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APPENDIX C.4

SAN DIEGO SEDIMENT MAPPING STUDY

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APPENDIX C.4

San Diego Sediment Mapping Study

Table of Contents

	Page
C.4-1 INTRODUCTION	C.4-1
C.4-2 GENERAL METHODS	C.4-2
Sample Collection and Processing	C.4-2
Data Analyses	C.4-4
C.4-3 SUMMARY FOR PHASE 1	C.4-5
Sample Grid Design	C.4-5
Benthic Infauna	C.4-6
Sediments	C.4-8
C.4-4 SUMMARY FOR PHASE 2	C.4-11
Background	C.4-11
Sample Grid Design	C.4-11
Preliminary Results	C.4-12
C.4-5 LITERATURE CITED	C.4-13

List of Tables

Table C.4-1 Sampling effort for Phase 1 of the Sediment Mapping study for both Point Loma and South Bay outfall regions

Table C.4-2 Summary of macrofaunal community parameters for all samples collected during Phase 1 Sediment Mapping study in 2004

Table C.4-3 Summary of the ten most abundant taxa comprising cluster groups A–G

Table C.4-4 Summary of particle sizes and chemistry concentrations for Phase 1 Sediment Mapping samples collected in 2004

Table C.4-5 Results of Spearman rank correlation analyses of depth, percent fines and various sediment chemistry parameters from Phase 1 of the Sediment Mapping study

Table C.4-6 Sampling effort in the Point Loma Ocean Outfall region for Phase 2 of the Sediment Mapping study in 2012

Table C.4-7 Summary of particle size and chemistry concentrations for Phase 2 Sediment Mapping samples collected in 2012

Table C.4-8 Results of Spearman rank correlation analyses of depth, percent fines and various sediment chemistry parameters from Phase 2 of the Sediment Mapping study

List of Figures

Figure C.4-1 Example variogram

Figure C.4-2 Overview of the site distribution for Phase 1 of the Sediment Mapping study

Figure C.4-3 Expanded view of the Phase 1 Sediment Mapping sites located within the Point Loma Ocean Outfall region

Figure C.4-4 Classification results and nMDS ordination analyses of macrofaunal abundance data from Phase 1 of the Sediment Mapping study in 2004

Figure C.4-5 An inverse distance weighted interpolation for percent fines across the full Phase 1survey area of the Sediment Mapping study in 2004

Figure C.4-6 Scatterplots of depth, percent fines and various sediment chemistry parameters from Phase 1 of the Sediment Mapping study in 2004

Figure C.4-7 Results of ordinary kriging for six metals from the Point Loma Ocean Outfall region sampled during Phase 1 of the Sediment Mapping study in 2004

Figure C.4-8 Relationship of sample spacing and statistical confidence for the Point Loma Ocean Outfall region based on cost efficiency model results

Figure C.4-9 Lag distribution (station-to-station distances) for Phase 2 Sediment Mapping study sampling locations in 2012

Figure C.4-10 Detailed sample design for the Phase 2 of the Sediment Mapping study

Figure C.4-11 An inverse distance weighted interpolation for percent fines across the full Phase 2survey area of the Sediment Mapping study in 2012

Figure C.4-12 Scatterplots of depth, percent fines and various sediment chemistry parameters from Phase 2 of the Sediment Mapping study in 2012

List of Attachments

Att. C.4-A Constituents and method detection limits (MDL) of sediments collected during Phase 1 (2004) and Phase 2 (2012) of the Sediment Mapping study

Att. C.4-B Macrofaunal community parameters at all stations sampled as part of the Phase 1 Sediment Mapping, 2004

APPENDIX C.4

San Diego Sediment Mapping Study

SECTION C.4-1 | INTRODUCTION

The Sediment Mapping Study was one of the first research projects approved by the San Diego Regional Water Quality Control Board (RWQCB) to meet the requirements of the "special studies" clause that was added to the NPDES permits and waiver for the first time in 2002 (NPDES Permit No. CA0107409, Order No. R9-2002-0025, Addendum No. 1). As such, the City is mandated to conduct this “special study” as part of the regulatory requirements governing the discharge of wastewater from the Point Loma Wastewater Treatment Plant (PLWTP) through the Point Loma outfall. The Model Monitoring Program for Large Ocean Discharges in Southern California (Schiff et al. 2001) defines special studies as unique mechanisms to focus monitoring efforts on specific questions. In the case of the City of San Diego's Ocean Monitoring Program, special studies are intended to address the need for enhanced environmental monitoring of the San Diego coastal region as recommended by the final finding of the Point Loma Outfall Project (PLOP) report (SIO 2004).

The goal of this Sediment Mapping study was to investigate the potential of the kriging geostatistical interpolation technique for developing an accurate map of sediment and infauna conditions for the benthic marine environment off the coast of San Diego. Maps are easy to display, intuitively easy to understand, and since they give the viewer context over the entire area of interest, they are highly effective communication tools. Maps provide environmental managers with the ability to assess spatial patterns over a large spatial extent to detect any changes in sediment conditions (e.g., sediment quality, biotic communities) over time and distinguish impacted areas from reference areas. Despite their potential utility, however, most maps have traditionally been built using simple statistical tools to contour the data derived from relatively coarse sampling grids. As a result, most current maps of sediment condition (such as contaminant concentrations or grain size distributions) represent interpolations that do not include confidence estimates of their predictions. If the sample density is too low and combined with unsophisticated statistical tools, the accuracy of the resultant map can't be quantified, and the results should not be considered reliable.

To overcome this limitation and in partnership with the Southern California Coastal Water Research Program (SCCWRP), the City of San Diego proposed a resource-intensive study using a "multi-lag cluster design". This carefully constructed sampling scheme was designed to optimize the results obtained from the kriging method of spatial statistics, one of the more powerful statistical tools for mapping. Kriged maps are constructed using spatial variance among neighboring sampled locations to predict values in unsampled areas located between the sampled sites. Modeling spatial variance also enables calculation of confidence, which informs the process of determining optimal distances between sampling sites for mapping. If the spatial variance is high, then samples should be collected closer together to increase confidence at unsampled locations. If spatial variance is low, then samples can be spaced further apart to achieve the same confidence. Unless spatial variance is characterized, the sample locations will likely be placed inefficiently, suffering from imprecision if samples are spaced too far apart or wasted resources if samples are placed too close together. If the spatial variability for an area is known, on the other hand, then optimal sampling distances can be selected based on the level of confidence desired by the end-user.

The San Diego Sediment Mapping Study was conceptualized as a two-phased project to achieve two primary goals: 1) estimate spatial variance; and 2) create a map of sediment condition using kriging of samples from an optimized sampling grid. Phase 1 was expansive and extended over a large area (over 400 km^2). It was designed to estimate spatial variance for both sediment quality and benthic macrofaunal community condition in two distinct areas of interest off San Diego, the Point Loma Ocean Outfall and South Bay Ocean Outfall monitoring areas (Stebbins et al. 2004). The fieldwork for this phase was completed during the summer of 2004. The goal of Phase 2 was to utilize an optimal resolution (spacing) of sample sites to generate a completed map of sediment chemistry conditions within a 30 km^2 area surrounding the Point Loma Ocean Outfall. The fieldwork for this phase was completed during the summer of 2012. A summary of findings for Phase 1 and preliminary results from Phase 2 are presented herein.

SECTION C.4-2 | GENERAL METHODS

Sample Collection and Processing

Samples for benthic community analyses were collected for Phase 1 at each station using a double 0.1-m^2 Van Veen grab. To ensure consistency of grab samples, protocols established by the USEPA were followed to standardize sample disturbance and depth of penetration (USEPA 1987). One macrofauna grab was collected at most sites, but at "field duplicate" sites, two macrofauna grabs were collected. Samples collected for benthic community assessment were sieved aboard ship through a 1.0 mm screen setup. The organisms retained on the screen were placed in separate containers, relaxed for 30 minutes in a magnesium sulfate solution, and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the sediment into major taxonomic groups by a subcontracted laboratory, and identified to species (or the lowest taxon possible) following SCAMIT (2013) nomenclature and enumerated by City of San Diego marine biologists.

For both Phase 1 and Phase 2, one or two (i.e., "field duplicate") sediment grabs were taken at each station for the analysis of various physical and chemical sediment parameters. Sub-samples were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987). All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory; a detailed description of analytical protocols can be found in City of San Diego (2005, 2014a). A summary of parameters measured during each survey is listed in Attachment C.4-A with method detection limits (MDLs). Sediment chemistry data were generally limited to values above the MDL for each parameter. However, concentrations below MDLs were included as estimated values if the presence of a specific constituent was verified by mass-spectrometry.

Particle size analysis was performed using either a Horiba laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from 0.5 to 2000 µm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 µm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm was used to divide the samples into seven fractions. Sieve results and output from the Horiba were classified into size fractions (i.e., fine particles, fine sands, medium-coarse sands, coarse particles) based on the Wentworth scale (Folk 1980) for subsequent analyses.

Data Analyses

Benthic Infauna

The following community structure parameters were calculated for each station: species richness (number of species per 0.1 m^2 grab), abundance (number of individuals per grab), Shannon diversity index (H' per grab), Pielou's evenness index (J' per grab), Swartz dominance (minimum number of species accounting for 75% of the total abundance in each grab), and Benthic Response Index (mean BRI per grab, see Smith et al. 2001).

To examine spatial and temporal patterns in the benthic macrofaunal data, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (MDS). The macrofaunal abundance data were square root transformed and the Bray-Curtis measure of similarity was used as the basis for both classification and ordination.

Sediments

Phase 1 and Phase 2 data summaries for the various sediment parameters included detection rates, minimum, median, maximum and mean values for all stations combined. All means were calculated using detected values only; no substitutions were made for non-detects in the data to avoid underestimating sediment contaminant loads (see Helsel 2005). Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane, and total PCB (tPCB) were calculated for each sample as the sum of all constituents with reported values. Sediment contaminant concentrations were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed, while values above the ERL but below the ERM represent levels at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998).

Spearman rank correlations were calculated to assess if values for the various parameters co-varied in sediments. This non-parametric analysis accounts for non-detects in the data without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in rank-based analyses may intensify with increased censoring (Conover 1980).

Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis.

SECTION C.4-3 | SUMMARY FOR PHASE 1

Sample Grid Design

Phase 1 focused on understanding spatial variability in the areas of interest. Once the spatial variability is known, then sampling distances (or lag distances) could be optimized for the second phase (Phase 2). A variogram plot is used to model spatial variability in an area of interest and is the key to determining the optimal lag distances and other model parameters to be used when creating a map using kriging. The variogram (Figure C.4-1) plots one-half the variance (gamma) against a series of fixed distances and has three reference points known as the nugget sill, and range.

The nugget indicates the variability between samples taken at very close proximities and represents both laboratory measurement error plus small-scale spatial variability. The sill is the variability achieved between samples spaced sufficiently far apart that a spatial relationship no longer exists. In this sense, the sill provides a measure of the variability among spatially independent samples. The range is the lag distance at which the sill is achieved and provides the limit to the extent of the spatial relationships between sample points.

The primary focus of Phase 1 was to generate sufficient information to create valid variograms for the analytes of interest in the areas of interest. This required sampling a large range of lag distances from the nugget, past the range, to the sill with a good number of samples collected at distances between the nugget and sill in order to best define the shape of the variogram curve. In order to generate these data, several clusters of sites were sampled at multiple locations throughout the mapping areas. Clusters were placed on top of existing regular monitoring grid sites to promote efficiency. S-shaped or more complex multi-lag clusters (i.e., overlapping S-clusters) can provide tremendous value since they cover a large range of lag distances (Ritter and Leecaster 2007).

To create variograms for sediment condition in two main areas offshore of San Diego, several S-shaped multi-lag clusters were placed in each area of interest. Five clusters were centered around the Point Loma Ocean Outfall, and another four clusters plus one half-cluster were centered around the South Bay Ocean Outfall. Additional spatial coverage was provided by sampling regular NPDES-mandated grid sites in both areas (Figures C.4-2 and C.4-3).

The clusters placed off Point Loma surrounded the existing outfall discharge/diffuser site (depth ~100 m). Sampling stations were located both north and south of the outfall, in shallower waters between the current wye and the old wye (depth ~60 m), and in an area bordering the LA-5 dredged materials disposal site located south-southwest of the outfall. Clusters in the South Bay region were placed near the present outfall diffusers (depth ~30 m), in slightly deeper waters west and north-northwest of the discharge site, and at several other locations north and south of the outfall.

A total of 216 sediment chemistry and 228 infauna samples were collected on the continental shelf off San Diego and northern Baja California at depths from 17 to 224 m from a large area surrounding the Point Loma and South Bay Ocean Outfalls (Table C.4-1). For the Point Loma region, 12 of the sites were primary core stations that are part of the existing Point Loma Ocean Outfall monitoring grid, and 8 other sites corresponded to stations sampled previously along the original inshore discharge depth contour. The remaining sites were new site locations allocated among five multi-lag clusters. For the South Bay region, 27 of the sites were part of the existing South Bay Ocean Outfall monitoring grid while the remaining 77 sites/samples were allocated to the multi-lag clusters. Duplicate samples were taken at 11 of the Point Loma area sites and 8 of the South Bay sites (~10% of sites) to help derive the variogram nugget, thus reducing the total number of distinct sites sampled.

Benthic Infauna

Community Parameters

A total of 984 macrobenthic taxa were identified during the survey. Of these, 17% represented rare or unidentifiable taxa that were recorded only once. The number of taxa per station ranged from 28 to 206 (Table C.4-2). Macrofaunal abundance ranged from 67–955 individuals per grab. The greatest number of animals occurred at stations SM028 and SM019, both of which had over 900 individuals per grab. Three other stations had abundance values greater than 800 individuals per grab, while most sites had values between 200–500 individuals per grab.

Species diversity (H’) varied among stations, and ranged from 1.9 to 4.6 (Table C.4-2). Although most of the stations had values between 3.0 and 4.0, stations with the highest diversity (i.e., ≥4.0, n=38) were found mostly along the mid shelf as expected. The lowest value occurred at station I15, a shallow water station located near the SBOO terminus. Species dominance was measured as the minimum number of species whose combined abundance accounts for 75% of the individuals in a sample (Swartz et al. 1986, Ferraro et al. 1994). Consequently, dominance as discussed herein is inversely proportional to numerical dominance, such that low index values indicate communities dominated by few species. These values varied widely throughout the region, ranging from 4 to 63 species per station.

Benthic Response Index (BRI) values at most stations were indicative of undisturbed communities or "reference conditions." Index values below 25 suggest undisturbed communities or "reference conditions," and those in the range of 25–33 represent "a minor deviation from reference condition," (Smith et al. 2001). Values greater than 44 indicate a loss of community function. BRI values throughout the San Diego Region were generally indicative of reference conditions. Index values ≥25 were restricted to 10 grabs: I9, I9 dup, SM042, SM043, SM089, SM130, SM138, SM143, SM145, and SM146 (Attachment C.4-B).

Classification of Assemblages

Ordination and classification (cluster) analyses illustrate the biological patterns at the community level for benthic stations sampled during Phase 1 of the Sediment Mapping study (Figure C.4-4). Cluster analysis discriminated seven groups (cluster groups A–G) that occurred at 1 to 114 sites each. Assemblages represented by each cluster group differed primarily by depth, location, and species composition (Table C.4-3, Figure C.4-4). The species composition and main descriptive characteristics of each cluster group are described below.

Cluster group A consisted of one station (I23, 21 m) with coarse sediments (11% fine particles) and contained 72 taxa and 830 individuals per grab. Total organic carbon (TOC) concentration at this station was 0.1%. Nematodes were the most abundant animals characterizing this assemblage, followed by *Saccocirrus* sp and *Hesionura coineaui difficilis*.

Cluster group B consisted of 47 nearshore stations located in the South Bay area that ranged in depth from 17 to 60 m. Sediments at stations within this group averaged 15% fines. Overall, the benthic assemblages represented by this group were typical of the shallow water sites in the region. Group B averaged 78 taxa and 284 individuals per grab. The dominant species included the polychaetes *Monticellina siblina*, *Spiophanes norrisi*, and *Spiophanes duplex*.

Cluster group C included 46 sites primarily located between 19 and 60 m, where sediments were coarse, containing only 4% fine particles. TOC at stations within this group averaged 0.1%. Assemblages represented by this group averaged 74 taxa and 354 individuals per grab. The polychaetes *Spiophanes norrisi*, and *Euchone arenae* and the crustacean *Ampelisca cristata cristata* were the numerically dominant species in this group.

Cluster group D represented the deepest eight outer shelf stations (mean depth=193 m). This group contained 64% fine sediments and averaged the highest concentration of TOC (1.1%). Group D had the lowest average number of species (55 taxa/grab and abundance (125 individuals/grab). The most abundant species were the polychaetes *Spiophanes kimballi* and *Paradiopatra parva*, and *Spiophanes berkeleyorum*.

