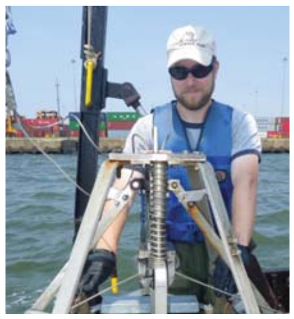
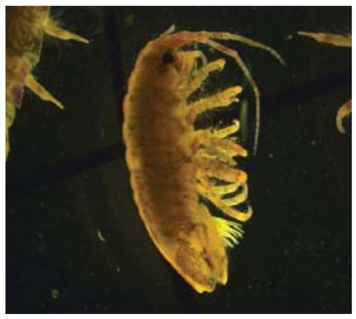
US Army Corps of Engineers®
New York District

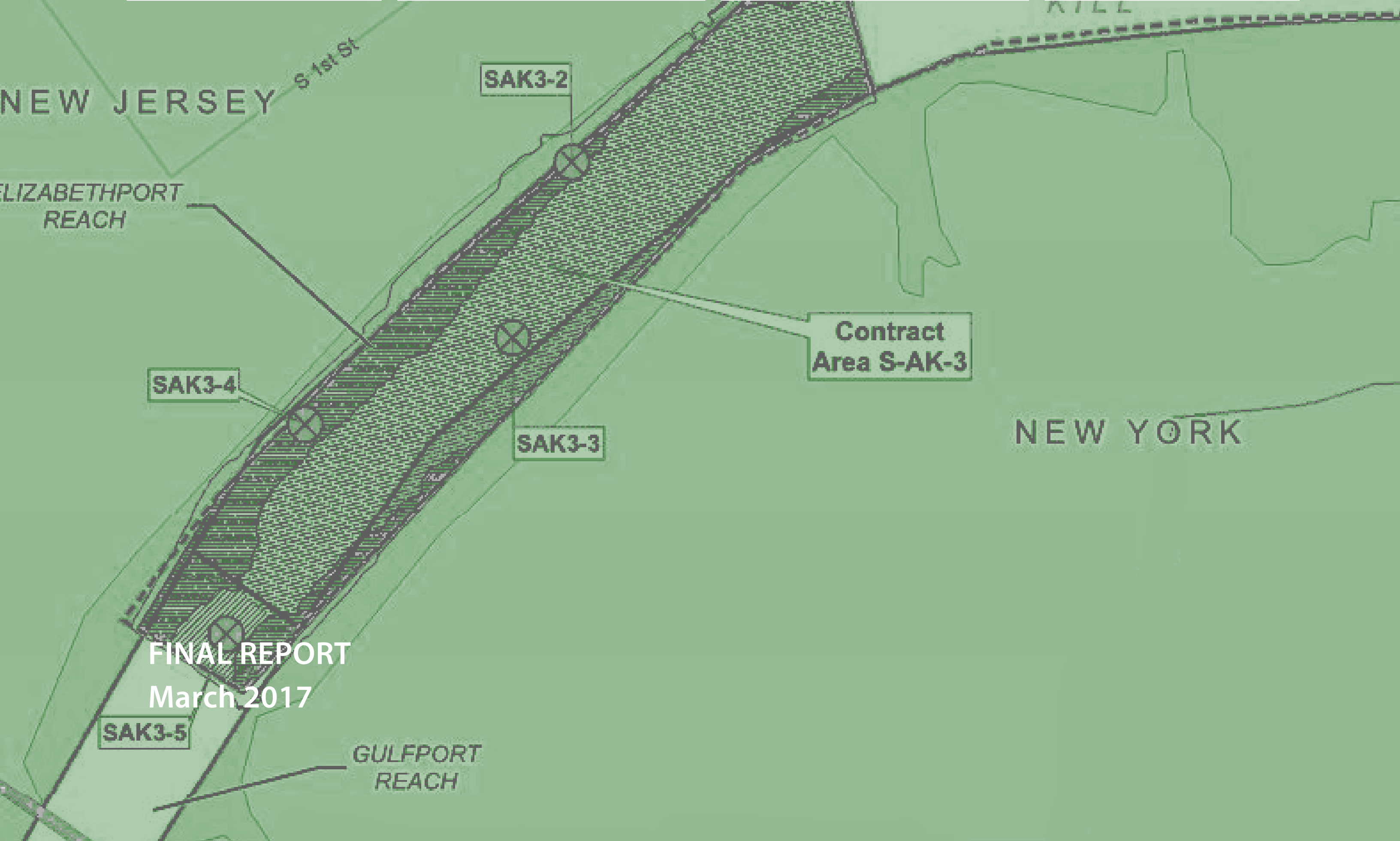
NEW YORK AND NEW JERSEY HARBOR DEEPENING PROJECT

BENTHIC RECOVERY REPORT

Contract Areas:
S-AK-2 and S-AK-3







FINAL REPORT
March 2017

Benthic Recovery Monitoring Report

Contract Areas: S-AK-2 and S-AK-3

Prepared for the:

United States Army Corps of Engineers - New York District

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) in partnership with the Port Authority of New York and New Jersey (PANYNJ) ("Port") is responsible for providing, commerce, and maintaining navigable waterways while maintaining the natural resources of the NY/NJ Harbor. 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 the NY/NJ Harbor. To meet current and anticipated shipping needs, including increased containerization using larger Post-Panamax shipping vessels, these existing navigation channels have recently been deepened as part of the Harbor Deepening Project (HDP), a multi-year Federal navigation program, 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 included the deepening of portions of the Ambrose (AM) Channel (from the Narrows to Port Jersey Channel), the Anchorage (AN) Channel (from the Narrows to Port Jersey Channel), the Kill Van Kull (KVK) Channel, Newark Bay (NB) Channel, the Arthur Kill (AK) Channel, and the Port Jersey (PJ) Channel.

The impacts of navigation channel dredging on benthic macroinvertebrate and finfish communities inhabiting and using the channels have been monitored by USACE-NYD in compliance with the Coastal Zone Management Act (CZMA). This report presents the results of pre-construction conditions in 2005 and the post-construction benthic macroinvertebrate community surveys conducted in 2016 within the following completed HDP contract areas: S-AK-2 and S-AK-3.

Benthic sampling was conducted approximately 38 and 20 months following completion of dredging in Contract Areas S-AK-3 and S-AK-2, respectively (Table 1). The benthic results can be used to document the Harbor's benthic community after channel deepening and provides a general timescale for benthic re-colonization. This report is the fourth in a series of benthic recovery reports that have been completed throughout the duration of HDP dredging as Contract Areas are completed (see also USACE 2011, USACE 2013, and USACE 2014).

Background

The benthic community in the Harbor consists of a wide variety of aquatic invertebrates which live burrowed into or in contact with the bottom, such as worms, mollusks, and amphipods (Pearce 1974, USACE 2006, USACE 2011, USACE 2013, USACE 2014). Benthic invertebrate communities 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 macroinvertebrates 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 decrease) 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 altered or disturbed, the community may re-colonize through natural succession to pre-disturbed 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). Dernie *et al.* 2003 found that clean sand communities had the most rapid recovery rate following disturbance, whereas communities from muddy sand habitats had the slowest physical and biological recovery rates.

Previous Benthic Invertebrate Sampling

Pre-construction benthic samples for the HDP were collected from navigation channel locations throughout the Harbor in July of 2005 (USACE 2006). The 2005 HDP sample locations were selected based primarily on sediment types, rather than by HDP Contract Area, to sample the entire harborwide complex. Previous benthic recovery reports in this series used the 2005 HDP data as a baseline to assess benthic recovery after HDP construction was completed in each Contract Area. However, there were no 2005 HDP pre-construction benthic sampling stations located in the S-AK-2 or S-AK-3 Contract Areas that could be used as a baseline in this study. Therefore, other surveys that provided benthic invertebrate information within or near the S-AK-2 or S-AK-3 Contract Areas were evaluated including the New York and New Jersey Harbor Navigation Study Biological Monitoring Report (USACE 1999) and the Post - Construction Assessment for the Arthur Kill Channel – Howland Hook Terminal 40 – 41 foot Deepening Project (USACE 2007).

Two locations were sampled in 1998-99 (identified as HW 6 in and HW 7), one in Contract Area S-AK-2 and the other in S-AK-3 (species and numbers of benthic invertebrates collected are available by location and month sampled in November 1998 and February, May, and August 1999). However, this data represents a benthic community that was present over 15 years earlier and is briefly discussed in this report. The Arthur Kill Channel – Howland Hook Terminal 40 – 41 foot Deepening Project (USACE 2007) data was collected in 2005 during the same time period as the HDP pre-construction data (USACE 2006) and therefore was used in this report as the baseline for primary comparison to the 2016 benthic recovery data collected in the S-AK-2 and S-AK-3 Contract Areas. USACE (2007) included benthic sampling at two sampling grids (Reach 1 and 1A) with 18 stations that were sampled in each grid during July and October 2005. The sampling methods and analysis were similar to the methods used in 2016. None of the 36 stations sampled in 2005 were in Contract Area S-AK-3 and four stations (7B, 7C, 8B, and 8C) in Reach IA were located at the eastern end of Contract Area S-AK-2 near stations SAK2-1 and SAK2-2 that were sampled in 2016 (Figure 1).

