in tanks containing clean artificial seawater at 20°C and 30 ppt, as during the bioassays, for a 24-hour purging period. Composite samples of test species from each of the triplicate tanks were made to provide adequate biomass for toxin analysis: 1-3 g dry weight for PNAH's; and at least 0.5 g for metals. The tissue samples were stored in solvent washed glass or acid washed plastic containers at -20°C until analyzed.

Statistical Analysis

A protocol of multivariate statistical analyses was used for the evaluation of each of the data sets. The preliminary step in each analytical series involved classification and ordination techniques. The classification or cluster analysis computer program used was that of Bloom et al. (1977). The selected method employed logarithmically transferred data, the Bray-Curtis (Czekonowski quantitative) similarity coefficient, and a group average sorting scheme. Dendrograms were produced by display similarities between stations and groups of stations for each of the data sets. Ordination analysis involved a Principal Components Analysis (PCA) (Kim, 1975) of each data set followed by the plotting of the most important PCA scores on graphs or maps.

Both the classification and ordination techniques served two purposes. First, they allowed selection of station groups which were similar in geological characteristics so that the a priori geological hypotheses could be tested for each of the data sets. Secondly, they provided effective methods for data reduction and display of patterns which may have not been apparent through the testing of the two a priori hypotheses. In other words, "hot spots" which are not related to the geological or broad geographic charac-

teristics of the region may be observed.

Once the geological station groups were defined through the evaluation of the ordination and classification results, a test series was conducted to determine whether each group was best considered a unique and separate entity or a subgroup of a larger agglomeration of groups. The evaluation of the "goodness" of the groups consisted of a series of discriminant analyses (Klecka, 1975) in which the site groups were compared as individual entities and as various combinations of agglomerated groups. The results of the discriminant analysis series provided a number of useful "tools" for the evaluation of the "goodness" of the various grouping regimes: the Wilk's Lambda, the multivariate test of the effectiveness of discrimination of the groups; F-values for the pair wise comparison of differences between groups; and a classification evaluation of the effectiveness of the discriminant functions. Most importantly, the Mahalanobis Distance method employed in creating the discriminant functions allows a classification of the similarities between groups based upon the Mahalanobis D^2 distance coefficient. This type of classification, unlike other types of cluster analysis, allows the evaluation of the variance in the data (i.e. replication within entities to be classified) as well as the means.

In testing the two a priori hypotheses, multivariate analysis of variance (MANOVA) (Hull and Nie, 1981) and discriminant analysis techniques were employed. The site groups defined on either a geological or geographic basis were compared by these multivariate techniques to determine whether significant differences were apparent between the groups and which parameters were most responsible for the differences. All data were logarithmically transformed prior to analysis. Once discriminant functions were defined, they were related to the original variables by Pearson's Corre-

lution analyses.

Parametric multivariate statistics such as MANOVA and discriminant analysis are, in part, based upon the assumption of multivariate normality. However, environmental data sets are seldom multivariate normal in distribution. In fact, most statistical packages do not have tests available for the assessment of multivariate normality. Therefore, a method suggested by Green (1979) was adopted to develop conservative test criteria for the analysis of nonnormal data. The method involved the evaluation of statistical methods in the face of violations of assumptions by simulating and testing data which have the undesirable properties of the data from nature, but which have been designed to satisfy the null hypothesis (H_0) concerning differences between groups. A computer simulation program (described in detail elsewhere) was employed to simulate the distribution of the data sets which most greatly deviated from normality. The MANOVA and discriminant models were run on a series of these simulated data sets which have a "worst case" distribution, but a valid H_0 . The nominal critical levels listed in statistical tables can be adjusted according to their relationship with the observed values from the simulations. For example, it may be possible to test at the $\alpha = 0.05$, once this relationship has been established. Rather than simulating each data set, one with a particularly nonnormal distribution was selected for establishing the relationship in order to make the tests conservative (i.e. few Type II errors or "false alarms").

RESULTS

A total of 42 sites were sampled during the three years of study (Figure 1b). The first two years were devoted to an extensive series of lethal and sublethal suspended solids bioassays, elutriate chemistry analyses and

geological investigations. Twenty sites were sampled in 1981 and 22 were studied in 1982. The third year study consisted of the longer term solid phase bioassays and bioaccumulation experiments on sediments from selected stations. Although virtually all of the sites selected for the 1981 study could be sampled, some of those selected for the 1982 and 1983 studies could not be reached because intensive disposal operations created quicksand-like conditions at certain of the interior sites. Alternate sites were selected from the original 55 to replace those which could not be reached.

The results of the evaluation of the statistical methods using simulated nonnormal data sets indicated the appropriate alpha levels to be used as conservative tests of the environmental data sets. The results from a series of 50 MANOVA tests indicated that this test is robust even when non-normal, highly skewed data were being tested. The observed alpha levels are nearly identical to the nominal values (e.g. when testing at a nominal α level of 0.05, the observed value was 0.52). On the other hand, the nominal α values for the multivariable statistical tests produced by the discriminant analysis are quite different from the observed values. To achieve a test at the $\alpha = 0.05$ (observed) level the nominal test alpha value (i.e. the probability level presented in tables of critical value) would have to be 0.002 for both the Wilk's lambda test of overall discrimination (50 tests evaluated) or the Mahalanobis D^2 test of significance between groups (200 tests evaluated). Therefore, the MANOVA test is considered the statistic of choice in interpreting the significance of patterns, with the results from the discriminant analysis being used for confirmation (at the appropriate α level) or data presentation purposes. A more detailed evaluation of these statistical techniques is presented in an accompanying report.

The appendix presents a key to the chemical abbreviations employed in the presentation and discussion of results of the various analyses.

Sediment Geology and Chemistry

Sediments evaluated in each of the suspended solid bioassay experiments were analyzed for geological characteristics. The results of the classification and ordination analyses are presented in Figures 2 and 3. The dendrogram produced by the cluster analysis suggested that there were five distinct groups of sites (Figure 2a). The ordination also indicated that there were 5 groups of sites which were arranged in a diagonal gradient with respect to the two PCA factors. The first factor explained 65% of the variance in the data and represented a direct particle size gradient (i.e. PCA I was positively correlated with coarser low phi sizes and negatively related to fine size classes) (Figure 3). The second PCA factor, explaining 14% of the total variance, was positively correlated with the coarsest sediment grain sizes and, to a lesser extent, to the finest sizes, but negatively related to the finer sands (Figure 3). Thus, the five groups represent a gradient of sediments from finest to coarsest, with the sediments of the fourth group containing a relatively larger proportion of fine sands in comparison to the extreme phi sizes.

The PCA scores for the first factor were plotted upon a schematic map of the Craney Island Facility (Figure 4a). As expected, coarser sediments tended to be found in areas near the input points, near the peripheries, and along the dikes. Fine sediments, although fairly ubiquitous, were found to be consistently abundant in the western ponding area.

In order to determine whether the five site groups were distinct or subsets of larger clusters, various combinations of the groups were tested

by a series of discriminant analyses employing the Mahalanobis D^2 distance measurement. The grouping which produced the greatest percentage correct classification (77%) clustered groups IIa and IIb into a single group. A cluster analysis dendrogram employing the Mahalanobis D^2 measurement as the classification coefficient confirmed the close relationship between groups IIa and IIb (Figure 2b). Since this second series of analyses considered the variance patterns within the data as well as the group means, the four geological groups were used for all further analyses: groups 1 (I), 2 (IIa and IIb), 3 (III), and 4 (IV).

The results of the definitive discriminant analysis are displayed in Figure 5a and Tables I and II. The pattern is basically the same observed for the PCA analysis: a direct particle size gradient was responsible for the greatest amount of separation (DF1); and a lesser trend of sediment distributions concentrated in the finer sands in the third group (Figure 5a). Mean values of each of the particle size categories are presented for each of the geological site groups is presented in Table III.

The a priori geographically defined site groups were also compared with MANOVA and discriminant analyses. Both tests indicated a very highly significant difference between the groups (Table I). Although there was a moderate number of misclassifications, primarily between the western group and the others, there were highly significant differences between all groups (Table II). The group S and group C sites were separated by the fact that the sediments from the southern sites, although not as fine as those found at N or W, were relatively more concentrated in the fine range, while the central group sediments were more heavily loaded in the coarser sizes (DF1 in Figure 5b and Table III). The second function (DF2) separated groups directly by particle size: sediments from W were somewhat finer than from

N, which in turn were finer than S or C (Figure 5b).

During 1981, the sediments were analyzed for eight metals: cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn). The classification analysis indicated that the pattern of metals were very similar (>95% similarity) between all stations except for station 19 and, to a lesser degree, 11 and 24 which had far lower concentrations. The PCA analysis produced a single factor which explained 96% of the variance in the data and was highly and positively correlated with all of the metals ($r > +0.96$). The PCA factor for metals was very highly and negatively correlated with the first PCA factor for sediment grain size ($r = -0.97$), suggesting that the concentrations of most metals were determined by sediment characteristics (i.e. fine sediments contain more metals than coarser materials). The PCA scores for metals plotted on a schematic map of Craney Island (Figure 4b) also indicated that stations 19, 24, and 11 had lower concentrations of metals than the other stations, probably due to their coarse sediments (Figure 4a).

The tests of the a priori geological hypothesis indicated highly significant differences between site groups (Table I, II and IV). As would be expected, the groups were separated by all metals (DF1 in Figure 6a). All metals except manganese and nickel were correlated with the DF2.

The a priori geographical groups also exhibited highly significant differences (Tables I, II and IV). The discriminant analysis produced functions with the same relative classification capacity (78% correct) as did the geological site group functions. Although concentrations of metals were fairly similar between groups (Table IV), specific combinations of metals were responsible for the discrimination between groups (Figure 6b). The C and, to a lesser extent, the W groups were higher in most metals,

while the S and N sediments were separated by the relative content of Cd, Zn, Pb and Mn.

Since the bulk metal content of the sediments was so highly correlated to the sedimentological characteristics, the sediment metals analyses were dropped during the 1982 and 1983 studies so that resources could be used for the initiation of other investigations (see below).

The first two factors produced by PCA analysis of the inorganic elutriate chemistry variables explained nearly 70% of the variance of the data. The first factor (PCA 1) was highly correlated with nitrogen-based compounds (NH_3 , TKN, NO_2 , NO_3) and negatively correlated with total phosphorus (TPQ_4). The highest PCA 1 scores were generally observed at the interior stations (Figure 7a). The higher PCA 2 scores tended to be found towards the northern end of the study area and the lowest values were at the southern end (Figure 7b).

The geological site groups were highly significantly different (Table I and II). The overall classification success rate for the discriminant functions was over 70%, although samples from groups 1, 2, and 3 were misclassified with each other at a low to moderate degree (Table II). As would be expected, metals and nutrients in the elutriates were highest in the groups with fine sediments and lowest in the coarse groups (DF1 in Figure 8a, Table V). The DF2, which separated group 2 from the remaining groups, was positively correlated with Cr and orthophosphates (OPO_4) and negatively related to NO_3 and TKn (Figure 8a).

The geographic site groups were also very highly significantly different with respect to the elutriate chemistry (Tables I, II and V). The overall rate of successful classification by discriminant functions was better (80%) than for the geological groupings. Nutrients and certain metals were

collected with the separation produced by DF1: S < C < N=W (Figure 8b). The western group has the highest levels of certain of these components, which separated it from group N (DF2 in Figure 8b).

During 1981, colateral studies on the sediment quality of the Port indicated that there were very high levels of PNAH's in the sediments of certain channels of the Elizabeth River. Therefore, PNAH analysis was included in the elutriate chemistry study in 1982. The PCA analysis of the PNAH data produced two factors which explained 88% of the variance in the data. The PCA 1 was highly positively correlated with all PNAH's (Figure 7c) and explained 71% of the variance. The PCA 2 was positively correlated with the heaviest compounds and negatively related to the lighter PNAH's (Figure 7d). The highest PCA 1 scores were found at the sites in the middle of the western ponding area and at the single site (36) sampled in the central section of the Facility during 1982 (Figure 7c). These same sites were also those which were associated with the heavier PNAH's, while sites in the S and N regions tended to be characterized by negative PCA 2 scores (Figure 7d).

The geological site groups exhibited very highly significant differences with respect to PNAH's in elutriates (Table I, II and VI). Discriminant analysis produced a classification with a high success rate (97%; Table II). The highest levels of PNAH's tended to be associated with the elutriates from the finest sediments (DF1 in Figure 9a and Table VI). Group 4 also had fairly high levels of certain PNAH's (DF2 in Figure 9a and Table VI). This trend was primarily due to elutriates from site 36 sediments which, despite being coarse, exhibited high levels of PNAH's, possibly due to its proximity to a major input point. Groups 2 and 3 were not significantly different from each other (Table II) and exhibited the lowest levels

of PNAH's in the elutriates (Figure 9a).

The geographic site groups were significantly separated by PNAH's in the elutriates, although the statistical level of differences was considerably less than for the other physical and chemical data sets (Tables I and II). The northern and central groups were not significantly different from each other and all group C samples except those from site 36 were misclassified as group N cases (Table II). Except for this anomalous site, the N and C groups were intermediate in PNAH concentration while group S elutriates were lower and those from group W were higher (Table VI; Figure 9b). The sediments of the ponding area (Group W) produced elutriates with relatively higher levels of most PNAH's in general (DF1) and the heavier compounds in particular (DF2) (Figure 9b).

All elutriates were analyzed for chlorinated hydrocarbons. However, none of the samples contained more than trace levels (parts per trillion) of any given CHC, while the vast majority of elutriates were found to be below detection levels (BDL) for all chlorinated compounds. Therefore, it was impractical to subject this data set to any further statistical analysis.

Biological Effects

Sediments from a total of 42 sites were evaluated by a series of 10 lethal and sublethal experiments during 1981 and 1982. The average 96 hour mortalities for the Palaeomonetes pugio exposed to sediments from each site are presented in Figure 10a, along with indications of the values which were significantly higher (at the $\alpha = 0.05$ an ANOVA/Duncan's Test) than the experimental controls. The mortalities were very low, with even the significantly elevated values seldom rising above 10% and never above 20%.

The average values for the five daily respiration rate ($\mu\text{g O}_2 \text{ g}^{-1}\text{hr}^{-1}$)

readings for each site are presented in Figure 10b. Time effects were evaluated with ANCOVA models. The sites with sediments producing decreasing respiration rates with time are indicated on Figure 10b, along with those which produced depressed or elevated metabolism in the shrimp throughout the experiments. The respiration rates of the control populations varied over the course of the two year study, but the depressed values were, at times, nearly 40% below control levels (Figure 11a). Most of the sediments producing a significant depression in respiration were found in the western ponding area.

The internal osmolality of shrimp exposed to low salinities following exposure to sediments are presented in Figure 10c, while those exposed to high salinities are presented in Figure 10d. Significant differences in the low salinity experiments were few and scattered throughout the Facility, while those in the high salinity experiments were more numerous and tended to be found in the western and northern areas (Figure 10c and 10d). Nonetheless, the experimental values seldom deviated from controls by more than 10-15% and none approached the osmolalities of the stressing media (ca. 300 mOsmKg⁻¹ and 1060 mOsmkg⁻¹), so none of the test organisms appeared to lose osmoregulation capacities completely (Figure 11b).

The PCA scores for biological effects are presented in Figure 12a and 12b. The PCA 1 factor explained 45% of the variance and was positively loaded on respiration rates and negatively related to the internal osmolality of shrimp exposed to high salinities (Figure 12a). Most of the low PCA 1 scores, which were associated with more depressed respiration and evaluated osmolality readings, were found in the southern region and across the interior of the Facility. The PCA 2 factor explained 14% of the variance and were directly correlated with the rather low levels of mortalities

observed during the experiments (Figure 12b). Highest PCA 2 scores were found in the eastern sites and scattered through the middle portion of the ponding area.

Since the sublethal experiments tested various populations during the two years of study, the respiration rates and osmolalities were standardized by subtracting values observed for control organisms for the same period. These standardized values were then subjected to the multivariate statistical analyses. Mortalities were not standardized in this manner because most control mortalities were very close to zero throughout the study (Figure 10a).

The geological site groups were not significantly different with respect to biological effects in the suspended solids experiments (Tables I, II and VII). In fact, the univariate tests produced by the MANOVA and discriminant programs indicated that the respiration rate on Day 5 was the only parameter to exhibit a significant difference with respect to the geological groups: the elutriates from the finest sediments produced the lowest respiration rates (Table VII).

The geographical site groups were significantly different with respect to the biological effects produced by the sediment elutriates (Tables I, II, and VII). Site groups W and S were separated by DF1 which was positively correlated with respiration rates of the shrimp on days 2-4 of the experiments and negatively correlated with the osmolality of shrimp exposed to low salinities (Figure 13). On the other hand, sites N and C were separated by DF2 which was directly related to osmolality of shrimp exposed to high salinities, respiration on the first and fifth days of the experiment, and mortality. Although the differences between the site groups were significant, the classification success rate was rather poor (54%). Therefore,

the geographic model does not completely describe the subtle patterns of biological effects of elutriates.

During 1983, a series of solid phase bioassays were conducted on Palaemonetes pugio, Nereis virens, Mercenaria mercenaria and Mytilus edulis. Due to heavy disposal activities, certain of the 23 sites selected for the solid phase bioassays had to be relocated away from the interior region which was impossible to reach. The mortalities observed during the experiments were quite low. In fact, the worms, N. virens and the clams, M. mercenaria exhibited no mortalities during the experiments. Mortalities of the grass shrimp, P. pugio were less than 25% and none of the experimental conditions produced values which were significantly above control levels (Figure 14a). The blue mussel (M. edulis) mortalities were within the same range, but sediments from several of the sites produced values which were significantly different from the controls (Figure 14b). Due to the negligible levels of mortalities observed in the test species, the multivariate tests were not considered to be practical for this data set.

Following the solid phase bioassays, the four test species were allowed to purge in clean seawater for 24 hours and the tissues were analyzed for heavy metals and PNAH's. The levels of metals found in the tissues of the test species were quite low. Few of the sites contained sediments which produced higher contained sediments which produced higher body burdens than those found in the control organisms (Table VIII).

A classification analysis indicated that all sites were quite similar (greater than 95% similarity) in body burden patterns, probably due to the lack of statistically significant bioaccumulation for most of the species/site/metal combinations. However, subtle but significant trends could be detected with the other multivariate analyses which emphasize differences.

A PCA analysis was conducted for each species. The first two PCA factors for the shrimp tissue metals explained 36% and 22% of the variance in the data set, respectively. The PCA 1 was positively loaded on Cu, Zn, Pb, and Cd and negatively loaded on Ni, while PCA 2 scores were positively correlated with Mn, Fe, and Ni and negatively related to Cd (Figure 15a). The PCA 2 scores exhibited a more variable pattern (Figure 15b).

The factor produced by the PCA analysis of the nereid worms data produced only one significant factor which explained 68% of the variance. The PCA 1 scores were highly correlated with Mn, Fe, Zn, Cu and Ni and negatively related to Cd and Pb. The PCA 1 scores for the worms exhibited a nearly identical pattern as the PCA 1 scores for the shrimp positive values for sediments from eastern sites and negative values at western sites (Figure 15c).

The PCA 1 and PCA 2 factors for clams explained 35% and 19% of the variance. The PCA 1 scores were positively correlated with all the metals (Cd, Zn, Pb, Mn, Cu, Ni, Fe) (Figure 15d). These scores were found in a pattern similar to those observed for the PCA 1 scores for both P. pugio and N. virens. The PCA 2 scores were positively associated with Fe and Mn and negatively related to Cu and Pb (Figure 15c). The positive PCA 2 values tended to be found associated with the interior sites of the ponding area while negative values were observed for the eastern and southern sites.

The PCA 1 factor for mussels explained 30% of the variance and was positively loaded on Pb, Fe, Mn, and Cu and negatively loaded on Cd (Figure 15f). Like the PCA 1 scores for the other species, the positive values were associated with the eastern sites, while negative scores were found for western sites. The PCA 2 scores for mussels explained 28% of the variance

and was positively related to Ni, Zn, and Cd and negatively correlated with Cu (Figure 15g). The negative PCA 2 scores were found in the southern area and along the periphery of the western region.

The geological site groups were significantly discriminated with respect to body burdens of metals in the test species (Tables I, II and IX). The classification phase of the discriminant analysis indicated that the discriminant functions produced a very high (90%) success rate. The DF1 separated the first three geological site groups and was positively correlated with all metals in worms and clams and all but Zn in mussels (Figure 16a). The metal content of the organisms appeared to increase when exposed to coarser sediments. The DF2 separated the coarsest group 4 from the other three and was negatively correlated with the same species-metals combinations in a different order of consequence.

The geographic site groups were also shown to be highly significantly different with respect to body burdens of metals in the test species (Tables I, II and IX). The discriminant analysis produced functions which significantly separated the groups with a high classification success rate (85% correct overall) (Table II). The pattern of separation appeared to be similar to that produced for the biological effects data: Group W was primarily discriminated from Group S by DF1; and Groups C and N were separated by DF2 (Figure 16b). The DF1 scores were positively correlated with most of the metals in the test species, particularly the two bivalves, while being negatively related to cadmium in the worms and the blue mussels and lead in the worms (Figure 16b). The DF2 scores were positively correlated with certain species-metal combinations: most of the metals in P. pugio; lead in N. virens; copper in M. mercenaria; and nickel in M. edulis. They were

negatively related only to iron in the clams. Thus, except for the few species-metal combinations which were negatively related to the discriminant scores, either Group S or Group N exhibited the highest values of most metals in the biological tissues (Table IX).

The concentrations of PNAH's in tissues were compared to those observed in control populations (Table X). In comparison to the other species, the blue mussel tissues had much higher levels of most PNAH's for a larger number of collection sites (Table X). Fluoranthene, pyrene and benz(b)fluoranthene were the PNAH's which were most consistently and, generally, most abundantly found among the test species (Table X) both in terms of the tissue concentrations for "hop spot" sites as well as with respect to site group averages (Table XI). The shrimp, worms and clams all exhibited the same pattern; benz(b)fluoranthene values were the greatest, followed by pyrene levels which were only slightly higher than those observed for fluoranthene. Blue mussel tissues contained the same compounds, but in a different order of predominance: fluoranthene and pyrene were greatest and roughly equal in concentration, followed by benz(b)fluoranthene (Tables X and XI). Also shown to be significant in various mussel samples were benz(a)pyrene, benzanthracene, fluorene, and chrysene (Tables X and XI).

The PCA analysis of the shrimp PNAH body burden data produced two factors which explained 61% of the variance. The PCA 1 scores, which explained 41% of the variance, were highly and directly correlated with total PNAH's, carcinogenic PNAH's, pyrogenic PNAH's, and benz(b)fluoranthene (Figure 17a). Of course, the first three composite categories are mainly composed of the benz(b)fluoranthene which dominates the PNAH's in shrimp tissues. The PCA 2 scores were highly and positively loaded on fluoranthene and pyrene, and

negatively, but not as greatly, related to benz(a)pyrene and indenopyrene (Figure 17b). The positive PCA 1 scores were found to be associated with sites at the eastern end of the Facility (Figure 17a). The positive PCA 2 scores were scattered at a few sites throughout the Facility (Figure 17b).

The PCA analysis for PNAH's in nereid worms produced two factors which explained 73% of the total variance (46% for PCA 1, 27% for PCA 2). The worm PCA 1 scores, like those for the shrimp were highly loaded on total PNAH's, carcinogenic PNAH's, pyrogenic PNAH's and, most importantly, benz(b)fluoranthene (Figure 17c). The PCA 2 scores were positively correlated with fluoranthene, pyrene, and, to a lesser extent, naphthalene (Figure 17d). The positive PCA 1 scores were primarily found in the interior of the ponding area, while the positive PCA 2 scores were somewhat more scattered in distribution (Figure 17c, d).

The first two PCA factors for the clams PNAH concentrations explained 36% and 25% of the variance, respectively. The PCA 1 scores were positively correlated with total PNAH's, pyrogenic PNAH's, fluoranthene, pyrene, chrysene and indenopyrene (Figure 17e). The PCA 2 scores were positively loaded by benz(b)fluoranthene, carcinogenic PNAH's and pyrogenic PNAH's, and were somewhat negatively correlated with pyrene, chrysene, and fluoranthene (Figure 17f). The positive PCA 1 scores were found primarily towards the interior of the ponding area (Figure 17e). The positive PCA 2 scores were found to be associated with sites toward the northern end of the ponding area, as well as the eastern regions of the northern and central subcontainment area (Figure 17f).

The first two PCA factors for blue mussels explained 43% and 22% of the total variance, respectively. The PCA 1 scores were positively correlated with total PNAH's, the pyrogenic PNAH's, fluoranthene, pyrene, chrysesne and

benz(b)fluoranthene (Figure 17g). The PCA 2 scores were highly loaded on carcinogenic PNAH's, benz(a)pyrene and benzo(a)anthracene and were related negatively to pyrene and fluoranthene (Figure 17h). The positive PCA 1 scores appeared to be found for sites mainly located in the southern containment region, while positive PCA 2 scores were scattered throughout the Facility (Figure 17g, h).

The geological site groups were marginally different with respect to PNAH's in tissues (Tables I, II, and XI). The overall success rate for the classification of cases grouped by the discriminant functions was quite high (86% correct) (Table II). The DF1 separated groups 1-3 (Figure 18a), although groups 2 and 3 were not significantly different (Table II). The DF1 scores were positively correlated with various carcinogenic PNAH's in mussels and shrimp, and negatively related to pyrogenic compounds in the clams and the worms (Figure 18a). Group 4 was separated from the rest of the groups by DF2 which was positively correlated with pyrogenic compounds, particularly fluoranthene, in various species and negatively correlated to PNAH's in shrimp (Figure 18a).

The differences between PNAH tissue levels for the geographic site groups were highly significant (Tables I, II and XI). The discriminant analysis produced a high classification success rate (82% correct), although groups N and C were not significantly separated (Table II). The DF1 scores were positively correlated with PNAH's in mussels and shrimp and was negatively related to concentrations of total PNAH's, pyrogenic PNAH's and carcinogenic PNAH's in the clams and the worms (Figure 18b). The DF2 scores were positively related to pyrene and fluoranthene in all species (Figure 18b). The DF2 scores were negatively related to benz(a)pyrene in shrimp and mussels (Figure 18b). Unlike the metals in tissues, the western group had

the highest levels of most PNAH's except for those found in the mussels which were at the highest levels in Group S sites. On the other hand, test species exposed to sediments from Groups C and N only had higher levels of the PNAH benz(a)pyrene.

DISCUSSION

Despite numerous studies concerning the environmental effects of dredged materials, little work has been done on the sediment quality of confined disposal sites. Virtually all studies of confined disposal sites have concentrated upon the water quality of effluents (e.g. Krizak *et al.*, 1976; Barnard, 1976) or on the engineering characteristics of the sediments (e.g. Lamar and Laier, 1976; ASEC, 1977; Montgomery *et al.*, 1976; Nekker and d'Angremond, 1976; and Smith, 1976). The only type of study which involved an evaluation of the quality of the sediments concerned a laboratory simulation of the effects of contaminated dredged materials on heavy metal uptake by various wetland plants. Nonetheless, many of the techniques which have proven useful for the assessment of ocean disposal of dredged materials from channels (EPA/COE, 1978), coupled with multivariate environmental monitoring strategies, can be applied effectively to the evaluation of sediment quality in confined disposal sites.

The patterns of particle size distribution in Craney Island were basically those which would be anticipated from a knowledge of the source material and the operation of the Facility. Most of the sediments are quite fine, as would be expected of materials which would settle in the navigation channels of the region between maintenance dredging operations (Palermo *et al.*, 1981). The finest silt/clay materials were found in the ponding area of the western section of the Facility, which was most remotely located from the

heavily used input points along the eastern dike (Figure 16b). Conversely, the coarser materials were either found in closest proximity to the inputs, or along the peripheral or interior dikes. As would be expected, these patterns are from an east to west movement of dredged materials which deposits coarser materials near inputs and maintains fine silt/clays in suspension until the slow flow and longer residence time in the ponding area allows deposition. Coarse materials deposited in the vicinity of the dike could be construction materials slumped from the dikes themselves, or may be associated with the hydrodynamic regime set up by the dike structures.

It is widely recognized that the results of bulk chemical analyses are not very fruitful for environmental assessment studies (see, for example, Brennan *et al.*, 1976; Lee *et al.*, 1977; Pequegnat and Presley, 1978; Pequegnat *et al.*, 1978; Allen and Hardy, 1980; and Engler, 1980). However, comparisons of the metals in sediment from the present study with older sediment criteria are useful for descriptive purposes. The metal content of sediments from Craney Island were within the ranges considered to be "moderately polluted" for lead (40-60 ug/g), nickel (20-50 ug/g), chromium (25-75 ug/g), and copper (25-50 ug/g); and "heavily polluted" for zinc (>200 ug/g), iron (> 25,000 ug/g) and manganese (> 1,500 ug/g) when classified according to recent bulk sediment criteria (Engler, 1980). However, most of the observed values (Table IV) were considerably lower than those found for sediments in the navigational channels of the industrialized regions of the Hampton Roads Harbor (Johnson and Villa, 1976) and, more recently, (J. H. Rule, unpublished data): cadmium (1.5-3.5 ug/g), chromium (56-72 ug/g), copper (60-236 ug/g), nickel (35-67 ug/g), lead (65-228 ug/g), and zinc (260-550 ug/g). The only exceptions were iron and manganese (38,250-39,500

ug/g and 320-685 ug/g, respectively in Hampton Roads channel sediments). The fact that these two metals were higher than the "parent" dredged materials may have geochemical significance, since it is known that under conditions found in anaerobic sediments, iron and manganese form sulfides which are quite soluble relative to the other heavy metals (Morton, 1977). These soluble metal sulfides may be mobilized through interstitial water of the sediment column until they reach the sediment-water or sediment-air interface where they may be oxidized into insoluble hydrated oxides. Therefore, iron and manganese in the sediments of Craney Island may tend to be deposited and concentrated in the surface sediments through this mobilization/precipitation process. Since the present study only sampled the top two meters of sediment, this process may explain why concentrations of iron and manganese were quite high.

The very strong inverse relationship between sediment particle size and bulk metal content was also anticipated. The finer sediments have a much greater surface area than coarse particles for adsorption of metals. In addition, the high relative organic content of most silt-clays can complex metals directly or can influence their retention as insoluble sulfides through the process of sulfate reduction in the associated anaerobic conditions. A third possibility of the strong relationship is that fine precipitates of hydrated iron and manganese oxides may be formed when anaerobic dredged materials are aerated upon hydraulic input into the Facility. These metal oxides can scavenge other metals (see review by Morton, 1977), which would then be deposited in locations where other fine materials accumulate.

Since bulk chemical analysis of sediments has proven to be inadequate in the potential environmental effects of ocean disposal, the "elutriate test" was developed (Federal Register 38(198), 1973; O'Connor, 1976; Lee *et*

al., 1976; EPA/COE, 1978). Elutriate chemistry has been shown to be an environmentally conservative predictor of releases in the field, as well as, a potentially useful indicator of long-term release of certain contaminants from resettled dredged materials (see review by Engler, 1980). However, most studies have indicated that the majority of contaminants are not released to a significant degree in dredged material elutriates (see reviews by Alden and Hardy, 1980; and Kester et al., 1983).

In the present study, the elutriates taken from the test tanks at the beginning of the suspended solids toxicity tests were not filtered through a 0.45 micron filter prior to analysis, as is traditionally done. Therefore, it is not possible to compare the results directly with those from previous liquid phase chemistry studies. A large portion of the contaminant load in the unfiltered elutriates would be expected to be associated with the fine sediments remaining in suspension following the settling period (see Allen and Hardy, 1980). Therefore, the values from the present study would be expected to be higher than those reported for filtered samples. Nonetheless, most of the contaminants analyzed in the unfiltered elutriates were found to be only slightly higher than water quality standards for the protection of marine life (EPA, 1973, 1976). Only iron, manganese, zinc and ammonia were more than an order of magnitude greater than their respective criteria. Lead levels were 5-6X the reference level (0.05 mg/l). Since dilution occurs rapidly under the conditions of open ocean disposal, it has been recommended that elutriate test results be evaluated against water quality criteria only in the context of the dilution which would occur within the initial mixing zone (EPA/COE, 1978; Engler, 1980). Even with a very conservative dilution factor which would produce 0.06% of the original concentration of disposal materials following the initial mixing period at open

ocean disposal sites such as the Norfolk Site (Alden and Young, 1982), only iron, manganese, and a few of the zinc values would remain above the criteria after four hours. Since both iron and manganese are quite low in toxicity and they were quite likely bound to, or incorporated in (e.g. as fine hydrated oxide precipitates), the suspended materials in the elutriates, this trend may be of little ecological significance to the ecosystems surrounding an ocean disposal site. This observation concerning acute effects of these metals in the undiluted elutriates is confirmed by the low mortality observed in the suspended solids bioassay.

It is interesting to note that the contaminants found to be in the highest relative concentrations in the elutriates of the present study were very similar to those found in previous studies. Allen and Hardy (1980) reviewed the literature and reported that numerous studies have found that most potential toxins except iron, manganese, and ammonia are not released from dredged materials under conditions simulating open ocean conditions (e.g. moderate to high oxygen levels, high pH, high salinities, etc.). A more recent review (Kester *et al.*, 1983) came to similar conclusions. Results from studies by Engler (1979) on a series of sites indicated that only manganese, iron, zinc, and to a lesser extent, lead were found to be higher in elutriates than in the background site water. These patterns parallel closely those of the present study, although Engler's concentrations were generally lower, presumably because the elutriates were filtered. It may be possible to generalize from these observations that metals other than manganese and iron and, to a lesser degree zinc and lead, are not released from dredged materials under conditions simulating ocean disposal and that the levels of these four metals probably would not be of great ecological significance to surrounding ecosystems.

The site group patterns of elutriate chemistry were not surprising. The elutriates of sediments from the western ponding area had the highest levels of most nutrients and metals, followed by those from the northern, central and southern areas. This pattern basically parallels the relative distribution of fine sediments, so the contribution of suspended solids to the elutriate chemistry is strongly suggested. However, the geographic site group model produced a slightly "better" discrimination, so other factors such as the source of dredged materials characteristically introduced at each input point may influence the pattern to some degree (e.g. the materials placed in the southern subcontainment areas from the rehandling basin may contain less nutrients and metals available for release than those from other regions, etc.).

In reviewing the literature for previous elutriate chemistry studies of organic compounds, it becomes obvious that little work has been done on organic chemicals other than chlorinated hydrocarbons (e.g. PCB's and pesticides) or "generic" organics (e.g. "grease and oil," and "total hydrocarbons") (Fulk *et al.*, 1975; DiSalvo *et al.*, 1977; Hirsch *et al.*, 1978; Engler, 1980). No studies could be found which specifically examined the concentrations of PNAH's in elutriates.

The levels of PNAH's in the elutriates of the present study were generally quite low (mean total PNAH's values below 250 ng/l). Most of the lower molecular weight PNAH's (< 5-rings) were considerably below saturation levels reported by EPA (1980). This trend is not unexpected since May (1980) has demonstrated that PNAH's will preferentially partition from water into sediments when mixed. It is quite likely that the PNAH's which were found in the elutriates were associated with the suspended solids. In fact, most of the heavier PNAH's (> 5-rings) which have characteristic low

solubilities were found at levels exceeding saturation levels (EPA, 1980; May, 1980), strongly indicating that most must be sediment bound.

No water quality has been established for PNAH's, primarily due to the lack of adequate information concerning environmental effects (EPA, 1980). However, the levels found in the elutriates were lower than the lowest level reported by EPA (1980) as being toxic to saltwater aquatic life (300 ug/l). When one takes into account the fact that this reference level represents dissolved PNAH's rather than those bound up in the suspended solids phase (i.e. in a form that is potentially more biologically active than that tested in the present study), the potential acute toxicity of PNAH's in the unfiltered elutriates of the present study would appear to be quite low.

The levels of PNAH's in the elutriates appeared to be related directly to the distribution of the fine sediments. The fine particles and the associated high organic content of the silt/clay fraction would be expected to be characterized with much larger partition coefficients for PNAH's than would coarser sediment (Karickhoff *et al.*, 1979), so this pattern is not surprising. Perhaps equally important is the fact that the suspended solid load for elutriates produced from fine sediments would be much higher than that for coarser sediments, so sediment bound PNAH's remaining in the water column would be expected to be much higher. Therefore, it is difficult to determine whether elutriate PNAH levels were higher for fine sediments because of a greater absolute amount at sites within the Facility with a high silt/clay content (i.e. PNAH partitioning, transport and deposition of processes were associated with fine sediments) or because the heavy suspended solid load of the fines maintained more of the PNAH's in the water column after the settling period, or both.

The geographic site group model indicated that elutriates from the

western region sediments had the greatest PNAH load, those from the southern group had the least, and those from the northern and control areas were intermediate. This distribution could be due to the geological distribution among the subcontainment areas. However, one of the few sites with coarser sediments (site 36) exhibited high PNAH levels in the elutriates suggesting that geographic factors (e.g. proximity to the input point receiving PNAH contaminated dredged materials from the Southern Branch of the Elizabeth River) may have some influence on the overall load.

in general, toxicity tests with dredged materials have shown that the acute toxicity appears to be the exception rather than the rule (see, for instance, review by Engler, 1979). This trend appears to hold true even when sediments have been selected specifically (see, for example, Shuba et al., 1978). The results of the present study follow this generalized trend. The mortalities of Palaemonetes pugio exposed to suspended solid elutriates from sites throughout Craney Island produced only low mortalities, despite the fact that sediments from some of the source areas of the dredged materials have been shown to be quite toxic under identical conditions (Alden and Young, 1982). The longer term solid phase experiments yielded similar results: little or no mortalities in test species selected to represent a variety of ecological lifestyles. It is apparent that the dilution of contaminated with noncontaminated sediments and/or the various processes of biological and chemical "weathering" have rendered the sediments of Craney Island fairly nontoxic.

The potential sublethal effects of dredged material fractions on test organisms have not been well studied. DeCoursey and Vernberg (1975) examined the effects of water taken from active dredge sites and onshore disposal areas in Charleston Harbor, South Carolina on the physiology of larval zoo-

plankton. These investigators reported that the respiratory rates of the cladoceran Daphnia pulex and the larvae of the polychaete Polydora sp. were significantly depressed for sites which eventually produced significant lethal effects in long-term studies of up to 20 day's duration. Swimming activities were also observed to be depressed in Daphnia, larval Polydora, and larval P. pugio which were exposed to water taken from the vicinity of the various dredge and disposal sites.

In another dredge spoil assessment study, Shuba et al. (1978) reported that elutriates of contaminated sediments significantly retarded growth of P. pugio larvae. Prior to the start of the present study in 1980, these two investigations appear to be the only ones in which sublethal effects of dredge spoils fractions have been examined. However, other investigators have expressed concern over sublethal effects of dredge material disposal (Pequegnat et al., 1978).

Although grass shrimp exposed to the test sediments in the present study exhibited little mortality, some of the experimental conditions did produce significant sublethal effects. Suspended solid elutriates from certain sites produced depressed respiration, and, to a lesser extent, decreased osmoregulation capacity, particularly at the higher salinity regime. These effects did not appear to be related to the geological characteristics of the sediments. The biological effects were related to geographic location, but there were numerous misclassifications respiration and osmoregulation (Figures 10b and 10d) suggests that, although somewhat sporadic, the effects seem to be found for sites stretching across the western portions of all subcontainment areas. The cause of this trend is unknown since it does not parallel closely those found for the physicochemical parameters. The poor relationship between sublethal effects and physicochemical character-

istics of the sediments found in this study perhaps reflects the overall lack of significant correlations between sediment contaminants and acute toxicity found for previous studies (Hirsch et al., 1978). On the other hand, the cause for the sublethal effects may be due to combinations of contaminants or factors not measured during the study. Since the stations containing sediments producing the greatest respiratory depression and decline in hyporegulatory capacity generally were those that were flooded during the study (i.e. those in the western ponding area and near input points) (Figures 10b and 10d), the factor(s) creating the sublethal effects may be associated with waterlogged, anaerobic sediments. These factors may be dissipated when the sediments begin to dry out in the nonflooded regions.

The ecological significance of the sublethal effects observed is difficult to determine. Respiration rates were depressed to 60% of control values but effects of this magnitude were only observed in less than 10% of the experiments (Figure 11a). In fact, significant respiratory effects were seen in less than 25% of the tests. Although significant hyporegulatory effects were found for more of the experimental conditions, the magnitude of the deviations from control levels were far less (Figure 11c). However, since the patterns for both effects overlap geographically to a considerable degree, common causative agent(s) may be implied. The observations and speculations reported by Katz (1979) concerning the mechanisms of nonspecific damage of membrane function by many toxins may be true in the present study: test organisms may be sublethally affected by contaminants which disrupt membrane permeability, and therefore, impair osmotic respiratory and ion exchange capacities of the gills. Agents such as ammonia (Katz, 1979), heavy metals (Thurberg et al., 1973; Katz, 1979), petrohydrocarbons (Ander

son, 1979) and chlorinated hydrocarbons (Rao et al., 1979) all have been implicated in the production of these types of sublethal effects. However, the effects may be reversible if the contaminants are removed or diluted (Katz, 1979). Regardless of the causative agents in the present study, the potential reversibility of the effects may mean that the rapid dilution associated with ocean disposal conditions would prevent similar effects from ever occurring in the field. Nonetheless, the observation of the sublethal responses may be useful as one tool in the evaluation of the relative sediment quality patterns within the Facility.