Cluster group E consisted of two stations nearest the PLOO terminus (97 m). Sediments at these two stations were relatively coarse, averaging 12% fines. Species richness averaged 118 taxa and abundance averaged 818 individuals per grab. The dominant species included two polychaetes, *Mediomastus* sp and *Chloeia pinnata*, and the bivalve *Parvilucina tenisculpta*.

Cluster group F was composed of 9 transitional stations that were located at depths between 38 and 58 m. The sediments at these sites were generally mixed with about 27% fines and TOC concentrations were about 0.5%. Group F averaged 149 taxa and 485 individuals per grab. Dominate species included the polychaetes *Spiophanes duplex*, and *Sthenelanella uniformis* as well as the ostracod *Euphilomedes carcharodonta*.

Cluster group G comprised most (114) of the mid-shelf sites ranging in depth from 55 to 143 m. This cluster group, characterized by mixed sediments averaging 39% fines (23–58%), had an average species richness of 101 taxa and an average abundance of 388 individuals per grab. Assemblages represented by this group are typical of the ophiuroid dominated community that occurs along the mainland shelf off southern California. The most abundant species representing this mid-shelf group were the ophiuroid *Amphiodia urtica* and juvenile amphiurids, as well as the polychaetes *Myriochele striolata, Spiophanes duplex* and *Proclea* sp A.

Sediments

Sediment particle size and chemistry parameters are summarized across all stations and by region in Table C.4-4. Sediment composition was highly variable, with percent fines ranging from 0 to 76%, fine sands ranging from 3 to 82%, medium-coarse sands ranging from <1% to 86%, and coarse particles ranging from 0 to 58%. Detection rates were ≥77% for total nitrogen (TN), total organic carbon (TOC), total solids (TS), total volatile solids (TVS), and 15 out of 18 trace metals. In contrast, detection rates of selenium, silver, thallium, and total DDT ranged from 11 to 44%, while total PCB was found at ≤1% of the sites, and the pesticide chlordane was not detected. Overall, concentrations of the various parameters were variable with very few exceedances of available ERL and ERM thresholds (see Long et al. 1995). For example, arsenic, cadmium, chromium, lead, and silver never exceeded their ERL or ERM (for threshold values, see Table C.4-7), while exceedances for copper, mercury, nickel, and total DDT were rare (i.e.,

≤1.4% of the Phase 1 sites). Zinc exceeded its ERL and its ERM at ~4% and <1% of all stations, respectively. None of the exceedances found during Phase 1 of this study occurred at PLOO or SBOO regular fixed-grid monitoring stations, or at the two Sediment Mapping stations located within close proximity to the PLOO (i.e., SMO42, SM043).

An initial investigation of an inverse distance weighting interpolation map for the percent fines results suggested that the data for the Point Loma region and the data for the South Bay region represent distinctly different sediment regimes with substantial patchiness within each survey area (Figure C.4-5). This conclusion is supported by sediment composition found at PLOO stations, which averaged 46% fines, 45% fine sands, and <6% medium-coarse sands or coarse particles, versus the sediment composition found at SBOO stations, which averaged 15% fines, 45% fine sands, 37% medium-coarse sands, and ~3% coarse particles (Table C.4-4). These results are also consistent with historical findings for the PLOO and SBOO monitoring regions (City of San Diego 2014b, 2014c).

The Spearman rank correlation results for this study indicated that over half of the sediment chemistry analytes that were detected frequently enough (see methods) for correlation analysis co-varied with percent fines (10 analytes had high correlation, see Table C.4-5). This finding, combined with the well-established differences in the percent fines distribution for the Point Loma versus South regions (see Figure C.4-6), made it clear why attempts to krige across the entire Phase 1 sediment mapping region did not yield coherent models.

Instead, ordinary kriging was performed on Point Loma region samples separately from the South Bay samples. The results presented here are for the Point Loma sample grid only, and examples of the ordinary kriging results are provided in Figure C.4-7. Models were based on lognormal transformed values with a second order trend removal and anisotropic correction applied. Most analytes demonstrated an angle of anisotropy ~160 degrees. Variability showed strong spatial dependence for each parameter but range and nugget values varied widely among analytes. Major range results were as low as 2.5 km and as high as 24 km (which was the full distance of the North-South extent of the Point Loma Phase 1 sampling grid).

Because the strength of the variance differences between the major and the minor directions was unanticipated, and since the sample design was strongly North-South oriented (especially with regard to closely-spaced samples) the kriging results were of limited use in capturing a usable standard error for the models. The extent of the sampling grid also caused difficulties for interpreting kriging results due to the presence of multiple sources of possible contaminant input (e.g., from tidal flushing of San Diego Bay and Mission Bay, as well as from the LA5 dredge disposal site). The kriging predictions exhibited especially large errors as the prediction surface approached the east and west edges of the sample grid. These model limitations seem to suggest that the trend removal method was not adequate. It may be that a localized trend removal method based on field knowledge would be more effective than the universal second order polynomial trend correction that was used.

With the major range values highly variable across analytes, the high standard errors occurring along the outer portions of the study area in the minor range direction, and the relationship with depth likely a further complicating factor (due to the coarse resolution of the bathymetric digital elevation model available at the time), it was determined that a cost-efficiency curve would be estimated using just the percent fines and BRI models since these parameters gave acceptable error values when manually-imposed effective range values were applied to the models. Evaluating the model at varying spatial grid resolutions showed that, according to this model, there are diminishing returns to sampling with a grid resolution below 1000 m. Quadrupling effort/costs and sample sizes from 1000 m between samples down to 500 m between samples only gains ~4% reduction in error.

These models were then used to construct Figure C.4-8, a cost efficiency model (curve) which illustrates the relationship between percent of total error (i.e., statistical confidence) and distance between samples for estimating grain size (% fines) and biological condition (benthic response index or BRI). This curve shows about a 5-10% increase in confidence for every 500 m reduction in spacing.

These findings were used to develop the sampling design for Phase 2 of the sediment mapping project. With a finely-spaced grid spanning a more limited, localized area that was pre-rotated to best account for the strong degree of anisotropy exhibited by most analytes, it was anticipated that the Phase 2 dataset would better capture the small-scale variability in the region surrounding the Point Loma Ocean Outfall. It was also anticipated that designing a tighter grid to keep the extent of the study area restricted to the immediate area surrounding the outfall would reduce the effects of other possible anthropogenic sources of contaminants. In short, the new sample design customized to the sediment conditions surrounding the PLOO was expected to provide accurate kriging models make it possible to create of a series of statistically defensible maps representing the concentrations of many of the analytes measured.

SECTION C.4-4 | SUMMARY FOR PHASE 2

Background

The second phase of the Sediment Mapping Study was intended to leverage the information captured by the first phase of the project regarding the spatial characterization of sediment chemistry conditions in the region immediately surrounding the Point Loma Ocean Outfall.

The ultimate question to be answered by this study was whether an accurate map of benthic conditions could be generated from an intensive sampling effort based on a spatially optimized sampling grid. Since the results from the first phase of the study covered a very large area, with a complex suite of contaminant inputs, it was determined that attempting to utilize kriging interpolation methods to characterize the area encompassing both the Point Loma and South Bay offshore regions was ineffective. The regions are distinctive in every regard, from contaminant load to distribution of sediments and current regimes.

One useful finding that resulted from the first phase of the project was related to the fairly consistent angle of anisotropy for most analytes. This allowed the sampling grid for the second phase of the project to be rotated to match the angle of anisotropy. Aligning the grid with the dominant angle of anisotropy allowed the development of a sample grid that balanced variability between the major and minor ranges. These optimized asymmetrical distances allowed a reasonable number of sampling stations to cover a wider area. This carefully constructed sampling scheme was designed to optimize the results from the kriging method of modeling spatial autocorrelation.

The sampling design was subjected to iterative improvements in satellite station placement, most notably to balance areal coverage versus sampling density. The final design maximized the area covered while still providing enough closely-spaced point pairs (see Figure C.4-9) to establish confidence in the final spatial model.

Sample Grid Design

Using the estimates of spatial variance from Phase 1, as well as the directions of highest and lowest variance, and the subregions that were identified areas of interest, an optimized sample grid was designed to achieve the goal of Phase 2: to create a cost efficient and statistically defensible map of sediment quality for the Point Loma outfall region. There were 133 sample sites distributed in an optimized design that utilized two different sampling densities within different regions of the survey area. The base grid had sites spaced 800 m apart in the cross-shore (greatest variability) direction and 1200m apart in the along-shore (least variability) direction. The enhanced grid area, which immediately surrounds the outfall, had samples spaced 550 m x 800 m apart (in the cross-shore and along-shore directions, respectively). Additional “satellite” stations were placed short distances (either 250 m or 500 m) away from their anchor points, which were a selected subset of the grid stations intended to provide good spatial coverage of the full study area (Figure C.4-10 and Table C.4-6). The rotation (tilted placement) of the Phase 2 station grid was to account for the strong directionality to the spatial variability of the distribution of percent fines and some of the metals in the Point Loma region derived from Phase 1. Finally, duplicate samples were collected at a subset of the new grid stations in order to estimate measurement error and small scale variability.

Preliminary Results

Sediment particle size and chemistry parameters are summarized across all Phase 2 Sediment Mapping stations in Table C.4-7. Sediment composition averaged 54% fines, 44% fine sands, and only traces of medium-coarse sands or coarse particles. Detection rates were ≥70% for total nitrogen (TN), total organic carbon (TOC), total solids (TS), total volatile solids (TVS), total DDT, and 16 out of 18 trace metals. In contrast, detection rates of selenium, aldrin, hexachlorobenzene (HCB), total chlordane, and total PCB were found at ≤42% of the stations, and thallium, HCH, dieldrin, endosulfan, endrin, and Mirex were never detected. Overall, concentrations of various parameters were variable with very few exceedances of available ERL and ERM thresholds (see Long et al. 1995). For example, arsenic, cadmium, chromium, lead, and zinc never exceeded their ERL or ERM, while exceedances for copper, mercury, nickel, and total DDT were rare (i.e., ≤7.5% of the samples included in this study). Silver exceeded its ERL and its ERM at 50% and <1% of all stations, respectively.

Preliminary results suggest that, even with a limited study area and an optimized sampling grid, it is still challenging to develop robust kriged models of the spatial variability of sediment chemistry parameters in the region surrounding the PLOO. The variability seems to exhibit a strong, locally varying trend. Models will need to be developed that will effectively account for this trend that, for most of the studied analytes, appears correlated with percent fines, fines-associated metals, and with depth (Table C.4-8, Figures C.4-11 and C.4-12). In contrast, the distance from outfall factor was not well correlated with any analyte studied (data not shown). Considering these complicated relationships will require a robust method of trend removal before accurate, reliable kriging models can be developed. That de-trending and modeling process is currently underway with results expected to be published in Fall 2015.

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APPENDIX C.4

San Diego Sediment Mapping Study

TABLES

TABLE C.4-1
Sampling effort for Phase 1 of the Sediment Mapping study for both the Point Loma and South Bay Ocean Outfall regions.

Sample Type	Number of Samples		
	Regular NPDES grid sites*	New mapping sites†	Total number of samples
Point Loma			
sediment	13	88	101
macrofauna	13 (26)*	88	101 (123)*
South Bay			
sediment	27	77	104
macrofauna	27	77	104

* Regular NPDES sites for Pt Loma = Primary core stations currently monitored along the 98-m discharge depth contour; sampling at these 12 sites includes two replicate macrofauna grabs per NPDES permit requirements.

† Included as “new” mapping sites off Pt Loma were the locations of: (a) one Secondary core station currently monitored along the 116-m depth contour, and (b) eight old inshore stations located along the original 60-m discharge depth contour.

TABLE C.4-2

Summary of macrofaunal community parameters for all samples (n) collected during Phase 1 of the Sediment Mapping study in 2004. SR=species richness (no. taxa/0.1 m^2); Abun =abundance (no. individuals/0.1 m^2); H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index.

Region	Depth (m)	SR	Abun	H'	J'	Dom	BRI
PLOO Region (n=123)							
Min	45	42	67	2.0	0.40	4	0
Max	224	160	955	4.6	1.00	63	35
Mean	97	98	378	3.7	0.80	30	8
95%CI	6	4	29	0.0	0.00	2	2
SBOO Region (n=104)							
Min	17	28	82	1.9	0.50	6	3
Max	64	206	830	4.5	0.90	57	28
Mean	34	83	339	3.4	0.80	23	17
95%CI	2	6	27	0.2	0.00	2	2
All Stations (n=227)							
Min	17	28	67	1.9	0.50	4	0
Max	224	206	955	4.6	1.00	63	35
Mean	68	91	360	3.6	0.80	27	12
95%CI	6	4	20	0.0	0.00	2	2

TABLE C.4-3

Summary of the most abundant taxa comprising cluster groups A–G (see Figure C.4-4). Data are expressed as mean abundance per cluster group; n=number of grabs per cluster group.

		Cluster Group						
		A	**B**	**C**	**D**	**E**	**F**	**G**
Species/Taxa	**Taxa**	**n=1**	**n=47**	**n=46**	**n=8**	**n=2**	**n=9**	**n=114**
Ampelisca cristata cristata	Crustacea	—	4.4	9.3	—	—	0.2	0.1
Amphiodia urtica	Echinodermata	—	—	0.5	0.5	—	6.2	37.4
Amphiuridae	Echinodermata	1.0	1.2	4.5	0.4	0.5	2.4	22.4
Aoroides inermis	Crustacea	—	0.1	0.5	—	28.0	1.9	0.3
Aricidea (Acmira) simplex	Polychaeta	—	—	0.3	0.4	4.5	12.2	2.3
Gadila aberrans	Mollusca	—	9.4	0.7	—	—	1.6	0.4
Chloeia pinnata	Polychaeta	—	1.5	1.1	2.3	53.0	9.8	11.6
Euchone arenae	Polychaeta	70.0	—	15.8	0.1	—	0.1	0.2
Euphilomedes carcharodonta	Crustacea	—	10.4	2.9	—	1.0	12.4	6.5
Hesionura coineaui difficilis	Polychaeta	71.0	—	0.9	—	—	—	—
Mediomastus sp	Polychaeta	—	2.3	1.0	3.6	182.5	4.1	4.1
Monticellina siblina	Polychaeta	—	39.0	1.1	0.3	9.5	6.1	1.2
Mooreonuphis sp	Polychaeta	—	—	7.9	—	—	—	—
Myriochele striolata	Polychaeta	—	1.8	0.9	—	—	—	53.5
Nematoda	Nematoda	199.0	1.0	7.1	—	35.0	7.3	0.4
Paradiopatra parva	Polychaeta	—	0.5	0.1	5.0	6.5	5.3	4.7
Parvilucina tenuisculpta	Mollusca	—	0.5	0.1	2.0	43.5	1.7	1.4
Phyllochaetopterus limicolus	Polychaeta	—	0.1	—	3.5	—	—	—
Pisione sp	Polychaeta	56.0	—	0.5	—	—	—	—
Proclea sp A	Polychaeta	—	—	—	0.1	—	1.0	12.7
Saccocirrus sp	Polychaeta	95.0	—	—	—	—	—	—
Spiophanes berkeleyorum	Polychaeta	—	2.6	1.5	4.4	8.0	2.1	2.5
Spiophanes norrisi	Polychaeta	7.0	31.5	108.7	—	—	8.7	0.2
Spiophanes duplex	Polychaeta	—	10.4	3.5	0.9	2.5	64.0	12.2
Spiophanes kimballi	Polychaeta	—	—	—	20.5	12.5	0.4	6.9
Sthenelanella uniformis	Polychaeta	—	0.3	0.1	—	3.0	17.4	1.1

TABLE C.4-4

Summary of particle sizes and chemistry concentrations for Phase 1 Sediment Mapping samples collected in 2004. Data include detection rate (DR), minimum, median, maximum, mean, and 95% confidence intervals (CI) for the entire survey area, as well as mean and 95%CI by region; n=number of samples.