METHODS

In May 2016, benthic samples were collected from navigation channel locations within each of the most recently completed HDP Contract Areas and compared with 2005 stations located within or nearest to the Contract Areas (Table 2). When available, the 2005 pre-construction channel sampling locations were selected and re-sampled, otherwise 2016 stations were chosen based on sediment type and location within the Contract Areas to distribute samples over the existing habitats in the Contract Area and sample as diverse an area as possible.

Two stations sampled in 2016 (SAK2-1 and SAK2-2) represented stations that were sampled previously in 2005. The remaining 8 stations (3 in S-AK-2 and 5 in S-AK-3) were spaced to cover the various sediment types identified in the Contract Areas (Figures 1 and 2). Sediment data provided in the USACE – New York District Public Notice FP63-SAK2-2011 were used to select these 8 stations.

Sample Collection

Pre- (2005) and post-construction (2016) benthic samples were collected using a 0.1 m^2 Smith-McIntyre Grab. In 2016, 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 grain 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 facilitate 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 and enumerated. Identifications were made to the lowest practical identification level (LPIL) 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 Diversity Index, and Pielou's Evenness. 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. Average density was also calculated for each Contract Area (e.g. Arthur Kill Channel S-AK-2) 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. Since the 2005 surveys, benthic macroinvertebrate nomenclature and taxonomic changes have occurred, and all changes are used in this report. 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.

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:

[1] The following taxonomic nomenclature changes have been incorporated into USACE 2013, USACE 2014 and this report, respectively: *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 USACE (2011) containing 2005 and 2009 data.

[2] For the Harborwide Benthic Report describing the 2005 sampling results (USACE 2006), the Shannon-Wiener Diversity Index was calculated using Log base 10 (Log10). To remain current with existing benthic community literature, the 2005 and 2016 diversity in this report was calculated using the natural log (Ln).

$$J' = \frac{H'}{H'_{max}}$$

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}= Ln*S*).

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 among 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*.

RESULTS

Previous Arthur Kill Channel Surveys

1998-1999 Samples (USACE 1999)

The Arthur Kill Channel – Howland Hook Terminal 40' – 41' foot Deepening Project included dredging in the S-AK-2 and S-AK-3 Contract Areas prior to 2005. Pre-dredge samples included seasonal benthic grab samples at pre-construction Station HW-6 in clay and sand with some rock that were collected in the S-AK-2 Contract Area during 1998 and 1999. Benthic grab samples were also collected at Station HW-7 in clay and sand with some rock in the S-AK-3 Contract Area during 1998 and 1999 (USACE 1999). These samples were collected nearly 13 years pre-construction and they were composed primarily of the ubiquitous polychaete *Streblospio benedicti* followed by polychaetes in the family Ampharetidae, *Scoloplos fragilis*, family Phyllodocidae, and family Paraonidae; with a small component of amphipods (*Leucon americanus* and *Ampelisca abdita*) and mollusks (*Mulinina lateralis* and *Mya arenaria*). A total of 20 taxa were distributed among three primary phyla: annelids (69% of the total), arthropods (18%), and mollusks (8%).

2005 Samples (USACE 2007)

Four station locations were in the S-AK-2 Contract Area: 7B, 7C, 8B, and 8C. Stations 7B and 7C were approximately 30% mud and 30% coarse sand with the remainder very fine to medium sand and little gravel (USACE 2007). Station 8B was approximately 32% gravel, 18% mud, with the remainder mostly composed of very fine to coarse sands; while station 8C was approximately 42% gravel with very little mud and the remainder mostly composed of fine to very coarse sands. An average benthic community density of 5,570 organisms/m^2 was calculated from four grab samples distributed within the east end of the S-AK-2 Contract Area in 2005 (pre-construction), comprising a total of 21 taxa (Table 3). These taxa, excluding nematodes, consisted of 12 annelids (60% of the total), five arthropods (25%), and 3 mollusks (15%) (Table 5).

The majority of the individuals collected in 2005 were nematodes (average density of 3,605 organisms/m^2), followed by the polychaetes *Pectinaria gouldii* (530 organisms/m^2) and

Scoloplos fragilis (388 organisms/m^2). An acorn barnacle, *Semibalanus balanoides* (288 organisms/m^2) and Oligochaetes in the family Enchytraeidae (228 organisms/m^2) were also common (Table 3). Other common species included the polychaetes *Eteone lactea*, *Glycinde solitaria*, *Nephtys picta*, and *Sabellaria vulgaris* and the cyclopoid copepod *Halicyclops magniceps*. Of these four stations, 8B had the greatest number of non-nematode individuals, the second highest species density, and the highest species richness and diversity (Tables 3 and 6).

Diversity within the Contract Area ranged from 0.49 to 1.91 with an overall total diversity of 1.41; while evenness within the Contract Area ranged from 0.19 to 0.67 with an overall total evenness of 0.46 (Table 6). The percentage of the total 2005 assemblage consisting of pollution tolerant taxa was 15% compared to the percentage of pollution sensitive taxa which was 0.05% (Table 6).

2016 Arthur Kill Channel (S-AK-2) Survey

Five stations were sampled in the S-AK-2 Contract Area in 2016 (Figure 1). These post-construction samples were composed primarily of mud (silt and clay), while one sample (SAK2-5) had a sand component (Table 7). An average benthic community density of 2,890 organisms/m^2 was calculated from these five grab samples distributed within the S-AK-2 Contract Area, comprising a total of 25 taxa (Table 6). These taxa were distributed among three primary phyla; the relative richness and density of organisms collected among all samples consisted of 10 annelids (40% of the total), 7 arthropods (28%), and 8 mollusks (32%) (Table 5).

Across the five stations, the average station density ranged from 410 to 10,200 organisms/m^2 and the species richness ranged from 9 to 15 taxa (Table 6). Oligochaetes (phylum Annelida) (1,686 organisms/m^2) were the most abundant taxa, accounting for 58% of the total benthic organisms collected in the Contract Area (Table 4). The dwarf surfclam (*Mulinia lateralis*) (495 organisms/m^2) was the second most abundant species accounting for 17% of the total benthic organisms collected, followed by the bubble snail *Acteocina canaliculata* (211 organisms/m^2) which accounted for 7% of the total. Four species accounted for 11% of the total. They included two polychaetes, *Nephtys incisa* (108 organisms/m^2) and *Pectinaria gouldii* (106 organisms/m^2);

a tube-dwelling amphipod (Ampeliscidae; 70 organisms/m^2); and a spoon clam *Yoldia limatula* (44 organisms/m^2).

Diversity within the Contract Area ranged from 0.77 to 2.18 with an overall total diversity of 0.98 and evenness ranged from 0.35 to 0.80 with an overall total evenness of 0.30 (Table 6). The percentage of the total 2016 assemblage consisting of pollution tolerant taxa was 55% compared to the percentage of pollution sensitive taxa of 6% (Table 6).

2016 Arthur Kill Channel (S-AK-3) Survey

Five stations were sampled in the S-AK-3 Contract Area in 2016 (Figure 2). These post-construction samples were composed primarily of mud (silt and clay), while one sample (SAK3-5) had a coarse sand component (Table 7). An average benthic community density of 1,040 organisms/m^2 was calculated from five grab samples distributed within the S-AK-3 Contract Area in 2016 (post-construction), comprising a total of 27 taxa (Table 6). These taxa were distributed among three primary phyla; the relative richness and density of organisms collected among all samples consisted of 13 annelids (48%), 4 arthropods (15%), and 10 mollusks (37%) (Table 5).

Across the five stations, the average station density ranged from 520 to 1,880 organisms/m^2 and the species richness ranged from 7 to 15 taxa (Table 6). The dwarf surfclam (*Mulinia lateralis*) (604 organisms/m^2) was the most abundant taxa, accounting for 58% of the total benthic organisms collected in the Contract Area (Table 4). The bubble snail *Acteocina canaliculata* (85 organisms/m^2) was the second most abundant species accounting for 8% of the total, followed by the soft-shell clam *Mya arenaria* (66 organisms/m^2) which accounted for 6% of the total. The fourth most abundant species was the New England dog whelk *Nassarius trivitatus* (62 organisms/m^2) which accounted for 6% of the total. Four species accounted for approximately 10% of the total, they included the polychaete *Pectinaria gouldii* (31 organisms/m^2), a polychaete in the Family Orbiniidae (28 organisms/m^2), the pitted baby-bubble snail *Rictaxis punctostriatus* (23 organisms/m^2) and another polychaete *Nephtys incise* (17 organisms/m^2) (Table 4).

Diversity within the Contract Area ranged from 0.88 to 1.86 with an overall total diversity of 1.47 and evenness ranged from 0.38 to 0.69 with an overall total evenness of 0.46 (Table 6). The percentage of the total 2016 assemblage consisting of pollution tolerant taxa was 46% compared to the percentage of pollution sensitive taxa of 12% (Table 6).

DISCUSSION

The benthic community in the NY/NJ 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 by invasions of species in existing nearby/adjacent communities (expedited via tidal transport) to pre-disturbance conditions depending on the similarity of the remaining / modified habitat to the disturbed habitat (habitat suitability). 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). Dernie et al. 2003 found that clean sand communities had the most rapid recovery rate following disturbance, whereas communities from muddy sand habitats had the slowest physical and biological recovery rates. 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).