Basic concepts concerning the bioaccumulation of heavy metals associated with dredging and/or dredged material disposal have changed in recent years. Originally, many scientists feared that dredging/disposal operations would release heavy metals with a high degree of bioavailability to the biota of the area. This concern was amplified by bulk chemical analyses of the sediments from many navigational channels which indicated high concentrations of many potentially toxic metals. However, more recent investigations have indicated that metal concentrations measured by bulk chemical analyses have little, if any, correlation with the levels of toxins entering the biota during dredging/disposal operations (Lee et al., 1975; Hirsch et al., 1978; Neff et al., 1978; Pequegnat et al., 1978). Furthermore, Cross and Sunda (1979) reviewed the literature on the bioavailability of heavy metals and commented on the fact that heavy metal levels found in the tissues of benthic organisms often do not reflect the concentrations found in the sediments from their natural habitat. The mechanisms of bioaccumulation of heavy metals appear to be quite complex, depending on such factors as the metal in question, the particular biological species examined, the chemical matrix of the environment, the season, the salinity regime, and many other

factors (Neff et al., 1978; Hirsch et al., 1978; and Cross and Sunda, 1979).

One trend that does become apparent upon reviewing the literature of dredging-related bioaccumulation is that significant accumulation of metals in the biota appears to be the exception rather than the rule (see reviews by Hirsch et al., 1978; Allen and Hardy, 1980; Engler, 1978; Peddicord and Hansen, 1983; etc.). Studies conducted during and after dredging operations have led investigators to conclude that the availability, uptake, and accumulation of metals is extremely limited (Sims and Presley, 1976; and Sustar and Wakeman, 1977). Similar conclusions have been reached by investigators examining potential effects of dredge spoil disposal, where only a fraction (less than 25%) of the experiments indicated make significant trends in bioaccumulation (Neff et al., 1978; Engler, 1979; Peddicord and Hansen, 1983; Rubenstein et al., 1983). These findings parallel the results of the present study where less than 3% of nearly 650 metal-site-species combinations were found to exhibit statistically significant bioaccumulation patterns in relation to the controls. This number of "significant" tests could be expected to occur due to chance alone.

Even in cases where "statistically significant" bioaccumulation may occur there is some question concerning the ecological significance of the trends. Numerous investigators (Neff et al., 1978; Engler, 1979; Allen, 1980; and others) have suggested that, in many cases where statistically significant accumulation has been detected, the levels were of doubtful ecological significance. This is probably the case for the present study, where metal concentrations in the biota were generally much lower than those found in the sediments and were of the same order of magnitude as those of the controls, so a great deal of bioaccumulation does not appear to have oc

curred. In fact, the average experimental body burdens of the metals were below those reported for the same or similar species under control conditions in other studies (Engler, 1980; Peddicord, 1980; Peddicord and Hansen, 1983; Rubenstein et al., 1983). Moreover, the iron and manganese are the two metals displaying the most reoccurring significant test results and, as previously stated, these metals display an extremely low degree of toxicity.

Despite the fact that few of the experimental conditions produced metal levels in test species which exceeded those of controls, it is quite interesting to note the distributional pattern of body burden within the Facility. The metals in tissues were directly related to the geological characteristics of the sediments. The finer the sediments, the lower the relative amounts of metals accumulated in the biota. This trend is completely opposite to the pattern observed for the bulk metal analyses which indicated that higher levels of metals were associated with the fine sediments. Perhaps the metals were so strongly bound to the organic-rich fine sediments that they are less biologically available than for the coarser materials. Geographically, this means that the test species exposed to the coarser sediments near the input points on the eastern end of the Facility produce higher levels of metals in the biota than those from the more metal laden fine sediments of the western ponding area.

The potential bioaccumulation of PNAH's from dredged materials has been poorly studied. DiSalvo et al. (1977) reported on the biotic uptake of "grease and oil" from contaminated sediments. In his review of bioaccumulation of toxic substances from contaminated sediments, Engler (1979) cites only this study in discussing nonchlorinated organic toxins. However, there have been a number of field studies of the distribution of PNAH's in biota

from various marine environments (Dunn, 1976; Pancirov and Brown, 1977; Grahl-Nielsen et al., 1978; Mix and Schaffer, 1979; Pancirov et al., 1980; Murray et al., 1980; and Iosifidou et al., 1982), as well as laboratory experiments into the biological uptake of petroleum hydrocarbons from contaminated water and marine sediments (Hansen et al., 1978; Lee et al., 1978; Roesijadi et al., 1978; and Anderson, 1979). Generally, the studies which have been conducted have been limited to a few specific PNAH's in relatively few species, especially the fishes, bivalves, and a few crustaceans (Anderson, 1979; Eadie et al., 1982). Nonetheless, it is useful to compare the findings of the present study with those of previous investigators.

Only a little over 2% of the 1472 PNAH-site-species combinations were shown to produce body burden concentrations which were significantly greater than those found for the controls. Since at least this number of "significant" results would be expected to occur by chance alone (at $\alpha = 0.05$), the overall bioaccumulation potential of PNAH's in general from Craney Island sediments would appear to be minimal. Of course, certain of the PNAH's were found to be elevated in all species, so some degree of bioaccumulation of specific compounds may have occurred. All four test species exhibited greater concentrations of heavier PNAH's, particularly fluoranthene and pyrene, than the lighter 2- and 3-ring compounds. Similar patterns have been reported by Hansen et al. (1978) for Mytilus edulis and Roesijadi et al. (1978) for another bivalve Mocoma inquinata. Anderson (1979) hypothesized that heavier PNAH's would be expected to have greater steady-state concentrations in tissues than lighter ones due to their lower depuration rates in most species.

Although the levels of certain PNAH's found during the present study were higher than those found for similar organisms in more pristine environ-

ments (e.g. Dunn, 1976; Pancirov and Brown, 1977; Mix and Schaffer, 1979; Murray et al., 1980; Pancirov et al., 1980; and Iosifidou et al., 1982). the values were well below those produced by exposure to highly contaminated sediments (e.g. Dunn, 1976; Pancirov and Brown, 1977; Pancirov et al., 1980; Iosifidou et al., 1982), especially following oil spills (e.g. Grahl-Mielson et al., 1978; Lee et al., 1978; and Roesijadi et al., 1978). However, the mixture of PNAH's found in the test species of the present study was indicative of a pyrogenic rather than a fossil fuel origin: high temperature combustion products such as fluoranthene, pyrene and benzofluoranthene predominate.

Despite the fact that few of the site-species combinations resulted in levels of tissue PNAH's which were significantly greater than controls, it is interesting to note the overall distribution trends. There appears to be some indication of species specific bioaccumulation patterns. The magnitude of overall PNAH accumulation was greater in M. edulis than the other test species. This phenomenon is not expected since bivalves in general and mussels in particular have long been known to accumulate xenobiotics such as PNAH's (Roesijadi et al., 1978; Anderson, 1979; and Pancirov et al., 1980). However, the clam Mercenaria mercenaria did not display nearly the same body burden of PNAH's as did M. edulis. The shrimp and worms also did not accumulate PNAH's to the same degree as the mussels. This trend was not surprising because other species of worms and shrimp have been reported previously to have low accumulation rates for PNAH's (Anderson, 1979).

Regardless of the magnitude of accumulation, there appeared to be two distinct patterns of PNAH bioaccumulation with respect to the characteristics and collection location of the test sediments. The shrimp and mussels tended to exhibit higher concentrations of pyrogenic PNAH's following expo-

sure to materials from the eastern portion of the Facility, even though these sites often contained coarser sediments. On the other hand, the worms and clams tended to accumulate more of their body burdens of PNAH's from the fine sediments of the western ponding area.

Observations during the solid phase experiments indicated that the worms and clams remained buried in the test sediments. However, the blue mussels generally used byssal thread locomotion to move to the sides of the tanks, where they attached themselves above the sediment surface. Likewise, the shrimp tended to remain on the surface of the sediment or in the water column. The difference in exposure conditions could be responsible for the observed variations in accumulation patterns. The worms and clams were directly exposed to PNAH's in the sediments and interstitial water. The fine organic-rich sediments would generally contain more PNAH's and would, therefore, potentially provide a greater potential for exposure through the body or through ingestion. The shrimp and mussels were exposed to PNAH's on the sediment surface, and/or in the water column. The coarser sediments would be expected to be characterized by a relatively greater potential for partitioning of PNAH's into the water column than would more organic-rich fine sediments. Rubenstein *et al.* (1983) have suggested that the biological availability of xenobiotics may be affected dramatically by the physico-chemical characteristics of the sediment, particularly the organic load (i.e. the greater the organic load, the lower the bioavailability). It is, therefore, possible that the shrimp and mussels "extract" more PNAH's from the water column and surface of coarser sediments to which the PNAH's are more loosely bound.

SUMMARY AND CONCLUSIONS

An intensive series of investigations have been conducted in order to evaluate the sediment quality of Craney Island Disposal Facility. The sediments were characterized as being quite fine in nature, with coarser materials being located near the peripheries, dikes and input points. The bulk metal content of the sediments was related inversely to particle size and most metals were found in concentrations below those of the contaminated dredged materials from the navigational channels of the inner harbor.

The elutriates of the sediments contained relatively low levels of most metals and nutrients. Only levels of iron, manganese, zinc and ammonia were elevated in the elutriates. However, this trend is of questionable ecological significance due to the relatively low toxicity of these contaminants and the high dilution potential under open ocean conditions. The PNAH's in the elutriates were, likewise, fairly low in concentration and were indicative of a pyrogenic origin. The concentrations of most of the contaminants in the elutriates were greater for the fine sediments of the western ponding area than for the other subcontainment areas.

In general, the biological effects of the sediment fractions were minimal. The mortalities in the 96 hour and 10 day experiments were negligible for all test species. Therefore, all of the sites would meet the toxicity criteria for open ocean disposal. Although sediments from some sites produced significant sublethal effects on respiration and osmoregulation capacity, these effects were not strongly correlated to physicochemical or geographic patterns. More importantly, the dilution rates at an open ocean site would make such effects unlikely in the field.

The number of sites producing indications of significant bioaccumulation of metals or PNAH's was extremely low. Iron and manganese were the

metals most often observed to accumulate, while fluoranthene, pyrene and benzofluoranthene were the predominant PNAH's. Higher body burdens of most metals in the test species were greater for coarse sediments, particularly those found near the input points. The PNAH concentrations in shrimp and mussels had a similar pattern, but the worms and clams exhibited greater body burdens in fine sediments of the western ponding area.

The vast majority of the sediments tested would appear to meet criteria for open ocean disposal. The patterns of relative sediment quality appear to be generally related to particle size as well as geographic location. Bulk chemical analysis and elutriate chemistry tests have suggested that the western ponding region has the poorest sediment quality, followed by the northern, central and southern subcontainment areas. Although less clear-cut, the low level biological effects also appeared to be somewhat associated with the sediments from the interior portion of the western region. The PNAH body burden data from two of the test species tend to amplify the same pattern, but PNAH's in the other two species and metals in all species displayed exactly the opposite pattern, with highest concentrations being produced by sediments from eastern and southern sites. Therefore, the definition of the distribution of sediment quality by the patterns of low level body burdens appears to be problematic.

Most of the sediments of the Craney Island Facility appear to have been rendered fairly innocuous by dilution and "weathering" processes. If it is ever necessary to prioritize the regions of Craney Island for selection for excavation and ocean disposal, most of the indicators of "pollution potential" would appear to be least for the southern region and greatest for the western area, with the northern and central regions being intermediate. The exceptions to this trend were the bioaccumulation patterns produced by the

Table 1. Summary of multivariate statistics. For each data set and effect tested, the multivariate statistical test, its value, degrees of freedom and probability level are presented. The MANOVA tests employed the Hotelling's test statistic, while the discriminant analysis employed the Wilk's Lambda.

<u>Data Set</u>	<u>Effect</u>	<u>Analysis</u>	<u>Test</u>	<u>Value</u>	<u>d.f.</u>	<u>Probability</u>
Particle Size	Geological Site Groups	MANOVA	Hotelling's	4.300	27,695	<0.0000
	" (DF1)	Discriminant	Wilk's	0.046	1,39	<0.0000
	" (DF2)	"	"	0.313	1,24	<0.0000
	Depth	MANOVA	Hotelling's	0.054	18,462	<0.815
	Geographic Site Groups	MANOVA	Hotelling's	0,504	27,758	<0.0000
	" (DF1)	Discriminant	Wilk's	0.247	1,48	<0.0000
Metals in Sediments	" (DF2)	"	"	0.488	1,30	<0.0000
	Geological Site Groups	MANOVA	Hotelling's	23,764	24,209	<0.000
	" (DF1)	Discriminant	Wilk's	0,016	1,24	<0.000
	" (DF2)	"	"	0,371	1,14	<0.000
	Geographic Site Groups	MANOVA	Hotelling's	1,796	24,182	<0.000
	" (DF1)	Discriminant	Wilk's	0,264	1,21	<0.000
" (DF2)	"	"	0,533	1,12	<0.000	

Table I. Continued

<u>Data Set</u>	<u>Effect</u>	<u>Analysis</u>	<u>Test</u>	<u>Value</u>	<u>d.f.</u>	<u>Probability</u>
Inorganic Elutriate Chemistry	Geological Site Groups	MANOVA	Hotelling's	2.825	42,330	<0.000
	" (DF1)	Discriminant	Wilk's	0.180	1,33	<0.000
	" (DF2)	"	"	0.529	1,20	<0.000
	Geographic Site Groups	MANOVA	Hotelling's	2.134	42,312	<0.000
	" (DF1)	Discriminant	Wilk's	0.233	1,39	<0.000
	" (DF2)	"	"	0.560	1,24	<0.000
PNA's Elutriate Chemistry	Geological Site Groups	MANOVA	Hotelling's	5.678	54,104	<0.000
	" (DF1)	Discriminant	Wilk's	0.181	1,18	<0.000
	" (DF2)	"	"	0.651	1,10	0.0150
	Geographic Site Groups	MANOVA	Hotelling's	2.449	57,110	0.021
	" (DF1)	Discriminant	Wilk's	0.322	1,24	0.0001
	" (DF2)	"	"	0.543	1,14	0.0035
Biological Effects	Geological Site Groups	MANOVA	Hotelling's	0.323	24,341	0.069
	" (DF1)	Discriminant	Wilk's	0.782	1,15	0.014
	" (DF2)	"	"	0.926	1,8	0.317
	Geographic Site Groups	MANOVA	Hotelling's	0.464	24,351	0.001
	" (DF1)	Discriminant	Wilk's	0.665	1,18	0.0001
	" (DF2)	"	"	-	-	-

Table I. Concluded

<u>Data Set</u>	<u>Effect</u>	<u>Analysis</u>	<u>Test</u>	<u>Value</u>	<u>d.f.</u>	<u>Probability</u>
Metals in Tissues	Geological Site Groups	MANOVA	Hotelling's	5.63	84,88	0.0030
	" (DF1)	Discriminant	Wilk's	0.049	1,48	<0.0000
	" (DF2)	"	"	0.244	1,30	0.0001
	Geographic Site Groups	MANOVA	Hotelling's	8.18	84,88	<0.0000
	" (DF1)	Discriminant	Wilk's	0.090	1,36	<0.0000
	" (DF2)	"	"	0.454	1,22	0.0100
PNA's in Tissues	Geological Site Groups	MANOVA	Hotelling's	2.38	66,128	0.0190
	" (DF1)	Discriminant	Wilk's	0.361	1,27	0.0001
	" (DF2)	"	"	0.631	1.16	0.0288
	Geographical Site Groups	MANOVA	Hotelling's	3.210	54,140	<0.0000
	" (DF1)	Discriminant	Wilk's	0.137	1,39	<0.0000
	" (DF2)	"	"	0.376	1,214	0.0001

Table II. Summary of group comparisons produced by multivariate statistical analysis. For each data set, a contingency matrix is presented for the geological and geographic site groups (Groups 1-4 and Groups N, W, C, S, respectively). The values represent the percent classification of each group produced by discriminant analysis. The values in parentheses represent the probability levels of Mahalanobis D² comparisons of each pair of groups.

Data Set	Geological				Geographic				
	1	2	3	4	N	W	C	S	
Particle Size	1	90.7 (0.0000)	7.4 (0.0000)	1.9 (0.0000)	0	57.1 (0.0000)	33.9 (0.0000)	1.8 (0.0000)	7.1 (0.0000)
	2	20.0 (0.0000)	65.3 (0.0000)	14.7 (0.0000)	0	11.9 (0.0000)	81.6 (0.0000)	0 (0.0000)	1.5 (0.0000)
	3	7.1 (0.0000)	17.9 (0.0000)	73.2 (0.0000)	1.8	11.4 (0.0000)	28.6 (0.0000)	57.1 (0.0000)	2.9 (0.0000)
	4	0 (0.0000)	4.8 (0.0000)	4.8 (0.0000)	90.5	20.5 (0.0000)	17.9 (0.0000)	2.6 (0.0000)	59.0 (0.0000)
Metals in Sediments	1	78.9 (0.0000)	18.4 (0.0000)	2.6 (0.0000)	0	90.5 (0.0000)	4.8 (0.0000)	0 (0.0000)	4.8 (0.0000)
	2	24.1 (0.0000)	75.9 (0.0000)	0 (0.0000)	0	8.0 (0.0000)	80.0 (0.0000)	8.0 (0.0000)	4.0 (0.0000)
	3	0 (0.0000)	25 (0.0000)	75 (0.0000)	0	0 (0.0000)	33.3 (0.013)	66.7 (0.0000)	0 (0.0000)
	4	0 (0.0000)	0 (0.0000)	0 (0.0000)	100	0 (0.0000)	22.2 (0.0000)	11.1 (0.0000)	66.7 (0.0000)
Inorganic Elutriate Chemistry	1	68 (0.0000)	22 (0.0000)	10 (0.0000)	0	73.3 (0.0000)	13.3 (0.0000)	13.3 (0.0000)	0 (0.0000)
	2	15.4 (0.0000)	66.7 (0.0000)	17.9 (0.0000)	0	6.7 (0.0000)	82.2 (0.0000)	8.9 (0.0000)	2.2 (0.0000)
	3	20.8 (0.0000)	8.3 (0.0000)	70.8 (0.0000)	0	5.9 (0.0060)	23.5 (0.0050)	70.6 (0.0000)	0 (0.0000)
	4	0 (0.0000)	0 (0.0000)	0 (0.0000)	100	0 (0.0000)	7.4 (0.0000)	3.7 (0.0000)	88.9 (0.0000)

Table II. Concluded

Data Set	Geological				Geographic				
	1	2	3	4	N	W	C	S	
PNA's Elutriate Chemistry	1	93.3 (0.0000)	0	6.7	0	86.7 (0.0051)	6.7 (0.0218)	6.7 (0.0030)	0
	2	0 (0.0000)	85.7 (0.1042)	9.5	4.8	29.2 (0.5126)	70.8 (0.0218)	0	0
	3	0 (0.0000)	46.7 (0.1042)	53.3	0	66.7 (0.5126)	0 (0.0218)	33.3	0
	4	0 (0.0000)	33.3 (0.0115)	0 (0.0021)	66.7	33.3 (0.0071)	16.7 (0.0009)	0 (0.0030)	50
Biological Effects	1	49.0	35.3	2.0	13.7	45.5	21.2	0	33.3
	2	17.9 (0.0041)	66.7	2.6	12.8	8.9 (0.0071)	62.2	6.7	22.2
	3	16.7 (0.0383)	66.7 (0.8271)	8.3	8.3	22.2 (0.0116)	16.7 (0.0481)	27.8	33.3
	4	25.0 (0.1167)	58.3 (0.2522)	0 (0.1535)	16.7	6.7 (0.0434)	23.3 (0.0005)	3.3 (0.0959)	66.7
Metals in Tissues	1	89.7	10.3	0	0	90.9	0	9.1	0
	2	5.0 (0.0000)	95.0	0	0	12.1 (0.0000)	87.9	0	0
	3	16.7 (0.0000)	16.7 (0.0115)	66.7	0	8.3 (0.0078)	8.3 (0.0030)	83.3	0
	4	0 (0.0002)	0 (0.0016)	0 (0.0062)	100.0	20.0 (0.0121)	0 (0.0000)	10.0 (0.0145)	70.0
PNA's in Tissues	1	94.9	2.6	2.6	0	75.0	16.7	8.3	0
	2	23.8 (0.0087)	71.4	4.8	0	3.0 (0.0015)	97.0	0	0
	3	16.7 (0.0016)	16.7 (0.2312)	66.7	0	41.7 (0.6158)	0 (0.0000)	33.3	25.0
	4	0 (0.0084)	0 (0.0260)	0 (0.0014)	100	0 (0.0001)	8.3 (0.0000)	0 (0.0000)	91.7

TABLE III. Site group statistics for sediment grain size data. For each of the geological and geographic site groups (Groups 1-4 and Groups N, W, C, S, respectively), the three values represent the mean, standard error of the mean, and the number of replicates of grain size data for each of the indicated phi (ϕ) sizes. For the coarser grain size classes (ϕ -0.05 to ϕ 4, and total sand), the values are based upon the weight of sediment retained by each sieve size from 60 grams of processed sediment. The data presented for fine grain size classes (ϕ 4 to ϕ 10) are based upon values obtained from pipet analysis.

Parameter	Geological				Geographic			
	1	2	3	4	N	W	C	S
ϕ 10	.68 +.02 (54)	.56 +.02 (76)	.43 +.02 (56)	.14 +.03 (21)	.57 +.02 (57)	.61 +.02 (67)	.36 +.05 (35)	.46 +.04 (39)
ϕ 9	.85 +.02 (54)	.68 +.02 (75)	.51 +.02 (56)	.15 +.03 (21)	.69 +.02 (56)	.73 +.03 (67)	.42 +.06 (35)	.57 +.05 (39)
ϕ 8	1.02 +.01 (54)	.80 +.02 (76)	.59 +.03 (56)	.17 +.04 (21)	.81 +.02 (57)	.85 +.03 (67)	.51 +.06 (35)	.69 +.05 (39)
ϕ 7	1.17 +.01 (54)	.93 +.02 (76)	.67 +.03 (56)	.19 +.04 (21)	.94 +.02 (57)	.97 +.03 (67)	.58 +.07 (35)	.79 +.06 (39)
6	1.32 +.01 (54)	1.07 +.02 (76)	.79 +.04 (56)	.22 +.05 (21)	1.09 +.03 (57)	1.08 +.04 (67)	.67 +.09 (35)	.92 +.07 (39)
ϕ 5.5	1.37 +.01 (54)	1.14 +.02 (75)	.83 +.04 (56)	.24 +.06 (21)	1.17 +.03 (56)	1.14 +.03 (67)	.72 +.09 (35)	.95 +.07 (39)
ϕ 5	1.41 +.01 (54)	1.22 +.02 (75)	.94 +.04 (56)	.26 +.06 (21)	1.24 +.03 (56)	1.19 +.03 (67)	.77 +.09 (35)	1.04 +.07 (39)
ϕ 4.5	1.44 +.02 (54)	1.29 +.02 (76)	1.03 +.03 (56)	.29 +.07 (21)	1.31 +.02 (57)	1.26 +.03 (67)	.80 +.10 (35)	1.11 +.07 (39)
LAP4	1.46 +.02 (54)	1.35 +.02 (76)	1.15 +.03 (56)	.34 +.07 (21)	1.37 +.02 (57)	1.33 +.02 (67)	.86 +.10 (35)	1.18 +.07 (39)

Table III. Continued.

Parameter	Geological				Geographic			
	1	2	3	4	N	W	C	S
T SAND	.51 +.05 (54)	3.64 +.35 (76)	13.67 +1.44 (56)	48.06 +3.05 (21)	3.03 +.58 (57)	4.75 +.73 (67)	26.12 +4.10 (35)	14.10 +2.84 (39)
UAP4	0 0 (54)	.10 +.02 (76)	1.22 +.26 (56)	.44 +.05 (21)	.24 +.13 (57)	.26 +.07 (67)	.31 +.07 (35)	.37 +.10 (39)
†4	0 0 (54)	.67 +.19 (76)	3.44 +.39 (56)	2.20 +.21 (21)	.89 +.31 (57)	1.54 +.31 (67)	1.51 +.26 (35)	1.64 +.34 (39)
†3.5	0 0 (54)	.44 +.12 (76)	3.19 +.39 (56)	4.20 +.48 (21)	.59 +.17 (57)	.88 +.19 (67)	2.10 +.38 (35)	2.86 +.59 (39)
†3	0 0 (54)	.23 +.07 (76)	2.68 +.61 (56)	10.33 +1.39 (21)	.20 +.08 (57)	.33 +.10 (67)	4.70 +.99 (35)	4.36 +1.11 (39)
†2.5	0 0 (54)	.07 +.02 (76)	.80 +.19 (56)	7.51 +.91 (21)	.04 +.02 (57)	.22 +.09 (67)	3.49 +.74 (35)	1.61 +.56 (39)
†2	0 0 (54)	.04 +.02 (76)	.44 +.12 (56)	7.67 +.85 (21)	.03 +.02 (57)	.17 +.09 (67)	3.86 +.81 (35)	.92 +.39 (39)
†1.5	0 0 (54)	.01 +.01 (76)	.14 +.04 (56)	4.72 +.64 (21)	.01 +.01 (57)	.05 +.03 (67)	2.54 +.55 (35)	.33 +.18 (39)
†1	0 0 (54)	.01 +.00 (76)	.05 +.01 (56)	2.75 +.50 (21)	.01 +.00 (57)	.01 +.01 (67)	1.52 +.38 (35)	.14 +.09 (39)

Table III. Concluded

Parameter	Geological				Geographic			
	1	2	3	4	N	W	C	S
4.5	0 0 (54)	0 0 (76)	.02 +.01 (56)	1.78 +.45 (21)	.00 +.00 (57)	.01 +.00 (67)	1.01 +.31 (35)	.08 +.04 (39)
10	0 0 (54)	0 0 (76)	.01 +.00 (56)	.80 +.26 (21)	.00 +.00 (57)	.00 +.00 (67)	.47 +.17 (35)	.02 +.01 (39)
NP.5	0 0 (54)	0 0 (76)	.01 +.00 (56)	.49 +.17 (21)	.00 +.00 (57)	.00 +.00 (67)	.29 +.11 (35)	.01 +.00 (39)

Geological

Geographic

At right

Table IV. Site group statistics for metals in sediment data. (Format is the same as for Table III.) The data is presented in units of ug/g dry weight. The detection limits (mg/g) are shown in parentheses below the metal abbreviations.

Parameter	GEOLOGICAL				GEOGRAPHIC			
	1	2	3	4	H	W	C	S
Cd (0.2)	1.5 ± 0.110 (38)	1.13 ± 0.091 (29)	0.07 ± 0.055 (12)	0.1 ± 0.017 (3)	1.0 ± 0.052 (21)	1.4 ± 0.166 (25)	1.8 ± 0.241 (9)	1.1 ± 0.130 (18)
Cr (1.0)	75 ± 1.289 (38)	66 ± 1.815 (29)	45 ± 4.595 (12)	8 ± 3.853 (3)	68 ± 1.861 (21)	70 ± 3.142 (25)	73 ± 2.848 (9)	61 ± 6.116 (18)
Cu (0.5)	42.6 ± 1.801 (38)	40.3 ± 1.654 (29)	23.8 ± 3.306 (12)	1.9 ± 0.633 (3)	38.1 ± 0.888 (21)	36.2 ± 1.784 (25)	46.0 ± 3.992 (9)	40.7 ± 5.299 (18)
Fe (1.0)	50128 ± 764.734 (38)	45457.3 ± 1054.146 (29)	30846 ± 2622.995 (12)	6145 ± 208.706 (3)	44278 ± 1114.359 (21)	47466 ± 1253.342 (25)	48526 ± 657.90 (9)	44028.1 ± 4353.062 (18)
Mn (1.0)	650 ± 16.204 (38)	663 ± 20.016 (29)	41 ± 41.171 (12)	28 ± 5.115 (3)	664 ± 22.587 (21)	667 ± 17.383 (25)	603 ± 42.310 (9)	537 ± 61.518 (18)
Ni (1.0)	38 ± 0.607 (38)	35 ± 0.840 (29)	24 ± 2.356 (12)	BDL ± --- (3)	36 ± 0.842 (21)	36 ± 1.338 (25)	36 ± 0.842 (9)	30 ± 3.37 (18)

Table IV. Concluded

Parameter	GEOLOGICAL				GEOGRAPHIC			
	1	2	3	4	N	W	C	S
Pb (6.0)	57 ± 1.913 (38)	56 ± 2.537 (29)	34 ± 3.717 (12)	7 ± 1.667 (3)	49 ± 0.966 (21)	51 ± 2.506 (25)	64 ± 6.72 (9)	54 ± 5.86 (18)
Zn (0.5)	277.34 ± 13.444 (38)	257.1 ± 17.584 (29)	140.3 ± 16.832 (12)	10.2 ± 0.328 (3)	211.95 ± 7.354 (21)	244.6 ± 13.577 (25)	363.1 ± 51.81 (9)	255.9 ± 29.85 (18)

Table V. Site group statistics for inorganic elutriate chemistry data. (Format is the same as for table III). The data is presented in units of mg/l, except for nitrates which are in ug/l. The detection limits are presented in parentheses below the parameter abbreviations.

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>
<u>Metals:</u>								
Cd (0.001)	0.006 ± 0.001 (51)	0.004 ± 0.001 (39)	0.002 ± 0.001 (24)	0.001 ± 0.001 (12)	0.004 ± 0.001 (30)	0.005 ± 0.001 (45)	0.005 ± 0.001 (18)	0.004 ± 0.001 (25)
Cr (0.005)	0.42 ± 0.06 (51)	0.48 ± 0.06 (39)	0.29 ± 0.06 (24)	0.008 ± 0.005 (12)	0.38 ± 0.07 (30)	0.44 ± 0.06 (45)	0.26 ± 0.09 (18)	0.27 ± 0.06 (25)
Cu (0.003)	0.28 ± 0.03 (51)	0.28 ± 0.04 (39)	0.17 ± 0.03 (24)	0.005 ± 0.004 (12)	0.19 ± 0.04 (30)	0.29 ± 0.03 (45)	0.16 ± 0.05 (18)	0.22 ± 0.05 (25)
Fe (0.05)	327.67 ± 48.96 (51)	291.63 ± 42.20 (39)	200.90 ± 46.72 (24)	102.78 ± 51.33 (12)	231.62 ± 46.25 (30)	364.94 ± 52.66 (45)	97.37 ± 28.55 (18)	216.86 ± 44.45 (25)
Nb (0.001)	0.002 ± 0.000 (51)	BDL — (39)	0.001 ± 0.000 (24)	BDL — (12)	BDL — (30)	0.002 ± 0.000 (45)	BDL — (18)	0.001 ± 0.001 (25)
Mn (0.03)	5.10 ± 0.45 (51)	5.67 ± 0.66 (39)	3.37 ± 0.54 (24)	0.29 ± 0.10 (12)	4.58 ± 0.68 (30)	5.86 ± 0.53 (45)	3.29 ± 0.87 (18)	2.50 ± 0.49 (25)

Table V. Continued

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>
Ni (0.005)	0.23 ± 0.03 (51)	0.24 ± 0.03 (39)	0.15 ± 0.03 (24)	0.006 ± 0.005 (12)	0.16 ± 0.03 (30)	0.26 ± 0.02 (45)	0.13 ± 0.04 (18)	0.15 ± 0.04 (25)
Pb (0.003)	0.35 ± 0.04 (51)	0.38 ± 0.05 (39)	0.24 ± 0.05 (24)	0.02 ± 0.01 (12)	0.28 ± 0.05 (30)	0.37 ± 0.04 (45)	0.22 ± 0.07 (18)	0.24 ± 0.06 (25)
Zn (0.002)	2.02 ± 0.27 (51)	1.63 ± 0.22 (39)	0.98 ± 0.20 (24)	0.03 ± 0.01 (12)	1.16 ± 0.22 (30)	1.89 ± 0.24 (45)	1.51 ± 0.59 (18)	1.12 ± 0.25 (25)
<u>Nutrients:</u>	3.82	3.81	2.27	0.50	3.20	1.81	3.26	2.00
PH ₃ (0.05)	± 0.22 (51)	± 0.27 (39)	± 0.31 (24)	± 0.10 (12)	± 0.25 (30)	± 0.26 (45)	± 0.49 (18)	± 0.33 (25)
TKN (0.05)	73.02 ± 15.97 (51)	25.73 ± 6.08 (39)	22.76 ± 9.02 (24)	0.68 ± 0.18 (12)	35.62 ± 7.50 (30)	75.48 ± 18.01 (45)	28.73 ± 13.00 (18)	7.71 ± 0.73 (25)
NO ₃ (0.05)	0.23 ± 0.05 (51)	BDL --- (39)	0.05 ± 0.02 (24)	BDL --- (12)	0.18 ± 0.05 (30)	0.14 ± 0.04 (45)	0.11 ± 0.06 (18)	BDL --- (25)

Table V. Concluded

Parameter	GEOLOGICAL				GEOGRAPHIC			
	1	2	3	4	N	W	C	S
NO ₂ (0.001)	2.67 ± 0.29 (51)	3.08 ± 0.60 (39)	1.11 ± 0.18 (24)	0.26 ± 0.10 (12)	3.12 ± 0.51 (30)	2.87 ± 0.46 (45)	2.39 ± 0.44 (18)	0.56 ± 0.18 (25)
TOP ₄ (0.005)	2.92 ± 0.57 (51)	3.16 ± 0.93 (39)	2.61 ± 0.61 (24)	BDL --- (12)	1.59 ± 0.61 (30)	4.33 ± 0.78 (45)	0.64 ± 0.10 (18)	2.11 ± 0.87 (25)
OPO ₄ (0.005)	BDL --- (51)	0.007 ± 0.003 (39)	BDL --- (24)	BDL --- (12)	0.009 ± 0.003 (30)	BDL --- (45)	BDL --- (18)	BDL --- (25)

Table VI. Site group statistics for PNAH's in elutriates data. (Format is the same as for Table III). The data are presented in units of ug/l. The detection limits are presented in parentheses below the parameter abbreviations.

Parameter	Geological				Geographic			
	1	2	3	4	N	W	C	S
TPNA	227.66 +47.28 (18)	10.05 +3.46 (21)	18.72 +5.47 (15)	162.13 +75.23 (6)	14.36 +4.99 (15)	169.23 +40.85 (24)	109.50 +55.23 (9)	25.00 +9.15 (12)
N (0.135)	7.0 +1.90 (18)	.5 +20 (21)	.7 +26 (15)	5.0 +2.55 (6)	.3 +18 (15)	5.3 +1.54 (24)	3.5 +1.82 (9)	1.2 +.34 (12)
Acy (0.07)	1.47 +1.02 (18)	.21 +.17 (21)	.14 +.09 (15)	2.73 +2.20 (6)	.30 +.23 (15)	1.06 +.77 (24)	1.82 +1.49 (9)	.24 +.15 (12)
Acn (0.087)	2.97 +1.36 (18)	NDL (21)	.11 +.11 (15)	2.88 +1.48 (6)	NDL (15)	2.23 +1.05 (24)	1.92 +1.07 (9)	.16 +.13 (12)
F1 (0.038)	4.18 +1.78 (18)	2.91 +2.54 (21)	.41 +.15 (15)	7.11 +1.91 (6)	3.89 +3.55 (15)	3.28 +1.37 (24)	4.74 +1.71 (9)	.46 +.20 (12)
Ph (0.022)	13.56 +5.31 (18)	.21 +.14 (21)	.66 +.25 (15)	8.39 +3.90 (6)	.18 +.13 (15)	9.30 +4.18 (24)	5.59 +2.88 (9)	2.71 +1.13 (12)
A (0.028)	6.46 +2.25 (18)	1.13 +.31 (21)	2.65 +.95 (15)	10.04 +3.45 (6)	1.21 +.34 (15)	6.00 +1.74 (24)	6.69 +2.79 (9)	1.45 +.58 (12)
F (0.053)	29.12 +10.48 (18)	.24 +.13 (21)	2.90 +1.61 (15)	10.90 + 5.73 (6)	.26 +.18 (15)	21.57 +8.26 (24)	7.26 +4.12 (9)	4.27 +1.94 (12)
Pyre (0.050)	15.81 +4.62 (18)	.18 +.10 (21)	1.77 +1.00 (15)	5.93 +3.14 (6)	.16 +.13 (15)	10.92 + 3.77 (24)	3.95 +2.25 (9)	4.20 +1.61 (12)

Table VI. Concluded

Parameter	Geographic				N	Geographic		
	1	2	3	4		i	C	S
B(a)A (0.095)	11.73 +4.35 (18)	.52 +.32 (21)	1.91 +1.08 (15)	2.03 +1.43 (6)	1.44 +.87 (15)	8.33 +3.40 (24)	1.36 +.98 (9)	2.42 +1.50 (12)
Ch (0.100)	14. +5.27 (18)	1.1 +.42 (21)	3.7 +2.11 (15)	9.0 +4.84 (6)	3.0 +1.94 (15)	10.1 +4.14 (24)	6.8 +3.32 (9)	3.2 +1.62 (12)
DIB(a,h)A (0.197)	18.6 +4.02 (18)	BDL — (21)	.2 +.23 (15)	20.8 +13.27 (6)	BDL — (15)	14.1 +3.41 (24)	13.9 +9.24 (9)	.3 +.28 (12)
B(ghi)F (0.146)	15.3 +3.44 (18)	BDL — (21)	BDL — (15)	22.3 +10.47 (6)	BDL — (15)	10.5 +2.90 (24)	14.9 +7.71 (9)	2.0 +1.95 (12)
B(a)F (0.185)	26.0 +6.59 (18)	.3 +.23 (21)	1.7 +1.41 (15)	12.1 +7.82 (6)	.8 +.41 (15)	19.6 +5.48 (24)	8.7 +5.44 (9)	1.6 +.86 (12)
F(b)F (0.170)	19.7 +9.14 (18)	BDL — (21)	.9 +.86 (15)	3.8 +3.79 (6)	.9 +.86 (15)	14.80 +7.13 (24)	2.5 +2.53 (9)	BDL — (12)
B(k)F (0.158)	34.7 +9.33 (18)	1.0 +.51 (21)	1.0 +.78 (15)	27.7 +18.08 (6)	2.0 +.96 (15)	25.8 +7.66 (24)	18.9 +12.48 (9)	.8 +.37 (12)
I (0.204)	6.8 +3.27 (18)	1.5 +1.54 (21)	BDL — (15)	11.4 +7.87 (6)	BDL — (15)	6.5 +2.75 (24)	7.6 +5.42 (9)	BDL — (12)
C	87.29 +15.85 (18)	2.91 +1.57 (21)	3.50 +1.82 (15)	54.99 +31.53 (6)	3.58 +1.36 (15)	66.59 +14.04 (24)	37.10 +22.23 (9)	2.44 +1.15 (12)
Pyro	116.42 +20.16 (18)	3.15 +1.57 (21)	6.40 +2.19 (15)	65.88 +33.88 (6)	3.84 +1.35 (15)	88.15 +18.20 (24)	44.36 +24.38 (9)	6.71 +2.20 (12)

Table VII. Site group statistics for biological effects data. (Format is the same as for Table III). Days 1-5 are the respiration rates of *Palaemonetes pugio* on days 1-5 of the experiments in units of $\mu\text{g O}_2\text{g}^{-1}\text{hr}^{-1}$. The 10 ppt and 35 ppt represent the osmolality of the *P. pugio* body fluids (mOsm Kg^{-1}) when exposed to low and high salinities following the suspended solid bioassays. The mortality values (Mort 96) for *P. pugio* following the 96 hour experiments are expressed as a proportion.

