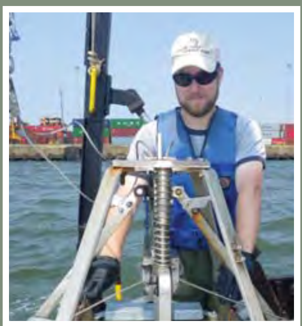
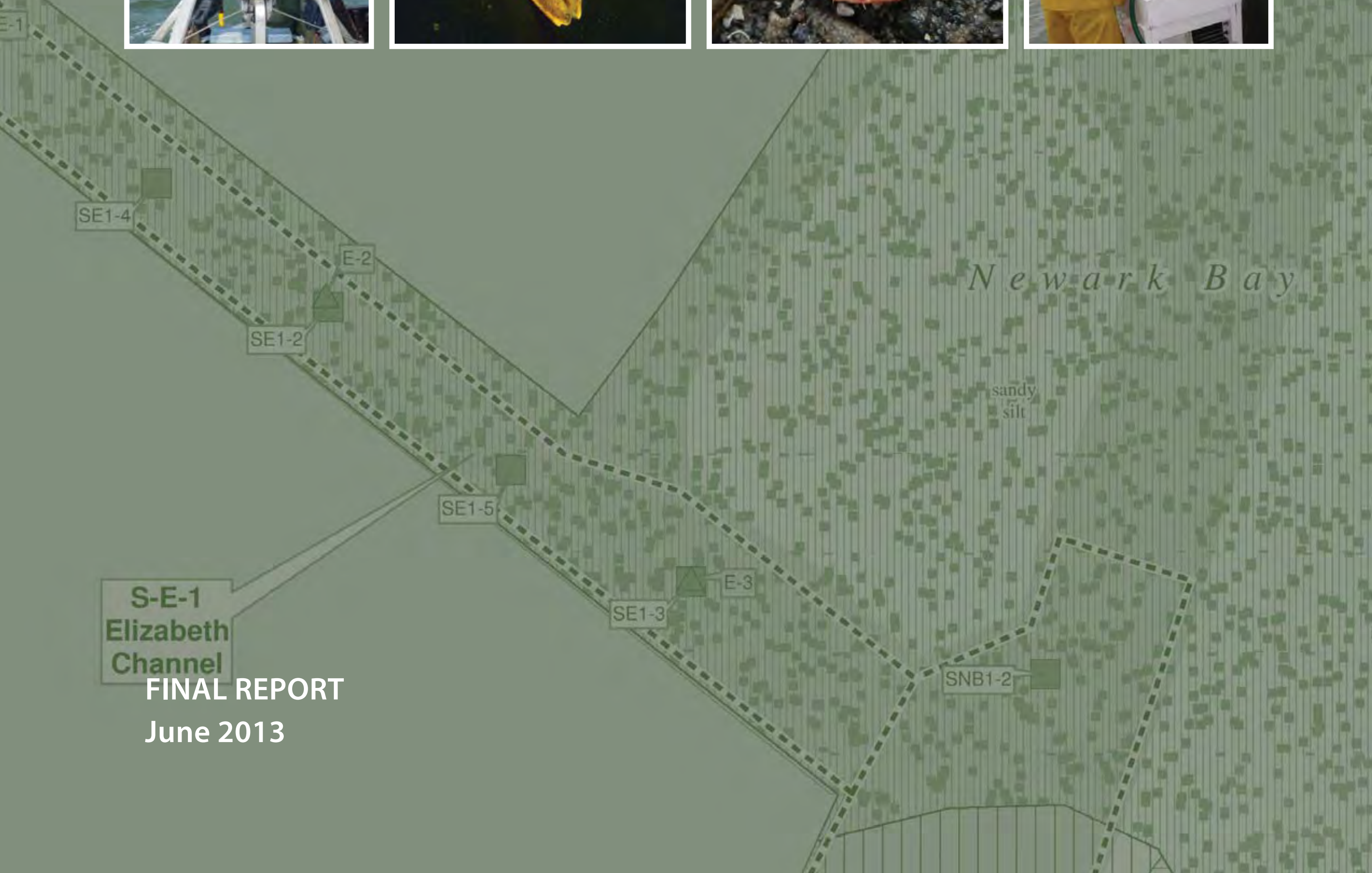
US Army Corps of Engineers®
New York District

NEW YORK AND NEW JERSEY HARBOR DEEPENING PROJECT

2012 BENTHIC RECOVERY REPORT





FINAL REPORT
June 2013

Benthic Recovery Monitoring Report

Contract areas: S-AN-2, S-AN-1b, S-E-1, and S-NB-1

Prepared for the:

United States Army Corps of Engineers - New York District

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US Army Corps of Engineers®
New York District

Final Report

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INTRODUCTION

The U.S. Army Corps of Engineers, New York District (USACE-NYD) has played a major role in the navigation, development and maintenance of water resources in The Port of New York/New Jersey for more than two centuries. The Port is a critical economic component of the New York City Metropolitan region, providing more than 230,000 direct and indirect jobs and $20 billion in economic activities to the States of New York and New Jersey (USACE 2010). However, the Port is located within a naturally shallow estuary, with an average depth of less than 20 feet (USACE 2008). Since the late 19th century, periodic maintenance dredging and improvement of navigation channels has been necessary for the continued use and economic vitality of the Port.

Today, there are more than 200 miles of federally maintained navigation channels within NY/NJ Harbor ("Harbor"). To meet current and anticipated shipping needs, including increased containerization using larger Post-Panamax shipping vessels, these existing navigation channels are currently being deepened. The Harbor Deepening Project (HDP), a multi-year Federal navigation program led by USACE and sponsored by the Port Authority of New York and New Jersey, is aimed at improving navigation in the Harbor while minimizing impacts to the aquatic environment and incorporating beneficial aspects that seek to improve the environment. Ongoing improvements to the Port since 1999 include the deepening of portions of the Ambrose Channel (from the Narrows to Port Jersey Channel), the Anchorage Channel (from the Narrows to Port Jersey Channel), the Kill Van Kull Channel, Newark Bay Channel, the Arthur Kill Channel, and the Port Jersey Channel.

The impacts of navigation channel dredging on benthic macro-invertebrate and finfish communities residing in the channels have been monitored by USACE-NYD in compliance with the Coastal Zone Management Act (CZMA). This report presents the results of baseline conditions in 2005 and the post-dredging benthic macro-invertebrate community surveys conducted in 2012 within four completed HDP contract areas: S-AN-2 (Anchorage Channel), S-AN-1b (Anchorage Channel), S-E-1 (Elizabeth Channel), and S-NB-1 (Newark Bay Channel).

Benthic sampling was conducted approximately one to two and a half years following completion of dredging in these contract areas (Table 1). The benthic recovery results can be used to document impacts to the Harbor's benthic community as a result of channel deepening and provides a general timescale for benthic re-colonization. This report is the second in a series of benthic recovery reports that will be completed throughout the duration of HDP dredging, as contract areas are completed.

Table 1. Dredging events within sampled contract areas.

Contract Area	Dates of Harbor Deepening Dredging	Dates of Maintenance Dredging*
S-AN-2 (Anchorage Channel)	October 2010 – March 2011	None since 1993 (*adjacent contract area S-AN-1a maintenance dredging took place at Red Hook Flats in 2001*)
S-AN-1b (Anchorage Channel)	March 2010 – January 2011	None since 1993
S-E-1 (Elizabeth Channel)	June 2009 – February 2010	Elizabeth Channel 1998; adjacent maintenance dredging occurred in the Port Elizabeth Pierhead 2001 (S-NB-1 contract area;
S-NB-1 (Newark Bay Channel)	May 2010 – January 2011	Port Elizabeth Pierhead 2001 Port Newark and Portion of Main Channel 2008;

**Source: New York New Jersey Harbor Historical Maintenance Data 1993 – 2008*

Background

The benthic community in the Harbor consists of a wide variety of small aquatic invertebrates which live burrowed into or in contact with the bottom, such as worms, mollusks, and amphipods (Pearce 1974). Benthic invertebrate communities play an important role in the Harbor. They are an essential part of the marine food web, they cycle nutrients from the sediment and water column to higher trophic levels, and they modify the substrate through bioturbation and the formation of fecal pellets (Wildish and Kristmanson 1997, Wolff 1983).

Life strategies of marine benthic macro-invertebrates and sediment characteristics of their habitats are tightly coupled (Levinton 1982). The distribution and abundance of benthic invertebrates are influenced by a wide variety of physical parameters, such as substrate, water temperature, dissolved oxygen, pH, salinity, and hydrodynamics, as well as disturbance and pollution (Cristini 1991, Watson and Barnes 2004). Benthic organisms are good indicators of local environmental conditions and anthropogenic disturbance since they live and feed on the sediment and have limited mobility, thus they cannot avoid exposure to pollution or disturbance (Dauer 1993). Benthic communities generally respond in stages to habitat disturbance. Response stages include an increase (or decease) in abundance; increase (or decrease) in diversity, and a shift to (or from) a pollution-tolerant to pollution-intolerant assemblage (USEPA 2009).

When a benthic community is physically disturbed, the community may re-colonize through natural succession to pre-disturbance conditions within approximately one to five years following the cessation of the disturbance (Blake *et al.* 1996, Van Dolah *et al.* 1992). However, recovery may take longer if physical characteristics (e.g. sediment, hydrology, etc.) are changed and different species re-colonize (Schaffner *et al.* 1996, Van Dolah *et al.* 1994, Wilber and Stern 1992).

METHODS

Sample Collection

Pre-construction benthic samples were collected from navigation channel locations throughout the Harbor in July of 2005. Data from a subset of 2005 stations were selected for purpose of comparison with the 2012 contract areas. These stations included three from the Elizabeth Channel (S-E-1 contract area), two from the vicinity of the S-AN-2 Anchorage Channel contract area, one from the S-AN-1b Anchorage Channel contract area, and two stations from the S-NB-1 Newark Bay contract area (Figure 1, Table 2). Because benthic distribution is not uniform and the areas that were proposed to be dredged were throughout the Harbor, sample locations in 2005 were chosen by sediment types, rather than by contract area.

In June 2012, five post-deepening samples were collected from navigation channel locations within each of the four completed HDP contract areas (Table 2), discussed in this report.

Table 2. Pre and post-deepening sampling stations per contract area.

Contract Area	2005 Stations	2012 Stations
Anchorage Channel (S-AN-2)	AN-2*, AN-3*	SAN2-1, SAN2-2, SAN2-3, SAN2-4, SAN2-5
Anchorage Channel (S-AN-1b)	BRC3	SAN1b-1, SAN1b-2, SAN1b-3, SAN1b-4, SAN1b-5
Elizabeth Channel (S-E-1)	EC-1, EC-2, EC-3	SE1-1, SE1-2, SE1-3, SE1-4, SE1-5
Newark Bay Channel (S-NB-1)	NBC-1, NBC-3	SNB1-1, SNB1-2, SNB1-3, SNB1-4, SNB1-5

**Because 2005 samples were not collected in the S-AN-2 contract area, AN-2 and AN-3 were selected as the nearest stations. AN-2 was located north of the S-AN-2 contract area, and AN-3 was located south in the S-AN-1 contract area.*

When available, the 2005 pre-dredge channel sampling locations were selected and re-sampled, so 2005 and 2012 samples were co-located, otherwise 2012 stations were chosen based on sediment type and location within the contract areas to sample as diverse an area as possible. Note that benthic samples from 2005 are designated by the initials of the channel sampled (e.g., Anchorage = AN) followed by a dash and the sample number (e.g. Sample AN-2). Samples from 2012 follow a similar nomenclature but are designated by the contract area (e.g. sample 1 in the S-AN-2 contract area is SAN2-1).

Pre (2005) and post-dredge benthic samples were collected using a 0.1 m^2 Smith-McIntyre Grab. At each sampling location, one benthic sample was collected and washed onboard by gently rinsing the sample through a 500-µm mesh sieve to remove fine sediment prior to preservation. Material retained within the sieve was placed into a labeled sample bottle and preserved with 10% buffered Formalin containing Rose Bengal stain to enhance sorting and identification during laboratory analysis. For each grab sample, the date, time, location, weather/oceanographic conditions, water depth, and sediment characteristics were recorded.

In the laboratory, organisms were sorted from the remaining debris, identified by taxonomists and enumerated. Identifications were made to the lowest practical identification level when not to the species level. Sub-sampling was conducted using the fixed-count method to process samples in an unbiased manner. Sub-sampling was conducted using a sampling tray with 30 grids, each 6 cm x 6 cm. For all samples, organisms in randomly selected grids were counted until the total number of organisms reached 100 or the entire sample was sorted, whichever occurred first. Note that the selected grid in which the cumulative organism count reached 100 was counted in its entirety so the total sub-sampled count could exceed 100. The sub-sampled count was then multiplied by the split fraction to determine the total number of organisms in the sample. For example, if the 100 count was reached in the tenth grid (out of 30 grids) and the count was 111 organisms, then the total count for the sample was 333 organisms.

Data Analysis

The benthic community was assessed through calculation of density, taxa richness, Shannon-Wiener's diversity index, and Pielou's Evenness from the benthic grab data. To assess the community within each completed contract area, biodiversity indices were calculated from the sum of all samples collected within that area.

Benthic density, or abundance, can be used as an indicator of benthic community health (Becker et al. 1990). Density, the number of organisms per meter squared (organisms/m^2), was calculated for each taxa in each sample collected. Density was based on the total grab area sampled (0.1 m^2) and the applicable laboratory split fraction, if the sample was sub-sampled. Density was also calculated for each contract area as a whole (e.g. Elizabeth Channel S-E-1) by taking the sum of each taxa collected at each station in that area.