Newell *et al.* (1998) provides a potential description of 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. polychaetes of the family 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 the Atlantic nutclam (*Nucula proxima*), 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 the previous benthic recovery survey (USACE 2013, USACE 2014). 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 majority of species identified in grab samples collected during the 2005 (pre-construction) and 2016 (post-construction) benthic macroinvertebrate 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.* 2000, Gandarillas and Brinkhuis 1981). USACE (2007) found shifts in species and densities within the same sampling grids between samples collected in July 2005 compared to October 2005. Seasonal shifts in species and densities were also found in seasonal collections at two locations within the S-AK-2 and S-AK-3 Contract Areas from 1998 to 1999 (USACE 1999). Therefore, differences in species, densities, and distribution may occur naturally in relatively small areas and it would be anticipated that greater difference could be expected over large areas.

During this study, benthic sampling was conducted approximately 20 to 38 months following the completion of HDP dredging in Contract Areas S-AK-2 and S-AK-3, respectively (Table 1). Benthic community recovery was assessed through density, taxa richness, Shannon-Wiener's diversity index, and Pielou's Evenness from data within the completed HDP Contract Areas: S-AK-2 and S-AK-3. Figures 3 through 7 illustrate summaries of calculated indices in each Contract Area sampled for both the 2005 and 2016 sampling efforts.

Arthur Kill Channel (S-AK-2) Summary

Benthic macroinvertebrate sampling occurred approximately 38 months post HDP construction in the S-AK-2 Contract Area. Overall, average benthic macroinvertebrate density decreased from 5,570 organisms/m^2 in 2005 to 2,890 organisms/m^2 in 2016 (Figure 3), while species richness increased from 21 species in 2005 to 25 species in 2016 (Table 6). Community diversity (Figure 4) and evenness (Figure 5) dropped from 1.41 and 0.46, respectively in 2005 to 0.98 and 0.30 in 2016, suggesting that although the total number of taxa within the study area had increased not all of the benthic community indices had fully recovered to the 2005 condition. These results were consistent with previous sampling efforts in other similar high energy and high flow channel areas such as S-AK-1 (USACE 2014) and S-KVK-2 (USACE 2011). In the nearby S-AK-1 Contract Area, for example, which was sampled in 2013 approximately five months after the completion of HDP dredging, results showed an increase in the number of taxa from 12 in 2005 to 19 in 2013 but a decrease in average density similar to S-AK-2. In S-AK-1, however, diversity and evenness did improve as a result of the increased number of taxa collected, unlike S-AK-2.

In 2005, nematodes were the dominant organisms collected from all four stations located in S-AK-2. Nematode density was 3,605 organisms/m^2 in 2005, however no nematodes were collected in 2016. In 2016, pollution tolerant oligochaetes were the dominant species at SAK-2-2 (8,400 organisms/m^2); while few to none were collected at the other four stations (Table 4). In 2016, the dwarf surfclam (*Mulinia lateralis*) a pollution tolerant mollusk and the bubble snail (*Acteocina canaliculata*) were common to abundant in the S-AK-2 Contract Area; few bivalve mollusks were collected in 2005. Polychaetes were well represented in both 2005 and 2016;

Scolopus fragilis was the dominant polychaete species in 2005 compared to 2016 when *Nephtys incisa* and *Pectinaria gouldii* were co-dominant polychaetes. Arthropods densities were similar in both 2005 and 2016; the acorn barnacle *Semibalanus balanoides* and the cyclopoid copepod *Halicyclops magniceps* were common in 2005 and a tube-dwelling amphipod (in the family Ampeliscidae) was common in 2016.

In May 1999, taxa richness was 16 and average station density was 480 organisms/m^2 at Station HW-6 in the S-AK-2 Contract Area (USACE 1999 Table F1-6), which was similar to 2005 results and lower than that observed in 2016. The percentage of the total 2016 assemblage consisting of pollution tolerant taxa was 55% which was much higher than observed in 2005 (15%) (Figure 6) and due primarily to a high density of Oligochaetes at one station (SAK-2-2) and high densities of the *Mulinia lateralis* at stations SAK-2-1, 2, 3, and 4 (Table 4). However, an increase in the percentage of pollution sensitive taxa from <0.1% in 2005 to more than 6% in 2016 (Figure 7) suggests that overall benthic habitat conditions may be improving within the Contract Area.

Arthur Kill Channel (S-AK-3) Summary

Benthic macroinvertebrate sampling occurred approximately 20 months post HDP construction in the S-AK-3 Contract Area. Overall, average benthic macroinvertebrate density decreased from 5,570 organisms/m^2 in 2005 to 1,040 organisms/m^2 in 2016 (Figure 3), while species richness increased from 21 species in 2005 to 27 species in 2016 (Table 6). Community diversity increased from 1.41 in 2005 to 1.47 in 2016 (Figure 4) and evenness was unchanged from 2005 to 2016 at 0.46 (Figure 5), suggesting that although benthic macroinvertebrate density had decreased, overall benthic community indices within the Contract Area had recovered to the 2005 condition.

Nematodes were dominant in 2005 samples from the S-AK-2 Contract Area and accounted for 3,605 organisms/m^2 in 2005; however, no nematodes were collected in 2016. In 2016, the dwarf surfclam (*Mulinia lateralis*) a pollution tolerant mollusk and the bubble snail *Acteocina canaliculata* were abundant in the S-AK-3 Contract Area, whereas few bivalve mollusks were collected in the 2005 study area. Polychaetes were well represented in both 2005 and 2016; *Scolopus fragilis* was the dominant polychaete species in 2005 compared to 2016 when *Nephtys incisa* and *Pectinaria gouldii* were co-dominant. Arthropod densities were similar in both 2005 and 2016; the acorn barnacle *Semibalanus balanoides* and the cyclopoid copepod *Halicyclops magniceps* were common in 2005 and a tube-dwelling amphipod (in the family Ampeliscidae) was common in 2016.

In May 1999, taxa richness was 13 and average density was 590 organisms/m^2 at Station HW-7 in the S-AK-3 Contract Area (USACE 1999 Table F1-7) which was lower than that observed in 2016. The percentage of the total 2016 assemblage consisting of pollution tolerant taxa was 46% which was much higher than found in the S-AK-2 Contract Area in 2005 (15%) and this was due primarily to high densities of the *Mulinia lateralis* in the S-AK-3 Contract Area in 2016 (Table 4 and Figure 6). However, an increase in the percentage of pollution sensitive taxa from <0.1% in 2005 to almost 12% in 2016 (Figure 7) suggests that overall benthic habitat conditions may be improving within the Contract Area.

LITERATURE CITED

Adams, D.A., J.S. O'Connor, and S.B. Weisberg. 1998. Sediment Quality of the NY/NJ Harbor System. U. S. Environmental Protection Agency, Report No. 902-R-98-001.

Barry A. Vittor & Associates, Inc. (BVA). 1998. Hudson/Raritan Bay Estuary Benthic Community Assessment. Prepared for US Department of Commerce – NOAA.

Becker, D.S., G.R. Bilyard, and T.C. Ginn. 1990. Comparisons between sediment bioassays and alterations of benthic macro-invertebrate assemblages at a marine Superfund site: Commencement Bay, Washington. Environmental Toxicology and Chemistry 9:669-685.

Blake, N.J., L.J. Doyle, and J.J. Culter. 1996. Impacts and direct effects of sand dredging for beach renourishment on the benthic organisms and geology of the west Florida shelf. Prepared for U.S. Dept. of Interior, Minerals Management Service, Office of International Activities and Marine Minerals (INTERMAR). OCS Report MMS 95-0005.

Cerrato, R.M., H.J. Bokuniewicz, and M.H. Wiggins. 1989. A Spatial and Seasonal Study of the Benthic Fauna of Lower Bay of New York Harbor. Special Report 84. Marine Science Research Center, State University of New York, Stony Brook, NY.

Cristini, A. 1991. Synthesis of Information on the Distribution of Benthic Invertebrates in the Hudson/Raritan System. Final Report. Ramapo College of New Jersey, Mahwah, NJ.

Dauer, D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. Marine Pollution Bulletin 26:149–157.

Dean D. 1975. Raritan Bay Macrobenthos Survey, 1957-1960. Data Report 99. National Marine Fisheries Service (NMFS), Seattle, WA.

Dernie, K.M., M.J. Kaiser and R.M. Warwick. 2003. Recovery rates of benthic communities following physical disturbance. Journal of Animal Ecology 72:1043–1056.

Gandarillas, F.E. and B.H. Brinkhuis. 1981. Benthic Faunal Assemblages in the Lower Bay of New York Harbor. Marine Sciences Research Center, State University of New York. Stony Brook, New York.

Gray, J.S. and M. Elliott. 2009. Ecology of Marine Sediments: From Science to Management. OUP, Oxford, 225 pp.

Iocco, L.E., P. Wilber, R.J. Diaz, D.G. Clarke, and R.J. Will. 2000. Benthic Habitats of New York/New Jersey Harbor: 1995 Survey of Jamaica, Upper, Newark, Bowery and Flushing Bays. Prepared for NOAA, USACE-NY District, and the states of New York and New Jersey.

