Choptank Ecological Assessment: Digital Atlas - Baseline Status Report

NOAA National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment

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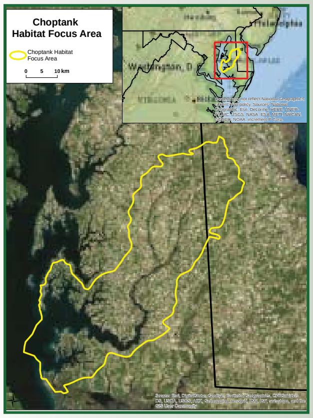

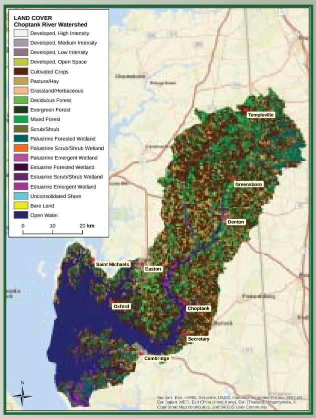

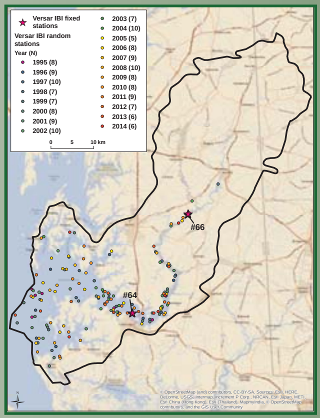

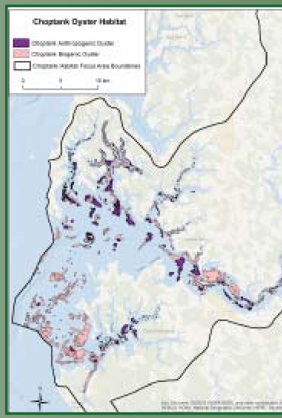

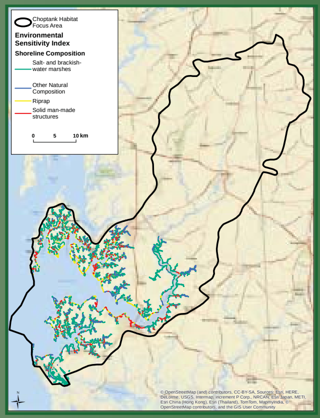

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Choptank Ecological Assessment: Digital Atlas - Baseline Status Report

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Foreword

In 2014, the Chesapeake Bay Watershed Agreement *was signed and commits the signatories to specific outcomes aligned under ten goals to advance the restoration and protection of the Bay watershed. The number of signatories to the 2014 agreement is expanded from state and federal restoration efforts begun in 1983 to include all political jurisdictions in the watershed. Specifically, the agreement was signed by six states - New York, Pennsylvania, West Virginia, Virginia, Maryland and Delaware - the District of Columbia, Chesapeake Bay Commission and the Federal Leadership Committee. Federal agencies are represented by EPA and include NOAA, U.S. Army Corps of Engineers, U.S. Forest Service, U.S. Fish and Wildlife Service, and National Park Service.*

The same year, NOAA designated the Choptank River complex as one of its Habitat Focus Areas under NOAA's Habitat Blueprint. The Choptank and Little Choptank Rivers are ecologically productive and important components of the Chesapeake Bay ecosystem. NOAA has focused resources on this watershed around these objectives: habitat restoration and protection; integrating science to inform management; and, community engagement.

In support of these objectives, NOAA's National Centers for Coastal Ocean Science developed a digital atlas as a means of making accessible a variety of datasets collected over decades that describe aspects of the Choptank watershed. This document is intended as an introduction to the datasets available so you can explore and discover the watershed. In addition to this document, you can access the data via a web portal or digital atlas, and the datasets are available as a geodatabase for those with expertise in ArcGIS. Requests for the geodatabase can be sent directly to Mr. Dan Dorfman at Dan.Dorfman@noaa.gov.*

I encourage you to use the data presented here and online to learn more about the Choptank and Little Choptank Rivers. And in so doing, I hope you are motivated to take action to ensure the sustainability of this productive ecosystem for future generations.

Sincerely,

Suzanne Skelley
Director, Cooperative Oxford Lab
NOAA National Centers for Coastal Ocean Science

*http://noaa.maps.arcgis.com/apps/webappviewer/index.html?id=54850fb8f903412da6cedd8f14ac96c8

Chapter 1: Introduction

The Choptank River watershed sits on the eastern shore of the Chesapeake Bay. The upper reaches of the watershed extend into Delaware, while the river flows west through Maryland and into the Chesapeake Bay. It encompasses 2,360 km^2 (583,344 acres), of which, 1,916 km^2 (473,456 acres) are land and 445 km^2 (109,888 acres) are open-water habitat (Figure 1.1). The area is notable for its extensive and important marine natural resources, including oyster bars, fish spawning and recruitment areas, and abundant blue crabs.

On land, the Choptank watershed is dominated by agricultural uses, but also features important “working waterfront” areas and expanding urban and suburban development. The population centers are Easton, Cambridge, and Denton, Maryland.

The Choptank watershed was selected by NOAA as a Habitat Focus Area (HFA) for the Habitat Blueprint Program. As such, NOAA plans an integrated set of activities combining resources from multiple programs to leverage the full weight of its efforts (Figure 1.2). The HFA Implementation Plan includes programs for:

- Oyster Restoration
- Wetlands, Living Shorelines
- Fish Passage
- Ecological Assessment
- Water Column Habitat
- Ecosystem, Community Services
- Climate Resiliency
- Collective Impact
- K-12 Education
- Communication, Outreach

As one component of the Ecological Assessment, NOAA’s National Centers for Coastal Ocean Science (NCCOS) has developed a Digital Atlas. The Digital Atlas integrates information from the full spectrum of research and monitoring within the watershed, compiles it as a single resource, and serves that information via an internet mapping portal.

This report is intended to introduce information contained in the Digital Atlas. It highlights seven topics of ecological significance within the Choptank HFA. However,

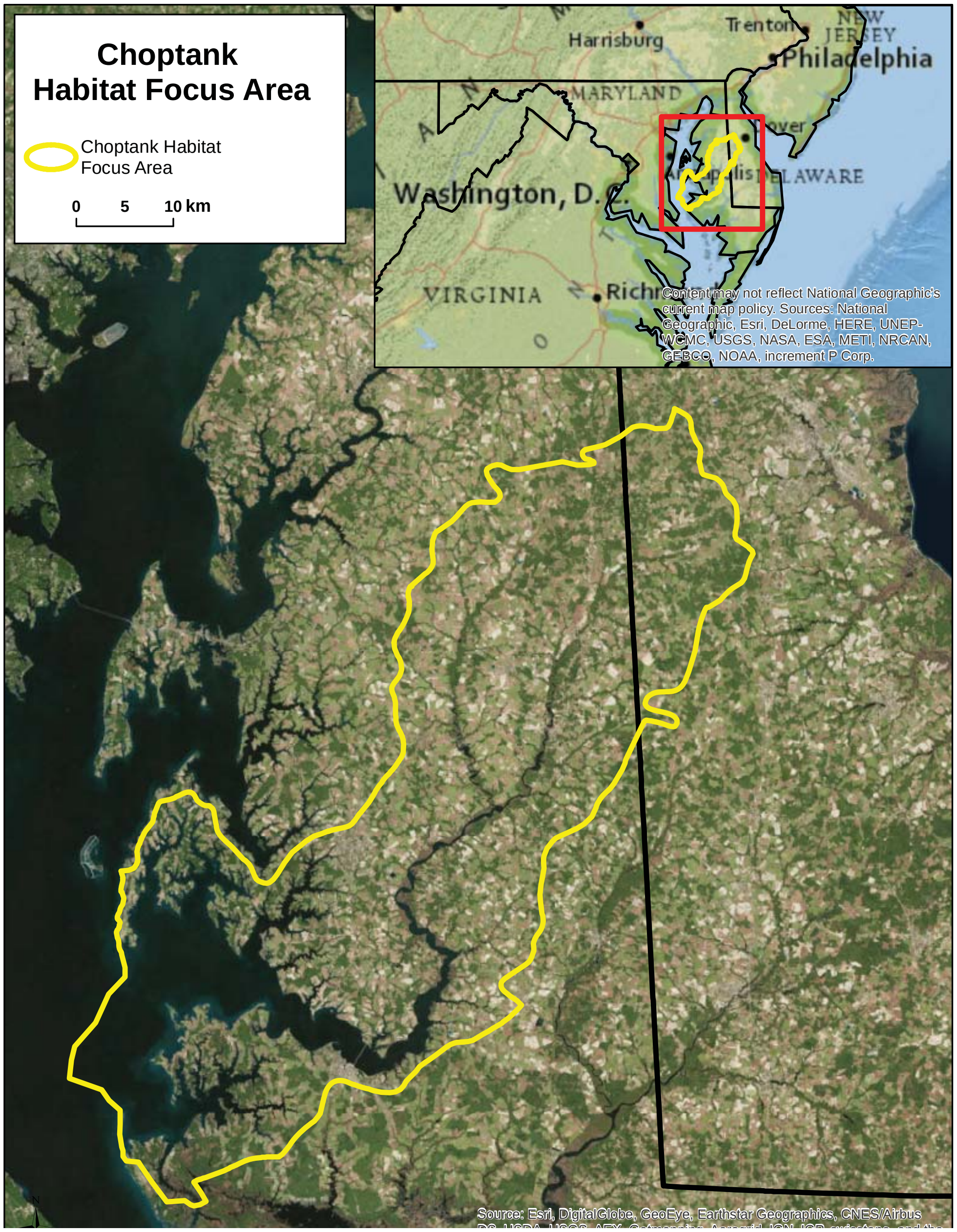

Figure 1.1. Choptank watershed habitat focus area.

this report does not encompass the full suite of spatial information available from all of the monitoring and research programs in the area.

The topics emphasized through this report are:

- Land Cover
- Shoreline Composition
- Water Quality
- Benthic Index of Biotic Integrity
- Submerged Aquatic Vegetation
- Fish
- Oysters

The Land Cover Chapter focuses on the information developed by NOAA's Coastal Change Analysis Program (C-CAP). That program, within NOAA's Office of Coastal Management, tracks changes to coastal land cover through image classification of the LandSat™ satellite.

The Shoreline Composition Chapter analyzes data from NOAA's Environmental Sensitivity Index and Maryland's Shoreline Situation Reports.

The Water Quality Chapters analysis is based on long-term monitoring stations from the Chesapeake Bay Monitoring Program and also information collected by the Mid-Shore River Keepers Program.

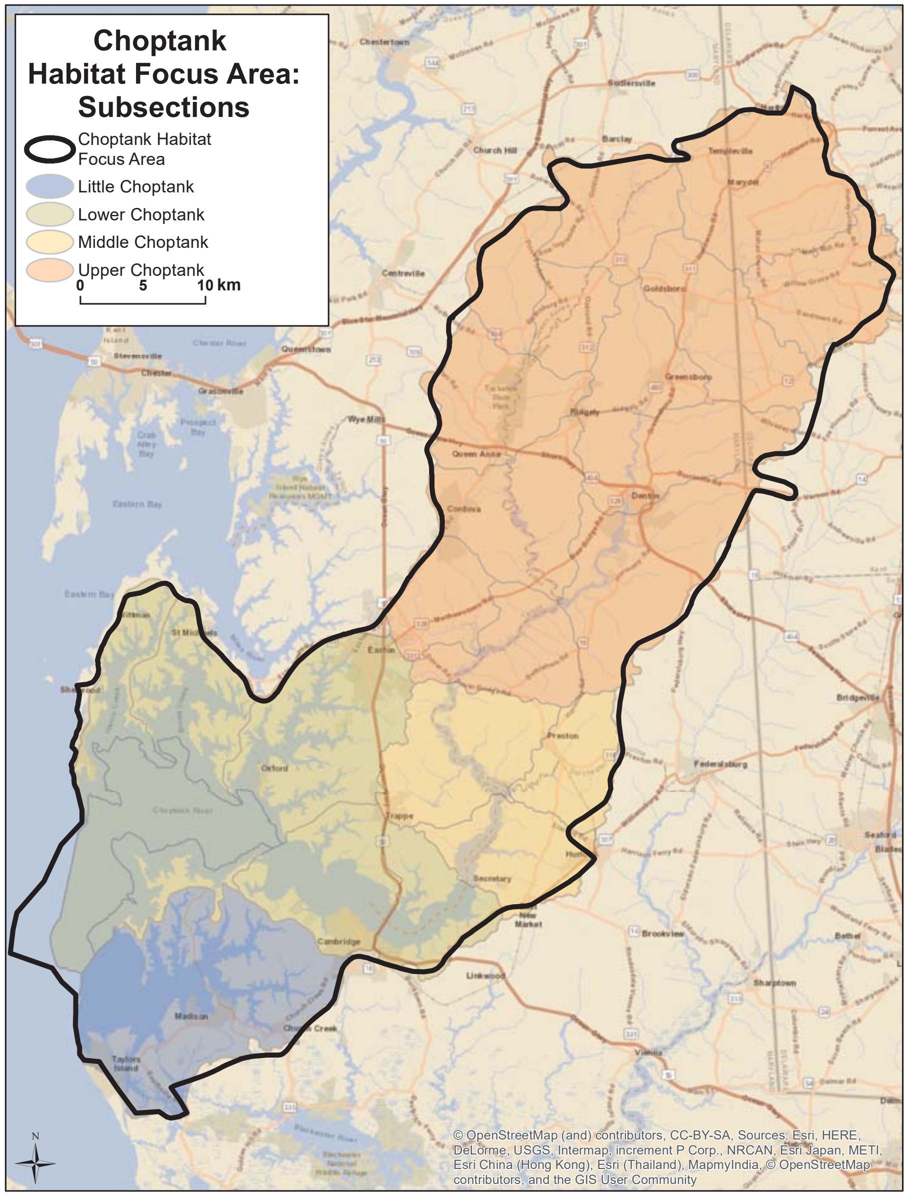

Figure 1.2. Choptank habitat focus area.

The Benthic-Index of Biotic Integrity Chapter used two primary sources of information. The first is information collected by the environmental consulting firm Versar, Inc., in collaboration with the State of Maryland and the Chesapeake Bay Program. This data covers the tidal portion of the HFA. The second source is the Maryland Biological Stream Survey, which covers the non-tidal portion of the HFA.

For the Submerged Aquatic Vegetation Chapter, a time series of information collected by the Virginia Institute of Marine Science was analyzed.

The Fish Chapter analyzed the spawning habitat and the juvenile striped bass seine survey data from the Maryland's Department of Natural Resources (MD DNR), Fisheries Service. Data collected by the MD DNR's Fisheries Habitat and Ecosystem Program, the Maryland Biological Stream Survey, and the University of Maryland's menhaden gear comparison, seine, and trawl surveys were also analyzed.

The Oyster Chapter focuses on: historical harvest records; recruitment; mortality; disease; biomass; habitat distribution; restoration efforts; and management efforts.

Throughout this document information on the Choptank HFA is presented as a whole or broken down into subsections. The Harris Creek and Tred Avon tributaries as well as the Little Choptank River are reported on individually. These focus sites are shown in Figure 1.3.

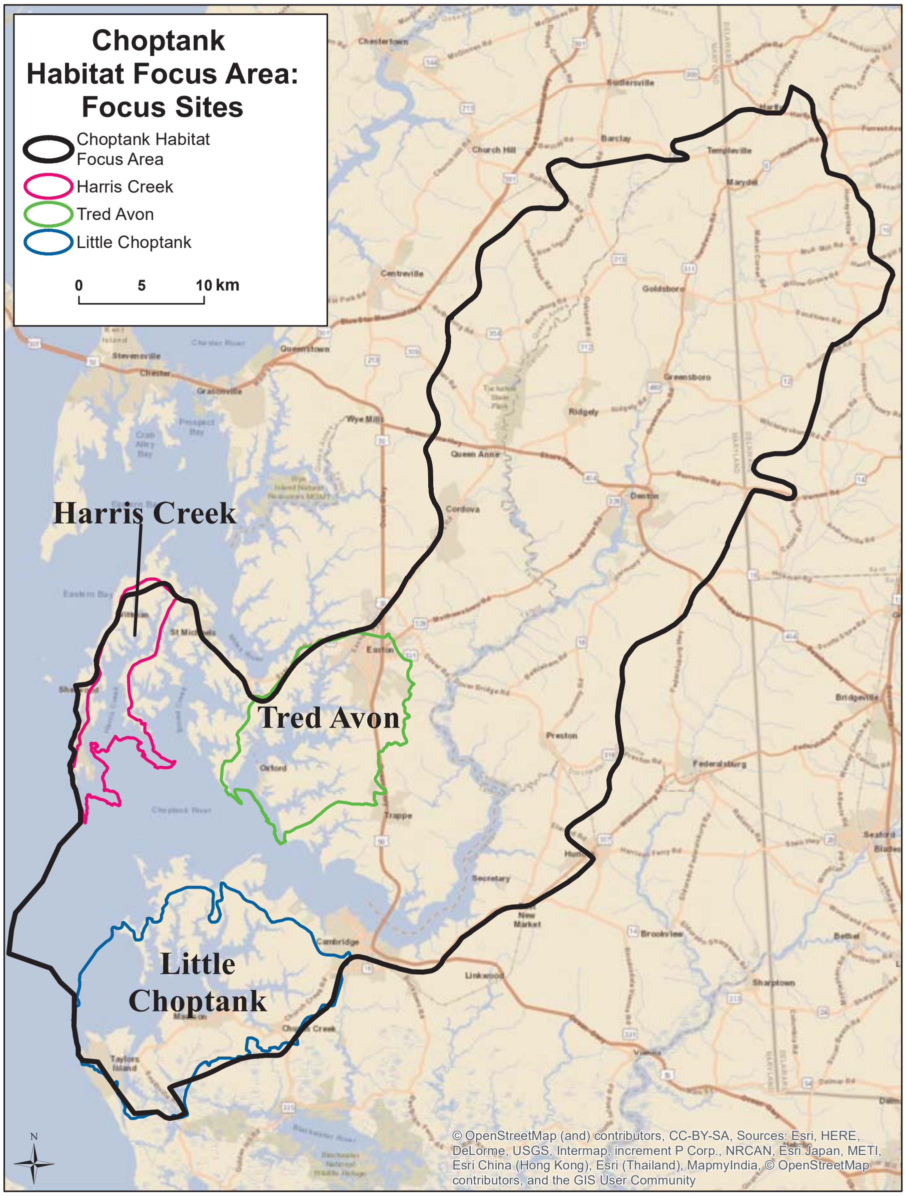

Figure 1.3. Choptank habitat focus area map showing Harris Creek, Tred Avon, and Little Choptank focus sites.

Chapter 2: Land Cover Characterization

INTRODUCTION

Land cover status and trend information can help in developing a scientific understanding of watershed condition and its response to natural and human-induced changes. This understanding can aid in assessing the impacts caused by these changes, helping coastal resource managers make more informed decisions.

Agricultural landscape in the Choptank River watershed. Photo credit: Dave Harp.

DATA SOURCES AND METHODS

The land cover data used in this report (Figure 2.1) is produced as part of NOAA's Coastal Change Analysis Program (C-CAP). C-CAP is a nationally standardized, raster-based data set that covers coastal intertidal areas, wetlands, and adjacent uplands for the coastal U.S. Data are derived from the analysis of remotely sensed Landsat imagery. This analysis includes analyzing each 30x30 meter Landsat imagery pixel, and classifying the entire pixel as a particular standardized land cover type (i.e. cultivated crop, high intensity developed, estuarine emergent wetland, etc.). It is important to note that land cover does not necessarily equate to land use; some categories such as evergreen forest can be difficult to determine whether they are natural or anthropogenic occurrences based on C-CAP data alone. There are two types of files available from the C-CAP program: individual dates of land cover that supply a wall-to-wall map for each area, and change files that compare one date to another in order to highlight what type of land cover change occurred between those dates. For more information about the C-CAP, and to access the data visit: coast.noaa.gov/dataregistry/search/collection/info/ccapregional

C-CAP files for the eastern United States are available for 1996, 2001, 2006 and 2010. These files were obtained and then clipped to the Choptank River sub-basin watersheds (12 Digit Watershed Boundary Dataset). The Watershed Boundary Dataset was obtained through the USDA Natural Resource Conservation Service Geospatial Data Gateway: https://gdg.sc.egov.usda.gov. For each sub-basin, land cover cell counts were calculated in square kilometers.

The impervious surface data (2011 Percent Developed Imperviousness) was obtained from the Multi Resolution Land Characteristics Consortium (MRLC) and is available at http://www.mrlc.gov/nlcd11_data.php. This data comes as 30x30 meter pixel cell counts. Each cell in the data set has an impervious value, which is the percentage of the cell that contains impervious surface. All cells for each impervious value (e.g. 0, .01, .02, … 1) were multiplied by the area (900 m^2), and then summed to determine the total square kilometers of impervious surface for a sub-basin. Some pervious land covers, such as turf grasses, behave similarly to impervious surfaces, but are not counted as impervious surface in this data set.

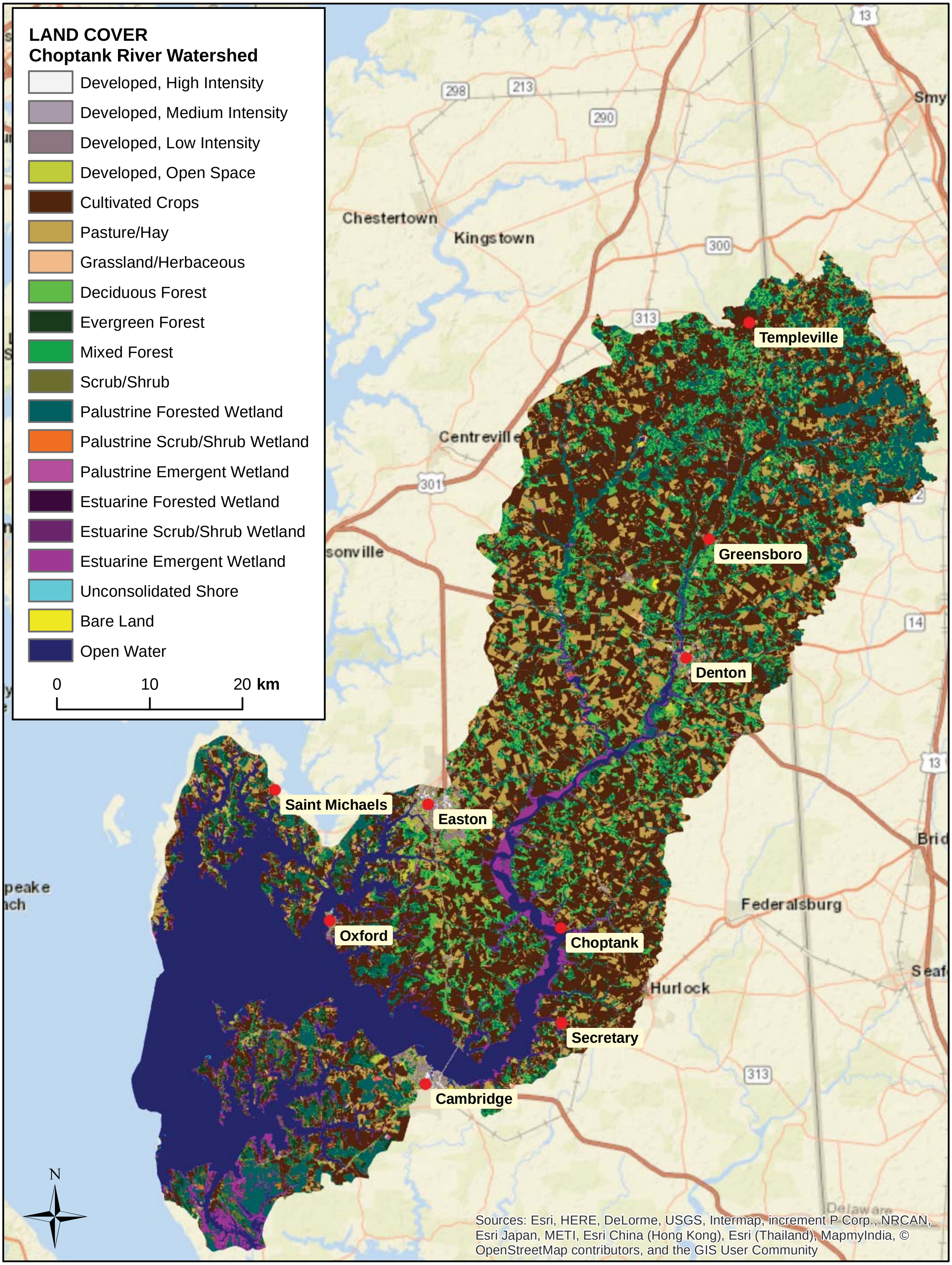

Figure 2.1. Land cover types found in the Choptank River watershed in 2010.

RESULTS

Choptank River Watershed Land Cover

The Choptank River watershed comprises an area of about 2,367.25 km² (584,960 acres) of which approximately 445.48 km² (110,080 acres) is open water. The total watershed land area therefore is about 1,921.77 km² (474,880 acres). In 2010, the predominant land cover type was agricultural, followed by forested wetlands. Between 1996 and 2010 the largest loss of land cover was 11.91 km² (2,944 acres) of forested area including 3.89 km² (960 acres) of forested wetlands. The largest land cover type to increase was 8.55 km² (2,112 acres) of developed area (Figure 2.2).

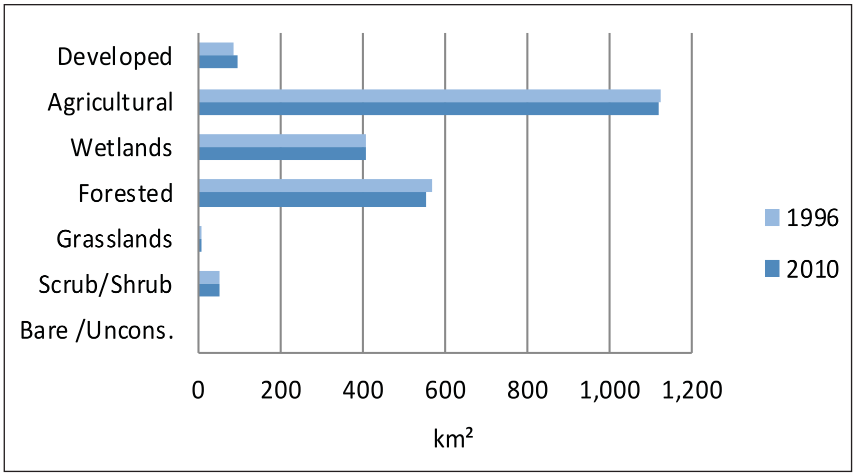

Figure 2.2. Land cover types in the Choptank River watershed 1996 and 2010.

Developed Area

In 2010, there was 95.83 km² (23,680 acres) of developed area, comprising five percent of the total watershed land area. This compares to 87.28 km² (21,568 acres) developed area in 1996, an increase of 8.55 km² (2,112 acres). The majority of the developed area falls within the low intensity developed and developed open space categories. A little less than one percent of the land area constituted moderate to high intensity developed area. Total impervious surface accounted for 1.5 percent of the total watershed land area (Table 2.1).

Table 2.1. Developed area. % WS = percent of watershed

Category	1996		2010		96-10
	km²	% WS	km²	% WS	Change (km²)
High Intensity Developed	2.7	0.1	3.2	0.2	0.4
Medium Intensity Developed	7.7	0.4	9.5	0.5	1.8
Low Intensity Developed	44.0	2.3	46.8	2.4	2.8
Developed Open Space	33.0	1.7	36.4	1.9	3.4
Total	**87.4**	**4.5**	**95.8**	**5.0**	**8.4**

Agricultural Land

Agriculture is the largest land cover class in the Choptank River watershed. In 2010 approximately 58 percent (1,121 km², 277,120 acres) of the watershed was in agricultural production. Of this, 886 km² (218,880 acres) were in cultivated crops and 236 km² (58,240 acres) were in pasture/hay. The amount of area in agricultural production did not change appreciably since 1996, although there was a shift of roughly 9.5 km² from pasture/hay to cultivated crop area (Table 2.2).

Table 2.2. Agricultural land. % WS = percent of watershed

Category	1996		2010		96-10
	km²	% WS	km²	% WS	Change (km²)
Cultivated Crops	878.1	45.7	885.6	46.1	7.5
Pasture/Hay	245.9	12.8	236.5	12.3	-9.5
Total	**1,124.1**	**58.5**	**1,122.1**	**58.4**	**-2.0**

Forested Land

In 2010 there were 556 km² (137,472 acres) of forested area in the watershed, constituting about 29 percent of the land area of the watershed. The largest type of forested area was forested freshwater wetlands. Since 1996 there was a loss of about 12 km² (2,912 acres) of forested area. A small amount (0.86 km²) was a conversion to developed area and approximately 2.6 km² (640 acres) were changed to agriculture. The rest was lost mostly to scrub/shrub and grassland categories (Table 2.3).

Table 2.3. Forested land. % WS = percent of watershed

Category	1996		2010		96-10
	km²	% WS	km²	% WS	Change (km²)
Deciduous Forest	155.4	8.1	150.7	7.8	-4.7
Evergreen Forest	43.0	2.2	41.0	2.1	-2.0
Mixed Deciduous/Evergreen	41.4	2.2	40.2	2.1	-1.2
Palustrine Forested Wetland	328.2	17.1	324.3	16.9	-3.9
Total	**568.1**	**29.6**	**556.3**	**28.9**	**-11.8**

Wetlands

In 2010, there were a little over 407 km² (100,572 acres) of wetlands in the watershed. Since 1996, there was a loss of 3.86 km² (954 acres) of freshwater forested wetlands, but also a smaller, roughly 1.75 km² (432 acres) gain in total scrub/shrub wetlands. The net loss for all wetlands was 2.31 km² (571 acres) (Table 2.4).

Table 2.4. Wetlands. % WS = percent of watershed

Category	1996		2010		96-10
	km²	% WS	km²	% WS	Change (km²)
Palustrine Forested Wetland	328.2	17.1	324.3	16.9	-3.9
Palustrine Scrub/Shrub Wetland	17.6	0.9	19.3	1.0	1.6
Palustrine Emergent Wetland	11.4	0.6	11.7	0.6	0.3
Estuarine Forested Wetland	0.0	0.0	0.0	0.0	0.0
Estuarine Scrub/Shrub Wetland	1.0	0.1	1.1	0.1	0.1
Estuarine Emergent Wetland	51.5	2.7	51.0	2.7	-0.5
Total	**409.7**	**21.3**	**407.4**	**21.2**	**-2.3**

Scrub/Shrub, Grassland, Bare Land, and Unconsolidated Shore

There were 53.50 km² (13,120 acres) of scrub/shrub cover and 8.03 km² (1,984 acres) of grassland in 2010, accounting for about three percent of watershed area. Bare land and unconsolidated shoreline comprised less 2.5 km² (640 acres) of total land cover. None of these categories changed appreciably since 1996.

Impervious Surfaces

Impervious surfaces cover 1.49% of the land area of the Habitat Focus Area, amounting to 28.67 km² (7,084 acres). This information is developed by the MRLC from 2011 LandSat imagery Figure 2.3.

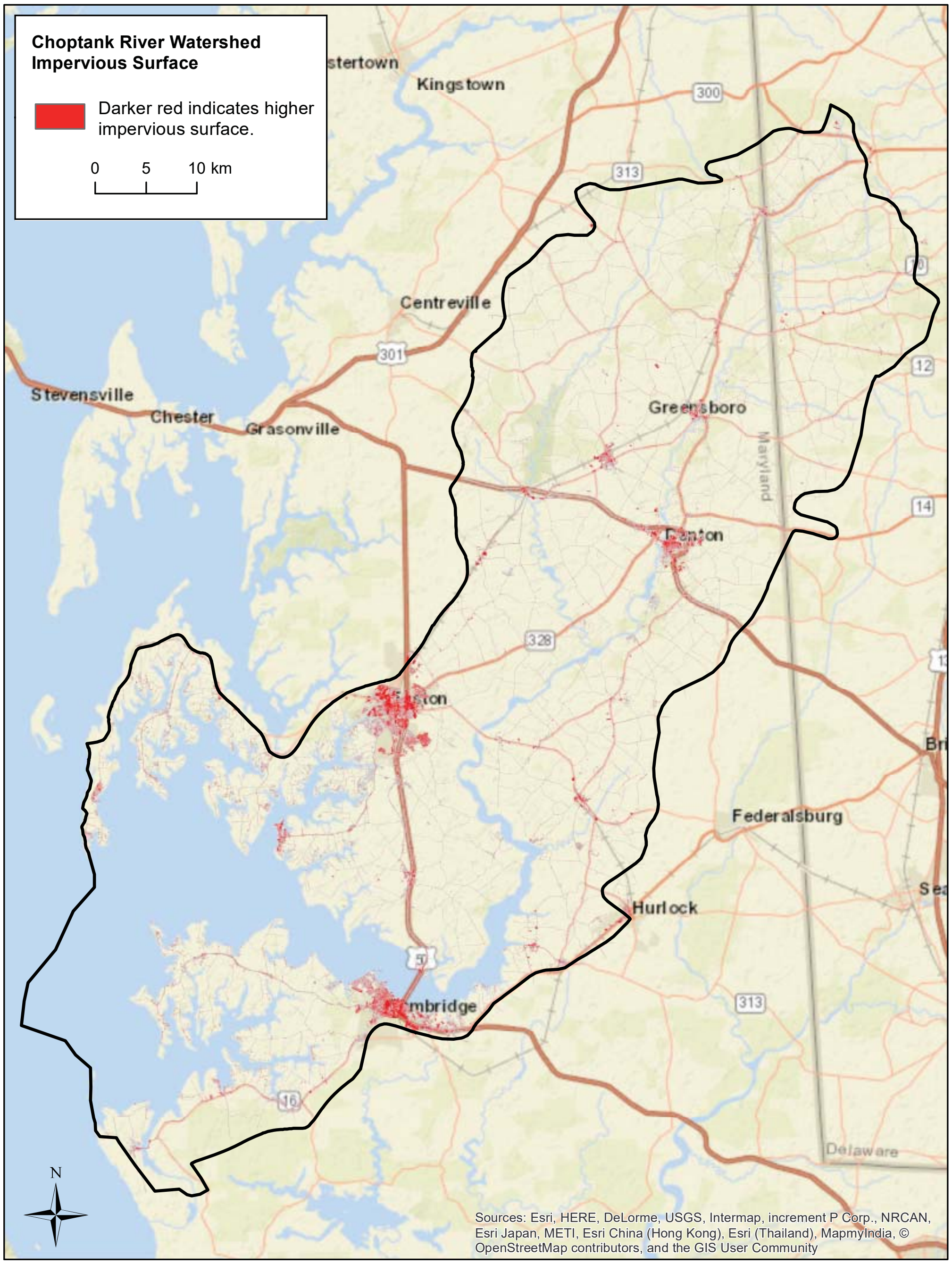

Figure 2.3. Impervious surfaces of the Choptank Habitat Focus Area from 2011.

HIGHLIGHT AREAS

Harris Creek

The Harris Creek watershed has a land area of about 31 km² (7,680 acres) and an equally large open water area. Half of the land cover is in the agricultural category. A quarter of the land area is forested, much of which is forested wetlands. Twelve percent of the land area is developed (mostly low density or open space developed) and 2.8 percent of the land area is covered with impervious surfaces. The amount of developed area did not change appreciably since 1996 (Figures 2.4 and 2.5).

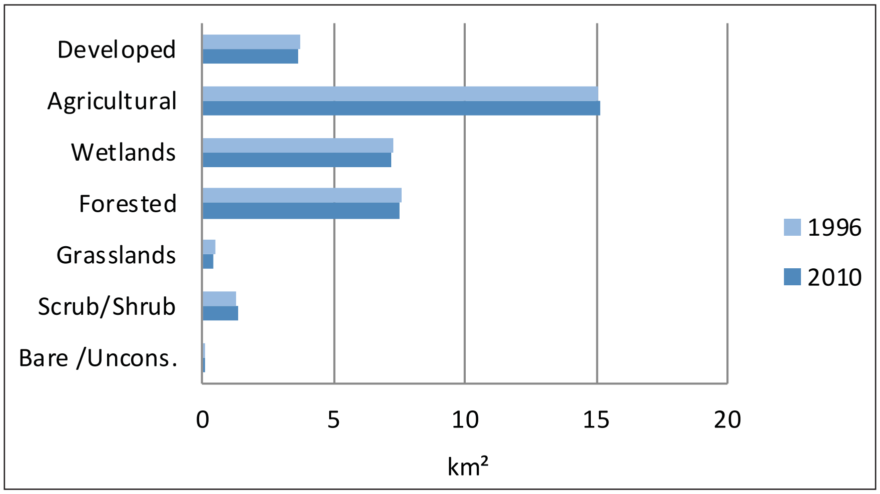

Figure 2.4. Land covers of the Harris Creek watershed for 1996 and 2010.

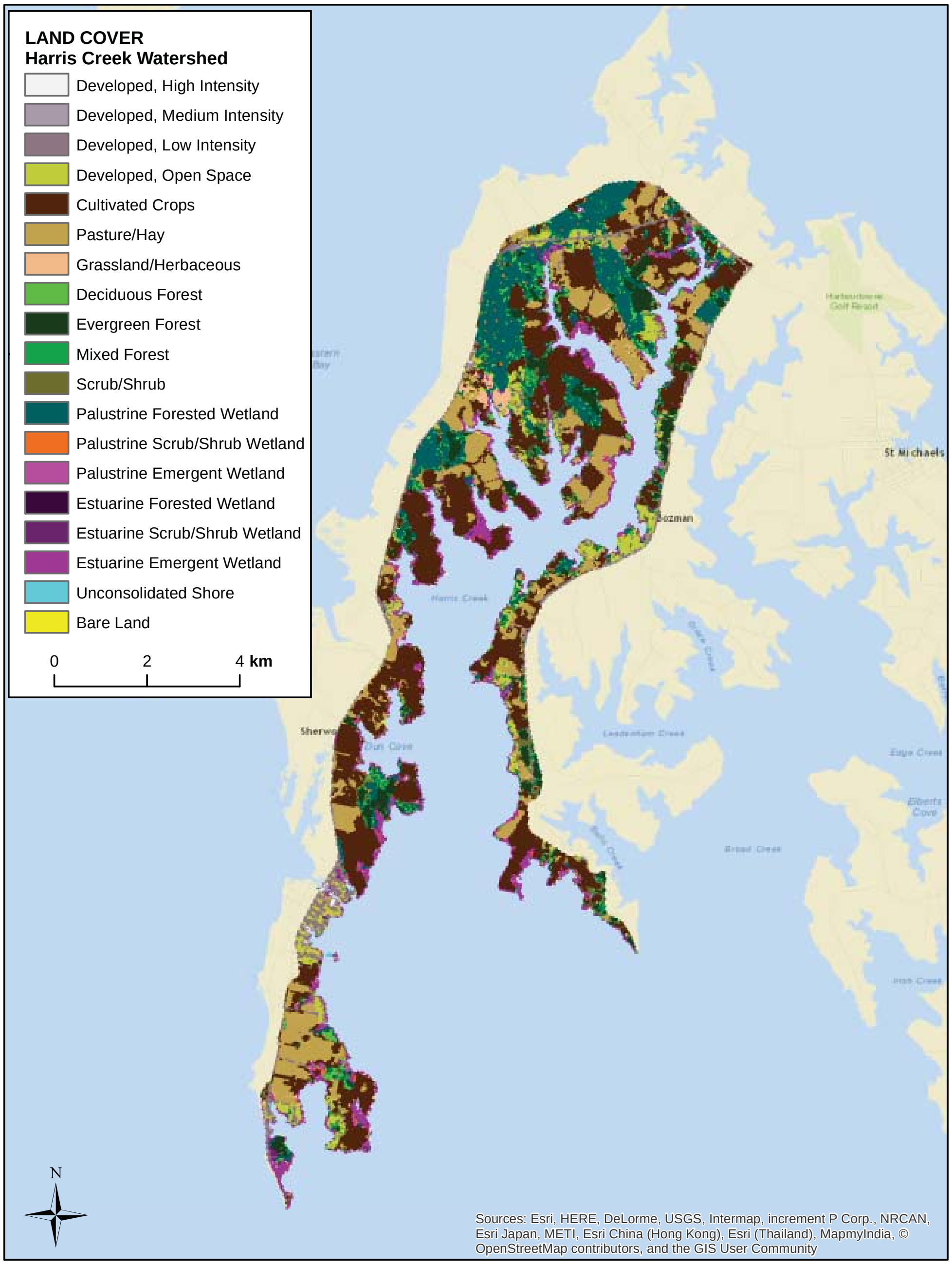

Figure 2.5. The land cover of Harris Creek watershed in 2010.

Tred Avon River

The Tred Avon River watershed has a land area of 126.91 km² (31,360 acres) and an open water area of almost 31 km² (7,680 acres). Eighteen percent of the watershed is in the developed category and since 1996, the amount of developed area has increased by just over 2.5 km² (640 acres) (converted mostly from agricultural land cover). The amount of impervious surface coverage is 5.2 percent of the land area. The predominant land cover is agricultural at 59.57 km² (14,720 acres), most of which is in cultivated crops (Figures 2.6 and 2.7).

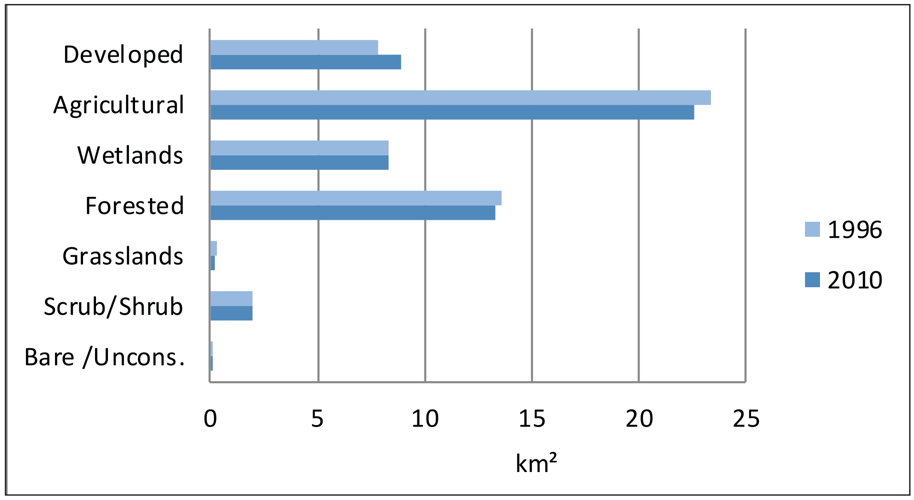

Figure 2.6. Land covers of the Tred Avon River for 1996 and 2010.