Species richness is a measure of the total number of individual taxa collected at a site. In counting the number of taxa present, taxonomic designations at the genera, familial, and higher taxonomic levels were dropped if there was one valid lower level designation for that group. For example, if *Scoloplos* sp., *Scoloplos fragilis*, and *Scoloplos robustus* were all identified in one sample, then *Scoloplos* sp. was not counted in the total number of taxa. The number of taxa recorded in this example would be two. Species richness was calculated in this manner to be as conservative as possible with the number of species present. Over the last two years, benthic macroinvertebrate nomenclature and taxonomic changes have occurred, and all changes are noted in Tables 3 and 4. For example, *Amage auricula* is no longer grouped under the order Canalipalpata and is now under order Terebellida. The 2005 data were updated to match the current taxonomic classifications.[1]

The Shannon-Wiener Diversity Index (H') is a widely used species diversity index (Washington 1984). It provides more information about the benthic community structure than taxa richness because it takes into account the relative abundance of each taxa as well as taxa richness (Morin 1999). In comparing between samples, lower values of H' indicate lower taxa richness and an uneven distribution of abundance among species while higher values indicate higher taxa richness and an even distribution of abundance among taxa. Typically, a healthy benthic macro-invertebrate community would have a relatively high H′ value.

[1] The following taxonomic nomenclature changes have been incorporated into this report: *Scoloplos* sp. was formerly *Leitoscoloplos* sp.; *Marenzellaria* sp. was formerly *Scolocolepides* sp.; *Polydora cornuta* was formerly *Polydora ligni*, *Amage auricula* was formerly under the order Canalipalpata. The former taxonomic nomenclature was used in the USACE-NYD's 2006 Harborwide Benthic Monitoring Program containing 2005 data and the 2011 Benthic Recovery Report containing 2005 and 2009 data.

The index is computed as follows:

$$H' = -\sum_{i=1}^{s}(p_i Lnp_i)$$

S is the total number of species per sample (i.e., taxa richness) and p_i is the proportion of total individuals in the i^{th} species. Mathematically, p_i is defined as n_i/N where n_i is the number of individuals of a taxa in a sample and N is the total number of individuals of all taxa in the sample.[2]

Pielou's Evenness (*J'*) measures the distribution among species within the community by scaling one of the diversity measures relative to its maximal possible value. Evenness can range from 0 to 1. It is computed as follows:

$$J = \frac{H}{H_{max}}$$

where H' is the observed diversity (as cited above) and H'_{max} is the natural logarithm of the total number of taxa (S) in the sample (H'_{max}= LnS).

The percentage of benthic organisms characterized as pollution tolerant (i.e., indicators of potentially degraded habitat conditions) and pollution sensitive (indicators of quality habitat) were also calculated for each sample based on Adams *et al.* 1998, Llansó *et al.* 2002, and Weiss 1995. The percentage of pollution tolerant species is one parameter amongst others, such as sediment and water quality, that describes the overall habitat quality of the benthic community. Typically, pollution tolerant species are found in heavily disturbed areas and are opportunistic species. Pollution tolerant taxa include: Oligochaeta, *Scoloplos* sp., Capitellidae, *Streblospio benedicti*, and *Mulinia lateralis*. Pollution sensitive taxa include: *Diopatra cuprea, Spiophanes bombyx, Cyathura polita*, *Acteocina canaliculata, Ensis directus*, *Mercenaria mercenaria*, *Spisula solidissima,* and *Tellina agilis*.

[2] For the 2006 Harborwide Benthic Report describing the 2005 sampling results, the Shannon-Wiener diversity index was calculated using Log base 10 (Log10). To remain current with existing benthic community literature, the 2012 diversity was calculated using the natural log (Ln) and the 2005 results were updated using Ln.

RESULTS

Anchorage Channel (S-AN-2)

2005 Samples

A total of 33 taxa were collected in a sub-set of the grab samples from 2005 that were proximate to the S-AN-2 contract area (Table 3). These taxa were distributed among the primary phyla: annelids (52%), arthropods (18%), mollusks (27%), and 'other' including Nemertea (3%) (Table 5). The benthic community in these Anchorage Channel stations during 2005 exhibited an average density of 1,290 organisms/m^2 with annelids composing the majority collected (48%), followed by mollusks and arthropods (25 and 24%, respectively) (Table 5). Overall Anchorage Channel diversity was 2.56, ranging from 1.83 to 2.23, and evenness was 0.73, ranging from 0.68 to 0.71 (Table 6). The arthropod family Ampeliscidae made up the highest percentage of the total density (23%). The mollusk *Tellina agilis* and annelid *Spio setosa* also contributed to the benthic community in this area (17 and 16%, respectively). Pollution tolerant and pollution sensitive taxa were collected in similar percentages in 2005, with <1% difference (Table 6).

Sediment in AN-2 and AN-3 was composed primarily of silt (Table 7). The consistency in sediment type across the two sampling stations, explains similar densities recorded in Sample AN-2 (1,360 organisms/m^2) and AN-3 (1,220 organisms/m^2) (Table 3). Despite the consistency across sediment types, AN-2 had more than double the taxa richness of AN-3. This contributed to the lower diversity and evenness calculated for AN-3.

2012 Samples

An average density of 12,539 organisms/m^2 was collected in the S-AN-2 contract area in 2012, distributed among 40 taxa (Table 4). These taxa consisted of annelids (58%), arthropods (15%), mollusks (25%) and 'other', including unsegmented worms from the phylum Sipuncula (3%) (Table 5). The organisms collected among all samples were composed primarily of annelids (88%). Diversity within the contract area ranged from 0.46 to 2.37 with a total diversity of 1.39 which was lower than in 2005 for the Anchorage Channel (Table 6). Evenness within the contract area ranged from 0.19 to 0.79 with a total evenness of 0.38 (Table 6). The majority of the individuals collected were composed of the annelids *Polydora cornuta* (58%) and Capitellidae (27%). The arthropod family Ampeliscidae that made up the highest percentage of the total density in 2005 comprised only 2% of the average density in 2012. The percentage of the total assemblage consisting of pollution tolerant taxa (29%) was greater than pollution sensitive taxa (<1%) collected in 2012 (Table 6).

The sediments collected within the S-AN-2 contract area in 2012 were similar to those collected within the Anchorage Channel in 2005 and were composed of fine sand and silt. Samples SAN2-1 and SAN2-2 were composed of a combination of clayey silt, fine sand and shell hash (Table 7). SAN2-1 was the most dense (39,482 organisms/m^2) in the contract area, and SAN2-3 and SAN2-5 were the least dense (1,030 and 1,900 organisms/m^2, respectively). Individual sample collections within the S-AN-2 contract area averaged 12,539 organisms/m^2, which was higher than the 2005 collection average within the Anchorage Channel due to the high numbers collected in sample SAN2-1 (Table 6).

Anchorage Channel (S-AN-1b)

2005 Samples

The benthic sample collected at BR-3 in Anchorage Channel proximate to the S-AN-1b contract area during 2005 displayed a taxa richness of 10 taxa (Table 3). These taxa were distributed among annelids (60%), arthropods (30%), and mollusks (10%) (Table 5). Total density at this station was 260 organisms/m^2, with diversity of 1.81, and evenness of 0.79 (Table 5). Northern dwarf tellin (*Tellina agilis*) and the polychaete worm *Nereis* sp. dominated the assemblage in Anchorage Channel, accounting for 31% and 23% of the density in 2005, respectively (Table 3). Pollution sensitive taxa comprised 32% of the total during 2005 while pollution tolerant taxa comprised 6% (Table 6). Sediment in sample BR-3 was composed of shell (Table 7).

2012 Samples

A total of 34 unique taxa were collected in the S-AN-1b contract area in 2012 (Table 4). Taxa were distributed among annelids (17%), arthropods (5%), and mollusks (78%) (Table 5). The average density for the contract area was 12,838 organisms/m^2 with the highest density occurring in sample SAN1b-5 (37,387 organisms/m^2) and the lowest in sample SAN1b-1 (350 organisms/m^2). Average sample density was more than an order of magnitude higher in 2012 than in 2005 (Table 6). Sample SAN1b-3 was located in the same location as the 2005 sample, and was found to have a higher density than the 2005 sample (920 organisms/m^2 in 2012 compared to 260 organisms/m^2 in 2005), and similar diversity and evenness values (Table 6). Diversity for the contract area (1.00) was lower than in 2005 (1.81) and samples ranged from 0.61 to 2.13 in 2012 (Table 6). Evenness for the contract area was also lower in 2012 (0.28 compared to 0.79), with samples ranging from 0.23 to 0.86 (Table 6). This was due to the high numbers of blue mussel (*Mytilus edulis*) that dominated the total density in 2012 (77%) (Table 5). Pollution tolerant and sensitive taxa each made up low percentages of the total catch, with each being 1% (Table 6).

Samples SAN1b-1, and SAN1b-2, consisted of fine sand. Sample SAN1b-3, SAN1b-4, and SAN1b-5 consisted of a combination of fine sand, shell hash, and stones (Table 7).

Elizabeth Channel (S-E-1)

2005 Samples

A total of 11 taxa were collected in the three Elizabeth Channel grab samples collected in 2005 that were proximate to the S-E-1 contract area (Table 3). These taxa were distributed among annelids (64%), arthropods (18%), and mollusks (18%) (Table 5). Overall, the benthic community of Elizabeth Channel exhibited a community diversity of 0.90 and evenness of 0.38, and an average density of 490 organisms/m^2 (Table 6). The annelid S*coloplos* sp. was the dominant organism in the species assemblage, accounting for 67% of the average density (Table 3). The annelid species *Pectinaria gouldii* was the second most abundant species in the Elizabeth Channel (26%). Pollution tolerant taxa represented the majority of all organisms collected (61%). No pollution sensitive taxa were collected at Elizabeth Channel stations in 2005 (Table 6).

Sediment types in 2005 consisted of a combination of silt and clay (Table 7). Sample EC-3 had the highest density of organisms (950 organisms/m^2) and consisted of silt/clay (Tables 6 & 7).

By comparison, the lowest sample density was found in sample EC-1 (265 organisms/m^2), which consisted of silt.

2012 Samples

A total of 19 individual taxa were collected in the S-E-1 contract area in 2012, across the five samples taken (Table 4). These taxa were distributed primarily among three phyla: annelids (58%), arthropods (16%), and mollusks, (21%) with others consisting of Chordata, Cnidaria, and Nematoda (5%) (Table 5). Average density for the contract area in 2012 was 16,498 organisms/m^2, the highest average density of any contract area in 2005 and 2012 (Table 6). Diversity and evenness were higher than 2005, with a 2012 diversity of 1.52 (ranging from 1.01 to 1.63), and an evenness of 0.52 (ranging from 0.41 to 0.74) (Table 6). The sample with the highest diversity and evenness (SE1-2) contained the lowest density (640 organisms/m^2) indicating a collection of many species with densities of similar magnitude (Table 6).

Annelids dominated the total catch during 2012 (96% of the total organisms collected), mostly due to Capitellidae, and to a lesser extent *Cossura longocirrata* and Oligochaeta (Table 4 and 5). Arthropods represented 3.9% of the total catch and were mostly comprised by organisms of the order Cumacea, and to a lesser extent isopods and decapods. Similar to 2005, pollution tolerant species accounted for the majority of all organisms collected during 2012 (72%) (Table 6).

Similar to 2005, the sediment samples taken in 2012 consisted of mostly silt. Only sample SE1-2 consisted of clay. This sample had the lowest organism density (640 organisms/m^2) of any samples in this contract area (Tables 6 and 7).

Newark Bay Channel (S-NB-1)

2005 Samples

A total of 19 taxa were collected in two 2005 samples collected in Newark Bay grab samples proximate to the S-NB-1 contract area (Table 3). These taxa were distributed among the primary phyla: annelids (47%), arthropods (26%), mollusks (16%) with ‘other’ including Nematoda and Chordata (11%). The benthic community in Newark Bay Channel during 2005 exhibited an average density of 2,259 organisms/m^2 with the annelid *Pectinarea gouldii* and Chordata *Molgula* sp. composing the majority collected (1,059 and 917 organisms collected, respectively) (Table 4). Overall, Newark Bay Channel diversity was 1.21, ranging from 0.35 to 0.81, and evenness was 0.41, ranging from 0.15 to 0.32. Pollution tolerant taxa were collected at a higher percentage (5%) than pollution sensitive taxa (1%) (Table 6).

Sediment in the two Newark Bay Channel stations collected in 2005 was composed of a combination of silt, clay and rock (Table 7). NBC-1 contains silt and clay while NBC-3 contained clay and rock. Despite the difference in sediment, similar total densities were collected at these two stations.

2012 Samples

An average density of 1,142 organisms/m^2 was collected in the S-NB-1 contract area in 2012, distributed among 20 taxa (Table 4). These taxa consisted of annelids (60%), arthropods (20%) and mollusks (20%). Annelids dominated the density across all five samples of the contract area with 94%, consistently ranging from 87% to 96% among individual stations. The remaining percentage was mollusks and arthropods, making up 3.3 and 2.3%, respectively (Table 5). Diversity and evenness of the 2012 stations was similar to 2005 samples with values of 1.23 and 0.41, respectively (Table 6). Pollution tolerant taxa make up the majority of species that were collected in 2012 at 88%. Only 1% of the total organisms collected in 2012 were pollution sensitive taxa with all occurrences collected in the SNB1-2 sample (Table 6).

Sediment type was similar to 2005 samples, with all 2012 samples being a silty clay combination (Table 7).

