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Sediments

Partnership for the DELAWARE ESTUARY

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Partnership for the Delaware Estuary—Host of the Delaware Estuary Program

5 Sediments

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5.1 Sediment Loading and Availability

Introduction

Estuaries in the Mid-Atlantic region are recognized as traps for watershed-derived sediments and it has been estimated that less than 5% of these sediments are transported to the continental shelf or deep sea (Meade 1982). The mean supply of sediment delivered to the Delaware Estuary from its watershed has been estimated to be 1–2 × 109 kg year $^{-1}$ (Mansue and Commings 1974) and is largely attributable to its three largest rivers: the Delaware River, the Schuylkill River and the Brandywine-Christina River which have mean annual discharges of 330, 77 and 19 $m^3 s^{-1}$, respectively, and together supply ~80% of the total freshwater inflow to the Delaware Estuary (Sommerfield and Wong 2011). Seasonal variations in sediment discharge to the estuary covary with freshwater inflow which peaks in March and experiences a minimum in September (Ross et al., 2015). An important feature of many estuaries, including the Delaware Estuary, is the estuarine turbidity maximum (ETM), which in the Delaware Estuary is generally located 70-115 km up-estuary (Fig 5.1.1). The ETM is a permanent feature of the Delaware Estuary and results from seaward advection of fluvial sediment combined with the landward flux of suspended sediment driven by gravitational circulation (Delaware Estuary Regional Sediment Management Plan 2013). The ETM acts as both a trap and reservoir for sediments and the total mass of sediment suspended in the water column can approach the mean annual input from the watershed (Sommerfield and Wong 2011).

Sediment plays an important role in the function of the Delaware Estuary. First, light limitation restricts phytoplankton growth despite extremely high anthropogenic nutrient inputs (Penncock 1985; McSweeney et al., 2017). Thus, reductions in turbidity could allow for an increased phytoplankton growth and enhanced vulnerability of the Estuary to anthropogenic nutrient inputs. Sediments also play an important role in the maintenance of Bay beaches and wetlands. Tidal wetlands are ecologically and economically valuable ecosystems that are threatened by climate change and their ability to adapt to rising seas is intimately tied to sediment availability (Weston 2014). Similarly, beaches are also threatened by the confluence of disruptions to sediment transport pathways and climate change. A recent study suggested that half of the world's beaches could disappear by the end of the century (Vousdoukas et al., 2020). As such, reductions in sediment inputs may compromise survival of bay beaches and wetlands. However, in the context of aquatic habitats— such as for fish and submerged aquatic vegetation— increased sediment is an ecosystem stressor.

Description of Indicator

Here, we use total suspended solids (TSS) as an indicator of water column suspended sediment concentration in the Delaware Estuary (see Boat Run data; accessible from the Delaware River Basin Commission website, also available on the Delaware Water Quality Portal). TSS refers to the dry weight of suspended particles in a sample of water that can be trapped by a filtering apparatus. TSS is comprised of both inorganic and organic material. While clear water and low TSS are generally indicative of good ecosystem health (Teodosiu et al., 2015), the decline of water column TSS may threaten the future sustainability of Delaware Bay tidal wetlands and beaches, and causes increasing phytoplankton blooms in Delaware Bay.

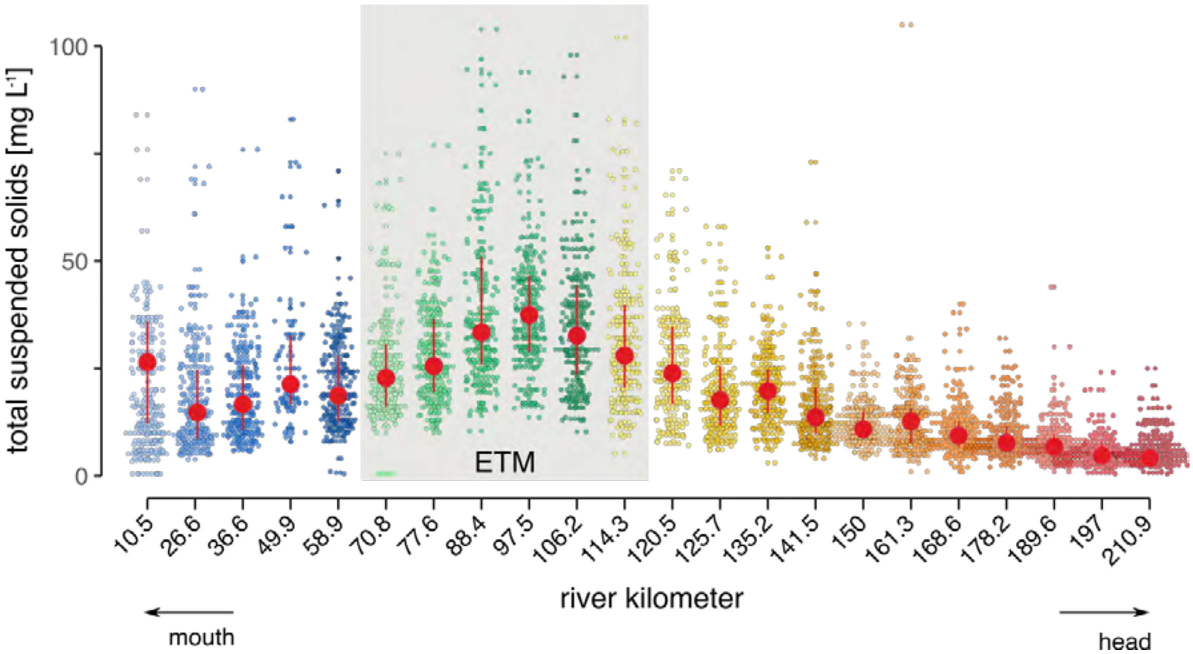

Figure 5.1.1 Spatial patterns in total suspended solids measured down the axis of Delaware Bay from 2005-2021. The estuarine turbidity maximum (ETM) is indicated at river km 70-115. Red circles denote mean at that river km, inter-quartile range is indicated by red lines. Data from DRBC 2022.

Present Status

TSS (measured from 2017-2021) varies spatially across the Delaware Estuary, from 6.33 mg L^{-1} at the most landward station monitored in the upper estuary, on the tidal Delaware River, to 8.83 mg $^{-1}$ in the most seaward station monitored where the Delaware Bay meets the ocean, with peak values at 43.0 mg L^{-1} at the estuarine turbidity maximum. The mean value measured from 2017-2021 was 19.3 mg L^{-1} (Fig 5.1.2).

Past Trends

Data suggests that suspended sediment measured as water column total suspended solids have been declining in Delaware Bay. Examination of TSS trends in stations measured from spring to fall as part of the "Boat Run" along the axis of Delaware Bay from 2005-2021 (Fig 5.1.1) suggest that suspended sediment concentration in most regions of the estuary is declining (Fig 5.1.2). On average, TSS values in 2017-2021 were found to be 16.7% lower than found in 2005-2010. Larger differences were observed at the mouth of the estuary, smaller differences were observed at the head of the estuary and minimal differences were observed at the ETM (Fig 5.1.2). This data agrees with Weston's analysis of water column suspended sediment inputs to Delaware Bay, which suggests that sediment inputs have declined from the 1950s to the present, and further that Mid-Atlantic streams are undergoing declines in suspended sediment fluxes of 2-3% year (Weston 2014). This decline in TSS may be expected based on the "cycle of urbanization" proposed by Wolman as urban development tends to result in increasing and then decreasing watershed sediment inputs (Wolman and Schick 1967). Additionally, regulations that require erosion control may be contributing to decreased sediment inputs. An additional explanation is increased accommodation space - the space available for sediment deposition - is increasing due to dredging and sea level rise. This increased accommodation space may be creating sediment sinks that lead to declines in sediment mixing over tidal cycles (Van Maren et al., 2016).