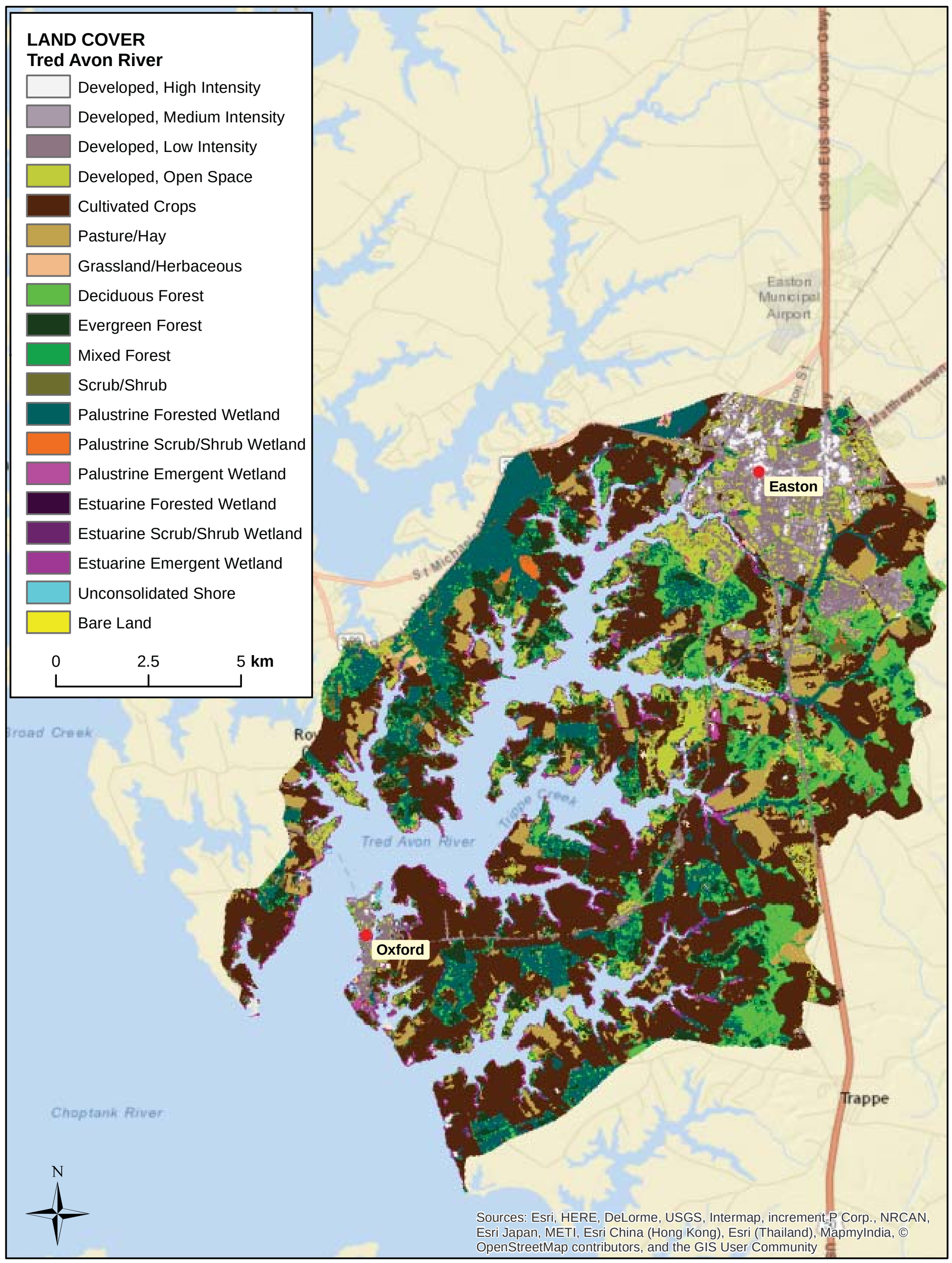

Figure 2.7. The land cover of Tred Avon River watershed in 2010.

Little Choptank River

The Little Choptank River drains approximately 160.58 km² (39,680 acres) from the Fishing Creek and Slaughter Creek drainages. The largest land cover is wetlands, consisting of 75.11 km² (18,560 acres) of area (of which 49.21 km² (12,160 acres) are forested wetlands), representing nearly half of the watershed area. The wetland area also includes over 18.13 km² (4,480 acres) of estuarine emergent wetlands. Agricultural area consists of 51.80 km² (12,800 acres), or about 32 percent of the watershed.

The watershed also contains 6.48 km² (1,600 acres) (4 percent) of developed area and has just over one percent of impervious surface coverage. Since 1996, the amount of developed area did not change appreciably (Figures 2.8 and 2.9).

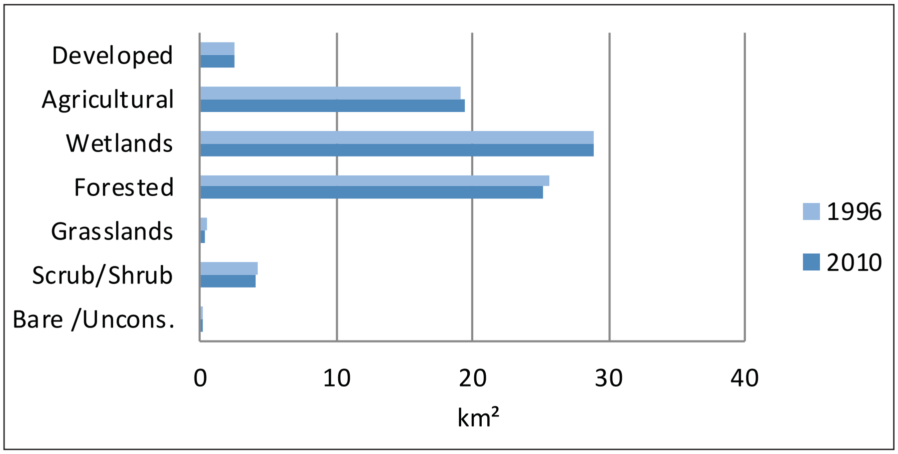

Figure 2.8. Land covers of the Little Choptank River for 1996 and 2010.

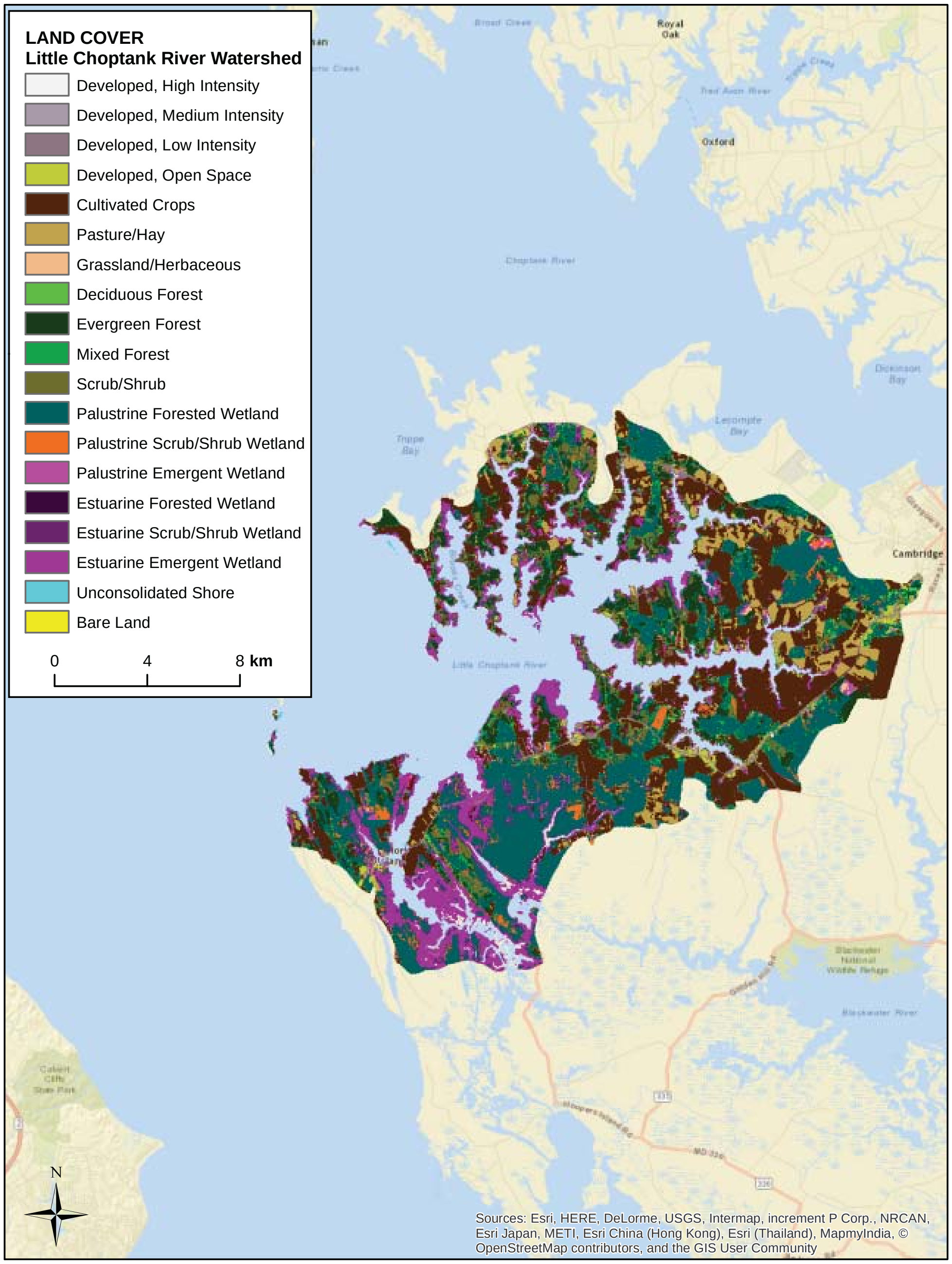

Figure 2.9. The land cover of Little Choptank River Watershed in 2010.

SECTIONS

Lower Choptank

This study area is comprised of 331.52 km² (81,920 acres) of land area and 326.34 km² (80,640 acres) of open water. In 2010, fourteen percent of the land area was in the developed category and four percent of the watershed land area is covered by impervious surfaces. Developed area increased by 4.40 km² (1,088 acres) from 1996 to 2010. Agriculture was the predominant land cover comprising nearly 259 km² (64,000 acres) (78%) of the watershed land area (Figure 2.10).

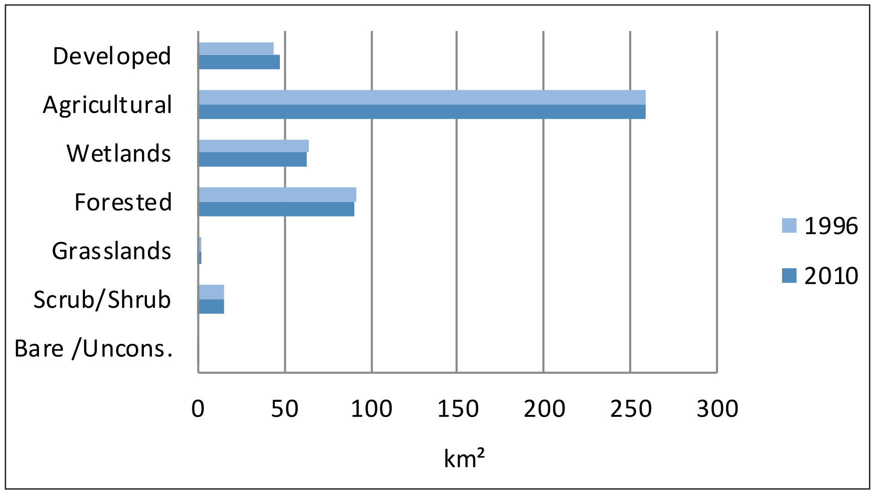

Figure 2.10. Land covers of the Lower Choptank River for 1996 and 2010.

Upper Choptank

The Upper Choptank River study area contains about 1,194 km² (295,040 acres) of land and 13 km² (3,200 acres) of open water. In 2010, land cover was predominately agricultural with 572.39 km² (141,440 acres) in cultivated crops and another 181.30 km² (44,800 acres) in pasture/hay. There was also a large amount of forested area totaling 365.19 km² (90,240 acres), of which 214.97 km² (53,120 acres) was forested wetlands. Developed area accounted for 33 km² (8,155 acres) and just less than one percent of the land area was covered with impervious surface. Developed area increased by a little over 2.6 km² (640 acres) during the period from 1996 to 2010 (Figure 2.11).

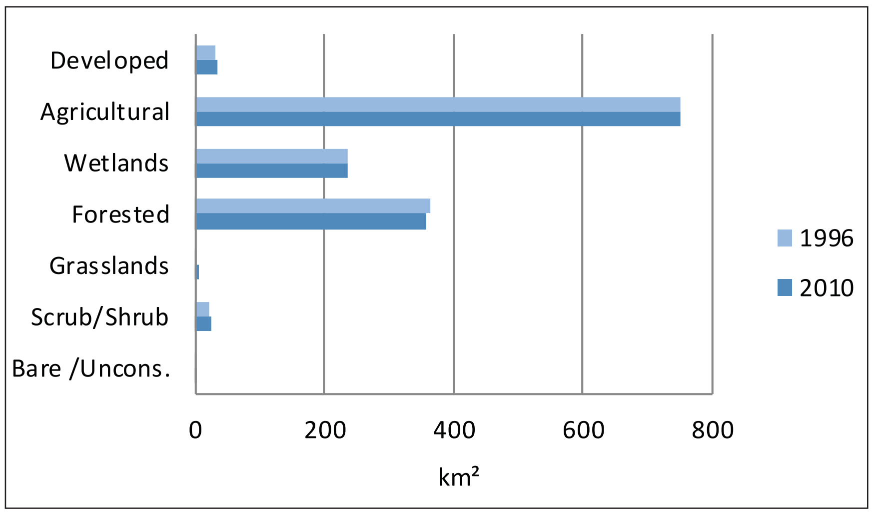

Figure 2.11. Land covers of the Upper Choptank River for 1996 and 2010.

CURRENT ACTIVITIES AND DATA GAPS

C-CAP is an ongoing and actively supported program within NOAA's Office of Coastal Management. Each region is updated approximately every five years. The MRLC strives to stay on a five year update cycle for impervious surface data.

Differences from other Land Cover/Land Use Data Compilations

Other studies of the Choptank River, such as "The Maryland Tributary Strategy Choptank River Basin Summary Report" (Karrh, 2007), may present land cover/land use statistics that differ from this report. Below is an explanation of some of the factors that influence the final results of land cover/land use studies and why there will be differences when compared.

Watershed Definition. The shape and size of the land area that land cover data is clipped to affects the final tabulation results of each land cover class. This study includes the Delaware portion of the watershed but not the Honga River portion. Other studies may or may not include these areas.

Land Cover Classification Definitions. Differences in how land cover classes are defined may cause differences in the final tabulation of the numbers. Most studies do not use the same definitions. C-CAP has a well-defined classification scheme. For more information: https://coast.noaa.gov/digitalcoast/training/ccap-land-cover-classifications.html

Methodologies. There are different methods for determining land cover and land use. The source data and how it is processed will impact the final results. Therefore, any efforts to assess land cover/land use that use different methodologies will end up with at least slightly different results. The C-CAP methodology is based on satellite data interpretation and only produces land cover results (no compilation of land use). For more information: https://coast.noaa.gov/dataregistry/search/collection/info/ccapregional

Dates of Source Data Collection. If the "snapshot" dates of land cover data sets that are being compared are different, then there will be reporting differences.

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Chapter 3: Shoreline Condition

INTRODUCTION

The shoreline addressed here can be identified as the place where the land meets the Chesapeake Bay within the Choptank watershed. Here, we address the shoreline of the Choptank River and Little Choptank River from the Chesapeake Bay to the upper reaches of tidal influence. The shoreline described here will address the tidal and estuarine portions of the watershed.

In natural systems, the shoreline is typically a dynamic place, both in terms of coastal geomorphology as well as biological and ecological patterns. Natural shorelines provide a diversity of habitat which serves multiple ecological functions. Natural shorelines provide habitat for many species, particularly juvenile fishes, invertebrates, and shorebirds. Man-made shorelines typically support a different assemblage of species than those found in natural conditions. Natural shoreline also provides physical services, such as reducing wave energy and erosion. Furthermore, natural coastal ecosystems can provide filtration services, such as reducing nutrient and contaminant inputs to near-shore habitats. Many species components and ecosystem habitats can be affected by shoreline condition. Man-made or hardened shorelines can alter habitats and species distributions as well as reduce the dynamic nature of the geomorphology.

Typical natural shoreline components include wetlands, beaches, and vegetated banks. The shoreline of the watershed is dominated by salt and brackish water marshes. Typical man-made shoreline components include riprap, bulkheads, groin fields and marinas, with riprap being the most common in the watershed.

There are many research groups investigating shoreline condition and its effects on biology and ecology. These groups include federal agencies, state agencies, academic programs and non-profits. A group of researchers led by the Smithsonian Environmental Research Center and sponsored by the National Centers for Coastal Ocean Science have recently completed a five year (2010-2015) investigation into the effects of shoreline change on ecology and biology for Mid-Atlantic coastal ecosystems, including the Chesapeake Bay.

Here we report on the most recent information on the shoreline composition for the Choptank watershed.

Harris Creek a tributary of the Choptank River complex. Photo credit: Jane Thomas, IAN Image Library

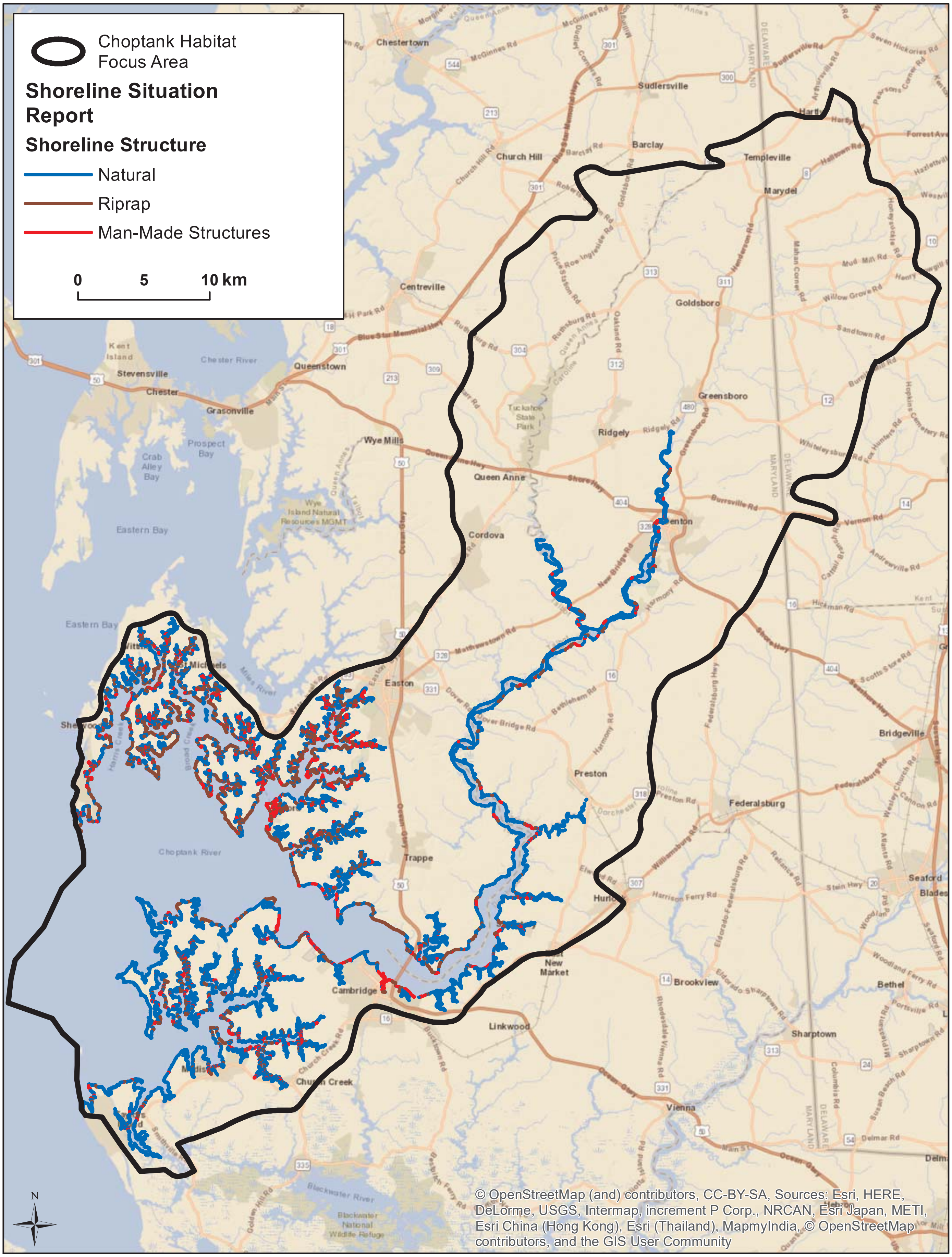

Figure 3.1. Choptank watershed shoreline composition from Shoreline Situation Report (SSR).

DATA SOURCES AND METHODS

There are two important datasets which describe the shoreline conditions of the Choptank watershed. The first is the Digital Shoreline Situation Report (SSR), which was produced by the Virginia Institute of Marine Science (VIMS), Comprehensive Coastal Inventory Program (CCI) in 2005 (Berman et. al., 2005). The shoreline base-map used for this effort was developed by using photo-interpretation techniques applied to digital orthogonal quarter quadrangle aerial photographs. Shoreline structures were identified by field survey from small boats and GPS location tracking.

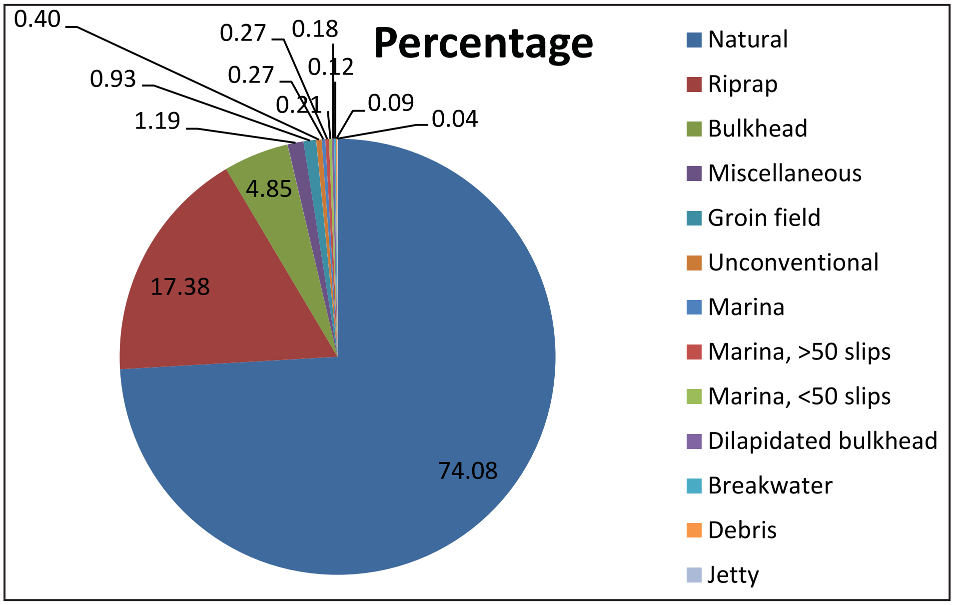

Figure 3.2. Shoreline composition from SSR.

The SSR is collected for the shorelines of Chesapeake Bay. The SSR identifies 1,227 kilometers of shoreline for the Choptank River. Man-made structures compose 318 km or 26% of this area. Details are provided in Figures 3.1 and 3.2.

The second important data source we analyzed for the Choptank watershed is the Environmental Sensitivity Index (ESI) which is produced by NOAA's Office of Response and Restoration (NOAA OR&R, 2007). The ESI assesses and ranks shorelines for sensitivity to oil spills and other hazards. It is produced through photo image interpretation, but does not feature an *in-situ* survey component. ESI is a national program which is updated periodically on a regional basis. The Chesapeake Bay region is currently being updated.

Choptank River tributary. Photo credit: Dave Harp

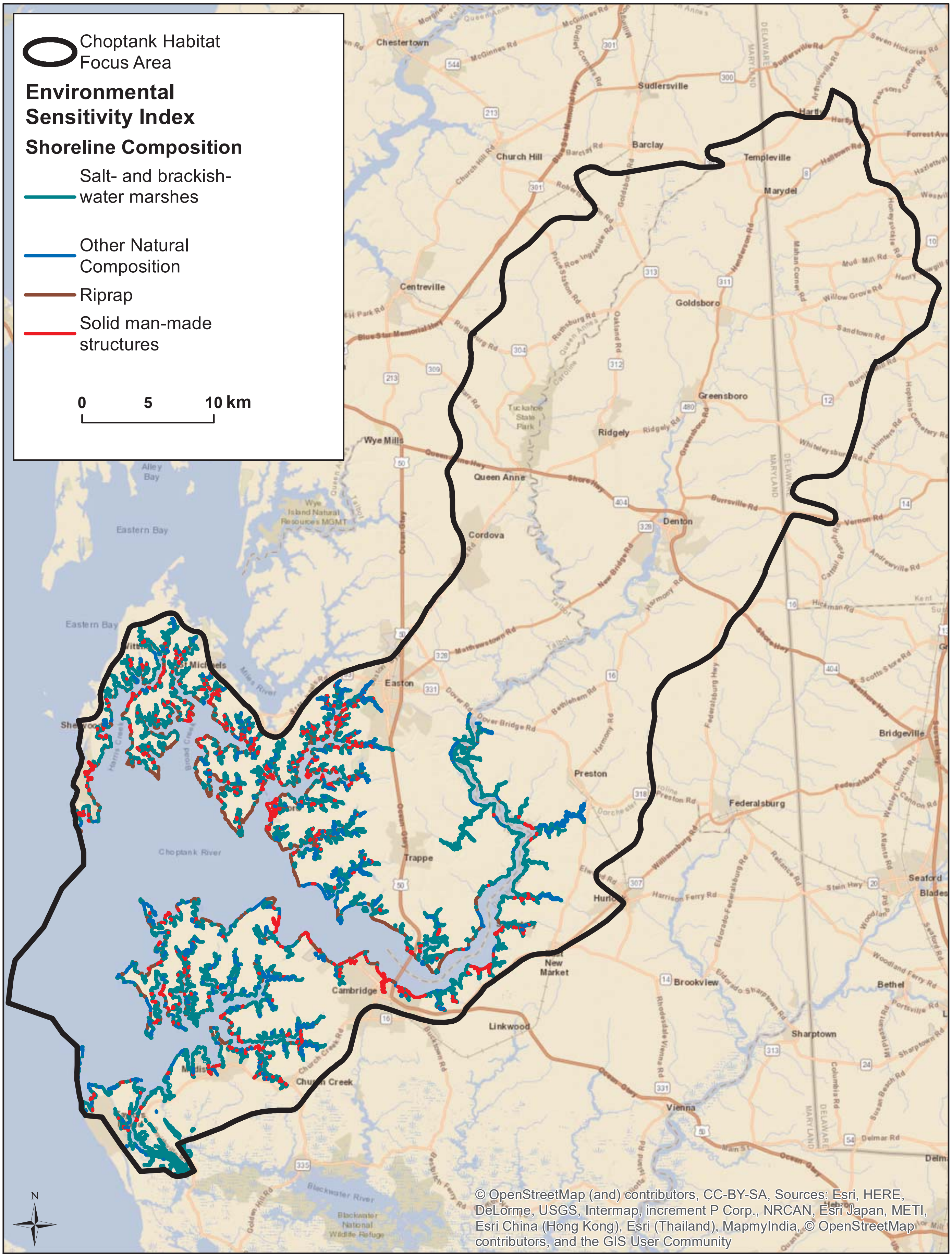

Figure 3.3. Choptank watershed shoreline composition from the Environmental Sensitivity Index (ESI).

The ESI shoreline dataset ranks 1,280 km of shoreline within the Choptank watershed. Hardened or man-made structures account for 25% of this shoreline.

Details of the information in the ESI shoreline dataset are provided in Figures 3.3 and 3.4. Both datasets track man-made and riprap shorelines. However, the SSR provides greater detail on man-made structures and the ESI provides greater detail on natural features.

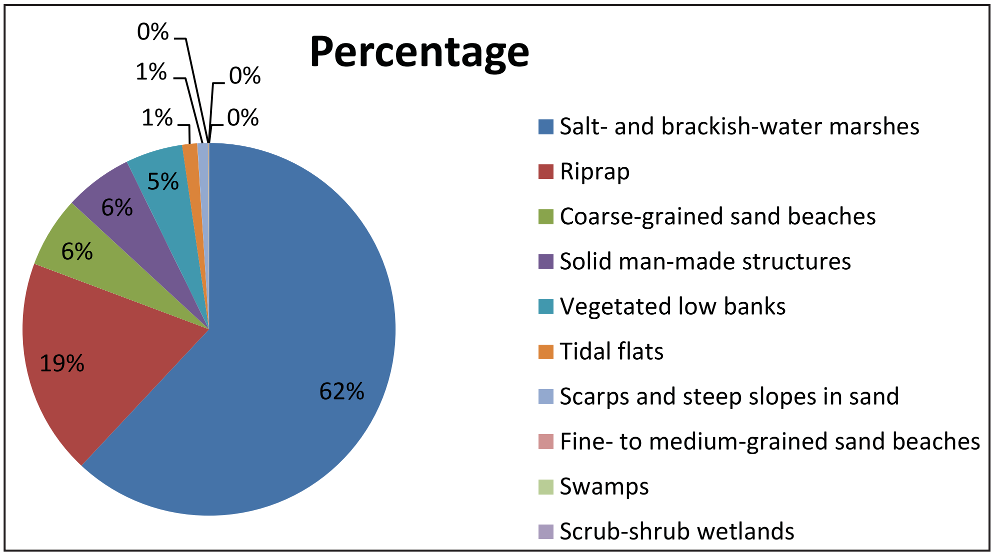

Figure 3.4. Choptank watershed shoreline composition from ESI.

WATERSHED COMPARISON

The sub-watersheds of the Choptank Habitat Focus Area span a range from almost entirely natural in Hunting Creek to more than 44% altered in Broad Creek. Below we summarize the amount of hardened shoreline in each of the Choptank sub-watersheds (Table 3.1).

Table 3.1. Summary of hardened shoreline for Choptank sub-watersheds from ESI data.

Name	Kilometers	Hard	Percent
Broad Creek-Choptank River	159.5	70.8	44.4
Harris Creek-Choptank River	99.4	38.9	39.1
Tred Avon River-Choptank River	240.9	81.5	33.9
La Trappe Creek-Choptank River	106.9	32.1	30.0
Brannock Bay-Choptank River	55.9	16.7	29.9
Bolingbroke Creek-Choptank River	81.6	15.4	18.9
Fishing Creek-Little Choptank River	145.8	26.0	17.8
Slaughter Creek-Little Choptank River	219.1	29.7	13.6
Warwick River-Choptank River	52.9	5.6	10.7
Marsh Creek-Choptank River	93.0	2.3	2.5
Hunting Creek	24.6	0.5	1.8


Choptank wetland. Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory

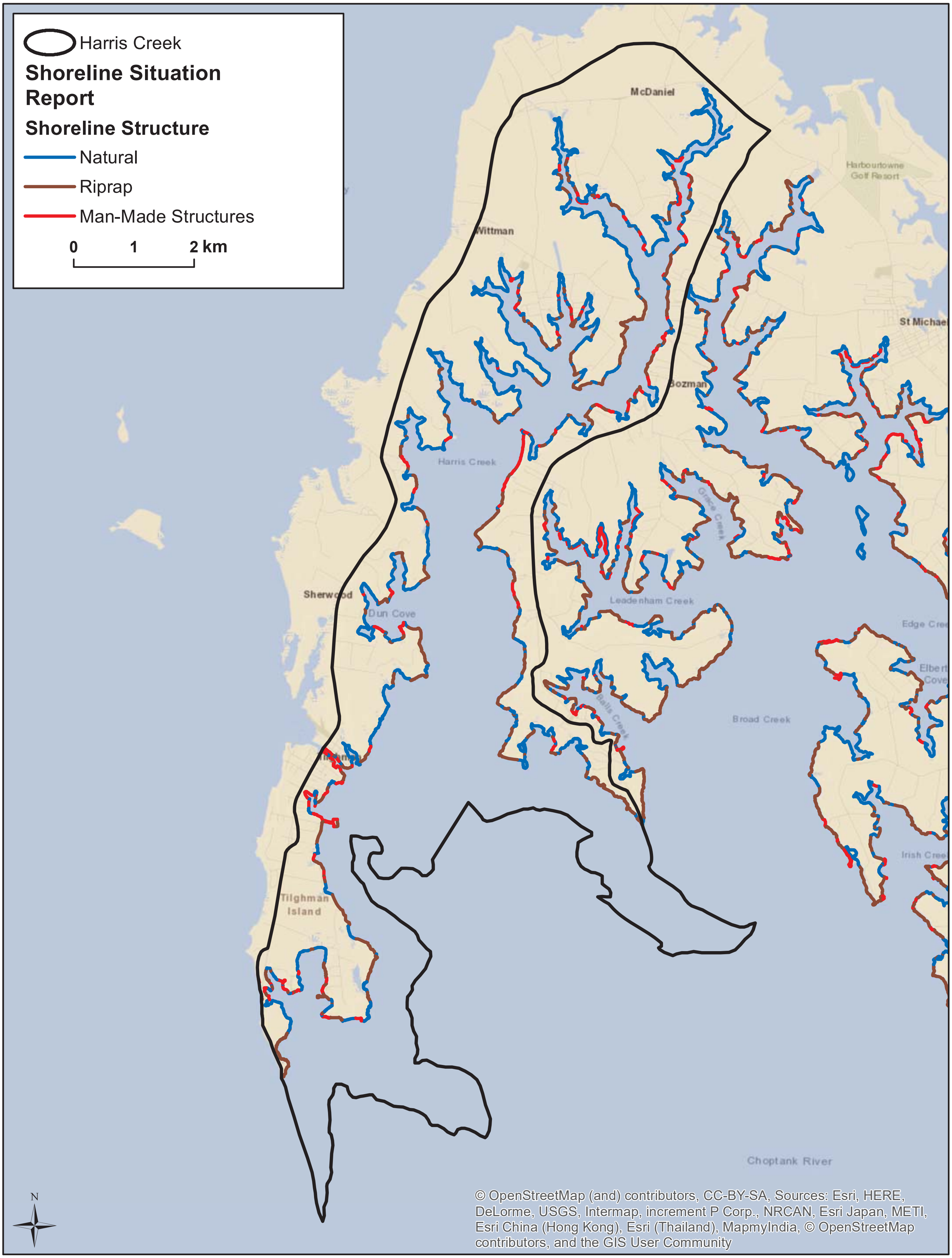

Figure 3.5. Harris Creek shoreline composition from SSR.

Harris Creek

The shoreline of the Harris Creek sub-watershed is one of the most altered shorelines in the watershed. Within the Harris Creek sub-watershed, the VIMS SSR indicates 99.4 km of shoreline, with 34.9 km (38%) hardened and 61.8 km (62%) in natural composition. The hardened shoreline is primarily composed of riprap, 27.3 km (27%). Details are provided in Figures 3.5 and 3.6.

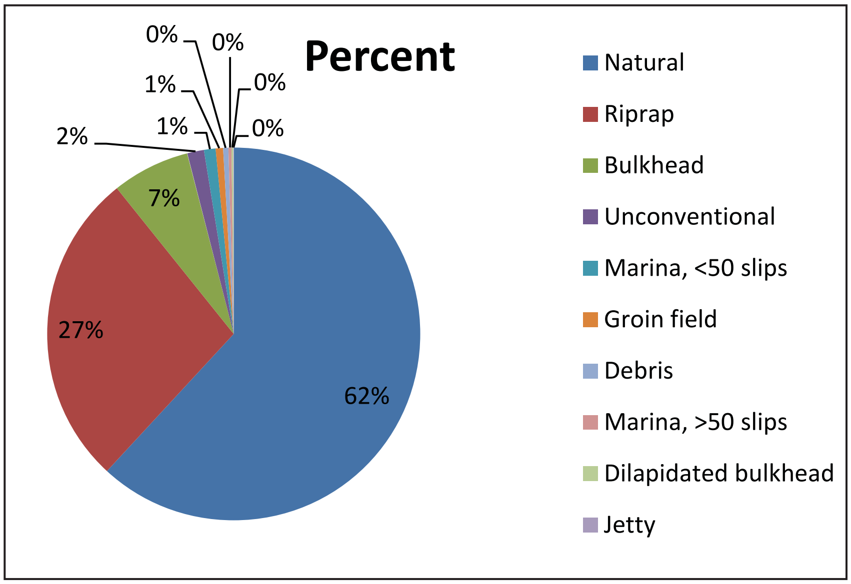

Figure 3.6. Harris Creek shoreline composition from SSR.

Harris Creek wetland. Photo credit: NOAA National Centers for Coastal Ocean Science

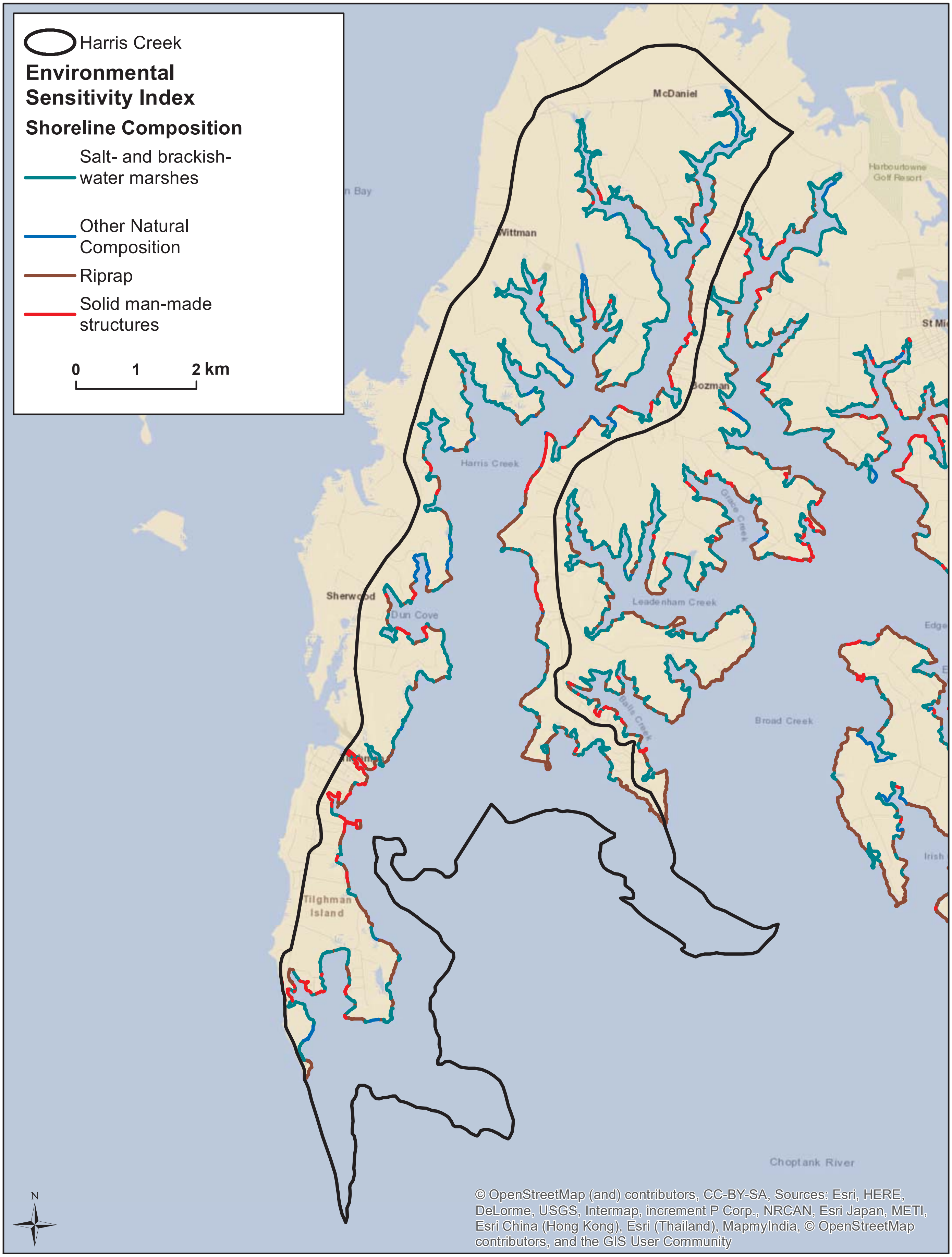

Figure 3.7. Harris Creek shoreline composition from ESI.

The ESI for the Harris Creek sub-watershed indicates 99.4 km of shoreline. The shoreline composition is highly altered, with 34.9 km (35%) of shoreline consisting of man-made structures and 64.5 km (65%) of shoreline consisting of natural features. The natural component of the shoreline is dominated by salt and brackish water marshes (57.5 km, 58%). The man-made component is dominated by riprap (26.8 km, 27%). Details are provided in Figures 3.7 and 3.8.

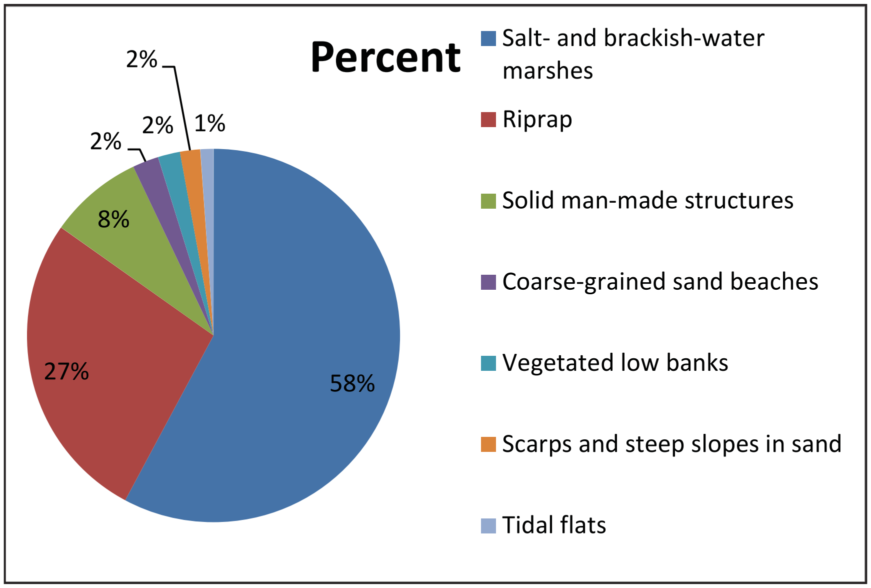

Figure 3.8. Harris Creek shoreline composition from ESI.