DISCUSSION

The benthic community in the New York/New Jersey Harbor consists of a wide variety of aquatic invertebrates which play an important ecological role in the Harbor. Physical disturbance to a benthic community is typically followed by a period of re-colonization through natural succession to pre-disturbance conditions. This natural recovery of the benthic community typically occurs within approximately one to five years following the cessation of the disturbance (Blake *et al.* 1996, Van Dolah *et al.* 1992). For example, the offshore benthic community in the USACE-NYD's Manasquan Inlet study recovered rapidly following sand borrow area dredging in 1997 and 1999; by the spring of 2000 no statistically detectable differences were noted between dredged and reference areas in benthic abundance and biomass (USACE 2001). However, other studies indicate that a less rapid recovery in areas of benthic disturbance is also possible, particularly if physical characteristics (e.g. sediment, hydrology, etc.) are changed and different species re-colonize (Schaffner *et al*. 1996, Van Dolah *et al.* 1994, Wilber and Stern 1992). Previous pre- and post-dredge sampling in the Harbor in other HDP contract areas, for example, showed benthic communities which appeared to be in a transitional state during the natural succession process more than one year after the areas were dredged (USACE 2011). Newell *et al.* (1998) observed that borrow areas at higher latitudes recover at slower rates than borrow areas at lower latitudes. They also noted that relatively weaker currents through a borrow area could decrease the rate of recovery to as much as 2-8 years (Newell *et al.* 1998).

The majority of species identified in grab samples collected during the 2005 (pre-construction) and 2012 (post-construction) benthic macro-invertebrate surveys were annelids (oligochaetes and polychaetes), arthropods (Ampeliscidae), and mollusks (bivalves and gastropods). These taxa are typically found in the Harbor, and vary considerably in occurrence and abundance both seasonally and spatially (BVA 1998, Cerrato *et al.* 1989, Dean 1975, Iocco *et al.* 2000Gandarillas and Brinkhuis 1981). In this study, benthic community recovery was assessed through the calculation of density, taxa richness, Shannon-Wiener's diversity index, and Pielou's Evenness from the benthic grab data within four completed dredging contract areas (S-AN-2, S-AN-1b, S-E-1, and S-NB-1). Figures 3 through 7 display summaries of calculated indices in each area sampled for both the 2005 and 2012 sampling efforts.

Anchorage Channel (S-AN-2 & S-AN-1b)

Anchorage Channel contract areas S-AN-2 and S-AN-1b experienced significant increases in average density between 2005 and 2012. High densities within S-AN-2 in 2012 were driven by opportunistic colonizers of the Polycheate family, including Capitellidae and Spionidae. These taxa are known to be early colonizing species capable of producing multiple, large broods per season, where densities in disturbed habitats can exceed undisturbed conditions (Zajac and Whitlatch 1982, Levin 1984).

In contract area S-AN-1b, high 2012 densities arose due to the presence of blue mussels, with densities exceeding 20,000 organisms/m^2 at some stations. The high densities at SAN1b-4 and 5 were most likely due to the sediment type at these locations, which were comprised of shells and stones. These sediment types are typical of blue mussels and are commonly found in subtidal areas with hard substrate where they can establish a reef. Juvenile mussels go through an initial settlement period where they grow in a temporary location to about 1.5 millimeters in shell length. Upon reaching this length, the mussels release from the substrate and are passively carried by currents in bottom waters until they reach an adult mussel reef, where they permanently establish themselves (Newell 1989). The dense accumulations of juvenile blue mussels collected in 2012 were likely in the transition stage of initial settlement.

Within the S-AN-1b and S-AN-2 contract areas, diversity and evenness decreased. Annelids were the dominant phylum in S-AN-2 contract area during 2012, compared to 2005 when densities were more equitably distributed among annelids, arthropods, and mollusks. The high annelid densities in 2012 can be attributed to a shift towards higher densities of pollution tolerant species within this phylum. Similarly, the percentage of pollution sensitive species decreased from 32% and 20% within contract areas S-AN-1b and S-AN-2, respectively, in 2005 to less than 2% in both areas with decreases in pollution sensitive species such as *Tellina agilis*, *Spisula solidissima*, and *Mulinia lateralis*.

Elizabeth Channel (S-E-1)

Average benthic macroinvertebrate density increased significantly from 2005 to 2012 in Elizabeth Channel resulting from large collections of annelids (96% of the total organisms collected in 2012), which were mostly opportunistic species such as Capitellidae, and to a lesser extent *Cossura longocirrata* and Oligochaeta. Of note, both benthic diversity and evenness increased (68% and 37%, respectively), indicating a more diverse benthic community in 2012. However, similar to 2005, pollution tolerant species accounted for the majority of all organisms collected during 2012 (72%) and no pollution sensitive species were collected in either sampling event, suggesting that impacted benthic conditions existed within this channel prior to harbor deepening dredging and that this baseline condition did not change significantly after the construction.

Newark Bay Channel (S-NB-1)

Benthic macroinvertebrate indices within Newark Bay S-NB-1 contract area were fairly consistent between the baseline condition observed in 2005 compared to 2012. Although average benthic density decreased in 2012, diversity and evenness were consistent between sampling events (<1% decrease), indicating a comparatively stable community. In 2012, annelids dominated the collections compared to 2005, which was co-dominated by annelids and chordates. The abundant chordate densities in 2005 were the result of *Molgula* spp. (sea grapes) collections at NBC-3, a station not sampled in 2012 and located just beyond the southern boundary of the S-NB-1 contract area where small areas of sandy-gravel substrate occur near Bayonne. Sea grapes are a species typically associated with hard bottom substrates, like the rocky substrate documented at Station NBC-3, and would be less likely to occur in the silt and clay substrates typical of the Newark Bay Channel, which may explain the minor observed differences in average density between the two events. Although the percentage of pollution sensitive species remained constant between the two events, the percentage of pollution tolerant species increased from 5% in 2005 to 88% in 2012 as a result of the collections of *Scoloplos fragilis* and Capitellidae. These pollution tolerant species are opportunistic colonizers known to rapidly re-populate an area after disturbance (see summary discussion below).

Summary

During this study, benthic sampling was conducted approximately one to two and a half years following dredging in all contract areas. Newell *et al.* (1998) describes the process of ecological succession and the re-colonization process of marine macro-benthic communities. Within the first year following disturbance, there is typically rapid re-colonization and population growth by R-selected species, which are opportunistic and reproduce quickly (e.g. the polycheate Capitellidae and the amphipod *Ampelisca* sp.) (Gray and Elliot 2009, Santos and Simon 1980, Tsutsumi 1987). Typically, less than one year after disturbance, the number of species is relatively low, but the number of organisms in the disturbed area is extremely high. At one year post-disturbance a second group of species begin to re-colonize the area. Species richness increases, but the number of organisms decreases. Mollusks such as *Nucula proxima*, which were collected in 2012 (S-AN-2 contract area), usually re-establish during this time frame. During this transitional period, a mixture of R-selected colonizers and stable (K-selected) species are present, as was generally observed in each of the contract areas sampled during 2012. Eventually, the species composition and density begin to reach pre-disturbance conditions, or resemble a relatively stable community (Pearson and Rosenberg 1978). This community, though perhaps different from the pre-existing community, will nonetheless continue to provide trophic support and material/nutrient processing functions which contribute to maintenance of the estuarine benthos.

The New York/New Jersey Harbor is an example of an estuarine system that is affected by urbanization. However, despite this urbanization, the Harbor remains a productive estuary, and supports fairly diverse communities of benthic invertebrates (Iocco *et al.* 2000, Steimle and Caracciolo-Ward 1989, Woodhead *et al.* 1999). As documented in these and other recent studies, benthic habitats within the Harbor that experience disturbance may undergo a high degree of spatial variability and dominance by opportunistic species under these conditions (Iocco *et al.* 2000, USACE 2008, USACE 2011). The results from this study suggest that the physical conditions and sediment habitats of the navigation channels following dredging were generally comparable to the baseline conditions observed in 2005. For example, areas like Elizabeth Channel that were found to have degraded habitat and no pollution-sensitive taxa in 2005, similarly had no pollution-sensitive taxa in 2012 while other areas, such as Newark Bay Channel, which showed an increase in pollution-tolerant species such as *Scoloplos* sp. and Capitellidae had comparable benthic density, diversity and evenness indicators between 2005 and 2012. The major differences in density and diversity between pre- and post-deepening in this study likely reflect the high natural variability of estuarine benthic communities compounded by disturbance factors associated within an active commercial and industrial harbor.

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Table 3. Benthos density (organisms/m^2) by station in the NY/NJ Harbor Navigation Channels, 2005.

						Anchorage Channel (S-AN-2)			Anchorage Channel (S-AN-1b)		Elizabeth Channel (S-E-1)				Newark Bay Channel (S-NB-1)		
Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**	**AN-2**	**AN-3**	**AN**	**BRC-3**	**BRC**	**EC-1**	**EC-2**	**EC-3**	**EC**	**NBC-1**	**NBC-3**	**NBC**
Annelida	Oligochaeta	---	---	---	---	20	50	**35**	15	**15**	0	0	0	**0**	0	0	**0**
	Polychaeta	---	---	---	---	0	0	**0**	5	**5**	0	10	0	**3**	0	45	**23**
		Ariciida	Orbiniidae	*Scoloplos**	---	150	0	**75**	0	**0**	140	105	740	**328**	55	168	**112**
		Capitellida	Capitellidae	---	---	100	75	**88**	0	**0**	0	0	0	**0**	5	0	**3**
			Maldanidae	---	---	35	0	**18**	0	**0**	0	0	0	**0**	0	0	**0**
		Cirratulida	Cirratulidae	---	---	0	10	**5**	0	**0**	0	0	0	**0**	0	0	**0**
		Eunicida	Onuphidae	*Diopatra*	*cuprea*	0	0	**0**	0	**0**	0	0	0	**0**	5	0	**3**
		Magelonida	Magelonidae	*Magelona*	---	0	5	**3**	0	**0**	0	0	0	**0**	0	0	**0**
		Phyllodocida	Glyceridae	*Glycera*	---	35	30	**33**	35	**35**	0	15	20	**12**	10	25	**18**
			Nephtyidae	*Nephtys*	---	10	30	**20**	60	**60**	5	0	0	**2**	0	0	**0**
			Nereidae	*Nereis*	---	0	0	**0**	0	**0**	0	0	0	**0**	25	0	**13**
					succinea	5	0	**3**	0	**0**	5	0	0	**2**	0	0	**0**
			Phyllodocidae	---	---	0	0	**0**	5	**5**	0	0	5	**2**	0	50	**25**
				Eteone	---	5	0	**3**	0	**0**	0	0	0	**0**	0	0	**0**
				Phyllodoce	---	0	0	**0**	0	**0**	0	0	5	**2**	0	0	**0**
			Polynoidae	*Lepidonotus*	---	0	0	**0**	15	**15**	0	0	0	**0**	0	0	**0**
		Spionida	Chaetopteriadae	---	---	10	0	**5**	0	**0**	0	0	0	**0**	0	0	**0**
			Paraonidae	---	---	0	0	**0**	0	**0**	0	0	0	**0**	0	8	**4**
				Paraonis	---	0	0	**0**	0	**0**	0	10	0	**3**	0	0	**0**
			Sabellariidae	*Sabellaria*	*vulgaris*	0	0	**0**	0	**0**	0	0	0	**0**	0	8	**4**
			Spionidae	---	---	5	15	**10**	0	**0**	0	0	0	**0**	0	0	**0**
				Spio	---	20	90	**55**	30	**30**	0	0	0	**0**	0	0	**0**
					setosa	0	405	**203**	0	**0**	0	0	0	**0**	0	0	**0**
				Spiophanes	---	5	0	**3**	0	**0**	0	0	0	**0**	0	0	**0**
				Streblospio	*benedicti*	10	0	**5**	0	**0**	0	0	0	**0**	0	0	**0**
		Terebellida	Ampharetidae	---	---	10	0	**5**	0	**0**	0	0	0	**0**	0	0	**0**
				Amage	*auricula**	15	0	**8**	0	**0**	0	0	0	**0**	0	0	**0**
			Pectinariidae	*Pectinaria*	*gouldii*	85	0	**43**	0	**0**	110	110	160	**127**	2,100	18	**1,059**
Arthropoda	Crustacea	Amphipoda	Ampeliscidae	---	---	590	0	**295**	0	**0**	0	0	0	**0**	0	0	**0**
				Ampelisca	---	0	0	**0**	5	**5**	0	0	0	**0**	0	0	**0**
			Gammaridae	---	---	0	0	**0**	5	**5**	0	0	0	**0**	0	8	**4**
		Decapoda	Crangonidae	*Crangon*	*septemspinosa*	0	0	**0**	0	**0**	5	0	10	**5**	5	10	**8**
			Paguridae	*Pagurus*	---	0	0	**0**	5	**5**	0	0	0	**0**	0	8	**4**
					longicarps	5	0	**3**	0	**0**	0	0	0	**0**	0	0	**0**
			Portunidae	*Carcinus*	*maenas*	5	0	**3**	0	**0**	0	0	0	**0**	0	0	**0**
				Ovalipes	*ocellatus*	0	5	**3**	0	**0**	0	0	0	**0**	0	0	**0**
			Xanthidae	*Panopeus*	*herbstii*	5	0	**3**	0	**0**	0	0	0	**0**	0	10	**5**
		Isopoda	Idoteidae	*Idotea*	---	0	0	**0**	0	**0**	0	0	0	**0**	20	0	**10**
		Mysidacea	---	---	---	0	0	**0**	0	**0**	0	5	0	**2**	0	0	**0**
			Mysidae	*Neomysis*	*americana*	5	0	**3**	0	**0**	0	0	0	**0**	0	0	**0**
Chordata	Ascidacea	Pleurogona	Molgulidae	*Molgula*	---	0	0	**0**	0	**0**	0	0	0	**0**	0	1,833	**917**
Mollusca	Bivalvia	Eudesmodontida	Pandoridae	*Pandora*	*gouldiana*	10	0	**5**	0	**0**	0	0	0	**0**	0	0	**0**
		Myoida	Myidae	*Mya*	*arenaria*	0	0	**0**	0	**0**	0	0	5	**2**	0	0	**0**
		Mytioida	Mytilidae	*Mytilus*	*edulis*	0	50	**25**	0	**0**	0	0	0	**0**	5	35	**20**
		Nuculoida	Nuculanidae	*Yoldia*	*limatula*	5	0	**3**	0	**0**	0	0	0	**0**	0	0	**0**
		Veneroida	Mactridae	*Mulinia*	*lateralis*	45	0	**23**	0	**0**	0	0	5	**2**	5	0	**3**
				Spisula	*solidissima*	30	35	**33**	0	**0**	0	0	0	**0**	0	0	**0**
			Solenidae	*Ensis*	*directus*	5	5	**5**	0	**0**	0	0	0	**0**	0	0	**0**
			Tellinidae	*Tellina*	*agilis*	25	410	**218**	80	**80**	0	0	0	**0**	0	50	**25**
			Veneridae	*Mercenaria*	*mercenaria*	15	0	**8**	0	**0**	0	0	0	**0**	0	0	**0**
	Gastropoda	Neogastropoda	Nassariidae	*Ilyanassa*	*trivittata*	0	5	**3**	0	**0**	0	0	0	**0**	0	0	**0**
Nematoda	---	---	---	---	---	0	0	**0**	0	**0**	0	0	0	**0**	5	0	**3**
Nemertea	---	---	---	---	---	95	0	**48**	0	**0**	0	0	0	**0**	0	0	**0**
Taxa Richness						**27**	**13**	**33**	**10**	**10**	**5**	**5**	**7**	**11**	**11**	**13**	**19**
Benthos Density (organisms/m^2)						**1,360**	**1,220**	**1,290**	**260**	**260**	**265**	**255**	**950**	**490**	**2,240**	**2,278**	**2,259**

