Chapter 5. Aquatic Habitats

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5. Aquatic Habitats

5.1 Subtidal Habitats

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5.1.1 Introduction

While surveys of the benthos have occurred in the Delaware Bay and River since the 1950s (Table 5.1.1) the recent Delaware Estuary Benthic Inventory (DEBI) is the most comprehensive and intensive study ever conducted (Fig 5.1.1). Due to the extent of the data produced in the DEBI project, it is the focus, though not exclusively, of this indicator.

The DEBI project was led by The Partnership for the Delaware Estuary, one of twenty-eight National Estuary Programs. In 2005, The Partnership for the Delaware Estuary recognized a fundamental need for a benthic ecosystem assessment that would inventory the physical and biological conditions of the bottom of the open water tidal system of the Delaware River and Bay. This priority need was articulated in early 2005 when the Partnership convened a science and management conference that brought together more than 250 scientists, managers and science-interested people to summarize the current state of science and to identify and prioritize science and management needs for the Estuary. Consensus views from the conference were summarized in the "White Paper on the Status and Needs of Science in the Delaware Estuary" (Kreeger, et al. 2006) that called for a better understanding of benthic conditions.

Soon after the white paper, The Partnership and its collaborators around the estuary designed the Delaware Estuary Benthic Inventory (DEBI) program to fill the vital data gap in our understanding of the estuary's ecosystem by characterizing bottom dwelling biological communities. By adding a more spatially comprehensive biological layer to existing maps of physical bottom conditions and historical surveys of benthic communities, findings from DEBI are expected to aid scientists, coastal managers, stakeholders, and decision-makers interested in trophic relationships, fisheries, pollutant distributions, water quality, and other

Figure 5.1.1 Pictures from sampling during the 2009 Delaware Estuary Benthic Inventory (DEBI). Photo credit: Partnership for the Delaware Estuary.

Table 5.1.1 Summary of benthic Surveys in the Delaware River and Estuary conducted 1951-2008 in DEBI final report.

Metadata	Amos DRIC	Maurer et al.	EMAP	NOAA S&T	MAIA	NCA	DEBI	Comments
Year(s) and Seasonality	1950's, mostly summer	1972-73, summers	1990-1993, summers	1997, September	1997-98, summers	2000-2006, summers	2008, summers	Summertime for peak abundances, most favorable weather
Spatial Domain	Delaware River and Estuary	Delaware Bay	Delaware Bay	Delaware River and Bay and coastal Atlantic	Delaware River (to Trenton) and Bay	Northeast U.S., Delaware Bay to Maine	Delaware River and Bay	
Number of Stations	Estimated to be about 130	207	25	81	88	138	230	Remarkably, almost 900 stations over all 7 surveys
Sampling Design	Various, piggybacked on hydrographic and zooplankton projects	Lines running along channels, bathymetry	Probabilistic	Probabilistic with strata	Probabilistic	Probabilistic with strata	Probabilistic with salinity and sediment strata	
Sampling Gear	Grabs, dredges, buoy scrapings, plankton tows	0.1 m2 Petersen grab and 1.0-mm mesh	EMAP grabs and water quality, 0.5-mm mesh sieve	Young modified Van Veen, 0.5-mm mesh sieve	0.04-m2 Young-modified Van Veen grab sampler, 0.5-mm mesh screen	0.04 m2 Young-modified Van Veen, 0.5-mm mesh sieve	0.04 m2 Young-modified Van Veen, 0.5-mm mesh sieve	Note differences in sampling gear and sieve mesh sizes
Additional Data	Hydrographic	Hydrographic and sediment	Hydro-graphic, sediment and stressors	Hydrographic, sediment and stressors	Hydrographic, sediment and stressors	Hydro-graphic, sediment and stressors	Hydrographic, sediment and stressors	Hydrographic: temperature and salinity; sediment: grain size or % sand, % silt-clay; stressors: DO, heavy metals, organic pollutants
Total Number of Species	≈396, but includes plankton, epifauna species	169	268	239	179	203	235 with Taxonomic Serial Numbers (TSN's)	
Mean Abundance	Not applicable, presence/ absence sampling only, abundances not recorded	722 m-2	[to be computed]	Mean densities: 1412.5 m-2 to 26985.0 m-2, but Hartwell and Hameedi report mean of 451 m-2(?)	[to be computed]	770 m-2 from all stations [to be computed for just Delaware Bay]	Nearly 9000 m-2	Values to be recomputed
Statistical Methods	n/a, see below	Cluster analysis	EMAP BI	Cluster analyses	Benthic indices	PRIMER MDS ordination and VPI and B-IBI indices	Diversity indices, ordination plots, dominance plots	
Overall Conclusions	1st survey, data exceeded manual analysis, data awaits analysis (2011)	Low abundance implies low productivity, faunal assemblages better related to sediment than salinity	One-fourth of the Delaware Estuary has impacted benthic communities	Diversity and abundance lowest in low salinity dominated by tubificids and oligochaetes; species richness correlated with grain size	One-third of Delaware Estuary received poor score using Paul et al. (1999) benthic index (EMAP-VP)	Ordination suggests salinity and latitude subregions; NCA data with VPI: 34% good, 29% poor, 37% missing	Salinity drives distribution and diversity overall	Distinct estuarine fauna as in, e.g., Remane diagram, but recent studies discount existence of true "estuary species" and interpret distribution and assemblages in light of salinity, sediment and stressors
Key References	Amos (1952, 1954 and 1956) but largely unpublished	Maurer et al. (1978), Kinner et al. (1974)	Billheimer et al. (1997), Billheimer et al. (2001)	Vittor (1998), Hartwell et al. (2001) Tech Memo 148	USEPA 2002; EPA/ 620/ R-02/ 003	Hale (2011)	[This report is the first look at these data]	
Web URL for Data	Digitized, awaiting analysis	Results published, availability of raw data unknown	http://www.epa.gov/emap/html/data/geographic.html	http://ccma.nos.noaa.gov/about/coast/nsandt/download.aspx	http://www.epa.gov/emap/maia/html/data/estuary/9798/index.html	http://www.epa.gov/emap/nca/index.html	http://www.delawareestuary.org/science_projects_baybottom.asp	

topics. These results also furnish an important baseline for tracking future ecosystem responses to changing climate and continued development in the watershed.

A top priority of this project was to use standard methods to examine the spatial distribution and relative abundance of bottom communities living in soft-bottom substrates that span the broad salinity gradient of the Delaware Estuary. Sediment chemistry and water quality were also examined at the same sample stations. A second priority was to explore biological communities living on selected hard-bottom habitats. Although the RARE-funded (Regional Applied Research Project) project, through USEPA, was of foundational importance in launching the program and furnishing base layers, follow-up studies are planned to continue DEBI, such as further exploration and mapping of hard bottom communities and mapping of benthic ecosystem services.

By creating a biological layer, to complement existing habitat and bathymetry layers, insight can be gained to the benthic communities that inhabit the Bay and River. Benthic invertebrates tend to live a longer life than most planktonic organisms and can therefore suggest the environmental conditions over time. The Delaware Bay and River consist of both hard bottom and soft bottom, each revealing different knowledge. The soft bottom is a dynamic system that can reveal information about anthropogenic inputs, the history of anthropogenic changes caused to hard bottoms in the lower Bay, and the legacy that it has left is also of relevance. These changes have possibly lead to compositional and structural changes to the biological communities.

As a first step in launching DEBI, the Partnership for the Delaware Estuary (PDE) partnered with United States Environmental Protection Agency (USEPA) Regions 2 and 3, USEPA Office of Research and Development, and other academic and agency partners to create a technical work group affiliated with the PDE Science and Technical Advisory Committee. PDE and this work group held workshops and summarized existing benthic data from seven prior bay-wide scientific studies. In addition, specimen collections from surveys by William Amos and colleagues in the 1950s were retrieved from storage and digitalized to augment the growing compendium of existing benthic information.

The soft-bottom survey was completed during the summer of 2008, consisting of 230 sampling sites from the mouth of Delaware Bay to the confluence of the Schuylkill and Delaware River, stratified by three salinity zones and sampled using a probabilistic design. USEPA Region 3 provided critical in kind support for the 2008 cruises, including ship time and staffing. Bottom grab samples were taken at each station and split for biological taxonomic examination and chemical analyses. USEPA Region 3 analyzed samples for a suite of sediment chemistry parameters, and the Delaware River Basin Commission examined splits samples for PCBs. Macroinvertebrate analyses were conducted via a subcontract to Versar Inc.

Exploratory surveys of selected hard bottom habitats were conducted in 2008, 2009 and 2010. Hard bottoms are more difficult to survey than soft bottoms in the Delaware Estuary because of naturally high turbidity and the ineffectiveness of grab samplers used for soft bottoms. Consequently, much less is known about these areas despite the belief that they are biologically active and ecologically important. Epibenthic sleds, oyster dredges, divers, and remotely operated underwater vehicles (ROVs) were used, where possible, yielding important new information for areas that were surveyed. For example in the lower Bay, extensive "sponge gardens" and worm reefs were found in deeper troughs using the dredge, and divers observed greater fish use of these complex habitats compared to adjacent sand soft-bottoms. In the freshwater tidal zone of the estuary, at least two types of Submerged Aquatic Vegetation (SAV) and seven species of scarce or rare unionid mussels were discovered in substantial abundance. Two of the mussel species were considered locally extinct by state agencies. These discoveries of sensitive, rare biota were unexpected considering that they were found in the urban corridor which has had historically poor water quality. Although further work is needed to examine their range and abundance, these beds of freshwater mussels and SAV (which coexisted in many areas) could be important for sustaining fish habitat and water quality in the upper Estuary.

Taken together, results from the soft- and hard-bottom surveys have yielded important discoveries and provided the most spatially complete biological layer ever for the bottom of the Delaware Estuary. The new biological layer clearly shows that bottom communities of the Delaware Estuary are spatially complex, spanning the many salinity zones and influenced by the presence and absence of sediment chemistry and stressors. From this layer climate change scientists will have a comprehensive baseline to track future changes in biological communities. The Delaware Estuary has over 200 migrant and resident finfish species that use the Estuary for feeding and spawning, and these new data will also provide managers with a better geospatial understanding of how benthic food resources and habitat support fisheries productivity and/or critical habitat for endangered species such as sturgeon. Maps of filter-feeding organisms may lead to a better understanding of pelagic-benthic coupling and ecosystem services that benefit water quality. Certain hard-bottom communities such as intertidal *Sabellaria* reefs and shallow subtidal oyster reefs are also increasingly appreciating for helping offset storm surge and coastal flooding.

The work supported by the RARE grant greatly increased our understanding of the estuary's bottom ecology and will have a direct bearing on diverse management priorities. More effort will be needed to build on the DEBI data to increase our understanding of benthic processes, hard-bottoms, and temporal (seasonal or inter-annual) variability that occurs across the Delaware Estuary. To track anthropogenic and climate driven changes, the benthic biota should also be broadly sampled using comparable methods at least every ten years.

5.1.2 Description of Indicator

Because of their abundance, diversity, sessile nature and recognized responses to environmental conditions, benthic organisms have long been used to assess the "health" of estuarine systems. In this context, the responses of the benthos to disturbance, organic enrichment associated with eutrophication and pollution, including oil and heavy metals, are of particular interest. To obtain benthic faunal data, typically a grab sampler is used to retrieve a bottom sample, and the sample is subsequently sieved to retain animals, which are then preserved. In the laboratory, macrofauna are identified, enumerated and weighed, allowing metrics such as the number of species, diversity indices or other statistical comparisons of stations to be computed. Examinations of patterns in these metrics are then used to infer the state of, or trends in, the benthic community. Alternatively, direct comparison of assemblages between impacted and reference sites may be used to infer habitat degradation and by extension the overall state of the benthic system.

The condition of the benthic community is well known to respond to physical (especially salinity and sediment properties such as particle size) and biological (primary productivity, food web structure, especially predators) factors as well as to chemical stressors (e.g., organic enrichment, metals, oil and other organics). Typically, estuaries are spatially and temporally variable in these physical, biological and chemical factors, and benthic species abundance and assemblage composition is accordingly found to be highly variable in time and space as well. In addition, the faunal or assemblage response(s) to a given factor are often not unique, that is, an observed change cannot always be associated with a single causative agent (i.e., chemical), trend or process, whether natural or anthropogenic. Polluted sites may have assemblages resembling that of naturally disturbed sites and to complicate matters further, stressors may act in combination, and cause and effect may thus be difficult to resolve using simple measures, especially where observed differences are embedded within the overall natural variability of the estuarine environment.

2012 was the first time an analysis of the subtidal benthic community was used as a metric in the State of the Estuary report. Below, we review sampling of the Bay conducted under the aegis of the Delaware Estuary Biotic Inventory (DEBI) project and present some preliminary findings and conclusions. These results are then placed in the context of past surveys and followed by some consideration of the use of historical surveys for assessing trends across decadal time scales.

5.1.3 Present Status

In summer 2008, the Delaware Estuary Benthic Inventory (DEBI) was conducted. To gather soft-bottom benthic data, extensive benthic grab and water column sampling was conducted throughout the Delaware Bay and River at 229 sites allocated in a design based on random locations within salinity and bottom sediment strata. Sediments were sampled using a 0.04-m^2 modified Young grab, sieved on a 0.5-mm mesh, and processed. A summary of environment parameters measured during this survey is presented in Table 5.1.2. Benthic species composition, sediment characteristics and measurements of metal concentrations as potential stressors were analyzed using diversity indices, multivariate ordinations, and dominance curve techniques.

Overall, 233 benthic species were identified in 112 families and 9 phyla. Five stations had 40 or more species and the mean species richness (number of species) was 13. The most diverse groups were: polychaetes (27 families, 79 species), amphipods (15 families, 35 species), bivalves (17 families, 27 species), and gastropods (15 families, 25 species). The mean benthic invertebrate abundance was 8,800 individuals per square meter. The greatest total abundance was 142,000 individuals per square meter at Egg Island Point; this abundance was dominated by the polychaetes, *Sabellaria vulgari*s and *Polydora cornuta*. The most abundant single species at any station was the bivalve, *Gemma gemma* (71,000 individuals per square meter) near Nantuxent Creek. The dominance by polychaetes, bivalves and amphipods was expected for the estuary's mixed sand-silt sediment as well as from previously published studies, although the abundances reported here are considerably larger than some previous reports (as discussed below). Together, the DEBI data represent the most intensive and comprehensive assessment of the Delaware Estuary's benthic fauna ever conducted, and these data are especially valuable in comparison with surveys of Delaware Bay conducted in the 1950's, 1970's and more regularly since 1990 (Table 5.1.1, page 162).

Figure 5.1.2 displays the estuary-wide patterns of benthic species diversity. Species richness (number of species) versus bottom salinity (Fig 5.1.2A) and river mile (Fig 5.1.2B), with approximate demarcations of polyhaline, mesohaline, oligohaline and tidal freshwater zones. Both plots show a characteristic shape of a Remane diagram (Remane and Schlieper 1971) where the pattern is of high diversity at the Bay mouth (and

Table 5.1.2 Summary of benthic Surveys in the Delaware River and Estuary conducted 1951-2008. (< D.L. means below the detection limit).

Parameter	Mean	Minimum	Maximum	Units
Salinity	13.3	0.2	31.8	‰
Temperature	24.8	17.1	27.8	°C
Dissolved Oxygen	6.8	4.3	11.8	mg/l
pH	7.7	7.0	8.5	-
Turbidity	41.3	3.4	919.2	NTU
% Sand	58.4	0.8	98.8	%
TOC	1.6	< D.L.	7.8	%
Arsenic	7.35	< D.L.	330	µg g-1
Cadmium	0.44	< D.L.	4.6	µg g-1
Chromium	23.7	1.1	132	µg g-1
Copper	13.5	< D.L.	112	µg g-1
Lead	22.6	1.4	256	µg g-1

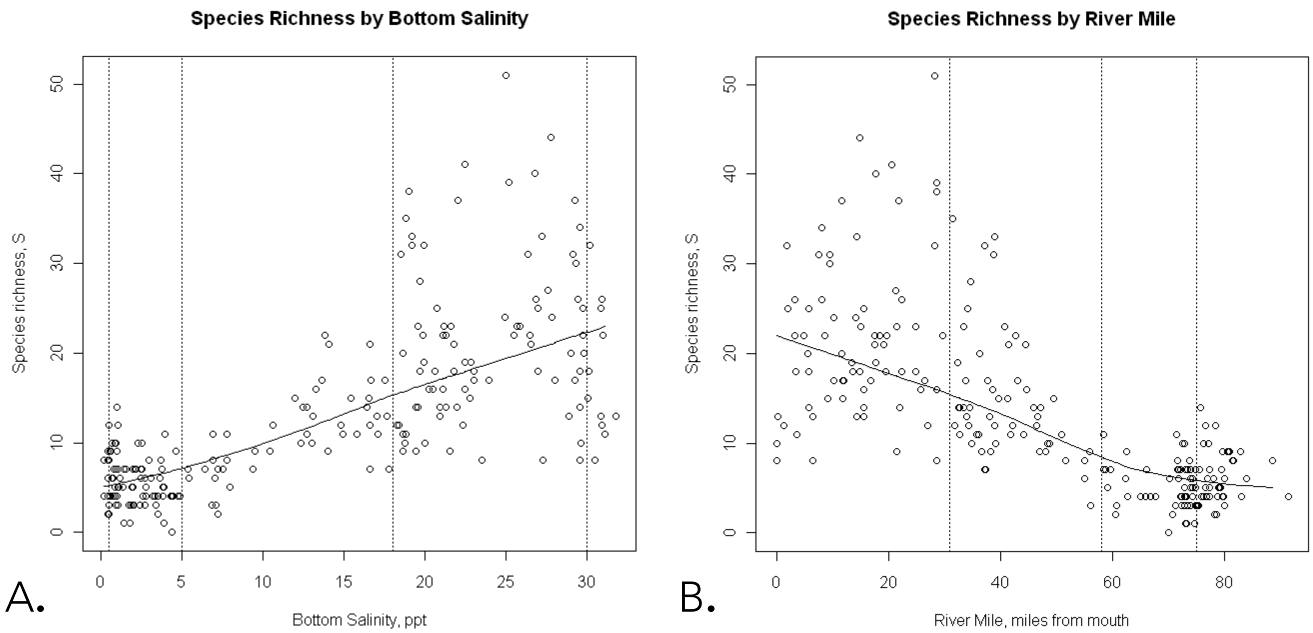

Figure 5.1.2 Patterns of benthic species diversity, comparing species richness versus A) bottom salinity and B) river mile.

at high salinity), decreasing upstream into the mesohaline, reaching a minimum, then higher (and here, more variable) in the oligohaline (near 80 miles from the Bay mouth). This is the pattern of benthic diversity commonly seen across estuaries and described in marine ecology textbooks, see Levinton (2001) or Kaiser et al. (2005) and references therein. Figure 5.1.3 shows benthic diversity in a spatial context using another commonly used metric, the Shannon-Wiener diversity index, H'. The interpretation of this plot is similar to those above: the concentration of red and orange dots in the Lower Bay suggests higher diversity there as compared to the riverine sections of the Bay denoted by green and black dots.

Figure 5.1.4 is a species accumulation curve showing the number of species expected versus number of samples taken in the DEBI survey; as more samples are taken, more species are recorded. A leveling off of this curve would indicate that few new species would be recorded by additional sampling, and thus the asymptote represents the total diversity as number of species in the estuary. The shapes of these curves (i.e. initial slope and asymptote) can be compared among studies in order to gauge the effectiveness of sampling and assess the degree to which the full diversity has been sampled. The upward slope at the right of the DEBI curve shown here indicates that even this extensive survey did not capture the full (technically, alpha) diversity of the Delaware Bay soft-bottom benthos. However, the observed diversity of 233 species is generally consistent with other surveys summarized in Table 5.1.1.

A more detailed view of the estuary's benthos is provided using a non-metric multidimensional scaling (MDS) ordination of the full species by assemblage abundance matrix. Figure 5.1.5 shows all 299 stations' similarities based on all 233 species using fourth-root transformed abundances and the Bray-Curtis similarity metric, computed using the PRIMER-E package (Clarke and Warwick 2001, Clarke and Gorley 2006). Each symbol represents a station: symbols close together have similar species composition (low dissimilarity), while points far apart differ in species composition (i.e. are dissimilar) in accordance of their separation. The stress value reported here, 0.13, indicates that the two-dimensional plot adequately represents the multivariate (high-dimensional) dissimilarities among stations. The broad ellipses represent groups of stations determined as by a cluster analysis as superimposed on the ordination and are show here for visual reference. When stations are coded by salinity zone (Fig 5.1.5A) it is clear that benthic assemblages relate

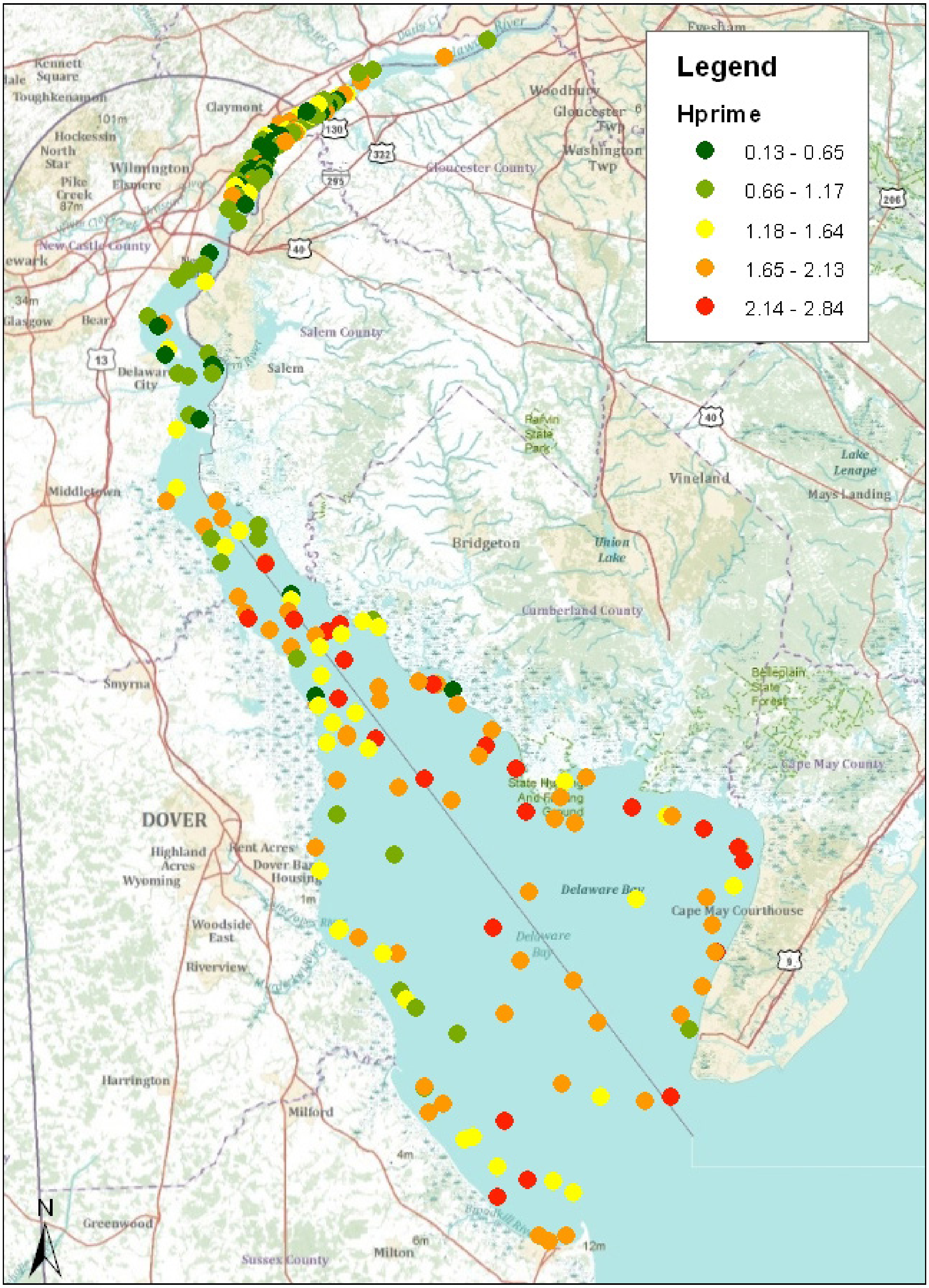

Figure 5.1.3 Dots show DEBI sampling locations, and are colored to show benthic diversity in a spatial context, using the Shannon-Wiener diversity index, H′ (Hprime).