Riprap along Harris Creek. Photo credit: NOAA National Centers for Coastal Ocean Science

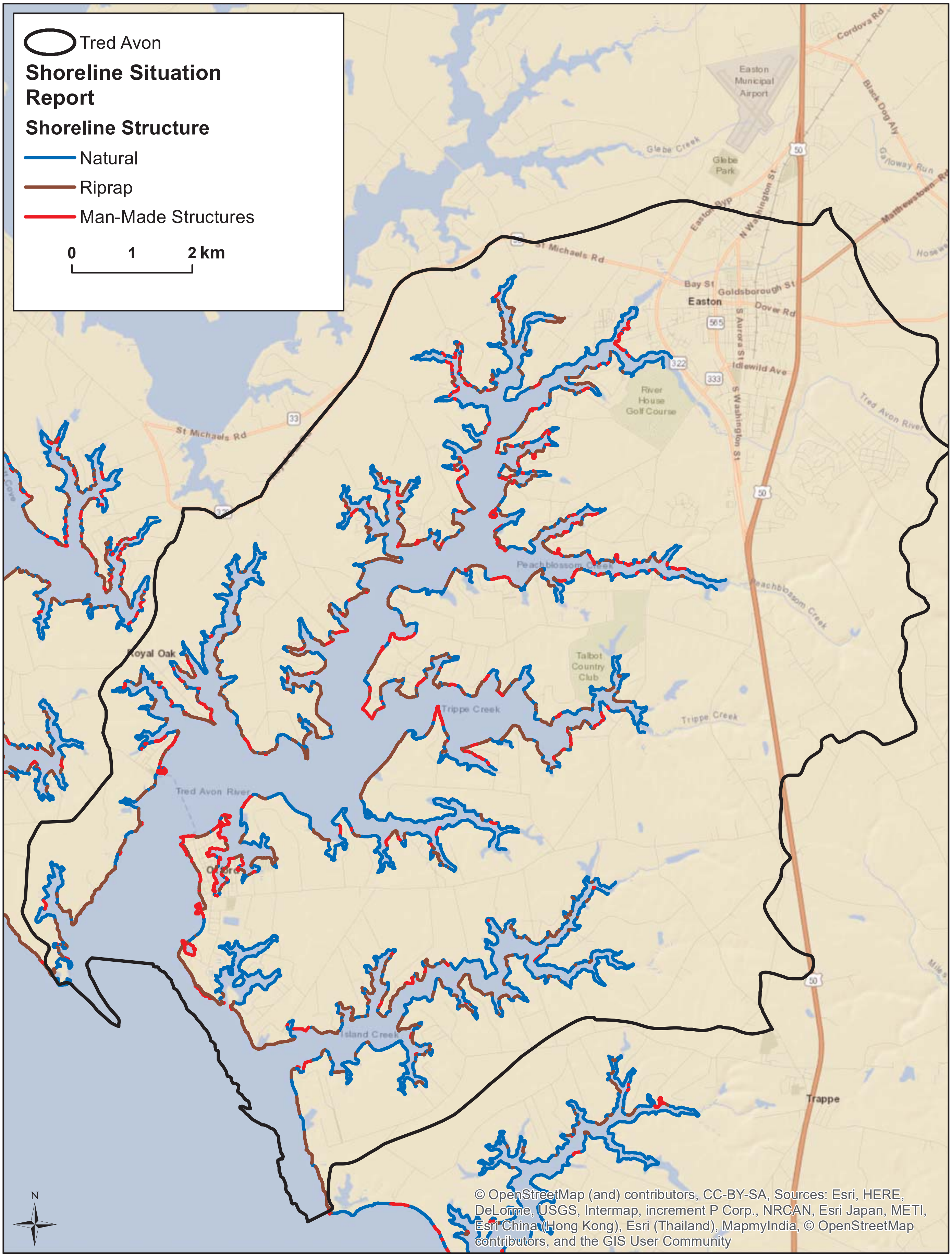

Figure 3.9. Tred Avon shoreline composition from SSR.

Tred Avon

Based on the SSR, the shoreline of the Tred Avon sub-watershed is roughly 37% hardened (83.9 km of 226.7 km). The sub-watershed includes the town of Easton, the largest populated area in the watershed. Of the hardened area, 58.4 km of shoreline are composed of riprap, representing 26% of the sub-watershed. Details are provided in Figures 3.9 and 3.10.

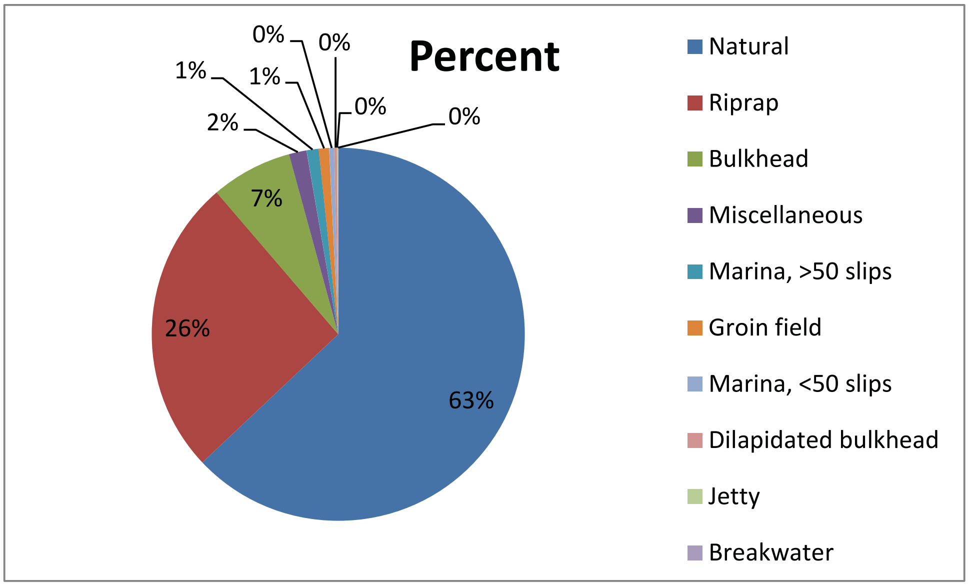

Figure 3.10. Tred Avon shoreline composition from SSR.

Shoreline in the Tred Avon. Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory

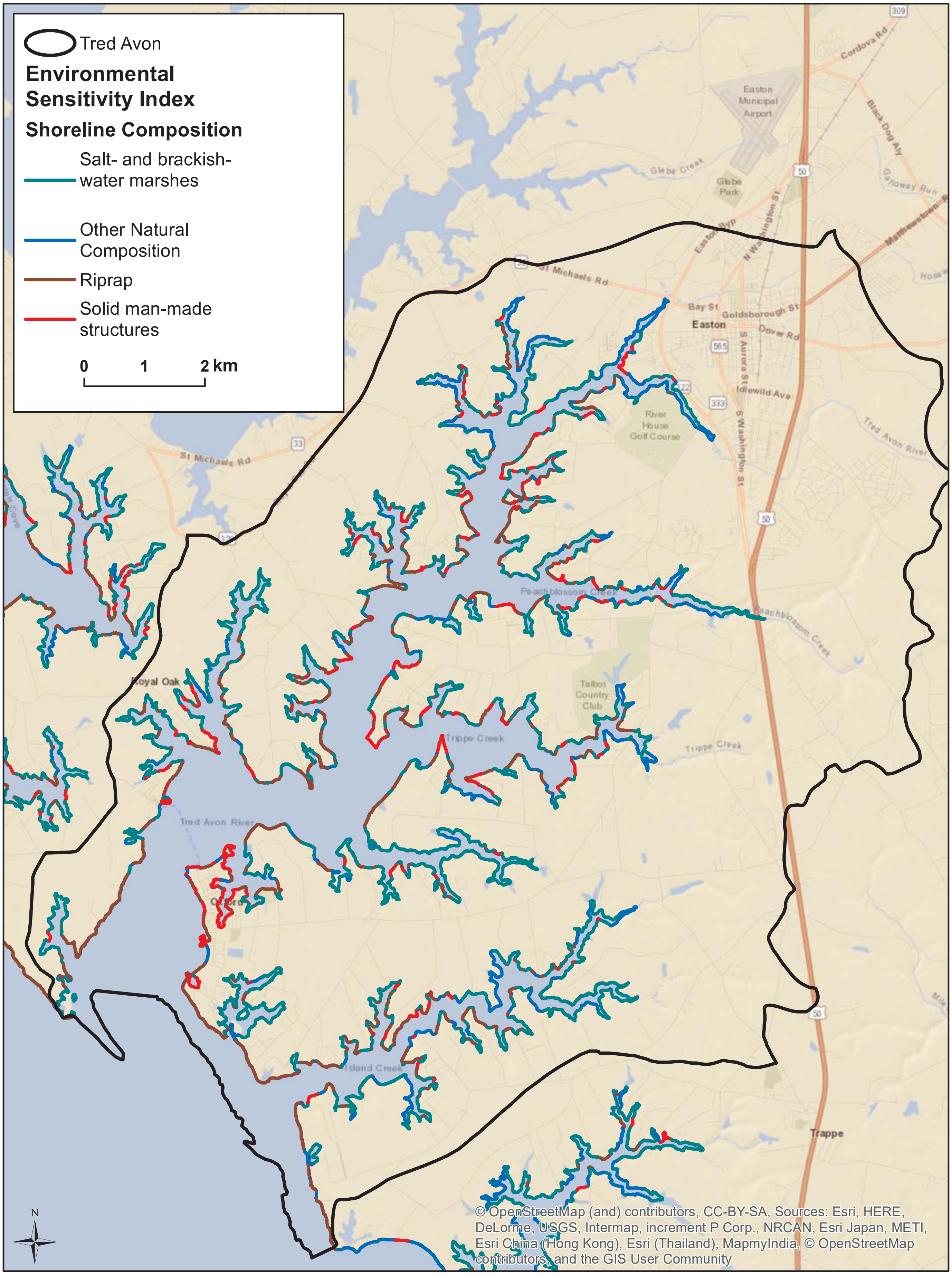

Figure 3.11. Tred Avon shoreline composition from ESI.

The ESI indicates 240.9 km of shoreline within the Tred Avon sub-watershed. Of this, 159.3 km (66%) have natural composition and 81.5 km (34%) have man-made composition. The natural component is dominated by salt and brackish water marshes, 120.9 km (50%). The man-made component is dominated by riprap, 62.8 km (26%). Details are provided in Figures 3.11 and 3.12.

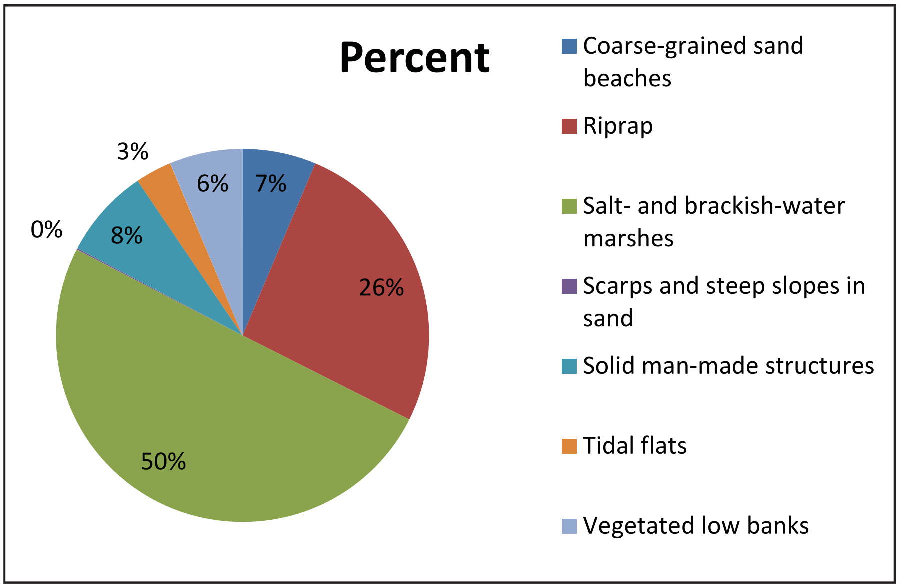

Figure 3.12. Tred Avon shoreline composition from ESI.

Riprap along the Tred Avon. Photo credit: NOAA National Centers for Coastal Ocean Science

Figure 3.13. Little Choptank shoreline composition from SSR.

Little Choptank

The shoreline of the Little Choptank River generally has a more natural composition than those for the Choptank River. The Little Choptank River is divided into two sub-watersheds, Slaughter Creek and Fishing Creek. Here, we consider these areas as a single unit. The SSR indicates 302.9 km of shoreline within the Little Choptank basin. Of this, 248.9 km (82%) have natural composition, while 53.9 km (18%) have man-made composition. Riprap dominates the man-made component at 31.9 km (11%). Details provided in Figures 3.13 and 3.14.

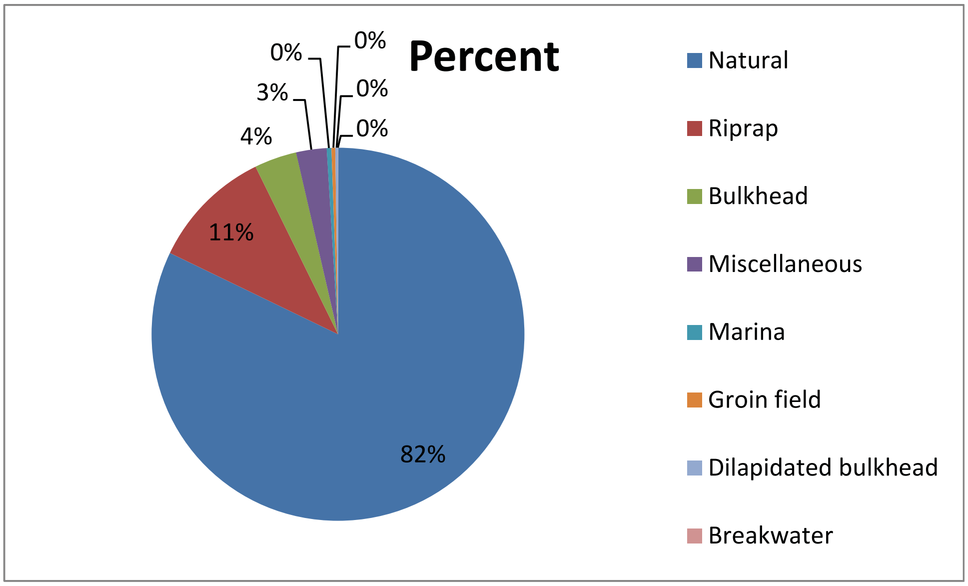

Figure 3.14. Little Choptank shoreline composition from SSR.

Wetlands along the Little Choptank. Photo credit: NOAA National Centers for Coastal Ocean Science

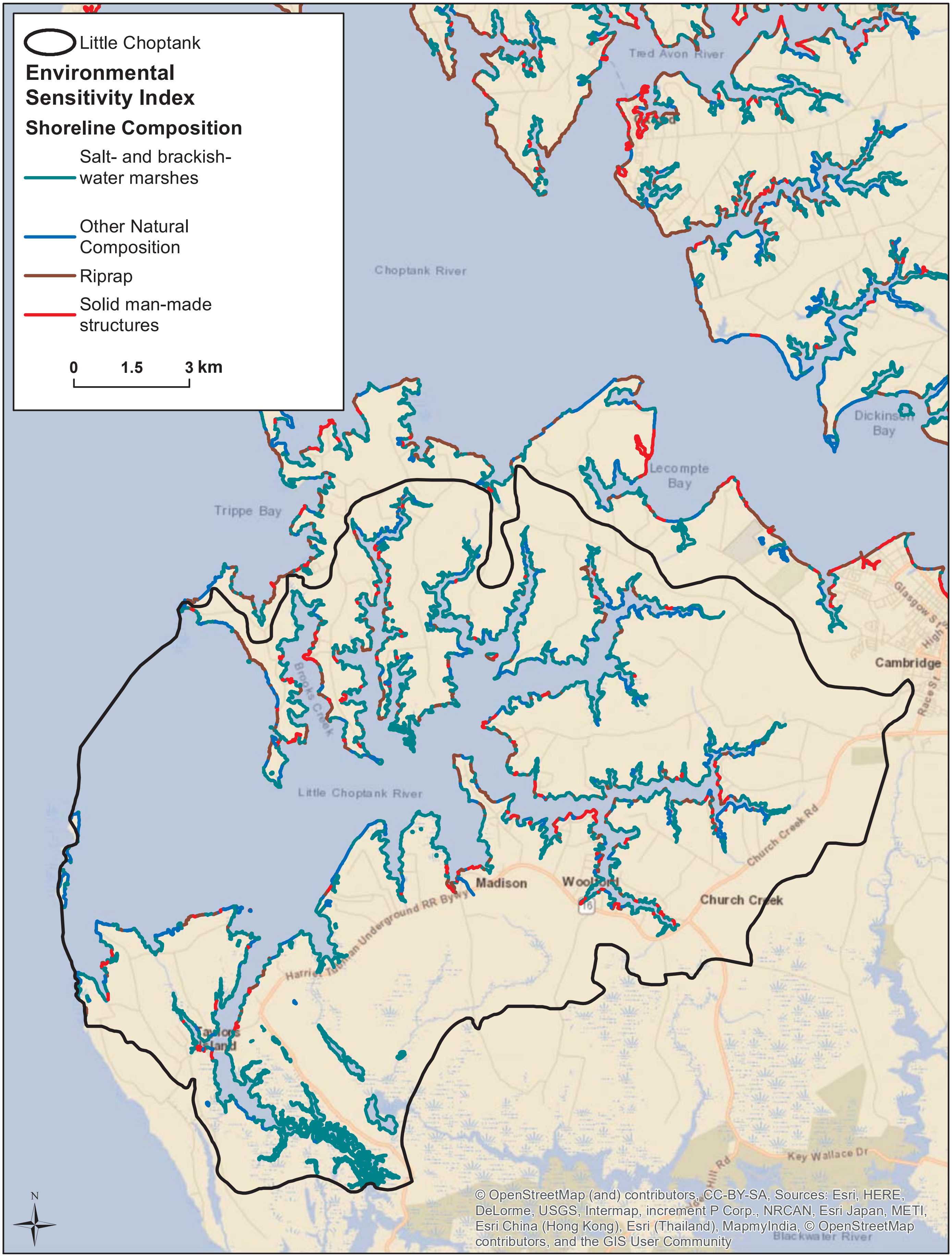

Figure 3.15. Little Choptank shoreline composition from ESI.

The ESI indicates 364.9 km of shoreline within the Little Choptank basin. The shoreline is dominated by natural features (309.2 km, 85%), primarily composed of salt and brackish water marshes (263.7 km, 72%). The man-made component of the shoreline (55.7 km, 15%) is dominated by riprap (41.8 km, 11%). Details provided in Figures 3.15 and 3.16.

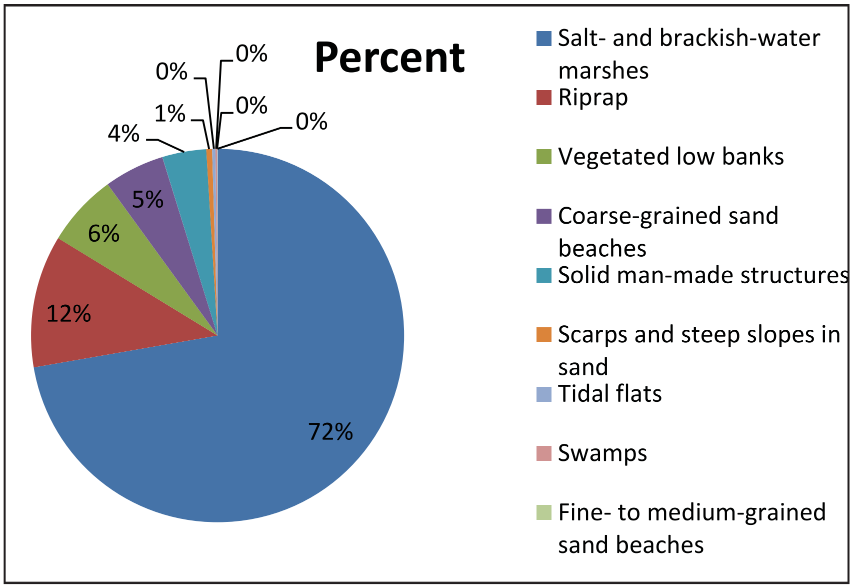

Figure 3.16. Little Choptank shoreline composition from ESI.

Shoreline along the Little Choptank. Photo credit: NOAA National Centers for Coastal Ocean Science

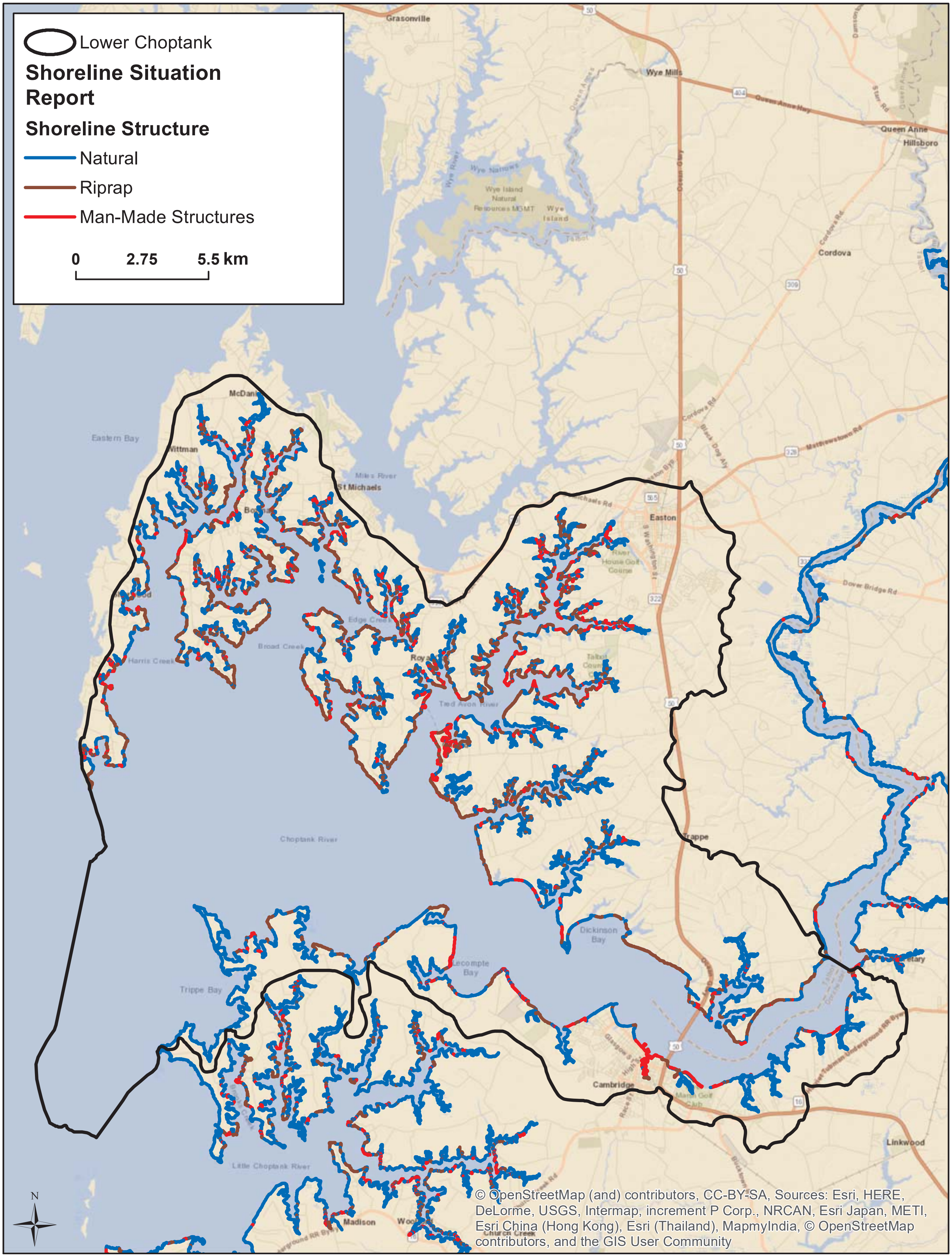

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Figure 3.17. Lower Choptank shoreline composition from SSR.

Lower Choptank

The SSR indicates 709.7 km of shoreline within the Lower Choptank watershed. Of this, 463 km (65%) is described as natural, while the remaining 246.7 km (35%) consists of man-made structures. These man-made structures are dominated by riprap, 173 km (24%). Details provided in Figures 3.17 and 3.18.

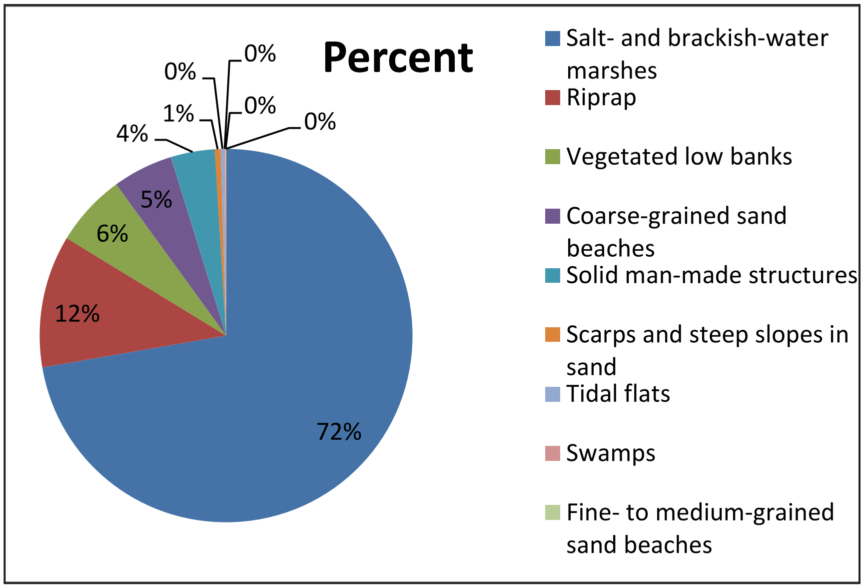

Figure 3.18. Lower Choptank shoreline composition from SSR.

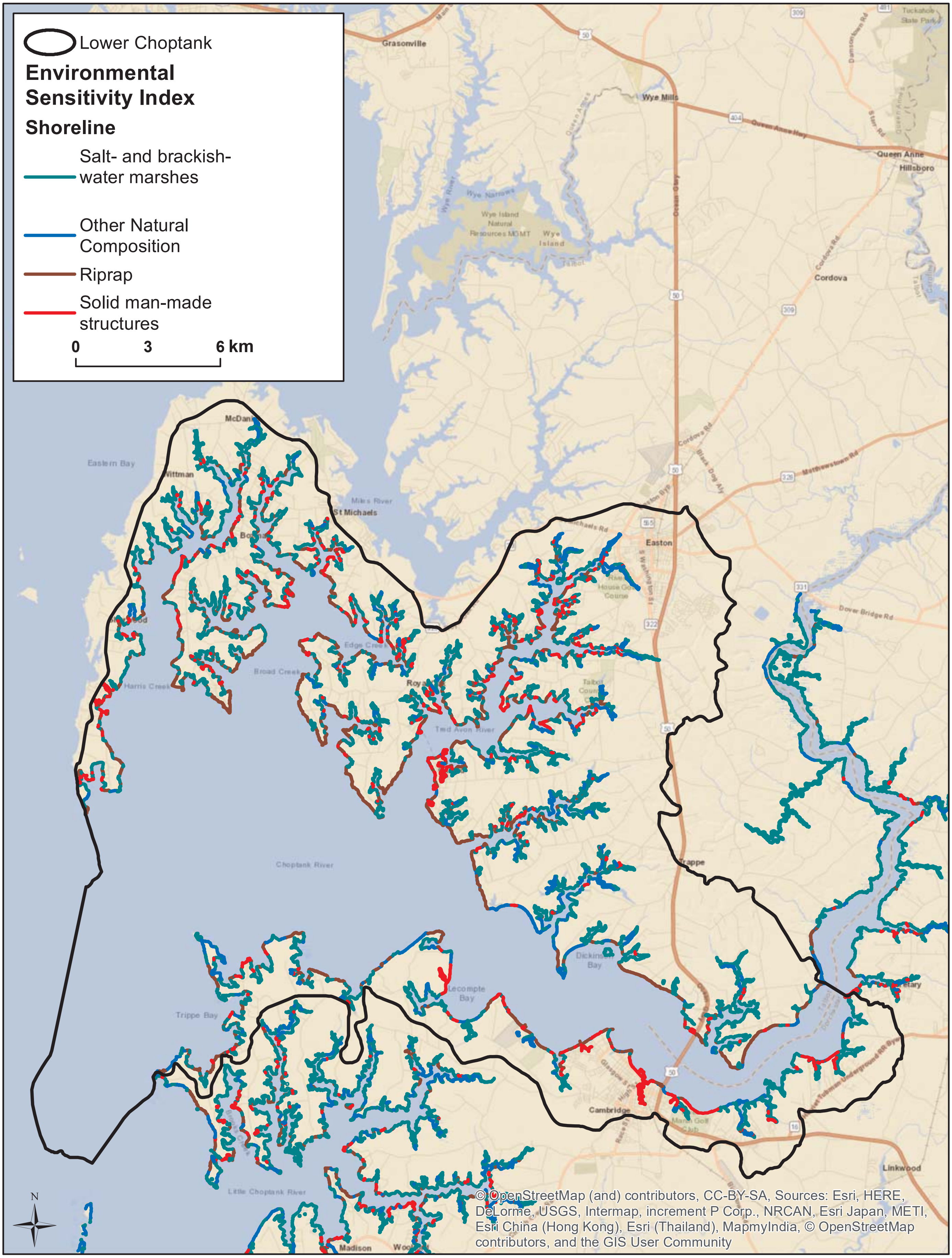

Figure 3.19. Lower Choptank shoreline composition from ESI.

The ESI indicates 744.2 km of shoreline in the Lower Choptank watershed. Of this, 492.9 km (66%) is composed of natural features, dominated by 395.3 km (53%) of salt and brackish water marshes. The man-made component (251.3 km, 34%) is dominated by riprap (193.0 km, 26%). Details provided in Figures 3.19 and 3.20.

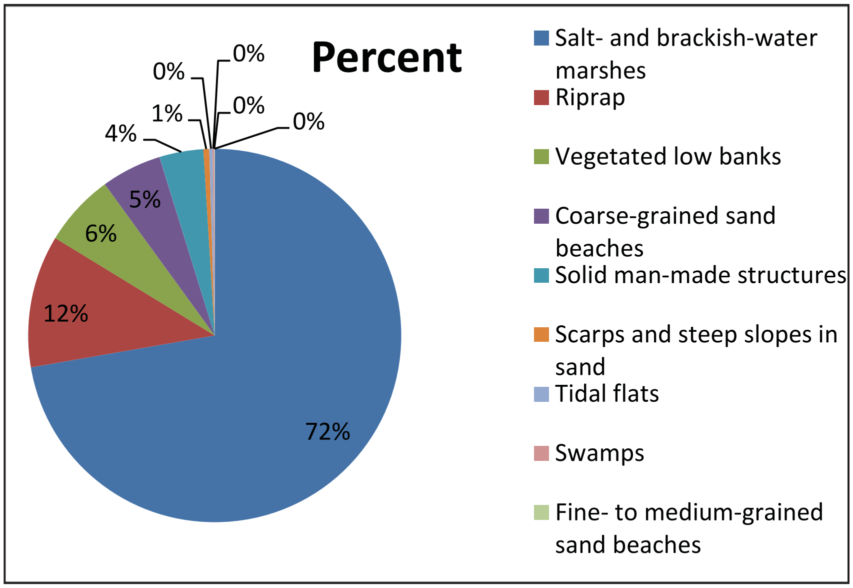

Figure 3.20. Lower Choptank shoreline composition from ESI.

FUTURE STUDY

NCCOS recently funded a five year study (2010-2015) of shoreline changes and associated environmental impacts in Mid-Atlantic coastal ecosystems, including the Chesapeake Bay. The study addressed the impacts of shoreline hardening on wetlands, submerged aquatic vegetation, fish and shellfish species, and benthic communities. Project results could be used to inform shoreline policies and target protection and restoration efforts in the Chesapeake Bay, including in the Choptank Habitat Focus Area. For more information contact: Tom Jordan, Principal Investigator at the Smithsonian Environmental Research Center.

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National Oceanic and Atmospheric Administration (NOAA), National Ocean Service, Office of Response and Restoration, Emergency Response Division. 2007. Maryland Environmental Sensitivity Index. National Oceanic and Atmospheric Administration (NOAA), National OceanService, Office of Response and Restoration, Emergency Response Division, Seattle, WA.

Chapter 4: Water Quality

Figure 4.1. Choptank monitoring segments, long term monitoring stations and the significant wastewater treatment plants WWTP.

INTRODUCTION AND METHODS

This chapter provides an assessment of our findings on the water quality for the Choptank River. The chapter is structured as follows:

A. Choptank Nutrients and Sediments Loads
- 1) Total Maximum Daily Load (TMDL) Tracking System
  - Simulated TMDL Progress for Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS) 1985 to 2025
- 2) Point Source Loads from Wastewater Treatment Plants (WWTPs)
  - Cambridge WWTP Load for TN, TP and TSS 1984 to 2012
  - Easton WWTP Load for TN, TP and TSS 1984 to 2012
  - Denton WWTP Load for TN, TP and TSS 1984 to 2012
- 3) Non-Point Source Loads (U.S. Geological Survey (USGS) non-tidal monitoring stations)
  - Non-tidal Upper Choptank TN, TP and TSS Loads 1984 to 2013
  - Non-tidal Tuckahoe Creek TN, TP and TSS Loads 2005 to 2013

B. Assessment for Choptank Water Quality
- 1) Choptank Long Term Water Quality
  - Water Quality Criteria
  - Trend Analysis for Dissolved Oxygen (DO), TN, TP, Chlorophyll *a* (CHLA), TSS, Secchi disk depth, Salinity, and Water Temperature 1984 to 2014
  - Water Quality Present Status and Index Assessment (Assessment for DO, TN, TP, CHLA, TSS, and Secchi Disk Depth for 2014)
  - Monthly Assessment for the Water Quality Parameters (2000-2015)
- 2) Maryland Biological Stream Survey Program
  - Monitoring TN and TP Upstream (Upper Choptank and Tuckahoe Creek) 2000 to 2014
- 3) Midshore Riverkeeper Conservancy (MRC) Water Quality Program
  - Detailed Assessment for Choptank (52 sampling stations) using MRC Data for DO, TN, TP, CHLA and Secchi disk depth for 2014

Good water quality is essential for healthy habitats and important for biodiversity, recreational use, aquaculture, and human health. Excess nutrients and sediment loads may degrade the water quality of the river. For example, these loads can stimulate algal blooms, reduce dissolved oxygen, block sunlight and increase the possibility of a hypoxic event, all of which threaten healthy aquatic fauna and flora in the river. Accordingly, monitoring and assessment of water quality is very important to ensure sustainable use of the Choptank River. We focus here on the long term monitoring (1984-2014) for the Chesapeake Bay Monitoring Segments of the Choptank River (Figure 4.1), for nutrients and sediment loads, and chemical and physical parameters.

These parameters (DO, TN, TP, CHLA, TSS, Secchi disk depth, salinity and temperature) have been used traditionally as indicators of the impact of anthropogenic activities on water quality (Mason et al., 2011). Additionally, we assessed the present situation of the water quality of the Choptank River. This was done by comparing the results of these parameters with the established and published threshold values for the Chesapeake Bay. Although the Maryland Department of Natural Resources (MD DNR) is the main authority responsible for monitoring water and habitat quality in the Choptank River, other agencies (state, federal and non-governmental agencies (NGOs)) are also involved. Consequently, different water quality data sources were used in this assessment, mainly from USGS, Chesapeake Bay Program (CBP), Maryland Biological Stream Survey (MBSS), and Midshore Riverkeeper Conservancy (MRC).

CHOPTANK NUTRIENTS AND SEDIMENT LOADING

The Chesapeake Bay has been negatively impacted from an excess of nutrients and sediment causing the Bay to be listed as “impaired” and not meeting the water quality standards for DO, CHLA, and overall water quality. In 2010, the U.S. Environmental Protection Agency (EPA) and the states of the Chesapeake Bay watershed, through the CBP, established a target TMDL for the Bay to reach by 2025. This was done in order to reduce nutrients and sediment and improve water quality of the Bay (EPA, 2010). Each jurisdiction in the watershed is required to develop and implement a Watershed Implementation Plan (WIP) to reach the target TMDL. Additionally, EPA and CBP developed a tracking system to monitor the progress toward reaching the Bay TMDL target.

The Choptank River was first identified as impaired by sediment and nutrients in 1996 by the EPA and the Maryland Department of the Environment (MDE). Agriculture (62% of the land use) was the main source of nutrients (nitrogen and phosphorus), and sediment loads to the Choptank River. Half of this loading was in the Upper Choptank segment, see Figure 4.1, where two-thirds of the land is in agriculture use (MD DNR, 2012). TMDLs were allocated for each of the Choptank monitoring segments, with interim TMDL targets for 2017, and final targets for 2025. Additionally, the progress was tracked using a TMDL Tracking and Accounting System (TAS).

Three types of data for nutrients and sediment load for the Choptank River are investigated here: the TMDL TAS; WWTPs loads; and nutrient and sediment load estimates from non-point sources.

Total Maximum Daily Load (TMDL) Tracking System

The Chesapeake Bay Program developed the Bay TMDL Tracking and Accounting System (BayTAS) to inform federal and state agencies, and the public on the progress of implementing the Bay TMDL. Loads for TN, TP, and TSS were simulated using version 5.3.2 of the Chesapeake Bay Program Watershed Model. This model estimates loads from different sources, including point sources such as wastewater treatment plants and urban stormwater systems, and non-point sources such as runoff from agricultural lands, and non-regulated stormwater from urban and suburban lands, using average weather conditions. TMDL data was acquired from the CBP (CHESAPEAKE STAT, https://stat.chesapeakebay.net/?q=node/130&quicktabs_10=1) for each segment of the Choptank River, including the Little Choptank. Figures 4.2 through 4.4 show the modeled simulated TMDL for the whole Choptank River declining toward the interim target 2017 and the 2025 target. Additionally, Figures 4.5 through 4.7 show the declining simulated loads for each monitoring segment, and the higher loads for the Upper Choptank compared to the other segments.

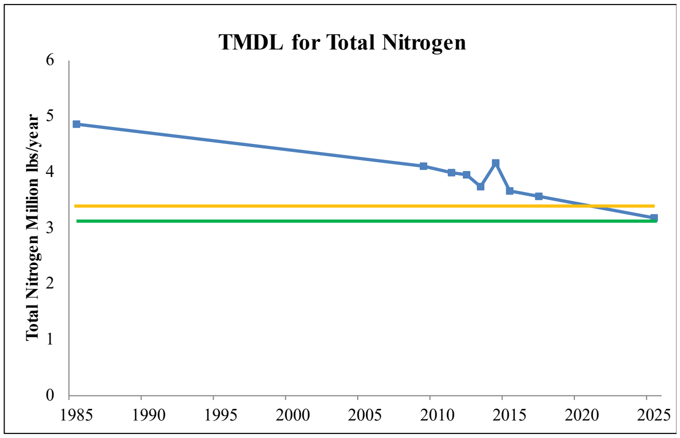

Figure 4.2. Choptank River simulated TMDL progress for TN (blue line), interim target 2017 (yellow line), and 2025 final target (green line).

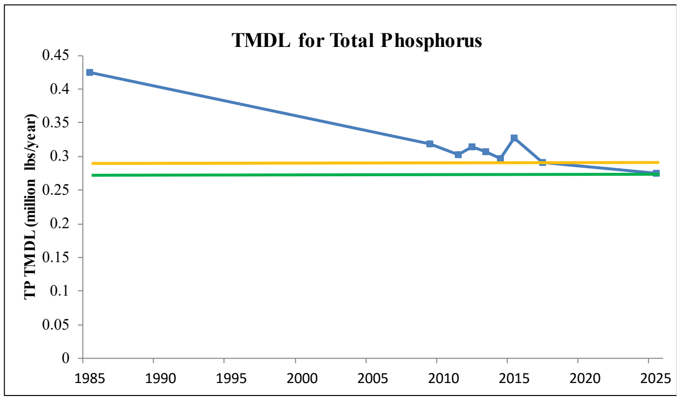

Figure 4.3. Choptank River simulated TMDL progress for TP (blue line), interim target 2017 (yellow line), and 2025 final target (green line).

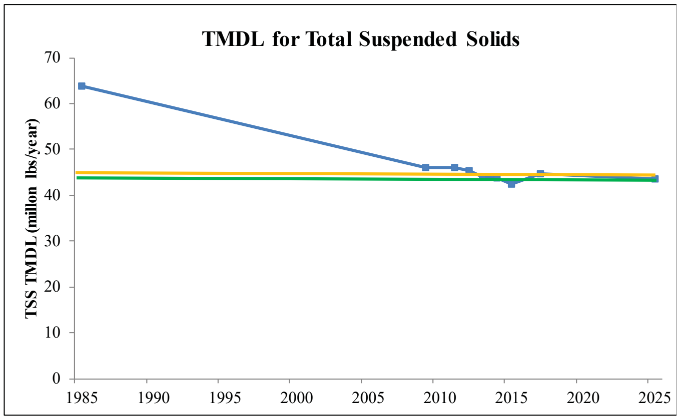

Figure 4.4. Choptank River simulated TMDL progress for TSS (blue line), interim target 2017 (yellow line), and 2025 final target (green line).

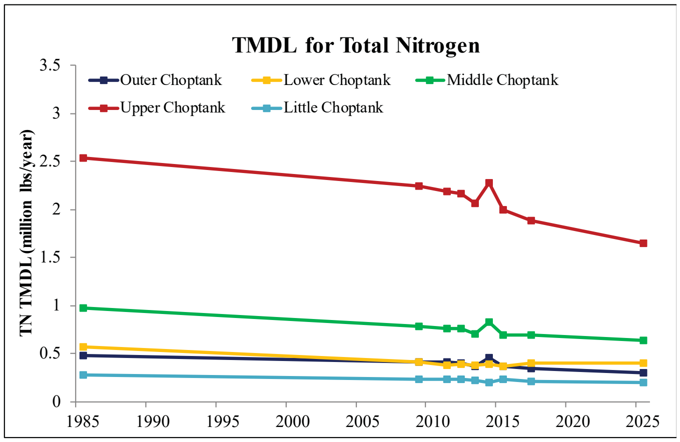

Figure 4.5. Choptank River segments simulated TMDL progress for TN.