*Note - nomenclature changes: *Scoloplos* sp. was formerly *Leitoscoloplos* sp.; *Amage auricula* was formerly under the order Canalipalpata.

Table 4. Benthos density (organisms/m^2) by station in the NY/NJ Harbor Navigation Channels, 2012.

						Anchorage Channel (S-AN-2)						Anchorage Channel (S-AN-1b)					
Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**	**SAN2-1**	**SAN2-2**	**SAN2-3**	**SAN2-4**	**SAN2-5**	**SAN2**	**SAN1b-1**	**SAN1b-2**	**SAN1b-3**	**SAN1b-4**	**SAN1b-5**	**SAN1b**
Annelida	Oligochaeta	---	---	---	---	0	180	20	0	0	**40**	0	0	0	0	150	**30**
	Polychaeta	---	---	---	---	0	20	0	0	0	**4**	0	0	0	0	0	**0**
		Aciculata	Hesionidae	---	---	0	0	0	0	0	**0**	0	0	0	150	0	**30**
		Archiannelida	Polygordiidae	*Polygordius*	---	0	0	0	60	0	**12**	0	10	10	0	150	**34**
		Ariciida	Opheliidae	*Travisia*	*carnea*	0	100	0	0	0	**20**	0	20	0	0	0	**4**
			Orbiniidae	---	---	0	20	0	0	0	**4**	0	0	0	0	0	**0**
				*Scoloplos**	*fragilis*	0	0	0	0	10	**2**	40	20	0	0	0	**12**
		Capitellida	Capitellidae	---	---	360	6,880	180	9,279	100	**3,360**	0	0	0	300	0	**60**
			Maldanidae	*Clymenella*	*torquata*	0	0	0	60	360	**84**	0	0	0	0	0	**0**
			Cirratulidae	---	---	0	0	0	0	0	**0**	0	0	0	0	150	**30**
		Eucinida	Lumbrinereidae	---	---	0	0	0	0	0	**0**	0	0	0	150	0	**30**
				Lumbrineris	*tenuis*	0	0	0	0	0	**0**	0	0	0	150	0	**30**
				Ninoe	*nigripes*	0	20	0	0	0	**4**	0	0	0	0	0	**0**
		Flabelligerida	Flabelligeridae	---	---	0	60	30	0	0	**18**	0	0	0	0	0	**0**
				Pherusa	*affinis*	0	40	0	0	0	**8**	0	0	0	450	150	**120**
		Magelonida	Magelonidae	*Magelona*	---	0	0	0	0	0	**0**	10	10	0	0	0	**4**
		Phyllodocida	Glyceridae	*Glycera*	---	0	0	10	0	0	**2**	0	0	0	0	0	**0**
			Goniadidae	---	---	0	0	0	60	20	**16**	0	0	0	0	0	**0**
			Nephtyidae	*Nephtys*	*incisa*	0	0	180	120	40	**68**	0	0	0	0	0	**0**
					picta	0	0	0	0	0	**0**	60	100	200	0	0	**72**
			Nereidae	*Nereis*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Phyllodocidae	---	---	0	0	0	0	0	**0**	0	0	0	0	150	**30**
				Eteone	---	0	40	0	0	0	**8**	0	0	0	0	0	**0**
				Paranaitis	*speciosa*	0	40	0	0	0	**8**	0	0	0	0	0	**0**
				Phyllodoce	---	120	0	0	0	0	**24**	0	0	0	0	0	**0**
					arenae	0	0	0	0	30	**6**	0	0	0	0	0	**0**
			Syllidae	---	---	0	0	0	0	50	**10**	0	0	0	0	0	**0**
		Scolecida	Cossuridae	*Cossura*	*longocirrata*	0	0	0	30	0	**6**	0	0	0	0	0	**0**
			Paraonidae	*Aricidea*	*jeffreysii*	0	20	0	0	10	**6**	0	70	350	150	7,207	**1,555**
				Paraonis	---	0	0	0	0	0	**0**	0	0	0	300	0	**60**
			Spionidae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
				Marenzellaria	*viridis*	120	20	0	0	20	**32**	0	0	0	150	0	**30**
				Polydora	*cornuta**	36,001	280	0	0	0	**7,256**	0	0	0	0	150	**30**
				Streblospio	*benedicti*	0	180	0	0	0	**36**	0	0	0	0	0	**0**
Arthropoda	Crustacea	Amphipoda	Ampeliscidae	*Ampelisca*	*abdita*	1,200	180	140	30	0	**310**	0	0	0	150	0	**30**
			Aoridae	*Unciola*	---	120	140	10	0	60	**66**	0	0	20	300	1,351	**334**
			Gammaridae	---	---	120	0	0	0	0	**24**	0	0	0	0	0	**0**
			Lysianassidae	*Lysianopsis*	*alba*	0	0	0	0	0	**0**	0	0	0	0	150	**30**
			Phoxocephalidae	*Harpinia*	---	0	0	0	0	0	**0**	10	40	0	0	0	**10**
				Trichophoxus	---	0	0	0	0	0	**0**	130	110	120	150	0	**102**
		Brachyura	---	---	---	0	0	0	0	0	**0**	20	0	0	0	0	**4**
		Cumacea	---	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Diastylidae	*Diastylis*	---	0	0	10	0	0	**2**	0	0	0	0	0	**0**
					quadrispinosa	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Decapoda	---	---	---	0	0	0	0	0	**0**	0	0	0	10	0	**2**
			Caridea	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Crangonidae	*Crangon*	*septemspinosa*	0	20	50	0	10	**16**	0	0	0	0	0	**0**
			Magidae	*Libinia*	*emarginata*	0	0	0	0	0	**0**	0	0	0	150	0	**30**
			Paguridae	*Pagurus*	*longicarps*	0	0	10	0	10	**4**	10	0	10	0	0	**4**
			Portunidae	*Carcinus*	*maenas*	0	0	0	0	0	**0**	0	0	0	10	0	**2**
			Xanthidae	---	---	0	0	0	0	0	**0**	0	0	0	10	0	**2**
		Isopoda	Ancinidae	*Ancinus*	*depressus*	0	0	0	0	0	**0**	0	0	30	0	0	**6**
			Anthuridae	*Cyathura*	*polita*	0	0	0	0	0	**0**	0	0	0	0	300	**60**
			Chaetiliidae	*Chiridotea*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Idoteidae	*Edotea*	*triloba*	0	0	0	0	0	**0**	0	0	0	0	300	**60**
Cnidaria	Anthozoa	Actiniaria	---	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Mollusca	Bivalvia	Eudesmodontida	Pandoridae	*Pandora*	---	0	0	0	0	0	**0**	0	0	0	0	150	**30**
		Myoida	Myidae	*Mya*	*arenaria*	0	20	20	60	80	**36**	20	20	10	300	0	**70**
		Mytioida	Mytilidae	*Mytilus*	*edulis*	0	0	0	0	30	**6**	40	20	150	22,202	27,027	**9,888**
			Nuculanidae	*Nucula*	*proxima*	120	0	0	120	10	**50**	0	0	0	0	0	**0**
				Yoldia	*limatula*	0	0	120	450	370	**188**	0	0	0	0	0	**0**
		Veneroida	Mactridae	*Mulinia*	*lateralis*	360	20	10	721	80	**238**	0	0	0	0	0	**0**
			Petricolidae	*Petricola*	*pholadiformis*	840	0	0	0	0	**168**	0	0	0	0	0	**0**
			Solenidae	*Ensis*	*directus*	0	0	0	0	0	**0**	0	20	10	0	0	**6**
			Veneridae	*Pitar*	*morrhuanus*	120	0	10	450	230	**162**	10	10	10	0	0	**6**
	Gastropoda	Archaeogastropoda	Naticidae	*Euspira*	*heros*	0	0	0	30	0	**6**	0	0	0	0	0	**0**
		Cephalaspidea	Scaphandridae	*Acteocina*	*canaliculata*	0	0	0	0	20	**4**	0	0	0	0	0	**0**
		Neogastropoda	Nassariidae	*Ilyanassa*	*obsoleta*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
					trivittata	0	0	0	30	20	**10**	0	0	0	0	0	**0**
Sipuncula	---	---	---	---	---	0	200	230	300	340	**214**	0	0	0	0	0	**0**
Taxa Richness						**11**	**18**	**15**	**15**	**21**	**40**	**10**	**12**	**11**	**15**	**13**	**34**
Benthos Density (organisms/m^2)						**39,482**	**8,480**	**1,030**	**11,802**	**1,900**	**12,539**	**350**	**450**	**920**	**25,083**	**37,387**	**12,838**

* Note - nomenclature changes: *Scoloplos* sp. was formerly *Leitoscoloplos* sp.; *Marenzellaria* sp. was formerly *Scolocolepides* sp.; *Polydora cornuta* was formerly *Polydora ligni*

Table 4. Benthos density (organisms/m2) by station in the NY/NJ Harbor Navigation Channels, 2012.