Levinton, J.S. 1982. Marine Ecology. Prentice-Hall Publ. Co. Englewood Cliffs, NJ, 526 pp.

Llansó, R.J., L.C. Scott, J.L. Hyland, D.M. Dauer, D.E. Russell, and F.W. Kutz. 2002. An estuarine benthic index of biotic integrity for the mid-Atlantic region of the United States. II. Index development. Estuaries 25:1231-1242.

Morin, P. J. 1999. Community Ecology. Blackwell Science, Inc. Malden, MA. 424 pp.

Newell, R.C., L.J. Seiderer, and D.R. Hitchcock. 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Annual Reviews in Oceanography and Marine Biology 36:127-178.

Pearce, B. 1974. Invertebrates of the Hudson River Estuary. Hudson River Colloquium, Annals of the New York Academy of Sciences 250 pp. 137-143.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review 16:229–311.

Santos, S. L., and J. L. Simon. 1980. Marine soft-bottom community establishment following annual defaunation: Larval or adult recruitment. Marine Ecology Progress Series 2: 235–241.

Schaffner, L.C., C.H. Hobbs, and M.A. Horvath. 1996. Effects of Sand-Mining on Benthic Communities and Resource Value: Thimble Shoal, Lower Chesapeake Bay. Technical Report, Virginia Institute of Marine Science, Gloucester Point, VA.

Tsutsumi, H. 1987. Population dynamics of *Capitella capitata* (Polychaeta; Capitellidae) in an organically polluted cove. Marine Ecology Progress Series 36: 139-149.

United States Army Corps of Engineers (USACE).1999. Biological Monitoring Program for the New York and New Jersey Harbor Navigation Study Final Report. U.S. Army Corps of Engineers – New York District, New York, NY.

United States Army Corps of Engineers (USACE). 2006. Harborwide Benthic Monitoring Program. Final Report. U.S. Army Corps of Engineers – New York District, New York, NY.

United States Army Corps of Engineers (USACE). 2007. Post-Construction Assessment Arthur Kill Channel – Howland Hook Terminal 40' – 41' Deepening Project. Final Report. U.S. Army Corps of Engineers – New York District, New York, NY.

United States Army Corps of Engineers (USACE). 2008. Dredged Material Management Plan for the Port of New York and New Jersey: Update - Volume 1. U.S. Army Corps of Engineers, New York District, New York, NY.

United States Army Corps of Engineers (USACE). 2010. New York & New Jersey Harbor (50 ft. Deepening) Navigation Project Public Notice. Available at: http://www.nan.usace.army.mil/project/newjers/factsh/pdf/nynj.pdf

United State Army Corps of Engineers (USACE). 2011. Benthic Recovery Monitoring Report: Contract Areas S-AM-1, S-AN-1a, and S-KVK-2. U.S. Army Corps of Engineers – New York District, New York, NY.

United States Army Corps of Engineers (USACE). 2013. Benthic Recovery Monitoring Report: Contract Areas S-AN-2, S-AN-1b, S-E-1, and S-NB-1. U.S. Army Corps of Engineers – New York District, New York, NY.

United States Army Corps of Engineers (USACE). 2014. Benthic Recovery Monitoring Report: Contract Areas S-KVK-1, S-NB-2/S-AK-1, S-AM-2(a&b), and S-AM-3(a&b). U.S. Army Corps of Engineers – New York District, New York, NY.

United States Environmental Protection Agency (USEPA). 2009. Biological Indicators of Watershed Health - Invertebrates as Indicators. Friday, December 04, 2009. Available at: http://www.epa.gov/bioindicators/html/invertebrate.html.

Van Dolah, R.F., P.H. Wendt, R.M. Martore, M.V. Levisen, and W.A. Roumillat. 1992. A Physical and Biological Monitoring Study of the Hilton Head Beach Nourishment Project. Final Report to Town of Hilton Head, SC and the South Carolina Coastal Council.

Van Dolah, R.F., R.M. Martore, A.E. Lynch, M.V. Levisen, P.H. Wendt, D.J. Whitaker, and W.D. Anderson. 1994. Environmental Evaluation of the Folly Beach Nourishment Project. Final Report to U.S. Army Corps of Engineers, Charleston District, Charleston, SC.

Washington, H.G. 1984. Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. Water Research 18:653-694.

Watson D.I. and D.K.A. Barnes. 2004. Quantifying Assemblage Distinctness With Time: An Example Using Temperate Epibenthos. Journal of Experimental Marine Biology & Ecology 312: 367-383.

Weiss, H.M. 1995. Marine animals of southern New England and New York: Identification keys to common nearshore and shallow water macrofauna. State Geological and Natural History Survey of Connecticut. Department of Environmental Protection Maps and Publications Office. Hartford, CT.

Wilber, P. and M. Stern. 1992. A re-examination of infaunal studies that accompany beach nourishment projects. pp. 242-257 in: New Directions in Beach Management: Proceedings of the 5th Annual National Conference on Beach Preservation Technology, St. Petersburg, FL, February 12-14, 1992. Florida Shore and Beach Preservation Association, Tallahassee, FL.

Wildish, D. and D. Kristmanson. 1997. Benthic Suspension Feeders and Flow. Cambridge University Press. New York.

Wolff, W.J. 1983. Estuarine Benthos. in: Ketchum, B.H. (ed.). Estuaries and Enclosed Seas. Elsevier, Amsterdam. pp. 151-182.

Zajac, R.N., and R.B. Whitlatch. 1982. Responses of estuarine infauna to disturbance. I. Spatial and temporal variation of initial recolonization. Marine Ecology – Progress Series 10:1-14.

TABLES & FIGURES

Table 1. Dredging events within Contract Areas sampled in 2016.

Contract Area	Channel	Completion Dates of HDP Dredging	Benthic Recovery Period
S-AK-2	Arthur Kill	Work started 14 DEC, 2011 and was completed 5 MAR 2013.	38 Months
S-AK-3	Arthur Kill	Work started 21 MAR 2013 and was completed 25 SEP 2014.	20 Months

**Source: Provided by USACE-NYD.*

Table 2. Pre and post-deepening sampling stations representative of Contract Areas.

Contract Area	Channel	2005 Stations	2016 Stations
S-AK-2	Arthur Kill	7B, 7C, 8B, 8C	SAK2-1, SAK2-2, SAK2-3, SAK2-4, SAK2-5
S-AK-3	Arthur Kill	None[1]	SAK3-1, SAK3-2, SAK3-3, SAK3-4, SAK3-5

(1) Stations 7B, 7C, 8B, and 8C located in the S-AK-2 Contract Area were the nearest sampled locations in 2005 and were used as the pre-construction data for both Contract Areas.

Table 3. Benthic invertebrates collected in July 2005 within the S-AK-2 Contract Area of the Arthur Kill Navigation Channel.

	Benthic Grab Density (Organisms/m^2)				
Species	**7B**	**7C**	**8B**	**8C**	**Average Four Stations**
ANNELIDA					
Polychaeta					
Amage auricula	30	0	50	0	20
Capitella capitata	0	30	30	0	15
Eteone lactea	20	30	230	0	70
Glycinde solitaria	10	20	320	0	88
Leitoscoloplos fragilist	0	0	0	60	15
Scolopus fragilis	330	790	430	0	388
Nephtys picta	20	0	290	0	78
Nereis pelagica	0	30	10	0	10
Pectinaria gouldii	200	30	1,770	120	530
Sabellaria vulgaris	150	0	60	0	53
Streblospio benedicti	30	10	30	0	18
Oligochaeta					
Enchytraeidae LPIL	230	230	0	450	228
ARTHROPODA					
Isopoda					
Cyathura polita	0	0	10	0	3
Edotea triloba	10	10	0	0	5
Amphipoda					
Corophium tuberculatum	0	0	30	0	8
Copepoda					
Halicyclops magniceps	100	0	70	340	128
Thoracica					
Semibalanus balanoides	20	120	560	450	288
MOLLUSCA		0			
Bivalvia					
Mulinia lateralis	0	30	10	10	13
Mya arenaria	20	0	20	0	10
Gastropoda					
Crepidula formicata	0	10	0	0	3
NEMATODA LPIL	1,880	7,760	1,440	3,340	3,605
Total Macrobenthic Density	3,050	9,100	5,360	4,770	5,570
Total No. of Taxa	14	13	17	7	13

Table 4. Benthic macroinvertebrate density (organisms/m^2) by station in the Arthur Kill Channel in Contract Areas S-AK-2 and S-AK-3 During May 2016.