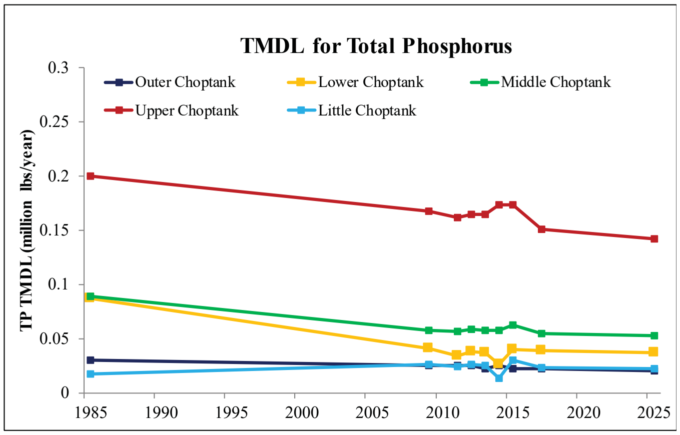

Figure 4.6. Choptank River segments simulated TMDL progress for TP.

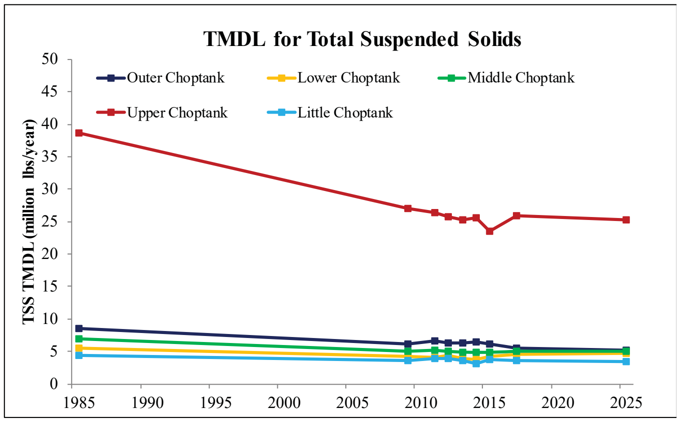

Figure 4.7. Choptank River segments simulated TMDL progress for TSS.

Point Source Loads

Wastewater treatment plants (WWTPs) are considered one of the main point sources of nutrient and suspended solids loads to any watershed. However, they are easy to monitor and manage. There are three major WWTPs (Figure 4.1) with a combined permitted flow of 11.25 million gallons per day (MGD) discharging their effluents into the Choptank River. These facilities were upgraded through the Chesapeake Bay Restoration Fund to reduce their nutrient loads. The MGD data for these facilities were obtained from the CBP (http://data.chesapeakebay.net/PointSource), and the annual loads in million pounds per year for total nitrogen, phosphorus, and suspended solids were estimated for the time period 1984-2012 based on the available data.

The Cambridge WWTP is the largest facility, with a permitted flow of 8.1 MGD, and estimated flow that ranged from 2.07 to 5.35 MGD. It contributed 55% of the WWTP nitrogen and phosphorus loads to the Choptank River (MD DNR, 2012). The facility discharges to the Lower Choptank segment (Figure 4.1). It was upgraded through the Biological Nutrient Removal (BNR) program in 2003. As a result, the total loads for nitrogen, phosphorus, and suspended solids were reduced dramatically (Figures 4.8 through 4.10).

Cambridge Wastewater Treatment Plant. Various tanks and ponds of the wasterwater treatment plant in Cambridge, Maryland. Photo credit: Adrian Jones, Integration & Application Network, U of MD Center for Environmental Science (ian.umces.edu/imagelibrary/).

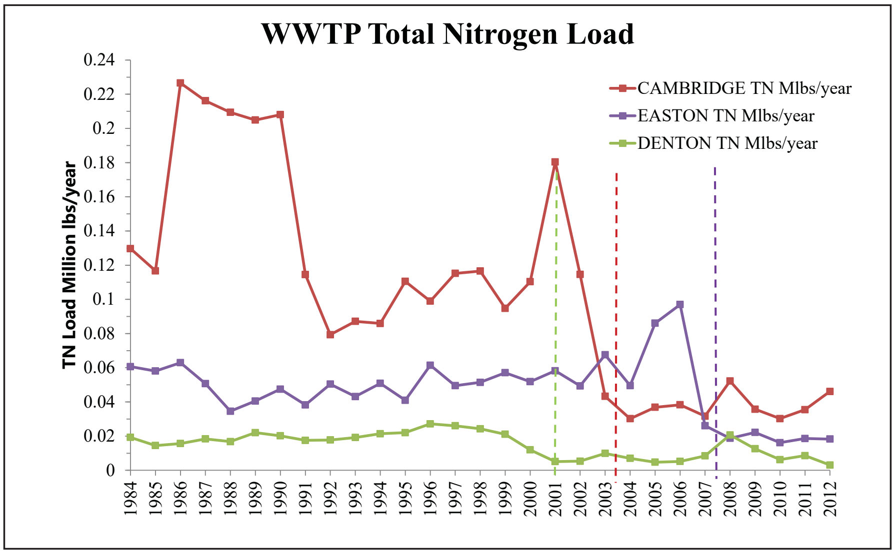

Figure 4.8. Annual total nitrogen (TN) from WWTPs to the Choptank River, dotted vertical lines indicate when each WWTP was upgraded.

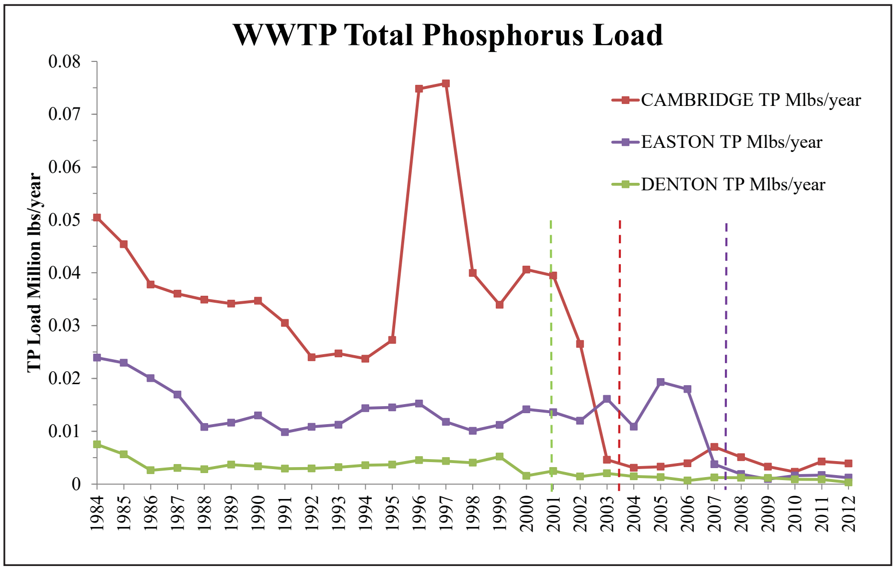

Figure 4.9. Annual total phosphorus (TP) from WWTPs to the Choptank River, dotted vertical lines indicate when each WWTP was upgraded.

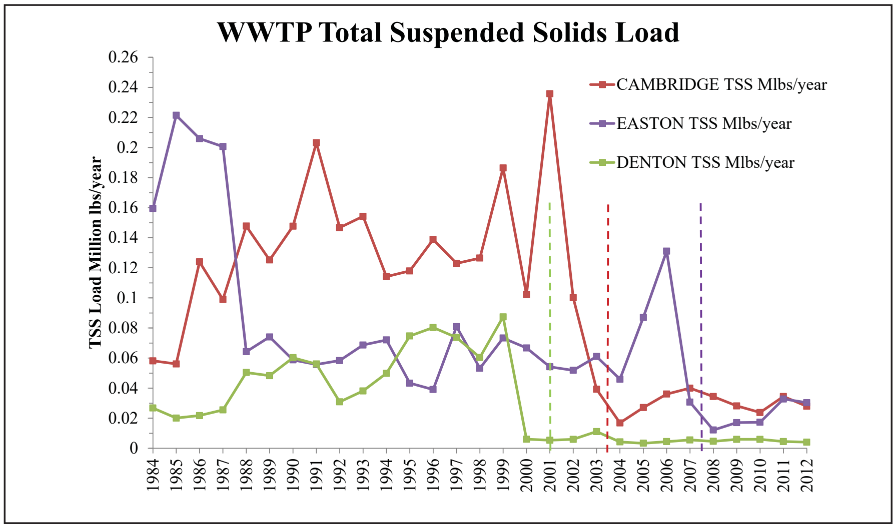

Figure 4.10. Annual total suspended solids (TSS) from WWTPs to the Choptank River, dotted vertical lines indicate when each WWTP was upgraded.

Easton is the second largest WWTP, with a permitted flow of 2.35 MGD. It discharges directly to the Middle Choptank water quality monitoring segment with an estimated flow ranging from 1.34 to 2.74 MGD. The facility contributed 25% of the WWTP nitrogen and phosphorus loads to the Choptank River. By 2007, the facility completed the upgrading through the BNR and Enhance Nutrient Removal (ENR) programs, reducing nutrients and sediment loads.

Denton is the smallest of the three WWTPs, with a permitted flow of 0.8 MGD and estimated flow ranging from 0.27 to 0.58 MGD. It contributed 18% of the WWTP nitrogen and phosphorus loads to the Choptank River. The facility was upgraded through the BNR and ENR programs at the end of 2001 and 2012, respectively.

Non-Point Source Loads

Agricultural runoff is the main non-point source of nutrient and sediment loads for the Choptank River, especially in the Upper Choptank, which delivers half of the load to the Choptank River. Reducing the loads from agricultural lands is considered one of the main challenges to the state of Maryland, and many regulations and programs were developed, such as The Water Quality Improvement Act in 1998, the Soil Conservation and Water Quality Plans (SCWQPs), and Best Management Practices (BMPs). All these measures aim to reduce the nutrients and sediment loads to the Chesapeake Bay rivers. The USGS estimates water quality trends and nutrient and sediment loads from non-point sources by monitoring the non-tidal rivers of the Chesapeake Bay. There are 150 non-tidal monitoring stations in the Chesapeake Bay, but only two are in the Choptank River (Upper Choptank sub-basin ET5.0 and Tuckahoe Creek TUK0181) (Figure 4.1), where monitoring is conducted on a monthly basis. Station ET5.0 has a long term monitoring history from 1984, while at TUK0181 monitoring started in 2005.

Data for the TN, TP and TSS loads for the two stations were acquired from the USGS (http://cbrim.er.usgs.gov/loads_query.html). Both total nitrogen and phosphorus loads showed a significant increasing trend ($p=0.0288$ and $p=0.001$ respectively) from 1984 to 2013 at ET5.0 (Upper Choptank sub-basin). Results were contradictory, with the modeled estimated nutrient loads (Figures 4.5 and 4.6 from the TMDL tracking progress system) and supporting the results from the Environmental Integrity Project[1] report (Murky Waters) on the Chesapeake Bay (EIP[1], 2014) Additionally total suspended solids load showed an increasing trend but it was not significant ($p=0.1755$) (Figures 4.11 through 4.13).

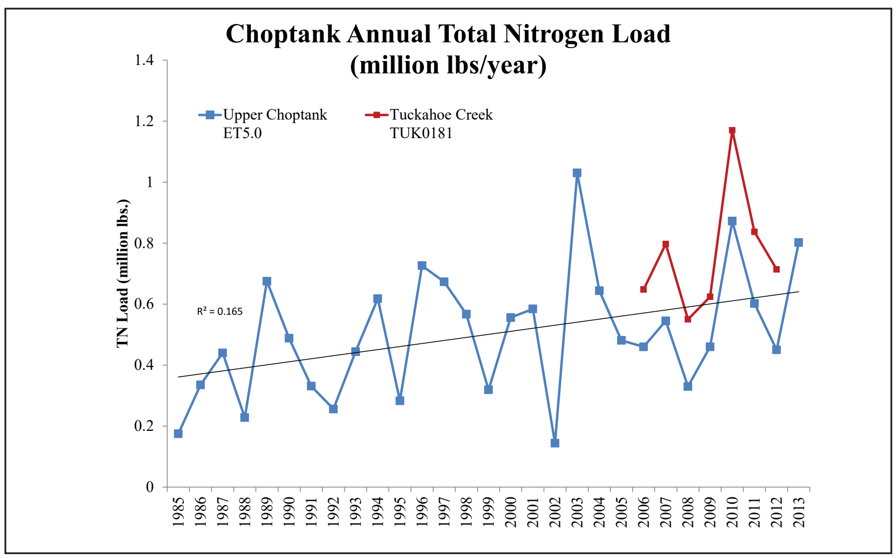

Figure 4.11. Annual total nitrogen load (TN) to the tidal water of the Choptank River, based on the USGS non-tidal monitoring stations data.

[1] *The Environmental Integrity Project (EIP) is a nonpartisan nonprofit organization dedicated to the enforcement of the nation's anti-pollution laws and to prevention of political interference with those laws.*

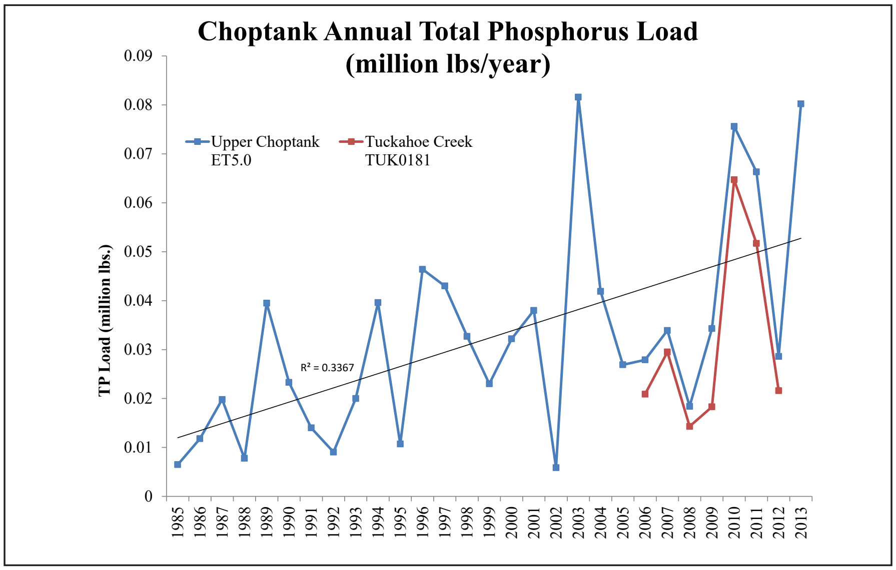

Figure 4.12. Annual total phosphorus load (TP) to the tidal water of the Choptank River, based on USGS non-tidal monitoring station data.

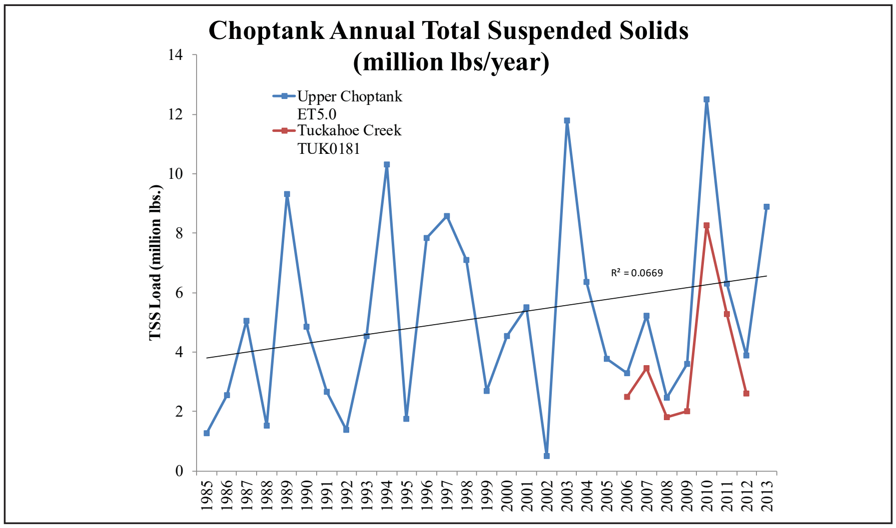

Figure 4.13. Annual total suspended solids load (TSS) to the tidal water of the Choptank River, based on USGS non-tidal monitoring station data.

CHOPTANK WATER QUALITY ASSESSMENT

Choptank Long Term Water Quality

The Chesapeake Bay Monitoring Program was established in 1984. It is a long term fixed station monitoring program which operates as a cooperative effort with state and federal agencies, NGOs and scientific institutions. The program's main objectives are to monitor the changes in water quality over time, to better understand the changes in the Chesapeake Bay environment, and to provide decision makers and managers with valuable information for best management practices. Through the long term monitoring (1984-2014), 44 stations were established on the Choptank River. Five of them were consistent in testing the target water quality indicators (DO, TN, TP, CHLA, TSS, Secchi disk depth, salinity and temperature). A sixth station, TUK0181 (Tuckahoe Creek), was added to the long term monitoring in 2005 (Figure 4.1), however, not all of the target parameters were sampled. Water quality data for the Choptank River was acquired from the CBP's water quality database (http://data.chesapeakebay.net/WaterQuality).

Water Quality Criteria

Water quality parameter data from the different sources were compared with U.S. EPA threshold values necessary for seagrass habitat, fisheries and other published water quality criteria (Table 4.1). The water quality criteria for shallow water DO (year round) was 5 mg/l, below this value waters were impaired or failed to meet the criteria. Summer (June - September), bottom dissolved oxygen (BDO) was considered healthy (good) if levels were 5 mg/l or greater, impaired (poor) if levels were less than 3 mg/l, and fair if levels were between 3 mg/l and 5 mg/l (U.S. EPA, 2000 and 2003; Mason et al., 2011).

Table 4.1. The water quality thresholds values for the indicators parameters according to U.S. EPA and other published water quality criteria.

Salinity Regime	Dissolved Oxygen mg/l	Bottom Dissolved Oxygen Summer mg/l	Total Nitrogen mg/l	Total Phosphorus mg/l	Chlorophyll *a* µg/l	Total Suspended Solids mg/l	Secchi Disk Depth m
Tidal Fresh (0-0.5 ppt)	5	3-5	0.650	0.037	15	15	0.850
Oligohaline (0.5-5 ppt)	5	3-5	0.650	0.037	15	15	0.650
Mesohaline (5-18 ppt)	5	3-5	0.650	0.037	15	15	1.625

TN concentrations met the water quality criteria when it was < 0.65 mg/l, while TP met the water quality criteria at < 0.037 mg/l. The TSS threshold was 15 mg/l and CHLA was 15 µg/l. Secchi disk depth criteria were different for the different salinity regimes, consequently for the tidal fresh area (0 to 0.5 ppt) it was 0.85 meters, for oligohaline (salinity of 0.5 to 5 ppt) it was 0.65 meters, and for mesohaline (salinity of 5-18 ppt) it was 1.625 meters (US EPA, 2000; Lacouture et al., 2006; Wazniak et al., 2007; Leight et al., 2014).

Trend Analysis

Non-tidal and tidal water quality data were tested for linear trends from 1984-2014, except for TP and TSS parameters, due to a laboratory change in 1998 (Wazniak et al., 2007). Trends were significant if $p \leq 0.01$. When trends are significant at $p \leq 0.01$ results are abbreviated as INC for increasing trends and DEC for decreasing trends. When trends are significant ($0.01 < p < 0.05$), results are abbreviated as MB INC (may be increasing) or MB DEC (may be decreasing). If there was no trend detected, it was abbreviated as NT (Appendix A). In 1998, a laboratory change occurred for TP and TSS analysis. As a result, step trends were determined for 1985-1997 and 1999-2014, but for only these two parameters.

Water Quality Present Status and Index Assessment

In order to evaluate the present situation for the water quality of the Choptank River, water quality data for 2014 (annual average for the indicator parameters) were compared to the water quality threshold values. As a result, an assessment for the tidal monitoring stations was developed to define if they meet the EPA criteria or not (MD DNR, 2012) (Appendix B).

A water quality index was developed for the tidal stations for 2014 (Table 4.2), to compare between these stations and rank them using a single index based on the water quality threshold values. Six criteria were used; summer BDO, >5 mg/l; TN, <0.65 mg/l; TP, <0.37 mg/l; CHLA, <15 µg/l; TSS, <15 mg/l; and Secchi disk depth criteria (differ due to salinity regimes), (Dennison et al., 1993; Stevenson et al., 1993; Ritter and Montagna, 1999; Breitburg, 2002; US EPA, 2000 and 2003; Wazniak et al., 2007). The annual mean for each parameter was compared with the established threshold values and if it met the criteria was scored as one and if failed was scored as zero. The scores for each station were summed and divided by six resulting in an index value ranging from zero to 1. Zero indicated that the station did not meet the water quality criteria and would not be expected to support seagrasses or fisheries, while a score of one indicated that the station met all water quality criteria and should support ecosystem services. An assessment of the water quality for the tidal stations were developed based on the water quality index (WQINDX). These were: Excellent, ≤1.0>0.8; Good, ≤0.8>0.6; Poor, ≤0.6>0.4; Degraded, ≤0.4>0.2, and Very Degraded ≤0.2>0. Additionally, the mean

Table 4.2. Assessment for the Choptank water quality parameters and the water quality index WQINDX for tidal stations for 2014.

Station	BDO mg/l		TN mg/l		TP mg/l		CHLA µg/l		TSS mg/l		Secchi Disk m		WQINDX	Status
	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014		
Outer Choptank EE2.1	5.625	Meet	0.680	Fail	0.023	Meet	9.465	Meet	5.500	Meet	1.440	Fail	0.833	Excellent
Little Choptank EE2.2	0.425	Fail	0.650	Meet	0.022	Meet	9.635	Meet	5.354	Meet	1.358	Fail	0.667	Good
Lower Choptank ET5.2	5.300	Meet	0.998	Fail	0.036	Meet	15.183	Fail	9.108	Meet	0.909	Fail	0.500	Poor
Middle Choptank ET5.1	6.500	Meet	2.431	Fail	0.100	Fail	11.996	Meet	23.833	Fail	0.333	Fail	0.333	Degraded
Overall Assessment for the Tidal Station for Choptank River													0.583	Poor

of the WQINDX for all the tidal stations (EE2.1, EE2.2, ET5.1 and ET 5.2 (Figure 4.1)) was calculated to assess the water quality for the tidal Choptank River as a whole. Results showed that the WQINDX for the Outer Choptank stations EE2.1 was Excellent (0.83), and for Little Choptank EE2.2 station was Good (0.67). Going upstream, the WQINDX decreased with the Lower Choptank Station ET5.2 Poor (0.50) and Middle Choptank Station ET5.1 Degraded (0.33), giving an overall Poor WQINDX for the Choptank River (Table 4.2). The overall result confirms the overall health index for the Choptank River (Chesapeake Bay Report Card) developed by the University of Maryland Center for Environmental Science.

<u>Dissolved Oxygen (DO) (mg/l)</u>

Annual averages for DO in mg/l for the water column were calculated for each station and compared to the threshold value for DO (5 mg/l) (Figure 4.14). The Upper Choptank (ET5.0), Tuckahoe Creek (TUK0181), and the Outer Choptank (EE2.1) were always higher than 6 mg/l and met the DO criteria, while Little Choptank (EE2.2), the Middle Choptank (ET5.1), and the Lower Choptank (ET5.2) did not meet the DO criteria in some years. However, in the last 3 years all six stations met the DO criteria and were above the 5 mg/l threshold. Only Middle Choptank ET5.1 had a significant ($p=0.0220$) decreasing trend, with $r^2=0.1679$.

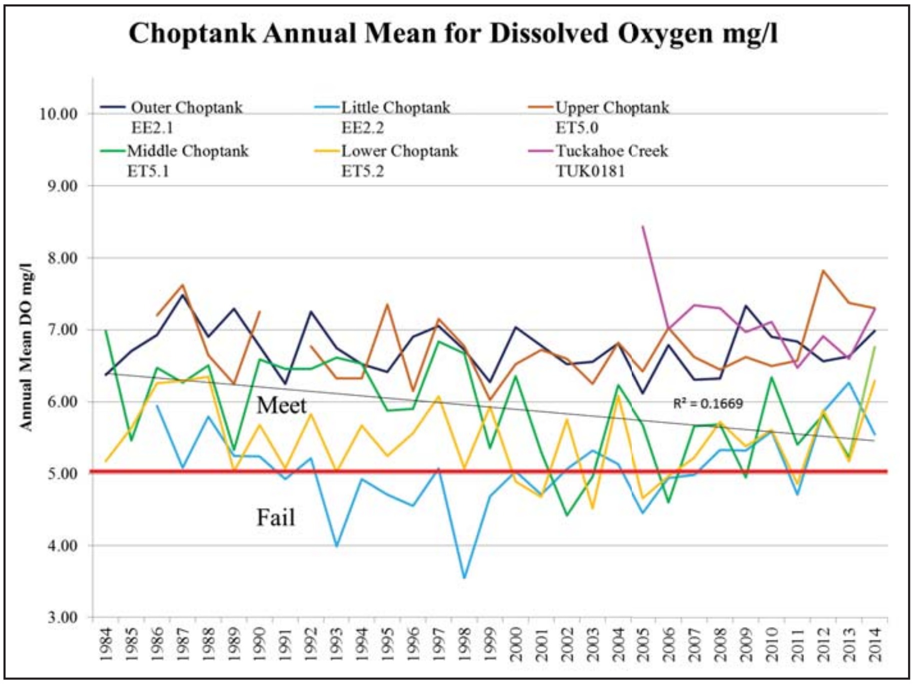

Figure 4.14. Annual means for dissolved oxygen (mg/l) for the Choptank River from 1984 to 2014, with the dissolved oxygen threshold (red line).

The mean summer (June-September) BDO concentrations were also calculated each year for the tidal stations (Figure 4.15). Little Choptank was the lowest in BDO and did not meet the water quality criteria, while Lower Choptank showed a fair BDO (> than 3 mg/l), but in many years was less than 5 mg/l. Outer Choptank and Middle Choptank stations showed good BDO concentrations, with only a few years having a failing BDO. Only Middle Choptank ET5.1 had a significant ($p=0.0073$) decreasing trend, with $r^2=0.2233$.

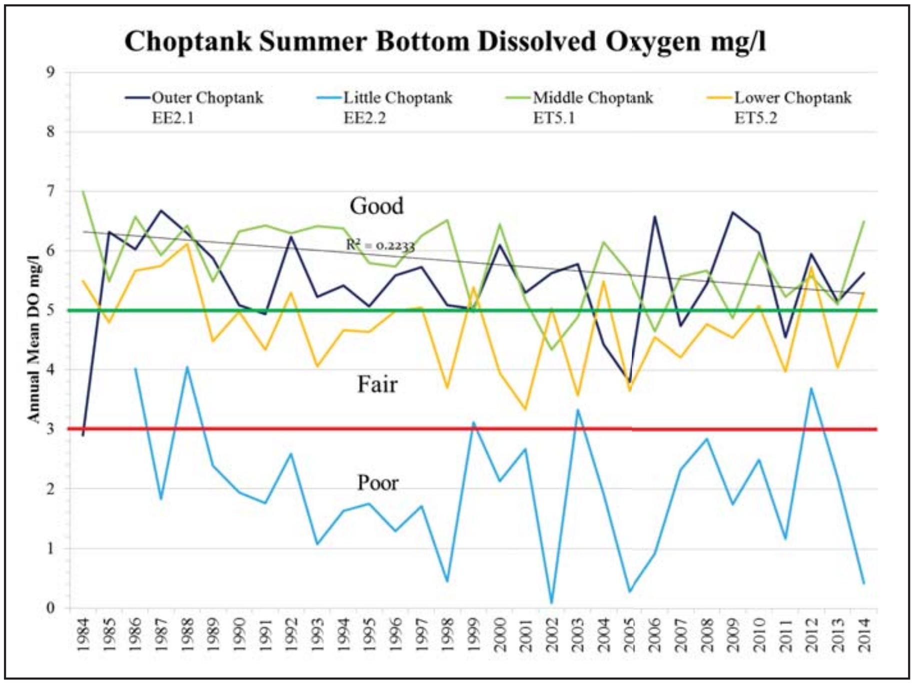

Figure 4.15. Annual mean for summer bottom dissolved oxygen (mg/l) for the Choptank River from 1984 to 2014, with bottom dissolved oxygen thresholds (green and red lines).

Total Nitrogen (TN) (mg/l)

Annual averages for TN for surface water (0-0.5 m depth) were calculated for each station, and compared to the established threshold value of 0.65 mg/l. None of the stations met the TN criteria, except for Little Choptank and Outer Choptank for some years. Tuckahoe Creek showed significantly declining TN, with $r^2=0.4396$ (Figure 4.16).

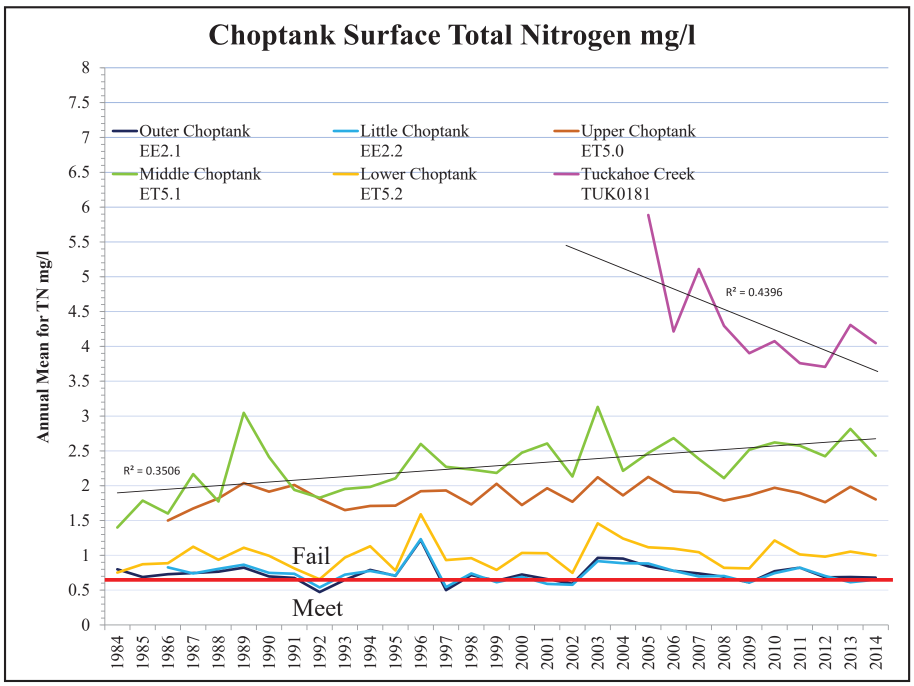

Figure 4.16. Annual mean for total nitrogen (mg/l) for the Choptank River surface water from 1984 to 2014, with total nitrogen threshold (red line).

Total Phosphorus (TP) (mg/l)
Annual averages for TP for surface water (0-0.5 m depth) were calculated for each station and compared to the established threshold value of 0.037 mg/l. None of the stations met the TP criteria except for Little Choptank and Outer Choptank stations (Figure 4.17). Tuckahoe Creek was the highest in TP concentration, followed by the Middle Choptank River. Step trends analysis of the Little Choptank showed a significant ($p=0.0029$) decreasing trend (1985-1997), with $r^2=0.5353$, and Outer Choptank possibly showed a significant ($p=0.0266$) decreasing trend with $r^2=0.3247$, while for 1999-2014 there was no significant trend for any of the stations (Appendix A).

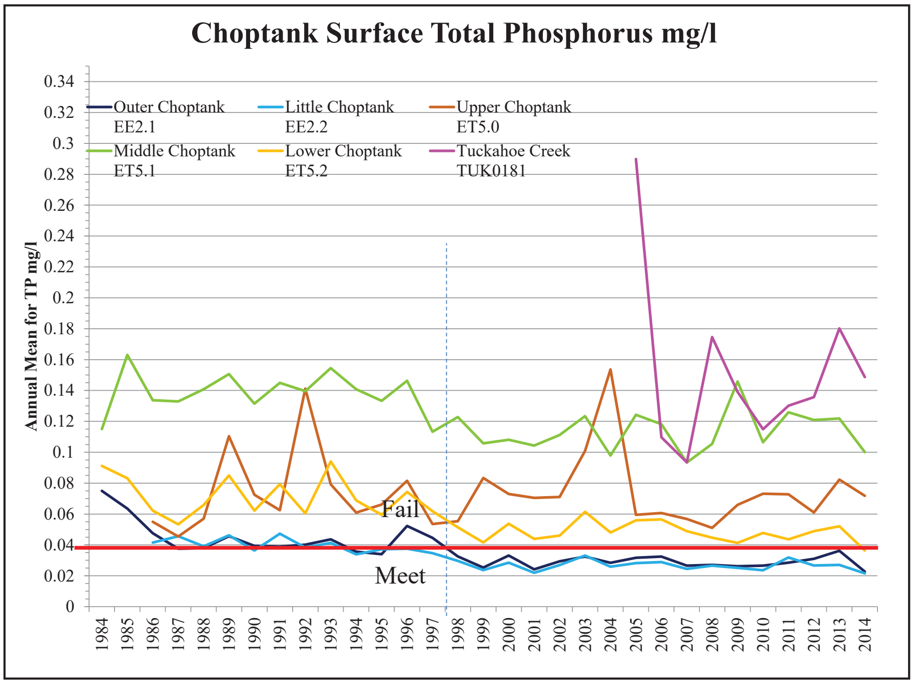

Figure 4.17. Annual mean for total phosphorus (mg/l) for the Choptank River surface water from 1984 to 2014, with the total phosphorus threshold (red line).

Chlorophyll *a* (CHLA) (µg/l)
Annual averages for CHLA in µg/l for surface water (0-0.5 m depth) were calculated for each station, and compared to the established threshold value of 15 µg/l. The Upper Choptank showed the lowest CHLA levels and met the CHLA criteria with no trend detected (Figure 4.18), while all the other stations fluctuated between meeting and failing with different trends (Appendix A). The Middle Choptank showed a significant ($p=0.0012$) decreasing trend, with $r^2=0.3091$, while Lower Choptank, Outer Choptank and Little Choptank showed a significant increasing trend, with the latter two lowest in CHLA levels.

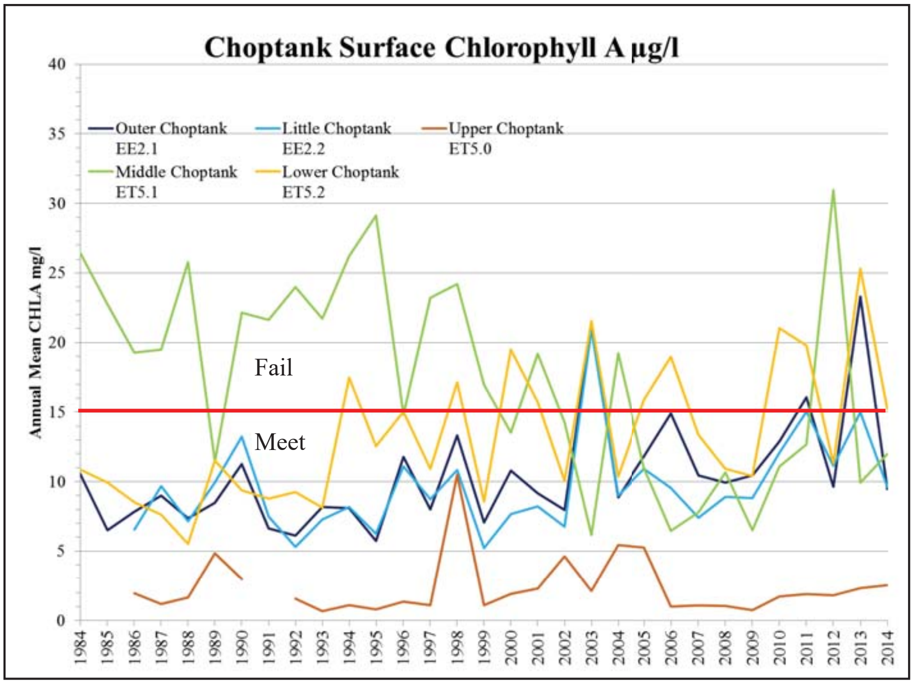

Figure 4.18. Annual mean for chlorophyll a (µg/l) for the Choptank River surface water from 1984 to 2014, with the chlorophyll a threshold (red line).

Total Suspended Solids (TSS)

Annual means for TSS in mg/l for surface water (0-0.5 m depth) were calculated for each station and compared to the established threshold value of 15 mg/l. Middle Choptank was the highest in TSS concentration and didn't meet the water quality criteria, in contrast to the Upper Choptank which always met the water quality criteria, having the lowest TSS levels (Figure 4.19). The step linear trend analysis for 1985 - 1997 and 1999 - 2014 was performed and showed that, for 1985 - 1997, there was a significant increasing trend for Lower Choptank, Outer Choptank, and Little Choptank, while for 1999 - 2014, there was a significant decreasing trend for Upper Choptank (Appendix A).

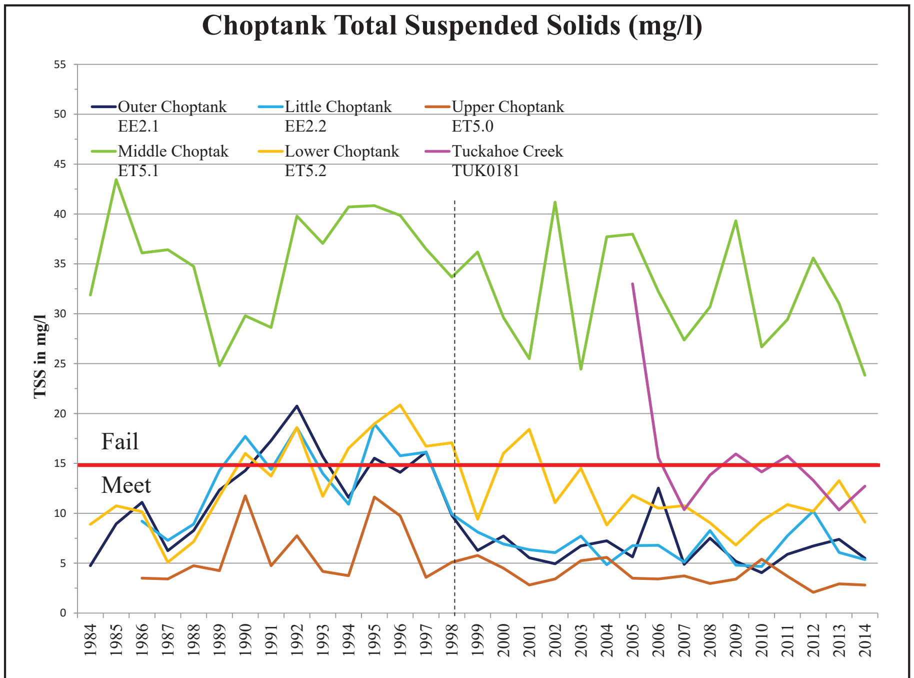

Figure 4.19. Annual mean for total suspended solids (mg/l) for the Choptank River surface waters from 1984 to 2014, with the total suspended solids threshold (15 mg/l; red line).

Secchi disk depth (meters)

Annual averages for the Secchi disk depth in meters were calculated for the tidal stations and compared to the water quality criteria based on the salinity regime system for each station. The four tidal stations did not meet the water quality criteria, and water clarity was poor (Figure 4.20). Additionally, Lower Choptank, Little Choptank, and Outer Choptank stations showed a significant decreasing trend in Secchi disk depth (Appendix A).

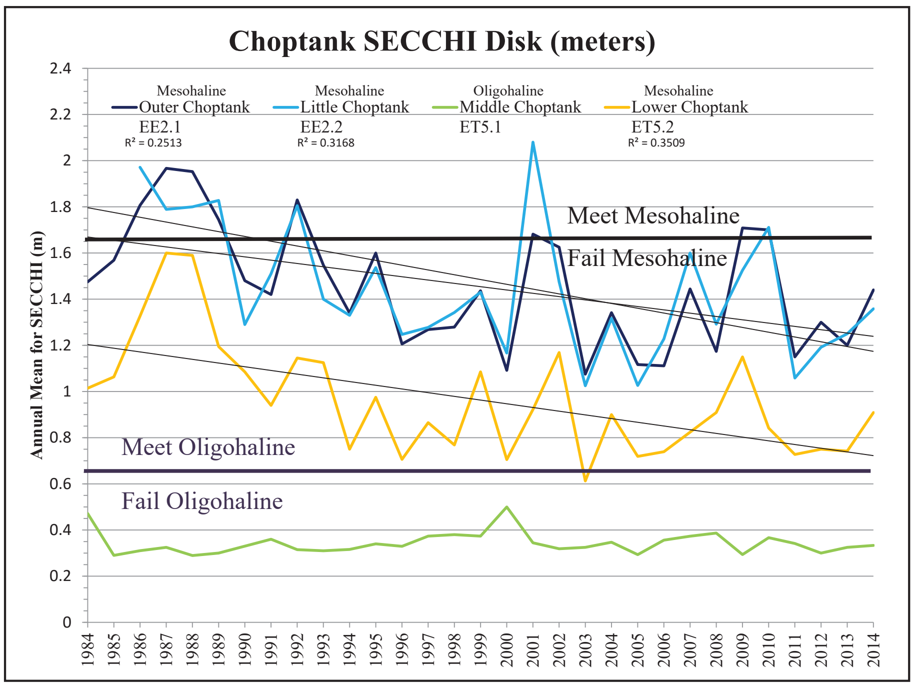

Figure 4.20. Annual mean for Secchi disk depth at the different salinity regimes criteria for the Choptank River from 1984 to 2014, with the thresholds for mesohaline (black line) and oligohaline (green line).

Salinity (PPT)

Choptank River stations were found to be under three salinity regimes: Outer Choptank, Little Choptank, and Lower Choptank were under the Mesohaline regime (5 - 18 ppt), Middle Choptank was mainly Oligohaline (0.5 - 5 ppt), while Tuckahoe Creek and Upper Choptank were under the Tidal Fresh regime (0 - 0.5 ppt) (Figure 4.21). Middle Choptank showed a 'maybe' significant ($p = 0.0488$) decreasing salinity trend, with $r^2 = 0.1239$ (Appendix A).