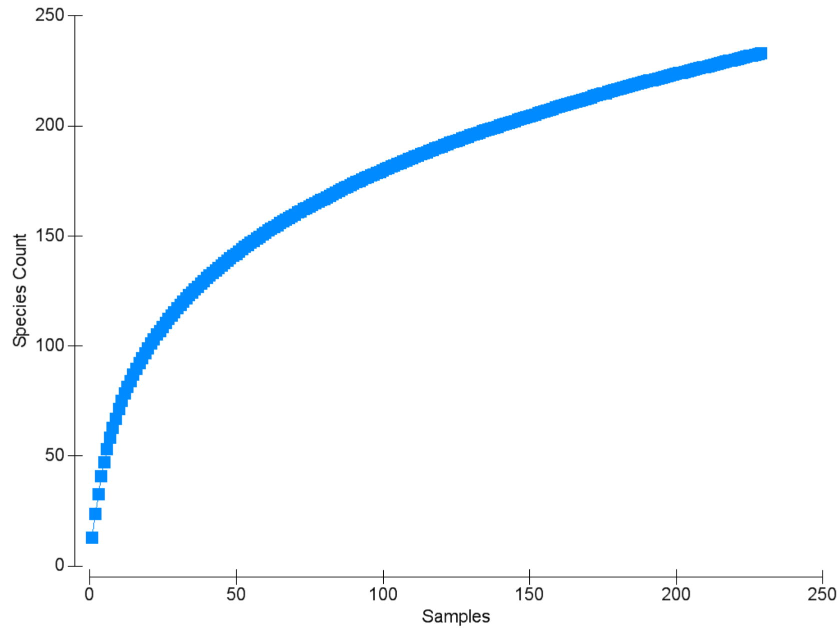

Figure 5.1.4 Species accumulation curve, number of species versus number of samples taken during DEBI project.

to salinity, with freshwater and oligohaline stations grouped together on the left, mesohaline concentrated in the middle and polyhaline and euhaline falling together to the right. Figure 5.1.5B is the same ordination (i.e., the pattern of station points is identical), but the color key represents sediment grain size measured as percent sand. Sandy, silty-sand and silty sites are not separated, but intermixed and not clearly related to species composition, thus sediment composition is not simply associated with broad patterns in species composition. As was found using simple diversity metrics, salinity is the dominant factor correlated with benthic community structure.

Additionally, MDS ordination plots of benthic assemblages can be used to investigate the benthic response to stressors. Figure 5.1.6 shows four such ordinations (with points identical to those already shown) with the symbol size representing the level of each of two potential stressors: dissolved oxygen near bottom and total organic carbon. Figure 5.1.7 shows another two potential stressors: cadmium and chromium. Dissolved oxygen measured near the bottom was in all cases 4.4 mg/l or greater (Table 5.1.2), and it is not surprising that there is little association of bubble size with stations clusters or broad patterns in the ordination in figure 5.1.6A. Total organic carbon show larger bubbles associated with stations in the upper and lower Bay (Fig 5.1.6B), likely associated with fine sediments (compare with Fig 5.1.5B). A distinct association of high metal concentrations and benthic assemblages and stations is apparent in both figures 5.1.7A and 5.1.7B as a knot of large bubbles associated with lower salinity stations (Fig 5.1.5B). This suggests that metal concentrations may be affecting benthic assemblages at these stations and that further analysis is warranted.

Dominance curves can likewise be used to investigate patterns in benthic fauna. Potentially disturbed or polluted assemblages have been found to be dominated by a few but abundant species (Warwick 1986, Warwick and Clarke 1994, Elliott and Quintino 2007). Figure 5.1.8 shows these lots for DEBI species data pooled by salinity (A) or sediment class (B) or both jointly (Fig 5.1.9). The plots show the cumulative percent of individuals for the most abundant species, the second most and so on, by species. A gradual rise to 100% is apparent for these categories, for all sediment classes (Fig 5.1.8B) and mesohaline, polyhaline and euhaline classes, while oligohaline and freshwater curves show higher dominance, higher curve on the left side (Fig 5.1.8A). When jointly classified (Fig 5.1.9) the oligohaline-silt and fresh-silt stations show high dominance, considerably greater than that of the rest of the salinity-sediment classifications.

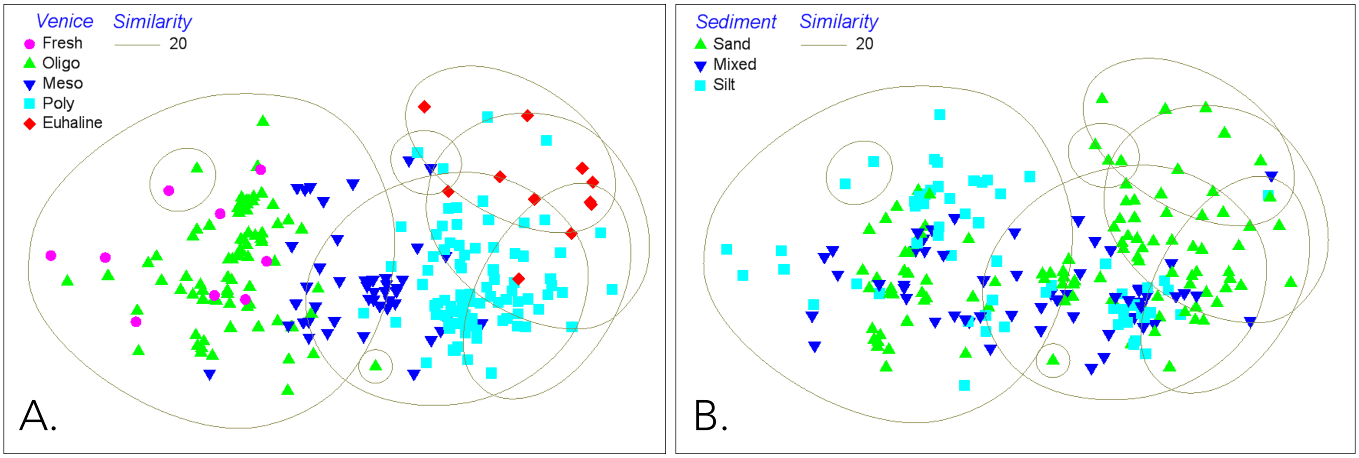

Figure 5.1.5 MDS ordination analysis showing species similarities based on A) salinity zones and B) sediment types.

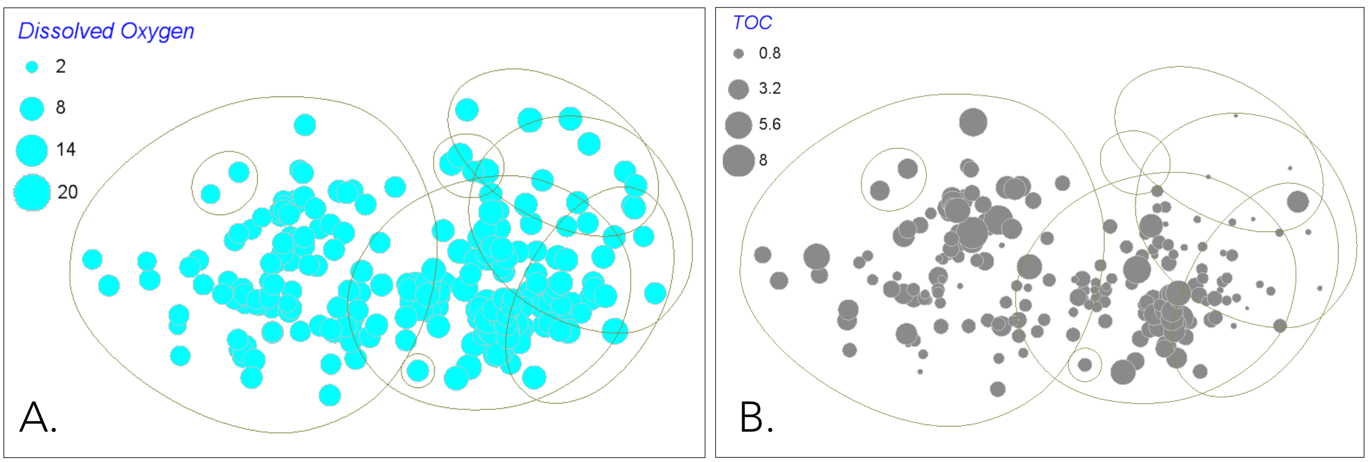

Figure 5.1.6 MDS ordination analysis showing species similarities based on A) dissolved oxygen concentrations and B) total organic carbon.

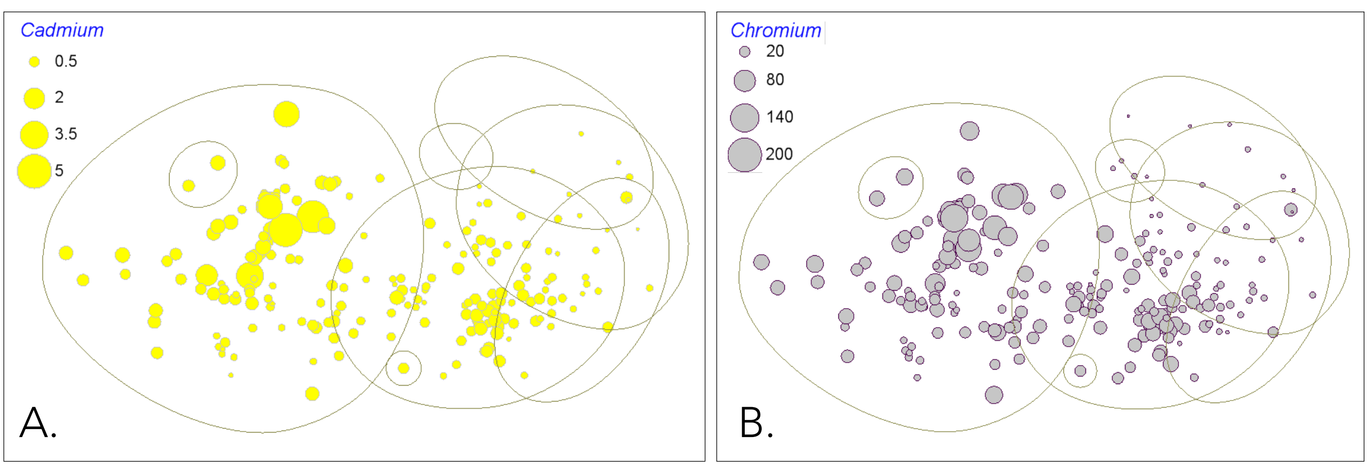

Figure 5.1.7 MDS ordination analysis showing species similarities based on A) Cadmium concentrations and B) Chromium concentrations.

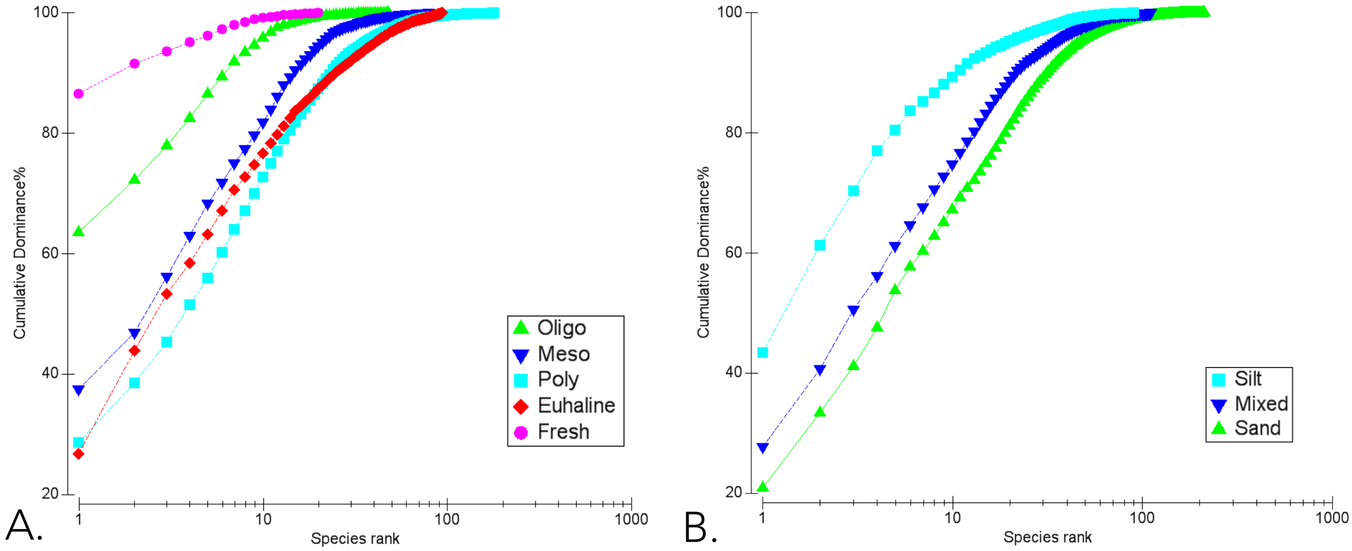

Figure 5.1.8 Dominance curves for DEBI species data, pooled by A) salinity and B) sediment class.

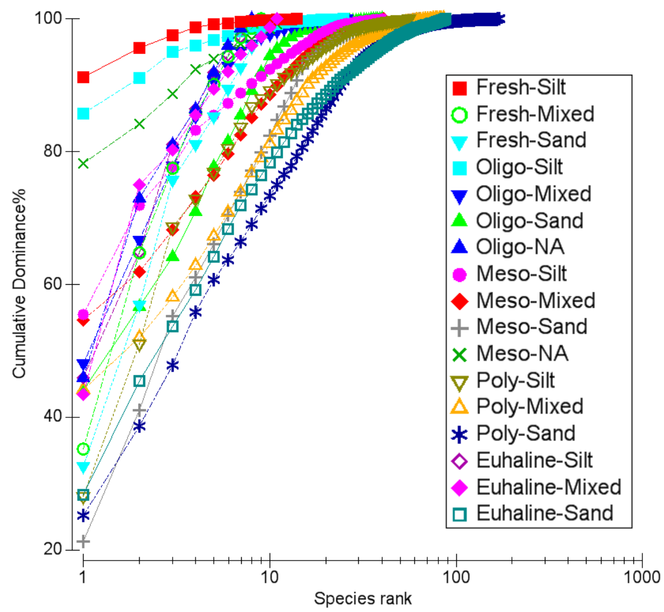

Figure 5.1.9 Dominance curves for DEBI species data pooled by salinity and sediment class.

Biomass curves can also be used to identify disturbed or polluted conditions: the cumulative percent biomass by species rank is superimposed on the dominance curve in a combined abundance-biomass comparison (ABC; Fig 5.1.10) plot. In unpolluted conditions, the biomass curve lies above the abundance curve (Warwick 1986, Warwick and Clarke 1994, Elliott and Quintino 2007), representing an assemblage with many species of moderate abundance and biomass dominated by a few large species, and this interpretation is consistent with that of the classical Pearson and Rosenberg (1978) paradigm (see also Gray and Elliott 2009). In disturbed or polluted conditions, a few but abundant, yet small species dominate (i.e., the large species are eliminated), and the abundance curve lies above that of the biomass. For the DEBI data, fresh and silt ABC curves (Figs 5.1.10A and 5.1.10B) are inverted, in comparison to mesohaline and sand (Figs 5.1.10C and 5.1.10D). Inversion of the ABC curves is also clearly apparent in the fresh-silt and oligohaline-silt curves (Figs 5.1.10E and 5.1.10F), and these stations are located in the C&D Canal to state-line region (and

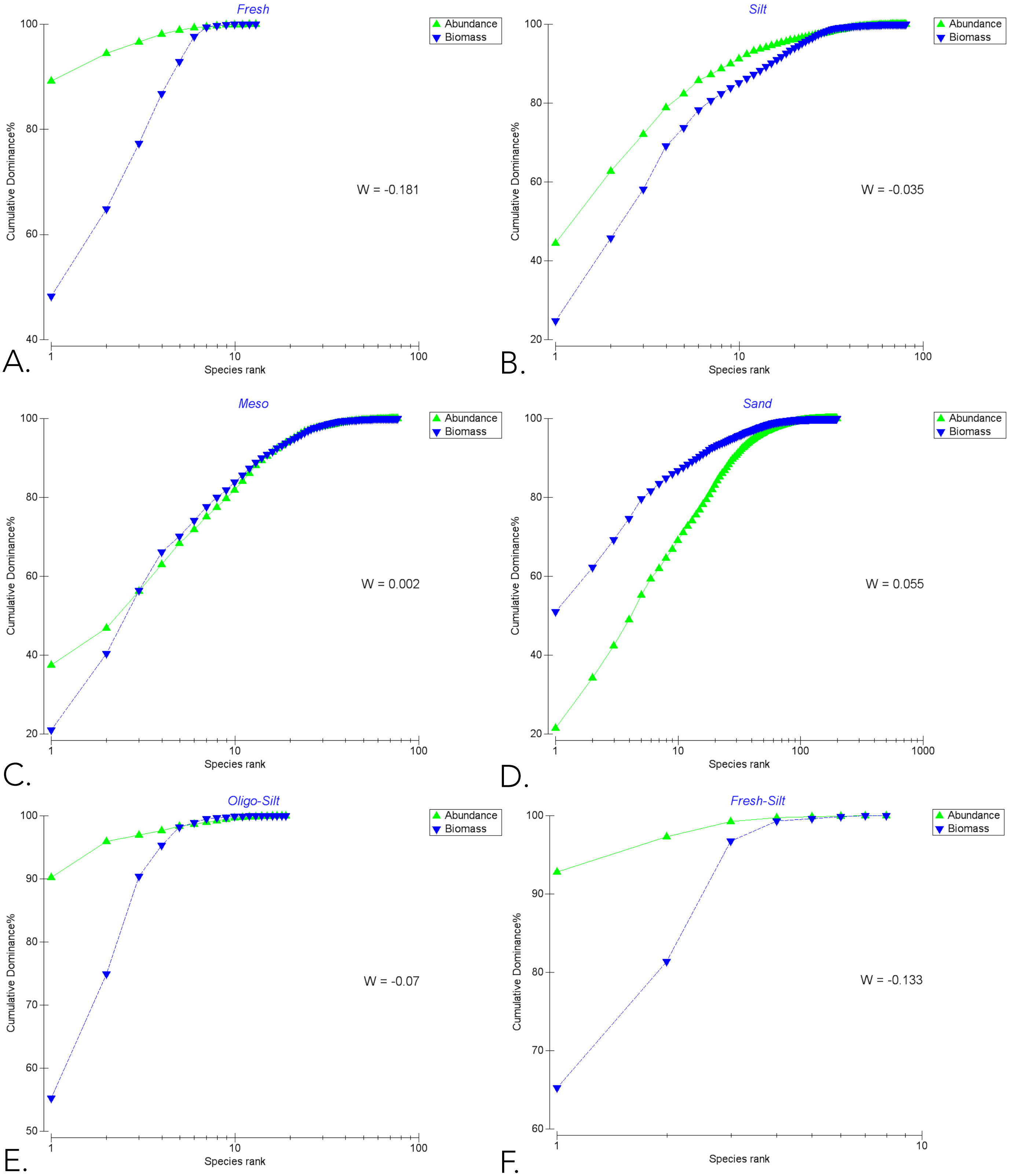

Figure 5.1.10 Abundance-biomass curve for A) freshwater stations B) silty sediment stations, C) mesohaline stations, D) oligohaline and sandy stations, E) oligohaline and silty sediment stations, and F) fresh-silty sediment stations.

within DRBC's Zone 5) of the estuary. Especially as this area has been characterized as degraded in benthic condition in past studies, these patterns at these stations merit further investigation.

The conclusions from this analysis are that broad-scale estuarine patterns are as expected for a temperate Atlantic estuary and that the soft-bottom benthic diversity of the Delaware has been sampled to a reasonable though, not exhaustive, extent. Bay-wide, salinity drives the patterns among benthic assemblages to a greater degree than sediment composition, and that high metal concentrations are associated with assemblages at certain stations. Further analysis within salinity and sediment classes reveals assemblages highly dominated by a few, abundant species, which also exhibit inverted abundance-biomass curves, further suggesting disturbed or polluted conditions. In summary, while these overall patterns among the benthic fauna are as expected in terms of abundance, diversity and biomass, stations in the C&D Canal to state line region (DRBC's Zone 5) are distinct in their assemblages, associated with high metal concentrations and have abundance and biomass curves consistent with polluted conditions. This region has been characterized as degraded in past studies on benthic assemblages.

5.1.4 Past Trends

Starting in the early 1950's, there is an extensive history of scientific benthic study in the Delaware River and Estuary (Table 5.1.1). Since 1990, surveys have used probabilistic designs for station selection (i.e., Fig 5.1.3) as well as consistent methodologies for sample collection and processing, faunal identification and taxonomy, and data summary and compilation. Specifically, there have been five separate federal programs using the benthos as indicators in Delaware Bay. Conclusions from the early 1990 Environmental Monitoring and Assessment Program (EMAP) survey are reported in Sutton et al. (1996). According to the EMAP benthic index, 93% of the area of the tidal river has benthic communities classified as degraded (68% area) or severely degraded (25% area, see Sutton et al. 1996 Fig 7-14 on page 116). In comparison, only 2% of the Bay's area south of the C&D canal was degraded, and no stations were severely degraded. Several benthic indices have been applied to Delaware Bay stations as part of the broader-scale, National Coastal Assessment (NCA) studies beginning in 2000. Using the Virginian Province Benthic Index and 2000-2001 data, 34% of the stations were rated "good," 29% "poor," and 37% "missing," and this mixture of conditions was found throughout the Bay and River (USEPA 2006).