Phylum	Class	Order	Family	Genus	Species	SAK2-1	SAK2-2	SAK2-3	SAK2-4	SAK2-5	AVERAGE SAK2	SAK3-1	SAK3-2	SAK3-3	SAK3-4	SAK3-5	AVERAGE SAK3
Annelida	Oligochaeta	---	---	---	---	0	8,400	0	10	20	1,686	30	0	0	0	0	6
	Polychaeta	Aciculata	Hesionidae	---	---	0	0	0	0	0	0	0	10	0	20	0	6
		Ariciida	Opheliidae	---	---	0	0	0	0	0	0	0	0	0	0	40	8
			Orbiniidae	---	---	0	0	0	0	0	0	0	100	0	40	0	28
			Orbiniidae	Scoloplos	fragilis	0	0	0	0	20	4	0	0	0	0	20	4
		Canalipalpata	Spionidae	---	---	0	0	0	0	10	2	0	0	0	20	0	4
		Capitellida	Maldanidae	---	---	0	0	0	0	20	4	0	0	0	0	0	0
		Eucinida	Dorvilleidae	Schistomeringos	rudolphi	13	0	0	10	0	5	0	0	0	0	0	0
		Eunicida	Onuphidae	Diopatra	cuprea	13	0	0	0	20	7	15	10	10	0	30	13
		Phyllodocida	Glyceridae	Glycera	---	13	100	0	0	0	23	0	10	0	0	0	2
			Goniadidae	---	---	0	0	0	0	0	0	0	0	0	20	0	4
			Nephtyidae	Nephtys	incisa	38	100	260	120	20	108	45	0	30	0	10	17
			Nereidae	Nereis	---	13		80	0	0	23	15	0	10	40	0	13
			Syllidae	---	---	0	0	0	0	0	0	0	10	0	0	0	2
		Terebellida	Pectinariidae	Pectinaria	gouldii	288	0	160	50	30	106	15	50	30	40	20	31
Arthropoda	Crustacea	Amphipoda	Ampeliscidae	---	---	0	100	60	20	170	70	0	10	0	0	0	2
			Ischyroceridae	Jassa	marmorata	0	0	0	0	20	4	45	0	0	0	10	11
			Pleustidae	---	---	0	0	0	0	0	0	0	10	0	0	0	2
		Cumacea	---	---	---	0	0	0	0	10	2	0	0	0	0	0	0
		Decapoda	Crangonidae	Crangon	septemspinosa	13	0	0	0	0	3	0	0	0	0	0	0
			Xanthidae	Rhithropanopeus	harrisii	0	0	0	10	0	2	0	0	0	0	0	0
		Mysidacea	Mysidae	---	---	0	0	0	0	10	2	60	0	0	20	0	16
	Malacostraca	Decapoda	Hippidae	Emerita	talpoida	0	0	0	0	10	2	0	0	0	0	0	0
Mollusca	Bivalvia	Eudesmodontida	Lyonsiidae	Lyonsia	hyalina	25	0	40	0	0	13	0	10	0	20	60	18
		Myoida	Myidae	Mya	arenaria	0	0	0	0	0	0	0	30	0	0	300	66
		Nuculoida	Nuculanidae	Nucula	proxima	0	0	0	0	0	0	15	0	0	0	0	3
				Yoldia	---	0	0	0	0	0	0	0	10	0	0	0	2
				Yoldia	limatula	0	100	120	0	0	44	0	0	0	0	0	0
		Veneroida	Mactridae	Mulinia	lateralis	525	300	880	740	30	495	1,079	170	270	1,500	0	604
			Tellinidae	---	---	0	100	0	0	0	20	0	0	30	0	0	6
	Gastropoda	Archaeogastropoda	Naticidae	Euspira	heros	0	0	0	0	0	0	0	0	0	0	10	2
		Cephalaspidea	Acteonidae	Rictaxis	punctostriatus	0	0	40	20	10	14	105	10	0	0	0	23
			Scaphandridae	Acteocina	canaliculata	13	800	180	50	10	211	75	10	170	160	10	85
		Neogastropoda	Nassariidae	Nassarius	obsoletus	25	0	0	0	0	5	0	0	0	0	0	0
					trivittatus	13	200	0	0	0	43	0	300	0	0	10	62
Benthic Macroinvertebrate Density (organisms/m²)						988	10,200	1,820	1,030	410	2,890	1,499	750	550	1,880	520	1,040
Taxa Richness						12	9	9	9	15	11	11	15	7	10	11	11

Table 5. Taxa richness and density by station and average density by Contract Area (organisms/m^2) from samples collected in Arthur Kill Channel in Contract Areas S-AK-2 and S-AK-3 during 2005 and May 2016.

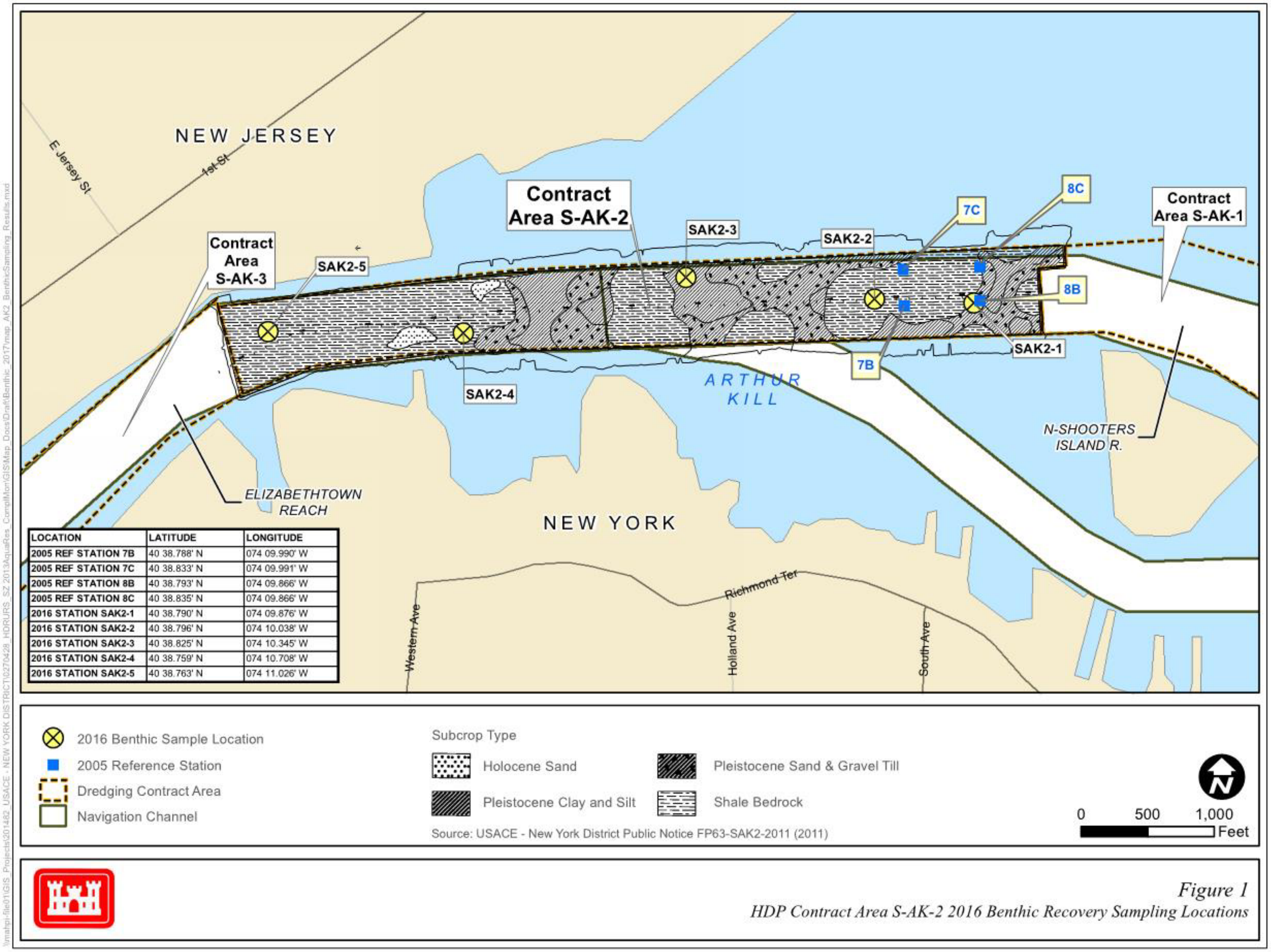
Contract Area	Sampling Year	Sample Name	Taxa Richness						Density (organisms/m²)					
			Annelida		Arthropoda		Molluska		Annelida		Arthropoda		Molluska	
			NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
S-AK-2	**2005**	7B	9	69%	3	23%	1	8%	1,020	87%	130	11%	20	2%
		7C	8	67%	2	17%	2	17%	1,170	87%	130	10%	40	3%
		8B	10	59%	4	29%	2	12%	3,220	82%	690	18%	30	1%
		8C	3	50%	2	33%	1	17%	630	44%	790	55%	10	1%
		All Reaches	**12**	**60%**	**5**	**25%**	**3**	**15%**	**1,510**	**77%**	**435**	**22%**	**30**	**1%**
S-AK-2	**2016**	SAK2-1	6	50%	1	8%	5	42%	375	38%	13	1%	600	61%
		SAK2-2	3	33%	1	11%	5	56%	8,600	84%	100	1%	1,500	15%
		SAK2-3	3	33%	1	11%	5	56%	500	27%	60	3%	1,260	69%
		SAK2-4	4	44%	2	22%	3	33%	190	18%	30	3%	810	79%
		SAK2-5	7	47%	5	33%	3	20%	140	34%	220	54%	50	12%
		SAK2	**10**	**40%**	**7**	**28%**	**8**	**32%**	**1,961**	**68%**	**85**	**3%**	**844**	**29%**
S-AK-3		SAK3-1	5	45%	2	18%	4	36%	120	8%	105	7%	1,274	85%
		SAK3-2	6	40%	2	13%	7	47%	190	25%	20	3%	540	72%
		SAK3-3	4	57%	0	0%	3	43%	80	15%	0	0%	470	85%
		SAK3-4	6	60%	1	10%	3	30%	180	10%	20	1%	1,680	89%
		SAK3-5	5	45%	1	9%	5	45%	120	23%	10	2%	390	75%
		SAK3	**13**	**48%**	**4**	**15%**	**10**	**37%**	**138**	**13%**	**31**	**3%**	**871**	**84%**

Table 6. Benthic community taxa richness, density (organisms/m2), Diversity (H'), Evenness (J'), and relative pollution sensitivity from samples collected in NY/NJ Harbor Navigation Channels from the Arthur Kill Channel in Contract Areas S-AK-2 and S-AK-3 during 2005 and May 2016.