						Elizabeth Channel (S-E-1)						Newark Bay Channel (S-NB-1)					
Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**	**SE1-1**	**SE1-2**	**SE1-3**	**SE1-4**	**SE1-5**	**SE1**	**SNB1-1**	**SNB1-2**	**SNB1-3**	**SNB1-4**	**SNB1-5**	**SNB1**
Annelida	Oligochaeta	---	---	---	---	10,880	0	40	4,920	10	**3,170**	0	0	0	0	30	**6**
	Polychaeta	---	---	---	---	0	0	10	0	0	**2**	0	10	0	0	10	**4**
		Aciculata	Hesionidae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Archiannelida	Polygordiidae	*Polygordius*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Ariciida	Opheliidae	*Travisia*	*carnea*	0	0	0	0	0	**0**	0	0	0	0	70	**14**
			Orbiniidae	---	---	0	20	0	0	0	**4**	0	0	10	0	0	**2**
				*Scoloplos**	*fragilis*	8,720	70	20	360	50	**1,844**	100	300	30	120	400	**190**
		Capitellida	Capitellidae	---	---	7,680	140	2,020	23,161	1,250	**6,850**	220	90	120	1,180	2,250	**772**
			Maldanidae	*Clymenella*	*torquata*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Cirratulidae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Eucinida	Lumbrinereidae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
				Lumbrineris	*tenuis*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
				Ninoe	*nigripes*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Flabelligerida	Flabelligeridae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
				Pherusa	*affinis*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Magelonida	Magelonidae	*Magelona*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Phyllodocida	Glyceridae	*Glycera*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Goniadidae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Nephtyidae	*Nephtys*	*incisa*	0	0	10	0	10	**4**	0	0	30	0	0	**6**
					picta	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Nereidae	*Nereis*	---	0	40	0	0	0	**8**	0	0	0	0	0	**0**
			Phyllodocidae	---	---	80	30	60	480	200	**170**	10	0	0	0	0	**2**
				Eteone	---	0	0	0	0	0	**0**	0	0	0	0	70	**14**
				Paranaitis	*speciosa*	0	0	0	0	0	**0**	0	0	0	0	10	**2**
				Phyllodoce	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
					arenae	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Syllidae	---	---	0	0	0	0	0	**0**	0	0	0	10	40	**10**
		Scolecida	Cossuridae	*Cossura*	*longocirrata*	2,640	0	40	14,641	70	**3,478**	0	0	0	0	0	**0**
			Paraonidae	*Aricidea*	*jeffreysii*	0	0	10	0	0	**2**	0	0	0	0	0	**0**
				Paraonis	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Spionidae	---	---	0	0	0	1,200	0	**240**	0	0	0	20	0	**4**
				Marenzellaria	*viridis*	0	0	0	0	0	**0**	0	0	0	0	10	**2**
				Polydora	*cornuta**	0	0	50	0	0	**10**	10	10	40	40	30	**26**
				Streblospio	*benedicti*	0	0	50	0	40	**18**	0	0	0	0	120	**24**
Arthropoda	Crustacea	Amphipoda	Ampeliscidae	*Ampelisca*	*abdita*	0	0	0	0	0	**0**	20	0	0	0	70	**18**
			Aoridae	*Unciola*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Gammaridae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Lysianassidae	*Lysianopsis*	*alba*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Phoxocephalidae	*Harpinia*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
				Trichophoxus	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Brachyura	---	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Cumacea	---	---	---	160	80	70	240	140	**138**	0	0	20	0	0	**4**
			Diastylidae	*Diastylis*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
					quadrispinosa	80	190	320	360	1,410	**472**	0	0	0	10	0	**2**
		Decapoda	---	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Caridea	---	---	0	0	0	0	0	**0**	0	0	0	0	10	**2**
			Crangonidae	*Crangon*	*septemspinosa*	0	20	0	0	0	**4**	0	0	0	0	0	**0**
			Magidae	*Libinia*	*emarginata*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Paguridae	*Pagurus*	*longicarps*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Portunidae	*Carcinus*	*maenas*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Xanthidae	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Isopoda	Ancinidae	*Ancinus*	*depressus*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Anthuridae	*Cyathura*	*polita*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Chaetiliidae	*Chiridotea*	---	0	0	0	120	10	**26**	0	0	0	0	0	**0**
			Idoteidae	*Edotea*	*triloba*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Cnidaria	Anthozoa	Actiniaria	---	---	---	0	10	0	0	0	**2**	0	0	0	0	0	**0**
Mollusca	Bivalvia	Eudesmodontida	Pandoridae	*Pandora*	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Myoida	Myidae	*Mya*	*arenaria*	160	0	0	0	0	**32**	0	0	10	20	40	**14**
		Mytioida	Mytilidae	*Mytilus*	*edulis*	0	0	20	0	0	**4**	0	0	0	0	0	**0**
			Nuculanidae	*Nucula*	*proxima*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
				Yoldia	*limatula*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Veneroida	Mactridae	*Mulinia*	*lateralis*	0	30	50	0	10	**18**	0	10	0	30	30	**14**
			Petricolidae	*Petricola*	*pholadiformis*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
			Solenidae	*Ensis*	*directus*	0	0	0	0	0	**0**	0	10	0	0	0	**2**
			Veneridae	*Pitar*	*morrhuanus*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
	Gastropoda	Archaeogastropoda	Naticidae	*Euspira*	*heros*	0	0	0	0	0	**0**	0	0	0	0	0	**0**
		Cephalaspidea	Scaphandridae	*Acteocina*	*canaliculata*	0	0	0	0	0	**0**	0	40	0	0	0	**8**
		Neogastropoda	Nassariidae	*Ilyanassa*	*obsoleta*	0	10	0	0	0	**2**	0	0	0	0	0	**0**
					trivittata	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Sipuncula	---	---	---	---	---	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Taxa Richness						**7**	**9**	**12**	**8**	**10**	**19**	**5**	**6**	**6**	**7**	**14**	**20**
Benthos Density (organisms/m^2)						**30,400**	**640**	**2,770**	**45,482**	**3,200**	**16,498**	**360**	**470**	**260**	**1,430**	**3,190**	**1,142**

* Note - nomenclature changes: *Scoloplos* sp. was formerly *Leitoscoloplos* sp.; *Marenzellaria* sp. was formerly *Scolocolepides* sp.; *Polydora cornuta* was formerly *Polydora ligni*

Table 5. Taxa richness and density by station and average density by contract area (organisms/m^2) from samples collected in NY/NJ Harbor Navigation Channels, 2005 and 2012.

Contract Area	Sampling Year	Sample Name	Taxa Richness								Density (organisms/m^2)							
			Annelida		Arthropoda		Molluska		Other		Annelida		Arthropoda		Molluska		Other	
			NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
Anchorage Channel (S-AN-2)	2005	AN-2	14	51.9%	5	18.5%	7	25.9%	1	3.7%	520	38.2%	610	44.9%	135	9.9%	95	7.0%
		AN-3	7	53.8%	1	7.7%	5	38.5%	0	0.0%	710	58.2%	5	0.4%	505	41.4%	0	0.0%
		AN	**17**	**51.5%**	**6**	**18.2%**	**9**	**27.3%**	**1**	**3.0%**	**615**	**47.7%**	**308**	**23.8%**	**320**	**24.8%**	**48**	**3.7%**
	2012	SAN2-1	4	36.4%	3	27.3%	4	36.4%	0	0.0%	36,601	92.7%	1,440	3.6%	1,440	3.6%	0	0.0%
		SAN2-2	12	66.7%	3	16.7%	2	11.1%	1	5.6%	7,900	93.2%	340	4.0%	40	0.5%	200	2.4%
		SAN2-3	5	33.3%	5	33.3%	4	26.7%	1	6.7%	420	40.8%	220	21.4%	160	15.5%	230	22.3%
		SAN2-4	6	40.0%	1	6.7%	7	46.7%	1	6.7%	9,610	81.4%	30	0.3%	1,862	15.8%	300	2.5%
		SAN2-5	9	42.9%	3	14.3%	8	38.1%	1	4.8%	640	33.7%	80	4.2%	840	44.2%	340	17.9%
		SAN2	**23**	**57.5%**	**6**	**15.0%**	**10**	**25.0%**	**1**	**2.5%**	**11,034**	**88.0%**	**422**	**3.4%**	**868**	**6.9%**	**214**	**1.7%**
Anchorage Channel (S-AN-1b)	2005	BRC-3	6	60.0%	3	30.0%	1	10.0%	0	0.0%	165	63.5%	15	5.8%	80	30.8%	0	0.0%
		BRC	**6**	**60.0%**	**3**	**30.0%**	**1**	**10.0%**	**0**	**0.0%**	**165**	**63.5%**	**15**	**5.8%**	**80**	**30.8%**	**0**	**0.0%**
	2012	SAN1b-1	3	30.0%	4	40.0%	3	30.0%	0	0.0%	110	31.4%	170	48.6%	70	20.0%	0	0.0%
		SAN1b-2	6	50.0%	2	16.7%	4	33.3%	0	0.0%	230	51.1%	150	33.3%	70	15.6%	0	0.0%
		SAN1b-3	3	27.3%	4	36.4%	4	36.4%	0	0.0%	560	60.9%	180	19.6%	180	19.6%	0	0.0%
		SAN1b-4	7	46.7%	6	40.0%	2	13.3%	0	0.0%	1,800	7.2%	780	3.1%	22,502	89.7%	0	0.0%
		SAN1b-5	7	53.8%	4	30.8%	2	15.4%	0	0.0%	8,108	21.7%	2,102	5.6%	27,177	72.7%	0	0.0%
		SAN1b	**16**	**47.1%**	**13**	**38.2%**	**5**	**14.7%**	**0**	**0.0%**	**2,162**	**16.8%**	**676**	**5.3%**	**10,000**	**77.9%**	**0**	**0.0%**
Elizabeth Channel (S-E-1)	2005	E-1	4	80.0%	1	20.0%	0	0.0%	0	0.0%	260	98.1%	5	1.9%	0	0.0%	0	0.0%
		E-2	4	80.0%	1	20.0%	0	0.0%	0	0.0%	250	98.0%	5	2.0%	0	0.0%	0	0.0%
		E-3	4	57.1%	1	14.3%	2	28.6%	0	0.0%	930	97.9%	10	1.1%	10	1.1%	0	0.0%
		Elizabeth	**7**	**63.6%**	**2**	**18.2%**	**2**	**18.2%**	**0**	**0.0%**	**480**	98.0%	**7**	**1.4%**	**3**	**0.7%**	**0**	**0.0%**
	2012	SE1-1	5	71.4%	1	14.3%	1	14.3%	0	0.0%	30,000	98.7%	240	0.8%	160	0.5%	0	0.0%
		SE1-2	4	44.4%	2	22.2%	2	22.2%	1	11.1%	300	46.9%	290	45.3%	40	6.3%	10	1.6%
		SE1-3	9	75.0%	1	8.3%	2	16.7%	0	0.0%	2,310	83.4%	390	14.1%	70	2.5%	0	0.0%
		SE1-4	6	75.0%	2	25.0%	0	0.0%	0	0.0%	44,762	98.4%	720	1.6%	0	0.0%	0	0.0%
		SE1-5	7	70.0%	2	20.0%	1	10.0%	0	0.0%	1,630	50.9%	1,560	48.8%	10	0.3%	0	0.0%
		SE1	**11**	**57.9%**	**3**	**15.8%**	**4**	**21.1%**	**1**	**5.3%**	**15,800**	**95.8%**	**640**	**3.9%**	**56**	**0.3%**	**2**	**0.0%**
Newark Bay Channel (S-NB-1)	2005	NBC-1	6	54.5%	2	18.2%	2	18.2%	1	9.1%	2,200	98.2%	25	1.1%	10	0.4%	5	0.2%
		NBC-3	6	46.2%	4	30.8%	2	15.4%	1	7.7%	323	14.2%	37	1.6%	85	3.7%	1,833	80.5%
		Newark Bay	**9**	**47.4%**	**5**	**26.3%**	**3**	**15.8%**	**2**	**10.5%**	**1,262**	**55.8%**	**31**	**1.4%**	**48**	**2.1%**	**919**	**40.7%**
	2012	SNB1-1	4	80.0%	1	20.0%	0	0.0%	0	0.0%	340	94.4%	20	5.6%	0	0.0%	0	0.0%
		SNB1-2	3	50.0%	0	0.0%	3	50.0%	0	0.0%	410	87.2%	0	0.0%	60	12.8%	0	0.0%
		SNB1-3	4	66.7%	1	16.7%	1	16.7%	0	0.0%	230	88.5%	20	7.7%	10	3.8%	0	0.0%
		SNB1-4	4	57.1%	1	14.3%	2	28.6%	0	0.0%	1,370	95.8%	10	0.7%	50	3.5%	0	0.0%
		SNB1-5	10	71.4%	2	14.3%	2	14.3%	0	0.0%	3,040	95.3%	80	2.5%	70	2.2%	0	0.0%
		SNB1	**12**	**60.0%**	**4**	**20.0%**	**4**	**20.0%**	**0**	**0.0%**	**1,078**	**94.4%**	**26**	**2.3%**	**38**	**3.3%**	**0**	**0.0%**

Table 6. Benthic community taxa richness, density (organisms/m^2), Diversity (H'), Evenness (J'), and relative pollution sensitivity from samples collected in NY/NJ Harbor Navigation Channels, 2005 and 2012.

Contract Area	Sampling Year	Sample Name	Taxa Richness	Total Density (organisms/m^2)	Average Density (organisms/m^2)	Diversity (H')	Evenness (J')	Percent of Pollution Tolerant Taxa (%)	Percent of Pollution Sensitive Taxa (%)
Anchorage Channel (S-AN-2)	2005	AN-2	27	1,360	--	2.23	0.68	24%	6%
		AN-3	13	1,220	--	1.83	0.71	6%	38%
		AN	**33**	--	**1,290**	**2.56**	**0.73**	**21%**	**20%**
	2012	SAN2-1	11	39,482	--	0.46	0.19	2%	0%
		SAN2-2	18	8,480	--	0.91	0.32	86%	0%
		SAN2-3	15	1,030	--	2.14	0.79	20%	0%
		SAN2-4	15	11,802	--	0.96	0.36	85%	0%
		SAN2-5	21	1,900	--	2.37	0.78	10%	1%
		SAN2	**40**	--	**12,539**	**1.39**	**0.38**	**29%**	**0%**
Anchorage Channel (S-AN-1b)	2005	BRC-3	10	260	--	1.81	0.79	6%	32%
		BRC	**10**	--	**260**	**1.81**	**0.79**	**6%**	**32%**
	2012	SAN1b-1	10	350	--	1.90	0.82	11%	0%
		SAN1b-2	12	450	--	2.13	0.86	4%	4%
		SAN1b-3	11	920	--	1.62	0.67	0%	1%
		SAN1b-4	15	25,083	--	0.61	0.23	1%	0%
		SAN1b-5	13	37,387	--	0.93	0.36	0%	1%
		SAN1b	**34**	--	**12,838**	**1.00**	**0.28**	**1%**	**1%**
Elizabeth Channel (S-E-1)	2005	EC-1	5	265	--	0.93	0.58	53%	0%
		EC-2	5	255	--	1.10	0.68	41%	0%
		EC-3	7	950		0.71	0.36	79%	0%
		EC	**11**	--	**490**	**0.90**	**0.38**	**61%**	**0%**
	2012	SE1-1	7	30,400	--	1.34	0.69	90%	0%
		SE1-2	9	640	--	1.63	0.74	38%	0%
		SE1-3	12	2,770	--	1.01	0.41	79%	0%
		SE1-4	8	45,482	--	1.19	0.57	63%	0%
		SE1-5	10	3,200	--	1.18	0.51	43%	0%
		SE1	**19**	--	**16,498**	**1.52**	**0.52**	**72%**	**0%**
Newark Bay Channel (S-NB-1)	2005	NBC-1	11	2,240	--	0.35	0.15	3%	0%
		NBC-3	13	2,278	--	0.81	0.32	8%	2%
		NBC	**19**	--	**2,259**	**1.21**	**0.41**	**5%**	**1%**
	2012	SNB1-1	5	360	--	1.02	0.63	89%	0%
		SNB1-2	6	470	--	1.06	0.59	85%	11%
		SNB1-3	6	260	--	1.47	0.82	58%	0%
		SNB1-4	7	1,430	--	0.68	0.35	93%	0%
		SNB1-5	14	3,190	--	1.18	0.45	89%	0%
		SNB1	**20**	--	**1,142**	**1.23**	**0.41**	**88%**	**1%**

Table 7: Sediment type of samples collected from NY/NJ Harbor Navigation Channels, 2005 and 2012.