	Phase 1 Survey Area (n=216) [b]						PLOO Region (n=112) [b]		SBOO REgion (n=104) [b]	
	DR	**Min**	**Median**	**Max**	**Mean**	**95%CI**	**Mean**	**95%CI**	**Mean**	**95%CI**
Particle Size (%)										
Coarse Particles	—	0.00	0.00	58.20	2.85	0.96	2.80	1.33	2.90	0.70
Med-Coarse Sands	—	0.23	5.55	86.43	20.69	3.75	5.47	5.21	37.07	6.31
Fine Sands	—	3.37	47.20	81.67	45.21	2.75	45.45	3.82	44.95	5.25
Fines	—	0.00	30.99	76.43	31.28	2.69	46.30	3.73	15.10	2.34
Organic Indicators (%)										
TN[a]	98	nd	0.04	0.16	0.04	0.00	0.06	0.00	0.02	0.00
TOC[a]	99	nd	0.36	1.55	0.40	0.04	0.58	0.05	0.18	0.03
TS	100	2.98	72.95	82.30	72.59	1.01	69.39	1.57	76.03	0.87
TVS	100	0.38	1.99	68.20	2.29	0.62	3.37	1.16	1.12	0.14
Metals (ppm)										
Aluminum	100	1750	14450	32300	13575	896	17762	828	9065	1106
Antimony	88	nd	0.95	4.37	1.52	0.13	1.77	0.16	1.21	0.20
Arsenic	100	0.68	3.05	7.85	3.17	0.17	3.58	0.15	2.73	0.30
Barium	100	2.86	43.40	230.00	45.24	3.86	60.80	4.97	28.48	3.96
Beryllium	96	nd	0.18	0.43	0.18	0.01	0.21	0.02	0.15	0.01
Cadmium	77	nd	0.06	0.47	0.10	0.01	0.13	0.01	0.06	0.01
Chromium	100	5.28	18.50	50.40	19.77	1.02	24.14	1.25	15.05	1.07
Copper	100	0.16	7.24	35.10	8.80	0.92	12.37	1.08	4.96	1.12
Iron	100	2260	16100	33100	15825	801	19560	766	11802	968
Lead	99	nd	2.95	9.55	3.36	0.23	3.42	0.34	3.28	0.32
Manganese	100	31.8	245.5	605.0	238.1	12.5	281.9	9.7	190.9	20.2
Mercury	84	nd	0.022	0.212	0.031	0.004	0.044	0.005	0.010	0.003
Nickel	100	0.63	6.78	33.00	6.73	0.57	9.47	0.69	3.77	0.50
Selenium	7	nd	nd	0.72	0.38	0.02	0.41	0.03	0.17	0.03
Silver	31	nd	nd	0.46	0.11	0.01	0.15	0.01	0.11	0.01
Thallium	44	nd	nd	2.89	1.15	0.10	0.92	0.10	1.75	0.19
Tin	80	nd	0.72	3.38	1.13	0.10	0.77	0.14	1.48	0.11
Zinc	100	3.61	29.60	908.00	42.99	10.55	43.42	8.52	42.52	19.97
Pesticides (ppt)										
Total DDT	11	nd	nd	17000	1695	473	2121	852	1141	268
Alpha Chlordane	0	nd	—	—	—	—	—	—	—	—
Oxychlordane	0	nd	—	—	—	—	—	—	—	—
Gamma Chlordane	0	nd	—	—	—	—	—	—	—	—
Total PCB (ppt)	<1	nd	nd	1590	1590	—	1590	—	—	—

[a] Only 210 samples were analyzed for TN and TOC; see Attachment C.4 for MDLs and abbreviations

[b] Minimum, median, and maximum values were calculated using all samples, whereas means and CIs were calculated on detected values only; nd = not detected

TABLE C.4-5

Results of Spearman rank correlation analyses of depth, percent fines and various sediment chemistry parameters from Phase 1 of the Sediment Mapping study. Correlation coefficients of 0.70 – 0.80 are highlighted in blue; 0.80 – 0.90 in pink; >0.90 in yellow. For all analyses, n= the number of detected values. See Attachment C.4-A for abbreviations.

	Fines	*Organic Indicators (%)*				Metals (ppm)														
	(%)	TN	TOC	TS	TVS	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Sn	Zn
n	216	206	208	216	216	216	190	216	216	207	167	216	216	216	213	216	181	216	173	**216**
Depth (m)	0.65	0.59	0.62	-0.31	0.67	0.52	0.24	0.43	0.43	0.06	0.45	0.43	0.47	0.59	-0.21	0.47	0.62	0.62	-0.71	0.26
Fines (%)		0.96	0.96	-0.84	0.93	0.88	0.46	0.34	0.76	0.52	0.64	0.82	0.71	0.81	-0.04	0.70	0.85	0.90	-0.61	0.44
Organic Indicators (%)																				
TN			0.99	-0.83	0.91	0.83	0.47	0.29	0.71	0.59	0.64	0.82	0.69	0.77	-0.02	0.65	0.82	0.89	-0.60	0.39
TOC				-0.82	0.91	0.84	0.46	0.30	0.72	0.59	0.65	0.82	0.69	0.77	-0.02	0.65	0.84	0.90	-0.60	0.39
TS					-0.78	-0.82	-0.47	-0.15	-0.70	-0.64	-0.58	-0.81	-0.66	-0.67	-0.05	-0.56	-0.62	-0.78	0.40	-0.41
TVS						0.87	0.50	0.39	0.78	0.50	0.64	0.86	0.75	0.86	0.00	0.73	0.86	0.94	-0.62	0.52
Metals (ppm)																				
Al							0.39	0.26	0.91	0.59	0.58	0.85	0.73	0.84	0.11	0.66	0.76	0.90	-0.47	0.55
Sb								0.34	0.35	0.49	0.73	0.68	0.72	0.45	0.01	0.24	0.42	0.52	-0.52	0.33
As									0.21	0.06	0.28	0.31	0.21	0.41	-0.04	0.26	0.56	0.39	-0.37	-0.06
Ba										0.61	0.61	0.82	0.73	0.79	0.25	0.62	0.68	0.85	-0.36	0.61
Be											0.69	0.72	0.53	0.44	0.27	0.27	0.43	0.61	-0.04	0.15
Cd												0.78	0.74	0.55	-0.14	0.38	0.56	0.73	-0.36	0.25
Cr													0.85	0.80	0.05	0.62	0.73	0.92	-0.49	0.53
Cu														0.70	0.08	0.45	0.68	0.78	-0.62	0.72
Fe															0.11	0.78	0.81	0.85	-0.49	0.55
Pb																-0.21	0.08	0.03	0.47	0.25
Mn																	0.62	0.69	-0.46	0.35
Hg																		0.84	-0.51	0.29
Ni																			-0.58	0.49
Sn																				-0.34

TABLE C.4-6

Sampling effort in the Point Loma Ocean Outfall region for Phase 2 of the Sediment Mapping study in 2012. The "enhanced grid" stations were in the area of interest directly surrounding the outfall, whereas the "base grid" area was the region surrounding the enhanced grid area. The "outside grid area" stations were fixed-grid regular monitoring stations.

	No. of Stations by Area of Interest				
Station Type	**Enhanced Grid**	**Base Grid**	**Outside Grid Area**	**Total Stations**	**No. of Samples**
P2 Grid					
Regular (1 rep)	49	34	0	83	83
Duplicate (2 reps)	6	6	0	12	24
P2 satellite (1 rep)	11	15	0	26	26
PLOO Primary Core (1 rep)	7	1	4	12	12
TOTAL	73	56	4	133	145

TABLE C.4-7

Summary of particle sizes and chemistry concentrations for Phase 2 Sediment Mapping samples collected in 2012. Data include the detection rate (DR), minimum, median, maximum and mean values[a] for the entire survey area. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold. See Attachment C.4-A for MDLs and other abbreviations.

	All Depths (n=133)						
	DR	Min	Median	Max	Mean	ERL[b]	ERM [b]
Particle Size (%)							
Coarse Particles	—	0.00	0.00	12.34	0.36	na	na
Med-Coarse Sands	—	0.19	0.78	16.46	1.24	na	na
Fine Sands	—	17.97	44.98	64.80	44.49	na	na
Fines	—	24.20	53.43	81.66	53.92	na	na
Organic Indicators (%)							
TN	100	0.027	0.069	0.182	0.076	na	na
TOC	100	0.253	0.644	2.330	0.776	na	na
TS	100	53.40	69.30	77.60	68.68	na	na
TVS	100	1.71	2.70	7.35	3.08	na	na
Metals (ppm)							
Aluminum	100	5170	15600	31700	16137	na	na
Antimony	79	nd	0.70	1.30	0.77	na	na
Arsenic	100	1.71	2.89	4.50	2.91	8.2	70
Barium	100	24.10	51.80	151.00	53.20	na	na
Beryllium	100	0.02	0.28	0.59	0.29	na	na
Cadmium	75	nd	0.14	0.35	0.17	1.2	9.6
Chromium	100	10.7	21.0	38.8	22.0	81	370
Copper	100	5.0	10.5	60.8	12.2	34	270
Iron	100	9240	15400	27000	15809	na	na
Lead	100	3.8	9.9	20.9	10.1	46.7	218
Manganese	100	75.1	172.0	257.0	172.6	na	na
Mercury	100	0.016	0.044	0.193	0.052	0.15	0.71
Nickel	100	4.2	9.8	23.7	10.8	20.9	51.6
Selenium	24	nd	nd	0.91	0.42	na	na
Silver	70	nd	0.99	5.54	1.38	1	3.7
Thallium	0	—	—	—	—	na	na
Tin	99	nd	2.40	6.95	3.37	na	na
Zinc	100	21.20	37.40	79.80	39.42	150	410
Pesticides (ppt)							
Aldrin	2	nd	nd	120	90	na	na
HCB	5	nd	nd	860	339	na	na
Total Chlordane	3	nd	nd	2800	1053	na	na
Total DDT	89	nd	390	18940	897	1580	46100
Total PCB (ppt)	42	nd	nd	3445240	64679	na	na

[a] Minimum, median, and maximum values were calculated based on all samples (n = 133), whereas means were calculated on detected values only (n ≤ 133); na = not available, nd = not detected

[b] From Long et al. 1995

TABLE C.4-8

Results of Spearman rank correlation analyses of depth, percent fines and various sediment chemistry parameters from Phase 2 of the Sediment Mapping study. Correlation coefficients of 0.70 – 0.80 are highlighted in blue; 0.80 – 0.90 in pink; >0.90 in yellow. For all analyses, n= the number of detected values. See Attachment C.4-A for abbreviations.

	Fines	*Organic Indicators (%)*				Metals (ppm)																Total DDT
	(%)	TN	TOC	TS	TVS	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Ag	Sn	Zn	(ppt)
n	133	133	133	133	133	133	105	133	133	133	100	133	133	133	133	133	133	133	93	132	133	119
Depth (m)	0.11	0.11	0.29	-0.10	0.31	0.05	0.17	-0.49	-0.03	0.21	-0.02	0.18	0.28	0.15	0.08	-0.08	0.20	0.15	0.02	0.07	0.16	0.06
Fines (%)		0.92	0.80	-0.92	0.87	0.91	0.25	0.60	0.79	0.65	0.64	0.89	0.73	0.81	0.81	0.52	0.68	0.93	0.19	0.24	0.81	0.74
Organic Indicators (%)																						
TN			0.85	-0.96	0.89	0.84	0.18	0.61	0.69	0.60	0.74	0.86	0.66	0.73	0.74	0.46	0.59	0.92	0.14	0.12	0.75	0.74
TOC				-0.85	0.92	0.77	0.23	0.47	0.57	0.67	0.64	0.87	0.64	0.76	0.66	0.44	0.55	0.85	0.12	0.30	0.75	0.64
TS					-0.89	-0.85	-0.22	-0.64	-0.72	-0.64	-0.75	-0.87	-0.67	-0.75	-0.77	-0.48	-0.61	-0.92	-0.12	-0.17	-0.77	-0.76
TVS						0.84	0.27	0.47	0.67	0.69	0.62	0.90	0.72	0.81	0.75	0.48	0.62	0.90	0.18	0.30	0.81	0.66
Metals (ppm)																						
Al							0.35	0.55	0.87	0.67	0.65	0.95	0.78	0.91	0.85	0.68	0.70	0.94	0.38	0.46	0.90	0.70
Sb								-0.14	0.27	0.23	-0.15	0.39	0.28	0.43	0.19	0.83	0.23	0.32	0.68	0.72	0.38	0.18
As									0.55	0.40	0.50	0.49	0.34	0.45	0.53	0.21	0.34	0.53	-0.15	-0.02	0.45	0.50
Ba										0.68	0.69	0.82	0.88	0.86	0.92	0.53	0.79	0.79	0.32	0.32	0.91	0.68
Be											0.75	0.74	0.74	0.69	0.86	0.28	0.57	0.69	0.07	0.24	0.74	0.61
Cd												0.68	0.71	0.63	0.75	0.13	0.45	0.70	0.00	-0.02	0.71	0.60
Cr													0.83	0.95	0.84	0.64	0.68	0.96	0.33	0.42	0.93	0.72
Cu														0.86	0.88	0.41	0.81	0.75	0.27	0.30	0.92	0.66
Fe															0.81	0.67	0.67	0.87	0.37	0.49	0.95	0.64
Pb																0.42	0.77	0.81	0.22	0.23	0.89	0.73
Mn																	0.38	0.60	0.78	0.71	0.60	0.34
Hg																		0.64	0.29	0.29	0.76	0.57
Ni																			0.25	0.33	0.87	0.73
Ag																				0.53	0.37	0.10
Sn																					0.43	0.09
Zn																						0.69

APPENDIX C.4

San Diego Sediment Mapping Study

FIGURES

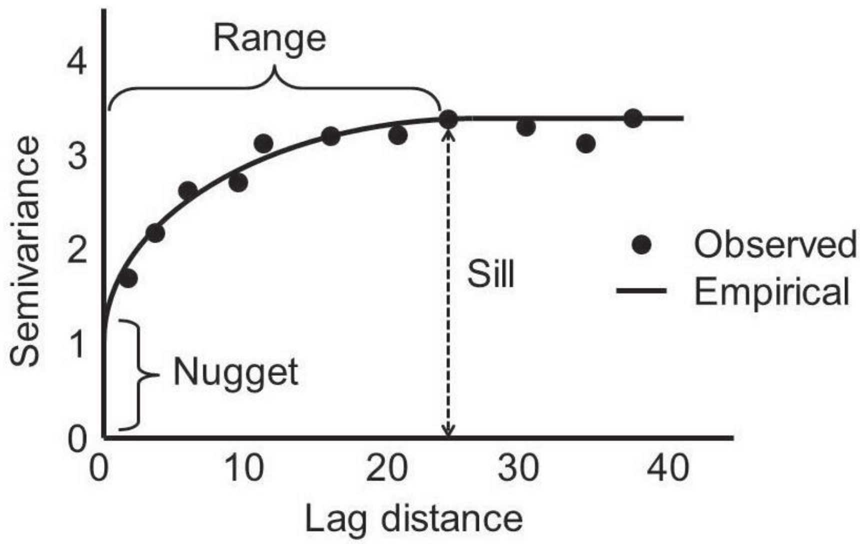


FIGURE C.4-1
Example variogram.

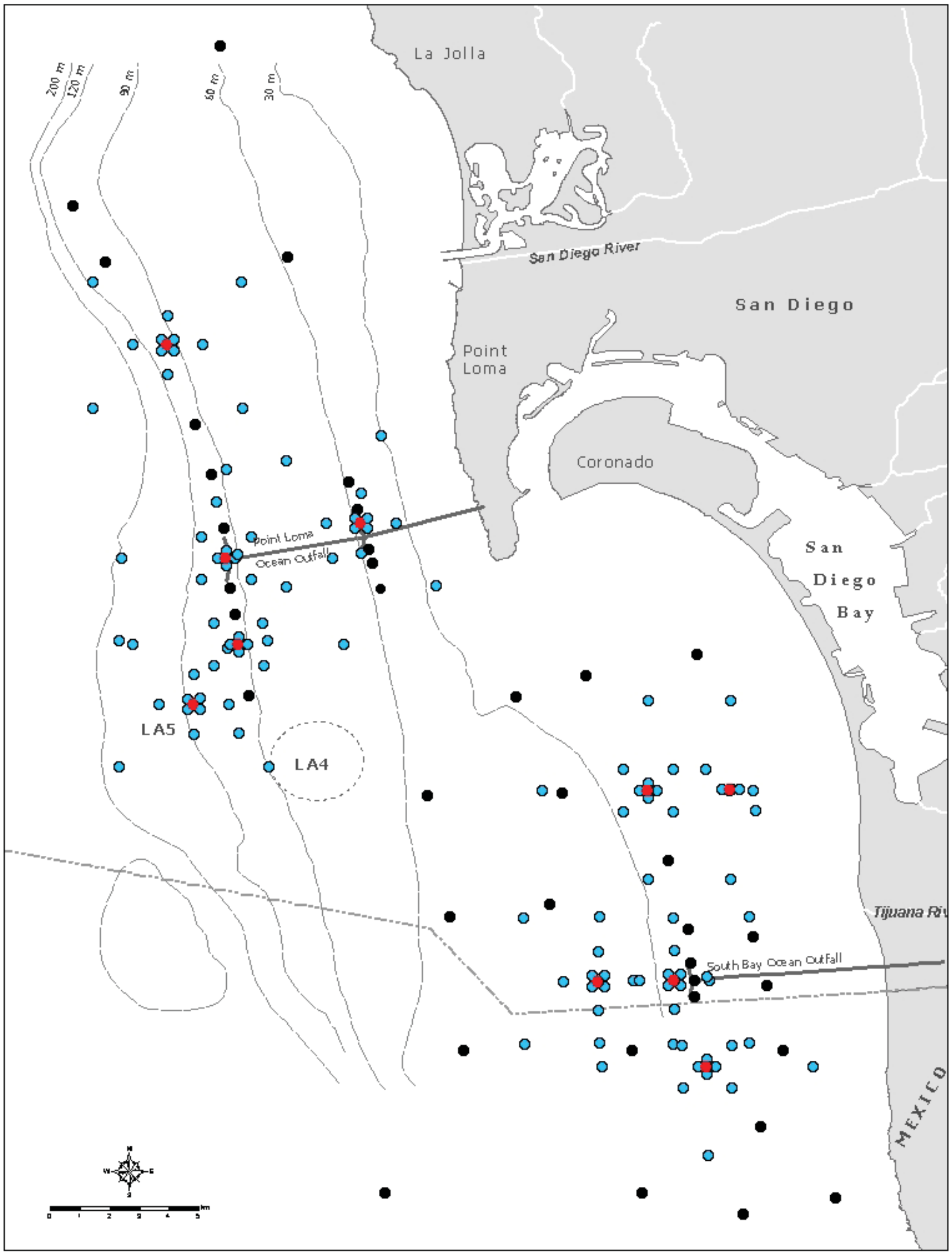


FIGURE C.4-2
Overview of the site distribution for Phase 1 of the Sediment Mapping study. Blue circles = new mapping sites, black circles = current or old NPDES grid stations, red circles = cluster enhancement areas representing 3-5 sites, 50-m lag distances apart. See Figure C.4-3 for a magnified view of the site distribution for just the Point Loma Ocean Outfall region.