In addition to the federal studies, there are "historical" surveys undertaken by Amos in the 1950's and Maurer and colleagues in the 1970's (Table 5.1.1). In total, sampling has been reported at nearly 900 stations, and the total number of species reported from these studies is consistently 200 or more (cf. Fig 5.1.4), with the mean (over stations) total abundances (number of organisms per meter squared) in the expected range of 1000 – 10,000 per square meter, although two surveys reported abundances well below 1000 per square meter. In particular, low abundances were noted by Maurer et al. (1978), wherein they concluded that low abundance reflected low benthic productivity in the Delaware Bay. Low abundance could equally be explained by their use of a 1-mm mesh sieve as compared to the 0.5-mm mesh (a smaller sieve retains more, smaller fauna) used in the present DEBI 2008 sampling as well as other recent federal surveys), although Maurer et al. (1978) discuss this point and explicitly discount this explanation in their report. The reason(s) for the low mean abundance reported by Hartwell and by Hale are not resolved at present. Future studies by comparing abundance of large species and small (i.e., those not expected to be completely retained by a coarse sieve) selectively, may make it possible to confirm a sieve-bias explanation for at least the Maurer et al. (1978) results.

All or most of the federal data are hosted online although distributed over several federal agency web sites and presented in various data formats. In most cases, data are tabulated as species abundances, and fortunately the consistency of sampling, laboratory analysis and ready availability of these data will allow synthesis by modern statistical techniques. Any trends in these data over the past 30 years should be resolvable once challenges of data formatting and merging are overcome.

5.1.5 Future Predictions

Summary plots of diversity, faunal assemblage ordinations and dominance plots above show that likely sufficient sampling has been conducted to facilitate development of conclusions and that broad, estuary-scale patterns are as expected based on typical estuarine patterns of diversity. It is important to note that the federal agencies have routinely included stressor variables, such as dissolved oxygen, organic carbon, heavy metals and organic pollutants in their measurement suite (Table 5.1.2). These individual surveys have consistently assessed the benthos in light of possible stressors, yet there have been few if any attempts at cross-survey synthesis of these data to assess trends in benthic community structure and condition over time.

5.1.6 Actions and Needs

The ready availability of extensive data clearly justifies a cross-survey analysis of the past 30 years. Additional effort will be required to determine if differences among data sets are due to a sampling design (spatial allocation of locations) or sampling gear-bias (especially sieve mesh size) or truly represents significant change in estuary conditions. Only limited, broad conclusions can be drawn from the simple data summaries and plots presented here. Further analyses using multivariate methods like multi-dimensional scaling and dominance curves may reveal patterns and relationships impossible to discern among multiple possible natural variation and anthropogenic effects. Effective analysis of these benthic data will require additional effort to identify sensitive and tolerant species, reference and control sites (to develop customized and calibrated indices), and the application of more sophisticated multivariate, phylogenetic/taxonomic structural analysis or regression-based species distribution modeling.

5.1.7 Summary

The benthos of Delaware River and Estuary has been extensively studied and well characterized in surveys conducted over the past 60 years. The most recent, 2008 DEBI survey, represents a firm baseline demonstrating patterns in diversity similar to those found before and typical of temperate estuaries. Overall patterns among the benthic fauna are as expected in terms of abundance, diversity and biomass, but stations in the C&D Canal to state line region are distinct in their assemblages and associated with high metal concentrations. The current DEBI survey data are consistent with other recent studies employing standardized methodology and refute previous conclusions that the Bay's fauna is depauperate and unproductive. The availability and congruence of several previous data sets with the current DEBI results clearly justifies a cross survey analysis of all of the data from the past 30 years. Further effort will be required to determine if perceived differences may be due to sampling gear-bias issues, sampling locations differences, or represents real and significant changes in estuary conditions. Effective analysis of these data will require additional effort to identify sensitive and tolerant species, reference and control sites, and the application of more sophisticated multivariate, structural (i.e., phylogenetic/taxonomic) or regression-based species distribution modeling.

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5.1.8 Delaware Bay Benthic Mapping Project

Bartholomew Wilson, P. G., PhD • North Atlantic Coastal Resiliency Coordinator • U.S. Fish and Wildlife Service

Through an integrated effort by the Delaware Coastal Programs and the University of Delaware, a benthic and sub-bottom imaging project to identify and map the benthic habitat and sub-bottom sediments of Delaware Bay and River was initiated in 2004. This project would not have been possible without the following partners: University of Delaware Geosciences Department, Delaware Fisheries Section, Delaware Shoreline and Waterway Division, Delaware State University, Partnership for the Delaware Estuary, New Jersey Department of Environmental Protection, and New Jersey Shellfish Bureau.

This project integrates the use of three types of acoustical systems: Roxann Seabed Classification System, CHIRP sub-bottom profiling, and multi-beam bathymetric mapping. Verification of the acoustic data with bottom and sub-bottom sediments is performed through the collection of grab and core samples and underwater video images.

This effort has resulted in many major milestones, which include: mapping over 906 square km, identifying the spatial extent and relative density of the oyster and *Corbicula* beds, identification of borrow sites for beach replenishment, facilitating a greater understanding of the local and regional sediment distribution patterns and pathways, locating key habitats for species (such as: Atlantic Sturgeon, sharks, and *Sabellaria vulgaris*), and starting to understand the relative impact that humans have upon the bay bottom and its living resources. Most importantly integrating the bottom and sub-bottom sediment with species tracking information, in a 3D GIS environment, has provided a new opportunity to assess the habitat relationship between Atlantic Sturgeon and several key regions in the Delaware River.

The program has many accomplishments including an integration of the benthic and sub-bottom data was used to identify sand borrow sites within the Delaware Bay that are located in areas that minimize the impact upon essential fish habitat (especially *Sabellaria vulgaris* habitat). Borrow sites have been located for three coastal communities, and will determine sand resources for 4 additional coastal communities. In addition, the project has worked with The Nature Conservancy (TNC) and the Partnership for the Delaware Estuary to develop benthic habitat maps for the Delaware Estuary. In September 2011, TNC produced a report entitled; Delaware River Basin Priority Conservation Areas and Recommended Conservation Strategies (http://nj.gov/drbc/library/documents/DEbasin-priority-areas_2011NFWF.pdf). In Appendix V; Benthic Habitats of The Delaware Bay, an attempt was made to create benthic habitat maps using bathymetry, salinity and seafloor substrate. Maps of Ecological Marine Units were created taking into account species data provided by the DEBI project.

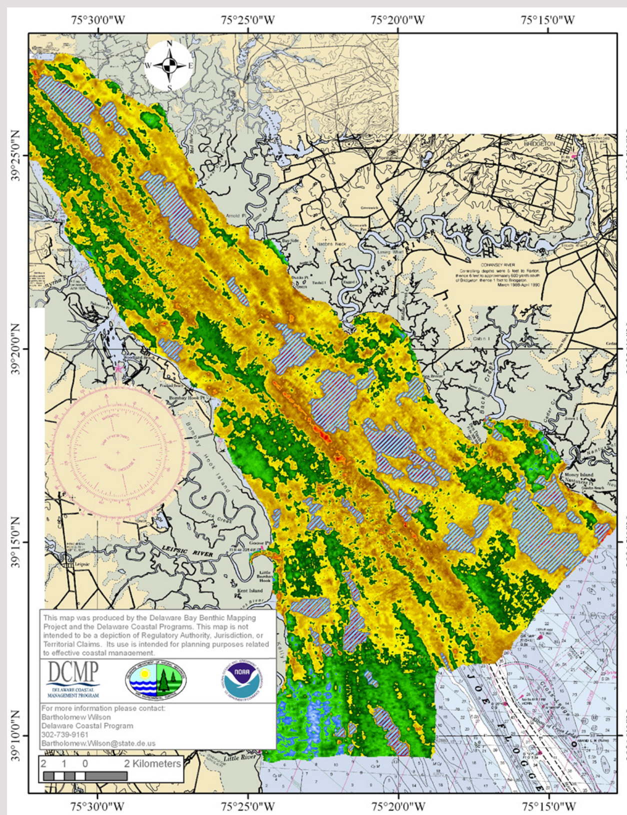

Figure 5.1.8.1 Bottom sediment map showing the distribution of sediments and locations of oyster beds over a 180 square mile area in the upper Delaware Bay Estuary. In this region, 40 distinct oyster beds were located.

5.1.9 Amos Historical Benthic Collection Analysis

Douglas Miller, PhD • Professor • University of Delaware College of Earth, Ocean, and Environment

The Delaware River Invertebrate Collection (DRIC) was the first scientific collection of benthic organisms for the Delaware River and Estuary. William H. Amos' handwritten 5" x 8" data cards along with preserved master specimens from the 1950's are currently housed at the University of Delaware in Lewes. Standing 25 cm (10") high when stacked vertically, these invertebrate cards were scanned for archival purposes in October, 2008 and later digitized.

The Amos DRIC includes over 5,500 records of nearly 400 species from over 130 stations within the Delaware River and Estuary. Information in a locality field in addition to uncovered charts promises to yield much more precise information for sampling locations. These data include collection of benthic organisms by trawl, dredge and Peterson grab, planktonic organisms by net and epifauna as part of the "buoy scrapes" sampling. Chronologically, these data represent mostly the years 1952-54 and 1956, and primarily July and August collections. Many records are included from the DelZoop plankton sampling that occurred several times a year from October 1951 through August 1953.

Amos identified over 400 taxonomic groupings of which about 396 represent species of invertebrates present in the Delaware River and Estuary. This estimate of species number is generally consistent with numbers Amos gave in University of Delaware Marine Laboratory annual reports. Any such "biodiversity" estimate is clearly provisional, depending on updated nomenclature, taxonomic confirmation, and assessment of the influence of sampling effort and gear bias.

Amos summarized his species distribution data in geographical form using a grid of 40 "sectors" including 37 over the main part of the bay from Philadelphia south, in the bay or just outside, plus Rehoboth Bay, Indian River Bay, and the Lewes & Rehoboth Canal. Samples near Joe Flogger and the Leipsic River have the most records, likely reflecting the intensity of zooplankton sampling in that part of the bay. Sectors near Lewes Beach and the Bayside Lab, along the main channel in the lower bay, and at the Shears/Harbor of Refuge have over 200 records each. Most collections are from the main channel and lower Delaware side, and with the exception of the Nantuxent Point area, far fewer are from New Jersey waters.

In addition to representing a time in the history of the Delaware Estuary before major industrialization and development, these data present a uniquely comprehensive picture in terms of the functional group, life habit, and taxonomy of the fauna of the river and estuary. Hopefully now that this historical data set is digitized, scientists around the region will be able to access it and use it in their studies of the benthic ecology of the Delaware River and Estuary.

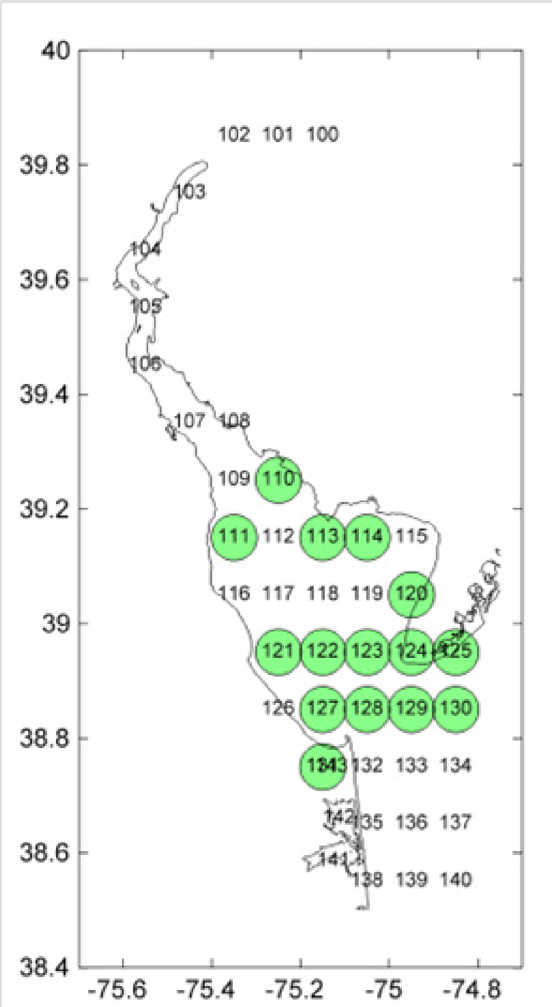

Figure 5.1.9.1 Map of Delaware Bay and Amos' grid used in his pioneering benthic study. Green bubbles show the number of record for the sand builder worm (*Sabellaria vulgaris*).

5.2 Intertidal Habitats

LeeAnn Haaf[1], Danielle Kreeger[1], and Andrew Homsey[2]

1. Partnership for the Delaware Estuary; 2. University of Delaware

5.2.1 Introduction

Tidal wetlands, or marshes, are aquatic habitats which occur in the intertidal zone between open water and upland areas not directly exposed to tidal exchange. Tidal wetlands of the Delaware Estuary extend along both shores spanning the broad salinity gradient from the head-of-tide near Trenton, New Jersey, and down to the mouth of Delaware Bay at Cape May, New Jersey, and Cape Henlopen, Delaware. These habitats undergo daily flooding and draining, and are therefore critical components in the sensitive interaction between land and water in the Delaware Estuary. The traditional definition of a wetland requires that vegetation be present, typically vascular plants. For management purposes, state and federal agencies might also consider many types of non-vegetated aquatic habitats as wetlands, such as shallow ponds, mud flats, and some areas dominated by benthic algae (e.g., Cowardin classification system). But, for the purposes of this report, the principal focus is on vegetated tidal wetlands, which are a hallmark habitat within the Delaware Estuary.

Tidal wetlands are among the most productive habitats in the world and they perform a wide variety of vital services. They are critical to protecting inland areas from tidal and storm damage, provide water storage to protect against flooding, provide important habitat to a wide variety of wildlife, including waterfowl, serve as a filter to remove pollutants and help sustain water quality, provide spawning and nursery habitat to support commercial fisheries, support recreation, and provide aesthetic value. Tidal wetlands are therefore regarded as the most critical habitat type in the Delaware Estuary for supporting broad ecological health. Assuring that these wetlands remain intact and continue to provide these critical functions is therefore fundamental to the protection and the overall quality of the Delaware Estuary and the Delaware River Basin as a whole.

The largest portion of tidal wetlands are composed of salt marshes fringing Delaware Bay, dominated by smooth cordgrass, *Spartina alterniflora* (Fig 5.2.1A). Smaller high salt marsh areas are composed of salt-tolerant grasses (e.g., *Spartina patens* and *Distichlis spicata*) and scrub/shrub vegetation. In the upper estuary and in headwater areas of tidal rivers and creeks, nationally rare communities of freshwater tidal vegetation can be dominant wherever salt concentrations are below 3 ppt (Fig 5.2.1B). These freshwater

Figure 5.2.1 Types of tidal wetlands in the Delaware Estuary: A) salt marsh dominated by smooth cordgrass in Cape May County, New Jersey; and B) tidal freshwater marsh, with spatterdock in the foreground, along Crosswicks Creek, in Mercer County, New Jersey. Photo credit: LeeAnn Haaf and Kathleen LaForce, Partnership for the Delaware Estuary.

tidal wetlands consist of marshes dominated by herbaceous plants (i.e. emergent marshes), but there are some scrub/shrub and forested tidal wetlands as well. Typically, freshwater tidal emergent marshes contain a greater number of species than salt marshes; a few diagnostic species are annual wild rice (*Zizania aquatica*), and low marsh forbs such as spatterdock (*Nuphar lutea*) and arrow arum (*Peltandra virginica*).

5.2.2 Description of Indicator

The science and management community of the Delaware River Basin elevated tidal wetland extent and condition as top priorities for monitoring and management, considering these habitats as one of our leading environmental indicators for the Basin as a whole (Kreeger et al., 2006). Efforts via the Mid-Atlantic Coastal Wetland, established in 2010, to assess the condition (specifically rapid assessments and long term monitoring) of tidal wetlands across the Delaware Estuary have been ongoing (Kreeger et al. 2011).

National Wetlands Inventory Data on wetland distribution were gathered for each state from the U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI). The NWI is a nationwide program which seeks to inventory the nation's wetlands. The NWI provides detailed, consistent, high resolution data that enables clear differentiation of wetland types and flooding regimes; however, it is of limited value in trend analyses for the whole system because of the different times that data are collected in different states and areas. For instance, the latest NWI data in New Jersey are from approximately 2002 to the north and 1999 to the south; in Delaware 2009; and new to this report, Pennsylvania in 2015.

Despite shortcomings in the temporal scale, NWI is field verified and provides high quality distribution data on specific wetland types. This makes these data most suitable for assessing the current status of wetlands at the spatial scale. To determine the current extent of the various types of wetlands in the Estuary, the latest of each of three state-wide NWI datasets were categorized using the classification scheme developed by Cowardin (Cowardin, 1979). A simplified classification was developed to allow for a synoptic assessment of status of broad categories with special attention to the differentiation of freshwater and salt water intertidal wetlands (Table 5.2.1).

Land Cover Data Determination of the landscape level changes in different wetland types of the Delaware Estuary requires consistent data in both space and time. Since NWI could not be used for this purpose due to inconsistent temporal scales, changes in wetlands over time (trends) were deduced using land cover data derived from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC). These data are derived from Landsat imagery at a 30m ground resolution.

Categories of wetlands distinguished by the CSC land cover are: Palustrine Forested, Palustrine Scrub/Shrub, Palustrine Emergent, Estuarine Forested, Estuarine Scrub/Shrub, Estuarine Emergent, Unconsolidated Shore, and Palustrine Aquatic Bed. CSC land cover data 1996, 2001, 2006, and 2010 were used. Of these six land cover categories provided by CSC, only one category (estuarine emergent) consists wholly of tidal wetlands (i.e., salt marshes). Although CSC Landsat data are most useful for trend analyses, these data have limited resolution and are not ground-truthed like the NWI datasets. For example, CSC land cover data cannot discern various degrees of flood frequency among wetland types. Previous comparisons of the wetland categories of the CSC land cover data with NWI, however, indicates that the data are comparable to a relatively small percent difference, especially for estuarine emergent wetlands. Therefore, only CSC data were used to assess trends in this tidal wetlands report.

5.2.3 Present Status – NWI Data

Wetlands cover a significant portion of the Delaware Estuary and River Basin (Fig 5.2.2). From expansive salt marsh complexes in the lower part of the Estuary, to isolated wetlands and ponds in the upper riverine reaches, wetlands are an important part of the ecology and hydrology of the watershed. In all, there are 413,000 acres (167,000 hectares) of wetlands (tidal and nontidal) in the Delaware Estuary, representing

Table 5.2.1 Simplified Cowardin classification codes of intertidal wetlands based on NWI categories.

Code	Category	Description
SAITEM	Saline, emergent vegetation	Category includes the typical "salt marsh" characterized by salt tolerant grasses. This is the predominant intertidal wetland type in the Delaware estuary.
SAITV	Saline, other vegetation	Vegetation other than salt-tolerant grasses, including scrub/shrubs and forest. Typical "high-marsh" habitat.
SAIT	Saline, not vegetated	Non-vegetated intertidal area. Comprises mudflats, pannes, unconsolidated shoreline, and beaches. An increase in this indicator typically accompanies a degradation of salt marshes, due to vegetation loss, subsidence, and/or sea level rise.
FRITEM	Fresh, emergent vegetation	Typical fresh water tidal wetlands characterized by emergent vegetation. Generally occur farther up the estuary, or landward of salt marshes in the lower estuary.
FRITV	Fresh, other vegetation	Fresh water tidal wetlands, including scrub/shrub and forested wetland types.
FRIT	Fresh, not vegetated	Non-vegetated fresh water tidal wetlands. Generally comprises only a small portion of intertidal wetlands.

about 5.1% of the total land area. Of all wetlands in the Delaware Estuary, 39.9% (165,000 acres; 66,800 hectares) are tidal wetlands and, of those tidal wetlands, 89.4% are salt marshes. As of 2009, there were a total of 110 million acres (44.6 million hectares or 5.5% of the total land area; USFW, 2011) of wetlands in the conterminous United States, of these, 5% were estuarine. Total wetland density within the Delaware Estuary and River Basin is similar to national values (i.e. 5.1%). Estuarine wetlands within the Delaware Estuary represent nearly 7% of the estuarine wetlands found along the Atlantic sea board, from Maine to the eastern coast of Florida (~2.4 million acres; Dahl and Stedman 2013).

Areas of tidal wetlands will be considered separately by states in which they are found in the Delaware Estuary (PA, NJ, and DE). The following figures illustrate the status of wetland acreage based on the latest NWI data for each state (Figs 5.2.3-5.2.5).

5.2.4 Past Trends – CSC Data

Historical losses in the Delaware Estuary occurred primarily due to the development and conversion of wetlands for agriculture or other purposes. Despite increased regulatory oversight and "no net loss" policies that have greatly slowed rates of wetland conversion, we continue to lose all types of wetlands within the Delaware Estuary and Basin. Indeed, the pace of loss for some types of wetlands might be increasing due to a mix of factors (e.g. sea level rise, climate change, erosion). The focus of this analysis was to examine trends in wetland acreage within the past two decades (1996-2010) because we do not have resources or datasets to carefully document earlier declines.