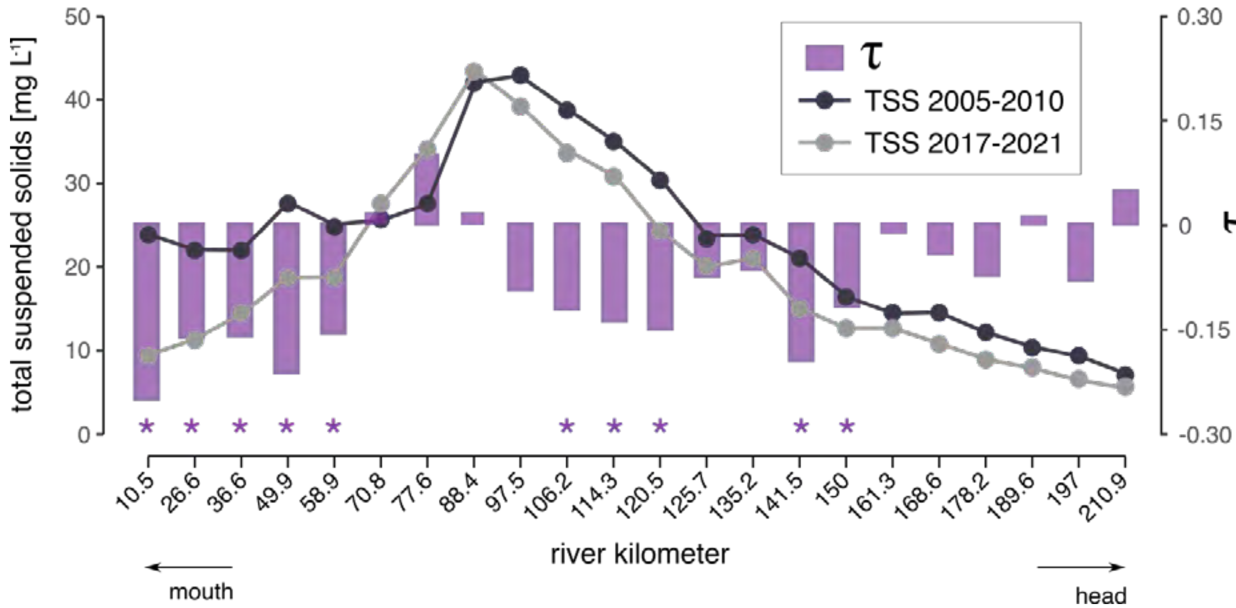

Figure 5.1.2 Differences in total suspended solids measured between 2005-2010 and 2017-2021. Generally, declines were observed between 2005 and 2021. A Mann-Kendall test was used for trend detection at each river kilometer station (R Core Team 2019; McLead 2022), where negative values for τ reflect negative trends. Statically significant trends are denoted by a star: at 17 of 22 sampling locations, TSS was lower in 2017-2021 than during 2005-2010. Negative trends were statistically significant at 10 of 17 sampling locations. No sites had statistically significant positive trends.

Future Predictions

Confounding factors may contribute to alterations in TSS trends. Increasing frequency and intensity of storms may exacerbate watershed sediment export (Chen et al. 2020). Alternatively, TSS declines may continue if watershed sediment inputs have declined due to better sediment and watershed management.

Actions and Needs

Analysis of sediment rating curves could reveal whether trends in estuarine turbidity are a function of reduced watershed inputs, altered circulation, or increased accommodation space. While Weston (2014) and Kauffman et al. (2011) have reported on trends in TSS and sediment discharge, neither have completed an analysis of sediment rating curves to detect changes in slope. An analysis of rating curves, might tell us if similar sized flow events are now carrying less sediment than in the past. Additionally, looking at trends in TSS in areas that are developing rapidly may help determine the effects of land use change on estuarine turbidity. Finally, analysis of historic satellite imagery, which dates to the 1970s, might also reveal longer term trends (or lack thereof) that are not revealed by analyzing about 15 years of sediment monitoring data.

Perspectives on Diversity, Equity, Inclusion, and Environmental Justice

Sediment inputs indirectly affect people because sustaining beaches and wetlands depend on sediment inputs and because high sediment inputs degrade quality in streams. Interactions between environmental equity and sediment are described in sections 5.3 and 4.4.

Summary

Here we assess estuarine turbidity through examination of trends in TSS from data collected from 2005-2021. These data suggest that suspended sediment concentrations in the estuary have declined 1.4% per year from 2005 to 2021. Trends in the future will depend on the interplay between increasing storm intensity which may increase suspended sediment discharge vs. improved sediment management practices which may decrease TSS. While declining turbidity may be beneficial for fish and submerged aquatic vegetation, the rapidity by which loads are declining may threaten the survival of beaches and tidal wetlands, which depend on suspended sediment to build elevation with sea level rise.

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5.2 Tidal Wetland Sediment Accumulation

Introduction

At more than 65,000 ha, tidal wetlands are a characteristic habitat of the Delaware Estuary (Haaf et al., this volume), cover about one-third of its area, and thus play an important role in coastal sediment budgets (Stammermann and Piasecki 2012). In Delaware Bay, terrestrial sediments enter the basin and accumulate in tidal wetland or open water sedimentary environments. Coastal sediment accumulation is a critical factor in determining tidal wetland survival relative to climate change. If marsh sediment accumulation rates are exceeded by that of tidal flooding increases associated with sea level, the marsh falls in elevation relative to the tides and may convert to open water (Orson et al. 1985). Conversely, if marsh sediment accumulation matches or exceeds rates of tidal flooding increases, inundation will not increase, and the marsh can survive within its existing footprint. Thus, sediment accretion is an important factor in predicting coastal habitat transitions in response to climate change (Kirwan et al. 2010).

However, the role of sediment accretion in tidal wetland survival under current and projected climate change is nuanced. First, the rate of sediment accumulation and the rate of marsh elevation change can be partially decoupled (Nolte et al. 2013). A marsh may accumulate large volumes of sediment, but still lose elevation relative to the tides due to subsurface consolidation and organic matter decomposition. In some portions of the Estuary, organic matter plays an important role in marsh accumulation (Haaf et al., 2022), so decreased vegetation health could be the driver of elevation loss or accumulation deficit. Secondly, the positive feedback between inundation and sediment accumulation means that high rates of accumulation can also be treated as a sign of a rapidly submerging marsh, rather than one that is resilient to climate change (Ganju et al. 2015). Lastly, a recent analysis of marsh elevation and habitat loss in the region suggests that higher elevation marshes are being replaced by open water even more rapidly than low elevation marshes (Elsey-Quirk et al. 2022). This suggests that high rates of sediment deposition, and high elevation, do not prevent marsh loss due to open water conversion.

A further dimension of marsh sediment accumulation focuses on the ability of tidal wetlands to sequester significant volumes of carbon and thus contribute to climate change mitigation (Drake et al. 2015). Tidal wetlands are particularly effective at doing this due to high rates of primary production, sediment deposition, and anoxic soils that limit decomposition rates, and high soil salinities that inhibit methanogenesis (Bridgham et al. 2006; Poffebarger et al. 2011). Tidal wetlands sequester more carbon than most other ecosystems including terrestrial forests (McLeod et al. 2011).

Description of Indicator

Here, we report on marsh sediment accretion and carbon accumulation as indicators of the important functions of sediment dynamics in the Delaware Estuary. Sediment accumulation is measured using the feldspar marker horizon method. A layer of feldspar, which is a dense, white-colored group of minerals that are used as flux agents in glass and ceramics industries, is laid out in a tidal marsh, and over time, soil cores are taken to assess the thickness of material that has deposited above the marker bed (Cahoon and Turner 1989). Carbon sequestration is reported as carbon accumulation measured in radiometrically dated sediment cores (^{210}Pb, ^{137}Cs) interpolated across the Delaware Estuary (Champlin et al. 2020). These rates of sediment accumulation integrate over different time intervals (yearly for marker bed; decadal for radiometric dating). While some research suggests that yearly vs. decadal measures are not directly comparable, little difference was observed for the Delaware Estuary in previous study (Champlin et al. 2020).

Sediment wetland carbon accumulation can be used to estimate the greenhouse gas mitigation function of wetlands. Here we report on sediment carbon density in tidal wetland soils, as well as estimates of the economic value of this resource using the social cost of carbon (Carr et al. 2018).