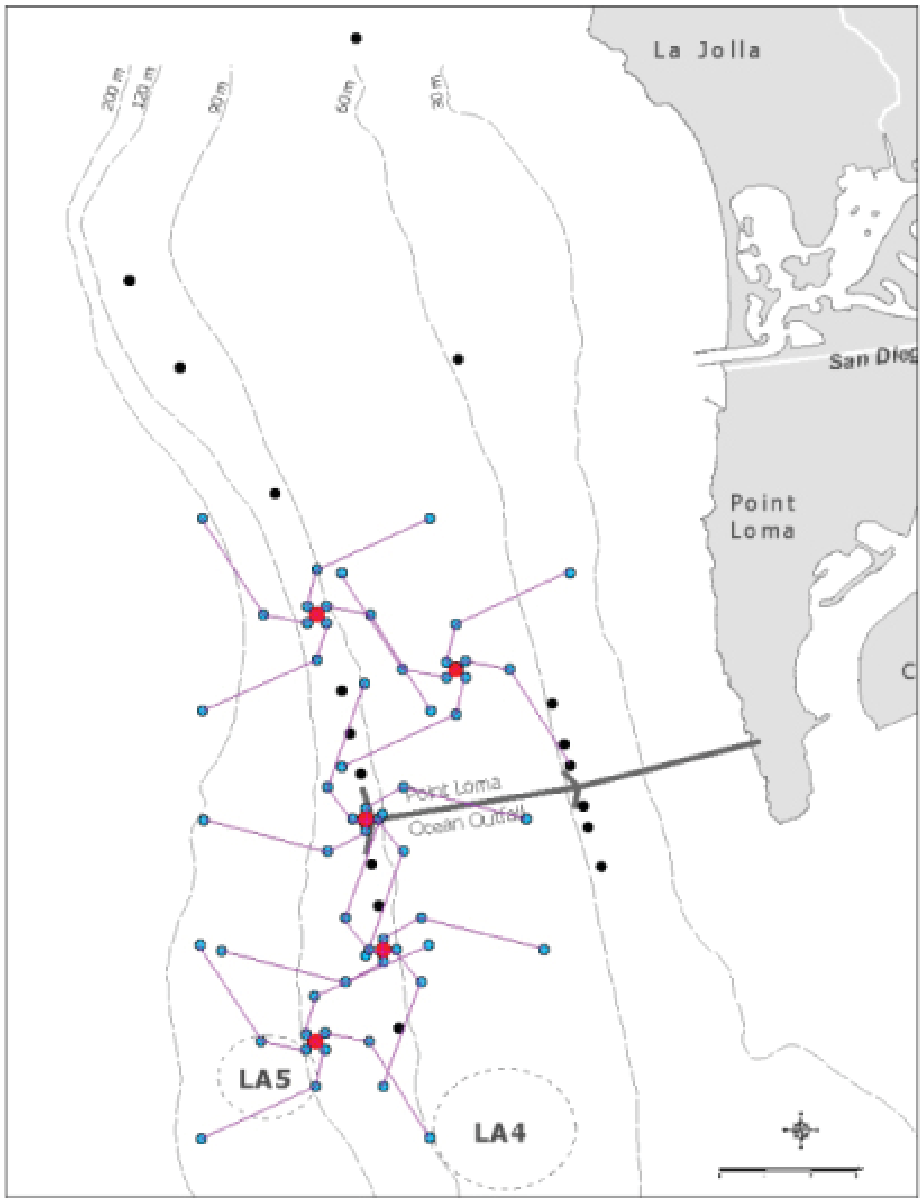
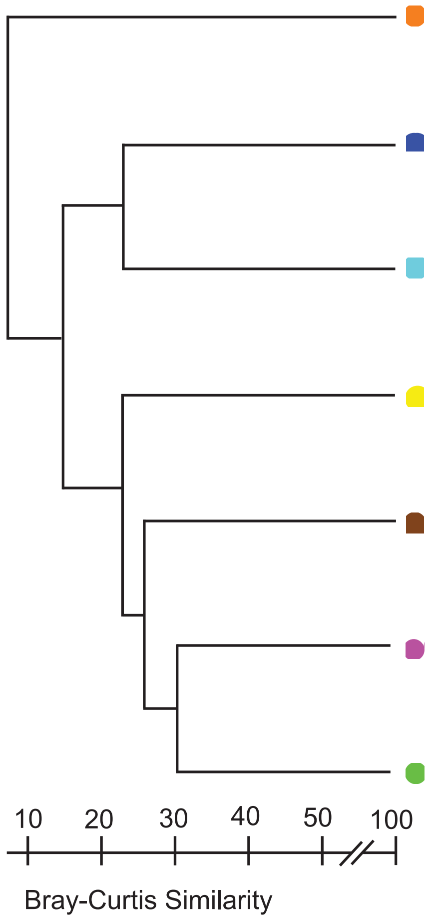


FIGURE C.4-3
Expanded view of the Phase 1 Sediment Mapping sites located within the Point Loma Ocean Outfall region showing location of multi-lag clusters: blue circles = new mapping sites; black circles = current NPDES 98-m grid stations or old NPDES stations along inshore 60-m depth contour; red circles = cluster enhancement areas representing five sites in close proximity only 50-m lag distances apart (1 grid or new station in center surrounded by 4 new sites).

A



CG	% Fines	TOC	SR	Abun	Top Taxa
A	11	0.1	72	830	Nematoda *Saccocirrus* sp *Hesionura coineaui difficilis*
B	15	0.2	78	284	*Monticellina siblina* *Spiophanes norrisi* *Spiophanes duplex*
C	4	0.1	74	354	*Spiophanes norrisi* *Euchone arenae* *Ampelisca cristata cristata*
D	64	1.1	55	125	*Spiophanes kimballi* *Paradiopatra parva* *Spiophanes berkeleyorum*
E	12	0.2	118	818	*Mediomastus* sp *Chloeia pinnata* *Parvilucina tenuisculpta*
F	27	0.5	149	485	*Spiophanes duplex* *Sthenelanella uniformis* *Euphilomedes carcharodonta*
G	39	0.5	101	388	*Myriochele striolata* *Amphiodia urtica* Amphiuridae

B

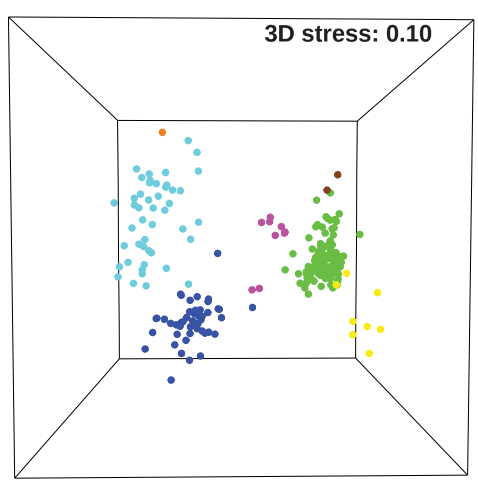


FIGURE C.4-4
Results of (A) classification and (B) nMDS ordination analyses of macrofaunal abundance data from Phase 1 of the Sediment Mapping study in 2004. Data are expressed as mean values per 0.1 m^2 grab for each group.

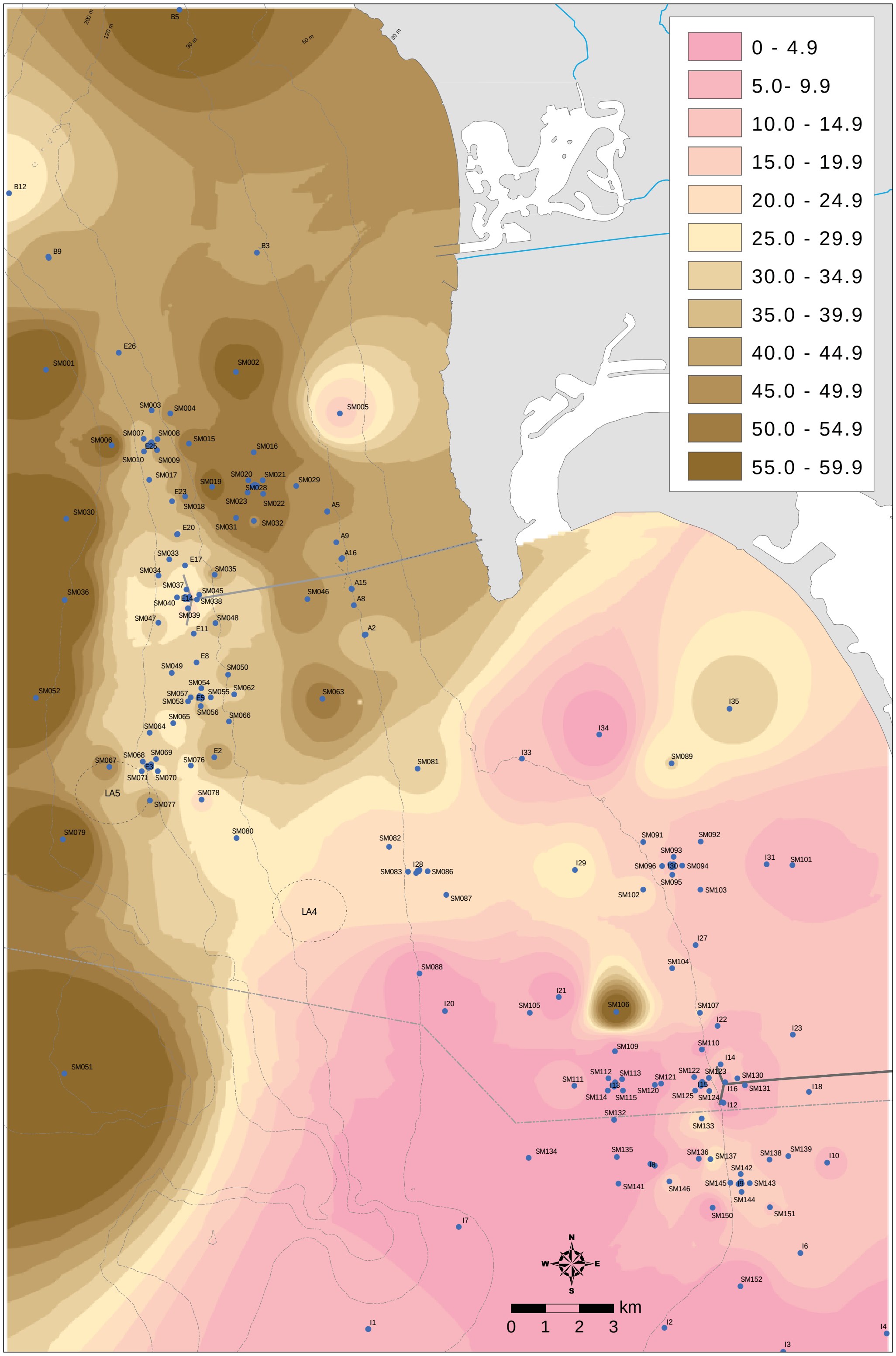


FIGURE C.4-5
An inverse distance weighted interpolation (which does not provide a measure of uncertainty) for percent fines across the full Phase 1 survey area of the Sediment Mapping study in 2004.

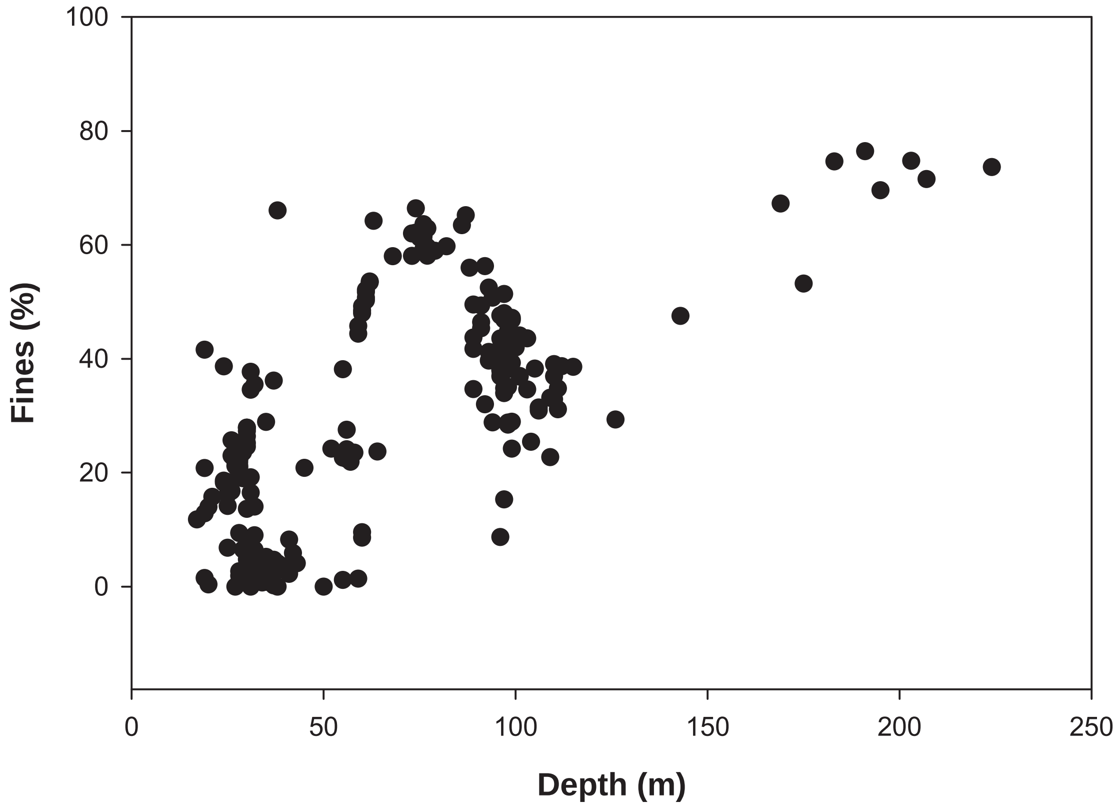


FIGURE C.4-6a
Scatterplot of depth versus percent fines from Phase 1 of the Sediment Mapping study in 2004.

