1994 annual soft-bottom benthic monitoring: Massachusetts Bay outfall studies

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1994 ANNUAL SOFT-BOTTOM BENTHIC MONITORING MASSACHUSETTS BAY OUTFALL STUDIES

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SUMMARY

In 1992, the Massachusetts Water Resources Authority (MWRA) instituted a long-term field monitoring program in conjunction with the planned installation of a new outfall located in Massachusetts Bay, approximately 15 km from the recently-expanded sewage treatment facilities at Deer Island. The purpose of the monitoring program is to verify that environmental impacts from effluent discharge at the future outfall site do not exceed those predicted during the outfall siting process (EPA, 1988). There are many types of studies incorporated in the monitoring program. This report summarizes one component of the benthic monitoring tasks. A companion soft-bottom benthic monitoring task is being conducted within Boston Harbor and is reported elsewhere.

This report is the third in an ongoing series of reports addressing the benthic environment within Massachusetts and Cape Cod Bays. It encompasses sediment sampling for bulk properties, chemical contaminants, and infauna. This field sampling is directed at determining future impacts on the benthos from effluent discharged from a series of diffusers aligned along 2 km of seafloor immediately shoreward of Stellwagen Basin in a water depth of 32 m (Figure 1). Although now installed, the outfall is not yet operational, so the present phase of monitoring is directed at specifying background benthic conditions for comparison with the post-discharge benthos. The scope of the baseline monitoring extends far beyond the narrow region immediately-adjacent to the diffuser-cap corridor where benthic impacts are most-likely to occur. The field program includes sediment sampling as far away as Cape Cod Bay, 60 km from the diffusers.

This report departs significantly from the two previous annual reports that summarize the analysis of benthic samples collected in Massachusetts and Cape Cod Bays in 1992 (Blake *et al.*, 1993b) and in 1993 (Coats *et al.*, 1995a). Now, with three years of benthic baseline data, the entire data set can be analyzed for interannual variability in addition to the spatial trends addressed in the previous reports. Moreover, the design of the field sampling program has changed in each of the three years of benthic surveys conducted. The primary focus of this report is to assess these three designs insofar as their ability to detect anthropogenic impacts from the effluent. As such, it details the benthic data collected from sampling stations immediately adjacent to the diffuser-cap corridor where any impacts are likely to be restricted. Nevertheless, data from the entire region is initially examined to identify those nearfield stations with regionally-consistent temporally-stable infauna. These stations act as sentinels for the detection of infaunal impacts from the outfall.

The changes in the sampling design of the three annual benthic surveys reflect different philosophies for assessing impacts. The changes occurred primarily at nearfield stations (<6 km) from the diffuser. In the first year of benthic monitoring (1992), unreplicated samples were collected at a large number (20, see Table 1) of stations with the intent of mapping a post-discharge gradient of effects radiating from the diffuser-cap corridor. A comparison of maps generated before and after discharge would indicate both the presence and extent of impacts. Concern over potentially large variability across small spatial scales, on the order of the ability to reoccupy precisely the same seafloor location each year, prompted a shift to a fully replicated design in 1993. Collection of duplicate chemistry and triplicate infaunal samples at each station would allow this inherent sampling variability to be measured and impacts could be assessed by contrasting pre and post-discharge averages in an analysis of variance. However, to maintain the same allocation of field resources, replicate samples could only be collected at nine of the original twenty nearfield stations. Comparison of the two years of sampling revealed substantial interannual variability. Now the concern was over the ability to detect effluent impacts from only nine stations in the presence of significant interannual variability coupled with the spatially heterogeneous grain size and infauna. In 1994, a hybrid design was adopted wherein replicate samples were again collected, but only at two of the nine stations sampled in 1993. In addition, four new stations were sampled, one with replication. This new replicated station, designated S4, is only 440 m from the diffuser-caps.

This report finds that the latest (1994) sampling design is far superior to the prior designs as far as its ability to detect impacts from a pool of samples collected close to the diffuser. Moreover, it is capable of detecting contaminant buildup and anthropogenic changes in infauna that meet the goals prescribed in the baseline monitoring plan (MWRA, 1991). These findings are based on a specific statistical model, namely, a two-group contrast with a multivariate response assuming stations are resampled post-discharge (Green, 1989). In this optimal impact design, the temporal and spatial changes contrasted under impacted and baseline conditions, are computed from a pool of samples in the extreme nearfield of the diffuser (impacted stations) and a set of samples collected some distance away from the diffuser (reference stations). The findings are further dependent on the parameters used in this statistical model, namely the error rates, the level of inherent background variability, and the number of samples present in the impact region. The Type I (α) and Type II (β) error rates reflect the probability associated with false alarms and with missing an existing impact, respectively. Although, when fixed, they do not affect conclusions comparing the relative detection capabilities of the different field designs, they do affect absolute estimates of detectability. Although, these absolute estimates are compared with the monitoring plan goals, the plan does not specify these error rates. For a full specification of the detection goals, future versions of the monitoring plan should recommend these error rates in addition to the level of meaningful change in benthic parameters.

The two other components of the statistical model, namely, the number of pooled samples and their variance, are determined from an analysis of the baseline benthic data. First, a 2-km region of impact is estimated from results of effluent deposition modeling described elsewhere. This defines the largest number of samples that can be pooled in each of the three field surveys. While there are many reference stations available for impact assessment, it is the limited availability of samples in the extreme nearfield that really provides the statistical contrast among the three field designs. The inherent background variance in contaminants is estimated from the full suite of samples and is used to assess the ability of the three designs to detect change. The detection capability of the optimal (1994) design is found to be well below levels of biological effects. Also, detectable contaminant increases and biological effects levels are compared to the projected rate of contaminant buildup in the sediments from effluent discharge. Based on effluent contaminant loading in a simple depositional model, estimates are that it will take years before contaminant increases in sediments are detected and decades before concentrations become biologically meaningful.

Determination of variability in infaunal communities is much more difficult than for chemical contaminants. Again, variance estimates are a crucial component of the statistical hypothesis tests used to evaluate the various field designs as far as their ability to detect change. In this report, a measure of infaunal variability is carefully designed through the application of multivariate analysis to a community metric that accounts for a wide natural variation in sediment properties. It is found that infauna are closely-linked to the mud content of sediments. Without accounting for this inter-relationship, estimates of infaunal variance would be grossly inflated and the associated power to detect change would be nil. The computation of inherent background variability is further complicated by significant regional differences in infauna and by temporal instability in sediments at some nearfield sites. A careful examination of infaunal differences among all samples results in a core set of stations, whose stability and proximity to the diffuser allows a consistent estimate of infaunal variance. These stations will act as sentinels for detecting future anthropogenic impacts to the infaunal community surrounding the new outfall.

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1.0 INTRODUCTION

This report describes the results of three years of benthic monitoring in Massachusetts and Cape Cod Bays. The data consist of enumerations of benthic infaunal taxa and physicochmical characteristics of surficial sediments. The latter include chemical contaminant concentrations, namely pesticides and trace metals, and bulk sediment properties, such as grain size distribution, total organic carbon (TOC) content, and *Clostridium perfringens* spore counts. These data establish baseline benthic conditions prior to discharge of a large volume (>390 MGD) of sewage effluent from an outfall terminating in Massachusetts Bay. This report specifies those baseline conditions and investigates the adequacy of the benthic sampling design insofar as its ability to detect meaningful anthropogenic change.

1.1 BACKGROUND

The Massachusetts Water Resources Authority (MWRA) was created in 1985 to operate, regulate, finance, and improve sewerage collection, disposal, and treatment systems. Waters within Boston Harbor had become polluted through centuries of uncontrolled discharge from the dense population in the surrounding Greater Boston Metropolitan Area. Since its inception, MWRA has implemented a number of steps to reduce the impacts of sewage and effluent sludge discharged into Boston Harbor. These include improvement of existing sewage treatment plants to remove sludge and the construction of a new secondary-treatment plant on Deer Island. An important component of these mitigation measures is the relocation of effluent discharges from the harbor to Massachusetts Bay. Relocation will reduce impacts from the effluent discharge both because of the larger receiving-water volume in the Bay and because of a substantial improvement in initial dilution, which linearly increases with diffuser depth (Fischer *et al.*, 1979). To that end, an effluent tunnel has been constructed which extends 15 km from the Deer Island treatment plant to a point on the continental shelf in Massachusetts Bay (Figure 1). At its terminus, a series of risers lead to the diffuser caps aligned along 2 km of seafloor in a water depth of 32 m. Discharge of effluent through the new outfall will probably be initiated in 1998.

1.1.1 Regulatory Setting

In 1972, in response to public concerns over a possible decline in natural marine resources, the U.S. Congress enacted the Clean Water Act. It required publicly owned treatment works to provide secondary treatment for discharged effluent by 1977. This meant the removal of most suspended solids from discharges using biological and chemical methods. This often involved a considerable expenditure of public monies. From 1972 to 1977, questions arose concerning the validity and economic feasibility of global application of this approach. Congress was persuaded to amend (Section 301(h)) the Clean Water Act in 1977 to authorize the U.S. Environmental Protection Agency (EPA) to grant variances (waivers) from full secondary treatment for publicly owned treatment works that: a) discharged into deep, well-mixed marine waters; b) administered a rigorous industrial waste source control program; and c) demonstrated protection of public health and the environment. To achieve a Section 301(h) waiver, publicly owned treatment works must demonstrate, through a monitoring program, that the effects of the outfall discharge are ecologically insignificant and essentially restricted to a zone of initial dilution. Now, even those publicly owned treatment works not operating under a Section 301(h) waiver are required to monitor the impact of their outfall.

The Metropolitan District Commission (MDC), a precursor to MWRA, submitted its original 301(h) waiver application in 1979. It proposed to: a) discharge primary effluent into Massachusetts Bay through an 11-km long outfall pipe, b) abate the uncontrolled combined sewer overflows, and c) cease the discharge of sludge into marine waters. The waiver was supplemented in 1982. Both applications were supported by limited marine monitoring in Massachusetts Bay as part of the application process. Following the EPA's denial of the waiver in 1983, the application was revised by extending the proposed outfall to 15 km and additional field sampling was conducted in the Bay. Following denial of the new waiver and as a result of lawsuits filed for violation of the Clean Water

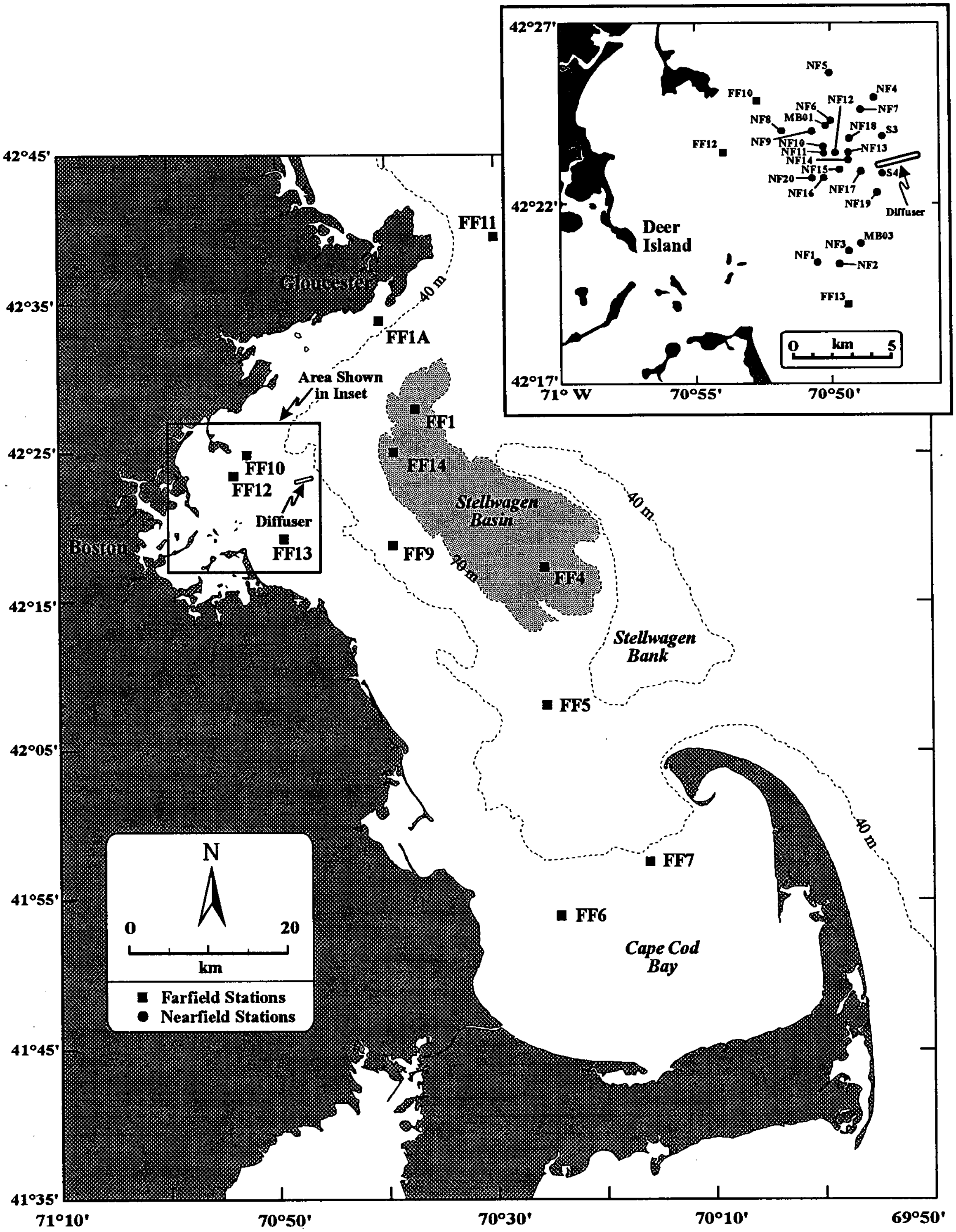

Figure 1. Location of outfall monitoring stations in Massachusetts and Cape Cod Bays.

Act, the MWRA was created to carry out a court-mandated schedule for a secondary treatment plant on Deer Island. In 1987, marine monitoring in the Bay was expanded as part of the new the Secondary Treatment Facilities Plan, to help determine the best outfall location.

The present long-term monitoring program within Boston Harbor and Massachusetts Bay is significantly expanded and largely serves to verify that environmental impacts from effluent discharge at the future outfall site do not exceed those predicted during the outfall siting process (EPA, 1988). In addition, the expanded monitoring within Boston Harbor will document the recovery of the estuarine environment as a result of sewer system improvements and the future diversion of effluent through the new outfall. A summary of benthic conditions within Boston Harbor in 1992 is reported by Blake (1993a) and in 1993, by Kropp and Diaz (1994). Recent marine environmental monitoring within Massachusetts and Cape Cod Bays is the subject of this and two prior reports (Blake *et al.*, 1993b; and Coats *et al.*, 1995a). This monitoring is directed at measuring environmental impacts from the new outfall by establishing baseline, predischarge conditions.

1.1.2 Outfall Monitoring

The long-term monitoring of the new ocean outfall consists of several components. Most basic is the analysis of chemical constituents in the effluent collected before discharge (*e.g.*, Hunt *et al.*, 1995). In the receiving water, both the water column and benthos are monitored. Monitoring for enrichment of nutrients in the water column requires the collection and analysis of water quality and plankton samples. These field studies are supported by water quality modeling (HydroQual, 1995) to project the likelihood and extent of potential nitrogen enrichment which can cause local eutrophication. The eutrophication model is driven by a three-dimensional hydrodynamic model developed by the U.S. Geological Survey (USGS) under a cooperative agreement with the MWRA. Assessments of toxic accumulation in fish and shellfish are based on chemical and pathological studies of lobster, flounder and blue mussels. On and within the seafloor, accumulation of contaminants and their potential effect on benthic organisms is the subject of this report. Presently, the Outfall Monitoring Task Force (OMTF) is MWRA's oversight body and provides scientific guidance for the entire environmental monitoring program associated with the new outfall.

Benthic monitoring is important to the overall program for several reasons. First, most infauna, as opposed to planktonic or pelagic systems, are relatively sessile and cannot easily move away from regions of pollutant exposure. Consequently, it may be easier to detect adverse anthropogenic effects on benthic organisms. Second, infauna represent a food source for organisms that are higher on the food chain and are more likely to bioaccumulate contaminants. In that sense, adverse effects detected in infauna provide an early warning of possible damage to the larger marine ecosystem. Third, infauna, by definition, live within the seafloor sediments where effluent particulates are likely to accumulate over time. Benthic environments are suspected sinks for discharged effluent particulates. Fourth, benthic infauna are small and can be easily and more adequately sampled with collection apparatus of moderate physical dimension, without complications from organism avoidance associated with, for instance, pelagic trawls.

This report focuses on the component of benthic monitoring conducted with a grab sampler deployed over soft-substrates. These are sites where sediments of substantial depth (>1 m) have accumulated on the seafloor. Some semi-quantitative monitoring of hard-substrate epifauna has also recently been conducted in the region, but it is the subject of a separate report (Coats *et al.*, 1995b). For the soft-bottom benthic sampling conducted over the past three years, stations are designated as either nearfield, within 6 km of the diffuser, or farfield. The nearfield sites are intended to measure the severity and extent of future effects from sewage effluent. Farfield stations, which are designated with a "FF" prefix in Figure 1, serve largely as reference stations for inferring causality by comparison to the nearfield data. As will be shown in this report, this distinction is not clear in practice. Nevertheless, distant farfield stations may also provide a warning should anthropogenic effects reach farther than expected. The benthic sampling at all soft-bottom stations includes the measurement of several environmental parameters beyond enumeration of benthic infauna. These other parameters include: biochemical contaminants (PAH, PCB, and trace metals), sediment bulk properties (grain size, grab penetration depth), and sewage effluent tracers (*Clostridium perfringens* spore counts and Linear Alkyl Benzenes).

1.1.3 Geologic Setting

The geologic setting controls the baseline monitoring of surficial sediments because the location of benthic stations is dictated by the irregular distribution of sediment facies. Specifically, the viability of grab sampling at a particular station is determined by the lateral extent and depth of soft sediments. In the region surrounding the outfall in western Massachusetts Bay, the distribution of depositional environments is patchy and restricted to topographic lows. As a consequence, the location of nearfield benthic stations are restricted to these bathymetric lows surrounding the outfall (Figure 2). The outfall diffuser itself is located in a topographic low. The baseline monitoring described here, reveals that sediments, and the benthic infaunal communities within them, are unstable at some of these sites and therefore unsuitable for long-term monitoring. Occasionally, sites were relocated in recent surveys because of an inability to collect adequate grab samples when past stations were revisited (Table 1).

The distribution seafloor sediments has been mapped with an extensive set of sidescan sonar records supplemented by bathymetric data, grab samples, and bottom photographs (Knebel, 1993). The bathymetry and therefore the distribution of sedimentary environments on the continental shelf, is the result of a complex history of glaciation and sea-level change during the late Quaternary period. As a result of glaciation, the regional seafloor physiography is characterized by a series of relict elliptical drumlins with major axes oriented along 290°N. Erosional environments occur on top of these ubiquitous knolls, with deposition or reworking of fine-grained sediments occurring at depth between the drumlins. Large boulders, some with diameters exceeding 3 m, were deposited along with other glacial till as part of the moraines. The epifauna associated with hard-substrate surfaces on the top of glacial moraines adjacent to the outfall were mapped as part of a survey conducted in 1994 (Coats *et al.*, 1995b). These boulders trains or erratics can be traced as strong acoustic reflectors in sub-bottom profiles as they extend under the sediments that fill adjacent depressions. Thus, large hard-substrate features are not absent at depth, but are buried and have no surficial expression within the topographic lows unless short-term erosional processes occur locally.

1.1.4 Historical Benthic Studies

This is the third in an ongoing series of reports describing the results of monitoring benthic conditions associated with the new outfall in Massachusetts Bay. These studies all address the first phase of outfall monitoring, namely, samples collected before effluent discharge. These baseline samples are crucial for evaluation future impacts which will be based on a comparison of pre- and post-discharge (Phase II) monitoring results. The first Phase I report (Blake *et al.*, 1993b) dealt with data collected in 1992 and focussed on the benthic infauna alone. Surficial sediment chemistry data collected in 1992 was discussed by Shea (1993). Sediment chemistry and benthic infaunal data collected in 1993 were described in Coats *et al.* (1995a). Benthic conditions before 1992 were addressed in several studies, both as part of the outfall siting studies (Battelle, 1987; Blake *et al.*, 1987; and Blake *et al.*, 1988) and earlier regional investigations (Gilbert *et al.*, 1976). The scope of benthic infaunal sampling conducted between 1978 and 1984 as part of the MDC 301(h) waiver application process (Metcalf & Eddy, 1984), was limited compared to recent field investigations. In 1987, additional infaunal and sediment chemistry samples were collected as part of the Secondary Treatment Facilities Plan (Blake *et al.*, 1987). Some of these earlier investigations are summarized by Shea *et al.* (1991).

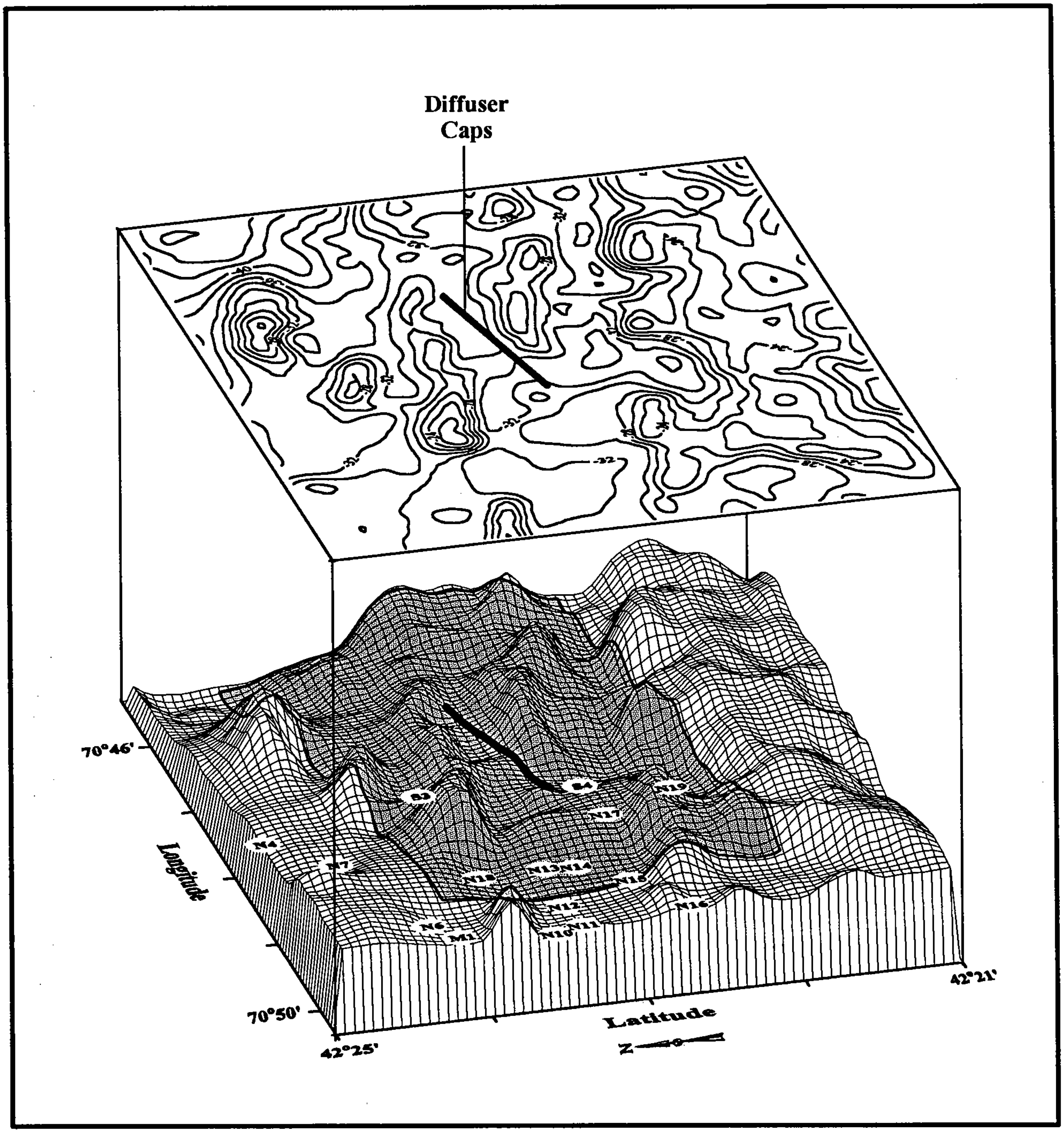

Figure 2. High-resolution bathymetry (meters) surrounding the diffuser caps as determined by Bothner *et al.*, 1992. Shading on the surface (lower) map delineates a 2-km region surrounding the diffuser. Station locations are labeled on the surface map where the prefix "N" indicates a nearfield station.

Table 1. Location of outfall benthic stations and infaunal replicates analyzed.

Station	Latitude	Longitude	Distance[a] (km)	Depth[b] (m)	Infaunal Replicates Analyzed		
					1992	1993	1994
			Nearfield Stations				
NF1	42°20.35′N	70°50.51′W	5.98	42	1	—	—
NF2	42°20.31′N	70°49.69′W	5.56	30	1	3	1
NF3	42°20.67′N	70°49.35′W	4.77	29	1	—	—
NF4	42°24.93′N	70°48.39′W[c]	3.05	37	1	3	1
NF5	42°25.62′N	70°50.03′W	4.98	36	1	—	0[d]
NF6	42°24.30′N	70°49.99′W	3.01	31	1	—	—
NF7	42°24.60′N	70°48.89′W	2.57	35	1	—	1
NF8	42°24.00′N	70°51.81′W	4.99	31	1	3	1
NF9	42°23.99′N	70°50.69′W	3.55	31	1	3	1
NF10	42°23.57′N	70°50.29′W	2.82	33	1	3	1
NF11	42°23.39′N	70°50.25′W	2.73	30	1	—	—
NF12	42°23.40′N	70°49.83′W	2.16	34	1	3	3
NF13	42°23.40′N	70°49.35′W	1.52	35	1	—	1
NF14	42°23.20′N	70°49.36′W	1.66	34	1	3	1
NF15	42°22.93′N	70°49.67′W	1.96	34	1	—	1
NF16	42°22.70′N	70°50.26′W	2.82	33	1	3	1
NF17	42°22.88′N	70°48.89′W	0.95	32	1	3	3
NF18	42°23.80′N	70°49.31′W[e]	1.71	35	1	—	1
NF19	42°22.30′N	70°48.30′W	1.43	35	1	—	1
NF20	42°22.69′N	70°50.69′W	3.39	30	1	—	1
MB01	42°24.16′N	70°50.19′W	3.08	30	—	—	1
MB03	42°20.87′N	70°48.90′W	4.24	30	—	—	1
S3	42°23.86′N	70°48.10′W	1.07	30	—	—	1
S4	42°22.83′N	70°48.10′W	0.44	30	—	—	3
			Farfield Stations				
FF1A	42°33.84′N	70°40.55′W	21.65	35	—	—	3
FF1	42°27.94′N	70°37.31′W	15.50	84	3	3	—
FF4	42°17.30′N	70°25.50′W	30.72	90	3	3	3
FF5	42°08.00′N	70°25.35′W	40.64	65	3	3	3
FF6	41°53.90′N	70°24.20′W	63.13	35	3	3	3
FF7	41°57.50′N	70°16.00′W	63.82	39	3	2[f]	3
FF9	42°18.75′N	70°39.40′W	12.89	50	3	3	3
FF10	42°24.84′N	70°52.72′W	6.70	29	3	3	3
FF11	42°39.50′N	70°30.00′W	38.13	89	3	3	3
FF12	42°23.40′N	70°53.98′W	7.75	25	3	3	3
FF13	42°19.19′N	70°49.38′W	7.49	23	3	3	3
FF14	42°25.00′N	70°39.29′W	10.62	77	3	3	3

[a] Closest approach distance to diffuser.

[b] Based upon an average of depths recorded during 1993 and 1994 surveys, when available (Campbell, 1993 and 1994). Otherwise, for stations sampled only in 1992, water depths were as reported in the 1992 survey (Blake *et al.*, 1992). As described in the 1992 survey report, the fathometer transducer inadequately represented depths in excess of 60 m.

[c] In 1993, Station NF4 was relocated 188 m to the west and the revised location is reflected here.

[d] The sample collected in 1994 at Station NF5 is excluded from infaunal analysis for reasons described in the text.

[e] In 1994, Station NF18 was relocated 100 m to the west and the revised location is reflected here.

[f] Replicate 2 collected in 1993 at Station FF7 is excluded from analysis for reasons described in Coats *et al.* (1995).

1.2 BASELINE BENTHIC SAMPLING

With any environmental monitoring program, the availability of temporal controls, in the form of baseline data, significantly increases the power to detect impacts. This baseline data also lends insight into the temporal and spatial scales of natural variability in the benthic environment and can be used to optimize the field sampling design.

1.2.1 Changes in Baseline Sampling Design

In each of the three years of baseline benthic sampling conducted to date, the field sampling design has changed. These modifications were in response to improved knowledge concerning the temporal and spatial scales of background variability in the physicochemical properties of sediments, and in the associated infauna. The differences in infaunal sample replication and spatial coverage at outfall stations is summarized in Table 1 and Figure 1, respectively. A summary of sediment chemistry replication is presented in Table 2. Most of the interannual differences in field design occurred at nearfield stations within 6 km of the diffuser.

Nearfield Changes

In the 1992 benthic survey, unreplicated chemistry and infaunal samples were collected at a large (20) number of nearfield stations with the intent of mapping the distribution of benthic parameters. Following review of the results of the 1992 sampling survey, the OMTF mandated modification of the sampling design to incorporate replication of samples at a small subset of nearfield stations. In the 1993 survey, two chemistry and three infaunal replicate samples were collected at a total of nine nearfield stations. Modification of the nearfield sampling design was motivated by a concern that observed interannual differences in infaunal communities may not be purely a result of actual temporal changes, but could be partially due to the small-scale heterogeneity seen in 1992 samples. Some of the observed temporal variability may be confounded by the small-scale spatial variability that arises because of an inability to reoccupy precisely the same seafloor locations with a grab sampler. Sample replication would provide a measure of this small-scale spatial variability.

To maintain a field sampling effort similar to that of the initial benthic survey in 1992, only nine of the twenty original nearfield stations could be sampled with replication. The strategy used to select these nearfield stations (listed in Table 1) was based on three considerations. First, a station's proximity to the outfall increases the likelihood of detecting impacts and consequently, stations close to the diffuser (such as Station NF17) were selected as were some distant stations to be used as controls. Second, stations with a greater fraction of fine-grained sediment contain increased infaunal abundances. Finally, three infaunal cluster groups were determined from an analysis of the 1992 data, and stations from each group were designated for resampling.

Upon comparison of the results from the unreplicated 1992 sampling survey and preliminary findings from the fully-replicated 1993 benthic survey, a hybrid approach was adopted for 1994 nearfield data collection (Hunt *et al.*, 1994). Concern was expressed over the ability to detect effluent effects from only nine stations given the observed temporal instability of sediments at some of the stations and the spatially heterogeneous nature of sediment grain size and infauna. In the hybrid approach, replicate samples would again be collected but only at three of the 20 nearfield stations. In addition, four new stations were to be sampled. All nine nearfield stations sampled in the 1993 were resampled in the 1994 survey, although some were without replication. Replicate sampling was maintained at Station NF12, because long-term sampling by the USGS near this location suggested sediments are relatively stable there. Replicates were also collected again at Station NF17 because of its proximity to the outfall.

Two of the four new stations (MB01 and MB02) were selected because they have been occupied for benthic nutrient flux studies (Giblin *et al.*, 1993), which consistently observed soft sediments at these locations. The

Table 2. Location of outfall benthic stations and sediment chemistry replicates analyzed.

Station	Latitude	Longitude	Distance[a] (km)	Depth[b] (m)	Chemistry Replicates Analyzed		
					1992	1993	1994
			Nearfield Stations				
NF1	42°20.35′N	70°50.51′W	5.98	42	1	—	—
NF2	42°20.31′N	70°49.69′W	5.56	30	1	2	1
NF3	42°20.67′N	70°49.35′W	4.77	29	1	—	—
NF4	42°24.93′N	70°48.39′W[c]	3.05	37	1	2	1
NF5	42°25.62′N	70°50.03′W	4.98	36	1	—	1
NF6	42°24.30′N	70°49.99′W	3.01	31	1	—	—
NF7	42°24.60′N	70°48.89′W	2.57	35	1	—	1
NF8	42°24.00′N	70°51.81′W	4.99	31	1	2	1
NF9	42°23.99′N	70°50.69′W	3.55	31	1	2	1
NF10	42°23.57′N	70°50.29′W	2.82	33	1	2	1
NF11	42°23.39′N	70°50.25′W	2.73	30	1	—	—
NF12	42°23.40′N	70°49.83′W	2.16	34	1	2	2
NF13	42°23.40′N	70°49.35′W	1.52	35	1	—	1
NF14	42°23.20′N	70°49.36′W	1.66	34	1	2	1
NF15	42°22.93′N	70°49.67′W	1.96	34	1	—	1
NF16	42°22.70′N	70°50.26′W	2.82	33	1	2	1
NF17	42°22.88′N	70°48.89′W	0.95	32	1	2	2
NF18	42°23.80′N	70°49.31′W[d]	1.71	35	1	—	1
NF19	42°22.30′N	70°48.30′W	1.43	35	1	—	1
NF20	42°22.69′N	70°50.69′W	3.39	30	1	—	1
MB01	42°24.16′N	70°50.19′W	3.08	30	—	—	1
MB03	42°20.87′N	70°48.90′W	4.24	30	—	—	1
S3	42°23.86′N	70°48.10′W	1.07	30	—	—	1
S4	42°22.83′N	70°48.10′W	0.44	30	—	—	2
			Farfield Stations				
FF1A	42°33.84′N	70°40.55′W	21.65	35	—	—	2
FF1	42°27.94′N	70°37.31′W	15.50	84	2	2	—
FF4	42°17.30′N	70°25.50′W	30.72	90	2	2	2
FF5	42°08.00′N	70°25.35′W	40.64	65	2	2	2
FF6	41°53.90′N	70°24.20′W	63.13	35	2	2	2
FF7	41°57.50′N	70°16.00′W	63.82	39	2	2	2
FF9	42°18.75′N	70°39.40′W	12.89	50	2	2	2
FF10	42°24.84′N	70°52.72′W	6.70	29	2	2	2
FF11	42°39.50′N	70°30.00′W	38.13	89	2	2	2
FF12	42°23.40′N	70°53.98′W	7.75	25	2	2	2
FF13	42°19.19′N	70°49.38′W	7.49	23	2	2	2
FF14	42°25.00′N	70°39.29′W	10.62	77	2	2	2

[a] Closest approach distance to diffuser.

[b] Based upon an average of depths recorded during 1993 and 1994 surveys, when available (Campbell, 1993 and 1994). Otherwise, for stations sampled only in 1992, water depths were as reported in the 1992 survey (Blake *et al.*, 1992). As described in the 1992 survey report, the fathometer transducer inadequately represented depths in excess of 60 m.

[c] In 1993, Station NF4 was relocated 188 m to the west and the revised location is reflected here.

[d] In 1994, Station NF18 was relocated 100 m to the west and the revised location is reflected here.

other two new stations (S3 and S4) were selected for their proximity to the diffuser and because maps of sediment facies constructed by the USGS (Bothner *et al.*, 1992) suggest that these sites have sediments suitable for grab sampling. The viability of sampling at Station S4 was further confirmed by video reconnaissance during the hard-substrate survey in 1994 (Coats *et al.*, 1995b). This site is extremely close (<500 m) to the western terminus of the diffuser-cap corridor. Also, because of uncertainty in the ability to collect grab samples in the new locations, the 1994 field survey integrated a deck- readout video camera system on the grab sampler to facilitate *in situ* location of suitable sediment patches during sampling (Campbell, 1994).

Farfield Changes

The first baseline survey, conducted in August 1992, collected twelve replicated samples at farfield stations. Eleven are listed in Tables 1 and 2. An additional farfield Station (FF8) was located well out in the Gulf of Maine and was only sampled in 1992. Its infauna was indicative of deep benthic communities that are clearly different from the balance of stations on the shelf (Blake *et al.*, 1993b). Consequently, it was not resampled in subsequent years and will not be considered further in this study. The elimination of this farfield station in field surveys subsequent to 1992 allowed reallocation of sampling resources to the nearfield and resulted in an additional replicated nearfield station in the 1993 survey.

Triplicate infaunal and duplicate chemistry samples were collected at the remaining farfield stations throughout the three baseline years. The only exception was at Station FF1. In 1994, it was relocated inshore, from a position within Stellwagen Basin to a shallow location near the mouth of Gloucester Harbor. The rationale for relocation was that stations within the Stellwagen Basin have a high degree of similarity and two other stations already exist there. Upon relocation, the station designator became FF1A (Figure 1). Station FF1A of this study lies close to Biological Station 5 of the Gloucester 301(h) monitoring program, which has conducted benthic sampling for infauna, chemistry, and grain size, biannually in the region since 1985 (Allan D. Michael and Associates, 1993). Also, Station FF1A lies in a water depth (35 m) close to that of the nearfield stations, but at a substantial distance (22 km) from the diffuser where any conceivable impact from effluent discharge is unlikely.

1.2.2 Evaluation of Field Sampling Designs

There are a variety of statistical approaches that can be applied to test whether apparent impacts to the benthos are statistically significant, and by inference, related to human activities. This discussion focuses on two statistical paradigms related to mapping and optimal impact studies as they apply to the baseline data. In this study, the baseline data serve to measure the unimpacted state from which departures in the post-discharge environment can be compared to detect and assess impact effects. The duration and complexity of baseline monitoring depend on the level of natural trends and fluctuations that exist in the unimpacted state. One purpose of the baseline study is to quantify this background spatial and temporal variation in the pre-discharge environment.

Other innovative techniques have been applied in environmental damage assessment studies and some were recently summarized by Skalski (1995). Two of these approaches may be particularly suitable for application to the outfall monitoring program. First, the long-term benthic sampling program will eventually record a time series of the annual increases in effluent particulates along with their potential impact on the infauna. This data would be ideal for a repeated measures study of mean time series at reference and contaminated sites are compared statistically. The second approach that can be applied is more global than the statistical analyses described here which test each parameter independently. Meta-analyses (Hedges and Olkin, 1985) wherein the results of separate studies, such as benthic infaunal, histopathological, and water quality, are integrated in a global statistical design. Even within the benthic monitoring program, statistical tests performed on individual chemical constituents and effluent tracer parameters can be combined in a more global statistical analysis that would improve the overall power of the design. Here, within the limited scope of this benthic report, a much simpler approach is applied.

Two fundamentally different questions can be posed when designing benthic monitoring programs. With no other information, the most basic is whether the benthic environment has been affected at all by anthropogenic activities. This is investigated by testing the null hypothesis of no impact; H_o^1: there is no change in the benthic environment from the baseline state. When testing purely for the presence of effects, the field sampling design concentrates on extreme conditions with highly replicated samples at impacted stations, directly adjacent to the outfall, and at control stations away from exposure to outfall contaminants. The nearfield sampling design, adopted in 1993, is an example of a replicated design suited to testing H_o^1. However, by pooling similar samples, as described below, all three nearfield designs can be cast into this inferential model. For detecting biologically significant increases in contaminants, the hypothesis test can be further refined to test whether the power of the sampling design is capable of detecting changes equal to contaminant levels known to have biological effects. These contaminant levels can be derived from summaries of effects detected in dose-response data and other field studies (*e.g.*, Long *et al.*, 1995). In this case, the modified hypothesis becomes H_o^2: there is no change in the contaminant that exceeds a specified impact level. Thus, "acceptable" impacts are distinguished from "measurable" changes due to discharged effluent.

While the statistical power of the null hypothesis tests is optimized by a high-contrast replication approach, little information as to the regional or temporal extent of damage is provided. The question of extent is fundamentally different from that tested by the null hypotheses described above. The associated sampling design also differs. For a large outfall, some increase in contaminant concentrations within surficial sediments close to the diffuser is likely. There, quantifying the extent of effects, by mapping contaminant concentrations between impact and control stations, is more pertinent than whether effects exist. However, mapping requires redistribution of the sampling resources over a range of exposures and will sacrifice the power to test the presence of impacts. The nearfield sampling design adopted in 1992 is best adapted to the mapping approach. Thus, evaluation of field sampling designs, is dependent on which of these two competing approaches is considered most important.

In any regard, specification of the inherent uncertainty in baseline conditions is a crucial consideration in all benthic sampling programs. This uncertainty arises both because of natural variability in the chemical and infaunal properties, and because of inherent sampling error as measured by variation among replicates. For the null hypotheses H_o^1 and H_o^1, the statistical power of a particular sampling design is based on the ratio of the variation <u>among</u> control (baseline) and impact (nearfield post-discharge) sites, to the natural (error) variation <u>within</u> those sites. Lacking data from impacted sites, this investigation estimates the natural (error) variation by pooling baseline samples. The hypothesis test is associated with confidence levels which measure the likelihood of not detecting an existing effect (β, Type II error), and of detecting an effect when one does not exist (α, Type I error rate of false alarms). The complement of the Type II error ($1-\beta$) is the statistical power of the design to correctly detect impacts represented by a given change in the measured parameters. Procedures for estimating the inherent background variance, both for mapping and replication, are described below.

Mapping

If the source of contaminants is localized along a line, as with the new outfall, then it is possible that a spatial gradient of effects radiating from the source will indicate impact. Isopleths of biological response could be superimposed on contaminant maps to confirm interaction. Kriging procedures (*cf.* Keckler, 1994) provide objective estimates of the isopleths along with the inherent error variance associated with their locations. Variance estimates allow confirmation that the observed patterns are real and not artifacts of the sampling process. With anisotropy in the sampling fields, it is possible that some of the observed pattern occurs naturally. By specifying these naturally-occurring patterns before discharge, with a baseline mapping program, the true impact of the outfall can be isolated.

Anisotropy may play a role in this monitoring program. Recall from Section 1.1.3, that the bathymetric structure near the diffuser (Figure 2) restricts the location of soft-bottom stations. The physiography is such that there is a comparative a lack of depositional lows immediately east of the diffuser. Consequently, the station pattern close to the diffuser is skewed toward the west with a paucity of soft-substrate stations in the east (Figure 1). This asymmetry in measurement locations creates variability in the local accuracy of environmental isopleths. Nevertheless, the presence of weak mean currents in the region (Signell, *et al.*, 1992) suggests that the effluent exposure will be radially symmetric.

The error variance associated with background contaminant distributions within Massachusetts and Cape Cod Bays has been estimated by Shea *et al.* (1991). In particular, they mapped the spatial distribution of some selected contaminants using kriging procedures applied to data collected before the baseline outfall monitoring program. Kriging provided the spatial correlation structure of these contaminants across a wide range of distances. The spatial correlation extrapolated to zero lag approximates the inherent error variation term needed for hypothesis testing of the significance of post-discharge effects. For chromium, the variance determined from the kriging procedure at short spatial lags (~400 m) was less than 100 $\mu g^2\ g^{-2}$ and was in rapid decline toward smaller lag. This compares well with the ~10 $\mu g^2\ g^{-2}$ variance determined in this investigation considering the reduction in variance afforded by normalization to aluminum concentration applied in the present study. Although, this focuses on an optimal impact design approach using pooled samples rather than a mapping approach, the sampling design conducted in 1992 is well suited to an application of kriging and should be pursued at some point.

As an aside, a field sampling program designed purely for mapping without any replication, has a disadvantage that is not readily apparent from the above discussion. Namely, it limits sample quality control. Without replication, there is no direct method for revealing abnormal samples arising from errors in processing or sampling. These ramifications are apparent in this study in the unreplicated sample from Station NF5 in 1994. The infaunal community structure at this station is a substantial outlier to all of the other 170 samples collected over the entire baseline program. Environmental properties associated with this sample are normal. This study ascribes its anomalous character to problems in post-processing of the infaunal sample, although concrete evidence sufficient for excluding it from the analysis is limited (*cf.* Table 1 and Section 2.2.4). It is likely that replication of this sample would have offered direct independent confirmation of its abnormality. This was the case in the analysis of 1993 benthic data, where one replicate at Station FF7 was thought to have been damaged during sorting (Coats *et al.*, 1995a). This was confirmed through a comparison of abundances with other replicates from the same station. If the present analysis was to include the anomalous sample at Station NF5, this single outlier would dramatically inflate the sampling error term and significantly decrease the apparent power to detect future infaunal impacts.

Replication

The forgoing suggests that there are a variety of statistical analyses that can be applied to test the power of the various sampling designs and to assess whether samples can be combined or pooled in those analyses. This report focuses on the optimal impact design approach described by Green (1979) because it is a commonly accepted approach (EPA, 1992) and because the sampling design appears to have the necessary temporal and spatial controls for the multivariate analysis of variance (ANOVA). The crucial components of the optimal impact design are the presence of both spatial (distant/near) and temporal (before/after) controls, wherein reference and potentially impacted areas are monitored before and after exposure to contaminants. The large set of baseline data collected to date provides the requisite temporal control for evaluating the ecological and contaminant impacts of the outfall.

However, because of changes in the baseline sampling design, replicate samples were not collected at all sites during each of the three years. Also, at most only three infaunal replicates and two chemistry replicates were collected at these sites. Thus, the interaction between outfall proximity and grain size is difficult to model in an ANOVA of infaunal community structure. Also, the spatial extent of future impacts is unknown and there are few available sites immediately adjacent to the diffuser that span the full range of grain size. Finally, as in all benthic field programs, there is some question whether grab samples represent true replicates or contain some bias. This bias can arise from pseudoreplication (Hurlbert, 1984) or small-scale spatial variability due to an inability to resample precise locations with a core deployed from a vessel on the sea surface.

This investigation ameliorates the lack of power due to low sample size by pooling data from adjacent stations. To determine the samples to be pooled, some sense for the spatial extent of the potential effluent impact must be specified. Without actual post-discharge measurements, this study relies on the approximations determined from existing models of particulate deposition. While other statistical constructs may yield a different picture of the power of the various benthic sampling designs, these are best pursued when post-discharge measurements are available.

1.3 SCOPE

The primary objective of this report is to assess the benthic monitoring program for its ability to determine whether future changes in benthic chemistry, bulk sediment characteristics (grain size, TOC, clostridium), and infaunal biology are related to effluent discharge or whether they are the product of natural processes. Each of the field sampling designs employed in the collection of the three years of baseline benthic data, will be evaluated in terms of their ability to detect environmental change within stated levels of statistical confidence. To accomplish this, a methodology for statistically evaluating post-discharge data is established. This methodology includes the specification of environmental parameters and baseline stations, along with an estimate of their associated natural (error) variability. The latter can be used in comparisons with post discharge data. Many other topics pertinent to the baseline data, but ancillary to the primary objective, are left for other investigations.

The two prior outfall reports dealing with baseline benthic conditions near the new outfall site (Blake *et al.*, 1993b and Coats *et al.*, 1995a) focussed on the analysis of data collected from surveys conducted within a single year. Now, with three years of baseline data and with the pending onset of effluent discharge from the new outfall, this report investigates the entire multiyear data set for temporal (interannual) changes in infauna and surficial sediments. Also, and perhaps more importantly, the comprehensive analyses presented herein, provide more reliable estimates of the natural physical and biological variability in the benthos. This permits an accurate evaluation of the adequacy of the sampling design and a prediction of the likely levels of anthropogenic change that can be detected. To avoid repetition, raw benthic chemistry and infaunal data for only the 1994 survey is presented in Appendices A and B of this report.

Also, in contrast to previous investigations, the entire benthic data set, including all farfield stations, is analyzed as a whole to determine those samples most suitable for determining the background infaunal variability. These samples also suggest which stations can act as sentinels for detecting future impacts from effluent discharge. This subset of "sentinel" stations are selected based on variety of criteria, including the similarity and stability of their benthic infaunal community, and their proximity to the diffuser. One crucial issue in evaluating the sampling design, and impacts in general, is the selection of the parameter(s) used to measure changes in the infaunal community structure. Rather than using ambiguous diversity indices as biological indicators of community structure, as suggested in the Combined Work/Quality Assurance Project Plan (CW/QAPP, Kropp and Peven, 1993), this study constructs linearly additive functions (principal components) based on overall trends observed in the baseline data. As demonstrated in this report, these represent a much more robust criterion for biological change in the entire infaunal community.

1.3.1 Questions Addressed

Again, as its primary focus, this report explores whether the benthic sampling design used in baseline monitoring will be adequate for determining impacts on the benthos from effluent discharges. To achieve this determination, the following questions are addressed.

1) What data transformations are needed to approach normality and homogeneity of variance in sediment properties and contaminants?
2) How many chemistry and infaunal samples must be pooled to meet detection goals outlined in the effluent monitoring plan?
3) What is a suitable parameter for measuring change in the benthic infaunal community and are diversity indices adequate?
4) What is the relative ability of the three sampling designs to detect changes in the surficial chemistry and in the infaunal community?
5) What is the likely region of impact for measurable increases in contaminants after effluent discharge begins?
6) How long will it take for contaminant concentrations to reach levels where infaunal effects become apparent in the impact region?
7) What stations exhibit distinct zoogeographic differences and what taxa are associated with them?
8) How does inherent (replicate) variability in infaunal samples compare with interannual and spatial trends?
9) Which baseline samples are appropriate for determining the natural background variability in infauna for use in impact assessments? What stations can act as sentinels for potential future impacts on infauna because of their proximity to the diffuser, temporal stability in environmental properties, and uniformity in community structure?
10) What association exists between the benthic community structure and bulk sediment properties at these sentinel stations and what taxa are responsible for major differences in community structure?
11) What level of anthropogenic change in the infaunal community can be detected at these sentinel stations and how does it compare with the guidelines from the monitoring plan?

1.3.2 Topics Deferred to Other Reports

Ecological interpretation of the benthic biota, including trophic relationships and mechanistic interpretations of their interaction with environmental variables (*e.g.*, sediment grain size), is left for other reports. Not only are these topics complex, as exemplified by a recent review of animal-sediment relationships (*cf.*, Snelgrove and Butman, 1994), but some ecological interpretations have already been presented in previous MWRA reports (Shea *et al.*, 1991; Blake *et al.*, 1993b; Kropp and Diaz, 1994; and Coats *et al.*, 1995a). They will undoubtedly be the subject of future interpretations resulting from a discussion of any observed impacts from effluent discharge. This investigation limits discussion to a listing of those taxa, whose variability in abundance, separates samples into major zoogeographic cluster groups.

Also deferred to other studies, is a complete treatment of the effect of chemical contaminants in surficial sediments on the benthic infauna in baseline samples. As described in later sections, sediment contaminant concentrations are generally well below those associated with observed biological effects. Also, at these low contaminant concentrations vary collinearly with sediment bulk properties, such as grain size or TOC, whose gross effects are addressed here. Prior to the analysis of observations of higher contaminant levels associated with post-discharge sampling, it is difficult to sort out the contaminant effects from the gross effects of variability in bulk sediment properties.

Although two size fractions of infauna were collected from 0.3-mm and 0.5-mm sieves, the combined enumerations were examined in this study. Analysis of different size fractions could be used to infer juvenile and adult stages of specific taxa and to examine their interannual succession. Also, analysis of the 0.5-mm fraction would allow comparison with infaunal sampling conducted as part of the 301(h) waiver (Metcalf & Eddy, 1984) and the Secondary Treatment Facilities Plan (Blake *et al.*, 1987). These comparisons are left to other reports. Taxa not identified to species level or not considered to be infaunal species *(i.e.*, were motile epifaunal or pelagic organisms), were excluded from the analysis described in this report.

Finally, because the focus of this report is on interannual variability, data from other seasons, namely the farfield data collected in May 1992, is excluded from the analysis. The balance of the data, used to investigate long-term variability, is from the summer season. Seasonal variability is explored in the first baseline report (Blake *et al.*, 1993b). Moreover, the reports dealing with the first two years of benthic sampling, split the analysis between nearfield and farfield stations (Blake *et al.*, 1993b; and Coats *et al.*, 1995a). However, since there is no *a priori* reason to differentiate those stations that lie beyond 6 km from the diffuser, all samples are initially combined in an overall analysis. In fact, one farfield station is a member of the group of sentinel stations recommended for inclusion in statistical hypothesis tests of impact assessment. It displays an infaunal community similar to other nearfield sentinel stations and is comparatively close to the diffuser.

1.4 ORGANIZATION

This report consists of seven major sections and two appendices. The following section (2.0) describes the sample collection and processing methods, as well as some of the analysis techniques applied to the data. Section 3.0 presents the results of analyses of chemical contaminants and focuses on the likely region of future impacts in the sediments immediately surrounding the new outfall. Present and projected increases in contaminant levels are compared with published levels of biological effects. This sets the stage for the discussion of benthic infauna presented in Section 4.0. There, stations are categorized in terms of their infaunal community structure and a group of sentinel stations are recommended for comparison with post-discharge communities to detect impacts. Baseline samples collected at these sentinel stations are used to compare the power of the three different sampling designs used to date. Finally, Section 5.0 reiterates the findings and conclusions resulting from the analysis of three years of baseline benthic data. This is followed by a list of citations (Section 6.0) and acknowledgements (Section 7.0). Appendices report the raw data collected in the 1994 outfall survey.

2.0 METHODS

2.1 SAMPLE COLLECTION

As described in Section 1.2.1, the field sampling design of the soft-bottom benthic monitoring program changed in each of the three annual baseline surveys conducted to date. The design changes were primarily related to the station location and replication. Differences in collection methods do not materially affect the compatibility of data used in the interannual comparisons described in this study.

2.1.1 1992 Field Survey

Most of the data collected in the first summer field survey, conducted in August 1992 (Blake *et al.*, 1992a), were incorporated in this investigation. There were three benthic replicate grab samples collected at each of the twenty nearfield and 12 farfield stations during that survey. Except for Station FF8, the station locations are listed in Table 1 and are shown in Figure 1. Navigation was provided by a Northstar 800 LORAN-C and MX4200 Global Positioning System. Depth measurements, collected with the ship's depthsounder, were only accurate to depths of 60 m.

The benthic grab samples were retrieved using a Young grab that covered a 0.04-m^2 surface area. Samples were then sieved onboard through a 0.3-mm mesh sieve and preserved in buffered 10% formalin. Before sorting in the laboratory, specimens were resieved through nested 0.5-mm and 0.3-mm mesh sieves. Only one of the three replicate infaunal grab samples, collected at each nearfield station, was sorted and enumerated. The remaining two replicate samples from each nearfield station were archived.

Samples collected for physicochemical analyses were acquired with a Kynar-coated Young grab covering a 0.1-m^2 area of the seafloor. One replicate grab sample was collected at each nearfield station and two were collected at farfield stations (Table 2). These grabs were subsampled for grain size, TOC, *C. perfringens*, and organic and trace-metal chemistry analyses. Subsamples were collected from the top 1 cm of sediment with a Teflon scoop. In addition to the collection of grab samples, *in situ* sediment profile images were recorded at a number of locations. These were discussed by Blake *et al.* (1993b) and are not addressed further here.

2.1.2 1993 Field Survey

Three replicate grab samples for infaunal analysis were collected at each nearfield and farfield station occupied in the 1993 outfall survey (Campbell, 1993). Except for Station FF8, all farfield stations occupied in the 1992 survey were resampled as indicated in Table 1. The three replicate infaunal grabs were collected at a subset of nine nearfield stations. In contrast to the 1992 survey, all replicate infaunal samples were analyzed. Due to the presence of rocky substrate at the 1992 coordinates for Station NF4, samples were collected at a site 188 m to the west of the original location (Table 1). Navigational fixes for station locations were determined from a Northstar 8000/Magnavox 4200D differential GPS receiver with a Magnavox MX-5OR DGPS beacon receiver. The resulting navigation system had an absolute accuracy of 5 m. The Battelle Ocean Sampling System (BOSS) navigation computer tracked and recorded the coordinates of each sampling location along with the time that grab sampler contacted the seafloor. Bottom depth was measured with an accuracy of 0.1 m and qualitative observations of weather and sea state were recorded. Ancillary observations of the infaunal grab samples included penetration depth (±0.5 cm), sediment volume (±0.5 L), and Redox Potential Discontinuity Depth (RPD, ±0.5 cm). These observations were collected in both the 1993 and 1994 surveys and are summarized in Table 3. Quality control was as described in the CW/QAPP (Kropp and Peven, 1993).

In contrast to the onboard sieving procedure used in the 1992 survey, infaunal samples in the 1993 and 1994 surveys were washed through nested 0.5-mm and 0.3-mm mesh sieves before preservation in buffered 10%

Table 3. Measured properties of sediment grab samples used in the infaunal analysis.

1993 Station	Replicate	Penetration (cm)	Volume (L)	RPD (cm)
NF2	1	8.5	2.50	>8.5
NF2	2	8.0	2.50	0.5
NF2	3	9.0	2.50	1.5
NF4	1	9.0	2.50	>9.0
NF4	2	8.5	1.75	4.5
NF4	3	7.0	1.50	>7.0
NF8	1	9.0	2.50	4.0
NF8	2	9.0	2.50	1.0
NF8	3	9.0	2.00	6.0
NF9	1	6.5	1.50	2.0
NF9	2	7.0	1.50	7.0
NF9	3	7.0	1.50	5.5
NF10	1	7.0	1.50	>7.0
NF10	2	9.0	2.00	>9.0
NF10	3	7.0	1.50	4.5
NF12	1	9.0	2.50	>9.0
NF12	2	9.0	2.00	>9.0
NF12	3	9.0	2.50	>9.0
NF14	1	8.5	2.50	>8.5
NF14	2	7.5	1.50	>7.5
NF14	3	8.5	2.50	>8.5
NF16	1	9.0	2.50	>9.0
NF16	2	9.0	2.50	7.0
NF16	3	6.5	1.50	>6.5
NF17	1	8.5	2.50	>8.5
NF17	2	9.0	2.00	>9.0
NF17	3	9.0	2.50	>9.0
FF1	1	9.0	2.50	3.5
FF1	2	9.0	2.50	5.0
FF1	3	9.0	2.50	4.5
FF4	1	9.0	2.50	>9.0
FF4	2	9.0	2.50	>9.0
FF4	3	9.0	2.50	>9.0
FF5	1	8.5	2.50	>8.5
FF5	2	8.5	2.50	4.5
FF5	3	8.5	2.50	3.5
FF6	1	9.0	2.50	5.0
FF6	2	8.5	2.50	6.0
FF6	3	8.5	2.50	5.5
FF7	1	9.0	2.50	>9.0
FF7	2	9.0	2.50	7.0
FF7	3	9.0	2.50	7.0
FF9	1	7.5	2.00	>7.5
FF9	2	7.5	2.00	>7.5
FF9	3	7.5	2.00	>7.5
FF10	1	8.5	2.50	5.0
FF10	2	9.0	2.50	4.5
FF10	3	9.5	2.50	5.0
FF11	1	9.0	2.50	>9.0
FF11	2	9.0	2.50	6.5
FF11	3	9.0	2.50	>9.0
FF12	1	7.5	1.50	2.0
FF12	2	7.0	1.50	3.5
FF12	3	9.0	1.75	2.5
FF13	1	9.0	2.50	2.5
FF13	2	8.0	2.00	3.5
FF13	3	8.5	2.50	1.0
FF14	1	9.0	2.50	>9.0
FF14	2	9.0	2.50	>9.0
FF14	3	9.0	2.50	>9.0

1994 Station	Replicate	Penetration (cm)	Volume (L)	RPD (cm)
NF2	1	8.0	2.75	1.0
NF4	1	8.5	2.75	>8.5
NF5	1	9.0	2.75	4.0
NF7	1	9.0	2.75	2.5
NF8	1	9.0	2.75	>9.0
NF9	1	8.5	2.75	5.0
NF10	1	9.5	2.75	4.0
NF12	1	8.5	2.75	3.5
NF12	2	8.5	2.75	3.0
NF12	3	8.5	2.75	4.0
NF13	1	8.0	2.75	>8.0
NF14	1	8.0	2.75	>8.0
NF15	1	9.0	2.75	4.0
NF16	1	10.0	2.75	3.0
NF17	1	8.5	2.75	>8.5
NF17	2	8.5	2.75	>8.5
NF17	3	8.0	2.75	>8.0
NF18	1	7.5	2.50	>7.5
NF19	1	8.5	2.75	>8.5
NF20	1	8.5	2.75	>8.5
MB01	1	9.5	2.75	4.0
MB03	1	8.5	2.75	1.5
S3	1	9.0	2.75	4.0
S4	1	9.0	2.75	2.0
S4	2	8.5	2.75	4.0
S4	3	9.0	2.75	2.5
FF1A	1	9.0	2.75	4.0
FF1A	2	9.0	2.75	4.0
FF1A	3	8.5	2.75	4.0
FF4	1	8.5	2.75	>8.5
FF4	2	8.5	2.75	>8.5
FF4	3	8.5	2.75	>8.5
FF5	1	9.0	2.75	>9.0
FF5	2	8.5	2.75	>8.5
FF5	3	8.5	2.75	>8.5
FF6	1	8.5	2.75	4.0
FF6	2	9.0	2.75	2.0
FF6	3	9.0	2.75	2.0
FF7	1	9.0	2.75	>9.0
FF7	2	9.0	2.75	>9.0
FF7	3	9.0	2.75	>9.0
FF9	1	9.0	2.75	>9.0
FF9	2	9.0	2.75	>9.0
FF9	3	9.0	2.75	>9.0
FF10	1	8.5	2.75	4.0
FF10	2	9.0	2.75	5.0
FF10	3	8.5	2.75	4.0
FF11	1	8.5	2.75	4.0
FF11	2	10.0	2.75	5.0
FF11	3	9.0	2.75	5.0
FF12	1	9.0	2.75	>9.0
FF12	2	9.0	2.75	>9.0
FF12	3	9.0	2.75	>9.0
FF13	1	8.5	2.75	1.0
FF13	2	8.5	2.75	4.0
FF13	3	8.5	2.75	1.0
FF14	1	8.5	2.75	>8.5
FF14	2	8.5	2.75	>8.5
FF14	3	8.5	2.75	>8.5

formalin. The 1992 survey initially washed samples only through a single 0.3-mm mesh sieve before preservation. For specimens collected in the 1992 survey, apportioning into 0.5-mm and 0.3-mm fractions occurred in the laboratory, after fixation. This difference in "live" sieving processing may be an important consideration for analyses (not conducted here) where size fractions are examined separately. There is some evidence that retention of some polychaete species differs between "live" and "dead" sieving (Ohwada, 1988). Ohwada compared results obtained by washing sediment samples both before and after fixation. For a given sieve size, abundances are generally higher when specimens were sieved after fixation. The differences in washing samples before and after fixation is largely restricted to soft-bodies organisms, such as polychaetes, which lack shells or exoskeletons. Also, the differences are greatest for large sieve sizes (0.5-mm mesh) and less significant for sieve sizes of roughly 0.3 mm. Because the analyses conducted in this study are based on a combination of both size fractions, and because all surveys initially wash samples through same minimum sieve size of 0.3 mm before preservation, any differences in combined abundances due to sieving are negligible.