Present Status and Past Trends

Sediment accumulation rates varied throughout the Delaware Estuary, with broadly higher rates of sediment accumulation in the upper estuary, and lower rates near the mouth of the Bay (Fig 5.2.1). At some sites, sediment accretion rates were greater than rates of sea level rise, while in other locations sediment accretion rates were less than rates of sea level rise. Overall, analysis of sediment accretion data based on radiometric dating found a mean tidal wetland sediment accretion rate of 2.57 ± 2.03 kg m^{-2} yr^{1} in the Delaware Estuary (Boyd et al. 2017). Given that the Delaware Bay has 67,084 ha of tidal wetlands, this translates to a 1.7 ± 1.4 x 109 km yr^{1} of sediment deposited in tidal wetlands, which is similar to the amount of sediment delivered to the estuary from watershed sources at 1-2 x 109 kg yr^{1} (Mansue and Commings, 1974). Although it can be expected that there are other sediment sinks in the estuary, the high uncertainty in inputs and deposition rates makes it difficult to balance a sediment budget.

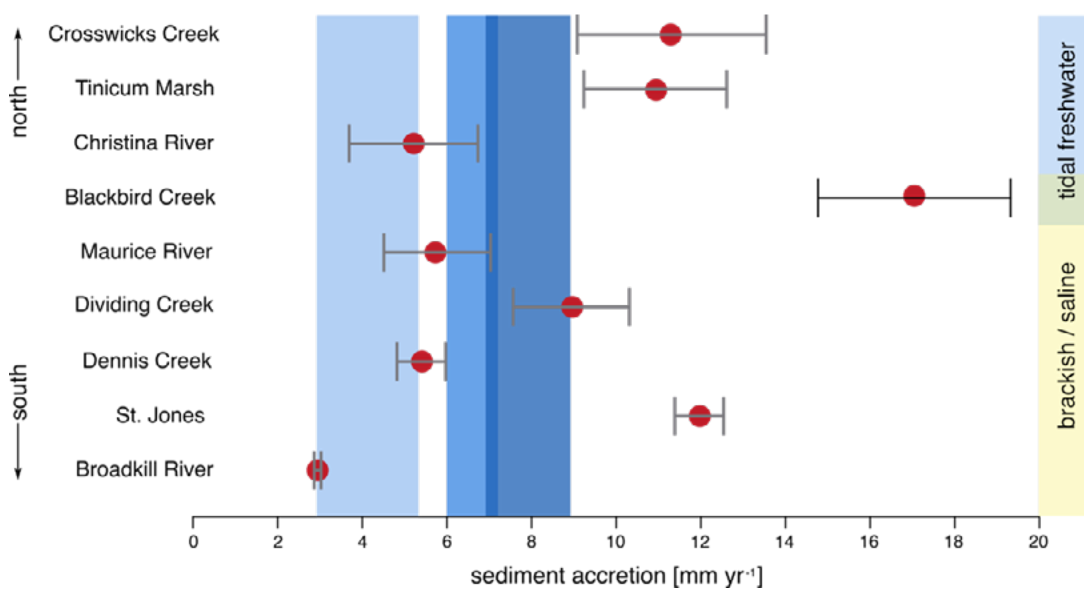

Figure 5.2.1 Sediment accumulation rates, based on marker horizons, measured in the Delaware Estuary relative to rates of long-term sea level rise based on trends from tide gauges (light blue), 19-yr sea level rise (medium blue), and 19-yr rise in mean high water (MHW) (darkest blue). Ranges in sea level rise depict variability between the different gauges. Stations are organized from north to south, and integrate measurements from several plots. Uncertainties for sediment accumulation measures are standard error. Original data found in Haaf et al. 2022; St Laurent et al., 2020. Tide gauge data is from Lewes, DE (8557380), Cape May, NJ (8536110), Reedy Point, DE (8551910), and Philadelphia, PA (8545240) (NOAA 2022a; b; c; d; e).

Interpolation mapping extrapolated to the extent of Delaware Bay wetlands suggests that tidal wetland carbon accumulation averages 127,000 ±103,200 tons of organic C yr^{1} (based on marker bed measures) or 153,500 ± 58,600 tons of organic C yr^{1} (based on radiometric dating) (Champlin et al., 2020) (also see Wetlands Feature 3 "A Closer Look at Blue Carbon in the Delaware Bay"). Carr and others, in a study of wetland carbon sequestration in the Delaware Estuary, estimated the annual carbon sequestration value to be $42,000 for a square kilometer of tidal wetlands, given a social cost of carbon of $37.15 per ton of CO_2, a 3% discount rate, and a 2.2% annual increase in the social cost of carbon (Carr et al., 2018). Applying this estimate over the present area extent of tidal wetlands in the estuary (estimated by Carr at 704 km^2), gives a sequestration value of $3.66 billion.

Future Predictions

A variety of factors suggest that watershed-derived sediment supply will not be a sufficient to support tidal wetlands in coming decades. Although uncertainties are high, the current sediment delivery from the Delaware watershed roughly equals the amount of sediment deposited in Delaware Estuary tidal wetlands, suggesting that the sediment supply is limited. Sea level rise rates are increasing, which causes the formation of additional accommodation space, and past epochs of rapid sea level rise have been associated with erosion of tidal wetlands in Delaware Bay (Fletcher et al., 1992). In addition, there are suggestions of declining water column turbidity (see Fig 5.1.1) and sediment supply (Weston 2014). Thus, it appears declining sediment availability may threaten the survival of tidal wetlands in Delaware Estuary. However, declining turbidity may be beneficial to other aquatic organisms, such as submerged aquatic vegetation and fish.

It is generally accepted that carbon accumulation will increase with sea level rise, as increased flooding leads to increased sediment deposition. Increasing the rate of sediment accumulation will result in increased carbon burial (Wang et al., 2019). However, increased carbon burial may be somewhat offset by marsh erosion, if the carbon stored in these wetlands is remobilized and decomposes to yield carbon dioxide or methane.

The survival of tidal wetlands with sea level rise will also depend to a degree on their capacity to migrate upslope. Coastal development may also limit the capacity of tidal wetlands to transgress (Mitchell et al., 2020).

Actions and Needs

As mentioned previously, a better understanding of sediment inputs to Delaware Bay will help ascertain whether sediment demands are outstripping supply. It is important to acknowledge and regulate sediment as both as an ecosystem stressor, and a critical component of resilience to climate change, as robust coastal sediment supplies are important for maintenance of wetlands and beaches.

To better utilize the carbon sequestration capacity of tidal wetlands, additional studies of methane emissions across Delaware will help ascertain where restoration and conservation may best promote carbon sequestration benefits. Carbon sequestration rates are highest in the fresher part of the Estuary, where methane emissions may be expected to be greater as well.

Perspectives on Diversity, Equity, Inclusion, and Environmental Justice

Wetland sediment and carbon accretion affect people because sustaining wetlands depend on sediment inputs, and carbon sequestration within wetlands mitigates climate change. Accelerating sea level rise will also reconfigure coastal areas, and attention to the human dimensions of these landscapes is necessary to ensure that the vulnerability of communities is not unfairly amplified in service to ecological resilience goals (Jurjonas and Seekamp 2020, Bhattachan et al. 2018; Van Dolah et al. 2020). Although it is increasingly recognized that disinvestment has led to disproportionate harms to some overburdened communities, which are often composed of populations that are minoritized, low-income, indigenous, rural, or otherwise lacking in opportunity for public participation. In some states, however, efforts have been made to address these wrongs. For instance, during 2020 New Jersey passed the country's strongest environmental justice bill, which seeks to reduce environmental harms in overburdened communities. It is important to consider such issues proactively, as sediment management and climate change adaptation may also lead to disproportionate impacts on overburdened communities.

Summary

This assessment of sediment and carbon accumulation in Delaware Bay tidal wetlands reveals several important findings. Sediment accumulation varies throughout the Bay with trends towards more rapid sediment accumulation in the freshwater portion of the estuary. Overall, wetland sediment accumulation roughly matches sediment supply delivered via coastal watersheds, meaning that as sea level rise accelerates in the future, sediment supply may become limiting. The carbon sequestered in tidal wetlands is a valuable resource and its further preservation can aid in carbon dioxide emissions mitigation.

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5.3 Sediment Quality

Introduction

Estuaries are among the most productive ecosystems found globally (Underwood and Krompkamp 1999), and can also play a crucial role in the life history and development of many aquatic species. Estuaries receive anthropogenic inputs from upstream point and non-point sources and from metropolitan areas and industries located near estuaries (Chapman and Wang 2001). This pollution can not only negatively affect aquatic organisms, but also humans that harvest fish and seafood for consumption. Thus, it is critical that sediment contamination and its significance be assessed.