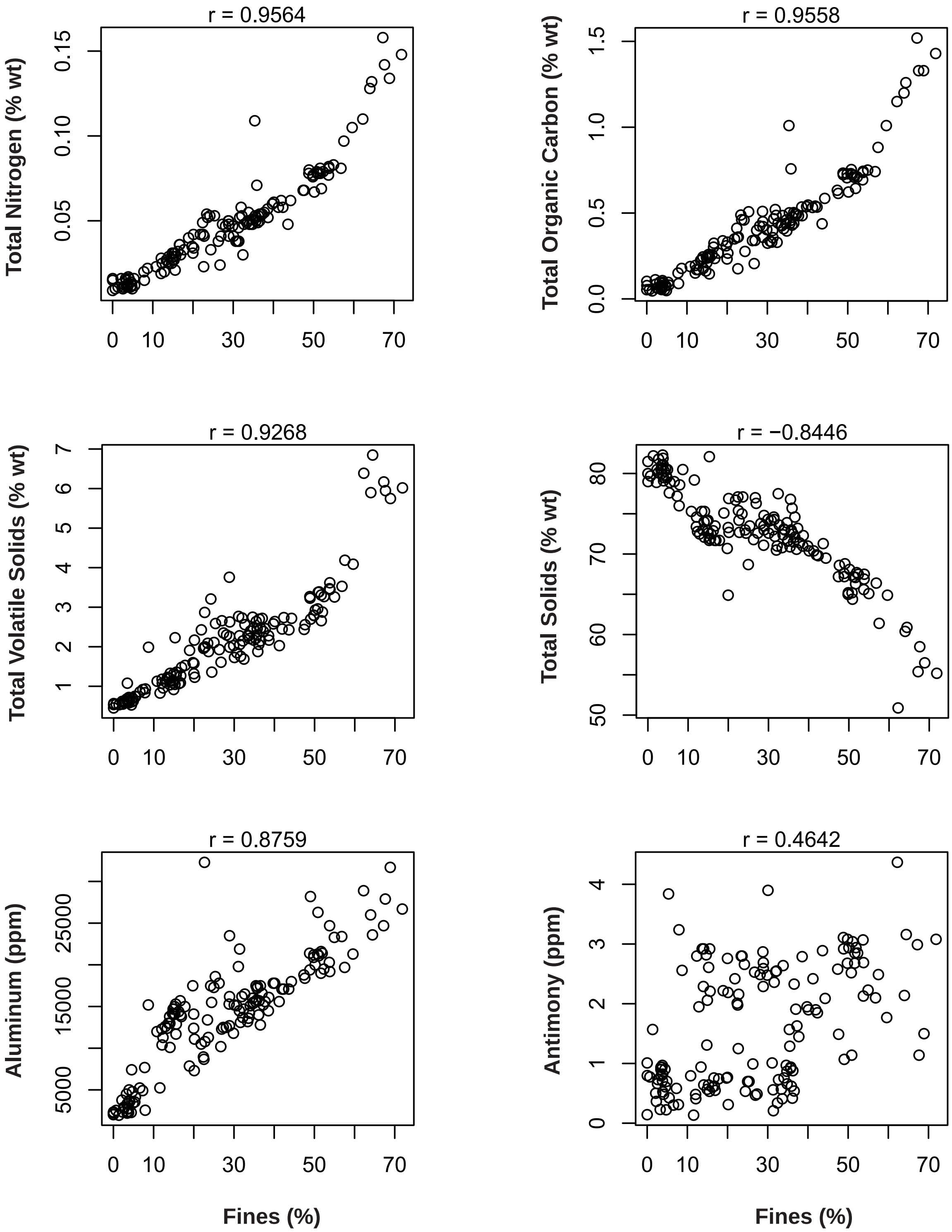


FIGURE C.4-6b

Scatterplots of percent fines versus various sediment chemistry parameters from Phase 1 of the Sediment Mapping study in 2004.

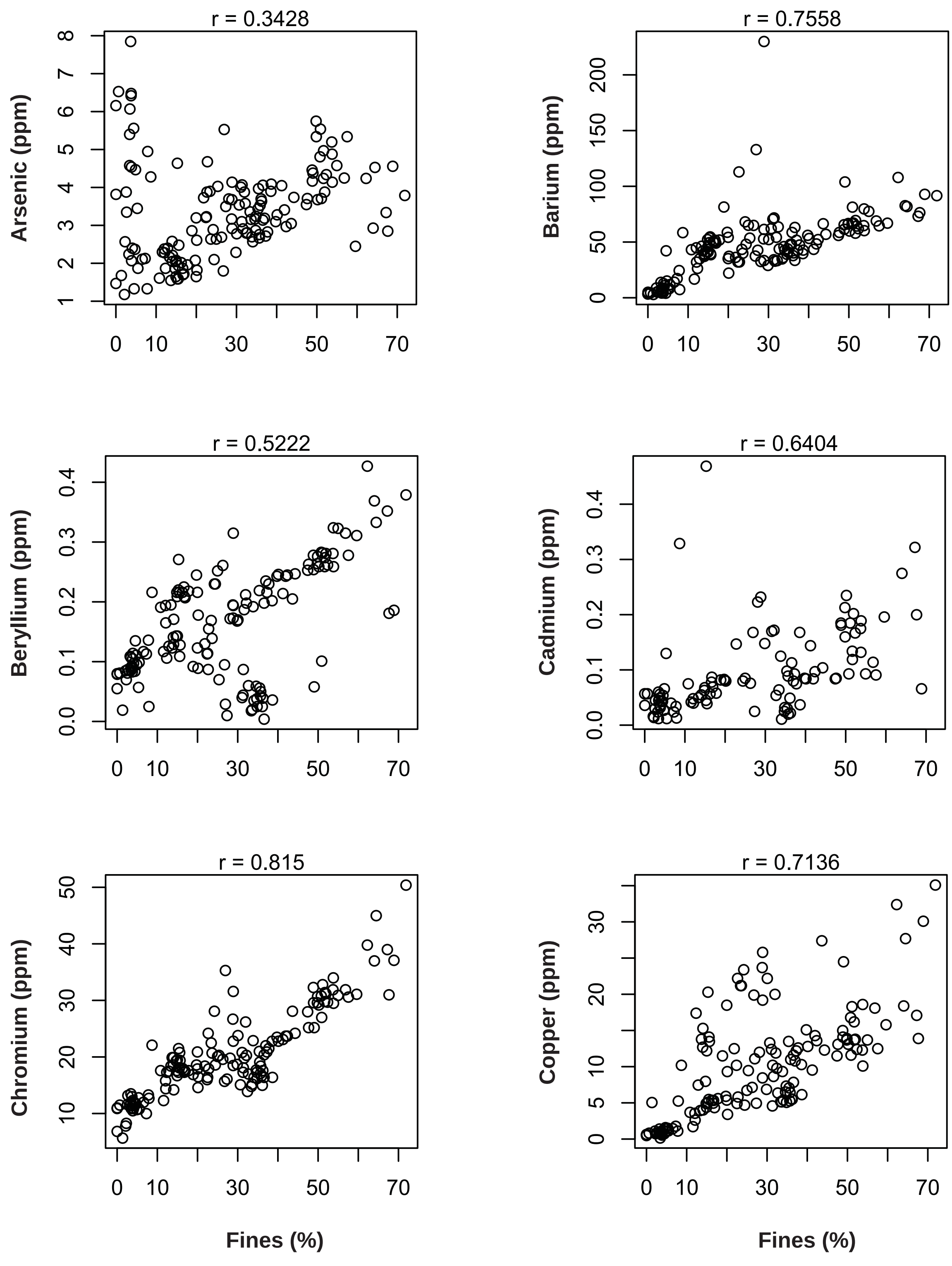


FIGURE C.4-6b (continued)

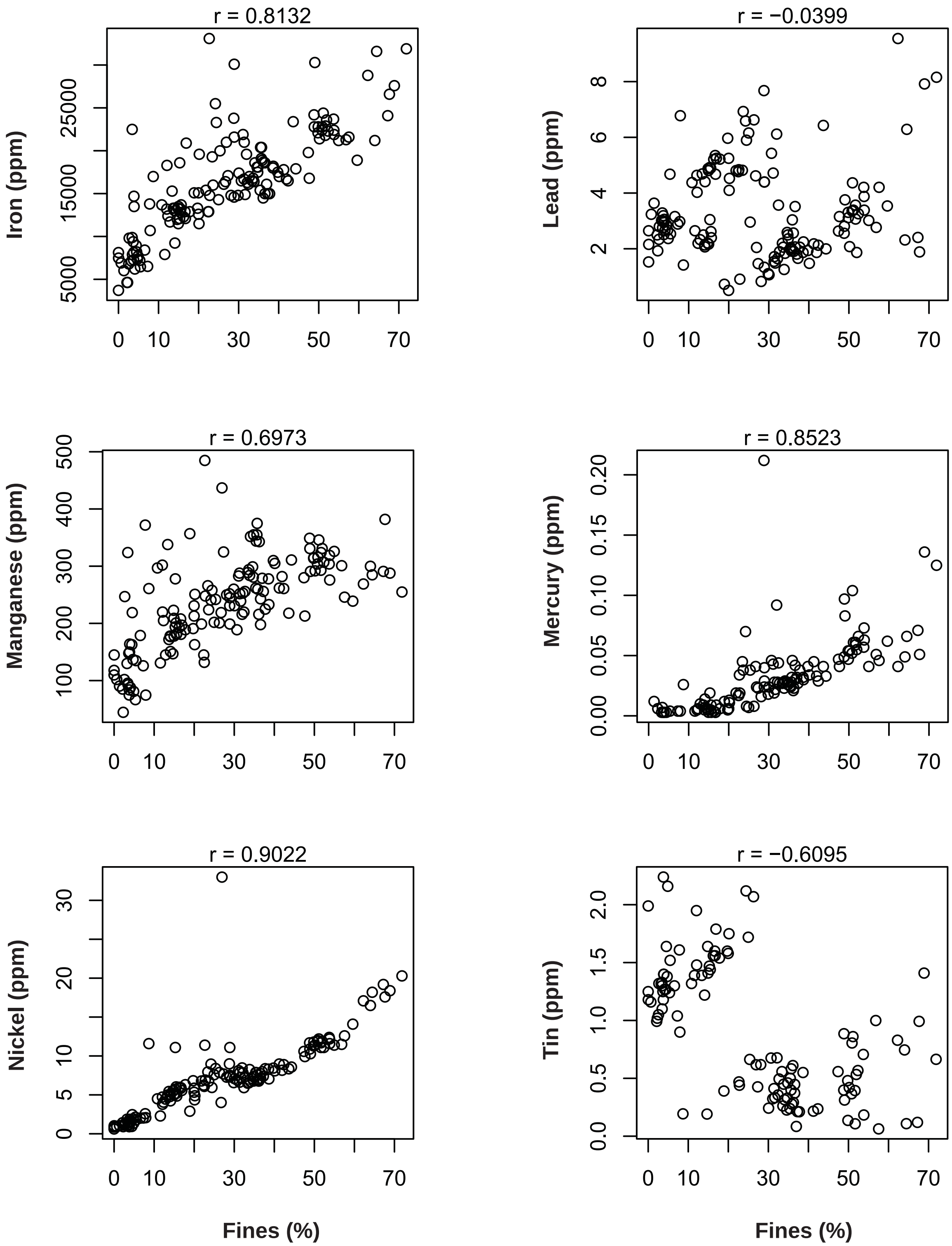


FIGURE C.4-6b (continued)

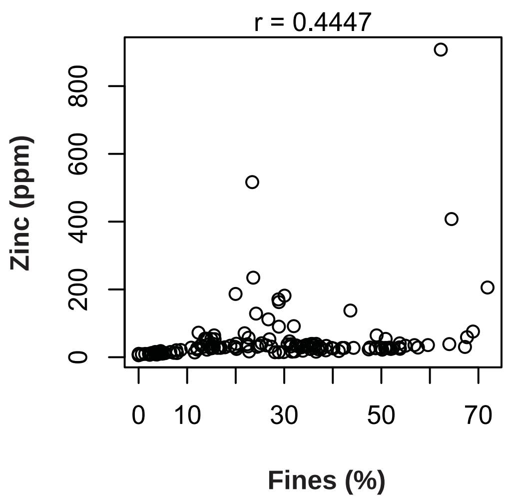


FIGURE C.4-6b (continued)

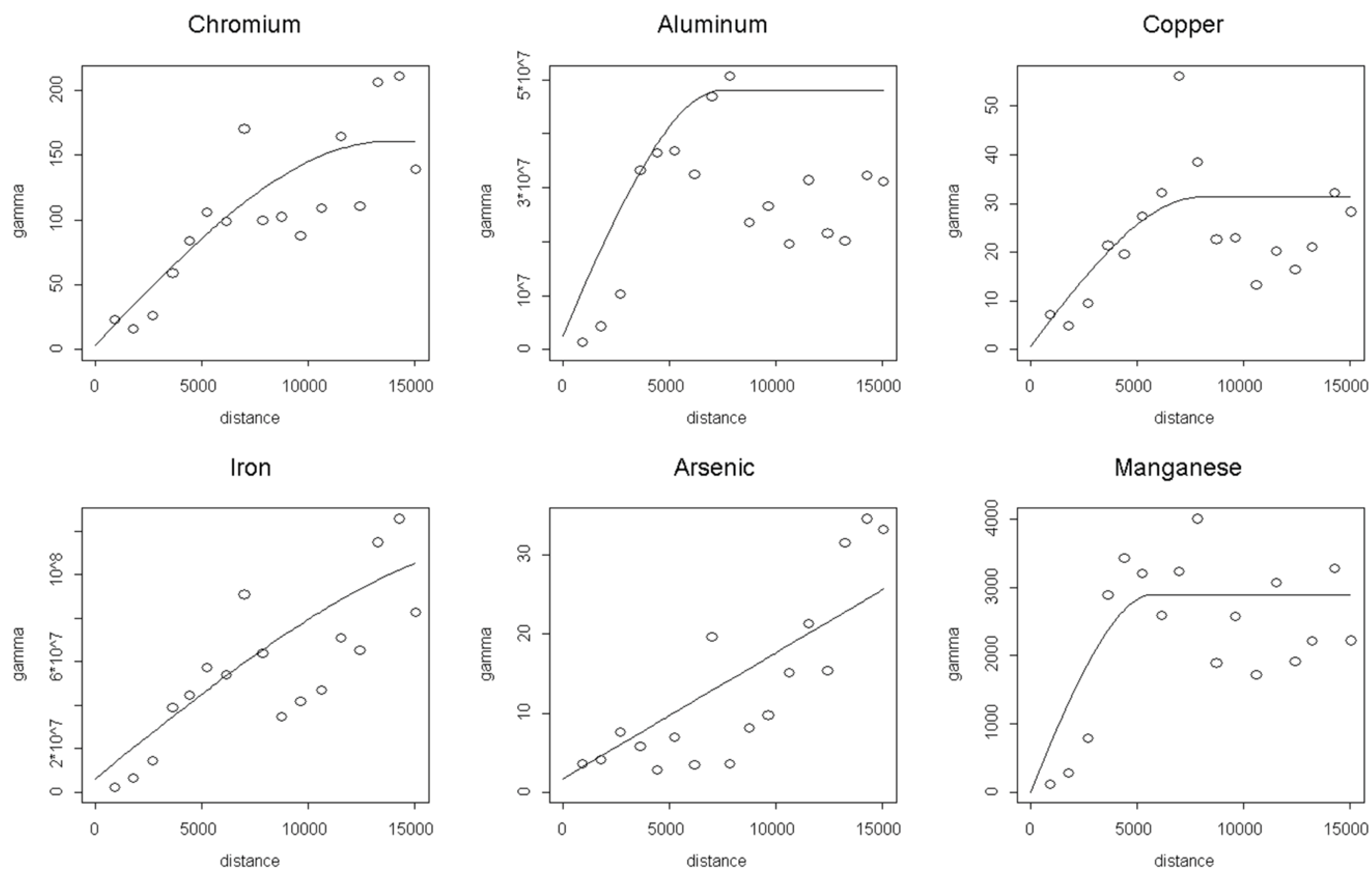


FIGURE C.4-7
Results of ordinary kriging for six metals from the Point Loma Ocean Outfall region sampled during Phase 1 of the Sediment Mapping study in 2004.

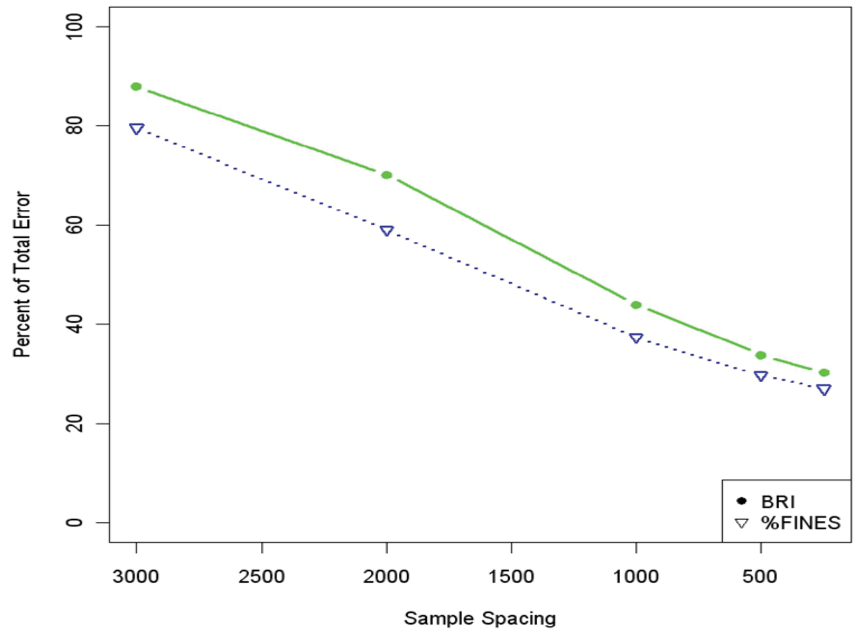


FIGURE C.4-8
Relationship of sample spacing and statistical confidence for the Point Loma Ocean Outfall region based on cost efficiency model results. Sample spacing in meters; %fines = grain size fraction ≤ 62.5 μm; BRI = benthic response index.