Parameter	Geological				Geographic				Control
	1	2	3	4	N	H	C	S	
Day 1	1.34 +.09 (51)	1.41 +.08 (39)	1.31 +.14 (24)	1.36 +.15 (12)	1.47 +.10 (36)	1.28 +.09 (45)	1.47 +.10 (18)	1.23 +.11 (30)	1.48 +.16 (27)
Day 2	1.53 +.09 (51)	1.35 +.08 (39)	1.27 +.17 (24)	1.42 +.15 (12)	1.30 +.11 (36)	1.51 +.08 (45)	1.71 +.16 (18)	1.20 +.11 (30)	1.20 +.10 (27)
Day 3	1.63 +.12 (51)	1.34 +.10 (39)	1.40 +.14 (24)	1.27 +.09 (12)	1.30 +.11 (36)	1.60 +.12 (45)	1.70 +.20 (18)	1.25 +.10 (30)	1.37 +.10 (27)
Day 4	1.35 +.09 (51)	1.32 +.06 (39)	1.37 +.12 (24)	1.39 +.12 (12)	1.28 +.09 (36)	1.42 +.10 (45)	1.52 +.12 (18)	1.19 +.07 (30)	1.59 +.15 (27)
Day 5	1.21 +.08 (51)	1.30 +.08 (39)	1.29 +.13 (24)	1.38 +.09 (12)	1.23 +.09 (36)	1.29 +.09 (45)	1.24 +.10 (18)	1.26 +.09 (30)	1.49 +.16 (27)
10 PPT	619 +5.21 (51)	636 +5.60 (39)	631 +6.37 (24)	618 +21.11 (12)	634 +5.46 (36)	623 +5.37 (45)	604 +12.70 (18)	637 +7.49 (30)	614 +7.29 (27)
35 PPT	720 +9.51 (51)	783 +6.72 (39)	810 +10.23 (24)	802 +13.62 (12)	809 +8.65 (36)	802 +5.47 (45)	776 +17.33 (18)	779 +10.19 (30)	756 +10.24 (27)
Mort 96	.07 +.01 (51)	.05 +.01 (39)	.07 +.01 (24)	.02 +.01 (12)	.07 +.01 (36)	.05 +.01 (45)	.05 +.01 (18)	.06 +.01 (30)	.02 +.01 (27)

Table VIII. Summary of ANOVA/Duncan's Test comparisons of bioaccumulation of metals data. The sediment collection sites producing significantly higher body burdens of metals as compared to control organisms are indicated. The site producing the greatest bioaccumulation effect for each species-metal combination is underlined and the mean concentration for this experiment is indicated in parentheses. The species-metal combinations for which no significant differences were found are indicated by N.S. (not significant at the $\alpha = 0.05$ level).

Metals	SPECIES			
	<u>P. pugio</u>	<u>N. virens</u>	<u>M. mercenaria</u>	<u>M. edulis</u>
Cd	NS	NS	<u>45</u> (1.05)	NS
Cu	NS	NS		
Fe	<u>2, 9, 18, 26</u> (271.65)	<u>18, 25, 26, 37, 42</u> (377.16)	<u>5</u> (920.54)	<u>42</u> (400.35)
Mn	<u>13, 37</u> (45.97)	NS	NS	<u>37</u> (10.84)
Ni	<u>4, 5, 9</u> (9.26)	NS	NS	NS
Pb	NS	NS	<u>36, 47</u> (2.93)	NS
Zn	NS	NS	NS	NS

Table IX. Site group statistics for bioaccumulation of metals data. (Format is the same as for Table III). The abbreviations for the species-metal combinations are given in the Appendix. The data are presented in units of ug/g dry weight. The detection limits are presented in parentheses below the abbreviations.

Parameter	Geological				Geographic				Control
	1	2	3	4	N	W	C	S	
Pcd	.2 +.05 (39)	.5 +.06 (21)	.4 +.11 (6)	.6 +.06 (3)	.6 +.08 (12)	.2 +.05 (33)	.4 +.08 (12)	.5 +.07 (12)	1.3 +.76 (3)
NCd	.3 +.02 (39)	.1 +.04 (21)	.3 +.22 (6)	.1 +.08 (3)	.1 +.04 (12)	.3 +.02 (33)	.1 +.04 (12)	.2 +.11 (12)	.3 +.04 (3)
MCd	.5 +.02 (39)	.7 +.05 (21)	1.0 +.17 (6)	.8 +.13 (3)	.6 +.06 (12)	.4 +.01 (33)	.7 +.06 (12)	.8 +.10 (12)	.6 +.07 (3)
MyCd	1.3 +.05 (39)	1.0 +.07 (21)	1.3 +.14 (6)	.9 +.11 (3)	1.0 +.08 (12)	1.4 +.05 (33)	1.2 +.10 (12)	1.0 +.12 (12)	1.2 +.09 (3)
PCu	130.6 +2.71 (39)	148.1 +2.92 (21)	155.6 +2.84 (6)	156.7 +3.92 (3)	146.1 +5.54 (12)	130.4 +2.55 (33)	141.2 +5.60 (12)	154.7 +2.44 (12)	161.4 +8.05 (3)
NCu	8.3 +.26 (39)	9.2 +.50 (21)	9.8 +.24 (6)	9.5 +.78 (3)	8.8 +.85 (12)	8.2 +.29 (33)	9.0 +.35 (12)	9.8 +.16 (12)	10.4 +.43 (3)
MCu	11.4 +.25 (39)	12.4 +.35 (21)	13.5 +.46 (6)	13.6 +1.48 (3)	12.0 +.45 (12)	11.6 +.29 (33)	12.4 +.61 (12)	12.8 +.42 (12)	13.5 +.74 (12)
MyCu	6.4 +.17 (39)	7.3 +.41 (21)	7.6 +1.07 (6)	7.6 +.56 (3)	7.6 +.59 (12)	6.4 +.19 (33)	6.9 +.13 (12)	7.3 +.56 (12)	9.0 +.81 (3)
PFe	139 +11.79 (39)	162 +15.42 (21)	191 +21.17 (6)	105 +21.00 (3)	203 +25.23 (12)	123 +9.98 (33)	131 +18.40 (12)	184 +17.35 (12)	84 +11.13 (3)

Table IX. Continued

Parameter	Geological				N	Geographic			Control
	1	2	3	4		W	C	S	
NFe	278 +5.69 (39)	337 +13.14 (21)	320 +12.56 (4)	323 +16.86 (3)	326 +16.97 (12)	278 +5.93 (33)	321 +18.53 (12)	323 +12.90 (12)	302 +11.86 (3)
MFe	244 +52.52 (39)	222 +9.03 (21)	212 +8.44 (6)	180 +5.44 (3)	225 +12.56 (12)	185 +15.93 (33)	393 +161.69 (12)	206 +7.46 (12)	197 +14.64 (3)
MyFe	112 +7.18 (39)	128 +8.87 (21)	204 +113.42 (6)	86 +10.70 (3)	139 +9.81 (12)	102 +6.79 (33)	121 +14.07 (12)	192 +56.78 (12)	85 +6.12 (3)
PMn	23.7 +.91 (39)	29.3 +2.18 (21)	26.4 +2.46 (6)	13.7 +.39 (3)	26.2 +1.70 (12)	23.7 +.97 (33)	29.3 +3.96 (12)	24.2 +2.01 (12)	18.7 +.16 (3)
NMn	4.8 +.12 (39)	6.2 +.43 (21)	5.8 +.40 (6)	4.8 +.15 (3)	5.6 +.26 (12)	4.7 +.11 (33)	6.0 +.78 (12)	5.9 +.26 (12)	6.1 +.26 (3)
MMn	8.1 +.54 (39)	9.9 +.86 (21)	9.0 +.80 (6)	8.2 +.84 (3)	9.5 +1.17 (12)	8.3 +.57 (33)	10.0 +1.21 (12)	7.8 +.11 (12)	10.6 +1.96 (3)
MyMn	7.9 +.36 (39)	9.3 +.64 (21)	10.5 +1.00 (6)	8.8 +1.47 (3)	9.3 +.67 (12)	7.8 +.40 (33)	8.9 +.78 (12)	9.6 +.73 (12)	6.5 +.62 (3)
PNi	4.8 +.54 (39)	3.3 +.57 (21)	3.7 +.43 (6)	3.2 +.91 (3)	4.1 +.91 (12)	4.3 +.55 (33)	5.0 +.99 (12)	2.9 +.45 (12)	2.5 +.87 (3)
NNi	2.2 +.09 (39)	3.1 +.18 (21)	2.8 +.39 (6)	3.2 +.40 (3)	2.7 +.30 (12)	2.3 +.11 (33)	2.9 +.26 (12)	2.8 +.21 (12)	4.2 +.30 (3)

Table IX. Concluded

Parameter	Geological				N	Geographic			Control
	1	2	3	4		W	C	S	
MNI	5.3 + .23 (39)	5.7 + .34 (21)	5.2 + .62 (6)	6.6 + 1.00 (3)	5.3 + .53 (12)	5.5 + .25 (33)	6.0 + .50 (12)	5.1 + .33 (12)	6.6 + .62 (3)
MyNI	7.5 + .30 (39)	6.7 + .40 (21)	7.4 + .82 (6)	4.6 + .84 (3)	7.7 + .69 (12)	7.2 + .25 (33)	6.6 + .78 (12)	6.8 + .52 (12)	7.8 + .67 (3)
PPb	.66 + .29 (34)	1.09 + .29 (21)	1.32 + .83 (6)	.02 + .01 (3)	.92 + .24 (12)	.40 + .14 (28)	1.55 + .85 (12)	1.04 + .46 (11)	1.91 + 1.14 (3)
NPb	2.76 + .19 (39)	2.40 + .22 (21)	.92 + .58 (6)	.79 + .79 (3)	2.86 + .26 (12)	2.90 + .18 (33)	1.63 + .36 (12)	1.35 + 0.0 (12)	2.43 + .12 (3)
MPb	.68 + .13 (39)	1.18 + .27 (21)	.63 + .12 (6)	4.82 + 2.51 (3)	1.34 + .40 (12)	.46 + .04 (33)	1.76 + .79 (12)	1.44 + .39 (12)	.62 + .09 (3)
MyPb	1.43 + .08 (39)	1.53 + .09 (21)	1.96 + .15 (6)	1.72 + .41 (3)	1.65 + .12 (12)	1.31 + .08 (33)	1.53 + .11 (12)	1.94 + .13 (12)	1.76 + .11 (3)
PZn	73 + 1.62 (39)	78 + 1.16 (21)	81 + 3.72 (6)	80 + 2.50 (3)	76 + 2.20 (12)	74 + 1.02 (33)	75 + 1.54 (12)	76 + 5.12 (12)	76 + 3.16 (3)
NZn	103 + 2.67 (39)	118 + 4.07 (21)	117 + 4.88 (6)	115 + 12.13 (3)	118 + 4.17 (12)	102 + 2.53 (33)	111 + 6.71 (12)	120 + 5.06 (12)	110 + 2.12 (3)
MZn	91 + 2.68 (39)	96 + 3.72 (21)	106 + 5.78 (6)	114 + 5.46 (3)	92 + 4.94 (12)	87 + 2.69 (33)	106 + 4.11 (12)	107 + 3.32 (12)	113 + 2.63 (3)
MyZn	110 + 4.13 (39)	97 + 4.98 (21)	140 + 16.87 (6)	101 + 7.67 (3)	113 + 8.96 (12)	104 + 4.23 (33)	104 + 6.20 (12)	122 + 10.86 (12)	104 + 22.29 (3)

Table X. Summary of ANOVA/Duncan's test comparisons of bioaccumulation of PNAHs data. The sediment collection sites producing significantly higher body burdens of PNAHs as compared to the control organisms are indicated. The site producing the greatest bioaccumulation effect for each species-PNAH combination is underlined and the mean concentration for this experiment is indicated in parentheses. The species-metal combinations for which no significant differences were found are indicated by N.S. (not significant at the $\alpha = 0.05$ level). The abbreviations for the species-PNAH combinations are given in the Appendix.

PNA	SPECIES			
	<u>P. pugio</u>	<u>N. virens</u>	<u>M. mercenaria</u>	<u>M. edulis</u>
TPNA	<u>26</u> (3954)	NS	<u>2,54</u> (1259)	<u>9,18,45,47</u> (10,875)
N	<u>2</u> (960)	<u>3</u> (265)	NS	NS
F1	NS	NS	NS	<u>13</u> (493)
F	<u>53</u> (107)	NS	<u>2,3</u> (325)	<u>18,45,47,53</u> (5019)
Pyre	<u>53</u> (126)	<u>3</u> (277)	<u>2,3,23</u> (401)	<u>18,45,47</u> (4036)
B(a)A	NS	NS	NS	<u>9</u> (3234)
Ch	NS	NS	NS	<u>18,47</u> (282)
B(a)P	<u>37</u> (490)	NS	NS	NS
B(b)F	<u>26</u> (3954)	NS	<u>25,54</u> (935)	NS
C	NS	NS	NS	NS
Pyro	NS	NS	NS	NS

Table XI. Site group statistics for bioaccumulation of PNAHs data. (Format is the same as for Table III). The abbreviations for the species-PNAH combinations are given in the Appendix. The data are presented in units of ng/g dry weight. The detection limits (ng/g) are presented in parentheses below the abbreviations.

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>				<u>CONTROL</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>	
P TPNA	321	1493	580	626	1406	319	821	1192	597
	+ 85.028	+ 579.830	+ 391.664	+388.051	+754.438	+ 96.834	+367.828	+ 691.091	+ 382.399
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
N TPNA	804	465	858	56	604	844	480	467	791
	+175.464	+ 141.744	+468.744	+ 56.190	+221.293	+197.671	+200.385	+ 254.847	+ 279.128
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M TPNA	507	335	126	351	448	528	4275	211	64
	+ 93.856	+ 87.978	+ 85.867	+259.664	+137.142	+105.509	+113.089	+ 78.703	+ 64.189
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
Hy TPNA	2841	1977	3120	BDL	1818	2145	852	5684	1245
	+548.745	+ 502.145	+1204.451	---	+1069.198	+ 279.578	+435.659	+1244.816	+1092.615
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P H (52)	107	93	BDL	BDL	163	126	BDL	BDL	BDL
	+ 76.475	+ 67.031	---	---	+ 115.138	+ 90.175	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M H (37)	173	BDL	507	BDL	BDL	205	BDL	253	BDL
	+121.987	---	506.810	---	---	143.814	---	253.405	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>				<u>CONTROL</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>	
MH (61)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M ₂ P (37)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P Acy (20)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M Acy (14)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M Acy (23)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M ₂ Acy (14)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P Acn (17)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

<u>Parameter</u>	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>				<u>CONTROL</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>	
N Acn (12)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M Acn (19)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
My Acn	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P F1 (4)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
N F1 (3)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M F1 (5)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>				<u>CONTROL</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>	
N Ph (2)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M Ph (3)	4	BDL	BDL	65	BDL	3	21	BDL	BDL
	\pm 2.694	---	---	\pm 65.064	---	\pm 2.789	\pm 16.464	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
Hy Pn (2)	BDL	17	BDL	BDL	BDL	BDL	BDL	29	BDL
	---	\pm 11.583	---	---	---	---	---	\pm 19.836	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P A (4)	BDL	BDL	BDL	BDL	BDL	<u>BDL</u>	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
N A (3)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M A (4)	29	12	BDL	BDL	16	28	22	BDL	BDL
	\pm 9.280	\pm 8.327	---	---	\pm 11.400	\pm 8.643	\pm 21.605	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. (Continued)

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>				<u>CONTROL</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>	
My A (3)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P F (4)	16	BDL	BDL	BDL	BDL	13	BDL	16	BDL
	+ 9.876	---	---	---	---	+ 10.243	---	+ 16.288	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M F (3)	38	BDL	25	BDL	BDL	45	BDL	13	BDL
	+ 19.913	---	+ 25.010	---	---	+ 23.386	---	+ 12.505	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M F (4)	92	71	55	BDL	66	104	20	79	BDL
	+ 22.503	+ 28.715	+ 36.349	---	+ 43.686	+ 25.829	+ 10.566	+ 31.506	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
My F (3)	996	542	1238	BDL	209	779	54	2399	BDL
	+ 224.317	+ 184.489	+ 555.731	---	+ 114.484	+ 124.427	+ 36.636	+ 579.113	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P Pyre (6)	13	BDL	BDL	BDL	BDL	11	BDL	12	BDL
	+ 7.612	---	---	---	---	+ 8.007	---	+ 12.027	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

Parameter	GEOLOGICAL				GEOGRAPHIC				CONTROL
	1	2	3	4	N	W	C	S	
N Pyre (4)	46	16	51	BDL	BDL	65	BDL	26	BDL
	+ 18.851	+ 15.814	+ 32.741	---	---	+ 23.475	---	+ 17.429	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M Pyre (7)	128	64	70	BDL	25	144	23	120	BDL
	+ 28.424	+ 22.199	+ 49.907	---	+ 13.262	+ 32.337	+ 12.418	+ 40.410	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
My Pyre (4)	1039	660	1255	BDL	215	927	92	2301	BDL
	+ 178.444	+ 253.969	+ 502.382	---	+ 61.735	+ 110.763	+ 40.303	+ 524.396	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P B(a)A (24)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
N B(a)A (17)	BDL	22	BDL	BDL	BDL	22	BDL	BDL	BDL
	---	+ 22.170	---	---	---	+ 15.933	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M B(a)A (2 β)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

Parameter	GEOLOGICAL				GEOGRAPHIC				CONTROL
	1	2	3	4	N	W	C	S	
Hy B(a)A (17)	427 ± 270.808	83 ± 54.459	131 ± 84.639	BDL	809 ± 808.712	203 ± 139.090	BDL	230 ± 82.016	BDL
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P Ch (53)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M Ch (37)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M Ch (62)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	64 ± 64.189
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
My Ch (37)	BDL	39 ± 28.241	128 ± 83.597	BDL	BDL	BDL	BDL	203 ± 82.321	BDL
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P DiB(a,h)A (70)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

Parameter	GEOLOGICAL				GEOGRAPHIC				CONTROL
	1	2	3	4	N	W	C	S	
N D1B(a,h)A (50)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M D1B(a,h)A (d2)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
My D1B(a,h)A (50)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P B(gh1)P (17)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
N B(gh1)P (12)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M B(gh1)P (20)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	---	---	---	---	---	---	---	---	---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>				<u>CONTROL</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>	
My B(ghi)P (12)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P B(a)P (17)	BDL ---	70 +51.511	BDL ---	181 +180.940	BDL ---	17 +17.089	168 ± 94.319	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M B(a)P (12)	38 +38.049	136 +80.581	230 +179.909	BDL ---	53 +53.281	22 +22.355	246 +165.949	115 + 92.520	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
M B(a)P (20)	BDL ---	36 +35.630	BDL ---	BDL ---	62 +62.352	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
My B(a)P (12)	172 +101.316	209 +157.440	BDL ---	BDL ---	358 +303.252	88 +49.617	297 +275.167	27 + 27.286	596 +595.516
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P B(b)P (40)	167 + 45.870	1158 +566.163	580 +391.664	445 +445.476	1233 +756.409	151 +48.766	354 +163.093	1164 +692.184	437 +436.513
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)

Table XI. Continued

Detection Limits (ng/g)

Parameter	<u>GEOLOGICAL</u>				<u>GEOGRAPHIC</u>				<u>CONTROL</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>N</u>	<u>W</u>	<u>C</u>	<u>S</u>	
N B(b)F (28)	500 +131.528 (39)	270 + 84.551 (21)	45 +45.020 (6)	56 + 56.190 (3)	513 +199.204 (12)	482 +143.476 (33)	234 +103.252 (12)	60 +41.995 (12)	791 +279.128 (3)
M B(b)F (47)	162 + 54.006 (39)	119 + 66.405 (21)	BDL --- (6)	286 +286.008 (3)	220 +116.792 (12)	164 + 58.691 (33)	136 +91.565 (12)	BDL --- (12)	BDL --- (3)
My B(b)F (28)	124 +47.237 (39)	280 +110.200 (21)	222 +154.218 (6)	BDL --- (3)	145 +71.884 (12)	97 +40.411 (33)	257 +176.476 (12)	335 +135.961 (12)	382 +381.830 (3)
P C (-)	182 +46.753 (39)	1400 +581.742 (21)	580 +391.664 (6)	626 +388.051 (3)	1233 +756.409 (12)	168 +50.089 (33)	822 +367.828 (12)	1164 +692.184 (12)	597 +382.399 (3)
N C (-)	538 +137.302 (39)	427 +125.707 (21)	275 +173.924 (6)	56 +56.190 (3)	604 +221.293 (12)	505 +144.997 (33)	480 +200.385 (12)	175 + 95.220 (12)	791 +279.128 (3)
M C (-)	189 + 57.911 (39)	155 + 72.495 (21)	BDL --- (6)	286 +286.008 (3)	282 +122.636 (12)	196 + 63.668 (33)	136 + 91.565 (12)	BDL --- (12)	BDL --- (3)

Table XI. Continued

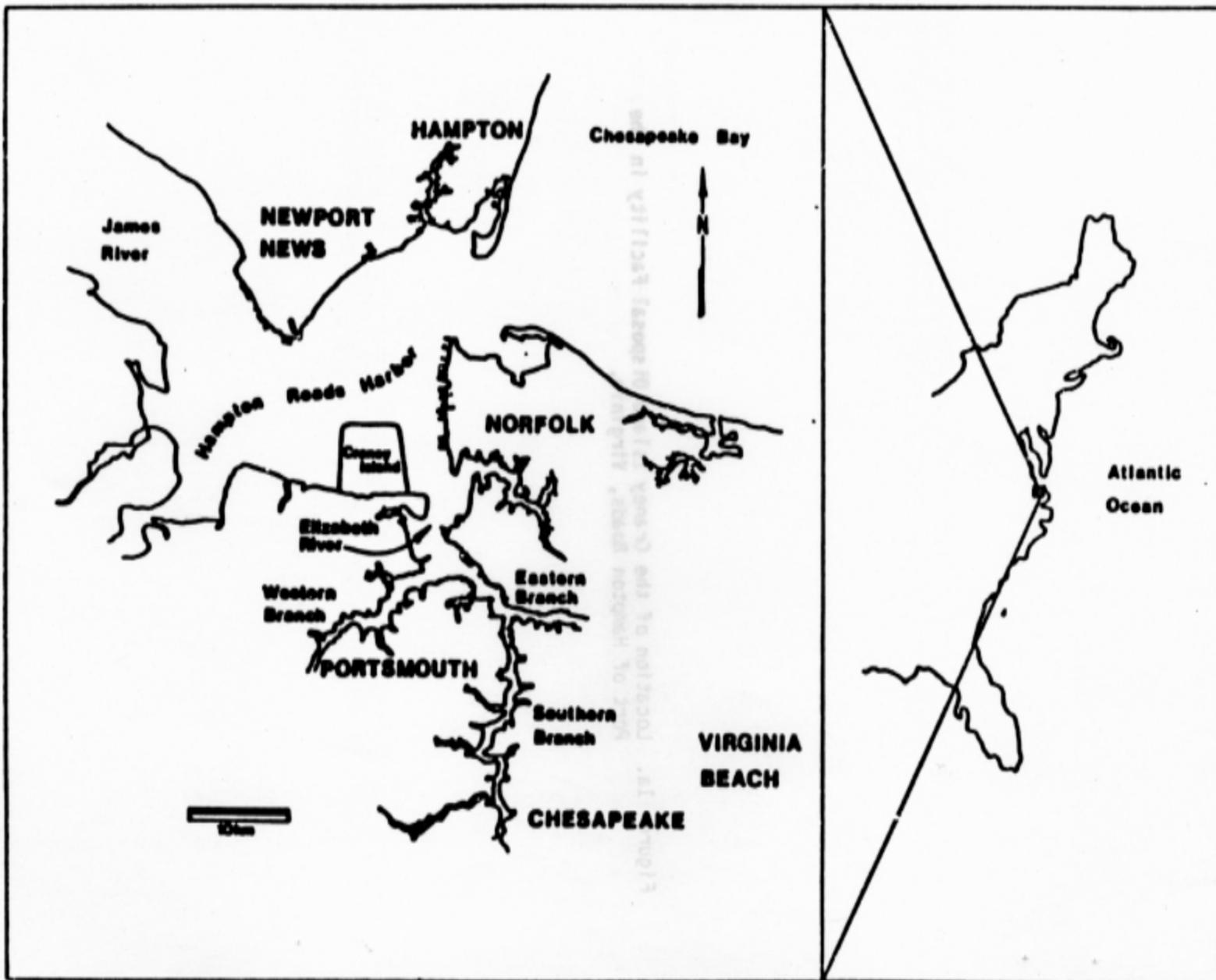
Parameter	GEOLOGICAL				GEOGRAPHIC					CONTROL
	1	2	3	4	N	W	C	S		
My C (-)	314	513	222	BDL	548	185	554	421	977	
	+112.542	+269.833	+154.218	---	+322.432	+ 75.480	+445.593	+141.535	+977.345	
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)	
P Pyro (-)	198	1400	580	626	1233	181	822	1180	597	
	+ 47.905	+ 581.742	+391.664	+388.051	+ 756.409	+ 49.750	+367.828	+ 691.414	+382.399	
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)	
N Pyro (-)	576	427	300	56	604	549	480	188	791	
	+135.807	+125.707	+175.877	+56.190	+221.295	+143.298	+200.385	+ 97.282	+279.128	
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)	
M Pyro (-)	276	225	55	286	348	294	155	79	BDL	
	+ 61.767	+ 70.642	+36.349	+286.008	+116.523	+ 63.555	+ 89.499	+31.506	---	
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)	
Hy Pyro (-)	1309	1031	1460	BDL	711	963	608	2820	977	
	+ 272.705	+ 302.017	+ 626.714	---	+300.756	+155.648	+444.313	+ 685.853	+977.345	
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)	
P B(k)F (23)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	161	
	---	---	---	---	---	---	---	---	+160.627	
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)	

Table XI. Continued

Detection Limits (ng/g)

GEOGRAPHIC

Parameter	<u>GEOLOGICAL</u>				N 37	<u>GEOGRAPHIC</u>			CONTROL BDL
	1	2	3	4		W BDL	C BDL	S BDL	
N B(k)F (16)	BDL ---	21 +21.204	BDL ---	BDL ---	37 +37.106	BDL ---	BDL ---	BDL ---	BDL (3)
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
H B(k)F (27)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
My B(k)F (16)	18 +18.141	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	59 +58.958	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
P I (73)	BDL ---	172 +171.578	BDL ---	BDL ---	BDL ---	BDL ---	300 +300.262	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
N I (51)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)
H I (85)	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---	BDL ---
	(39)	(21)	(6)	(3)	(12)	(33)	(12)	(12)	(3)



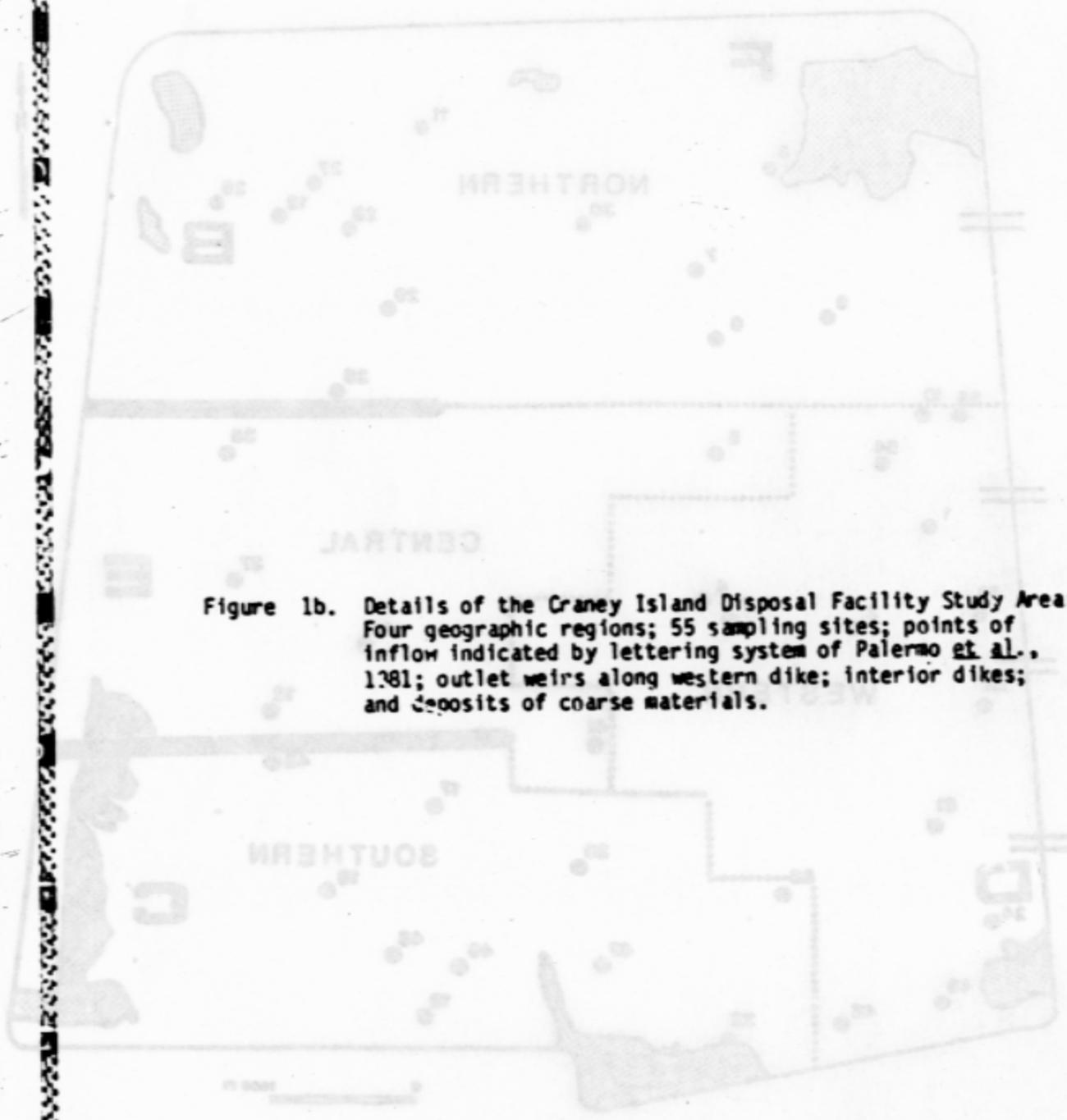


Figure 1b. Details of the Crane Island Disposal Facility Study Area: Four geographic regions; 55 sampling sites; points of inflow indicated by lettering system of Palermo *et al.*, 1981; outlet weirs along western dike; interior dikes; and deposits of coarse materials.

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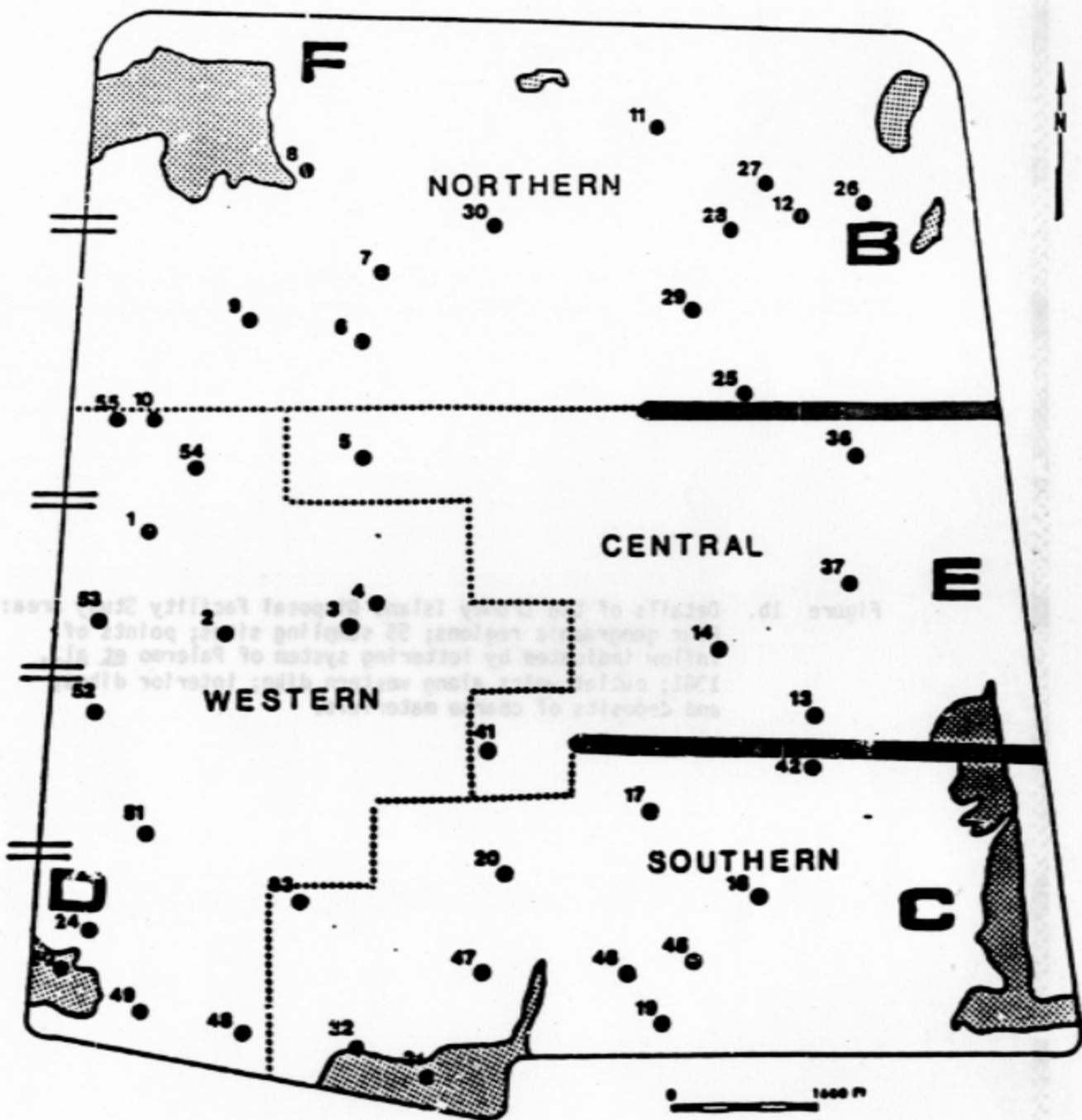




Figure 2a. Dendrogram presenting the results of a Bray-Curtis cluster analysis of grain size characteristics of collection sites. The site numbers are those indicated in Figure 2b, and the roman numerals indicate site groups. (Top)

Figure 2b. Dendrogram presenting the results of a confirmation cluster analysis of grain size characteristics of site groups (suggested by the Bray-Curtis analysis) employing the Mahalanobis D^2 distance measurement. The roman numerals indicate the site groups suggested by A, while the arabic numbers represent the site groups used in all subsequent analyses. (Bottom)



100 90 80 70 60 50 40 30 20 10 0

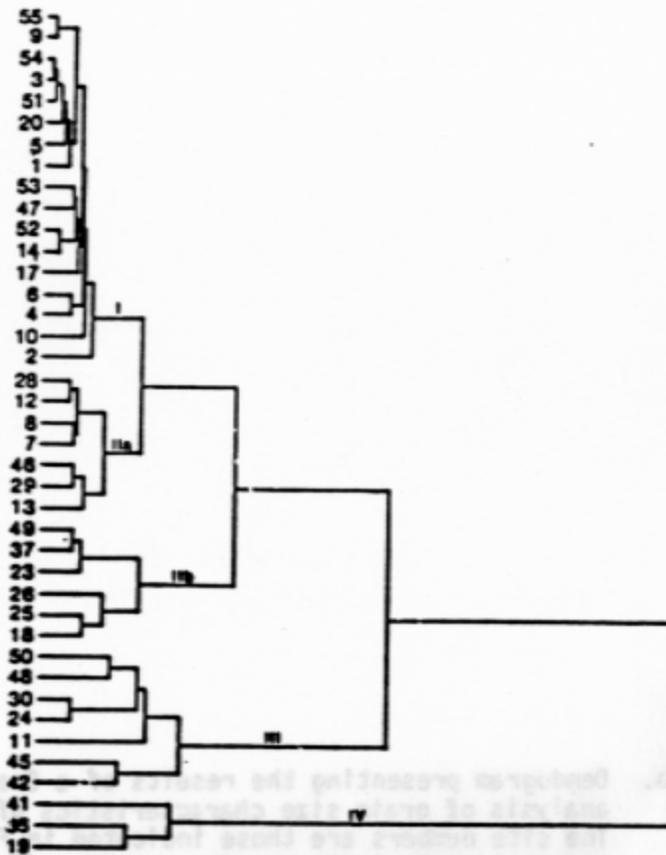
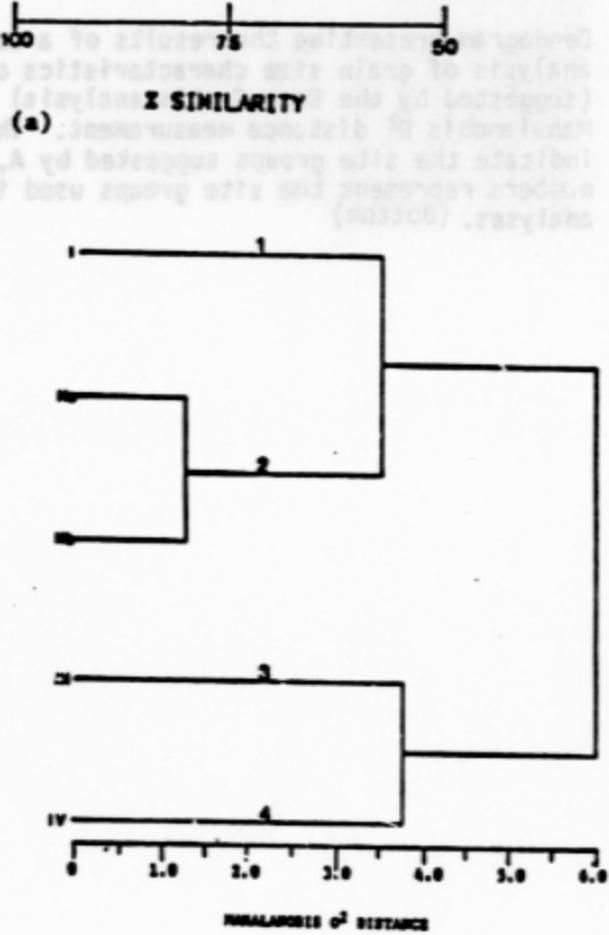


Figure 21. Dendrogram showing the results of hierarchical clustering of grain size characteristics of site groups (suggested by the distance measurement) employing the method of distance measurement. The Roman numerals indicate the site groups suggested by A, while the Arabic numerals represent the site groups used in all subsequent analysis. (bottom)



(b)

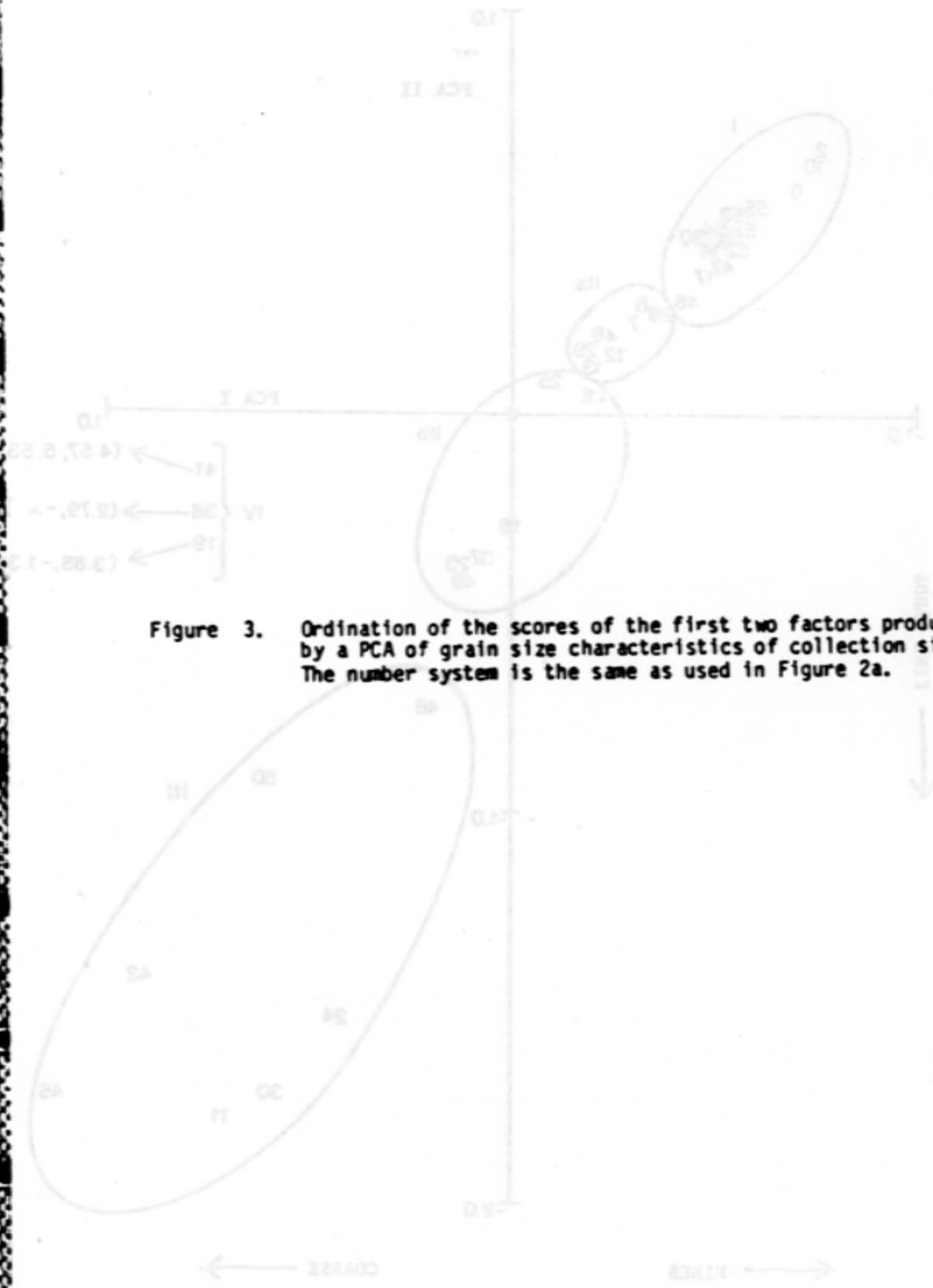


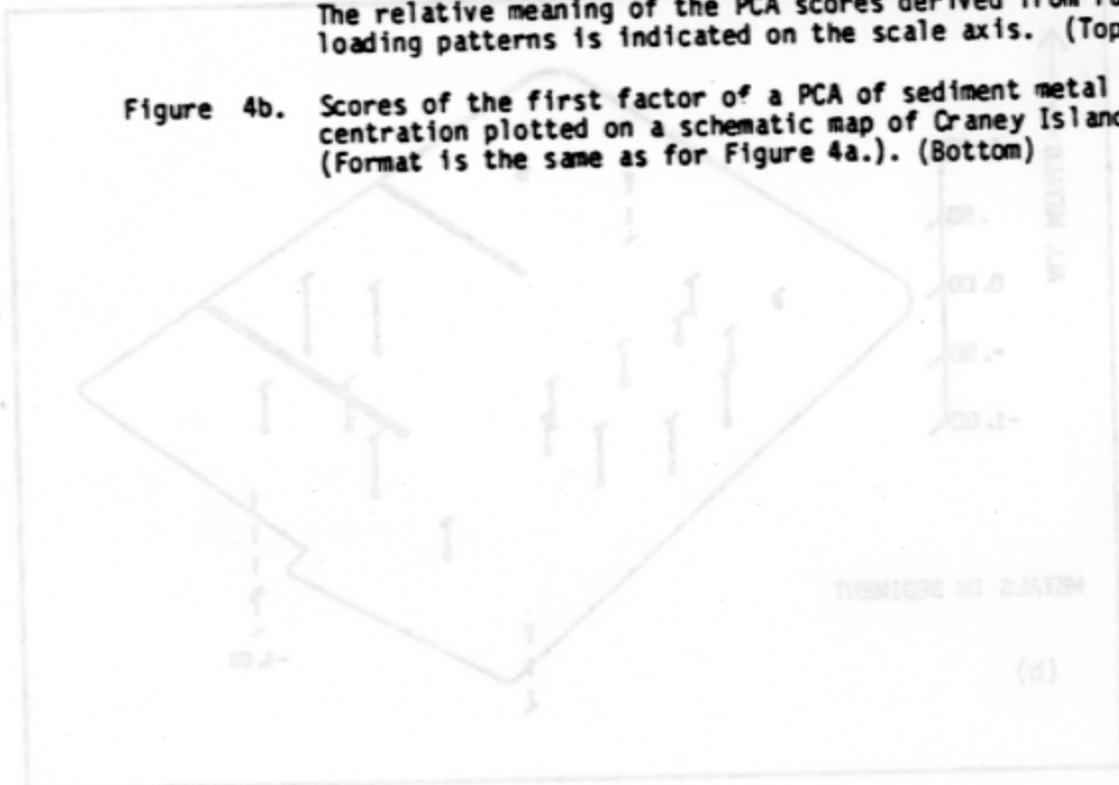
Figure 3. Ordination of the scores of the first two factors produced by a PCA of grain size characteristics of collection sites. The number system is the same as used in Figure 2a.