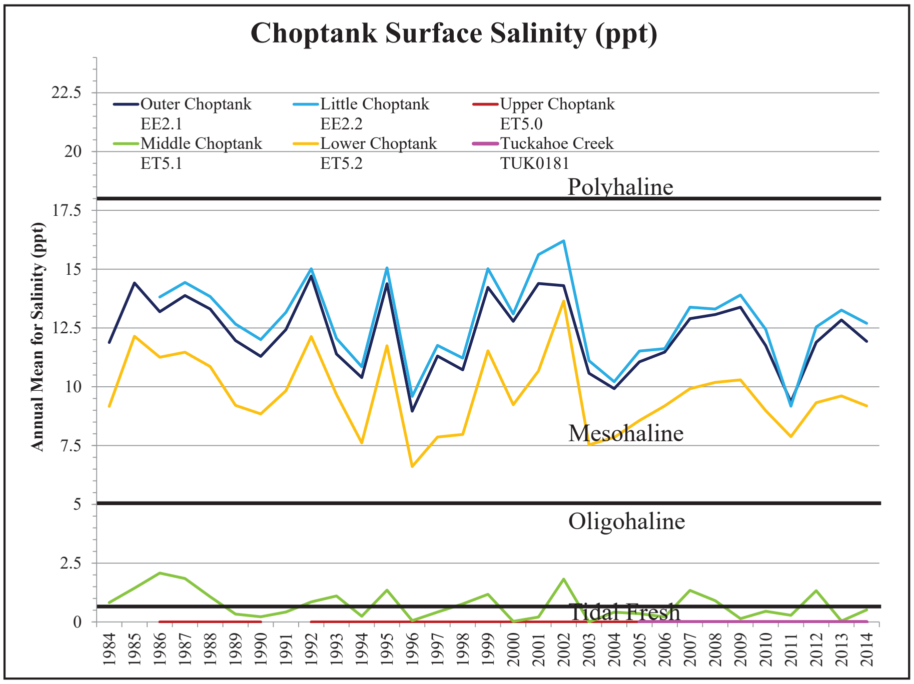

Figure 4.21. Annual mean for surface water salinity (ppt), with the different salinity regime ranges for the Choptank River from 1984 to 2014.

Temperature T ºC

Annual averages for surface water temperature ºC (0-0.5 m depth) were calculated for each station, Upper Choptank showed the lowest water temperature, while Middle Choptank showed the highest temperature (Figure 4.22). Outer Choptank, Lower Choptank, and Middle Choptank were found to be significantly decreasing in trend (Appendix A).

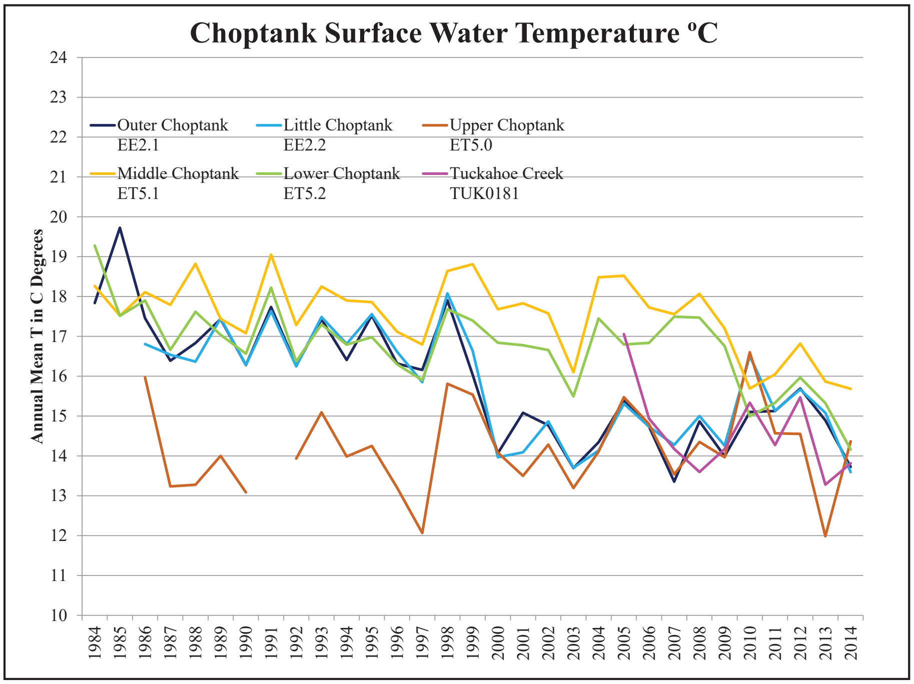

Figure 4.22. Annual mean for surface water temperature (ºC) for the Choptank River from 1984 to 2014.

Monthly Assessment for the Water Quality Parameters (2000-2015)

Two dimensional graphs were plotted for the water quality parameters (DO, TN, TP, CHLA) to show the monthly changes over years (2000 to 2015) (Appendix C). The graphs assessed these parameters using the water quality criteria.

Maryland Biological Stream Survey Program (MBSS)

The MBSS was established in 1993 by the MD DNR in order to monitor and evaluate the health of the freshwater streams statewide (>10,000 stream miles). MBSS started to survey Maryland freshwater streams in 1995, collecting physical, chemical, and biological data to evaluate the overall conditions of the State's streams. The Program surveyed 151 sites between 1996 to 2014 for the Choptank River. Sites were mainly selected using the stratified random design. However, only TN and TP were measured at 83 sites from 2000 to 2014, and most of the sites were in the Upper Choptank and Tuckahoe Creek (Figure 4.23).

Total Nitrogen (TN) (mg/l)

Annual averages for TN (mg/l) were calculated. Only Upper Choptank and Tuckahoe Creek were continuously surveyed over years, with the later surveyed only from 2007-2012 and had the highest total nitrogen concentration. Meanwhile, Upper Choptank was continuously surveyed from 2000 to 2014, and had a lower TN concentration, but still did not meet the water quality criteria and no trend was detected (Figure 4.24).

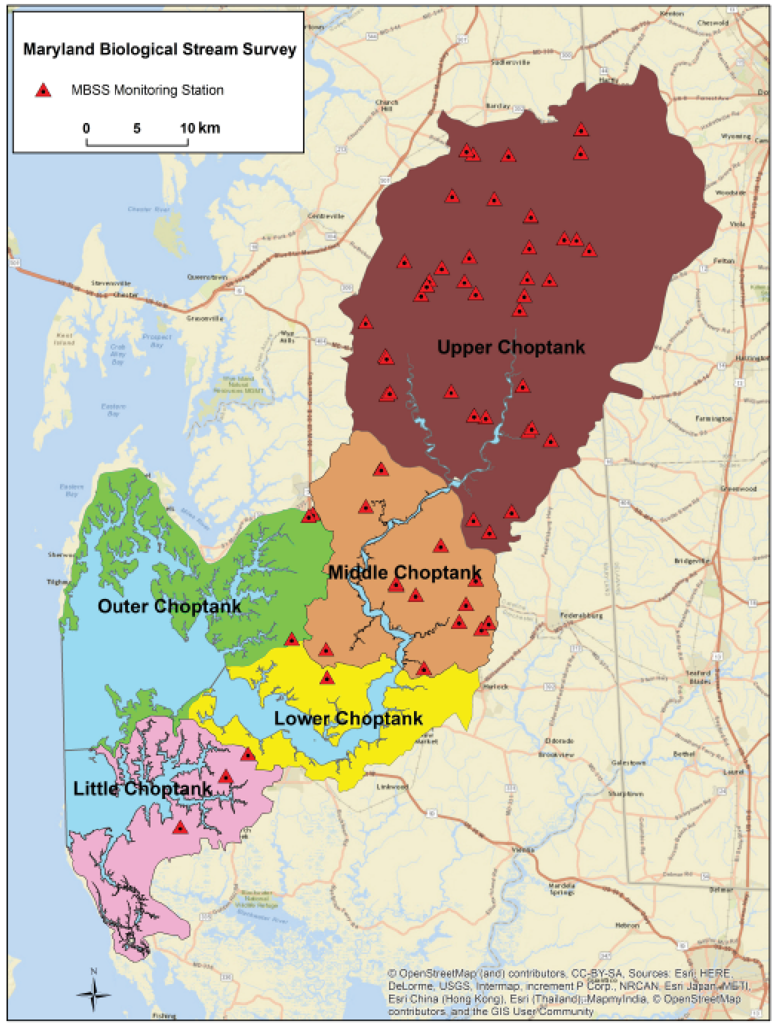

Figure 4.23. Maryland Biological Stream Survey (MBSS) monitoring Stations for the Choptank watershed 2000-2014.

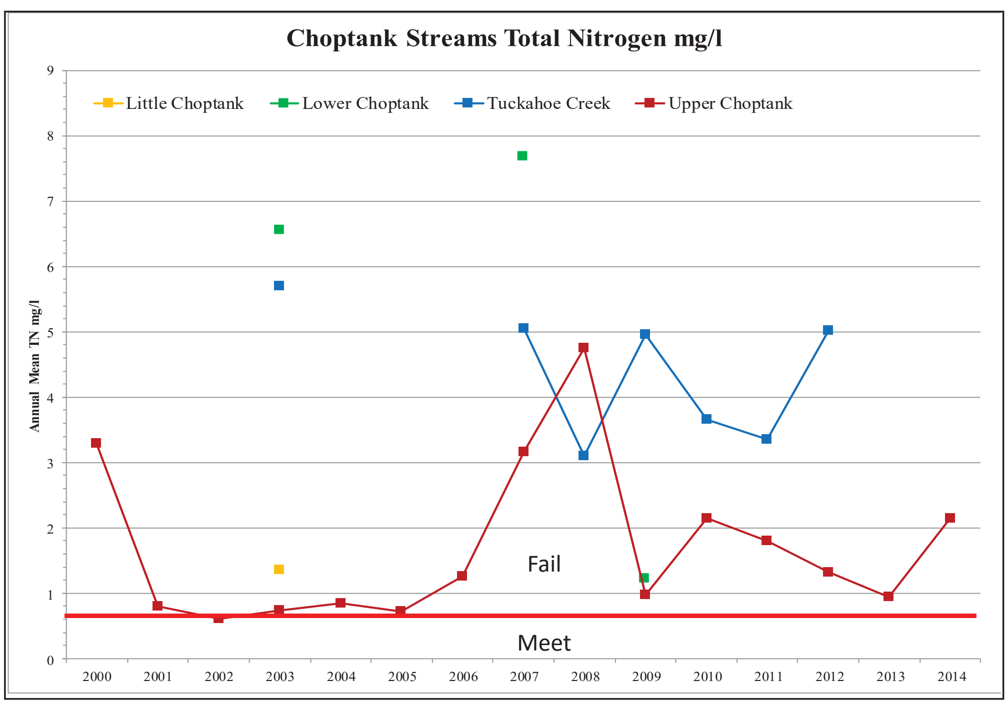

Figure 4.24. Annual mean for total nitrogen (mg/l) for the Choptank River streams from 2000 to 2014, with total nitrogen threshold (red line).

Total Phosphorus (TP) (mg/l)
Annual averages for TP (mg/l) were calculated, only Upper Choptank and Tuckahoe Creek were continuously surveyed over years, with the later only from 2007-2012. Contrary to the TN results, Upper Choptank showed relatively higher concentrations of TP than Tuckahoe Creek. However, both sub-watersheds often failed to meet the water quality criteria for TP over the survey period and no trend was detected (Figure 4.25).

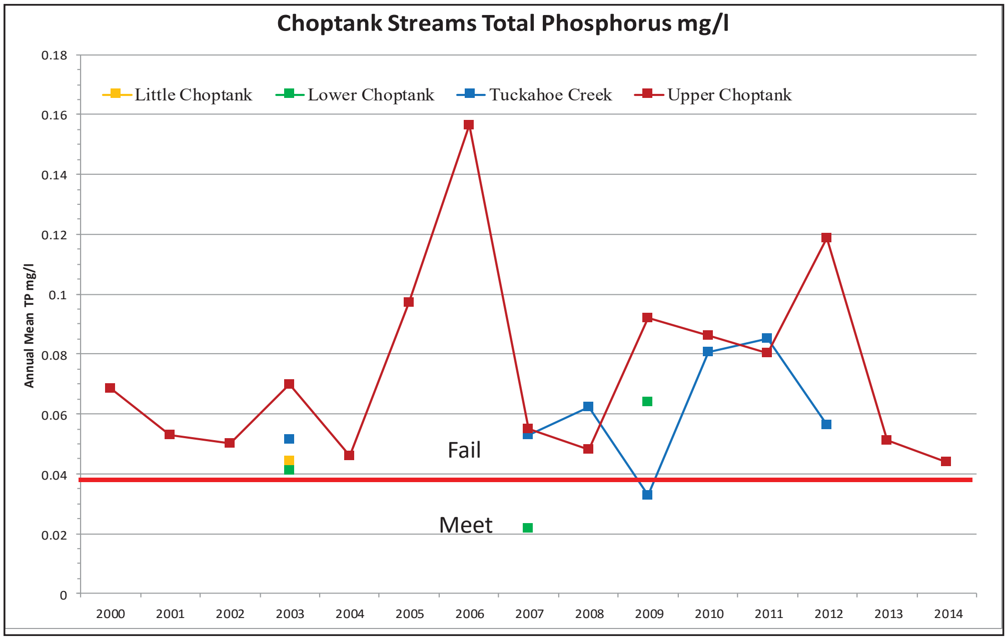

Figure 4.25. Annual mean for total phosphorus (mg/l) for the Choptank River streams from 2000 to 2014, with total phosphorus threshold (red line).

Midshore Riverkeepers Conservancy (MRC) Water Quality Monitoring Program
The MRC is an NGO that works in the field of environmental awareness, protection and restoration, focusing mainly on the Choptank watershed. One of its core activities is to monitor and assess the water quality of the Choptank River. It started as an ambitious water quality monitoring program in 1999 for the Choptank River, mainly in Harris Creek, Broad Creek, Tred Avon River, Island Creek, La Trappe Creek, and the Upper Choptank, with a total of 48 sampling sites. Sampling was done mainly in shallow water from the shore and conducted from March to October for the following water parameters: DO, TN, TP, CHLA, Secchi disk, salinity, and temperature. In 2012, the locations of the sampling sites, numbers, and technique were changed resulting in sampling of 52 stations representing ten monitoring segments (sub-watersheds). However, Little Choptank was not included in the survey (Figure 4.26), see Appendix D for the list of the monitoring segments and sampling station locations. The stations were sampled once a month from May to October, using a boat to reach deeper water. Data from 2000 to 2007 were collected, as well as recent data for 2013 and 2014.

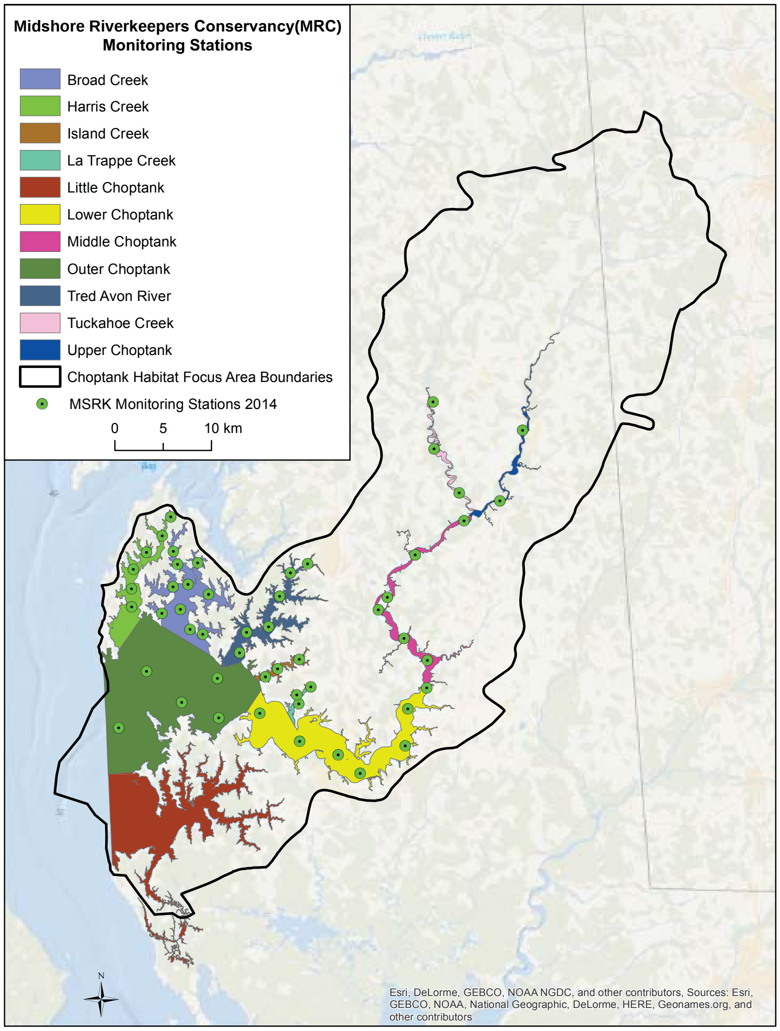

Figure 4.26. The Midshore Riverkeepers Conservancy (MRC) Water Quality Monitoring Stations and the monitoring segments for the Choptank River in 2014.

In an effort to provide a more detailed assessment of the current status of the Choptank Rivers water quality the data from 2014 was used. The averages at each sampling site were calculated for the different parameters and were compared to the water quality criteria to determine if the sites meet them or not. Additionally, results are also presented on maps to visualize the spatial changes in the water quality in the Choptank River.

Water Quality Assessment

In order to evaluate the present water quality situation for the Choptank River, the 2014 averages for the indicator parameters collected at each monitoring segment were compared to the water quality threshold values. Each segment was analyzed to determine if they met the established criteria (Table 4.1). WQINDX was not calculated due to the lack of data on important water quality parameters, such as CHLA and TSS. Spatial distribution of the Choptank water quality parameters over the 52 sampling stations was plotted on maps and assessed based on the water quality criteria (Figures 4.27 through 4.33).

Dissolved Oxygen (DO) (mg/l) 2014

Averages for DO (mg/l) for surface water were calculated for each of the ten monitoring segments, and the median was box plotted with standard error, outliers, and DO threshold (Figure 4.27; Appendix E, Figure 1). All the segments met the DO criteria (Table 4.3). Tred Avon, Broad Creek and Outer Choptank were the highest in DO concentration, while Upper and Middle Choptank were the lowest. Analysis of variance (ANOVA) for the means was conducted and there was a significant difference ($p < 0.0001$) in DO concentration between the monitoring segments.

Bottom Dissolved Oxygen (BDO) (mg/l) 2014

The averages for summer BDO for each segment were also calculated and compared to the BDO criteria of 3-5 mg/l. The BDO means for all segments were above the 5 mg/l (good) threshold, except for Island Creek and La Trappe Creek which were in the 3-5 mg/l (fair) status. Additionally, Harris Creek and Outer Choptank

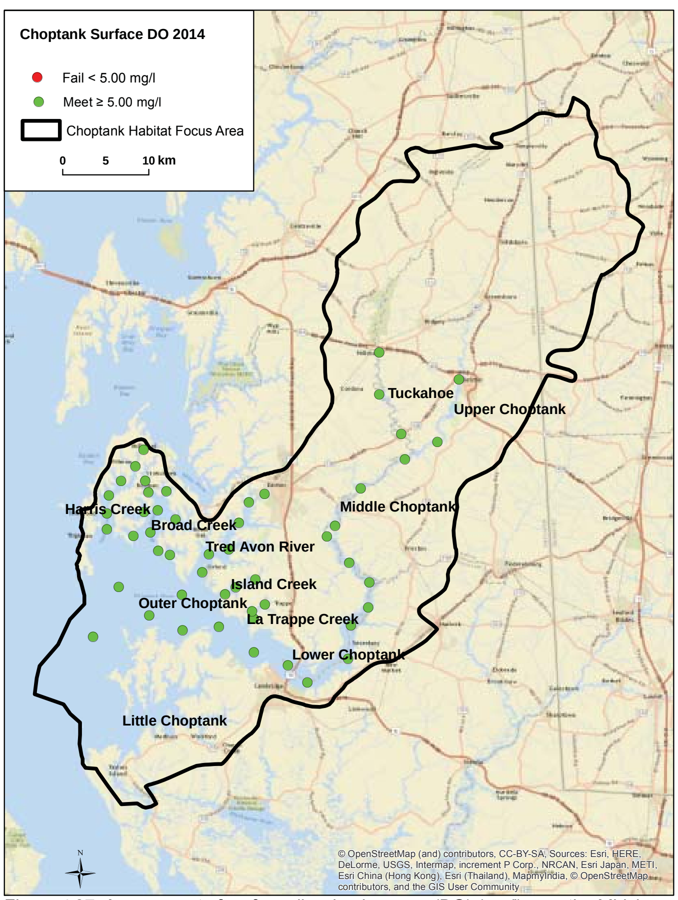

Figure 4.27. Assessment of surface dissolved oxygen (DO) (mg/l) over the Midshore Riverkeepers Conservancy (MRC) sampling sites in the Choptank River for 2014.

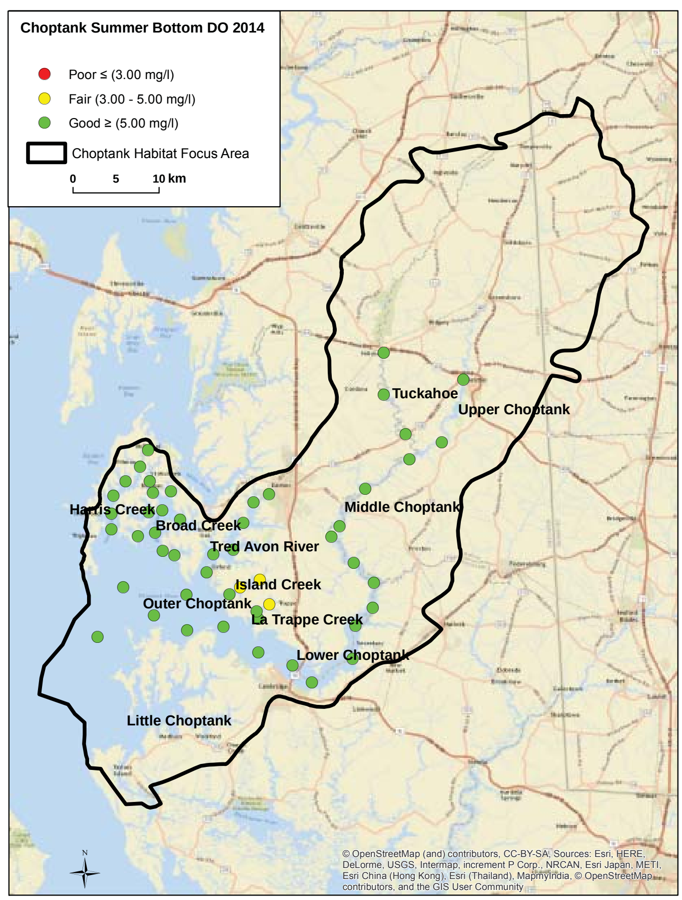

Figure 4.28. Assessment of summer bottom dissolved oxygen (BDO) (mg/l) over the Midshore Riverkeepers Conservancy (MRC) sampling sites in the Choptank River for 2014.

Table 4.3. Evaluation of the Midshore Riverkeepers Conservancy (MRC) water quality indicator parameters for the Choptank River monitoring segments for 2014.

Segment	DO (mg/l)		BDO (mg/l)		Secchi Depth (m)		TN (mg/l)		TP (mg/l)		CHLA (µg/L)	
	Mean	Status	Mean	Status	Mean	Status	Mean	Status	Mean	Status	Mean	Status
Broad Creek	7.088	Meet	6.890	Meet	0.531	Meet	0.045	Fail	7.450	Meet	1.233	Fail
Harris Creek	6.963	Meet	6.917	Meet	0.653	Meet	0.045	Fail	8.222	Meet	0.851	Fail
Island Creek	7.355	Meet	6.092	Meet	0.567	Meet	0.041	Fail	7.448	Meet	0.939	Fail
La Trappe Creek	7.488	Meet	6.117	Meet	0.693	Fail	0.069	Fail	NA	NA	0.946	Fail
Lower Choptank	6.127	Meet	4.838	Meet	0.533	Meet	0.052	Fail	NA	NA	0.687	Fail
Middle Choptank	6.361	Meet	4.932	Meet	0.607	Meet	0.064	Fail	NA	NA	0.585	Fail
Outer Choptank	6.653	Meet	6.307	Meet	0.699	Fail	0.055	Fail	9.250	Meet	0.731	Fail
Tred Avon River	5.775	Meet	5.271	Meet	1.579	Fail	0.103	Fail	11.540	Meet	0.456	Fail
Tuckahoe Creek	6.727	Meet	6.071	Meet	3.308	Fail	0.098	Fail	NA	NA	0.536	Fail
Upper Choptank	6.142	Meet	5.400	Meet	2.128	Fail	0.083	Fail	10.318	Meet	0.602	Fail

were the highest in BDO concentration (Figure 4.28; Appendix E, Figure 2). ANOVA for the means was also significant ($p<0.0001$) between the monitoring segments.

<u>Total Nitrogen (TN) (mg/l) 2014</u>

The averages for TN for each segment were calculated and compared to the TN threshold value (0.65 mg/l). Lower Choptank, Middle Choptank, Tred Avon River, Upper Choptank and Tuckahoe Creek did not meet the TN criteria, with Upper Choptank, and Tuckahoe Creek having the highest TN concentration (Figure 4.29; Appendix E, Figure 3). The ANOVA shows that there was a significant difference ($p<0.0001$) between the monitoring segments.

<u>Total Phosphorus (TP) (mg/l) 2014</u>

The averages for TP for each segment were calculated, and compared to the TP threshold value (0.037 mg/l). All monitoring segments failed to meet the TP criteria (Table 4.3). Middle Choptank, Upper Choptank and Tuckahoe Creek were the highest in TP concentration, while Outer Choptank, Harris Creek, and Broad Creek were the lowest in TP (Figure 4.30; Appendix E, Figure 4). Meanwhile, running the ANOVA revealed a significant difference ($p<0.0001$) between the Choptank monitoring segments.

<u>Chlorophyll *a* (CHLA) (mg/l) 2014</u>

Means for CHLA were calculated for each segment and compared to the CHLA threshold value (15 µg/l). The numbers of samples were very low compared to the other parameters. As a result, some segments had no samples tested for CHLA (Table 4.3), others had only one sample tested (Outer Choptank) (Appendix E, Figure 5). However, all the sampled segments met the CHLA criteria (Figure 4.31) and running the ANOVA revealed no significant difference ($p=0.5003$) between the Choptank monitoring segments.

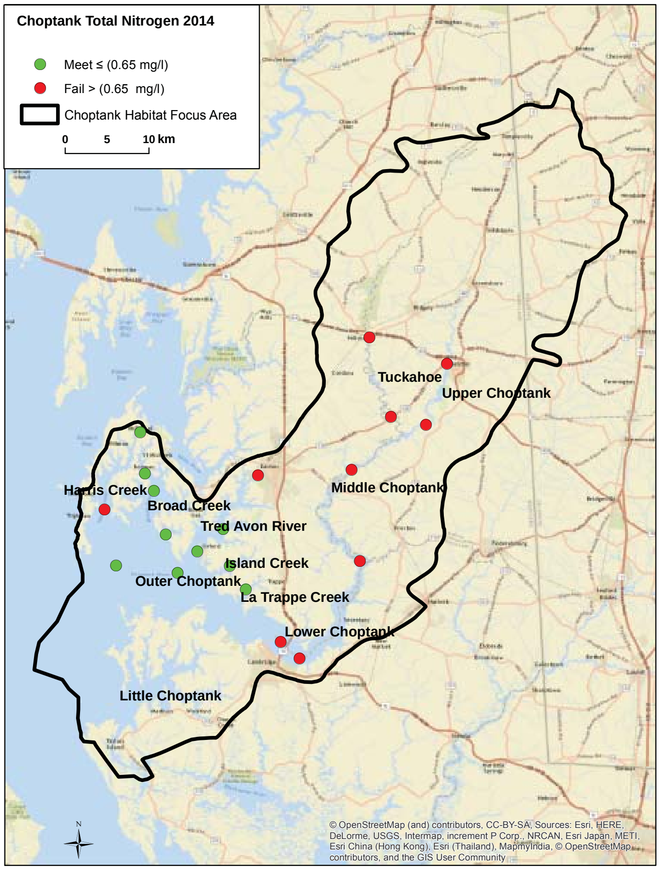

Figure 4.29. Assessment of total nitrogen (TN) (mg/l) over the Midshore Riverkeepers Conservancy (MRC) sampling sites for surface water in the Choptank River for 2014.

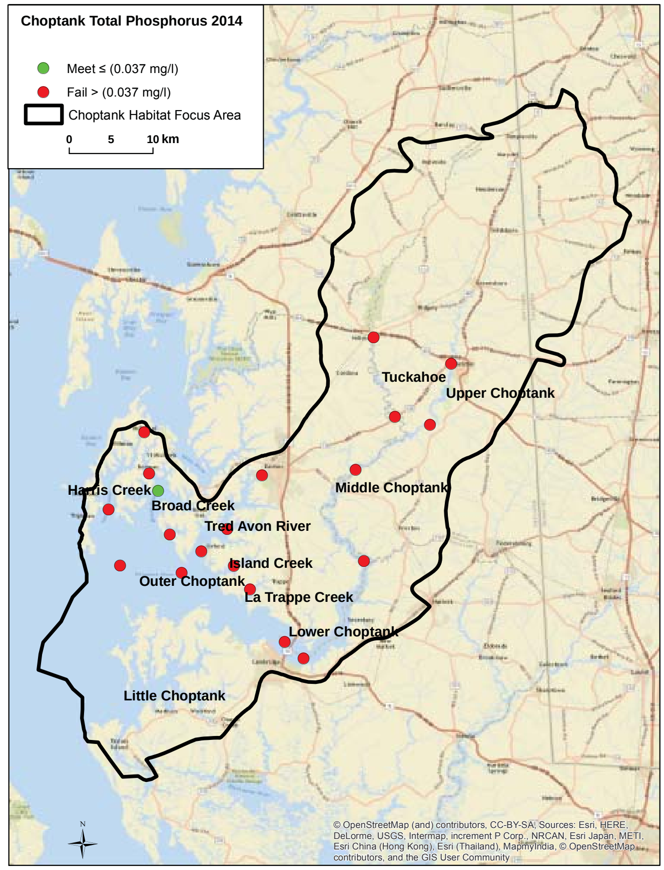

Figure 4.30. Assessment of total phosphorus (TP) (mg/l) over the Midshore Riverkeepers Conservancy (MRC) sampling sites for surface water in the Choptank River for 2014.

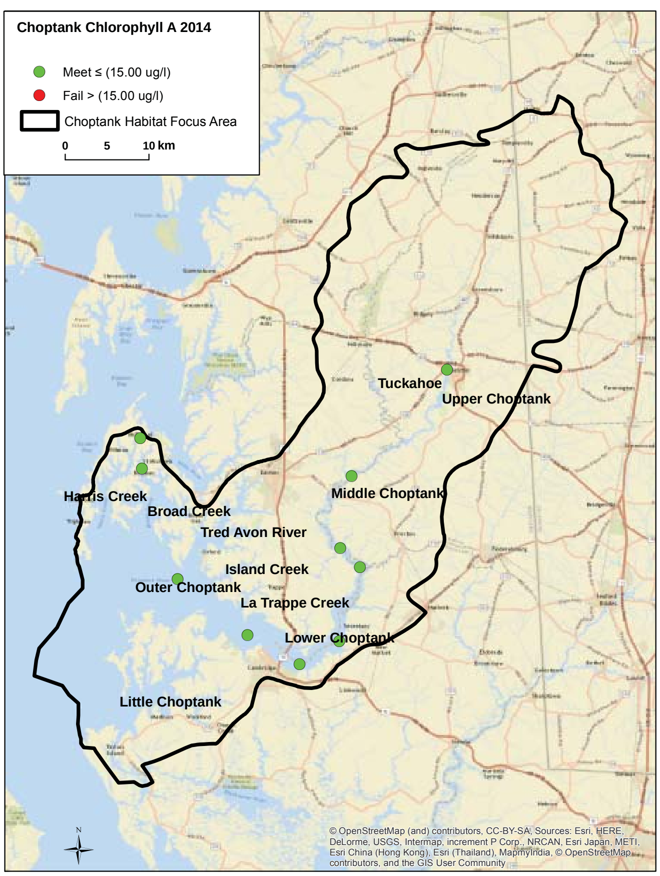

Figure 4.31. Assessment of chlorophyll a (CHLA) (mg/l) over the Midshore Riverkeepers Conservancy (MRC) sampling sites for surface water in the Choptank River for 2014.

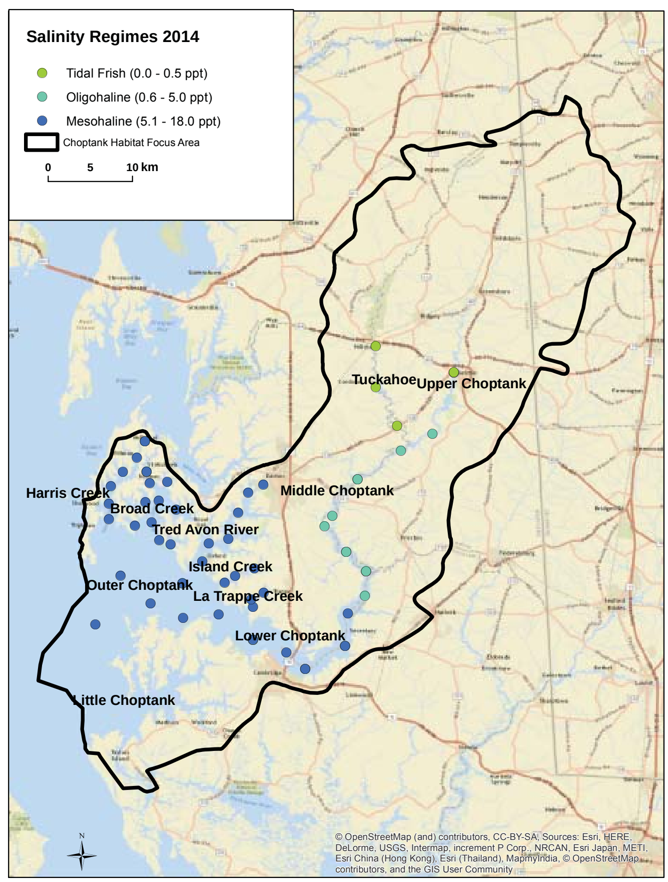

Figure 4.32. Spatial distribution for salinity regimes over Midshore Riverkeepers Conservancy (MRC) monitoring stations in the Choptank River 2014.

Salinity (PPT) 2014

Choptank river segments were found to be under three salinity regimes: Outer Choptank, Harris Creek, Broad Creek, Tred Avon River, Island Creek, LaTrappe Creek and Lower Choptank were under the Mesohaline regime (5-18 ppt); Middle Choptank was mainly under the Oligohaline (0.5-5 ppt); while Tuckahoe Creek and Upper Choptank were mainly under the Tidal Fresh (0-0.5 ppt) (Figure 4.32; Appendix E, Figure 6).

Secchi Disk Depth (m) 2014

Average Secchi disk depths were calculated for each monitoring segment and compared with the water quality criteria, where each salinity regime had different criteria. No segment met the water quality criteria (Table 4.3); however, Outer Choptank, Tred Avon River and Broad Creek had the highest clarity, while Middle Choptank was lowest (Figure 4.33; Appendix E, Figure 7).

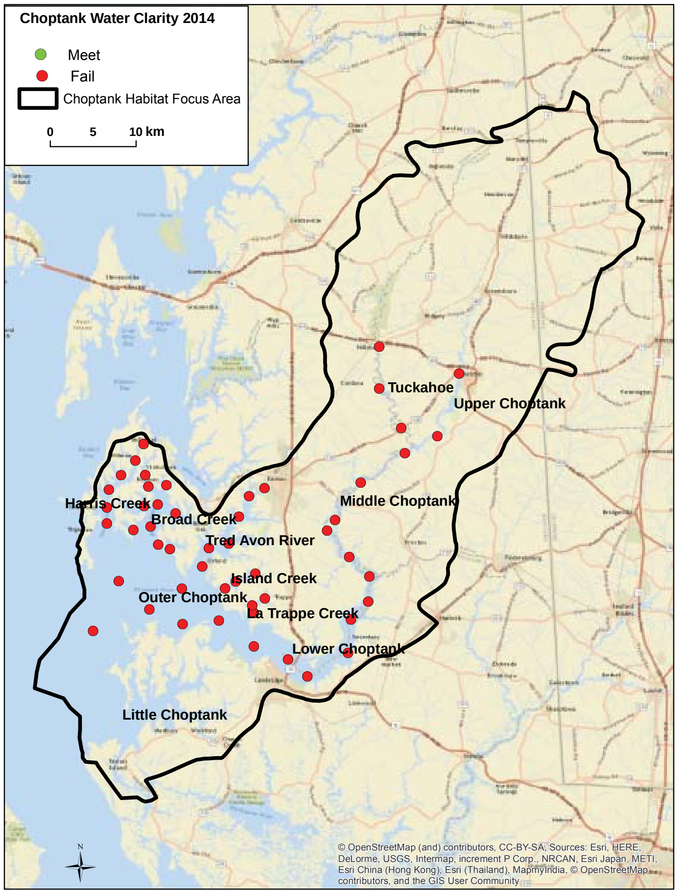

Figure 4.33. Assessment of the water clarity over the Midshore Riverkeepers Conservancy (MRC) sampling sites in the Choptank River 2014.

Midshore Riverkeeper Conservancy (MRC) personnel conducting water quality sampling on the Choptank River. Photo credit: MRC

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Chapter 5: Benthic Index of Biotic Integrity

INTRODUCTION

Benthic organisms can be a useful indicator of environmental quality in aquatic ecosystems due to their limited mobility and sensitivity to low levels of oxygen on the bottom and accumulation of environmental contaminants in sediments (Gray, 1979; Bilyard, 1987; Dauer, 1993). The Index of Biotic Integrity (IBI), first developed for fish species by Karr (1981), is a measure of community health. It has since been adapted to evaluate benthic community condition in a variety of regions and water bodies, including freshwater streams in Tennessee (Kerans and Karr, 1994), urban streams in the Puget Sound basin (Morley and Karr, 2002), and the Chesapeake Bay (Weisburg et al., 1997). The B-IBI is dependent on habitat, salinity, and season, and integrates multiple parameters, such as total abundance/biomass, species diversity, and prevalence of pollution tolerant/sensitive taxa relative to reference communities/conditions. In the Choptank watershed, there are two monitoring programs, the Chesapeake Bay Program (CBP)/Versar and the Maryland Biological Stream Survey, that measure B-IBI in tidal and non-tidal waters, respectively. The purpose of this chapter is to describe the available B-IBI data for the Choptank watershed, spatial patterns, and temporal trends.

Scientists prepare the Young Grab for sampling. Photo credit: NOAA CCMA COAST

DATA SOURCES AND METHODS

Tidal

A B-IBI was developed for the Chesapeake Bay to assess the status and condition of summer benthic communities in tidal waters of the Bay (Weisburg et al., 1997; Alden et al., 2002). Since 1984, Versar, in conjunction with the State of Maryland and the U.S. Environmental Protection Agency (U.S. EPA) CBP, has conducted yearly bay-wide benthic monitoring from July-September. The sampling design has changed over time as program objectives have evolved (Llansó et al., 2013). Fixed sites have been sampled since 1984; initially 70 sites were visited multiple times per year, but since 1989, 27 fixed sites are sampled once annually, with three replicate samples taken at each site. A probability based sampling component was added in 1994 to assess benthic community condition at randomly selected sites throughout the Chesapeake Bay mainstem and tributaries. While the fixed sites are used to identify temporal trends, the stratified-random selected sites are sampled to assess bay-wide patterns and spatial variability. In each of ten strata, 25 randomly selected sites are allocated each year, with one sample collected at each site.

Four types of gear are used to collect samples depending on habitat type and whether the site is fixed or probability based (Llansó et al., 2013). At fixed stations, a 0.025 m^2 hand operated box corer is used in the nearshore shallow habitats, while a 0.0225 m^2 Wildco box corer is used in the deepwater (>4 m) habitats. Probability based samples are collected with a 0.044 m^2 surface area Young grab. Organisms are sieved through a 0.5 mm screen and are further processed back in the lab to sort and identify taxa to the lowest possible taxonomic level. In addition, water quality parameters are also collected at each sampling site (e.g., temperature, salinity, dissolved oxygen). Metrics that are included in the calculation of the overall B-IBI score vary by habitat (Llansó, 2002) and include:

- Shannon-Weiner Species Diversity Index
- Total Species Abundance
- Total Species Biomass
- Percent Abundance of Pollution-Indicative Species
- Percent Abundance of Pollution-Sensitive Species
- Percent Biomass of Pollution-Indicative Species
- Percent Biomass of Pollution-Sensitive Species
- Percent Abundance of Carnivores and Omnivores
- Percent Abundance of Deep Deposit Feeders
- Tolerance Score
- Tanypodinae to Chironomidae percent abundance ratio

Summary statistics for each metric are scored on a ranking of 1, 3, or 5, with least disturbed sites receiving a 5 and severely degraded sites receiving a 1. The scoring is done by comparing observed metrics with established thresholds derived from reference data (Llansó, 2002). These thresholds, called “Restoration Goals” (Ranasinghe et al., 1994), were established as the 5th (or 95th) and 50th (median) percentile values of reference sites, and were derived for each habitat, based on sediment type (sand, mud) and salinity (tidal freshwater, oligohaline, low/high mesohaline, polyhaline) (for details, see Llansó, 2002). The overall B-IBI score is then calculated by averaging the scores for all individual 1-5 metrics. The Chesapeake Bay Benthic Monitoring Program classifies benthic community condition into four levels: “meets goals”, “marginally degraded”, “degraded”, and “severely degraded” according to the following breakpoints (CBP, 2012; Llansó, 2002):

- ≥3.0 Meets restoration goals
- 2.7-2.9 Marginal
- 2.1-2.6 Degraded
- ≤2.0 Severely degraded

Alternative ways for classifying condition by average B-IBI value take into consideration habitat specific combinations (Llansó et al., 2003). However, for this report we follow the criteria used by the CBP. The tidal B-IBI metric is incorporated into the spatially explicit Chesapeake Bay Health Index (BHI), which integrates multiple parameters of Bay status, including water quality and area of submerged aquatic vegetation (SAV) (Williams et al., 2009).