This assessment focuses on trace metals and metalloids as pollution indicators in the Delaware Estuary measured in the 2008-2010 benthic inventory of Delaware Bay (Kreeger et al. 2010). These metals and metalloids tend to result in decreased diversity, decreased abundance, increased mortality, and behavioral changes among benthic species (CCME 2022a;b;c;d;e;f;g). Fish consumption advisories in Delaware Bay are based on a number of contaminants, including mercury (DRBC 2022).

Description of Indicator

Here we examine sediment concentrations of arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc as indicators of sediment pollution. We leverage a dataset collected in 2009, as part of a projected entitled the Delaware Estuary Benthic Inventory (or DEBI), that inventoried marine invertebrates, and sediment characteristics, including metal concentrations at more than 200 stations across the Delaware Estuary (Kreeger et al. 2010). Metal concentrations were measured using EPA methods 200.7 (ICP-OES), 200.8, (ICP-MS) and 245.5 (atomic adsorption). Arsenic and cadmium were measured using ICP-OES, chromium, copper, lead, nickel, and zinc were measured using ICP-MS, and mercury was measured using atomic absorption spectroscopy. Values were compared against sediment quality guidelines and Probable Effect Levels for protection of aquatic life (Table 5.3.1).

Table 5.3.1 Sediment quality guidelines (SQG) for metals and metalloids, and Probable Effect Levels (PEL) (CCME 2022a;b;c;d;e;f;g; Ingersoll et al. 2000). The lowest of freshwater and marine SQG and PELs were utilized.

Metal or metalloid	Mean value (mg kg^{-1}) Delaware Bay	Percentage of stations exceeding PEL	SQG (mg kg^{-1}) non polluted	PEL (mg kg^{-1}) polluted
arsenic	7.35	4.4%	<5.9	17
cadmium	0.45	0.89%	<0.6	3.5
chromium	24	19%	<37.3	90
copper	14	19%	<18.7	108
lead	23	16%	<30.2	91.3
mercury	0.10	15%	<0.13	0.486
nickel	13	0.89%	<20	36
zinc	96	20%	<123	271

Present Status and Past Trends

As of 2010, a significant portion of sediment samples exceeded PEL levels, including chromium (19%), copper (19%), lead (16%), mercury (15%), and zinc (20%). Values were lower for arsenic (4.4%), cadmium (0.89%), and nickel (0.89%). Generally, the sediments had the highest concentrations of pollutants in the tidal Delaware River, near Wilmington, and the lowest concentrations in Delaware Bay (Fig 5.3.1-4). Sediment cores from Oldmans Creek and Woodbury Creek, in the more urban and industrialized tidal freshwater portion of the Delaware River, were analyzed for metals from cores taken in summer of 2001. Sediment cores from accretionary environments record temporal changes in contamination. Near-surface sediments were 2-4 times as enriched in arsenic, cadmium, chromium, copper, and zinc, and 10x as enriched in lead (values for mercury and nickel were not reported) compared to depths dated prior to the 1950s (Church et al, 2006). Near-surface sediments often had lower values than peaks from deeper depths (e.g., 1970s), suggesting improvements in sediment contamination over recent decades (Church et al, 2006).

Future Predictions

Given that sediment contamination appears to have declined recently relative to the 1950s (Church et al. 2006), we may expect sediment contamination to decrease if deeper sediments are not remobilized by storms. However, emerging contaminants (PFAS, microplastics) may increase even as previously regulated pollutants decline. In addition, some metals can be mobilized by changes as pH in well (Xeng et al., 2015), meaning that ocean acidification may increase metal pollution.

Actions and Needs

Spatial and temporal analysis of additional pollutants is needed to help constrain where sediment contamination issues occur. More recent sediment data, or dated from sediment cores collected in depositional environments, can help reveal where sediment contamination is declining. Additional focus might include other compounds linked with fish consumption advisories. To assist in recovery from contamination, and to recover the ability to consumer fish from Delaware Bay, pollution sources would need to be reduced and/or contaminated sediments would need to be remediated.

Perspectives on Diversity, Equity, Inclusion, and Environmental Justice

As an indicator of environmental justice (EJ) concerns, we analyze the metal and metalloid concentrations to determine whether they are disproportionately higher in EJ communities. To determine the location of environmental justice communities, we utilized the methodology used by the PADEP, which defines an environmental justice community as a census track inhabited by a 30% or more Hispanic or non-white population and/or where 20% or more of the population lives below the poverty line, using the data from the 2015 community survey and 2010 census (PA DEP 2022; Figure 4.3.5). To look at sites across the Delaware Bay, we used a 5-km buffer around the EJ communities. We found that there was no significant difference in sediment contamination in areas bordering EJ communities versus areas not bordering EJ communities.

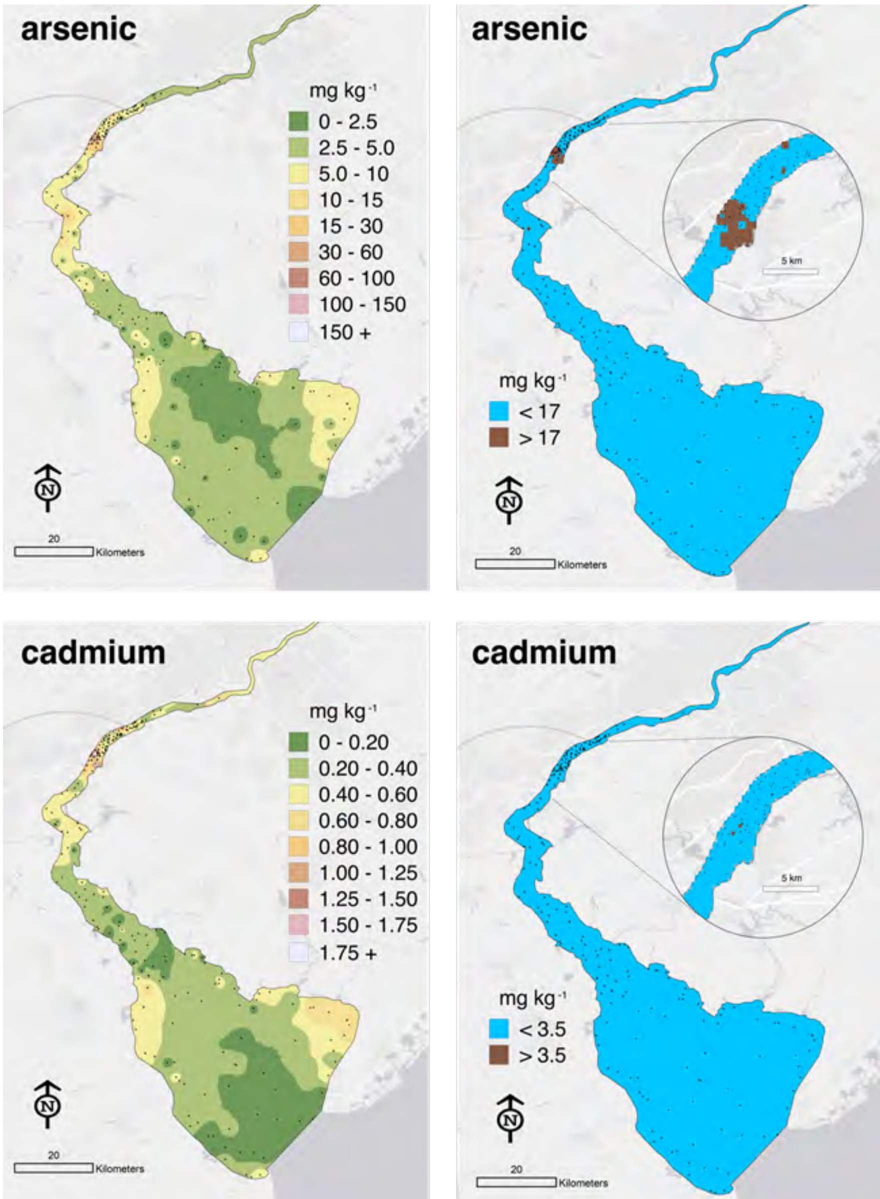

Figure 5.3.1 Interpolation maps of sediment arsenic and cadmium concentrations across the Delaware Estuary. Maps at left show metal concentrations. Maps at right show areas where sediment metal concentrations exceed Probably Effect Levels.