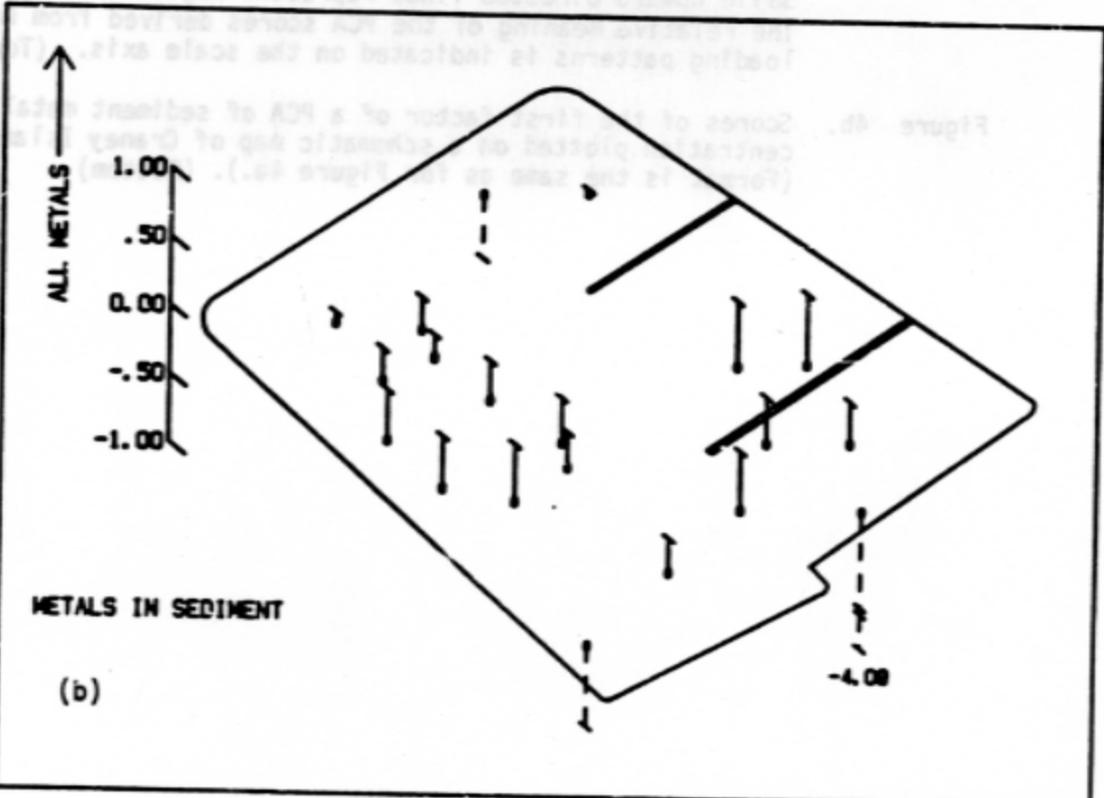
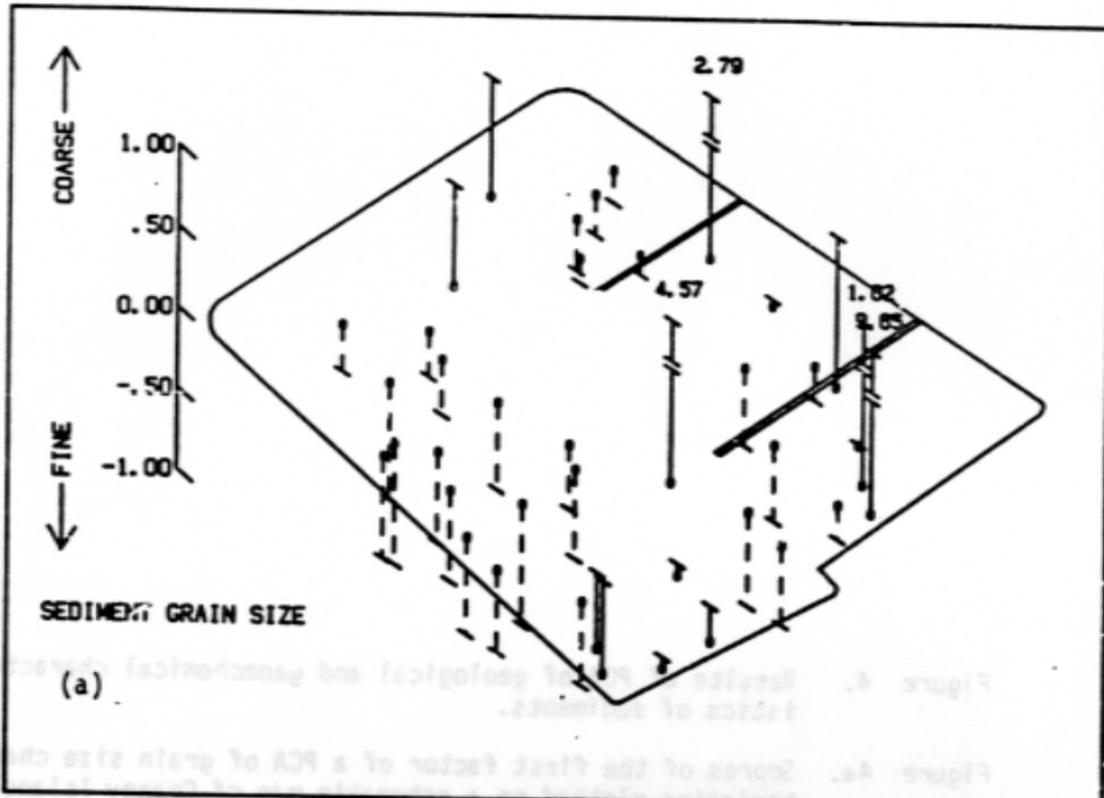


Figure 4. Results of PCA of geological and geochemical characteristics of sediments.

Figure 4a. Scores of the first factor of a PCA of grain size characteristics plotted on a schematic map of Craney Island. The site locations correspond to those shown in Figure 1b. Solid upward directed lines represent negative PCA scores. The relative meaning of the PCA scores derived from factor loading patterns is indicated on the scale axis. (Top)

Figure 4b. Scores of the first factor of a PCA of sediment metal concentration plotted on a schematic map of Craney Island. (Format is the same as for Figure 4a.). (Bottom)





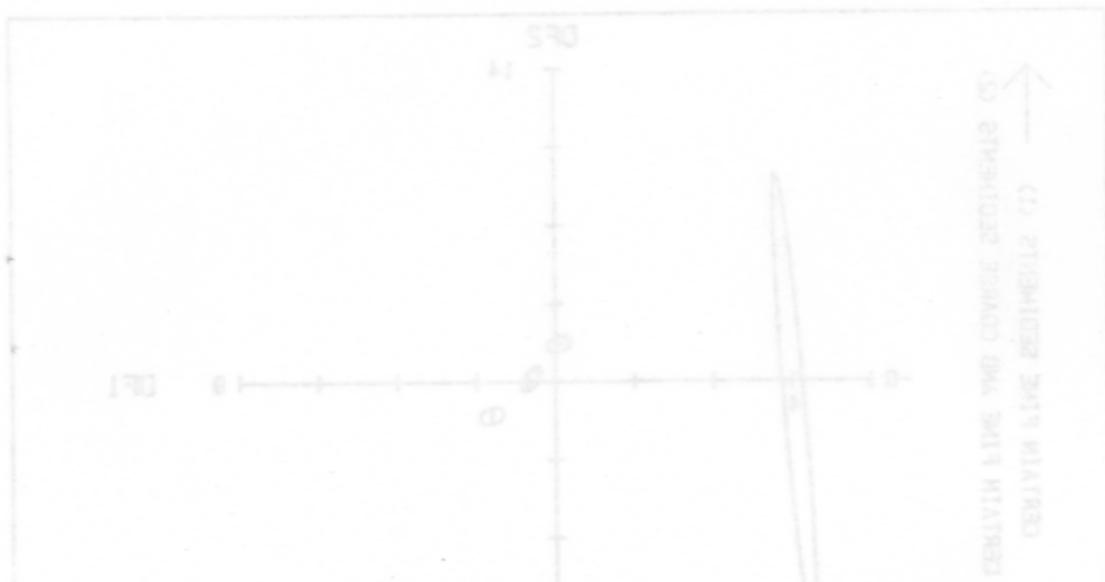


Figure 5a. Confidence ellipses (= 95%) of geological site groups plotted on a graph of the first two discriminant functions (DF1 and DF2) produced by a discriminant analysis of sediment grain size characteristics of Craney Island. The labels presented the relative meaning of each axis have been derived from a Pearson's correlation analysis of relationships between the discriminant functions and the original variables. (Top)

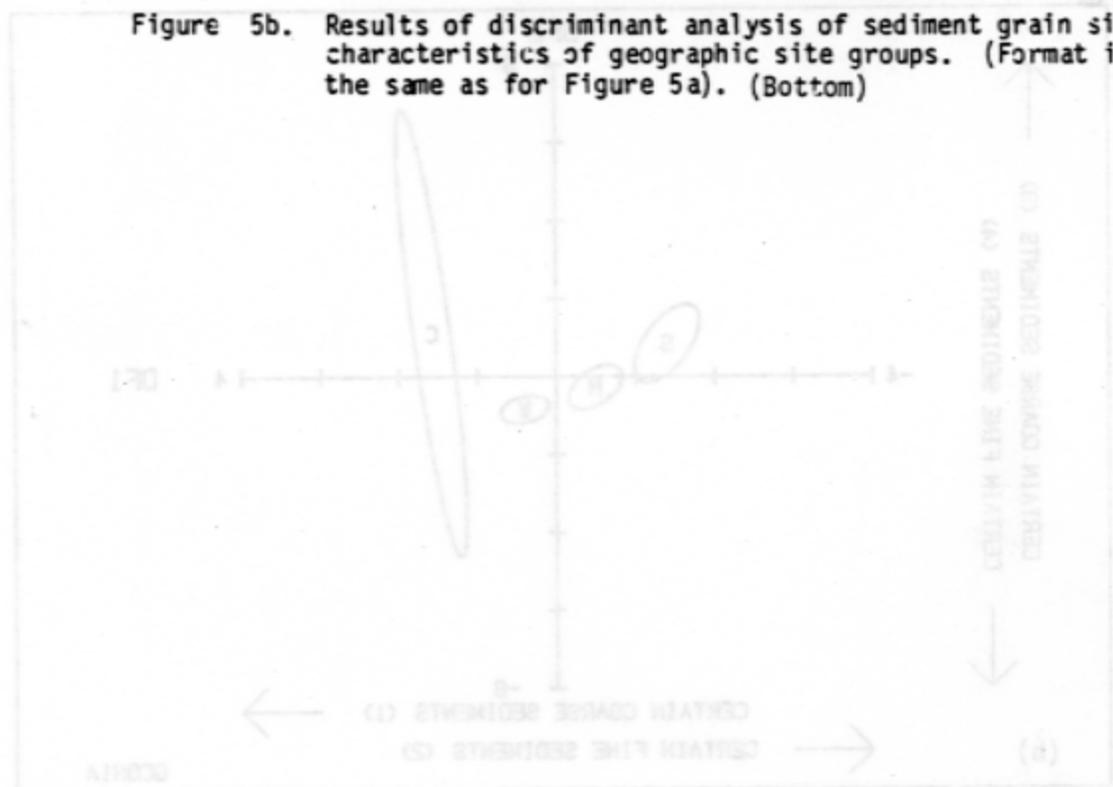
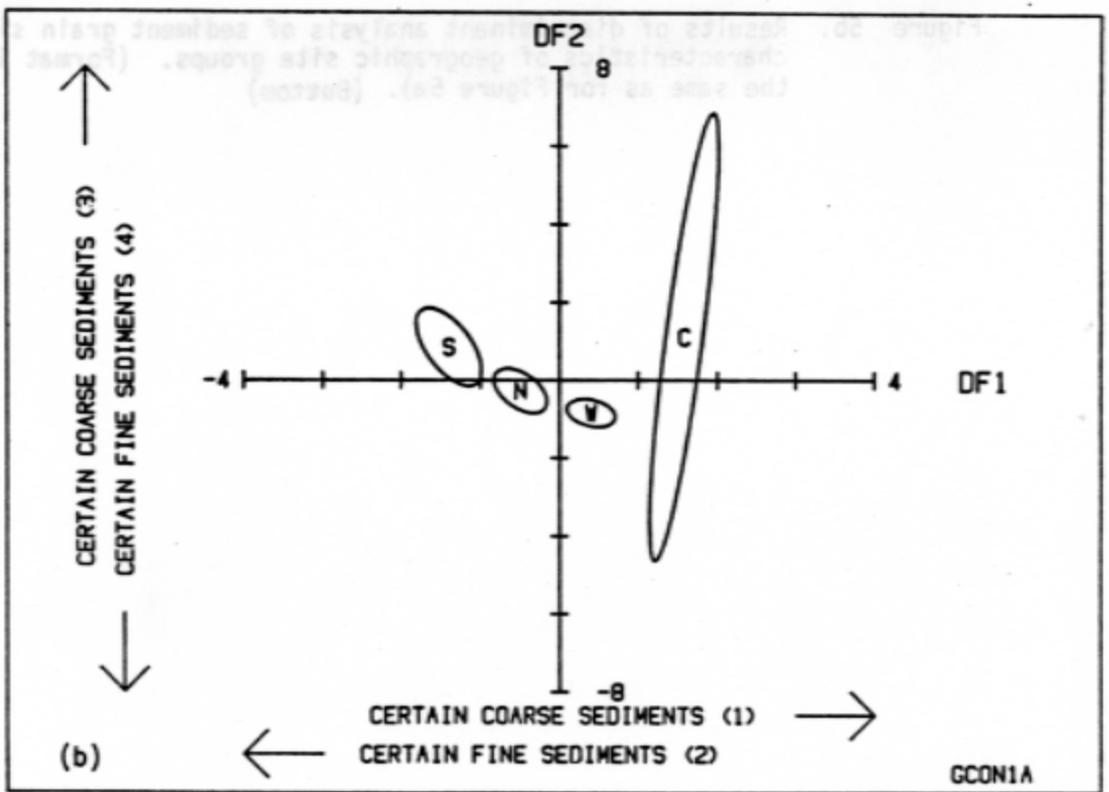
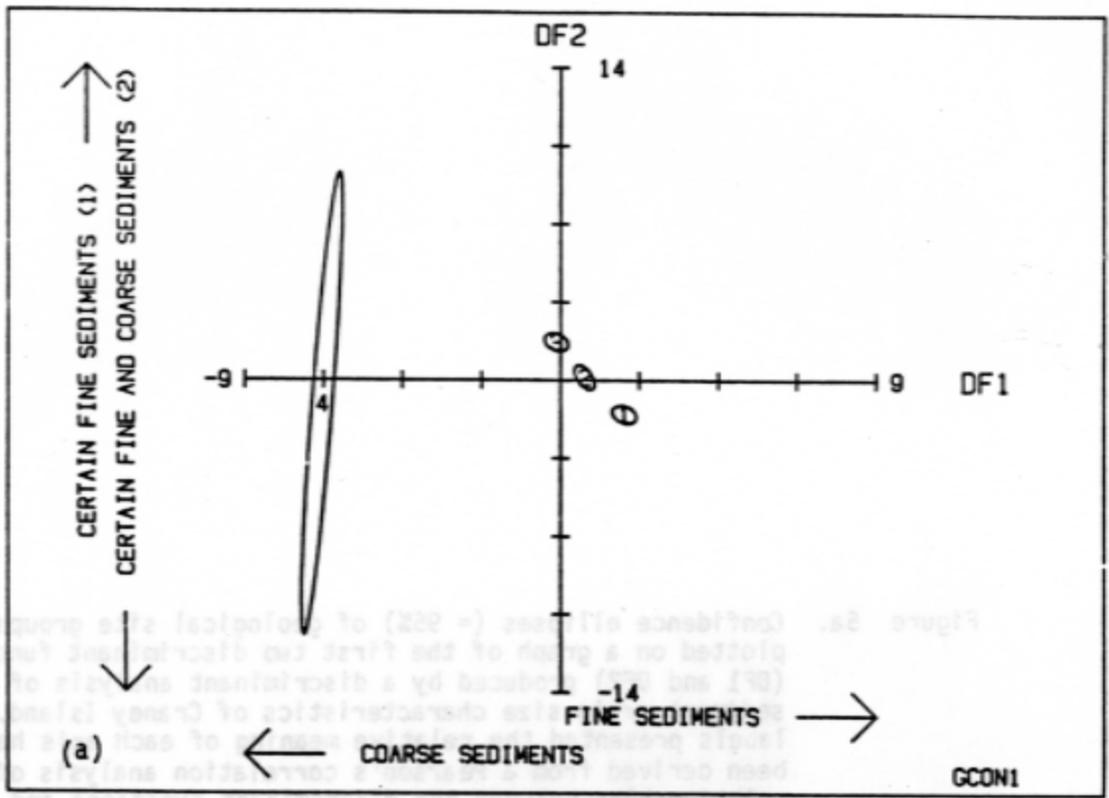


Figure 5b. Results of discriminant analysis of sediment grain size characteristics of geographic site groups. (Format is the same as for Figure 5a). (Bottom)



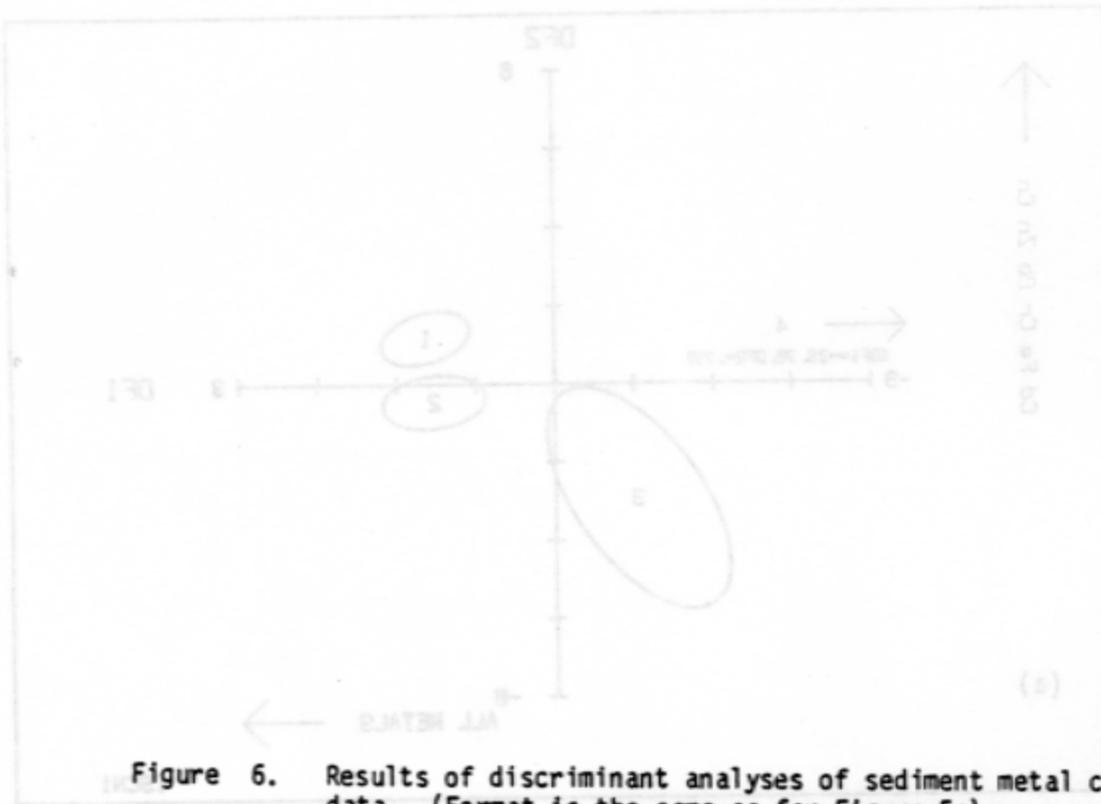
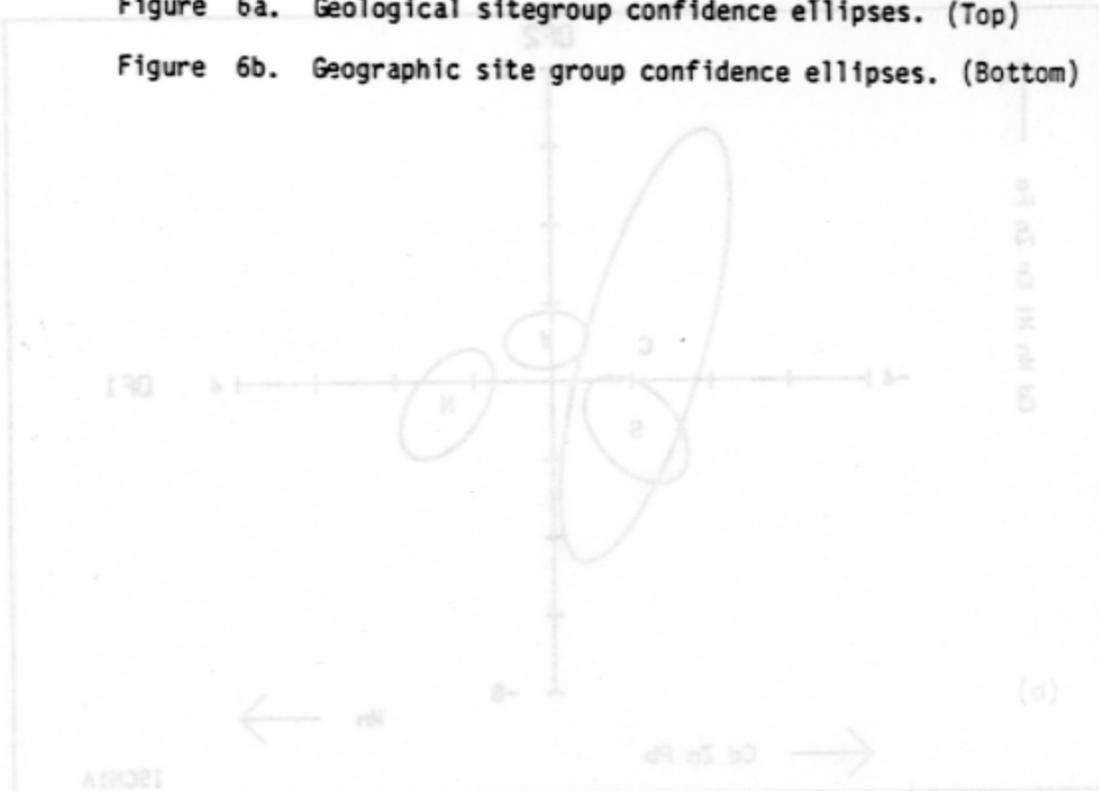


Figure 6. Results of discriminant analyses of sediment metal content data. (Format is the same as for Figure 5a).

Figure 6a. Geological site group confidence ellipses. (Top)

Figure 6b. Geographic site group confidence ellipses. (Bottom)



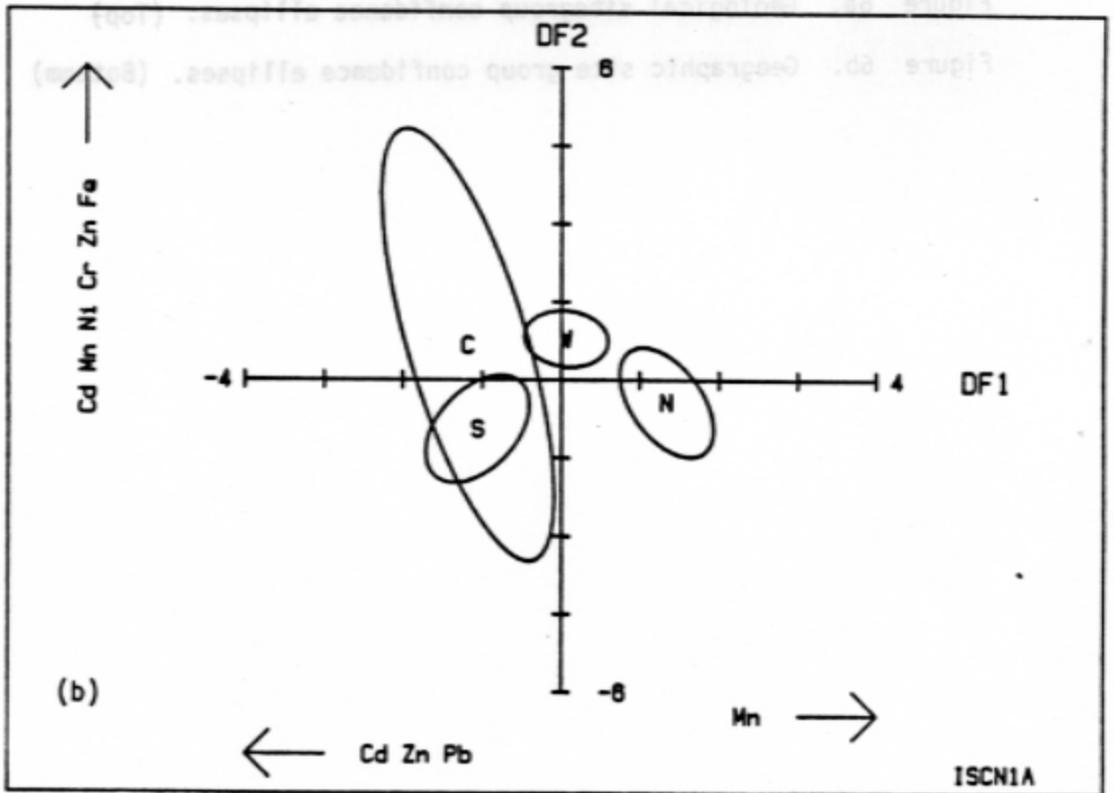
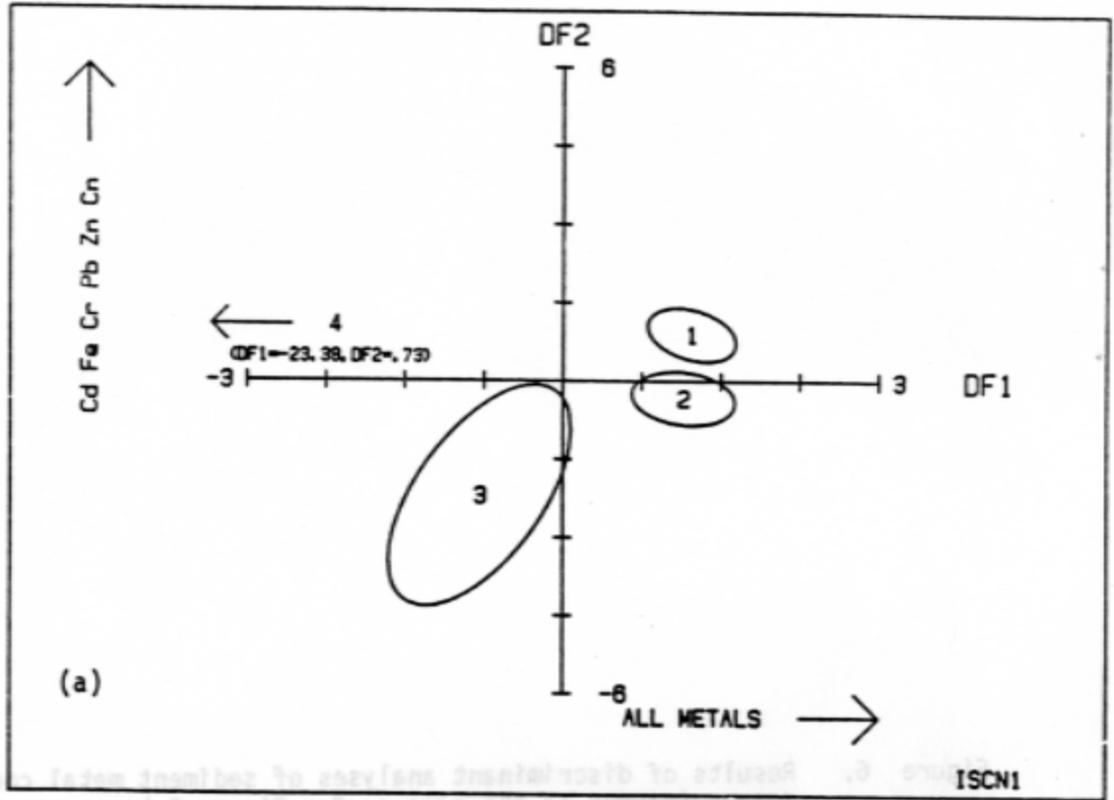




Figure 7. Results of PCA of elutriate chemistry data. (Format is the same as for Figure 4a).

Figure 7a. PCA1 scores for inorganic elutriate chemistry data. (Top)

Figure 7b. PCA2 scores for inorganic elutriate chemistry data. (Bottom)



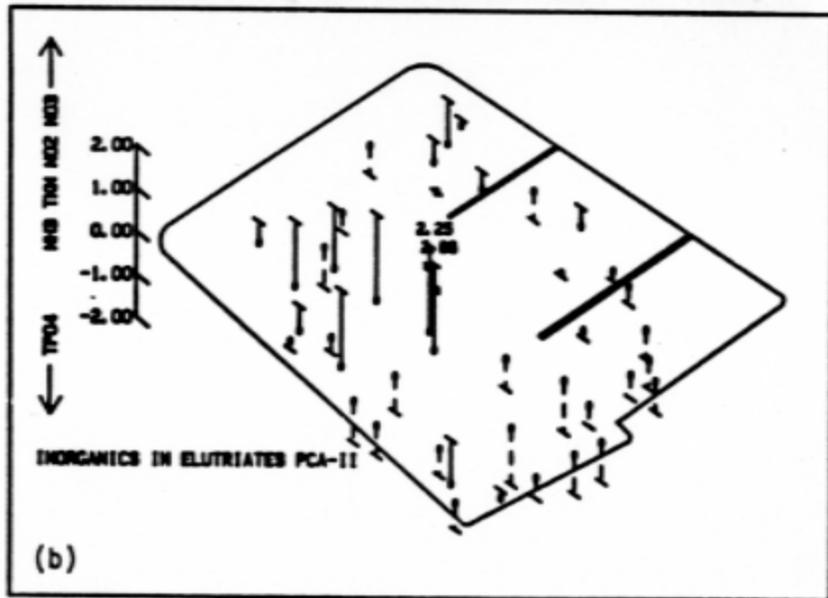
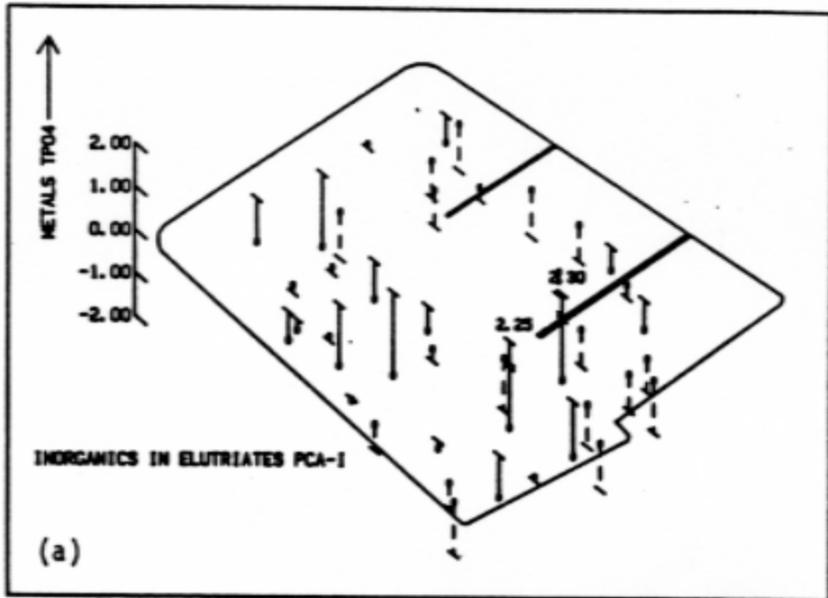


Figure 10. PCA scores for inorganic elutriate chemistry data. (Bottom)

Figure 11. PCA scores for inorganic elutriate chemistry data. (Top)

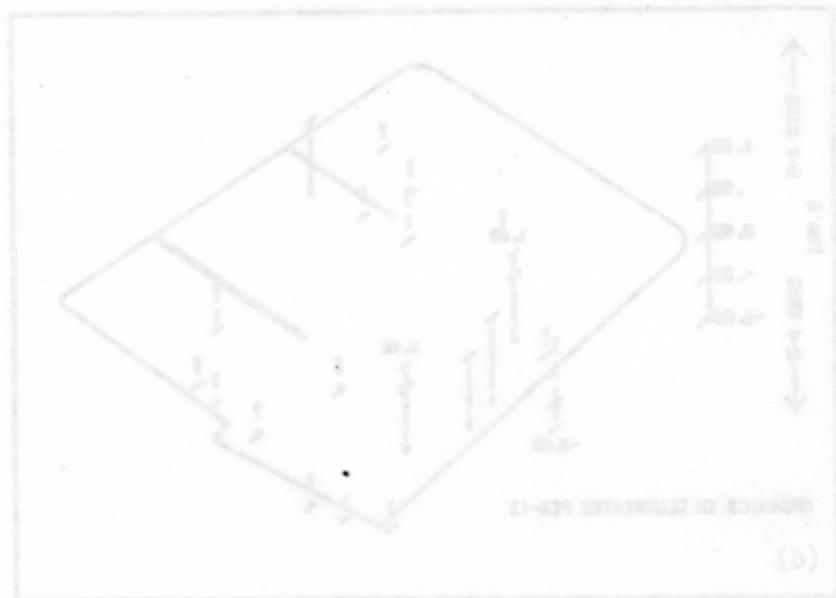
Figure 12. PCA scores for inorganic elutriate chemistry data. (Bottom)

Figure 13. PCA scores for inorganic elutriate chemistry data. (Top)



Figure 7c. PCA1 scores for PNAH elutriate chemistry data. (Top)

Figure 7d. PCA2 scores for PNAH elutriate chemistry data. (Bottom)



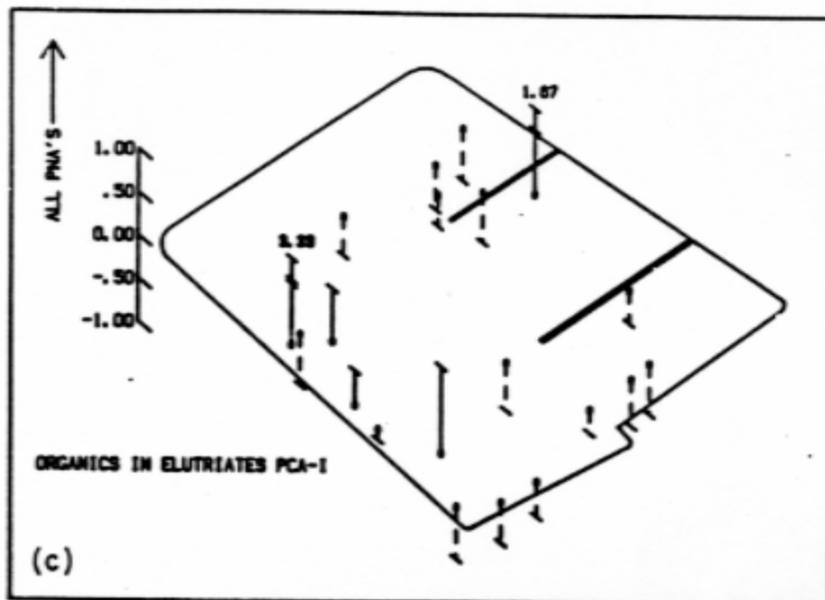
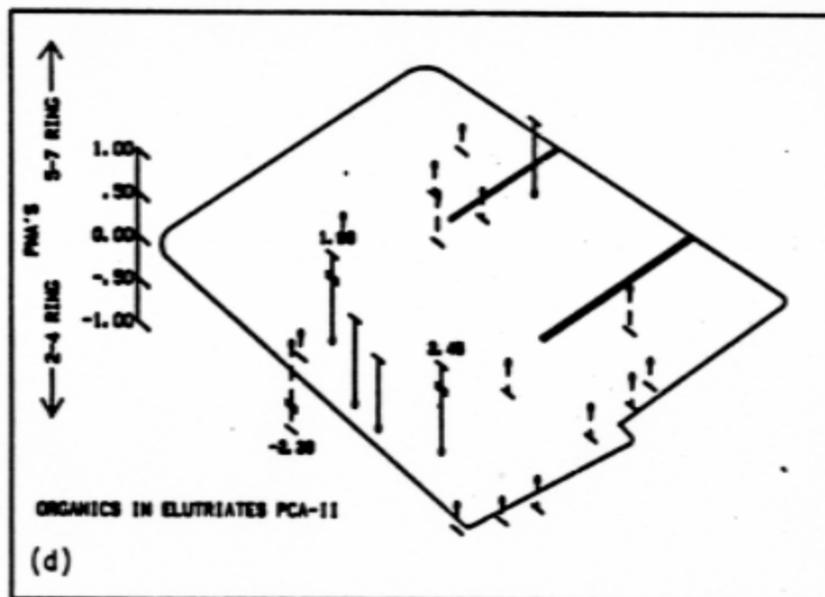


Figure 1c. PCAS scores for PNH elutriate chemistry data. (Top)

Figure 1d. PCAS scores for PNH elutriate chemistry data. (Bottom)



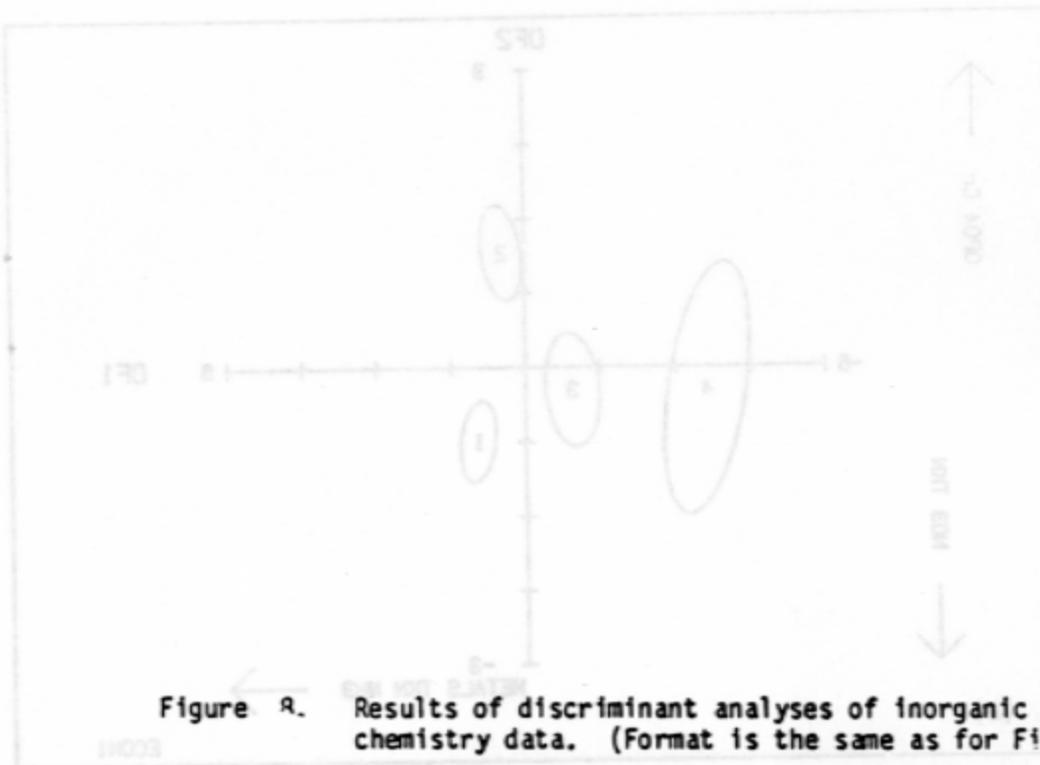
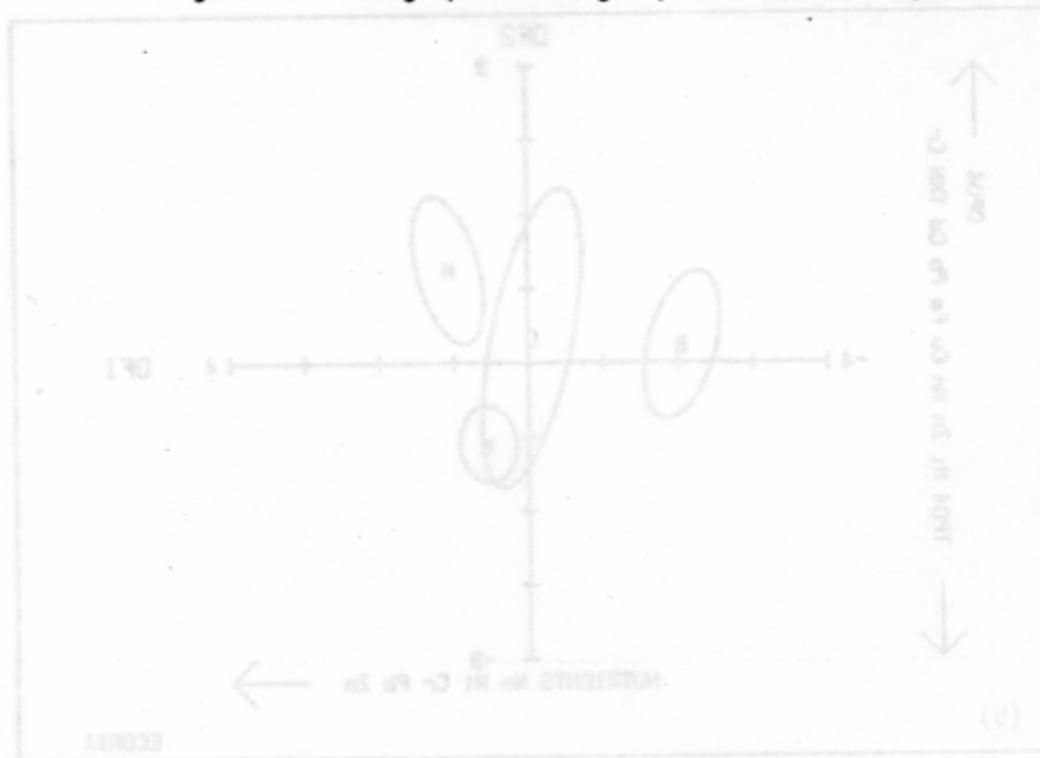


Figure 8a. Results of discriminant analyses of inorganic elutriate chemistry data. (Format is the same as for Figure 5a).