More than 4,096 acres (1,658 hectares) of palustrine wetlands and more than 2,720 acres (1,100 hectares) of estuarine wetlands were lost in the Delaware Estuary during the fourteen year study period (1996-2010;

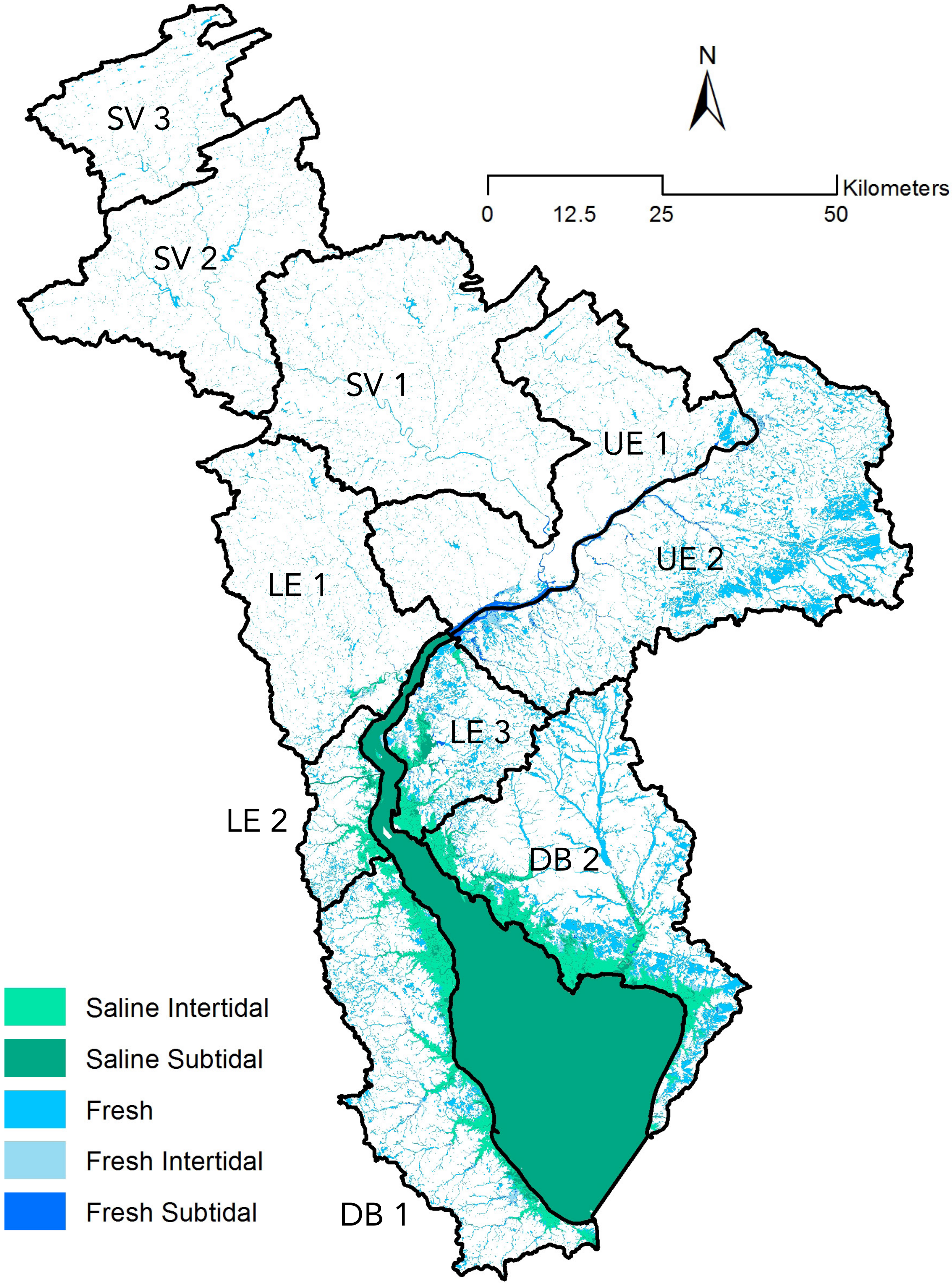

Figure 5.2.2 Latest NWI wetland layer for the lower Delaware River Basin. The estuarine basin was divided into 10 sub watersheds (sub-sheds) which correspond to the Upper Estuary (UE), the Schuylkill Valley (SV), the Lower Estuary (LE), and the Delaware Bay (DB).

Table 5.2.2 and Figures 5.2.6-5.2.7). Although losses in the Upper Estuary add up to smaller acreage, losses are proportionately larger, and they are nevertheless important considering their benefits to people, fish and wildlife, and water quality in the urban corridor.

Between 1996-2010, tidal wetlands have declined in acreage across the delaware Estuary, including both palustrine (-1.02%; -293 acres or -119 hectares per year) and estuarine (-1.77%; -194 acres or -79 hectares per year) wetlands (Table 5.2.2). The largest estuarine wetland losses were in the lower New Jersey Bayshore (denoted Delaware Basin 2, or DB2), which saw a decrease of 1,915 acres (3.08%; 775 hectares) and along the Upper Estuary (UE2, New Jersey) which saw a decrease of 414 acres (10.95%; 168 hectares). Estuarine wetlands in Delaware also experienced a large decline in downstream watersheds (LE2 and DB1; corroboration of findings in Tiner et al., 2011). Palustrine wetlands (tidal and nontidal) also saw a decline across the Estuary. Interestingly, there was one watershed area that experienced a net increase in tidal wetland extent between 1996 and 2010, which was the Lower Estuary watershed region in New Jersey (Table 5.2.2), which is discussed in Callout Box - 5.2.9. Another area of note is the PSEG restoration site on the west bank of the mouth of the Maurice River (Weishar, et al. 1998; Philipp, 2005), which may also be experiencing small increases in vegetated area. Although these small gains are good news and may reflect progress on restoring tidal wetlands, they are overshadowed by the ongoing cumulative losses of tidal wetlands throughout other areas of the Delaware Estuary. Figures 5.2.6 and 5.2.7 illustrate the trends for salt marsh (estuarine emergent) and palustrine (vegetated freshwater) wetlands from 1996 to 2010.

5.2.5 Mechanisms of Loss

There are many reasons why we continue to lose tidal wetlands in the Delaware Estuary. A recent examination of coastal wetland stressors (USEPA, 2015) cited a mix of deleterious practices such as mosquito control ditching, incremental filling, lack of regulatory oversight, regulatory loopholes for developers, shoreline hardening, hydrological alterations such as dredging, and pollution. These same stressors likely also contribute directly to wetland losses in the Delaware Estuary. In addition, increased rates of sea level rise and the spread of invasive species also contribute to the decline of coastal wetlands.

Riter and Kearney (2010) reported findings from satellite imagery, which suggested that marshes in the system are showing decreasing amounts of vegetative cover and increasing proportions of open water. Their effort updated the earlier study by Kearney et al. (2002) of both Chesapeake and Delaware Bays, which suggested that more than two-thirds of the salt marshes studied were in degraded condition, a sign of anticipated loss in the near future. Rapid shoreline erosion, measured at rates of up to 6 meters per year (Fig 5.2.8), also poses a significant threat to the sustainability of tidal wetland acreage in the Delaware Estuary. Plausibly, the erosion and loss of some wetlands might be helping to sustain others by subsidizing sediment supplies, but the net balance is still negative per year as determined by decreasing acreage, continued shoreline retreat, and lower overall vegetative cover.

The largest attribute of intertidal wetland loss is conversion to open water, which is the resulting effect of shoreline erosion and interior marsh drowning. Nationally, 96.4% of tidal wetland losses were due to conversion to open water, with about 3.5% attributable to human effects in the upland areas (Stedman and Dahl, 2008). Wetland loss from direct human influence is relatively small, but their impacts particularly on the quality of coastal ecosystems have undoubtedly been significant. Over 53% of the U.S. population lives in coastal counties, which make up only 17% of the land area of the conterminous U.S. (Crossett, et al., 2004). Development pressures and concomitant stresses on coastal systems are considerable and will likely increase. Since the advent of protections afforded by provisions in the 1972 Clean Water Act, direct loss of wetlands has slowed considerably; however, the effects of development still have detrimental impacts to estuarine environments. In the Delaware Estuary, human pressure by population growth, development, pollution, and/or land management will likely continue to have net negative effects on wetland acreage unless aggressive intervention strategies are implemented. These issues will also be exacerbated with

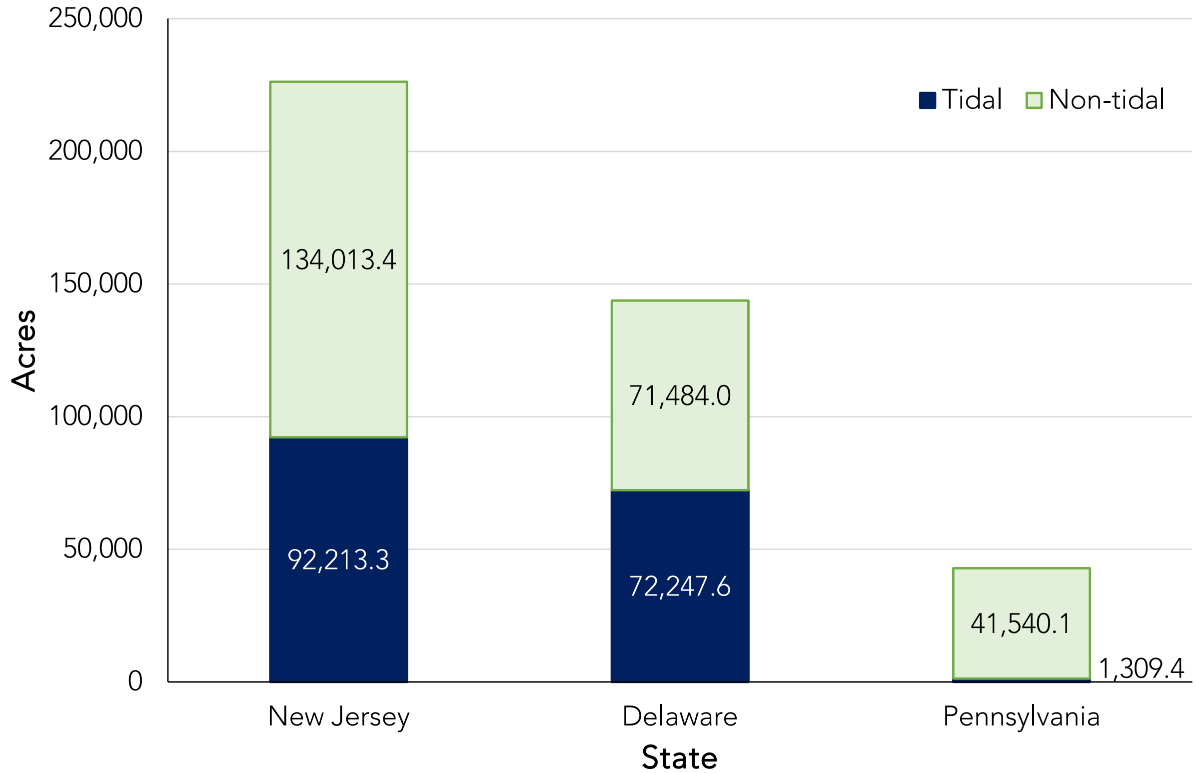

Figure 5.2.3 Proportion of tidal and nontidal wetlands by state in the Delaware Estuary (from NWI data).

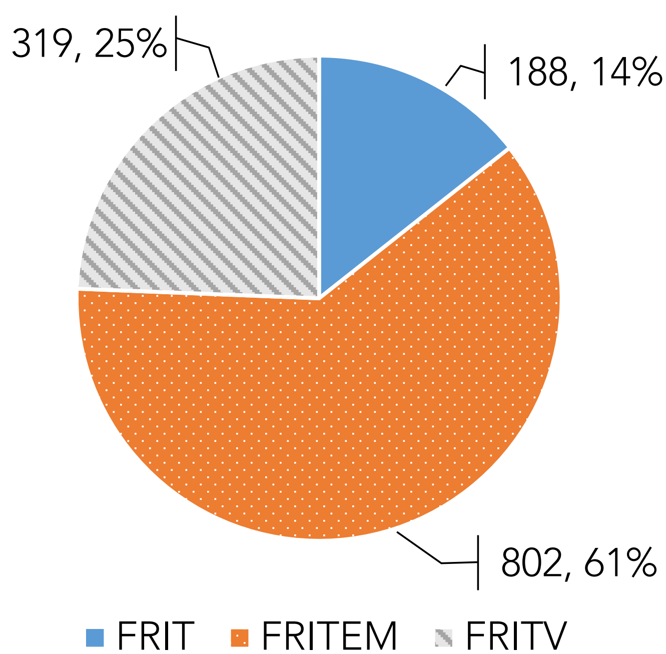

Figure 5.2.4 Proportion of the types of tidal wetlands in Pennsylvania, which are predominately freshwater. For descriptions of types, see Table 5B.1. Labels are acres, percent. These NWI data are as of 2015.

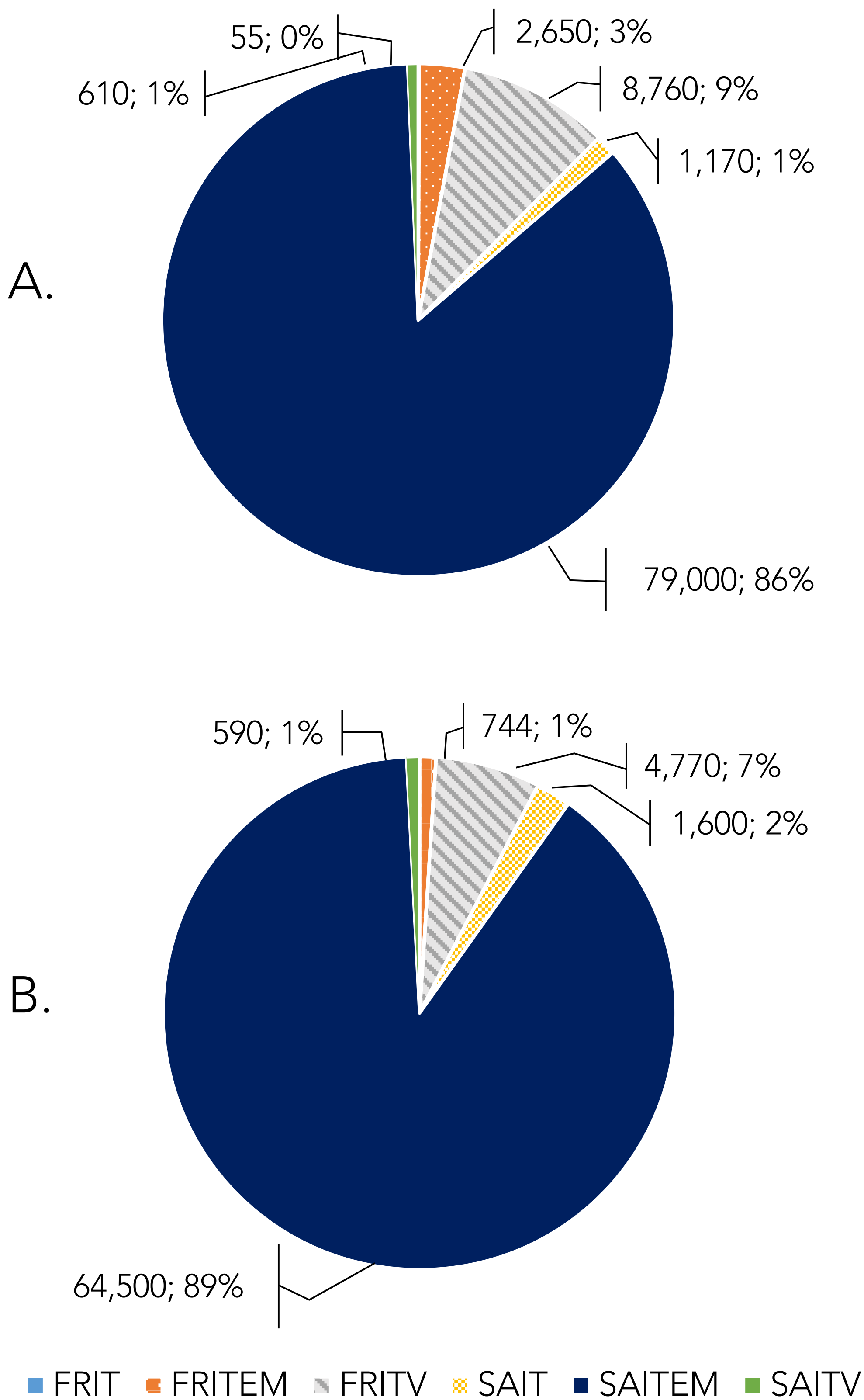

Figure 5.2.5 Proportion of the types of tidal wetlands in A) New Jersey and B) Delaware. These NWI data span the years of 1999-2002 in New Jersey and 2009 for Delaware. For description of types, see Table 5.2.1. Labels are acres, percent.

A.

B.

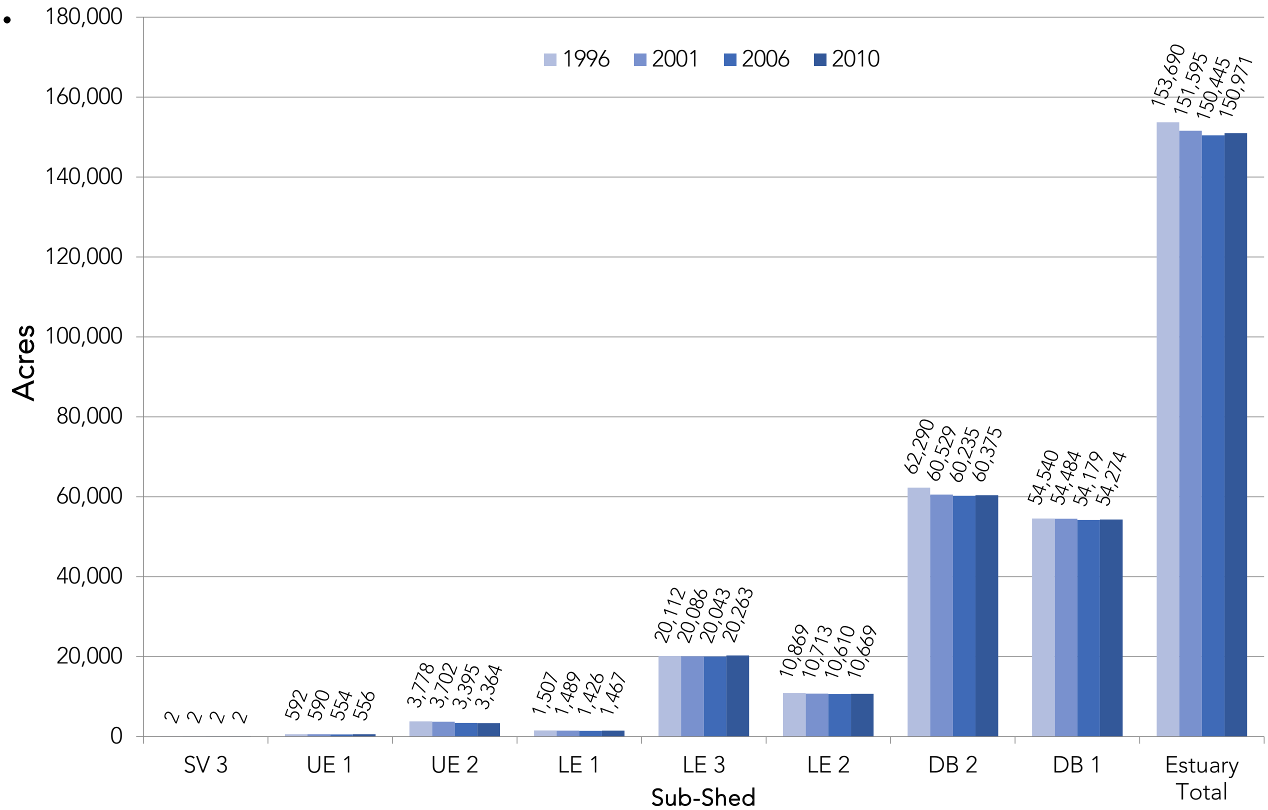

Figure 5.2.6 Total acreage of A) palustrine and B) estuarine wetlands in the Delaware Estuary by sub-shed (see Fig 5.2.2 for sub-shed locations) from 1996-2010.

Table 5.2.2 Change in palustrine and estuarine wetlands in the Delaware Estuary from 1996-2010 (see Fig 5.2.2 for sub-shed locations).

Sub-shed	Palustrine		Estuarine	
	Change (acres)	% Change	Change (acres)	% Change
SV 1	12.4	0.79%	0.0	0.00%
SV 2	-183.6	-3.08%	0.0	0.00%
SV 3	-255.5	-1.62%	-0.3	-14.74%
UE 1	-520.9	-3.48%	-35.2	-5.95%
UE 2	-1101.4	-0.84%	-413.9	-10.95%
LE 1	-327.7	-2.20%	-40.1	-2.66%
LE 3	-494.2	-1.48%	151.2	0.75%
LE 2	-114.1	-1.07%	-199.2	-1.83%
DB 2	-452.5	-0.40%	-1915.9	-3.08%
DB 1	-658.8	-1.13%	-265.2	-0.49%
TOTAL	-4096.2	-1.02%	-2718.7	-1.77%

climate change, so planning for negative, synergistic effects between sea level rise, storm frequency/intensity, and the human element will be crucial to sustaining coastal ecosystems.

A mechanism of regional concern is sediment management in the Delaware Estuary. Tidal marshes need ample sediment supplies to keep pace with sea level. The Delaware Estuary is a naturally muddy, wetland-rich system, but more sediments are removed each year through maintenance dredging than enter the system through surface runoff. Although there continues to be high suspended sediment loads in the water column and the overall budget (inputs and outputs) appears to be in balance (Walsh, 2011; Delaware Estuary Regional Sediment Management Plan, 2013), sediment studies suggest that the budget is currently subsidized by large inputs of sediments from eroding tidal wetlands. Tidal wetland loss through erosional forces is an ongoing and pervasive problem in the Delaware Estuary, especially in the Bay, where small coastal communities fight to keep their homes nearshore (e.g. Gandy's Beach; Fig 5.2.8). Organic sediments, like those derived from marshes themselves, may help sustain these systems now, but recent studies also suggest that mineral sediments, like those meant to be traveling downstream from the River, will become more important for marsh resilience with continuously increasing rates of sea level rise (Morris et al. 2016). Another regional concern is the effect of prolonged, high nutrient concentrations (Deegan et al. 2012; Turner et al. 2006). Salt marshes are naturally adapted for low nutrients; salt marsh grasses invest heavily in below ground production (i.e. roots and rhizomes) as a strategy for nutrient scavenging. Typically, this strategy contributes to peat accumulation and therefore elevation building with sea level rise. Nutrient loadings, however, may reduce below ground production, potentially impairing a marsh's ability to keep pace with sea level rise.