Two replicate grab samples were collected for sediment chemistry, grain size, TOC, and *Clostridium perfringens* spores at each of the nine nearfield and eleven farfield stations (Table 2). Shipboard sampling methods were similar to those of the 1992 survey and follow the protocols specified in the CW/QAPP (Kropp and Peven, 1993). Sediment chemistry subsamples were collected from the top 2 cm of the grab sample, a depth somewhat greater than samples collected in 1992. Analysis methods for sediment chemistry samples and *Clostridium perfringens* spore counts follow those specified by the National Oceanic and Atmospheric Administration for the National Status and Trends Mussel Watch Project (Battelle Ocean Sciences, 1992). TOC content of solid samples was determined using a LECO model 761-100 carbon analyzer. Sediment grain size analyses were performed according to methods presented in Folk (1974). *C. perfringens* analysis was performed on sediment samples using methods developed by Emerson and Cabelli (1982) as modified by Saad (D. Saad, MTH Environmental Associates, personal communication). Average physicochemical properties for each station and year are summarized in Table 4.

2.1.3 1994 Field Survey

Triplicate infaunal grab samples and duplicate sediment chemistry grab samples were collected at three nearfield and eleven farfield stations occupied in the 1994 outfall survey (Campbell, 1994). Unreplicated samples were collected at an additional 17 nearfield stations. Four new nearfield stations were successfully sampled. Farfield Station FF1within Stellwagen Basin, sampled in 1992 and 1993, was relocated to an inshore position near one of the farfield reference stations for the Gloucester municipal outfall. It was redesignated FF1A. Due to the presence of rocky substrate at the 1992 location of Station NF18, samples were collected at a site 100 m to the west of the original position (Table 1). All samples were analyzed in the laboratory using the methods described in Section 2.1.2 for the 1993 survey.

2.2 INFAUNAL DATA

2.2.1 Laboratory Processing

Infaunal samples were transferred from formalin to 70% ethanol in the laboratory. Sorting was accomplished under dissecting microscopes where organisms were picked by fine dissecting forceps. Upon sorting into major taxonomic groups (polychaetes, arthropods, mollusks, and miscellaneous), samples were shipped to taxonomists for identification and enumeration. Identifications were made to the lowest practical taxonomic level, which in most cases was to species level. Kropp and Peven (1993) describe the quality control methods. Macroinfaunal abundance data were coded and entered into the Battelle database. Enumeration of samples collected in 1994 is summarized in Appendix B of this report and raw data for prior years is contained previous annual reports (Blake *et al.*, 1993b; Coats *et al.*, 1995a).

Table 4. Bulk environmental properties of surficial sediments computed from an average of replicate samples.

	Gravel (%)			Mud (%)			TOC (%)			*C. perfringens*		
Station	**1992**	**1993**	**1994**	**1992**	**1993**	**1994**	**1992**	**1993**	**1994**	**1992**	**1993**	**1994**
FF1	0.80	0.18		86.6	72.4		2.15	2.08		736	1490	
FF1A			0.54			20.5			0.34			856
FF4	0.15	0.00	0.00	83.6	78.5	88.3	2.17	2.10	2.15	608	1400	1405
FF5	0.65	0.00	0.39	62.5	45.4	58.9	1.24	0.93	0.83	591	759	827
FF6	0.05	0.08	0.11	63.0	48.3	69.9	1.48	1.04	1.20	678	1593	1810
FF7	0.00	0.00	0.09	79.2	66.5	81.0	2.31	2.14	1.99	150	769	763
FF9	0.10	0.48	2.65	18.6	15.0	16.7	0.77	0.39	0.39	705	522	690
FF10	1.00	0.37	1.61	31.0	33.2	46.5	0.76	0.52	0.68	1680	1810	2285
FF11	0.05	0.00	0.07	77.7	71.8	81.8	1.86	1.56	1.61	2937	937	1117
FF12	2.75	3.61	0.13	28.0	20.6	33.1	0.83	0.37	0.61	7615	2640	4085
FF13	39.40	0.09	0.10	26.4	28.0	37.5	1.29	0.72	0.89	7165	4555	6175
FF14	0.20	0.82	0.08	79.6	66.6	75.4	1.71	1.25	1.29	978	993	1026
NF1	0.80			7.0			0.57			632		
NF2	0.00	0.00	0.66	77.2	3.1	10.7	2.64	0.10	0.17	8470	850	3110
NF3	0.70			35.1			0.82			615		
NF4	37.70	2.35	0.04	3.6	3.3	2.4	0.39	0.11	0.01	1670	219	103
NF5	0.50		1.95	22.3		34.2	0.78		0.78	207		2910
NF6	0.20			37.6			1.00			1800		
NF7	0.10		0.26	40.5		31.2	1.20		0.73	462		6160
NF8	0.00	0.00	0.00	82.0	74.6	84.4	3.17	2.95	1.87	8100	8835	9060
NF9	0.10	5.02	0.62	43.9	33.3	39.7	1.03	0.50	0.55	364	3295	3660
NF10	0.10	0.00	0.05	39.6	33.9	35.7	0.75	0.54	0.51	1360	3010	2990
NF11	5.30			25.5			0.72			1300		
NF12	0.00	0.00	0.00	70.7	62.0	85.8	0.97	1.72	1.75	2140	6555	7080
NF13	0.20		4.67	3.8		4.6	0.45		0.19	923		466
NF14	8.90	36.89	11.52	13.2	5.5	6.7	0.92	1.49	1.06	686	1575	1580
NF15	3.70		2.33	19.5		9.1	0.92		0.83	176		1130
NF16	0.00	0.00	0.45	76.5	36.6	33.9	2.04	0.87	1.73	3900	3475	5450
NF17	0.10	0.03	0.50	1.2	1.9	1.7	0.43	0.06	0.04	154	210	180
NF18	54.10		30.75	9.8		19.9	0.75		0.81	1450		2850
NF19	8.80		3.51	6.3		15.4	0.50		0.41	417		1880
NF20	1.50		33.45	57.8		18.8	1.45		0.63	6240		3640
S3			23.44			5.4			0.15			812
S4			0.00			68.9			1.19			4425
MB01			0.03			74.3			1.17			5380
MB03			0.09			68.0			0.86			4730

2.2.2 Taxa Analyzed

Taxa included in the infaunal analyses of this report are summarized in Table 5. The taxa are arranged phylogenetically and the total number of individuals recovered over the entire three years of sample collection is also shown. The taxa analyzed herein represent a subset of the total number of organisms collected. Of the 258,338 organisms enumerated into 416 taxa, 94% or 244,040 organisms representing 322 species were analyzed in 170 samples. Two samples were excluded as described below.

The selection of the subset of taxa used in the analysis was based on several criteria. First, only those individuals identified to species level were included. This eliminated 85 of the original 416 taxa. Nine additional species were excluded because they were not strictly considered macroinfaunal organisms or because their size or motility suggested that they could be undersampled by the collection and sampling methods. These were all crustaceans of in the mysidae, leuconidae, and axiidae families. Carrying the full set of 322 remaining species in this study's analysis, regardless of their rarity in the baseline data, allows a fuller determination of impacts. Some rare species in the baseline data may display an affinity for the increased particulate organic carbon loads associated with the discharge, and significantly increase in abundance in the impact region after discharge. Also, numerically rare taxa, such as the holothurian *Molpadia oolitica*, may represent a keystone species whose presence can dramatically affect the community structure through trophic group amensalism (Rhoads and Young, 1971) as discussed by Blake *et al.* (1993b) for Cape Cod Bay. As described in Section 2.3.2, this investigation's multivariate analysis procedure is capable of resolving changes in rare specie abundance. Unfortunately, including this large number of species and samples, requires analysis of a large (322 species x 170 samples) matrix, which is memory-intensive and computationally time-consuming.

2.2.3 Samples Excluded

Table 1 lists the infaunal samples included in this study's infaunal analyses. Two of the total 172 samples collected were excluded from the infaunal analysis. In the 1993 data, Replicate 2 at Station FF7 was known to have been damaged during postprocessing. Infaunal enumerations for taxa in this replicate were significantly lower than the abundances in the two other replicates collected concurrently at this station (Coats *et al.*, 1995a).

The other sample excluded from the infaunal analysis was collected at Station NF5 in 1994. Again, this sample was probably damaged in transit or during postprocessing. It's infaunal community structure differed substantially from all the remaining 170 samples while the observed condition of the grab sample (Table 3) and measured environmental properties (Table 4) were close to mean conditions. Possible independent confirmation of its abnormality arose from a recent re-examination of the residue from sorting which indicated an anomalously low volume and possible desiccation of fragments. Although the field log indicated the presence of polychaete tubes, the reported polychaete abundance was low and *Spio limicola*, a species largely responsible for the formation of tube mats, was completely absent (Appendix B).

However, there was no direct record of damage to this sample. All sample tracking forms were reverified with taxonomists and the taxonomists were asked to re-examine samples and confirm counts. Data entry was also reconfirmed. Overall, the abundance and number of species were much lower in the sample collected at Station NF5 in 1994 than in 1992 (Table 6). Abundances of pollutant indicator species, such as *Capitella capitata* complex, *Streblospio benedicti*, and *Polydora cornuta*, were low or absent. These species are known for their ability to rapidly colonize stressed environments and to establish large populations in polluted sediments (Pearson and Rosenberg, 1978). Their absence in this sample suggests that the anomalous community structure was not induced *in situ* by anthropogenic influences.

Table 5. Number of individuals collected for each taxon included in the infaunal analysis.

CNIDARIA	
Ceriantharia	
Cerianthidae	
Ceriantheopsis americanus	13
Actiniaria	
Actiniaria sp.1	1
Actiniaria sp.2	201
Actiniaria sp.3	1
Actiniaria sp.6	4
Edwardsiidae	
Edwardsia elegans	154
PLATYHELMINTHES	
Turbellaria	
Turbellaria sp.1	2
Turbellaria sp.2	1
NEMERTEA	
Nemertea sp.2	90
Nemertea sp.3	1
Nemertea sp.4	1
Tubulanidae	
Tubulanus pellucidus	34
Carinomella lactea	123
Lineidae	
Cerebratulus lacteus	256
Amphiporidae	
Amphiporus angulatus	425
Tetrastemmatidae	
Tetrastemma vittatum	54
ANNELIDA	
Polychaeta	
Polynoidae	
Antinoella sarsi	1
Arcteobia anticostiensis	30
Gattyana amondseni	62
Gattyana cirrosa	80
Harmothoe imbricata	16
Hartmania moorei	3
Enipo torelli	98
Bylgides groenlandicus	11
Pholoidae	
Pholoe minuta	1258
Amphinomidae	
Paramphinome jeffreysii	22
Phyllodocidae	
Phyllodoce groenlandica	3
Phyllodoce mucosa	1072
Phyllodoce maculata	87
Eteone longa	1209
Eulalia bilineata	2
Mystides borealis	11
Eulalia viridis	1
Paranaitis speciosa	1
Eumida sanguinea	2
Phyllodoce arenae	33
Hesionidae	
Microphthalmus aberrans	32
Pilargidae	
Ancistrosyllis groenlandica	5

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

Syllidae	
Pionosyllis sp.A	41
Typosyllis sp.1	45
Typosyllis alternata	16
Exogone verugera	4330
Exogone hebes	4560
Exogone longicirris	51
Sphaerosyllis erinaceus	50
Sphaerosyllis longicauda	125
Syllides japonica	147
Syllides longocirrata	381
Nereidae	
Neanthes virens	2
Nereis zonata	2
Nereis grayi	114
Websterinereis tridentata	2
Nephtyidae	
Nephtys neotena	852
Nephtys ciliata	31
Nephtys caeca	23
Nephtys discors	2
Nephtys incisa	536
Aglaophamus circinata	331
Sphaerodoridae	
Sphaerodoropsis minuta	48
Sphaerodoridium claparedii	5
Glyceridae	
Glycera capitata	7
Goniadidae	
Goniada maculata	62
Lumbrineridae	
Abyssoninoe winsnesae	4
Eranno spp.	1
Scoletoma fragilis	162
Lumbrineris tenuis	3
Scoletoma impatiens	22
Scoletoma hebes	880
Ninoe nigripes	4878
Arabellidae	
Drilonereis filum	1
Dorvilleidae	
Dorvillea sociabilis	20
Ophryotrocha sp.1	7
Parougia caeca	840
Orbiniidae	
Scoloplos armiger	331
Leitoscoloplos acutus	3569
Leitoscoloplos sp.B	91
Paraonidae	
Aricidea cerrutii	14
Aricidea quadrilobata	3018
Aricidea minuta	14
Levinsenia gracilis	4846
Aricidea catherinae	18459
Apistobranchidae	
Apistobranchus tullbergi	498

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

Spionidae	
Spionidae sp.1	1
Laonice sp.1	5
Laonice cirrata	15
Polydora cornuta	444
Polydora socialis	16247
Polydora caulleryi	4
Polydora quadrilobata	2874
Prionospio steenstrupi	17508
Spio thulini	169
Spio filicornis	151
Spio setosa	3
Spio limicola	51749
Spiophanes bombyx	623
Spiophanes kroeyeri	27
Pygospio elegans	198
Streblospio benedicti	5
Scolelepis squamatus	1
Scolelepis foliosa	1
Minuspio cirrifera	12
Trochochaetidae	
Trochochaeta carica	104
Trochochaeta watsoni	3
Trochochaeta multisetosa	124
Cirratulidae	
Cirratulus cirratus	6
Aphelochaeta sp.A	11
Tharyx sp.1	108
Tharyx sp.H	9
Aphelochaeta monilaris	167
Tharyx acutus	10674
Monticellina baptisteae	4972
Tharyx marioni	3090
Tharyx dorsobranchialis	584
Chaetozone sp.A	1767
Chaetozone sp.B	29
Chaetozone setosa	45
Cossuridae	
Cossura longicirrata	4390
Flabelligeridae	
Brada villosa	13
Flabelligera affinis	7
Pherusa plumosa	1
Pherusa affinis	34
Diplocirrus longisetosus	4
Diplocirrus hirsutus	9
Scalibregmatidae	
Scalibregma inflatum	2113
Opheliidae	
Ophelina acuminata	20
Sternaspidae	
Sternapsis scutata	166
Capitellidae	
Capitella capitata complex	1162
Heteromastus filiformis	297
Mediomastus californiensis	26057
Barantolla americana	3

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

Maldanidae	
Clymenella torquata	230
Maldane sarsi	350
Maldane glebifex	1216
Axiothella catenata	8
Praxillella gracilis	26
Praxillella praetermissa	255
Praxillella affinis	34
Rhodine bitorquata	2
Rhodine loveni	62
Euclymene collaris	253
Clymenura sp.A	6
Clymenura polaris	8
Praxillura ornata	64
Oweniidae	
Owenia fusiformis	682
Myriochele heeri	2
Galathowenia oculata	106
Pectinariidae	
Pectinaria gouldii	6
Pectinaria granulata	23
Ampharetidae	
Ampharete arctica	61
Ampharete acutifrons	1963
Ampharete finmarchica	1
Amphicteis gunneri	1
Melinna cristata	11
Anobothrus gracilis	927
Asabellides oculata	1620
Terebellidae	
Amphitrite cirrata	1
Nicolea zostericola	2
Pista cristata	2
Polycirrus medusa	13
Polycirrus eximius	111
Polycirrus phosphoreus	1
Proclea graffii	4
Trichobranchidae	
Terebellides atlantis	490
Terebellides stroemi	11
Trichobranchus glacialis	1
Trichobranchus roseus	2
Sabellidae	
Chone infundibuliformis	1
Chone duneri	13
Euchone incolor	1728
Euchone elegans	230
Potamilla neglecta	1
Potamilla reniformis	3
Laonome kroeyeri	261
Archiannelida	
Polygordiidae	
Polygordius sp.A	401
Oligochaeta	
Enchytraeidae	
Enchytraeidae sp.3	1
Tubificidae	
Tubificidae sp.2	1455
Tubificoides pseudogaster	4
Tubificoides apectinatus	2072

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

GASTROPODA	
Gastropoda sp.A	2
Gastropoda sp.1	1
Gastropoda sp.2	1
Archaeogastropoda	
Trochidae	
Solariella obscura	24
Mesogastropoda	
Rissoidae	
Rissoidae sp.A	6
Alvania areolata	1
Alvania harpa	2
Onoba pelagica	639
Pusillina pseudoareolata	4
Skeneopsidae	
Skeneopsis planorbis	1
Naticidae	
Polinices pallidus	1
Euspira heros	1
Stenoglossa	
Buccinidae	
Colus sp.A	1
Colus pubescens	1
Colus pygmaeus	5
Nassariidae	
Ilyanassa trivittata	21
Toxoglossa	
Turridae	
Turridae sp.A	1
Oenopota turricula	1
Oenopota pyrimidalis	4
Oenopota incisula	27
Oenopota cf. cancellatus	1
Oenopota exaratus	5
Cephalaspidea	
Cylichnidae	
Cylichna alba	62
Cylichna gouldi	76
Diaphanidae	
Diaphana minuta	7
Retusidae	
Retusa obtusa	11
APLACOPHORA	
Chaetodermatida	
Chaetodermatidae	
Chaetoderma nitidulum	18
BIVALVIA	
Bivalvia sp.A	9
Nuculoidea	
Nuculidae	
Nuculoma tenuis	181
Nucula annulata	276
Nucula delphinodonta	3247
Nuculanidae	
Nuculana pernula	8
Megayoldia thraciaeformis	104
Yoldia sapotilla	705
Yoldiella lucida	3

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

Mytiloida	
Mytilidae	
Mytilus edulis	226
Crenella decussata	1809
Crenella glandula	89
Musculus niger	31
Musculus discors	3
Pteriina	
Pectinidae	
Placopecten magellanicus	28
Veneroida	
Thyasiridae	
Thyasira gouldii	1337
Montacutidae	
Pythenella cuneata	1
Carditidae	
Cyclocardia borealis	26
Astartidae	
Astarte undata	399
Cardiidae	
Cerastoderma pinnulatum	364
Mactridae	
Mulinia lateralis	1
Solenidae	
Ensis directus	83
Tellinidae	
Macoma baltica	3
Tellina agilis	1
Arcticidae	
Arctica islandica	749
Veneridae	
Pitar morrhuana	7
Myina	
Myidae	
Mya arenaria	153
Hiatellidae	
Cyrtodaria siliqua	1
Hiatella arctica	3579
Pholadomyacea	
Lyonsiidae	
Lyonsia arenosa	28
Periplomatidae	
Periploma papyratium	260
Thraciidae	
Asthenothaerus hemphilli	7
Thracia conradi	23
SCAPHOPODA	
Dentalida	
Dentaliidae	
Dentulium entale	211
PYCNOGONIDA	
Pantopoda	
Nymphonidae	
Nymphon grossipes	2

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

CRUSTACEA	
Cumacea	
Lampropidae	
Lamprops quadriplicata	15
Leuconidae	
Leucon nr. acutirostris	64
Eudorella hirsuta	2
Eudorella pusilla	229
Eudorellopsis deformis	12
Diastylidae	
Diastylis polita	1
Diastylis quadrispinosa	25
Diastylis sculpta	129
Diastylis abbreviata	7
Diastylis cornuifer	6
Leptostylis cf. ampullacea	4
Leptostylis longimana	48
Pseudocumidae	
Petalosarsia declivis	50
Campylaspidae	
Campylaspis rubicunda	44
Dikonophora	
Paratanaidae	
Tanaissus psammophilus	74
Gnathiidea	
Gnathiidae	
Gnathia cerina	1
Anthuridea	
Anthuridae	
Ptilanthura tenuis	383
Flabellifera (Isopoda)	
Cirolanidae	
Politolana polita	69
Valvifera	
Idoteidae	
Edotia montosa	809
Edotia triloba	3
Chiridotea tuftsi	117
Asellota	
Munnidae	
Munna sp.2	27
Paramunnidae	
Pleurogonium spinosissimum	42
Pleurogonium rubicundum	278
Pleurogonium inerme	50
Amphipoda	
Amphipoda sp.1	155
Gammaridea	
Ampeliscidae	
Ampelisca macrocephala	142
Ampelisca abdita	116
Byblis nr. gaimardi	16
Haploops fundiensis	187
Amphilochidae	
Gitanopsis arctica	2
Ampithoidae	
Amphithoe rubricata	1
Aoridae	
Microdeutopus anomalus	11
Leptocheirus pinguis	116
Argissidae	
Argissa hamatipes	216
Corophiidae	
Corophium nr. crassicorne	4699
Erichthonius rubricornis	37
Aoridae	
Unciola inermis	437
Unciola irrorata	21
Pseudunciola obliquua	256
Eusiridae	
Pontogeneia inermis	1
Gammaridae	
Melita dentata	1
Casco bigelowi	5
Haustoriidae	
Acanthohaustorius millsi	18
Isaeidae	
Photis pollex	863
Ischyroceridae	
Ischyrocerus anguipes	93
Jassa falcata	1
Lysianassidae	
Anonyx lilljeborgi	95
Hippomedon sp.1	10
Hippomedon serratus	121
Orchomenella minuta	30
Oedicerotidae	
Oedicerotidae sp.2	9
Oedicerotidae sp.A	1
Monoculodes cf. intermedius	5
Monoculodes edwardsi	55
Phoxocephalidae	
Harpinia propinqua	407
Phoxocephalus holbolli	38
Rhepoxynius hudsoni	58
Pleustidae	
Pleustidae sp.1	8
Pleustes panoplus	1
Stenopleustes inermis	217
Podoceridae	
Dyopedos monocantha	282
Stenothoidae	
Metopella angusta	414
Proboloides holmesi	1
Synopiidae	
Syrrhoe crenulata	8
Caprellidea	
Caprellidae	
Mayerella limicola	76
Aeginina longicornis	132
Anomura	
Paguridae	
Pagurus acadianus	1
Cancridea	
Cancridae	
Cancer borealis	37
SIPUNCULOIDEA	
Golfingiidae	
Nephasoma diaphanes	2
Phascolion strombi	56

Table 5 (continued). Number of individuals collected for each taxon included in the analysis.

PRIAPULIDA				
		Priapulidae		
			Priapulus caudatus	22
PHORONIDA				
		Phoronidae		
			Phoronis architecta	934
ECHINODERMATA				
	Cribellina			
		Porcellanasteridae		
			Ctenodiscus crispatus	17
	Leptognathina			
		Echinasteridae		
			Henricia sanguinolenta	3
	Chilophiurina			
		Ophiolepididae		
			Ophiura sp.A	6
			Ophiura sarsi	50
			Ophiura robusta	334
	Scutellina			
		Echinarachniidae		
			Echinarachnius parma	178
	Holothuroidea			
		Molpadiidae		
			Molpadia oolitica	2
HEMICHORDATA				
	Enteropneusta			
		Harrimaniidae		
			Stereobalanus canadensis	8
UROCHORDATA				
	Stolidobranchia			
		Molgulidae		
			Molgula manhattensis	39
			Bostrichobranchus pilularis	70

Table 6. Benthic infaunal community indices.

Station	Number of Species			Abundance (Individuals m^{-2})			Diversity H'			Evenness J'			Dominance C'			Richness d'		
	1992	1993	1994	1992	1993	1994	1992	1993	1994	1992	1993	1994	1992	1993	1994	1992	1993	1994
FF1	78	84		9942	14692		3.29	3.19		0.76	0.72		0.06	0.06		8.37	8.65	
FF1A			90			19750			3.17			0.70			0.09			9.00
FF4	75	50	60	21208	8558	13150	2.17	2.66	2.93	0.50	0.68	0.72	0.30	0.15	0.08	7.43	5.41	6.22
FF5	73	77	60	25750	21425	7725	1.61	2.69	3.23	0.38	0.62	0.79	0.49	0.15	0.06	7.09	7.62	6.59
FF6	73	89	64	40175	40442	13233	2.48	2.93	2.90	0.58	0.65	0.70	0.16	0.10	0.11	6.79	8.30	6.64
FF7	70	59	40	45792	63400	9692	2.42	2.51	2.26	0.57	0.62	0.61	0.13	0.14	0.21	6.43	5.25	4.25
FF9	102	83	95	68333	26883	56200	2.16	2.21	2.22	0.47	0.50	0.49	0.23	0.24	0.23	9.07	8.04	8.59
FF10	118	85	104	90608	36608	67617	3.12	3.22	2.86	0.65	0.72	0.62	0.08	0.07	0.14	10.25	7.99	9.26
FF11	54	69	65	15958	24883	16692	2.37	2.75	2.77	0.59	0.65	0.66	0.15	0.10	0.11	5.48	6.72	6.58
FF12	78	56	48	53675	26742	16767	2.46	2.07	2.54	0.56	0.51	0.66	0.14	0.25	0.15	7.07	5.40	4.83
FF13	69	60	59	23958	33358	38025	2.63	2.27	2.58	0.62	0.55	0.63	0.12	0.17	0.13	6.74	5.66	5.50
FF14	63	65	63	12600	24167	14267	2.58	2.72	2.96	0.62	0.65	0.71	0.18	0.11	0.09	6.57	6.34	6.48
NF1	59			26925			2.91			0.71			0.09			5.69		
NF2	47	61	60	16400	23108	45550	2.84	1.80	2.51	0.74	0.44	0.61	0.10	0.42	0.14	4.74	5.97	5.50
NF3	68			77075			2.72			0.64			0.11			5.95		
NF4	48	85	41	18875	19700	29750	2.54	3.07	2.13	0.66	0.69	0.57	0.14	0.08	0.19	4.77	8.49	3.88
NF5	92		48	71325		18000	2.54		2.52	0.56		0.65	0.16		0.15	8.14		4.80
NF6	65			83100			1.93			0.46			0.28			5.65		
NF7	85		51	140700		32000	2.35		2.10	0.53		0.53	0.18		0.32	7.09		4.82
NF8	30	64	45	31225	92400	53725	1.84	1.72	2.04	0.54	0.41	0.54	0.27	0.32	0.24	2.80	5.51	4.04
NF9	80	75	45	57050	27383	44725	2.91	2.92	2.24	0.66	0.68	0.59	0.11	0.11	0.21	7.21	7.24	4.11
NF10	55	76	61	45175	31425	71925	2.56	2.59	2.13	0.64	0.60	0.52	0.14	0.14	0.26	5.04	7.24	5.37
NF11	72			39200			2.54			0.59			0.16			6.71		
NF12	53	64	75	28550	40758	73250	2.50	2.38	2.25	0.63	0.57	0.52	0.13	0.16	0.20	5.07	5.93	6.61
NF13	67		54	31850		45450	2.69		2.36	0.64		0.59	0.12		0.16	6.37		4.94
NF14	72	66	63	57650	20650	41850	2.79	2.92	2.67	0.65	0.70	0.64	0.10	0.08	0.12	6.48	6.54	5.83
NF15	63		65	67000		39450	2.55		3.12	0.62		0.75	0.13		0.07	5.58		6.05
NF16	48	79	38	31350	22650	9625	2.42	2.86	2.49	0.63	0.65	0.68	0.16	0.11	0.15	4.54	7.78	4.03
NF17	51	35	68	15600	4992	46625	3.02	2.30	1.80	0.77	0.65	0.43	0.08	0.24	0.39	5.18	3.99	6.23
NF18	73		75	45325		38350	2.87		3.06	0.67		0.71	0.11		0.09	6.72		7.01
NF19	78		66	99800		28875	2.45		3.16	0.56		0.75	0.19		0.08	6.69		6.33
NF20	47		37	31650		9375	2.28		2.91	0.59		0.81	0.17		0.09	4.44		3.94
S3			74			44375			3.06			0.71			0.09			6.82
S4			93			76817			2.41			0.53			0.17			8.18
MB01			55			61600			2.37			0.59			0.21			4.90
MB03			71			105850			2.39			0.56			0.15			6.05

2.3 INFAUNAL ANALYSIS

There are a variety of approaches for determining anthropogenic impacts on marine biota. Some examples include histopathology of individual organisms or dose-response studies conducted in the laboratory. The approach used in this study is based on comparison of the infaunal community structure among samples. There are many infaunal distance measures that characterize the similarity and differences in community structure among samples. Two are discussed below. By far the simplest is a comparison of diversity indices among samples. These succinct ecological indices are comparatively simple to compute, but they are fraught with bias problems and difficulties in ecological interpretation. In this investigation, a much more robust distance measure is applied in a series of multivariate analyses that: a) categorize baseline stations by similar infaunal communities (cluster analysis), b) define the ability of the baseline field designs to detect future anthropogenic changes (power and ordination analyses), and c) relate the infaunal community to physicochemical sediment properties (regression analysis).

2.3.1 Diversity Indices

Abundance and diversity indices are presented in Table 6. All community parameters, other than abundance, were computed using the subset of taxa listed in Table 5. Although the interpretation of baseline data in this report does not rely on these indices, they are commonly used in sewage outfall impact assessments to compare infaunal community properties among samples (*cf.*, Maurer and Hydock, 1995). They are presented here for completeness and compatibility with these other studies. Also, this study applies them in some representative statistical analyses to demonstrate their limitations compared to a more robust species-abundance measure.

Diversity indices are often difficult to interpret ecologically. Evidently diversity is not always correlated with environmental quality and many derived indices, based upon combinations of the other measures, result in ambiguous biological interpretations. Also, they may not represent unbiased estimates of the diversity of the community because they are not independent of sample size. Finally, they do not robustly reflect changes in the abundance of individual species, particularly those of rare specimens. This is an important aspect in environmental assessment studies where some benthic taxa are known to be sensitive to contaminants in wastewater effluent while others thrive on the increased organic carbon loads (Pearson and Rosenberg, 1978). It is conceivable that two communities could have an identical diversity index, but have no species in common. At the price of increased computational intensity, the multivariate analyses used in this study carry more information concerning the relative abundance of individual species. The sample collected at Station NF5 in 1994 is a case in point. As discussed in Section 2.2.3, this sample was excluded from the analysis because of possible damage as reflected by its dramatically-different community structure. Nevertheless, it exhibits diversity H', evenness J', and dominance C' indices that are nearly identical to the sample collected in 1992 at this station (Table 6).

Diversity indices can be categorized into those that quantify *species richness* (number of species at a station), *species evenness* (distribution of abundance among species) or a *combination* of these community properties. These general categories are discussed below along with the limitations associated with each.

Species Richness

In its simplest form, the total number of individual species (S) present in a benthic sample characterizes the diversity of the infaunal community. However, to allow comparison of species richness from samples of varying size, indices are normalized by the total number of individuals (N) present in the sample. The Margalef species richness index (d') (Margalef, 1951) is commonly used. It strongly increases for increasing number of species and increases only logarithmically for decreasing number of individuals. If only one species is present, then d' vanishes. For other distributions, the Margalef richness index is given by

$$d' = \frac{S-1}{\ln N} \tag{1}$$

where: S is the total number of species, N is the total number of individuals, and **ln** is the natural logarithm (base e).

The usefulness of this index is limited by an *a priori* assumption of a uniform logarithmic relationship between S and N. This assumption is not likely to hold in general and some bias may be introduced in d'. A less-biased method for investigating species richness is Hurlbert's (1971) modification of Sander's (1968) rarefaction method. This method predicts the expected number of species $E(S_m)$ present in increasingly rarefied subsamples of m individuals selected at random from the finite collection of organisms.

$$E(S_m) = \sum_{j=1}^{S} \left[1 - \frac{\binom{N-n_j}{m}}{\binom{N}{m}} \right] \tag{2}$$

where n_j is the number of individuals in the j^th^ species. The family of curves generated by plotting **(2)** as a function of m at several stations provides a measure of richness. This is accomplished by comparing $E(S_m)$ at the same m, namely the smallest sample size. In this way, rarefaction curves provide a more rigorous method to account for differences in the total number of organisms among a group of samples, each having a unique functional relationship between S and N. Rarefaction is based on the hypergeometric probabilities also used in the multivariate analyses of this study.

Species Evenness

The Pielou evenness index (J') (Pielou, 1977) measures the evenness of the distribution of individual organisms among the species present in the sample. J' increases for more even distributions of individuals among species. It expresses the diversity (measured by H' described below) relative to the maximum value it can attain when species are perfectly even, namely **ln** S. Thus, if each species contains the same number of individual organisms, then J' will be a maximum at 1.00. For other distributions, the Pielou evenness index is given by

$$J' = \frac{H'}{\ln S} \tag{3}$$

where H' is the Shannon-Wiener diversity index defined in (5) below. Peet (1974) has shown that J' is influenced by species richness and that its high sensitivity to variation in sample size, makes it difficult to interpret.

A community parameter inversely related to diversity and evenness indices, is the Whittaker dominance index (C') (Whittaker, 1965). C' increases with increasing proportions of individuals associated with a few species. If all individuals are of one species, then C' is maximum and equal to 1.00. If individual organisms are evenly distributed among species (J'=1.00), then C' asymptotically approaches 0.00 with increasing numbers of individuals. The Whittaker dominance measure is given by

$$C' = \sum_{j=1}^{S} \left(\frac{n_j}{N} \right)^2 . \tag{4}$$

Combined Properties

A measure of species diversity that combines the concepts of species richness and evenness is the Shannon-Wiener diversity index (H') (Shannon and Weaver, 1949; Green, 1979). It quantifies the relative distribution of individual organisms among the species present in the sample. H' increases for broader distributions of individuals among species (evenness) and for a larger number of evenly distributed species (richness). If only one species is present, then all individuals are members of that species and H' is 0.00. If each individual organism is a separate species, then H' will be a maximum determined by the logarithm of the number of individuals. For other distributions, the Shannon-Wiener diversity index is given by

$$H' = -\sum_{j=1}^{S} \left[\left(\frac{n_j}{N} \right) \ln \left(\frac{n_j}{N} \right) \right] . \tag{5}$$

Alone, this index is difficult to interpret ecologically because the same value can arise from a community with low richness and high evenness or from a community with high richness and low evenness. Nevertheless, it is a measure that is often cited, is used in the evenness index described above, and has been included in past MWRA reports.

2.3.2 Infaunal Distance Metric

In this study, multivariate analyses are applied to hypergeometric probabilities of specie abundances within samples. Because these analyses retain more information about which taxa characterize the community structure within each sample, they are far more robust than analyses using individual ecological indices. For comparing the community structure among samples, an index derived from theses hypergeometric probabilities which measures the similarity or difference between the infaunal communities. This distance measure is selected from the CNESS (chord-normalized expected species shared) family of metrics introduced by Gallagher (1995) and applied by Trueblood *et al.* (1994). For a given subsample size (***m***), the CNESS distance between two samples ***i*** and ***j*** is

$$CNESS_{ij|m} = \left\{ 2 - \left[\frac{2\, ESS_{ij|m}}{\left(ESS_{ii|m} \; ESS_{jj|m} \right)^{1/2}} \right] \right\}^{1/2} \tag{6}$$

where ESS_{ijm} is the expected number of species shared between samples. By extension of **(2)**, ESS_{ijm} is derived from hypergeometric probabilities.

$$ESS_{ij|m} = \sum_{K=1}^{S} \left\{ \left[1 - \frac{\binom{N_i - n_{ik}}{m}}{\binom{N_i}{m}} \right] \left[1 - \frac{\binom{N_j - n_{jk}}{m}}{\binom{N_j}{m}} \right] \right\} \tag{7}$$

where N_i is the total number of individuals in the i^{th} sample and n_{ik} is the abundance of the k^{th} species in the i^{th} sample. From (6), CNESS ranges between 0 and $\sqrt{2}$, with increasing values representing greater dissimilarity in samples.

As a combination of Grassle and Smith's (1976) NESS (normalized expected species shared) similarity index and Orloci's (1978) chord distance, it offers advantages of both statistics. First, CNESS distances are the metric equivalent of NESS, a non-metric. Their metric behavior is evident because with $m=1$, CNESS becomes Orloci's (1978) chord distance metric (Gallagher, 1995). This attribute improves ordination of infaunal samples (Pielou, 1984) because metrics provide quantitative intervals for measuring distance among groups of samples so that meaningful comparisons can be made. Specifically, metrics satisfy the triangular inequality rule, which states that for three samples i, j, and k

$$CNESS_{ik|m} \leq CNESS_{ij|m} + CNESS_{jk|m} . \tag{8}$$

The second major advantage of CNESS is that, like NESS, the influence of dominant species relative to that of rare species can be controlled by selection of an appropriate subsample size m. Both statistics are directly related to hypergeometric probabilities, which measure the likelihood of selecting a particular specie in a random draw of m organisms from the sample. As larger numbers of organisms are drawn, it is more likely a rare specie will be drawn in the subsample. Other distance measures that focus only on dominant species have been criticized for their lack of sensitivity to rare species (Peet, 1974; ter Braak, 1983). Because it is synonymous with CNESS at $m=1$, Orloci's (1978) chord distance is a distance measure that only emphasizes dominants. Its extension with CNESS allows far more flexibility.

A distance measure that accounts for a broad range in taxa, such as CNESS with $m>1$, is important for impact assessments because there is no *a priori* reason to assume that anthropogenic effects will be restricted to dominant species. Other measures that focus primarily on the community of dominants, such as diversity indices and most other similarity measures, could underestimate impacts on the entire infaunal community. For example, a number of taxa with extremely low abundance in baseline data, such as *C. capitata* complex or *P. cornuta* (Table 5), could exhibit a marked increase in abundance in response to effluent discharge. Even with this increase, they may not attain an abundance comparable to that of the dominant species. Thus, a significant anthropogenic change in rare taxa would go unnoticed in statistics that emphasize the dominant species. To allow the entire community to be represented in a single measure, rather than just the dominant species, an intermediate subsample size (m) is selected in this investigation. The challenge is in selecting an optimal subsample size (m) for computation of hypergeometric probabilities.

2.3.3 Subsample Size

The approach used here for the selection of the subsample size m, follows that of Trueblood *et al.* (1994). Here, CNESS dissimilarities are computed from the baseline data for a range of m. The degree of association or correlation between a CNESS distance matrix with a particular m, and distance matrices computed with extreme values of subsample size (***m***=1 and ***m*** large) are then examined. From these correlations, an intermediate ***m*** is selected such that the resulting distance matrix exhibits some association with both extremes of ***m***. Thus, the measure exhibits some sensitivity to both rare and dominant species. Strictly speaking, the largest ***m*** at which the hypergeometric probabilities can be computed is set by the total abundance of the sample with fewest individuals. At this maximum ***m***, hypergeometric probabilities are uniform across the species contained in the sample, because subsample size matches that of the original sample. In other words, all species are represented in the selected subsample. An equivalent probability distribution is obtained from a Boolean transformation where abundances are converted to presence-absence data. Thus, a Boolean transformation of all samples results in hypergeometric probabilities extrapolated to ***m***=∞, as described by Gallagher (1995).

Relationship Between Small and Large Subsamples

The functional dependence of the correlation between CNESS distance matrices with an intermediate ***m*** and those with the extrema in ***m*** are shown in Figure 3. This correlation was performed on a subset of 108 mid-field infaunal samples collected within 10 km of the diffuser over the three years of baseline monitoring. The solid line shows the association between the CNESS matrix computed with ***m***=1 and matrices computed with a range of ***m***. As ***m*** increases, the association decreases as matrices emphasizing dominant species (***m***=1) are compared with matrices increasingly sensitive to rare species (increasing ***m***). The dashed lines show the association between the CNESS matrices computed at large ***m***, which are highly sensitive to rare species, and matrices computed with a range of ***m***. The largest subsample size available computationally (***m=360***) is shown along with an extrapolation to ***m***=∞, as described above.

To place precisely equal emphasis on rare and dominant species, the optimal ***m*** corresponds to the point where the ***m=1*** crosses the ***m***=∞ curve. Thus, a CNESS distance matrix with this subsample size near ***m=45*** is equally sensitive to the contribution of both rare and dominant species. As expected, the optimal ***m*** by this criterion would be lower for the ***m=360*** curve, around ***m=28***. The associations determined from Kendall's τ_b and Spearman rank correlation coefficients (Norušis, 1992) were computed from the lower triangular elements of the CNESS distance matrices. Both measures of association suggest equivalent values for the optimal ***m***, although the form of the relationships differs for the two non-parametric correlation algorithms.

Increasing the Influence of Dominants

While incorporating the influence of rare species in the infaunal distance metric is desirable, there are two reasons the dominant species should be given slightly greater emphasis. The first is a practical matter. Out of the 244,040 organisms enumerated in 322 identified species, there are 47 singleton species which are represented by a single specimen that occurs in only one sample. If for no other reason than the taxonomist's greater familiarity with common species, the accuracy and consistency of taxonomic identifications are likely to be greater for dominants than for these extremely rare specimens that represent less than 0.02% of all the organisms collected. Because of the greater taxonomic uncertainty associated with extremely rare species, it follows that they should receive somewhat less emphasis through selection of a smaller ***m***. Also, to avoid placing undue emphasis on species represented by single individuals, hypergeometric transformations are applied to enumerations of raw data (Appendix B) rather than abundance normalized to a square meter, as reported in Table 6. Normalization would artificially inflate the relative importance of rare species and skew the correlations computed above.

The second reason to give dominants greater weight pertains to their ecological influence. Even if the rare species abundance increases in response to anthropogenic impacts, it is unlikely that the extremely rare species will ever approach the abundances associated with the dominants. Thus, they are less likely to represent significant food sources for organisms higher on the food chain or to influence ecological relationships in other ways, such as modification of the environment, namely sediments.

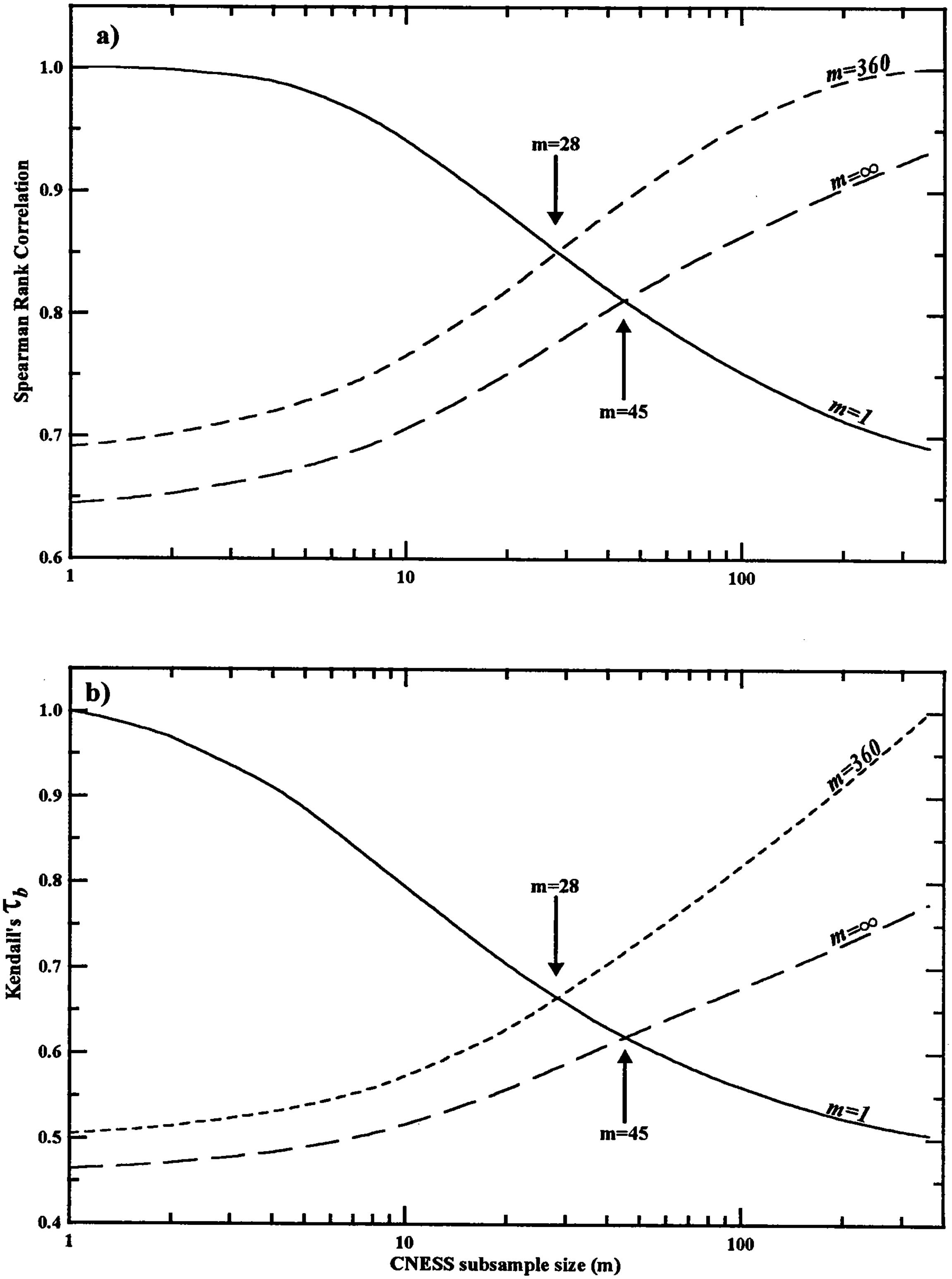

Figure 3. Selection of optimal subsample size (*m*) using: a) Spearman and b) Kendall non-parametric correlation coefficients. The solid lines represent the correlation between a CNESS distance matrix computed with the smallest subsample size (*m*=1) and those computed with the *m* shown along the abscissa. The dashed lines represent the rank-order correlation of the CNESS distance matrices computed with the maximum subsample size (*m*=360, small dashes) and presence-absence transformation (m=∞, large dashes) and those computed with a range in *m*.

With these considerations, subsample size of ***m=18*** was selected to place about 25% greater emphasis on the dominants. At this subsample size, the Spearman rank correlation for matrices computed with ***m=1*** and ***m=18*** is 23% larger than the equally weighted case where ***m=45***. This subsample size results in a CNESS distance matrix that is equally well correlated with matrices computed using ***m=1*** (dominants only) and ***m≈100***, a subsample containing about 28% of the organisms in the smallest midfield sample.

2.3.4 Cluster Analyses

This study uses cluster analyses to identify groups of samples with similar infaunal properties close to the diffuser. These samples are used in power analyses to define the relative ability of the three field sampling designs to detect anthropogenic change. In the cluster analyses of this study, the complement of CNESS reflects the similarity among samples, and dendrograms are generated using the unweighted pair-group method (Sneath and Sokal, 1973). As recommended by Gallagher (1995), species are clustered using similarity computed with Pearson's product-moment correlations among normalized hypergeometric probabilities. These correlations are related to $\cos\theta$, where θ is the angle between species vectors in a covariance biplots (ter Braak, 1983). Single-linkage R-mode clustering is used to generate species dendrograms rather than the unweighted pair-group method used in sample (Q-mode) clustering (Boesch, 1977).

2.3.5 Community Ordination

The community ordination technique used here is directly related to the cluster analyses described above. It condenses the species-abundance data to a few factors responsible for the observed cluster patterns while retaining the ecologically-meaningful biological information. The ordination technique is related to principal component analysis (*cf.*, Ludwig and Reynolds, 1988) which is similar to the reciprocal averaging method used in prior baseline benthic reports. The major difference is that it is applied to hypergeometric probabilities computed with ***m=18*** as described above. The approach follows that of Trueblood *et al.* (1994) where Gallagher first described a metric scaling of CNESS distances such that the species-sample matrix is converted to hypergeometric probabilities, normalized, and then centered. Principal component analysis of this matrix, denoted PCA-H, provides an ordination of CNESS distances among samples. In this study, PCA-H is augmented with detrending and regression analyses to focus on the underlying biological and environmental factors responsible for determining infaunal community structure. The results are used to establish confidence limits on the baseline infaunal data and to test the ability of various sampling designs to detect change with a given statistical power.

2.4 ENVIRONMENTAL PARAMETERS

Similar to infaunal analyses, this investigation examines sediment chemistry data to evaluate the adequacy of the field sampling designs. The raw data for the 1994 sampling survey are presented in Appendix A and data from the 1993 field survey are included in the report by Coats *et al.* (1995a). Of greatest interest for analysis, are those contaminants that have been consistently measured, are enriched in the effluent, are particularly toxic, or have established toxic effects levels. The analysis of background contaminant levels, examined the following trace metal concentrations in detail: silver (Ag), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn). Trace metals are reported in parts per million (ppm) or micrograms of contaminant per grams dry weight of sediment. Because of naturally-high collinearity among trace metals, metal concentrations for each sample are normalized by the amount of aluminum (Al) present, and normalized concentrations are reported in µg per grams dry weight of aluminum.

Besides the trace metals, a subset of organic chemicals is examined for detectability and sampling design comparisons. These include the organic contaminants DDT, Chlordane, Lindane, and Dieldrin as well as polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB). The concentrations of each DDT/DDD/DDE isomer are summed to specify total DDT and the concentrations of each PCB congener are summed for total PCB. The p,p'-DDE isomer is also examined separately from total DDT. Finally, *Clostridium perfringens* spore counts, total organic carbon (TOC), and silt and clay (mud) fraction are included as either tracers of effluent particulates or as normalization for the other parameters. High natural collinearity between organic chemical concentrations and the amount of organic carbon in samples leads to the normalization of the organic chemicals by TOC. While raw concentrations are reported in parts per billion (ppb) or nanograms of contaminant per gram of dry weight sediment, normalized values are per gram of TOC. The concentration of organic chemicals went undetected in a number of samples (Appendix A). The method detection limits vary among these organic chemicals, but are generally low compared to range of biological effects. In the analysis, undetected concentrations are taken to be zero.

The statistical evaluation of the sampling designs is based on an analysis of variance (ANOVA). The ANOVA of background contaminant concentrations determines their ability to detect significant differences in mean concentrations. ANOVA is premised on an assumption that each variable is derived from a normal population whose variance is not a function of the mean. Standard statistical tests for violations of these assumptions can be applied to the normalized contaminant concentrations. A Levene test for homogeneity of variance and Shapiro-Wilks' and Lilliefors tests for normality (Norušis, 1992) show significant departures from the assumptions. These departures are also evident in normal probability plots. The ANOVA of this study applies data transformations to the normalized contaminant concentrations to improve normality and homogeneity of variance. For almost all variables, a $log_{10}(X)$ transformation significantly improves the distributions. Variables that are proportions, such as the mud fraction and TOC, are well recognized as having a non-uniform variance (Draper and Smith, 1981). The variance for these parameters is stabilized with an arc-sine transformation of the form $2sin^{-1}(\sqrt{X})$.

3.0 CHEMICAL CONTAMINANTS

This section examines a subset of the broad suite of contaminant concentrations measured in surficial sediments as part of the benthic baseline monitoring program. In evaluating the chemistry sampling design, this discussion uses the contaminant concentrations to: 1) estimate the relative ability of the three nearfield sampling designs to detect change, 2) estimate baseline (background) concentrations within 2 km of the diffuser, 3) project contaminant accumulation rates after the onset of effluent discharge, and 4) project the length of time before contaminant levels increase to detectable or toxic-effect levels near the outfall.

3.1 DATA ANALYSIS

As described in Section 1.2.1, the benthic sampling design has changed in each of the three years of baseline monitoring. The changes in sampling strategy near the outfall affect the ability of statistical tests to detect anthropogenic impacts due to effluent discharge. Assuming some or all of the stations sampled in one of these three years will be revisited after initiating discharge, then a paired *t*-test can assess impacts by comparing the mean concentration in a group of potentially contaminated samples collected directly adjacent to the outfall, with the mean from a similar group remote from outfall effects or collected prior to effluent discharge. Alternatively, one-way ANOVA could be used to combine spatial controls with temporal controls (pre and post-discharge) in a more rigorous "optimal impact" design (Green, 1979). However, for the purposes of the power analysis conducted here, a simple two-group contrast of means will be assumed.

3.1.1 Pooled Samples

In contrast to power analyses using benthic infaunal metrics, it is not practical to use individual stations to test the null hypothesis of no impact. This is due to the reduced number of replicates (generally, two or less) collected for sediment chemistry as compared to biological replication at any given station (often as high as three). Consequently, to achieve a reasonable number of degrees-of-freedom (dof) for hypothesis tests, samples are best pooled into a group of impacted stations close to the diffuser, and a group of control stations presumably distant from significant deposition of effluent particulates. While this pooling approach increases the risks of pseudoreplication (Hurlbert, 1984) and spatial autocorrelation, it is the only practical approach when there are relatively few benthic stations directly adjacent to the diffuser (closest approach less than 2 km) and when the replicates at these stations have no more than one error degree-of-freedom (dof) available for contrasting means.

3.1.2 Error Rates

The power of the null hypothesis tests for a given station pattern is measured by the percent increase in the mean concentration that would be statistically significant at a probability level of $\alpha=0.05$, a Type I error rate measuring the likelihood of false alarms, and $\beta=0.2$, a Type II error rate measuring the likelihood of not detecting an existing effect. Note that although $1-\beta=0.8$ is by strict definition, the statistical power of the test to correctly detect an impact, it will be fixed in this investigation and the relative detectable increase will instead be used to compare station patterns. Because increases in contaminants are of primary concern, a one-tailed *t*-test is performed on the transformed and normalized contaminant concentrations. Power analyses also require estimates of the inherent variability about mean concentrations. This is estimated from the entire set of baseline samples covering all three years. Depending on the contaminant, the number of samples ranges from 122 to 132 (Table 7). In contrast to power analysis of infaunal samples, no attempt is made to improve error variance estimates by excluding temporally unstable or geographically distinct stations. Temporal and spatial patterns in baseline contaminant distributions are comparatively weak and any attempt to analyze a subset of the data is inappropriate due to the potential introduction of bias.

Table 7. Detectable percent increase in sediment contaminant concentrations as a function of the number of samples included in the computation of the mean[a].

	Number of samples in mean					Total number of observations
	2	4	6	10	12	
Tracers	**Detectable Increase (percent)**					
Silt and Clay (Mud) Fraction[b]	131	108	87	66	59	129
Total Organic Carbon Fraction[c]	322	149	107	74	66	129
C. perfringens Counts[d]	2301	467	272	162	138	129
Aluminum[d]	70	34	25	18	16	132
Iron[e]	95	44	32	23	20	132
Contaminants						
Lead[e]	139	61	43	30	27	132
Mercury[e]	526	187	126	84	73	129
Nickel[e]	486	163	108	71	62	132
Silver[e]	878	260	166	107	93	129
Cadmium[e]	432	162	111	74	66	129
Chromium[e]	221	89	62	42	37	132
Copper[e]	361	130	88	59	52	132
Zinc[e]	186	78	54	37	33	132
p,p'-DDE[f]	1705	387	232	141	121	122
Total DDT[f]	2870	537	306	179	152	122
Total PCB[f]	636	197	128	83	72	122
Chlordane[f]	4051	667	368	210	177	122
Lindane[f]	23239	1930	892	443	361	122
Total PAH[f]	1124	292	181	113	98	122
Dieldrin[f]	53024	3063	1285	592	473	122

[a] Based on a one-sided *t*-test assuming paired sampling (revisit the same stations in post-discharge surveys), $\alpha=0.05$, and $\beta=0.2$.

[b] Arc-sine square-root transformation of un-normalized mud fraction. The percent increase is a function of the initial mean value, computed to be the mean of all baseline samples = 42.89%.

[c] Arc-sine square-root transformation of un-normalized TOC fraction. The percent increase is a function of the initial mean value, computed to be the mean of all baseline samples = 0.978%.

[d] Log_{10} transformation of un-normalized parameter.

[e] Log_{10} transformation of concentration normalized by Al fraction.

[f] Log_{10} transformation of concentration normalized by TOC fraction.

3.2 POWER OF THE SAMPLING DESIGNS

3.2.1 Availability of Impact Sites

The number of samples that are pooled to estimate mean values at impact and control sites, depends on the spatial extent of impact and the post-discharge sampling design. Because of the comparatively few stations directly adjacent to the diffuser, the number of samples in the pool is primarily dictated by the station pattern in the extreme near field. The 1994 station design had the largest number of sediment chemistry samples (10) collected within 2 km of the diffuser (Table 2, Figure 4). This sets a lower-bound for detectable increases at ten pooled samples. Sampling designs in the two preceding years had six or fewer samples collected within 2 km of the diffuser. However, as will be discussed subsequently, the impact area may not be limited to a 2-km closest approach distance from the diffuser. Furthermore, the post-discharge sampling design may not correspond to any of previous station patterns either through conscious decisions to change the design or through possible sampling difficulties in the field. Consequently, the detectable increases provided in Table 7 are computed for a wide range in the number of pooled samples.

3.2.2 Monitoring Goals

Goals for detectable change in the soft-bottom benthos are identified in the effluent outfall monitoring plan (MWRA, 1991). In the nearfield, detectable changes are anticipated between 10 and 100%. These detection goals will only be met for the majority of contaminants considered in Table 7, when ten or more samples are pooled. This can be achieved for stations within 2 km of the diffuser with the sampling design used in 1994, but the sampling designs of prior years include only four to six samples within this region of potential impact. For ten pooled samples, detectable increases below 100% can be achieved in eight of the fifteen contaminants considered. For six pooled samples, the detectable increase is amplified by a factor of 1.5 to 2, and only four trace metals achieve detectable levels below 100%.

The 1993 sampling design includes only four samples within 2 km of the diffuser and detection levels are amplified by a factor of 2 to 5 over the detection achieved with ten pooled samples. From this perspective, the most-recent (1994) sampling design is a significant improvement over previous designs and is the only one that achieves the detection goals for the majority of contaminants. Without pooling of impacted stations in a contrasted means ANOVA, the sampling design goal of detecting increases of 100% in contaminants cannot be achieved because there is only a maximum of two replicated samples available at any given station.

3.2.3 Detectable Increases in Individual Contaminants

Two other aspects of Table 7 are noteworthy. First, the detectable increase for total DDT is higher than that of the p,p'-DDE metabolite. This difference is primarily due to an anomalously high ($>2\sigma$) concentration of another DDT metabolite (p,p'-DDT) in the second replicate sample collected at Station S4 in 1994 (Appendix A). The veracity of this high value was reviewed and confirmed.

The second aspect deals with the normalization and transformation. Except where noted, all detectable increases reported in Table 7 apply to normalized contaminant concentrations. However, the detectable increase is computed after inverse transformation of the concentrations. Consequently, the increases for arc-sine transformations depend on the initial mean value used. Also, for log-transformed variables, the detectable increases and decreases are not symmetric about the mean. This is because the coefficient of variation becomes the relevant measure of error variation in log-transformed variables (Green, 1989). Anyway, detectable decreases in concentration are not pertinent because the *t*-tests are one-sided and because, in practice, impacts will only be observed with increased contaminant concentrations.

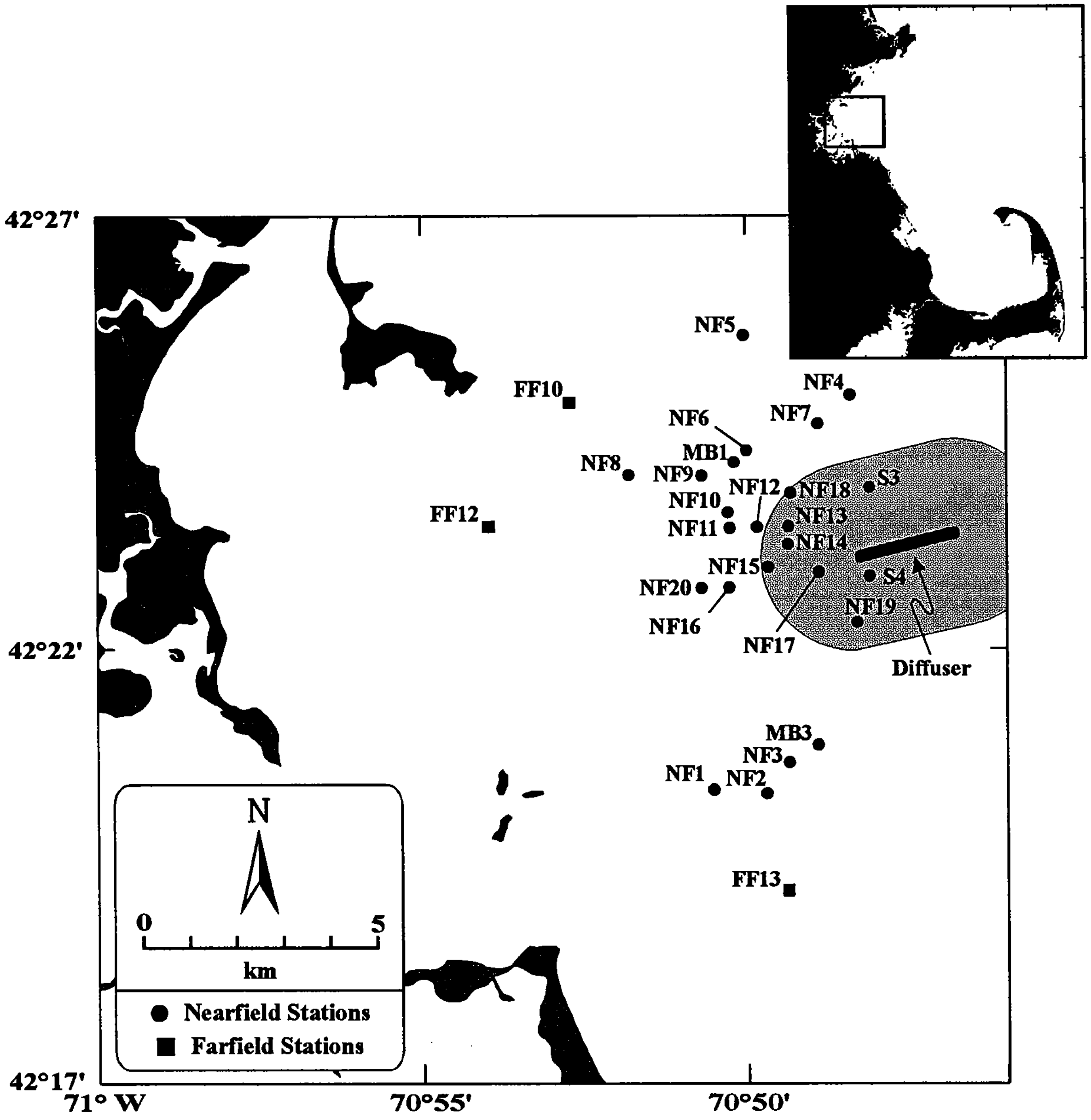

Figure 4. Location of near and farfield stations at midfield distances from the diffuser. The shaded area is the locus of points at a 2 km distance from the outfall. The inset shows the midfield study area location within Massachusetts and Cape Cod Bays.