Figure 8a. Geological site group confidence ellipses. (Top)

Figure 8b. Geographic site group confidence ellipses. (Bottom)



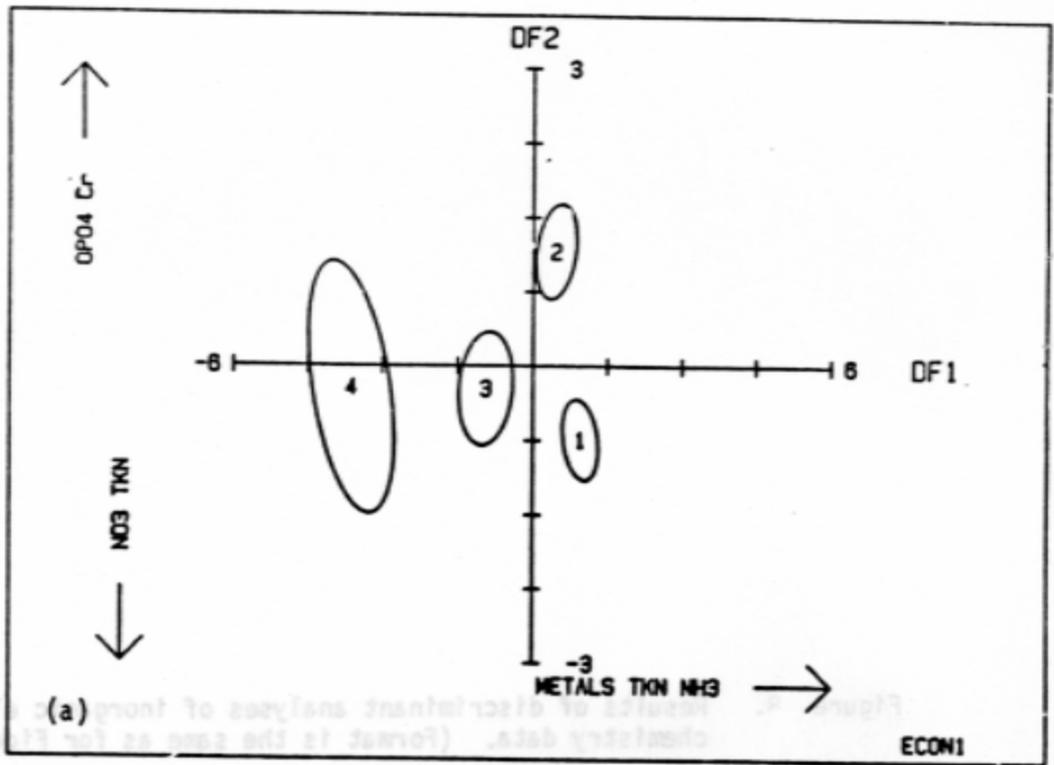
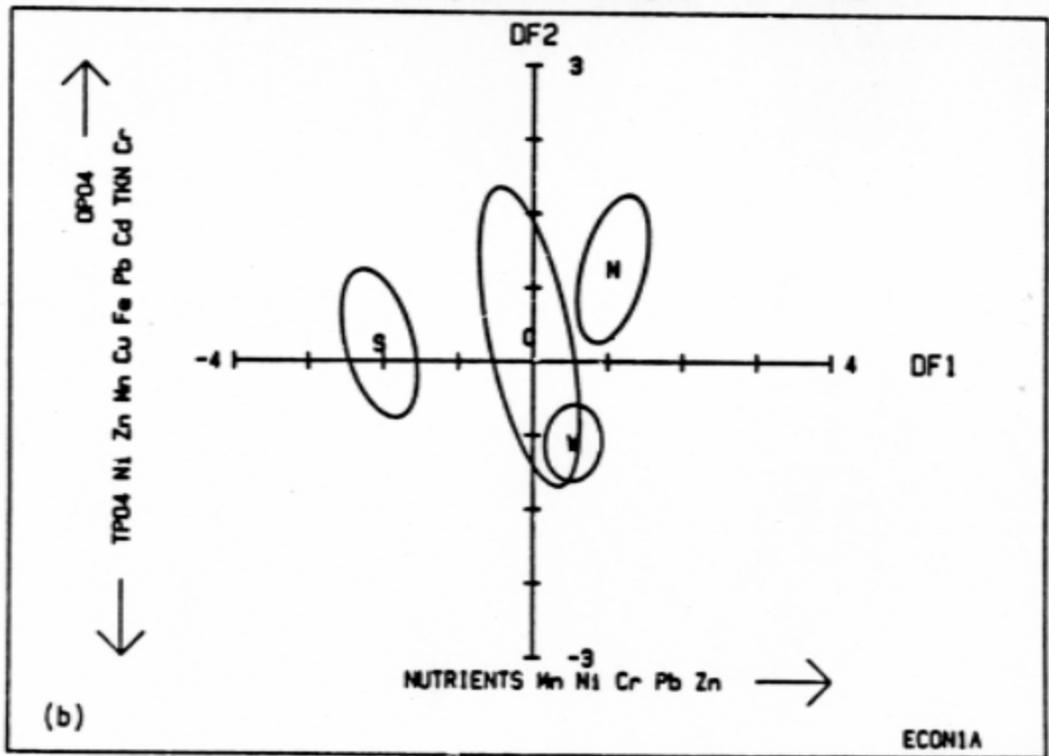


Figure 8a. Geologic site group confidence ellipses. (Top)
 Figure 8b. Geographic site group confidence ellipses. (Bottom)



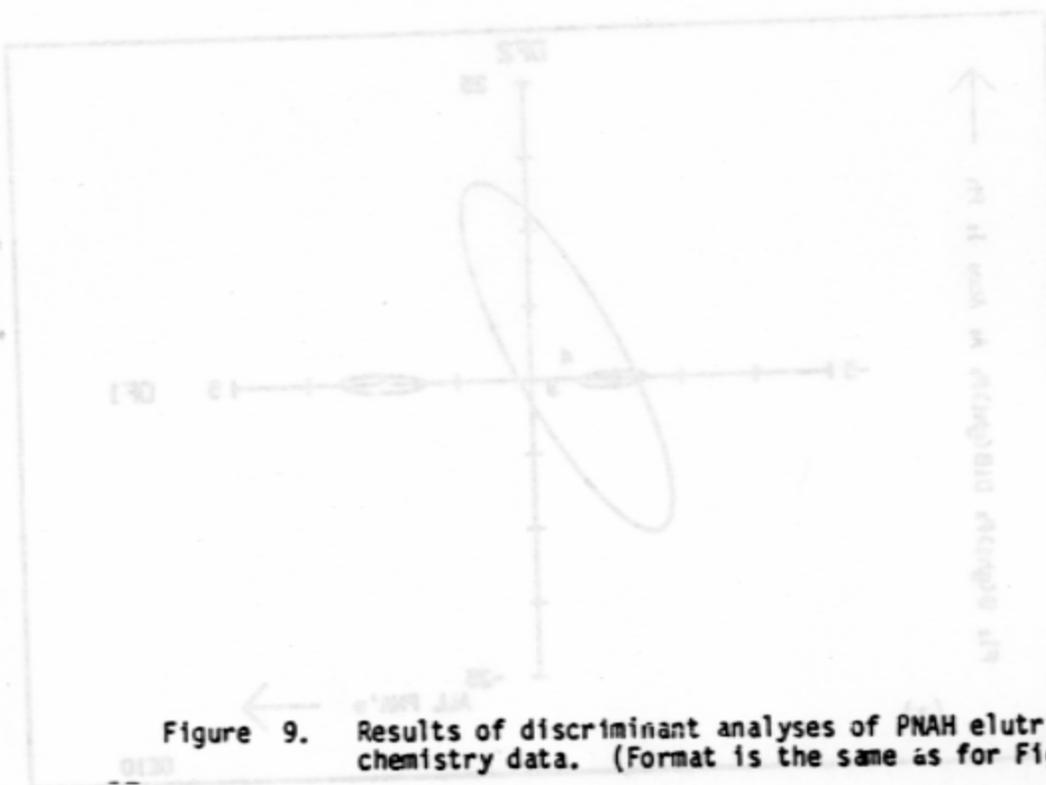
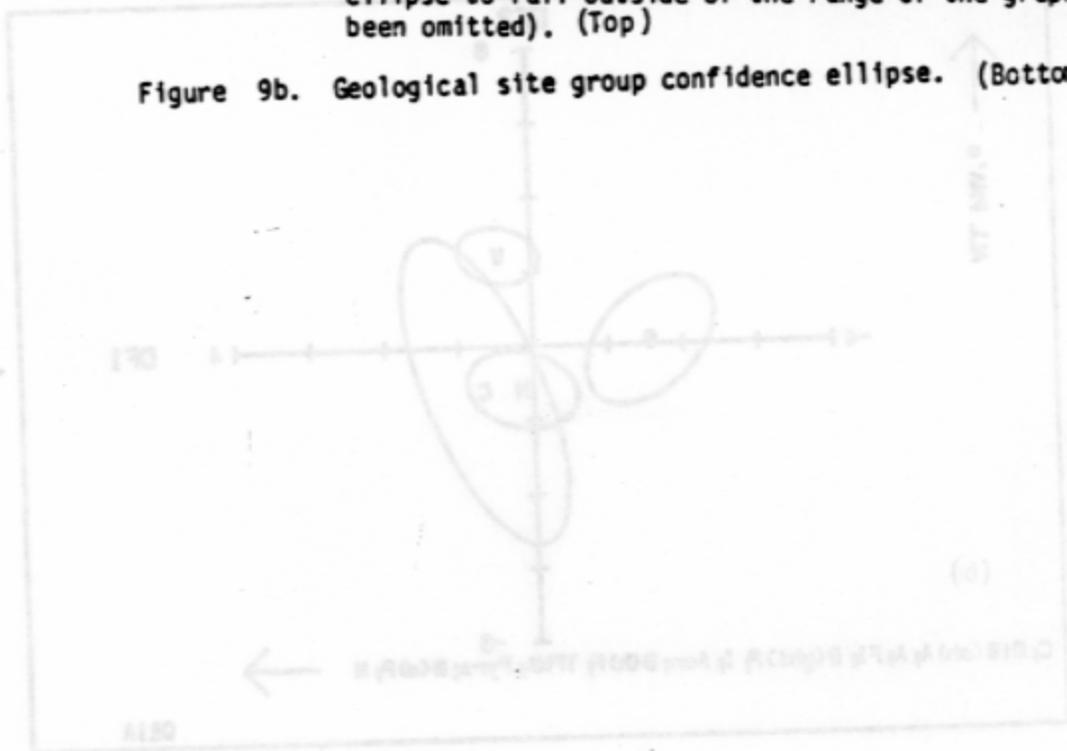


Figure 9a. Geological site group confidence ellipse. (NOTE: Since low numbers of replicates caused portions of the group 3 ellipse to fall outside of the range of the graph it has been omitted). (Top)

Figure 9b. Geological site group confidence ellipse. (Bottom).



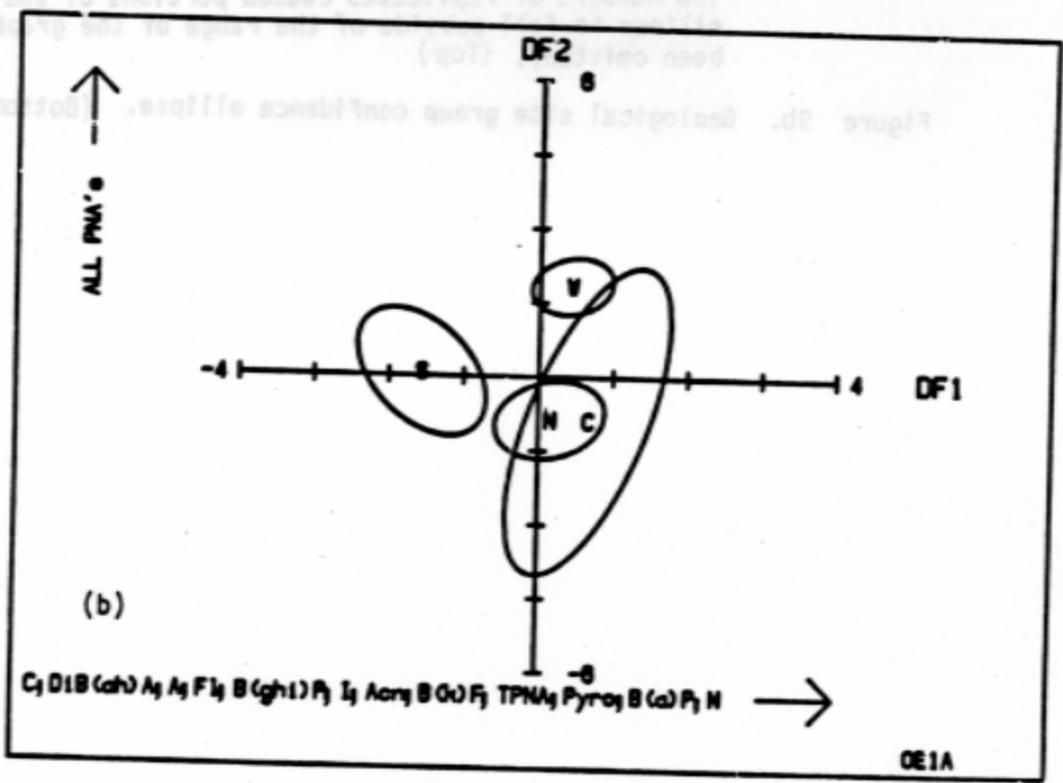
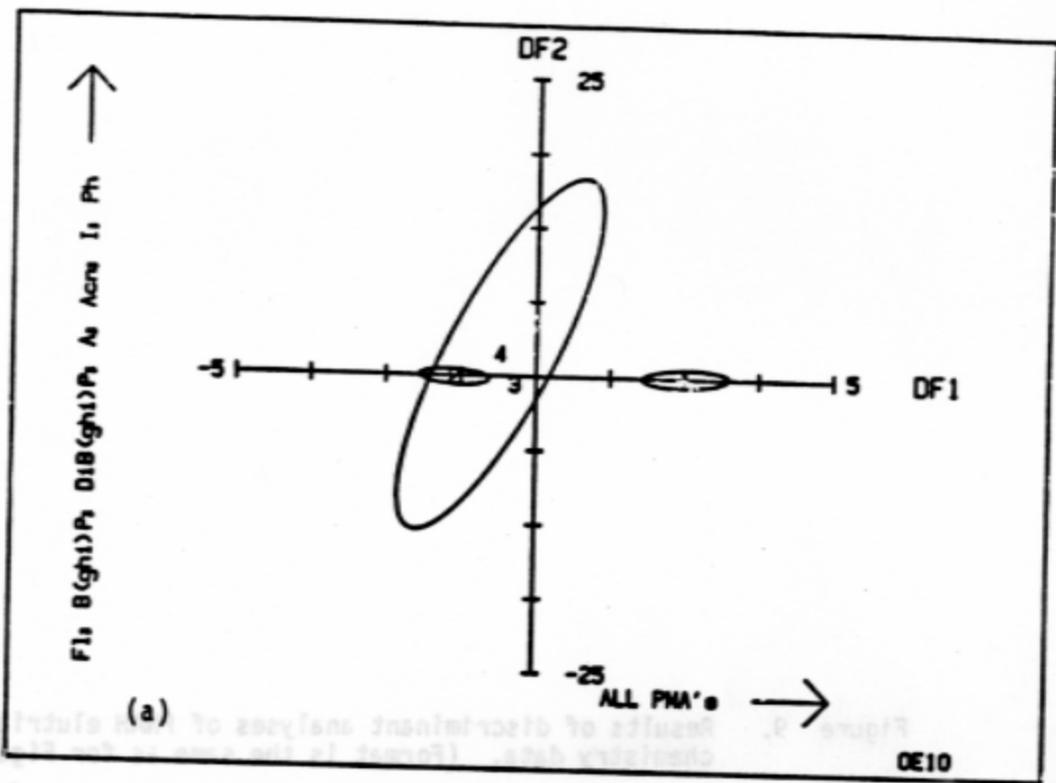
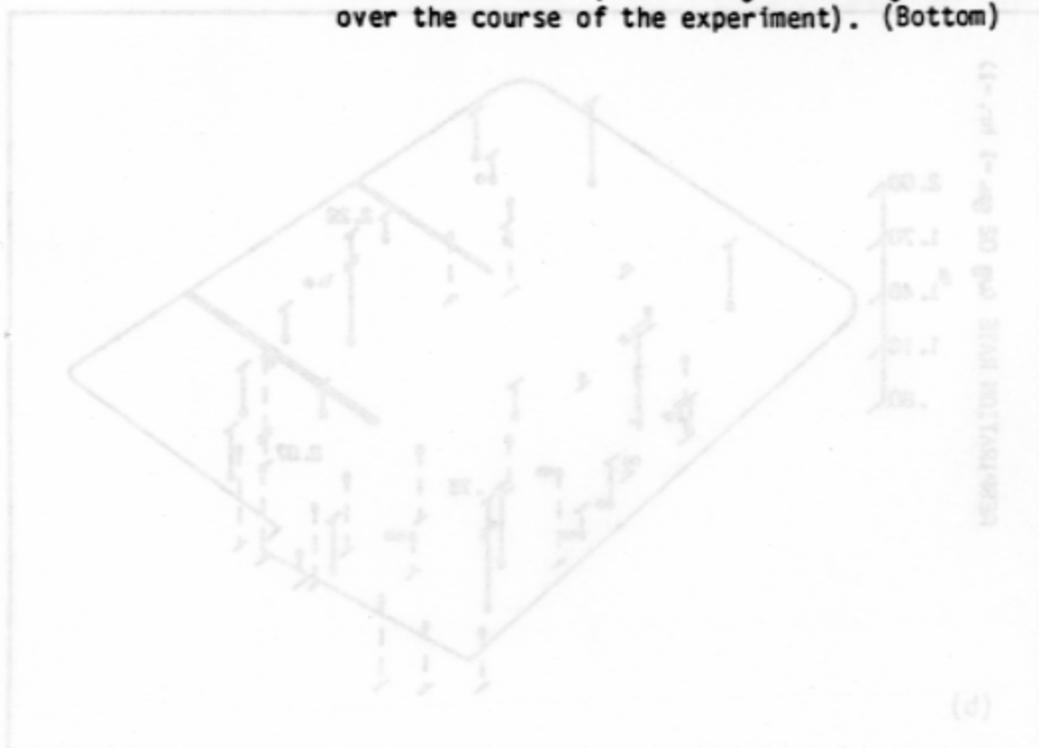




Figure 10. Results of biological tests of *Palaemonetes pugio* exposed to suspended solid elutriates for 96 hours. Single stars indicate stations containing sediment fractions producing biological responses which are significantly ($\alpha = 0.05$) different from those observed under control conditions.

Figure 10a. Mortalities. (Top)

Figure 10b. Respiration rates. (Five day average). Double stars indicate stations producing a significant time effect in the ANCOVA model (i.e. a significantly declining respiration over the course of the experiment). (Bottom)



100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200

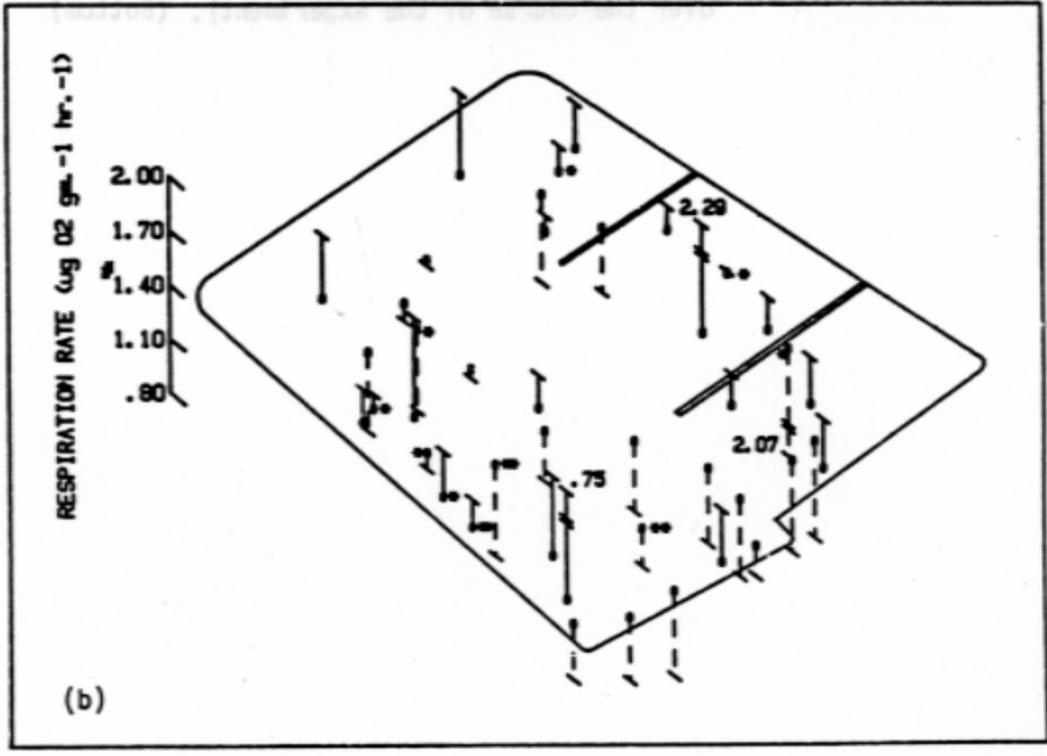
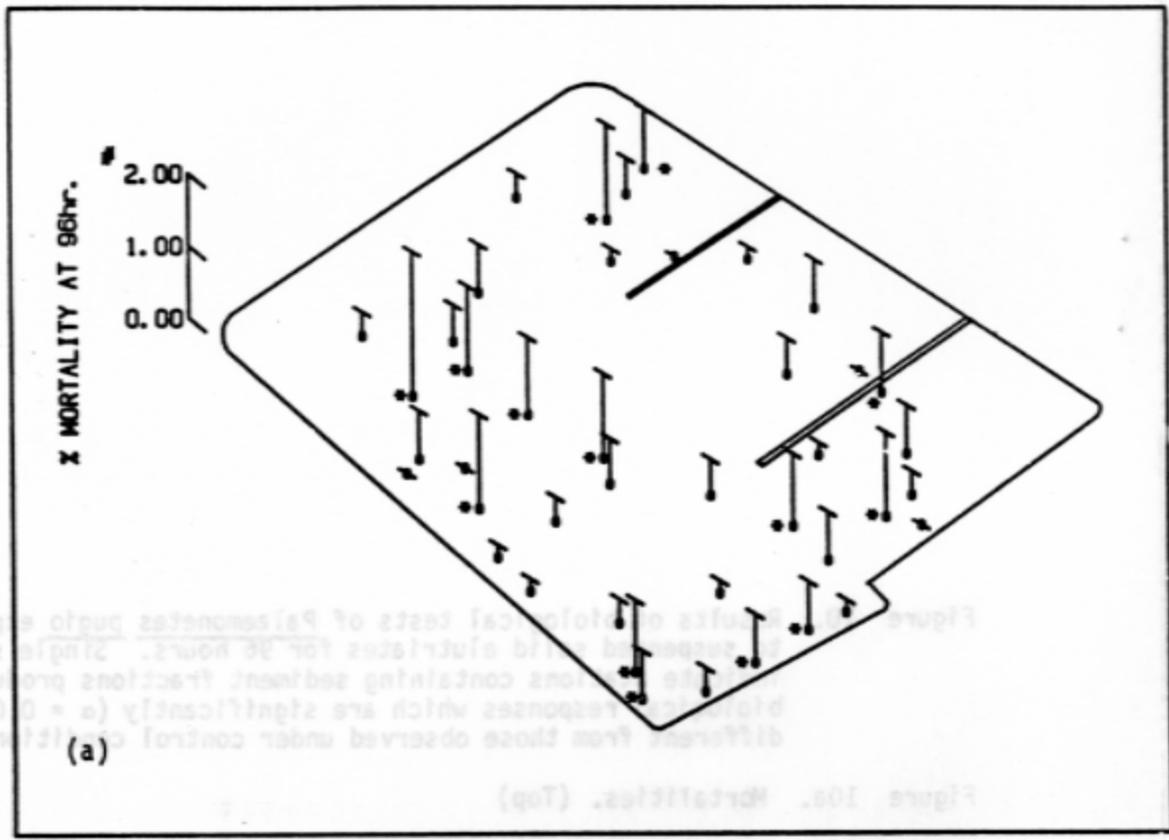




Figure 10c. Internal osmolality of shrimp exposed to low salinity conditions (10 ppt) following the 96 hour experiment. (Top)

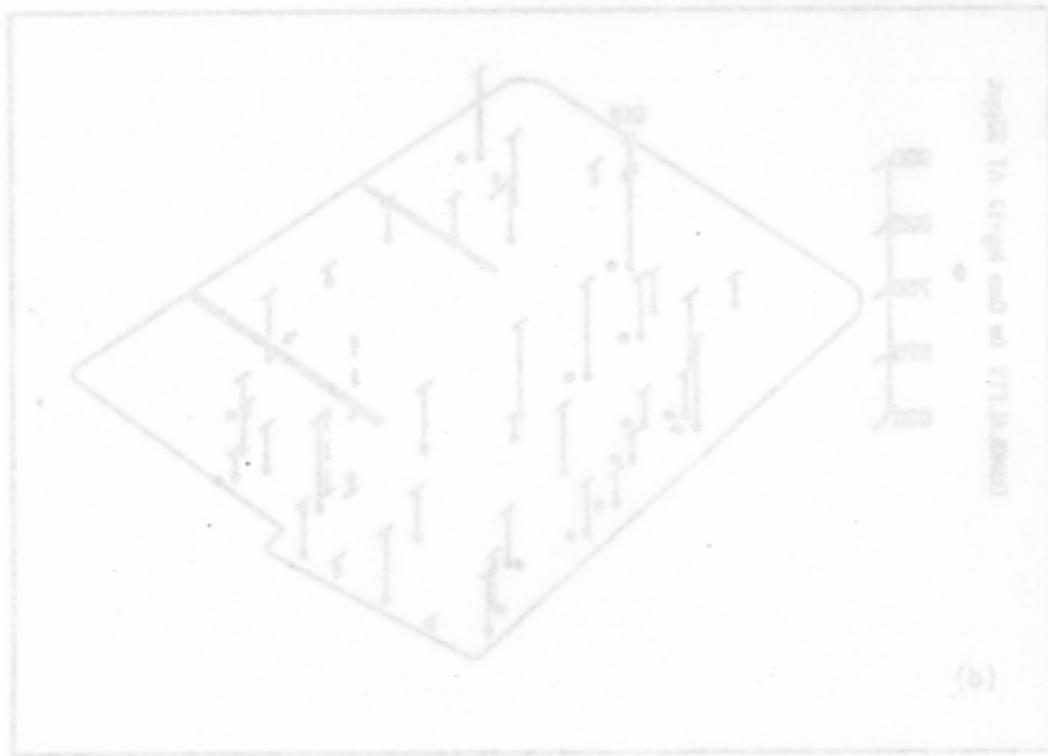


Figure 10d. Internal osmolality shrimp exposed to high salinity conditions (35 ppt) following the 95 hour experiment. (Bottom)

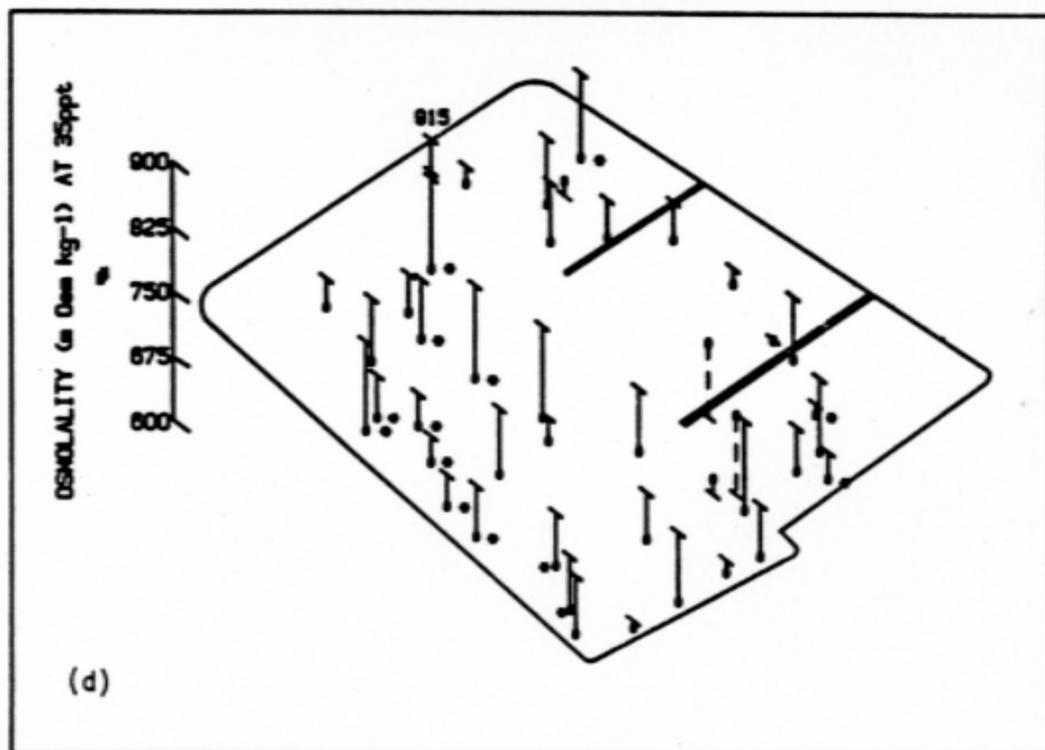
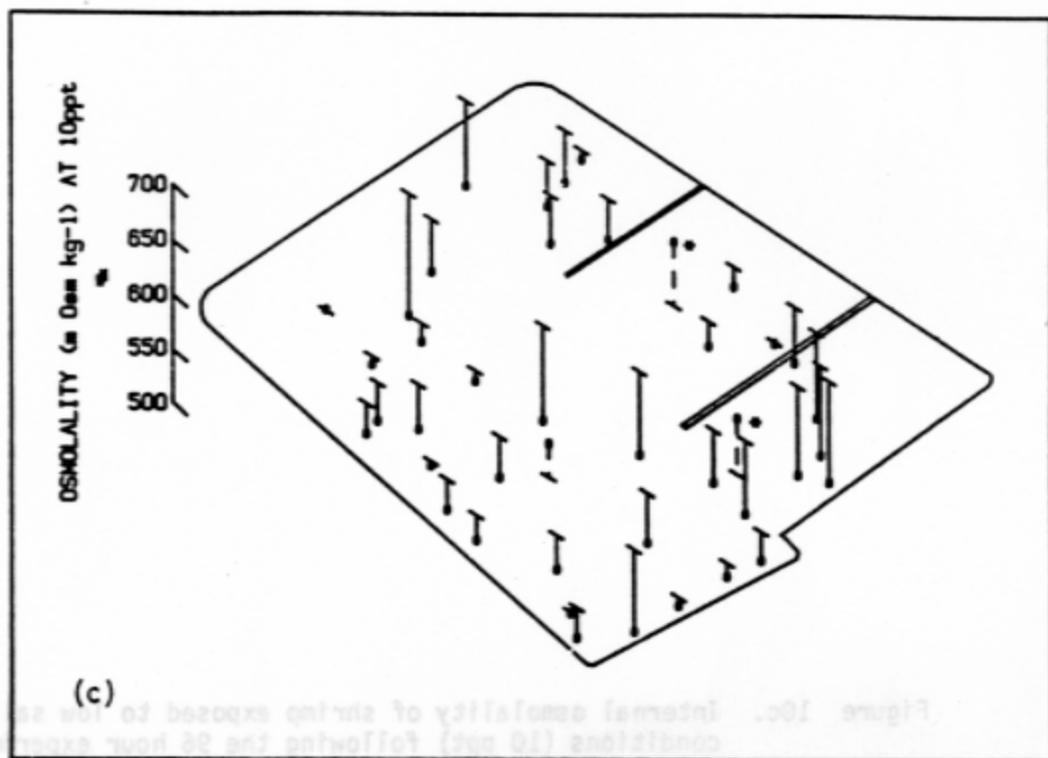
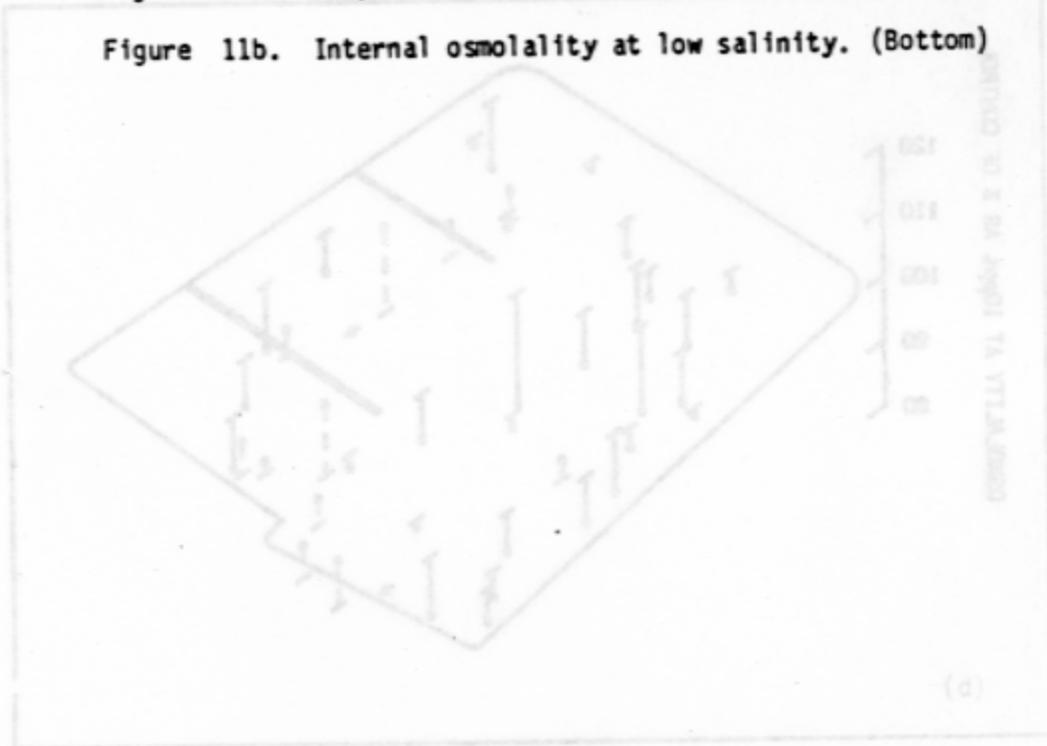


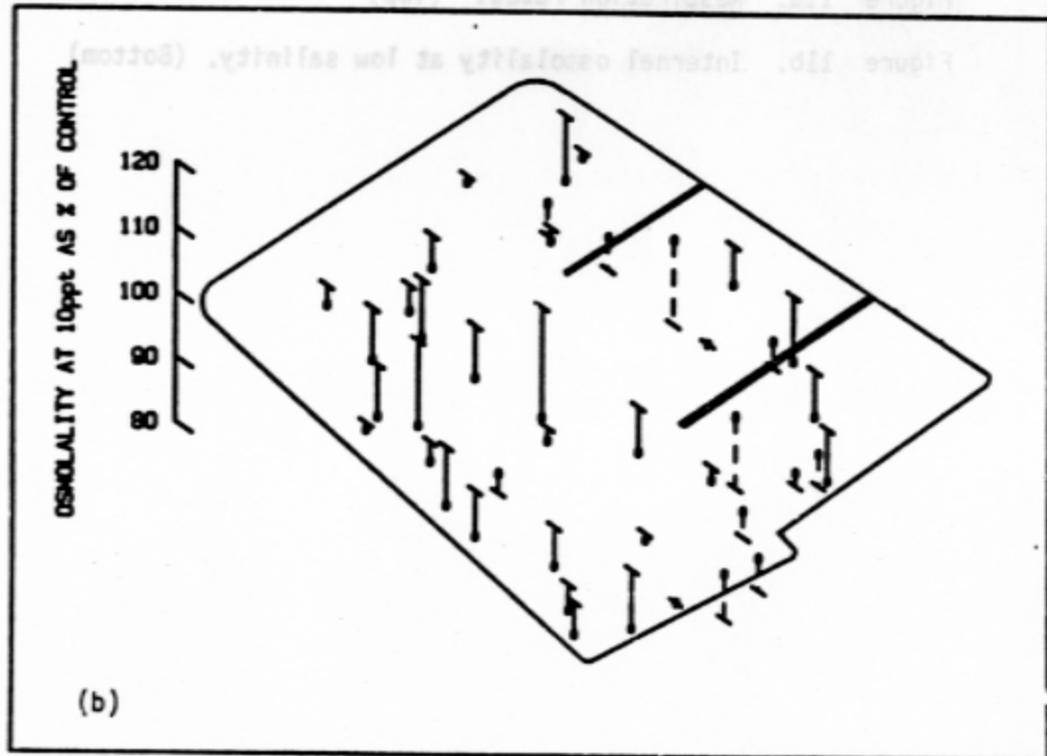
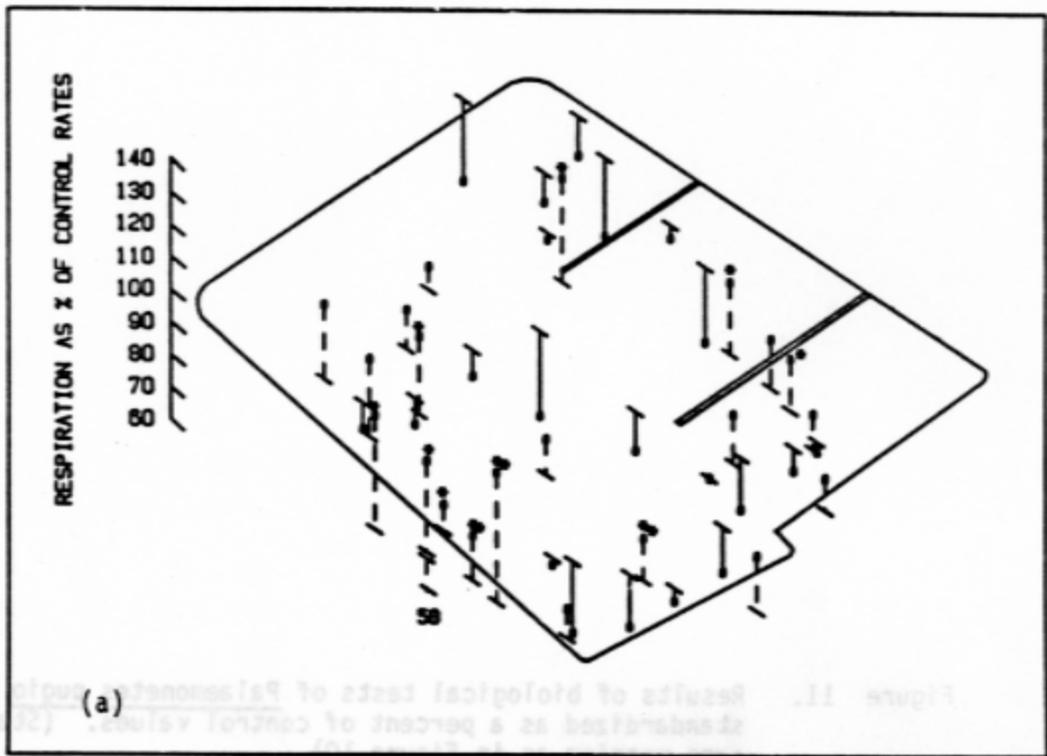


Figure 11. Results of biological tests of Palaemonetes pugio standardized as a percent of control values. (Stars remain same meaning as in Figure 10).