Contract Area	Sampling Year	Sample Name	Taxa Richness	Density (organisms/m²)	Diversity (H')	Evenness (J')	Percent of Pollution Tolerant Taxa (%)	Percent of Pollution Sensitive Taxa (%)
S-AK-2	2005	**7B**	14	3,050	1.32	0.50	19%	0%
		7C	13	9,100	0.49	0.19	12%	0%
		8B	17	5,360	1.91	0.67	9%	0.2%
		8C	7	4,770	0.99	0.51	19%	0%
		All Stations	**21**	**5,570**	**1.41**	**0.46**	**15%**	**0.05%**
S-AK-2	2016	SAK2-1	12	988	1.39	0.56	53%	3%
		SAK2-2	9	10,200	0.77	0.35	85%	8%
		SAK2-3	9	1,820	1.67	0.76	48%	10%
		SAK2-4	9	1,030	1.07	0.49	73%	5%
		SAK2-5	15	410	2.18	0.80	17%	7%
		SAK2	**25**	**2,890**	**0.98**	**0.30**	**55%**	**6%**
S-AK-3		SAK3-1	11	1,499	1.17	0.49	74%	6%
		SAK3-2	15	750	1.86	0.69	23%	3%
		SAK3-3	7	550	1.33	0.69	49%	33%
		SAK3-4	10	1,880	0.88	0.38	80%	9%
		SAK3-5	11	520	1.56	0.65	4%	8%
		SAK3	**27**	**1,040**	**1.47**	**0.46**	**46%**	**12%**

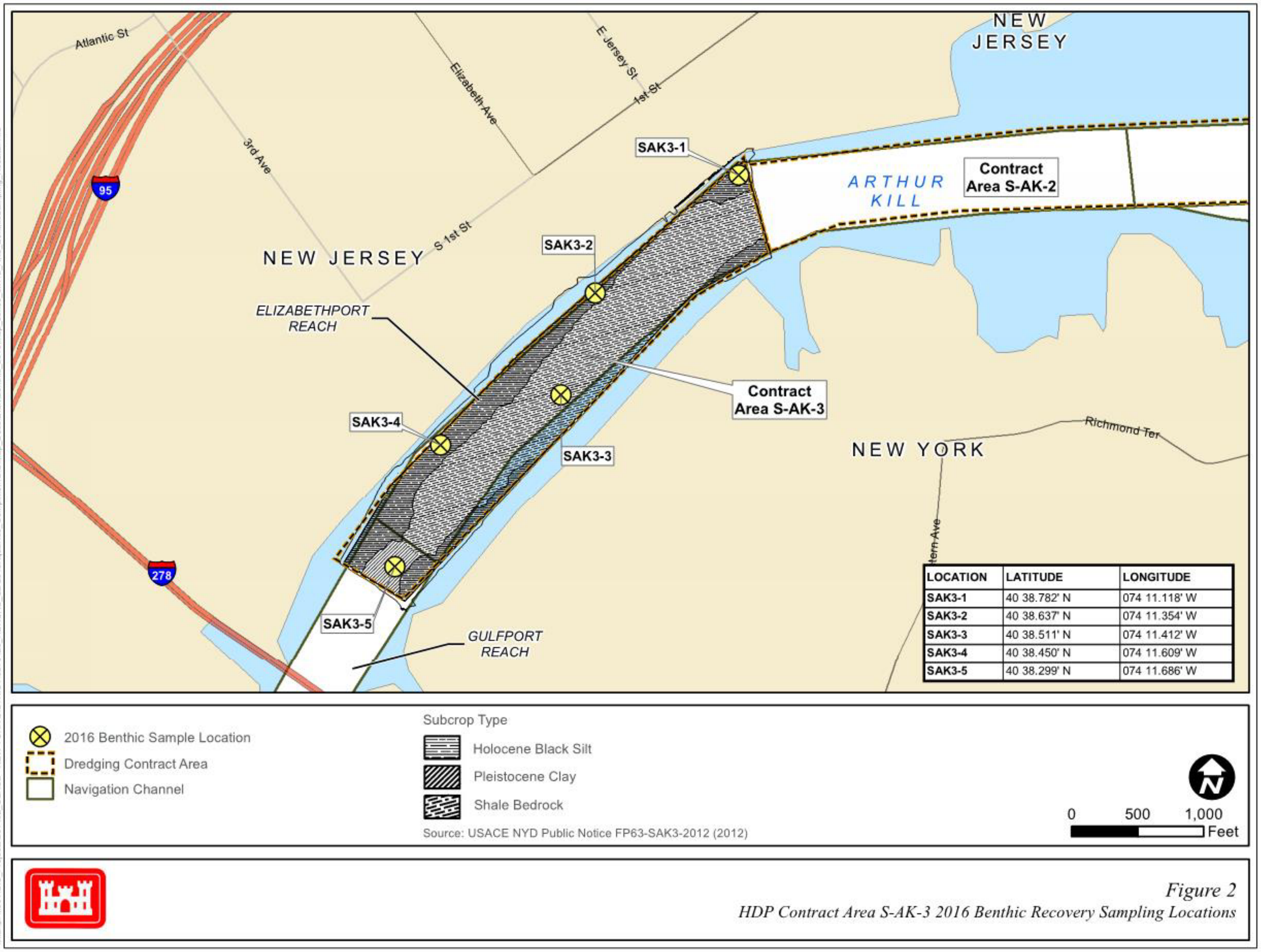
Table 7. Sediment type observed during collection of samples from NY/NJ Harbor Navigation Channel, 2016.

Contract Area	Sampling Year	Sampling Name	Sediment Type
S-AK-2	2005	7B	Muddy sand
		7C	Muddy sand
		8B	Sand and gravel with some mud
		8C	Sandy gravel
S-AK-2	2016	SAK2-1	Silt
		SAK2-2	Silt and clay
		SAK2-3	Silt
		SAK2-4	Silt
		SAK2-5	Silt, clay, and sand
S-AK-3		SAK3-1	Silt
		SAK3-2	Leaves and silt
		SAK3-3	Silt with a little clay
		SAK3-4	Silt and some clay
		SAK3-5	Silt and clay with coarser sand



LOCATION	LATITUDE	LONGITUDE
2005 REF STATION 7B	40 38.788' N	074 09.990' W
2005 REF STATION 7C	40 38.833' N	074 09.991' W
2005 REF STATION 8B	40 38.793' N	074 09.866' W
2005 REF STATION 8C	40 38.835' N	074 09.866' W
2016 STATION SAK2-1	40 38.790' N	074 09.876' W
2016 STATION SAK2-2	40 38.796' N	074 10.038' W
2016 STATION SAK2-3	40 38.825' N	074 10.345' W
2016 STATION SAK2-4	40 38.759' N	074 10.708' W
2016 STATION SAK2-5	40 38.763' N	074 11.026' W

Figure 1. HDP Contract Area S-AK-2 2016 Benthic Recovery Sampling Locations.



LOCATION	LATITUDE	LONGITUDE
SAK3-1	40 38.782' N	074 11.118' W
SAK3-2	40 38.637' N	074 11.354' W
SAK3-3	40 38.511' N	074 11.412' W
SAK3-4	40 38.450' N	074 11.609' W
SAK3-5	40 38.299' N	074 11.686' W

Figure 2. HDP Contract Area S-AK-3 2016 Benthic Recovery Sampling Locations.