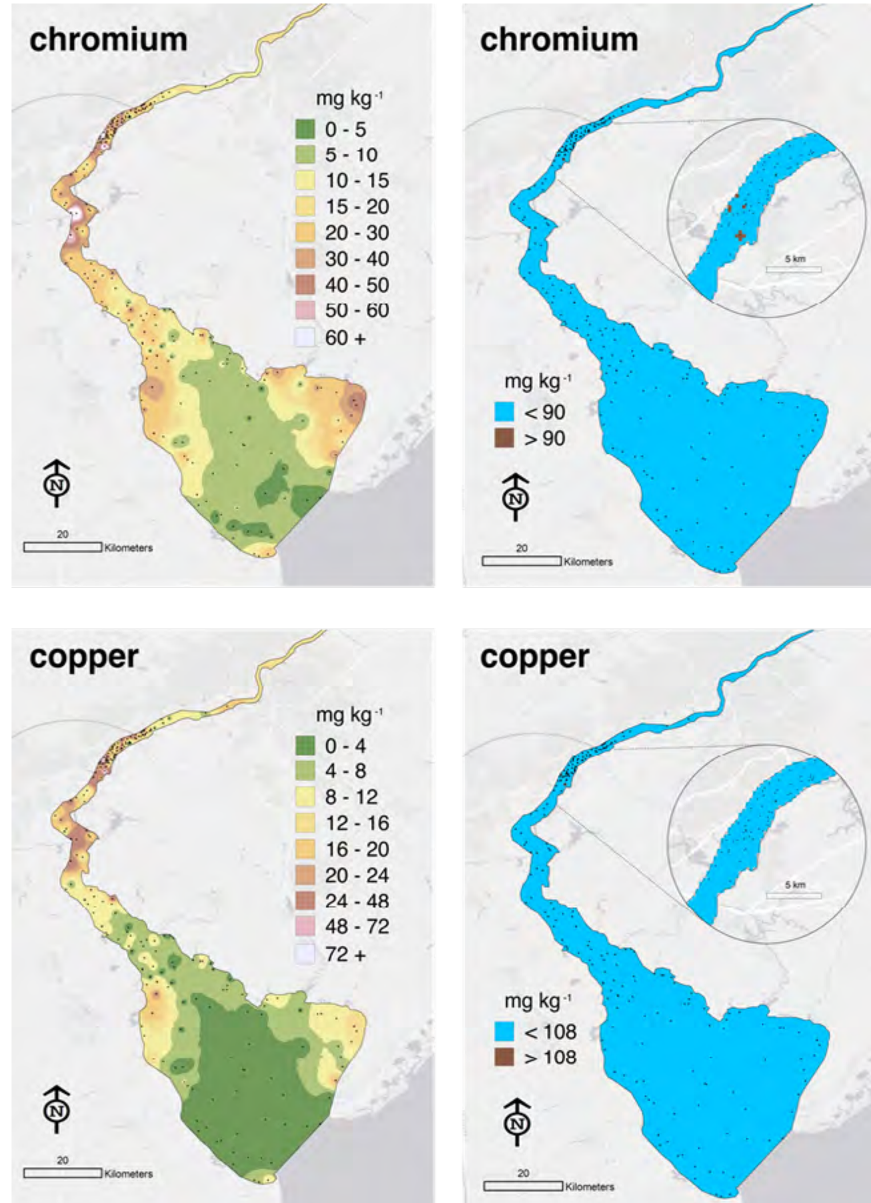

Figure 5.3.2 Interpolation maps of sediment chromium and copper concentrations across the Delaware Estuary. Maps at left show metal concentrations. Maps at right show areas where sediment metal concentrations exceed Probably Effect Levels (which are minor for chromium and for copper are non-existent).

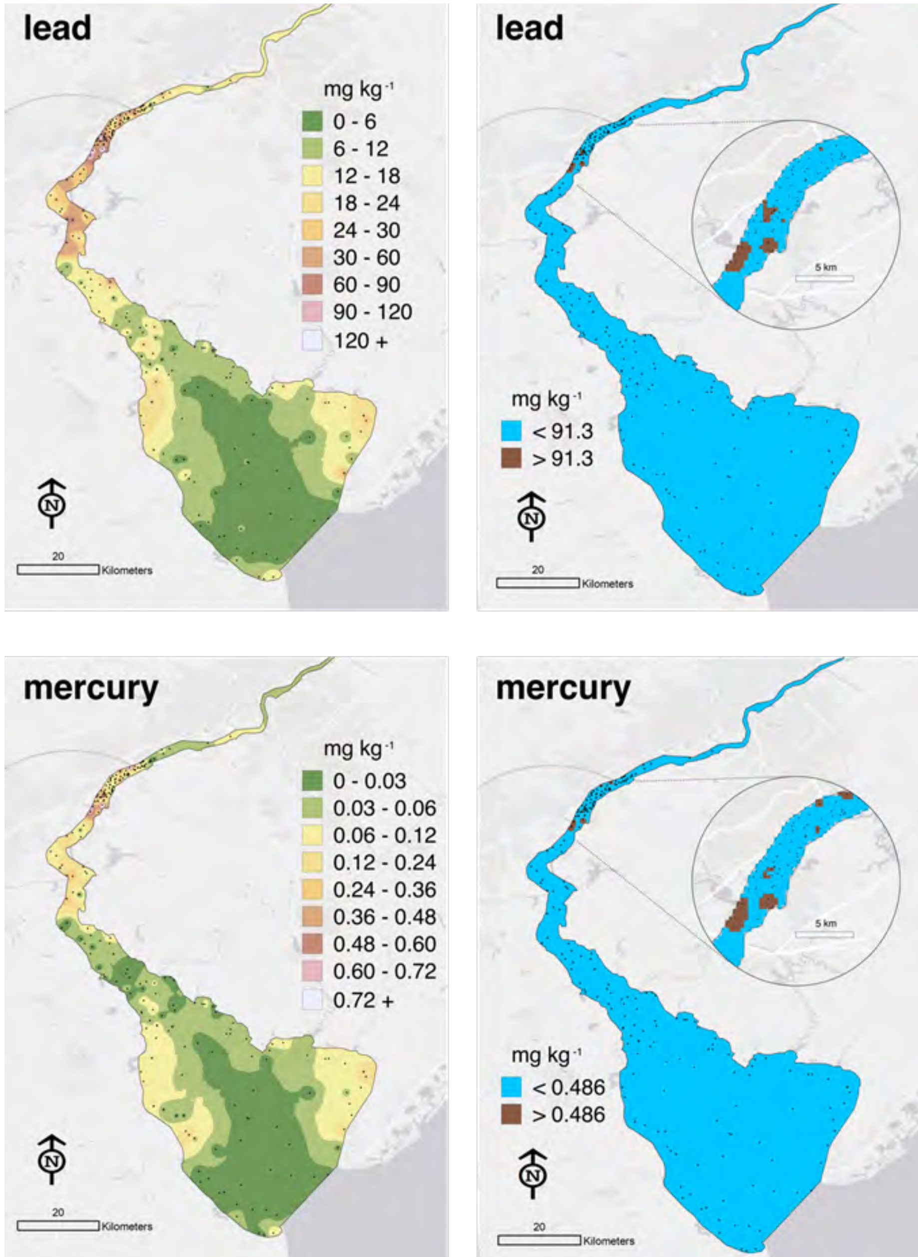

Figure 5.3.4 Interpolation maps of sediment lead and mercury concentrations across the Delaware Estuary. Maps at left show metal concentrations. Maps at right show areas where sediment metal concentrations exceed Probably Effect Levels.