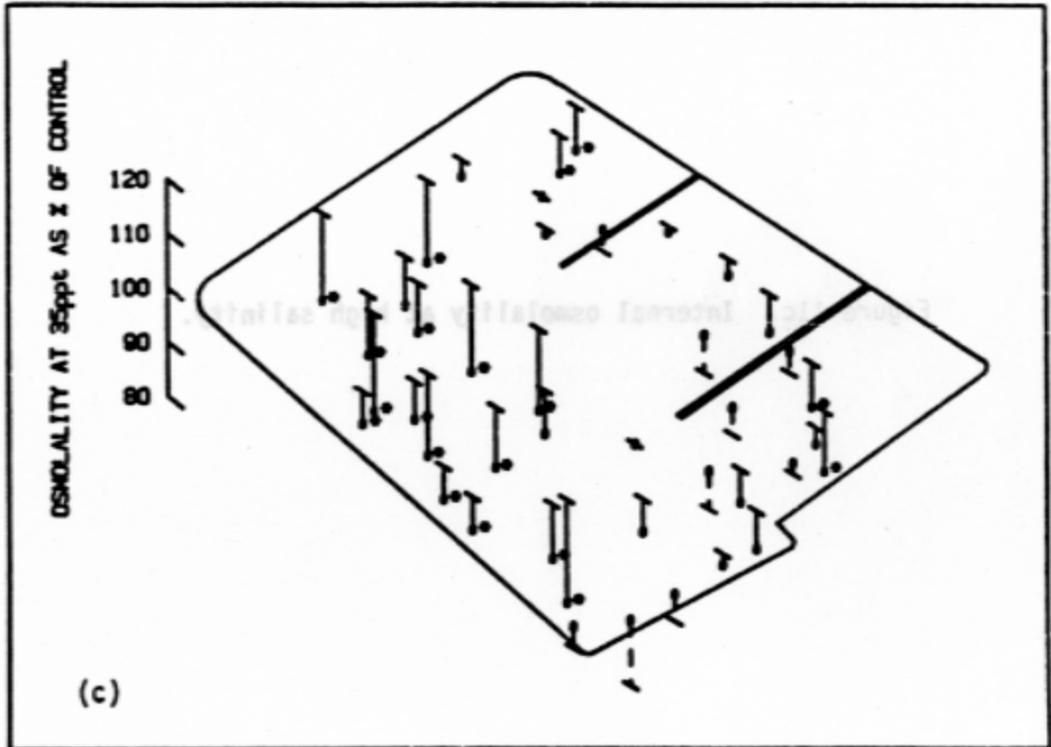
Figure 11a. Respiration rates. (Top)

Figure 11b. Internal osmolality at low salinity. (Bottom)





17 206 002 202 204 206 208 210 212 214 216 218 220 222 224 226 228 230 232 234 236 238 240 242 244 246 248 250 252 254 256 258 260 262 264 266 268 270 272 274 276 278 280 282 284 286 288 290 292 294 296 298 300 302 304 306 308 310 312 314 316 318 320 322 324 326 328 330 332 334 336 338 340 342 344 346 348 350 352 354 356 358 360 362 364 366 368 370 372 374 376 378 380 382 384 386 388 390 392 394 396 398 400 402 404 406 408 410 412 414 416 418 420 422 424 426 428 430 432 434 436 438 440 442 444 446 448 450 452 454 456 458 460 462 464 466 468 470 472 474 476 478 480 482 484 486 488 490 492 494 496 498 500 502 504 506 508 510 512 514 516 518 520 522 524 526 528 530 532 534 536 538 540 542 544 546 548 550 552 554 556 558 560 562 564 566 568 570 572 574 576 578 580 582 584 586 588 590 592 594 596 598 600 602 604 606 608 610 612 614 616 618 620 622 624 626 628 630 632 634 636 638 640 642 644 646 648 650 652 654 656 658 660 662 664 666 668 670 672 674 676 678 680 682 684 686 688 690 692 694 696 698 700 702 704 706 708 710 712 714 716 718 720 722 724 726 728 730 732 734 736 738 740 742 744 746 748 750 752 754 756 758 760 762 764 766 768 770 772 774 776 778 780 782 784 786 788 790 792 794 796 798 800 802 804 806 808 810 812 814 816 818 820 822 824 826 828 830 832 834 836 838 840 842 844 846 848 850 852 854 856 858 860 862 864 866 868 870 872 874 876 878 880 882 884 886 888 890 892 894 896 898 900 902 904 906 908 910 912 914 916 918 920 922 924 926 928 930 932 934 936 938 940 942 944 946 948 950 952 954 956 958 960 962 964 966 968 970 972 974 976 978 980 982 984 986 988 990 992 994 996 998 1000



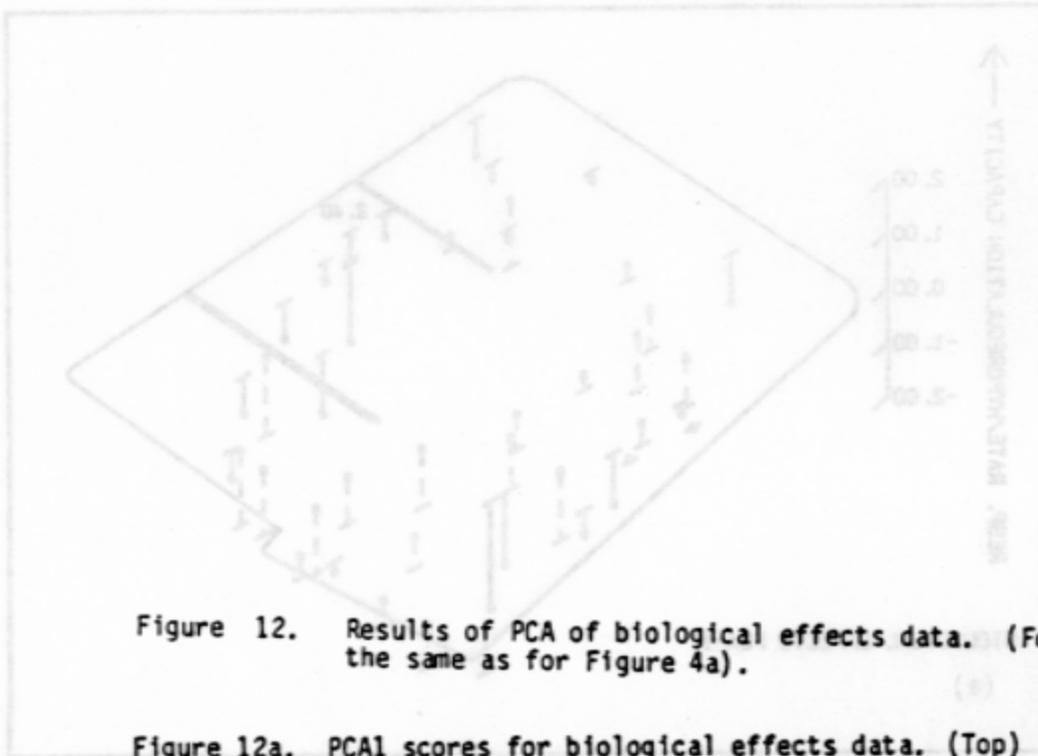
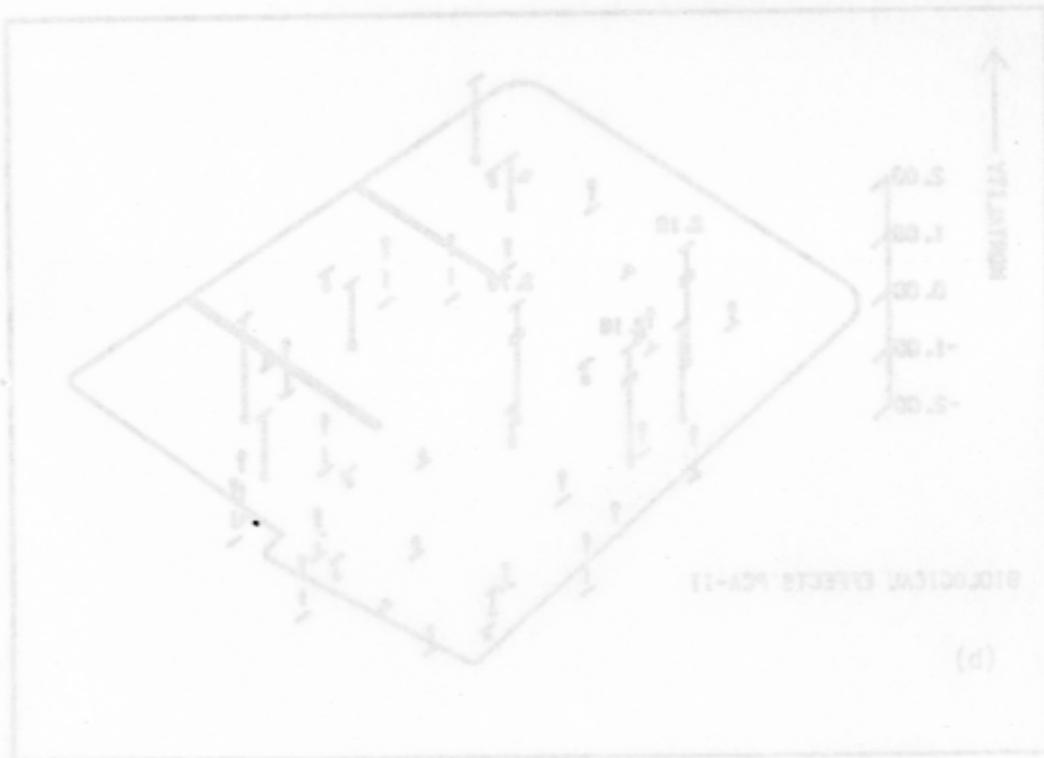
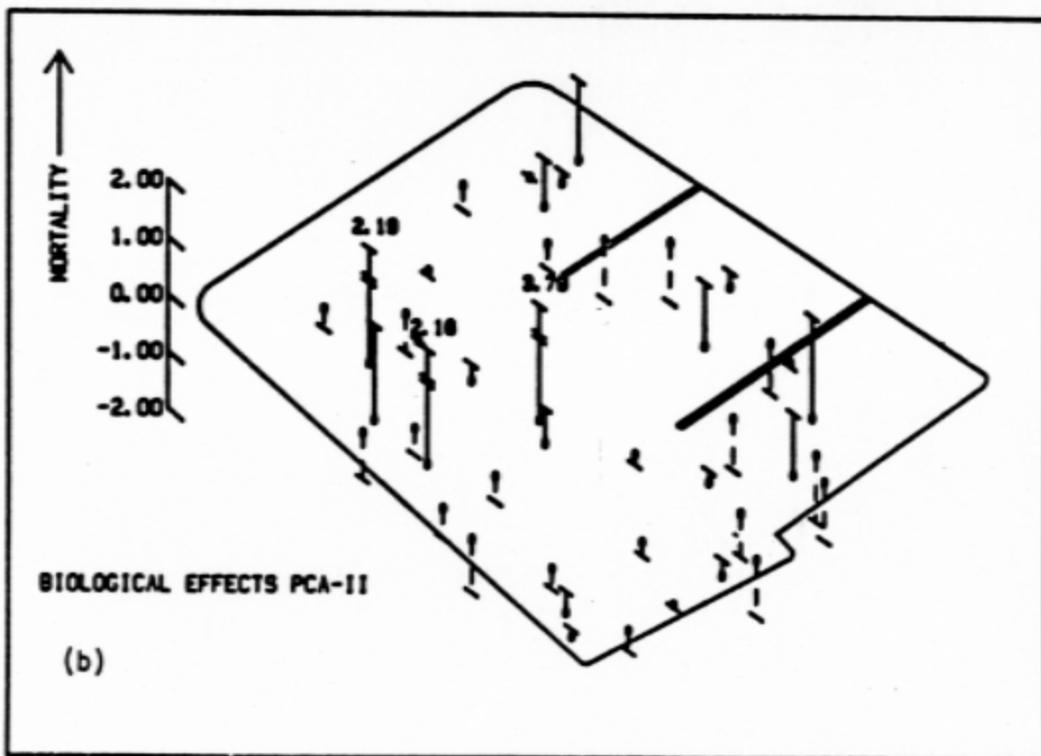
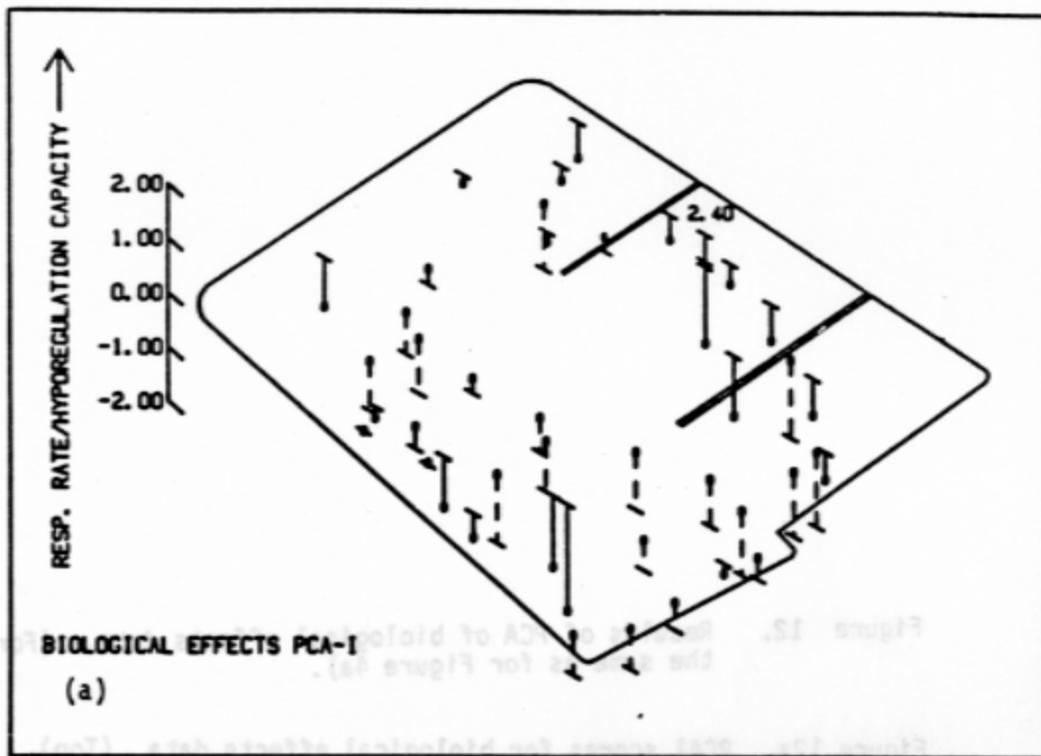


Figure 12b. PCA2 scores for biological effects data. (Bottom)





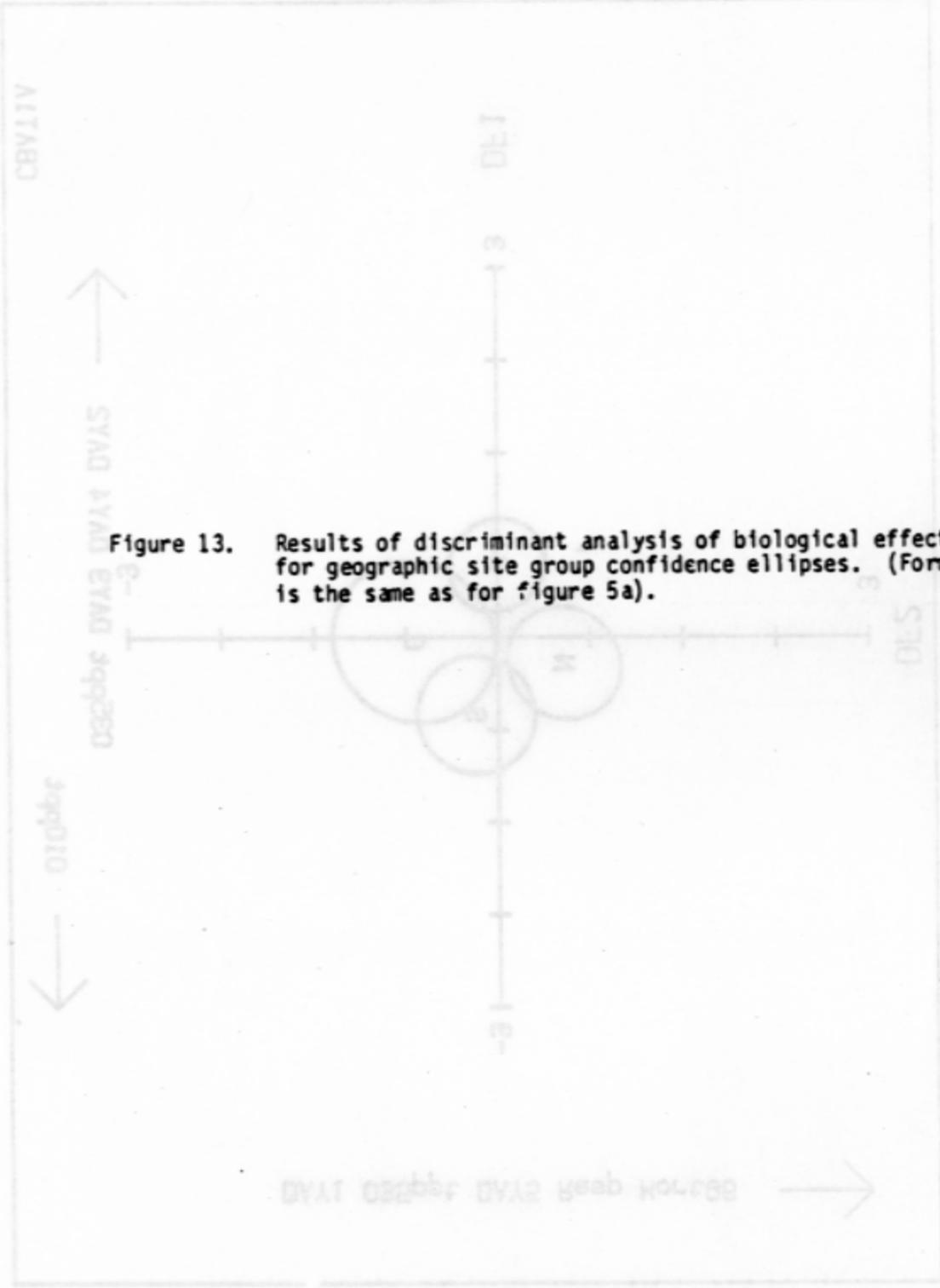


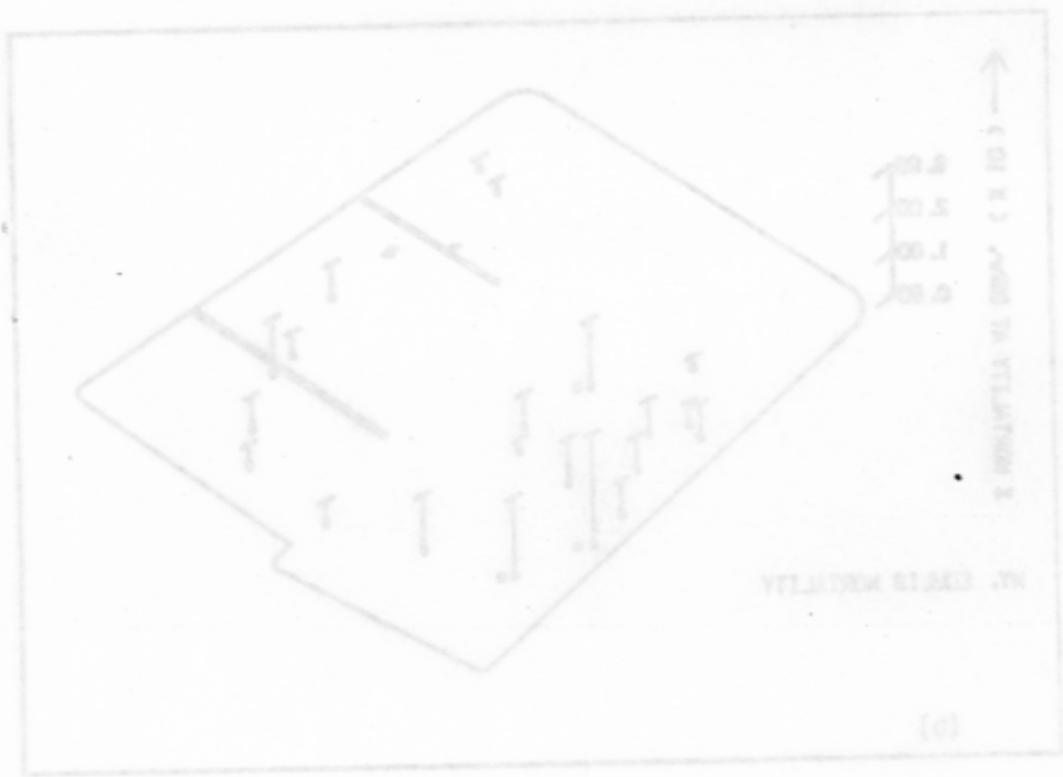
Figure 13. Results of discriminant analysis of biological effects data for geographic site group confidence ellipses. (Format is the same as for figure 5a).



Figure 14. Mortalities observed for solid phase bioassays. (Stars retain same meaning as in Figure 10).

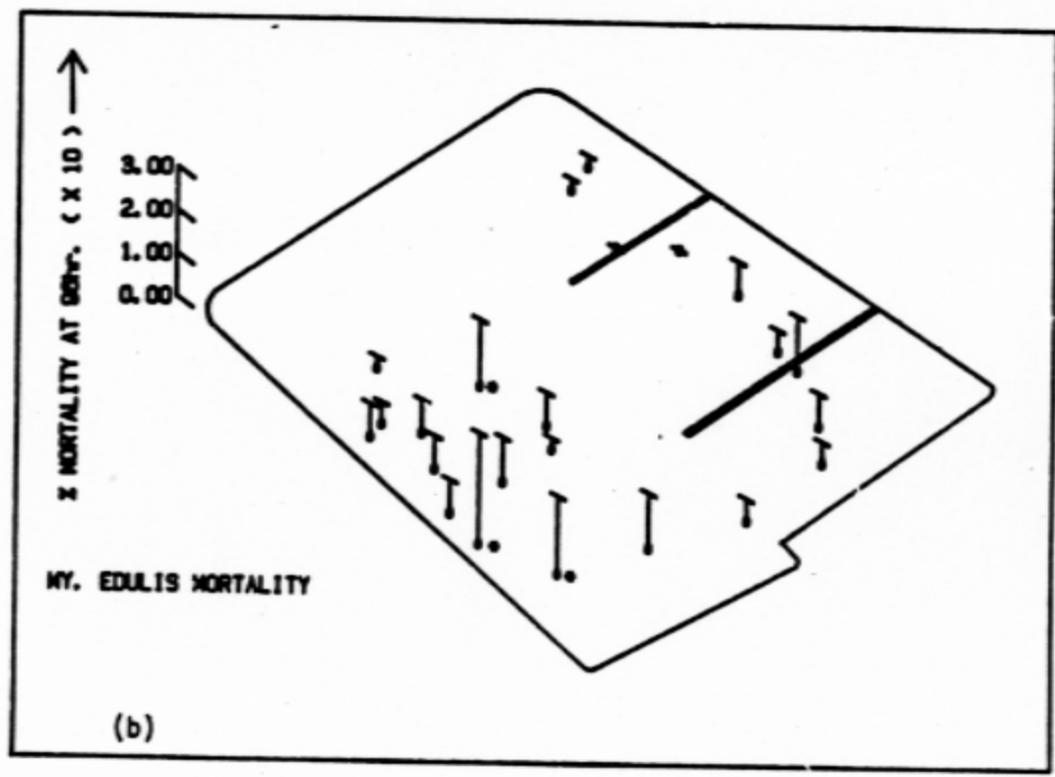
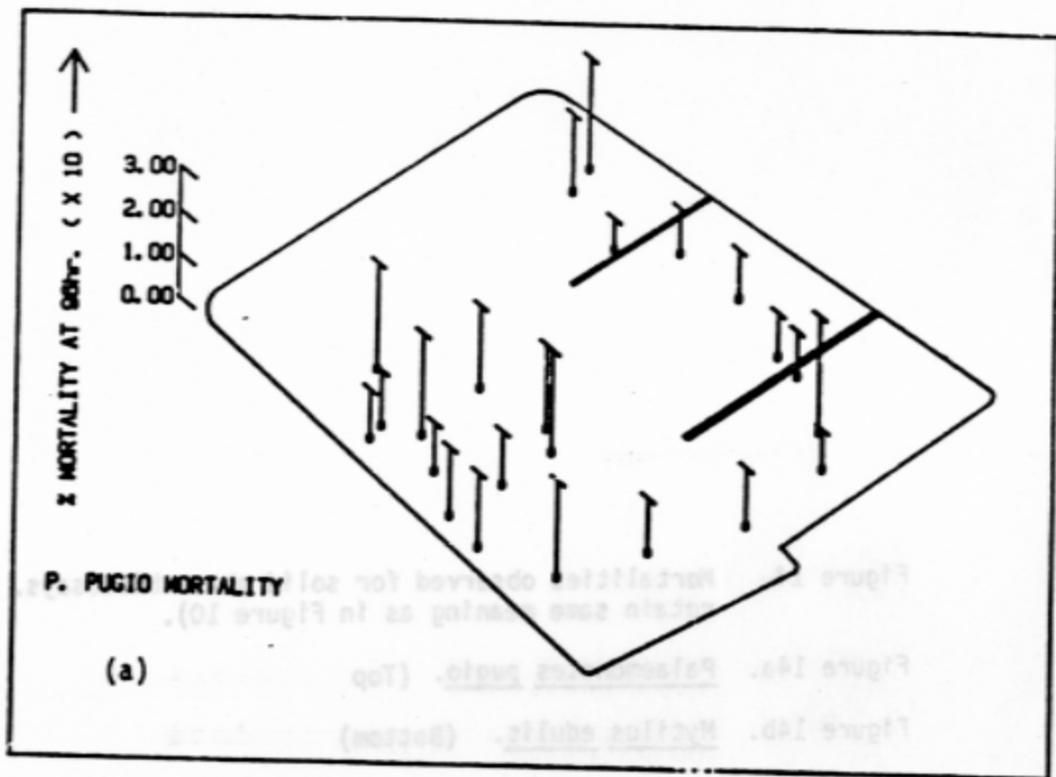
Figure 14a. Palaemonetes pugio. (Top)

Figure 14b. Mytilus edulis. (Bottom)



(c)

118 117 116 115 114 113 112 111 110 109 108 107 106 105 104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80 79 78 77 76 75 74 73 72 71 70 69 68 67 66 65 64 63 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1



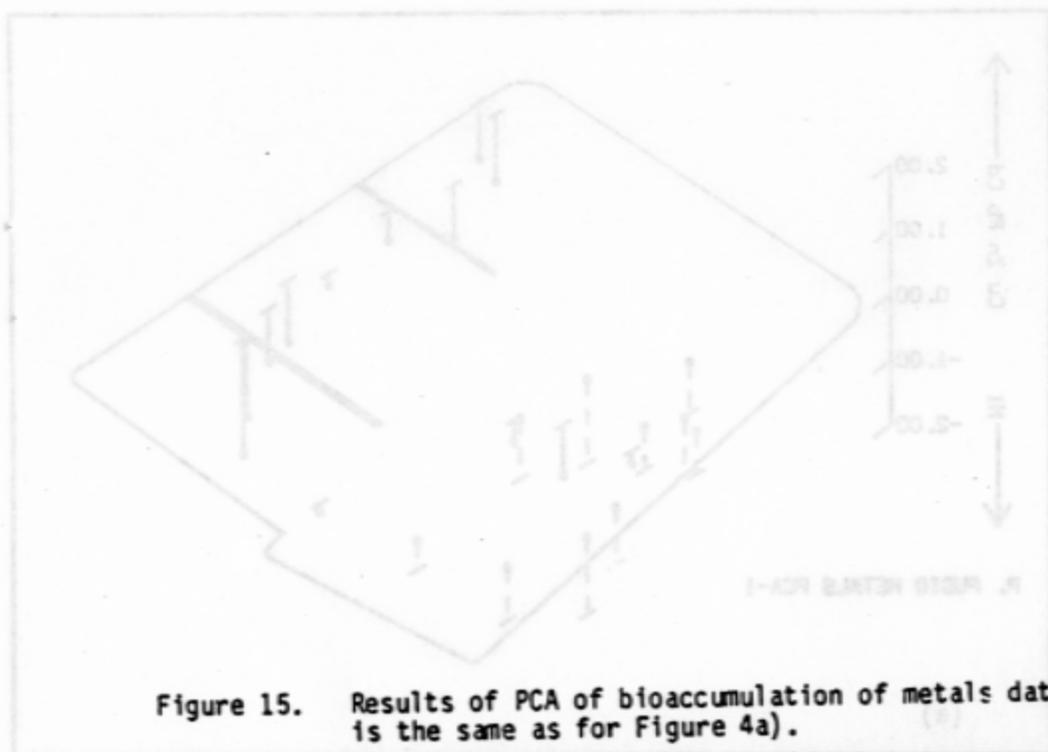
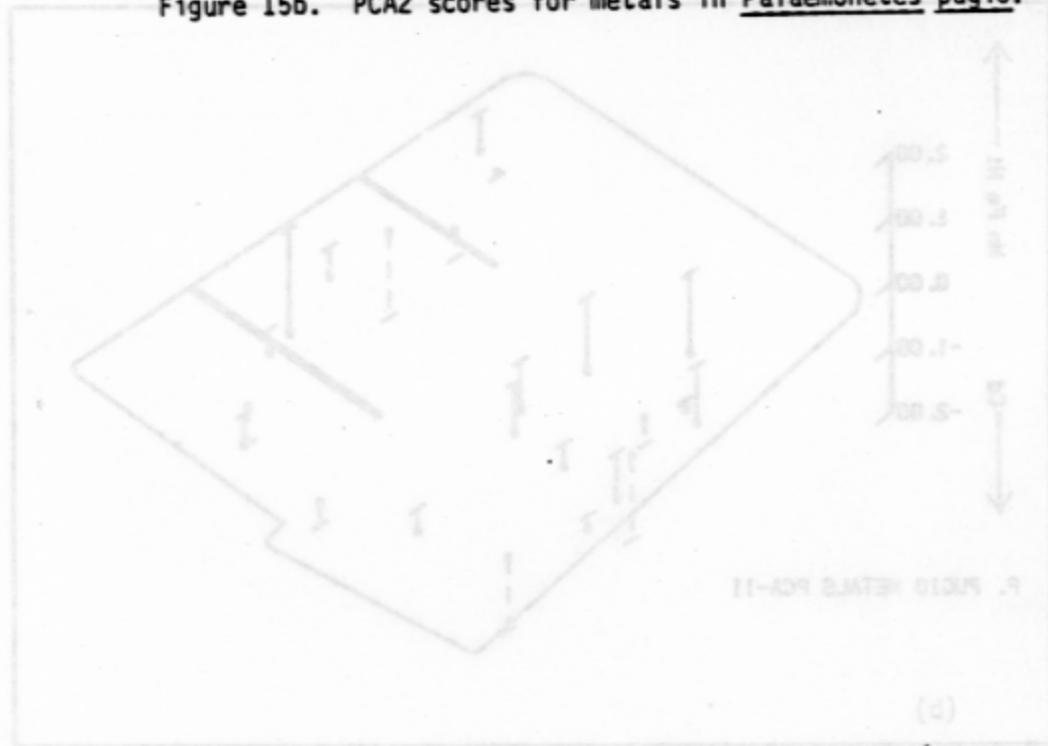


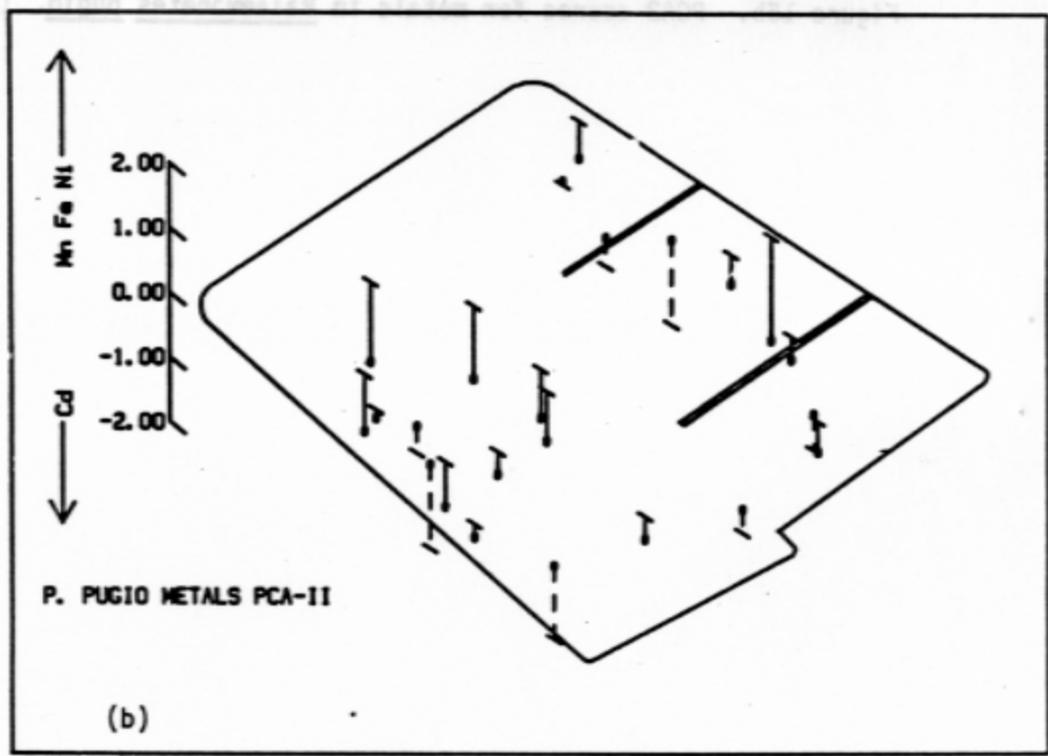
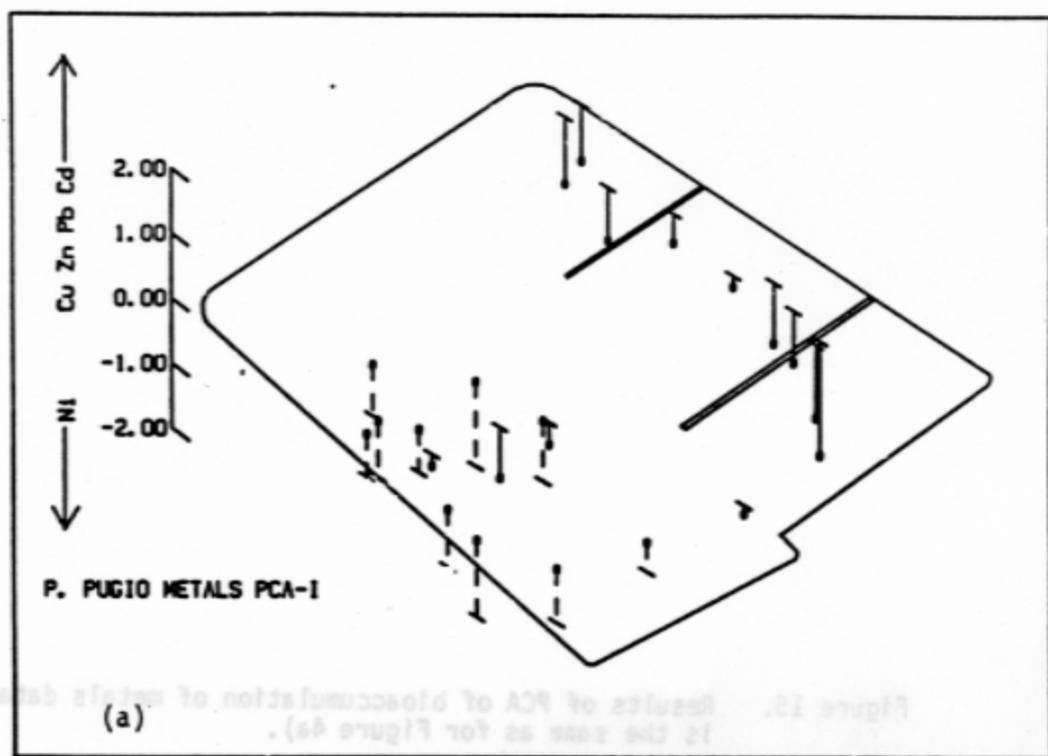
Figure 15. Results of PCA of bioaccumulation of metals data. (Format is the same as for Figure 4a).