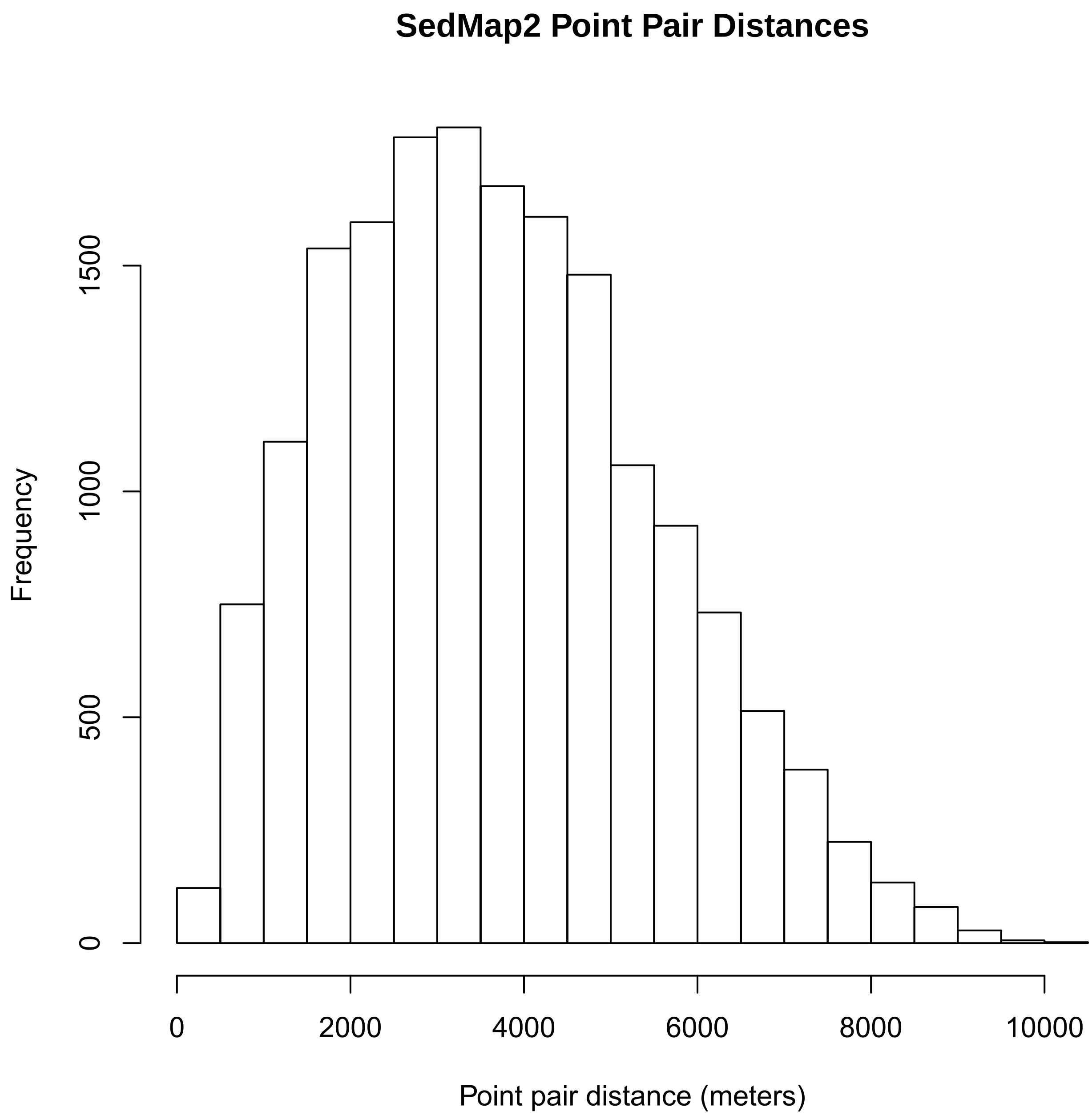


FIGURE C.4-9
Lag distribution (station-to-station distances) for Phase 2 Sediment Mapping study sampling locations in 2012.

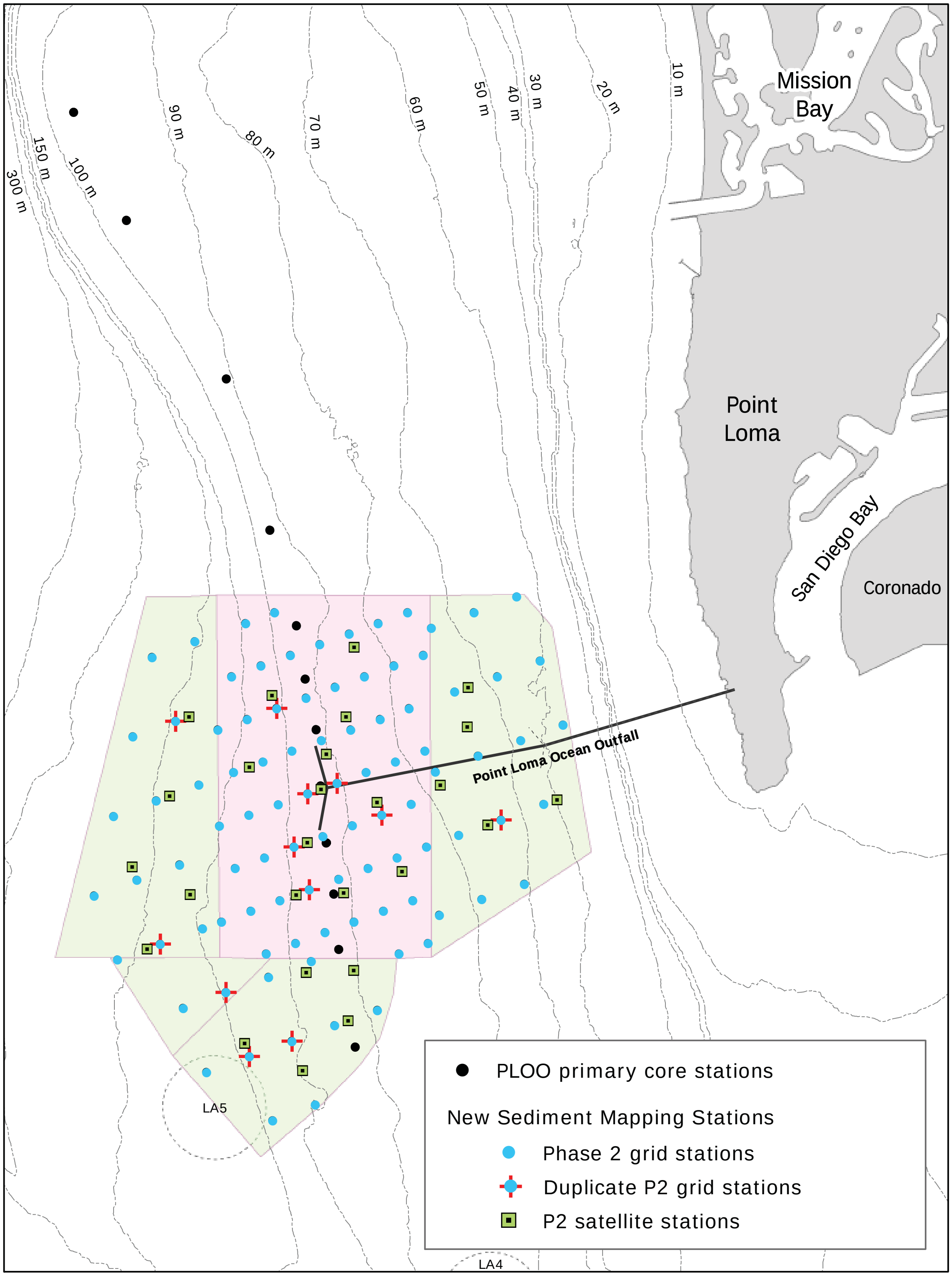


FIGURE C.4-10
Detailed sample design for Phase 2 of the Sediment Mapping study in 2012. The optimized grid of sample locations was rotated to account for anisotropy, used closely spaced satellite stations to allow improved estimation of the nugget, and used two resolutions for the different areas of interest. Green area = base grid (800m x 1200m spacing). Pink area = enhanced grid (550m x 800m spacing).

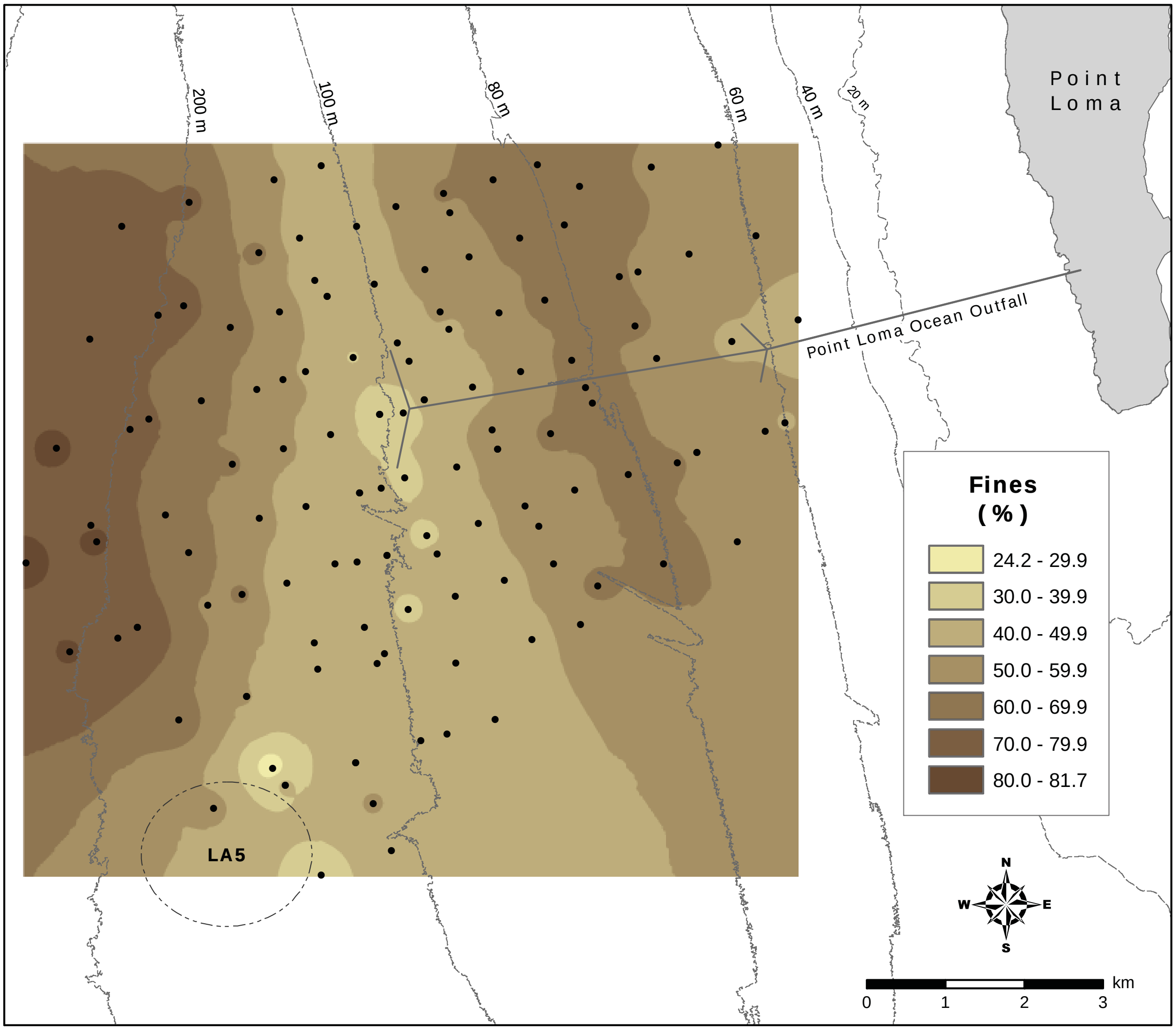


FIGURE C.4-11
An inverse distance weighted interpolation (which does not provide a measure of uncertainty) for percent fines across the full Phase 2 survey area of the Sediment Mapping study in 2012.

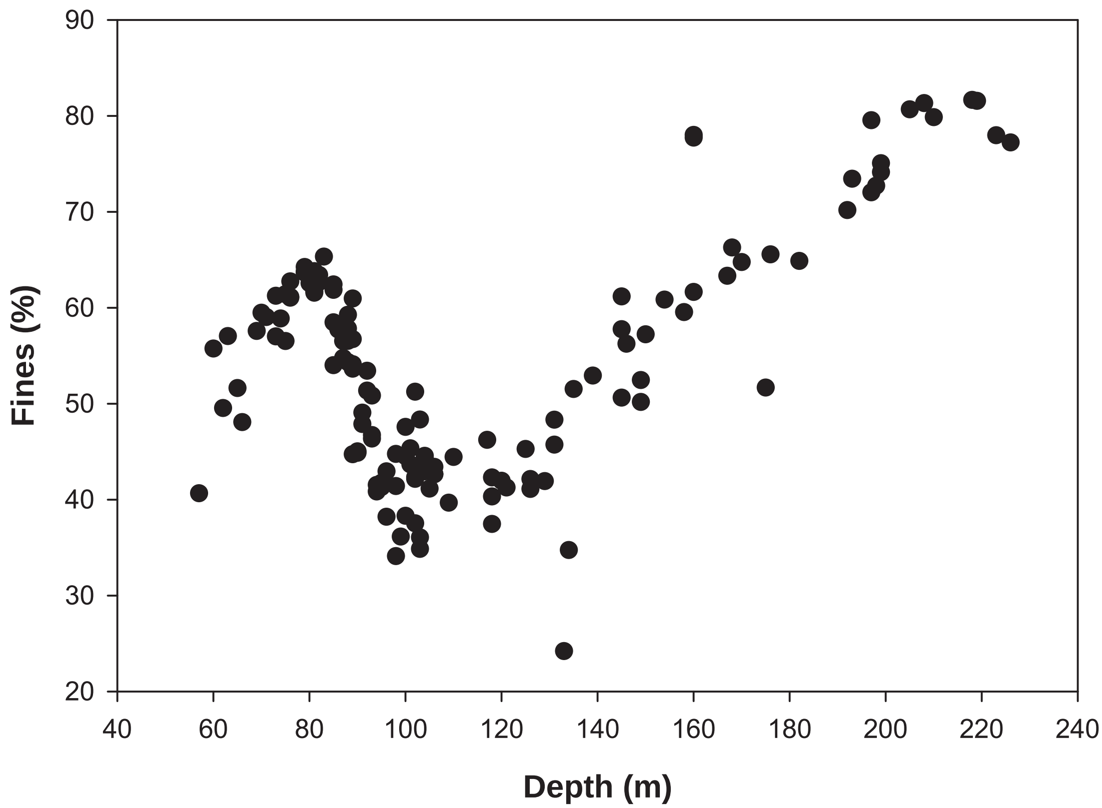


FIGURE C.4-12a
Scatterplot of depth versus percent fines from Phase 2 of the Sediment Mapping study in 2012.