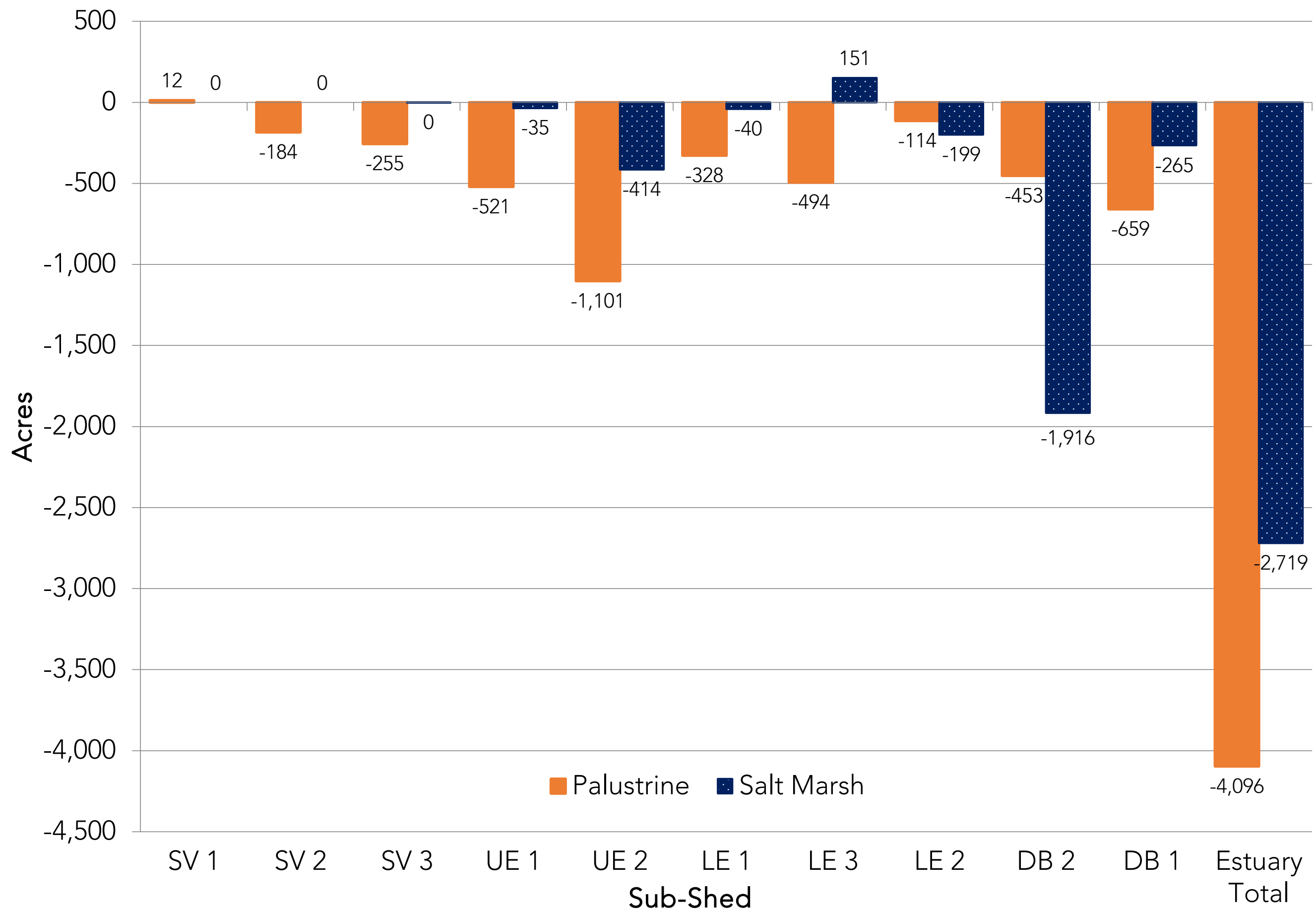

Figure 5.2.7 Total change of palustrine and estuarine wetlands in the Delaware Estuary by sub-shed (see Fig 5.2.2 for sub-shed locations) from 1996-2010.

5.2.6 Future Predictions

If the intensity and frequency of storms and associated tidal surges also increase with climate change, this could exacerbate the other threats and stressors discussed in Section 5.2.5. Warming trends are expected to boost the incidence of coastal storms, including nor'easters and hurricanes. On the other hand, a longer growing season and warmer temperatures are predicted to enhance primary productivity within smooth cordgrass dominated tidal wetlands (Kirwan, et al., 2009). A panel of wetland experts predicted, however, that the potential boost to primary production would be dwarfed by the threats posed by salinity intrusion and especially sea level rise (PDE, 2010). Moreover, all tidal wetlands face barriers to landward migration within the Delaware Estuary, most significantly in the Upper Estuary, which is more heavily urbanized (e.g. Wilmington, DE; Philadelphia, PA; Trenton, NJ). The potential for tidal wetlands to migrate landward is affected by habitat condition, slope, and degree of development. Areas that do not allow wetlands to easily migrate landward will need to accrete in place to preserve acreage (with little or no net shoreline loss) or subsequently drown.

By 2100 with a 1 meter rise is sea level, 119,000 acres (48,000 hectares) of irregularly flooded tidal wetlands were predicted to be lost based on model predictions from the Sea Level Affecting Marsh Model (SLAMM, V.6) (Kassakian, et al. 2017; Kreeger, et al. 2010). The loss of dry land and shrub-scrub habitat by migration was estimated to be 63,000 acres (25,500 hectares), but the conversion of marsh to open water was estimated to be 100,000 acres (40,000 hectares). Importantly, since no other habitat types rival tidal wetlands in productivity, the net loss of ecosystem services will be disproportionately large compared to acreage losses.

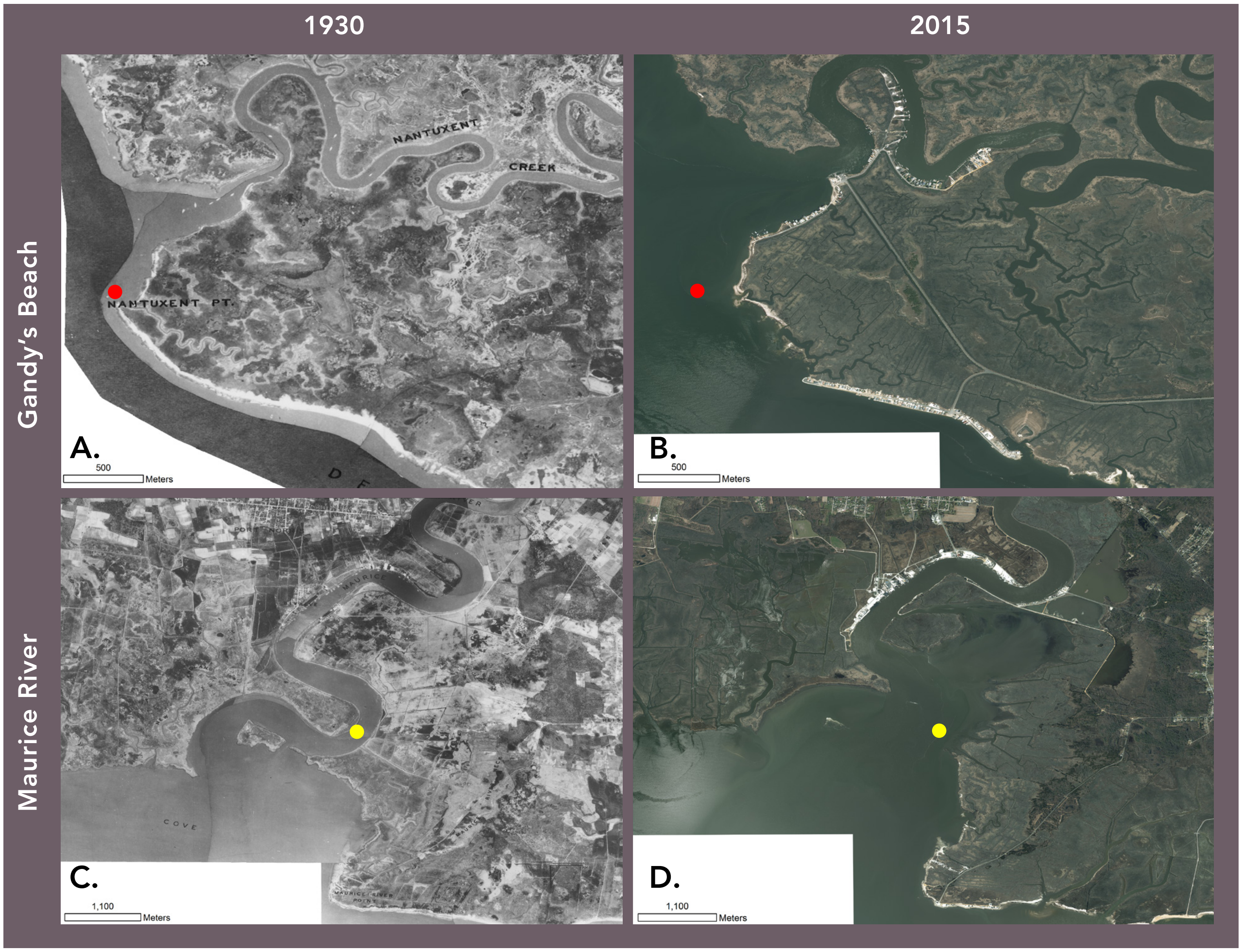

Figure 5.2.8 Aerial photographs of Gandy's Beach (A and B) and the mouth of the Maurice River (C and D). Left panes (A and C) are from 1930; right panes (B and D) are natural color images from 2015. Imagery courtesy of NJDEP's GIS web service. Red and yellow dots mark the same coordinates for Gandy's Beach and Maurice River, respectively.

The current rate of sea level rise in the Delaware Estuary is between 2.9-4.5 mm/year (0.11-0.18 in/year; NOAA Sea Level Rise Trends). This is in contrast to a long term average of ~1.8 mm/yr (0.074 in/yr)(4,000 year before present to about 1900; Engelhart and Horton, 2012). The last time the rate of sea level rise was as high as present was more than 4,000 years ago (Engelhart and Horton, 2012). Late Holocene reductions in sea level corresponded with the development of expansive tidal wetlands between 12 (at the mouth of the Bay) and 2 thousand years ago (upper Bay) in the Delaware Estuary (Fletcher et al., 1990). Lower rates of sea level rise are likely more conducive to tidal wetland development, as might be suggested from the late Holocene shift, but current sea level rise is beginning to accelerate towards more destructive rates.

In addition, the land of the Mid Atlantic is subsiding (sinking) from the collapse of a forebulge created by the glaciers more than 15,000 years ago; this process is called isostatic rebound (estimated at ~1.7 mm/yr in Delaware; Engelhart 2010). The effects of subsidence on sea levels are further compounded by changes in ocean currents (e.g. the Gulf Stream; Najjar 2010), which together result in greater rates of local relative sea level rise than global models predict. Intergovernmental Panel on Climate Change (IPCC) global sea level rise rates were calculated at 1.7 mm/yr (0.067 in/yr) between 1901-2010, but had increased to 3.2 mm/yr (0.13

in/yr) from 1993-2010 (Church et al. 2013). Globally, sea level is projected to rise, at the highest, ~0.74 m (2.4 ft) by 2100 (Church et al. 2013). In climate adaptation planning at the Partnership for the Delaware Estuary, 1.3 meters (4.3 ft) of relative sea level rise for every 1.0 meter (3.3 ft) of global sea level rise was estimated. For the 0.74 m (2.4 ft) expected globally, 0.96 m (3.1 ft) might be expected within the Delaware Estuary by 2100. Under the unlikely scenario of a linear increase, this would be ~11.6 mm/yr (0.46 in/yr).

The rate of relative sea level rise (RSLR) is critically important for determining the fate of tidal wetlands in the Delaware Estuary because of the tipping point that can be breached when the RSLR exceeds the rate at which marshes can build vertically. Many studies find that the suspended sediment load is intrinsically linked to the capacity of marshes to build vertically. The more suspended sediments within a tidal system, the better the capacity for building marsh with increasing rates of sea level rise. From long term monitoring of coastal marshes in the Delaware Estuary, most studied marshes have suspended sediment concentrations between 25-35 mg/L (Raper et al. 2016), suggesting tipping points to sea level rise may be between 10-20 mm/yr (D'Alpaos et al. 2011). If sea level increases exponentially through 2100, lower rates (4.5-6 mm/yr; 0.18-0.24 in/yr) in the next years would be followed by rates of larger magnitude in the latter half of this century (>12 mm/yr; 0.47 in/yr). A 2013 publication by Miller et al. suggested that coastal regions in the Mid Atlantic could potentially experience a 25 cm rise in sea level by 2030; if such projections are accurate, the sea level rise tipping point for marsh sustainability could be exceeded in the next 20 years. The immediate prognosis of tidal wetland extent in the Delaware Estuary will largely depend on the availability of sediments on which to build, but the longer term prognosis unfortunately suggests continued precipitous losses.

5.2.7 Actions and Needs

Sea level rise, salinity rise, development, outdated management paradigms, and pollutants are likely to continue to contribute to degradation and loss of tidal wetlands in the Delaware Estuary, unless very swift actions are taken to abate these impacts. The following are needed to aid efforts to reduce coastal wetland losses:

Proactive Adaptive Management Despite the dynamic nature of the coastline, many regulatory policies continue to treat the landscape as fixed in place. Restoration paradigms set goals based on historic conditions rather than future sustainability. It is generally still easier to obtain a permit for a bulkhead or other hard structure, which do not keep pace with sea level rise and contribute to degradation of tidal wetlands, than it is for a living shoreline. The state of Delaware had taken a lead in making living shoreline permitting and construction easier, and is now being followed by New Jersey and Pennsylvania. Ditching, diking, excavating, and filling of tidal wetlands still occur, often without a good understanding or monitoring of the consequences. To adapt to both climate change and continued watershed development, tidal wetland managers and landowners will need to adjust targets, expectations, and tactics to sustain the most tidal wetland habitat in the future.

In order to address the threats to the intertidal zone in the Delaware Estuary, an approach combining policy and regulatory remedies and actions on the ground is required. The Clean Water Act (1972), Coastal Zone Management Act (1972), and the Coastal Barriers Resources Act (1982), are evidence of the increasing importance of tidal wetlands in the policy and legal arena. Many states and counties have followed the lead of federal agencies and implemented their own regulations covering such wetland protection measures as buffer requirements, impervious cover limitations, and implementation of federal National Pollutant Discharge Elimination System (NPDES) and total daily maximum load (TMDL) guidelines. Continued promulgation and refinement of regulations and policies is a critical need, as demonstrated by the various emergency measures that are already underway or being called for in some Delaware and New Jersey areas (e.g. Prime Hook, Delaware; Gandy's Beach, New Jersey; Maurice Township, New Jersey) where tidal wetland losses are contributing to the decline of coastal communities. Given accelerating development and population pressures, as well as increases in relative sea level rise and climate change, these measures will need to be augmented just to maintain the current integrity of the intertidal zone. In particular, local differences in the extent of regulatory protection provided to wetlands poses a challenge to maintaining consistently high level of wetland quality and function throughout the Estuary.

Continued Monitoring and Scientific Study Another need for both managers and for future reporting is continued and complete monitoring data on tidal wetland status and trends, as well as scientific information on the causes of wetland loss and best management practices for averting such losses. Although monitoring efforts have been underway through MACWA efforts, the synthesis and continued support of these programs is paramount to understand the complex factors which impact coastal wetlands. These data will also be useful for prioritizing and planning intervention strategies across the Estuary.

Since the array of ecosystem services furnished by tidal wetlands scale with their condition, continued health assessments are also needed. Systematic watershed-level rapid assessments have been carried out for most of the tidal watersheds in Delaware, but there still are large gaps in surveys for New Jersey. Pennsylvania rapid assessments on tidal wetland condition were carried out in 2010. Changes to the urban corridor in the last seven years may have observable effects on tidal wetland condition, so these areas should be resurveyed to quantify these changes in tidal wetland condition. Vulnerability assessments which match site specific needs to appropriate intervention tactics, called Marsh Futures, has been spearheaded by the Partnership for the Delaware Estuary and partners. These methods can continue to be refined to address emerging needs of wetland managers. More scientific studies and restoration R&D pilot projects are also needed to strengthen current management and restoration practices to sustain greatest tidal wetland acreage cost effectively.

Investment in tidal marsh monitoring and science is difficult to fund at the multi-state scale of the Delaware Estuary. However, the benefits of tidal wetlands are beginning to be captured and capitalized (e.g. flood protection, nutrient and carbon capture, fish production), especially following Hurricane Sandy in 2012 when the protective function of coastal wetlands was confirmed. Tidal wetlands are already regarded as the most valuable natural lands. Managers should carefully consider how a projected loss of 25-75% of the tidal wetlands in the Delaware Estuary might affect coastal communities (lives and property) and regional economies (fisheries and shellfisheries, property values, nutrient criteria for industry). As markets for ecosystem services develop in the future, there could be increasing demand for essential information on trends in tidal wetland extent and condition, as well as tactics to protect and enhance tidal wetlands. However, until markets that can generate needed resources to sustain monitoring and assessment evolve, there will continue to be a need to collaborate and leverage funds to fill vital information gaps.

On-the-ground Action Efforts at preservation, both through regulatory and physical means, have had some beneficial impacts across the Estuary, but many areas are still undergoing degradation or conversion to open water. New active policies and tactics are needed to both facilitate the horizontal migration and vertical accretion of tidal wetlands. Given the rapid pace of change in tidal wetland extent and health, swift action to physically protect or enhance tidal wetlands is warranted to stem losses even if monitoring and scientific information are still developing. Marsh migration plans are needed and will require conflict resolution and education. Seaward protections and marsh enhancements can be just as difficult to implement due to permitting, logistical and funding challenges. However, there are efforts to explore beneficial use of sediments for enhancement (Delaware Estuary Regional Sediment Management 2013), develop new types of hybrid living shoreline tactics (Moody, et al. 2016; Fig 5.2.9), and craft estuary-wide strategies for intervention (e.g. Delaware Estuary Living Shoreline Initiative; Moody et al. 2017).

5.2.8 Summary

Tidal wetlands of the Delaware Estuary are some of the most productive habitats in the world, and they arguably represent the most ecologically and economically important type of natural habitat in the entire

Photo credit: Joshua Moody, Partnership for the Delaware Estuary

Photo credit: Joshua Moody, Partnership for the Delaware Estuary

Photo credit: LeeAnn Haaf, Partnership for the Delaware Estuary

Figure 5.2.9 Hybrid living shoreline concepts of DELSI: A) utilizing oyster shell bags to attenuate problematic boat wakes at Matts Landing, Maurice River, NJ; B) A mosaic of shell bags and oyster castles were installed to attenuate waves and provide substrate for oysters to improve water quality, at Nantuxent Creek, NJ; and C) Planting smooth cordgrass on coconut fiber logs (foreground), which were coupled with oyster castle pods (background) to expand the existing oyster reef footprint to improve water quality as well as attenuate waves at the Mispillion River Inlet, DE.

Delaware River Basin. By their very nature they are transient. They absorb tidal energy from the open marine environment and provide a buffer and sink for contaminants from upland areas. They also provide essential habitat for a wide range of organisms, as well as recreational opportunities for people. As long as the intertidal zone remains in a state of dynamic equilibrium, the benefits that they provide are maintained. However, when the processes which threaten the viability of the intertidal zone come to predominate over the processes which maintain equilibrium, this delicate ecosystem becomes imperiled. Current trends suggest that tidal wetlands, and hence the ecosystem services and direct financial and aesthetic benefits they provide, are being degraded and lost across all areas of the Delaware Estuary, especially salt marshes around Delaware Bay. Future projections suggest that these losses will increase, perhaps rapidly, likely resulting in a dramatic shift in the character and function of the Estuary ecosystem. More study and monitoring, along with proactive management and on-the-ground actions, are urgently needed to minimize ongoing losses since no type of replacement habitat will provide the same net level of ecosystem services that are currently furnished by these vital coastal wetlands.

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5.2.9 Annual Variation of *Zizania aquatica*-dominated Marsh Extent: A case study of Mannington Meadows, Salem, New Jersey

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Introduction Amid prevailing decreasing trends of coastal wetland extent in the Delaware Estuary, CSC updates for 2010 showed an increase in acreage in Salem, New Jersey, or LE3. These coastal wetlands are brackish (2-8 ppt on average) and are a mosaic of marshes dominated by perennials (*Spartina alterniflora, Phragmites australis*) and the annual *Zizania aquatica* or Annual Wildrice (AWR; Fig 5.2.9.1). As AWR typically occupies fresher systems, the Salem River marshes are likely the farthest downstream stands along the Delaware River's estuarine gradient. The unique floral composition of these marshes called into question potential discrepancies in the CSC analyses, given that AWR is short lived compared to other plants (germination to senescence is May-August, peak growth ~July). To test if these marshes had indeed undergone expansion, despite continued loss in other areas, additional Landsat imagery analyses were carried out within the window of maximum AWR extent.

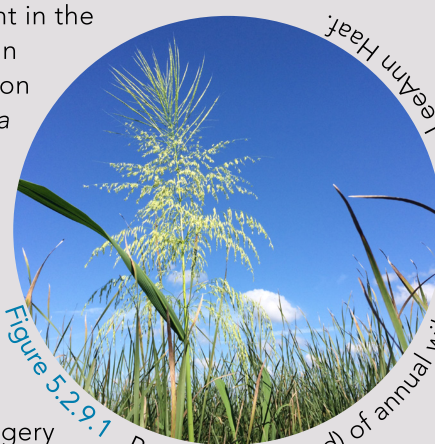

Figure 5.2.9.1 Panicle (seedhead) of annual wild rice. Photo by LeeAnn Haaf.

Methods Landsat scenes with <20% cloud cover were selected from July to early August (a 47 day period) to capture extent of AWR (Earthexplorer.usgs.gov; resolution is 30x30 m). Years chosen were 1995, 1996, 2006, 2007, 2010, and 2016. Each scene was clipped to the study area (Fig 5.2.9.2) and the ArcMap Image Classification tool bar (Spatial Analyst) was used to perform supervised classification of marsh extent (no differentiation of vegetation type). Sea level (SL) anomaly data (NOAA station Reedy Point, DE ID#8551910) were obtained and averaged for seasonal and annual anomalies. Seasonal periods included concurrent winter, spring, and summer, as well as the previous year fall and summer. Spearman's rank correlation statistic was performed to evaluate correlation between SL anomalies, Julian day, and marsh extent. A linear regression was run on marsh extent. Standard errors were calculated for SL anomalies. SL rose at 3.45±0.51 mm/yr at the tidal station, regardless of anomalies observed.

Figure 5.2.9.2 Aerial photograph (2015) of the Mannington Meadows marsh complex study area (grey outline), in Salem, NJ.

Results Marsh extent correlated positively ($p=0.019$; $rho = 0.8857$) with SL anomalies in the previous year's autumn months (Aug.-Oct.; Fig 5.2.9.3). No significance was found for other SL anomalies averages ($p>0.05$); these correlations, despite non-significance, were generally negative, whereas the fall SL variation was positive. There was no significant correlation with Julian day ($rho = 0.6$, $p=0.208$). It should be noted that despite this, 47 days is over a third of the plant's life cycle and the day of image capture could affect results of other analyses. Regression results were not significant ($p=0.64$). Average marsh extent was 400 ± 38 hectares (± 95% CI; Fig 5.2.9.4).

Discussion Extent of the marsh in this study increased on average from 1996-2016 by 84 hectares (~207 acres); intra-annual variation, however, was high (±38 hectares or ~94 acres) and perhaps driven by fall sea level variations of the previous year. CSC reports from 1996-2010 suggested that 61 hectares (151 acres) of estuarine wetlands had developed in LE3. These additional analyses corroborated this increase.