3.3 DETECTION LIMITS

3.3.1 Projected Detection Limits

The previous section identified the fractional increase in contaminant concentration that would be statistically significant for a given number of pooled samples. These number of samples included in the computation of the mean concentration depend on the availability of samples within impact and control areas. This section compares these projected detection limits with established sediment guidelines based on contaminant concentrations associated with adverse biological effects. The projected detection limit is computed as the mean concentration that would represent a significant increase in the impact region assuming: 1) that outfall-related impacts occur within a 2-km closest-approach distance from the diffuser; and 2) that the 1994 sampling design is repeated after effluent discharge is initiated. For the 1994 sampling design, ten samples lie within 2-km of the diffuser and are pooled to compute a mean concentration for the impact region (Table 8).

3.3.2 Region of Impact

Benthic sampling stations impacted by significant deposition of effluent particulates are conservatively assumed to lie within 2 km of the diffuser. This impact distance is based on initial dilution modeling results and fate models advanced by other investigators (EPA, 1988; Shea and Kelly, 1992; Shea, 1993; EPA, 1993; and HydroQual, 1995). The present diffuser location lies between the alternative diffuser Sites 4 and 5 modeled in the Supplemental Environmental Impact Statement (SEIS) for the new outfall (EPA, 1988). Table 5.1.3.a of the SEIS predicts an area of 12.2 km^2 will experience changed sediments due to the accumulation of organics around a diffuser at Site 5 under stratified water column conditions and discharge of effluent with primary treatment. This area is nearly equivalent to a circle with a diameter of 2 km. Although the SEIS area of predicted change is not circular (Figure 5.1.3.a of EPA, 1988), the region around the adjacent Site 4, is closer to a circle with a larger (18.9 km^2) area of changed benthic conditions. With this information, identifying impacted stations as those that lie within 2 km of the present diffuser location represents a reasonable upper bound on the extent of impacts.

Figure 4 shows the distribution of mid-field stations relative to the prolate ellipsoid encompassed by the locus of points that lie 2 km from a 2-km long diffuser of infinitesimal width. All of the eight stations within the impact region were sampled in 1994 (Table 2) and two of them had two replicate chemistry samples. The average contaminant concentrations of these ten 1994 samples are reflected in Table 8 as the baseline mean. The mean post-discharge contaminant concentration that would be considered a statistically-significant increase above this mean is also listed in Table 8. These detection levels were computed by applying the fractional detectable increase for 10 samples (Table 7) to the baseline means. The concentration levels reported in Table 8 have been inverse transformed and un-normalized where appropriate. The baseline mean aluminum and TOC concentration were assumed constant for this purpose.

3.4 LEVELS OF BIOLOGICAL EFFECTS

Conversion to raw concentrations allows a comparison of baseline and detectable contaminant levels with sediment guidelines advanced by the National Oceanic and Atmospheric Administration (NOAA) (Long and Morgan, 1990; Long *et al.* (1995) and by the Florida Coastal Management Program (MacDonald, 1993). These guidelines are based on correlations between chemical concentrations and biological effects in a wide array of studies, including those dealing with benthic community structure. Differences in the two sets of guidelines arise from the data bases used and the assumptions used in analyzing the toxicity data. The NOAA guidelines identify Effects Range-Low (ERL) and Effects Range-Median (ERM) values. ERL guidelines reflect levels below which adverse effects are not expected to occur. ERM guidelines represent the level above which adverse effects are expected.

Table 8. Comparison of background mean concentrations, significantly increased levels, and various sediment guidelines.

	Mean Concentration within 2 km[a]		Sediment Guidelines				
	Baseline Mean	Significant Increase[b]	TEL[c]	ERL[d]	PEL[c]	90% ERM[e]	ERM[d]
Tracers							
Silt and Clay (Mud) Fraction[f] (%)	16	41					
Total Organic Carbon Fraction[g] (%)	0.46	0.99					
C. perfringens[h] (Counts/gm dry wt)	1074	2809					
Aluminum[h] (%)	4.2	5.0					
Iron[i] (ppm)	1.7	2.1					
Contaminants							
Lead[i] (ppm)	41	53	30	47	112	196	218
Mercury[i] (ppm)	0.12	0.22	0.13	0.15	0.70	0.64	0.71
Nickel[i] (ppm)	12	20	16	21	43	46	52
Silver[i] (ppm)	0.16[k]	0.35	0.73	1.00	1.77	3.33	3.70
Cadmium[i] (ppm)	0.05	0.10	0.68	1.20	4.21	8.64	9.60
Chromium[i] (ppm)	50	71	52	81	160	333	370
Copper[i] (ppm)	15	24	19	34	108	243	270
Zinc[i] (ppm)	39	53	124	150	271	369	410
p,p'-DDE[j] (ppb)	0.1[k]	0.6	2.1	2.2	374.2	24.3	27.0
Total DDT[j] (ppb)	0.8	2.3	3.9	1.6	51.7	41.5	46.1
Total PCB[j] (ppb)	7.9	14.5	21.6	22.7	188.8	162.0	180.0
Chlordane[j] (ppb)	0.05[k]	0.16[k]	2.26	0.50[l]	4.79	5.40	6.00[l]
Lindane[j] (ppb)	[k]	[k]	0.32		0.99		
Total PAH[j] (ppb)	2061	4395	1684	4022	16771	40313	44792
Dieldrin[j] (ppb)	[k]	[k]	0.72	[k]	4.30	7.20	8.00[l]

[a] Mean computed from ten samples collected within 2 km of the diffuser in 1994 (Figure 6.1.1).

[b] Based on *t*-test for ten samples described in Table 6.1.1.

[c] Threshold Effect Level (TEL) and the Probable Effects Level (PEL) of MacDonald (1993).

[d] Effects Range-Low (ERL) and Effects Range-Median (ERM) of Long *et al.* (1995).

[e] Excedence level for meaningful effects in the MWRA monitoring plan.

[f] Arc-sine square-root transformation of un-normalized mud fraction. The percent increase is a function of the initial mean value, computed to be the mean (15.94%) of samples collected within 2 km of the diffuser.

[g] Arc-sine square-root transformation of un-normalized TOC fraction. The percent increase is a function of the initial mean value, computed to be the mean (0.46%) of samples collected within 2 km of the diffuser.

[h] Log_{10} transformation of un-normalized parameter.

[i] Log_{10} transformation of concentration normalized by Al fraction.

[j] Log_{10} transformation of concentration normalized by TOC fraction.

[k] Below detection limit.

[l] From Long and Morgan (1992).

The proposed hypothesis tests in the revised MWRA monitoring plan (MWRA, 1995) are based on 90% of the ERM concentration. The State of Florida (MacDonald, 1993) developed sediment guidelines that are somewhat more conservative than those of NOAA. These guidelines describe a Threshold Effects Level (TEL) and the Probable Effects Level (PEL). These sediment guidelines are shown in Table 8 for comparison with mean baseline concentrations and detection levels derived in this study.

For all 15 contaminants considered here, the detection levels are well below the ERM and PEL guidelines for probable effects. In addition, they are well below the 90% ERM exceedence level designated as a detection goal in the MWRA monitoring plan. This shows that the 1994 field sampling design is capable of detecting statistically-significant increases in mean contaminant concentrations at levels well below those considered meaningful in terms of biological effects. The baseline concentrations for many of the contaminants are comparable to the much-lower ERL and TEL sediment guidelines. For the most part, contaminant increases approaching these lower-level guidelines would not be considered statistically significant for the 1994 sampling design with the stated Type I and II error rates.

3.5 CONTAMINANT ACCUMULATION TIMES

3.5.1 Particulate Deposition Model

Given the detectability estimates for the various nearfield sampling designs, a simple box model can be applied to estimate the length of time between the onset of effluent discharge and the detection of contaminant increases in sediments (Table 9). Conservative assumptions are included in this mass-balance model to obtain an upper bound on future increases in contaminant levels at benthic sampling stations within 2 km of the outfall. For example, in this model, the sediments only represent a sink for contaminants and redistribution due to resuspension, diffusion, decay, or mixing deeper into the sediment column is neglected. These processes would tend to reduce contaminant levels from those estimated with the simple box model. As a result, the length of time to reach detectable or guideline contaminant concentrations would be increased. Other investigations (Shea, 1995; HydroQual, 1995) have suggested that these processes may be important in determining the ultimate fate of contaminants.

Another conservative assumption is reflected by neglect of the depositional mass of effluent particulates compared to the mass of surficial sediments in the box. In this model the increase in concentration of a particular contaminant is related to the mass of contaminant deposited divided by the mass of the sediment in the box.

$$C(t) = C(t_0) + \frac{Lf}{\rho D A}(t - t_0) \tag{9}$$

where:

$C(t)$ = contaminant concentration at time t in years,
$C(t_0)$ = background contaminant concentration at the time t_0 when the new outfall begins discharging,
L = contaminant loading in the effluent in metric tons (MT) year^{-1},
f = fraction of discharged effluent particulates that deposit within an impact area where changed sediments are anticipated,
ρ = dry bulk density of sediment,
D = depth of sediment that accumulates contaminants (2 cm),
A = area covered by changed benthic sediments (12.2 km^2).

Table 9. Projected time required to reach detectable or meaningful contaminant concentrations in sediments near the diffuser.

	Loading[a] (MT/yr)	**Accretion Rate[b]**	**Years[c]**			
			Detect	**ERL**	**90% ERM**	**PEL**
Lead	0.900	0.214	57	28	725	333
Mercury	0.023	0.005	18	5	94	105
Nickel	1.650	0.393	21	23	88	79
Silver	0.520	0.124	1.5	6.8	26	13
Cadmium	0.185	0.044	1.1	26	195	94
Chromium	0.735	0.175	121	177	1616	630
Copper	5.730	1.365	6.5	14	167	68
Zinc	8.880	2.116	6.9	53	156	110
p,p'-DDE	0.006[d]	0.001	352	1468	16926	261648
Total DDT	0.005	0.001	1235	639	34137	42707
Total PCB	0.001	0.0002	27596	61973	646586	759019
Chlordane	0.004	0.001	119	472	5613	4973
Lindane	0.005	0.001	16			831
Total PAH	0.550	0.131	17811	14962	291880	112240
Dieldrin	1.200	0.286	[f]	[f]	25	15

[a] From Table 20 of Hunt *et al.* (1995) for full secondary treatment except where indicated.

[b] Increase in concentration per year in ppm/yr for trace metals and ppb/yr for pesticides.

[c] Number of years before concentration reaches level specified in Table 6.1.2.

[d] From loading of p,p'-DDT in Table 7 (primary treatment) of Hunt *et al.* (1995).

[e] From loading in Table 7 (primary treatment) of Hunt *et al.* (1995).

[f] Concentration below method detection limit.

3.5.2 Contaminant Loading

Loadings (*L*) for a number of contaminants were obtained from the 1994 effluent discharge estimates for full secondary treatment described in Table 20 of Hunt *et al.* (1995). Predicted contaminant loading from the new outfall has been reexamined several times since the SEIS (*e.g.*, Shea, 1993; Hunt, *et al.*, 1995). Some important revisions to the predictions include incorporation of recent effluent measurements and the consideration of secondary treatment. Most, if not all, effluent is expected to receive secondary treatment before the new outfall comes on line and consequently, projected contaminant loading from effluent discharge is expected to be significantly lower than that anticipated by the SEIS for primary treatment only (Hunt, *et al.*, 1995; Table 20). Even without secondary treatment, the loading from many contaminants in primary effluent was overestimated in the SEIS compared to more recent measurements (Shea, 1993).

The background contaminant concentration $C(t_0)$ was determined from average concentrations at stations within a 2-km closest-approach distance to the diffuser (Table 8). The fraction (*f*) of particulates deposited near the diffuser was set at 0.1 after Shea (1993). In addition to elevated estimates of contaminant concentrations in the effluent, previous models of initial dilution were found to be excessively conservative in their estimate of the deposition of effluent particulates in the nearfield (Shea and Kelly, 1992; Shea, 1993; EPA, 1993). Based on recent models of particulate transport in Boston Harbor and on new estimates of effluent particle settling rates, Shea (1993) estimated that 10% of the total contaminant load is a reasonable upper bound for deposition in the near-field. He considered a depositional region that extended over a much larger area than the 12-km^2 region of the box model. Use of a 10% depositional fraction in the box model lends further conservatism to the results.

The dry bulk sediment density (ρ) was determined to be 1.72 g m^{-3} from the product of the solids density (2.65 g m^{-3}) and a solids volume concentration (0.65) applicable to loosely-compacted fine-grained sediments. The depth of sediments (*D*) that accumulate contaminants is assumed to be equal to 2-cm depth of the chemistry subsample collected from the grabs in the most recent surveys. The area of impact (*A*), over which the fraction (*f*) of effluent particulates deposits, is taken to be 12.2 km^2 after the SEIS prediction for the area changed from discharge of primary treated effluent at Site 5 during stratified conditions.

3.5.3 Contaminant Buildup

Upper-bound quantitative estimates of contaminant build-up in sediments within 2 km of the diffuser indicate that it will probably take several years before increased contaminant levels can be detected (Table 9). An even longer period (decades) is anticipated before levels reach the range of probable biological effects. Silver and cadmium are the only contaminants whose increases in concentrations are likely to be detected in 1 to 2 years. The detectable increases in other contaminants exceed six years. Consequently, the frequency of annual benthic sediment chemistry sampling can probably be reduced, at least for a large number of contaminants. Instead efforts could be directed at the detection of effluent-specific tracers, such as silver, TOC or *C. perfringens* spore counts. The assumptions incorporated in the box model were highly conservative and it is likely that the buildup of contaminants will be much slower than that reflected here. Consideration of bioturbation alone suggests that contaminants will rapidly mix to depths exceeding 10 cm in the sediment column and not accumulate in the upper 2 cm.

4.0 BENTHIC INFAUNA

This discussion is divided into two parts. The first section describes an analysis of the entire set of baseline benthic infaunal data. Through an investigation of temporal and spatial differences among samples, it identifies the samples to be pooled for an estimate of the natural background variability in infauna. This subset of samples suggests a group of stations that can act as sentinels for post-discharge infaunal impacts. They are selected by virtue of their temporal stability, spatial infaunal uniformity, and proximity to the diffuser. In the second major section, the estimate of background variability is used in power analyses and evaluations of field sampling designs.

4.1 REGIONAL INFAUNA

The global data set of infaunal abundance analyzed in this section consists of an enumeration of 322 species in 170 samples collected from three annual surveys. While the discussion relies primarily on cluster analyses of CNESS distances, these analyses are essentially equivalent to a PCA-H analysis of the global data set. However, cluster groups appear as excursions along a multitude of minor PCA-H dimensions that are difficult to visualize in a report format. Multidimensional results from the global PCA-H were examined interactively but are not presented herein until Section 4.1.6, after the dimensionality is reduced by exclusion of distant zoogeographically-distinct stations.

Also, this initial global analysis does not directly assess the adequacy of the overall baseline sampling program to detect future anthropogenic impacts from the outfall. Instead, it is used to screen samples and to select a subset of sentinel stations based on a variety of considerations. The foremost consideration is proximity to diffuser as defined by consistency among infaunal communities. Both temporal and spatial variability determine consistency. Large interannual differences in community structure are related to temporal instability in grain size. Spatial infaunal variability arises from regional zoogeographic differences as well as small-scale divergence in replicate grab samples.

4.1.1 Small-scale (Replicate) Variability

As suggested by the question (8) posed in Section 1.3.1, the variation in replicates is pertinent only in a relative sense. If zoogeographic or interannual infaunal differences are large compared to the variation among replicate samples collected from the same station and in the same year (herein called station-year), then statistically-significant trends can be established based on this measure of small sampling error. However, if spatial (or temporal) trends are weak and station separation is small, then it is difficult to distinguish the different station-years among the replicates. In the limit of decreasing station separation, a point is reached where spacing between stations is comparable to the ability to reoccupy a precise location on the seafloor with a grab deployed from a surface vessel. In practice, surficial sediments are patchy (*cf.* Section 1.1.3) and infaunal communities within those patches are likely to be uniform. Thus, if infauna are indistinguishable among a group of closely-spaced stations, then their separation distance can provide an estimate of the scale of that patchiness.

Similar Replicate Samples

A cluster analysis of the global baseline data set (Figure 5) shows that, for the most part, replicate samples within each station-year exhibit the highest similarities. Thus, interannual and spatial differences in community structure on the order of station separation, exceed the inherent (replicate) sampling variability. The dashed lines in Figure 5 denote the 36 unreplicated station-years (Table 1). There were replicate samples collected at 45 of the 81 station-years of infaunal data. Thirty of these 45 replicated measurements exhibit the greatest similarity among replicates within a single station-year, as shown by the shaded regions in Figure 5. For these samples, the infaunal community structures are sufficiently distinct, temporally and spatially, from samples collected at

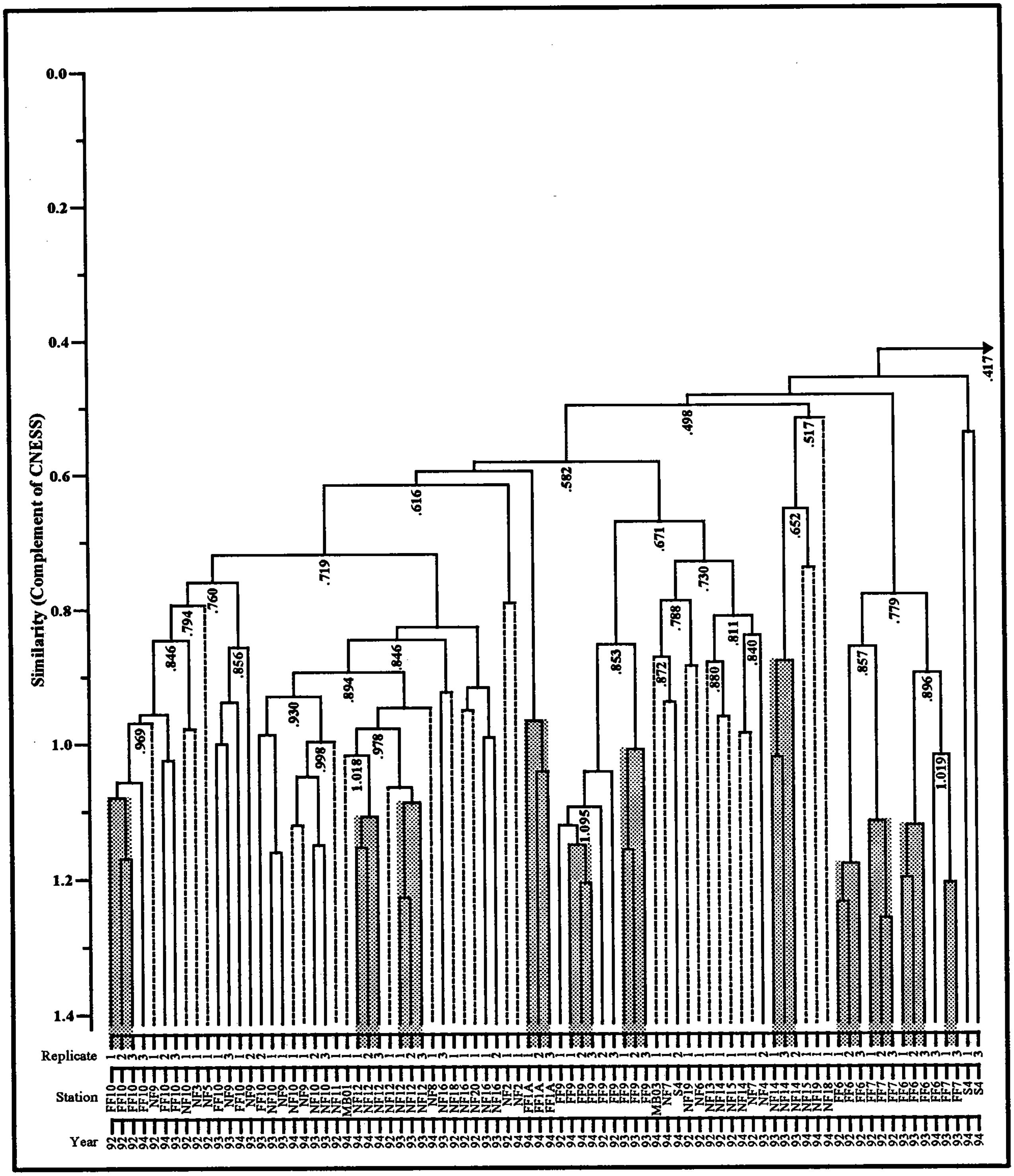

Figure 5. Dendrogram resulting from clustering (group average sorting) of similarity (complement of CNESS with m=18) among all infaunal samples. Dashed lines indicate unreplicated samples and shaded regions designate samples whose replicates exhibit the greatest similarity.

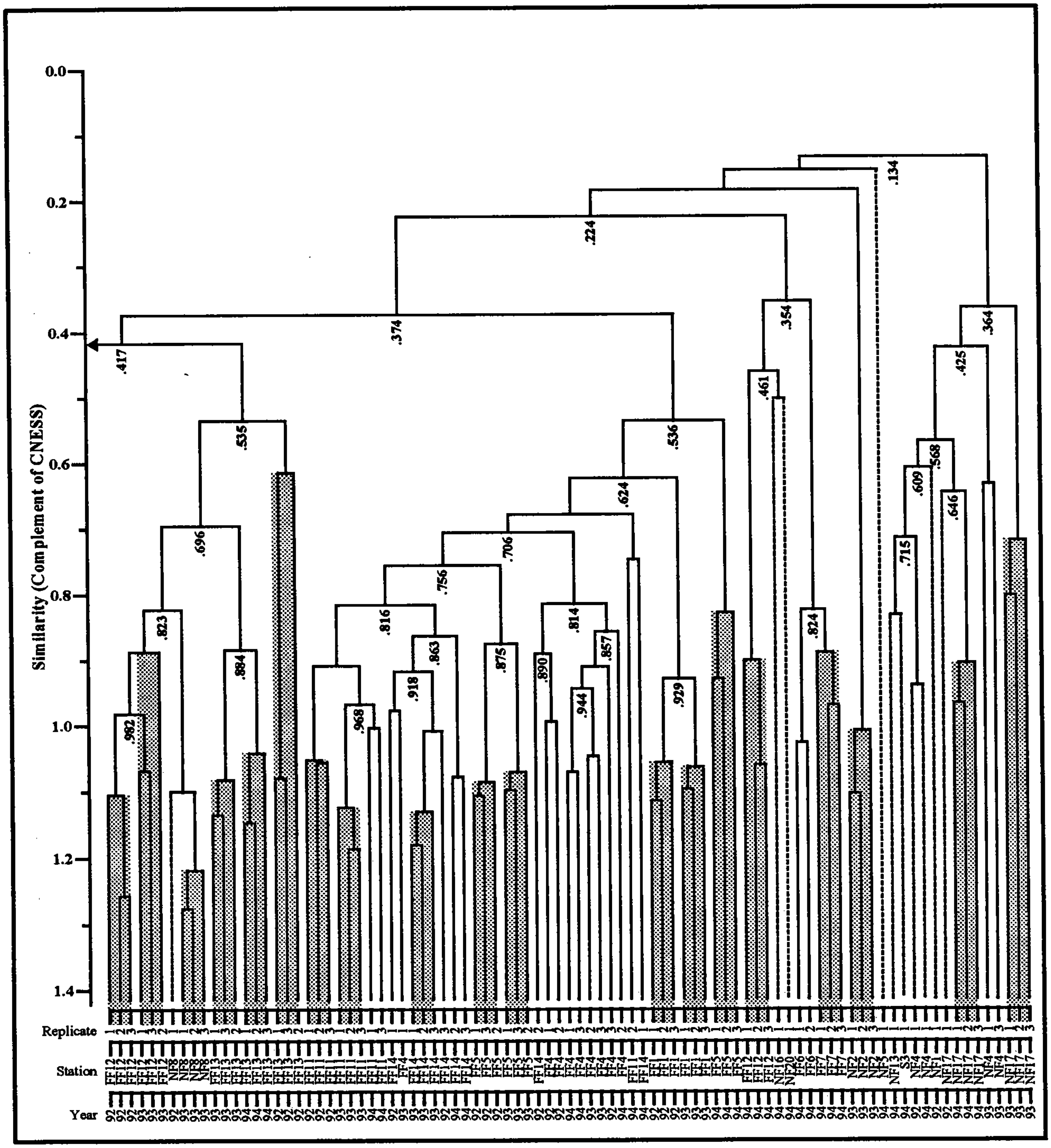

Figure 5 (continued). Dendrogram resulting from clustering (group average sorting) of similarity (complement of CNESS with m=18) among all infaunal samples. Dashed lines indicate unreplicated samples and shaded regions designate samples whose replicates exhibit the greatest similarity.

other station-years, that the replicate samples were uniquely identified in the presence of inherent sampling variability. Recall that the intermediate choice of the subsample size ($m=18$) indicates that the CNESS clustering of Figure 5 reflects a broad range of species composition (Section 2.3.3). Thus, both rare and dominant taxa are represented in this assessment of replicate similarity.

The remaining 15 replicated station-years, do not exhibit the greatest similarity among their respective replicates although inter-replicate similarity is high for many of these station-years. The 15 station-years with stray replicates are: Y3F10, Y4F10, Y3N9, Y3N10, Y3N16, Y2F9, Y4S4, Y3N4, Y4F11, Y2F14, Y3F4, Y4F14, Y2F4, Y4F4, and Y4F6. Here, station-years are denoted by the last digit of the collection year preceded by "Y" and the station number preceded by "N" for nearfield and "F" for farfield. Twelve of these exhibit high similarity among replicates, although not the highest similarity among all replicates from an individual station-year. For example, it has been noted previously (Coats *et al.*, 1995a) that numerical classification is unable to distinguish among the infaunal communities collected in replicate samples at three of the stations sampled in 1993 (Y3N9, Y3N10, and Y3N16). These stations are in close proximity which suggests that over distances of 1 to 2.5 km, inter-replicate variation in infauna approaches spatial variability among stations. Analogously, most of the remaining 12 station-years exhibit a high similarity with other samples in close spatial or temporal proximity, such that the community structure among replicates are indistinguishable from samples collected at other stations or in other years.

High Replicate Variability

Of the 15 station-year samples that do not exhibit the highest similarity among replicates, only three have significantly aberrant replicates whose inter-replicate similarity is less than 0.5 (Figure 5). These include Replicate 2 in Y4S4, Replicate 2 in Y3N4, and Replicate 3 in Y4F6. The observed properties of the grab sample cores (Table 3) independently confirm the anomalous character of two of these replicates. The depth of the apparent redox potential discontinuity (RPD) was measured for each grab sample collected in 1993 and 1994. The RPD approximates the boundary between oxygenated and anoxic sediments, and may bear some relation to infaunal community structure. For example, Kropp and Diaz (1994) find statistically significant correlations between the RPD and several infaunal community indices for samples collected in Boston Harbor. The grab penetration depth and associated volume of collected sediment in 1993 and 1994 surveys are also listed in Table 3. While replicate grab samples in most station-years, including Y4F6, are comparatively uniform, the RPD of Replicate 2 in Y3N4 departs from that of the other two replicates. It has an RPD of 4.5 cm when the other two replicates do not exhibit an RPD anywhere within the grab sample cores whose penetration depth exceeded 7 cm.

Replicate Variation at Station S4

Y94S4 also has variable sediment core properties. Replicate 2 has nearly double the RPD (4 cm) of the other two replicates. Station S4 has other unique attributes. It is the closest station to the diffuser and lies only 440 m from the closest diffuser cap (Table 1, Figure 2). As such, its infaunal community would be exposed to the highest levels of effluent contaminants and thus, would be a prime candidate for continued monitoring as a sentinel station. However, as mentioned previously, there is a large difference in the community structure among replicates collected at Station S4. Also, it was only sampled in 1994, after some effort was expended guaranteeing that successful sediment collection could be accomplished. For example, the grab was fitted with a video camera to aid in positioning over deep sediment.

Information from other surveys further supports the unique character of benthic fauna near Station S4. Video surveys were conducted in the region with a remotely operated vehicle as part the hard-substrate survey (Coats *et al.*, 1995b). The hard-substrate transects were extended to assess the viability of continued grab sampling in the vicinity of Station S4. Results of the survey found that although the region near Station S4 consists of deep sedimentary deposits, the local megafaunal community was distinct from that of the nine linear kilometers of sea floor surveyed in the surrounding region. Specifically, there was a large population of *Urophycis* spp. (hake) residing in a complex of small burrows hollowed out of the sediments. It is possible that one or more of the replicate grab samples could have collected material from these burrows. The burrows have seafloor dimensions on the order of the grab sampler and are evident in high numbers throughout the region. Additional evidence for variability at Station S4 arises from the larger-than-normal differences in grain size observed in the two additional replicates collected for sediment chemistry and bulk property analysis. Replicate 4 contained 75% mud while Replicate 5 had only 62%. Alternatively, a trophic relationship between *Urophycis* spp. and infauna may account for variability among infaunal replicate samples at Station S4.

In any regard, several independent sources suggest that the anomalous character of the infauna in Replicate 2 at Station S4 is real and not an artifact of damage to the sample after collection. Consequently, in contrast to Replicate 2 in Y3F7 and Y4N5 (see Section 2.2.3), this replicate will be included the analysis. Also, Station S4 is the closest site to the diffuser and it will not be excluded from the group of sentinel stations on the basis of departures in its infauna. Other, more distant midfield stations are excluded because of consistent trends or instability in infauna and environmental properties. However, to exclude Station S4 based solely on its unusual replicated variability, would distort power analyses. Power analysis depends on an accurate measure of the inherent background variability in infaunal measurements. It is curious to note, however, that the ordination analysis of Section 4.2.4 suggests that Replicates 1 and 3 from Station S4 have anomalous community structure and not Replicate 2. This is also evident from Figure 5 in which these two replicates exhibit low (≈ 0.45) similarity with other samples while Replicate 2 has similarities exceeding 0.90.

4.1.2 Temporal Variability

In the previous section, cluster analysis of the entire set of 170 samples was used to assess consistency among replicate samples within a given station-year. In the same manner, cluster analysis is used herein to assess infaunal consistency among multi-year samples collected at a given station. This lends insight into the interannual variability relative to regional zoogeographic differences. In this case, however, the number of elements in the dendrogram can be reduced by pooling replicates. The validity of this approach follows from the overall similarity among samples from individual station-years described above. Specifically, infaunal densities for each of the 322 taxa are computed from an average of replicate samples within each station-year. The resulting average abundance is consistent with station-years collected without replication. However, now abundances are not all whole numbers and hypergeometric probabilities were computed with the continuous ***ln(Γ)*** distribution (Gallagher, 1995).

The resulting dendrogram of 81 station-years is shown in Figure 6. Only a few stations are temporally consistent where all their interannual samples exhibit the highest similarity. The dashed lines represent the ten stations sampled in only one year (Table 1). Of the remaining 26 stations sampled in multiple years, two nearfield stations (NF12 and NF17) and six farfield stations (FF4, FF9, FF10, FF11, FF13, and FF14) comprise the set of stations that are entirely consistent interannually (shading in Figure 6). The infaunal community at these eight stations is temporally stable compared to the spatial variation in community structure. Except for the two nearfield stations, these "stable" communities occupy farfield stations with spatial separations on the order of 20 km (Figure 1). Twelve of the remaining eighteen stations also exhibit high similarity (>0.5) among the multi-year samples from a given station, albeit not the highest. This group of stations, with high overall similarity and indistinguishable temporal and spatial differences, tend to be near and midfield stations which span distances of less than 10 km. From the forgoing, it can be concluded that interannual variability in infauna is large but limited such that regional zoogeographic differences over distances beyond 10 to 20 km can be discerned in the baseline data. However, for most nearfield stations, interannual and spatial differences are difficult to distinguish. This suggests that baseline data collected at nearfield stations over multiple years can be pooled to estimate the natural background variance used in power analyses.

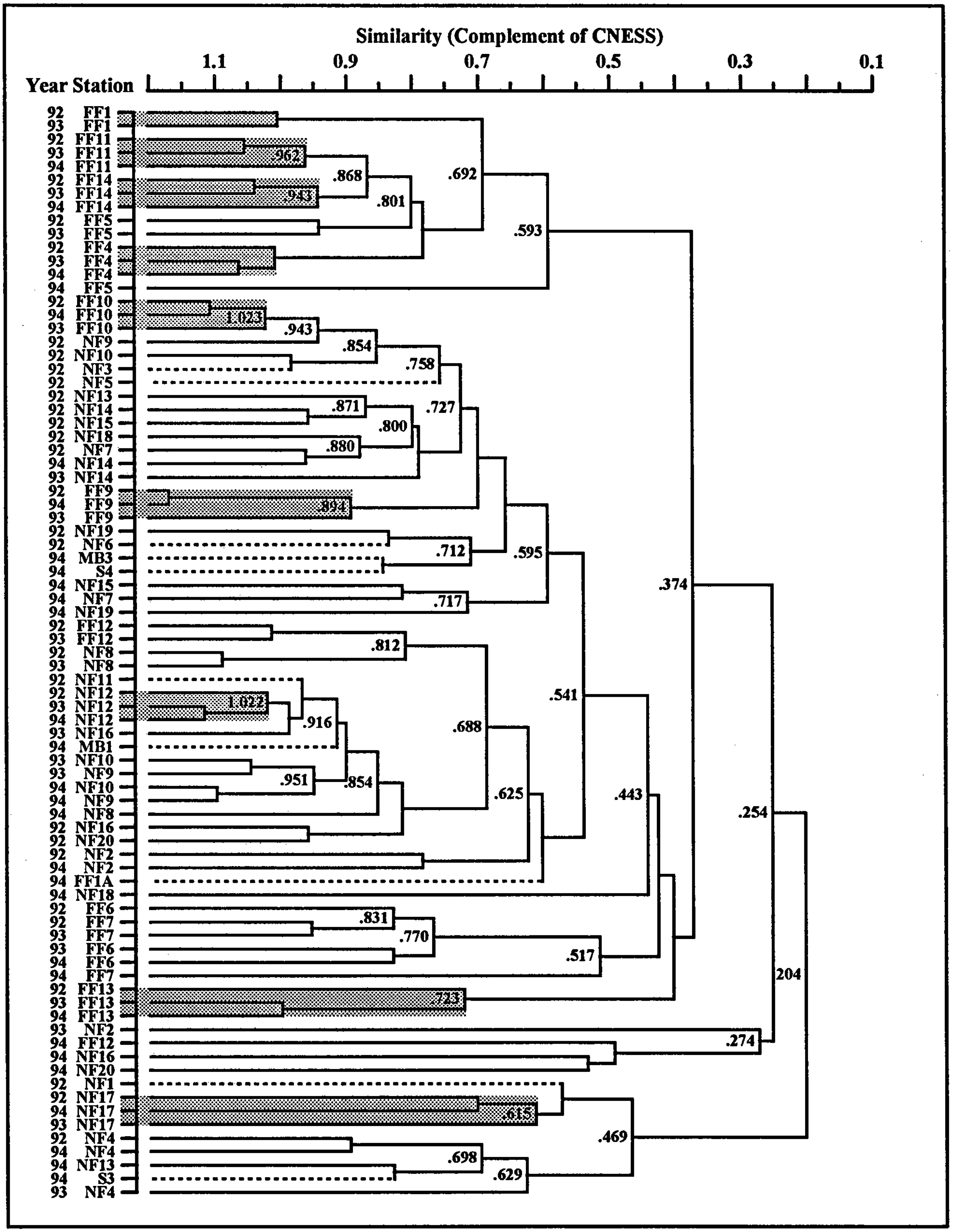

Figure 6. Dendrogram resulting from clustering (group average sorting) of similarity (complement of CNESS with m=18) among the samples with pooled replicates. The dashed lines indicate stations that were occupied in only one of the three years of sampling. The shaded regions designate stations where all interannual samples from an individual station exhibit the greatest similarity.

4.1.3 Temporal Instability

There are six remaining multiyear stations that exhibit large interannual variability. Station-years that depart significantly from the balance of multiyear samples are Y3N2, Y4N13, Y4N16, Y4N18, Y4N20, and Y4F12. Note that all of them, except Y3N2, were collected in the 1994 survey. All of these six station-years have low similarity (>0.5) with other samples from the same station (Figure 6). They are located in the lower portion of the dendrogram and three (Y4N16, Y4N20, and Y4F12) form cluster Group E in Figure 7. This dendrogram is a duplicate of Figure 6, except groups formed with a similarity of less than 0.45 are shaded and labeled alphabetically. The transient station-year Y3N2 is an outlier to Group E while another station-year with transient infauna (Y4N18) is an outlier of Group B. Despite their lack of affinity for other members of Group E, these station-years are included in the group of transient stations listed in Table 10 by virtue of their large interannual variation in infaunal properties coupled with a substantial change in surficial sediments.

The remaining station with a marked difference in infaunal properties among sampling years is NF13. It was only sampled in 1992 and 1994 while most other five unstable stations were sampled in all three years. Also, in contrast to the other five unstable stations its samples cluster with high similarity to the members of two other distinct groups. The infauna in the sample collected in 1992 at Station NF13 are similar (>0.871) to that of other midfield stations in Group B (Figure 7) despite its very coarse sediments (Table 10). The infauna in the 1994 sample more-appropriately compare with that of other station-years with very coarse sediments. Thus, Y4N13 is not included in the group of transient stations because the samples collected at NF13 are: 1) widely separated in time, 2) closely affiliated with other groups, and 3) associated with stable sediments.

Three of the five stations that constitute Group E exhibit substantial differences in surficial sediments after the initial sampling year. This is evident from Table 11 where the fine sediment fraction at Stations NF2, NF16 and NF20 dropped by 39 to 66% between the initial and latest sampling years. This is more than twice the change evident at any other station. When changes in grain size are averaged over all stations within each group, in the form of an instability index (Table 10), the samples in Group E are clearly distinguished from the other groups by their temporal inconsistency in grain size while their grain-size itself is comparable to that of other groups. The instability index is high despite the somewhat smaller interannual changes in sediments at Stations FF12 and NF18. The changes in grain size observed at some stations between 1992 and 1993 may be related to the unusually severe winter. One particularly violent storm on 11-16 December 1992 had wave heights that reached 8 m at the outfall site. Sediment transport associated with these severe winter storms has been suggested as the mechanism for the significant increase in silver and *C. perfringens* concentrations within surficial sediments that was observed near the outfall site in early 1993 (Bothner *et al.*, 1994).

At this point it is unclear why the infaunal community in Y4F12 is similar to other transient stations when grain size was relatively stable over time. However, as discussed below, Station FF12 possibly receives some estuarine influence from Boston Harbor and some transient event, not reflected in grain size, could have stressed the infauna. Transient infauna present in apparently stable sediments at Station NF18 can, however, be explained. Table 4 shows an increase in the mud fraction at this station between 1992 and 1994. However, these samples were not acquired at the same location (Table 1). In fact, Station NF18 was relocated in 1994 specifically because an adequate grab sample could not be collected at the original location due to the lack of soft sediments that would permit sufficient grab penetration. The presence of rocky substrate at the original coordinates (Campbell, 1994) shows that substantial reworking of sediments occurred at this location between 1992 and 1994.

The unique infaunal community of Group E appears to be a transient response to an external stress, usually a rapid decline in fine grain-size fraction. The cause of this localized decrease in the mud fraction is unknown. Two possibilities are that there is *in situ* reworking of sediments or, more likely, regional winnowing of fines by

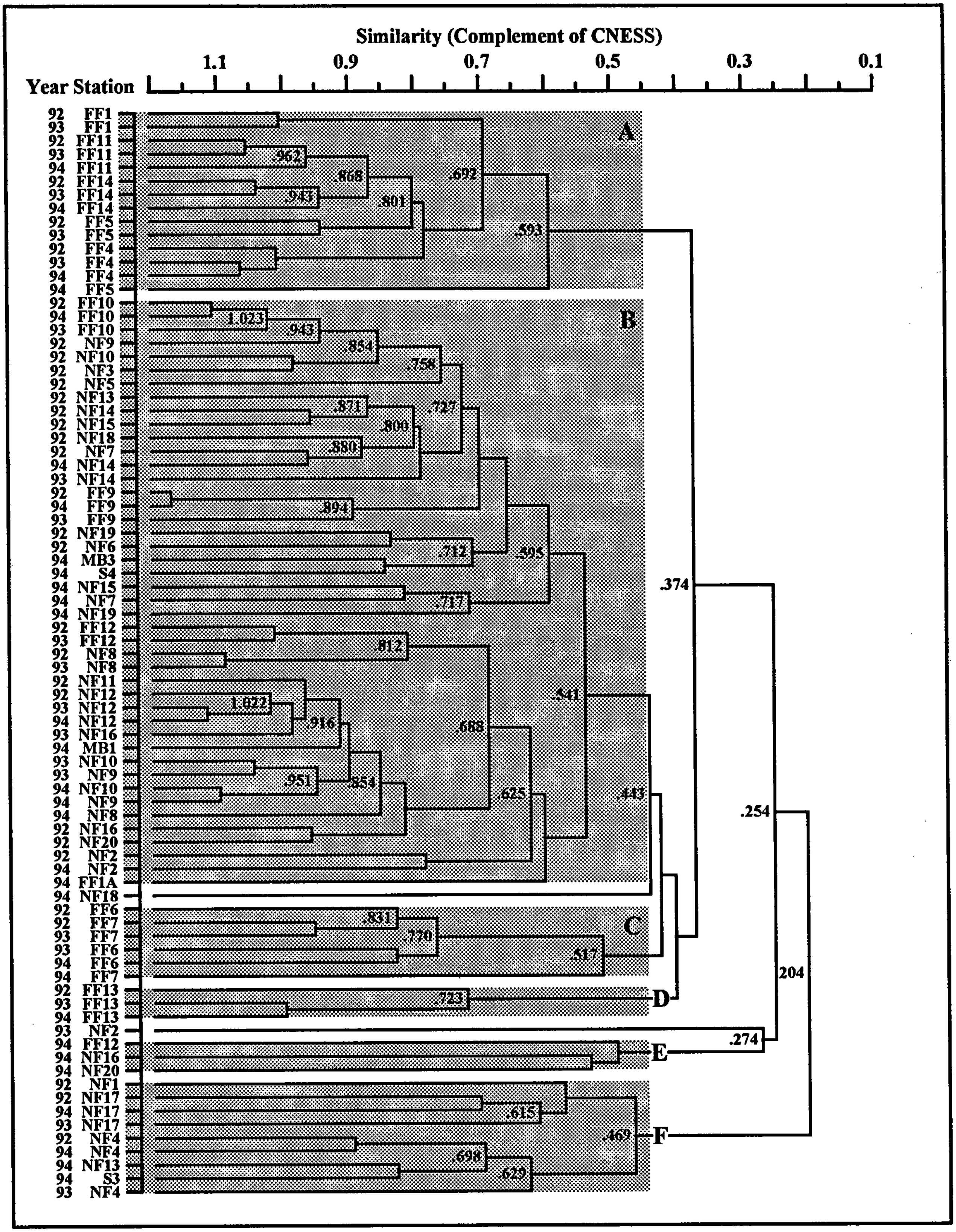

Figure 7. Dendrogram resulting from clustering (group average sorting) of similarity (complement of CNESS with m=18) among the samples with pooled replicates. The shaded regions designate groups of station-years that exhibit similarities exceeding 0.45.

Table 10. Properties of regional cluster groups shown in Figure 7.

Group	Description	Members[1]	Mud Fraction (%)	Instability Index[2]	Diffuser Distance (km)
A	Eastern Massachusetts Bay	FF1, FF4, FF5, FF11, FF14	73.5	5.1	28.0
B	Diffuser Mid-field	FF1A, FF9, FF10, FF12 (Y92, Y93), NF2 (Y92, Y94), NF3, NF5, NF6, NF7, NF8, NF9, NF10, NF11, NF12, NF13 (Y92), NF14, NF15, NF16 (Y92, Y93), NF18 (Y92), NF19, NF20 (Y92), MB1, MB3, S4	37.4	5.7	4.5
C	Cape Cod Bay	FF6, FF7	68.0	6.0	63.5
D	FF13	FF13	30.6	4.2	7.5
E	Transient	FF12 (Y94), NF2 (Y93);[3] NF16 (Y94), NF18 (Y94);[4] NF20 (Y94)	22.2	40.2	4.9
F	Coarse	NF1, NF4, NF13 (Y94), NF17, S3	3.4	0.4	2.3

[1] If only the station name is listed, then membership includes all sampling years for that station.

[2] Average of absolute values of the change in mud fraction from the entries in Table 11.

[3] NF2 (Y93) is an outlier to Group E, but coalesces with the group at a similarity of 0.27.

[4] NF18 (Y94) is an outlier, but is included with Group E because of its relocation and change in surficial sediment properties.

Table 11. Change in mean percent mud relative to the sample collected in 1992. Stations are ranked by decreasing absolute differences.

Station	1993 Change
NF2	-74.2
NF16	-39.9
FF5	-17.1
FF6	-14.7
FF1	-14.2
FF14	-13.0
FF7	-12.7
NF9	-10.6
NF12	-8.7
NF14	-7.7
NF8	-7.4
FF12	-7.4
FF11	-5.8
NF10	-5.7
FF4	-5.1
FF9	-3.7
FF10	2.2
FF13	1.6
NF17	0.7
NF4	-0.3

Station	1994 Change
NF2	-66.5
NF16	-42.6
NF20	-39.0
FF10	15.5
NF12	15.1
NF5	11.9
FF13	11.1
NF15	-10.4
NF18	10.1
NF7	-9.3
NF19	9.1
FF6	6.9
NF14	-6.5
FF12	5.2
FF4	4.8
FF14	-4.2
FF11	4.2
NF9	-4.2
NF10	-3.9
FF5	-3.6
NF8	2.4
FF9	-1.9
FF7	1.8
NF4	-1.2
NF13	0.8
NF17	0.5

resuspension processes. It is curious, however, that these transient stations are not directly adjacent to each other suggesting that the process is highly localized. Further field experiments may be in order, not only to identify the processes responsible for the localized change in grain size, but to investigate the mechanism involved in the overall animal-sediment relationship. The latter is not well understood despite a large body of literature (Snelgrove and Butman, 1994). Until the interrelationship is better understood, it will be difficult to apply these results prognostically; for example, to predict when the infauna will return to normal.

Nevertheless, some insight into infaunal recovery times is evident from the samples collected at NF2. At this station, a nearly 75% decline in the mud fraction occurred between 1992 and 1993 (Table 4), along with a dramatic change in infauna. In 1994, the mud fraction increased somewhat and the infaunal community returned to 1992 conditions as reflected in the high similarity between these station-years (Figure 7). This suggests that recovery times may be about a year for some sites.

There are certain species that thrive in these transient conditions. Table 12 lists the ten most abundant species for each of the station-years. It is organized by regional group derived from the dendrogram of Figure 7. The high relative abundance of the three polychaetes (*Scoletoma hebes*, *Monticellina baptisteae*, and *Asabellides oculata*) stood out in Group E. Also, a gastropod (*Hiatella arctica*) and an echinoderm (*Ophiura robusta*) were more abundant in transient conditions. Because of their temporal instability and the great dissimilarity between their infauna and those of other station-years, the members of Group E will be excluded from the computation of infaunal variability at sentinel stations.

4.1.4 Coarse Sediments

In Table 10, a comparatively large stability index differentiated the infaunal community of Group E in the regional data. A similar relationship is evident in the average mud fraction listed for Group F. The stations in this group are all characterized by stable, but extremely-low mud fractions. All have fine fractions below 7% (Table 4). The mean mud fraction for Group F is a factor of six lower than that of the other groups. Most of these coarse station-year samples consist primarily of sand, although Station NF4 had a high gravel fraction in 1992.

The infauna in this group departs substantially from that of other groups as indicated by the lowest (0.204) similarity measured among groups (Figure 7). Also, there is a somewhat greater infaunal variability among the samples within this group (similarities mostly below 0.70) than within other groups which exhibit similarities exceeding 0.70 among most samples. Despite the comparatively large infaunal variability among samples within Group F, all sampling years are represented for each station except NF13. The transient nature of this station's infauna was discussed in the previous section.

Although it is at the extreme end of an environmental gradient, Group F is included in the power analysis of Section 4.2. These stations are included because the infaunal community is internally consistent among replicates (Figure 5) and stable interannually (Figure 6). More important, these stations lie close to the diffuser and some will probably continue to be occupied in post-discharge surveys. One in particular, will undoubtedly act as a prime sentinel in detecting effluent impacts. Station NF17 lies within 1 km of the diffuser. It has been surveyed in all three sampling years and in the two most-recent surveys, has been sampled in triplicate (Table 1).

Station NF17's extremely low fine fraction presents a major difficulty in incorporating Group F in an overall estimate of inherent background variability. Not only is the variability among samples larger in Group F than in other groups, but the infaunal community is quite distinct as described above. Through some effort, the multivariate analysis in Section 4.2 successfully accounts for a relationship between infauna and the extreme gradient in grain size. However, caution must be used when ascribing causality to correlations between environmental factors and infauna. This is particularly true of animal-sediment relationships since a wide variety

Table 12. Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
A	FF1 (Y92)	1	*Cossura longocirrata*	1508	15.2	
		2	*Spio limicola*	1000	10.1	
		3	Chaetozone sp.A	825	8.3	
		4	*Tubificoides apectinatus complex*	692	7.0	
		5	*Maldane glebifex*	617	6.2	
		6	*Anobothrus gracilis*	492	4.9	
		7	*Prionospio steenstrupi*	475	4.8	
		8	*Thyasira gouldii*	375	3.8	
		9	*Heteromastus filiformis*	350	3.5	
		10	*Aricidea quadrilobata*	333	3.4	67.2
A	FF1 (Y93)	1	*Tubificoides apectinatus complex*	1475	10.0	
		2	*Maldane glebifex*	1450	9.9	
		3	Chaetozone sp.A	1433	9.8	
		4	*Cossura longocirrata*	1283	8.7	
		5	*Anobothrus gracilis*	1242	8.5	
		6	*Aricidea quadrilobata*	1167	7.9	
		7	*Spio limicola*	992	6.7	
		8	*Thyasira gouldii*	783	5.3	
		9	*Yoldia sapotilla*	483	3.3	
		10	*Mediomastus californiensis*	458	3.1	73.2
A	FF4 (Y92)	1	*Spio limicola*	11267	53.1	
		2	*Scalibregma inflatum*	1833	8.6	
		3	*Mediomastus californiensis*	1108	5.2	
		4	*Prionospio steenstrupi*	775	3.7	
		5	*Levinsenia gracilis*	758	3.6	
		6	*Cossura longocirrata*	533	2.5	
		7	Chaetozone sp.A	467	2.2	
		8	*Dentalium entale*	458	2.2	
		9	*Anobothrus gracilis*	342	1.6	
		10	*Heteromastus filiformis*	317	1.5	84.2
A	FF4 (Y93)	1	*Spio limicola*	3075	35.9	
		2	*Mediomastus californiensis*	667	7.8	
		3	*Levinsenia gracilis*	542	6.3	
		4	*Scalibregma inflatum*	525	6.1	
		5	*Prionospio steenstrupi*	517	6.0	
		6	Chaetozone sp.A	350	4.1	
		7	*Aricidea quadrilobata*	308	3.6	
		8	*Cossura longocirrata*	258	3.0	
		9	*Maldane glebifex*	258	3.0	
		10	*Yoldia sapotilla*	183	2.1	77.9
A	FF4 (Y94)	1	*Mediomastus californiensis*	2075	15.8	
		2	*Scalibregma inflatum*	1892	14.4	
		3	*Spio limicola*	1708	13.0	
		4	*Prionospio steenstrupi*	1033	7.9	
		5	Chaetozone sp.A	933	7.1	
		6	*Cossura longocirrata*	725	5.5	
		7	*Levinsenia gracilis*	683	5.2	
		8	*Aricidea quadrilobata*	658	5.0	
		9	*Leitoscoloplos acutus*	292	2.2	
		10	*Syllides longocirrata*	275	2.1	78.2
A	FF5 (Y92)	1	*Spio limicola*	17958	69.7	
		2	*Levinsenia gracilis*	1008	3.9	
		3	*Aricidea quadrilobata*	700	2.7	
		4	*Thyasira gouldii*	675	2.6	
		5	*Mediomastus californiensis*	600	2.3	
		6	*Prionospio steenstrupi*	583	2.3	
		7	*Polydora socialis*	575	2.2	
		8	Chaetozone sp.A	358	1.4	
		9	*Ninoe nigripes*	267	1.0	
		10	*Nucula delphinodonta*	233	0.9	89.0

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
A	FF5 (Y93)	1	*Spio limicola*	7242	33.8	
		2	*Aricidea quadrilobata*	2675	12.5	
		3	*Thyasira gouldii*	1583	7.4	
		4	*Mediomastus californiensis*	1300	6.1	
		5	*Levinsenia gracilis*	925	4.3	
		6	*Prionospio steenstrupi*	908	4.2	
		7	*Nucula delphinodonta*	775	3.6	
		8	Chaetozone sp.A	667	3.1	
		9	*Harpinia propinqua*	658	3.1	
		10	*Anobothrus gracilis*	467	2.2	80.3
A	FF5 (Y94)	1	*Spio limicola*	1008	13.1	
		2	*Levinsenia gracilis*	883	11.4	
		3	*Mediomastus californiensis*	583	7.6	
		4	*Ninoe nigripes*	500	6.5	
		5	*Aricidea quadrilobata*	475	6.1	
		6	*Thyasira gouldii*	433	5.6	
		7	*Yoldia sapotilla*	425	5.5	
		8	*Nucula delphinodonta*	275	3.6	
		9	*Polydora socialis*	267	3.5	
		10	*Harpinia propinqua*	258	3.3	66.2
A	FF11 (Y92)	1	*Spio limicola*	3975	24.9	
		2	*Prionospio steenstrupi*	3475	21.8	
		3	*Levinsenia gracilis*	2567	16.1	
		4	*Aricidea quadrilobata*	1533	9.6	
		5	*Tubificoides apectinatus complex*	850	5.3	
		6	*Mediomastus californiensis*	575	3.6	
		7	Chaetozone sp.A	367	2.3	
		8	*Anobothrus gracilis*	333	2.1	
		9	*Cossura longocirrata*	325	2.0	
		10	*Parougia caeca*	308	1.9	89.6
A	FF11 (Y93)	1	*Tubificoides apectinatus complex*	4592	18.5	
		2	*Aricidea quadrilobata*	3683	14.8	
		3	*Spio limicola*	3275	13.2	
		4	*Levinsenia gracilis*	2633	10.6	
		5	*Prionospio steenstrupi*	1892	7.6	
		6	Chaetozone sp.A	1208	4.9	
		7	*Euchone incolor*	958	3.9	
		8	*Mediomastus californiensis*	950	3.8	
		9	*Leitoscoloplos acutus*	883	3.5	
		10	*Anobothrus gracilis*	800	3.2	84.0
A	FF11 (Y94)	1	*Spio limicola*	3525	21.1	
		2	*Aricidea quadrilobata*	2583	15.5	
		3	*Levinsenia gracilis*	2550	15.3	
		4	*Tubificoides apectinatus complex*	1150	6.9	
		5	*Mediomastus californiensis*	908	5.4	
		6	*Anobothrus gracilis*	892	5.3	
		7	Chaetozone sp.A	675	4.0	
		8	*Cossura longocirrata*	617	3.7	
		9	*Maldane sarsi*	542	3.2	
		10	*Prionospio steenstrupi*	275	1.6	82.0
A	FF14 (Y92)	1	*Spio limicola*	5058	40.1	
		2	*Levinsenia gracilis*	933	7.4	
		3	*Aricidea quadrilobata*	900	7.1	
		4	Chaetozone sp.A	825	6.5	
		5	*Prionospio steenstrupi*	517	4.1	
		6	*Scalibregma inflatum*	433	3.4	
		7	*Cossura longocirrata*	408	3.2	
		8	*Tubificoides apectinatus complex*	275	2.2	
		9	*Thyasira gouldii*	267	2.1	
		10	*Mediomastus californiensis*	267	2.1	78.2

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
A	FF14 (Y93)	1	*Spio limicola*	5992	24.8	
		2	Chaetozone sp.A	3667	15.2	
		3	*Aricidea quadrilobata*	2408	10.0	
		4	*Levinsenia gracilis*	2058	8.5	
		5	*Tubificoides apectinatus complex*	1683	7.0	
		6	*Leitoscoloplos acutus*	958	4.0	
		7	*Prionospio steenstrupi*	917	3.8	
		8	*Thyasira gouldii*	867	3.6	
		9	*Mediomastus californiensis*	833	3.4	
		10	*Cossura longocirrata*	683	2.8	83.1
A	FF14 (Y94)	1	*Spio limicola*	3142	22.0	
		2	*Mediomastus californiensis*	1658	11.6	
		3	Chaetozone sp.A	1233	8.6	
		4	*Aricidea quadrilobata*	1050	7.4	
		5	*Tubificoides apectinatus complex*	667	4.7	
		6	*Heteromastus filiformis*	658	4.6	
		7	*Leitoscoloplos acutus*	608	4.3	
		8	*Levinsenia gracilis*	592	4.1	
		9	*Scalibregma inflatum*	542	3.8	
		10	*Nucula delphinodonta*	417	2.9	74.0
B	FF1A (Y94)	1	*Prionospio steenstrupi*	4667	23.6	
		2	*Tharyx acutus*	2025	10.3	
		3	*Nucula delphinodonta*	1950	9.9	
		4	*Mediomastus californiensis*	1317	6.7	
		5	*Spio limicola*	708	3.6	
		6	*Aricidea catherinae*	550	2.8	
		7	*Ninoe nigripes*	525	2.7	
		8	*Crenella decussata*	517	2.6	
		9	*Levinsenia gracilis*	467	2.4	
		10	*Eteone longa*	450	2.3	66.9
B	FF9 (Y92)	1	*Spio limicola*	28500	41.7	
		2	*Prionospio steenstrupi*	12450	18.2	
		3	*Polydora socialis*	7733	11.3	
		4	*Scalibregma inflatum*	4042	5.9	
		5	*Mediomastus californiensis*	2617	3.8	
		6	*Levinsenia gracilis*	2217	3.2	
		7	*Ampharete acutifrons*	2192	3.2	
		8	*Exogone verugera*	867	1.3	
		9	*Ninoe nigripes*	692	1.0	
		10	*Exogone hebes*	592	0.9	90.5
B	FF9 (Y93)	1	*Spio limicola*	10958	40.8	
		2	*Prionospio steenstrupi*	7200	26.8	
		3	*Mediomastus californiensis*	1233	4.6	
		4	*Exogone verugera*	883	3.3	
		5	*Levinsenia gracilis*	792	2.9	
		6	*Ampharete acutifrons*	450	1.7	
		7	*Polydora socialis*	358	1.3	
		8	*Exogone hebes*	358	1.3	
		9	*Ninoe nigripes*	325	1.2	
		10	*Scoloplos armiger*	283	1.1	85.0
B	FF9 (Y94)	1	*Spio limicola*	24167	43.0	
		2	*Prionospio steenstrupi*	8600	15.3	
		3	*Polydora socialis*	7975	14.2	
		4	*Scalibregma inflatum*	2683	4.8	
		5	*Mediomastus californiensis*	1958	3.5	
		6	*Exogone verugera*	1158	2.1	
		7	*Levinsenia gracilis*	1000	1.8	
		8	*Exogone hebes*	517	0.9	
		9	*Capitella capitata complex*	475	0.8	
		10	*Ampharete acutifrons*	408	0.7	87.1

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
B	FF10 (Y92)	1	*Spio limicola*	17175	19.0	
		2	*Prionospio steenstrupi*	8550	9.4	
		3	*Polydora socialis*	7817	8.6	
		4	*Mediomastus californiensis*	7617	8.4	
		5	*Polydora quadrilobata*	7275	8.0	
		6	*Nucula delphinodonta*	6958	7.7	
		7	*Exogone verugera*	2800	3.1	
		8	*Monticellina baptisteae*	2783	3.1	
		9	*Tharyx acutus*	2692	3.0	
		10	*Ninoe nigripes*	2417	2.7	73.0
B	FF10 (Y93)	1	*Spio limicola*	6775	18.5	
		2	*Prionospio steenstrupi*	4642	12.7	
		3	*Mediomastus californiensis*	2192	6.0	
		4	*Ninoe nigripes*	1925	5.3	
		5	*Monticellina baptisteae*	1858	5.1	
		6	*Nucula delphinodonta*	1475	4.0	
		7	*Leitoscoloplos acutus*	1292	3.5	
		8	*Tharyx acutus*	1258	3.4	
		9	*Aricidea catherinae*	1192	3.3	
		10	*Crenella decussata*	1092	3.0	64.8
B	FF10 (Y94)	1	*Spio limicola*	22808	33.7	
		2	*Prionospio steenstrupi*	6067	9.0	
		3	*Mediomastus californiensis*	6042	8.9	
		4	*Nucula delphinodonta*	3800	5.6	
		5	*Polydora socialis*	2442	3.6	
		6	*Monticellina baptisteae*	2167	3.2	
		7	*Tharyx marioni*	1925	2.8	
		8	*Polydora quadrilobata*	1908	2.8	
		9	*Aricidea catherinae*	1775	2.6	
		10	*Ninoe nigripes*	1567	2.3	74.5
B	FF12 (Y92)	1	*Mediomastus californiensis*	13117	24.4	
		2	*Aricidea catherinae*	9892	18.4	
		3	*Prionospio steenstrupi*	8100	15.1	
		4	*Tharyx acutus*	6475	12.1	
		5	*Owenia fusiformis*	2575	4.8	
		6	*Leitoscoloplos acutus*	2383	4.4	
		7	*Ninoe nigripes*	1942	3.6	
		8	*Monticellina baptisteae*	1050	2.0	
		9	*Scoletoma hebes*	1042	1.9	
		10	*Polydora quadrilobata*	675	1.3	88.0
B	FF12 (Y93)	1	*Aricidea catherinae*	12100	45.2	
		2	*Mediomastus californiensis*	3875	14.5	
		3	*Tharyx acutus*	2900	10.8	
		4	*Ninoe nigripes*	1375	5.1	
		5	*Scoletoma hebes*	1292	4.8	
		6	*Leitoscoloplos acutus*	1100	4.1	
		7	*Prionospio steenstrupi*	700	2.6	
		8	*Levinsenia gracilis*	467	1.7	
		9	*Spiophanes bombyx*	433	1.6	
		10	*Owenia fusiformis*	317	1.2	91.6
B	NF2 (Y92)	1	*Mediomastus californiensis*	3950	24.1	
		2	*Asabellides oculata*	1850	11.3	
		3	*Aricidea catherinae*	1525	9.3	
		4	*Hiatella arctica*	1050	6.4	
		5	*Tubificoides apectinatus complex*	875	5.3	
		6	*Polydora socialis*	850	5.2	
		7	*Tharyx acutus*	825	5.0	
		8	*Spio limicola*	800	4.9	
		9	*Prionospio steenstrupi*	725	4.4	
		10	*Arctica islandica*	450	2.7	78.6