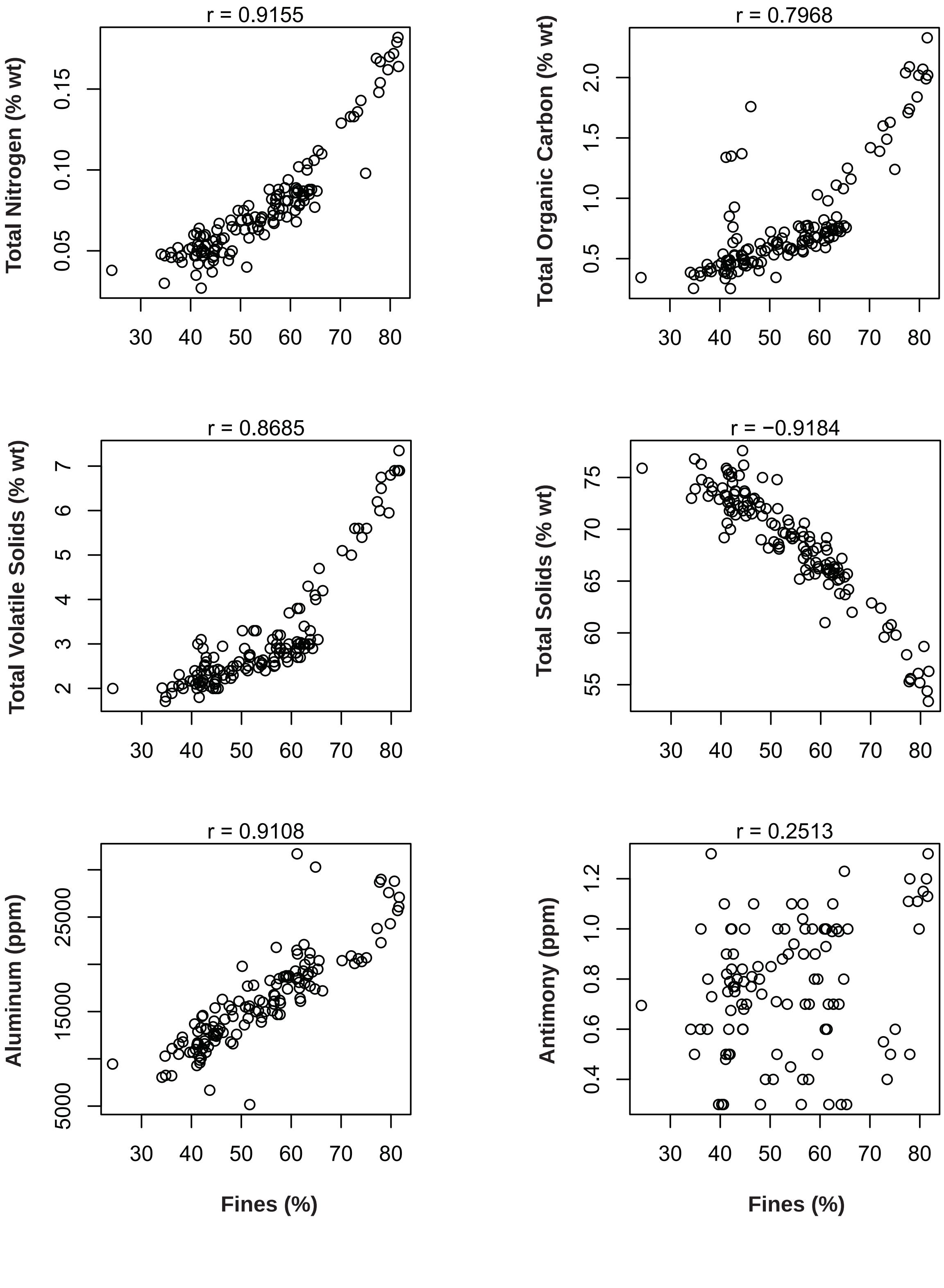


FIGURE C.4-12b
Scatterplots of percent fines versus various sediment chemistry parameters from Phase 2 of the Sediment Mapping study in 2012.

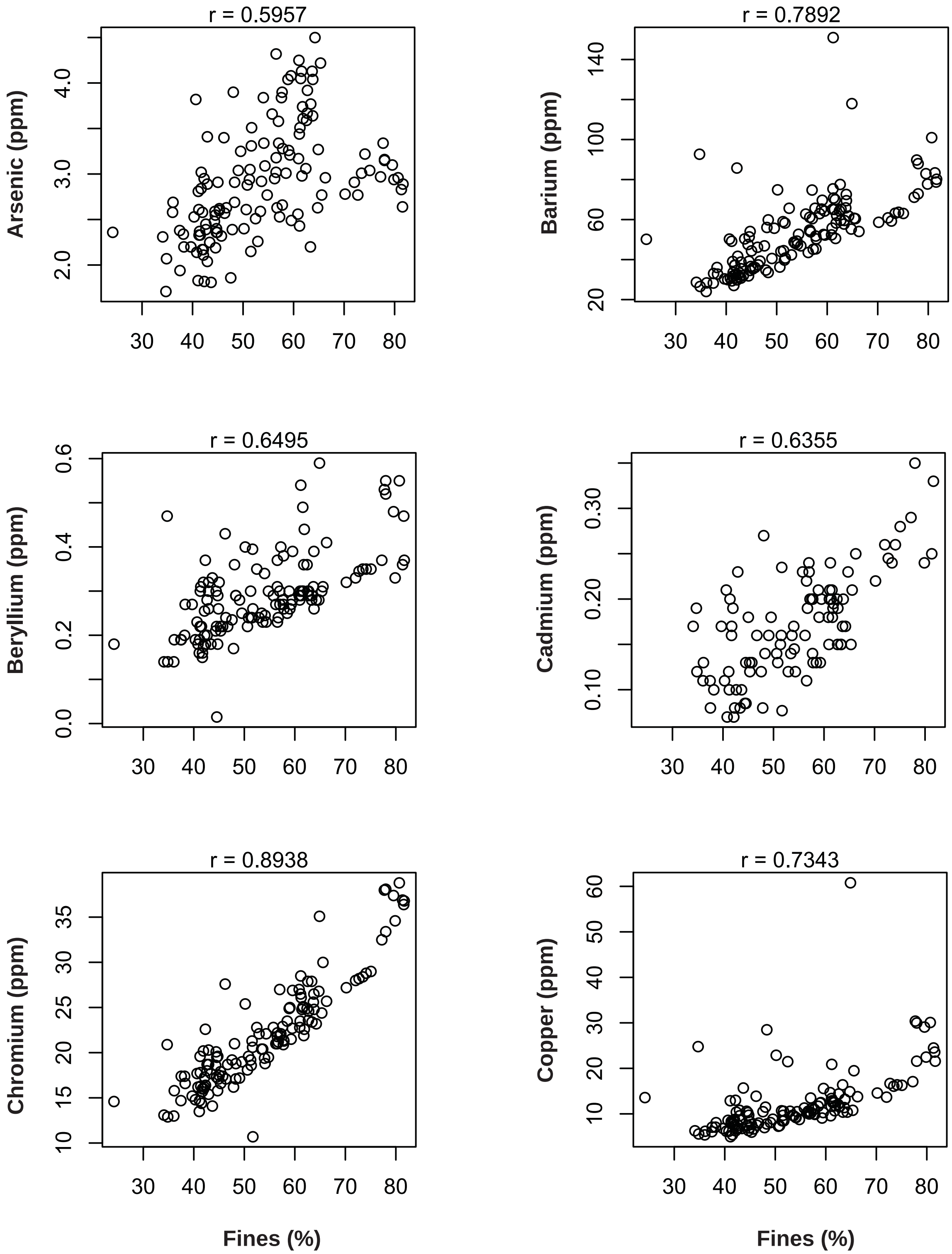


FIGURE C.4-12b (continued)

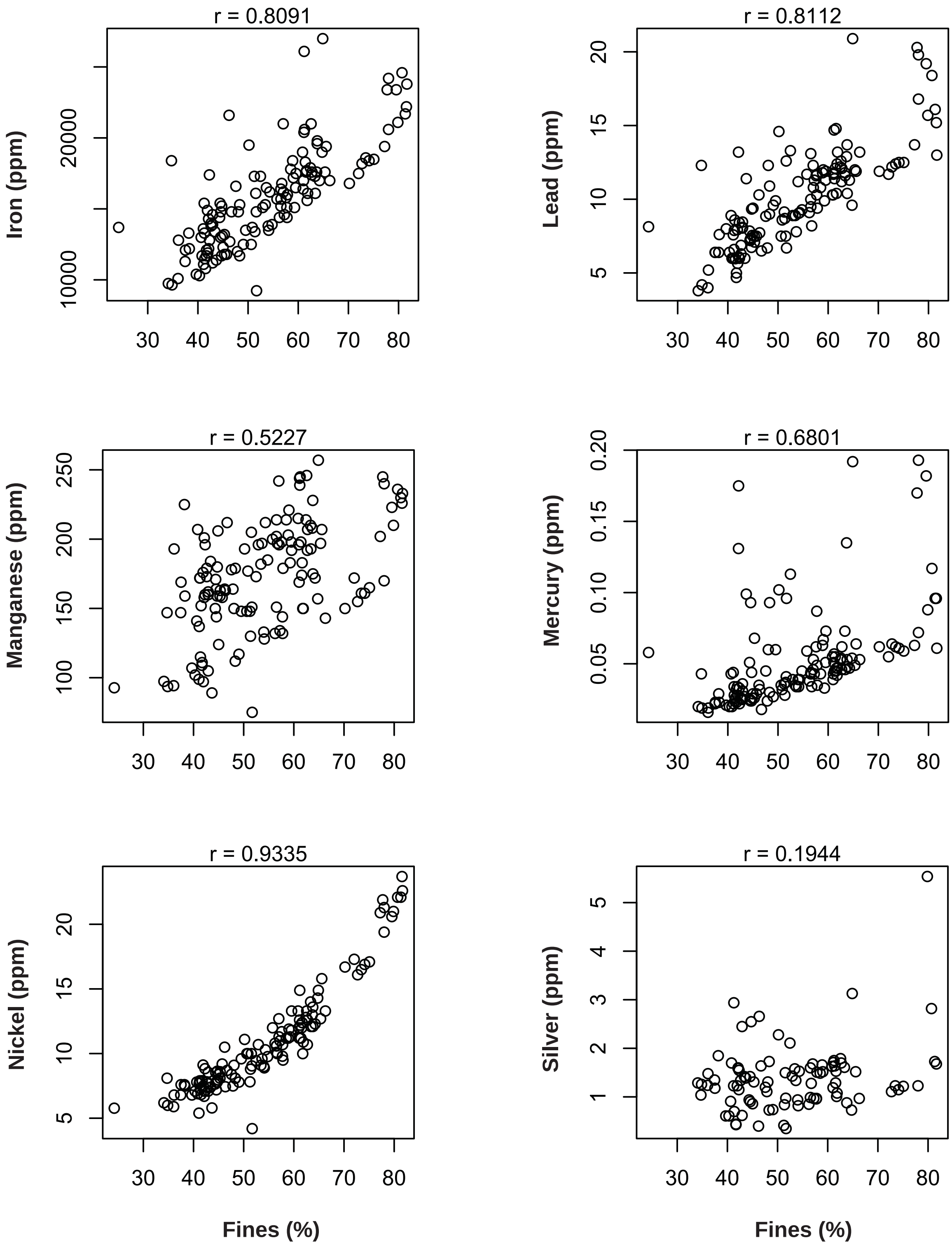


FIGURE C.4-12b (continued)

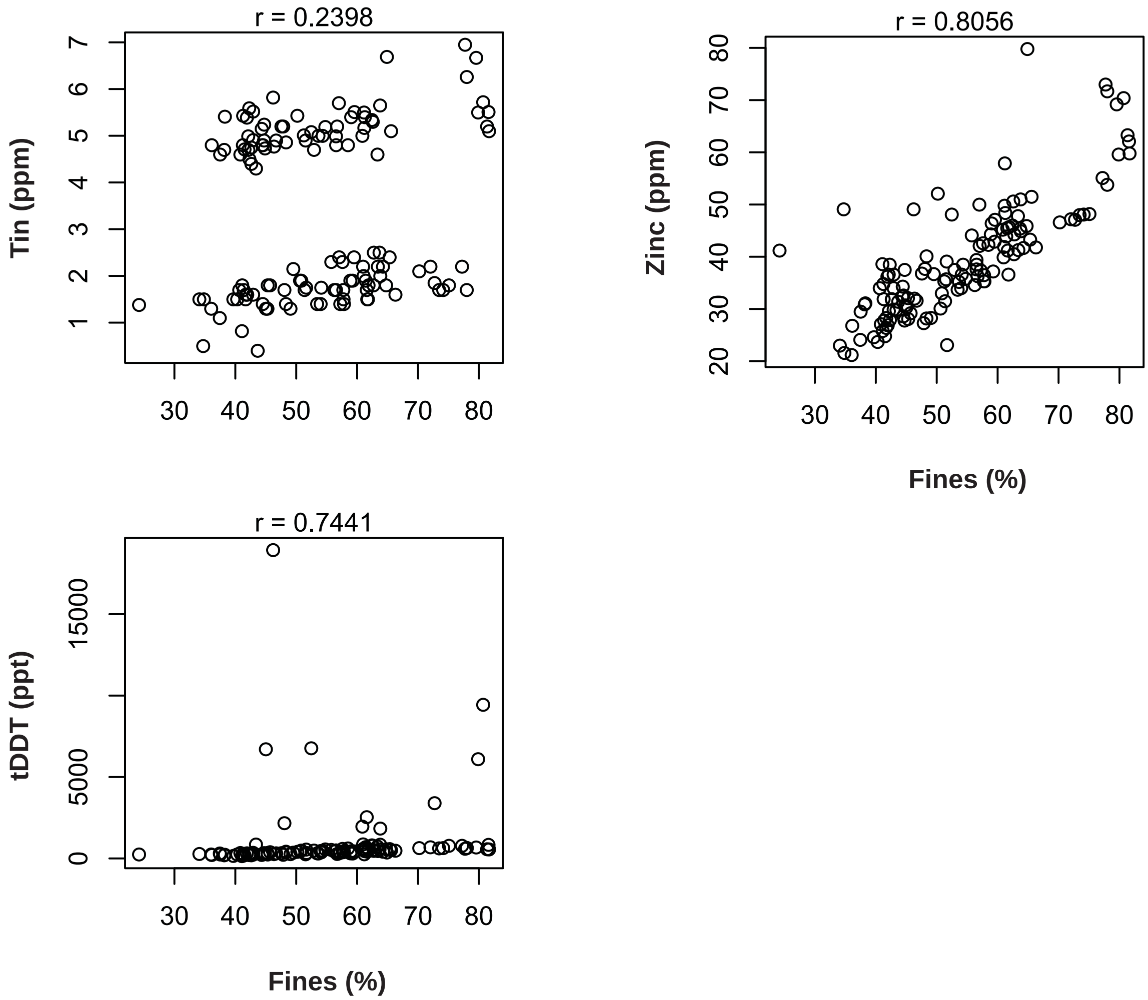


FIGURE C.4-12b (continued)

APPENDIX C.4

San Diego Sediment Mapping Study

ATTACHMENTS

ATTACHMENT C.4-A

Constituents and method detection limits (MDLs) used for the analysis of sediments collected during Phase 1 (2004) and Phase 2 (2012) of the Sediment Mapping study.

Parameter	Phase 1	Phase 2	Parameter	Phase 1	Phase 2
Organic Indicators					
Total Nitrogen (TN, %wt)	0.005	0.005	Total Volatile Solids (TVS, %wt)	0.11	0.11
Total Organic Carbon (TOC, %wt)	0.01	0.01	Total Solids (TS, %wt)	0.24	0.24
Metals (ppm)					
Aluminum (Al)	1.15	2	Lead (Pb)	0.142	0.8
Antimony (Sb)	0.13	0.3	Manganese (Mn)	0.00367	0.08
Arsenic (As)	0.33	0.33	Mercury (Hg)	0.003	0.004
Barium (Ba)	0.00182	0.02	Nickel (Ni)	0.0364	0.1
Beryllium (Be)	0.00119	0.01	Selenium (Se)	0.24	0.24
Cadmium (Cd)	0.0104	0.06	Silver (Ag)	0.0129	0.04
Chromium (Cr)	0.016	0.1	Thallium (Tl)	0.221	0.5
Copper (Cu)	0.0278	0.2	Tin (Sn)	0.0586	0.3
Iron (Fe)	0.76	9	Zinc (Zn)	0.0521	0.25
Chlorinated Pesticides (ppt)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	na	150	HCH, Delta isomer	na	700
HCH, Beta isomer	na	310	HCH, Gamma isomer	na	260
Total Chlordane					
Alpha (cis) Chlordane	5700	240	Heptachlor epoxide	na	120
Cis Nonachlor	na	240	Methoxychlor	na	1100
Gamma (trans) Chlordane	3800	350	Oxychlordane	5700	240
Heptachlor	na	1200	Trans Nonachlor	na	250
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	5700	830	p,p-DDE	3800	260
o,p-DDE	5700	720	p,p-DDMU [a]	—	—
o,p-DDT	3800	800	p,p-DDT	11000	800
p,p-DDD	3800	470			
Miscellaneous Pesticides					
Aldrin	na	430	Endrin	na	830
Alpha Endosulfan	na	240	Endrin aldehyde	na	830
Beta Endosulfan	na	350	Hexachlorobenzene (HCB)	na	470
Dieldrin	na	310	Mirex	na	500
Endosulfan Sulfate	na	260			

[a] No MDL available for this parameter

ATTACHMENT C.4-A (continued)

Parameter	Phase 1	Phase 2	Parameter	Phase 1	Phase 2
Polychlorinated Biphenyl Congeners (PCBs) (ppt)					
PCB 18	2600	540	PCB 126	3000	720
PCB 28	3000	660	PCB 128	2700	570
PCB 37	2100	340	PCB 138	3000	590
PCB 44	2600	890	PCB 149	2500	500
PCB 49	2700	850	PCB 151	2500	640
PCB 52	3100	1000	PCB 153/168	1200	600
PCB 66	2100	920	PCB 156	2900	620
PCB 70	2700	1100	PCB 157	2700	700
PCB 74	2700	900	PCB 158	2600	510
PCB 77	2100	790	PCB 167	3000	620
PCB 81	2500	590	PCB 169	2300	610
PCB 87	2800	600	PCB 170	3100	570
PCB 99	2500	660	PCB 177	3000	650
PCB 101	2600	430	PCB 180	2600	530
PCB 105	2600	720	PCB 183	2700	530
PCB 110	2900	640	PCB 187	2700	470
PCB 114	3000	700	PCB 189	2300	620
PCB 118	2700	830	PCB 194	2300	420
PCB 119	2400	560	PCB 201	2900	530
PCB 123	2800	660	PCB 206	1900	510

ATTACHMENT C.4-B

Macrofaunal community parameters at all stations sampled as part of the Phase 1 Sediment Mapping survey in 2004. SR=species richness (no. taxa/0.1 m2); Abun =abundance (no. individuals/0.1 m2); H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index.