Figure 15a. PCA1 scores for metals in Palaemonetes pugio. (Top)

Figure 15b. PCA2 scores for metals in Palaemonetes pugio. (Bottom)



1000 900 800 700 600 500 400 300 200 100 0



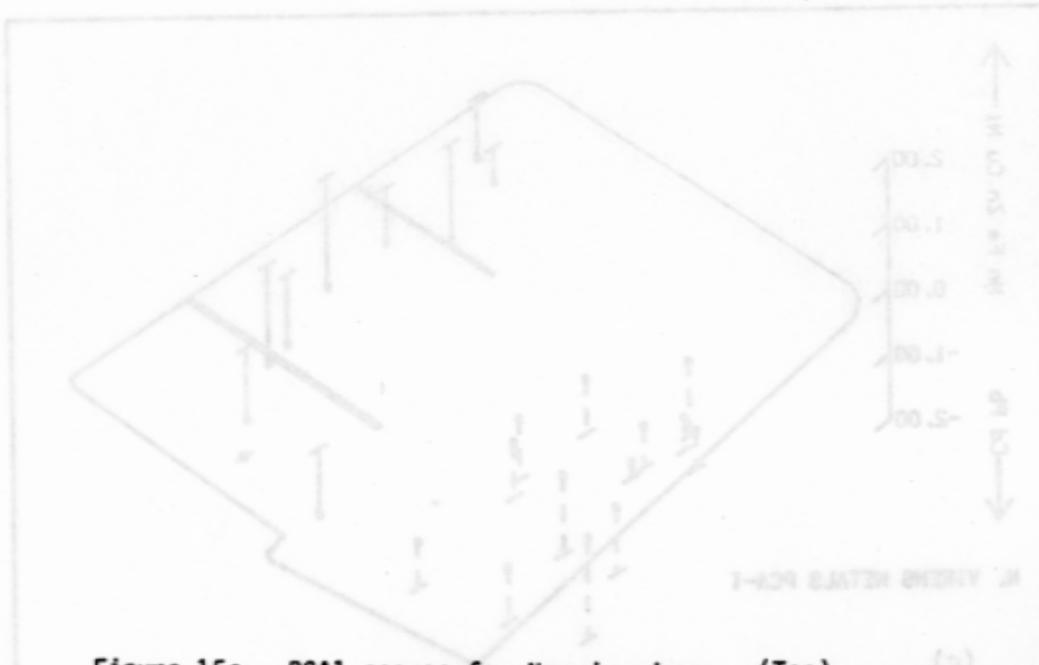
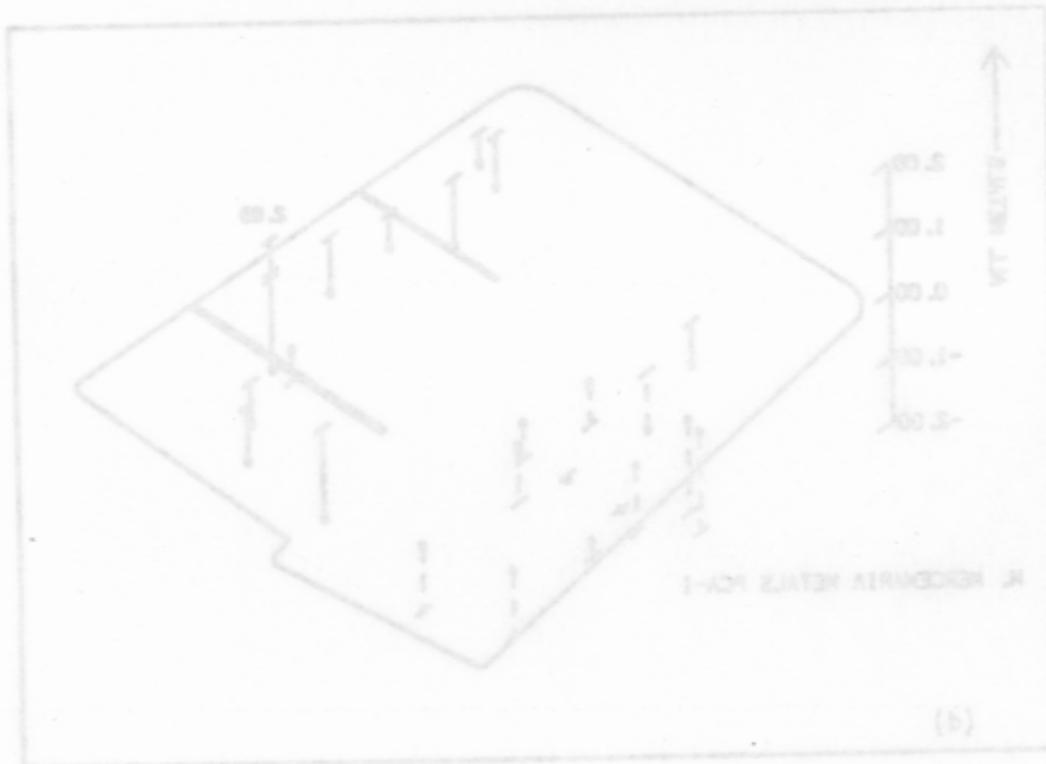


Figure 15c. PCA1 scores for *Nereis virens*. (Top)

Figure 15d. PCA1 scores for metals in *Mercenaria mercenaria*. (Bottom)



100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700 3800 3900 4000 4100 4200 4300 4400 4500 4600 4700 4800 4900 5000 5100 5200 5300 5400 5500 5600 5700 5800 5900 6000 6100 6200 6300 6400 6500 6600 6700 6800 6900 7000 7100 7200 7300 7400 7500 7600 7700 7800 7900 8000 8100 8200 8300 8400 8500 8600 8700 8800 8900 9000 9100 9200 9300 9400 9500 9600 9700 9800 9900 10000

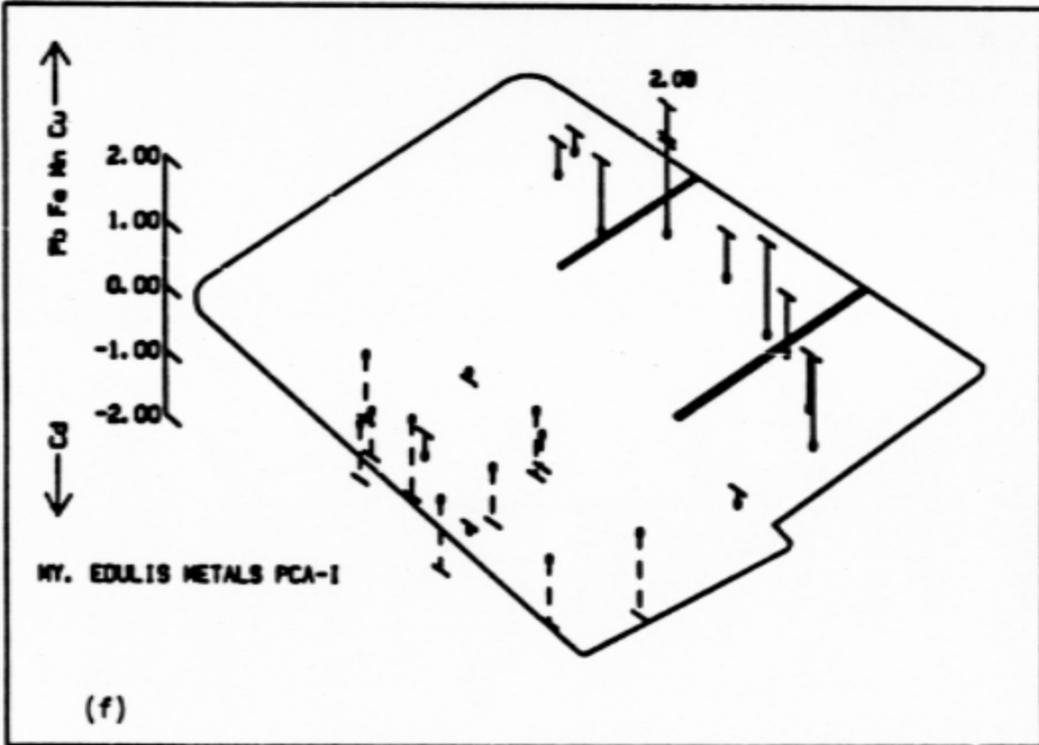
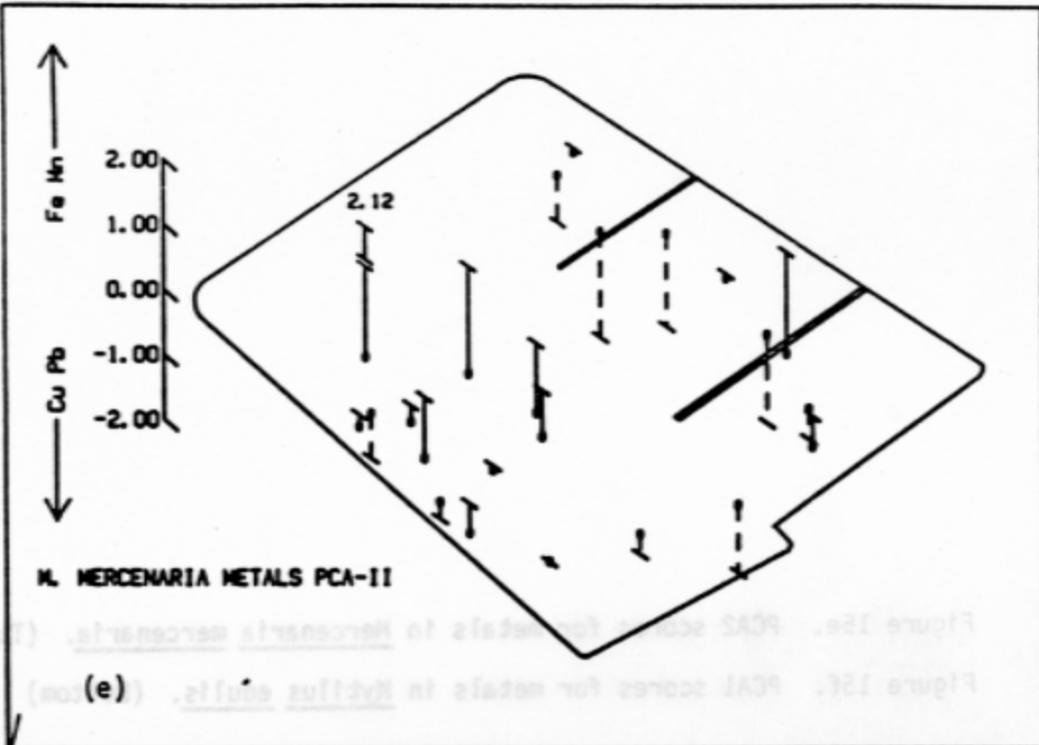
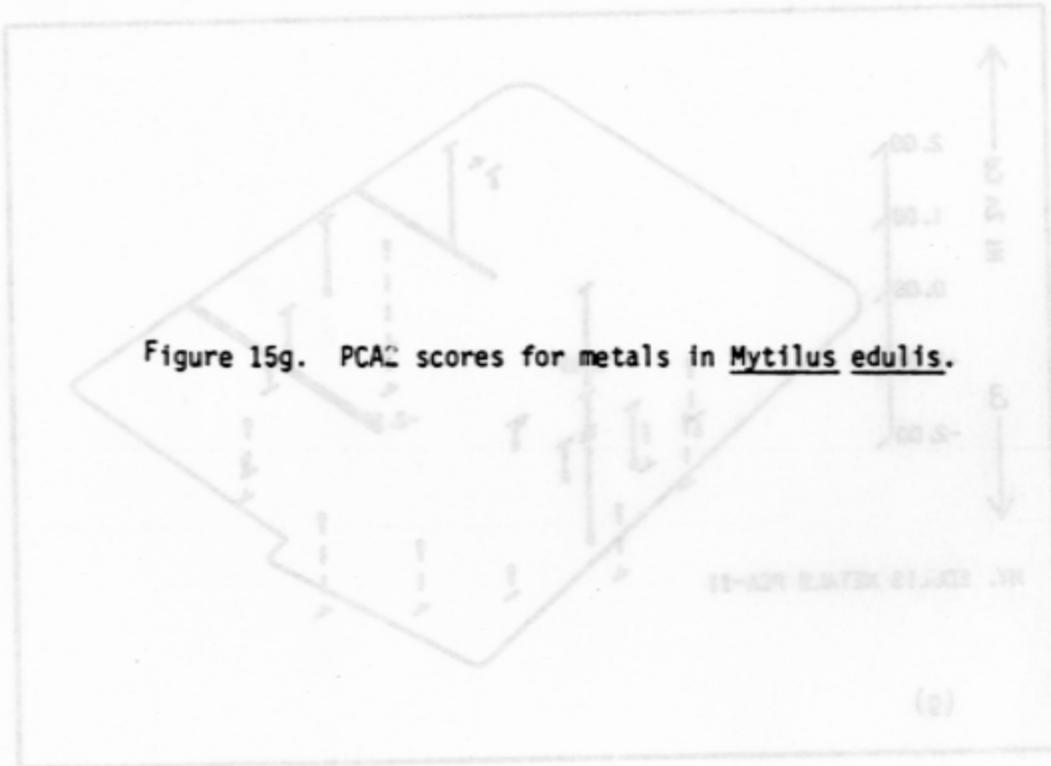


Figure 15g. PCA2 scores for metals in Mytilus edulis.



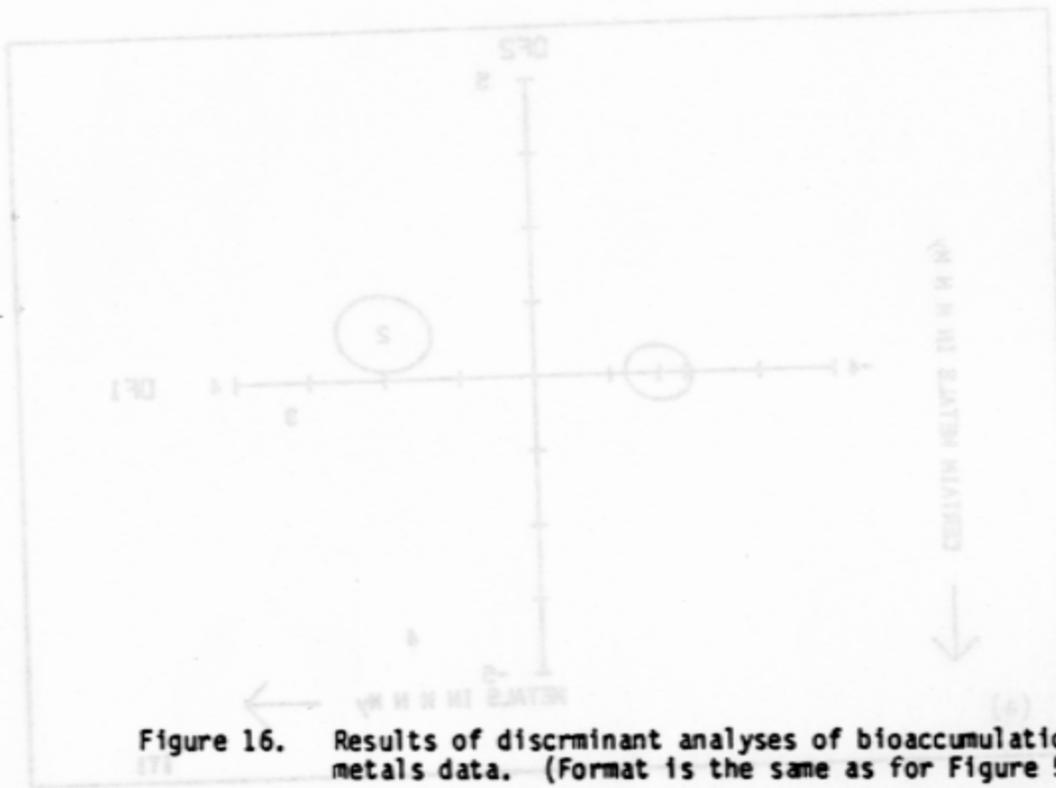
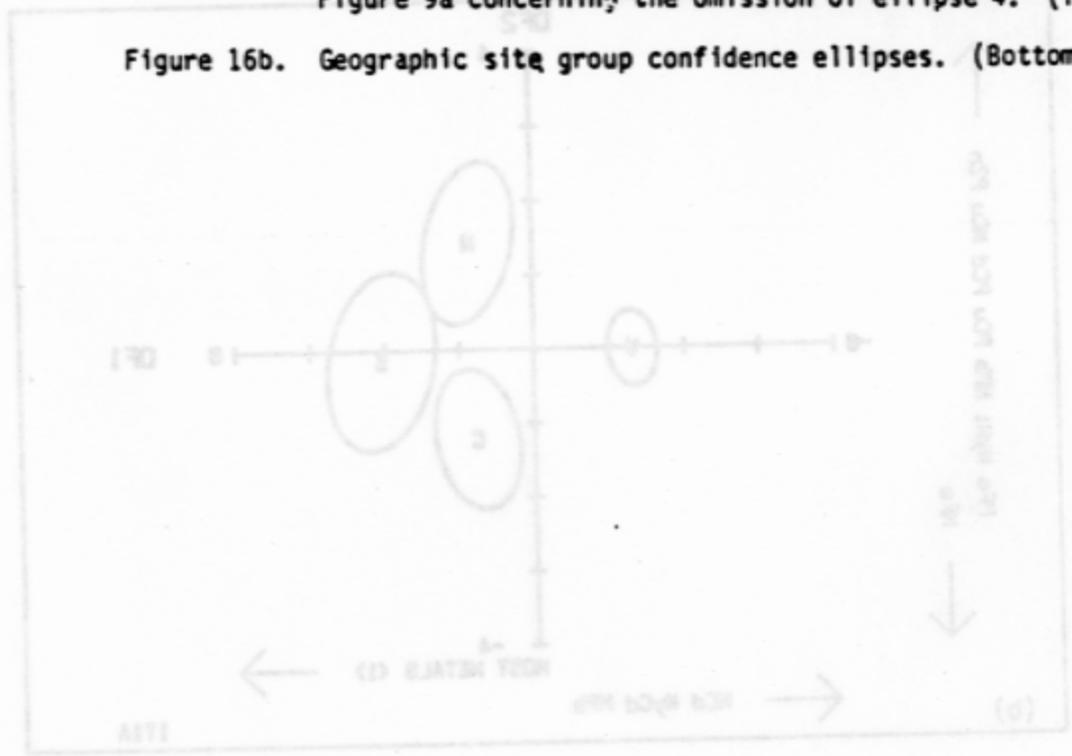


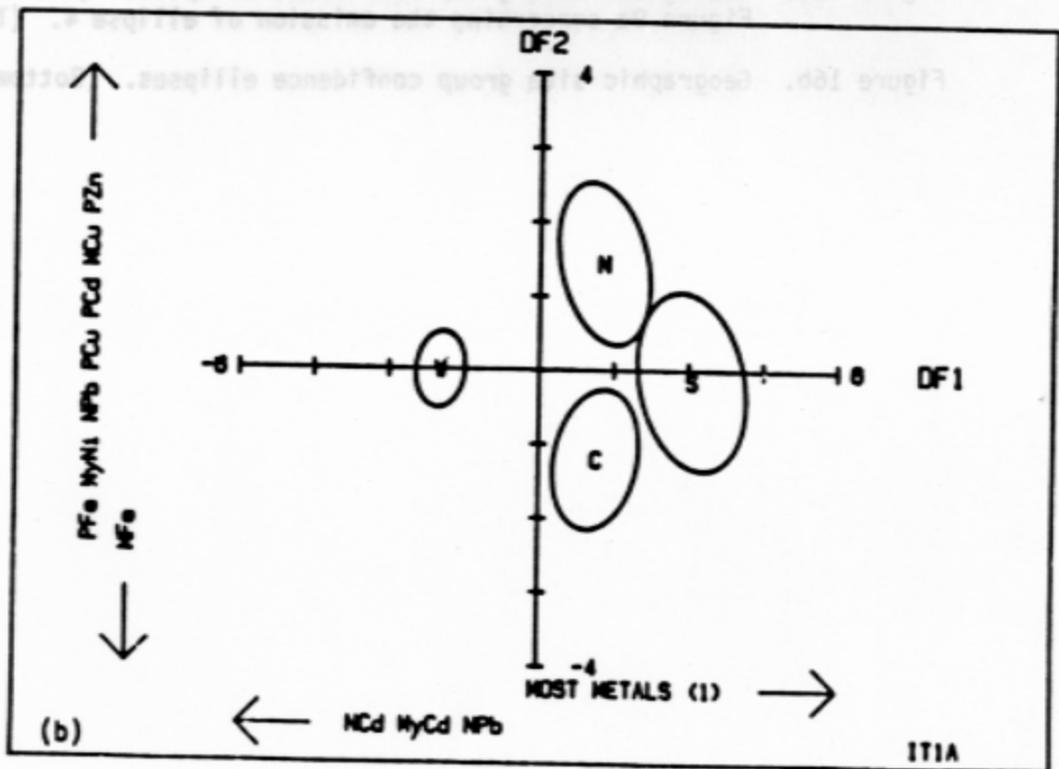
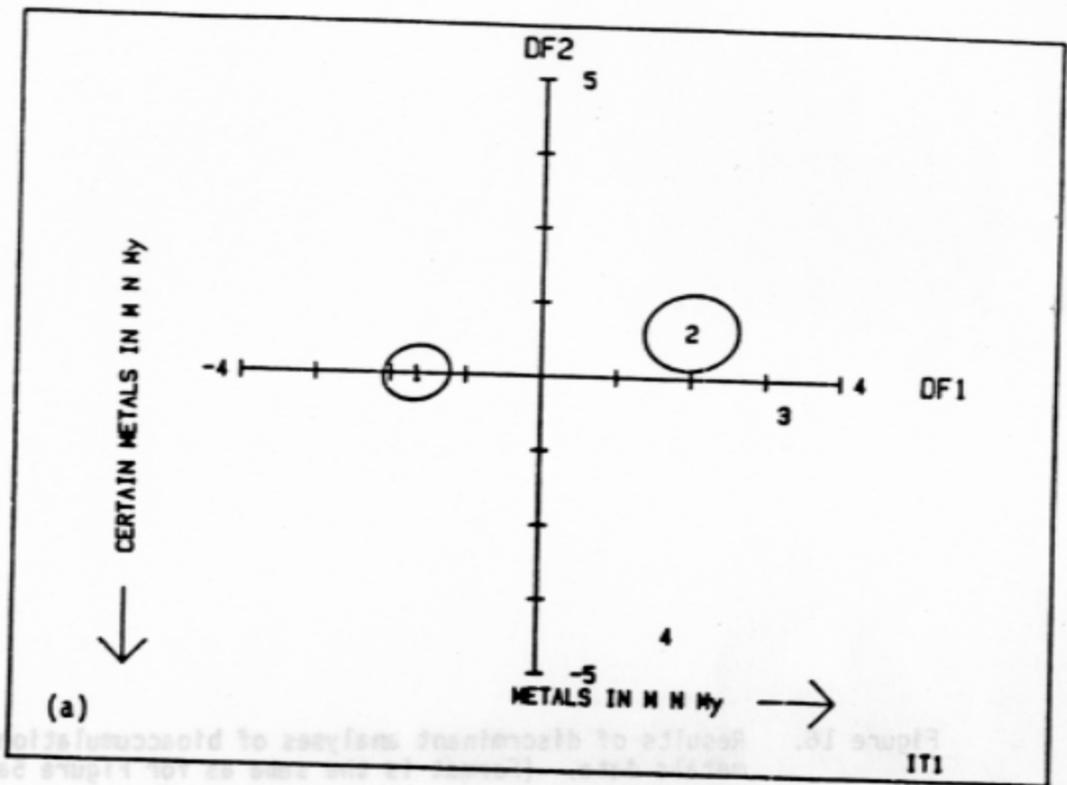
Figure 16. Results of discriminant analyses of bioaccumulation of metals data. (Format is the same as for Figure 5a).

Figure 16a. Geological site group confidence ellipses. (See note on Figure 9a concerning the omission of ellipse 4. (Top)

Figure 16b. Geographic site group confidence ellipses. (Bottom)



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100



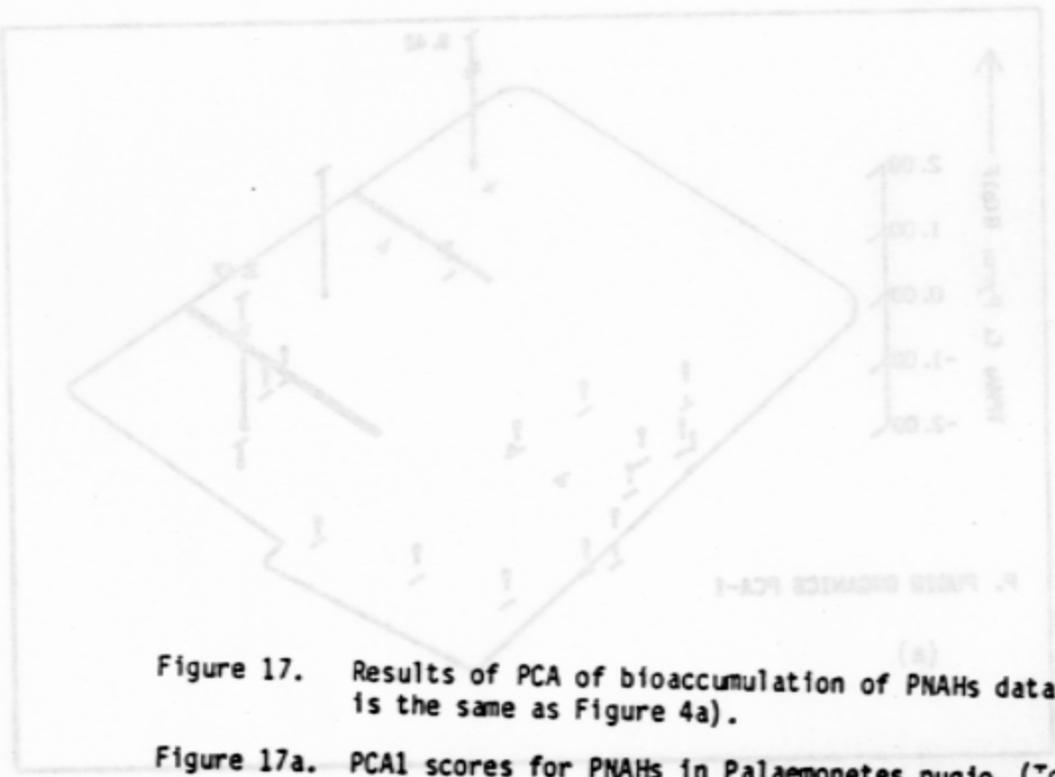
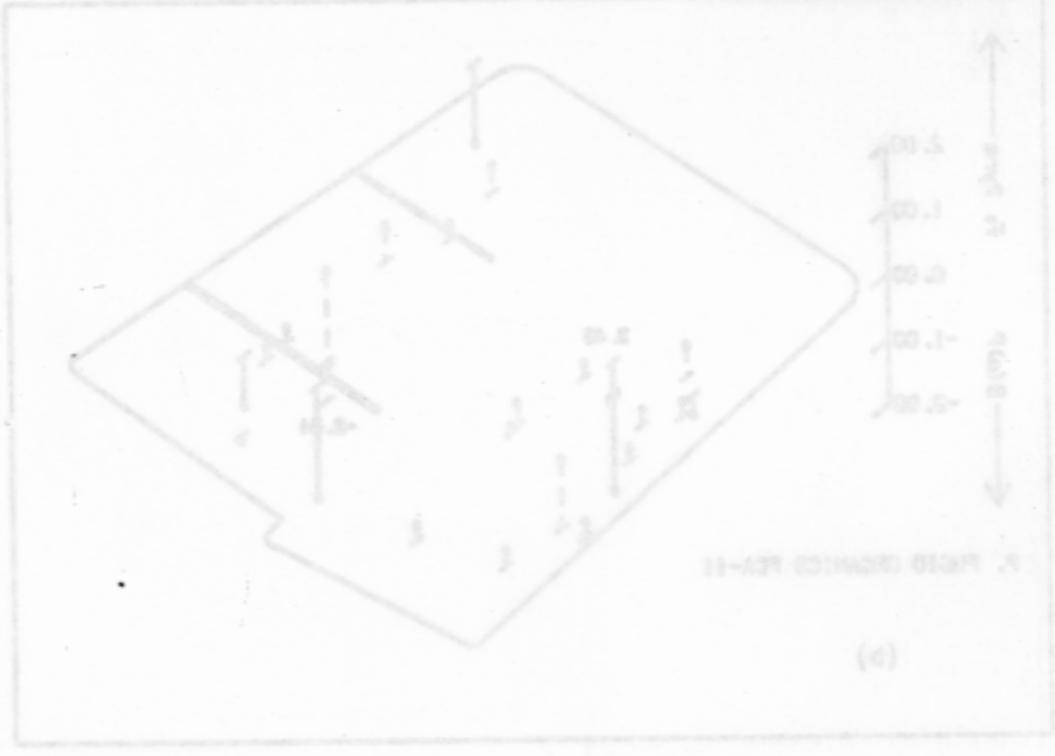
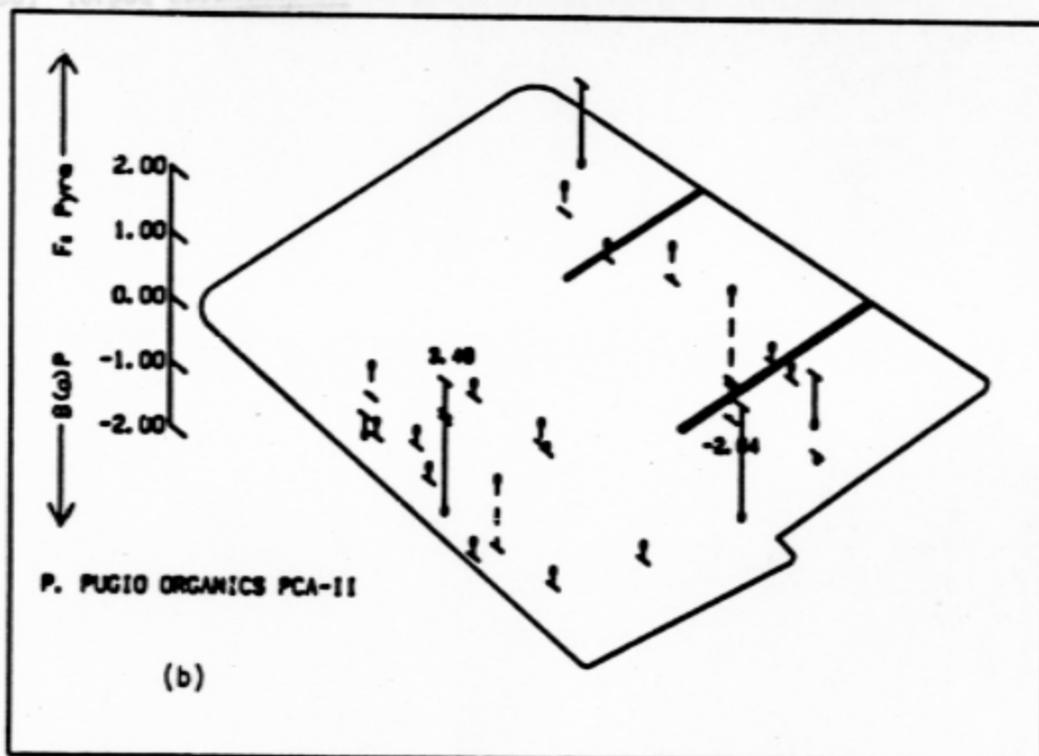
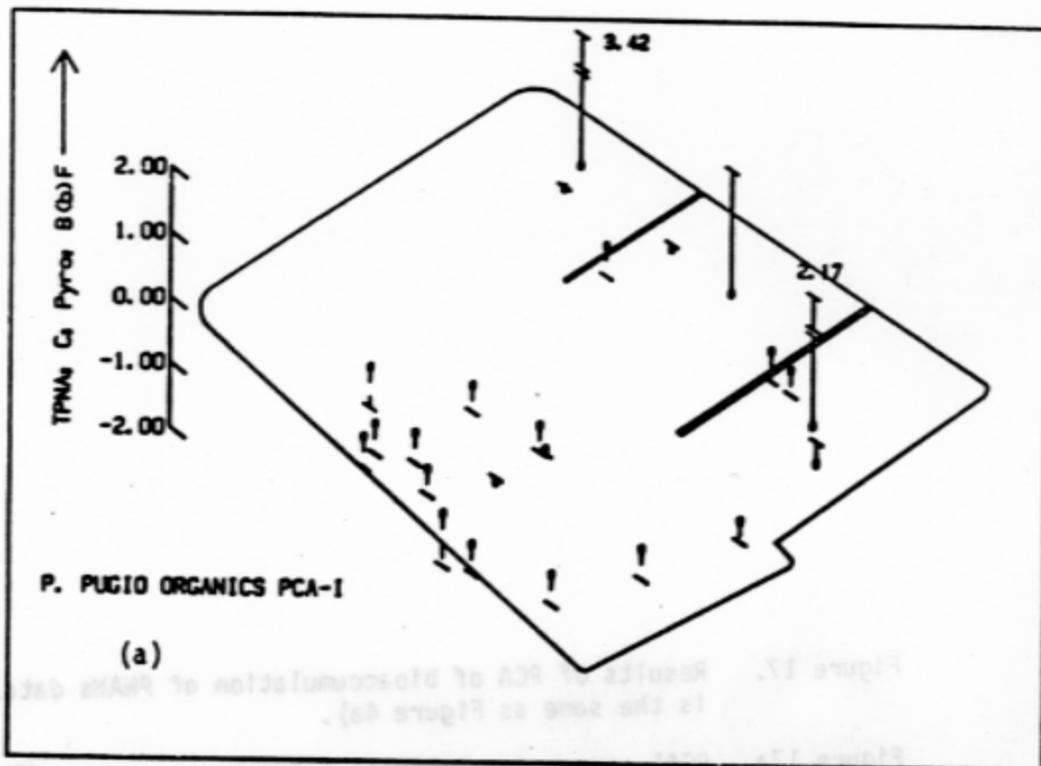


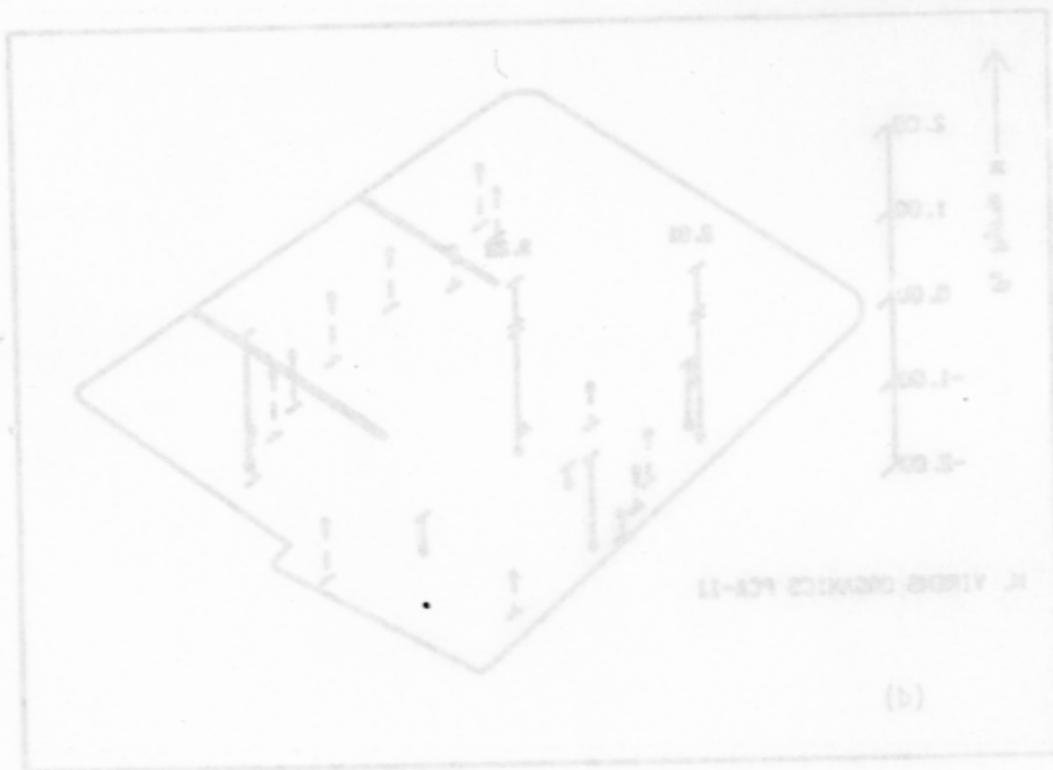
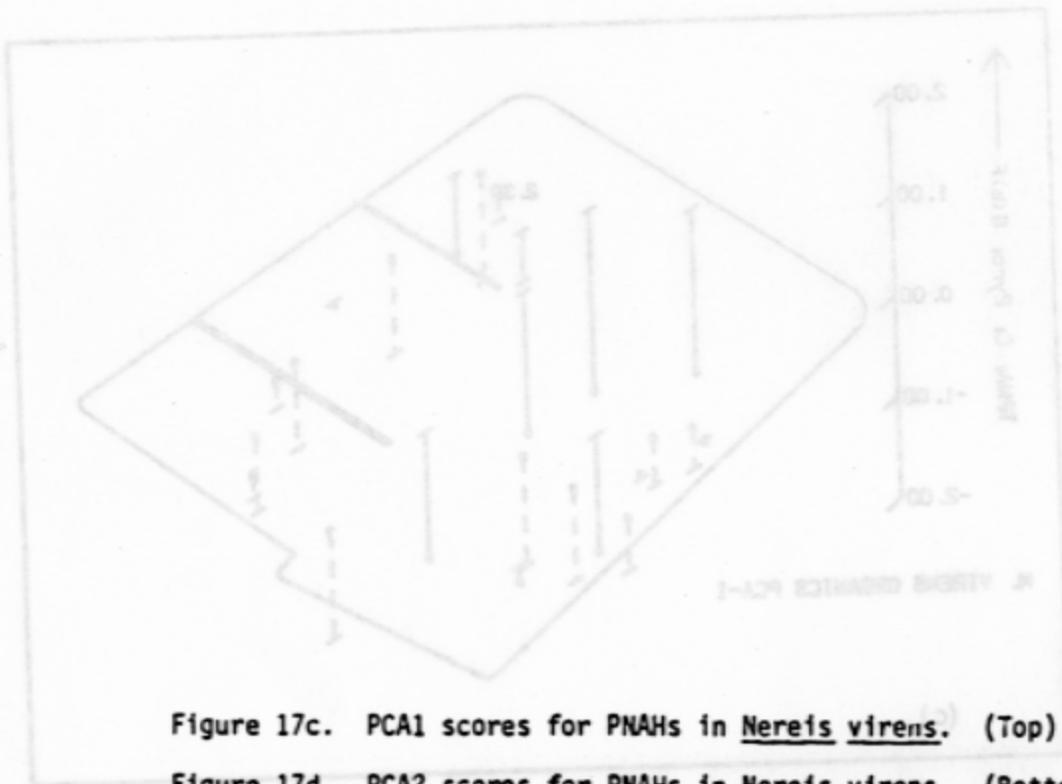
Figure 17. Results of PCA of bioaccumulation of PNAHs data. (Format is the same as Figure 4a).