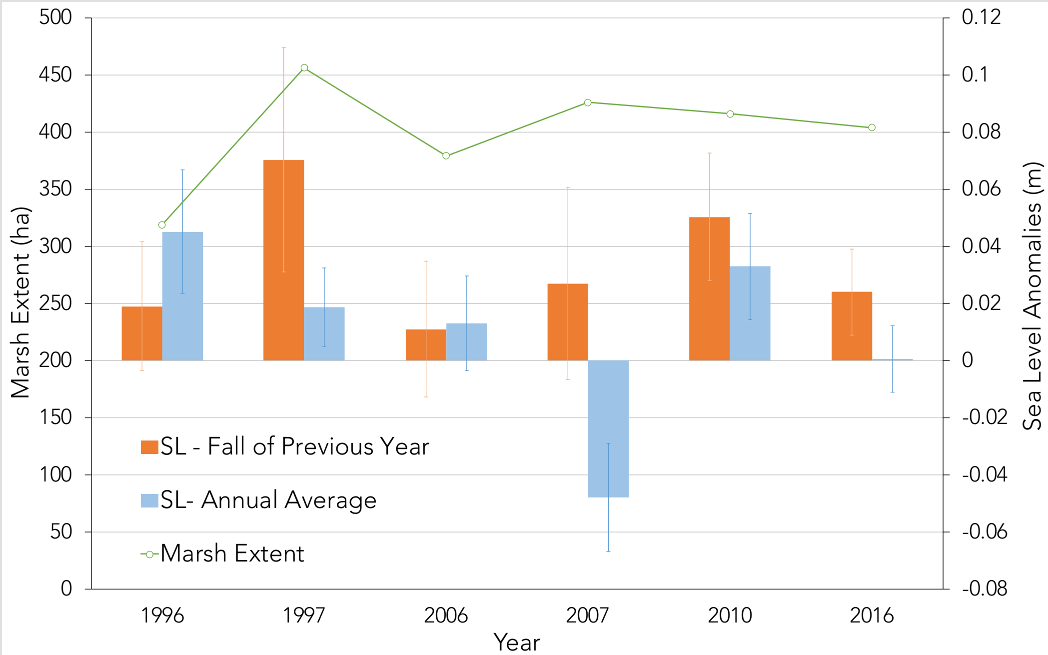

Figure 5.2.9.3 Change in marsh extent (green line, right axis) and sea level (SL) anomalies (left axis). Error bars are standard error (N=3 and 12, for fall and annual, respectively). Only fall anomalies were significantly correlated with marsh extent.

Landscape analyses taken at 5 year intervals or more, like CSC, may misrepresent net AWR- dominated wetland extent changes due to high year-to-year variability and intra-annual dependence. These fluctuations may become attenuated, however, by the invasion of perennial *Phragmites australis*, or salinity-driven shifts to the more salt tolerant, and perennial, *S. alterniflora*.

In conclusion, 2010 marsh extent was greater than in 1996, but high variability from year-to-year suggest that robust long term trends require more temporal resolution. For instance, if 1996 was excluded, the trend would suggest a net decrease in extent from 1997 to 2016. In the future, trend analyses should seek to address these needs and perform additional imagery analyses focusing on tidal wetlands dominated by annual species. Annual species' sensitivity to certain environmental parameters would yield important information about ecological relationships under changing conditions and about estuarine health over time.

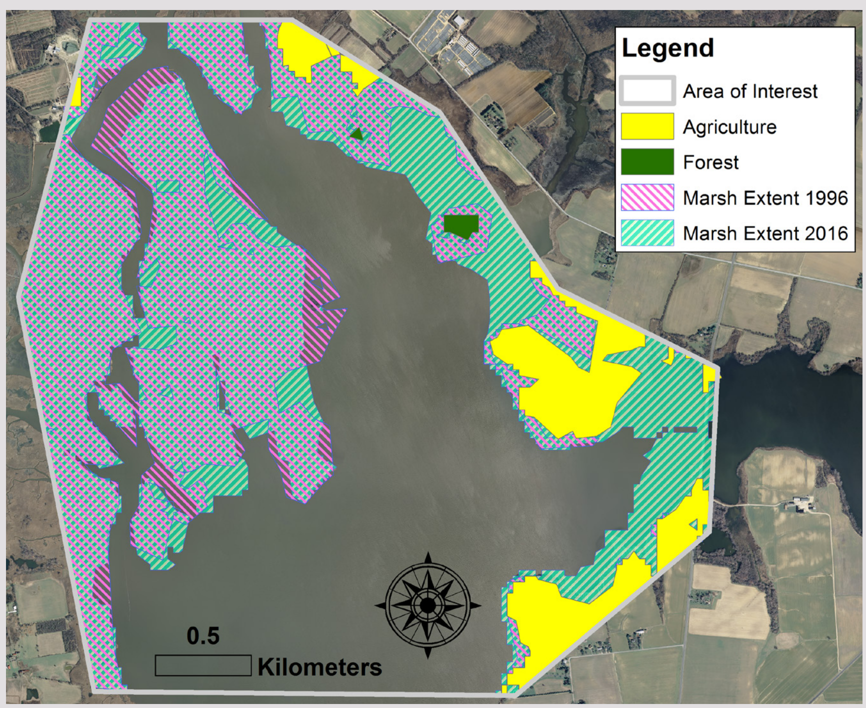

Figure 5.2.9.4 Image classification results of marsh extent.

5.3 Nontidal Habitats

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5.3.1 Freshwater Wetland Acreage

5.3.1.1 Introduction

Nontidal wetlands, including forested and shrub swamps, bogs, fens, vernal pools, and riverine wetlands, provide habitat for a diverse array of terrestrial, aquatic, amphibian, and bird species (Davis 1993, Mitsch and Gosselink 2000, Faber-Langendoen et al 2008). Wetlands also serve many hydrologic, biogeochemical, and habitat functions, which are strongly influenced by watershed position (Brinson et al. 1995). Headwater wetlands retain and store precipitation, recharging groundwater resources. They are important sources of water and organic and inorganic materials that support downstream aquatic systems. Riverine and floodplain wetlands can store overbank flows, dissipate energy, provide a local supply of large woody debris, and both supply and retain coarse particulate organic matter. Wetland size, density, and landscape context, including condition of adjacent lands and connectivity among riverine, wetland, and upland habitats, are important indicators of condition. Large wetlands are critical for maintaining suitable habitat for many of the priority species within the state wildlife conservation plans. For example, the Pennsylvania Comprehensive Wildlife Conservation Strategy (CWCS) emphasizes that conservation of large wetland habitat is especially critical for wildlife conservation (PGC and PFBC 2005). While the CWCS definition of "large wetlands" depends on the wetland type and species of concern, it typically defines large wetlands as between 12 and 100 acres (5 and 40 ha) (or larger).

Separating nontidal wetlands highlights the value and significance of these systems, which have experienced significant losses in the Basin. For example, in the state of Delaware more wetlands were lost between 1992 and 2007 than in the previous 10 years; approximately 99 percent of those losses were to nontidal/freshwater wetlands (Environmental Law Institute 2010).

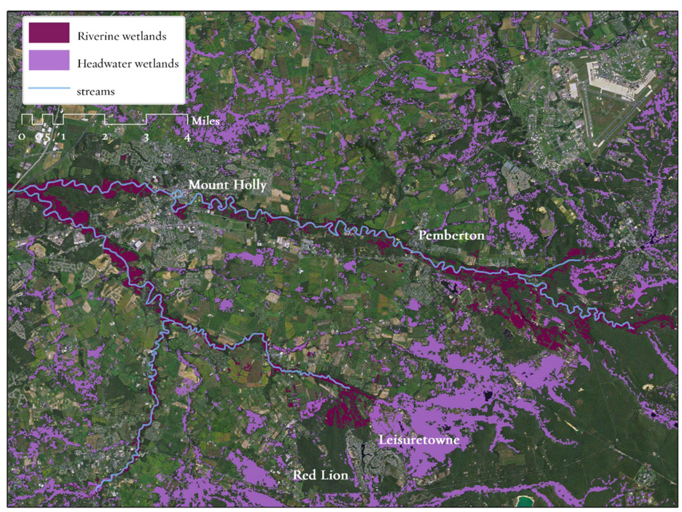

Figure 5.3.1 Riverine and headwater wetlands within the Rancocas Creek watershed, New Jersey.

5.3.1.2 Description of Indicator

Headwater wetland area and the number of large contiguous headwater wetlands (greater than 100 acres/ 40 ha) were calculated for each sub-basin within the Delaware River Basin. Together, these serve as potential indicators of the degree to which wetlands are providing critical functions in headwater regions, including recharging groundwater and storing and releasing water and organic and inorganic materials to support downstream aquatic systems.

Nontidal wetlands were defined by first selecting the woody and emergent wetland land cover classes from the National Land Cover Dataset (NLCD

2001). Open water features such as ponds, lakes, and reservoirs were not included. Nontidal wetlands were then classified according to the National Vegetation Classification System (NVCS) (Westervelt et al. 2006) and further separated into headwater and riverine wetlands (Fig 5.3.1). Riverine wetlands were associated with the floodplains of rivers with drainage areas greater than approximately 40 square miles (10,359 ha). Headwater wetlands exist along the riparian corridors of streams with drainage areas less than approximately 40 square miles (10,359 ha).

Within headwaters, contiguous headwater wetlands were defined as areas with connected wetland landcover (i.e., woody or emergent wetland pixels that are connected on a side or on the diagonal). These contiguous wetlands potentially include multiple wetland types according to various existing classifications, but the overall size is one indicator of potential wetland function. The total area of each contiguous headwater wetland was calculated.

5.3.1.3 Present Status

Figure 5.3.2 illustrates the total headwater wetland area and the number of contiguous headwater wetlands larger than 100 acres (40 ha) within each sub-basin. Despite wetland losses, the Delaware River watershed has several sub-basins with abundant headwater wetlands. Noteworthy concentrations are located in the Upper Central and Lehigh Valley sub-basins and on the coastal plain within Upper and Lower Estuary and Delaware Bay sub-basins.

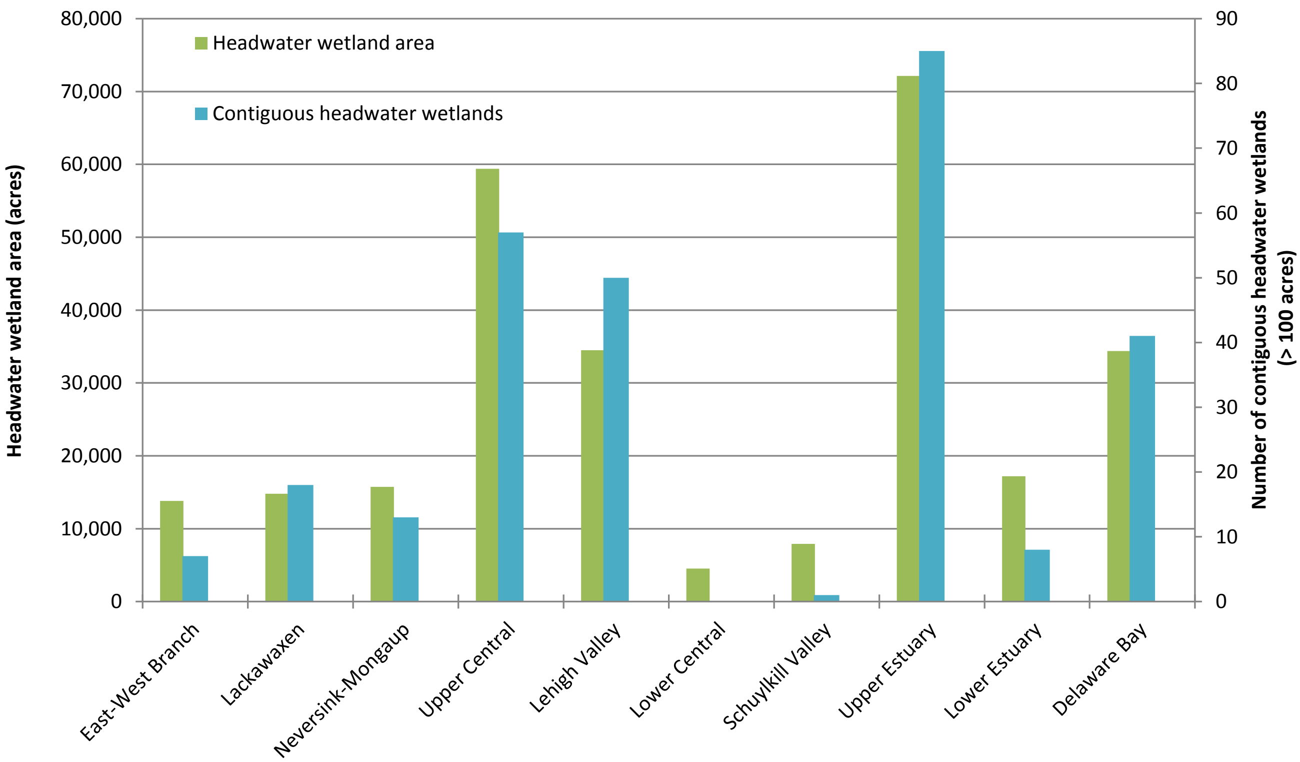

Figure 5.3.2 Total headwater wetland area ranges from approximately 4,500 acres (1821 ha) in the Lower Central sub-basin to over 72,000 acres (29,137 ha) in the Upper Estuary sub-basin. The Upper Estuary sub-basin also has 85 headwater wetlands that are larger than 100 acres (40 ha). This is the highest number of any sub-basin in the Delaware River watershed.

Both the Upper Central and Lehigh Valley sub-basins contain at least 50 headwater wetlands that are larger than 100 acres (40 ha). These sub-basins also overlap with the glaciated portions of the Pocono Plateau, which includes the greatest diversity of wetlands in the state of Pennsylvania (Davis 1993). Boreal conifer swamps, oligotrophic kettlehole bogs, cranberry and bog-rosemary peatlands, and acidic broadleaf swamps occur throughout the region. Other unique wetland communities are found along the limestone valley, where mineral-rich groundwater supports calcareous fens, seepage swamps, and limestone wetlands. Cherry Valley National Wildlife Refuge and the Mt. Bethel Fens in Pennsylvania and the Johnsonburg and Sussex Swamps in New Jersey contain examples of these systems. Vernal pools are also scattered throughout the region, with concentrations along the toe slopes of the Kittatinny Ridge.

Although the Upper Estuary sub-basin includes Trenton and Camden, NJ, Philadelphia, Pennsylvania, and other urban and suburban areas, this watershed contains over 70,000 acres (28,322 ha) of nontidal wetlands and 85 wetlands larger than 100 acres. These headwater wetlands are especially abundant on the coastal plain in New Jersey, including along Crosswicks Creek and the North and South Branch Rancocas Creek.

5.3.1.4 Past Trends

Wetlands slow down, capture and cleanse rainwater before releasing it to rivers, oceans, lakes and groundwater. They shelter wildlife and provide breeding and spawning grounds for commercial and recreational fisheries. They store stormwater, releasing it slowly to help prevent floods, and support recreational activities.

Yet for much of our history, wetlands have been undervalued. By the mid-1980s half the wetlands in the continental U.S. had disappeared, with losses averaging 500,000 acres (202,343 ha) per year. Regulations to control wetlands loss existed, but were often slow, unpredictable, expensive and frustrating for land owners.

In the summer of 1987, at the request of Lee Thomas, Administrator of the U.S. Environmental Protection Agency, The Conservation Foundation convened the National Wetlands Policy Forum, chaired by Governor Thomas H. Kean of New Jersey, to address major (32,374 ha) policy concerns about how the nation should protect and manage its valuable wetlands resources.

The goal of the Forum was to develop sound, broadly supported recommendations on how federal, state and local wetlands policy could be improved. In late 1988, the Forum published its final report, a 70-page consensus document that presented approximately 100 recommendations on a variety of issues including promoting private stewardship, improving regulatory programs, establishing government leadership and providing better information. Among the key recommendations was that national policy be guided by a goal of “no overall net loss” of the nation’s remaining wetlands and, over the long term, to increase the quantity and quality of the nation’s wetlands resources.

This goal has guided national wetlands regulatory and non-regulatory programs and policy ever since.

In the years since the Wetlands Forum, the rate of wetlands loss in the U.S. has slowed dramatically to the point where achieving the goal of “no net loss” may be in sight. This is truly a remarkable accomplishment.

Private land owners have made a major contribution, in recent years enrolling an average of 200,000 acres per year in the national Wetlands Reserve Program, one of the programs recommended by the Forum. Total acreage in the program now exceeds a million acres.

Federal and state agencies stepped up and provided increased leadership in numerous ways and in every Administration since the Forum’s recommendations, improving regulatory programs and providing better information. Shortly after the Forum’s report, USEPA and the Army Corps signed a Memorandum of Understanding to better coordinate regulatory programs, reducing confusion for landowners.

5.3.1.5 Future Predictions

While filling and conversion of wetlands for agricultural and urban development has generally decreased over time, different stressors in the form of new industrial development seeking a location in small headwater watersheds will have to be carefully managed. In addition, it is likely the precipitation patterns of the next 100 years will be more extreme than the past, resulting in changing water budgets at a watershed scale and even greater ecosystem service values attributed to freshwater wetlands in the future.

5.3.1.6 Actions and Needs

Many positive actions are underway and require continued vigilance by Basin management community:

1. Continued attention to quantifying ecosystem service values.
2. Continued attention to harmonizing state and federal regulatory programs.
3. Continued attention to funding conservation initiatives and wetland reserve programs.
4. Continued effort to quantify feedback loops like the United States Department of Agriculture (USDA) Conservation Effects Assessment Program.
5. Passage of the Delaware River Basin Conservation Act of 2011 - championed by Senators Carper and Coons of Delaware, Senator Schumer and Gillibrand of New York, and Senators Menendez and Lautenberg of New Jersey-- which would establish a federal program at the U.S. Fish and Wildlife Service to coordinate voluntary restoration efforts throughout the Delaware River watershed.

5.3.2 Riparian Corridor Condition

5.3.2.1 Introduction

Natural riparian corridors are important for stream and river health because they support physical and ecological processes and provide habitat corridors for river-associated birds and mammals. Depending on position within the watershed, riparian corridors play various functions. In headwater areas, hydrology, sediment input, and channel network formation is largely influenced by riparian corridors. Further downstream, riparian corridors often include well-developed floodplains, which may or may not be confined within steep valley walls. Floodplain condition affects channel and bank stability, water quality, sediment storage, and water storage during overbank flows. Riparian condition is one indicator of headwater and floodplain functions throughout a watershed.

5.3.2.2 Description of Indicator

The active river area model and land cover data were used to assess riparian corridor condition throughout the nontidal portion of the Delaware River Basin. The active river area framework is a spatially-explicit approach to identifying the areas within a watershed that accommodate the physical and ecological processes associated with river systems (Smith et al. 2008). The spatial model includes three primary components within the riparian corridor: floodplains, riverine wetlands, and riparian areas that are likely to contribute woody debris, coarse particulate organic matter, sediment, and energy to the riverine system. The area and percent of natural land cover (predominately forest and wetland land cover) for headwater riparian corridors (i.e., all streams with drainage areas less than approximately 40 square miles/10,359 ha) was calculated. The area and percent of natural cover within floodplains (i.e., all streams and rivers with drainage areas greater than 40 square miles/10,359 ha) for each major sub-basin was calculated. Comparing riparian condition in headwaters and floodplains is one indicator that reveals how ecological processes may have been altered in various subwatersheds throughout the nontidal portion of the Basin.

5.3.2.3 Present Status

In the Upper and Central Regions of the Delaware River Basin, the majority of riparian corridors are at or above 70% natural cover, both in headwaters and in floodplains (Fig 5.3.3). The riparian corridors in the Neversink-Mongaup sub-basin are in best overall condition compared to any other sub-basin; over 90% of the riparian corridors are in natural cover, both within headwaters and floodplains of larger rivers (Fig 5.3.4). Natural riparian corridors in the headwaters, such as those in the Upper Lehigh River and Tobyhanna Creek watersheds, are essential for maintaining water quality and quantity for downstream ecosystems and water users (Fig 5.3.5). In the Lower Region, riparian corridors are much more developed, although there are still some large areas of natural cover within floodplain riparian corridors in the Schuylkill and Lower Central Sub-basins. For example, the floodplain areas along the main-stem between Allentown, PA and Trenton, NJ, are approximately 78% forest and wetland cover. This area includes the Lower Delaware Wild and Scenic River, which is part of the National Wild and Scenic River system managed by the National Park Service.

5.3.2.4 Past Trends

Riparian corridors (floodplains, riverine wetlands and riparian areas) have long been recognized as environmentally sensitive, ecologically diverse, and hydrologically important areas within a watershed.

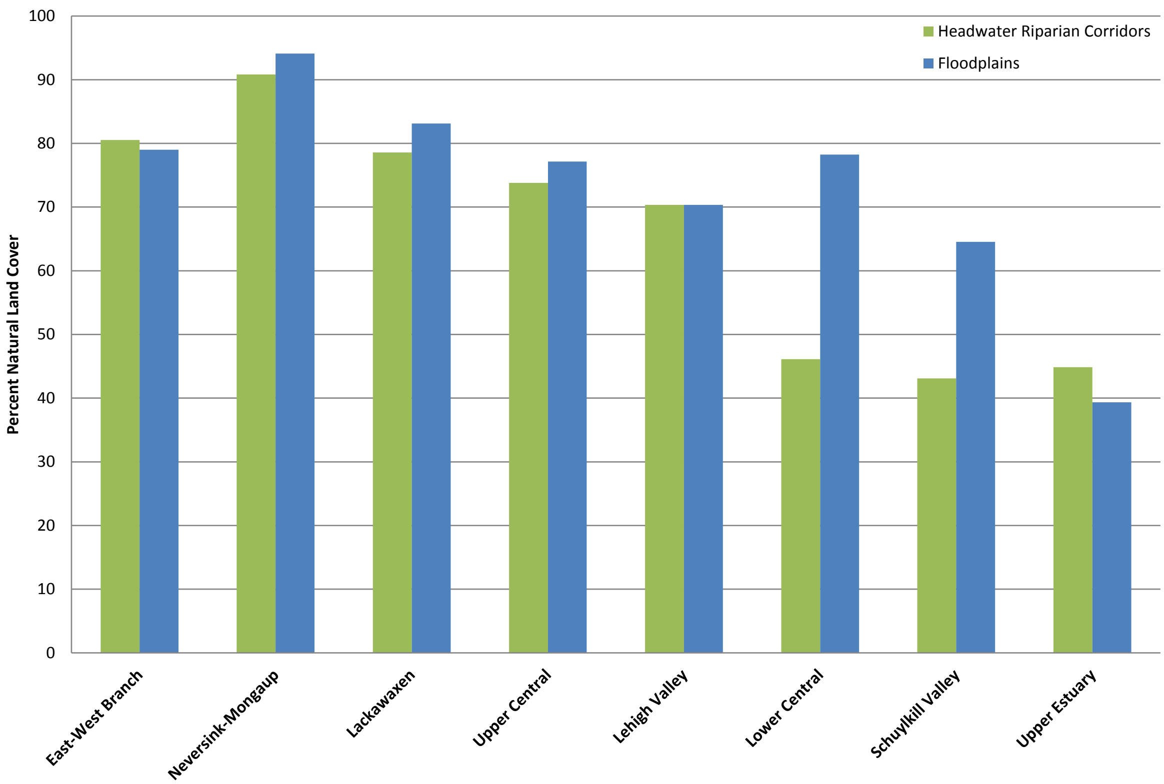

Figure 5.3.3 Headwater and floodplain riparian condition with Delaware River sub-basins. The majority of floodplain and headwater riparian corridors in the Upper and Central Regions of the Delaware Basin contain at least 70% natural cover. Although percent natural cover is lower in the nontidal portion of the Lower Region, there are still floodplain areas with extensive natural cover, including the portions of the Schuylkill Valley and mainstem Delaware between Allentown, PA, and Trenton, NJ (Lower Central sub-basin).