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
B	NF2 (Y94)	1	*Spio limicola*	11475	25.2	
		2	*Mediomastus californiensis*	8825	19.4	
		3	*Prionospio steenstrupi*	6350	13.9	
		4	*Aricidea catherinae*	4700	10.3	
		5	*Hiatella arctica*	2800	6.1	
		6	*Asabellides oculata*	2175	4.8	
		7	*Tharyx acutus*	1075	2.4	
		8	*Capitella capitata complex*	675	1.5	
		9	*Pholoe minuta*	650	1.4	
		10	*Spio thulini*	550	1.2	86.2
B	NF3 (Y92)	1	*Spio limicola*	16925	22.0	
		2	*Polydora socialis*	11525	15.0	
		3	*Mediomastus californiensis*	11225	14.6	
		4	*Ampharete acutifrons*	6125	7.9	
		5	*Aricidea catherinae*	4175	5.4	
		6	*Tharyx acutus*	4075	5.3	
		7	*Ninoe nigripes*	3925	5.1	
		8	*Prionospio steenstrupi*	3325	4.3	
		9	*Nucula delphinodonta*	1675	2.2	
		10	*Levinsenia gracilis*	1600	2.1	83.9
B	NF5 (Y92)	1	*Spio limicola*	19775	27.7	
		2	*Polydora socialis*	15200	21.3	
		3	*Polydora quadrilobata*	12200	17.1	
		4	*Prionospio steenstrupi*	3800	5.3	
		5	*Mediomastus californiensis*	3000	4.2	
		6	*Exogone verugera*	1550	2.2	
		7	*Crenella decussata*	1325	1.9	
		8	*Aeginina longicornis*	900	1.3	
		9	*Maldane glebifex*	875	1.2	
		10	*Tharyx marioni*	850	1.2	83.4
B	NF5 (Y94)	1	*Crenella decussata*	5650	31.4	
		2	*Nucula delphinodonta*	3050	16.9	
		3	*Exogone verugera*	1425	7.9	
		4	*Polydora quadrilobata*	1300	7.2	
		5	*Tharyx marioni*	1075	6.0	
		6	*Haploops fundiensis*	1025	5.7	
		7	*Astarte undata*	775	4.3	
		8	*Maldane sarsi*	575	3.2	
		9	*Ninoe nigripes*	300	1.7	
		10	*Mediomastus californiensis*	275	1.5	85.8
B	NF6 (Y92)	1	*Spio limicola*	36100	43.4	
		2	*Polydora socialis*	23425	28.2	
		3	*Mediomastus californiensis*	4350	5.2	
		4	*Crenella decussata*	3525	4.2	
		5	*Tharyx marioni*	2700	3.2	
		6	*Ampharete acutifrons*	1775	2.1	
		7	*Monticellina baptisteae*	1325	1.6	
		8	*Scalibregma inflatum*	1050	1.3	
		9	*Exogone verugera*	775	0.9	
		10	*Ninoe nigripes*	625	0.8	90.9
B	NF7 (Y92)	1	*Spio limicola*	47925	34.1	
		2	*Exogone verugera*	22350	15.9	
		3	*Prionospio steenstrupi*	18875	13.4	
		4	*Polydora socialis*	13625	9.7	
		5	*Mediomastus californiensis*	10025	7.1	
		6	*Tharyx acutus*	3400	2.4	
		7	*Tharyx marioni*	3125	2.2	
		8	*Exogone hebes*	2375	1.7	
		9	*Crenella decussata*	1725	1.2	
		10	*Ninoe nigripes*	1450	1.0	88.7

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
B	NF7 (Y94)	1	*Polydora socialis*	17700	55.3	
		2	*Spio limicola*	1950	6.1	
		3	*Mediomastus californiensis*	1850	5.8	
		4	*Tharyx acutus*	1075	3.4	
		5	*Pholoe minuta*	1000	3.1	
		6	*Exogone verugera*	950	3.0	
		7	*Exogone hebes*	775	2.4	
		8	*Eteone longa*	700	2.2	
		9	*Crenella decussata*	525	1.6	
		10	*Levinsenia gracilis*	525	1.6	84.5
B	NF8 (Y92)	1	*Aricidea catherinae*	14575	46.7	
		2	*Mediomastus californiensis*	4925	15.8	
		3	*Tharyx acutus*	4475	14.3	
		4	*Monticellina baptisteae*	1325	4.2	
		5	*Levinsenia gracilis*	1125	3.6	
		6	*Spio limicola*	1075	3.4	
		7	*Tharyx marioni*	1025	3.3	
		8	*Tubificoides apectinatus complex*	650	2.1	
		9	*Ninoe nigripes*	475	1.5	
		10	*Tharyx dorsobranchialis*	275	0.9	95.8
B	NF8 (Y93)	1	*Aricidea catherinae*	46542	50.4	
		2	*Tharyx acutus*	20650	22.3	
		3	*Mediomastus californiensis*	9400	10.2	
		4	*Monticellina baptisteae*	3192	3.5	
		5	*Tubificoides apectinatus complex*	1883	2.0	
		6	*Leitoscoloplos acutus*	1533	1.7	
		7	*Levinsenia gracilis*	1500	1.6	
		8	*Prionospio steenstrupi*	992	1.1	
		9	*Spio limicola*	883	1.0	
		10	*Tharyx dorsobranchialis*	567	0.6	94.4
B	NF8 (Y94)	1	*Spio limicola*	23000	42.8	
		2	*Aricidea catherinae*	10650	19.8	
		3	*Mediomastus californiensis*	6775	12.6	
		4	*Monticellina baptisteae*	1600	3.0	
		5	*Leitoscoloplos acutus*	1575	2.9	
		6	*Levinsenia gracilis*	1475	2.7	
		7	*Prionospio steenstrupi*	1300	2.4	
		8	*Tubificoides apectinatus complex*	825	1.5	
		9	*Eteone longa*	775	1.4	
		10	*Amphiporus angulatus*	700	1.3	90.4
B	NF9 (Y92)	1	*Spio limicola*	14625	25.6	
		2	*Mediomastus californiensis*	6950	12.2	
		3	*Polydora socialis*	6475	11.3	
		4	*Ampharete acutifrons*	3100	5.4	
		5	*Monticellina baptisteae*	2525	4.4	
		6	*Polydora quadrilobata*	2450	4.3	
		7	*Prionospio steenstrupi*	2425	4.3	
		8	*Tharyx marioni*	2075	3.6	
		9	*Ninoe nigripes*	1775	3.1	
		10	*Maldane glebifex*	1300	2.3	76.5
B	NF9 (Y93)	1	*Spio limicola*	7408	27.1	
		2	*Prionospio steenstrupi*	3650	13.3	
		3	*Mediomastus californiensis*	1875	6.8	
		4	*Nucula delphinodonta*	1417	5.2	
		5	*Hiatella arctica*	1192	4.4	
		6	*Crenella decussata*	1125	4.1	
		7	*Maldane glebifex*	975	3.6	
		8	*Ninoe nigripes*	917	3.3	
		9	*Monticellina baptisteae*	800	2.9	
		10	*Tharyx marioni*	792	2.9	73.6

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
B	NF9 (Y94)	1	*Spio limicola*	18325	41.0	
		2	*Mediomastus californiensis*	6375	14.3	
		3	*Prionospio steenstrupi*	5750	12.9	
		4	*Monticellina baptisteae*	2025	4.5	
		5	*Aricidea catherinae*	1400	3.1	
		6	*Nucula delphinodonta*	1150	2.6	
		7	*Edotia montosa*	975	2.2	
		8	*Maldane sarsi*	975	2.2	
		9	*Ninoe nigripes*	975	2.2	
		10	*Ampharete acutifrons*	850	1.9	86.9
B	NF10 (Y92)	1	*Spio limicola*	13050	28.9	
		2	*Mediomastus californiensis*	9300	20.6	
		3	*Maldane glebifex*	2975	6.6	
		4	*Prionospio steenstrupi*	2275	5.0	
		5	*Ninoe nigripes*	2275	5.0	
		6	*Aricidea catherinae*	1750	3.9	
		7	*Ampharete acutifrons*	1700	3.8	
		8	*Polydora socialis*	1650	3.7	
		9	*Tharyx acutus*	1200	2.7	
		10	*Leitoscoloplos acutus*	1200	2.7	82.9
B	NF10 (Y93)	1	*Spio limicola*	8608	27.4	
		2	*Mediomastus californiensis*	5967	19.0	
		3	*Prionospio steenstrupi*	4117	13.1	
		4	*Aricidea catherinae*	2008	6.4	
		5	*Leitoscoloplos acutus*	1325	4.2	
		6	*Monticellina baptisteae*	1233	3.9	
		7	*Maldane glebifex*	1117	3.6	
		8	*Ninoe nigripes*	950	3.0	
		9	*Nucula delphinodonta*	700	2.2	
		10	*Crenella decussata*	533	1.7	84.5
B	NF10 (Y94)	1	*Spio limicola*	34000	47.3	
		2	*Mediomastus californiensis*	9150	12.7	
		3	*Prionospio steenstrupi*	7650	10.6	
		4	*Aricidea catherinae*	3375	4.7	
		5	*Monticellina baptisteae*	2275	3.2	
		6	*Polydora socialis*	1575	2.2	
		7	*Ninoe nigripes*	1550	2.2	
		8	*Maldane sarsi*	1450	2.0	
		9	*Nucula delphinodonta*	1300	1.8	
		10	*Exogone verugera*	975	1.4	88.1
B	NF11 (Y92)	1	*Mediomastus californiensis*	12125	30.9	
		2	*Prionospio steenstrupi*	8425	21.5	
		3	*Spio limicola*	3400	8.7	
		4	*Ninoe nigripes*	2475	6.3	
		5	*Aricidea catherinae*	2300	5.9	
		6	*Monticellina baptisteae*	1150	2.9	
		7	*Levinsenia gracilis*	875	2.2	
		8	*Ampharete acutifrons*	750	1.9	
		9	*Leitoscoloplos acutus*	550	1.4	
		10	*Arctica islandica*	525	1.3	83.0
B	NF12 (Y92)	1	*Mediomastus californiensis*	6225	21.8	
		2	*Spio limicola*	4950	17.3	
		3	*Aricidea catherinae*	4475	15.7	
		4	*Ninoe nigripes*	3150	11.0	
		5	*Levinsenia gracilis*	2150	7.5	
		6	*Prionospio steenstrupi*	2100	7.4	
		7	*Leitoscoloplos acutus*	850	3.0	
		8	*Monticellina baptisteae*	550	1.9	
		9	*Nucula delphinodonta*	375	1.3	
		10	*Periploma papyratium*	325	1.1	88.0

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
B	NF12 (Y93)	1	*Mediomastus californiensis*	13008	31.9	
		2	*Aricidea catherinae*	6167	15.1	
		3	*Spio limicola*	4750	11.7	
		4	*Prionospio steenstrupi*	3583	8.8	
		5	*Ninoe nigripes*	2458	6.0	
		6	*Monticellina baptisteae*	2092	5.1	
		7	*Leitoscoloplos acutus*	1608	3.9	
		8	*Tharyx acutus*	1258	3.1	
		9	*Levinsenia gracilis*	1183	2.9	
		10	*Exogone verugera*	758	1.9	90.4
B	NF12 (Y94)	1	*Spio limicola*	28458	38.9	
		2	*Mediomastus californiensis*	13242	18.1	
		3	*Aricidea catherinae*	5958	8.1	
		4	*Monticellina baptisteae*	5267	7.2	
		5	*Prionospio steenstrupi*	3133	4.3	
		6	*Tharyx acutus*	2683	3.7	
		7	*Levinsenia gracilis*	2367	3.2	
		8	*Ninoe nigripes*	1700	2.3	
		9	*Exogone verugera*	1417	1.9	
		10	*Polydora socialis*	1325	1.8	89.5
B	NF13 (Y92)	1	*Spio limicola*	7850	24.6	
		2	*Polydora socialis*	5300	16.6	
		3	*Exogone hebes*	4900	15.4	
		4	*Mediomastus californiensis*	2000	6.3	
		5	*Aglaophamus circinata*	1325	4.2	
		6	*Aricidea catherinae*	1150	3.6	
		7	*Exogone verugera*	1050	3.3	
		8	*Tharyx acutus*	1025	3.2	
		9	*Prionospio steenstrupi*	800	2.5	
		10	*Ampharete acutifrons*	800	2.5	82.2
B	NF14 (Y92)	1	*Spio limicola*	10200	17.7	
		2	*Mediomastus californiensis*	8650	15.0	
		3	*Exogone hebes*	6850	11.9	
		4	*Polydora socialis*	6800	11.8	
		5	*Prionospio steenstrupi*	3825	6.6	
		6	*Ampharete acutifrons*	3400	5.9	
		7	*Asabellides oculata*	3075	5.3	
		8	*Ninoe nigripes*	2600	4.5	
		9	*Exogone verugera*	1500	2.6	
		10	Tubificidae sp.2	1175	2.0	83.3
B	NF14 (Y93)	1	*Exogone hebes*	3250	15.7	
		2	*Spio limicola*	2408	11.7	
		3	*Mediomastus californiensis*	2125	10.3	
		4	*Hiatella arctica*	1817	8.8	
		5	*Crenella decussata*	1592	7.7	
		6	*Polydora socialis*	1425	6.9	
		7	*Exogone verugera*	1342	6.5	
		8	*Ninoe nigripes*	1075	5.2	
		9	*Prionospio steenstrupi*	925	4.5	
		10	*Aricidea catherinae*	775	3.8	81.1
B	NF14 (Y94)	1	*Spio limicola*	9000	21.5	
		2	*Polydora socialis*	7350	17.6	
		3	*Exogone verugera*	6675	15.9	
		4	*Mediomastus californiensis*	3950	9.4	
		5	*Prionospio steenstrupi*	2400	5.7	
		6	*Exogone hebes*	1575	3.8	
		7	*Asabellides oculata*	1475	3.5	
		8	*Pholoe minuta*	1150	2.7	
		9	*Aricidea catherinae*	850	2.0	
		10	*Sphaerosyllis erinaceus*	675	1.6	83.7

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
B	NF15 (Y92)	1	*Spio limicola*	14800	22.1	
		2	*Polydora socialis*	13250	19.8	
		3	*Mediomastus californiensis*	10175	15.2	
		4	*Polydora quadrilobata*	5500	8.2	
		5	*Prionospio steenstrupi*	4375	6.5	
		6	*Ninoe nigripes*	3375	5.0	
		7	*Exogone hebes*	2925	4.4	
		8	*Ampharete acutifrons*	2425	3.6	
		9	*Aricidea catherinae*	1075	1.6	
		10	*Exogone verugera*	700	1.0	87.4
B	NF15 (Y94)	1	*Polydora socialis*	4900	12.4	
		2	*Polydora quadrilobata*	4750	12.0	
		3	*Mediomastus californiensis*	4600	11.7	
		4	*Crenella decussata*	3725	9.4	
		5	*Exogone hebes*	3175	8.0	
		6	*Spio limicola*	1750	4.4	
		7	*Asabellides oculata*	1600	4.1	
		8	*Pholoe minuta*	1500	3.8	
		9	*Capitella capitata complex*	1450	3.7	
		10	*Exogone verugera*	1175	3.0	72.5
B	NF16 (Y92)	1	*Mediomastus californiensis*	10675	34.1	
		2	*Aricidea catherinae*	5225	16.7	
		3	*Levinsenia gracilis*	2025	6.5	
		4	Tubificidae sp.2	1975	6.3	
		5	*Tharyx acutus*	1625	5.2	
		6	*Spio limicola*	1525	4.9	
		7	*Ninoe nigripes*	1475	4.7	
		8	*Monticellina baptisteae*	1175	3.7	
		9	*Euchone incolor*	1000	3.2	
		10	*Leitoscoloplos acutus*	925	3.0	88.3
B	NF16 (Y93)	1	*Mediomastus californiensis*	6150	27.2	
		2	*Spio limicola*	2200	9.7	
		3	*Aricidea catherinae*	1883	8.3	
		4	*Prionospio steenstrupi*	1842	8.1	
		5	*Ninoe nigripes*	1508	6.7	
		6	*Tharyx acutus*	1125	5.0	
		7	*Levinsenia gracilis*	1033	4.6	
		8	*Crenella decussata*	783	3.5	
		9	*Leitoscoloplos acutus*	758	3.3	
		10	*Monticellina baptisteae*	567	2.5	78.9
B	NF18 (Y92)	1	*Spio limicola*	10825	23.9	
		2	*Prionospio steenstrupi*	6975	15.4	
		3	*Mediomastus californiensis*	5275	11.6	
		4	*Tharyx acutus*	2300	5.1	
		5	*Polydora socialis*	2025	4.5	
		6	*Exogone verugera*	1975	4.4	
		7	*Exogone hebes*	1625	3.6	
		8	*Ninoe nigripes*	1525	3.4	
		9	*Aricidea catherinae*	1375	3.0	
		10	Tubificidae sp.2	1125	2.5	77.4
B	NF19 (Y92)	1	*Spio limicola*	33450	33.5	
		2	*Polydora socialis*	27025	27.1	
		3	*Mediomastus californiensis*	4650	4.7	
		4	*Ampharete acutifrons*	3450	3.5	
		5	*Scalibregma inflatum*	3275	3.3	
		6	*Asabellides oculata*	2350	2.4	
		7	*Tharyx acutus*	1850	1.9	
		8	*Owenia fusiformis*	1775	1.8	
		9	*Capitella capitata complex*	1575	1.6	
		10	*Phoronis architecta*	1400	1.4	81.2

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
B	NF19 (Y94)	1	*Polydora socialis*	6225	21.6	
		2	*Phoronis architecta*	2325	8.1	
		3	*Polydora quadrilobata*	1725	6.0	
		4	*Hiatella arctica*	1650	5.7	
		5	*Nucula delphinodonta*	1625	5.6	
		6	*Spio limicola*	1375	4.8	
		7	*Exogone hebes*	1325	4.6	
		8	*Exogone verugera*	1275	4.4	
		9	*Monticellina baptisteae*	1100	3.8	
		10	*Edotia montosa*	1050	3.6	68.2
B	NF20 (Y92)	1	*Mediomastus californiensis*	10500	33.2	
		2	*Aricidea catherinae*	5225	16.5	
		3	*Prionospio steenstrupi*	4725	14.9	
		4	*Ninoe nigripes*	2775	8.8	
		5	*Levinsenia gracilis*	1325	4.2	
		6	*Monticellina baptisteae*	1225	3.9	
		7	Tubificidae sp.2	1150	3.6	
		8	*Spio limicola*	725	2.3	
		9	*Tharyx acutus*	700	2.2	
		10	*Exogone verugera*	675	2.1	91.7
B	S4 (Y94)	1	*Spio limicola*	23667	30.8	
		2	*Polydora socialis*	15567	20.3	
		3	*Monticellina baptisteae*	9842	12.8	
		4	*Tharyx marioni*	6500	8.5	
		5	*Hiatella arctica*	4042	5.3	
		6	*Tharyx acutus*	3292	4.3	
		7	*Mediomastus californiensis*	1833	2.4	
		8	*Pholoe minuta*	1042	1.4	
		9	*Exogone hebes*	925	1.2	
		10	*Exogone verugera*	917	1.2	88.2
B	MB01 (Y94)	1	*Spio limicola*	25925	42.1	
		2	*Mediomastus californiensis*	7500	12.2	
		3	*Tharyx acutus*	5450	8.8	
		4	*Aricidea catherinae*	3425	5.6	
		5	*Monticellina baptisteae*	2575	4.2	
		6	*Prionospio steenstrupi*	2000	3.2	
		7	*Maldane sarsi*	1550	2.5	
		8	*Leitoscoloplos acutus*	1150	1.9	
		9	*Ninoe nigripes*	1150	1.9	
		10	*Tharyx marioni*	1050	1.7	84.1
B	MB03 (Y94)	1	*Spio limicola*	29825	28.2	
		2	*Tharyx acutus*	18550	17.5	
		3	*Polydora socialis*	16700	15.8	
		4	*Mediomastus californiensis*	12000	11.3	
		5	*Tharyx marioni*	7200	6.8	
		6	*Exogone verugera*	2225	2.1	
		7	*Aricidea catherinae*	2175	2.1	
		8	*Monticellina baptisteae*	2025	1.9	
		9	*Levinsenia gracilis*	1875	1.8	
		10	*Ninoe nigripes*	1400	1.3	88.8
C	FF6 (Y92)	1	*Spio limicola*	10408	25.9	
		2	*Polydora socialis*	8983	22.4	
		3	*Mediomastus californiensis*	7108	17.7	
		4	*Cossura longocirrata*	2642	6.6	
		5	*Euchone incolor*	817	2.0	
		6	Tubificidae sp.2	817	2.0	
		7	*Aricidea catherinae*	800	2.0	
		8	*Levinsenia gracilis*	717	1.8	
		9	*Terebellides atlantis*	683	1.7	
		10	*Tharyx acutus*	600	1.5	83.6

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
C	FF6 (Y93)	1	*Spio limicola*	9575	23.7	
		2	*Mediomastus californiensis*	6225	15.4	
		3	*Cossura longocirrata*	3150	7.8	
		4	*Terebellides atlantis*	2392	5.9	
		5	*Onoba pelagica*	2350	5.8	
		6	*Aricidea quadrilobata*	2158	5.3	
		7	*Tharyx acutus*	2142	5.3	
		8	*Aricidea catherinae*	1492	3.7	
		9	*Ninoe nigripes*	958	2.4	
		10	*Nucula annulata*	892	2.2	77.5
C	FF6 (Y94)	1	*Cossura longocirrata*	3433	25.9	
		2	*Aricidea catherinae*	2067	15.6	
		3	*Spio limicola*	892	6.7	
		4	*Levinsenia gracilis*	683	5.2	
		5	*Mediomastus californiensis*	683	5.2	
		6	*Onoba pelagica*	608	4.6	
		7	*Ninoe nigripes*	508	3.8	
		8	*Nucula annulata*	442	3.3	
		9	*Aricidea quadrilobata*	325	2.5	
		10	*Thyasira gouldii*	308	2.3	75.1
C	FF7 (Y92)	1	*Mediomastus californiensis*	9850	21.5	
		2	*Spio limicola*	9450	20.6	
		3	*Cossura longocirrata*	5225	11.4	
		4	Tubificidae sp.2	5108	11.2	
		5	*Euchone incolor*	4608	10.1	
		6	*Aricidea catherinae*	3483	7.6	
		7	*Polydora socialis*	1158	2.5	
		8	*Tharyx acutus*	1017	2.2	
		9	*Prionospio steenstrupi*	867	1.9	
		10	*Apistobranchus tullbergi*	767	1.7	90.7
C	FF7 (Y93)	1	*Cossura longocirrata*	16688	26.3	
		2	*Mediomastus californiensis*	12175	19.2	
		3	*Aricidea catherinae*	8925	14.1	
		4	*Spio limicola*	5350	8.4	
		5	*Tharyx acutus*	3213	5.1	
		6	*Aricidea quadrilobata*	2050	3.2	
		7	*Euchone incolor*	1688	2.7	
		8	*Ninoe nigripes*	1588	2.5	
		9	Tubificidae sp.2	1388	2.2	
		10	*Syllides longocirrata*	1163	1.8	85.5
C	FF7 (Y94)	1	*Cossura longocirrata*	3342	34.5	
		2	*Aricidea catherinae*	2792	28.8	
		3	*Ninoe nigripes*	367	3.8	
		4	*Nucula delphinodonta*	325	3.4	
		5	*Levinsenia gracilis*	292	3.0	
		6	*Ophiura sarsi*	242	2.5	
		7	*Metopella angusta*	242	2.5	
		8	*Eteone longa*	225	2.3	
		9	*Nucula annulata*	158	1.6	
		10	*Nephtys incisa*	158	1.6	84.0
D	FF13 (Y92)	1	*Prionospio steenstrupi*	5817	24.3	
		2	*Polydora cornuta*	3608	15.1	
		3	*Mediomastus californiensis*	3500	14.6	
		4	*Tharyx acutus*	2733	11.4	
		5	*Nephtys neotena*	1092	4.6	
		6	*Photis pollex*	925	3.9	
		7	*Phyllodoce mucosa*	892	3.7	
		8	Tharyx sp.1	575	2.4	
		9	*Aricidea catherinae*	525	2.2	
		10	*Ampelisca abdita*	425	1.8	84.0

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
D	FF13 (Y93)	1	*Tharyx acutus*	11292	33.8	
		2	*Aricidea catherinae*	5892	17.7	
		3	*Nephtys neotena*	3150	9.4	
		4	*Mediomastus californiensis*	3117	9.3	
		5	*Phyllodoce mucosa*	2483	7.4	
		6	*Leitoscoloplos acutus*	1642	4.9	
		7	*Prionospio steenstrupi*	1425	4.3	
		8	*Capitella capitata complex*	567	1.7	
		9	*Eteone longa*	517	1.5	
		10	*Scoletoma hebes*	508	1.5	91.5
D	FF13 (Y94)	1	*Prionospio steenstrupi*	9883	26.0	
		2	*Mediomastus californiensis*	7967	21.0	
		3	*Aricidea catherinae*	3758	9.9	
		4	*Leitoscoloplos acutus*	2525	6.6	
		5	*Nephtys neotena*	2083	5.5	
		6	*Tharyx acutus*	1792	4.7	
		7	*Phyllodoce mucosa*	1433	3.8	
		8	*Eteone longa*	925	2.4	
		9	Tubificidae sp.2	767	2.0	
		10	*Hiatella arctica*	683	1.8	83.7
E	FF12 (Y94)	1	*Aricidea catherinae*	5817	34.7	
		2	*Scoletoma hebes*	1908	11.4	
		3	*Pleurogonium rubicundum*	1233	7.4	
		4	*Monticellina baptisteae*	1117	6.7	
		5	*Eteone longa*	942	5.6	
		6	*Polydora socialis*	842	5.0	
		7	*Arctica islandica*	808	4.8	
		8	*Levinsenia gracilis*	433	2.6	
		9	*Photis pollex*	408	2.4	
		10	*Tharyx acutus*	392	2.3	82.9
E	NF2 (Y93)	1	*Hiatella arctica*	14800	64.0	
		2	*Ophiura robusta*	1267	5.5	
		3	*Aricidea catherinae*	900	3.9	
		4	*Phyllodoce mucosa*	683	3.0	
		5	*Tharyx acutus*	567	2.5	
		6	*Mytilus edulis*	483	2.1	
		7	*Cerastoderma pinnulatum*	475	2.1	
		8	Amphipoda sp.1	400	1.7	
		9	*Spio thulini*	367	1.6	
		10	*Mediomastus californiensis*	333	1.4	87.8
E	NF16 (Y94)	1	*Aricidea catherinae*	2975	30.9	
		2	*Levinsenia gracilis*	1725	17.9	
		3	*Ninoe nigripes*	825	8.6	
		4	*Crenella decussata*	775	8.1	
		5	*Tharyx dorsobranchialis*	400	4.2	
		6	*Eteone longa*	400	4.2	
		7	*Monticellina baptisteae*	300	3.1	
		8	*Cerebratulus lacteus*	300	3.1	
		9	*Pholoe minuta*	275	2.9	
		10	*Nucula delphinodonta*	275	2.9	85.9
E	NF18 (Y94)	1	*Prionospio steenstrupi*	8775	22.9	
		2	*Asabellides oculata*	3975	10.4	
		3	*Exogone verugera*	3525	9.2	
		4	*Mediomastus californiensis*	3450	9.0	
		5	*Syllides japonica*	1850	4.8	
		6	*Crenella glandula*	1750	4.6	
		7	*Exogone hebes*	1625	4.2	
		8	*Hiatella arctica*	1325	3.5	
		9	*Ninoe nigripes*	1000	2.6	
		10	*Astarte undata*	925	2.4	73.6

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
E	NF20 (Y94)	1	*Hiatella arctica*	2175	23.2	
		2	*Asabellides oculata*	1150	12.3	
		3	*Monticellina baptisteae*	650	6.9	
		4	*Aricidea catherinae*	600	6.4	
		5	*Eteone longa*	600	6.4	
		6	*Pholoe minuta*	500	5.3	
		7	*Tharyx acutus*	300	3.2	
		8	*Capitella capitata complex*	275	2.9	
		9	*Argissa hamatipes*	250	2.7	
		10	*Ninoe nigripes*	250	2.7	72.0
F	NF1 (Y92)	1	*Aricidea catherinae*	4925	18.3	
		2	*Exogone hebes*	4300	16.0	
		3	*Corophium nr. crassicorne*	3450	12.8	
		4	*Polydora socialis*	2150	8.0	
		5	*Prionospio steenstrupi*	1650	6.1	
		6	*Cerastoderma pinnulatum*	1025	3.8	
		7	*Spiophanes bombyx*	875	3.2	
		8	*Euclymene collaris*	875	3.2	
		9	*Aglaophamus circinata*	725	2.7	
		10	*Phoronis architecta*	700	2.6	76.7
F	NF4 (Y92)	1	*Polydora socialis*	4650	24.6	
		2	*Corophium nr. crassicorne*	3850	20.4	
		3	*Exogone hebes*	2800	14.8	
		4	*Exogone verugera*	1425	7.5	
		5	*Crenella decussata*	850	4.5	
		6	*Aglaophamus circinata*	750	4.0	
		7	*Unciola inermis*	575	3.0	
		8	*Astarte undata*	425	2.3	
		9	*Aricidea catherinae*	350	1.9	
		10	Chaetozone sp.B	325	1.7	84.7
F	NF4 (Y93)	1	*Exogone hebes*	3008	15.3	
		2	*Exogone verugera*	2517	12.8	
		3	*Unciola inermis*	2292	11.6	
		4	*Spio limicola*	2017	10.2	
		5	*Polydora quadrilobata*	1042	5.3	
		6	*Euchone elegans*	1033	5.2	
		7	*Polydora socialis*	800	4.1	
		8	*Ptilanthura tenuis*	742	3.8	
		9	*Corophium nr. crassicorne*	700	3.6	
		10	*Euclymene collaris*	525	2.7	74.6
F	NF4 (Y94)	1	*Exogone hebes*	9150	30.8	
		2	*Polydora socialis*	6650	22.4	
		3	*Corophium nr. crassicorne*	5775	19.4	
		4	*Exogone verugera*	2025	6.8	
		5	Amphipoda sp.1	1100	3.7	
		6	*Leptocheirus pinguis*	775	2.6	
		7	*Crenella decussata*	750	2.5	
		8	*Ptilanthura tenuis*	350	1.2	
		9	*Aricidea catherinae*	350	1.2	
		10	*Edotia montosa*	350	1.2	91.8
F	NF13 (Y94)	1	*Exogone hebes*	13550	29.8	
		2	*Spio limicola*	8350	18.4	
		3	*Polydora socialis*	7275	16.0	
		4	Polygordius sp.A	4325	9.5	
		5	*Exogone verugera*	1525	3.4	
		6	*Photis pollex*	1350	3.0	
		7	*Crenella decussata*	1175	2.6	
		8	*Corophium nr. crassicorne*	1050	2.3	
		9	*Leptocheirus pinguis*	900	2.0	
		10	*Spiophanes bombyx*	850	1.9	88.9

Table 12 (continued). Dominant (top ten) infaunal species sorted by cluster group, station, and year.

Group	Sample	Rank	Specie	Abundance	Percent	Total %
F	NF17 (Y92)	1	*Corophium nr. crassicorne*	2900	18.6	
		2	*Pygospio elegans*	1800	11.5	
		3	*Exogone hebes*	1750	11.2	
		4	*Unciola inermis*	1375	8.8	
		5	*Aglaophamus circinata*	875	5.6	
		6	*Aricidea catherinae*	825	5.3	
		7	*Pseudunciola obliquua*	675	4.3	
		8	*Chiridotea tuftsi*	575	3.7	
		9	*Spiophanes bombyx*	425	2.7	
		10	Polygordius sp.A	375	2.4	74.1
F	NF17 (Y93)	1	*Corophium nr. crassicorne*	2317	46.4	
		2	*Chiridotea tuftsi*	400	8.0	
		3	*Pseudunciola obliquua*	350	7.0	
		4	*Spiophanes bombyx*	183	3.7	
		5	*Politolana polita*	183	3.7	
		6	*Rhepoxynius hudsoni*	158	3.2	
		7	*Cerastoderma pinnulatum*	142	2.8	
		8	*Hippomedon serratus*	125	2.5	
		9	*Acanthohaustorius millsi*	117	2.3	
		10	*Ensis directus*	117	2.3	81.9
F	NF17 (Y94)	1	*Corophium nr. crassicorne*	28358	60.8	
		2	*Polydora socialis*	4917	10.5	
		3	*Exogone hebes*	1717	3.7	
		4	*Spiophanes bombyx*	1500	3.2	
		5	*Pseudunciola obliquua*	1400	3.0	
		6	Polygordius sp.A	1125	2.4	
		7	*Echinarachnius parma*	1092	2.3	
		8	*Pygospio elegans*	975	2.1	
		9	*Aglaophamus circinata*	583	1.3	
		10	Chaetozone sp.A	417	0.9	90.2
F	S3 (Y94)	1	*Exogone hebes*	9550	21.5	
		2	*Corophium nr. crassicorne*	5350	12.1	
		3	*Polydora socialis*	5250	11.8	
		4	*Spio limicola*	2200	5.0	
		5	*Exogone verugera*	2200	5.0	
		6	*Prionospio steenstrupi*	2125	4.8	
		7	Polygordius sp.A	1675	3.8	
		8	*Photis pollex*	1100	2.5	
		9	*Aricidea catherinae*	1050	2.4	
		10	*Mediomastus californiensis*	1050	2.4	71.3

of mechanisms are known to apply depending the species and physical environment. Snelgrove and Butman (1994) describe a number of processes, such as benthic boundary layer flow, that covary with sediment grain size and community structure. Not only does the near-bottom current regime dictate the bulk properties of surficial sediments through selective deposition or erosion, but it influences larval supply, flux of organic matter, pore-water chemistry, and microbial abundance and composition. While other measurements may be more useful for relating infauna to the environment, grain size is the principal one available for this study. Nevertheless, care should be used when applying the correlative results from this study to predict infaunal community structure from grain size measured in other regions, or most-importantly, at other times in this region (namely, to post-discharge changes in grain-size).

A further limitation on the infaunal-sediment correlation arises from the sampling of surficial sediments. Grain size is determined from the upper 2 cm of sediment yet infauna is collected from the entire grab where seafloor penetration often exceeds 8 cm. Moreover, interstitial biological processes often occur to depths much deeper than 2 cm as indicated by the RPD in Table 3. Consequently, there can be a great disparity between the infauna in a sample with vertically stratified sediments and another with uniform properties; yet the surficial sediments may appear similar.

4.1.5 Regional Zoogeography

Two of the four remaining cluster groups in Figure 7 are distinguished by their geographic separation from the other groups. Using a similarity of 0.5 as a decision rule, Groups A, and C definitively separate from the largest cluster (Group B). These cluster groups consist entirely of farfield stations that are geographically-isolated across distances exceeding 15 km (Figure 1). Group A contains the five easternmost stations within Massachusetts Bay, namely Stations FF1, FF4, FF5, FF11, and FF15. Group C consists of the two stations (FF6 and FF7) within Cape Cod Bay. The station-year affiliation of all groups is listed in Table 10 along with average properties that distinguish the groups. These two zoogeographically distinct groups are much farther from the diffuser than the members of other groups. Their average distance to the diffuser is a factor of four greater.

Within these groups, samples collected in multiple years from an individual station do not always exhibit the highest similarity. Nevertheless, each group contains all the sampling years for each station represented in the group. As described in Section 4.1.2, the strength of the infaunal differences among these groups is sufficient to resolve a distinct community structure despite the presence of significant interannual variability. Because the members of Groups A and C are zoogeographically distinct, and are far removed from the diffuser, they are excluded from the group of samples analyzed for their ability to detect impacts due to effluent discharge from the outfall. The remaining cluster groups (B, D, and F) considered for power analysis, all have a mean distance to the diffuser of less than 8 km. At these midfield distances, interannual variability is comparable to spatial variability and mean infaunal properties can be computed from the pool of stations over all sampling years. Moreover, midfield stations act as sentinels because they are more likely to exhibit infaunal impacts from effluent discharge.

Consistent with the selection of an intermediate subsample size for CNESS (see Section 2.3.3), dominant species play an important roll in distinguishing infaunal communities within each group. From a comparison of the top ten dominants for each station (Table 12), those species indicative of major cluster groups can be derived. Alternatively, for sentinel stations, a metric scaling of species in the PCA-H analysis (Section 4.2) reveals the influential species. Distinguishing species for all the major groups are summarized in Table 13. Stations within Eastern Massachusetts Bay (Group A) are characterized by the unique dominance of six polychaetes (*Aricidea quadrilobata*, Chaetozone sp.A, *Scalibregma inflatum*, *Anobothrus gracilis*, and *Maldane glebifex*). Also, one oligochaete (*Tubificoides apectinatus* complex) and one bivalve (*Thyasira gouldii*) are indicative of the deep Stellwagen Basin and surrounding areas. A smaller number of unique dominants characterize the two stations within Cape Cod Bay. For Group C, important species consist of two polychaetes (*Cossura longocirrata* and

Table 13. Summary of infaunal numerical classification and its relation to environmental factors and location.

Description	Stations	Possible External Influence	Important Species
Eastern Massachusetts Bay	FF1, FF4, FF5, FF11, FF14	Regional Zoogeography	*Aricidea quadrilobata*, Chaetozone sp.A, *Tubificoides apectinatus* complex, *Scalibregma inflatum*, *Thyasira gouldii*, *Anobothrus gracilis*, and *Maldane glebifex*
Cape Cod Bay	FF6, FF7	Regional Zoogeography	*Cossura longocirrata*, *Euchone incolor*, and Tubificidae sp.2
Transient Infauna[1] (temporally unstable)	FF12, NF2, NF16, NF18, NF20	Response to significant decrease in fine grain-size fraction after initial sampling year.	*Hiatella arctica*, *Monticellina baptisteae*, *Scoletoma hebes*, *Ophiura robusta*, and *Asabellides oculata*
Transition from eastern to western Massachusetts Bay	FF9	Local Zoogeography	*Scalibregma inflatum* and *Ampharete acutifrons*
Estuarine	FF1A, FF12[1], FF13, NF8	Possible coastal influence due to shallow water depth and proximity to Boston or Gloucester Harbors	*Nephtys neotena*, *Eteone longa*, and *Polydora cornuta*
Sentinel (Coarse)	NF1, NF4, NF13, NF17, S3	Proximity to outfall diffuser in sediments with a fine-grain size fraction of 7% or less.	*Corophium* nr. *crassicorne* (1)[3], *P. socialis* (2), *Exogone hebes* (6), *Pseudunciola obliquua* (10), *Spiophanes bombyx* (11), *Polydora quadrilobata* (12), and *Exogone verugera* (13)
Sentinel (Medium)	FF10, NF3, NF5, NF6, NF7, NF9, NF10, NF11, NF14, NF15, NF18[1], NF19	Sediments with a fine-grain size fraction generally between 7% and 60%	*Spio limicola* (3), *Mediomastus californiensis* (4), and *Tharyx acutus* (16)
Sentinel (Fine)	S4[2], MB1, MB3, NF2[1], NF12, NF20[1]	Sediments with a fine-grain size fraction generally exceeding %60	*Prionospio steenstrupi* (5), *Aricidea catherinae* (7), *Monticellina baptiste* (8), *Ninoe nigripes* (9), *Leitoscoloplos acutus* (14)

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[1] These stations exhibited a substantial drop in fine grain-size fraction in only one sampling year (Table 11). Samples collected in prior years, when surficial sediments were stable, or in future samples, after redeposition of the fine fraction and recovery of the infaunal community, allow their inclusion in other groups, including the Sentinel Station Group.

[2] Samples collected at Station S4 exhibit a wide variation in sediment properties and infaunal community. It is included in the Sentinel Station Group by virtue of its extreme proximity to the diffuser.

[3] Numbers in parenthesis indicate the ranking of the species in terms of the amount of CNESS variance explained in the principal ordination plane of baseline sentinel samples.

Euchone incolor) which are members of families different from the important polychaetes that characterize Group A. In addition, the dominance of an oligochaete taxon (Tubificidae sp.2) differs from taxa that distinguish the other groups.

4.1.6 Zoogeographic Transition

To further refine the selection of samples appropriate for power analysis, the remaining 102 midfield samples are can be analyzed in more detail. In the forgoing discussion, the 68 infaunal samples that were members of Groups A, C and E were excluded from further analysis because they were either distinct zoogeographically from mid-field stations or were subject to instability in surficial sediments. The viability of the remaining stations for monitoring impacts on infaunal communities is the subject of this and the next section. Assessment of these remaining stations is based on an examination of CNESS variability, using both cluster and PCA-H analysis of replicate samples. Based upon these focussed analyses, additional stations with anomalous infaunal communities will be excluded from the set of samples incorporated into the power analyses of Section 4.2.

The cluster analysis of the 102 stable midfield replicates is shown in Figure 8. As expected, it resembles the dendrogram from the full cluster analysis of all 170 replicate samples (Figure 5). Here, however, five stations with distinct community properties are highlighted based on the PCA-H analysis shown in Figure 9. Replicates collected at Station FF9 exhibit an internally-consistent infaunal community across all sampling years as reflected by high (>0.844) CNESS similarity in Figure 8. The ordination analysis of Figure 9 shows that this, and the other stations (FF1A, FF12, FF13, and NF8) highlighted in Figure 8, have infaunal communities quite distinct from the other 71 replicate samples. Almost all of the samples collected at these stations have components of their infaunal communities that are linearly independent of the majority of midfield samples. This is evident from their comparatively-large sample scores along PCA-H Axis 3. These minor-axis excursions are highlighted by closed curves in Figures 9b and 9c. The majority of samples from other midfield stations reside largely within the principal plane of CNESS variability (PCA-H Axes 1 and 2 of Figure 9a).

Here, the intent is to restrict the analysis to a subset of stations that exhibit the greatest variability along these first two principal axes. First, these axes account for much larger amounts of variability than minor axes, including PCA-H Axis 3. This is evident from the scree plot for the singular value decomposition (Figure 10). Only the first two eigenvalues make up the steep incline above the gently-sloping scree gradually trailing off at eigenvalues of three and above. Experimental evidence suggests that the optimal analysis is limited to those factors that lie above the scree (Cattell, 1966). The second reason to restrict attention to the principal plane is that in Section 4.2.2, the ordination axes will be correlated with only a limited number of environmental properties that are thought to highly influence infaunal distributions. It is unlikely that the linear orthogonalization along minor axes will significantly correlate with more-uniform environmental parameters such as the distribution of background contaminant concentrations (*cf.* Section 3.4).

Reasons for the infaunal differences at the stations highlighted in Figures 8 and 9 can be derived from their geographic location as shown in Figure 1. Most of the five stations are comparatively distant from the other midfield stations and all lie 5 km or more from the diffuser. While separation distances are not as great as those of the regional zoogeographic divisions discussed in the previous section (see also Table 10), local midfield separations appear sufficient to isolate their infaunal communities to some degree. From proximity considerations alone, one would expect Station FF9 to cluster with stations in Eastern Massachusetts Bay. However, Group A stations closest to Station FF9 lie within Stellwagen Basin at a significantly greater water depth (>70 m) as compared to the 50-m water depth at Station FF9. It is likely that the infauna at Station FF9 represent a transition to the shelf communities of Western Massachusetts Bay (Group B). This interpretation is consistent with the dominant species most indicative of FF9 (Tables 12 and 13). The polychaete *S. inflatum* is also a dominant at stations in Eastern Massachusetts Bay (Group A) while the polychaete *Ampharete acutifrons* is dominant only at nearfield stations within Group B. Because Station FF9 is somewhat distant

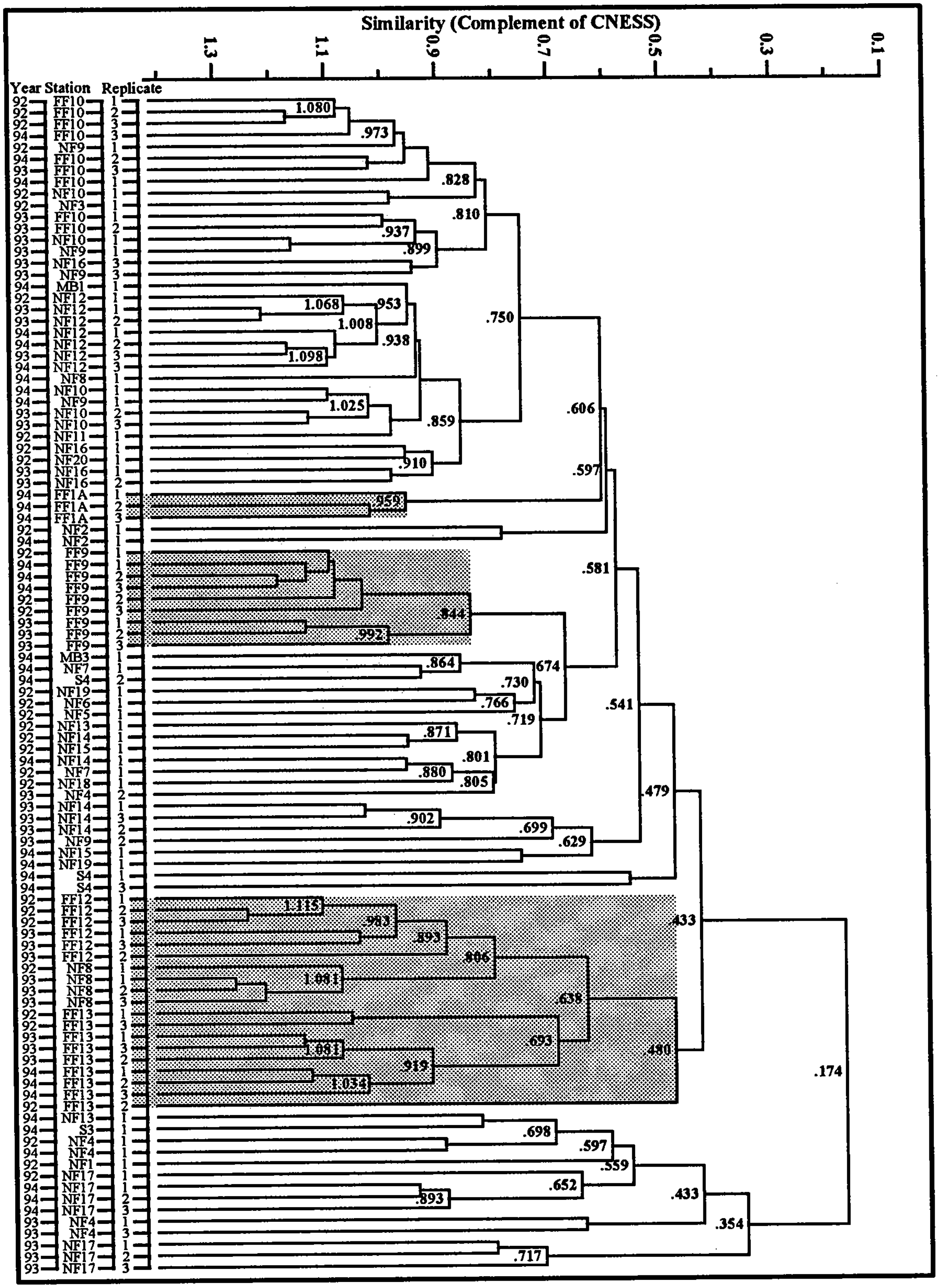

Figure 8. Dendrogram resulting from clustering (group average sorting) of similarity (complement of CNESS with *m*=18) among 102 replicate infaunal samples collected at temporally-stable midfield stations. Shaded areas draw attention to stations whose infaunal communities appear to be distinct based on the PCA-H analysis of Figure 9 and which are comparatively distant from majority of stations near the diffuser.

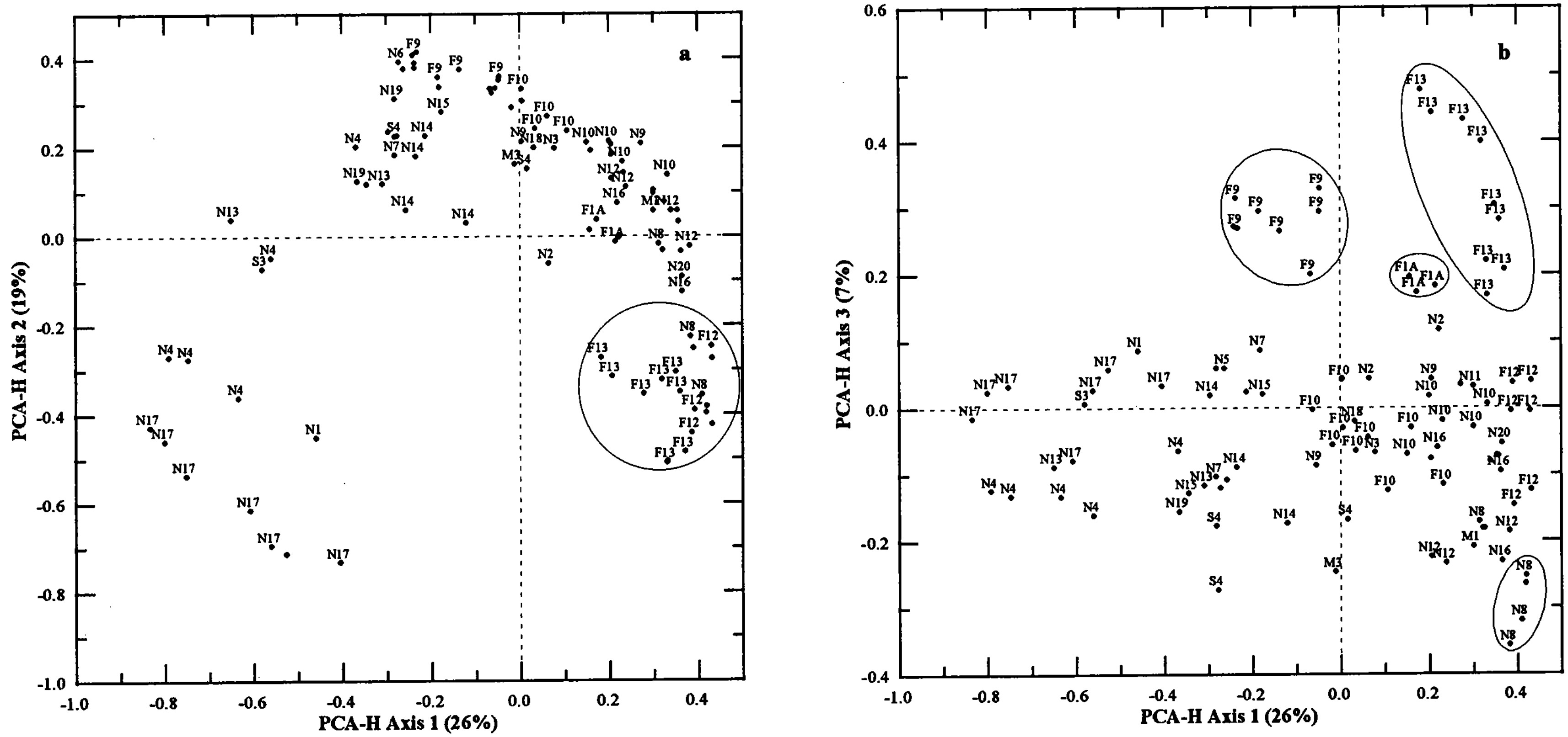

Figure 9. Three dimensional PCA-H ordination of 102 temporally-stable midfield replicates with m=18. The first frame (a) depicts the projection of the ordination onto the first principal plane. The two minor subplanes (b and c) include Axis 3 which accounts for less than half of the total CNESS variance explained by the second principal axis. Axis labels indicate the amount of total CNESS variance explained by the respective axes. . Where possible, replicate samples are labeled by the station number (preceded by "N" for nearfield and "F" for farfield). Closed curves highlight stations with consistently large excursions along minor axes.

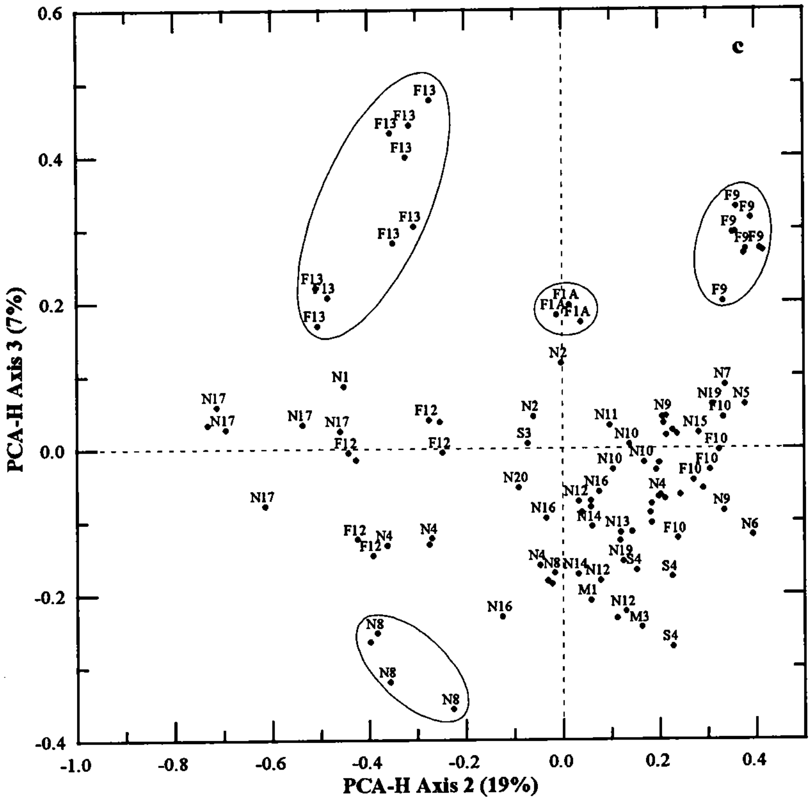

Figure 9 (continued). Three dimensional PCA-H ordination of 102 temporally-stable midfield replicates with m=18. The first frame (a) depicts the projection of the ordination onto the first principal plane. The two minor subplanes (b and c) include Axis 3 which accounts for less than half of the total CNESS variance explained by the second principal axis. Axis labels indicate the amount of total CNESS variance explained by the respective axes. Where possible, replicate samples are labeled by the station number (preceded by "N" for nearfield and "F" for farfield). Closed curves highlight stations with consistently large excursions along minor axes.

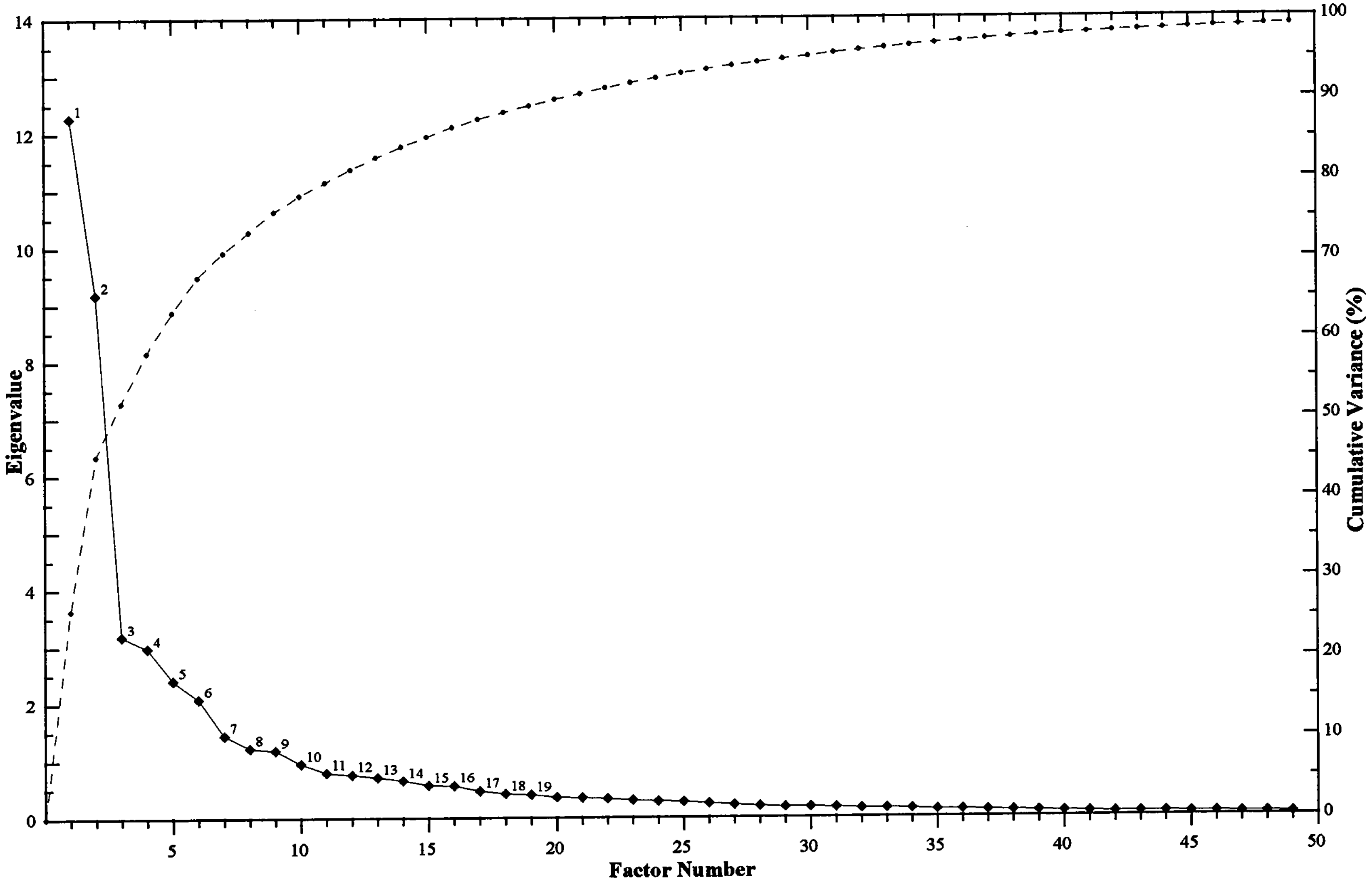

Figure 10. Scree plot (solid line) showing the ranked eigenvalues from the PCA-H ordination (*m*=18) of 102 temporally-stable midfield samples. The dashed line reflects the cumulative percent variance explained by the eigenvalues. Sample coordinates corresponding to the first three eigenvalues are shown in Figure 9.

(≈13 km) from the diffuser, and because it exhibits a transitional zoogeographic infauna, it is excluded from further analysis.

4.1.7 Estuarine Influence

Replicates collected at the two remaining groups of stations in Figure 8 (FF1A, FF12, NF8, and FF13) are also generally consistent across all sampling years. The only exception is Y4F12, which appears to have strong interannual variability. It was discussed in Section 4.1.3 and is not included the cluster analysis of Figure 8. Samples collected at these four stations all exhibit relatively large excursions along PCA-H Axis 3 in Figure 9. This axis explains a substantially smaller portion (7%) of the CNESS variability than the principal plane (45%) where the majority of midfield samples lie.

Again, the geographic distribution of these stations suggests a possible external influence on their infaunal communities (Figure 4). Stations FF12, FF13, and N8 are located in the westernmost reaches of the entire station pattern and all are near the entrance to Boston Harbor. The anthropogenic influence of Boston Harbor has been suggested as a source of the unique infauna, specifically the presence of *Polydora cornuta,* observed at some of these stations (Coats *et al.*, 1995a). Similarly, the isopod *Edotia triloba* was moderately abundant in Boston Harbor (Kropp and Diaz, 1994) but was only observed at Station FF13 in the outfall monitoring surveys. The hypothesis of estuarine influence is further supported by anomalously high *C. perfringens* spore counts observed at Stations FF12 and FF13 over all three years of sampling (Figure 11).

As with Station FF9, one would expect Station FF1A to cluster with the group of stations within the Eastern Massachusetts Bay (Group A) based on geographic considerations alone. However, in the case of Station FF1A, the water depth is much shallow (<40 m) and it is also close to the mouth of Gloucester Harbor (Figure 1). The station coincides with Biological Station 5 of the Gloucester 301(h) monitoring program (Allan D. Michael and Associates, 1993). In the sampling conducted in September 1991, the four dominant species observed at the Gloucester Station 5 matched those of Station FF1A (Table 12). Three other surrounding stations near the entrance to Gloucester Harbor were sampled as part of the 301(h) monitoring program, and all exhibited a similar infaunal community. This lends additional support to the notion that Station FF1A, in addition to Stations FF12, FF13 and NF8, represents a unique nearshore environment possibly influenced by the estuarine environment of adjacent harbors. Because the infauna at these four costal stations is comparatively distinct from the majority of samples collected near the diffuser, and because they are comparatively distant from the diffuser corridor, they are excluded from the sentinel stations recommended for the power analyses used to estimate detectable anthropogenic changes in infauna due to effluent discharge from the new outfall.

4.2 SENTINEL INFAUNAL COMMUNITIES

The foregoing discussion reduces the original infaunal data set, consisting of 170 samples, to 66 samples near the diffuser. These samples have internally-consistent infauna and exclude communities that are transient, zoogeographically distinct, or influenced by estuarine processes. Most of these 66 samples are members of the largest regional cluster (Group B), although samples associated with coarse sediments (Group F) are represented as well. In this section, these samples are analyzed in detail through an application of PCA-H that accounts for a widely varying environmental properties that cause significant non-linearity in the coordinates. The stations associated with this subgroup of samples are designated sentinel stations (Table 13) to reflect their use in future assessments of impacts from discharged effluent. Here, they establish baseline estimates of the infaunal variability which are used to test the ability of sampling designs to detect future infaunal changes.