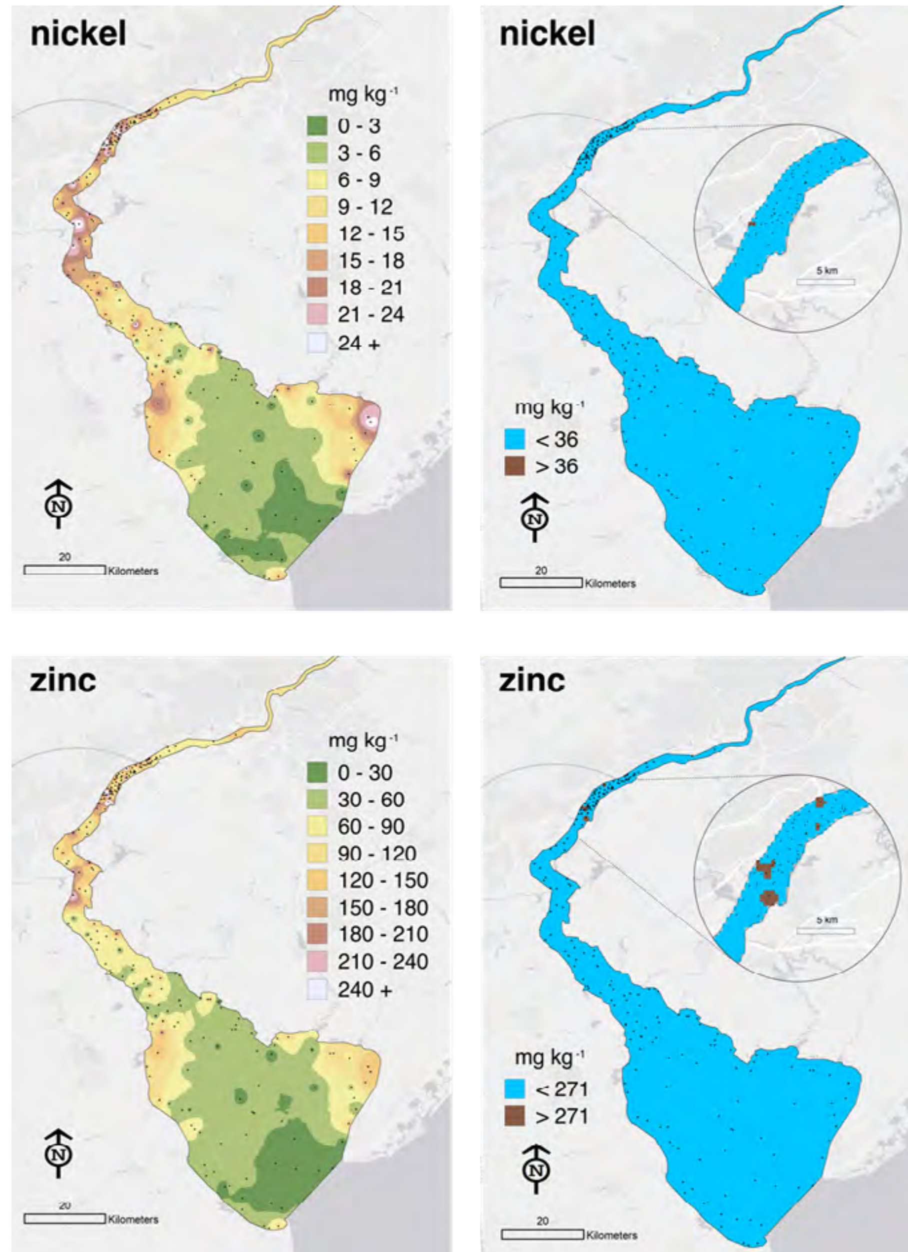

Figure 5.3.3 Interpolation maps of sediment nickel and zinc concentrations across the Delaware Estuary. Maps at left show metal concentrations. Maps at right show areas where sediment metal concentrations exceed Probably Effect Levels.

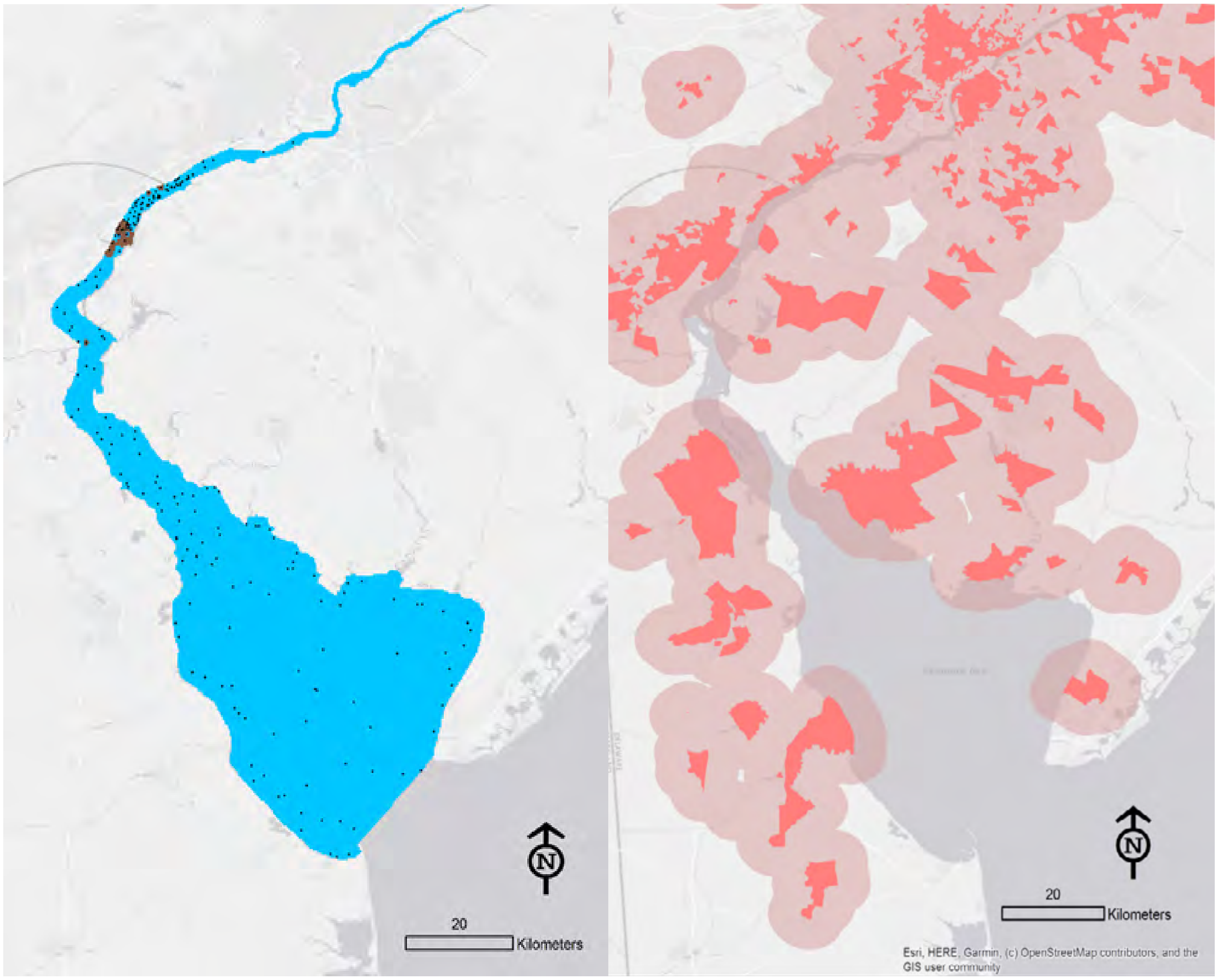

Figure 5.3.5 Location of where sediment concentrations exceed Probable Effect levels and location of environmental justice communities in the vicinity of the Delaware Estuary. Map at left shows location of PEL exceedances; the map at right shows EJ community locations (in red) and 5-km buffers (in rose).

Summary

Sediment metal concentrations were used as indicators of polluted sediments. Greater sediment pollution was found in the upper portion of the Delaware Estuary, but no significant differences was found in sediment pollution comparing waters adjacent to EJ communities vs. waters not adjacent to EJ communities. Based on analysis of dated sediment cores, sediments are more contaminated today than during the 1700s and 1800s, although sediment pollution has decreased over past decades.

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5.4 Sediment Management

Introduction

The earliest navigation improvements within the Delaware Estuary that involved dredging began in 1890 to meet the growing needs of waterborne commerce in the region. The U.S. Army Corps of Engineers has been the principal agency responsible for the construction and subsequent maintenance dredging of Federal navigation projects authorized by Congress. The first project was the construction of a 7.9 meter (26 ft) deep channel from Philadelphia to naturally deep water in the Bay in 1898. Between 1890 and 1942, the Delaware River Philadelphia to the Sea channel was incrementally deepened to 9.1 meters (30 ft), 11.0 meters (36 ft), and to a channel depth of 12.2 meters (40 ft). Congress additionally authorized the deepening of this channel to 13.7 meters (45 ft) in 1992, and this work was completed in 2020. Regular maintenance dredging will be required to maintain the channel at this depth.