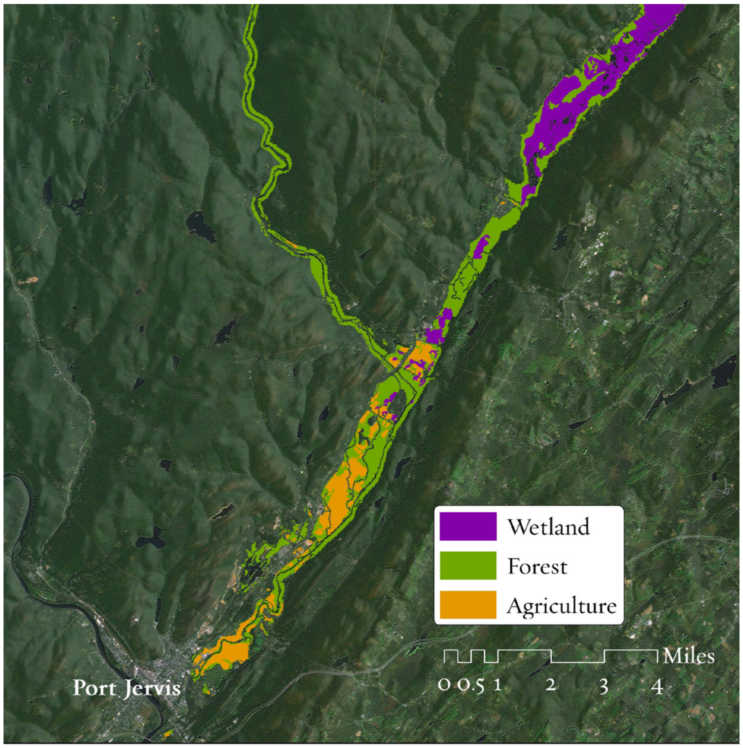

Figure 5.3.4 In the Neversink-Mongaup sub-basin, approximately 94% of the floodplain area is in forest or wetland land cover.

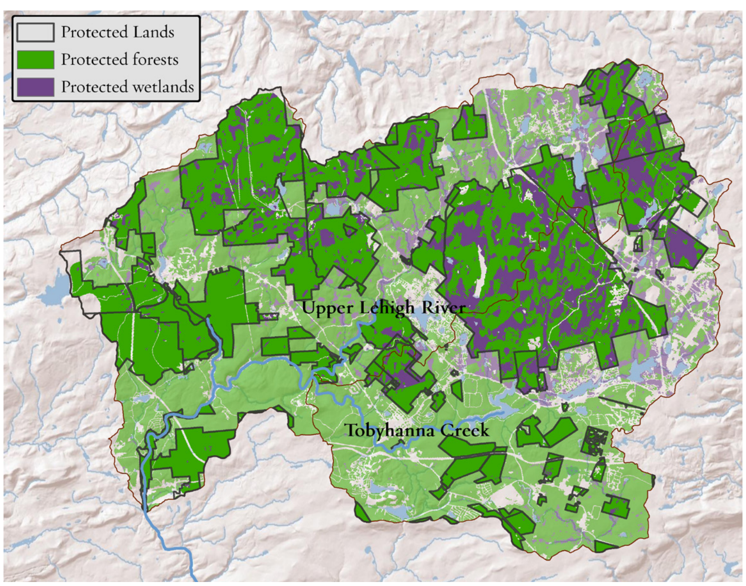

Figure 5.3.5 Headwaters within the upper Lehigh Valley sub-basin include extensive forests and wetlands within the riparian corridors. Much of this area is also in protected lands.

Even though the natural functions of these corridors and the hazards associated with their occupancy are widely known, people have always been attracted to water. Historically, settlements have arisen along waterways because they contain natural features beneficial to human societies (fertile soil, transportation links, water supply, hydropower, and aesthetic beauty). One consequence of human development of riparian corridors is the physical alterations of both stream channels (dams, levee construction, straightening, and dredging) and the floodplain landscape, impacting not only the integrity of the watercourse, but also resulting in significant social and economic consequences. Floods in developed floodplains devastate families, businesses, and communities, and cause more damage to life and property than any other natural hazard. These problems exist in many parts of the country, but the riparian corridor condition of the Delaware River Basin is relatively good. As noted above, riparian corridors associated with headwater watersheds and floodplains in the Upper Basin enjoy 70% or more natural cover. Similarly, riparian corridor condition associated with the Central Basin Delaware River floodplain has plentiful forest and wetland cover. The national status of the Delaware as the largest free flowing river East of the Mississippi, coupled with high water quality directly attributable to riparian corridor condition have led to inclusion of three-quarters of the nontidal Delaware River (about 150 miles) in the National Wild and Scenic Rivers System. In contrast, only one quarter of one percent (11, 000 miles) of the 3.5 million miles of rivers in the nation has been included in the System.

5.3.2.5 Future Predictions

In 2004, the four Basin Governors and federal agency Regional Executives signed a forward looking Basin Plan that identified five Key Result Areas, one of which focused on Waterway Corridor Management. Specifically, the Plan specified a Desired

Result involving: waterway corridors that function to minimize flood-induced loss of life, protect property and floodplain ecology, preserve channel stability, provide recreational access, and support healthy aquatic and riparian ecosystems. Work is now underway by many partners to implement the specific goals and objectives enumerated in the plan, including an annual report out of progress at the fall Delaware River Basin Commission meeting. Another significant milestone in 2011 was realized with the completion of the "Delaware River Basin Priority Conservation Areas and Recommended Conservation Strategies" Report. The report was developed by The Nature Conservancy, Partnership for the Delaware Estuary, and Natural Lands Trust, and funded by the National Fish and Wildlife Foundation. It focuses on Floodplains, Headwaters and Nontidal Wetlands and provides a platform for shared conservation and restoration priorities across the Basin.

5.3.2.6 Actions and Needs

The Water Resources Plan for the Delaware River Basin (Basin Plan) Objective 2.3 D called for "Implementing Strategies to protect critical riparian and aquatic habitat" and established milestones for identifying, mapping and prioritizing critical habitats. It also called for development and adoption of protection and restoration strategies.

1. Action: The Final Report for the National Fish and Wildlife Foundation titled "Delaware River Basin Priority Conservation Areas and Recommended Conservation Strategies" was completed in 2011. The report includes detailed maps by sub-basin showing watershed specific freshwater system priorities. For example, the Upper Delaware River Basin is divided into 22 watersheds and place-specific conservation strategies (Headwater Networks; Floodplain Complexes; Headwater Wetlands; and Riverine Wetlands) are identified and prioritized.

2. Action: The Conservation Plan referenced in Item #1 functions as vehicle for collaborative restoration and protection action.

3. Action: The Conservation Plan also serves as preliminary set of targets for implementation of the Delaware River Basin Conservation Act of 2011, if it is successful in becoming federal law.

4. Need: The Basin conservation community needs to work with its Congressional Delegation to continue to advocate for passage of the Delaware River Basin Conservation Act.

5. Action: The Delaware River Basin Commission Flood Advisory Committee conducted a careful assessment of Floodplain Regulations both in the Basin and around the country in 2008 and 2009. In October 2009, they presented a report containing twelve recommendations for more effective floodplain regulations to the Commission. The Committee determined that minimum floodplain regulations, administered by FEMA through the National Flood Insurance Program, do not adequately identify risk or prevent harm. They also found that floodplain regulations are inconsistent from State to State and from community to community. They recommended that floodplain regulations need to be applied more consistently and comprehensively, on a watershed basis that reaches across jurisdictional boundaries.

6. Need: DRBC needs to work with FEMA to advance their Risk Mapping, Assessment and Planning (Risk MAP) strategy to work with local officials to use flood risk data and tools to effectively communicate risk to citizens and better protect their citizens. The DRBC Flood Advisory Committee recommendations could be one component of the FEMA strategy to work with communities at a watershed scale to make the Basin more flood resilient.

5.3.3 Fish Passage

5.3.3.1 Introduction

The Delaware River lacks any dams on its main-stem that block passage of fish, a feature which is remarkable for a river of its size. Diadromous fish like American Shad, Alewife, Blueback Herring, Striped Bass, Sea Lamprey, and American Eel can travel over 300 miles (483 km) from the mouth of the river up to its origin (and back out to the ocean) without being blocked by a barrier. Unobstructed stream habitat like this is critical for migratory fish, especially for anadromous fish to be able to access freshwater spawning grounds. Long stretches of connected streams also are important for local movement of resident fish and other aquatic organisms. Some resident species, such as the tessellated darter, also serve as host fish for certain freshwater mussels. Consequently, the ability of fish like this one to move within a stream system is also critical for freshwater mussels, which rely on host fish to disperse their young and colonize new habitats.

Unlike the main-stem, most tributaries of the Delaware River have been dammed over time. Over 1,400 dams within the Basin are tracked by various federal and state agencies; additionally, many smaller, unregulated dams that are not captured by these databases exist in the Basin. While large dams pose clear barriers to fish passage, small run-of-river dams and even inadequate culverts can impede fish passage. Cumulative effects of barriers can dramatically reduce the amount of accessible habitat for fish within a stream network, although the first few barriers in a stream network have the greatest impact on connected habitat (Cote et al. 2009).

5.3.3.2 Description of Indicator

Using dams in state and Army Corps of Engineers (National Inventory of Dams) databases, as well as a small number of hand-mapped blockages in the Delaware Bay coastal area, we identified the length of each connected stretch of a river network (i.e., portions that have no dams occurring within that stretch) using the Barrier Analysis Tool (BAT, v.1). This tool calculates the total length of a connected stream network by adding the lengths of a river and all connected tributaries between barriers (or between a river origin and the first barrier downstream, or the river mouth and the first barrier upstream). Results of the analysis highlight the longest connected river networks, including those that have no blockages from their headwaters downstream to the Delaware River and out to the Bay.

It is important to note that our analysis included dams that have fish ladders installed on them. These dams were not removed from the analysis primarily because many fishways still pose barriers to fish passage; while they may allow for effective passage of a handful of species similar to those for which they were designed, many fish are still unable to use fish ladders effectively, if at all. Perched, undersized or blocked culverts also can be significant barriers to fish movement; however, this type of barrier was not included in our analysis, due to a lack of a basin-wide culvert dataset.

5.3.3.3 Present Status

The Delaware River is distinguished by being the longest free-flowing river in the eastern United States. Anadromous and catadromous fish species can travel unimpeded through over 500 miles (802 km) of connected rivers and streams, from the mouth of the Delaware River upstream to Hancock, New York and as far upstream on any connected tributary as the first barrier (Fig 5.3.6). Many tributaries lack dams in their downstream portions and thus allow migratory fish like river herring to access spawning habitat downstream of any barrier. For example, the Rancocas, Flatbrook, and Neversink River systems all have significant habitat available for migratory fish. A dam removal on the lower Neversink River in 2004 opened up the entire historic habitat available for American shad, while also improving access for American eel and sea lamprey. In the case of a river like the main-stem Schuylkill River, fish passage structures allow fish like shad to access upstream portions of the river; although our analysis does not recognize this degree of connectivity due to difficulties in fairly assessing where fishways effectively mitigate barriers that dams pose to most fish.

Despite the fact that the main-stem and connected portions of its many tributaries together provide over 500 miles (805 km) of unblocked aquatic habitat, the Delaware River's tributaries have suffered significant fragmentation from the construction of over 1,400 dams in the 1800s and 1900s. Notwithstanding the fact that they lack a direct connection to the main-stem or bay, some tributary stream networks in the Basin still offer significant mileage of connected habitat for resident fish. Some of the largest connected stream networks include the headwaters of the West Branch, the East Branch, the Lehigh River, and the Schuylkill River; a significant section of the middle Schuylkill also lacks tracked dams (Fig 5.3.6). The ability to move locally within stream systems like these is important to many species. In particular, potadromous species, such as the white sucker, make instream migrations to complete their life cycles.

It is important to note that while some of the shorter stream systems (e.g, small coastal streams) may not have especially high values in terms of total connected stream length, these streams, which are often highly productive, are 100% connected from their headwaters to the Bay, allowing fish access to their full historic range of stream habitats (e.g., Red Lion Creek or Augustine Creek in Delaware or Oranoaken Creek or Bidwell Creek in New Jersey).

5.3.3.4 Past Trends

In 1985, the Delaware River Basin Fish and Wildlife Management Cooperative identified three priority rivers for fish passage efforts: the Brandywine, Schuylkill, and Lehigh Rivers. How far upstream fish can swim in each of these rivers has changed over time in two of these three rivers as fish passage efforts like dam removal and fishway installation have been implemented (Fig 5.3.7).

On the main-stem Brandywine, fish ladders were installed during the mid-1970' on three of the first four dams, all located within the first four miles of the river. However, after several years of monitoring, the fish ladders were found to be ineffective and were removed. The Brandywine Conservancy has published feasibility studies for addressing fish passage for American Shad in the Delaware (2005) and Pennsylvania (2009) portions of the watershed. The studies included the 11 main-stem Brandywine dams in Delaware (~14 miles/23km of mainstem habitat) and 10 of the 28 current dams in Pennsylvania.

On the main-stem Schuylkill, three fish ladders and four dam removals since 2006 have increased access from river mile 15 up to river mile 100, a dramatic improvement. The effectiveness of the three fish ladders is still largely unknown, with only the Fairmount Dam fish ladder having associated long-term monitoring results published. In addition to the main-stem projects, between 2003 and 2007, five dams have been removed on the Perkiomen Creek main-stem, three on the Wyomissing Creek, and one each on the Tulpehocken and Pickering Creeks.

On the main-stem Lehigh, the first two dams had fish ladders (Easton & Chain) installed in 1994 and later retrofitted in 2000. The third dam, Hamilton St., had a fish ladder installed in 1984. A main-stem dam farther upstream, Palmerton Dam, was removed in 2006. After years of monitoring at both Easton and Chain dams, these fish ladders have been determined to be ineffective in passing their target species, American Shad. As a consequence, the Wildlands Conservancy and the PA Fish & Boat Commission recently requested proposals to evaluate the removal of Easton and Chain dams (July 2011) in the hopes of improving fish passage at these locations. Northampton Dam, the last of the lower four dams, is expected to have a fish passage feasibility study initiated in early 2012. In addition to these mainstem Lehigh projects, between 2000 and 2010, a total of 5 dams have been removed on Saucon Creek, East Branch Saucon Creek, Jordan Creek, Little Lehigh Creek, and Mahoning Creek. In addition to these three tributary watersheds, there are active fish passage efforts underway in smaller tributaries such as Ridley Creek (DE/PA), Pennypack Creek (PA), Bushkill Creek (PA), Lopatcong Creek (NJ) and the Musconetcong River (NJ).

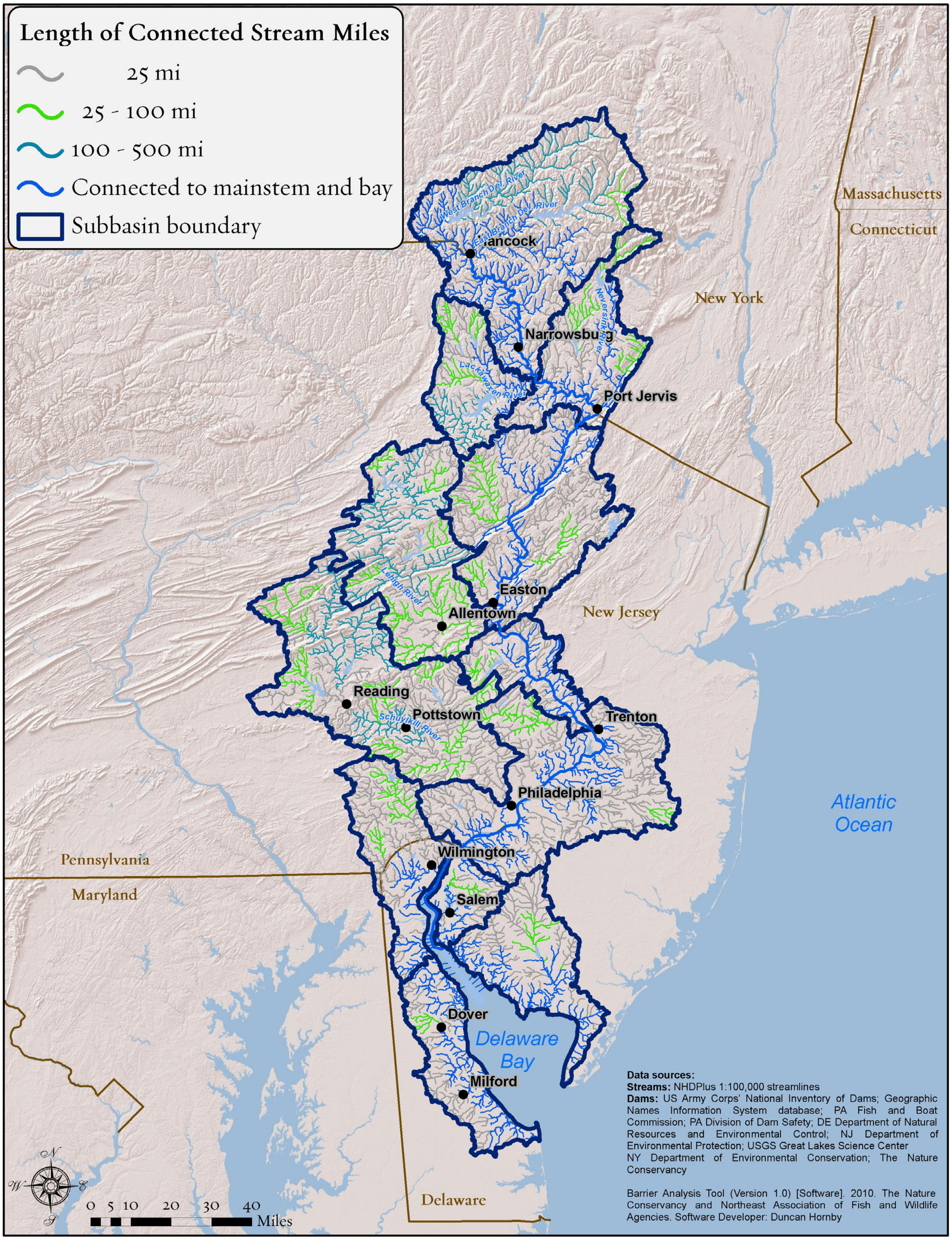

Figure 5.3.6 Connected stream networks in the Delaware River sub-basins.

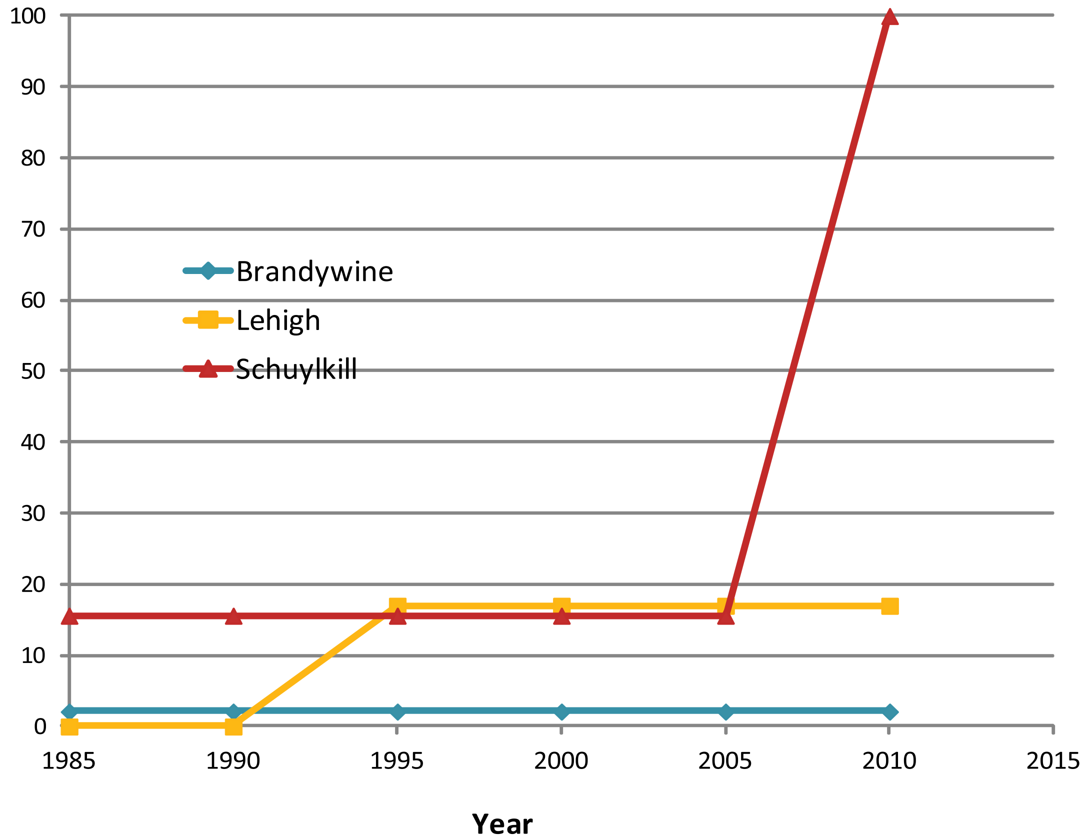

Figure 5.3.7 Number of connected stream miles accessible from the main stem Delaware River or Bay between 1985 and 2010 for each of the three priority fish passage rivers.

5.3.3.5 Future Predictions

The importance of river connectivity and associated fish passage is being recognized by many water resource agencies and the public and is evident in the recent number of dam removal projects and feasibility studies recently completed or currently underway. In addition to the direct impact on fish habitat, the relationship between keystone species such as freshwater mussels and their dependence on certain fish species for reproduction and colonization should only add momentum to addressing fish passage. Unless Basin prioritization is revisited, fish passage projects will likely continue to be haphazardly located throughout the Basin with more action occurring in tributaries with active watershed based organizations and cooperative dam owners rather than in strategic locations.