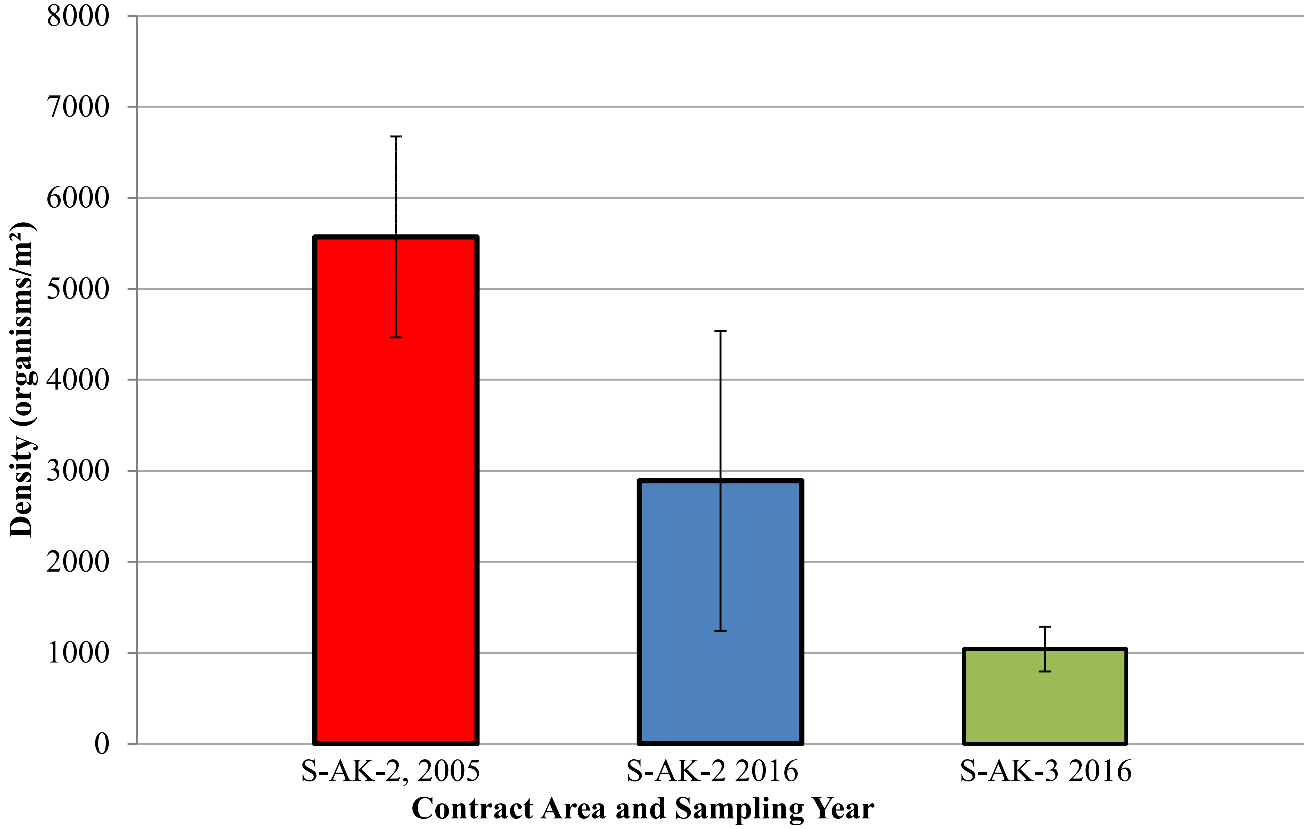


Figure 3. Benthic Macroinvertebrate Density (± 1 SE) by Contract Area and Sampling Year.

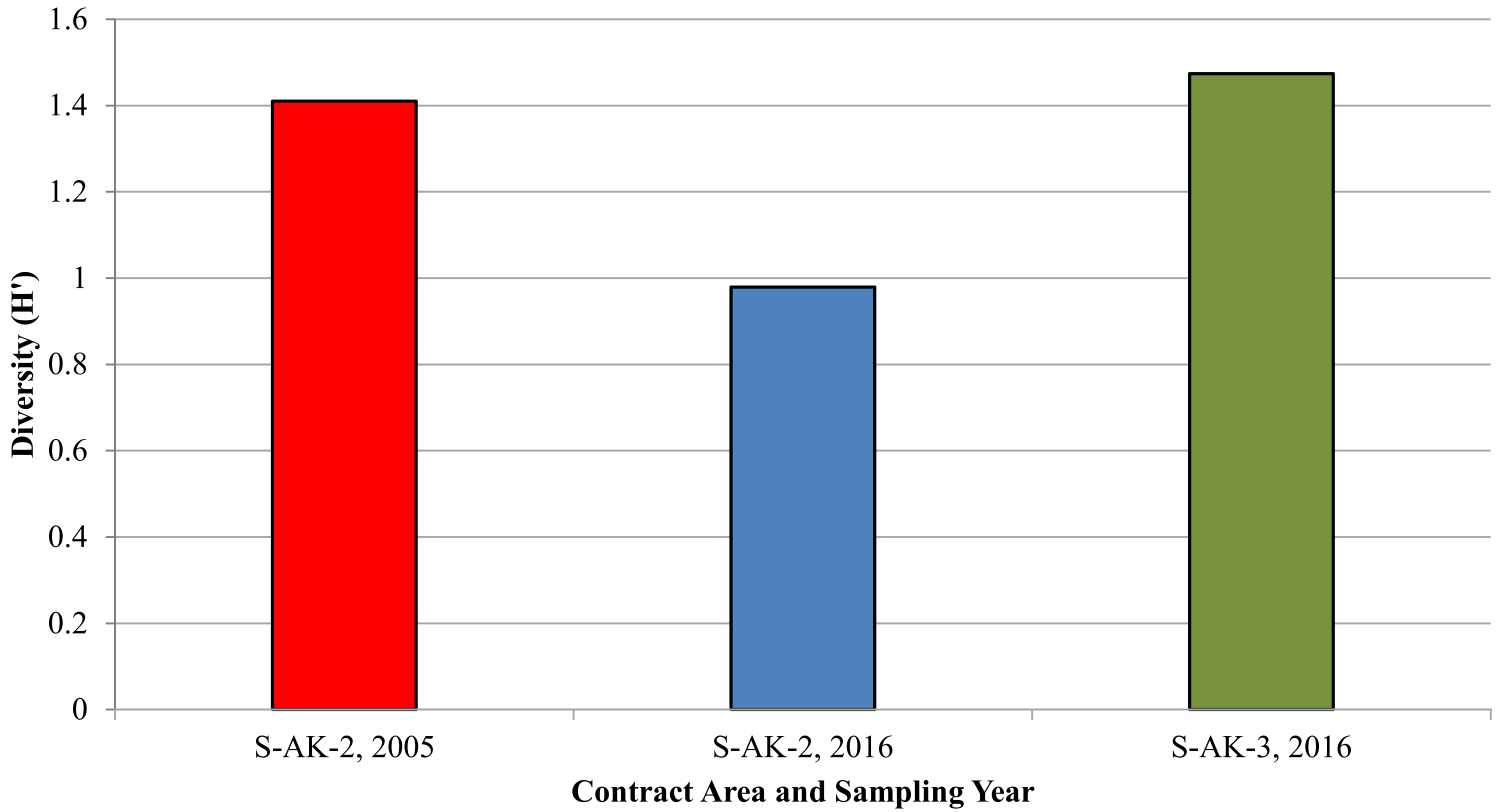


Figure 4. Benthic Macroinvertebrate Diversity by Contract Area and Sampling year.