Tidal B-IBI values were coded for condition based on the aforementioned criteria used by the CBP. The data was then analyzed separately for fixed and randomly selected stations. The mean ± standard error (SE) B-IBI for each fixed station was calculated and plotted by year. As the data was slightly skewed and not-normally distributed, a Mann-Kendall nonparametric test was used to determine if there was a temporal trend in the time series. In addition, a Spearman’s correlation was used to test for association between B-IBI score and the observed dissolved oxygen (DO) for all individual samples, as benthic communities can be sensitive to DO levels (Diaz and Rosenberg, 1995). For the randomly selected stations, condition levels were plotted in ArcGIS to qualitatively assess spatial variation of B-IBI in the Choptank. Randomly selected sites were classified by the previously defined regions of interest (Upper/Middle/Lower Choptank, Tred Avon, Harris Creek, Little Choptank, see Chapter 1, Figure 1.2), and within each region the percent occurrence of B-IBI surveys was calculated by condition level. In addition, a Spearman’s correlation was used to test for association between B-IBI score, depth, and observed DO at the time of the survey.

Non-tidal

Non-tidal benthic community monitoring is conducted by the Maryland Department of Natural Resources (MD DNR) as part of the Maryland Biological Stream Survey (MBSS). The goals of the MBSS, which began in 1995, are to assess current condition and changes in ecological resources of Maryland’s 1st through 4th order non-tidal streams, as well as provide an inventory of biodiversity and identify effects of stressors on the natural resources (Stranko et al., 2014). A benthic IBI was originally developed for the MBSS in 1998 and several refinements/improvements were made in 2004 (Southerland et al., 2005, 2007). The MBSS was started in 1995 and B-IBI data is available since 1996. The MBSS is a stratified random survey with a lattice design. Year and basin are included as strata and sampling is restricted each year to approximately one-third of the major drainage basins (Mercurio et al., 1999). In addition, a subset of sites are selected for repeat sampling in subsequent years; these include sites in the Sentinel Site Network, which were chosen in areas with minimal human impacts, and have been sampled annually since 2000 (Becker et al., 2010). From 2014-2018, a random selection of previously sampled sites are being targeted for a repeat visit (Stranko et al., 2014).

At each MBSS sampling location, benthic macroinvertebrates are sampled from a 20 ft^2 area with a standard D-net (Stranko et al., 2014). Samples are sieved and preserved in the field and then sorted and processed in the laboratory. Community composition data is used to calculate a suite of summary metrics that are included in the calculation of B-IBI for the Coastal Plain region (Southerland et al., 2005), which includes the Chesapeake Bay:

- Total number of taxa
- Number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa
- Number of Ephemeroptera taxa
- Percent Ephemeroptera
- Percent intolerant to urban
- Number of scraper taxa
- Percent climbers

Established criteria are then used to score the metrics 1, 3, or 5, and the average of all individual metric scores represents the B-IBI (Stribling et al., 1998). The MBSS B-IBI scores can be further classified into four condition ranges:

- ≥4.0 – Good
- 3.0-3.9 – Fair
- 2.0-2.9 – Poor
- 1.0-1.9 – Very Poor

Non-tidal B-IBI values within the Choptank Habitat Focus Area (HFA) were coded for condition based on the aforementioned criteria defined by the Maryland Biological Stream Survey. For the one Sentinel Site in the study area, the observed B-IBI was plotted by year, and linear regression was used to determine if there was a temporal trend in the time series. The remaining surveys were classified into groups by the regions of interest (Upper/Middle/Lower Choptank, Tred Avon, Harris Creek, Little Choptank), and within each region the percent occurrence of B-IBI surveys was calculated by condition level.

RESULTS

Tidal

There are two fixed tidal stations in the Choptank that have been monitored since 1984 (Figure 5.1). Station #64, located just downstream from the US Route 50 bridge at a depth of ~10 meters, is considered high mesohaline. Station #66, located downstream from the confluence of Tuckahoe Creek at a depth of ~4 meters, is classified as oligohaline. There was no significant temporal trend detected for either station from 1984-2014 (#64: tau=0.163, p=0.165; #66: tau=-0.062, p=0.629), but there was considerable variation among years (Figure 5.2). B-IBI values at site #64 tended to be higher, with values falling into the “Meets Restoration Goals” range in approximately two-thirds of the sampled years, while values at site #66 were most frequently classified as “Marginal” or “Degraded.” There was no significant correlation between B-IBI score and observed DO (Spearman’s rho= -0.045, p=0.71). In addition, several metrics that feed into the overall B-IBI score were plotted for the fixed station time series, including total species abundance, total species biomass, percent abundance of pollution-indicative (PI) taxa, percent abundance of pollution-sensitive (PS) taxa, and Shannon-Weiner species diversity index (Figures 5.3 and 5.4).

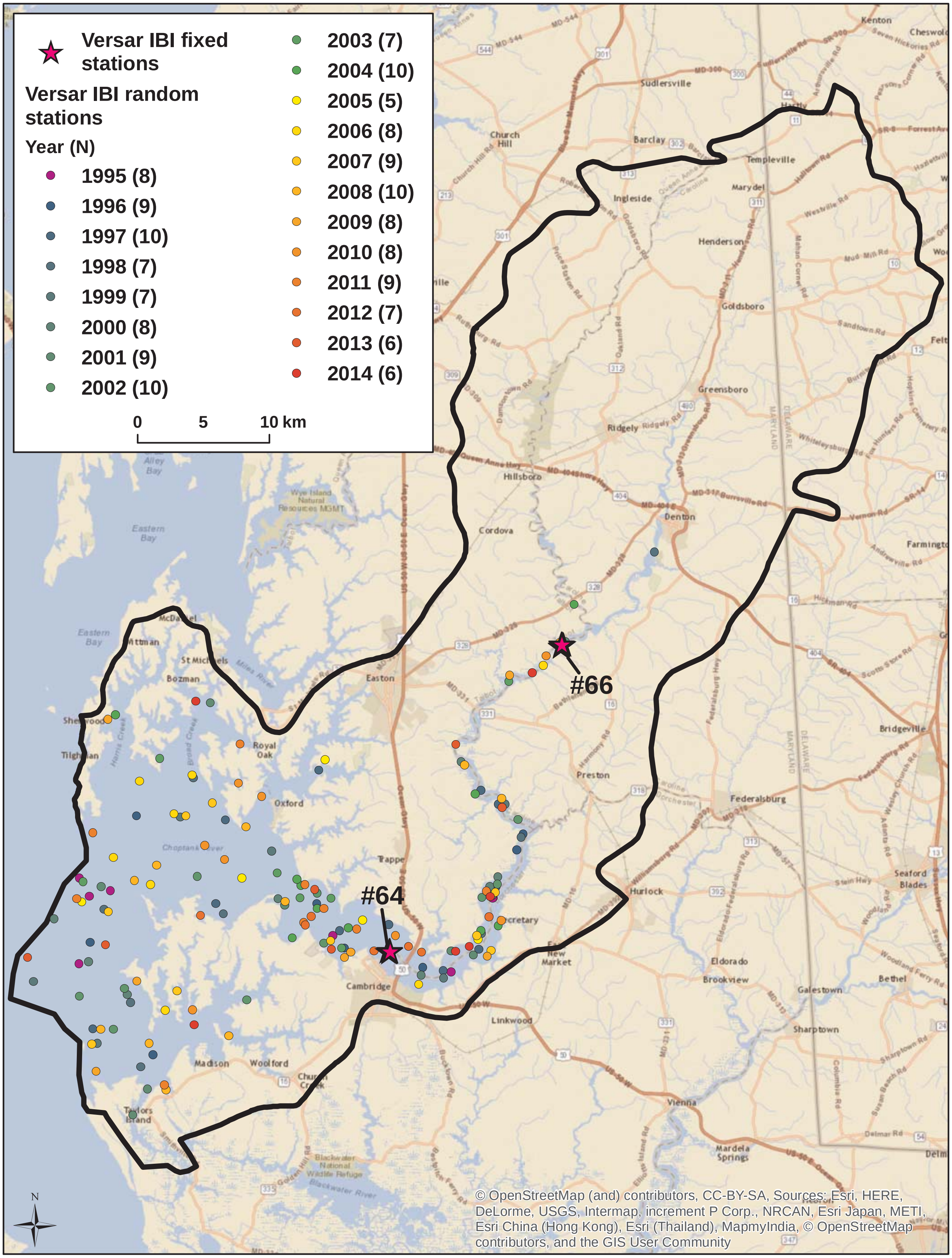

Figure 5.1. Locations of fixed and randomly selected tidal B-IBI survey sites in the Choptank HFA from 1995-2014. The number of randomly selected sites is displayed by year. Data were collected by Versar in conjunction with the State of Maryland and U.S. EPA Chesapeake Bay Program.

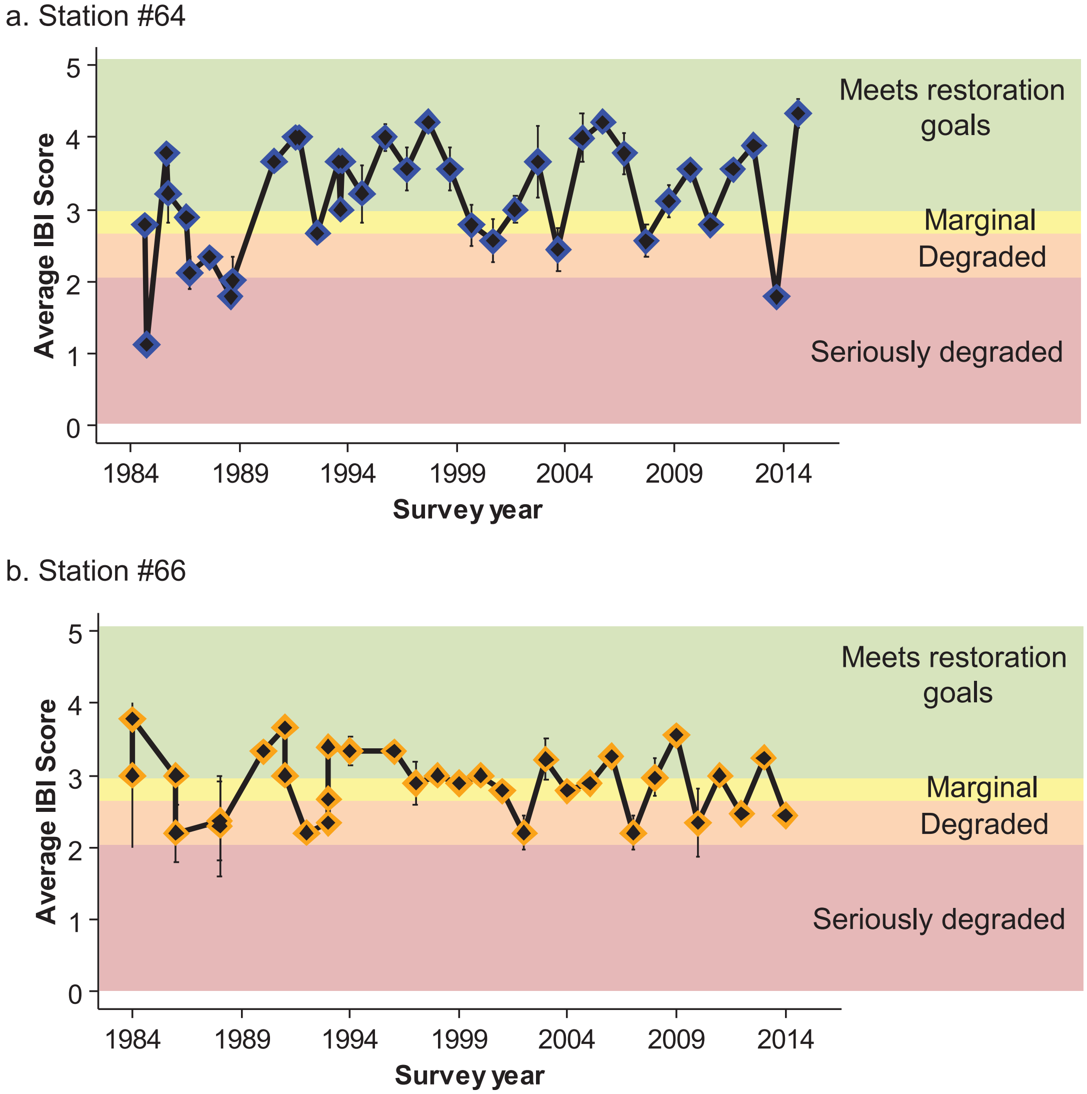

Figure 5.2. Observed B-IBI values at fixed tidal monitoring stations #64 (a) and #66 (b) from 1984-2014. Data source: Versar

Young Grab being deployed for sampling. Photo credit: NOAA CCMA COAST

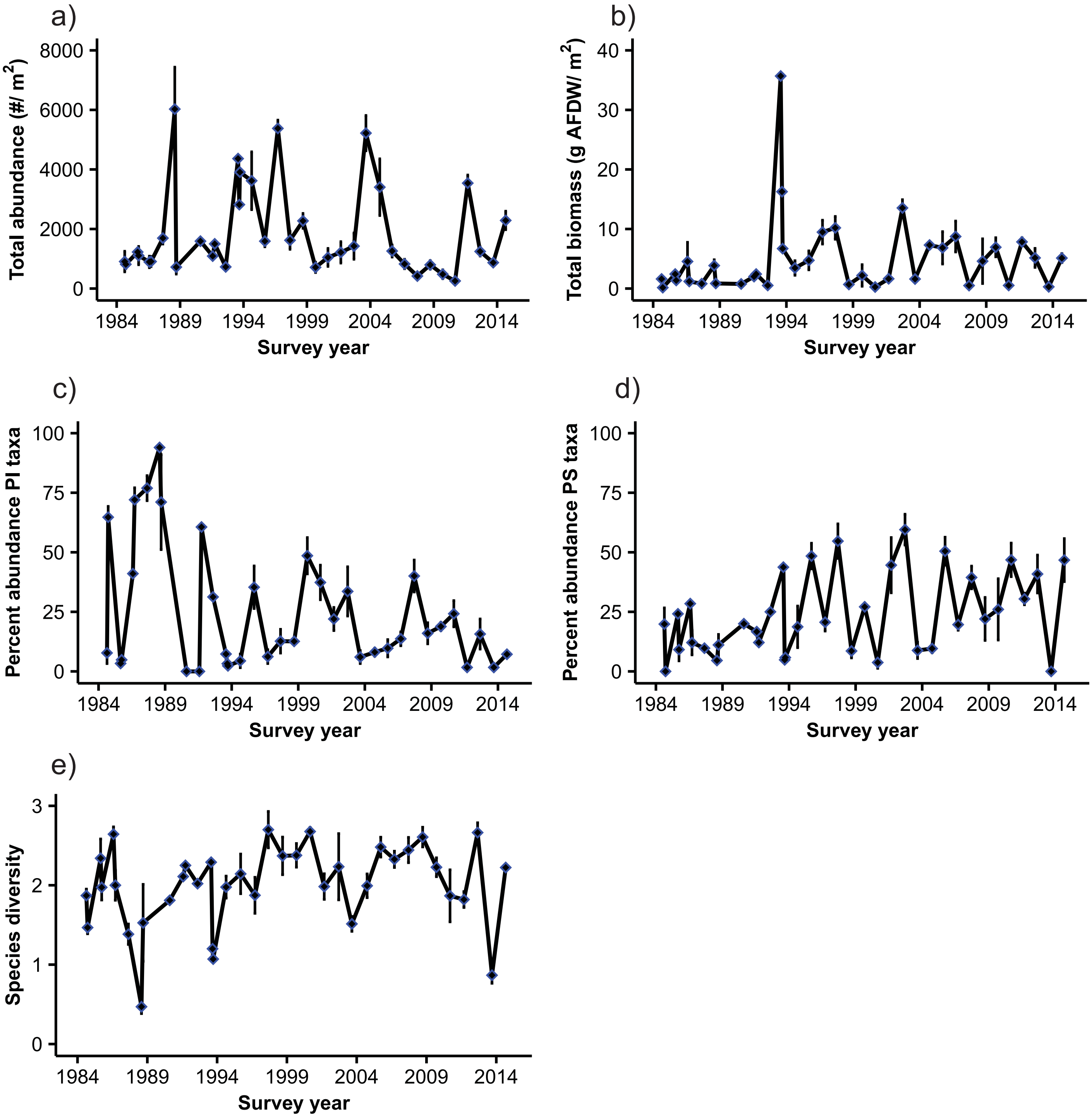

Figure 5.3. Observed mean (±SE) values of select benthic community metrics for fixed tidal monitoring station #64 from 1984-2014. a) total species abundance (#/m²), b) total species biomass (g ash free dry weight/m²), c) percent abundance of pollution-indicative (PI) taxa, d) percent abundance of pollution-sensitive (PS) taxa, and e) Shannon-Wiener species diversity index (log-base=2). Data source: Versar

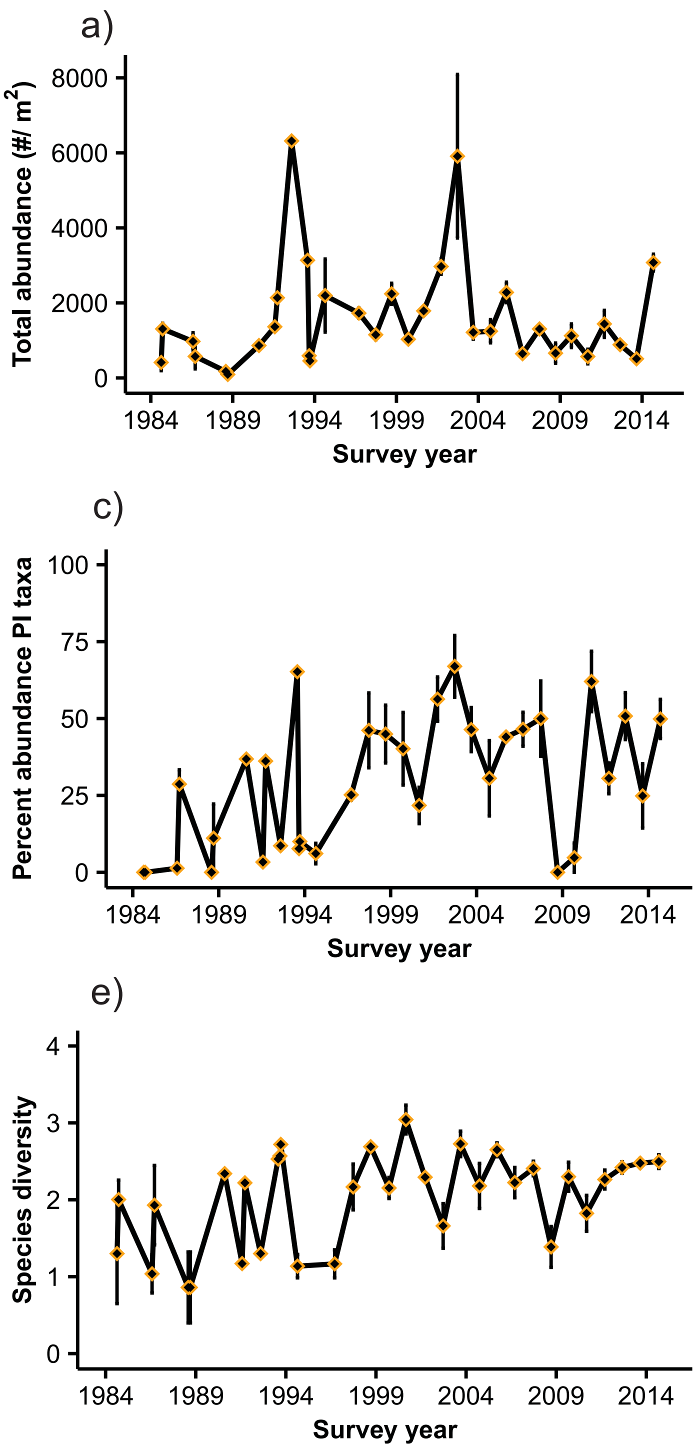

Figure 5.4. Observed mean (±SE) values of select benthic community metrics for fixed tidal monitoring station #66 from 1984-2014. a) total species abundance (#/m²), b) total species biomass (g ash free dry weight/m²), c) percent abundance of pollution-indicative (PI) taxa, d) percent abundance of pollution-sensitive (PS) taxa, and e) Shannon-Wiener species diversity index (log-base=2). Data source: Versar

There have been 161 randomly selected stations sampled in the Choptank from 1996-2014, ranging from 6-10 stations per year (Figure 5.1). A higher proportion of degraded sites were located near the mouth of the Choptank (Figure 5.5). Within the pre-defined areas of interest, a higher proportion of sites within the Little Choptank and Upper Choptank were "degraded" or "severely degraded". However, there was only a total of nine surveys within the Upper Choptank area (Figure 5.6). In addition, sample size was low within Harris Creek (N=2) and Tred Avon River (N=4), so these were not included. There was no significant correlation between B-IBI and total site depth (Spearmen's rho=-0.007, p=0.926) and B-IBI and DO (Spearman's rho =-0.078, p=0.323).

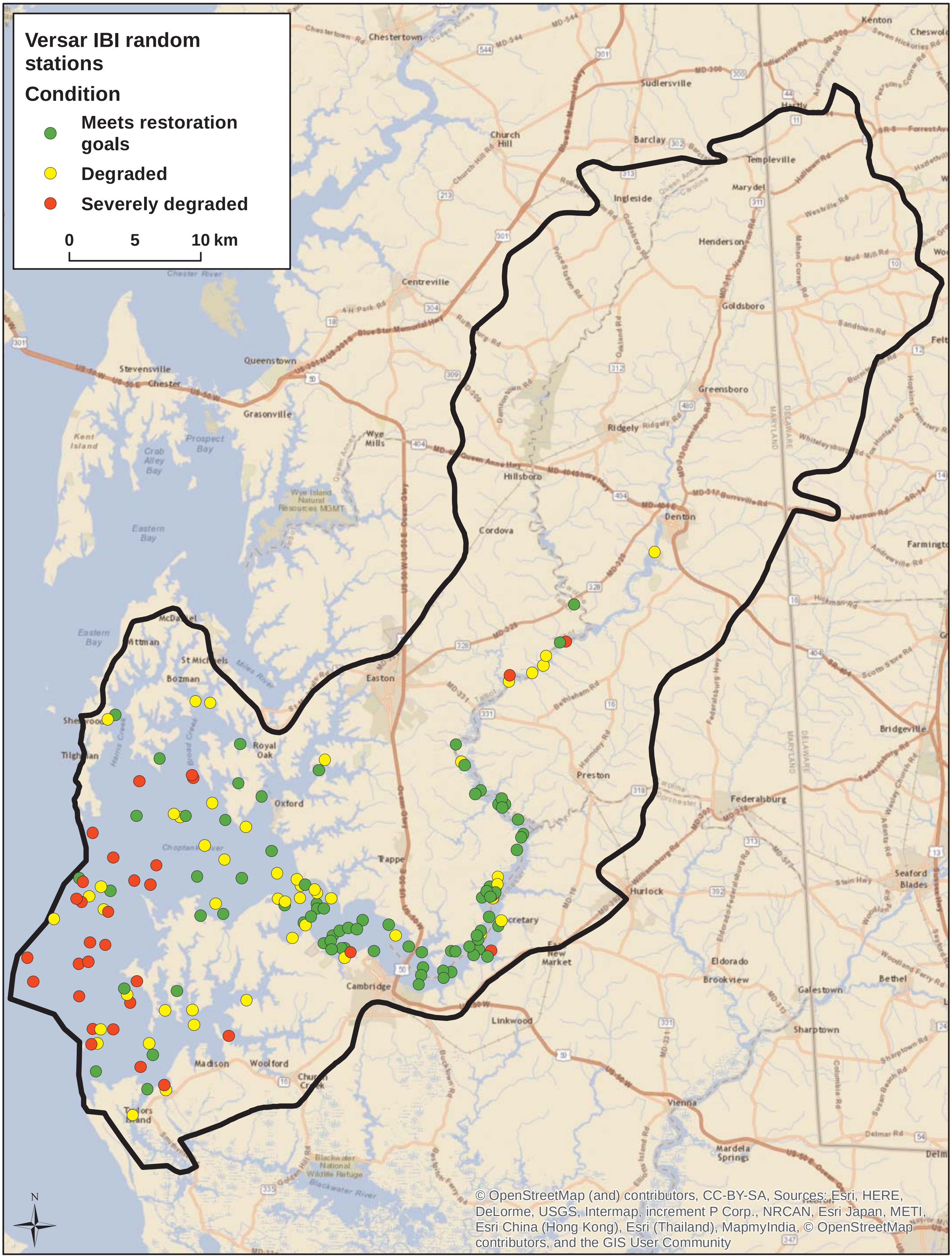

Figure 5.5. Classified condition at randomly selected Versar survey sites based on observed B-IBI values.

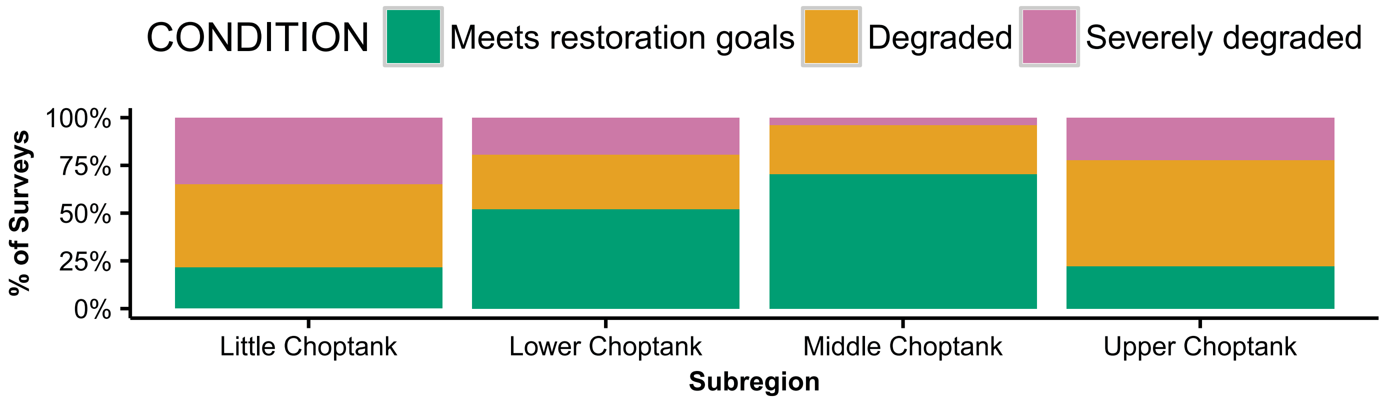

Figure 5.6. The proportion of tidal B-IBI sites classified by condition level based on observed B-IBI scores in subregions of the Choptank HFA. Sample sizes by subregion: Little Choptank (N=23), Lower Choptank (N=98), Middle Choptank (N=27), and Upper Choptank (N=9).

Non-tidal

A total of 130 MBSS surveys have been conducted in the Choptank watershed. The number of surveys is unevenly distributed among years (Figure 5.7). The majority of samples were collected in the early portion of the time frame, with approximately two-thirds of the sites sampled in four years (1996, 1997, 2000, 2003; Figure 5.7). In addition, one sentinel site, Skeleton Creek, is located in the Choptank watershed and accounts for 15 of the 130 surveys, having been sampled every year since 2000.

Tred Avon River. Photo credit: NOAA Oxford Lab

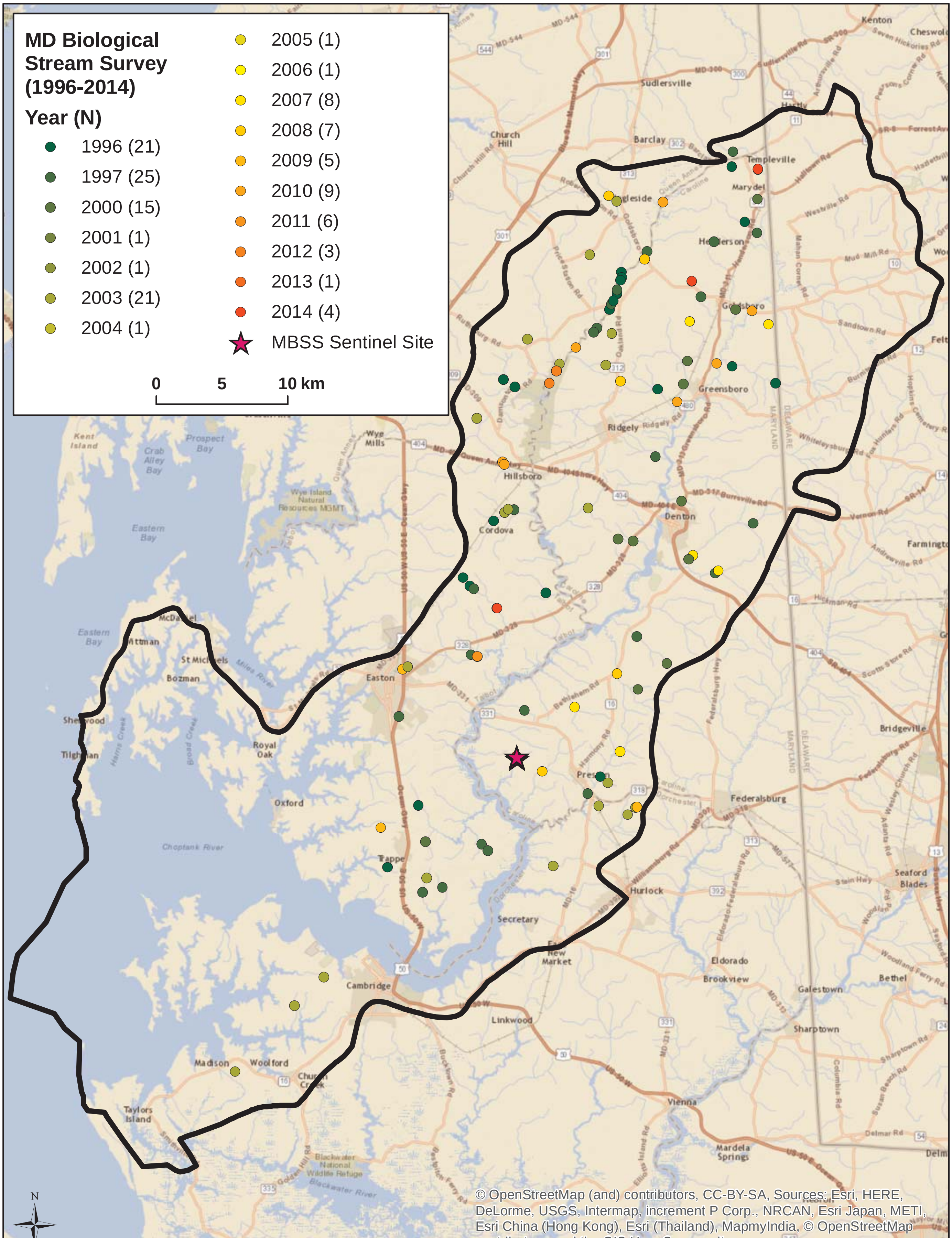

Figure 5.7. Locations of Maryland Biological Survey (MBSS) B-IBI surveys in the Choptank HFA from 1996-2014. The number of stations surveyed per year is displayed (excluding the regularly monitored sentinel site at Skeleton Creek).

There was a significant negative trend in B-IBI values at the sentinel site in Skeleton Creek (Figure 5.8, F=8.647, p=0.011). In the early years of the time series, the B-IBI values fell within the "Good" to "Fair" range, but in recent years in the "Fair" to "Poor" range, and since 2008 the B-IBI values have not exceeded 3.5.

In addition to the uneven distribution of MBSS surveys by year, due to the focus of the sampling on freshwater streams, the survey locations are unevenly distributed across space within the Choptank HFA. The majority of MBSS sites are located in the Upper Choptank (Figures 5.9 and 5.10). While there was a greater proportion of sites classified as "poor" or "very poor" in the Little and Lower Choptank, this should be interpreted with caution as the sample size was much lower for these subregions. Approximately 44% of surveys in the Upper Choptank had a B-IBI score in the "good" range. The majority of surveys classified as "very poor" were located in the upper reaches of the watershed from the border between Caroline and Queen Anne's County south to Greensboro (Figure 5.9).

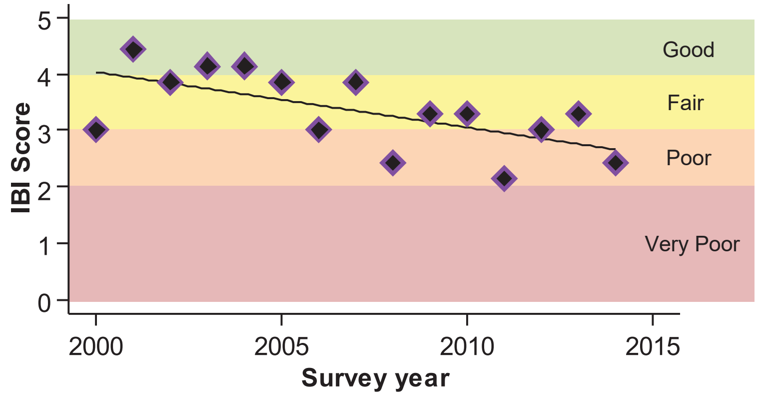

Figure 5.8. Observed B-IBI values and linear regression line at MBSS Sentinel Site at Skeleton Creek from 2000-2014. A significant negative trend was detected (F=8.647, p=0.011).

Researcher collects samples of sediment and benthic infauna in the Chesapeake Bay. Photo credit: NOAA CCMA COAST

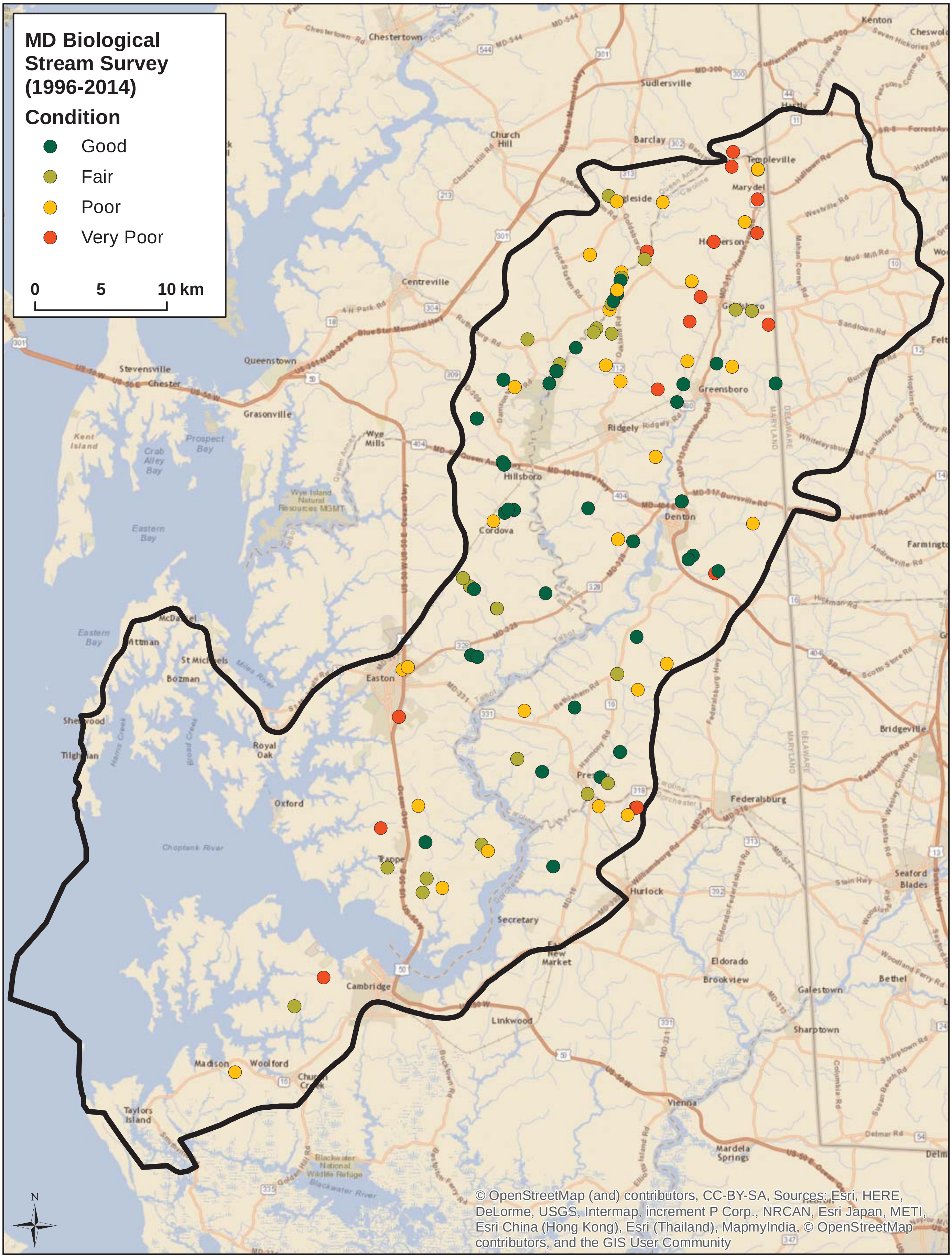

Figure 5.9. Classified condition based on observed B-IBI values at MBSS survey locations. Excludes the regularly monitored sentinel site at Skeleton Creek.

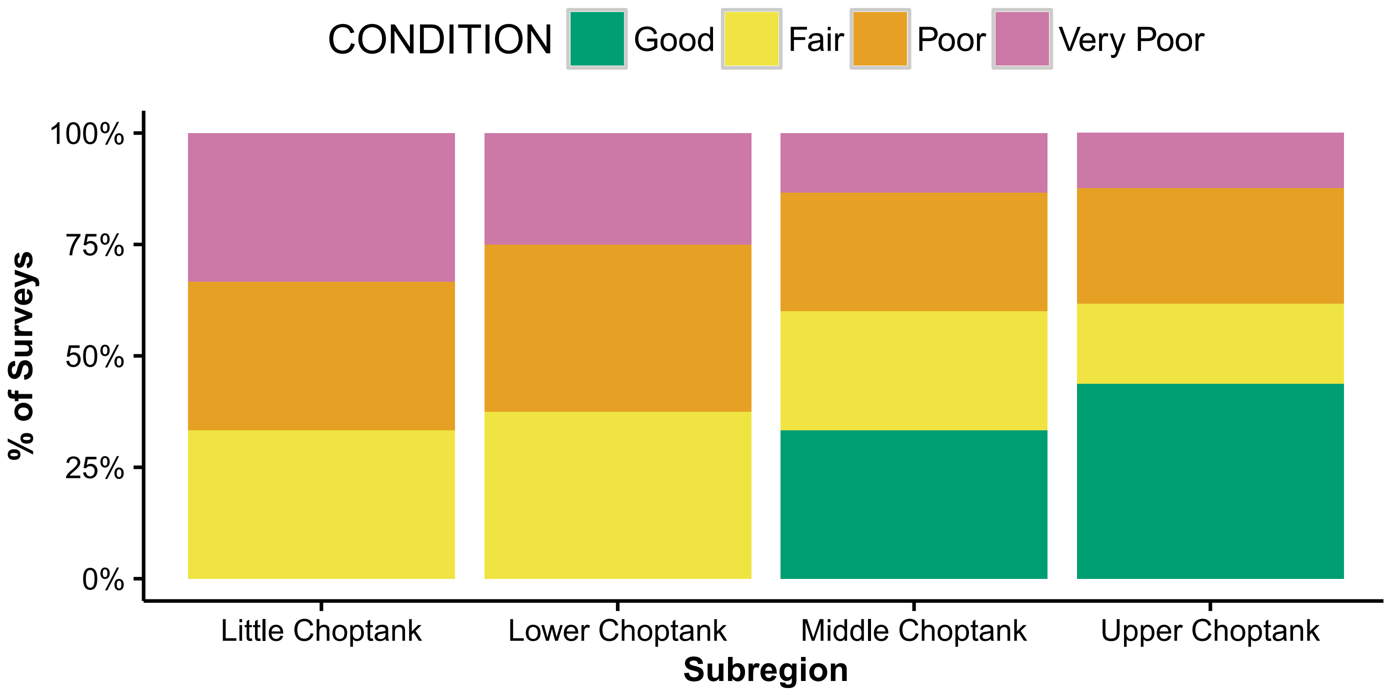

Figure 5.10. The proportion of MBSS B-IBI sites classified by condition level based on observed B-IBI scores in each subregion of the Choptank HFA. Excludes the regularly monitored sentinel site at Skeleton Creek. Sample sizes by subregion: Little Choptank (N=3), Lower Choptank (N=8), Middle Choptank (N=15), Upper Choptank (N=89).

CURRENT ACTIVITIES AND DATA GAPS

B-IBI is an indicator of benthic quality and may be a useful indicator for oyster restoration planning and implementation in the HFA. Benthic organisms also serve as food for many fish species such as striped bass, Atlantic croaker, spot, and white and yellow perch. Currently, long-term monitoring sites in tidal areas are limited to the Choptank mainstem, and only a handful of randomly selected sites have been sampled in tributaries where oyster restoration is occurring (Harris Creek, Tred Avon River, Little Choptank River). However, as an extension of work that was recently completed in three other Chesapeake watersheds (Leight et al., 2014), NOAA's Cooperative Oxford Lab (COL) is conducting additional monitoring and characterization of the Tred Avon River and Kings Creek. The health of each system will be evaluated using a suite of observations on water quality and living resources, including B-IBI. This additional data will provide important information on benthic condition within relatively under-sampled areas of the HFA.

MBSS monitoring data is used by the state of Maryland to identify impaired streams and watersheds that may be affected by stressors (Southerland et al., 2009). In non-tidal areas of the Choptank watershed, the MBSS sampling effort varies widely by year (Figure 5.7); the years with the highest sampling effort tended to occur in earlier years of the study (1990s). In more recent years, sampling effort tended to be relatively lower, with ≤6 sites/year sampled within the HFA from 2011-2014.

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Chapter 6: Submerged Aquatic Vegetation

INTRODUCTION

Submerged aquatic vegetation (SAV) is an important component of many estuarine ecosystems, including the Choptank River. These underwater grasses grow in shallow waters and provide crucial protective habitat for juvenile blue crabs and finfish, as well as food for waterfowl. The presence of SAV helps improve water quality by improving bottom sediment stability, absorbing wave energy, uptake of nutrients, and producing dissolved oxygen (Virginia Institute of Marine Science, 2016b).

DATA SOURCES AND METHODS

SAV distribution in the Choptank River is currently measured on a yearly basis by the Virginia Institute of Marine Science (VIMS) SAV mapping program. This program uses a consistent aerial photography methodology to assess the extent of SAV growth throughout the Chesapeake Bay at a scale of 1:24,000. The imagery is scanned, analyzed, and processed to create vector digital data from which GIS programs can calculate areal extents of SAV beds (Orth et al., 2015). In addition to aerial cover, VIMS also estimates the density of each SAV bed. VIMS has also analyzed the available historic aerial imagery for the Chesapeake Bay. For the Choptank, the first year a complete aerial survey record was available is from 1978. After that, VIMS was able to produce yearly aerial survey data available starting from 1984 through 2014. Prior to 1978, all available data on SAV coverage is from ground sampling surveys conducted at varying intervals and sampling scales by various researchers as far back as the 1930s (Orth et al., 2015).