5.3.3.6 Actions and Needs

Financial resources for addressing fish passage within the Basin are limited, and there is a need for an updated comprehensive evaluation of where best to prioritize fish passage. The prioritization needs to consider the best ecological return for each location addressed as well as the suitability of potential new habitat. An ongoing effort since 2008 by the Northeast Association of Fish and Wildlife Agencies and The Nature Conservancy (TNC), called the Northeast Aquatic Connectivity (NAC) Project, has developed tools and an initial assessment of opportunities for restoration of stream system connectivity across the Northeastern U.S. With input from the NAC workgroup, TNC calculated 72 ecologically relevant metrics for almost 14,000 dams across the region and developed tools to allow for tailored assessment of ecological returns of reconnection projects. Tools and final products include two assessment scenarios that rank dams for benefits for anadromous fish and for benefits for resident fish, produced using a subset of metrics weighted by the workgroup. While these products and tools will help inform prioritization efforts, site-specific factors still need to be considered in project selection. In addition to the forthcoming Northeast Aquatic Connectivity Project, Senator Tom Carper (Delaware) recently introduced the Delaware River Basin Conservation Act of 2011, which would establish a federal program at the U.S. Fish and Wildlife Service (USFWS) to coordinate voluntary restoration efforts throughout the Basin and oversee up to $5 million per year of grant funding. It is envisioned that a basin-wide fish passage prioritization project would be an ideal project worthy of funding through the Act and would help guide future distribution of grant monies. The fish ladders installed in the Lehigh River have also demonstrated that not all fish passage "remedies" are equal, with some being more successful than others. In cases where a dam no longer serves a critical use such as for public water supply, the first remedial option should be removal. In addition, where regulatory opportunities exist with dam owners during permitting actions, regulatory agencies need to adopt and implement a consistent approach as to when and why fish passage needs to be addressed. Many dam owners have argued that if anadromous fish are not present downstream of their dam, then there is no need to address fish passage. For dam locations that do not have anadromous fish downstream, addressing fish passage is still important for resident species. From the perspective of both anadromous and resident fish, assessing the degree to which road/stream crossing structures also are creating barriers to fish passage will be important, as well. While we currently lack good data, pilot field surveys conducted by The Nature Conservancy and others will provide some insight on the prevalence of problematic culverts within select tributary watersheds in the Basin. Following ecological standards for culvert design and replacement could be helpful to restore connectivity currently hindered by these small structures.

5.3.3.7 Summary

The Basin has experienced a large number of fish passage projects, primarily targeting American Shad, during the past 10 years. Most of the fish passage projects are occurring in Pennsylvania, with both financial and technical support from state resource agencies. Although three large tributaries were targeted in 1985 for priority consideration, it appears that the only tributary with significant progress may be the Schuylkill River. Recent fish passage efforts do not appear to be a component of a larger restoration plan. A new basin-wide reassessment of fish passage priorities is needed to ensure that limited resources are being targeted in an efficient and effective manner.

5.3.4 Hydrological Impairment

5.3.4.1 Introduction

Natural variations in hydrologic regime—the magnitude, timing, frequency, duration, and rate of change of stream flow—are critical for sustaining healthy river systems (Poff et al. 1997, Richter et al. 1997). Healthy floodplains also are dependent upon natural flows, as they require interaction with rivers whose flow regimes have sufficient variability to encompass the flow levels and events that support important floodplain processes (Opperman et al. 2010). Alterations to the natural flow regime of a river result from a variety of sources, such as flood control, water supply and hydropower dams, as well as water withdrawals and development in the watershed. Paved and other hard surfaces, collectively referred to as impervious cover, often increase the volume of and rate at which precipitation runs off into the stream channel and can increase the flashiness of streams (Leopold 1968). Impairment of a river's natural hydrologic regime can cause various negative impacts throughout a watershed. Dams that store large amounts of water can significantly change amounts of streamflow downstream of the dam, as well as change seasonal patterns of high and low flows on which many aquatic organisms depend (Poff et al. 1997). In addition, large dams change sedimentation patterns, potentially depriving the river downstream of the dam and causing significant changes in the stream channel and bed. Other impacts include changes in water temperature and nutrient transport, which in turn affect both aquatic and riparian species (Poff and Hart 2002).

5.3.4.2 Description of Indicator

All dams do not have the same effects on downstream rivers, and consequently, using one indicator to predict potential hydrological alteration is difficult across the entire Basin. However, one important indicator of potential alteration to the natural hydrologic regime is the ratio of upstream dam storage to mean annual flow downstream (Graf 1999). This ratio is calculated by expressing the cumulative volume of water stored by upstream dams as a percent of the mean annual flow of each downstream river segment. As this proportion increases, so does the likely alteration to natural stream flow. Ratios indicative of a high risk of hydrologic alteration have been demonstrated to be > 50% (Zimmerman and Lester 2006). Using storage values available in state and Army Corps of Engineers (National Inventory of Dams) databases and mean annual flow values associated with NHD^{+} streamlines, we applied the Barrier Analysis Tool (BAT, v.1) to calculate the percent of mean annual flow that is stored in upstream dams in the Delaware River Basin.

This indicator does not take into account day to day reservoir operations or specific dam configuration, which can influence the degree of hydrologic alteration in either a positive or negative way. Furthermore, this indicator also does not reflect the effects of other water diversions or withdrawals in the Basin, so it is limited to potential impairments to hydrologic regime caused only by dam storage. However, the basin-wide assessment of the risk of hydrologic impairment due to high dam storage is still a useful indicator; across large and small rivers, it can help identify which stream and river reaches may be suffering the hydrologic (and associated ecologic and biologic) impacts of upstream dams and which dams may warrant further investigation to address potential streamflow alteration.

In order to identify places most likely to be suffering hydrologic impairment due to land use change, examining the percent cover of impervious surface within a watershed can provide a useful complement to the measure of upstream dam storage. The high amounts of impervious cover associated with many highly developed areas are likely to cause hydrologic alteration downstream unless there are adequate stormwater management systems in place. The higher the percent cover of impervious surface across a small watershed, the more likely its streams are to be suffering hydrologic impairment. Because this metric cannot take into account effective stormwater management, it also should be used as a first-cut indicator to identify places that likely would benefit from stormwater management systems if they are not already in place.

5.3.4.3 Present Status

As many dams in the Basin are run-of-river dams and have relatively little effect on hydrologic regime, the vast majority of stream miles within the Basin are at low risk of hydrologic alteration, as indicated by their ratio of dam storage to mean annual flow value (Fig 5.3.8). However, over 300 stream and river miles (483 km) within the Basin could be considered at high risk as indicated by ratio values of >50%. Of these 300 miles, over 130 miles (209 km) of high-risk streams and rivers are those which drain less than 38 square miles (9842 ha). High ratios might be expected in these headwater areas where dams occur in small streams that have relatively low mean annual flow values. High risk on larger rivers may be caused by the cumulative storage of many dams upstream or by a major reservoir with significant storage capacity (or a combination of the two). Despite the limitations of the Basin-wide analysis of the risk of hydrologic impairment due to high dam storage, this ratio is still a useful indicator of locations where impaired hydrology may be occurring and affecting the health of our streams and rivers. While some significant impacts are occurring in the Delaware River Basin, most streams and rivers are at low risk of impairment from dam storage.

Similarly, the vast majority of watersheds within the Basin have relatively low (< 10 %) impervious cover (Fig 5.3.9). However, streams in or downstream of urbanized areas, particularly those with outdated or insufficient stormwater management in place, are likely to be suffering negative impacts of altered hydrology as well. Most at-risk watersheds are concentrated around the cities of Wilmington, DE, Philadelphia, PA, and Camden, NJ, though watersheds along the Lehigh, Schuylkill, and Maurice Rivers also may be experiencing substantial hydrologic impairment due to land use change. Localized land change certainly may also affect hydrology within a watershed, but this basin-wide analysis helps to identify where the greatest impairment is likely to be occurring.

5.3.4.4 Past Trends

Most of the Basin's large reservoirs were completed between 1960-1980 and were not specifically designed to operate with the longitudinal (high and low) and/or the temporal (seasonal) conservation flows that may be needed to maintain native aquatic communities. Recent advances in ecological flow science have resulted in many water resource agencies beginning to factor ecological flow needs into the way that large reservoirs are managed. Some smaller Basin reservoirs currently do not have any conservation release requirements, while most of the larger reservoirs have release requirements based on assimilative capacity needs ("Q7-10" - the consecutive 7-day flow with a 10-year recurrence interval) as opposed to one based on aquatic resource needs. Recent changes adopted by the Decree Parties for the three New York City Basin reservoirs have started to incorporate aquatic resource needs into their reservoir operation plans.

Most of the Basin's existing impervious cover was created prior to modern stormwater management (pre 2000). If any stormwater management did occur prior to 2000, it tended to focus on large storm events (>10 year storm). Modern stormwater management requirements have tended to focus on a broader range of rain events (0-100 year storm events), along with minimum infiltration requirements. The modern stormwater management requirements have largely centered on trying to maintain the existing hydrology of a project site from pre to postdevelopment conditions.

5.3.4.5 Future Predictions

As ecological flow science progresses and native aquatic communities' needs are further identified, water resource agencies can start to factor those data into the management of Basin reservoirs. New reservoirs will almost certainly be designed and permitted to consider ecological flow needs, while existing reservoirs operations are reviewed during the permit renewal process, which provides opportunities for operational revisions based on the latest science.

Stormwater management will need to focus in two areas – new development and retrofitting existing impervious cover. Almost all new development in the Basin is subject to modern stormwater management requirements. It is anticipated that the level of hydrological impairment due to "new development" will be minimal compared to the existing hydrological impairment caused by existing impervious cover.

5.3.4.6 Actions and Needs

A study of ecological flow needs to protect species and key ecological communities for the range of habitats in the Delaware River Basin is necessary in order to provide the scientific basis for any future modifications to reservoir operation plans.

Developing a strategy to deal with existing hydrological impairments due to existing impervious cover is necessary. Options range from mandatory stormwater management retrofits during the redevelopment of a site to voluntary retrofits incentivized by the implementation of stormwater runoff fees.

5.3.4.7 Summary

While most Basin streams are at low risk of hydrological impairment due to dam storage, some significant impacts are occurring in localized areas. The incorporation of ecological flow needs into reservoir management will likely increase in the future as those needs are further identified, which should result in a gradual minimization of impacts in those localized streams.

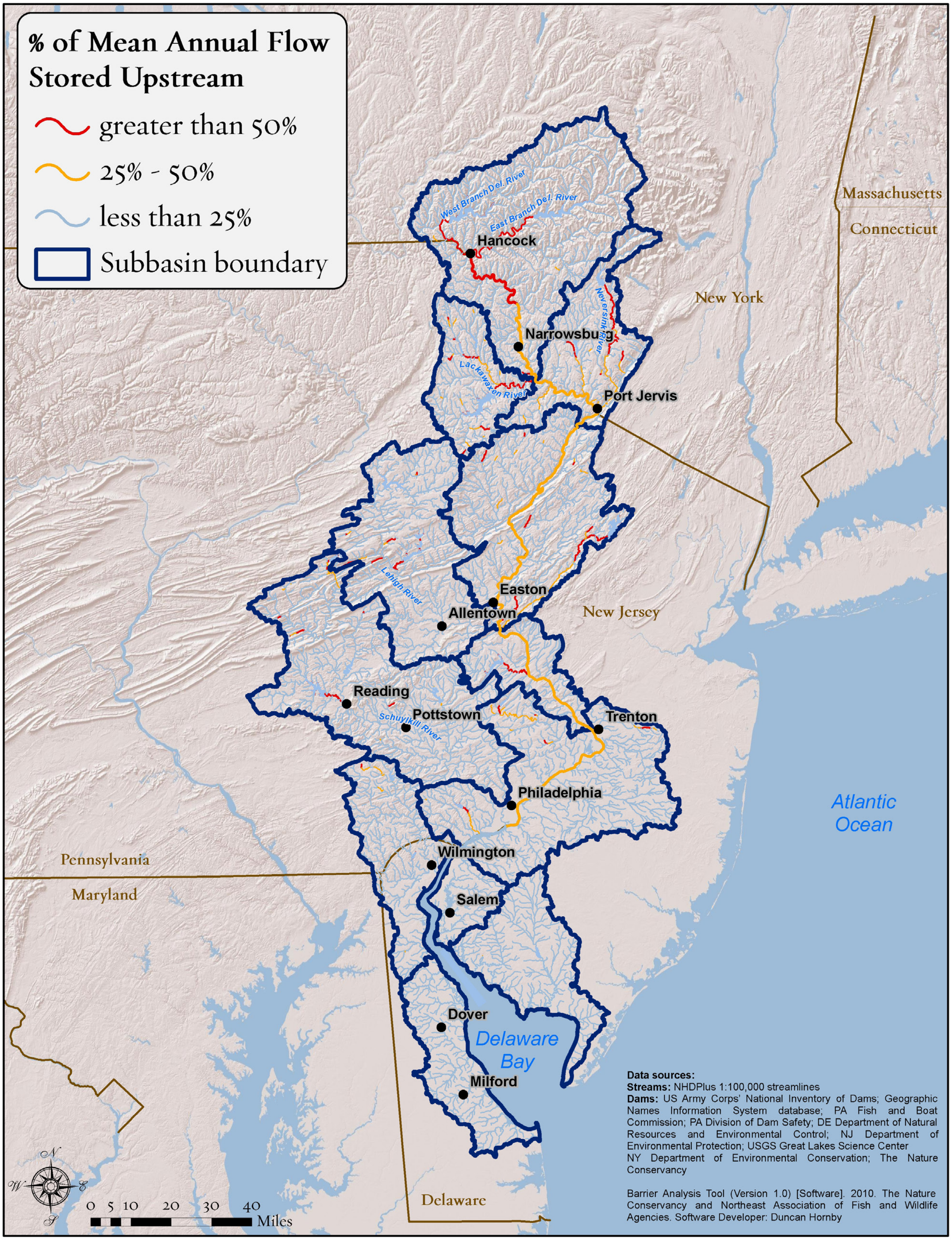

Figure 5.3.8 Ratio of upstream dam storage to mean annual flow for river reaches within Delaware River sub-basins.

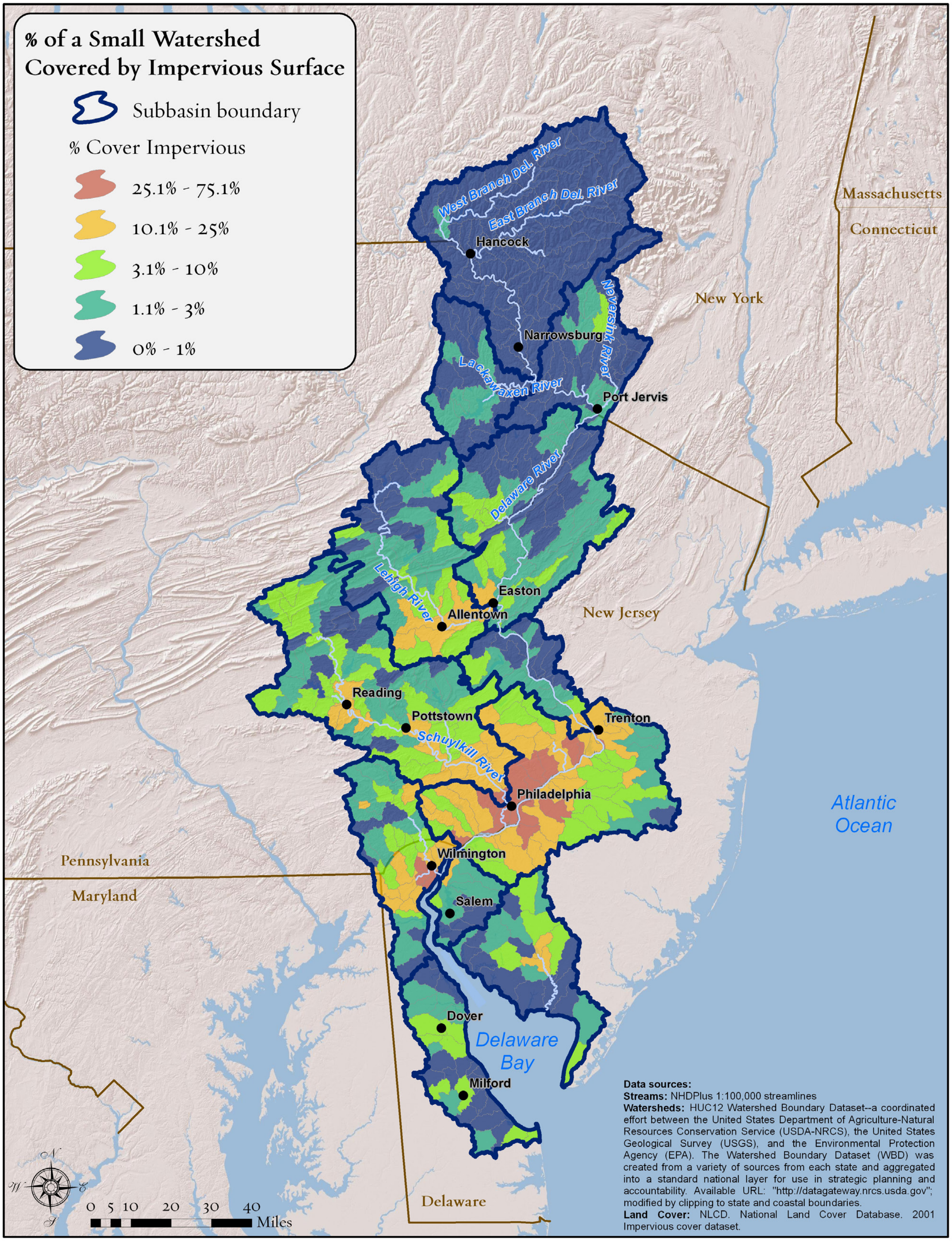

Figure 5.3.9 Percent cover by impervious surface across small watersheds in the Delaware River Basin.

5.3.4.11 Example Effects of Dam Storage and Operations on Hydrologic Impairment: Neversink River

Robert Tudor[1] • Ellen Creveling[2] • Michele M. DePhilip[3] • Chad Pindar[1]

1. Delaware River Basin Commission; 2. The Nature Conservancy, New Jersey; 3. The Nature Conservancy, Pennsylvania

The basin-wide indicator of dam storage ratios does not take into account actual dam operations. For example, this analysis indicates a high level of alteration downstream of the Neversink Reservoir. Indeed, the biologic effects of hydrologic alteration have been documented in the Neversink River, where macroinvertebrate surveys indicated that species composition in the river downstream of the reservoir showed signs of degradation similar to stretches impaired by acidity in other parts of the watershed (Ernst et al. 2008).

Altered temperatures and low flow in river stretches immediately downstream of the reservoir appeared to favor Chironomidae taxa over Ephemeroptera, Plecoptera, and Trichoptera taxa, similar to how pH and aluminum in the East Branch of the Neversink River appeared to influence macroinvertebrate composition there. This change in the biotic community of the river downstream of the reservoir likely was caused by adverse effects from dam storage (Ernst et al. 2008). However, more recently, a detailed study of the effects of changes in the management of the Neversink Reservoir just within the past few years illustrates that recent management changes have improved the degree of alteration to the Neversink River's natural hydrologic regime (Moberg et al. 2010).

Figure 5.3.4.11.1 below shows how the natural range of variability in flow on the Neversink has changed with the implementation of the Flexible Flow Management Plan (FFMP). Whether the biotic communities of the Neversink River downstream of the reservoir have shown any positive response to the return of a more natural hydrologic regime has not yet been studied.

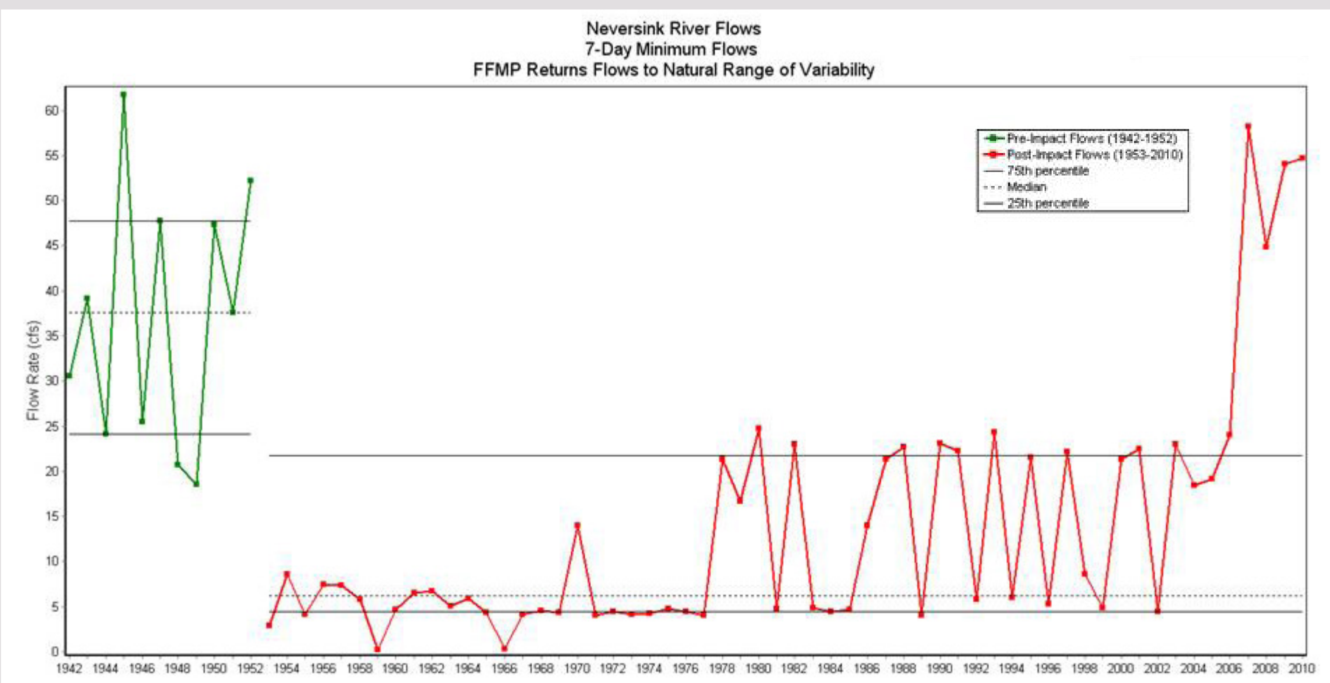

Figure 5.3.4.11.1 Neversink River 7-day minimum flows from 1942-1952 (green) and 1953-2010 (red).

While most Basin streams are at low risk of hydrological impairment due to existing impervious cover, there are significant impacts in the older urban/suburban areas of the Basin. Implementing stormwater management on existing impervious cover is expensive and may take several decades to address.

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