Region	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
PLOO	A02	59	88	288	3.8	0.90	30	16
PLOO	A02 DUP	59	114	355	4.1	0.90	42	16
PLOO	A05	62	101	466	3.5	0.80	22	13
PLOO	A05 DUP	62	94	325	3.8	0.80	28	11
PLOO	A08	60	110	360	4.0	0.80	36	15
PLOO	A08 DUP	60	91	272	3.8	0.80	33	12
PLOO	A09	61	109	330	3.9	0.80	39	13
PLOO	A09 DUP	62	94	362	3.7	0.80	28	12
PLOO	A15	60	102	309	4.0	0.90	37	8
PLOO	A15 DUP	60	92	257	3.9	0.90	37	12
PLOO	A16	61	110	373	4.0	0.80	39	12
PLOO	A16 DUP	61	101	282	3.9	0.90	40	9
PLOO	B03	61	85	291	3.5	0.80	26	8
PLOO	B03 DUP	61	68	245	3.3	0.80	18	11
PLOO	B05	63	131	733	3.6	0.70	30	4
PLOO	B05 DUP	61	136	719	3.4	0.70	26	5
PLOO	B09	99	132	387	3.6	0.70	24	0
PLOO	B09 DUP	99	91	310	3.9	0.90	31	2
PLOO	B12	98	160	428	4.4	0.90	44	8
PLOO	B12 DUP	98	114	367	4.2	0.90	42	7
PLOO	E02	97	145	316	4.1	0.80	35	2
PLOO	E02 DUP	97	107	369	4.0	0.90	37	2
PLOO	E03	110	107	276	4.2	0.90	43	4
PLOO	E03 DUP	110	134	347	4.6	0.90	61	2
PLOO	E05	97	119	308	3.8	0.80	27	4
PLOO	E05 DUP	97	89	268	4.0	0.90	35	6
PLOO	E08	96	130	301	4.0	0.80	34	5
PLOO	E08 DUP	96	90	349	3.7	0.80	29	5
PLOO	E11	96	113	201	3.9	0.80	31	7
PLOO	E11 DUP	96	89	282	3.9	0.90	34	11
PLOO	E14	97	150	497	3.8	0.80	31	14
PLOO	E14 DUP	97	89	396	3.3	0.70	24	14
PLOO	E17	96	126	364	3.8	0.80	33	9
PLOO	E17 DUP	96	95	321	4.1	0.90	35	8
PLOO	E20	98	113	271	3.8	0.80	29	5
PLOO	E20 DUP	98	79	224	3.9	0.90	30	4
PLOO	E23	97	103	209	3.8	0.80	27	5
PLOO	E23 DUP	97	78	260	3.7	0.90	28	8
PLOO	E25	97	125	419	3.6	0.70	23	4

ATTACHMENT C.4-B (continued)

Region	Station	Depth (m)	SR	Abun	H’	J’	Dom	BRI
PLOO	E25 DUP	97	91	483	3.6	0.80	23	6
PLOO	E26	97	131	718	2.5	0.50	11	1
PLOO	E26 DUP	97	93	702	2.7	0.60	11	5
PLOO	SM001	207	46	96	3.4	0.90	22	20
PLOO	SM002	74	96	695	2.7	0.60	9	5
PLOO	SM003	91	94	337	3.9	0.90	31	5
PLOO	SM004	88	90	490	3.3	0.70	18	4
PLOO	SM005	45	118	357	4.3	0.90	45	16
PLOO	SM006	169	59	182	3.4	0.80	22	13
PLOO	SM007	100	101	424	4.1	0.90	34	10
PLOO	SM008	93	113	586	3.6	0.80	28	6
PLOO	SM009	94	102	441	3.9	0.80	29	6
PLOO	SM010	101	105	399	4.1	0.90	33	9
PLOO	SM011	98	99	357	4.0	0.90	34	7
PLOO	SM012	96	108	528	3.7	0.80	28	8
PLOO	SM013	97	96	355	4.0	0.90	33	4
PLOO	SM014	99	111	460	3.9	0.80	29	5
PLOO	SM015	86	102	654	3.1	0.70	17	5
PLOO	SM016	73	80	410	3.2	0.70	16	0
PLOO	SM017	103	88	294	4.0	0.90	32	7
PLOO	SM018	92	88	342	3.8	0.80	28	8
PLOO	SM019	87	120	955	2.4	0.50	10	4
PLOO	SM020	76	93	793	2.5	0.50	6	5
PLOO	SM021	74	80	416	3.0	0.70	11	4
PLOO	SM022	75	85	464	3.2	0.70	15	8
PLOO	SM023	77	84	374	3.4	0.80	19	5
PLOO	SM024	76	58	302	2.8	0.70	10	6
PLOO	SM025	77	78	383	3.1	0.70	14	5
PLOO	SM026	77	81	468	3.2	0.70	17	6
PLOO	SM027	76	75	338	3.2	0.70	16	5
PLOO	SM028	76	92	568	2.9	0.60	10	1
PLOO	SM028 DUP	76	81	909	2.0	0.50	4	8
PLOO	SM029	68	89	311	3.5	0.80	26	7
PLOO	SM030	224	42	67	3.6	1.00	26	14
PLOO	SM031	82	89	539	3.0	0.70	13	5
PLOO	SM032	79	82	829	2.2	0.50	5	8
PLOO	SM033	105	81	262	4.0	0.90	30	7
PLOO	SM034	115	74	203	3.9	0.90	30	9
PLOO	SM035	89	82	281	3.6	0.80	25	7

ATTACHMENT C.4-B (continued)

Region	Station	Depth (m)	SR	Abun	H’	J’	Dom	BRI
PLOO	SM036	203	49	128	3.2	0.80	19	16
PLOO	SM037	97	70	404	2.8	0.70	14	15
PLOO	SM038	92	91	490	3.5	0.80	23	19
PLOO	SM039	98	91	381	3.9	0.90	31	19
PLOO	SM040	101	96	348	4.0	0.90	34	9
PLOO	SM041	89	111	587	3.5	0.80	28	14
PLOO	SM042	96	102	782	3.5	0.70	21	35
PLOO	SM043	97	133	853	3.8	0.80	25	26
PLOO	SM044	98	104	405	4.0	0.90	34	13
PLOO	SM045	93	82	309	3.8	0.90	27	11
PLOO	SM046	73	74	319	3.2	0.70	17	8
PLOO	SM047	101	118	446	4.3	0.90	41	6
PLOO	SM048	91	78	371	3.6	0.80	21	10
PLOO	SM049	103	103	283	4.2	0.90	42	4
PLOO	SM050	89	100	301	3.9	0.80	35	4
PLOO	SM051	191	47	110	3.3	0.80	20	13
PLOO	SM052	183	53	137	3.3	0.80	20	13
PLOO	SM053	99	85	320	3.8	0.80	26	1
PLOO	SM054	96	91	280	3.9	0.90	30	4
PLOO	SM055	93	95	314	3.9	0.90	33	2
PLOO	SM056	96	98	332	3.9	0.80	31	3
PLOO	SM057	99	78	206	3.8	0.90	28	4
PLOO	SM058	96	86	251	4.0	0.90	32	3
PLOO	SM059	96	90	322	3.9	0.90	31	5
PLOO	SM060	96	80	281	3.7	0.90	25	2
PLOO	SM061	97	74	233	3.7	0.90	25	5
PLOO	SM062	89	72	240	3.5	0.80	23	4
PLOO	SM063	76	94	415	3.3	0.70	21	11
PLOO	SM064	111	137	417	4.5	0.90	55	9
PLOO	SM065	104	100	329	4.0	0.90	37	6
PLOO	SM066	91	88	303	3.8	0.80	30	5
PLOO	SM067	175	76	158	4.0	0.90	37	16
PLOO	SM068	112	126	351	4.3	0.90	51	7
PLOO	SM069	106	127	302	4.5	0.90	58	5
PLOO	SM070	106	126	278	4.5	0.90	57	6
PLOO	SM071	126	83	261	3.9	0.90	32	6
PLOO	SM072	109	89	245	4.0	0.90	33	7
PLOO	SM073	109	153	580	4.2	0.80	50	5
PLOO	SM074	110	139	339	4.6	0.90	63	5

ATTACHMENT C.4-B (continued)

Region	Station	Depth (m)	SR	Abun	H’	J’	Dom	BRI
PLOO	SM075	111	132	312	4.5	0.90	56	3
PLOO	SM076	99	100	229	4.3	0.90	44	6
PLOO	SM077	143	96	224	4.2	0.90	40	11
PLOO	SM078	99	156	549	4.4	0.90	54	3
PLOO	SM079	195	69	124	4.0	0.90	38	9
PLOO	SM080	94	139	374	4.4	0.90	56	8
SBOO	I01	60	80	222	3.0	0.70	11	15
SBOO	I01 DUP	60	51	149	3.3	0.80	19	10
SBOO	I02	34	54	239	2.5	0.60	12	14
SBOO	I03	27	67	359	3.4	0.80	17	10
SBOO	I04	19	36	112	3.1	0.90	13	7
SBOO	I06	25	45	193	2.8	0.70	12	10
SBOO	I07	50	98	407	4.1	0.90	34	13
SBOO	I08	35	91	335	2.8	0.60	14	15
SBOO	I08 DUP	35	54	201	3.1	0.80	14	16
SBOO	I09	30	121	381	3.2	0.70	20	28
SBOO	I09 DUP	30	86	339	3.3	0.70	21	26
SBOO	I10	20	54	168	3.4	0.80	20	13
SBOO	I12	28	99	221	2.5	0.50	9	15
SBOO	I12 DUP	28	74	223	3.6	0.80	29	24
SBOO	I13	38	85	266	3.1	0.70	15	9
SBOO	I13 DUP	38	48	139	3.2	0.80	17	14
SBOO	I14	28	73	241	3.5	0.80	23	22
SBOO	I15	31	73	249	2.0	0.50	6	11
SBOO	I15 DUP	31	54	297	1.9	0.50	7	15
SBOO	I16	29	107	329	3.7	0.80	36	20
SBOO	I18	19	43	113	3.2	0.80	16	4
SBOO	I20	55	79	375	3.4	0.80	19	9
SBOO	I21	41	48	184	3.2	0.80	15	7
SBOO	I22	28	60	217	3.2	0.80	17	24
SBOO	I23	21	72	830	3.0	0.70	10	17
SBOO	I27	29	75	210	3.9	0.90	31	23
SBOO	I28	56	206	532	4.2	0.80	49	10
SBOO	I28 DUP	56	138	532	4.1	0.80	42	8
SBOO	I29	37	95	766	3.1	0.70	13	14
SBOO	I30	28	78	134	3.6	0.80	23	21
SBOO	I30 DUP	28	46	119	3.3	0.90	17	24
SBOO	I31	19	57	252	3.0	0.70	16	16
SBOO	I33	30	90	320	3.9	0.90	31	19

ATTACHMENT C.4-B (continued)

Region	Station	Depth (m)	SR	Abun	H’	J’	Dom	BRI
SBOO	I34	20	61	427	2.8	0.70	10	7
SBOO	I35	19	69	170	3.9	0.90	32	22
SBOO	SM081	55	116	377	4.0	0.80	41	14
SBOO	SM082	64	149	440	4.4	0.90	52	11
SBOO	SM083	58	153	462	4.5	0.90	57	9
SBOO	SM084	57	141	411	4.5	0.90	55	8
SBOO	SM085	56	169	650	4.4	0.90	50	10
SBOO	SM086	55	149	492	4.2	0.80	47	10
SBOO	SM087	52	143	541	4.2	0.80	41	9
SBOO	SM088	59	49	101	3.6	0.90	24	16
SBOO	SM089	24	81	274	3.7	0.80	30	25
SBOO	SM091	30	93	335	3.9	0.90	28	21
SBOO	SM092	24	89	456	3.4	0.80	24	19
SBOO	SM093	27	67	311	2.7	0.70	12	20
SBOO	SM094	28	57	199	3.3	0.80	17	24
SBOO	SM095	28	76	229	3.8	0.90	29	24
SBOO	SM096	28	60	214	3.1	0.70	18	22
SBOO	SM097	28	63	222	3.6	0.90	21	21
SBOO	SM098	28	75	222	3.4	0.80	25	23
SBOO	SM099	27	28	82	3.0	0.90	13	20
SBOO	SM100	28	66	188	3.6	0.90	24	23
SBOO	SM101	17	72	305	3.1	0.70	18	16
SBOO	SM102	31	82	228	3.9	0.90	33	20
SBOO	SM103	25	82	286	3.7	0.90	27	24
SBOO	SM104	30	88	325	3.9	0.90	30	23
SBOO	SM105	42	106	578	3.6	0.80	24	16
SBOO	SM106	38	122	387	4.1	0.80	42	19
SBOO	SM107	30	87	246	3.9	0.90	34	20
SBOO	SM109	38	89	439	3.5	0.80	25	16
SBOO	SM110	30	80	416	2.7	0.60	15	20
SBOO	SM111	41	96	437	3.6	0.80	25	8
SBOO	SM112	39	97	459	3.5	0.80	23	10
SBOO	SM113	38	70	304	3.4	0.80	22	12
SBOO	SM114	37	70	338	3.3	0.80	17	8
SBOO	SM115	38	86	493	3.6	0.80	23	12
SBOO	SM116	38	104	540	3.5	0.80	25	16
SBOO	SM117	35	66	255	3.6	0.90	23	9
SBOO	SM118	38	64	291	3.3	0.80	18	3
SBOO	SM119	38	69	351	3.4	0.80	19	10

ATTACHMENT C.4-B (continued)

Region	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
SBOO	SM120	35	78	342	3.5	0.80	22	12
SBOO	SM121	34	86	506	3.3	0.70	21	12
SBOO	SM122	32	72	347	2.8	0.60	18	17
SBOO	SM123	31	84	257	3.6	0.80	29	23
SBOO	SM124	30	110	403	4.0	0.80	38	22
SBOO	SM125	32	97	394	3.7	0.80	32	24
SBOO	SM126	31	70	302	2.9	0.70	17	18
SBOO	SM127	30	78	504	2.5	0.60	10	15
SBOO	SM128	32	72	558	2.1	0.50	6	18
SBOO	SM129	31	65	436	2.1	0.50	9	17
SBOO	SM130	26	91	301	3.6	0.80	30	26
SBOO	SM131	25	66	297	2.7	0.60	15	16
SBOO	SM132	37	45	325	2.4	0.60	8	5
SBOO	SM133	32	89	344	3.6	0.80	26	23
SBOO	SM134	43	87	344	3.8	0.80	27	15
SBOO	SM135	36	43	294	2.4	0.60	7	9
SBOO	SM136	32	53	247	2.8	0.70	14	23
SBOO	SM137	31	104	383	3.8	0.80	34	23
SBOO	SM138	25	110	570	3.4	0.70	22	25
SBOO	SM139	24	76	197	3.9	0.90	32	18
SBOO	SM141	37	96	462	3.8	0.80	27	11
SBOO	SM142	28	90	301	3.7	0.80	32	24
SBOO	SM143	26	97	391	3.6	0.80	29	25
SBOO	SM144	29	75	317	3.5	0.80	24	24
SBOO	SM145	35	92	409	3.6	0.80	28	25
SBOO	SM146	29	77	378	3.2	0.70	15	25
SBOO	SM147	29	100	508	3.8	0.80	29	23
SBOO	SM148	29	107	600	2.9	0.60	20	24
SBOO	SM149	29	84	298	3.8	0.90	28	24
SBOO	SM150	31	78	473	2.6	0.60	12	9
SBOO	SM151	26	77	334	3.2	0.70	17	23
SBOO	SM152	31	63	343	2.5	0.60	11	12