Only those environmental factors thought to greatly influence baseline infaunal communities are included in the PCA-H analysis. They are limited to the physicochemical and tracer properties of surficial sediments; namely, grain size, *C. perfringens* spore abundances, and total organic carbon. Other factors, such as concentrations of

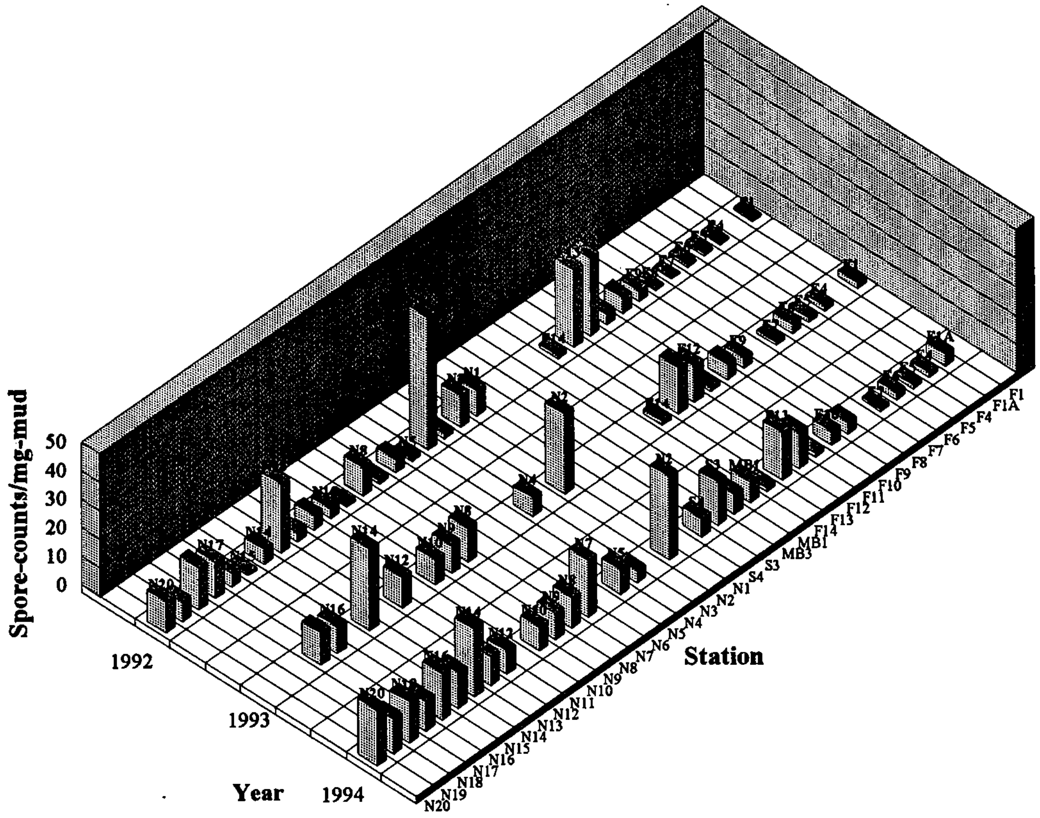

Figure 11. Temporal and spatial distribution of C. perfringens spore counts normalized by mud fraction.

specific contaminants, are not considered since their concentrations are generally much lower than the range of observed effects on benthic biota (*cf.* Section 3.4).

4.2.1 Detrended Principal Components Analysis

Ideally, the principal components resulting from the PCA-H analysis or other ordination would represent gradients in infaunal community structure that can be directly related to underlying environmental gradients. However, the response of organisms to environmental gradients is often non-linear, except over limited ranges. This non-linearity can result in ordinations with curvilinear distributions of observations rather than distributions aligned along the orthogonal principal components. Relative to most other ordination techniques, the PCA-H analysis performed here minimizes the impact of non-linearity. Nevertheless, PCA-H analysis of the 102 stable mid-field samples exhibits substantial curvature in the highest ordination plane (Figure 9a). The analogous PCA-H analysis of the reduced set of 66 samples at sentinel stations is shown in Figure 12. Because of the elimination of estuarine stations that contribute to the third principal axis (enclosed areas in Figure 9), the principal plane of Figure 12 accounts for more (nearly half) of the total CNESS variance. The minor axes (not shown) each account for less than 7% of the total CNESS variance in the analysis of the 66 sentinel samples. The enhanced influence of the first eigenvalue in the ordination of sentinel samples is evident from a comparison of the scree plots shown in Figure 13 and Figure 10.

The curvature in this principal plane is expected, because, as will be subsequently shown, the ordination is strongly related to the surficial-sediment grain size which has an extreme range in the samples included herein. Specifically, some samples, particularly the seven collected at Station NF17, were almost devoid of fine-grained sediments (mud fraction < 2%). In contrast, the mud fraction in samples collected in 1994 at Station NF12 exceeded 80%. Another ordination technique often used to reduce non-linearity, is nonmetric multidimensional scaling (Kruskal, 1964). However, as shown in Figure 14, application of this analysis technique yields results nearly identical to that of PCA-H (Figure 12), albeit with a difference in scaling. Trueblood *et al.* (1994) have also observed a resemblance in the results from these two techniques applied to an analysis of seasonal succession in Boston Harbor.

There are several methods available to account for the curvature that results from ordination of samples from broad environmental coordinates. Hill and Gauch (1980) describe a complex algorithm for detrending correspondence analysis results. However, a more direct method involves detrending or unfolding the curvilinear relationship through regression of a quadratic polynomial (Phillips, 1978). A modification of the latter approach, involving the regression of a piecewise-continuous polynomial, is applied herein and the detrended PCA-H coordinates are designated DPCA-H. Regression of a quadratic equation to the 66 PCA-H coordinates for sentinel stations is highly significant ($p<0.0001$). The solid line in Figure 12 shows the final fit of a regression equation given by

$$y = \begin{cases} -0.2490 + 0.6307x + 1.5899x^2; & \textit{for } x \leq -0.45 \\ -0.3085 + 0.4083x + 1.3899x^2; & \textit{for } -0.45 \leq x \leq -0.00 \\ -0.3072 + 0.4024x + 2.7443x^2; & \textit{for } x \geq 0.00 \end{cases} \tag{10}$$

where x and y are PCA-H Axes 1 and 2, respectively.

This piecewise-continuous polynomial achieves a better local fit to the majority of data than a single quadratic regression. Note that the community structure at stations with coarse sediments (Stations NF1, NF4, NF13, NF17, and S3) exhibits much greater variability than that of other stations (*cf.* the low-similarity clustering in

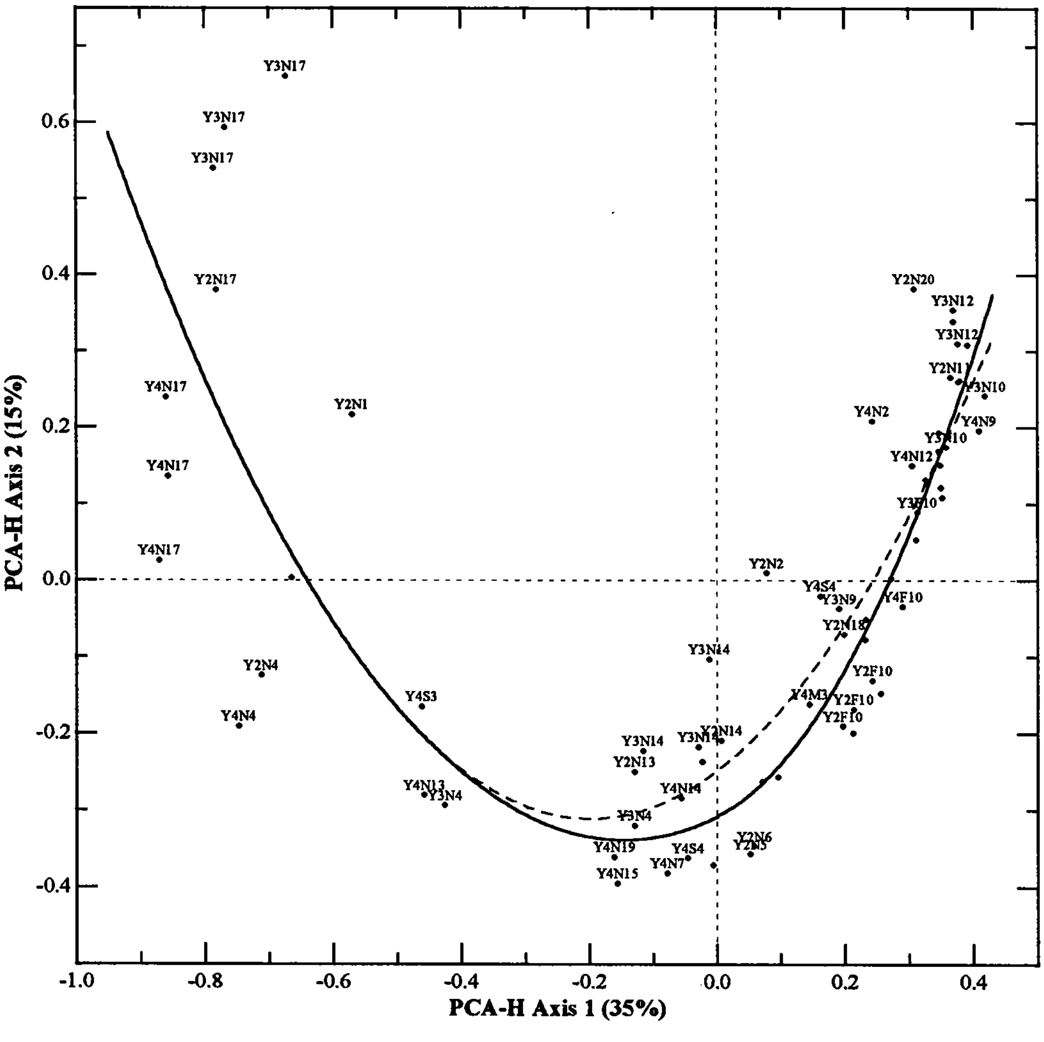

Figure 12. Principal plane of PCA-H ordination for 66 replicates at sentinel stations with m=18. The solid line is the piecewise-continuous parabolic regression used in detrending the principal components. The dashed line displays the regression of a single parabola. Where possible, replicates are labeled by the last digit of the collection year (preceded by "Y") and the station number (preceded by "N" for nearfield and "F" for farfield).

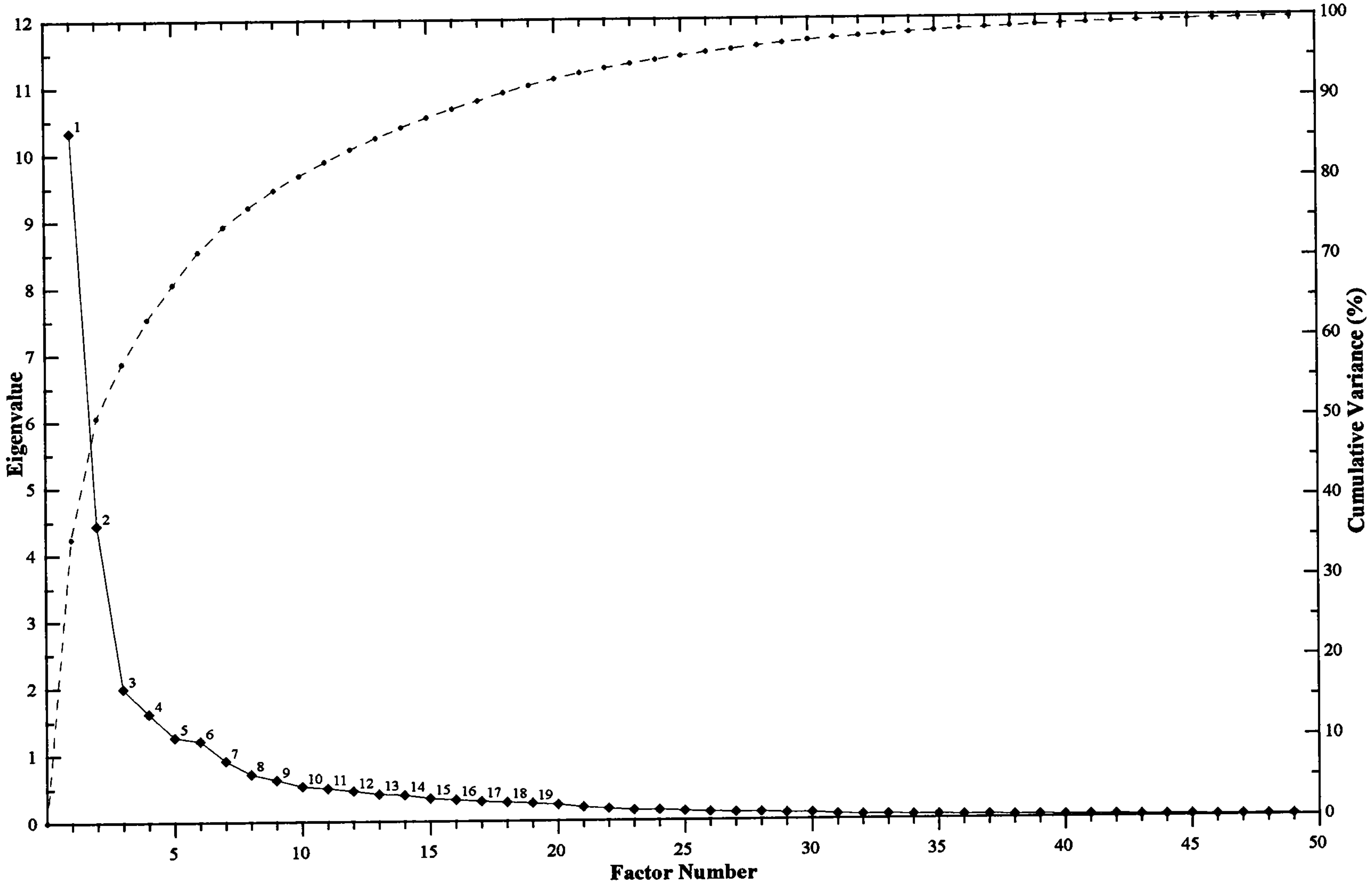

Figure 13. Scree plot (solid line) of the ranked eigenvalues from the PCA-H ordination (m=18) of 66 replicates at sentinel stations. The dashed line reflects the cumulative percent variance explained by the eigenvalues. Sample coordinates corresponding to the first two eigenvalues are shown in Figure 12.

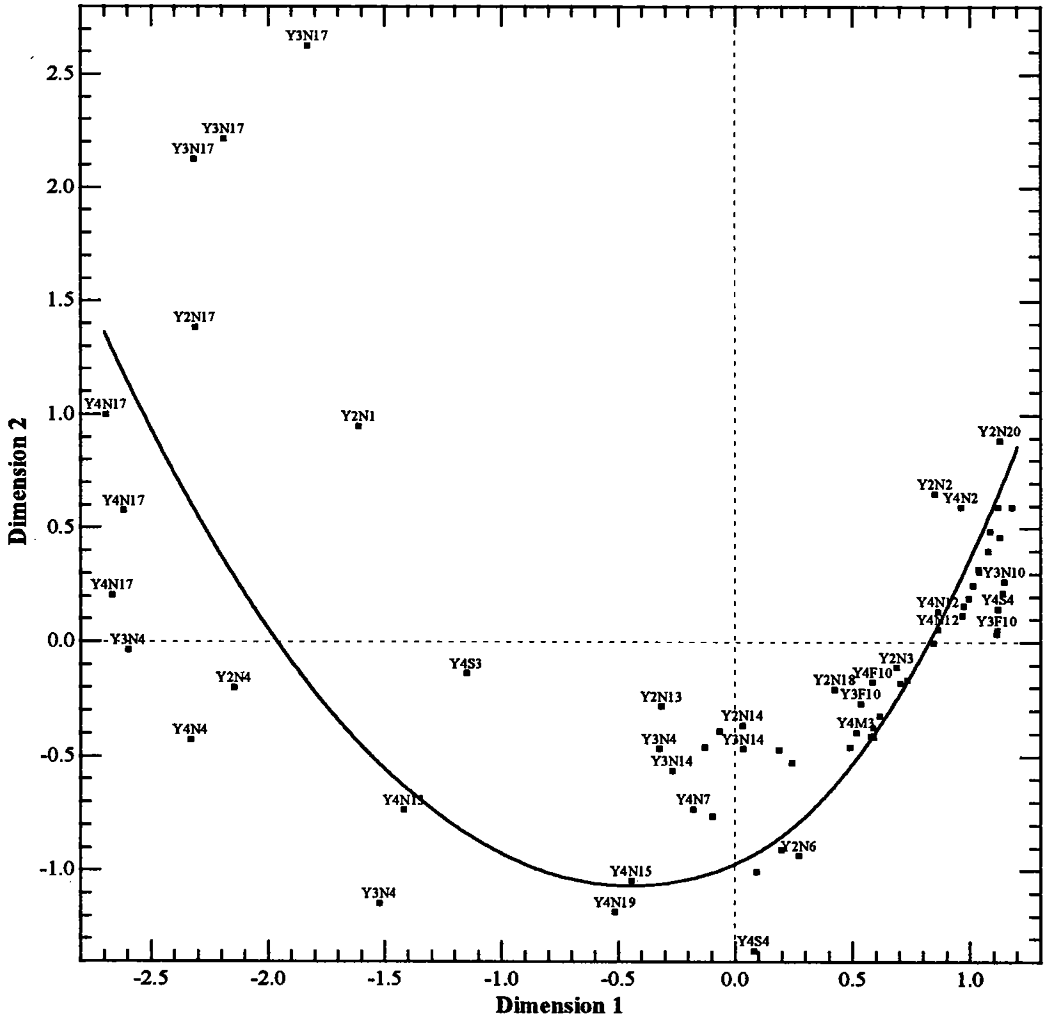

Figure 14. Coordinates determined from the nonmetric multidimensional scaling of the hypergeometric matrix (*m*=18) with 66 replicates at sentinel stations. The solid line is scaled from the piecewise-continuous parabolic regression shown in Figure 12. Replicate labeling is as described in Figure 12.

Group F of Figure 7 and the PCA-H coordinates along Axis1<-0.3 in Figure 12). Consequently, in a regression of a single polynomial, these few samples dominate the fit and significantly bias the regression above 0.3 along PCA-H Axis 1. This bias is evident from the Cook's distances (Figure 15) resulting from the regression of a single polynomial. The large Cook's distances in Figure 15 reflect the overwhelming influence of coarse grained stations on the fit (Cook, 1977). A separate regression on the subset of sentinel stations without coarse-grained samples, yielded a highly significant ($p<0.0001$) parabolic fit and eliminated the bias evident in Cook's distances.

The detrended coordinates, designated DPCA-H, are obtained by projecting the PCA-H coordinates onto the piecewise-continuous quadratic as shown in Figure 16. The resulting DPCA-H coordinates are shown in Figure 17. Clearly, much of the original curvature is eliminated so that the coordinates can better represent underlying environmental gradients. This is particularly true along the second orthogonal axis where much of the variability in Figure 12 was due to non-linear interaction between the infauna and their environment.

4.2.2 Relationship to Environmental Factors

In this section, sediment grain-size, *C. perfringens* spore abundances, and total organic carbon are examined for their relation to the DPCA-H coordinates. The same transformations on these environmental parameters, described in the analysis of surficial sediment contaminants (Section 2.4), are applied herein to achieve more normally-distributed parameters whose variance is not a significant function of the mean. Upon determination of the relationship between environmental parameters and DPCA-H coordinates, adjustments are made to remove the variation in these environmental properties among samples. This isolates the variability in species abundance due to inherent biological and sampling fluctuations, from that influenced by gross patterns in environment properties. The adjusted DPCA-H coordinates are pooled to estimate an overall infaunal variance among sentinel stations.

As expected from anecdotal observations of sample clustering (Figure 7) and categorization by sediment properties (Table 13), grain size is the most influential environmental factor on the infauna. This is confirmed by the highly significant ($p<0.0001$) linear regression of DPCA-H Axis-1coordinates on the transformed mud fraction of samples with medium to fine grain size. Regression on transformed *C. Perfringens* or TOC, although also statistically significant, explains much less (about half) of the variability accounted for by the grain size regression along the first principal axis. As with PCA-H detrending, the best local fit is achieved with a separate regression on the coarse samples. Again, the linear regression on these coarse samples is highly significant. The optimal piecewise-continuous linear regression is shown in Figure 18 and given by

$$DPCA\text{-}H\ Axis\ 1 = \begin{cases} -2.372 + 4.613\,\xi, & for\ \xi \le 0.52 \\ -0.220 + 0.409\,\xi, & for\ \xi \ge 0.52 \end{cases} \qquad (11)$$

where $\xi = 2\,sin^{-1}[(mud\,fraction)^{1/2}]$.

The two other transformed environmental parameters, *C. perfringens* spore counts and TOC, both exhibit a statistically significant ($p \approx 0.002$) linear relation to the second DPCA-H axis (Figure 19). Because of the uniform scatter of residuals, a single regression line is applied. Transformed *C. perfringens* spore counts are slightly more correlated with DPCA-H Axis 2 than transformed TOC. In fact, because of collinear variation in these environmental properties, a regression including both parameters only explains a small amount of additional variability along the second DPCA-H axis. Because of the higher correlation with transformed *C. perfringens* spore counts, the final regression equation (**12**) is limited to that parameter although TOC or both environmental parameters could have been used.

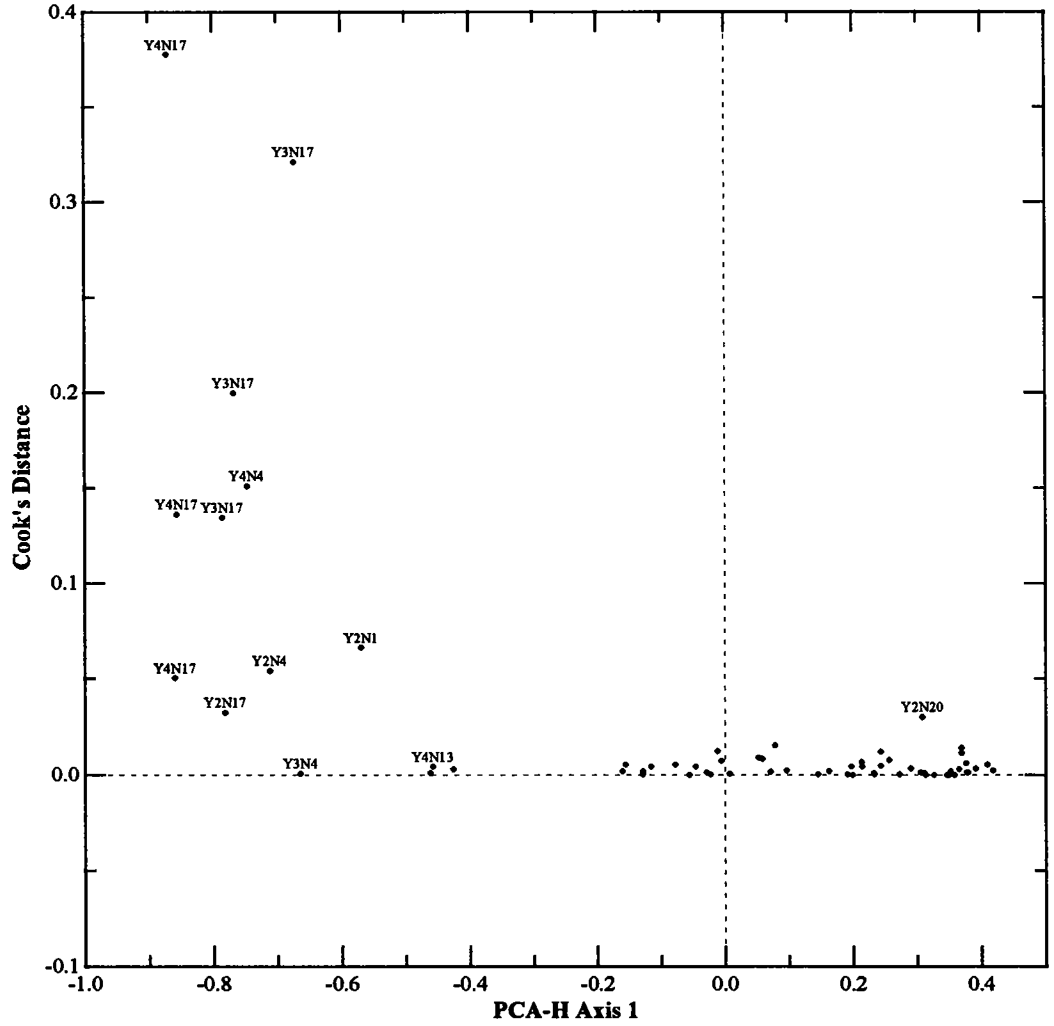

Figure 15. Cook's distances resulting from a regression of a single continuous quadratic on the 66 replicate scores computed in a PCA-H ordination (m=18) of sentinel stations. The Cook's distances are plotted as a function of the observations along the first principal axis. Where possible, replicates are labeled as described in Figure 12.

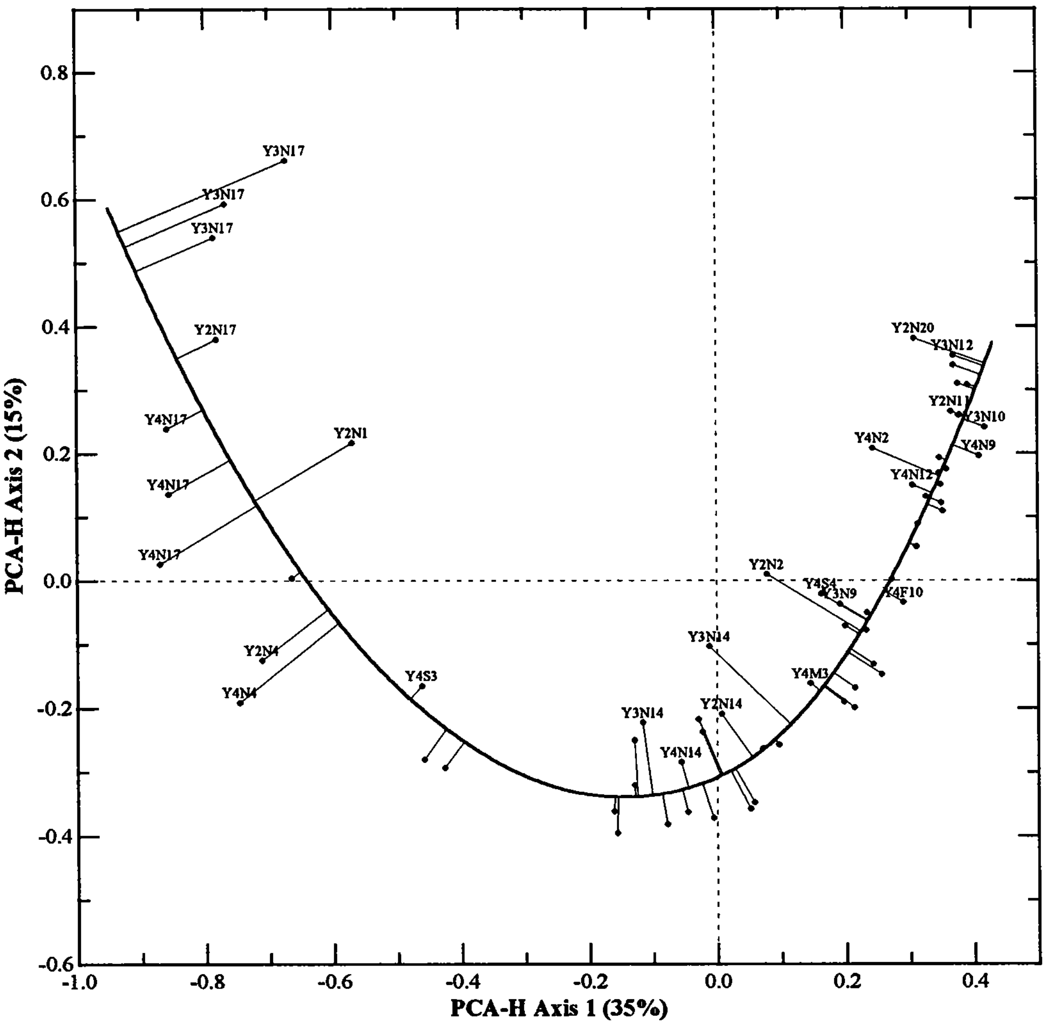

Figure 16. Projection of PCA-H coordinates (thin lines) for 66 replicates at sentinel stations onto the piecewise-continuous parabolic regression (thick line). These projections are unfolded to obtain the detrended principal components in Figure 17. Replicate labeling is as described in Figure 12.

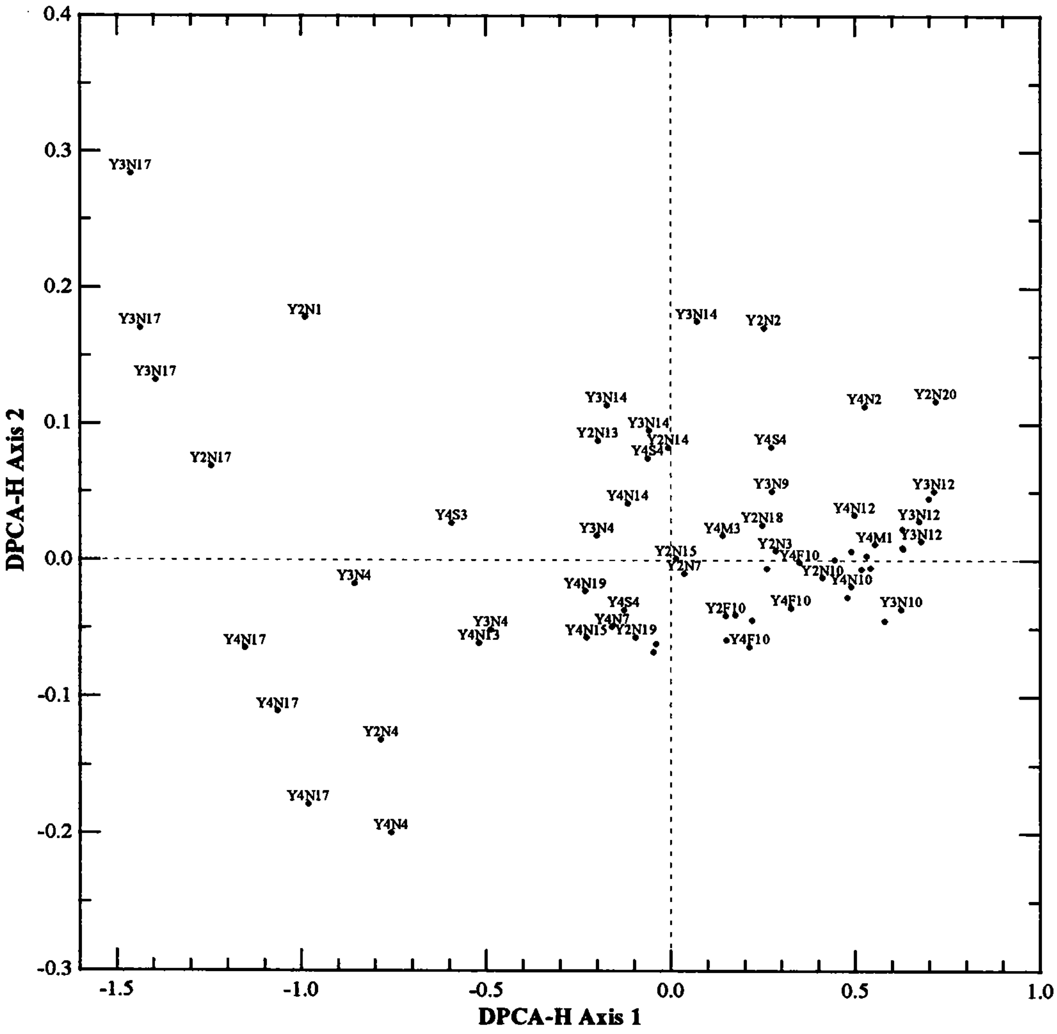

Figure 17. Detrended PCA-H coordinates (DPCA-H) determined from the projection in Figure 16. Replicate labeling is as described in Figure 12.

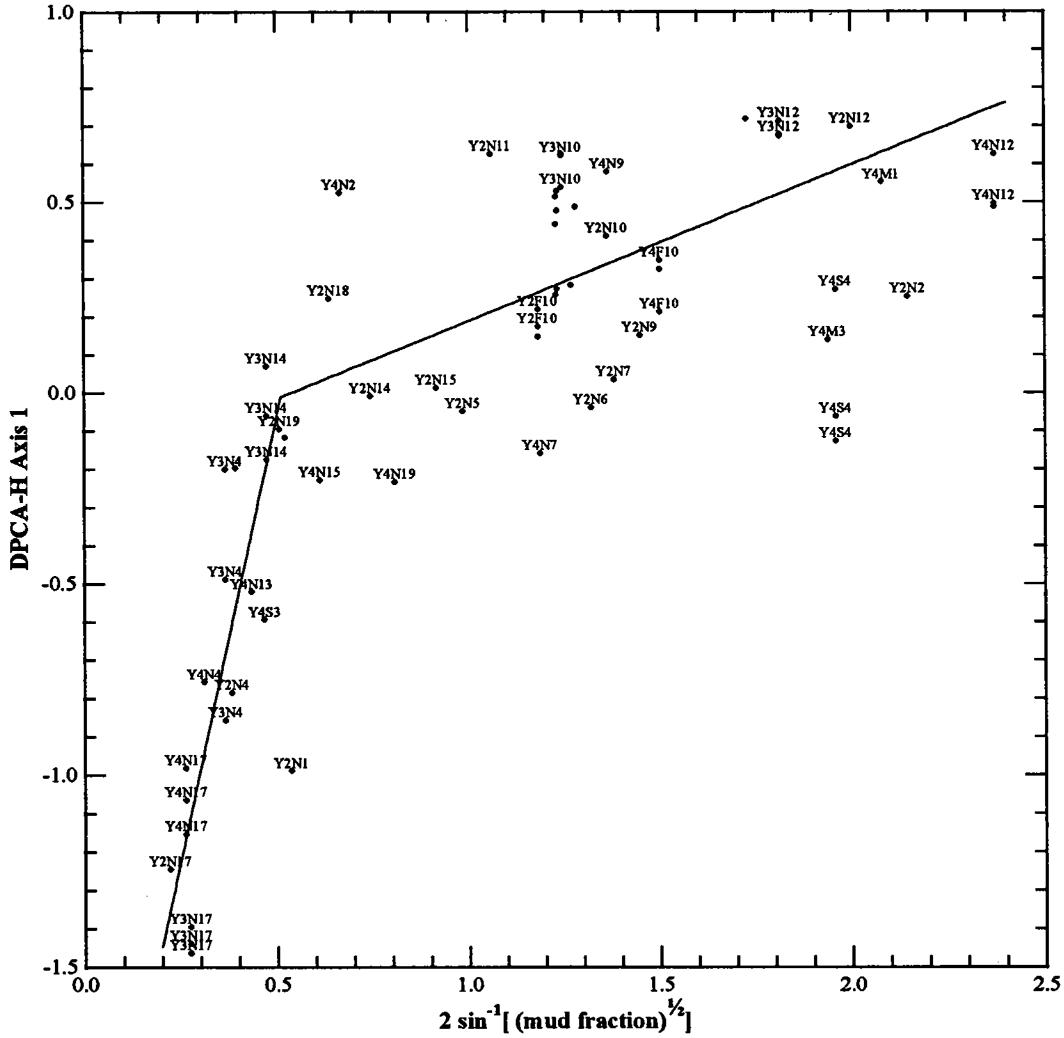

Figure 18. Regression of DPCA-H Axis 1 on transformed grain size. The solid line displays the results of the piecewise-continuous linear regression where samples, collected at stations with very coarse (mud<7%), were analyzed separately from the majority of sentinel stations. Replicate labeling is as described in Figure 12.

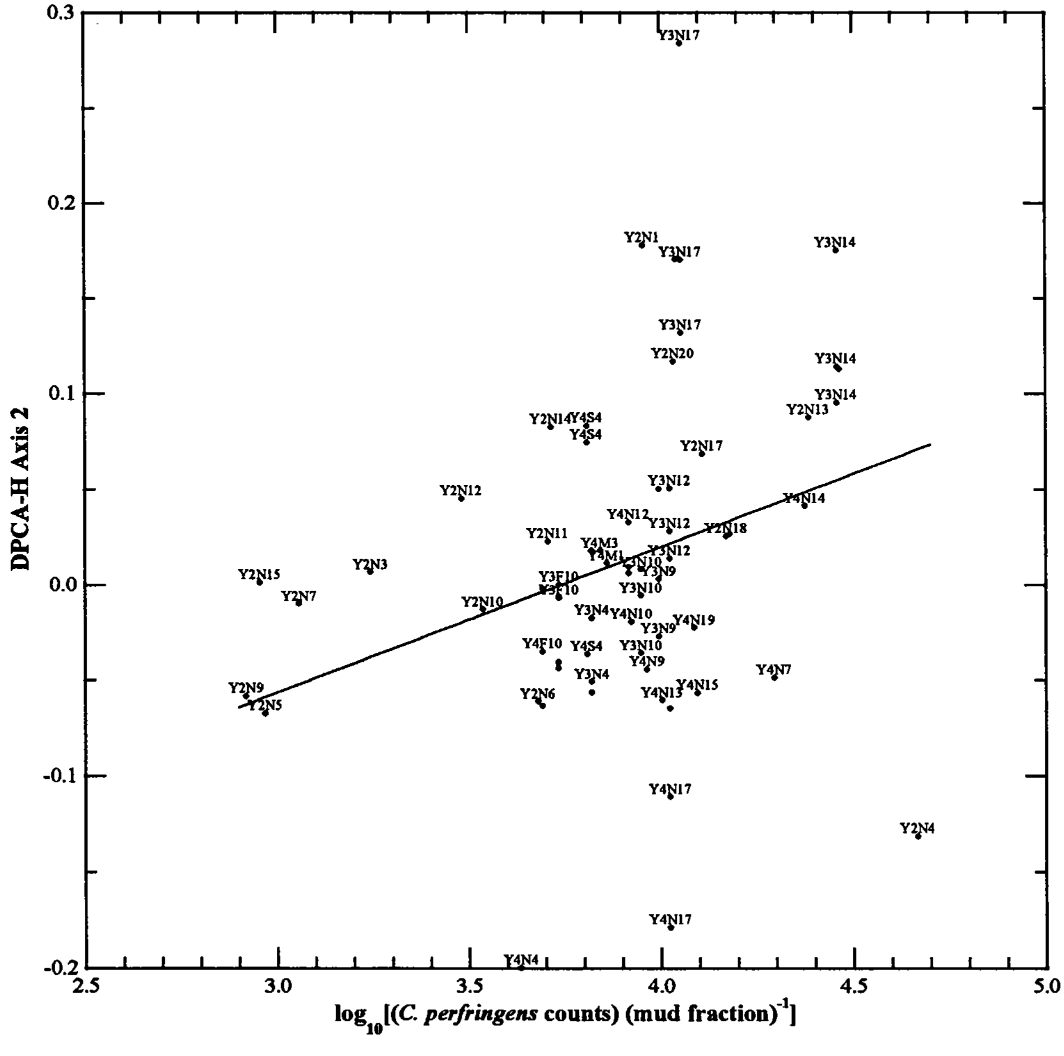

Figure 19. Regression of DPCA-H Axis 2 on transformed *C. perfringens* spore counts. Replicate labeling is as described in Figure 12.

$$DPCA\text{-}H\ Axis\ 2 = -0.2861 + 0.0765 \log_{10} \left[\frac{C.\ perfringens\ \text{counts}}{mud\ fraction} \right] \qquad (12)$$

The resulting multivariate regression of the two-dimensional DPCA-H coordinates on grain size and *C. perfringens* spore counts achieves a 77% decrease in the overall variance. Most of this reduction in DPCA-H variance arises from the adjustment for grain size. This is evident from a comparison of the scatter in DPCA-H coordinates prior to adjustment (Figure 17) and after (Figure 20). The reduction in variance would be even greater with a slightly smaller mud fraction in Y2N1. This sample is an outlier to the samples in Figure 20, largely as an artifact of the selection of the connecting point ($\xi=0.52$) in the piecewise regression (11). This sample has the largest mud fraction (7%, $\xi=0.54$) of all of the coarse samples in Group F, but still exhibits a community structure consistent with them (Figure 18). Had it been included in the regression on coarse samples, its adjusted DPCA-H coordinate along the first axis would have been +0.3 rather than -1.0 (Figure 20).

While the variance estimated from the DPCA-H residuals (Figure 20) may be slightly inflated due to an inconsistency in Y2N1, it represents a far more accurate estimate of the inherent variability in the baseline infauna than if environmental factors had not been included at all. This estimate of inherent infaunal variability is used to evaluate the power of various sampling designs in Section 4.2.5. Before that, however, the analysis in the next section identifies those species most indicative of variation in the environmental properties.

4.2.3 Important Sentinel Species

Species associated with the three subgroups of grain-size in baseline sentinel samples are shown in Table 13. Only 20 of the 322 taxa contribute more than 1% of the CNESS variation among sentinel samples. Those with the highest rank, in terms of contribution to CNESS variation in the highest plane, are listed. Their rank is shown in parenthesis. Further insight is gained from the PCA-H ordination of species vectors. In Figure 21, species vectors projected onto the highest Euclidian plane are superimposed on sample scores. The covariance biplot of Figure 22 reveals the relationship among species in multidimensional ordination space. This graphical representation is directly related to the (R-mode) cluster analysis of species shown in the dendrogram of Figure 23.

Coarse-grained Sediments

As expected by the high CNESS variation explained by the first two axes, many species that describe CNESS covariance in multiple dimensions (labeled vectors in Figure 22) are also important in the two-dimensional Euclidian display (Figure 21). In both cases, the crustacean *Corophium* nr. *crassicorne* and the spionid polychaete *Polydora socialis* are the primary contributors to stations with coarse sediments (Euclidean Axis-1 < 0 in Figure 21). Together, they account for 16% of the total CNESS variation and 26% of the variation when projected onto the highest plane defined by the first two PCA-H axes.

What is noteworthy about these two species is that the association between them is weak. This is evident from the nearly right angle between the vectors in covariance space (Figure 22) and the directly-related low similarity ($\theta = \cos^{-1}(-.408) = 114°$) between the major cluster groups where they reside (Figure 23). Associated with *Corophium* nr. *crassicorne*, are a large group of species that are indicative of very coarse sediments. *Corophium* nr. *crassicorne* is the dominant taxon only at Station NF17 (mud fraction < 2%), where it is dominant in all three sampling years (Table 12). The distribution of this crustacean is very closely tied ($\cos\theta \leq 0.786$) to that of another gammarid crustacean, *Pseudunciola obliquua*, and the spionid polychaete *Spiophanes bombyx* (Figure 23).

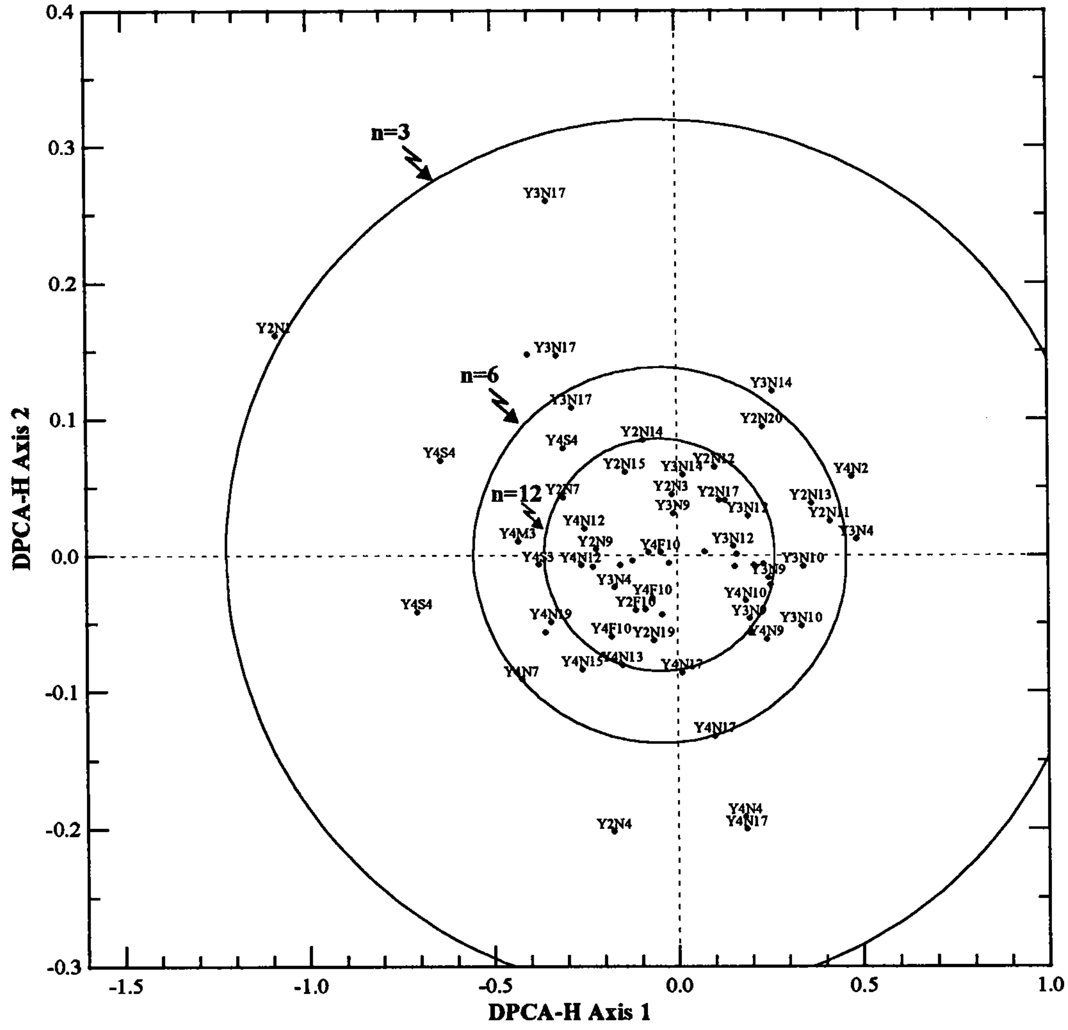

Figure 20. Adjusted DPCA-H coordinates. Equivalent to the residuals from the regression shown in Figures 18 and 19. The three ellipses delineate regions within which new mean values, computed with one of three sample sizes (*n*), would not be significantly different from that of the baseline sentinel stations at $\alpha = 0.05$ and $\beta = 0.5$. Replicate labeling is as described in Figure 12.

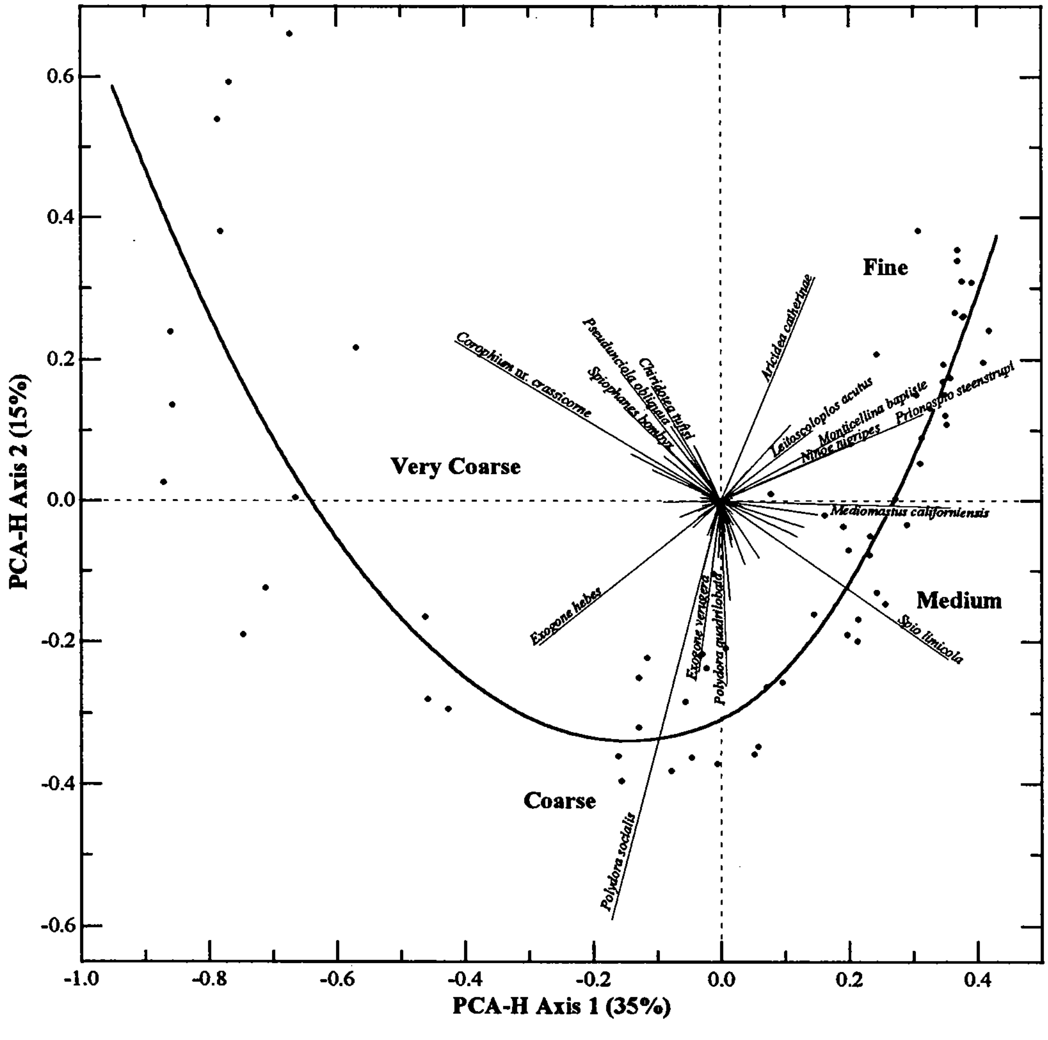

Figure 21. Metric scaling of the species vectors superimposed on the two-dimensional ordination of PCA-H (*m*=18) from Figure 12. Species that contribute more than 3% of the total CNESS variance to this plane are labeled. Quadrants corresponding to the grain-size classes listed in Table 13 are also labeled.

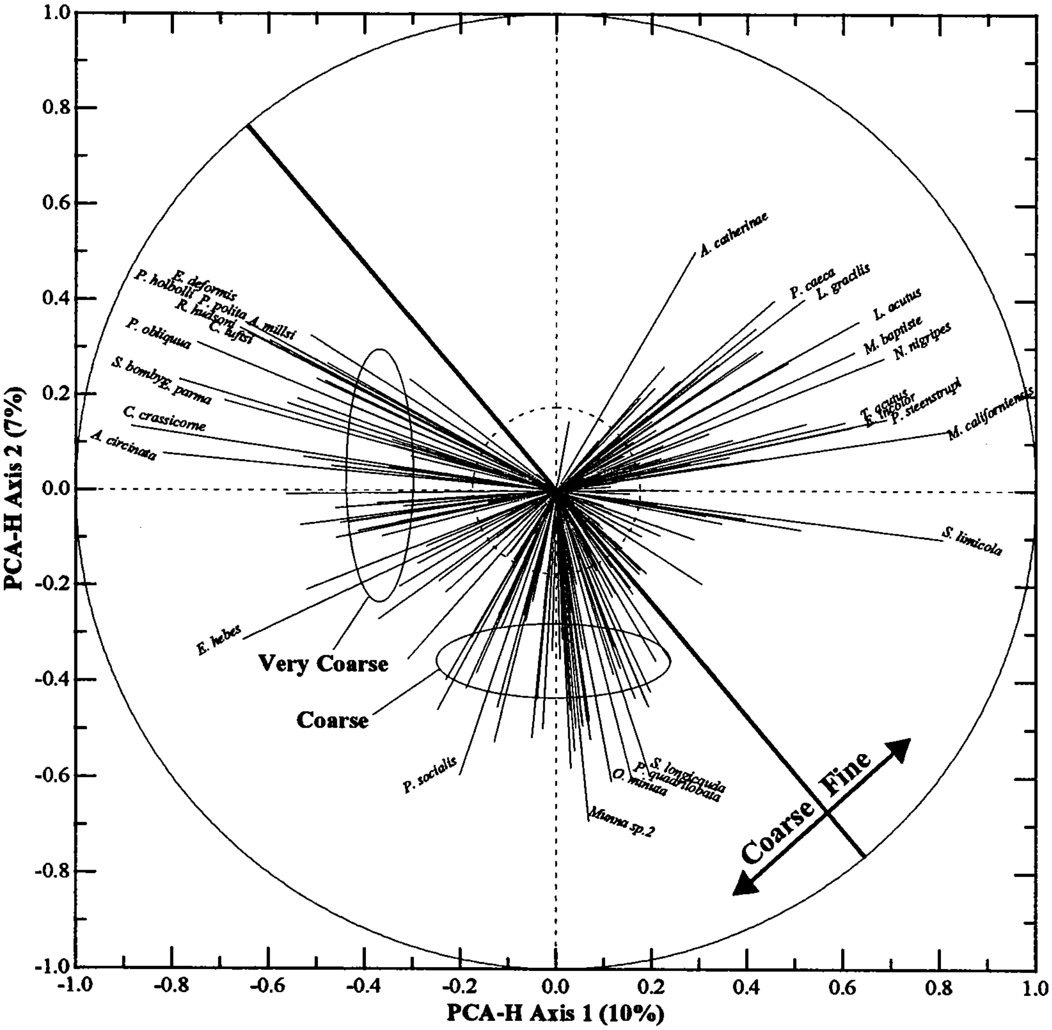

Figure 22. Multi-dimensional covariance plot of species vectors. Acute angles indicate highly associated species. Species that significantly contribute to overall CNESS variation are labeled.

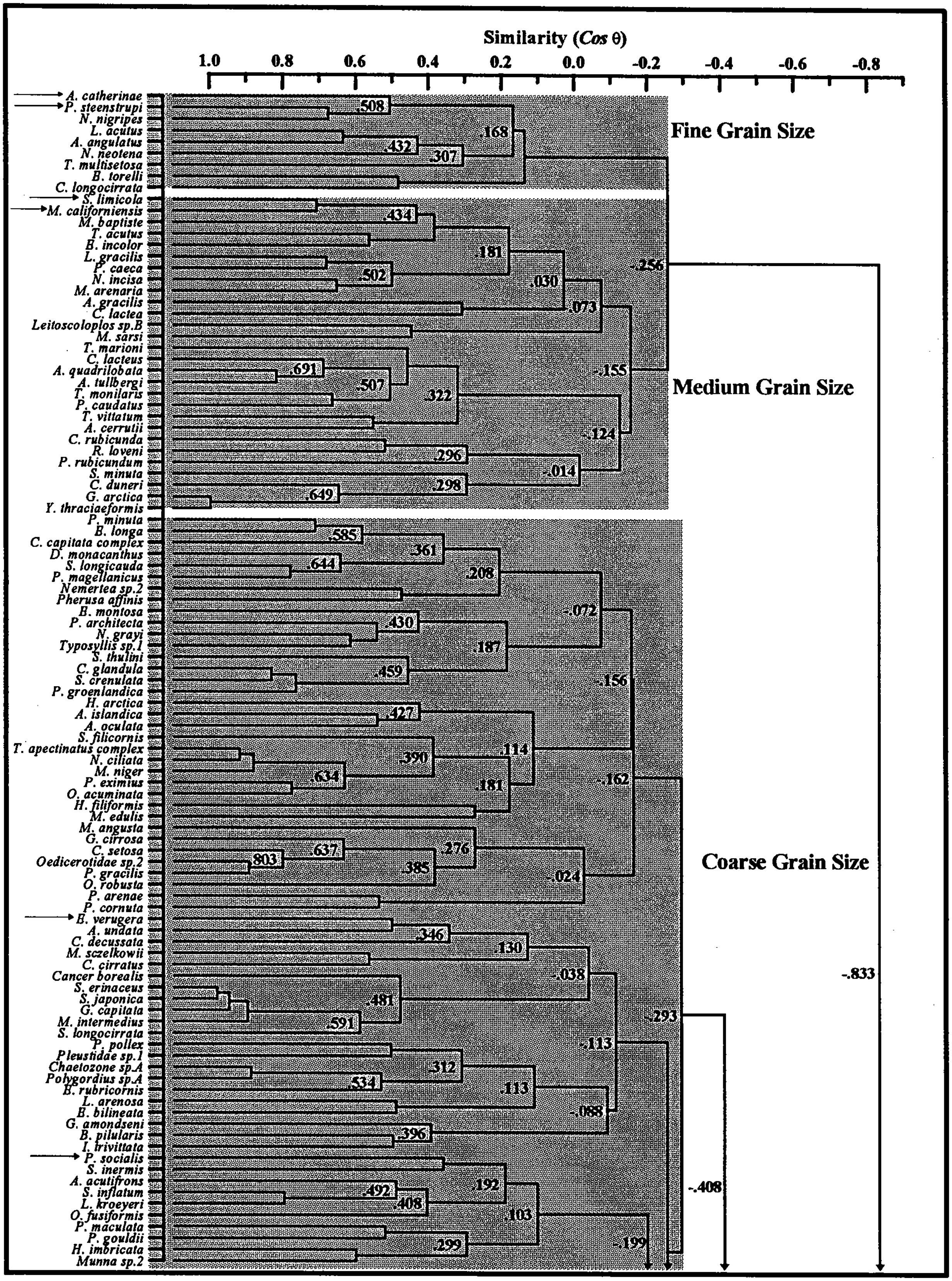

Figure 23. Dendrogram resulting from single linkage clustering of the columns of the hypergeometric probability matrix (*m*=18) using Pearson's correlation coefficient. This is equivalent to clustering the species shown in Figure 22 using *cos* θ similarity where θ is the angle between species vectors in the ordination hyperspace. The shaded regions distinguish among groups of species associated with sediment grain-size classes.

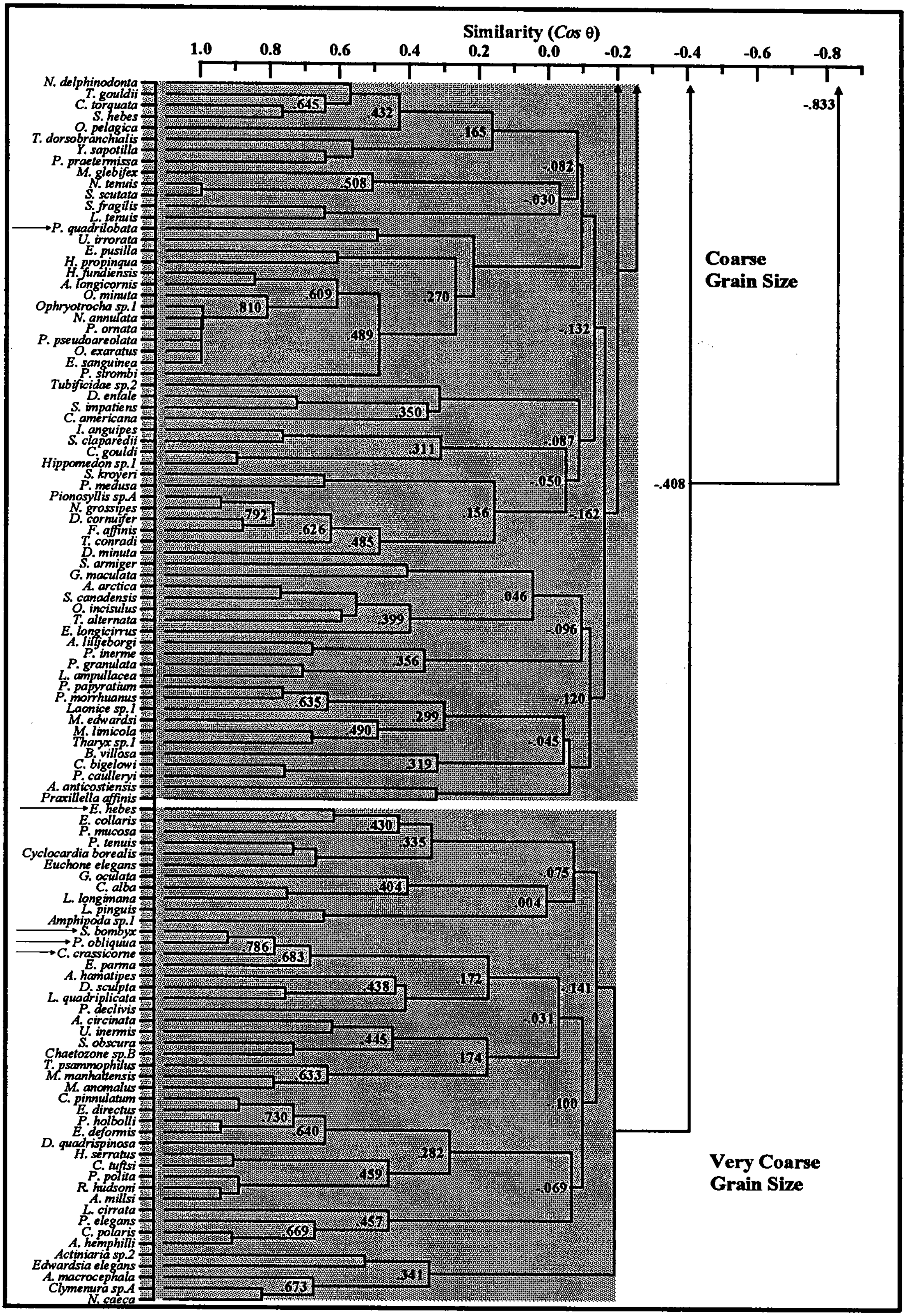

Figure 23 (continued). Dendrogram resulting from single linkage clustering of the columns of the hypergeometric probability matrix (m=18) using Pearson's correlation coefficient. This is equivalent to clustering the species shown in Figure 22 using $\cos\theta$ similarity where θ is the angle between species vectors in the ordination hyperspace. The shaded regions distinguish among groups of species associated with sediment grain-size classes.

An even larger group of species is indicative of moderately-coarse sediments. High abundances of the spionid *P. socialis* are the primary indicator of stations with a mud fraction between 2 and 7%. However, only two other species, namely the polychaetes *Polydora quadrilobata* and *Exogone verugera*, contribute significantly (more than 1%) to CNESS variation in the highest ordination plane. Inclusion of the spionid polychaete *P. quadrilobata* as an indicator of moderately-coarse sediments is noteworthy because this taxon is considered by some investigators (see Pearson and Rosenberg, 1978) to have an affinity for high organics and a tolerance for pollution. Because it is already present in the region, relative increases in its abundance at fine-grained stations close to the diffuser, in response to effluent discharge, are likely to be reflected by significant changes in adjusted DPCA-H coordinates for those post-discharge samples. Thus, the sensitivity of adjusted DPCA-H to changes in a broad range of taxa, while accounting for differences in grain size, allows it to resolve potential anthropogenic impacts possibly overlooked by indices that average effects over entire groups of taxa. Diversity indices or metrics based solely on an ordination of dominant species will not be as sensitive to changes in a few taxa that may be particularly responsive to pollution. In any regard, *P. quadrilobata* is an important sentinel specie.

Medium and Fine-Grained Sediments

The variability in species associated with medium and fine grained sediments is small compared to that of coarse sediments. This is evident from the comparatively small angle subtended by the vectors in the right hemisphere of Figure 22. In fact, as will be subsequently described, some variation may be related to differences in bulk properties other than grain size. Nevertheless, species separately indicative of medium and fine grain sizes, can be determined from the dendrogram of Figure 23. Two polychaetes, the deposit-feeding spionid *Spio limicola* and the capitellid *Mediomastus californiensis* are principally associated with medium-grained sediments. They are major contributors to overall CNESS covariance. Ranked third and fourth (Table 13), they contribute an additional 12% to the total CNESS variation among baseline sentinel samples. *M. californiensis* is another example of a taxon that exhibits an affinity for polluted marine environments (Pearson and Rosenberg, 1978). Like *P. quadrilobata* for coarse grained sediments, *M. californiensis* is likely to be an important sentinel specie.