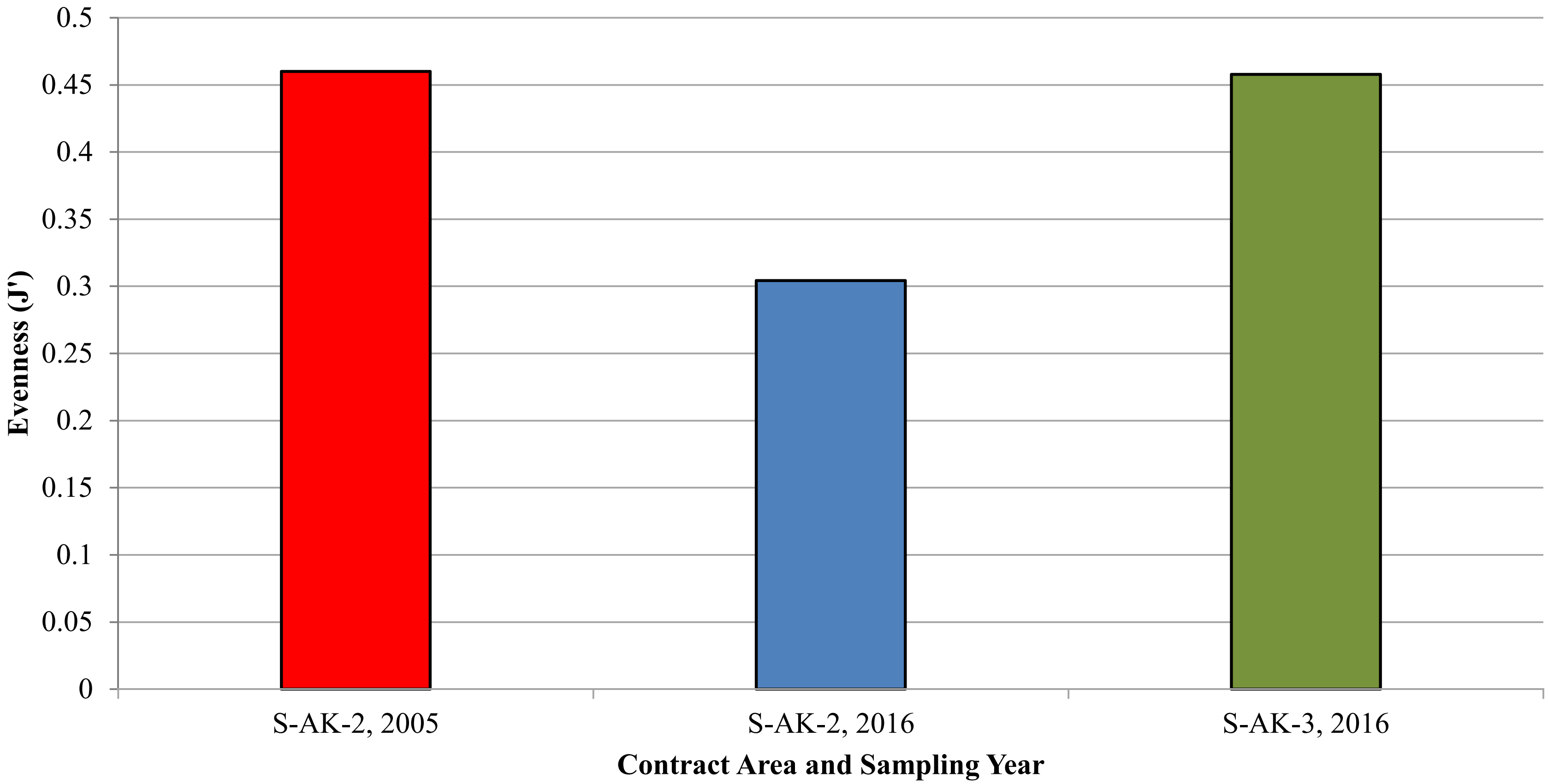


Figure 5. Benthic Macroinvertebrate Evenness by Contract Area and Sampling Year.

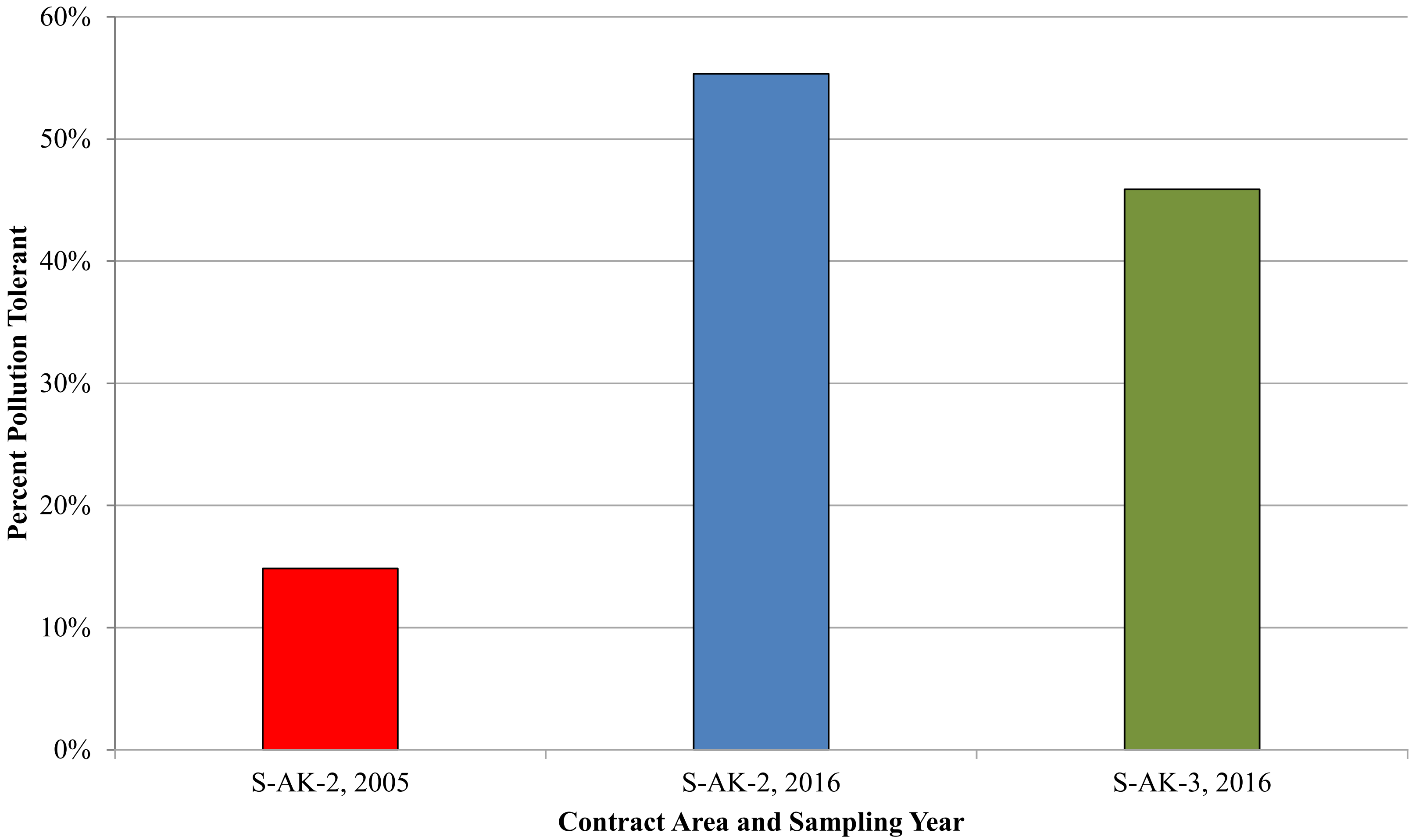


Figure 6. Percent Pollution Tolerant Species by Contract Area and Sampling Year.

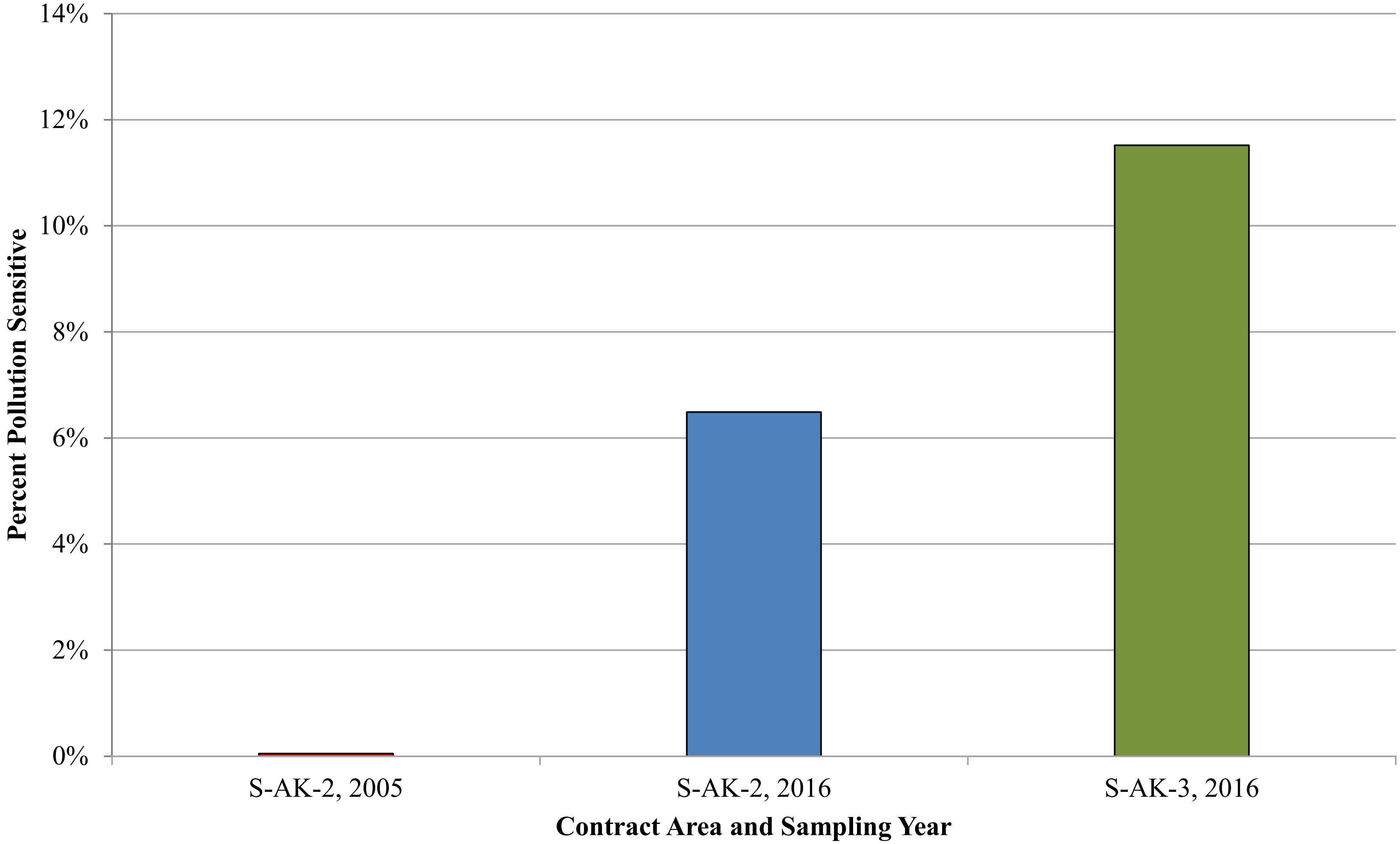


Figure 7. Percent Pollution Sensitive Species by Contract Area and Sampling Year.