Contract Area	Sampling Year	Sample Name	Sediment Type
Anchorage Channel (S-AN-2)	2005	AN-2	silt
		AN-3	silt
	2012	SAN2-1	clayey silt/shell hash
		SAN2-2	clayey silt/fine sand/shell hash
		SAN2-3	silt/fine sand
		SAN2-4	soft silt
		SAN2-5	sandy silt
Anchorage Channel (S-AN-1b)	2005	BRC-3	shell
	2012	SAN1b-1	fine sand
		SAN1b-2	fine sand
		SAN1b-3	fine sand/shell hash
		SAN1b-4	sand with shells/stones
		SAN1b-5	shells/seed mussels/fine sand
Elizabeth Channel (S-E-1)	2005	EC-1	silt
		EC-2	silt/clay
		EC-3	silt/clay
	2012	SE1-1	silt
		SE1-2	clay
		SE1-3	silt
		SE1-4	silt
		SE1-5	silt
Newark Bay Channel (S-NB-1)	2005	NBC-1	silt/clay
		NBC-3	clay/rock
	2012	SNB1-1	silt
		SNB1-2	silt/clay
		SNB1-3	silt
		SNB1-4	silt/clay
		SNB1-5	silt

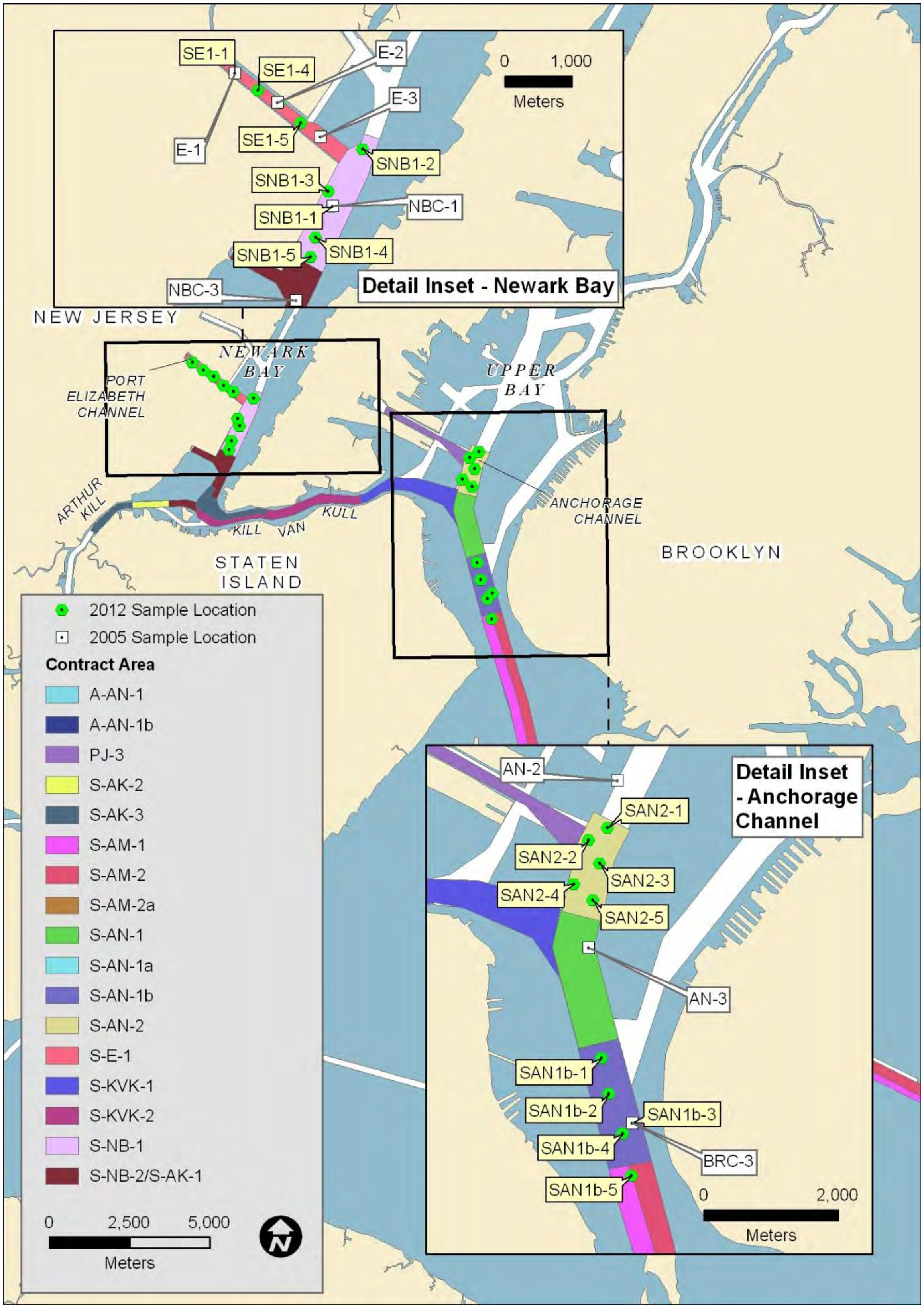

Figure 1. Overview of HDP contract areas and benthic sampling locations in 2005 and 2012.

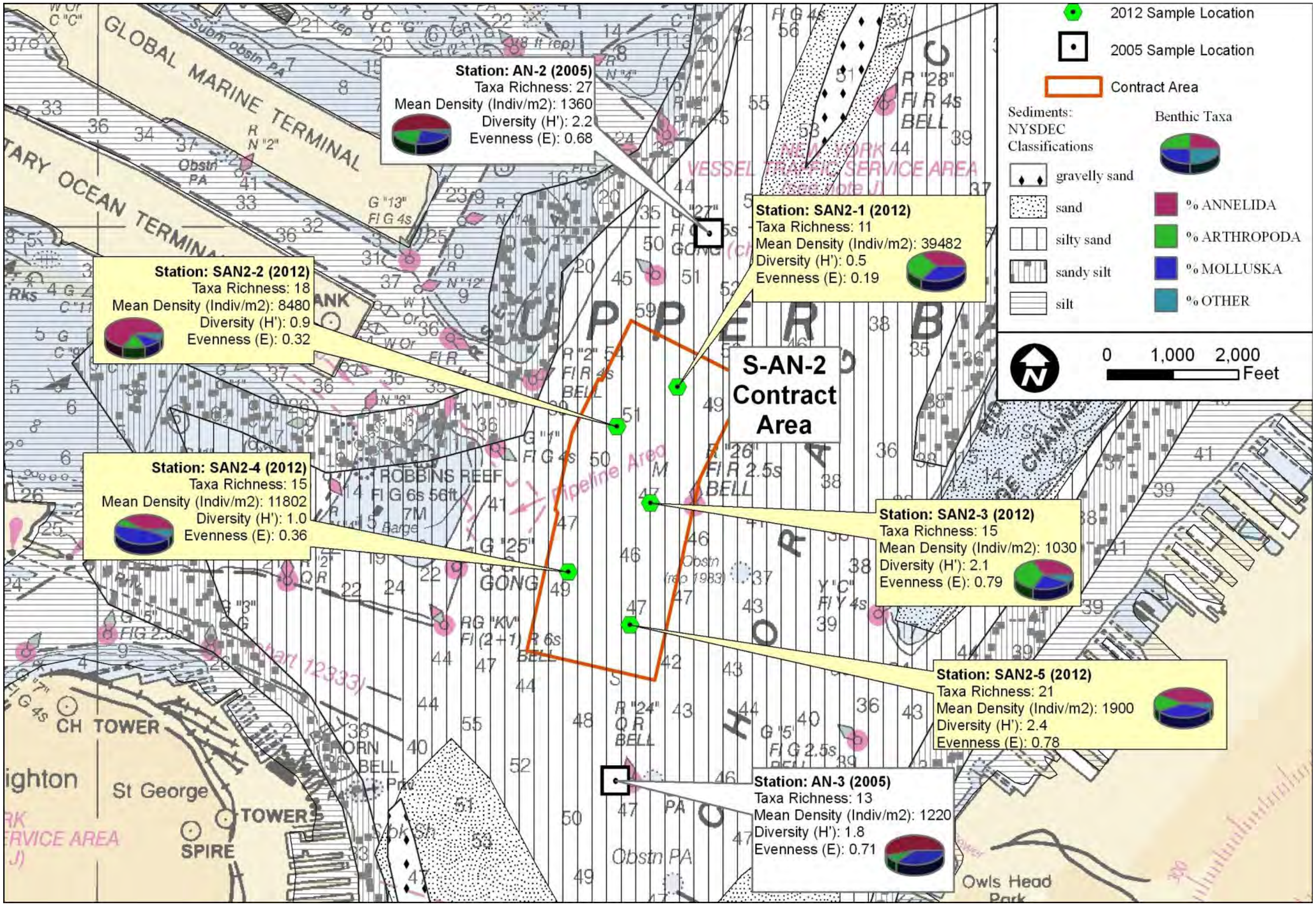

Figure 2a. HDP contract area S-AN-2 (Anchorage Channel) displaying benthic taxa and surface sediment for 2005 and 2012.

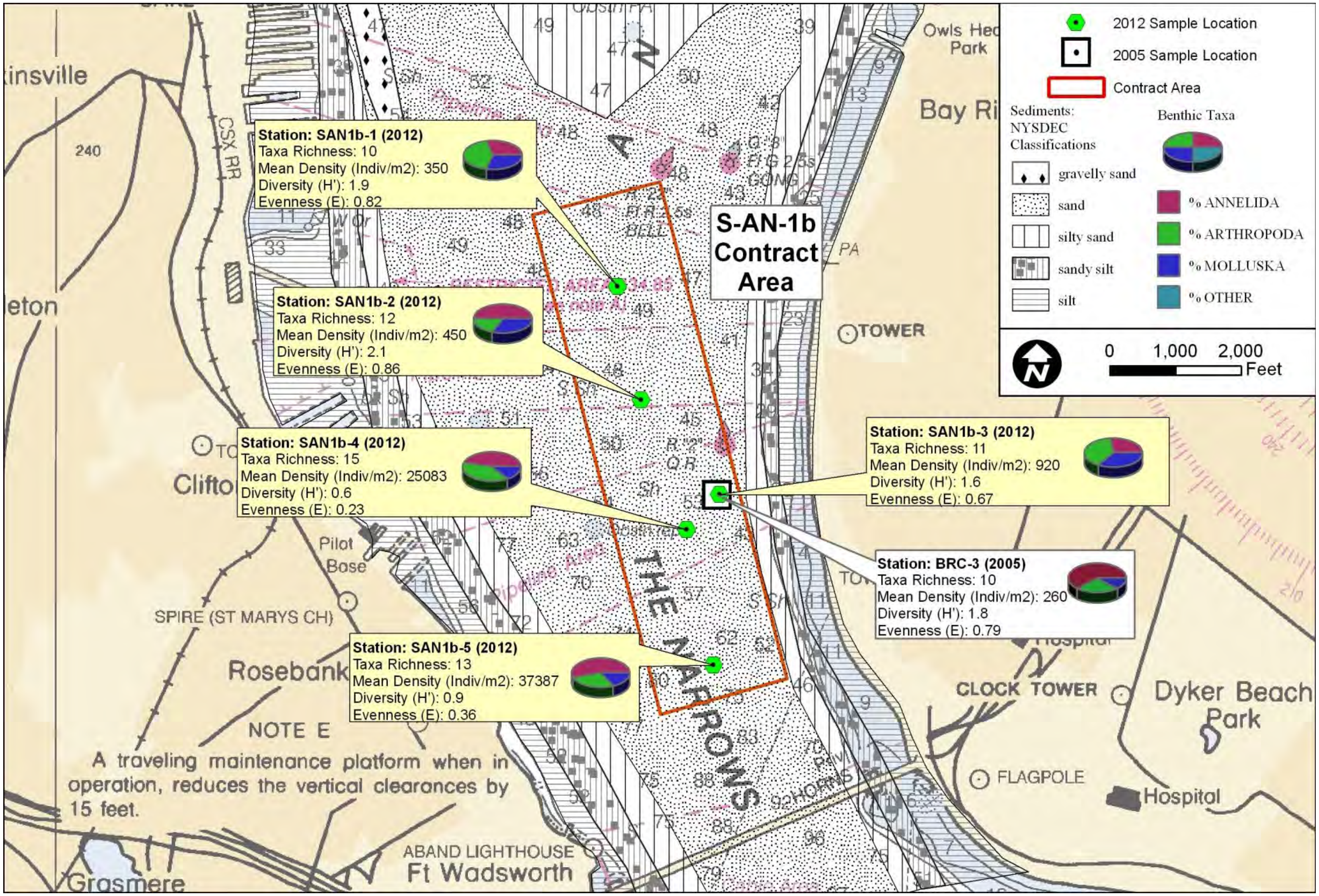

Figure 2b. HDP contract area S-AN-1b (Anchorage Channel) displaying benthic taxa and surface sediment for 2005 and 2012.