The species most indicative of fine-grained sediments at the sentinel stations are the deposit-feeding spionid *Prionospio steenstrupi* and the paraonid *Aricidea catherinae*. Together, they account for 10% of the total CNESS variation among baseline sentinel samples. A number of other taxa were also found to be indicative of fine-grained sediments (Table 13). The inclusion of the lumbrinerid *Ninoe nigripes* tends to support the re-evaluation of this taxa as a member of the "deposit-feeding" mud community rather than a dominant specie in Sanders' (1958) "suspension-feeding" sand community (Snelgrove and Butman, 1994). Although the trophic classification is tentative since closely-related species are predacious, their association with fine-grained sediments appears to be consistent with this study.

Nevertheless, the association of some species with the group of medium and fine-grained stations does not necessarily imply that the distribution of that taxon is highly correlated with grain size. In fact, the end points of several species vectors in Figure 21, do not coincide with the piecewise-continuous polynomial regression of PCA-H coordinates. Recall that the after detrending, the resulting DPCA-H Axis 2 represents distance from this piecewise-continuous polynomial. It correlated with sediment bulk properties other than grain size. These other properties, such as TOC, tended to vary collinearly, and were represented by *C. perfringens* spore counts. For medium and fine-grained sediments, two important species vectors (*Aricidea catherinae* and *Spio limicola*) have significant departures from the piecewise-continuous polynomial and therefore, are also related to variation along the DPCA-H Axis 2. This is consistent with other investigations (Coats *et al.*, 1995a; Shea *et al.*, 1991) of medium and fine-grained samples from the region. These studies found a general lack of correlation between sediment grain size and the abundance of *A. catherinae*, *S. limicola*, and *Tharyx acutus*.

4.2.4 Computation of Adjusted DPCA-H

For any new infaunal sample, the adjusted DPCA-H coordinates can be computed and the result compared with the baseline results shown in Figure 20. This is the procedure that would be used, for instance, to test a group of post-discharge samples for a significant infaunal change relative to the baseline sentinel samples. The steps involved in computing adjusted DPCA-H coordinates for a new sample are as follows.

1) Convert the number of individuals recorded for the 353 sentinel species to hypergeometric probabilities with a subsample size (***m***) of 18.

2) Normalize each sample to achieve a total sum-of-squares equal to unity and center the resulting value for each specie by removing the specie mean computed in the analysis of baseline sentinel stations.

3) Project the resulting vector onto the first two principal components computed for the baseline sentinel stations. This provides the coordinates on the highest plane in PCA-H hyperspace as shown in Figure 12.

4) Detrend the non-linearity in the PCA-H coordinates for the new sample by applying the regression equation **(10)** for the piecewise-continuous quadratic equation derived for baseline sentinel stations. This step establishes the detrended PCA-H coordinates (DPCA-H) comparable to Figure 17.

5) Adjust the new sample's DPCA-H coordinates for transformed bulk sediment properties (mud fraction, *C. perfringens* spore abundances, and total organic carbon) by applying the regression coefficients computed for the baseline sentinel stations (as in Figures 18 and 19).

If some or all of the new samples can be pooled, then the adjusted DPCA-H coordinates resulting from the last step are averaged over this pool. To decide whether a significant difference exists between the new samples and the baseline samples, the average can be compared to the confidence ellipse in Figure 20 appropriate to the number of pooled samples.

4.2.5 Detectable Change

The procedure described above is equivalent to performing a null hypothesis test of no statistically-significant difference between the means of new and baseline infaunal samples. The statistical significance of any departures from baseline conditions is based on the specific number of samples ***n***, that are pooled to compute the mean. The comparison is equivalent to a two-group contrast with a multivariate response assuming stations are resampled post-discharge (Green, 1989). The Type I (likelihood of false alarms) error rate is set at $\alpha=0.05$ and for computational convenience, the Type II (likelihood of missing an existing impact) rate is set at and $\beta=0.5$. The circular appearance of the ellipses is an artifact of the relative scaling of the two DPCA-H axes in the plot.

As in the case of the power analysis of chemical contaminants in surficial sediments, confidence ellipses are computed for several values of ***n***, the number of samples pooled to compute the mean infaunal parameters. The smallest sample size of $n=3$, corresponds to the largest number of infaunal replicate samples collected at any one time from any one station. From Figure 20 it is clear that a mean DPCA-H value, computed from three post-discharge replicate samples alone, can vary widely before it is considered significantly different from the baseline sentinel stations. The $n=3$ confidence interval encompasses all of the baseline data except the problematic Y2N1 discussed in Section 4.2.2. Thus, average changes in post-discharge infauna comparable to that of the widely-varying baseline data would not be considered significant.

If, as with sediment chemistry data, the mean impact can be computed by pooling samples from stations within 2 km of the diffuser, then the sample size increases to $n=6$ or $n=12$ and the detectability substantially improves with a decrease in confidence intervals of 50% or more. The choice between these two pooled sample sizes depends on the station design used in post-discharge monitoring. In the sampling design of 1992 and 1993, there were six infaunal samples collected within 2 km of the diffuser (Table 1). Assuming impacts from the effluent occur primarily within 2 km, then the 1994 sampling design is measurably superior with twelve pooled samples. The confidence ellipse vertices along the two DPCA-H axes in Figure 20 are approximately 58% to 65% larger for six samples than for twelve samples. Consequently, a post-discharge repetition of the 1993 sampling design would require anthropogenic infaunal changes that are at least 60% greater than for a repetition of the 1994 design, before those changes could be considered significant.

For the stated error rates and the statistical paradigm applied in this investigation, the goal of detecting of infaunal changes on the order of 100% (MWRA, 1991) would be met by a repeat of the 1994 sampling design but would probably not be met by a repeat of the 1993 and 1992 designs. Unless samples are pooled, it is unlikely that the power of any of the designs would even come close to the detection goal. This is evident from a simple test where impacts are inferred from temporal changes alone. Averaging the twelve 1994 samples collected with 2 km of the diffuser, yields a mean residual value of -0.24 and -0.049 along the adjusted DPCA-H axes 1 and 2, respectively. Assume for the purposes of this discussion, that this mean residual value represents the average pre-discharge infaunal conditions in the extreme nearfield where impacts are expected to occur. For $n=12$, the detection range is ±0.315 and ±0.085 for the ellipse vertices along the respective DPCA-H axes 1 and 2 in Figure 20. Thus, a change in the post-discharge infaunal mean of about 30% along Axis 1 and 75% along Axis 2 would be considered statistically significant for a repeat of the 1994 field design. However, revisiting the 1992 or 1993 field design would allow an average of only six samples. With $n=6$, the ellipse vertices are ±0.50 and ±0.14 for respective DPCA-H Axis 1 and 2. This would require a change in the post-discharge infaunal mean of about 100% along Axis 1 and 180% along Axis 2 before it would be detected. If samples are not pooled then $n=3$, the maximum number of replicate infaunal samples collected at any station in any year. Then, the detectable change is 500% and 650% along the two respective Axes.

Ultimately, the statistical power to detect change will depend on the actual post-discharge sampling, including the success of field sampling, the true extent of impacts, the viability of pooling samples, and the temporal stability of surficial sediments throughout monitoring. The power will also depend on the prescribed error rates as well as the specific statistical paradigm. For example, a purely spatial (mapping) analysis, using kriging to establish trends in the data, will yield different estimates of the power of the various sampling designs. This approach could disclose significant advantages of the unreplicated design of the 1992 survey; but this will depend on the spatial scale and amplitude of impacts. Since these impacts are unknown at this time, power analyses using alternative statistical paradigms are not pursued herein.

4.2.6 Comparison with Traditional Diversity Indices

The definition of the baseline infaunal community prescribed in Section 4.2.4, is far superior to that based on diversity indices. Adjusted DPCA-H coordinates are more robust in their ability to detect changes in infaunal community structure for two reasons. First, they are designed to be sensitive to changes in over 350 individual taxa. The CNESS metric has been tuned, through selection of the hypergeometric subsample size, to place somewhat (25%) greater emphasis on dominant species present in baseline infaunal samples collected at midfield distances from the diffuser. Nevertheless, significant increases in the abundance of comparatively rare species, for example in response to post-discharge effluent exposure, are also likely to be detected by the multivariate analysis. In contrast, diversity indices, such as those computed in Table 6, average effects over all species present. In fact, a community index could be identical for samples that have no species in common, as long as the relative abundance and number of species is the same. This would not be the case for DPCA-H coordinates. A comparison of the infaunal communities in Cape Cod Bay and at sentinel stations provides a case in point.

As will be subsequently shown at the end of this section, their diversity indices differ little despite wide zoogeographic differences in their infaunal communities.

The second reason that the adjusted DPCA-H coordinates are more robust than those based on diversity indices, is because of their ability to account for extreme ranges in grain size and other bulk sediment properties. This attribute is crucial if full use is to be made of samples collected at stations very close (<2 km) to the diffuser. As described in the power analysis of surficial sediment contaminants (Section 3.2.2), these stations are likely to experience the greatest changes in infauna due to impacts from the effluent. Specifically, Stations NF13, NF17, and S3 all lie within 2 km of the diffuser (Table 1) and all were sampled in the latest (1994) survey. They also have extremely coarse (<5.4% mud, Table 4) grain size fractions. The majority of other samples collected at midfield distances do not have surficial sediments this coarse. As shown previously, the associated infaunal community at these coarse stations departs substantially from majority of stations with fine fractions closer to the norm. As a consequence, it would be difficult to directly implement an optimal impact assessment study, since it requires pairing of reference and impacted stations with "similar" infauna prior to exposure. A case in point is Station NF17. It has no companion station distant from the diffuser.

Station NF17

Station NF17 is of particular interest for the outfall monitoring program. It was sampled in all three baseline surveys and included replication in the last two years (Table 1). It is also one of the closest stations to the diffuser (<1 km). To exclude it from the pool of stations used to test for post-discharge anthropogenic impacts of the effluent, would significantly reduce the power of the analysis. For comparisons using the 1993 sampling design, it would reduce the number of samples in the extreme nearfield (<2 km) from 6 to 3, and in the 1994 sampling design, exclusion of coarse stations would reduce the number of samples (***n***) from 12 to 7. Unfortunately, with a mud fraction of less than 2%, Station NF17 has consistently had the coarsest surficial sediments of any of the 37 stations sampled in the entire monitoring program (Table 4). Not surprisingly, its infaunal community departs substantially from that of stations with fine sediment fractions closer to the norm.

The influence of Station NF17 on the two approaches to detectability (DPCA-H versus diversity) is examined with the following paradigm. Consider the samples collected in 1993 to be pre-discharge and those collected in 1994 to have a community structure potentially influenced by the onset of effluent discharge. These sampling years are selected because they each consist of three replicates. With the knowledge that both years are actually predischarge, one would expect appropriately-designed hypothesis tests to find that any change in community structure between years is not statistically significant. The average adjusted DPCA-H coordinates for the three replicates from each of the two years is shown in Figure 24. As expected, averages are well within the confidence ellipse for three pooled samples and any differences are not significant at the stated error rates.

Now consider an equivalent test based on diversity indices. Table 14 shows a power analysis of the four diversity indices based on 66 baseline sentinel samples. For completeness, the raw specie counts and abundance are also shown. The detectable change in diversity indices is a factor of 2 to 3 higher for a pool of three samples (***n=3***, the maximum number of replicates at a given station within a particular year) than for a twelve-sample pool (***n=12***, the maximum number of samples collected within 2 km of the diffuser in the 1994 sampling design). Table 15 shows the results of a hypothesis test that compares the average of three 1993 samples at Station NF17 with that of 1994. Differences between years in all four diversity indices were found to be statistically significant at error rates equivalent to those used in testing the DPCA-H coordinates. Thus, a hypothesis test based on diversity indices leads to a false conclusion of impacts, when the equivalent DPCA-H test would correctly indicate no significant differences.

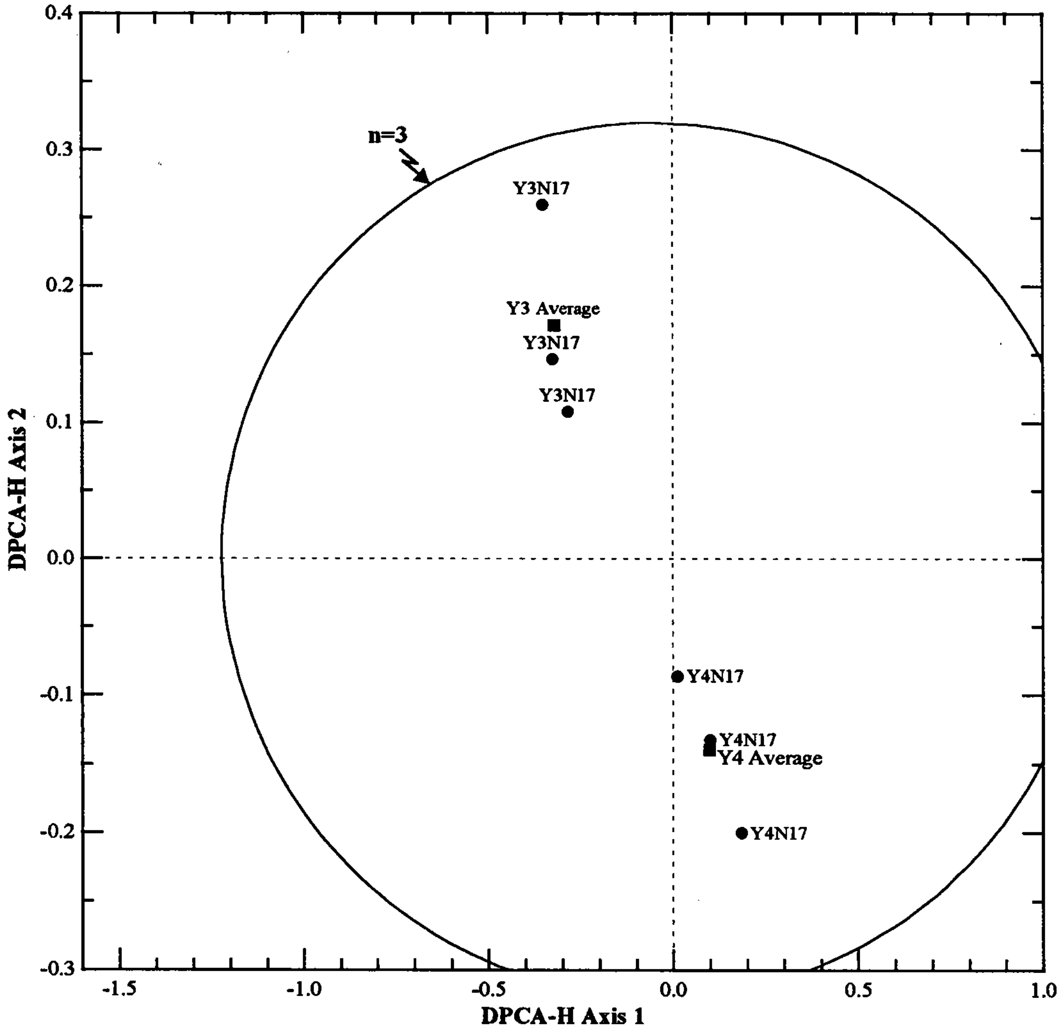

Figure 24. Adjusted DPCA-H coordinates (●) and means (■) of replicate samples collected at Station NF17 in 1993 and 1994. The ellipse encompasses the region within which mean values, computed from three replicates (n=3), do not depart significantly from that of the baseline sentinel stations at $\alpha = 0.05$ and $\beta = 0.5$. Replicate labeling is as described in Figure 12.

Table 14. Detectable percent increase in benthic infaunal community indices as a function of the number (n) of replicate samples included in the computation of the mean[a].

	Number of Species[b]	Abundance (Individuals m^{-2})	Diversity (H')	Evenness (J')	Dominance (C')	Richness (d')
Mean[c]	59	47787	2.55	0.63	0.16	7.81
Standard Deviation[c]	15	28361	0.39	0.091	0.085	1.55
Detectable Change (%)						
n=3	34	2016	21	20	73	27
n=6	20	1177	12	11	42	16
n=12	13	763	8	7	27	10

[a] Based on a one-sided *t*-test assuming paired sampling (revisit the same stations in post-discharge surveys), α=0.05, and β=0.5.

[b] Computed on a replicate sample basis in contrast to Table 6 which is normalized to stations.

[c] Baseline values computed from 66 samples at sentinel stations.

Table 15. Statistical significance[a] of differences in mean diversity indices computed at Station NF17 in 1993 and 1994.

	Three 1993 Replicate Samples			Three 1994 Replicate Samples		
	Mean	**Standard Deviation**	**Detectable Change (%)**	**Mean**	**% change**	**Statistical Significance**
Number of Species[b]	24	3	34	48	96	Significant
Abundance[c]	4900	2838	2016	46717	21335	Significant
Diversity (H')	2.23	0.54	21	1.72	-23	Significant
Evenness (J')	0.71	0.191	20	0.45	-37	Significant
Dominance (C')	0.22	0.169	73	0.4	79	Significant
Richness (d')	4.51	0.38	27	6.2	38	Significant

[a] Based on a one-sided *t*-test assuming paired sampling (revisit the same stations in post-discharge surveys), $\alpha=0.05$, and $\beta=0.5$.

[b] Computed on a replicate sample basis.

[c] Individuals m^{-2}.

Cape Cod Bay

The opposite problem of not detecting significant differences is provided by another comparison of the two approaches for testing for anthropogenic change. Consider the following paradigm based on the six samples collected each year at the zoogeographically-remote stations within Cape Cod Bay (Stations FF6 and FF7). These stations are the most distant baseline sampling locations from the sentinel stations (>60 km from the diffuser) and previous analyses (Section 4.1.5) suggest that their infauna are materially different from the balance of the monitoring stations. For example, the dominant species (Table 12 and 13) collected at the Cape Cod stations differ substantially from those of the other stations. Suppose that after effluent discharge begins, six samples collected in the nearfield yield infaunal communities identical to those collected at Stations FF6 and FF7 in any one of the three years of sampling. Because of their zoogeographic isolation, hypothesis tests should be able to distinguish between the infauna at the Cape Cod stations from those of the sentinel samples. The results of applying the five steps (Section 4.2.4) to compute adjusted DPCA-H coordinates for the "new" samples are shown in Figure 25. It shows that averages computed from the five to six samples collected in each year, all depart significantly from the confidence ellipse for ***n=6*** surrounding the baseline sentinel samples. This ellipse is identical to that of Figure 20. This shows that the infaunal community in these "new" post-discharge samples depart significantly from baseline conditions. Differences of this magnitude, if observed near the diffuser, could be ascribed to the impact of effluent discharge. This is the case for each of the three averages computed from the three years of samples collected in Cape Cod Bay.

Now consider the same paradigm tested with mean diversity indices. Table 16 shows the comparison of mean diversity indices computed for each of the three years of Cape Cod samples with that of significant detectable changes from baseline conditions derived from Table 14. Only one of the twelve diversity indices tested was statistically significant and with the stated error rates. These error rates (*viz.*, ***α=0.05)*** suggest that there is a one-in-twenty probability that a significant difference could occur by chance alone. Thus, despite clear differences in the infauna of the Cape Cod stations, the hypothesis tests based on diversity indices failed to distinguish between baseline conditions and these "new" post-discharge samples. This is a consequence of the insensitivity of diversity indices to changes in the faunal composition of individual taxa. Instead, they focus on total number of species and the relative distribution of abundance among taxa, without regard to what those taxa are. Here, samples from widely differing zoogeographic regimes have nearly identical diversity indices.

Thus, hypothesis tests based directly on diversity indices can potentially yield false alarms (Type I errors) because of their inability to accommodate the variability in community structure associated with sediment properties; case in point, Station NF17. Moreover, they are incapable of distinguishing large (even zoogeographic) differences in infaunal community structure that can lead to Type II errors where an existing impact is missed; Case in point, stations within Cape Cod Bay. In both instances, the DPCA-H is likely to provide a superior hypothesis test because of its ability to accommodate differences in bulk sediment properties and its robust sensitivity to changes in a large number of individual species.

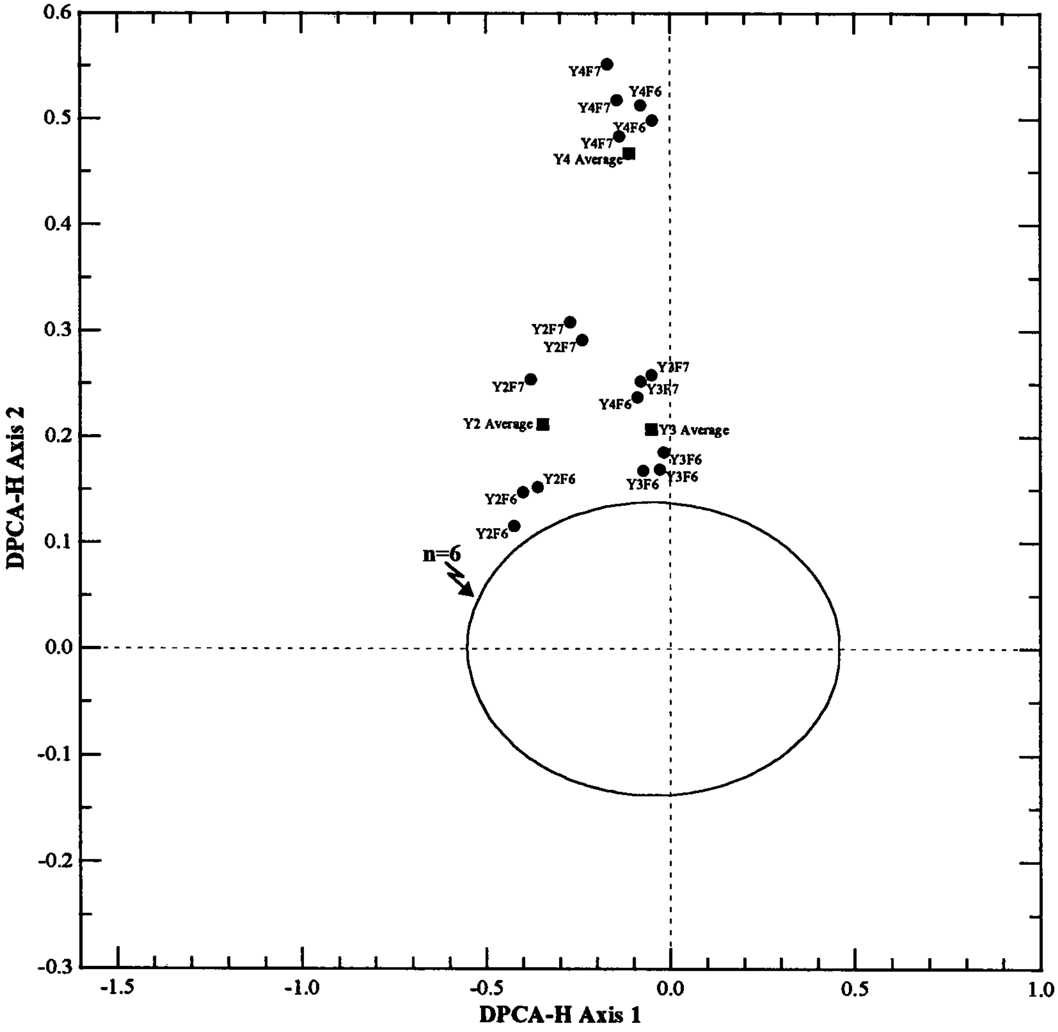

Figure 25. Adjusted DPCA-H coordinates (●) and means (■) of replicate samples collected at Cape Cod Stations FF6 and FF7 in 1992, 1993, and 1994. The ellipse encompasses the region within which mean values, computed from six replicates (n=6), do not depart significantly from that of the baseline sentinel stations at $\alpha = 0.05$ and $\beta = 0.5$. Replicate labeling is as described in Figure 12.

Table 16. Statistical significance[a] of differences in mean diversity indices between baseline sentinel samples and samples collected within Cape Cod Bay[b].

Six 1994 Replicate Samples			
	Mean	% change	Statistical Significance
Number of Species[c]	50	-15	Not Significant
Abundance[d]	42983	-251	Not Significant
Diversity (H')	2.4	-6	Not Significant
Evenness (J')	0.62	-3	Not Significant
Dominance (C')	0.15	-5	Not Significant
Richness (d')	6.62	-15	Not Significant
Five 1993 Replicate Samples			
	Mean	% change	Statistical Significance
Number of Species	60	1	Not Significant
Abundance	49625	96	Not Significant
Diversity (H')	2.72	7	Not Significant
Evenness (J')	0.67	6	Not Significant
Dominance (C')	0.12	-25	Not Significant
Richness (d')	7.79	0	Not Significant
Six 1992 Replicate Samples			
	Mean	% change	Statistical Significance
Number of Species	36	-39	Significant
Abundance	11463	-1900	Significant
Diversity (H')	2.47	-3	Not Significant
Evenness (J')	0.7	10	Not Significant
Dominance (C')	0.16	1	Not Significant
Richness (d')	5.76	-26	Significant

[a] Based on a one-sided *t*-test assuming paired sampling (revisit the same stations in post-discharge surveys), $\alpha=0.05$, and $\beta=0.5$.

[b] Stations FF6 and FF7.

[c] Computed on a replicate sample basis.

[d] Individuals m^{-2}.

5.0 FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

5.1 ENVIRONMENTAL PROPERTIES

5.1.1 Findings

1) Background concentrations of ten trace metals and seven organic contaminants in surficial sediments were analyzed to assess the adequacy of the nearfield sampling design. Depending on the contaminant, the total number of sediment samples collected for chemical analysis over the three years of benthic surveys ranged from 122 to 132. Trace metals were normalized by aluminum concentration and organic contaminants were normalized by the organic carbon fraction. A $log_{10}(X)$ data transformation of the normalized contaminant concentrations improved frequency distributions insofar as normality and homogeneity of variance.

2) With only one or two sediment chemistry replicates, it is not practical to use individual stations to test the null hypothesis of no impact. Instead, adequate statistical power is achieved by pooling samples in a group of impacted stations close to the diffuser, and a group of control stations presumably distant from significant deposition of effluent particulates. Based on a review of initial dilution models, a region lying within 2 km of the diffuser was conservatively designated as the region of impact. Field sampling conducted in 1994 had the largest number (10) of samples collected within the impact area. The 1992 sampling design had the next greatest number (6) of benthic chemistry samples within the impact area, while only four samples were collected within 2 km of the diffuser in 1993. With respective Type I and II error rates set at $\alpha=0.05$ and $\beta=0.2$, detection of significant increases in mean values of less than 100% can be achieved for the majority of contaminants by the 1994 sampling design. This detection goal, set in the Phase I effluent outfall monitoring plan, is met by less than five of the fifteen contaminants when power analysis is performed on the sampling designs for years prior to 1994. The power of the 1993 sampling design to detect change is a factor of two to five lower than that of 1994. Thus, the most-recent (1994) sampling design is a significant improvement over previous designs and is the only one which achieves the detection goals for the majority of contaminants.

3) The baseline mean and significant increases for the 1994 sampling design are well below published sediment guidelines for biological effects. The 1994 field sampling plan is capable of detecting statistically significant increases in mean contaminant concentrations at levels well below those considered meaningful in terms of biological effects. The baseline concentrations for many of the contaminants are comparable to low or threshold sediment guidelines and for the most part, contaminant increases approaching these lower-level guidelines would not be considered statistically significant for the given sampling design and Type I and II error rates.

4) A simple mass-balance box model estimates the length of time between the onset of effluent discharge and the detection of contaminant increases in sediments. Upper-bound quantitative estimates of contaminant build-up in sediments within 2 km of the diffuser indicate that it will probably take several years before increased contaminant levels can be detected. An even longer period (decades) is anticipated before levels reach the range of probable biological effects. Silver and cadmium are the only contaminants whose increase in concentrations would possibly be detected in one to two years. The detectable increase in other contaminants exceeds six years.

5.1.2 Answers to Contaminant Questions Posed

A series of questions were posed in the introduction. Based on the forgoing assumptions, those questions dealing with contaminants are now addressed. The answers to the questions reiterate and augment the findings resulting from this study and that were presented in the previous section. Numbers correspond to those listed in Section 1.3.1.

1) *What data transformations are needed to approach normality and homogeneity of variance in sediment properties and contaminants?*

For mud fraction and TOC, the best preprocessing of the raw data uses an arc-sine square-root transformation of the fractional values. It is of the form $2\sin^{-1}(\sqrt{X})$, where X is the fractional (not percentage) concentration. This transformation achieves a more normal distribution and homogeneous variance than logarithmic or square-root transformations. Normalization of trace metals by aluminum concentration and organic contaminants by TOC removes a substantial amount of collinearity between each group of contaminants. For the majority of these contaminants, a logarithmic transformation $[\log_{10}(X)]$ of these normalized concentrations results in near-Gaussian frequency distributions with homogeneity of variance.

2) *How many chemistry samples must be pooled to meet detection goals outlined in the effluent monitoring plan?*

For the statistical design and error rates described in Section 3.1, ten samples must be pooled to detect statistically significant increases below 100% for the majority of contaminants.

4) *What is the relative ability of the three sampling designs to detect changes in the surficial sediment chemistry?*

Assuming that impacts will occur within 2 km of the outfall, then only the 1994 field design is capable of achieving the monitoring goals with the statistical design and error rates stated in Section 3. The 1994 field design collects 10 chemistry samples within a 2-km impact region while the 1992 and 1993 designs collect six or fewer samples. For most chemical contaminants, the 1994 design is capable of detecting increases in concentrations that are 30% to 50% smaller than the earlier designs.

5) *What is the likely region of impact for measurable increases in contaminants after effluent discharge begins?*

Based on a review of available modeling results, the region within a 2-km closest-approach distance to the diffuser-cap corridor would be a highly conservative estimate of the region where measurable accumulation of effluent particulates will occur. The region is likely to be much smaller since the models do not account for a large array of dispersive processes that occur after initial deposition. Furthermore, a measurable increase in contaminant concentration does not imply biological impacts.

6) *How long will it take for contaminant concentrations to reach levels where infaunal effects become apparent in the impact region?*

For the 1994 field design of 10 samples collected in the 2-km impact region, the detectable increase in average concentration is well below median or probable levels of biological effects. After discharge begins, it will be at least six years before increased concentrations are detected for the majority of measured sediment contaminants. The exceptions are for increases in cadmium and silver which could be detected in less than two years. It will take more than five years before an increase in concentration in mercury or silver reaches low or threshold levels of biological effects. A simple box model predicts that it will take decades before contaminant concentrations averaged over the 2-km impact region reach levels considered meaningful in the baseline monitoring plan.

5.1.3 Recommendations

Two of the basic components of impact assessment were not rigorously established by this study. They can only be established as a matter of policy and not with scientific investigation alone. They are the two types of error rates associated with hypothesis tests. While the Phase I baseline monitoring plan (MWRA, 1991) identified changes in parameters that should be detectable by the monitoring program, it did not specify the associated risk of a false alarms (Type I error rate) nor the risk of missing meaningful impacts (Type II error rate). For each parameter, the Phase II monitoring plan should update the Phase I goal of detectable change to explicitly specify: 1) the level of change considered meaningful in terms of impacts since this is not synonymous with detectable change; 2) the error rate (α) associated with the probability of mistakenly rejecting a true null hypothesis; and 3) the error rate (β) associated with the probability of mistakenly failing to reject a false null hypothesis.

As more data are accumulated as part of the baseline monitoring program, more global approaches to the statistical analyses should be considered. Some of these are reviewed by Skalski (1995) and the include consideration of the interannual time series in a repeated measures analysis of temporal trends. Meta-analysis (Hedges and Olkin, 1985) would combine the information from the many different monitoring components and would thereby serve to increase the overall power of statistical analyses. Also, the results of the baseline statistical analyses presented in this report are based on a relatively-simple box model and a variety of assumptions. Future field studies into the dispersion of discharged effluent, such as plume tracking of dye released from the outfall, would serve to refine the fate model and lend additional credence to the projected contaminant-accumulation rates.

Based on the limited statistical findings summarized in this report, the existing (1994) baseline sampling design is capable of achieving the detection goals outlined in the baseline monitoring plan. Moreover, projected accumulation rates for contaminants are so low that it will be years before impacts are detected and even longer before they reach biological effects levels. Thus, the annual sediment chemistry sampling program could conceivably be reduced in scope, either by increasing the time between sampling or by monitoring only selected constituents on an annual basis. The selected constituents for continued annual monitoring would include: silver, cadmium, copper, and zinc, because these metals are anticipated to be the first to show increased concentration in surficial sediment. They could act as sentinels for triggering an increase in the scope of the sediment chemistry monitoring after significant changes are detected in their concentration some time after effluent discharge begins.

5.2 BENTHIC INFAUNA

5.2.1 Findings

1) Differences in field sieving procedures among surveys do not affect the interannual comparisons conducted in this study. This is because this investigation uses the combined enumerations from all size fractions. However, analysis of separate sieve-size fractions could affect interannual comparisons or comparisons with other data sets.

2) Collection of replicate samples is useful for data verification in addition to commensurate statistical advantages. Justification for the removal of Replicate 2 in Y3F7 from the analysis is strongly supported by comparison with the two other replicates from that station-year. Because the abnormal sample in Y4N5 was unreplicated, there is not the same level of confidence for its removal.

3) The baseline infaunal data set considered appropriate for community analysis, consists of 244,040 organisms representing 322 species in 170 samples. Taxa not identified to species level are excluded from this data set. Additional species are excluded because their size or motility suggests they are undersampled by the collection method.

4) Diversity indices are easy to compute and have historically been used to succinctly represent infaunal community structure. However, they can result in ambiguous biological interpretations and may not represent unbiased estimates of diversity because of an assumed relationship between species and sample size. A preferable approach estimates the probable number of species in subsamples of various sizes, ***m***. The rarefaction method is an example of an application of these hypergeometric probabilities. This study applies hypergeometric probabilities in multivariate analyses. As described in the response to Question 3 in Section 5.2.2, this investigation's approach offers significant advantages over diversity indices.

5) This study successfully defines community structure by applying existing computational techniques based on hypergeometric probabilities. The CNESS measure of distance (dissimilarity) between two samples is used in cluster analysis. It offers advantages because it is a metric distance measure and because its sensitivity to rare species can be tuned through the selection of an appropriate subsample size ***m*** which is used computing the hypergeometric probabilities. For the outfall monitoring data, a subsample size of ***m=18*** gives about 25% greater emphasis to dominant species while retaining some association with rare and even singleton species. Inclusion of rare species is important for impact assessments because comparatively-large anthropogenic changes in their low abundance may otherwise go unnoticed in parameters that focus only on the dominants. Species (R-mode) clustering is performed using published techniques based on hypergeometric probabilities that are direct companions to the (Q-mode) sample clustering based on CNESS.

6) Cluster analysis reveals that small-scale infaunal variability among replicate samples is comparable to the variability among stations separated by distances of less than 1 to 2.5 km. Temporal (interannual) variability is larger and comparable to variability among stations separated by distances of less than 10 or 20 km. Thus, farfield samples collected in any given year are capable of resolving regional zoogeographic differences. However, spatial differences among nearfield samples in any given year are confounded by interannual variation. Consequently, baseline data collected at nearfield stations over multiple years can be pooled to estimate the natural background variability in both time and space. This estimate of variance is used in power analyses.

7) Five stations support unique infauna associated with an instability in surficial sediments. Samples collected at Station NF2 in 1993 and Stations FF12, NF16, NF18, and NF20 in 1994 have a unique infaunal community. This community differs from that observed in samples collected at the same stations in prior years and from those associated with other stations having similar but stable surficial sediment characteristics. Because of the unique infauna associated with these samples and the temporally unstable surficial sediment conditions, these samples are excluded from the computation of natural background variability used in evaluating the power of the field program to detect anthropogenic change.

8) Cluster analysis also clearly delineates zoogeographic distinctions in two groups of farfield stations. These distinctions appear consistently across the three sampling surveys despite substantial interannual variability. The largest group consists of stations within Eastern Massachusetts Bay including those within Stellwagen Basin (FF1, FF4 and FF14) as well as Station FF11 well to the north and Station FF5, adjacent to the southern reaches of Stellwagen Bank. Station FF9, immediately inshore of Stellwagen Basin, also supports infaunal characteristics of Eastern Massachusetts Bay and may represent a transition to the shallower infaunal communities next to the diffuser. The second group consists of two stations (FF6 and FF7) within Cape Cod Bay which have infaunal communities distinct from all other groups of stations. Because of the unique infauna associated with these two zoogeographic groups of stations, and because of their large distance from the diffuser, they are also excluded from the sentinel stations used in computations of inherent background variability associated with detection of anthropogenic change from effluent discharge.

9) Additional stations that appear to be influenced by nearshore or estuarine processes are excluded from the estimate of infaunal variance. The remaining stations lie close to the diffuser and exhibit a homogeneous community structure. These stations act as sentinels for detecting future infaunal changes due to effluent discharge from the new outfall. There are sixty-six baseline samples associated with these sentinel stations. Samples collected at these sentinel stations over three years of monitoring establish baseline conditions for comparison with future post-discharge collections of samples and for estimating the inherent variability in infaunal properties that can be used to determine the power of various sampling designs.

10) Power analyses are based on an applications of multivariate techniques to community ordination. Again, the ordinations are based on published techniques that rely on hypergeometric probabilities. Principal component analyses of hypergeometric probabilities are designated PCA-H and are companions to the classification analysis using CNESS.

11) Infaunal variation among samples collected at sentinel stations is significantly correlated with the bulk sediment properties of grain size, TOC, and *C. perfringens*. Because contaminant concentrations in surficial sediments are generally below biological effects levels, no attempt was made to correlate infaunal abundance with them. The strongest infaunal correlation is with the silt and clay (mud) content of the samples. The mud content ranges from less than 2% to over 85%. Because of this large environmental gradient, nonlinear infaunal response is reflected by curvature along the linearly independent PCA-H axes. Other ordination techniques, such as non-metric multidimensional analysis, which accommodate substantial nonlinearity in coenclines, are also unable to eliminate the curvature. Detrending or unfolding of this curvature leads to a better representation of the infaunal variation related to the secondary benthic properties, TOC and *C. perfringens*. A piecewise-continuous quadratic regression, where infaunal variation in fine-grained sediments is considered separately from coarse sediments, provides the best local fit. The resulting detrended PCA-H coordinates (DPCA-H) along the two principal axes reflect variation in infaunal properties that independently correlate with grain-size (first axis) and *C. perfringens* (second axis). The second DPCA-H axis also exhibits a statistically-significant linear relation to TOC. Adjustment of the DPCA-H coordinates for bulk properties result in a 77% reduction in infaunal variance. This infaunal variance, which accounts for variation in bulk environmental properties, is used to estimate the power of the three baseline sampling designs.

12) Two species that account for substantial CNESS variation in the PCA-H hyperspace are also historically recognized as indicators of pollution. As suggested by the response to Question 10, they are not the principal indicator species but their prominence is noteworthy. Substantial variation in their post-discharge abundance, as reflected in large excursions in DPCA-H coordinates will provide a sensitive measure of effluent impacts. One of these sentinel specie is the spionid polychaete *Polydora quadrilobata* and is primarily present in moderately-coarse sediments in the baseline data. It is known to have an affinity for high organics and a tolerance for pollution. The other sentinel specie is the capitellid *Mediomastus californiensis* which is principally associated with medium-grained sediments.

13) The DPCA-H coordinates, adjusted for environmental properties, provide an estimate of the inherent variability of infaunal communities near the new outfall. With this variance estimate, the power of various field sampling designs can be assessed. For example, without pooling of replicate samples from adjacent stations in the extreme nearfield (<2 km) of the diffuser, the detection goals set forth in the outfall monitoring plan (MWRA, 1991) for benthic infauna will probably not be met. Specifically, for Type I and Type II error rates of $\alpha=0.05$ and $\beta=0.5$, respectively, the detectable change from the 1994 mean infaunal parameter (adjusted DPCA-H, discussed above) exceeds 500% for three replicate samples. This also assumes that stations are revisited during post-discharge surveys and that an optimal impact ANOVA design (Green, 1979) is applied where temporal and spatial changes under impacted and baseline conditions are contrasted. Three replicate samples are the maximum number of infaunal samples collected at any station in any given

year. Thus, statistical hypothesis tests comparing the mean infaunal parameter pre and post discharge, will be unable to resolve meaningful levels of impacts prescribed by the monitoring plan. However, significant improvement in the detection levels is achieved by pooling replicate samples from stations immediately adjacent to the diffuser. In the sampling designs of 1992 and 1993, six benthic infaunal samples were collected within the 2-km impact region, and the confidence levels were reduced to between 100% and 180% of the 1994 baseline average. With the twelve samples collected in the extreme nearfield of the 1994 sampling design, detection limits are further reduced to between 30% and 75%.

14) Pooling of replicate samples from adjacent stations requires multivariate analysis of a specially-designed infaunal community parameter, such as the adjusted DPCA-H described above. A large proportion of the extreme nearfield samples were collected at Station NF17. Surficial sediments at this station are extremely coarse (mud<2%) compared to the majority of other stations. The associated infaunal community also departs significantly from most other stations. In order to pool all extreme nearfield samples and achieve detection goals, Station NF17 must be included in hypothesis tests. Tests for impacts, based directly on changes in diversity indices, are not capable of accounting for the wide variation in grain size. The average difference between samples collected at Station NF17 in 1993 and 1994, is considered statistically significant if diversity indices are applied but not if the adjusted DPCA-H coordinates are used. This suggests that hypothesis tests based on diversity could lead to false conclusions of impacts when adjusted DPCA-H does not. A test of the statistical significance of infaunal differences at stations within Cape Cod Bay, exemplifies the opposite type of error. The infaunal community at those stations is substantially different from that of the sentinel stations near the diffuser, yet their average diversity indices are not significantly different. The average adjusted DPCA-H coordinates for the Cape Cod stations are, however, significantly different. This suggests that hypothesis tests based on diversity indices could miss existing impacts. The adjusted DPCA-H is more sensitive to differences in individual taxa and consequently, offers significant advantages when testing for impacts.

5.2.2 Answers to Infaunal Questions Posed

The infaunal portions of the questions posed in Section 1.3.1 are now addressed. Numbering for the questions in that section are preserved.

2) *How many infaunal samples must be pooled to meet detection goals outlined in the effluent monitoring plan?*

This is determined with a specific statistical design; namely, a two-group contrast, where stations are revisited before and after exposure to effluent, is tested with error rates of $\alpha=0.05$ and $\beta=0.5$. Also, as in the case of surficial sediment contaminants, impacts are assumed to occur within 2 km of the diffuser. Based on this design, pooling of between six and twelve samples will achieve the detection goal of less than 100% change in baseline conditions.

3) *What is a suitable parameter for measuring change in the benthic infaunal community and are diversity indices adequate?*

A multivariate analysis of an infaunal community metric, such as CNESS, which adjusts for bulk sediment properties, is recommended for determining impacts. In this investigation, adjusted DPCA-H coordinates based on this metric, are far more robust than diversity indices for several reasons. First, they account for infaunal effects from the wide natural variation in bulk sediment properties, particularly grain size. This allows a large number of samples in the extreme nearfield of the diffuser, such as the multiple replicates collected at Station NF17, to be pooled. More importantly, diversity indices could mistakenly perceive infaunal response to grain size variation as being the result of effluent exposure. Second, adjusted DPCA-H coordinates are sensitive to variations in the abundance of specific taxa. In contrast, the same diversity index can apply to two communities with no taxa in common. This can lead to false conclusions of no impact when impacts indeed exist. Despite their historical use in this and other monitoring programs, diversity indices alone are not adequate for testing impacts.

4) *What is the relative ability of the three sampling designs to detect changes in the infaunal community?*

For the given statistical design and associated error rates, the 1994 field design is capable of detecting infaunal changes that are 35 to 40% smaller than for the 1993 and 1992 designs. This assumes samples can be pooled in the extreme nearfield to compute average infaunal structure. If pooling cannot occur, then detectable increases more than double for the replicated designs of 1993 and 1994. With kriging, the unreplicated 1992 design is likely to a yield similarly-low detectability because variance at low spatial lag is comparable to that of replicates.

7) *What stations exhibit distinct zoogeographic differences and what taxa are associated with them?*

Two regions exhibit distinct zoogeographic differences despite strong interannual variability. Stations FF1, FF4, FF5, FF11, FF14, and possibly the transition station FF9, have a unique community structure. They lie within eastern Massachusetts Bay and are characterized by the dominance of *Aricidea quadrilobata*, Chaetozone sp.A, *Tubificoides apectinatus* complex, *Scalibregma inflatum*, *Thyasira gouldii*, *Anobothrus gracilis*, and *Maldane glebifex*. Stations FF6 and FF7 within Cape Cod Bay also exhibit an unequivocally unique infaunal structure characterized by the dominance of *Cossura longocirrata*, *Euchone incolor*, and Tubificidae sp.2. Less distinct local zoogeographic differences, possibly reflecting the estuarine influence of nearby harbors, are evident at Stations FF1A, FF12, FF13, and NF8. They are characterized by higher abundances of *Nephtys neotena*, *Eteone longa*, and *Polydora cornuta*.

8) *How does inherent (replicate) variability in infaunal samples compare with interannual and spatial trends?*

For the most part, infaunal variability among replicate samples is smaller than interannual and medium-to-large scale variability between stations and years. This is the case for most stations separated by more than 1 to 2 km. Spatial variation across smaller distances is on the order of inter-replicate variability. Interannual trends are generally much larger than replicate differences. The only exception is at Station FF4 in the southeastern Stellwagen Basin. That station is sufficiently stable and geographically isolated that replicates from among the three sampling years are indistinguishable. For the majority of stations, however, temporal variability is comparable to spatial variability over distances of 10 to 20 km.

9) *Which baseline samples are appropriate for determining the natural background variability in infauna for use in impact assessments? What stations can act as sentinels for potential future impacts on infauna because of their proximity to the diffuser, temporal stability in environmental properties, and uniformity in community structure?*

Of the total of 172 infaunal samples collected in the baseline monitoring program to date, 170 samples have valid infaunal enumerations. Sixty-six of these 170 samples are deemed appropriate for determining the natural background variability in infauna near the new outfall site. These 66 samples were collected at 24 stations close to the diffuser which have a zoogeographically-isolated infaunal community that is not subject to a major estuarine influences. However, samples collected at four of these stations (NF2, NF16, NF18 and NF20) in the most recent surveys were excluded because of temporal instability. Only 15 of the remaining 20 stations were successfully sampled in the latest (1994) field survey. These 15 stations are prime candidates for testing of post-discharge effluent impacts and are recommended for continued monitoring. These sentinel stations are NF4, NF7, NF9, NF10, NF12, NF13, NF14, NF15, NF17, NF19, MB01, MB03, S3, S4, and FF10.

10) *What association exists between the benthic community structure and bulk sediment properties at these sentinel stations and what taxa are responsible for major differences in community structure?*

For the sediment characteristics considered in this study, grain size has the strongest influence on the community structure. The influence is much greater for fractional changes in the mud content of coarse (<7% mud) sediments. Although the correlation is weaker for medium-to-fine sediments, it remains highly significant ($p<0.0001$). A weaker, but nevertheless significant ($p\approx0.002$) association exists between transformed *C. Perfringens* spore counts and community structure measured along the second DPCA-H axis. A similar but slightly weaker linear association also exist for TOC. The principal taxon associated with very coarse grain size (<2% mud) is *Corophium* nr. *crassicorne*. Moderately coarse sediments (2% to 7% mud) are populated by *Polydora socialis* with *Exogone hebes* acting as a transition between these groups. Medium-grained sediments (7% to 60% mud) are characterized by the presence of *Mediomastus californiensis* and *Spio limicola*, although the latter also bears some relation to TOC concentration and *C. Perfringens* spore counts. Fine-grained sediments (>60% mud) are largely delineated by the presence of *Prionospio steenstrupi* and *Aricidea catherinae* although again, the latter specie varies with the other sediment properties.

11) *What level of anthropogenic change in the infaunal community can be detected at these sentinel stations and how does it compare with the guidelines from the monitoring plan?*

Assuming the baseline mean infaunal community is computed from the 1994 samples within 2 km of the diffuser, the 1994 field design is capable of detecting changes of less than 75% of this average. This is well below the 100% detection goal cited in the monitoring plan (MWRA, 1991). However, no guidance on associated error rates is provided in the plan, and the power analysis performed in this study is based on rather-large (even) odds of not detecting an existing impact (β=0.5).

5.2.3 Recommendations

Three recent reports describing the infaunal distribution in the region rely on diversity indices. In Hyland and Costa (1994), the relationship between chemical contaminants and biological data in the nearshore ecosystem of Massachusetts and Cape Cod Bay is based in part, on a correlation analysis between the concentration of various chemical constituents and the species richness index (d') defined by **(1)**. Similarly, Kropp and Diaz (1994) test for statistically significant temporal and spatial differences in Boston Harbor infauna through application of the diversity index (H') defined by **(5)**, among other parameters. Finally, Coats *et al.* (1995a) qualitatively compare the full suite of diversity indices described in Section 2.3.1, with infaunal patterns from the same 1993 survey included in this investigation. Despite this historical precedence, this study finds that diversity indices alone should not be used to test for post-discharge anthropogenic impacts from the new outfall. Multivariate analyses are far more robust because they are sensitive to changes in a large number of individual infaunal species and they can be designed to accommodate large gradients in natural environmental properties that affect the infaunal distribution. The infaunal parameter recommended in this study is CNESS. Among its many advantages, it is a true metric and it can be tuned to be sensitive to both rare and dominant taxa.

Other than this recommendation for testing impacts with multivariate CNESS analyses, there are some less-definitive insights that arise from this investigation. What follow are a series of recommendations for future work. Since they do not consider limitations on monitoring resources nor the relative importance of other monitoring components, they should be considered less imperative than the forgoing recommendation for the infaunal analysis procedure.

The observations of 1994 soft-bottom monitoring program and related field studies pose interesting questions. One in particular is the presence of a large community of *Urophycis* spp. (hake) residing in burrows near Station S4 (Coats *et al.*, 1995b). They were not observed elsewhere. Recall that this station had wide variability among replicates both infaunal and physicochemical. Station S4 is important to the benthic monitoring because it is the closest station to the diffuser (by far) and is likely to be the first to detect impacts from the effluent. However, two questions arise concerning the hake:

1) Is there some trophic relationship between hake and benthic infauna? If there is, then this may account for the increased variability in infaunal abundances at Station S4. Some review of the literature, discussion with ichthyologists, or even stomach content analysis may reveal some of the needed insight.

2) Are they likely to remain in the region after effluent discharge or, for that matter, prior to discharge? Including this region in future video surveys is advisable. Perhaps their presence at Station S4 was transitory. If not, and if they remain in the region after discharge, their histopathology would be of interest. In fact, a few organisms collected as part of baseline monitoring could be used to establish background levels of response. This localized megafaunal sample collection could also be used for the stomach-content analysis.

The interannual sediment and infaunal instability observed at some stations is problematic. The infaunal community that populates these sites after a dramatic drop in the mud fraction is unique. It is not the same as the community that occupied the site prior to the change nor is it similar to stable sites with comparable mud fractions. This suggests that it is transitory and will undoubtedly affect tests concerning pre and post-discharge impacts. Here, it was assumed that these unstable stations have been fully identified and they were simply excluded from analysis. However, there does not appear to be any consistent pattern to the unstable stations. Because they are adjacent to stable stations and span a range in depth suggests that the cause of the instability is localized and perhaps not related to regional physical processes of resuspension and erosion. Also, the complexity and variety of mechanisms controlling the animal-sediment relationships (see Section 4.1.3) makes it difficult to predict infaunal communities from grain size, even at stable stations.

The problem is this; if post-discharge grain-size changes dramatically from baseline conditions at one of the "stable" sites, the credibility of the statistical design will be compromised unless additional information can be applied. Additional effort should be directed at determining the cause for the winnowing of fines at the unstable sites described here. At a minimum, all pertinent available data on physical processes in the region, including geological, oceanographic, and meteorological, should be examined for correlation with instability in the station-years listed here. Certainly, a detailed review of the location of sediment facies described by Bother *et al.* (1992) is in order. At a maximum, Geoprobe tripods (Cacchione *et al.*, 1987) could be deployed at unstable sites and controlled biological experiments addressing larval and food supply issues could be conducted. Also, in the interest of measuring effluent particulate deposition alone, not to mention resuspension at sites distant from the diffuser, deployment of sediment traps should be considered.

Station NF17 poses a related difficulty. The mud fraction at this station was much lower than at any other station. As a consequence, its infaunal community differed from that of any other station, even those considered to have coarse sediments. The difficulty is that a basic premise of optimal impact assessments is that similar stations at control and impact sites are compared pre and post-discharge. Station NF17 is close to the diffuser and there is no "similar" control site located at distance, or anywhere in the baseline surveys for that matter. It is unreasonable to simply exclude Station NF17 from the analysis because it now has a long history of baseline sampling and is the second-closest site to the diffuser. In this study, a significant effort was expended to account for extremes in grain size so that NF17 could be used in the pool of impact sites. Another approach would be to search for a site with similar infaunal and sediment characteristics at some distance from the diffuser. Again, this could begin with a minimal effort examining high-resolution sediment-facie maps (Bothner *et al.*, 1992).

5.2.4 Monitoring Criteria

During reviews of a draft of this report, two important issues were raised concerning the development of environmental criteria based on effluent-induced changes in the infaunal community. These issues can be accommodated in a variation of the statistical approach described in Section 4. First, the optimal impact study described in the body of this report focusses only on detecting infaunal changes without regard to when changes might be considered unacceptable. Based on the Supplemental Environmental Impact Statement (EPA, 1988) and other analyses described in this report, some localized impact is expected. In fact, detection of post-discharge changes in the extreme nearfield using the statistical design described in this study, would confirm the adequacy of the field sampling program. However, a key purpose of benthic monitoring is disclosure of unacceptable impacts on the infauna. These can occur both if the impacts unexpectedly expand over a wide geographic area, well outside the 2-km region in the extreme nearfield of the diffuser, or if unexpectedly-severe infaunal degradation occurs in the extreme nearfield, far beyond that predicted to occur under secondary treatment (EPA, 1988).

In the latter case, the optimal impact statistical design described in this report could be implemented with a specific warning level for excessive post-discharge changes in adjusted DPCA-H coordinates within the extreme nearfield. These unacceptable changes would be larger than the detection levels described in Section 4.2.5 and should be set through consultation with outside regulators and technical reviewers. One possibility is to establish the warning level for extreme degradation at a point where the post-discharge DPCA-H mean over extreme nearfield samples, exceeds the maximum range observed in individual samples collected during pre-discharge baseline surveys. This would warn of changes that exceed those expected from natural ambient variability.

For the other case, where impacts unexpectedly extend beyond the 2-km region in the extreme nearfield of the diffuser, a possible criterion for unacceptable midfield impacts is presented below. However, it should be noted that the associated statistical design differs from the optimal impact paradigm described in the body of this report. In the optimal impact design, changes are detected by contrasting the mean infaunal community structure at "control" and "impacted" sites before and after discharge. Sites were considered "impacted" by the outfall if they were located within about 2 km of the diffuser corridor. They were contrasted with "control" stations thought to lie at a distance of between 2 km and 7 km from the diffuser. If these midfield stations no longer represent control stations, then conclusions concerning the power of the various field sampling designs to detect infaunal change would be different. Nevertheless, detectable midfield changes can be readily computed using the same procedures described in Section 4.

Specifically, testing for infaunal changes at midfield sentinel stations would effectively eliminate spatial controls and reduce the statistical power. As described in Section 4, the subset of "sentinel" stations are optimal for detecting infaunal change because they have temporally-stable communities that are zoogeographically consistent. More distant stations have substantial zoogeographic differences and would be difficult to use as controls in an ANOVA design. If the midfield sentinel stations no longer represent unimpacted sites, then only a temporal contrast would be present in the statistical design and the comparison would be between the mean infaunal structure at midfield distances before and after discharge. Kriging procedures described in Section 1.2.2, would be a useful alternative to the ANOVA design inasmuch as the resulting maps would lend insight into the actual spatial extent of impacts.

The second important issue concerning implementation of infaunal monitoring criteria, pertains to the measurement of community structure using adjusted DPCA-H coordinates. Recall from Section 4.2.2 that the DPCA-H coordinates were adjusted for variation in background levels of *C. perfringens* spore counts. Although statistically significant, the adjustment was weak compared to grain size and could have been applied to the TOC fraction with nearly equal success. While this is a reasonable approach for specification of the baseline infaunal community, impacted sites in the post-discharge environment could experience significant changes in *C.*

perfringens spore counts as well as TOC. The spores are produced by a naturally occurring bacterium found in the intestinal tract of mammals and as with TOC, their distribution has been established as a sewage effluent tracer (Keay *et al.*, 1993; Hill *et al.*, 1993). By adjusting the DPCA-H measure of community structure for variation in *C. perfringens* spore counts in the post-discharge environment, some effluent-induced changes in the infauna, the very ones at issue, may be significantly reduced or missed. However, since regressions on *C. perfringens* spore counts in baseline data resulted in only modest reduction in the overall error variance, they could easily be eliminated from the DPCA-H adjustment without significant loss of generality. This approach would allow the full impact of effluent-induced changes to be observed in the infaunal community parameter.

With these two issues in mind, an example of a testable criterion for unexpectedly-widespread anthropogenic impacts on infauna resulting from effluent discharge is as follows.

> *The mean infaunal community structure at granularly-stable midfield (2-7km) stations shall not change by more than three standard deviations from baseline conditions after allowing for a 20% risk of falsely observing changes of this magnitude (type I error = α = 0.20) and a 20% risk of not observing change of this magnitude when they in fact exist (type II error = β = 0.20). The infaunal community structure shall be specified with a robust infaunal parameter that accounts for gross differences in granularity among midfield stations and that is sensitive to changes in both rare and abundant taxa.*

Note that the criterion focusses on the mid-field stations between 2 km and 7 km from the outfall, and that no mention is made of adjustment for *C. perfringens* spore counts or TOC. Also, while DPCA-H coordinates are not specifically mentioned, their desirable features are indicated; namely, sensitivity to a broad range of infauna and adjustment for grain size. Finally, the levels of both types of error are specified. While the actual level of risk, here set at 20%, is a matter for regulatory policy, it is also a function of available sampling effort. The "95% confidence" limits often quoted for controlled laboratory experiments, are rarely achieved in expensive field surveys conducted on highly-variable parameters. Also, the two types of error are set to be equal because, as Skalski (1995) points out, " . . . it seems reasonable for both parties to bear equal risk . . . ." The parties he is referring to are a) the public trustees of the environment and b) those responsible for the discharge.