Dredged material is typically placed in upland Confined Disposal Facilities (CDFs) or an open water disposal area (Buoy 10) (Fig 5.4.1),which have limited capacity and are challenging to establish. Beneficial use of sediment for beach or wetland enhancement can help reduce reliance on the current CDF facilities and can help meet needs for coastal protection and tidal wetland restoration given accelerating rates of sea level rise and coastal erosion. However, sediment contamination limits the beneficial use of sediment in some parts of the Delaware Estuary, and there is broad concern among the public about the human health and ecological consequences of dredging and dredged material placement (Dwinell et al. 2003). Elsewhere in Delaware Bay, factors such as cost, authority, and supply and demand gaps have limited its use.

Figure 5.4.1 Location of selected Confined Disposal Facilities in Delaware Bay.

Beneficial use of sediment includes adding sediment to beaches, dunes, and in some recent cases even including tidal wetlands (Ganju 2019). The goals of beach nourishment projects include the replenishment of narrowing beaches, and to prevent flooding and storm damage to adjacent infrastructure. Dredge sediment has also been used beneficially to remediate oxygen-depleted subaqueous borrow pits and to introduce sediment into the nearshore littoral system. Beach nourishment has been conducted along the Delaware Bay shore since the 1950s, although analysis of beach nourishment tracked by the American Shore and Beach Protection Association suggests that beach nourishment on the New Jersey side of the Bayshore has been extremely limited (Elko et al. 2021). In 2012, the Army Corps of Engineers released a report developing target sites for beneficial use, analyzing sediment toxicity, and coupling maintenance dredging with beach nourishment needs in Delaware, with the intention of wider implementation. Beneficial reuse focuses on matching areas with sediment generated through dredging. To match available sediment to beneficial use sites in the state of Delaware, three main data sources have been utilized: a population density and infrastructure index, social vulnerability index, and an environmental and cultural resources index (USACOE 2017; 2018).

Description of Indicator

Although sediment management occurs in various forms in the Delaware Bay, we report on beach nourishment as an indicator of demands for sediment to maintain beaches (Elko et al. 2021). Funds spent on beach nourishment were inflation adjusted to 2020 dollars. However, many projects were missing funding allocations. To estimate the amount spent on projects with missing data, we used an empirical relationship between cubic yards of sediment added to beaches and the cost for the 30 projects that had both sources of data available ($y=35.054x$; $r^2=0.979$; where y is cost and x is the cubic yards of sediment used to nourish beaches). The database we depended on for this information reported that, although New Jersey ranks first in the country in the amount of sediment added to Atlantic coast beaches (3 cubic yards for each foot of beach per year), New Jersey does not support regular nourishment of Delaware Bay beaches.

Present Status and Past Trends

Between 2010 and 2020, there were an estimated 3.6 million cubic yards of sediment placed on Delaware Bay beaches at an estimated cost of $124 million, which includes some upland sources (Fig 5.4.2). This exceeds the amount of beach nourishment performed over the time period from 1980 to 2010. Overall, we see beach nourishment increasing from the 1950s to 1980s, declines in the 1990s and 2000s, with increases over the past decade. This increase in beach nourishment between 2010-2020 is driven by two large projects, one at Broadkill Beach, and one at Prime Hook Wildlife Refuge that account for 78% of the total.

Future Predictions

Future changes to sediment management in the estuary are predicted to occur based on port expansion and climate change. Dredging to maintain the newly deepened navigation channel will require maintenance dredging. Port expansion projects and development will drive future dredging needs.

Globally, shorelines have receded over the past century globally in response to sea level rise, and this is true even where human interference is not a factor, as recession is occurring even on sparsely occupied and little developed coasts (Leatherman 1990). In the Delaware Bay, rates of shore erosion over the past century have averaged 2-3 m yr^{-1}, which is significantly greater than the U.S. Atlantic average (Maurmeyer 1979; French 1990). Marshy shorelines have supported the most rapid erosion rates, and pre-Holocene sediment deposits had slower erosion rates.

In the future, erosion rates may be expected to increase, and it appears likely that sediment demands for beach nourishment will increase concomitantly. If the aim is to retain beaches in their current position, significant beach nourishment will be required. An additional complication in the Delaware Bay is that barrier beaches help shelter tidal wetlands— which ring the bay— from erosion. Where barrier beaches have been lost over the past century, shoreline erosion can accelerate rapidly (Fig 5.4.3). If beaches along the Delaware Bayshore are not maintained, a major reconfiguration of the coast will likely result.

With some exceptions, sandy beaches faced with sea level rise transgress inland, although they may be maintained in place if sediment supply is adequate or may drown if sediment supply is constricted or sea level rise is rapid (Lorenzo-Trueba Ashton 2014). The rollover of beaches and sandy barriers subject to sea level rise is expected to occur as the barrier narrows, and is overwashed by storms. This moves sediment from the beach face to the rear of the beach or barrier, and which allows the barrier to enter a rollover phase (Leatherman 1979). This natural process of rollover can be prevented by coastal development which fixes the beach or barrier island in place.

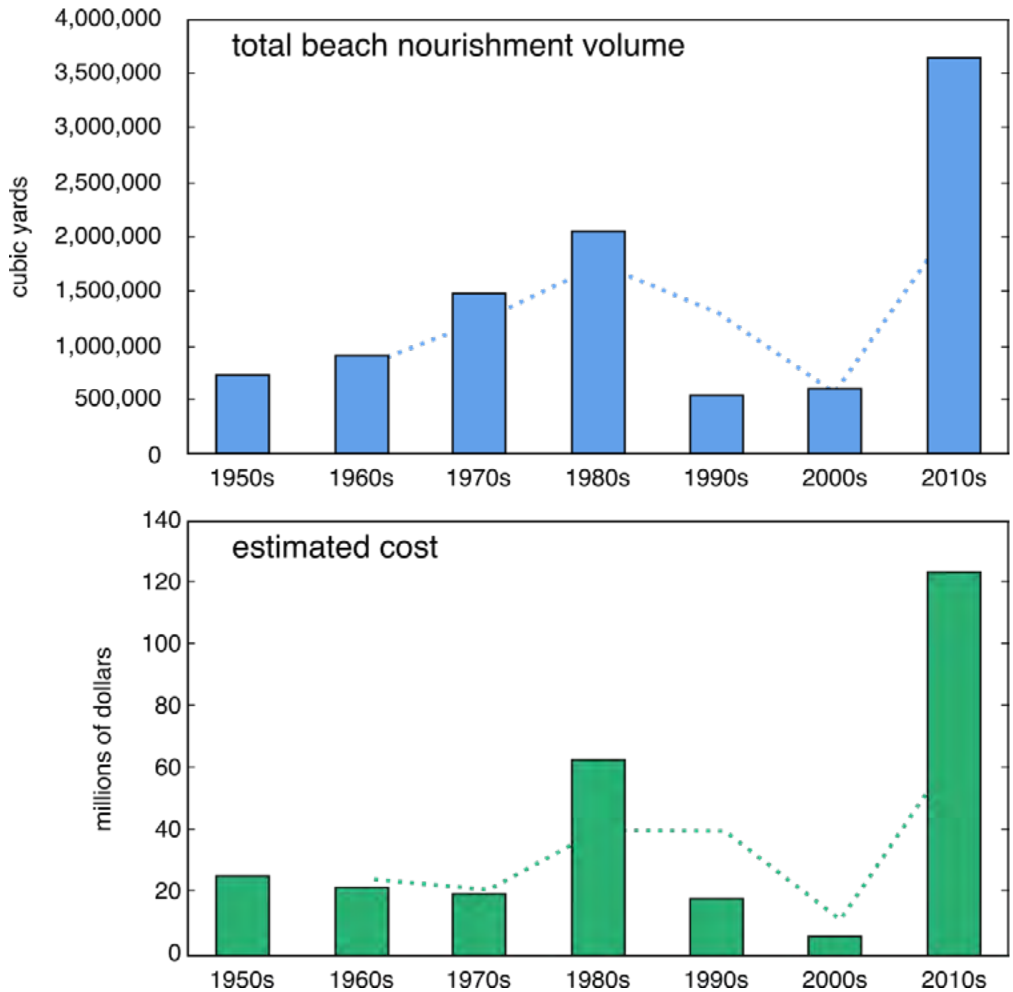

Figure 5.4.2 Estimates of total volume of beach nourishment that occurred in Delaware Bay from the 1950s-present and the cost spent on beach nourishment (Elko et al. 2021). Dashed lines show a 2-period moving average.