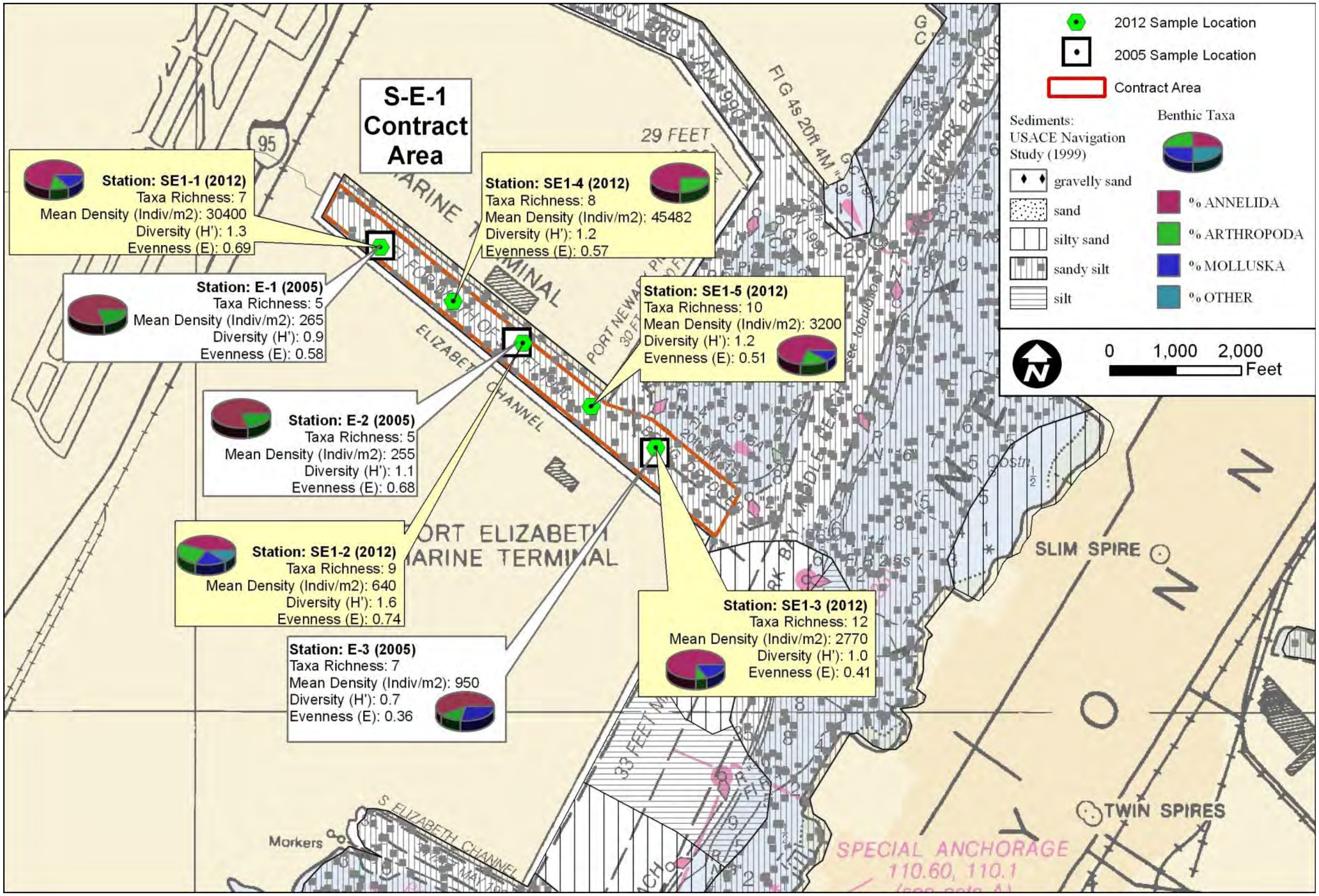

Figure 2c. HDP contract area S-E-1 (Elizabeth Channel) displaying benthic taxa and surface sediment for 2005 and 2012.

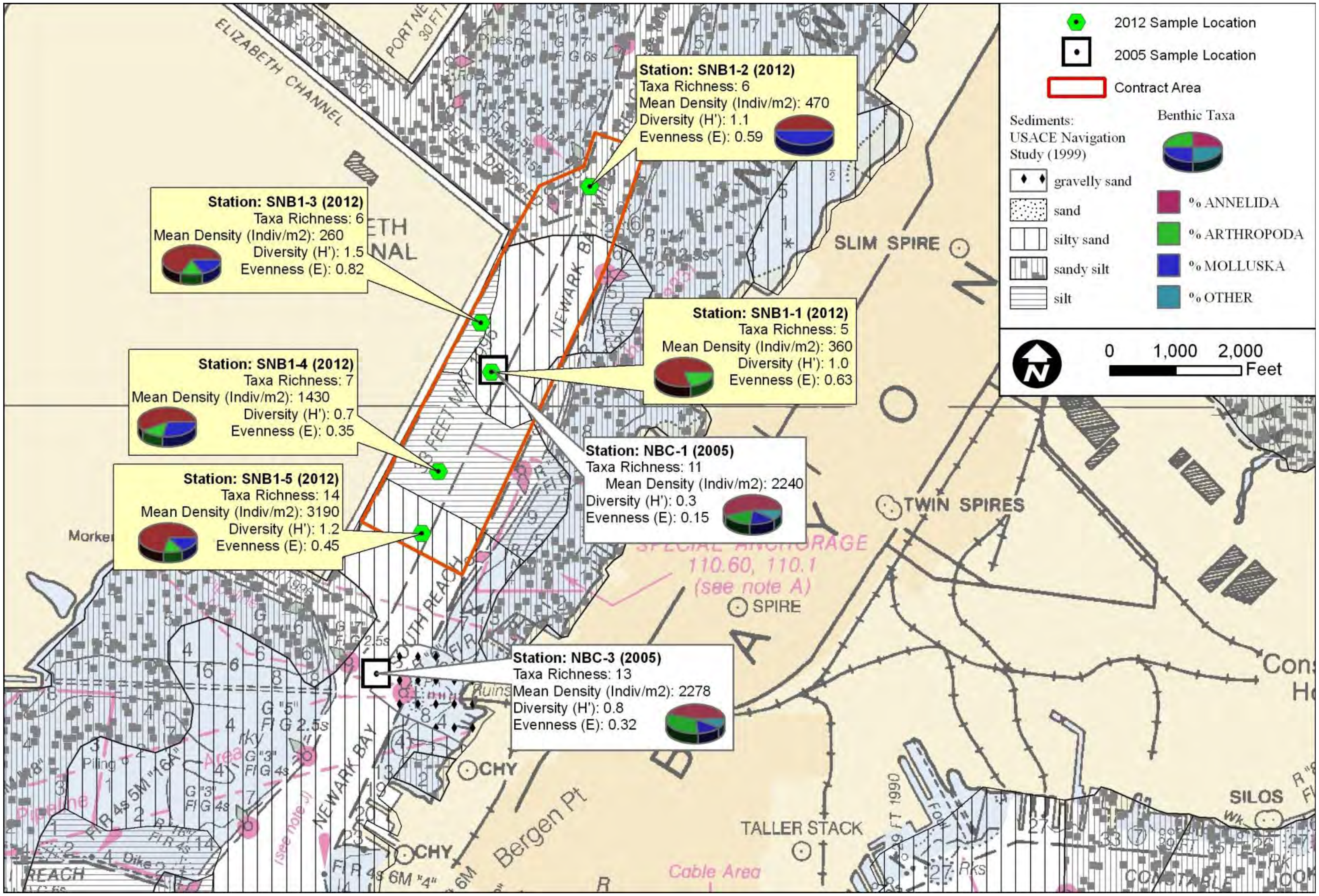

Figure 2d. HDP contract area S-NB-1 (Newark Bay Channel) displaying benthic taxa and surface sediment for 2005 and 2012.

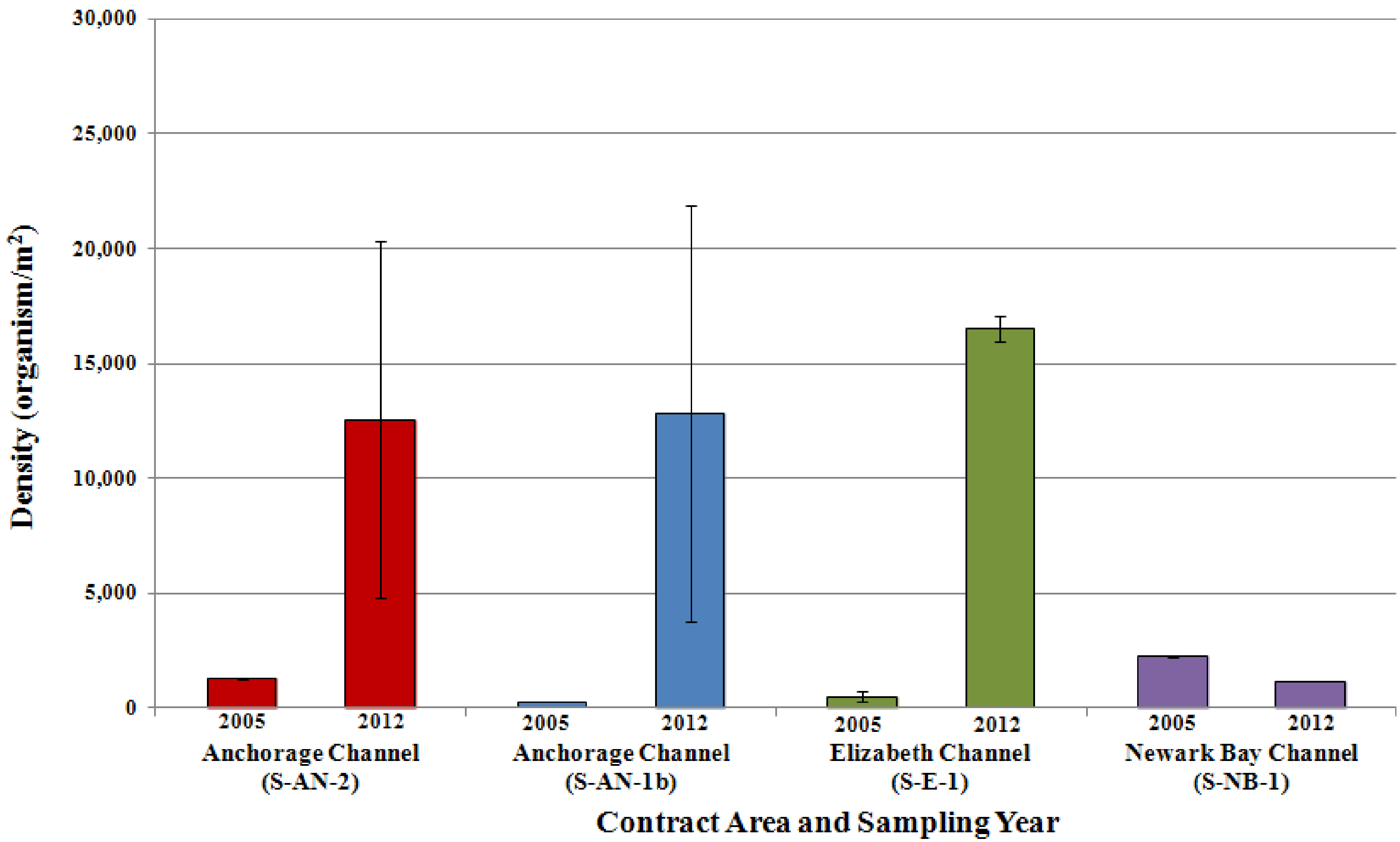

Figure 3. Average benthic macroinvertebrate density (± 1 SE) by contract area and sampling year.