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APPENDIX A-1: KEY TO SEDIMENT CHEMISTRY ANALYTES

PAH (ng/g)		PCB/Pesticides (ng/g dry wt)		Metals (µg/g)	
Column	**Full Analyte Name**	**Column**	**Full Analyte Name**	**Column**	**Full Analyte Name**
naphthalene	naphthalene	CL2(08)	CL2(08)	AL	ALUMINUM
C1-naphthal	C1-naphthalenes	HEXACHLOROB	HEXACHLOROBENZENE	FE	IRON
C2-naphthal	C2-naphthalenes	LINDANE	LINDANE	PB	LEAD
C3-naphthal	C3-naphthalenes	CL3(18)	CL3(18)	HG	MERCURY
C4-naphthal	C4-naphthalenes	CL3(28)	CL3(28)	NI	NICKEL
biphenyl	biphenyl	HEPTACHLOR	HEPTACHLOR	AG	SILVER
acenaphthyl	acenaphthylene	CL4(52)	CL4(52)	CD	CADMIUM
acenaphthen	acenaphthene	ALDRIN	ALDRIN	CR	CHROMIUM
dibenzofura	dibenzofuran	CL4(44)	CL4(44)	CU	COPPER
fluorene	fluorene	HEPTACHLOREPOXIDE	HEPTACHLOREPOXIDE	ZN	ZINC
C1-fluorene	C1-fluorenes	CL4(66)	CL4(66)		
C2-fluorene	C2-fluorenes	2,4-DDE	2,4-DDE		
C3-fluorene	C3-fluorenes	CL5(101)	CL5(101)		
phenanthren	phenanthrene	CIS-CHLORDA	CIS-CHLORDANE		
anthracene	anthracene	TRANS-NONAC	TRANS-NONACHLOR		
C1-phenanth	C1-phenanthrenes/anthracenes	DIELDRIN	DIELDRIN		
C2-phenanth	C2-phenanthrenes/anthracenes	4,4-DDE	4,4-DDE		
C3-phenanth	C3-phenanthrenes/anthracenes	CL4(77)	CL4(77)		
C4-phenanth	C4-phenanthrenes/anthracenes	2,4-DDD	2,4-DDD		
dibenzothio	dibenzothiophene	ENDRIN	ENDRIN		
C1-dibenzot	C1-dibenzothiophenes	CL5(118)	CL5(118)		
C2-dibenzot	C2-dibenzothiophenes	4,4-DDD	4,4-DDD		
C3-dibenzot	C3-dibenzothiophenes	2,4-DDT	2,4-DDT		
fluoranthen	fluoranthene	CL6(153)	CL6(153)		
pyrene	pyrene	CL5(105)	CL5(105)		
C1-fluorant	C1-fluoranthenes/pyrenes	4,4-DDT	4,4-DDT		
benz[a]anth	benz[a]anthracene	CL6(138)	CL6(138)		
chrysene	chrysene	CL5(126)	CL5(126)		
C1-chrysene	C1-chrysenes	CL7(187)	CL7(187)		
C2-chrysene	C2-chrysenes	CL6(128)	CL6(128)		
C3-chrysene	C3-chrysenes	CL7(180)	CL7(180)		
C4-chrysene	C4-chrysenes	MIREX	MIREX		
benzo[b]flu	benzo[b]fluoranthene	CL7(170)	CL7(170)		
benzo[k]flu	benzo[k]fluoranthene	CL8(195)	CL8(195)		
benzo[e]pyr	benzo[e]pyrene	CL9(206)	CL9(206)		
benzo[a]pyr	benzo[a]pyrene	CL10(209)	CL10(209)		
perylene	perylene				
indeno[1,2,	indeno[1,2,3-c,d]pyrene				
dibenz[a,h]	dibenz[a,h]anthracene				
benzo[g,h,i	benzo[g,h,i]perylene				
PH_DECANES	PHENYL DECANES				
PH_UNDECANE	PHENYL DODECANES				
PH_DODECANE	PHENYL NONANES				
PH_TRIDECAN	PHENYL TETRADECANES				
PH_TETRADEC	PHENYL TRIDECANES				
PH_NONANES	PHENYL UNDECANES				

Description of Qualifiers	
<	reported value is the method detection limit
&	surrogate recovery out of range
a	not detected
f	reported value below method detection limit
g	recovery below data objectives
j	estimated value
x	matrix interference

APPENDIX A-2: SEDIMENT CHEMISTRY DATA (PAH)

Station	ID	Naphthalene	C1_Naphthal	C2_Naphthal	C3_Naphthal	C4_Naphthal	Biphenyl	Acenaphthyl	Acenaphthen	Dibenzofura	Fluorene	C1_Fluorene
FF1A	S94030113	8.19	5.13	8.16	a	a	1.13 f	7.44	2.39	2.43	4.19	5.89
FF1A	S94030115	50.02	24.25	28.88	32.78	17.24	4.60	75.21	18.75	12.35	40.36	26.70
FF4	S94030168	43.44	18.42	25.20	a	a	6.53	24.97	7.89	11.49	15.38	15.85
FF4	S94030170	39.30	21.14	26.08	24.49	a	7.91	27.88	8.14	12.98	15.91	14.87
FF5	S94030224	16.95	7.38	11.59	11.53	a	2.82	9.70	3.38	4.85	6.15	5.82
FF5	S94030226	13.42	6.33	11.32	10.06	a	2.36	7.20	2.46	4.34	5.48	5.30
FF6	S94030210	38.63	15.84	22.38	25.95	a	5.81	18.35	7.68	10.64	14.02	9.11
FF6	S94030212	27.18	11.08	15.17	15.38	a	4.15	13.01	4.12	6.75	9.46	9.02
FF7	S94030195	23.97	12.79	15.78	17.16	a	4.36	11.13	4.27	8.12	9.02	7.28
FF7	S94030199	21.90	11.68	14.56	18.88	a	4.12	10.96	5.91	8.48	8.71	9.47
FF9	S94030155	38.32	8.68	12.57	a	a	3.10	11.28	2.98	5.00	6.51	6.25
FF9	S94030157	55.73	12.15	13.10	12.22	a	2.67	12.66	3.17	3.76	6.13	6.24
FF10	S94030283	40.07	19.35	35.94	29.41	16.23	6.44	33.81	11.92	14.66	27.19	17.22
FF10	S94030285	53.74	19.30	32.74	28.81	14.03	6.52	35.54	13.52	13.25	29.46	19.45
FF11	S94030127	42.58	31.52	47.06	39.12	23.27	9.82	47.04	10.72	13.95	23.33	16.15
FF11	S94030130	38.74	27.02	40.60	31.31	a	8.52	39.02	10.68	14.13	21.92	17.66
FF12	S94030016	42.36	23.03	41.06	40.02	24.56	6.35	33.01	13.69	14.53	26.59	23.79
FF12	S94030018	51.53	34.62	52.77	52.14	22.13	8.05	33.16	13.69	13.34	24.72	24.22
FF13	S94030236	123.99	48.36	65.16	51.42	24.78	18.10	27.97	31.09	29.90	33.54	21.73
FF13	S94030239	13.66	7.95	12.38	11.72	a	2.12	6.17	3.07	3.61	4.72	3.99
FF14	S94030143	55.19	25.55	31.19	23.01	a	7.66	29.31	7.72	11.65	16.50	11.23
FF14	S94030145	47.74	20.43	29.97	22.24	a	6.36	20.73	7.12	11.49	14.40	11.16
NF2	S94030254	14.65	7.49	14.45	14.66	a	2.17	6.93	3.57	4.03	6.01	5.79
NF4	S94030319	2.05	0.96	a	a	a	0.46 f	0.96 f	0.29 f	0.36 f	0.46 f	a
NF5	S94030302	98.33	32.53	64.57	102.82	130.07	9.67	131.77	13.97	23.99	68.24	68.47
NF7	S94030322	123.12	33.89	54.59	56.49	85.65	11.46	84.84	19.14	24.29	48.61	40.65
NF8	S94030370	108.32	65.09	98.26	119.16	124.83	17.55	75.94	21.46	28.26	41.82	47.64
NF9	S94030099	81.55	27.11	45.98	56.79	50.97	8.14	37.05	14.95	15.95	27.48	28.79
NF10	S94030073	90.70	32.11	45.24	48.56	70.62	9.66	43.69	28.14	22.92	40.34	31.29
NF12	S94030061	172.29	86.16	138.51	163.97	204.07	25.48	112.44	65.29	63.68	112.50	82.79
NF12	S94030065	123.94	59.50	94.38	111.42	129.44	17.80	71.59	57.13	44.28	74.87	56.84
NF13	S94030051	12.41	3.80	6.47	9.73	9.93	1.09 f	7.77	2.73	2.16	4.36	6.08
NF14	S94030358	29.19	11.98	22.74	51.71	43.01	3.63	11.72	10.62	10.37	18.07	16.89
NF15	S94030043	31.12	15.49	23.81	24.56	38.19	4.29	7.96	30.55	19.72	32.02	15.22
NF16	S94030036	144.15	91.13	164.48	186.15	264.20	26.45	77.44	131.18	96.48	159.18	96.81
NF17	S94030267	1.59	1.04	a	a	a	0.24 f	0.54 f	a	0.34 f	0.38 f	a
NF17	S94030270	6.18	2.94	3.84	a	a	0.98 f	2.63	1.17	1.10	1.79	1.41
NF18	S94030082	76.57	26.90	42.83	41.87	a	11.06	49.48	19.68	22.30	28.75	25.77
NF19	S94030328	26.22	8.75	11.23	14.47	a	2.95	12.59	5.33	6.19	8.50	8.06
NF20	S94030028	24.02	10.38	15.26	15.19	a	3.05	14.83	6.34	6.63	11.39	10.99
MB01	S94030092	239.97	80.58	115.01	86.55	49.39	25.58	111.78	38.24	52.11	74.62	55.40
MB03	S94030261	79.28	41.42	70.53	58.87	25.52	11.34	42.64	44.81	21.58	51.31	31.71
S3	S94030352	25.85	6.23	7.38	7.28	a	2.05	10.54	2.87	3.14	4.33	4.14
S4	S94030338	206.50	62.17	90.35	75.97	40.99	19.95	85.40	45.57	45.02	81.07	51.16
S4	S94030340	125.97	30.25	47.98	56.16	21.47	12.93	54.44	41.14	35.10	56.90	33.66

Station	ID	C2_Fluorene	C3_Fluorene	Phenanthren	Anthracene	C1_Phenanth	C2_Phenanth	C3_Phenanth	C4_Phenanth	Dibenzothio	C1_Dibenzot	C2_Dibenzot
FF1A	S94030113	7.29	a	45.08	10.09	27.62	22.60	14.79	15.61	3.01	3.92	7.32
FF1A	S94030115	58.15	58.58	235.61	100.47	180.82	256.30	100.48	74.82	16.66	17.61	74.35
FF4	S94030168	a	a	151.22	27.56	86.49	74.87	34.41	50.63	10.64	11.89	20.43
FF4	S94030170	21.23	a	152.00	30.25	88.89	76.26	40.43	47.33	11.92	11.93	19.33
FF5	S94030224	a	a	60.88	13.07	33.08	33.18	14.95	21.20	4.56	4.63	8.02
FF5	S94030226	a	a	48.15	8.71	27.55	22.59	12.63	15.07	3.03	3.34	8.12
FF6	S94030210	20.77	a	128.16	29.21	67.11	65.43	29.65	34.48	9.32	7.72	15.42
FF6	S94030212	17.10	29.00	85.02	18.86	53.35	47.12	23.61	25.01	6.06	7.08	11.33
FF7	S94030195	a	a	88.47	15.77	49.08	50.39	22.69	26.28	6.10	6.76	11.40
FF7	S94030199	a	a	89.54	16.64	47.95	51.45	23.07	32.14	6.28	6.03	11.08
FF9	S94030155	13.37	a	61.68	17.64	39.43	37.90	18.33	21.48	4.52	4.40	9.10
FF9	S94030157	17.75	a	50.57	15.95	34.58	29.70	16.61	18.46	4.06	4.57	9.14
FF10	S94030283	19.73	35.99	258.96	88.80	142.34	92.65	43.76	82.74	17.06	18.45	19.33
FF10	S94030285	21.86	36.72	244.88	84.83	157.52	105.55	47.22	87.47	15.42	20.00	22.92
FF11	S94030127	31.01	57.19	229.10	55.03	175.65	152.53	77.98	104.10	16.78	27.98	39.22
FF11	S94030130	30.75	a	219.20	56.00	163.70	137.42	73.07	93.27	15.98	23.17	33.27
FF12	S94030016	30.97	35.09	226.07	78.77	162.95	120.83	55.36	92.73	15.33	18.24	21.90
FF12	S94030018	27.66	a	240.55	74.94	178.96	138.85	72.95	99.34	16.32	21.69	28.04
FF13	S94030236	30.37	a	256.07	56.78	141.17	119.70	64.03	108.96	17.96	20.86	29.67
FF13	S94030239	a	a	46.51	11.88	29.33	27.16	19.37	a	3.43	4.58	6.81
FF14	S94030143	a	a	148.50	38.90	112.26	95.90	45.75	68.41	10.59	17.78	26.17
FF14	S94030145	19.78	28.19	130.73	32.14	93.70	74.96	38.40	54.35	9.84	15.21	19.38
NF2	S94030254	7.32	a	53.69	15.12	35.32	29.23	16.95	21.99	4.10	5.13	7.35
NF4	S94030319	a	a	3.41	1.25 f	2.74	2.33	a	a	0.23 f	0.59 f	a
NF5	S94030302	80.21	85.19	643.07	353.90	422.69	274.47	98.91	272.26	41.50	49.31	51.95
NF7	S94030322	54.73	57.99	312.64	195.75	253.26	187.86	94.85	169.35	26.23	31.19	35.79
NF8	S94030370	71.49	a	349.45	149.18	287.48	270.16	139.37	228.72	29.20	41.76	60.95
NF9	S94030099	43.79	48.20	210.43	89.90	181.89	141.17	67.52	108.37	15.15	22.53	24.61
NF10	S94030073	42.06	48.83	312.69	124.83	203.34	146.67	69.42	130.13	22.12	22.59	26.19
NF12	S94030061	110.78	142.59	782.12	313.51	528.49	415.36	191.70	333.45	59.54	63.42	72.09
NF12	S94030065	69.70	a	583.34	223.03	354.73	265.87	124.01	216.65	41.29	41.53	46.30
NF13	S94030051	8.76	a	60.00	19.99	47.05	29.62	13.14	26.45	3.36	5.89	6.44
NF14	S94030358	47.76	69.77	134.01	43.67	122.44	122.11	54.07	65.69	10.21	17.98	21.29
NF15	S94030043	22.31	23.09	222.65	68.24	100.14	65.26	26.61	49.30	15.50	11.40	11.39
NF16	S94030036	126.50	162.29	1159.91	377.98	633.19	449.52	186.94	315.71	80.77	70.64	65.27
NF17	S94030267	a	a	3.11	0.88 f	1.77	1.86 f	a	a	0.32 f	a	a
NF17	S94030270	a	a	13.79	4.54	8.36	7.56	4.50	5.63	0.78 f	2.21	1.71
NF18	S94030082	a	a	258.32	102.44	176.32	134.99	62.45	a	19.64	27.36	35.24
NF19	S94030328	a	a	75.27	28.01	45.47	38.53	19.77	23.00	5.31	4.66	8.42
NF20	S94030028	19.08	a	102.26	43.77	65.33	54.73	27.64	43.01	7.48	5.77	9.06
MB01	S94030092	72.91	a	485.58	199.76	357.73	272.34	135.44	a	39.27	46.35	58.40
MB03	S94030261	40.33	69.42	463.37	126.46	264.34	178.27	83.34	131.92	29.31	32.12	36.14
S3	S94030352	6.04	a	36.89	11.77	28.48	22.27	10.50	23.14	2.74	4.68	6.84
S4	S94030338	61.75	88.80	560.79	242.48	349.74	264.07	129.03	210.84	41.81	45.83	54.91
S4	S94030340	41.84	a	496.27	175.13	249.72	158.35	89.22	160.94	34.45	28.24	34.32

Station	ID	C3_Dibenzot	Fluoranthen	Pyrene	C1_Fluorant	Benz_A_Anth	Chrysene	C1_Chrysene	C2_Chrysene	C3_Chrysene	C4_Chrysene	Benzo_B_Flu
FF1A	S94030113	a	75.76	92.00	45.90	33.39	39.56	25.92	18.05	a	a	52.55
FF1A	S94030115	47.43	428.12	486.94	540.32	284.89	253.89	220.21	109.92	37.70	13.96	251.11
FF4	S94030168	a	262.85	277.37	134.24	97.15	122.55	74.65	46.66	a	a	179.80
FF4	S94030170	16.41	266.14	281.80	139.18	102.16	133.59	80.66	47.34	19.69	a	188.41
FF5	S94030224	a	105.73	112.88	51.89	42.45	51.50	30.37	27.16	a	a	75.34
FF5	S94030226	a	86.47	89.74	43.60	31.67	40.30	27.10	19.70	a	a	60.46
FF6	S94030210	13.85	210.37	241.15	112.60	91.78	108.70	71.49	44.91	22.68	a	157.09
FF6	S94030212	10.37	156.33	166.75	82.74	63.18	76.80	49.63	34.80	a	a	112.91
FF7	S94030195	14.23	163.87	165.57	76.62	56.95	71.94	43.62	25.45	a	a	106.94
FF7	S94030199	a	166.96	170.48	79.27	59.50	73.39	45.58	28.03	a	a	106.54
FF9	S94030155	9.42	105.19	116.23	62.83	50.22	55.77	39.38	26.99	a	a	79.85
FF9	S94030157	9.24	87.42	80.49	58.99	42.38	50.36	34.96	23.27	a	a	70.73
FF10	S94030283	13.10	386.58	346.00	219.70	176.69	174.71	81.62	39.37	a	a	233.05
FF10	S94030285	15.62	390.24	456.45	244.57	178.33	166.38	100.33	41.89	a	a	217.43
FF11	S94030127	29.88	389.68	364.85	276.20	183.15	203.00	113.02	73.94	a	a	261.50
FF11	S94030130	26.52	370.24	318.00	261.80	185.79	192.28	135.35	61.56	a	a	251.18
FF12	S94030016	19.59	351.38	311.20	252.29	175.40	165.04	81.43	67.48	a	a	222.90
FF12	S94030018	22.94	443.96	390.74	284.45	217.85	198.87	107.24	64.64	a	a	254.76
FF13	S94030236	28.61	371.26	361.42	225.88	203.62	218.37	99.74	66.21	a	a	307.56
FF13	S94030239	5.98	84.01	75.56	49.92	34.55	40.53	17.83	10.87	a	a	61.49
FF14	S94030143	17.07	261.10	223.51	181.70	117.20	131.78	69.97	40.75	a	a	183.89
FF14	S94030145	14.20	214.37	189.38	144.28	103.52	115.26	72.99	38.04	a	a	156.94
NF2	S94030254	7.08	94.62	92.75	55.79	39.71	43.97	28.70	14.33	6.68	a	63.91
NF4	S94030319	a	6.07	6.05	4.18	3.24	3.53	1.83 f	a	a	a	5.60
NF5	S94030302	35.38	1189.22	961.30	709.20	508.76	492.11	238.86	106.75	55.98	a	617.94
NF7	S94030322	29.46	620.30	579.32	460.19	311.13	314.74	188.66	91.05	59.32	a	396.58
NF8	S94030370	59.03	706.48	714.39	527.29	364.24	350.91	242.46	131.39	70.33	a	495.06
NF9	S94030099	19.86	377.09	364.81	284.04	189.20	185.41	125.19	67.36	28.16	a	249.80
NF10	S94030073	21.61	490.56	471.89	333.85	232.91	230.75	131.72	63.94	27.10	a	301.02
NF12	S94030061	59.85	1265.21	1178.74	833.67	614.05	581.19	366.71	176.88	120.41	a	761.57
NF12	S94030065	42.26	892.02	827.30	574.52	415.22	412.96	243.91	122.69	84.27	a	537.88
NF13	S94030051	4.55	130.78	113.29	69.97	52.98	46.82	25.01	10.27	a	a	60.96
NF14	S94030358	12.48	182.23	172.08	121.77	85.11	91.83	72.06	43.78	21.55	a	110.98
NF15	S94030043	7.91	234.94	206.22	120.43	98.41	99.05	54.26	26.90	10.56	a	118.27
NF16	S94030036	50.52	1383.41	1263.05	846.04	670.69	612.13	382.38	189.23	126.57	a	780.63
NF17	S94030267	a	4.85	4.89	2.80	2.39	2.61	1.28 f	a	a	a	3.64
NF17	S94030270	a	23.60	21.79	13.35	10.09	11.57	6.21	3.51	a	a	15.90
NF18	S94030082	24.73	492.11	432.60	293.66	180.43	180.71	110.93	64.42	a	a	233.26
NF19	S94030328	9.54	134.72	147.98	75.82	61.33	67.27	43.64	26.13	13.22	18.84	90.78
NF20	S94030028	a	202.50	232.46	119.94	91.05	88.36	56.32	33.43	a	a	115.77
MB01	S94030092	48.21	793.06	795.93	615.30	450.90	433.63	247.07	149.80	56.95	a	575.83
MB03	S94030261	28.33	541.50	569.24	382.53	263.25	266.88	136.07	85.78	a	a	346.68
S3	S94030352	5.78	83.56	68.08	51.64	43.80	41.82	24.61	10.70	a	a	59.80
S4	S94030338	44.82	855.15	797.67	598.72	444.47	443.76	218.31	118.60	a	a	585.39
S4	S94030340	32.25	752.60	805.23	414.60	301.78	336.64	125.27	107.91	a	a	398.50

Station	ID	Benzo_K_Flu	Benzo_E_Pyr	Benzo_A_Pyr	Perylene	Indeno_1_2	Dibenz_A_H	Benzo_G_H_I	Ph_Decanes	Ph_Undecane	Ph_Dodecane	Ph_Tridecan
FF1A	S94030113	17.34	28.14	37.60	9.88	28.58	5.68	26.09	a	a	a	a
FF1A	S94030115	94.66	129.91	232.22	48.58	125.21	31.28	111.52	a	a	a	a
FF4	S94030168	56.07	99.42	122.48	43.47	100.09	20.56	92.73	a	a	a	a
FF4	S94030170	60.64	103.42	122.34	36.84	108.59	21.70	99.54	a	a	a	a
FF5	S94030224	24.45	40.12	49.63	14.88	41.42	8.56	39.41	a	a	a	a
FF5	S94030226	19.21	33.05	40.85	11.73	33.89	6.86	30.94	a	a	a	a
FF6	S94030210	51.15	79.87	107.20	30.65	86.47	19.09	80.16	a	41.53	165.25	38.16
FF6	S94030212	36.57	58.22	74.59	21.31	63.79	12.40	57.46	a	35.00	169.21	a
FF7	S94030195	37.73	56.39	69.87	21.76	60.98	11.69	55.46	a	a	a	a
FF7	S94030199	35.41	57.81	69.52	22.44	60.00	11.35	57.17	a	a	a	a
FF9	S94030155	25.49	41.62	56.57	16.01	42.53	9.52	39.83	a	a	a	a
FF9	S94030157	22.59	38.33	52.95	13.64	40.35	8.70	36.51	a	20.48	81.25	a
FF10	S94030283	80.37	123.38	181.69	46.15	129.32	27.95	108.18	a	31.95	34.16	19.08
FF10	S94030285	70.09	117.89	173.01	43.30	121.61	26.65	104.41	a	35.24	40.95	a
FF11	S94030127	92.92	146.75	201.47	54.62	144.81	33.27	131.51	a	a	a	a
FF11	S94030130	82.28	133.33	192.87	58.15	133.20	29.50	121.31	a	43.16	42.34	29.50
FF12	S94030016	77.25	116.44	174.59	43.94	115.98	28.65	99.61	11.30	62.59	67.00	51.83
FF12	S94030018	95.31	132.58	210.25	51.75	133.08	32.95	116.04	14.21	42.67	69.51	52.53
FF13	S94030236	111.57	166.00	225.10	63.84	168.98	38.07	147.63	47.03	293.69	377.07	292.88
FF13	S94030239	18.99	31.47	41.76	11.84	32.80	7.07	30.84	a	58.32	77.72	67.50
FF14	S94030143	65.94	98.38	135.05	36.95	103.83	23.74	93.26	a	a	a	a
FF14	S94030145	55.29	87.90	112.37	32.14	88.60	19.01	82.17	a	25.29	18.46	a
NF2	S94030254	23.30	34.02	47.95	14.17	38.50	8.33	33.34	a	25.99	41.06	21.28
NF4	S94030319	1.97	3.03	3.72	1.17 f	3.38	0.69 f	3.12	a	a	a	a
NF5	S94030302	211.00	288.70	474.38	121.39	330.26	85.72	257.91	a	a	a	a
NF7	S94030322	134.45	200.64	319.78	77.68	211.06	55.03	170.42	a	55.92	82.92	19.65
NF8	S94030370	163.89	258.69	380.02	95.98	252.78	63.71	232.24	29.11	200.93	296.49	169.47
NF9	S94030099	90.57	131.36	200.25	54.18	142.69	34.86	114.82	a	40.68	60.73	19.00
NF10	S94030073	98.88	156.41	251.40	61.80	169.95	40.45	138.83	a	32.02	48.06	11.72
NF12	S94030061	268.15	385.68	608.05	153.22	409.87	103.68	324.50	a	133.37	152.14	83.29
NF12	S94030065	187.77	270.84	421.59	107.08	289.58	72.78	235.84	a	78.57	130.03	99.84
NF13	S94030051	22.23	30.48	51.00	12.87	34.11	7.77	27.40	a	a	a	a
NF14	S94030358	36.61	59.85	85.84	20.97	61.95	15.15	52.36	a	a	a	a
NF15	S94030043	43.67	61.34	97.60	24.56	68.15	15.85	55.94	a	a	a	a
NF16	S94030036	272.13	388.64	617.83	156.25	407.32	109.17	324.90	27.37	174.64	175.11	165.64
NF17	S94030267	1.47 f	2.10	2.53	0.98 f	2.49	0.53 f	3.03	a	a	a	a
NF17	S94030270	6.00	8.74	11.43	3.40 f	9.29	2.31	9.35	a	a	a	a
NF18	S94030082	88.92	117.91	168.77	42.66	106.17	26.04	91.36	a	a	20.24	18.58
NF19	S94030328	31.44	46.06	68.81	17.30	48.25	10.91	44.76	a	35.06	162.96	22.00
NF20	S94030028	38.77	57.57	90.69	22.27	61.74	14.06	51.27	a	30.90	162.67	25.08
MB01	S94030092	216.21	313.79	479.20	118.48	312.47	76.86	264.36	12.75	91.48	72.07	71.14
MB03	S94030261	125.07	193.33	283.70	69.09	189.82	44.75	171.29	18.72	109.41	119.15	93.16
S3	S94030352	19.81	31.26	46.65	12.25	34.87	7.87	30.02	a	15.07	16.98	a
S4	S94030338	201.07	310.28	468.48	121.17	310.71	76.15	262.97	a	75.04	73.40	48.27
S4	S94030340	160.72	201.19	299.26	75.11	200.90	39.38	178.88	a	a	a	a

Station	ID	Ph_Tetradec	Ph_Nonanes
FF1A	S94030113	a	78.00
FF1A	S94030115	a	85.00
FF4	S94030168	a	67.00
FF4	S94030170	a	84.00
FF5	S94030224	a	84.00
FF5	S94030226	a	77.00
FF6	S94030210	a	82.00
FF6	S94030212	a	78.00
FF7	S94030195	a	78.00
FF7	S94030199	a	81.00
FF9	S94030155	a	83.00
FF9	S94030157	a	80.00
FF10	S94030283	23.20	86.00
FF10	S94030285	a	80.00
FF11	S94030127	a	80.00
FF11	S94030130	a	72.00
FF12	S94030016	74.41	81.00
FF12	S94030018	40.13	79.00
FF13	S94030236	207.23	68.00
FF13	S94030239	46.85	82.00
FF14	S94030143	a	79.00
FF14	S94030145	a	82.00
NF2	S94030254	19.21	80.00
NF4	S94030319	a	78.00
NF5	S94030302	a	82.00
NF7	S94030322	a	82.00
NF8	S94030370	137.39	79.00
NF9	S94030099	a	82.00
NF10	S94030073	a	80.00
NF12	S94030061	70.61	86.00
NF12	S94030065	56.23	79.00
NF13	S94030051	a	76.00
NF14	S94030358	a	80.00
NF15	S94030043	a	81.00
NF16	S94030036	123.75	86.00
NF17	S94030267	a	82.00
NF17	S94030270	a	82.00
NF18	S94030082	11.40	38.00 g
NF19	S94030328	a	84.00
NF20	S94030028	21.78	67.00
MB01	S94030092	56.26	76.00
MB03	S94030261	101.42	79.00
S3	S94030352	a	78.00
S4	S94030338	a	83.00
S4	S94030340	a	76.00

APPENDIX A-3: SEDIMENT CHEMISTRY DATA (PCB/PESTICIDES)

Station	ID	CL2(08)	HEXACHLOROB	LINDANE	CL3(18)	CL3(28)	HEPTACHLOR	CL4(52)	ALDRIN	CL4(44)	HEPTACHLOREPOXIDE	CL4(66)	2,4-DDE
FF1A	S94030113	a	a	a	a	a	a	a	1.84	0.19	a	0.13	a
FF1A	S94030115	a	0.18	0.45	0.57	0.85	a	a	3.36	0.16	a	0.29	a
FF4	S94030168	a	a	a	a	1.87	a	0.52	6.61	0.51	a	0.71	a
FF4	S94030170	a	a	a	0.67	2.11	0.44	0.46	6.26	0.41	a	0.60	a
FF5	S94030224	a	0.33	a	0.00	1.07	a	0.30	2.80	0.29	a	0.28	a
FF5	S94030226	a	0.20	a	a	0.60	a	0.35	2.32	0.30	a	0.18	a
FF6	S94030210	a	0.44	a	a	1.19	a	0.38	4.53	0.33	a	0.62	a
FF6	S94030212	a	0.29	a	a	0.97	a	0.27	3.13	0.29	a	0.45	a
FF7	S94030195	a	0.31	a	a	0.78	a	0.54	3.96	0.41	a	0.38	a
FF7	S94030199	a	0.27	a	0.76	1.22	a	0.48	4.01	0.42	a	0.45	a
FF9	S94030155	a	0.28	a	a	0.54	a	a	2.13	0.21	a	0.22	a
FF9	S94030157	a	a	a	a	0.81	a	a	2.04	0.28	a	0.17	a
FF10	S94030283	a	0.24	0.93	1.05	1.25	a	a	4.35	0.15	a	0.40	a
FF10	S94030285	a	a	a	0.74	0.76	a	0.28	4.17	0.18	a	0.41	a
FF11	S94030127	a	0.56	a	a	a	a	a	7.26	0.53	a	0.54	a
FF11	S94030130	a	0.40	a	0.67	1.34	0.26	0.64	4.47	0.45	a	1.34	a
FF12	S94030016	a	a	a	a	1.02	a	0.66	4.04	0.37	a	0.43	a
FF12	S94030018	a	a	a	a	0.92	a	0.54	4.01	0.34	a	0.75	a
FF13	S94030236	a	a	a	a	2.29	a	a	6.02	0.42	a	0.69	a
FF13	S94030239	a	0.19	a	a	0.60	a	0.38	1.61	0.31	a	0.42	a
FF14	S94030143	a	0.37	a	0.78	1.79	a	0.73	5.34	0.66	a	0.74	a
FF14	S94030145	a	a	a	a	1.15	a	0.49	4.78	0.42	a	0.94	a
NF2	S94030254	a	0.12	a	a	0.43	a	0.42	1.63	0.28	a	0.36	a
NF4	S94030319	a	a	a	a	a	a	a	0.22	0.15	a	a	a
NF5	S94030302	a	a	a	1.01	1.15	a	0.36	4.65	0.27	a	0.74	a
NF7	S94030322	a	0.88	a	0.80	1.27	a	1.00	3.66	0.52	a	0.46	a
NF8	S94030370	a	0.99	a	1.33	1.76	a	1.27	6.55	0.75	a	1.30	a
NF9	S94030099	a	0.26	a	0.70	0.94	a	0.38	3.27	0.28	a	0.34	a
NF10	S94030073	a	0.27	a	0.69	0.92	a	0.27	3.19	0.23	a	0.36	a
NF12	S94030061	a	0.45	a	a	2.37	a	0.85	7.42	0.46	a	1.10	a
NF12	S94030065	a	0.57	0.61	1.12	1.36	a	0.60	6.14	0.48	a	0.64	a
NF13	S94030051	a	a	a	a	a	a	a	0.66	0.11	a	a	a
NF14	S94030358	a	0.23	a	0.72	0.56	a	0.98	1.51	0.21	a	0.10	a
NF15	S94030043	a	0.15	a	a	0.40	a	0.30	1.82	0.25	a	a	a
NF16	S94030036	a	0.43	0.79	0.94	2.48	a	0.79	8.77	0.56	a	1.05	a
NF17	S94030267	a	0.04	a	a	a	a	a	0.18	0.13	a	a	a
NF17	S94030270	a	a	a	a	0.10	a	0.11	0.52	0.14	a	0.07	a
NF18	S94030082	a	3.00	a	a	a	a	a	a	0.22	a	0.47	a
NF19	S94030328	a	0.20	a	0.80	0.68	a	0.63	2.29	0.21	a	0.33	a
NF20	S94030028	a	0.16	a	a	0.47	a	0.31	1.99	0.21	a	0.24	a
MB01	S94030092	a	a	a	1.13	1.83	2.21	1.13	6.65	0.53	a	0.92	a
MB03	S94030261	a	0.58	a	a	2.00	a	0.68	6.94	0.31	a	0.92	a
S3	S94030352	a	a	a	a	a	1.22	0.31	1.10	0.17	a	a	a
S4	S94030338	a	a	a	0.80	1.61	a	0.74	7.09	0.35	0.35	0.78	a
S4	S94030340	a	1.74	a	a	a	a	a	a	a	a	a	a

Station	ID	CL5(101)	CIS-CHLORDA	TRANS-NONACLOR	DIELDRIN	4,4-DDE	CL4(77)	2,4-DDD	ENDRIN	CL5(118)	4,4-DDD	2,4-DDT	CL6(153)
FF1A	S94030113	0.16	0.27	0.12	a	0.21	a	0.27	a	0.23	0.76	a	0.26
FF1A	S94030115	0.22	0.58	0.21	a	0.45	a	0.53	a	0.69	1.06	a	0.47
FF4	S94030168	0.80	0.62	0.61	a	1.08	a	1.07	a	0.99	2.24	a	1.03
FF4	S94030170	0.83	0.76	0.57	a	1.19	a	1.23	a	0.92	2.60	a	1.02
FF5	S94030224	0.37	0.26	0.23	a	0.54	a	0.75	a	0.61	1.34	a	0.63
FF5	S94030226	0.35	0.11	0.08	a	0.50	a	0.57	a	0.51	1.25	a	0.50
FF6	S94030210	0.65	0.32	0.41	a	1.15	a	1.00	a	1.36	2.31	0.56	1.50
FF6	S94030212	0.47	0.26	0.31	a	0.90	a	0.67	a	0.93	1.65	a	1.08
FF7	S94030195	0.52	0.18	0.34	a	1.07	a	0.60	a	0.84	1.39	a	1.06
FF7	S94030199	0.61	0.19	0.23	a	1.17	a	0.77	a	0.85	2.07	a	1.06
FF9	S94030155	0.22	0.15	0.21	a	0.30	a	0.39	a	0.43	1.03	a	0.42
FF9	S94030157	0.24	0.21	0.13	a	0.26	a	0.40	a	0.35	0.78	0.11	0.37
FF10	S94030283	0.40	0.48	0.43	a	0.86	a	0.91	a	0.85	1.61	a	0.85
FF10	S94030285	0.44	0.47	0.32	a	0.56	a	0.73	a	0.92	1.39	a	0.84
FF11	S94030127	0.61	0.69	0.74	a	1.06	a	2.04	a	1.15	3.24	a	0.87
FF11	S94030130	1.66	0.67	0.65	a	1.58	a	1.64	a	3.14	3.01	0.60	3.63
FF12	S94030016	0.86	0.35	0.44	a	0.70	a	0.67	a	1.50	1.79	a	1.70
FF12	S94030018	0.95	0.50	0.42	a	0.64	a	0.84	a	1.64	1.75	0.31	1.73
FF13	S94030236	0.43	0.57	0.72	a	0.51	a	1.35	a	0.84	2.90	a	0.62
FF13	S94030239	0.54	0.16	0.28	a	0.44	a	0.45	a	0.96	1.18	a	1.30
FF14	S94030143	0.97	0.51	0.68	a	1.00	a	1.75	a	1.15	2.93	0.90	1.64
FF14	S94030145	0.73	0.52	0.35	a	0.99	a	1.24	a	0.94	2.06	a	1.29
NF2	S94030254	0.87	0.16	0.21	a	0.49	a	0.36	a	1.06	0.86	a	1.29
NF4	S94030319	a	a	a	a	a	a	a	a	a	a	a	0.09
NF5	S94030302	0.36	0.32	0.40	a	0.56	a	0.91	a	0.93	1.30	0.00 a	1.24
NF7	S94030322	2.57	0.78	0.75	a	0.73	a	0.98	a	2.33	1.45	a	2.69
NF8	S94030370	2.81	1.23	0.81	a	2.35	a	2.09	a	4.30	8.37	a	4.95
NF9	S94030099	0.66	0.33	0.27	a	0.54	a	0.72	a	0.94	1.09	a	1.24
NF10	S94030073	0.52	0.22	0.26	a	0.87	a	0.60	a	0.85	1.05	a	1.20
NF12	S94030061	1.58	1.05	0.62	a	1.76	a	1.97	a	2.71	3.09	0.25	3.34
NF12	S94030065	1.25	0.70	0.53	a	1.34	a	1.23	a	2.04	2.36	a	2.54
NF13	S94030051	a	a	a	a	a	a	a	a	0.11	a	a	0.19
NF14	S94030358	0.25	0.21	0.33	a	0.21	a	0.39	a	0.34	0.43	a	0.43
NF15	S94030043	0.22	0.15	0.17	a	0.14	a	0.23	a	0.31	0.40	a	0.42
NF16	S94030036	1.52	0.79	0.62	a	1.77	a	2.37	a	2.63	2.57	a	3.36
NF17	S94030267	a	a	a	a	a	a	a	a	a	a	a	0.08
NF17	S94030270	0.17	0.11	0.10	a	0.09	a	0.10	a	0.17	0.23	a	0.20
NF18	S94030082	0.78	a	a	a	0.67	a	0.87	a	1.17	0.86	0.26	1.58
NF19	S94030328	0.28	0.19	0.16	a	0.41	a	a	a	0.46	1.01	a	0.61
NF20	S94030028	0.45	0.21	0.16	a	0.29	a	0.32	a	0.60	0.67	a	0.77
MB01	S94030092	1.88	0.97	0.76	a	1.13	a	1.76	a	2.62	3.42	0.72	2.91
MB03	S94030261	1.07	0.73	0.56	a	1.11	a	1.92	a	2.28	2.45	a	1.99
S3	S94030352	a	a	a	a	a	a	a	a	0.22	0.30	a	0.21
S4	S94030338	1.06	0.69	0.56	a	0.69	a	1.43	a	1.95	2.42	0.46	2.19
S4	S94030340	a	a	a	a	1.26	a	1.44	a	1.77	1.20	a	2.14

Station	ID	CL5(105)	4,4-DDT	CL6(138)	CL5(126)	CL7(187)	CL6(128)	CL7(180)	MIREX	CL7(170)	CL8(195)	CL9(206)	CL10(209)
FF1A	S94030113	0.10	a	0.30	a	0.11	0.57 j	0.14	a	a	a	a	a
FF1A	S94030115	0.29	a	0.56	2.05	0.21	a	0.59	a	0.25	0.16	0.25	a
FF4	S94030168	0.47	a	1.37	1.41	0.45	2.11	0.35	a	0.42	0.21	0.27	0.62
FF4	S94030170	0.62	1.47	1.38	1.18	0.45	2.09	0.35	a	0.40	0.20	0.24	0.60
FF5	S94030224	0.36	a	0.80	a	0.26	1.16 j	0.37	a	0.36	0.15	0.13	0.27
FF5	S94030226	0.24	0.33	0.74	a	0.24	0.80	0.19	a	0.25	0.08	0.11	0.16
FF6	S94030210	0.69	a	1.94	0.65	0.78	1.77	0.72	a	0.59	0.21	0.37	0.55
FF6	S94030212	0.50	a	1.42	1.51	0.50	1.39	0.48	a	0.38	0.14	0.21	0.40
FF7	S94030195	0.55	a	1.41	a	0.40	1.15	0.53	a	0.53	0.17	0.20	0.33
FF7	S94030199	0.49	a	1.38	a	0.45	1.37	0.35	a	0.29	0.17	0.21	0.41
FF9	S94030155	0.23	0.44	0.56	a	0.29	0.97 j	0.24	a	0.19	0.08	0.09	0.17
FF9	S94030157	0.29	0.47	0.48	1.23	0.23	0.96	0.14	a	0.18	0.09	0.08	0.19
FF10	S94030283	0.40	0.66	0.90	a	0.36	2.72 j	0.41	a	0.38	a	a	a
FF10	S94030285	0.43	0.46	0.97	a	0.38	2.41 j	0.53	0.24	0.36	0.15	0.19	0.37
FF11	S94030127	0.69	a	1.52	a	0.27	3.43 j	0.57	a	0.77	0.41	0.52	0.69
FF11	S94030130	1.37	a	4.45	a	1.35	2.38	1.95	0.40	1.59	0.60	1.27	1.08
FF12	S94030016	0.85	0.00 a	2.21	a	0.75	2.06	1.24	a	0.72	0.20	0.38	0.50
FF12	S94030018	3.55	0.27	1.97	a	0.64	1.94	1.35	a	0.76	0.23	0.49	0.56
FF13	S94030236	0.49	a	0.73	a	a	2.49 j	a	a	a	a	a	a
FF13	S94030239	0.56	a	1.57	a	0.72	0.70	1.44	a	0.78	0.18	0.28	0.28
FF14	S94030143	0.67	2.81	1.55	a	0.71	2.26	0.88	a	1.07	0.24	0.37	0.53
FF14	S94030145	0.59	a	1.44	0.00 a	0.58	1.75	0.63	a	0.68	0.19	0.32	0.85
NF2	S94030254	0.55	a	1.63	a	0.45	0.63	0.58	a	0.33	0.15	0.15	0.14
NF4	S94030319	0.04	a	0.09	a	0.05	0.10	a	a	a	a	a	a
NF5	S94030302	0.49	1.47	1.10	3.23	1.10	4.73 j	1.07	0.33	0.80	0.32	0.64	0.87
NF7	S94030322	1.58	4.15	3.37	a	1.35	3.77 j	2.12	0.34	1.50	0.42	0.88	0.75
NF8	S94030370	2.21	55.52 a	6.35	a	2.23	4.25	3.67	0.55	1.78	0.82	2.02	1.25
NF9	S94030099	0.54	1.32	1.50	a	1.04	1.76 j	1.09	a	0.83	0.26	0.60	0.74
NF10	S94030073	0.42	1.34	1.30	a	1.23	1.86 j	1.36	a	0.70	0.35	0.62	0.42
NF12	S94030061	1.75	23.30	3.67	3.45	2.42	7.22 j	3.28	0.98	4.28	0.84	1.56	1.29
NF12	S94030065	1.07	1.25	2.97	a	1.41	3.14 j	1.80	0.46	1.02	0.43	0.99	0.91
NF13	S94030051	0.09	a	0.21	a	0.16	0.35 j	0.14	0.00 a	0.08	0.05	0.12	0.08
NF14	S94030358	0.26	1.85	0.59	a	0.47	0.78 j	0.64	0.17	0.35	0.16	0.33	0.16
NF15	S94030043	0.18	a	0.42	a	0.21	0.48 j	0.27	a	0.19	0.09	0.11	0.13
NF16	S94030036	1.64	5.67	4.15	a	1.96	3.93 j	2.53	0.45	1.52	0.52	1.31	1.40
NF17	S94030267	0.04	a	0.09	a	0.06	0.10	a	a	a	a	a	a
NF17	S94030270	0.10	a	0.23	a	0.11	0.24	0.13	a	0.14	0.03	0.03	0.11
NF18	S94030082	0.30	0.25	1.11	a	0.93	1.74	0.86	a	1.50	a	a	a
NF19	S94030328	0.27	0.72	0.69	a	0.37	0.99 j	0.42	a	0.21	0.12	0.19	0.31
NF20	S94030028	0.28	a	0.89	a	0.42	0.92	0.59	a	0.32	0.11	0.21	0.17
MB01	S94030092	1.64	12.64	3.04	a	2.05	6.62	2.40	a	2.40	0.56	1.60	1.47
MB03	S94030261	1.14	1.25	2.58	a	1.13	2.72	1.52	a	1.02	0.38	0.53	0.71
S3	S94030352	1.37	a	0.38	a	0.32	a	0.41	a	2.72	0.17	a	a
S4	S94030338	0.92	3.48	2.49	a	1.89	3.81	2.43	0.47	1.62	0.64	1.57	1.16
S4	S94030340	0.71	a	1.26	a	1.36	3.43 j	1.46	a	a	a	a	a

APPENDIX A-4: SEDIMENT CHEMISTRY DATA (METALS)

Station	ID	Al (%)	Fe (%)	Pb	Hg	Ni	Ag	Cd	Cr	Cu	Zn
FF1A	S94030113	6.00	1.27	19.00	0.04	a	0.20	0.07	29.00	5.00	34.00
FF1A	S94030115	5.50	1.43	29.30	0.04	9.50	0.09	0.09	44.00	7.00	40.50
FF4	S94030168	6.00	3.44	51.10	0.10	30.00	0.30	0.11	116.00	23.00	105.00
FF4	S94030170	6.00	3.60	51.10	0.10	34.00	0.31	0.12	123.00	24.00	105.00
FF5	S94030224	6.00	2.09	29.20	0.07	16.00	0.21	0.08	61.00	12.00	57.00
FF5	S94030226	6.00	1.84	29.00	0.07	15.00	0.16	0.06	62.00	10.00	47.00
FF6	S94030210	6.00	2.83	45.40	0.16	26.00	0.66	0.14	100.00	22.00	80.00
FF6	S94030212	6.00	2.34	39.20	0.14	17.00	0.43	0.10	81.00	18.00	66.00
FF7	S94030195	7.00	3.55	42.20	0.11	30.00	0.46	0.17	102.00	20.00	97.00
FF7	S94030199	6.00	3.43	39.30	0.11	32.00	0.45	0.20	95.00	21.00	99.00
FF9	S94030155	6.00	1.76	28.90	0.06	14.00	0.16	0.07	57.00	8.00	38.00
FF9	S94030157	3.00	1.75	30.10	0.04	14.00	0.09	0.04	49.00	7.00	36.00
FF10	S94030283	6.00	1.97	33.70	0.15	16.00	0.38	0.20	98.00	22.00	50.00
FF10	S94030285	5.00	1.82	34.20	0.09	19.00	0.32	0.12	100.00	13.00	45.00
FF11	S94030127	7.00	3.10	46.00	0.09	31.00	0.27	0.17	101.00	20.00	86.00
FF11	S94030130	4.00	2.21	35.40	0.07	23.00	0.16	0.11	84.00	15.00	62.00
FF12	S94030016	6.00	2.10	35.80	0.37	14.00	0.90	0.33	83.00	19.00	51.00
FF12	S94030018	7.00	1.99	36.80	0.21	16.00	0.63	0.18	76.00	18.00	52.00
FF13	S94030236	4.00	2.89	52.60	0.31	24.00	1.80	0.23	122.00	39.00	86.00
FF13	S94030239	4.00	2.23	33.20	0.22	13.00	0.50	0.09	58.00	16.00	47.00
FF14	S94030143	7.00	2.68	42.10	0.10	22.00	0.20	0.14	94.00	17.00	78.00
FF14	S94030145	6.00	2.52	40.60	0.09	20.00	0.20	0.08	89.00	14.00	72.00
NF2	S94030254	6.00	2.54	27.30	0.12	18.00	0.31	0.09	54.00	12.00	52.00
NF4	S94030319	4.00	1.49	22.00	0.03	7.00	0.03	0.03	29.00	4.00	25.00
NF5	S94030302	6.00	2.20	38.40	0.09	13.00	0.24	0.09	98.00	17.00	53.00
NF7	S94030322	5.00	2.18	44.60	0.14	20.00	0.43	0.12	96.00	22.00	56.00
NF8	S94030370	6.00	2.92	64.50	0.32	31.00	1.73	0.56	169.00	44.00	98.00
NF9	S94030099	7.00	2.21	40.50	0.16	19.00	0.45	0.12	85.00	20.00	58.00
NF10	S94030073	6.00	1.94	37.60	0.14	19.00	0.31	0.07	61.00	17.00	49.00
NF12	S94030061	6.00	3.22	72.75	0.35	30.00	1.29	0.39	185.50	48.00	101.00
NF12	S94030065	6.00	3.11	66.40	0.33	28.00	1.10	0.26	163.00	42.00	95.00
NF13	S94030051	5.00	1.74	41.60	0.05	10.00	0.07	0.03	40.00	10.00	29.00
NF14	S94030358	5.00	1.54	51.60	0.13	11.00	0.13	0.01 a	44.00	15.00	34.00
NF15	S94030043	5.00	1.33	41.00	0.16	12.00	0.19	0.04	36.00	13.00	30.00
NF16	S94030036	5.00	2.78	71.40	0.32	3.00	1.31	0.33	141.00	44.00	95.00
NF17	S94030267	4.00	1.57	29.30	0.05	7.00	0.03	0.01 a	37.00	9.00	30.00
NF17	S94030270	2.00	0.63	27.90	0.03	4.00	0.08	0.02	14.00	16.00	19.00
NF18	S94030082	5.00	2.52	49.90	0.17	19.00	0.37	0.10	86.00	26.00	60.00
NF19	S94030328	5.00	2.01	33.50	0.07	12.00	0.21	0.05	55.00	10.00	41.00
NF20	S94030028	6.00	4.03	30.40	0.23	20.00	0.35	0.08	78.00	37.00	65.00
MB01	S94030092	5.00	2.46	55.70	0.32	24.00	0.84	0.36	125.00	32.00	80.00
MB03	S94030261	6.00	2.71	50.00	0.23	26.00	0.97	0.21	105.00	27.00	69.00
S3	S94030352	5.00	1.92	28.00	0.03	12.00	0.07	0.03	45.00	8.00	33.00
S4	S94030338	4.00	2.95	70.20	0.25	27.00	0.65	0.21	148.00	39.00	90.00
S4	S94030340	3.00	2.17	48.50	1.22	18.00	0.34	0.10	87.00	23.00	58.00

APPENDIX B-1: 1994 INFAUNAL ABUNDANCE (0.3-mm FRACTION)

Survey 9403 0.3 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Nemertea																					
Nemertea sp.2		9						5											1	1	
Nemertea spp. juv.		2		2		8										5	3			1	1
Tubulanidae																					
Tubulanus pellucidus				1	1																
Carinomella lactea						1															
Lineidae																					
Cerebratulus lacteus																					
Micrura spp.				1		1		1								1	1	1	1	1	
Amphiporidae																					
Amphiporus angulatus																4			5	1	8
Tetrastemmatidae																					
Tetrastemma vittatum				1					1												
Annelida																					
Polychaeta																					
Polynoidae																					
Gattyana																					
Harmothoinae spp. juv.																					
Pholoidae																					
Pholoe minuta	1	3	12			1		1		1		3	1	2	2		4	3	7	1	2
Amphinomidae																					
Paramphinome jeffreysii					1																
Phyllodocidae																					
Phyllodoce mucosa		2		1								1				1	1				
Phyllodoce maculata																					
Eteone longa	4	9	5	5			4	2		5	10	5	3	5	3	2	2	6	3	5	9
Mystides borealis									1												
Phyllodoce spp.																					
Phyllodoce arenae																					
Hesionidae																					
Microphthalmus aberrans																					
Syllidae																					
Syllidae spp. juv.																					
Typosyllis sp.1																					
Exogone verugera		1			1											8	2	10	24	18	14
Exogone hebes	2															3	3	15	14	22	17
Exogone longicirris																					
Sphaerosyllis brevifrons																					
Sphaerosyllis longicauda										1		1	1							2	1
Syllides japonica																					
Syllides longocirrata				5	9	9			1	4	1	1	3	1	2						
Nereidae																					
Nereidae spp.									1												
Nereis grayi		1	1	1												3	1				1
Nephtyidae																					
Nephtyidae spp. juv.	2	4	1	3	1																
Nephtys neotena																					
Nephtys spp.							2	1	2						1						
Nephtys incisa								1		1	1	7				1	3	4	2	2	5
Aglaophamus circinata																					
Sphaerodoridae																					

Survey 9403 0.3 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Sphaerodoropsis minuta											1									1	1
Goniadidae																					
Goniada maculata																1					
Lumbrineridae																					
Lumbrineridae spp. juv.	2	11	8						5	6	5	7	1				1	2	6	15	9
Scoletoma hebes																			1		
Ninoe nigripes		1									1	1							3		
Dorvilleidae																					
Dorvilleidae																					
Parougia caeca				2	2	3			1							1	1	1	4	1	
Orbiniidae																					
Scoloplos spp.																					
Leitoscoloplos acutus																1	1				
Leitoscoloplos sp.B																					
Leitoscoloplos spp.																					
Leitoscoloplos spp. juv.	1	2	2	4													2		5	3	7
Paraonidae																					
Aricidea cerrutii												1									
Aricidea quadrilobata		1	1	5	3	8	3	7	4		1				1	2	2	2			
Aricidea minuta																		2			
Levinsenia gracilis	4	2		1	18	1	6	17	7	2	9	3	5		10	2	3	10		1	
Aricidea catherinae	1	12	16							19	42	35	8	56	22				6	25	8
Levinsenia																					
Apistobranchidae																					
Apistobranchus tullbergi			2																		
Spionidae																					
Polydora socialis	1	1	1				2	1	4	1	1					55	21	28	4		9
Polydora quadrilobata																1					
Prionospio steenstrupi	89	197	128	18	10	16										102	94	88	72	30	164
Spio spp. juv.																					
Spio thulini																					
Spio filicornis		1	1																		2
Spio setosa																					
Spio limicola	10	11	17	8	3	17	8	40	20							275	69	89	142	93	249
Spiophanes bombyx																			1	1	
Pygospio elegans																					
Prionospio cirrifera								7	2												
Trochochaetidae																					
Trochochaeta spp.							1			1											
Trochochaeta multisetosa																					
Cirratulidae																					
Cirratulidae spp. juv.									1	2	2	6									
Aphelochaeta spp. juv.																					
Aphelochaeta monilaris																	1	1			
Tharyx acutus	3	57	81									2							2	26	16
Monticellina baptisteae											2	1							17	40	39
Aphelochaeta marioni																					
Monticellina dorsobranchialis																				1	1
Chaetozone sp.A		1		44	11	35											1			1	
Chaetozone setosa					1																
Cossuridae																					

Survey 9403 0.3 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cossura longicirrata				18	20	26	1	1	2	16	38	58	15	89	78						
Flabelligeridae																					
Flabelligeridae spp.														1							
Pherusa spp. juv.																					
Pherusa affinis																					
Scalibregmatidae																					
Scalibregma inflatum	2		4	53	33	126		5	21							24	53	55	1		2
Opheliidae																					
Ophelina acuminata																					
Capitellidae																					
Capitella capitata	1	10	9	2		1	1	2		1	2	1			8	3		6		2	6
Heteromastus filiformis								1													
Mediomastus californiensis	4	21	7	48	8	36		24	3			3			2	1	2	7	20	23	29
Maldanidae																					
Euclymeninae, unident.																		2			
Euclymene collaris																					
Oweniidae																					
Galathowenia oculata																					
Ampharetidae																					
Ampharetidae spp.			1																		
Ampharetidae spp. juv.																					
Ampharete acutifrons																			2		1
Anobothrus gracilis	1	1	1	2																	
Asabellides oculata		3	5					1										2	1		
Terebellidae																					
Terebellidae spp.																					
Polycirrus spp.																					
Polycirrus spp. juv.																					
Sabellidae																					
Sabellidae spp. juv.				4																	
Euchone incolor		2		1		1				1									1		4
Archiannelida																					
Polygordiidae																					
Polygordius sp.A																					
Oligochaeta																					
Tubificidae																					
Tubificidae sp.2												11									
Tubificoides apectinatus				1	2	3															
Gastropoda																					
Gastropoda spp.			1					5		1		6								1	
Bivalvia																					
Bivalvia spp.	13	32	43	4		3	5	5	15	2	1	5	6	1	1	21	41	12	5	17	16
Nuculoidea																					
Nuculidae																					
Nucula spp.										9	18	15		6	2						
Nuculoma tenuis						2															
Nucula delphinodonta		33	27				2	4	3							7	9	2	102	42	100
Nuculanidae																					
Yoldia sapotilla				5	4	8	3	10	14			3									
Mytiloida																					
Mytilidae																					

Survey 9403 0.3 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Mytilus edulis																					
Crenella spp.																					
Crenella decussata	6	23	10																22	14	29
Crenella glandula																					
Veneroida																					
Thyasiridae																					
Thyasira gouldii						3															
Astartidae																					
Astarte undata																					6
Arcticidae																					
Arctica islandica																					
Myina																					
Hiatellidae																					
Hiatella arctica		2	6													2		1			2
Pholadomyacea																					
Lyonsiidae																					
Lyonsia arenosa																					
Scaphopoda																					
Dentalida																					
Dentaliidae																					
Dentulium entale																					
Crustacea																					
Cumacea																					
Cumacea spp.																					
Leuconidae																					
Leucon nr. acutirostris				1			7	10	3												
Eudorella pusilla								2		3			1	1							
Diastylidae																					
Diastyis spp.			1																		
Diastylis sculpta																					
Leptostylis spp.																		1			
Pseudocumidae																					
Petalosarsia declivis			1																		
Dikonophora																					
Paratanaidae																					
Tanaissus psammophilus																					
Gnathiidea																					
Gnathiidae																					
Gnathia cerina			1																		
Anthuridea																					
Anthuridae																					
Ptilanthura tenuis			2																		
Valvifera																					
Idoteidae																					
Edotia montosa																					
Asellota																					
Munnidae																					
Munna spp.																					
Paramunnidae																					
Pleurogonium spp.																					1
Pleurogonium rubicundum		1	3				3	10	1								1		4		

Survey 9403 0.3 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Pleurogonium inerme																					
Amphipoda																					
Amphipoda spp.							1	7	3					1						2	
Gammaridea																					
Ampeliscidae																					
Ampelisca abdita										1											
Aoridae																					
Leptocheirus pinguis																					
Argissidae																					
Argissa hamatipes																					
Corophiidae																					
Corophium nr. crassicorne																			2		
Erichthonius rubricornis																					1
Aoridae																					
Unciola spp.																					
Unciola spp. juv.																4					
Unciola inermis																					
Pseudunciola obliquua																					
Isaeidae																					
Photis pollex	7	2	16							1	2	4	2	5	1	5	2	6	4	3	5
Lysianassidae																					
Orchomenella minuta			1													1					
Phoxocephalidae																					
Harpinia propinqua			4	2							1						2				
Pleustidae																					
Stenopleustes inermis														1	2			1			
Podoceridae																					
Dyopedos monocantha																					1
Stenothoidae																					
Metopella angusta			1	1				7	3		1	3	1	12	3	1	2	2	6	3	
Caprellidea																					
Caprellidae																					
Mayerella limicola										2		1			1						
Sipunculoidea																					
Sipuncula spp. juv.				1													1	1			
Priapulida																					
Priapulidae																					
Priapulus caudatus										1											
Phoronida																					
Phoronidae																					
Phoronis architecta		3	1																		3
Echinodermata																					
Ophiuroidea																					
Ophiuroidea spp. juv.								4													
Hemichordata																					
Enteropneusta																					
Harrimaniidae																					
Stereobalanus canadensis																					

Survey 9403 0.3 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Nemertea																					
Nemertea sp.2																					
Nemertea spp. juv.			3	1			6	2	2		2	4	6			1	11	1	14	5	14
Tubulanidae																					
Tubulanus pellucidus																					
Carinomella lactea																					
Lineidae																				1	
Cerebratulus lacteus																					1
Micrura spp.						1					1										6
Amphiporidae																					
Amphiporus angulatus							1	3					3				16	1		7	5
Tetrastemmatidae																					
Tetrastemma vittatum																					
Annelida																					
Polychaeta																					
Polynoidae																					
Gattyana																					
Harmothoinae spp. juv.											1										
Pholoidae																					
Pholoe minuta	7		2	1	5	7	13	11	12				25	4	3	25	1	2	9	2	2
Amphinomidae																					
Paramphinome jeffreysii																					
Phyllodocidae																					
Phyllodoce mucosa				3	1	1	33	18	26				17			1			1		
Phyllodoce maculata							2	1													
Eteone longa	3	1	12	8	15	11	7	4	9	3	8	2	15	1	3	16	12	4	13	4	14
Mystides borealis																					
Phyllodoce spp.														1							
Phyllodoce arenae																					
Hesionidae																					
Microphthalmus aberrans							3	3	2												
Syllidae																					
Syllidae spp. juv.																					
Typosyllis sp.1															1						
Exogone verugera	1		1											47	35	22		8	17	5	15
Exogone hebes	1				1	1	1						7	293	7	16	8		4	2	10
Exogone longicirris																					
Sphaerosyllis brevifrons																					
Sphaerosyllis longicauda													1				5		2		
Syllides japonica	1	1								1											
Syllides longocirrata		1	6									1									
Nereidae																					
Nereidae spp.														1							
Nereis grayi	1			1														1			
Nephtyidae																					
Nephtyidae spp. juv.															1	7			1		
Nephtys neotena						2	50	73	55				2	1							
Nephtys spp.	4	8	1	9	7	5				5	4	13									
Nephtys incisa				12	6	8											4	1	8	4	6
Aglaophamus circinata													7	5							
Sphaerodoridae																					

Survey 9403 0.3 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Sphaerodoropsis minuta																			1		
Goniadidae																					
Goniada maculata		1																			
Lumbrineridae																					
Lumbrineridae spp. juv.			1	42	5	9	1		1						1	9	18	3	11	16	11
Scoletoma hebes				2		6		1	1												
Ninoe nigripes							1		2				1					2	3		4
Dorvilleidae																					
Dorvilleidae												1				1	1				
Parougia caeca	2	1	2				2						1			1	8	3	8	25	13
Orbiniidae																					
Scoloplos spp.													1								
Leitoscoloplos acutus			1			1	9	10	1								5		2		1
Leitoscoloplos sp.B																				1	
Leitoscoloplos spp.																					
Leitoscoloplos spp. juv.			2	6		7				3	19	6	3			2	13	4	11	11	15
Paraonidae																					
Aricidea cerrutii																					
Aricidea quadrilobata	14	4	38			1					6	3				1					1
Aricidea minuta																					
Levinsenia gracilis	41	17	41		4	1	1			6	14	8	1		1	4	3	2		9	13
Aricidea catherinae				32	22	30	35	12					26	6		1	67	15	37	18	70
Levinsenia															4						
Apistobranchidae																					
Apistobranchus tullbergi																	2		1	3	2
Spionidae																					
Polydora socialis	1			3		1						1		28	3	101			5	3	
Polydora quadrilobata														1		3					
Prionospio steenstrupi	15		9				118	119	91	4	13	3	146			7	33	98	149	29	65
Spio spp. juv.																4					
Spio thulini													5								
Spio filicornis																					1
Spio setosa													1								
Spio limicola	77	15	45			2	1	1		8	46	65	35			49	116	194	277	53	223
Spiophanes bombyx								2					1								
Pygospio elegans																					
Prionospio cirrifera																					
Trochochaetidae																					
Trochochaeta spp.																					
Trochochaeta multisetosa																1					
Cirratulidae																					
Cirratulidae spp. juv.				3	4	6					6					39					
Aphelochaeta spp. juv.															2						
Aphelochaeta monilaris													1				2				
Tharyx acutus				3	14	13	46	17	3				24		1	38	6	10	4	7	35
Monticellina baptisteae			2	10	52	39				1		1					17	41	45	29	96
Aphelochaeta marioni											1		1						3		1
Monticellina dorsobranchialis				1	1	2										1	1				1
Chaetozone sp.A	14	3	36				2	5	7	7	63	11									
Chaetozone setosa																					
Cossuridae																					

Survey 9403 0.3 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Cossura longicirrata	6	6	11							3	13	5									
Flabelligeridae																					
Flabelligeridae spp.																					
Pherusa spp. juv.																					
Pherusa affinis							1				1										
Scalibregmatidae																				1	
Scalibregma inflatum	1		3							8	20	18				2					
Opheliidae																					
Ophelina acuminata										1											
Capitellidae																					
Capitella capitata	2		1	2		3	8	2	2	4	3		10		1	8	3	1	7	4	9
Heteromastus filiformis											1										1
Mediomastus californiensis	9	5	47	6		5	51	47	90		79	20	202	1		27	25	21	71	71	24
Maldanidae																					
Euclymeninae, unident.																					
Euclymene collaris																					
Oweniidae																					
Galathowenia oculata						1															
Ampharetidae																					
Ampharetidae spp.																					
Ampharetidae spp. juv.																					
Ampharete acutifrons																					
Anobothrus gracilis	1		2								1	1									
Asabellides oculata	1												1			3			1		1
Terebellidae																					
Terebellidae spp.																				1	
Polycirrus spp.																					
Polycirrus spp. juv.																			1		
Sabellidae																					
Sabellidae spp. juv.																					
Euchone incolor	4		5															2	4		2
Archiannelida																					
Polygordiidae																					
Polygordius sp.A																					
Oligochaeta																					
Tubificidae																					
Tubificidae sp.2							5	50	12				8				9	8			6
Tubificoides apectinatus	29	10	60			8	1	1	1	1	15	11	2				32			1	1
Gastropoda																					
Gastropoda spp.							1				7				2						
Bivalvia																					
Bivalvia spp.		2	4	4	10	7	3	3	7	3	23	11	22	9	23	21	4	3	5	2	1
Nuculoidea																					
Nuculidae																					
Nucula spp.	3		5							6	30	12									
Nuculoma tenuis																					
Nucula delphinodonta															32	1		26	31	2	4
Nuculanidae																					
Yoldia sapotilla			1							3	8										
Mytiloida																					
Mytilidae																					