Actions and Needs

If beaches along the New Jersey side of the Delaware Bayshore are to be maintained the into future, they will require additional sand placement. The utilization of sediment to build marsh elevation requires further study and consideration. Specifically, it is important to consider the timeline over which plants are expected to recolonize beneficial use sites, and function of the marsh to be restored.

Perspectives on Diversity, Equity, Inclusion, and Environmental Justice

As an indicator of environmental justice concerns, we analyze the location of CDFs to determine whether they are disproportionately cited in EJ communities. Secondly, we examined the location of beach nourishment relative to these same communities. To determine the location of environmental justice communities, we utilized the methodology described above (PA DEP 2022; see Fig 5.3.5). Overall, we found that all CDFs apart from the Reedy Point site (where the C&D canal enters the Delaware Bay) were located in or adjacent to EJ communities (Fig 5.4.1). However, the entire upper stretch of the Delaware River is in or adjacent to EJ communities. For beach nourishment, we found that $186 million has been spent on beach nourishment in non-EJ communities vs. $38 million spent in EJ communities. South of the D&C canal (where beaches begin), about 46% of the shoreline is adjacent to EJ communities versus 54% adjacent to non-EJ communities so we might expect similar amount of nourishment in these two areas of shoreline, although there are specific constrains on where the State of Delaware nourishes beaches.

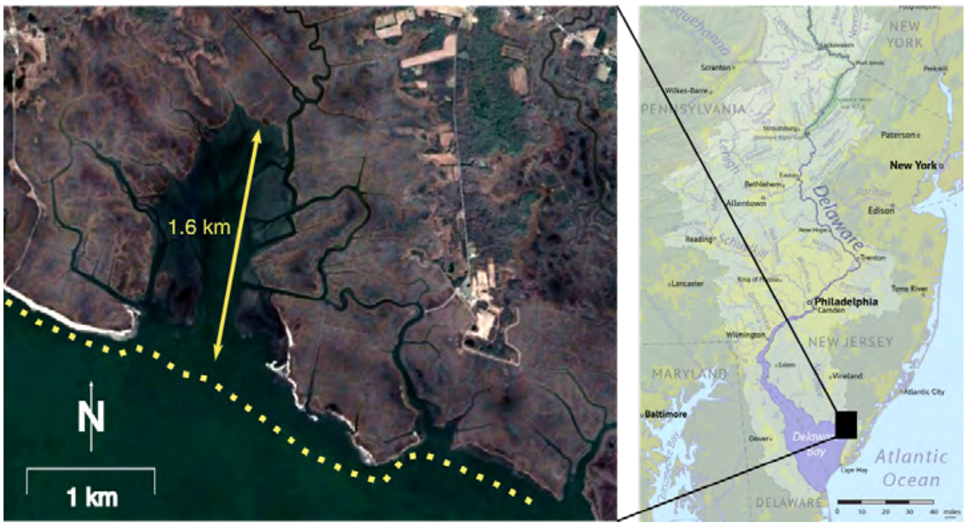

Figure 5.4.3 Shore edge erosion in an area of Delaware Bay where the beach has eroded and disappeared. This, combined with marshlands that had subsided due to levee construction, led to a rapid shoreline transgression (Smith et al. 2017). On areas to the northwest and southeast, less shoreline erosion has occurred in areas where the beach (which reflects white) has persisted, and more shore erosion has occurred in places where the beaches have disappeared. Image from 2017. Shoreline edge in 1985 is shown in dashed yellow. Imagery sources: (Wikimedia 2018; Google Earth 2022)

Summary

Overall beach nourishment and sediment management have increased over the past decade with the dredging of the Delaware Bay shipping channel to 45 feet. Beach nourishment has increased to support the maintenance of eroding Delaware beaches, although recent increases are tied to large projects at Broadkill Beach and Prime Hook Wildlife Refuge. Given climate change, additional beach nourishment may be needed if Delaware Bay beaches are to survive into the future. Navigation dredging projects of all scales may be able to provide sediment to remediate shoreline erosion through beach nourishment. In some cases, sandy beaches have been compromised or on the Delaware Bay shore, exposing marshes to wind-wave forces, which appears to enhance the rate of erosion. Several projects focused on the beneficial use of sediment to build resilience of coastal wetlands to climate change have been implemented in Delaware Bay and the US Northeast, however, questions remain about the costs and benefits of these projects, if the beneficial use of dredge sediment can sustain drowning coastal marshes on decadal and longer timescales, and how they fit into a program of coastal climate change adaptation.

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Sediment Feature

Beneficial Use of Sediment to Build Tidal Wetland Elevation

Metthea Yepsen

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Tidal marshes are an integral part of the Delaware Estuary. They form a charismatic green band that cleans water; provides critical habitat and food sources for fish, shellfish, and birds; and buffers coastal communities from storms and erosion. However, the continued existence of many tidal wetlands is threatened by sea level rise and anthropogenic alterations. To maintain healthy salt marsh vegetation, marshes must accrete sediment and plant matter to gain elevation at a rate that keeps pace with sea level rise and subsidence. Some salt marshes are stressed and literally "drowning" because they cannot gain surface elevation at a rate that keeps pace with accelerating sea level rise.

The beneficial use of dredge sediment to build marsh elevation has been recently tested at two sites that border Delaware Bay: Fortescue Fish and Wildlife Management Area, NJ, and Prime Hook National Wildlife Refuge, DE. An increase in marsh elevation reduces inundation, promoting the growth of vegetation. The vegetation in turn stabilizes the marsh soil and promotes further accretion and increased elevation via sediment trapping and root production. It forms a positive feedback loop that may increase marsh resilience to climate change.

While both projects used dredge sediment to restore dunes, beach, and marsh to sustain wildlife, there were important differences between the two projects. In NJ, several pilot projects were conducted, including but not limited to Fortescue, to build coastal ecosystem resilience to climate change as well as build capacity and advance new sediment management concepts. In Delaware, the Prime Hook restoration was a costly and complex project that incorporated beneficial use of sediment to revegetate freshwater impoundments to sustain wildlife and protect local communities. The Fortescue test site cost $4.8 million for 6.6 acres of thin-layer placement on the marsh, 1.5 acres of beach nourishments, and 2.5 acres of dune restoration (NJDEP & TNC 2021). Prime Hook's project cost $38 million for 4,000 acres of tidal marsh. Both of these projects presented several logistical challenges, and have a mixture of successes and lessons learned. Together, however, these projects reflect a paradigm shift in sediment management, and a reversal in the prohibition of placing sediment fill material in wetlands, which was not allowed for several decades after the passage of the Clean Water Act.

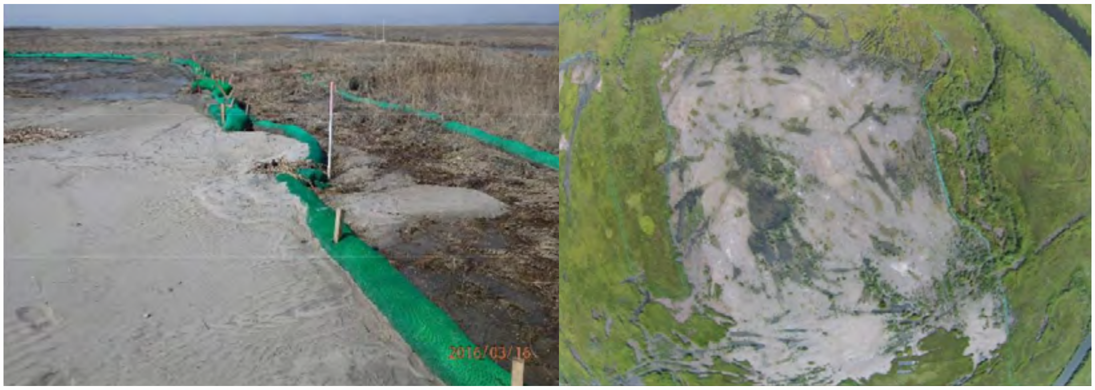

Figure 5.4.4 Close up of dredge material deposited on marshlands at Fortescue, NJ on the Delaware Bayshore (left) and landscape view (right) after placement was complete in 2016. For more information see TNC and NJ DEP 2021.