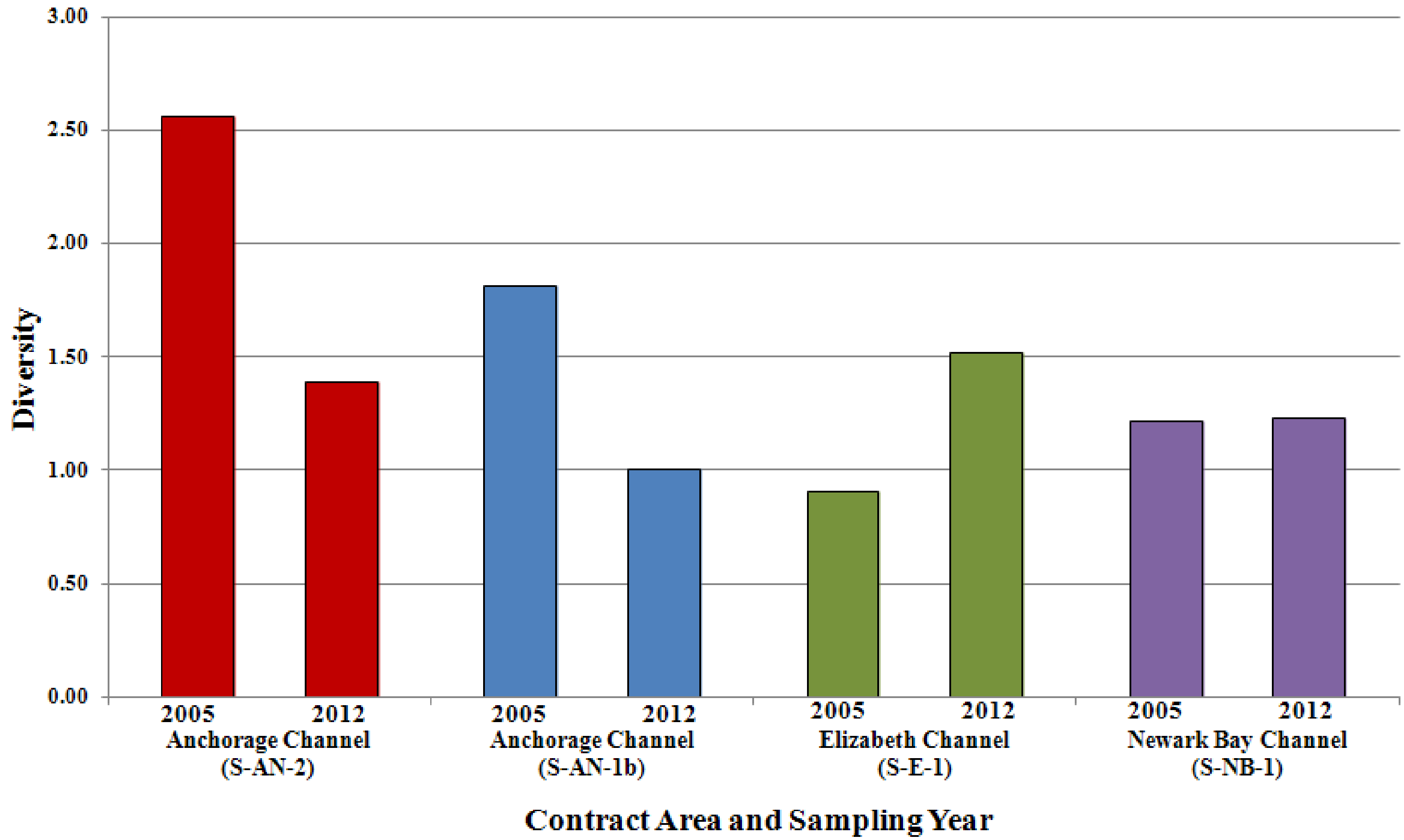

Figure 4. Benthic macroinvertebrate diversity by contract area and sampling year.

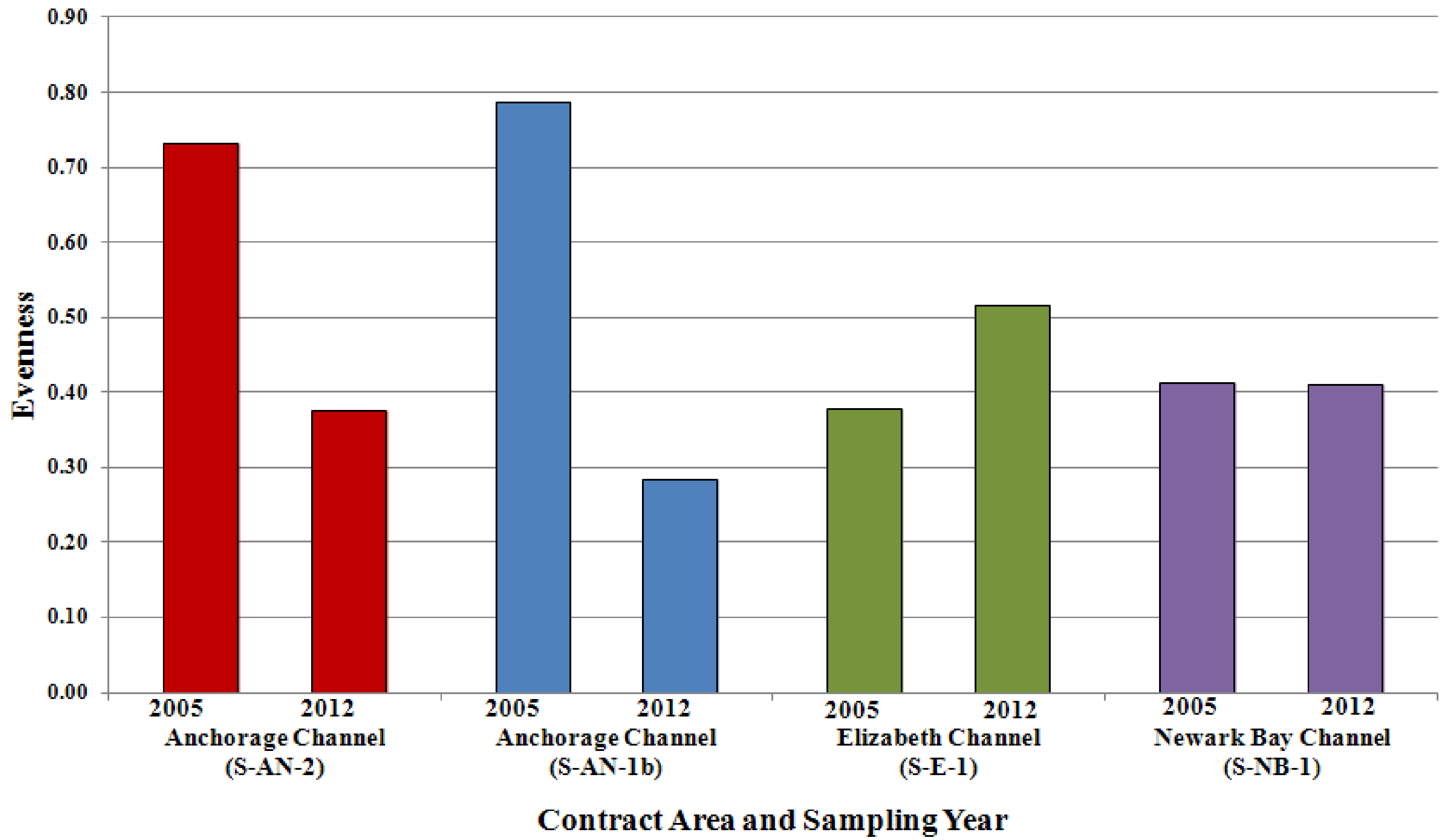

Figure 5. Benthic macroinvertebrate evenness by contract area and sampling year.

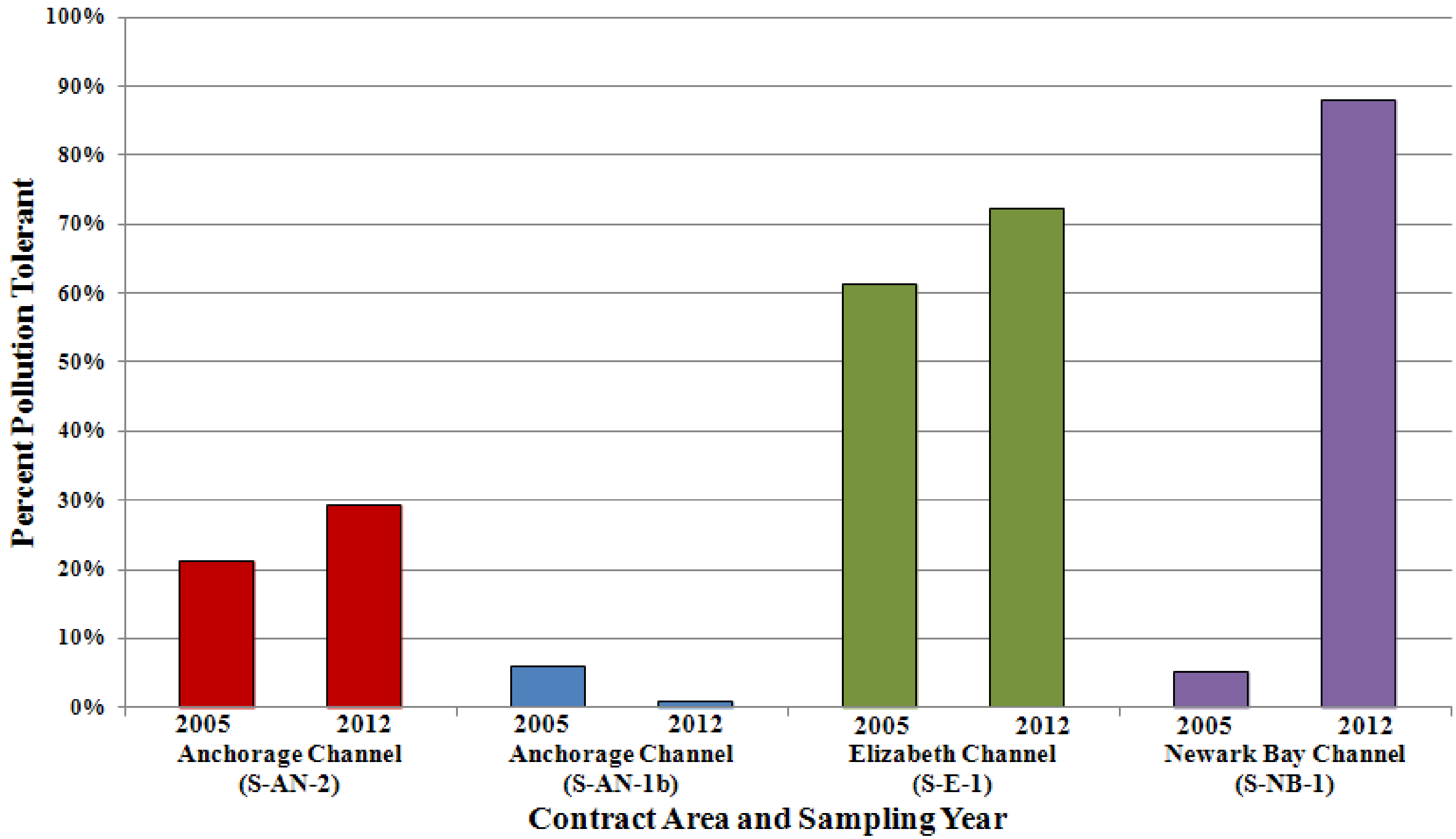

Figure 6. Percent pollution tolerant species by contract area and sampling year.

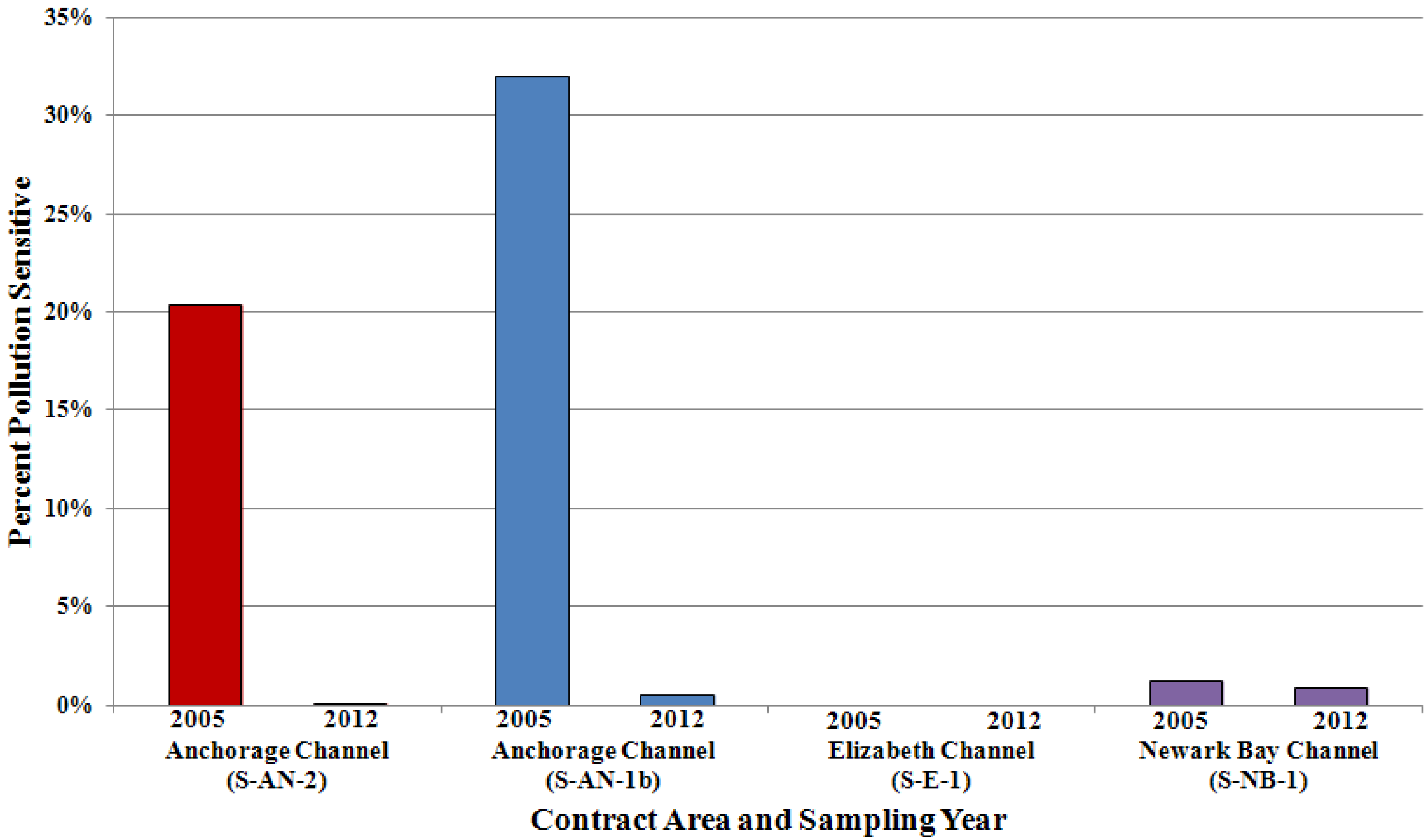

Figure 7. Percent pollution sensitive species by contract area and sampling year.