Survey 9403 0.3 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10		NF12
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Mytilus edulis				1			7	5	10												
Crenella spp.																					
Crenella decussata											2		1	28	23	12		2	8		4
Crenella glandula																					
Veneroida																					
Thyasiridae																					
Thyasira gouldii																					
Astartidae																					
Astarte undata																					
Arcticidae																					
Arctica islandica				1			1	2					6			1					
Myina																					
Hiatellidae																					
Hiatella arctica							10	18					4	1		3			1		1
Pholadomyacea																					
Lyonsiidae																					
Lyonsia arenosa																					
Scaphopoda																					
Dentalida																					
Dentaliidae																					
Dentulium entale											1										
Crustacea																					
Cumacea																					
Cumacea spp.																1					
Leuconidae																					
Leucon nr. acutirostris																					
Eudorella pusilla		1									3										
Diastylidae																					
Diastyis spp.																					
Diastylis sculpta						2			4					1	1						
Leptostylis spp.																					
Pseudocumidae																					
Petalosarsia declivis																					
Dikonophora																					
Paratanaidae																					
Tanaissus psammophilus														3							
Gnathiidea																					
Gnathiidae																					
Gnathia cerina																					
Anthuridea																					
Anthuridae																					
Ptilanthura tenuis														3							
Valvifera																					
Idoteidae																					
Edotia montosa																					
Asellota																					
Munnidae																					
Munna spp.															2						
Paramunnidae																					
Pleurogonium spp.															1	13					
Pleurogonium rubicundum				47	64	19	5	3	4				1								

Survey 9403 0.3 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Pleurogonium inerme													2								
Amphipoda																					
Amphipoda spp.		3				2					1			19	1	1			4		
Gammaridea																					
Ampeliscidae																					
Ampelisca abdita					1		6	1	4												
Aoridae																					
Leptocheirus pinguis																					
Argissidae																					
Argissa hamatipes				2					1												
Corophiidae																					
Corophium nr. crassicorne														120							
Erichthonius rubricornis																					
Aoridae																					
Unciola spp.															2						
Unciola spp. juv.																					
Unciola inermis																					
Pseudunciola obliquua																					
Isaeidae																					
Photis pollex		3		18	15	6	6	5	3			1	3	7	1	15		1	3		1
Lysianassidae																					
Orchomenella minuta				1																	
Phoxocephalidae																					
Harpinia propinqua	1		1																		
Pleustidae																					
Stenopleustes inermis				1	1								1			4					
Podoceridae																					
Dyopedos monocantha				1																	
Stenothoidae																					
Metopella angusta		3		3	5	1	1						1		1			1	5		
Caprellidea																					
Caprellidae																					
Mayerella limicola																			1	1	
Sipunculoidea																					
Sipuncula spp. juv.			1																		
Priapulida																					
Priapulidae																					
Priapulus caudatus																					
Phoronida																					
Phoronidae																					
Phoronis architecta																					
Echinodermata																					
Ophiuroidea																					
Ophiuroidea spp. juv.											1										
Hemichordata																					
Enteropneusta																					
Harrimaniidae																					
Stereobalanus canadensis																					1

Survey 9403 0.3 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Nemertea																	
Nemertea sp.2				17	1								3	4			12
Nemertea spp. juv.	14	19				16		16									
Tubulanidae																	
Tubulanus pellucidus																	
Carinomella lactea	1											1	1				
Lineidae																	
Cerebratulus lacteus					2												
Micrura spp.				2							1	1	1			1	1
Amphiporidae																	
Amphiporus angulatus	6												2				
Tetrastemmatidae																	
Tetrastemma vittatum			1					1		1						1	8
Annelida																	
Polychaeta																	
Polynoidae																	
Gattyana																	1
Harmothoinae spp. juv.																	
Pholoidae																	
Pholoe minuta	7	5	27	17	9	2	1	1	22	12	8	3	5	14	36	13	23
Amphinomidae																	
Paramphinome jeffreysii																	
Phyllodocidae																	
Phyllodoce mucosa		3				3	3	3		2			4		5		
Phyllodoce maculata						1							1	1			
Eteone longa	13	1	1	4	6				6	9	6	4	17		10	12	11
Mystides borealis																	
Phyllodoce spp.				1													
Phyllodoce arenae							1								1		
Hesionidae																	
Microphthalmus aberrans																	
Syllidae																	
Syllidae spp. juv.														1	1		
Typosyllis sp.1				1						4							
Exogone verugera	22	12	157	15		9	2	2	69	11	1	8	24	48	1	6	12
Exogone hebes	11	332	21	19	5	118	37	21	38	31		19	26	300	3	41	19
Exogone longicirris			1						6				3				
Sphaerosyllis brevifrons	1		24						4					1			
Sphaerosyllis longicauda	1		2	1					2	6	1			1	2	1	
Syllides japonica	1		10						46								
Syllides longocirrata			2						6								
Nereidae																	
Nereidae spp.												1		2			
Nereis grayi					1				1	1							
Nephtyidae																	
Nephtyidae spp. juv.		7	10	3	3				1	4		4			3	4	4
Nephtys neotena											3						
Nephtys spp.																	
Nephtys incisa	2								4			1	12		3		
Aglaophamus circinata						11	5	10						5			
Sphaerodoridae																	

Survey 9403 0.3 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Sphaerodoropsis minuta																	1
Goniadidae																	
Goniada maculata													1				
Lumbrineridae																	
Lumbrineridae spp. juv.	16			2					5		3	16	18				14
Scoletoma hebes																	
Ninoe nigripes	2								2			2					
Dorvilleidae																	
Dorvilleidae						1											
Parougia caeca	35			1					6			7	13		1		11
Orbiniidae																	
Scoloplos spp.										1			1				
Leitoscoloplos acutus	2								1			3					1
Leitoscoloplos sp.B																	
Leitoscoloplos spp.															4	1	9
Leitoscoloplos spp. juv.	24							1		6		8	1				
Paraonidae																	
Aricidea cerrutii																	1
Aricidea quadrilobata	3														1	1	4
Aricidea minuta																	
Levinsenia gracilis	12	1			5	1			4			7	13			8	21
Aricidea catherinae	29	11	12	2	2	1		2	14	4	3	28	27	8		1	
Levinsenia																	
Apistobranchidae																	
Apistobranchus tullbergi	2																4
Spionidae																	
Polydora socialis	4	15	7	1		72	16	10	3	17		1	42	35	21	67	3
Polydora quadrilobata			1							4			1	4			
Prionospio steenstrupi	73	7	32	2			1		175	6	1	44	8	60	12	13	29
Spio spp. juv.																	
Spio thulini				3		1		2	1	7			1				
Spio filicornis				1									1	1	1		
Spio setosa																	
Spio limicola	145	27	43	22		2	2		2	13		103	310	55	271	175	275
Spiophanes bombyx		1				11	3	6						2		1	1
Pygospio elegans						44	11										
Prionospio cirrifera																	
Trochochaetidae																	
Trochochaeta spp.																	
Trochochaeta multisetosa	1												4		1		
Cirratulidae																	
Cirratulidae spp. juv.					5	4			5	7	2		26	4	3		
Aphelochaeta spp. juv.																	
Aphelochaeta monilaris	1																
Tharyx acutus	49		3	3	2				18	11	3	135	208	6	13	36	118
Monticellina baptisteae	168	4	2	5	6					17	8	47	61	2	61	11	4
Aphelochaeta marioni												2	22		1		39
Monticellina dorsobranchialis					2								3				
Chaetozone sp.A	2	19	6			22	1	5				4	1	9	4		1
Chaetozone setosa																	
Cossuridae																	

Survey 9403 0.3 mm Taxon	 3	NF13 1	NF14 1	NF15 1	NF16 1	NF17 1	 2	 3	NF18 1	NF19 1	NF20 1	MB01 1	MB03 1	S3 1	S4 1	 2	 3
Cossura longicirrata																	
Flabelligeridae																	
Flabelligeridae spp.																	
Pherusa spp. juv.									1								
Pherusa affinis																	
Scalibregmatidae	1																
Scalibregma inflatum	7		2							1							1
Opheliidae																	
Ophelina acuminata																	
Capitellidae																	
Capitella capitata	8		2	17		1			3	5			11	7	1	2	7
Heteromastus filiformis													1				
Mediomastus californiensis	135		39	4		2			39	15		71	51	27	11	3	56
Maldanidae																	
Euclymeninae, unident.				1													
Euclymene collaris						1											
Oweniidae																	
Galathowenia oculata																	
Ampharetidae																	
Ampharetidae spp.				1													
Ampharetidae spp. juv.										1							
Ampharete acutifrons																	
Anobothrus gracilis									1								
Asabellides oculata	2		1						23								
Terebellidae																	
Terebellidae spp.						1											
Polycirrus spp.	2																
Polycirrus spp. juv.																	
Sabellidae																	
Sabellidae spp. juv.																	
Euchone incolor	2									2			2				1
Archiannelida																	
Polygordiidae																	
Polygordius sp.A		90				70		39		1				54			
Oligochaeta																	
Tubificidae																	
Tubificidae sp.2									7			2	4				4
Tubificoides apectinatus	1		3						7			11	7	3			2
Gastropoda																	
Gastropoda spp.			1				1	2	9			1				1	
Bivalvia																	
Bivalvia spp.	10	19	23	45	14	69	12	68	23	35	3	4	4	55	41	47	23
Nuculoidea																	
Nuculidae																	
Nucula spp.																	
Nuculoma tenuis																	
Nucula delphinodonta	8	1		4	6				5	11		4	6	7	1	16	1
Nuculanidae																	
Yoldia sapotilla																	
Mytiloida																	
Mytilidae																	

Survey 9403 0.3 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Mytilus edulis																	
Crenella spp.			59							7				86			
Crenella decussata	2	27		83	11						3	2	1				
Crenella glandula									17								
Veneroida																	
Thyasiridae																	
Thyasira gouldii												4					
Astartidae																	
Astarte undata	1															20	1
Arcticidae																	
Arctica islandica	1														1		
Myina																	
Hiatellidae																	
Hiatella arctica		2	4	5		18	4	5	23	17	7			12	34	5	11
Pholadomyacea																	
Lyonsiidae																	
Lyonsia arenosa															2		
Scaphopoda																	
Dentalida																	
Dentaliidae																	
Dentulium entale																	
Crustacea																	
Cumacea																	
Cumacea spp.																	
Leuconidae																	
Leucon nr. acutirostris																	
Eudorella pusilla													1	1			
Diastylidae																	
Diastyis spp.																	
Diastylis sculpta		2	1			3	1	6	1					16			
Leptostylis spp.																	
Pseudocumidae																	
Petalosarsia declivis		1	1				1	4	1				2	2		3	
Dikonophora																	
Paratanaidae																	
Tanaissus psammophilus						1	3	1						15			
Gnathiidea																	
Gnathiidae																	
Gnathia cerina																	
Anthuridea																	
Anthuridae																	
Ptilanthura tenuis																	
Valvifera																	
Idoteidae																	
Edotia montosa														1			
Asellota																	
Munnidae																	
Munna spp.									7	1							
Paramunnidae																	
Pleurogonium spp.				1	10				25	2	15			7	1	2	1
Pleurogonium rubicundum																	

Survey 9403 0.3 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Pleurogonium inerme																	
Amphipoda																	
Amphipoda spp.		9	9	5		23	1	7	7	4	2			18	2		
Gammaridea																	
Ampeliscidae																	
Ampelisca abdita																	
Aoridae																	
Leptocheirus pinguis							1										
Argissidae																	
Argissa hamatipes		2										1					
Corophiidae																	
Corophium nr. crassicorne		20	3		1	722	494	298			1			99			
Erichthonius rubricornis							2										
Aoridae																	
Unciola spp.																	
Unciola spp. juv.																	
Unciola inermis						8	2										
Pseudunciola obliquua						21	33	27									
Isaeidae																	
Photis pollex		53	2	4		8		1		11	3			41	1	6	4
Lysianassidae																	
Orchomenella minuta																	
Phoxocephalidae																	
Harpinia propinqua																	
Pleustidae																	
Stenopleustes inermis	1		1				2			2		1		5		1	
Podoceridae																	
Dyopedos monocantha				2					6								
Stenothoidae																	
Metopella angusta									1		2				4	8	2
Caprellidea																	
Caprellidae																	
Mayerella limicola																	
Sipunculoidea																	
Sipuncula spp. juv.																	1
Priapulida																	
Priapulidae																	
Priapulus caudatus																	
Phoronida																	
Phoronidae																	
Phoronis architecta										1			1			1	
Echinodermata																	
Ophiuroidea																	
Ophiuroidea spp. juv.						1			1						1	1	
Hemichordata																	
Enteropneusta																	
Harrimaniidae																	
Stereobalanus canadensis																	

APPENDIX B-2: 1994 INFAUNAL ABUNDANCE (0.5-mm FRACTION)

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cnidaria																					
Ceriantharia																					
Cerianthidae																					
Ceriantheopsis americanus																					
Actiniaria																					
Actinaria spp. juv.			1																		
Actiniaria sp.2										1	4	1							2	4	1
Edwardsiidae																					
Edwardsia elegans	13	16	17							2	1					1	1	2		4	
Platyhelminthes																					
Turbellaria																					
Turbellaria sp.1		1																			
Turbellaria sp.2																					
Nemertea																					
Nemertea sp.2																		1			
Nemertea spp. juv.				1												3	8	3			
Tubulanidae																					
Tubulanus pellucidus				3	2	2															
Carinomella lactea				1	1								1								
Lineidae																					
Cerebratulus lacteus				3	1				2					3	1				6	4	15
Micrura spp.		1	2	3	10	1	2		1	2	2	14	1	1	1	6	10	3	7	10	16
Amphiporidae																					
Amphiporus angulatus					1											1	1		3	3	6
Tetrastemmatidae																					
Tetrastemma vittatum																					
Annelida																					
Polychaeta																					
Polynoidae																					
Arcteobia anticostiensis																4	5	5			1
Gattyana																					
Gattyana amondseni			1														1		2	2	5
Gattyana cirrosa																					1
Harmothoinae spp.																					
Harmothoinae spp. juv.							1									1					
Harmothoe imbricata																					
Hartmania moorei					1	1															
Enipo torelli							1		1			1	1	2	1	1	1				
Pholoidae																					
Pholoe minuta	3	12	5	1	1		1			2	1	4	2	6	4	10	7	5		5	5
Amphinomidae																					
Paramphinome jeffreysii					1																
Phyllodocidae																					
Phyllodoce groenlandica																					
Phyllodoce mucosa								1				2				2	1	3			
Phyllodoce maculata																					
Eteone longa	4	7	25	6	1		5	1	1	3	5	6	3	7	6	1	7	8	4	13	17
Eulalia bilineata																					
Phyllodoce spp.																					
Phyllodoce spp. juv.																					
Phyllodoce arenae																					

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Hesionidae																					
Microphthalmus aberrans																	1				
Pilargidae																					
Ancistrosyllis groenlandica																					
Syllidae																					
Typosyllis sp.1																1			1	2	1
Typosyllis spp. juv.																					
Exogone verugera			1		4											44	45	30	12	60	28
Exogone hebes																17	12	12	6	21	11
Exogone longicirris																					
Sphaerosyllis brevifrons																					
Sphaerosyllis longicauda																2	1				4
Syllides japonica																2					
Syllides longocirrata					10					1	2	2		1							
Nereidae																					
Nereidae spp.																					
Neanthes virens																					
Nereis grayi		2	2	1												6	12	8	1	7	3
Nephtyidae																					
Nephtyidae spp. juv.	1	7	2	1																	
Nephtys neotena																					
Nephtys spp.									1												
Nephtys ciliata		1																		1	
Nephtys caeca																					
Nephtys incisa				1				6	3	2	8	12	8	6	5		7	1	2	9	4
Aglaophamus circinata			1																		
Sphaerodoridae																					
Sphaerodoropsis minuta												1				1			1	1	2
Glyceridae																					
Glycera capitata																					
Goniadidae																					
Goniada maculata	2	2				1											1	1			
Lumbrineridae																					
Lumbrineridae spp. juv.			4				1		1	1		11		2	2	3	3	1		3	5
Eranno spp.									1												
Scoletoma fragilis									1			2	3	2		4	1	1	3	1	4
Scoletoma hebes																			7	25	22
Ninoe nigripes	22	16	24	7	7	6	21	22	17	13	21	25	11	20	13	17	13	11	54	73	58
Arabellidae																					
Drilonereis longa																					
Dorvilleidae																					
Dorvilleidae																					
Parougia caeca				3	4	10						4					4	3		4	
Orbiniidae																					
Scoloplos spp.																					
Scoloplos armiger	1		2													8	2	8	3	13	17
Orbinia spp. juv.																					
Leitoscoloplos acutus	4	2		9	6	20	4	4	3	1						13	18	12	16	56	40
Leitoscoloplos sp.B																					
Leitoscoloplos spp.																					
Leitoscoloplos spp. juv.		1	2																		

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Paraonidae																					
Aricidea cerrutii										3	1	1									
Aricidea quadrilobata		11	7	11	25	27	24	6	13			38		2	1	9	15	7		1	1
Aricidea minuta																1					
Levinsenia gracilis	14	15	21	10	45	7	18	39	19	21	19	28	3	4	13	29	33	43	8	6	9
Aricidea catherinae	10	10	17							28	36	88	26	123	100				30	109	35
Apistobranchidae																					
Apistobranchus tullbergi				1		2														2	
Spionidae																					
Laonice sp.1																	1				
Laonice cirrata																		1		1	
Polydora socialis	2	14	7		1		13		12		1	5				265	300	288	26	109	145
Polydora caulleryi																					
Polydora quadrilobata		1	2													16	2	3	36	46	147
Prionospio steenstrupi	22	60	64	19	27	34						1				277	314	157	73	148	241
Spio spp. juv.																					
Spio thulini																					
Spio filicornis			1																2	3	6
Spio setosa		2																			
Spio limicola	11	19	17	24	20	133	21	11	21			107				851	932	684	236	1201	816
Spiophanes bombyx		2																	8	3	8
Spiophanes kroeyeri		1																2		1	
Pygospio elegans																					
Scolelepis foliosa																					
Prionospio cirrifera								1													
Trochochaetidae																					
Trochochaeta spp.												1									
Trochochaeta carica				2	8	2															
Trochochaeta multisetosa																2	1				
Cirratulidae																					
Cirratulidae spp.																					
Cirratulidae spp. juv.																					
Cirratulus cirratus																					1
Aphelochaeta spp. juv.																					
Aphelochaeta monilaris					1											5		1			
Tharyx acutus	19	34	49									15							9	60	53
Monticellina baptisteae		1									4	2							45	91	28
Aphelochaeta marioni	3	1	2	2	2	3	1		2	1		3				9	5	15	22	82	127
Monticellina dorsobranchialis		2	2															1	25	14	2
Chaetozone sp.A				13	2	7						2				4	11	5			
Chaetozone setosa				3	11	9															
Cossuridae																					
Cossura longicirrata				3	14	6	3	2	6	61	92	147	21	144	54		1				
Flabelligeridae																					
Flabelligeridae spp.							4														
Brada villosa																				1	
Pherusa affinis																			1		1
Diplocirrus hirsutus												1									
Scalibregmatidae																					
Scalibregma inflatum	1	1	7	6	6	3										18	103	69		3	5
Sternaspidae																					

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Sternapsis scutata				1	2	6						1						1			
Capitellidae																					
Capitella capitata		15	5	3	6	1			1	2	1	1		3	3	19	18	11	2	24	33
Heteromastus filiformis				2	7	7	1		1			1							1	1	
Mediomastus californiensis	20	35	71	42	49	66	26	1	16	1		78	6	2	2	82	66	77	145	269	239
Maldanidae																					
Maldanidae spp. juv.																					
Clymenella torquata																			13	10	5
Maldane					7														2	4	
Maldane sarsi	12	17	19	2	5	4			1							9		5	30	11	1
Maldane glebifex				1	2	1												1	6	3	
Praxillella gracilis					2																
Praxillella praetermissa	16	5	15	2							2	1				7	5	13	4	34	1
Rhodine loveni																3	2	4	10	3	2
Euclymeninae, unident.		1			3		4		1	1		2	1	2		1	2	5	3	2	1
Euclymene collaris																					
Clymenura																					
Clymenura sp.A																					
Praxillura ornata																4	12	4			
Oweniidae																					
Owenia fusiformis	4	9	2																	48	
Galathowenia oculata												1	1						1	2	1
Pectinariidae																					
Pectinaria gouldii																					
Pectinaria granulata																					
Ampharetidae																					
Ampharetidae spp.		18	3							1		7									
Ampharetidae spp. juv.									2												
Ampharete arctica		2			1																1
Ampharete acutifrons		3														12	10	27	2	38	61
Ampharete finmarchica																					
Melinna cristata						1															1
Anobothrus gracilis	2	7	8	2	3		3		10			8	1		3	17	10	18		3	
Asabellides oculata		25	11						4							9	31	7	13	44	44
Terebellidae																					
Terebellidae spp.												2									
Amphitrite cirrata																1					
Polycirrus spp.																	4				
Polycirrus phosphoreus																		1			
Trichobranchidae																					
Terebellides atlantis									1			15				2		1		1	
Terebellides spp.												12									
Terebellides stroemi																					
Sabellidae																					
Sabellidae spp. juv.					1																
Chone spp.																					
Chone duneri																					4
Euchone incolor		3	1	1								14				4	3	1	7	19	17
Euchone elegans																					
Laonome kroeyeri			1													1	3	1		11	2
Archiannelida																					

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Polygordiidae																					
Polygordius sp.A																	1				
Oligochaeta																					
Tubificidae																					
Tubificidae sp.2												1			6						1
Tubificoides apectinatus					7	2		1													
Gastropoda																					
Gastropoda sp.A																					
Gastropoda spp.					2		1											1	1	2	
Archaeogastropoda																					
Trochidae																					
Solariella obscura																					
Mesogastropoda																					
Rissoidae																					
Rissoidae sp.A																					
Onoba pelagica				1			6		14	22	29	22	2	10	5						10
Naticidae																					
Euspira heros											1										
Stenoglossa																					
Buccinidae																					
Colus sp.A	1																				
Colus pygmaeus				1																	
Nassariidae																					
Ilyanassa trivittata	3	2	2																		
Toxoglossa																					
Turridae																					
Turridae sp.A																					
Oenopota spp.																					
Oenopota incisula	1	1					1				1	1									1
Oenopota cf. cancellatus																					
Oenopota exaratus																					
Cephalaspidea																					
Cylichnidae																					
Cylichna spp.						2			5							1					1
Cylichna alba							1			1		5									
Cylichna gouldi							1	1		2		4	2		1						
Aplacophora																					
Chaetodermatida																					
Chaetodermatidae																					
Chaetoderma nitidulum						1	1														
Bivalvia																					
Bivalvia sp.A																					
Bivalvia spp.	8	9	22	5	11	3	1	3	20	3	2	5	2	1	1	2	1	5	45		7
Nuculoidea																					
Nuculidae																					
Nucula spp.									10												
Nuculoma tenuis				3	5	3			9								2				
Nucula annulata										9	15	29	3	6	10						
Nucula delphinodonta	39	71	64				11	4	9	6	9	15	3	18	18	3	6	3	121	41	50
Nuculanidae																					
Nuculana pernula																					

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Megayoldia thraciaeformis				5		2		1	1												2
Yoldia sapotilla		2	1	1	1	4	5	7	12	1	2	2	2	3	2	6	17	2		1	3
Mytiloida																					
Mytilidae																					
Mytilus edulis	3	5	2																		
Crenella spp.																					
Crenella spp. juv.																					
Crenella decussata	5	13	5									1				3	1		31	10	28
Crenella glandula																					
Musculus niger						2														1	
Pteriina																					
Pectinidae																					
Placopecten magellanicus	4	2	5																		
Veneroida																					
Thyasiridae																					
Thyasira gouldii	11	30	9	3	7	11	25	19	8	6	7	24	1	5	1	13	18	14	2	13	20
Carditidae																					
Cyclocardia borealis																					
Astartidae																					
Astarte undata			1													3	8	1	9	5	4
Cardiidae																					
Cerastoderma pinnulatum	11	21	6																		3
Arcticidae																					
Arctica islandica	1	6	5							2	6	7					2		6	12	7
Veneridae																					
Pitar morrhuana																					1
Myina																					
Myidae																					
Mya arenaria	1	1					1				1			1		1				9	3
Hiatellidae																					
Hiatella arctica			3																1	1	27
Pholadomyacea																					
Lyonsiidae																					
Lyonsia arenosa			1																		
Periplomatidae																					
Periploma papyratium	2	1	1				5	6		1	3	9	3	7	6	1			1		4
Thraciidae																					
Asthenothaerus hemphilli																					
Scaphopoda																					
Dentalida																					
Dentaliidae																					
Dentulium entale																					
Crustacea																					
Mysida																					
Mysidae																					
Mysis mixta											1				1			1			
Erythrops erythrophthalma																					
Cumacea																					
Lampropidae																					
Lamprops quadriplicata																					
Leuconidae																					

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Leucon nr. acutirostris				8		4	2	1	2												
Eudorella pusilla	2	2			1	2	4	5	5	1	1	3	2	8			2	2			
Eudorellopsis deformis																					
Diastylidae																					
Diastyis spp.																					
Diastylis quadrispinosa			1														2				
Diastylis sculpta			5																		
Diastylis abbreviata								3													
Diastylis cornuifer																					
Leptostylis spp.																					
Leptostylis cf. ampullacea																					
Leptostylis longimana										6		2		1			1				
Pseudocumidae																					
Petalosarsia declivis			7																		
Campylaspidae																					
Campylaspis rubicunda			1					1		1									4	1	4
Dikonophora																					
Paratanaidae																					
Tanaissus psammophilus																					
Anthuridea																					
Anthuridae																					
Ptilanthura tenuis	9	11	10													3	2	2	9		12
Flabellifera (Isopoda)																					
Cirolanidae																					
Politolana polita		1																			
Valvifera																					
Idoteidae																					
Edotia montosa	13	3	22						1					3		8	6	3	18	29	42
Edotia triloba																					
Chiridotea tuftsi																					
Asellota																					
Munnidae																					
Munna spp.																					
Paramunnidae																					
Pleurogonium spinosissimum																	6	2			
Pleurogonium rubicundum						1		1	3			1		1		1			2		2
Pleurogonium inerme			2																		
Amphipoda																					
Amphipoda sp.1																					
Amphipoda spp.	2		5													2			2		
Gammaridea																					
Ampeliscidae																					
Ampelisca macrocephala	5	4	13													1	2	1	1	2	
Ampelisca abdita																					
Byblis spp.							1										2	1			
Byblis nr. gaimardi																					
Haploops tubicola																					
Haploops fundiensis		4	1	1	5	4		2	4							3	6		7	1	2
Amphilochidae																					
Gitanopsis arctica																					2
Aoridae																					

Survey 9403 0.5 mm	FF1A			FF4			FF5			FF6			FF7			FF9			FF10		
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Leptocheirus pinguis																	3	1			
Argissidae																					
Argissa hamatipes			2				1			1				1			4	2		1	
Corophiidae																					
Corophium spp.																					
Corophium nr. crassicorne																			1	2	
Erichthonius rubricornis	1		3																1		
Aoridae																					
Unciola spp.																		2			
Unciola spp. juv.																					
Unciola inermis																					
Unciola irrorata	1		1													9					
Pseudunciola obliquua																					
Gammaridae																					
Casco bigelowi																	1				
Haustoriidae																					
Acanthohaustorius millsi																					
Isaeidae																					
Photis pollex						1	1	1					1		1		1	1	1		
Ischyroceridae																					
Ischyrocerus anguipes																					
Lysianassidae																					
Anonyx lilljeborgi		1	4					1	1			2		3			1		1		3
Hippomedon serratus		1					1		11									23			
Orchomenella minuta																3					2
Oedicerotidae																					
Oedicerotidae spp.								5	5	1	1	1	1	3						1	3
Monoculodes spp.																					
Monoculodes cf. intermedius																					
Monoculodes edwardsi	1	2	2				3														1
Phoxocephalidae																					
Harpinia propinqua		2	13	9	3	6	12	14	5	7	2	6						1			1
Phoxocephalus holbolli																					
Rhepoxynius hudsoni																					
Pleustidae																					
Pleustidae sp.1																					
Pleustes panoplus																					
Stenopleustes inermis			9											7	3	1	2	1		1	1
Podoceridae																					
Dyopedos monocantha								3	1						3	2	1		1	7	11
Stenothoidae																					
Metopella angusta							6	6	8	1		2		12	1	1			3		2
Synopiidae																					
Syrrhoe crenulata																		1			2
Caprellidea																					
Caprellidae																					
Mayerella limicola										10		4		1	2		1				
Aeginina longicornis		1	3																18		2
Caridea																					
Crangonidae																					
Crangon septemspinosa																					

Survey 9403 0.5 mm Taxon	FF1A 1	2	3	FF4 1	2	3	FF5 1	2	3	FF6 1	2	3	FF7 1	2	3	FF9 1	2	3	FF10 1	2	3
Anomura																					
Paguridae																					
Pagurus spp.			1																1		
Cancridea																					
Cancridae																					
Cancer borealis	1	1																			
Sipunculoidea																					
Sipuncula spp. juv.							1										3				1
Golfingiidae																					
Phascolion strombi			1													2	5	6		3	1
Priapulida																					
Priapulidae																					
Priapulus caudatus												1									
Phoronida																					
Phoronidae																					
Phoronis architecta		1			1							1				4	1	7	3	17	21
Echinodermata																					
Cribellina																					
Porcellanasteridae																					
Ctenodiscus crispatus																					
Ophiuroidea																					
Ophiuroidea spp.																					
Ophiuroidea spp. juv.																					
Chilophiurina																					
Ophiolepididae																					
Ophiura sarsi													10	7	12						
Ophiura robusta	2	1	2				2	2	3	7	3	6		2	2	1	1				3
Echinoidea																					
Echinoidea spp. juv.																					
Scutellina																					
Echinarachniidae																					
Echinarachnius parma																					
Urochordata																					
Stolidobranchia																					
Molgulidae																					
Bostrichobranchus pilularis																				1	

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Cnidaria																					
Ceriantharia																					
Cerianthidae																					
Ceriantheopsis americanus																1					
Actiniaria																					
Actinaria spp. juv.																					
Actiniaria sp.2				1			8	1					4			2	1	2		2	
Edwardsiidae																					
Edwardsia elegans							1	3						1			1	1			
Platyhelminthes																					
Turbellaria																					
Turbellaria sp.1																					
Turbellaria sp.2																					
Nemertea																					
Nemertea sp.2																					
Nemertea spp. juv.							1		4	2		2						1			
Tubulanidae																					
Tubulanus pellucidus											2										
Carinomella lactea	1	2								1	2	1	1				10	1		2	
Lineidae																					
Cerebratulus lacteus						1		2	1				5				21	3	3	8	5
Micrura spp.	1	4	7	3	1		3	12	2	1	6	1		1	1	5	4	3	8	13	16
Amphiporidae																					
Amphiporus angulatus								3	1								12		2	4	
Tetrastemmatidae																					
Tetrastemma vittatum							1	2	1												
Annelida																					
Polychaeta																					
Polynoidae																					
Arcteobia anticostiensis									1										1		
Gattyana																7					
Gattyana amondseni		3	2							1						1	3			2	2
Gattyana cirrosa													3	1			2		2		
Harmothoinae spp.																					
Harmothoinae spp. juv.	1	1																			
Harmothoe imbricata																					
Hartmania moorei																					
Enipo torelli										1	1										5
Pholoidae																					
Pholoe minuta	3	4	6		1		14	7	20	1			1	1	3	15	5	3	6	3	4
Amphinomidae																					
Paramphinome jeffreysii																					
Phyllodocidae																					
Phyllodoce groenlandica																					
Phyllodoce mucosa				3		1	35	24	36				2			1	1				
Phyllodoce maculata							3		2												
Eteone longa	4	1	2	11	55	13	26	28	37		3	5		1	1	12	19	3	13	10	7
Eulalia bilineata																					
Phyllodoce spp.														1	1	1					
Phyllodoce spp. juv.																					
Phyllodoce arenae													1	1							

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Hesionidae																					
Microphthalmus aberrans								8													
Pilargidae																					
Ancistrosyllis groenlandica		1	1																	1	
Syllidae																					
Typosyllis sp.1															2						
Typosyllis spp. juv.																					
Exogone verugera		1	3		1									34	22	16	4	8	22	28	51
Exogone hebes													1	73	1	15	1		2	7	2
Exogone longicirris																					
Sphaerosyllis brevifrons																					
Sphaerosyllis longicauda																					
Syllides japonica		1										1									
Syllides longocirrata		1	1								4										
Nereidae																					
Nereidae spp.																					
Neanthes virens						1															
Nereis grayi										1					4					1	
Nephtyidae																					
Nephtyidae spp. juv.																3		1	1		
Nephtys neotena							29	26	17												
Nephtys spp.	1		1	1						1	3	8									
Nephtys ciliata							1		3												
Nephtys caeca																					
Nephtys incisa				3	9						1				2	3	12	4	6	12	10
Aglaophamus circinata													7	7							
Sphaerodoridae																					
Sphaerodoropsis minuta																					1
Glyceridae																					
Glycera capitata																					
Goniadidae																					
Goniada maculata	6		2																		
Lumbrineridae																					
Lumbrineridae spp. juv.		1	1		7	1	3									1	1		1		2
Eranno spp.																					
Scoletoma fragilis		1	1																1		
Scoletoma hebes				35	116	70	22	27	5								1	1	1		
Ninoe nigripes	10	4	11	14	11	16	14	7	10	2	1	1	15	1	12	11	16	37	59	54	77
Arabellidae																					
Drilonereis longa															1						
Dorvilleidae																					
Dorvilleidae																					
Parougia caeca							2	1			2	1	3				1	1	3	13	14
Orbiniidae																					
Scoloplos spp.																					
Scoloplos armiger							4	11	2				4								
Orbinia spp. juv.																					
Leitoscoloplos acutus		2	24	5	16	1	133	108	42	4	44	25	12		1	11	58	25	36	23	42
Leitoscoloplos sp.B																	11	2	6	3	2
Leitoscoloplos spp.																					
Leitoscoloplos spp. juv.				1								4							2		3

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Paraonidae																					
Aricidea cerrutii																					
Aricidea quadrilobata	36	22	196							7	73	37								3	3
Aricidea minuta																					
Levinsenia gracilis	34	121	52	1	20	26		1		17	11	15	18		5	17	56	13	23	104	86
Aricidea catherinae	1			56	290	268	155	175	74				162	8	1	5	359	41	98	199	239
Apistobranchidae																					
Apistobranchus tullbergi											1									7	3
Spionidae																					
Laonice sp.1																					
Laonice cirrata																					
Polydora socialis				4	71	22	3				2			238	2	607			58	66	5
Polydora caulleryi															1						
Polydora quadrilobata	1	1		1	3	2	2	4						10	52	12			1	1	
Prionospio steenstrupi		2	7				264	390	204	2	14	8	108				19	132	157	40	105
Spio spp. juv.																3					
Spio thulini													17								
Spio filicornis													3						1		
Spio setosa																					
Spio limicola	125	51	110				12	35	3	71	69	118	424			29	804	539	1083	1171	989
Spiophanes bombyx				5	5	2	12	28	3				2	2		4	1		3		2
Spiophanes kroeyeri		1																1			
Pygospio elegans																					
Scolelepis foliosa							1														
Prionospio cirrifera																					
Trochochaetidae																					
Trochochaeta spp.																					
Trochochaeta carica		1	2							1											
Trochochaeta multisetosa		1						1				1	1						4	4	
Cirratulidae																					
Cirratulidae spp.																					
Cirratulidae spp. juv.					1																
Cirratulus cirratus																					
Aphelochaeta spp. juv.																4					
Aphelochaeta monilaris													4							4	1
Tharyx acutus	2				15	2	67	60	22				19			5	12	17	23	29	64
Monticellina baptisteae	3	2	9	2	23	8						1					47	40	46	74	71
Aphelochaeta marioni	6	2	6				1	1		2	5	3	1		43			20	10	27	45
Monticellina dorsobranchialis				3	1	10		1	3							7	17	9	3	1	1
Chaetozone sp.A	16	7	5				1	2	4	12	34	21									1
Chaetozone setosa																					
Cossuridae																					
Cossura longicirrata	10	33	8							10	6	7									
Flabelligeridae																					
Flabelligeridae spp.																					
Brada villosa																					
Pherusa affinis							1	4	3			3									
Diplocirrus hirsutus																					
Scalibregmatidae																					
Scalibregma inflatum		1								1	6	12					3			2	1
Sternaspidae																					

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Sternapsis scutata											7	3									
Capitellidae																					
Capitella capitata	5	1	1		19	3	13	22	10	7	2	3	17		2	8	2	7	22	10	9
Heteromastus filiformis	2	4	4					3	1	12	27	39	3				7			1	3
Mediomastus californiensis	30	4	14		6	1	251	221	296	10	47	43	151	2	11	47	246	234	295	365	634
Maldanidae																					
Maldanidae spp. juv.														1							
Clymenella torquata																			4		1
Maldane	4	6	1							3								9	8		
Maldane sarsi	13	44	8							5	4	1			23			39	58		
Maldane glebifex																		12	5		
Praxillella gracilis	4	1	2								1	1									
Praxillella praetermissa																					
Rhodine loveni														1							
Euclymeninae, unident.	4	4	3							1	1	1		5							1
Euclymene collaris														8	3						
Clymenura																					
Clymenura sp.A																					
Praxillura ornata																					
Oweniidae																					
Owenia fusiformis	1																				
Galathowenia oculata							1	1		1	8	7							1	1	
Pectinariidae																					
Pectinaria gouldii																					
Pectinaria granulata													5								
Ampharetidae																					
Ampharetidae spp.																			4	2	3
Ampharetidae spp. juv.																7					
Ampharete arctica													1								
Ampharete acutifrons													1					34	1		1
Ampharete finmarchica														1							
Melinna cristata		1	4																		
Anobothrus gracilis	6	12	86				1				3	6	1							1	
Asabellides oculata					1		2	1					86				1	30	10	2	1
Terebellidae																					
Terebellidae spp.																					
Amphitrite cirrata																					
Polycirrus spp.							2													3	
Polycirrus phosphoreus																					
Trichobranchidae																					
Terebellides atlantis	2		2																		
Terebellides spp.																					
Terebellides stroemi											3	1									
Sabellidae																					
Sabellidae spp. juv.													1					1		1	
Chone spp.																	1				
Chone duneri																					
Euchone incolor			10				1					17	1			1	5	4	9	2	17
Euchone elegans																					
Laonome kroeyeri													1				6		1		2
Archiannelida																					

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Polygordiidae																					
Polygordius sp.A									1												
Oligochaeta																					
Tubificidae																					
Tubificidae sp.2							3	18	4												
Tubificoides apectinatus	27	12					1	4	9	1	30	22	1				1			1	
Gastropoda																					
Gastropoda sp.A																					
Gastropoda spp.								1		47	6				2				3		
Archaeogastropoda																					
Trochidae																					
Solariella obscura														1							
Mesogastropoda																					
Rissoidae																					
Rissoidae sp.A															2						
Onoba pelagica	2	9	1							10	14	9	1								
Naticidae																					
Euspira heros																					
Stenoglossa																					
Buccinidae																					
Colus sp.A																					
Colus pygmaeus																					
Nassariidae																					
Ilyanassa trivittata				4	1									1	1						
Toxoglossa																					
Turridae																					
Turridae sp.A																					
Oenopota spp.				1						1											
Oenopota incisula							1		1											2	
Oenopota cf. cancellatus																					
Oenopota exaratus										1											
Cephalaspidea																					
Cylichnidae																					
Cylichna spp.										5	4	1									
Cylichna alba																					
Cylichna gouldi	2	1									3	1									
Aplacophora																					
Chaetodermatida																					
Chaetodermatidae																					
Chaetoderma nitidulum	1	1								1		1									
Bivalvia																					
Bivalvia sp.A					3	6															
Bivalvia spp.		1	3	4	19	6	17	6	6		4	12	11	3	4	33		10	12	2	
Nuculoidea																					
Nuculidae																					
Nucula spp.																					
Nuculoma tenuis	1	2	7								13	6									
Nucula annulata																					
Nucula delphinodonta	2	1	1							3	31	16	2		90	11	2	20	21	5	14
Nuculanidae																					
Nuculana pernula	1	1																			

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Megayoldia thraciaeformis	2		3								2	3									
Yoldia sapotilla	9	4	9							8	19	9						1		1	1
Mytiloida																					
Mytilidae																					
Mytilus edulis			1	3	3	2	9	18	14				7		1						
Crenella spp.																					
Crenella spp. juv.																				1	
Crenella decussata		1	3							1	4	1	1	2	203	9		4	1		2
Crenella glandula																					
Musculus niger													4								
Pteriina																					
Pectinidae																					
Placopecten magellanicus																			1		
Veneroida																					
Thyasiridae																					
Thyasira gouldii	3	3	2							2	30	5			3				1		1
Carditidae																					
Cyclocardia borealis															2	2					
Astartidae																					
Astarte undata														1	31			1			
Cardiidae																					
Cerastoderma pinnulatum													16	2	1						
Arcticidae																					
Arctica islandica				28	41	27	7	5	8				3	8	1	8			1	7	
Veneridae																					
Pitar morrhuana																					
Myina																					
Myidae																					
Mya arenaria		1					2	2	2				3			3		1	1	12	8
Hiatellidae																					
Hiatella arctica					1	1	40	10	4				108			6					
Pholadomyacea																					
Lyonsiidae																					
Lyonsia arenosa																				1	
Periplomatidae																					
Periploma papyratium	1	1									3	2			1		1	1	1	2	2
Thraciidae																					
Asthenothaerus hemphilli																					
Scaphopoda																					
Dentalida																					
Dentaliidae																					
Dentulium entale										3											
Crustacea																					
Mysida																					
Mysidae																					
Mysis mixta											1										
Erythrops erythrophthalma		1																			
Cumacea																					
Lampropidae																					
Lamprops quadriplicata						3															
Leuconidae																					

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Leucon nr. acutirostris											2	1									
Eudorella pusilla		1	2									1									
Eudorellopsis deformis																					
Diastylidae																					
Diastyis spp.					1																
Diastylis quadrispinosa														1		1					
Diastylis sculpta							1	1	2					2		1					
Diastylis abbreviata																					
Diastylis cornuifer																					
Leptostylis spp.																					
Leptostylis cf. ampullacea													1						1		
Leptostylis longimana																					
Pseudocumidae																					
Petalosarsia declivis																					
Campylaspidae																					
Campylaspis rubicunda																			1	2	3
Dikonophora																					
Paratanaidae																					
Tanaissus psammophilus														2							
Anthuridea																					
Anthuridae																					
Ptilanthura tenuis														11	9	2					
Flabellifera (Isopoda)																					
Cirolanidae																					
Politolana polita														3							
Valvifera																					
Idoteidae																					
Edotia montosa				13	19	1	6	6	8			2	4	14	4	5	1	39	16		
Edotia triloba							1														
Chiridotea tuftsi																					
Asellota																					
Munnidae																					
Munna spp.																					
Paramunnidae																					
Pleurogonium spinosissimum																					
Pleurogonium rubicundum					18		3	2	5				3			4					
Pleurogonium inerme													3								
Amphipoda																					
Amphipoda sp.1														44							
Amphipoda spp.		4		1		1								17	7						1
Gammaridea																					
Ampeliscidae																					
Ampelisca macrocephala														7	1	7	1		5	1	
Ampelisca abdita							7	7	5												
Byblis spp.											1										
Byblis nr. gaimardi		2																			
Haploops tubicola																					
Haploops fundiensis	1		2												41						
Amphilochidae																					
Gitanopsis arctica																					
Aoridae																					

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Leptocheirus pinguis														31	4	1					
Argissidae																					
Argissa hamatipes				2	10	4	8	7	4				5	1		1		1	1		
Corophiidae																					
Corophium spp.																					
Corophium nr. crassicorne														111							
Erichthonius rubricornis														1							
Aoridae																					
Unciola spp.																					
Unciola spp. juv.									1												
Unciola inermis																					
Unciola irrorata																					
Pseudunciola obliquua																					
Gammaridae																					
Casco bigelowi																					
Haustoriidae																					
Acanthohaustorius millsi																					
Isaeidae																					
Photis pollex				4	5	1	5	7					2			1			3		
Ischyroceridae																					
Ischyrocerus anguipes																					
Lysianassidae																					
Anonyx lilljeborgi													8		1	1	2				
Hippomedon serratus														3		3				1	
Orchomenella minuta				2					1												
Oedicerotidae																					
Oedicerotidae spp.		1									1										
Monoculodes spp.																1					
Monoculodes cf. intermedius														1							
Monoculodes edwardsi										1											
Phoxocephalidae																					
Harpinia propinqua	4	2	3		1					1	2				2			1			
Phoxocephalus holbolli										1											
Rhepoxynius hudsoni																					
Pleustidae																					
Pleustidae sp.1																					
Pleustes panoplus																					
Stenopleustes inermis																4			1		1
Podoceridae																					
Dyopedos monocantha				1	5	3	1						1		1	9				1	
Stenothoidae																					
Metopella angusta		2		1	3		1	1	1				2						1		1
Synopiidae																					
Syrrhoe crenulata																					
Caprellidea																					
Caprellidae																					
Mayerella limicola										1											1
Aeginina longicornis															2						
Caridea																					
Crangonidae																					
Crangon septemspinosa				1	5	1	1						1						1		

Survey 9403 0.5 mm	FF11			FF12			FF13			FF14			NF2	NF4	NF5	NF7	NF8	NF9	NF10	NF12	
Taxon	1	2	3	1	2	3	1	2	3	1	2	3	1	1	1	1	1	1	1	1	2
Anomura																					
Paguridae																					
Pagurus spp.																					
Cancridea																					
Cancridae																					
Cancer borealis					1	2									4	2					
Sipunculoidea																					
Sipuncula spp. juv.			1							1											
Golfingiidae																					
Phascolion strombi	1														5			1			
Priapulida																					
Priapulidae																					
Priapulus caudatus		1									1										
Phoronida																					
Phoronidae																					
Phoronis architecta					2		22	17								1	1	12	20	2	
Echinodermata																					
Cribellina																					
Porcellanasteridae																					
Ctenodiscus crispatus										2											
Ophiuroidea																					
Ophiuroidea spp.																					
Ophiuroidea spp. juv.																					
Chilophiurina																					
Ophiolepididae																					
Ophiura sarsi																					
Ophiura robusta		4								1	7	2			3	2	1		1		1
Echinoidea																					
Echinoidea spp. juv.														5							
Scutellina																					
Echinarachniidae																					
Echinarachnius parma																					
Urochordata																					
Stolidobranchia																					
Molgulidae																					
Bostrichobranchus pilularis														3		3					

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Cnidaria																	
Ceriantharia																	
Cerianthidae																	
Ceriantheopsis americanus													1				
Actiniaria																	
Actinaria spp. juv.																	
Actiniaria sp.2				1		1			1		1	2		1	2	4	
Edwardsiidae																	
Edwardsia elegans						1					1		1		3	1	
Platyhelminthes																	
Turbellaria																	
Turbellaria sp.1																	
Turbellaria sp.2					1												
Nemertea																	
Nemertea sp.2									4								
Nemertea spp. juv.													1				
Tubulanidae																	
Tubulanus pellucidus																	
Carinomella lactea												1	3				
Lineidae																	
Cerebratulus lacteus	7				10							5	4	1	2		19
Micrura spp.	10		9	9	6		3		2	11	2	11	5	2	7	10	8
Amphiporidae																	
Amphiporus angulatus	3						1					2	1				
Tetrastemmatidae																	
Tetrastemma vittatum	7					4				2							
Annelida																	
Polychaeta																	
Polynoidae																	
Arcteobia anticostiensis			1	1		2	2						1				
Gattyana																	
Gattyana amondseni	1	2	2	2					2			1	8	1	9	7	1
Gattyana cirrosa																	
Harmothoinae spp.										1							
Harmothoinae spp. juv.				2					2						2		
Harmothoe imbricata			1	1					1						3		
Hartmania moorei													1				
Enipo torelli	2																
Pholoidae																	
Pholoe minuta	2	3	19	43	2	3	1		10	23	12	9	4	9	30	17	6
Amphinomidae																	
Paramphinome jeffreysii																	
Phyllodocidae																	
Phyllodoce groenlandica			1						1	1							
Phyllodoce mucosa		8	3	2		6	9	2	1				4	3	10	1	1
Phyllodoce maculata			5			6	2		4	3				2			
Eteone longa	10	2	13	20	10		1			3	18	7	14	1	18	11	5
Eulalia bilineata														1			
Phyllodoce spp.										2							
Phyllodoce spp. juv.		2															
Phyllodoce arenae		2				2				1					1	1	

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Hesionidae																	
Microphthalmus aberrans																	
Pilargidae																	
Ancistrosyllis groenlandica																	
Syllidae																	
Typosyllis sp.1				3					4	2				1			
Typosyllis spp. juv.															1		
Exogone verugera	49	49	110	32	4	3	2	5	72	40	8	30	65	40	16	58	17
Exogone hebes		210	42	108	1	13	14	3	27	22	3	7	6	82	4	39	5
Exogone longicirris			7						7				5	1	1	1	
Sphaerosyllis brevifrons			3						2								
Sphaerosyllis longicauda			2	10	1				6	1	1	1			4		
Syllides japonica			5						28								
Syllides longocirrata																	
Nereidae																	
Nereidae spp.														3			
Neanthes virens																	
Nereis grayi		3	2	5	1				3	10					2	4	
Nephtyidae																	
Nephtyidae spp. juv.		9	4	3	1										2		
Nephtys neotena											1						
Nephtys spp.																	
Nephtys ciliata																	
Nephtys caeca						1		1		1							
Nephtys incisa	10			11					2			20	11		4	3	3
Aglaophamus circinata		5	3			15	13	16						6			
Sphaerodoridae																	
Sphaerodoropsis minuta																	
Glyceridae																	
Glycera capitata			6														
Goniadidae																	
Goniada maculata																3	
Lumbrineridae																	
Lumbrineridae spp. juv.	3		1	14	2				2	1	6		1		4	4	1
Eranno spp.																	
Scoletoma fragilis									3			1	1				
Scoletoma hebes													1				
Ninoe nigripes	67	2	12	27	33				38	19	10	44	56	2	4	21	18
Arabellidae																	
Drilonereis longa																	
Dorvilleidae																	
Dorvilleidae										1							
Parougia caeca	18			1					2			10	2		2	2	6
Orbiniidae																	
Scoloplos spp.										1							
Scoloplos armiger		1	1	9					10	5	3	6	5	6	6	24	9
Orbinia spp. juv.														1			
Leitoscoloplos acutus	47		1	20				1	3	11	7	43	28		5	11	15
Leitoscoloplos sp.B	1																
Leitoscoloplos spp.															4	2	
Leitoscoloplos spp. juv.			2							4				2			

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Paraonidae																	
Aricidea cerrutii															1	4	2
Aricidea quadrilobata	5											5	4		7		10
Aricidea minuta																	
Levinsenia gracilis	60			3	64				1		5	26	62		3	4	38
Aricidea catherinae	160	9	22	4	117	1	2		16	3	21	109	60	34		9	1
Apistobranchidae																	
Apistobranchus tullbergi	2								1			1			7		58
Spionidae																	
Laonice sp.1																	
Laonice cirrata												1					
Polydora socialis	81	276	287	195	1	261	190	41	13	232	5	1	626	175	888	877	12
Polydora caulleryi																	
Polydora quadrilobata	3	10	9	190					5	65	2		4	26	2		
Prionospio steenstrupi	64	8	64	3		2	1	1	176		1	36	34	25	1	7	
Spio spp. juv.																	
Spio thulini		6	16	2		5	7	1	2	11			3				
Spio filicornis			7	1			1		3				5				
Spio setosa																	
Spio limicola	834	307	317	48	1		6	3	3	42		934	883	33	820	885	414
Spiophanes bombyx		33		7		28	75	57		2		1	1	9	1	2	
Spiophanes kroeyeri																	
Pygospio elegans						36	26										
Scolelepis foliosa																	
Prionospio cirrifera																	
Trochochaetidae																	
Trochochaeta spp.																	
Trochochaeta carica																	
Trochochaeta multisetosa	8											6	3		3	2	
Cirratulidae																	
Cirratulidae spp.	1	1												1			
Cirratulidae spp. juv.				1						5	10						
Cirratulus cirratus									1								
Aphelochaeta spp. juv.																	
Aphelochaeta monilaris	7								4	2		16	19	3	6	4	12
Tharyx acutus	138		10	18	2				11	14	9	83	534	4	51	168	9
Monticellina baptisteae	194	3	1	1	6					27	18	56	20		1079	16	10
Aphelochaeta marioni	35			2					10	1		40	266	3	167	31	542
Monticellina dorsobranchialis	1	1		3	14				6		9	3	5	1		7	3
Chaetozone sp.A		4	2			4	9	9				6		12	1		
Chaetozone setosa																	
Cossuridae																	
Cossura longicirrata																	
Flabelligeridae																	
Flabelligeridae spp.																	
Brada villosa																	
Pherusa affinis			2	3	1					1							2
Diplocirrus hirsutus																	
Scalibregmatidae																	
Scalibregma inflatum	2		6						1			10	1	4			
Sternaspidae																	

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Sternapsis scutata																	
Capitellidae																	
Capitella capitata	10		3	41	1				4	27	11	9	5	1	11	23	10
Heteromastus filiformis												3			3	1	
Mediomastus californiensis	360		119	180	1				99	5	8	229	429	15	47	83	20
Maldanidae																	
Maldanidae spp. juv.																	
Clymenella torquata													2				
Maldane																	
Maldane sarsi												62					
Maldane glebifex												14					
Praxillella gracilis													1				
Praxillella praetermissa																	
Rhodine loveni																	
Euclymeninae, unident.	1			5										4			
Euclymene collaris		18	17	15		4	1		3			1	2	9			
Clymenura														1			
Clymenura sp.A						2											
Praxillura ornata																	
Oweniidae																	
Owenia fusiformis				9		30			3					1			
Galathowenia oculata				1		1										1	
Pectinariidae																	
Pectinaria gouldii			1														
Pectinaria granulata						1								2	3		
Ampharetidae																	
Ampharetidae spp.	8		2	16													
Ampharetidae spp. juv.										1	2						
Ampharete arctica				3		2											
Ampharete acutifrons				9					4	4		8	3		2	1	
Ampharete finmarchica																	
Melinna cristata																	
Anobothrus gracilis	2			4					3	3		12	12		2	2	
Asabellides oculata	8	2	58	64					136	25	46	5	7	9	28	6	
Terebellidae																	
Terebellidae spp.																	
Amphitrite cirrata																	
Polycirrus spp.									4			1		1	1		
Polycirrus phosphoreus																	
Trichobranchidae																	
Terebellides atlantis																	
Terebellides spp.																	
Terebellides stroemi																	
Sabellidae																	
Sabellidae spp. juv.	1		3														
Chone spp.																	
Chone duneri			1						1						1		
Euchone incolor	18	1		11								8	28		11	21	
Euchone elegans		3	1											7			
Laonome kroeyeri	6		4									2	7		2		
Archiannelida																	

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Polygordiidae																	
Polygordius sp.A		83	1			16		10						13			
Oligochaeta																	
Tubificidae																	
Tubificidae sp.2		1		2								1					
Tubificoides apectinatus	1	1							9			2	1			1	1
Gastropoda																	
Gastropoda sp.A									1								
Gastropoda spp.				1		4	23	1	6	1	1	2			2		
Archaeogastropoda																	
Trochidae																	
Solariella obscura						7	8										
Mesogastropoda																	
Rissoidae																	
Rissoidae sp.A									6								
Onoba pelagica				2													
Naticidae																	
Euspira heros																	
Stenoglossa																	
Buccinidae																	
Colus sp.A																	
Colus pygmaeus																	
Nassariidae																	
Ilyanassa trivittata			1										2		2	1	
Toxoglossa																	
Turridae																	
Turridae sp.A									1								
Oenopota spp.																	
Oenopota incisula				1													
Oenopota cf. cancellatus										1							
Oenopota exaratus																	
Cephalaspidea																	
Cylichnidae																	
Cylichna spp.																	
Cylichna alba																	
Cylichna gouldi													1				
Aplacophora																	
Chaetodermatida																	
Chaetodermatidae																	
Chaetoderma nitidulum																	
Bivalvia																	
Bivalvia sp.A																	
Bivalvia spp.	13	7	29	59	28		8	4	11	22	18	7	4	31	31	11	9
Nuculoidea																	
Nuculidae																	
Nucula spp.																	
Nuculoma tenuis																	
Nucula annulata																	
Nucula delphinodonta	6			16	5				5	54	1	36	19	12	2	2	1
Nuculanidae																	
Nuculana pernula																	

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Megayoldia thraciaeformis																	
Yoldia sapotilla										1			1			1	
Mytiloida																	
Mytilidae																	
Mytilus edulis				3	1				2	1	6				3	1	1
Crenella spp.														36			
Crenella spp. juv.																	
Crenella decussata		20	18	66	20					2	6	7	1	21	2	7	
Crenella glandula			7						53	4				5			
Musculus niger			1	1	1												
Pteriina																	
Pectinidae																	
Placopecten magellanicus				6					1	2						1	
Veneroida																	
Thyasiridae																	
Thyasira gouldii				2													
Carditidae																	
Cyclocardia borealis			4						2	3				1		4	
Astartidae																	
Astarte undata		1	6	7	1				37	9		1		36	1	4	
Cardiidae																	
Cerastoderma pinnulatum		1		5		3			17								
Arcticidae																	
Arctica islandica	1	5	2	8	3		1	1	2				19	15	37	5	3
Veneridae																	
Pitar morrhuana																	
Myina																	
Myidae																	
Mya arenaria	6			2		1					2	8	18		3	4	4
Hiatellidae																	
Hiatella arctica	1			34	2		2	4	30	49	80			6	332	71	32
Pholadomyacea																	
Lyonsiidae																	
Lyonsia arenosa				1					1	1				3	4	1	
Periplomatidae																	
Periploma papyratium	1																
Thraciidae																	
Asthenothaerus hemphilli							3										
Scaphopoda																	
Dentalida																	
Dentaliidae																	
Dentulium entale																	
Crustacea																	
Mysida																	
Mysidae																	
Mysis mixta																	
Erythrops erythrophthalma																	
Cumacea																	
Lampropidae																	
Lamprops quadriplicata						1		3									
Leuconidae																	

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Leucon nr. acutirostris																	
Eudorella pusilla	1				1										1		
Eudorellopsis deformis						3		1									
Diastylidae																	
Diastyis spp.																	
Diastylis quadrispinosa					2				1	1	1						1
Diastylis sculpta		5	3		1	3	8	18		1	1			5	2		
Diastylis abbreviata																	
Diastylis cornuifer															1		
Leptostylis spp.										1				1			
Leptostylis cf. ampullacea									2								
Leptostylis longimana																	
Pseudocumidae																	
Petalosarsia declivis							4	1								1	
Campylaspidae																	
Campylaspis rubicunda	1									2					2		2
Dikonophora																	
Paratanaidae																	
Tanaissus psammophilus								1						14			
Anthuridea																	
Anthuridae																	
Ptilanthura tenuis		2		2		7	5	1		3				26			
Flabellifera (Isopoda)																	
Cirolanidae																	
Politolana polita		2				4	16	10									
Valvifera																	
Idoteidae																	
Edotia montosa		4	3	32	6		1			42	2	1	2	29	16	19	9
Edotia triloba																	
Chiridotea tuftsi						9	29										
Asellota																	
Munnidae																	
Munna spp.									4	1					1		
Paramunnidae																	
Pleurogonium spinosissimum									17								
Pleurogonium rubicundum					4						6				3		
Pleurogonium inerme										3							
Amphipoda																	
Amphipoda sp.1			7				3	2						20			
Amphipoda spp.		7	32	5		7	17	3	19	16	5			35	5	5	
Gammaridea																	
Ampeliscidae																	
Ampelisca macrocephala		1			2	1	4	1						2			
Ampelisca abdita																	
Byblis spp.																	
Byblis nr. gaimardi																	
Haploops tubicola														1			
Haploops fundiensis																	
Amphilochidae																	
Gitanopsis arctica																	
Aoridae																	

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Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Leptocheirus pinguis		36	2			3	1		14								
Argissidae																	
Argissa hamatipes		8			2		1	7		2	10			5		8	
Corophiidae																	
Corophium spp.												1					
Corophium nr. crassicorne		22	11			362	1023	504			1			115			
Erichthonius rubricornis		3				7	1							6		1	
Aoridae																	
Unciola spp.			12														
Unciola spp. juv.																	
Unciola inermis		3				18	10	5						34			
Unciola irrorata				1													
Pseudunciola obliquua						14	49	24									
Gammaridae																	
Casco bigelowi																	
Haustoriidae																	
Acanthohaustorius millsi								4									
Isaeidae																	
Photis pollex		1		1	1		1				1			3			
Ischyroceridae																	
Ischyrocerus anguipes										7							
Lysianassidae																	
Anonyx lilljeborgi				1						7			1	2	1	1	1
Hippomedon serratus	1					12		2						1	1		
Orchomenella minuta										1							
Oedicerotidae																	
Oedicerotidae spp.		1															
Monoculodes spp.														1			
Monoculodes cf. intermedius			4														
Monoculodes edwardsi						1			2						2	1	
Phoxocephalidae																	
Harpinia propinqua		1												4		3	
Phoxocephalus holbolli						15	3	3									
Rhepoxynius hudsoni						8	10	10									
Pleustidae																	
Pleustidae sp.1		3												1		3	
Pleustes panoplus																1	
Stenopleustes inermis						4				12		3		6	4	6	
Podoceridae																	
Dyopedos monocantha	2	2		27	2		1	1	8	15	7		2	1	11	4	1
Stenothoidae																	
Metopella angusta		1								1				2	1	12	1
Synopiidae																	
Syrrhoe crenulata			2			1				1				1			
Caprellidea																	
Caprellidae																	
Mayerella limicola	1																
Aeginina longicornis										5							
Caridea																	
Crangonidae																	
Crangon septemspinosa						2											

Survey 9403 0.5 mm		NF13	NF14	NF15	NF16	NF17			NF18	NF19	NF20	MB01	MB03	S3	S4		
Taxon	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	2	3
Anomura																	
Paguridae																	
Pagurus spp.			1														
Cancridea																	
Cancridae																	
Cancer borealis		1	5	1		4	2	1	6		1			2			
Sipunculoidea																	
Sipuncula spp. juv.														1		1	
Golfingiidae																	
Phascolion strombi										1			1				
Priapulida																	
Priapulidae																	
Priapulus caudatus													2				1
Phoronida																	
Phoronidae																	
Phoronis architecta	4	6		11						92		14	14	4	5		1
Echinodermata																	
Cribellina																	
Porcellanasteridae																	
Ctenodiscus crispatus																	
Ophiuroidea																	
Ophiuroidea spp.				3													
Ophiuroidea spp. juv.						1				1						2	
Chilophiurina																	
Ophiolepididae																	
Ophiura sarsi																	
Ophiura robusta		1			1				4				1		3		
Echinoidea																	
Echinoidea spp. juv.		4															
Scutellina																	
Echinarachniidae																	
Echinarachnius parma						66	41	24						3			
Urochordata																	
Stolidobranchia																	
Molgulidae																	
Bostrichobranchus pilularis									1						30		

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