Figure 17a. PCA1 scores for PNAHs in Palaemonetes pugio. (Top)

Figure 17b. PCA2 scores for PNAHs in Palaemonetes pugio. (Bottom)







1000 900 800 700 600 500 400 300 200 100 0 100 200 300 400 500 600 700 800 900 1000

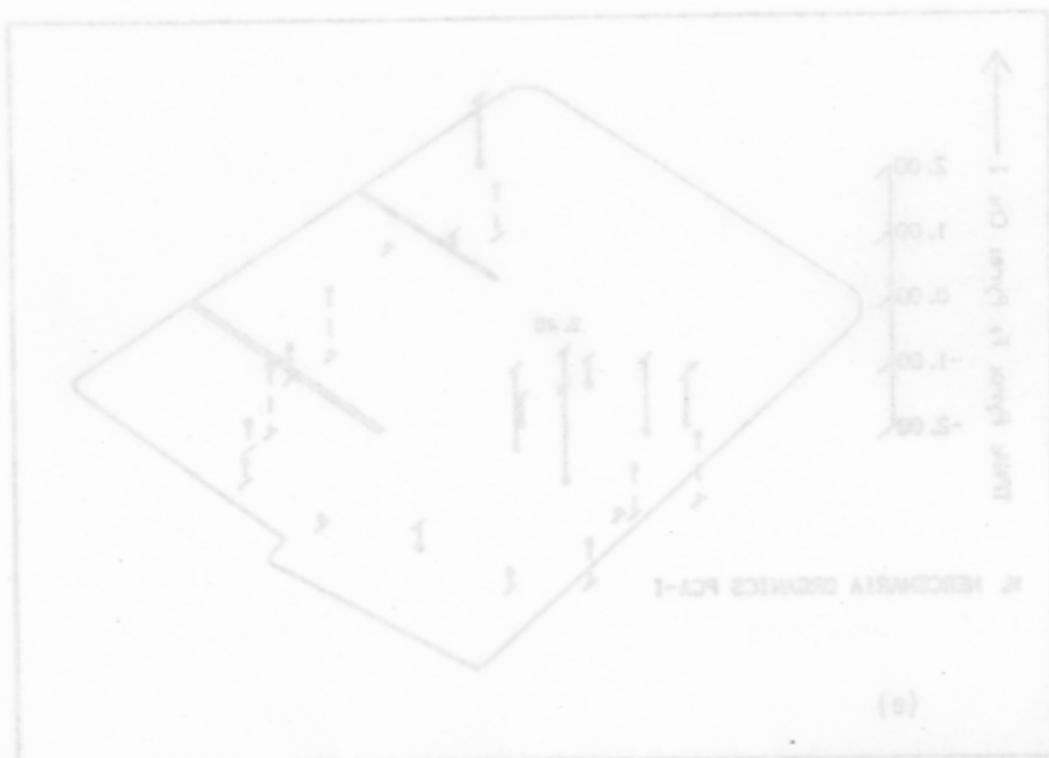
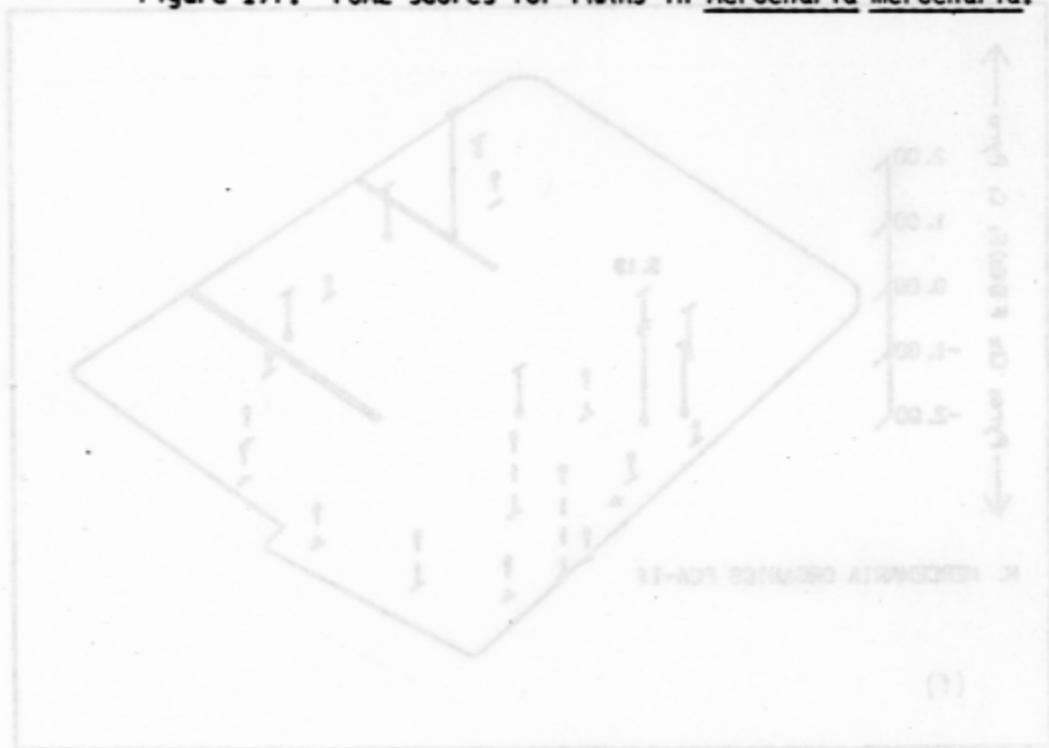


Figure 17e. PCA1 scores for PNAHs in Mercenaria mercenaria. (Top)

Figure 17f. PCA2 scores for PNAHs in Mercenaria mercenaria. (Bottom)



1000 900 800 700 600 500 400 300 200 100 0 100 200 300 400 500 600 700 800 900 1000

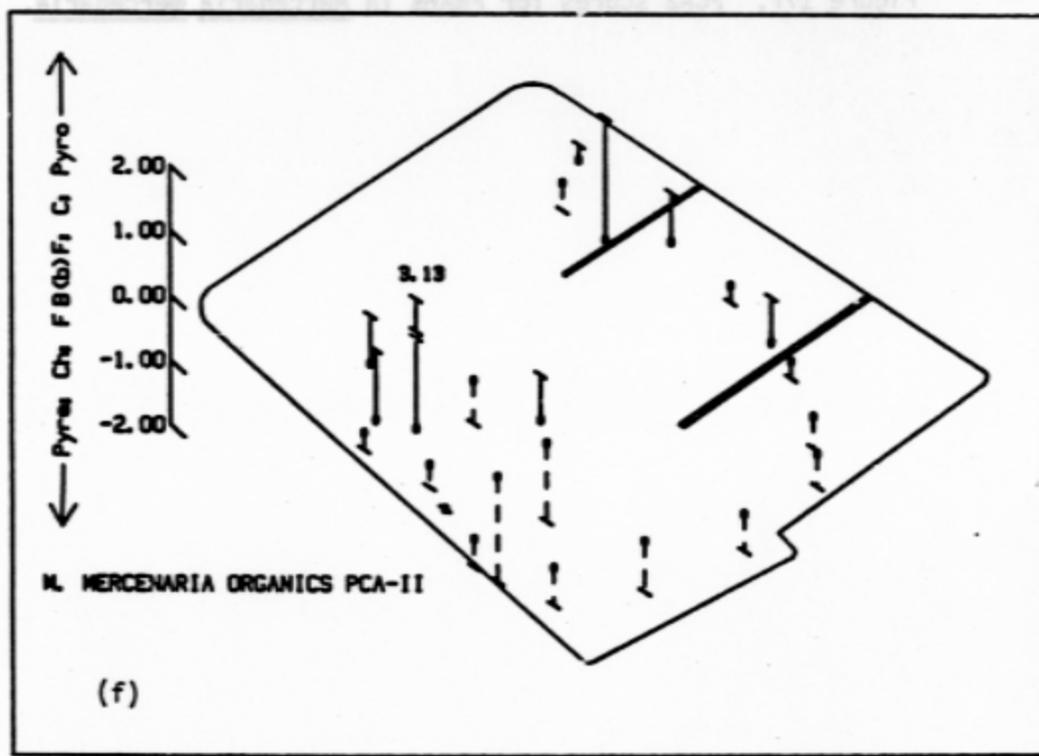
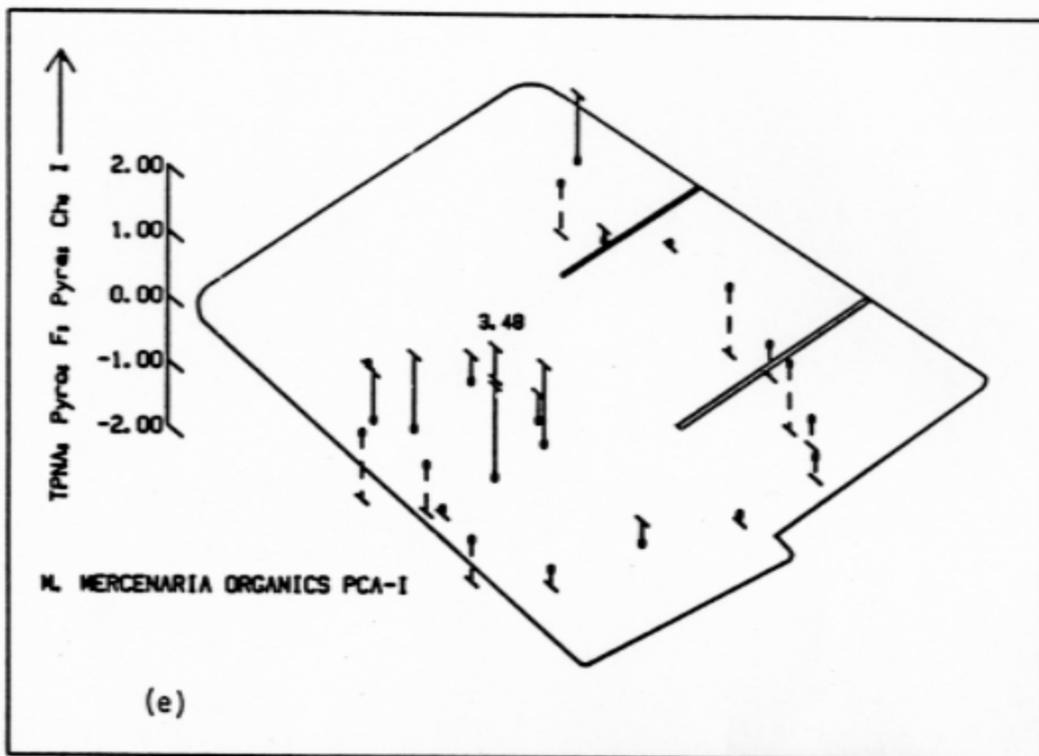
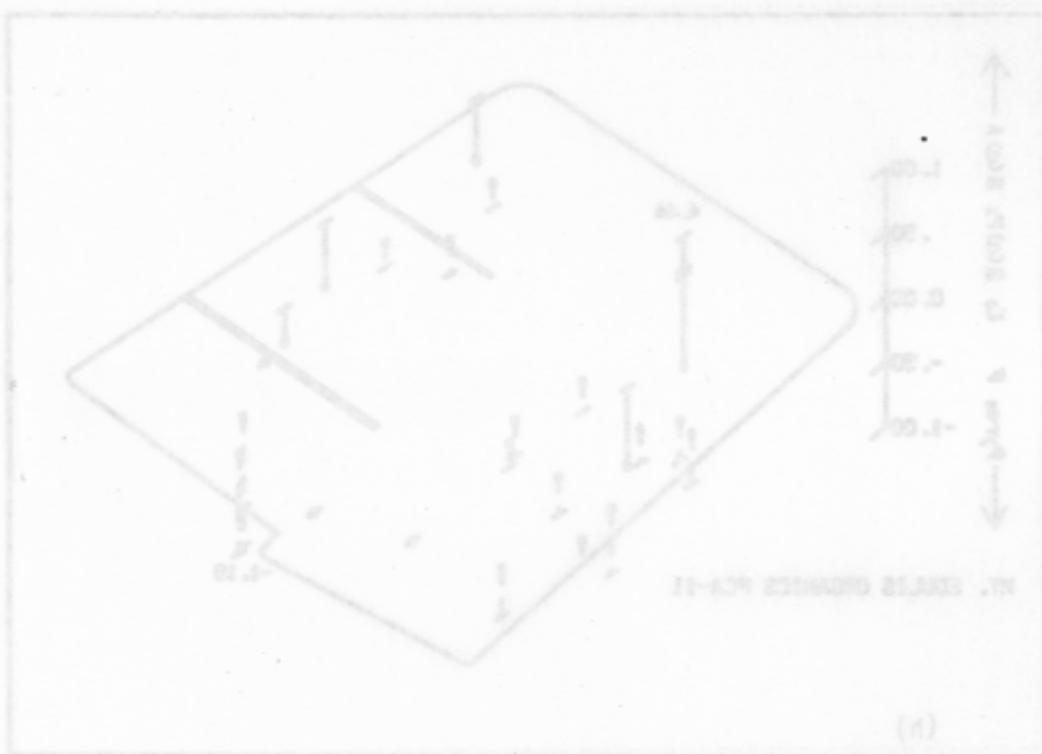




Figure 17g. PCA1 scores for PNAHs in Mytilus edulis. (Top)

Figure 17h. PCA2 scores for PNAHs in Mytilus edulis. (Bottom)



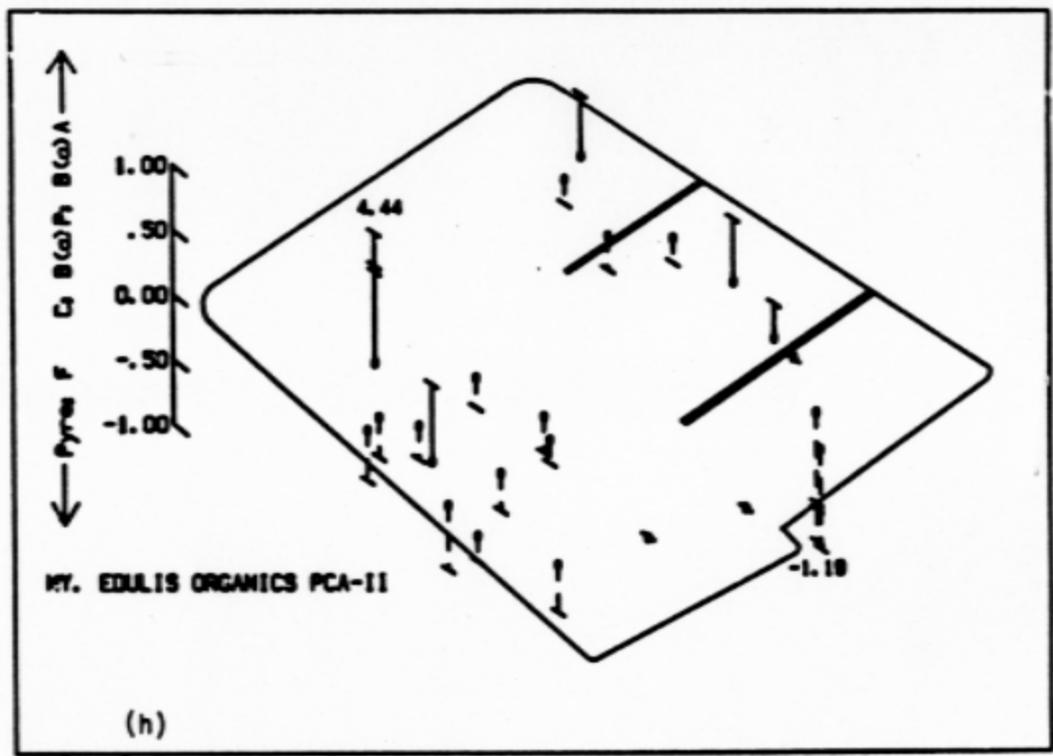
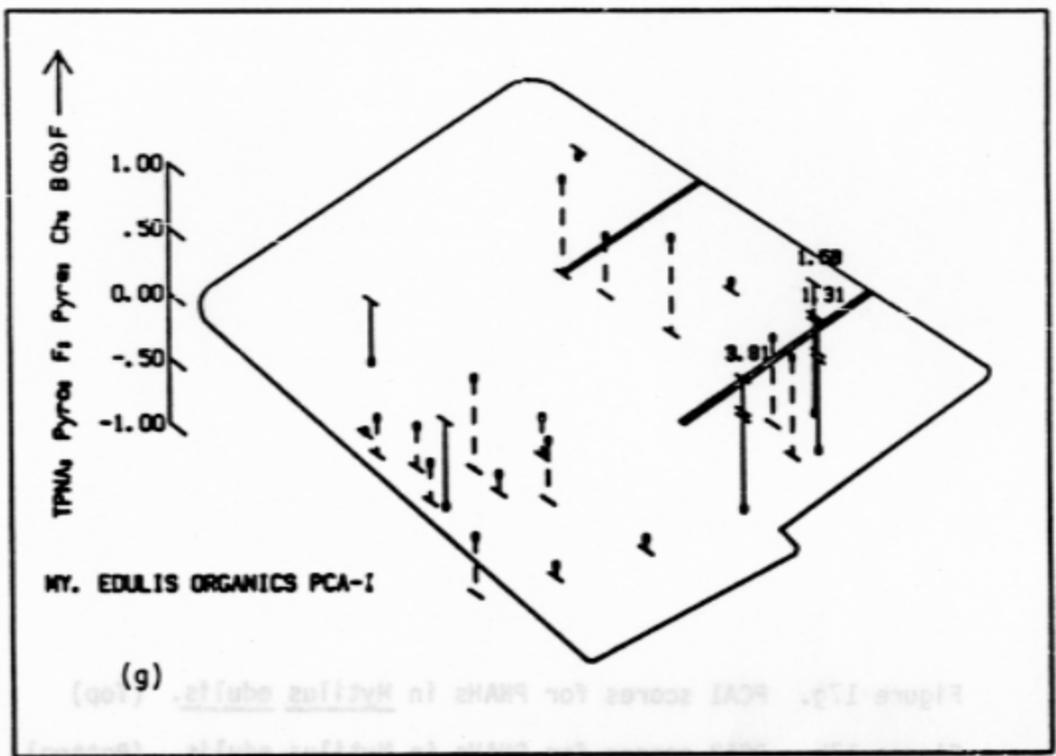
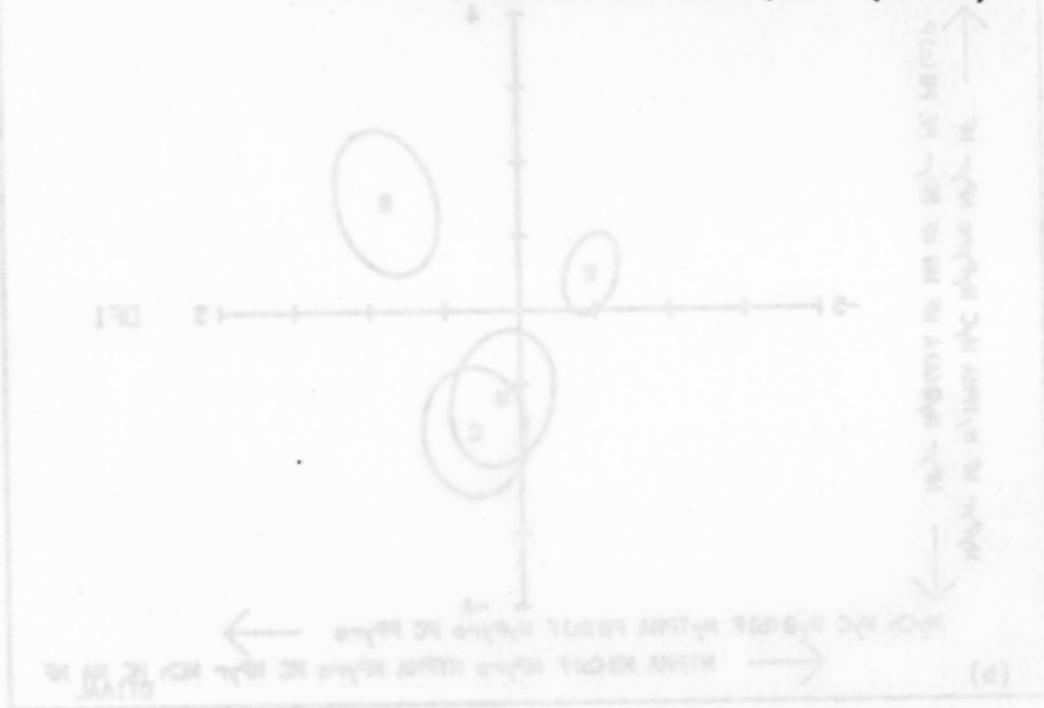


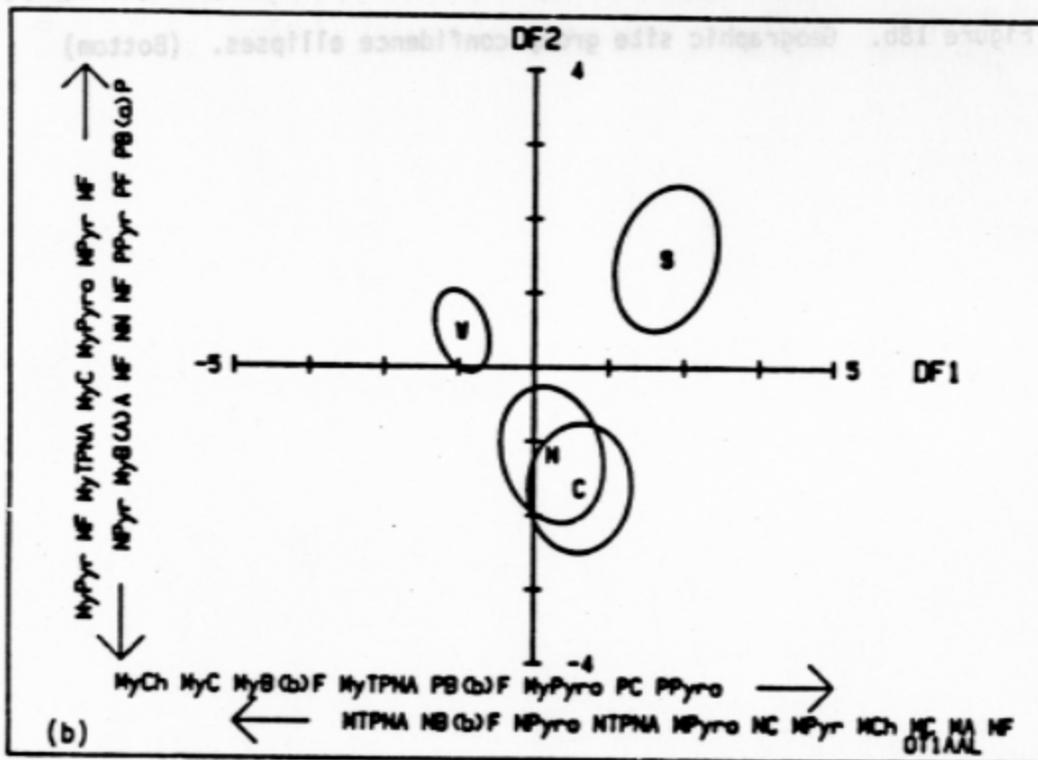
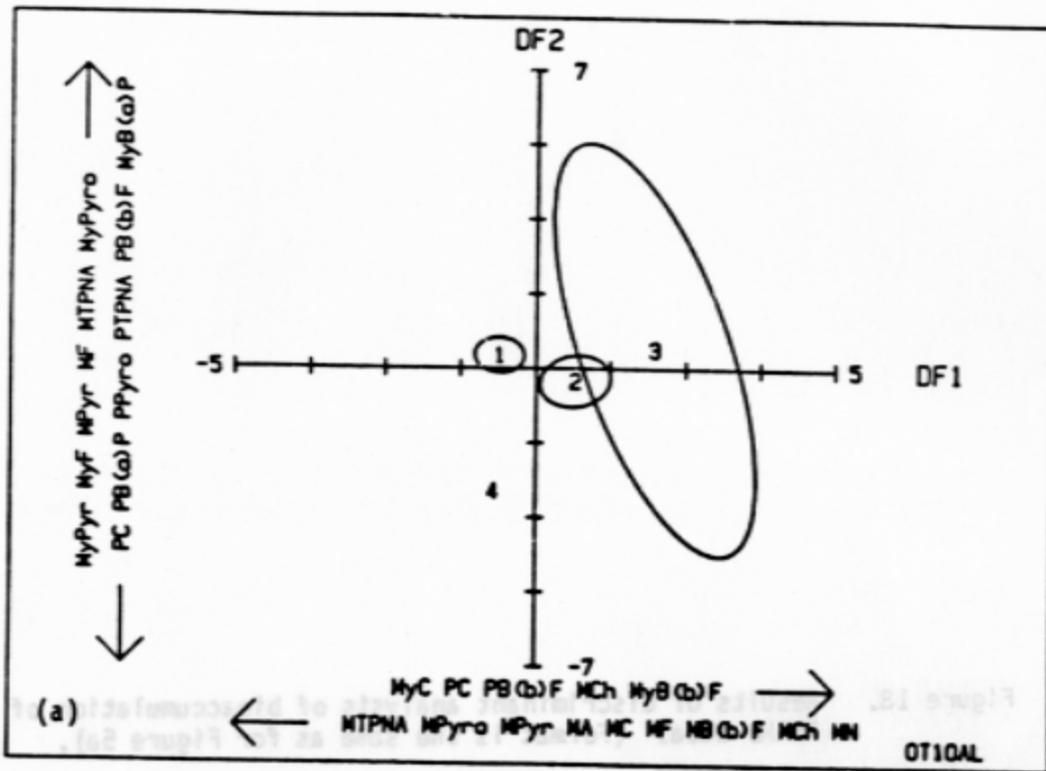


Figure 18. Results of discriminant analysis of bioaccumulation of PNAHs data. (Format is the same as for Figure 5a).

Figure 18a. Geological site group confidence ellipses (see note on Figure 9a concerning the omission of ellipse 3). (Top)

Figure 18b. Geographic site group confidence ellipses. (Bottom)





REFERENCES

- Alden, R. W., and R. J. Young. Open ocean disposal of materials dredged from a highly industrialized estuary: An evaluation of potential lethal effects. *Arch. Environm. Contam. Toxicol.* 11, p. 567 (1982).
- Alden, R. W. et al. (1982). Environmental studies at a proposed mid-Atlantic dredged material disposal site. *Oceans*, 1034. (1982).
- Allen, K. O. and J. W. Hardy. Impacts of navigational dredging on fish and wildlife: A literature review. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-80/07. 81 pp. (1980).
- Anderson, J. W. An assessment of knowledge concerning the fate and effects of petroleum hydrocarbons in the marine environment. In: W. B. Vernberg, (eds.); *Marine Pollution: Functional Responses*, Academic Press, N. Y. (1979).
- APHA. Standard Methods for Examination of Water and Wastewater, 14th edition. American Public Health Association, Washington, D. C., 1193 pp. (1979).
- ASEC. Geotechnical practice for disposal of solid waste materials American Society of Civil Engineers: NY, 885 pp. (1977).
- Barnard, W. D. Predicting and controlling turbidity around dredging and disposal operations. In: P. A. Krenkel, J. Harrison, and J. C. Burdick III (eds.); *Dredging and its environmental effects*. New York: Amer. Soc. Civil Engineers, p. 930. (1976).
- Bloom, S. A., S. L. Santos, and J. G. Field: A package of computer programs for benthic community analyses. *Bulletin of Marine Science* 27, p. 577 (1977).
- Boehm, P. D. Evidence for the decoupling of dissolved, particulate and surface microlayer hydrocarbons in northwestern Atlantic continental shelf waters. *Mar. Chem.* 9, p. 255 (1980).
- Brannon, J. M., R. M. Engler, J. R. Rose, P. G. Hunt, and I. Smith. Distribution of toxic heavy metals in marine and freshwater sediments. In: P. A. Krenkel, J. Harrison, and J. C. Burdick III (eds.); *Dredging and its environmental effects*. New York: Amer. Soc. Civil Engineers, p.455 (1976).
- Brown, D. W., L. S. Ramos, M. Y. Vyeda, A. F. Friedman, and W. D. MacLeod. Ambient temperature extraction of hydrocarbons from marine sediments - comparison with boiling solvent extractions. In: L. Petrakis and F. T. Weiss (eds.); *Petroleum in the marine environment adv. in chem. series* 185, p. 313, Washington, D.C.; ACS (1980).
- Cross, F. A. and W. G. Sunda. Relationship between bioavailability of transmittal and geochemical processes in estuaries. In: M. L. Wiley (ed.); *Estuarine Interactions*, Academic Press, N.Y., pp. 429-433. (1979).

- DeCoursey, P. T., and W. B. Vernberg. The effect of dredging in a polluted estuary on the physiology of larval zooplankton. *Water Research* 9, p. 149 (1975).
- DiSalvo, L. H., H. E. Guard, N. D. Hirsh, and J. Ng. Assessment and significance of sediment associated oil and grease in aquatic environments. Technical Report D-77-26, U.S. Army Waterways Experiment Station, Vicksburg, MS. (1977).
- Dunn, B. P. Techniques for determination of benzo(a)pyrene in marine organisms and sediments. *Environmental Science and Technology*, 10, p. 1018. (1976).
- Eadie, B. J., W. Faust, W. S. Gardner, and T. Malepa. Polycyclic aromatic hydrocarbons in sediments and associated benthos in Lake Erie. *Chemosphere* 11(2), p. 185. (1982).
- Engler, R. M. Bioaccumulation of toxic substances from contaminated sediments by fish and benthic organisms. In: S. A. Peterson and K. K. Randolph (eds.); *Management of bottom sediments containing substances; Proceedings of the fourth U.S.-Japan experts meeting*. October 1980, Tokyo, Japan. EPA 600/3-79-102, 325 pp. (1978).
- Engler, R. M. Prediction of pollution potential through geochemical and biological procedures: development of regulation guidelines and criteria for the discharge of dredge and fill material. In: R. A. Baker (ed.); *Contaminants and sediments, Volume I*, Ann Arbor Science, Ann Arbor, MI, pp. 143-169. (1980).
- Folk, R. L. *Petrology of sedimentary rocks*. Hemphill Publishing Co., Austin, TX, 182 pp. (1974).
- Fulk, R., D. Gruber, and R. Wallschleger. Laboratory study of the release of pesticides and PCB materials to the water column during dredging and disposal operations. Report D-75-6, Dredged Material Research Program, U.S. Army Engineer Waterways Experimental Station, Vicksburg, Miss., 88 pp. (1975).
- Grahl-Nielsen, O., J. T. Staveland and S. Wilhelmsen. Aromatic hydrocarbons in benthic organisms from coastal areas polluted by Iranian crude oil. *J. Fish. Res. Board Can.* 35, p. 615. (1978).
- Green, R. H. *Sampling design and statistical methods for environmental biologists*. Wiley-Interscience, N.Y., 257 pp. (1979).
- Hansen, N., V. B. Jensen, H. Appelquist and E. Mørch. The uptake and release of petroleum hydrocarbons by the marine mussel *Mytilus edulis*. *Prog. Wat. Techn.* 10, p. 351. (1978)
- Hirsch, N. D., L. H. DiSalvo, and R. Peddicord. Effects of dredging and disposal on aquatic organisms. Technical Report DS-78-5. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS., NTIS No. AD-A058 989. (1978).

- Hull, C. H. and N. H. Nie. MANOVA: multivariate analysis of variance. Chapter 1, In: C. H. Hull and N. H. Nie (eds.); Statistical package for the social sciences, update 7-9, p. 1. New York, McGraw-Hill. (1981).
- Iosifidou, H. G., S. D. Kilikidis, and A. P. Kamarianos. Analysis for polycyclic aromatic hydrocarbons in mussels (*Mytilus galloprovincialis*) from the Thermaikos Gulf, Greece. *Bull. Environm. Contam. Toxicol.* 28, p. 535 (1982).
- Johnson, P. G. and O. Villa, Jr. Distribution of metals in Elizabeth River sediments. Tech. Report No. 61. Annapolis Field Office, Region III, EPA, Annapolis, MD. (1976).
- Karickhoff, S. W., D. S. Brown, and T. A. Scott. Sorption of hydrophobic pollutants on natural sediments. *Water Research*, 13, p. 241 (1979).
- Katz, B. Relationship of the physiology of aquatic organisms to the lethality of toxicants: A broad overview with emphasis on membrane permeability. In: L. L. Marking and R. A. Kimerle, (eds.); Amer. Society for Testing and Materials, Philadelphia, PA, pp. 62-76, (1979).
- Kester, D. R., B. H. Ketchum, I. W. Duedall, and P. K. Park. The problem of dredged-material disposal. In: D. R. Kester et al. (eds.); Dredged-material disposal in the ocean, Volume 2, Wiley-Interscience, NY, pp. 1-27, (1983).
- Kim, J. O. Factor analysis. Chapter 24, In: N. H. Nie, C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent (eds.); Statistical package for the social sciences, p. 468, New York: McGraw-Hill. (1975).
- Klecka, C. Discriminant analysis. Chapter 23, In: N. H. Nie, C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent (eds.); Statistical package for the social sciences, p. 434. New York: McGraw-Hill. (1975).
- Krizak, R. J., J. A. Fitzpatrick, and D. K. Abmatzidis. Dredge material confinement facilities as solid-liquid separation systems. In: P. A. Krenkel, J. Harrison, and J. C. Bordick III (eds.); Dredging and its environmental effects. New York: Amer. Soc. Civil Engineers, p. 609. (1976).
- Lamar, J. H. and Laier, J. E. Experience in using dredge material for construction purposes. In: P. A. Krenkel, J. Harrison, and J. C. Bordick III (eds.); Dredging and its environmental effects. New York: Amer. Soc. Civil Engineers, p. 882. (1976).
- Lee, G. F., M. D. Piwoni, J. M. Lopez, G. M. Mariani, J. S. Richardson, D. H. Homer, and F. Y. Saleh. Research study for the development of dredged material disposal criteria. Report D-74-4, Dredged Material Research Program, U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. NTIS No. AD-019 953 (1975).
- Lee, G. F., R. A. Jones, and G. M. Mariani. Comments on U.S.E.P.A.-Corps of Engineers dredged sediment bioassay procedures. Occasional Paper No. 26, Environmental Engineering, Colorado State Univ., Ft. Collins, CO. (1977).

Lee, G. F., R. A. Jones, F. Y. Saleh, G. M. Mariani, D. H. Homer, J. S. Butler, and P. Bandyopadhyay. Volume II: Data report; Evaluation of the elutriate test as a method of predicting contaminant release during open water disposal of dredged sediments and environmental impact of open water dredged material disposal. Technical Report D-78-45. Waterways Experiment Station, U.S. Army Engineer, Vicksburg, MS. NTIS No. AD-A061 710 (1978).

Lee, G. F., J. M. Lopez, and M. D. Piwoni. Evaluation of the factors influencing the results of the elutriate test for dredged material disposal criteria. In P. A. Krenkel, J. Harrison, and J. C. Burdick III (eds.); *Dredging and its environmental effects*. New York: Amer. Soc. Civil Engineers, p. 253. (1976).

May, Willie E. Petroleum in the marine environment (the solubility behavior of polycyclic aromatic hydrocarbons in aqueous systems). In: ACS Sym. Series, N185, p. 143, (1980).

Mix, M. C. and R. L. Schaffer. Benzo(a)pyrene concentrations in mussels (*Mytilus edulis*) from Yaquina Bay, Oregon during June, 1976-May 1979. *Bull. Environm. Contam. Toxicol.* 23, p. 677. (1979).

Montgomery, R. L. and M. R. Palermo. First steps toward achieving disposal area reuse. In: P. A. Krenkel, J. Harrison, and J. C. Burdick III (eds.); *Dredging and its environmental effects*. New York: Amer. Soc. Civil Engineers, p. 529. (1976).

Morton, J. W. Ecological effects of dredging and dredge spoil disposal: A literature review. Technical paper 94, U.S. Fish and Wildlife Service, U.S. Dept. of the Interior, Washington, D. C., 33 pp. (1977).

Murray, H. E., G. S. Neff, Y. Hsung, and C. S. Giam. Determination of benzo(a)pyrene, hexachlorobenzene and pentachlorophenol in oysters from Galveston Bay, Texas. *Bull. Environm. Contam. Toxicol.* 25, p. 663. (1980).

Neff, J. W., R. S. Foster and J. F. Slowey. Availability of sediment-absorbed heavy metals to benthos with particular emphasis on deposit-feeding infauna. Technical Report No. D-78-42, Environmental Laboratory, U.S. Army Engineer Waterways Experimental Station, Vicksburg, Miss. (1978).

Nekker, J. de, d'Angremont, K. Dredge material: Natural resource or national nuisance. In: P. A. Krenkel, J. Harrison, and J. C. Burdick III (eds.); *Dredging and its environmental effects*. New York: Amer. Soc. Civil Engineers, p. 866. (1976).

O'Connor, T. P. Investigation of the elutriate test. In: P. A. Krenkel, J. Harrison, and J. C. Burdick III (eds.); *Dredging and its environmental effects*. New York: Amer. Soc. Civil Engineers, p. 299. (1976).

Palermo, M. R., F. D. Shields, and D. F. Hayes. Development of a management plan for Crane Island disposal area. Technical Report EL-81-11, U.S.

- Army Engineer Waterways Experiment Station, Vicksburg, MS. (1981).
- Pancirov, R. J. and R. A. Brown. Polynuclear aromatic hydrocarbons in marine tissues. *J. Environ. Sci. and Technol.* 11, p. 989. (1977).
- Pancirov, R. J., T. D. Searl, and R. A. Brown. Methods of analysis for polynuclear aromatic hydrocarbons in environmental samples. (1980).
- Peddicord, R. K. Direct effects of suspended sediments on aquatic organisms. In: R. A. Baker (ed.); *Contaminants and sediments Volume I*. Michigan: Ann Arbor Science, pp. 501-536. (1980).
- Peddicord, R. K. and J. C. Hansen. Technical Implementation of the regulations governing ocean disposal of dredged material. In: D. R. Kester et al. (eds.); *Dredged-material disposal in the ocean, Volume 2*, Wiley-Interscience, NY, pp. 71-88, (1983).
- Pequegnat, W. E., and B. J. Presley. An evaluation of selected bioassay techniques in assessing the potential impacts of dredged materials on two disposal sites in the Gulf of Mexico. Proposal RF-78-384, submitted to NOAA Ocean Dumping Program, Rockville, MD, from Oceanography Department, Texas A & M Univ., College Station, Texas.
- Pequegnat, W. E., D. D. Smith, R. M. Darnell, B. J. Presley, and R. O. Reid. An assessment of the potential impact of dredged material disposal in the open ocean. Technical Report D-78-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. NTIS No. AD-A053, 183 pp. (1978).
- Rao, K. R., F. R. Fox, P. J. Conklin, A. C. Cantelmo, and A. C. Brannon. Physiological and biochemical investigations of the toxicity of pentachlorophenol to crustaceans. In: F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. J. Vernberg (eds.); *Physiological responses of marine biota to pollutants*, p. 307, Academic Press, N.Y. (1979).
- Roesijadi, G., J. W. Anderson and J. Blaylock. Uptake of hydrocarbons from marine sediments contaminated with Prudhoe Bay crude oil: Influence of feeding type of test species and availability of polycyclic aromatic hydrocarbons. *J. Fish. Res. Board. Can.* 35, p. 608. (1978).
- Rubenstein, N. I., E. Lores and N. Gregory. Accumulation of PCB's, mercury, and cadmium by *Nereis virens*, *Mercenaria mercenaria*, and *Palaemonetes pugio* from contaminated harbor sediments. Technical report U-83-4, prepared by U.S. Environmental Protection Agency, Gulf Breeze, FL, for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (1983).
- Shuba, P. J., H. E. Tatem, and J. H. Carroll. Biological assessment methods to predict the impact of open-water disposal of dredged material. Report D-78-50, Environmental Laboratory, U.S. Army Corps of Engineers, Waterways Experimental Station, Vicksburg, Miss. (1978).
- Sims, R. R., Jr. and B. J. Presley. Heavy metal concentrations in organisms from an actively dredged Texas Bay. *Bull. Environ. Contam. and Toxicol.* 16(5), p. 520. (1976).

Smith, H. K. Habitat development on dredged material. In: P. A. Krenkel, J. Harrison and J. C. Bordick III (eds.); Dredging and its environmental effects. New York: Amer. Soc. Civil Engineers, p. 856. (1976).

Sustar and T. H. Wakeman. Dredging conditions influencing the uptake of heavy metals by organisms. In: Management of bottom sediments containing toxic substances. EPA-600/3-79-083. Environmental Research Laboratory, U. S. Environmental Protection Agency, Corvallis, Oregon. (1977).

Thurberg, F. P., M. A. Dawson and R. S. Collier. Effects of copper and cadmium on osmoregulation and oxygen consumption in two species of estuarine crabs. Mar. Biol. 23, p. 171-175. (1973).

U.S. Environmental Protection Agency. Water Quality Criteria 1972. Ecological Research Series, EPA.R3.73.033. (1973).

U.S. Environmental Protection Agency. Methods for chemical analysis of water and wastes. EPA Report 600/4-79-20, Environmental Monitoring & Support Laboratory, Cincinnati, OH. (1979).

U.S. Environmental Protection Agency. Quality criteria for water. (1976).

U.S. Environmental Protection Agency and U.S. Army Corps of Engineers. Ecological evaluation of proposed discharge of dredged material into ocean waters. Implementation Manual for Section 103 of Public Law 92-532. Environmental Effects Laboratory, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS. (1978).

U.S. Environmental Protection Agency. Ambient water quality criteria for polynuclear aromatic hydrocarbons. EPA 440/5-80-069. (1980).

U.S. Environmental Protection Agency. Interim methods for the sampling and analysis of priority pollutants in sediments and fish tissue. EPA report 600/4-81-055, Environmental Monitoring and Support Laboratory, Cincinnati, OH. (1980a).

U.S. Environmental Protection Agency. Methods for organic chemical analysis of municipal and industrial wastewater. EPA Report 600/4-82-057, Environmental Monitoring and Support Laboratory, Cincinnati, OH. (1982).

Yeith, G. D. L. M. Kiwus. An exhaustive steam-distillation and solvent-extraction unit for pesticides and industrial chemicals. Bull. Environ. Contam. Toxicol. 17(6): p. 631. (1977).

APPENDIX: KEY TO ABBREVIATIONS

<u>Organic</u>	<u>Abbreviation</u>	<u>Inorganics & Nutrients</u>	<u>Abbreviation</u>
TPNA	TPNA	Nitrate	NO ₃
NAPH	N	Nitrite	NO ₂
ACETHY	Acy	Total Phosphate	TPO ₄
ACETHA	Acn	Ortho Phosphates	OPO ₄
FLUOR	Fl	Total Keldhal	TKN
DIBTHIO	DiBT	Ammonia	NH ₃
PHENAN	Ph		
ANTHA	A	<u>Animals</u>	<u>Data Letter</u> <u>Abbreviation</u>
FLUORAN	F	<u>Palaemonetes pugio</u>	(A) P
PYRENE	Pyre	<u>Mercenaria mercenaria</u>	(C) M
BENZAN	B(a)A	<u>Mytilus edulis</u>	(D) My
CHRYSE	Ch	<u>Nereis virens</u>	(B) N
DIBENZAN	DiB(a,h)A		
BENZPERY	B(gh)P		
BENZPYR	B(a)P		
BENZFLUB	B(b)F		
BENZFLUK	B(b)F		
INDPYR	I		
CARSYN	C		
PVROSYN	Pyro		

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