*Widgeon grass (*Ruppia maritima*) grows in many places, from the rivers of the upper and middle Chesapeake Bay to the saltier lower Bay. Photo credit: U.S. Fish and Wildlife Service*

RESULTS

Current Conditions

In 2014, there were 255 individual beds of SAV mapped, representing approximately 1,543 hectares of SAV coverage in the Choptank River (Figure 6.1). SAV currently grows mostly in the outer part of the Lower

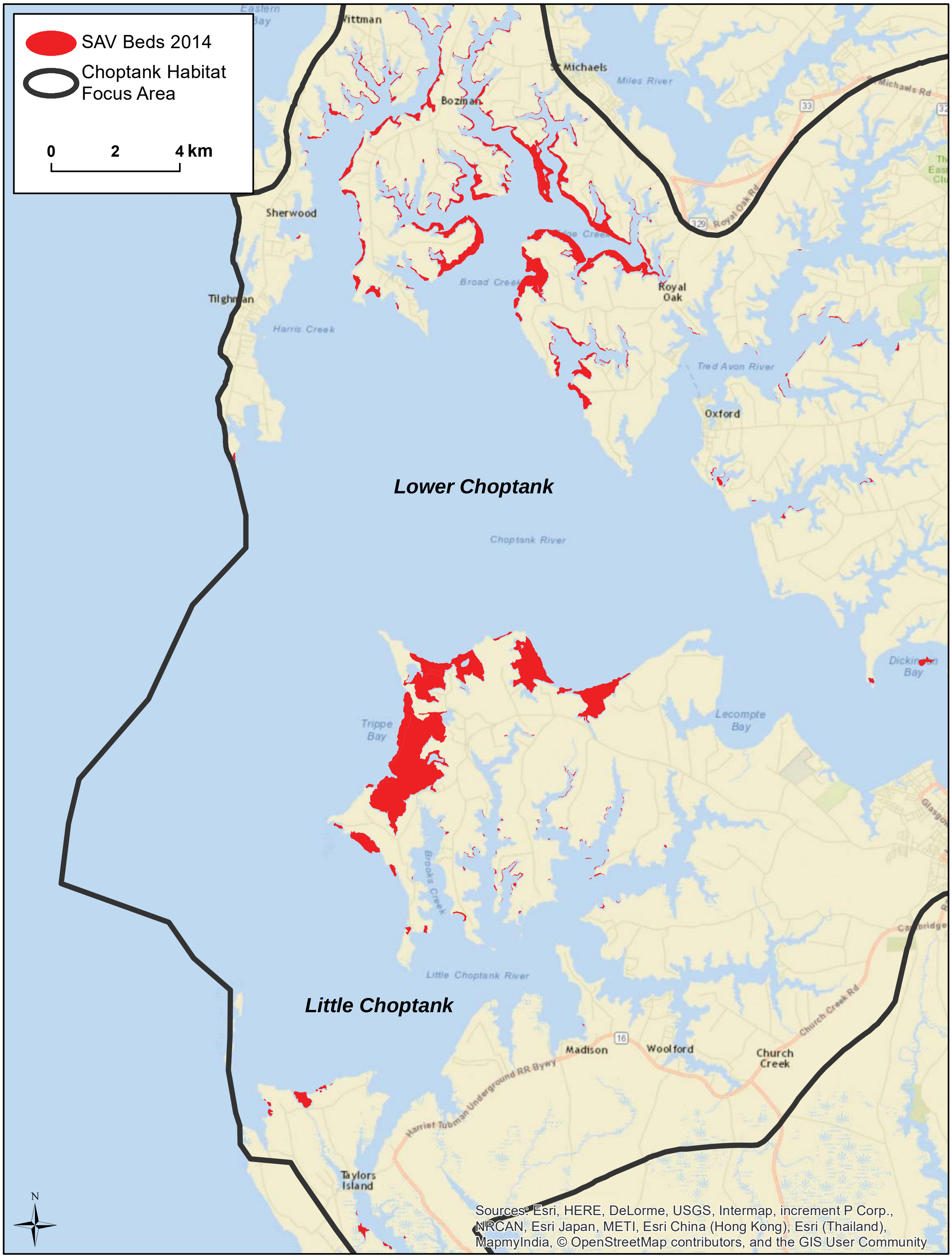

Figure 6.1. Locations of submerged aquatic vegetation (SAV) beds in 2014.

Choptank River in vicinity of Todds Bay, Armstrong Bay, Covey Creek and Brannock Bay, and also up in Harris Creek, Broad Creek, and Irish Creek. Smaller growth areas occur in the Tred Avon River, Boone Creek, Island Creek, and Dickinson Bay. In the Choptank, 71 percent of the individual SAV bed areas had a density rating of moderate to dense (greater than 40% coverage of the bed area). SAV beds do not appear to occur in appreciable amounts upstream of Dickinson Bay (Orth et al., 2015), although citizen groups have reported patches of horned pondweed growing in the vicinity of Bow Knee Point and Chancellors Point in the early season (Karrh, 2012). The dominant species of SAV found in the Choptank estuary is widgeon grass, but also sago pondweed in some locations. In very shallow areas, horned pondweed is an important species in the early growing season (Orth et al., 2015; Karrh, 2012; Kemp, 2015).

In the Little Choptank River there was close to 100 hectares of SAV coverage in 2014. The largest growth areas were near the mouth in the vicinity of Cators Cove and Hills Point Cove. There were also numerous smaller growth areas in the northern creeks and down in Slaughter Creek. About half of the individual SAV bed areas had a density rating of moderate to dense (greater than 40% coverage of the bed area) (Orth et al., 2015).

Recent Trends

The nature of SAV growth in the Choptank River and Little Choptank is sporadic, where large growth may occur one year and very little growth or precipitous declines the next (Figure 6.2). Since 2002, SAV has generally been in a state of decline in the Choptank River. In 2002, there were 2,727 hectares of SAV beds, compared to an average 727 hectares per year from 2003 to 2014. In the Little Choptank (Figure 6.3), there were 1,176 hectares of grass beds mapped in 2002 compared with an average 129 ha per year since then. However, in 2014, SAV coverage increased to 1,543 hectares in the Choptank River, its highest coverage since 2004 (Orth et al., 2015). Preliminary data released by VIMS indicates the positive trend continued in 2015, with an estimated increase of 893 additional hectares in the mouth of the Choptank River and an increase of 238 hectares in the Little Choptank River. Notably, the Middle Choptank River increased from no SAV to eight hectares (Virginia Institute of Marine Science, 2016a).

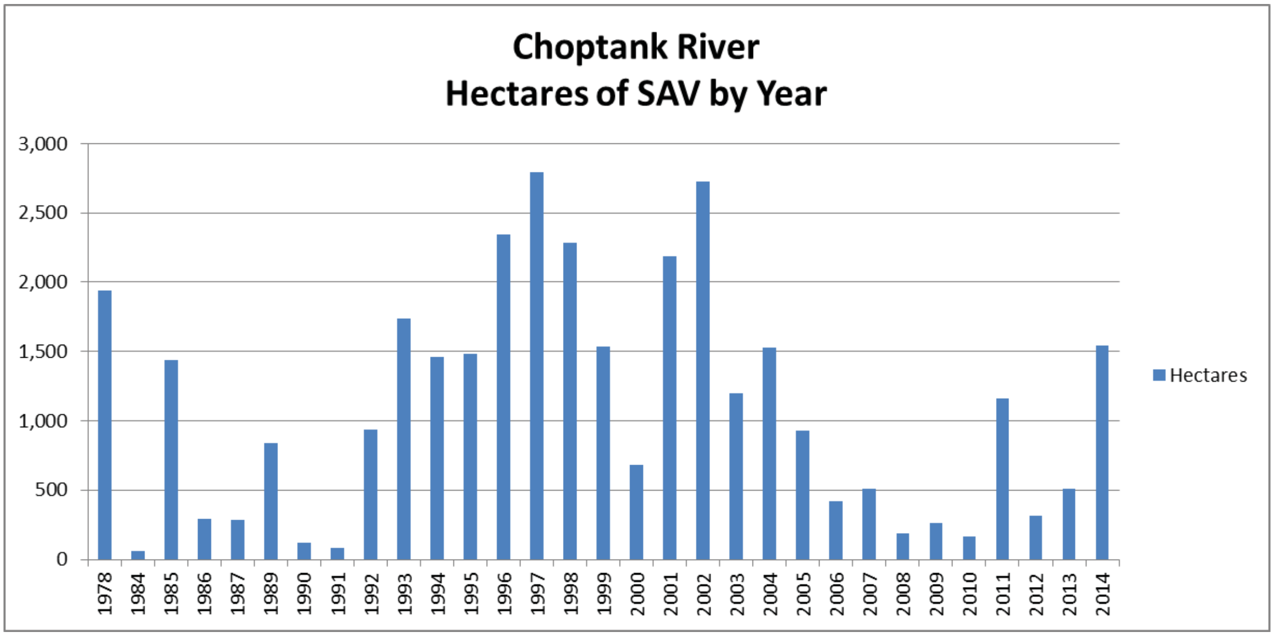

Figure 6.2. Submerged aquatic vegetation growth by year in the Lower Choptank River.

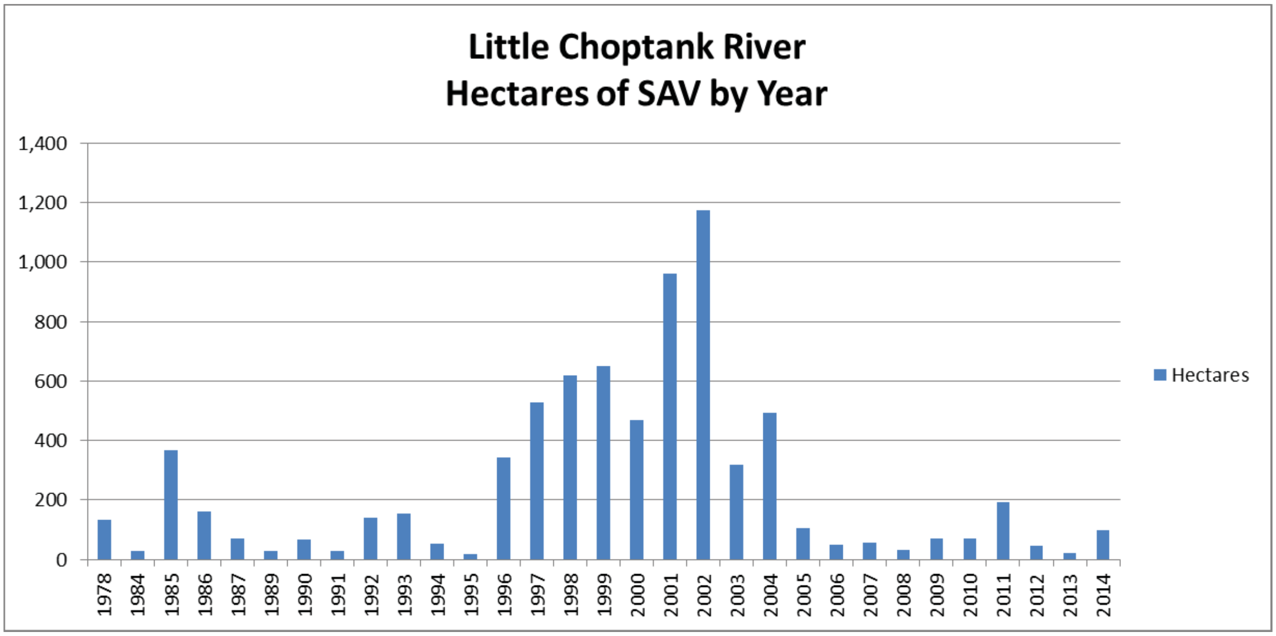

Figure 6.3. Submerged aquatic vegetation growth by year in the Little Choptank River.

Historic Distribution (early 1930s to mid-1970s)
Prior to the aerial photography surveys starting in the mid 1970s, there is only data from ground sampling surveys. Ground surveys of SAV beds have been conducted as far back as the early 1930s, however, these sampling programs occurred irregularly through the mid to late 1960s. Starting in the late 1960s, more thorough surveys were conducted on a regular basis lasting through the mid 1970s. Wild celery (*Valisneria americana*) was documented to occur in the Choptank in 1933. Wild celery is considered to be particularly valuable as a food source for waterfowl. It was noted to occur in the Choptank in only one other survey since, in 1968, and then only at one sampling station out of 146. Three other species were documented in 1939: redhead grass (*Potamogeton perfoliatus*), widgeongrass (*Ruppia maritima*), and eel grass (*Zostera marina*). Surveys conducted in the 1950s and in the 1960s also added Eurasian watermilfoil (*Myriophyllum spicatum*), sago pondweed (*Potamogeton pectinatus*), *Elodea Canadensis*, and horned pondweed (*Zannichellia palustris*) to the list of species documented as growing in the Choptank. In the Little Choptank four species have been documented since the 1960s: redhead grass (*Potamogeton perfoliatus*), widgeongrass (*Ruppia maritima*), eel grass (*Zostera marina*), and sago pondweed (*Potamogeton pectinatus*).

Sampling programs starting in 1968 and continuing through the mid 1970s noted redhead grass (*Potamogeton perfoliatus*) as a dominant species in the Choptank River estuary, with some beds recorded at stations almost as far upstream as the Warwick River mouth. After 1972 all occurrences were recorded at stations in the lower estuary near Dickinson Bay, Todds Bay, and Broad Creek. This species was not found to occur at any stations in the Little Choptank during this time period. Widgeongrass (*Ruppia maritima*) was commonly found during this time period at stations in the Lower Choptank and Little Choptank rivers. It was also found in 1972 up near the Warwick River, but never since. Eel grass (*Zostera marina*) was noted at a few stations in the Choptank and Little Choptank until 1972, but not thereafter. Sago pondweed (*Potamogeton pectinatus*) was recorded at a small number of stations prior to 1973, mostly around Armstrong Bay and Trippe Bay, but also near Broad Creek. Horned pondweed (*Zannichellia palustris*) was noted to be in high abundance in 1972 and in 1976 in the Lower Choptank River. No occurrences of horned pondweed were recorded for the Little Choptank. *Elodea Canadensis* was found to occur in the Choptank River at stations in the vicinity between Dickinson Bay and Goose Creek through 1972. Then, from 1972 to 1976 *Elodea* was only recorded in Dickinson Bay (Stevenson and Confer, 1978).

Tred Avon River
In 2014 there were 22 hectares of SAV in the Tred Avon River (Figure 6.4). About 70 percent of the individual beds had moderate to dense ratings for density (greater than 40% coverage of the bed area) (Orth et al., 2015).

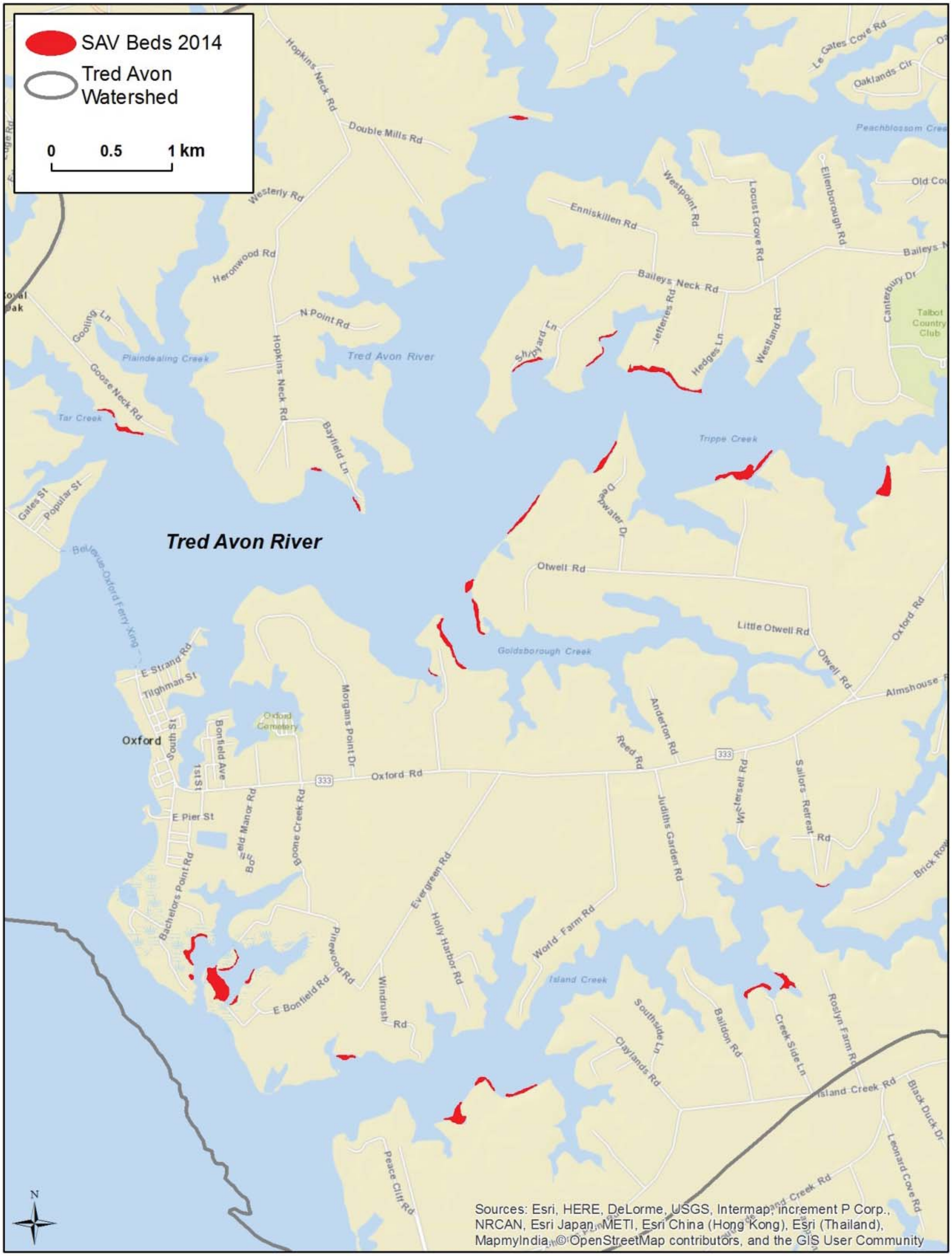

Figure 6.4. Tred Avon submerged aquatic vegetation beds in 2014.

Harris Creek

In 2014 there were 124 hectares of SAV in Harris Creek (Figure 6.5). About 66 percent of the individual beds had moderate to dense ratings for density (greater than 40% coverage of the bed area) (Orth et al., 2015).

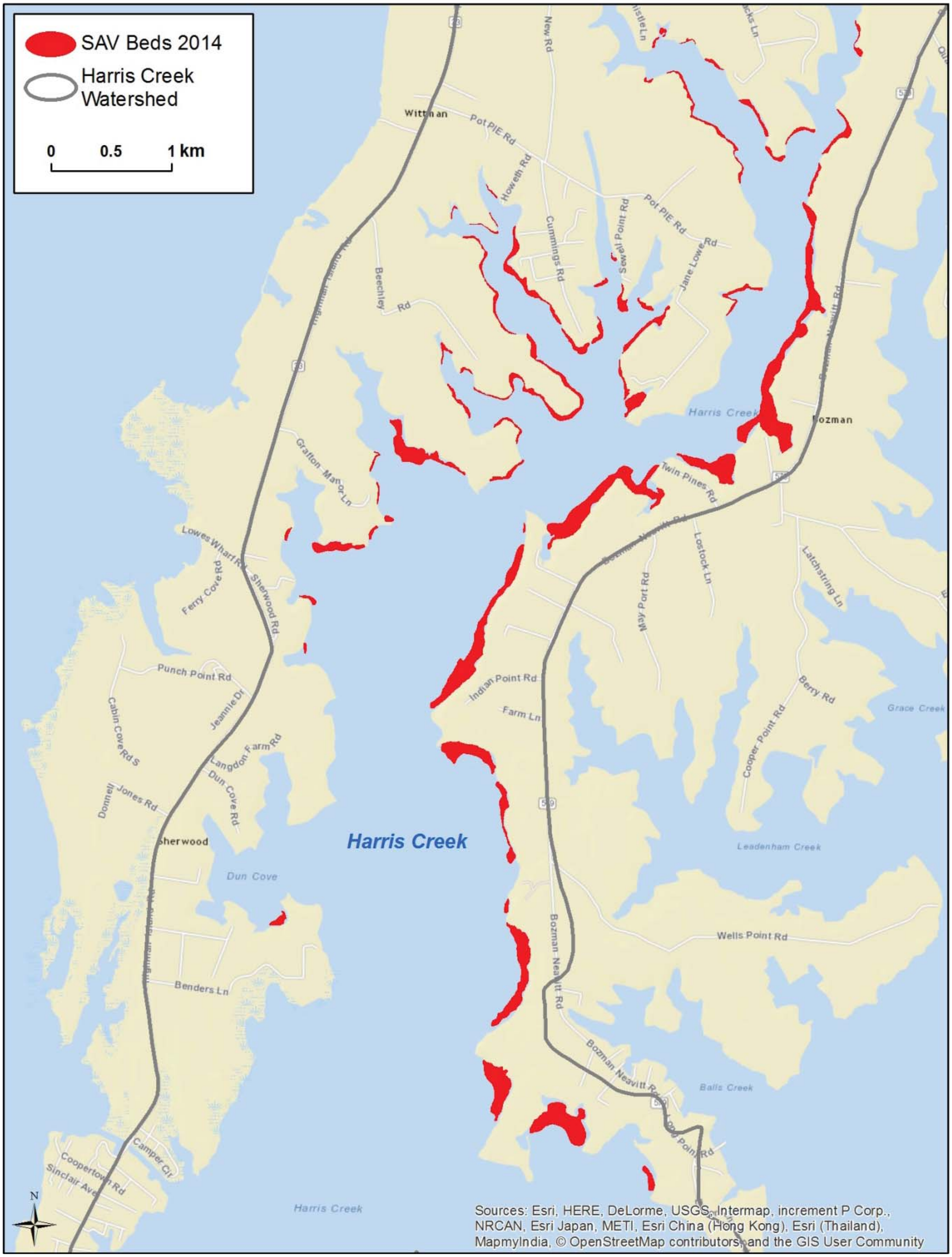

Figure 6.5. Harris Creek submerged aquatic vegetation beds in 2014.

CURRENT ACTIVITIES AND DATA GAPS

The VIMS aerial survey program is the only active program conducting comprehensive assessment of SAV status in the Choptank River. There currently are not any programs or efforts to examine species composition of SAV beds in the Choptank. VIMS does have a program to coordinate the voluntary collection of field observations of species, however, it is not a comprehensive database (Orth et al., 2015).

Sago pondweed (Potamogeton pectinatus) *has bead-like flowers that grow along a slender spike. It grows in fresh to moderately brackish waters throughout the Chesapeake Bay watershed. Photo credit: Maryland Department of Natural Resources (MD DNR)*

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Chapter 7: Fish

INTRODUCTION

The Choptank River complex includes important spawning and juvenile habitat for numerous anadromous fish species, including striped bass (*Morone saxatilis*), river herring (alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*), American shad (*Alosa sapidissima*), and hickory shad (*Alosa mediocris*), as well as resident fish such as white perch (*Morone Americana*) and forage fish such as bay anchovy (*Anchoa mitchilli*) and Atlantic menhaden (*Brevoortia tyrannus*). In turn, these fish support ecological and economic services to the community. One of the goals of the Habitat Focus Area (HFA) designation is to achieve “sustainable and abundant fish populations” (NOAA, 2015). Knowledge of the current status of habitat distribution, monitoring programs, and fish population levels is crucial to inform management decisions and prioritize future research efforts. The objective of this chapter is to describe the available datasets and spatial layers related to fish in the Choptank River complex, spatial patterns, and temporal trends.

*Striped bass (*Morone saxatilis*). Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory*

DATA SOURCES AND METHODS

Fish Spawning Habitat

Spawning habitat distribution information was obtained for multiple species. Geographic Information System (GIS) files showing spawning habitat for striped bass, white perch and yellow perch (*Perca flavescens*) were obtained from the State of Maryland iMap program. These GIS files were created using Lippson et al. (1973) and field survey data from the Maryland Department of Natural Resources (MD DNR) Fisheries Service (O’dell et al., 1970, 1975, 1980; Mowrer and McGinty, 2002), using the presence of anadromous fish eggs and larvae as an indicator of spawning activity. The spawning habitat layers were clipped to the Choptank HFA and merged to create a generalized fish spawning habitat layer, which was then plotted in ArcGIS.

Information on river herring (alewife, *Alosa pseudoharengus* and blueback herring, *Alosa aestivalis*) spawning habitat was obtained from the Smithsonian Environmental Research Center (SERC), which is working to characterize spawning habitat use of river herring in the Chesapeake Bay (M. Ogburn, SERC, unpublished data). Surveys were conducted at 27 sites in the Choptank River and its tributaries from March-May 2016; each site was visited 1-3 times. The presence of river herring adults and/or icthyoplankton, which is an indication of spawning activity, was determined in three ways: 1) visual observation of adult river herring, 2) capture of adult river herring by cast net, or 3) presence of likely river herring eggs or larvae in ichthyoplankton samples (which could also include hickory shad eggs). Ichthyoplankton samples were taken for five minutes following the standard methods used by MD DNR. Data were converted into a shapefile and plotted to show where adult and/or icthyoplankton river herring were observed in the Choptank.

Fish survey data

Several sources of survey data were obtained for the Choptank HFA, including the MD DNR Juvenile Striped Bass Seine Survey, University of Maryland (UMD) menhaden gear comparison seine and trawl surveys, MD DNR Fisheries Habitat and Ecosystem Program's (FHEP) estuarine fish community sampling in select Choptank tributaries, and the Maryland Biological Stream Survey (MBSS) non-tidal freshwater stream fish community monitoring.

The Juvenile Striped Bass Seine Survey has been conducted in the Maryland portion of the Chesapeake Bay since 1954 (http://dnr2.maryland.gov/fisheries/Pages/striped-bass/juvenile-index.aspx). The annual survey documents year-class success for young-of-the-year striped bass and relative abundance of other fish species. Sampling is conducted monthly from July-September at 22 fixed stations per year, although the frequency of sampling and locations of some stations has changed over time. The stations are allocated among four major spawning and nursery areas in the Bay: Potomac River, Head of the Bay area, Nanticoke River, and Choptank River, with four stations currently sampled in the Choptank. During each round of sampling, replicate seine hauls are taken at each site. In addition, auxiliary stations are occasionally sampled to enhance spatial coverage, although these are not included in survey indices. A 30.5 x1.24 m bagless beach seine with 6.4 mm bar mesh is laid out perpendicular to the beach and swept with the current for a target sample area of 729 m^2. All finfish are identified to species and counted, with striped bass and other select species measured and identified as age 0 or age +1. Select community metrics (total abundance, species richness) and abundance of key species (striped bass, white perch, yellow perch, Atlantic menhaden) were plotted over time to show general temporal and spatial patterns. Key species were selected with input from project partners due to their ecological and economic importance.

The University of Maryland conducted seine and trawl surveys in the Upper Bay, Choptank, and Patuxent Rivers from 2010-2013 (MD DNR, 2014), with the majority of the sampling effort occurring in 2012 and 2013. The primary purpose of this study was to compare the catch efficiency of Atlantic menhaden using beach seine and midwater trawl methods. Six sites were designated in the Choptank River along a salinity gradient. Seine hauls were conducted using the same protocol as MD DNR. Simultaneous mid-water trawls were conducted <0.5 km offshore of the beach seine locations. The duration of the trawl was 20 minutes, with the net fished from surface to bottom in 2 minute step increments. All fish caught in the gear were identified to species and counted. In addition, lengths and aggregate weights were measured for Atlantic menhaden, Bay anchovy, and alosines. Fish counts from the UMD survey were mapped by year and gear for striped bass, white perch, yellow perch, and Atlantic menhaden. Sites that fell outside the study area or appeared to have erroneous coordinates were removed from display. When stations were sampled multiple times over the course of a season, a yearly mean was calculated for map display.

The FHEP of MD DNR conducted estuarine fish community surveys in three tributaries of the Choptank River: Broad Creek (2012-2015), Harris Creek (2012-2015), and the Tred Avon River (2006-2015) (MD DNR, 2014). The objective of the study was to evaluate summer nursery and adult habitat for recreationally important finfish and evaluate the influence of watershed development on total finfish abundance, species richness, presence-absence, and abundance of target species. Sites were sampled every two weeks from July-September. Typically, four evenly spaced haul seine and bottom trawl sample sites were located in the upper two-thirds of each sub-estuary (to reduce influence of mainstem waters), with trawls conducted offshore but adjacent to seine sites (MD DNR, 2014). All fish were identified to species and counted. In addition, striped bass and yellow perch were separated into juveniles and adults, while white perch were separated into three size/life stage categories (juveniles, small adults, and harvestable size, i.e., >200 mm). Annual means (±SE) of striped bass, white perch, and Atlantic menhaden were calculated for each site and plotted to show trends over time (Note: yellow perch were excluded due to low frequency of occurrence). In addition, means over the 2012-2015 period were computed and plotted in ArcGIS to show general spatial patterns.

Non-tidal fish community monitoring has been conducted by MD DNR as part of the Maryland Biological Stream Survey (MBSS). The goals of the MBSS are to assess current condition and changes in ecological resources of Maryland's 1st through 4th order non-tidal streams, as well as provide an inventory of biodiversity and identify effects of stressors on the natural resources (Stranko et al., 2014). An electrofishing component has been utilized to survey fish communities. The MBSS was started in 1995 and fish abundance and a fish index of biological integrity (F-IBI) is available since 1996. The MBSS is a stratified random survey with a lattice design. Year and basin are included as strata and sampling has been restricted to approximately one-third of the major drainage basins each year (Mercurio et al., 1999). In addition, a subset of sites were selected for repeat sampling in subsequent years; these include sites in the Sentinel Site Network, which were chosen in areas with minimal human impacts, and have been sampled annually since 2000 (Becker et al., 2010). In addition, a random selection of previously sampled sites have been targeted for repeat visits (Stranko et al., 2014). Fish abundance, richness, and F-IBI were plotted over time for the Sentinel Site at Skeleton Creek, and linear regression was used to determine if there was a temporal trend in the time series. In addition, F-IBI scores of the randomly selected sites were plotted in ArcGIS to show spatial variability.

Commercial Fisheries Data

Commercial landings of striped bass and white perch in the Choptank (NOAA code 037) and Little Choptank Rivers (NOAA code 053) were obtained from MD DNR for years 1929-2014 and 1972-2014, respectively. Data were plotted to show patterns in commercial catch, and a linear regression was conducted to check for a significant trend over time.

Fish Blockage Locations and The Nature Conservancy (TNC) Fish Passage Prioritization

A layer showing the locations of fish blockage due to features such as dams, pipelines, and other features was obtained from the State of Maryland iMap program. Locations within the Choptank HFA were extracted and plotted.

A fish passage prioritization tool was created by TNC for the entire Chesapeake Bay watershed to help managers evaluate fish passage priorities (Martin and Apse, 2013). In summary, metrics encompassing five categories (connectivity status, connectivity improvement, watershed/local condition, ecological, and site/system type) were calculated for each dam, weighted, and combined to provide a ranking for each dam

Researchers sorting through a seine haul. Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory for three scenarios (diadromous fish, resident fish, and brook trout). Dams were tiered into twenty 5% bins based on their potential to benefit each scenario if removed or passage is provided. For example, dams in Tier 1 would provide the greatest ecological benefit, while those in Tier 20 would provide the least. These results are intended to be a screening level tool to help managers determine fish passage priorities. Dams and their tiered ranks were obtained for diadromous fish scenario and were extracted for the Choptank HFA.

RESULTS

Fish Spawning Habitat

Fish spawning habitat in the Choptank, has been identified by combining the MD iMap spawning habitat delineations of individual species, and includes areas in the Middle and Upper Choptank (Figure 7.1). Habitat extends from the confluence of Hunting Creek and the Choptank River north to Greensboro, and also includes Tuckahoe Creek.

The 2016 SERC river herring spawning habitat surveys were conducted in the upper reaches of the Choptank mainstem, as well as, several tributaries north of the Route 50 bridge, including Tuckahoe Creek, Hunting Creek, Gravelly Branch, and Watts Creek (Figure 7.2). River herring adults and/or icthyplankton were observed at 19 out of 27 sites. Currently, species specific information is unavailable as alewife and blueback herring eggs are visually indistinguishable. However, additional research is being conducted to quantify species specific presence and relative abundance of river herring DNA using Environmental DNA (eDNA) methods (M. Ogburn, SERC, pers. comm.).

Fish Survey Data

Locations of fish surveys conducted in the Choptank HFA are displayed in Figure 7.3.

Figure 7.1. Generalized anadromous fish spawning habitat in the Choptank HFA. Data source: compliation of layers from Maryland iMap

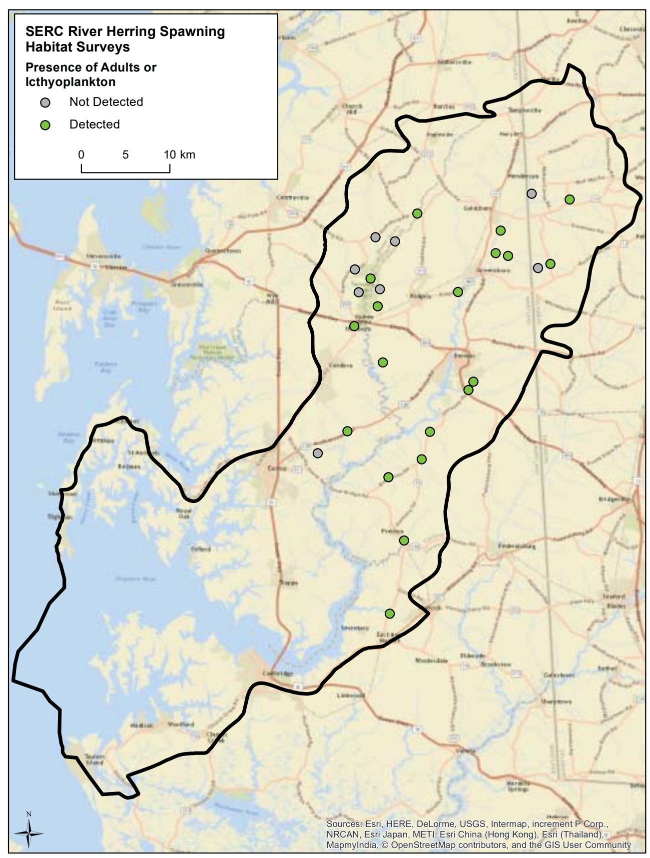

Figure 7.2. Locations of 2016 river herring spawning habitat surveys conducted by the Smithsonian Environmental Research Center. Sites are color-coded based on detection of adult river herring and/or icthyoplankton.

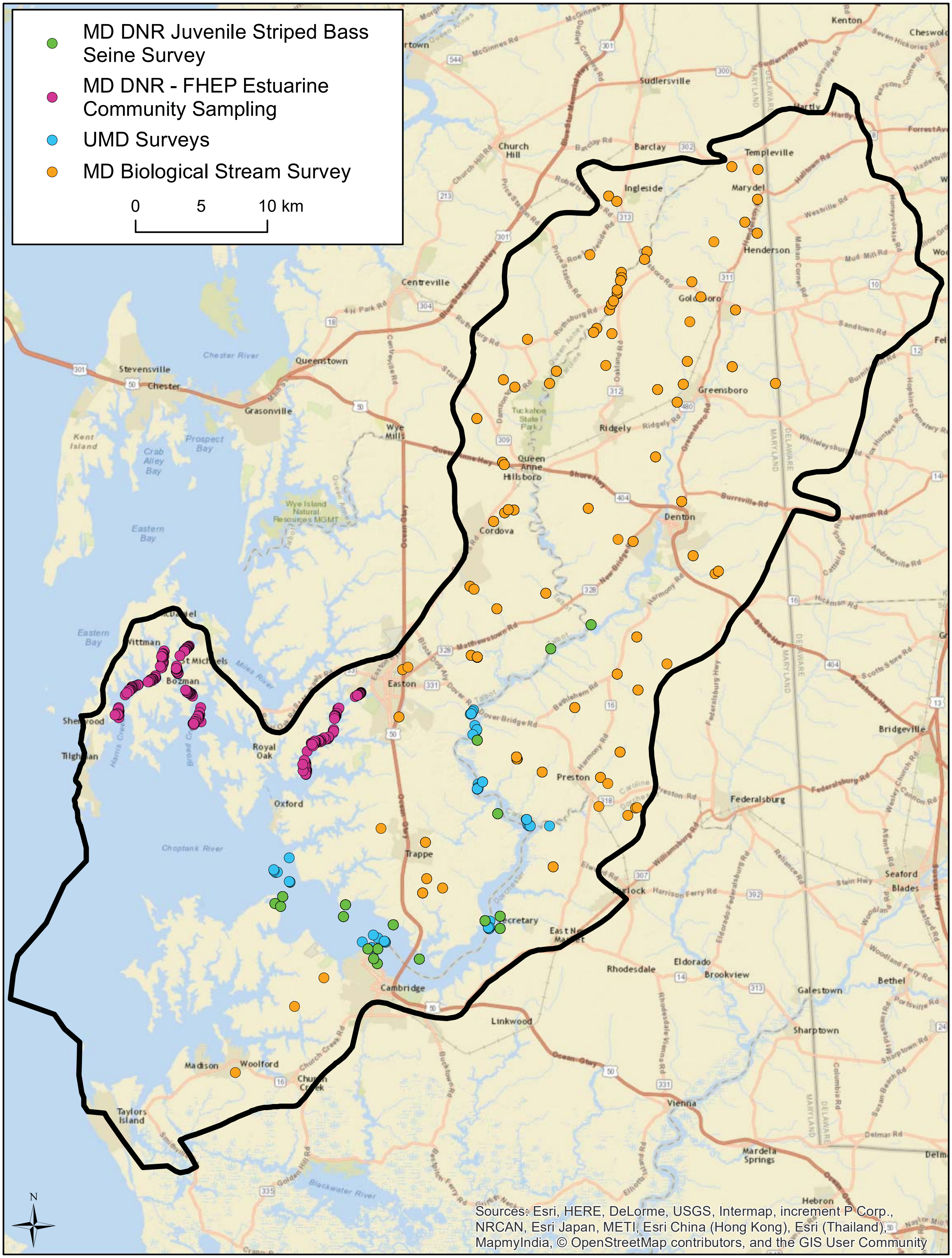

Figure 7.3. Fish sampling locations in the Choptank HFA.

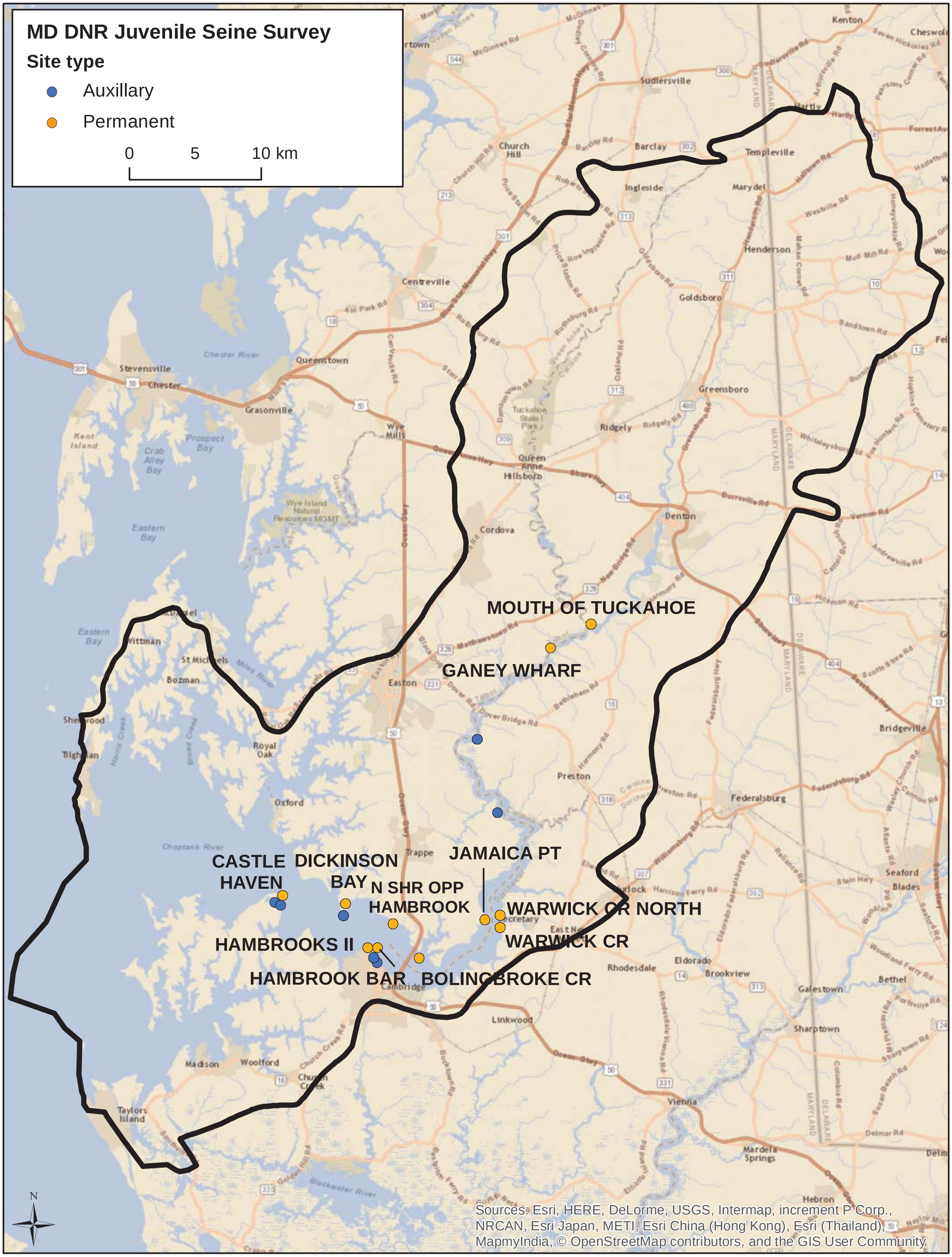

Figure 7.4. Locations of Juvenile Striped Bass Seine Survey in the Choptank HFA by site type. Permanent sampling sites are labeled by station name. The years of data collected at the permanent sites are listed in Table 7.1.

MD DNR Juvenile Striped Bass Seine Survey

Over the sampling period of the Juvenile Striped Bass Seine Survey, there have been 11 permanent sampling sites within the Choptank HFA, but the locations have changed over the years (Figure 7.4, Table 7.1). The majority have been located in the Middle and Lower Choptank sections, with fewer in the Upper Choptank. Only the Castle Haven site, located closest to the mouth of the Chesapeake Bay, has been sampled over the entire time period. In addition, a number of auxiliary stations have been sampled (Figure 7.7).

Sites located in close proximity to one another were grouped to examine general temporal patterns. There was a considerable amount of variability over time (Figures 7.5-7.10). In particular, years of zero menhaden catch were interspersed by periods of higher abundance in the 1970s and 80s (Figure 7.9). A recent retrospective analysis of

Table 7.1. Site names and years of data collection for MD DNR Juvenile Striped Bass Seine Survey permanent sites.

Site name	Years
Mouth of Tuckahoe	1984-2014
Ganey Wharf	1959-1983
Warwick Center North	1959-1980
Warwick Center	1981-1997
Jamaica Point	1998-2014
Boilingbroke Center	1960
N. Shore Opp. Hambrook	1994-2008
Hambrook Bar	1959-1990
Hambrooks II	1991-1993
Dickinson Bay	2009-2014
Castle Haven	1959-2014

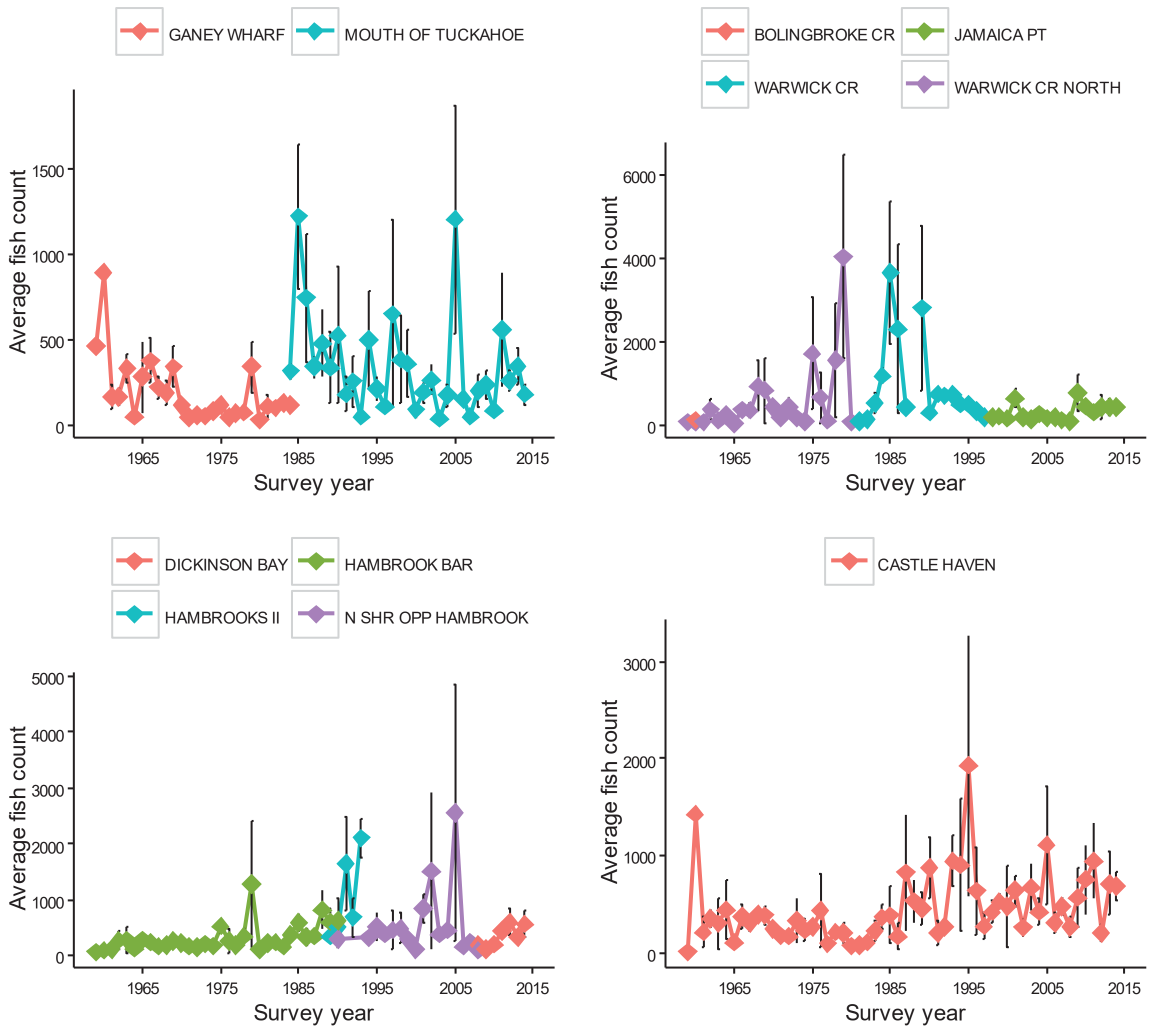

Figure 7.5. Mean (±SE) total fish abundance at permanent Juvenile Striped Bass Seine Survey sites in the Choptank HFA over time.

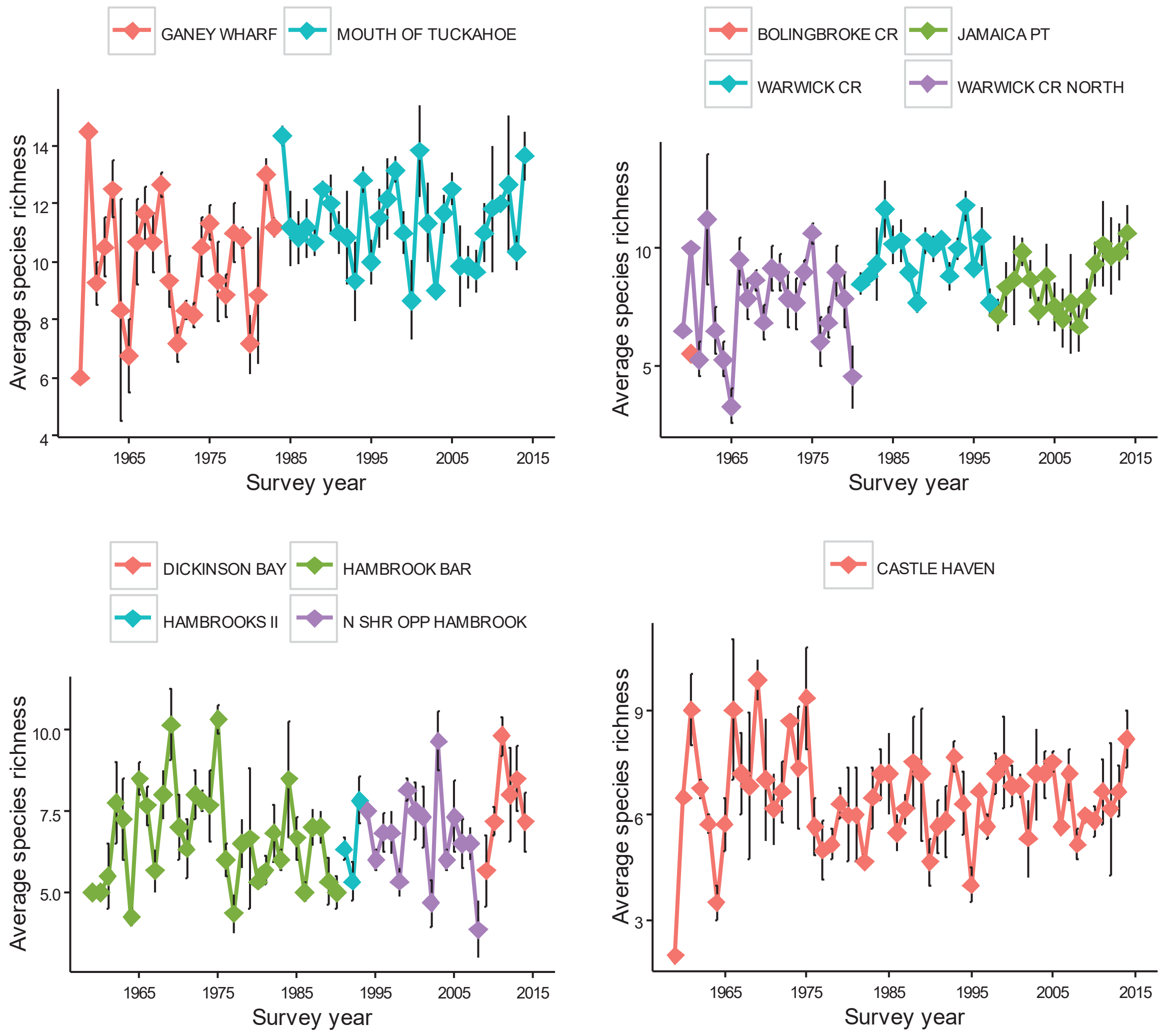

Figure 7.6. Mean (±SE) fish species richness at permanent Juvenile Striped Bass Seine Survey sites in the Choptank HFA over time.

the MD DNR seine survey data (Houde et al., 2014) indicates that young-of-the-year (YOY) menhaden abundance peaked in the Choptank in the late 1980s, and that overall bay-wide juvenile abundance of menhaden is largely driven by YOY populations in the Choptank and Nanticoke Rivers. White perch and striped bass abundance was relatively lower in the early portion of the time series, particularly at stations in the Middle and Lower Choptank (Figures 7.7 and 7.8). Overall, abundance of striped bass and white perch combined has increased since the inception of the juvenile seine survey in the Choptank (Houde et al., 2014). Yellow perch is primarily observed at the Upper Choptank stations with lower salinity (Figure 7.10). Although it previously occurred with frequency at the Warwick Center Stations, the species has not occurred in seine surveys at Jamaica Point since it began to be sampled in the late 1990s.

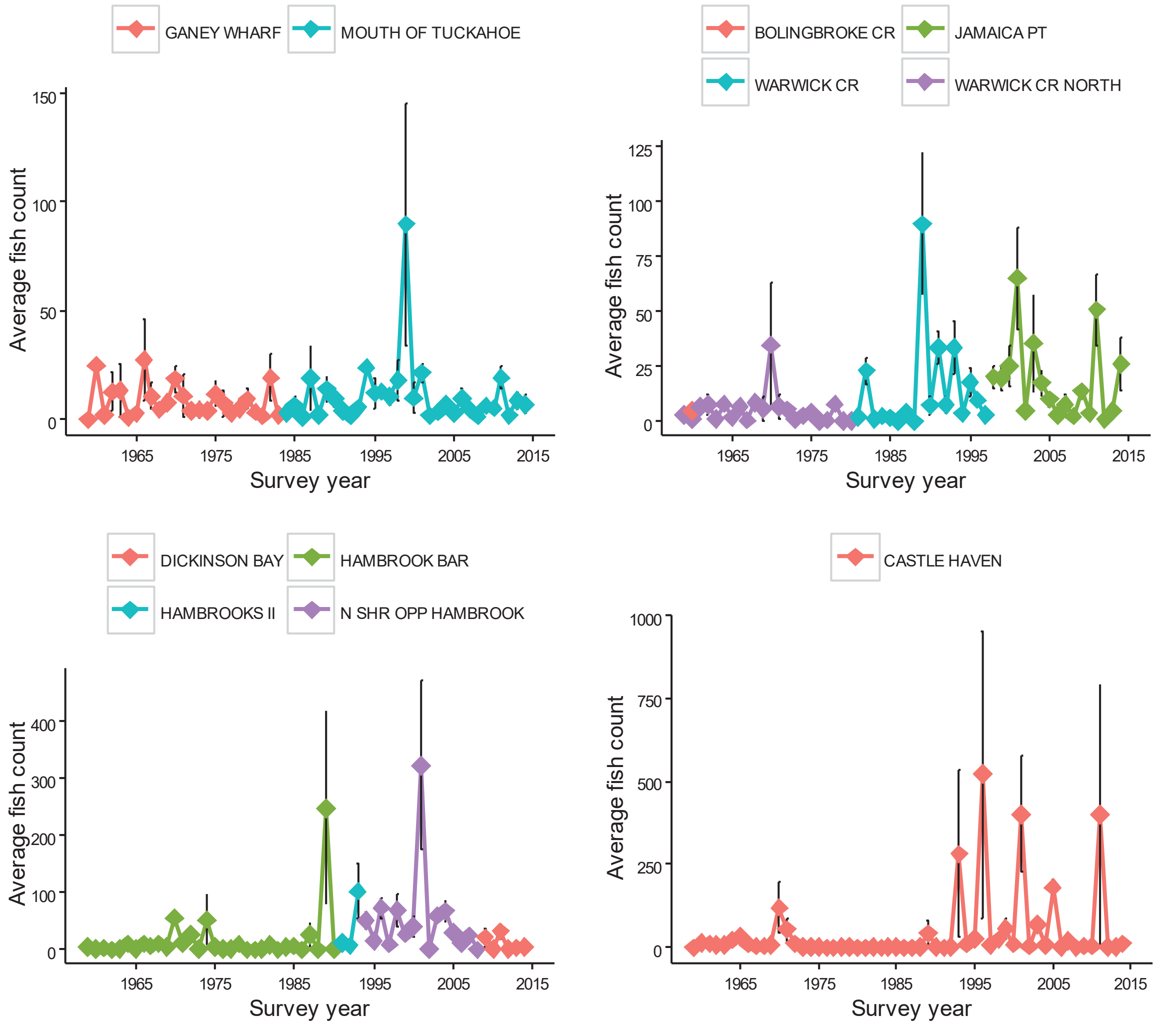

Figure 7.7. Mean (±SE) striped bass abundance at permanent Juvenile Striped Bass Seine Survey sites in the Choptank HFA over time.

*White perch (*Morone americana*). Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory*

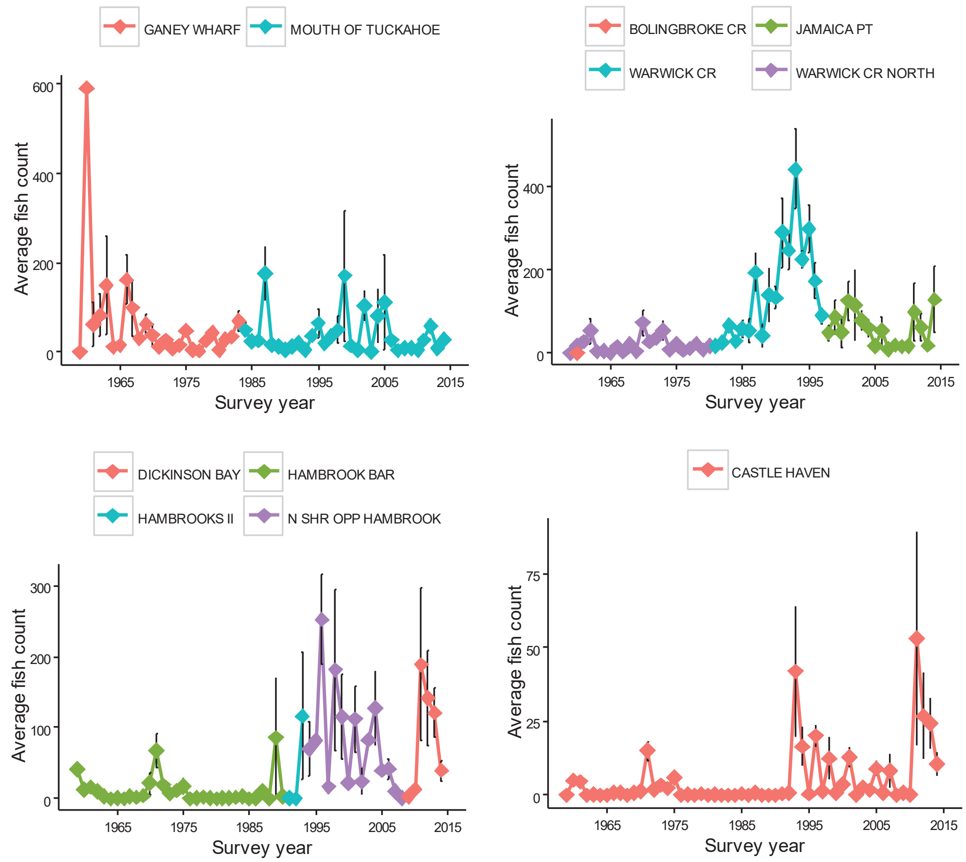

Figure 7.8. Mean (±SE) white perch abundance at permanent Juvenile Striped Bass Seine Survey sites in the Choptank HFA over time.

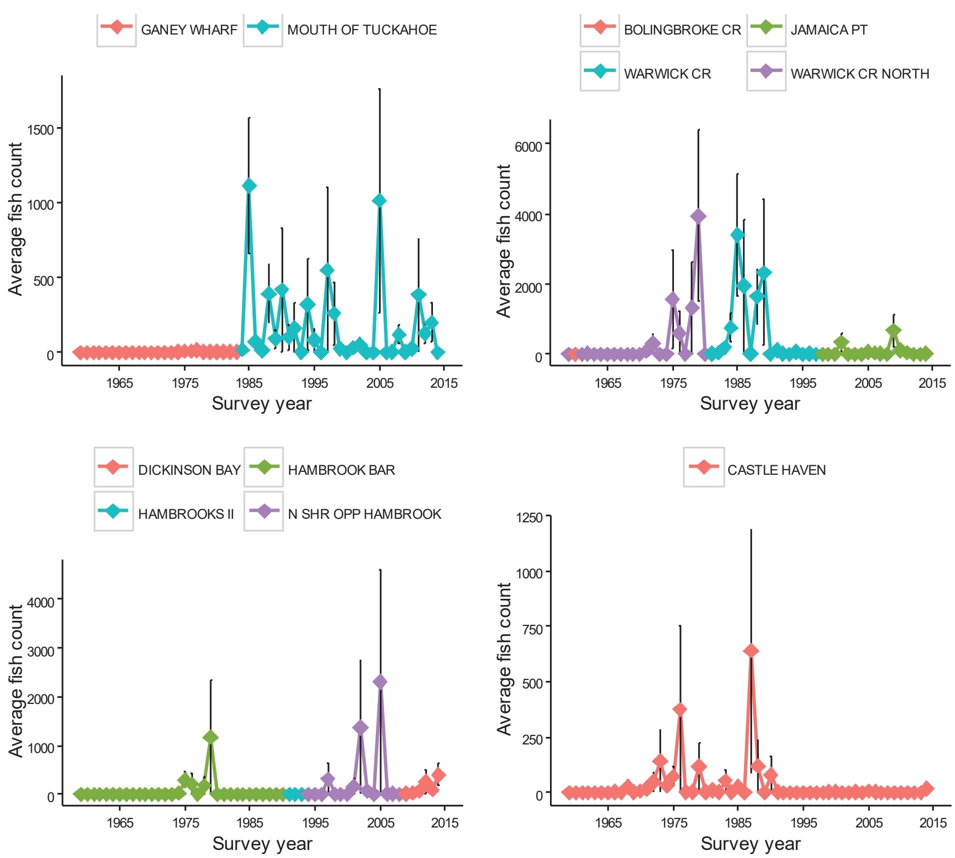

Figure 7.9. Mean (±SE) Atlantic menhaden abundance at permanent Juvenile Striped Bass Seine Survey sites in the Choptank HFA over time.

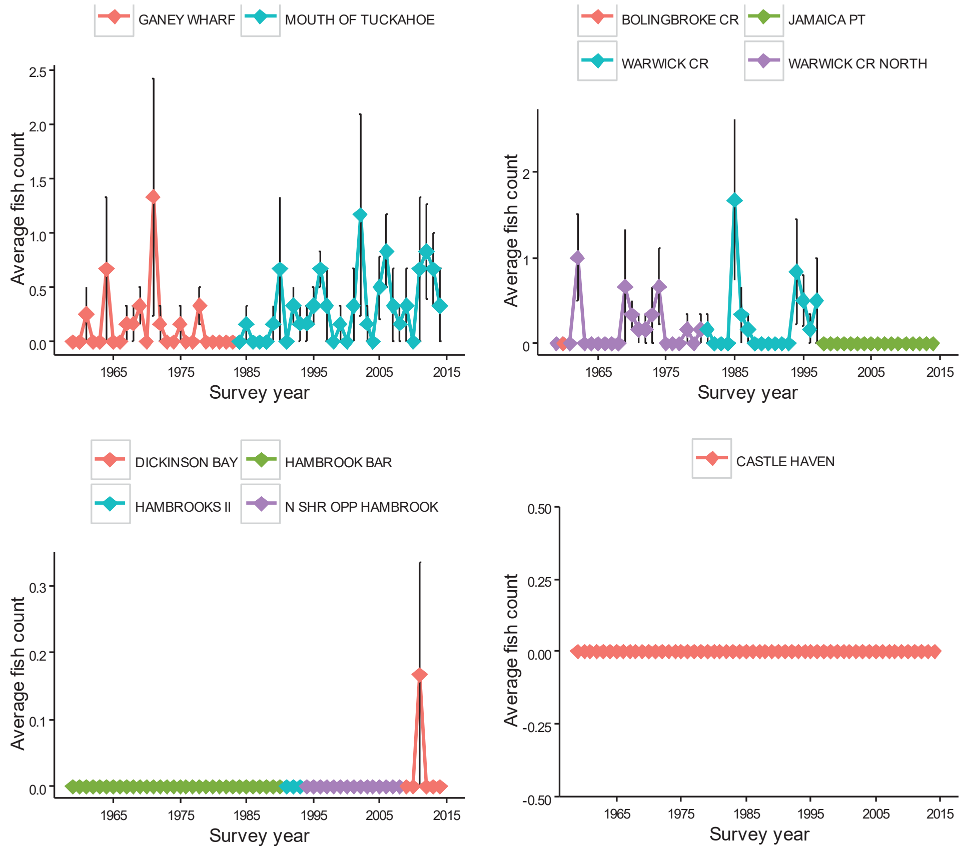

Figure 7.10. Mean (±SE) yellow perch abundance at permanent Juvenile Striped Bass Seine Survey sites in the Choptank HFA over time.

*Striped bass (*Morone saxatilis*). Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory*

UMD surveys

From 2010-2013, the University of Maryland conducted a total of 87 fish surveys within the Choptank HFA, including 44 midwater trawl and 43 seine surveys, with a higher proportion of samples in 2012 and 2013. Surveys were conducted between the MD-331 bridge and Castle Haven Point/ Oxford in the Lower Choptank. Mean catch per haul of striped bass was relatively higher in both seine and trawl gear in 2013 compared to 2012 (Figure 7.11), whereas white perch catches tended to be relatively higher in 2012 (Figure 7.12). Both species were observed at sites across the HFA. Yellow perch were infrequently observed in the surveys (Figure 7.13). Menhaden catches exhibited large variability (Figure 7.14), but generally were relatively higher in both gears in 2010 and 2013.

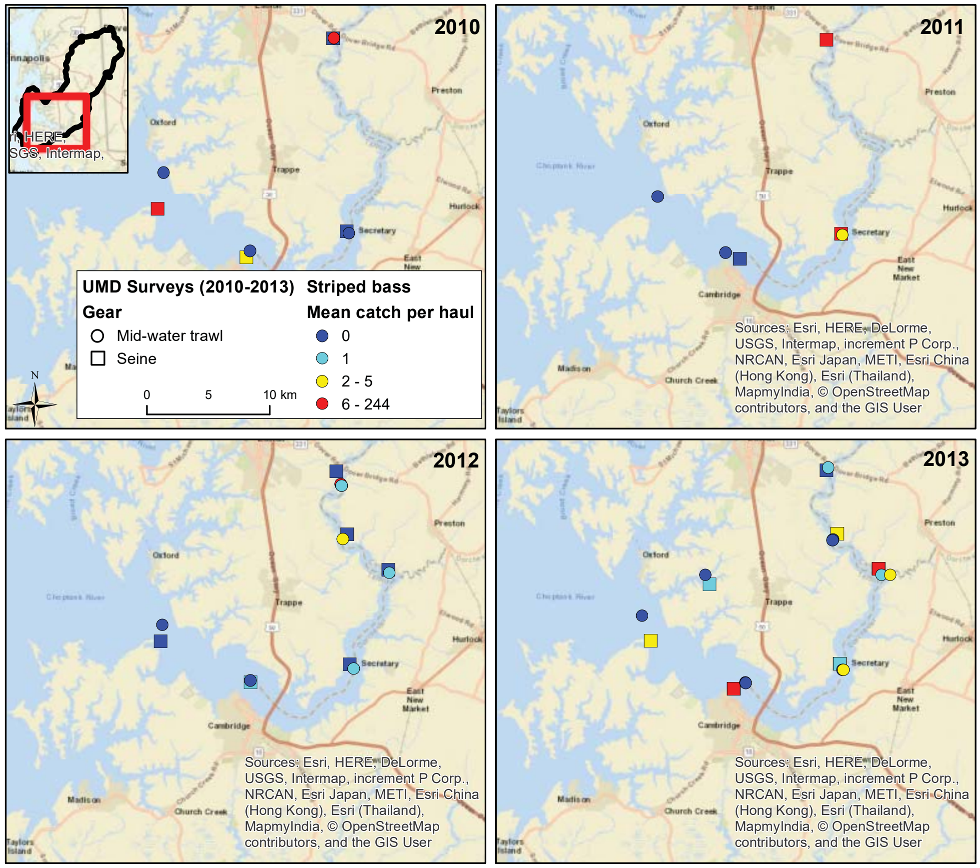

Figure 7.11. Mean striped bass catch per haul by gear type at University of Maryland gear comparison survey sites from 2010-2013. Quantiles were used to symbolize the data.

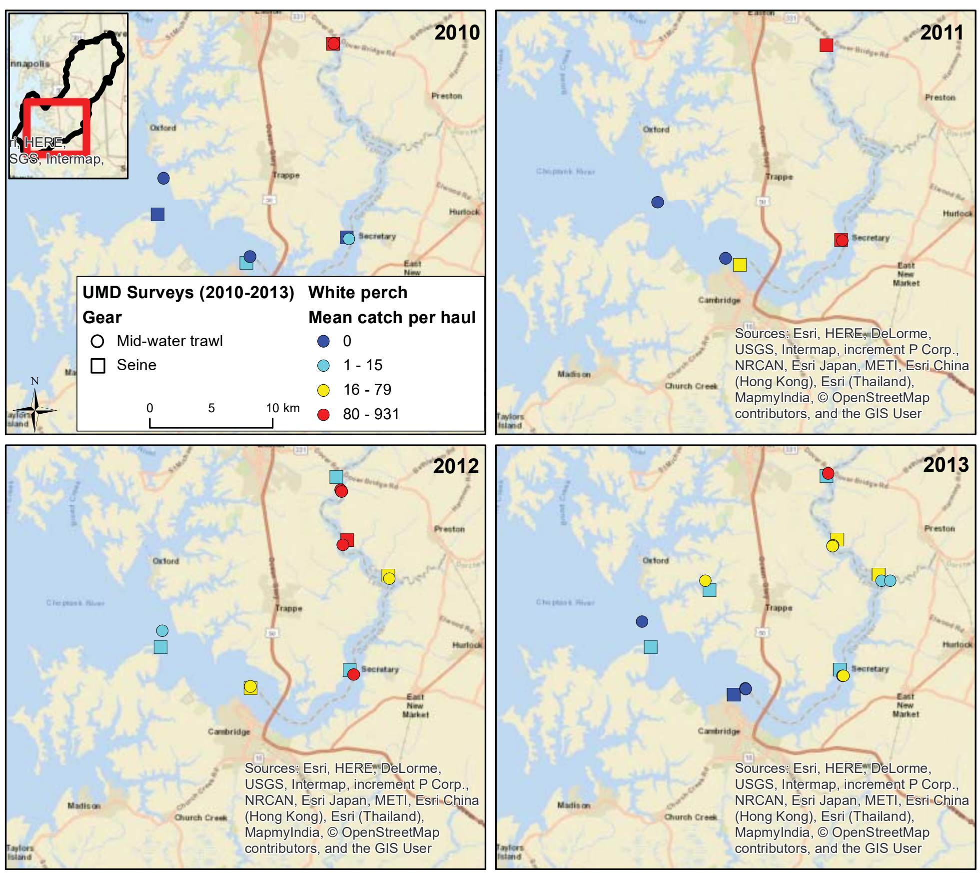

Figure 7.12. Mean white perch catch per haul by gear type at University of Maryland gear comparison survey sites from 2010-2013. Quantiles were used to symbolize the data.

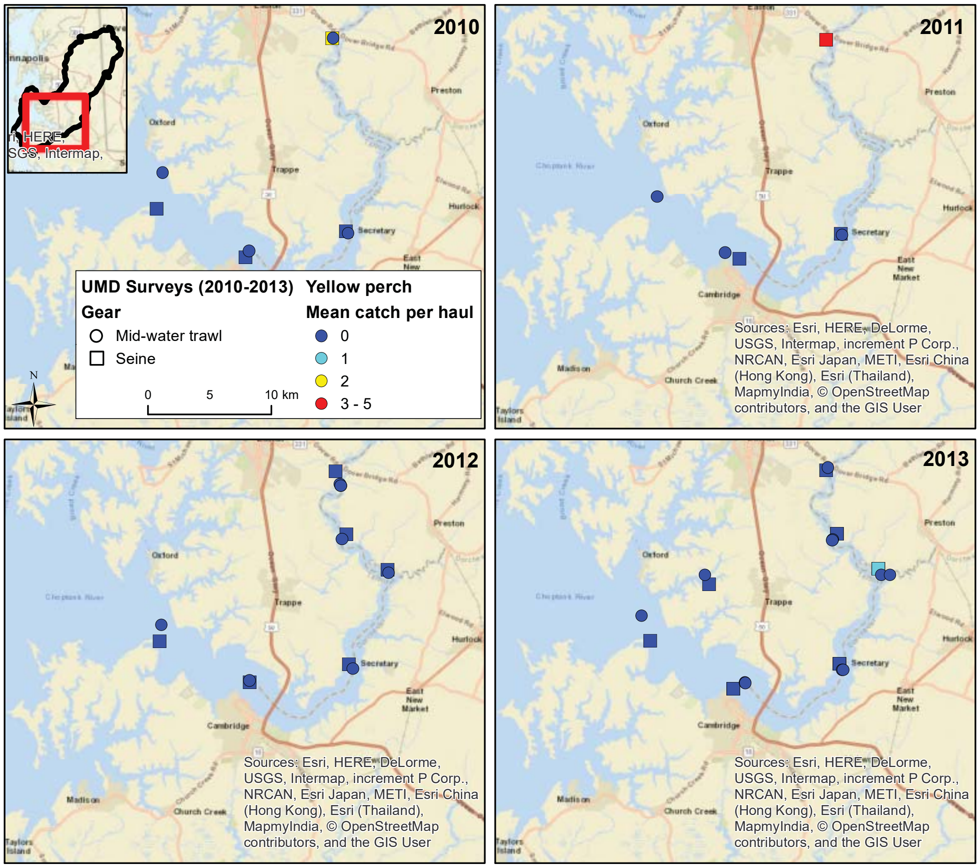

Figure 7.13. Mean yellow perch catch per haul by gear type at University of Maryland gear comparison survey sites from 2010-2013. Quantiles were used to symbolize the data.

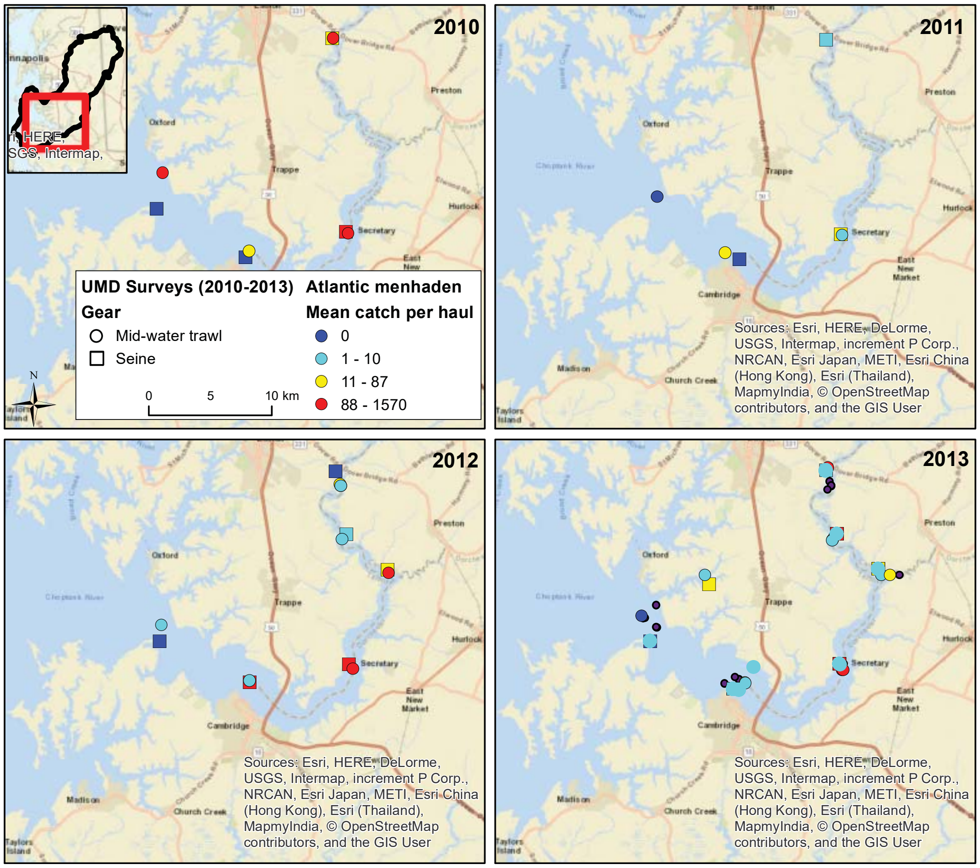

Figure 7.14. Mean Atlantic menhaden catch per haul by gear type at University of Maryland gear comparison survey sites from 2010-2013. Quantiles were used to symbolize the data.

MD DNR - FHEP Estuarine Community Sampling

A total of 242 seine and 243 trawl surveys have been conducted by the FHEP in the Tred Avon River from 2006-2015. In Broad Creek, 67 seine and 96 trawl surveys were conducted, respectively, from 2012-2015. A similar number of surveys have been conducted in Harris Creek over the same time period (70 seine and 92 trawl surveys). Although there is considerable variability in the data, cyclic patterns are apparent in the longer Tred Avon time series, with higher mean counts of white perch in 2006, 2011, and 2012 (Figure 7.15).

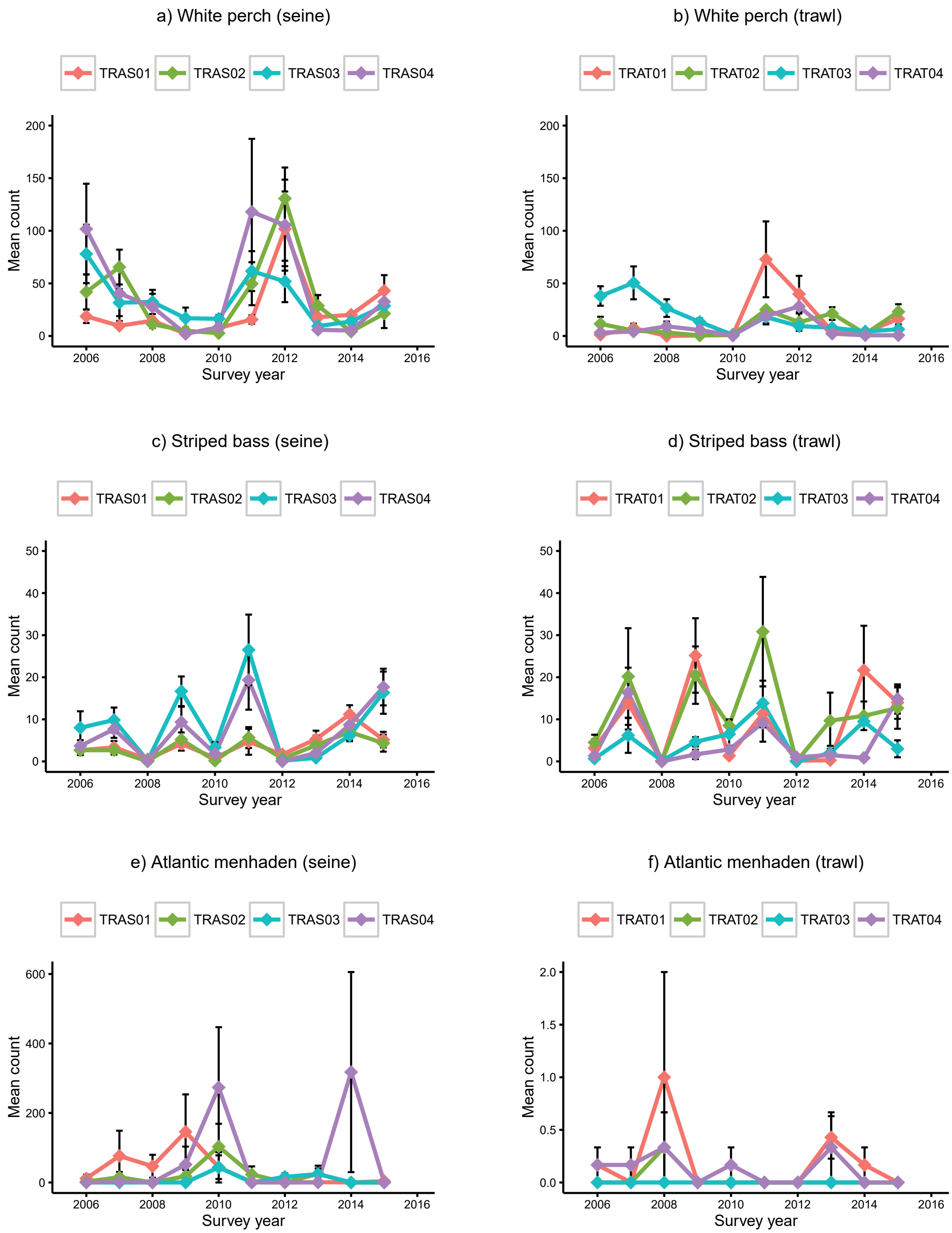

Figure 7.15. Mean (±SE) counts of white perch (a,b), striped bass (c,d) and Atlantic menhaden (e,f) in FHEP seine and trawl surveys in the Tred Avon from 2006-2015. White perch and striped bass include juveniles and adults combined.

Patterns in Broad and Harris Creeks largely mimicked the later years of the Tred Avon River time series, with lower counts in 2013 and 2014 (Figures 7.16 and 7.17). Similarly, striped bass was characterized by year to year variability in abundance. Across all three rivers, menhaden was alternatively absent or marked by high abundances in the seine surveys, and was rarely caught in the trawl surveys. From 2012-2015, on average a higher proportion of small adult white perch were observed in the Tred Avon seine surveys, whereas juveniles and small adults were more equitably distributed in Broad and Harris Creeks, with the

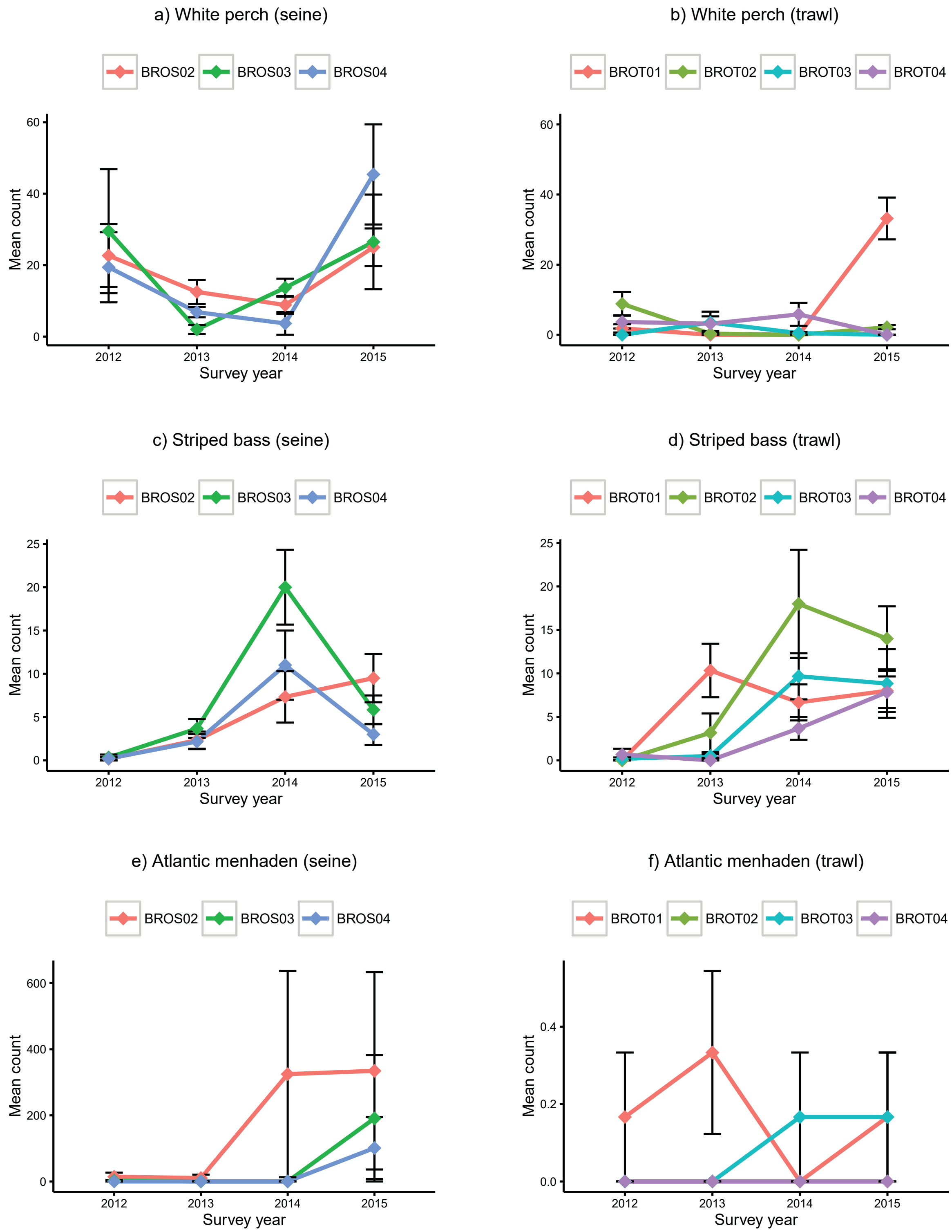

Figure 7.16. Mean (±SE) counts of white perch (a,b), striped bass (c,d) and Atlantic menhaden (e,f) in FHEP seine and trawl surveys in Broad Creek from 2012-2015. White perch and striped bass include juveniles and adults combined.

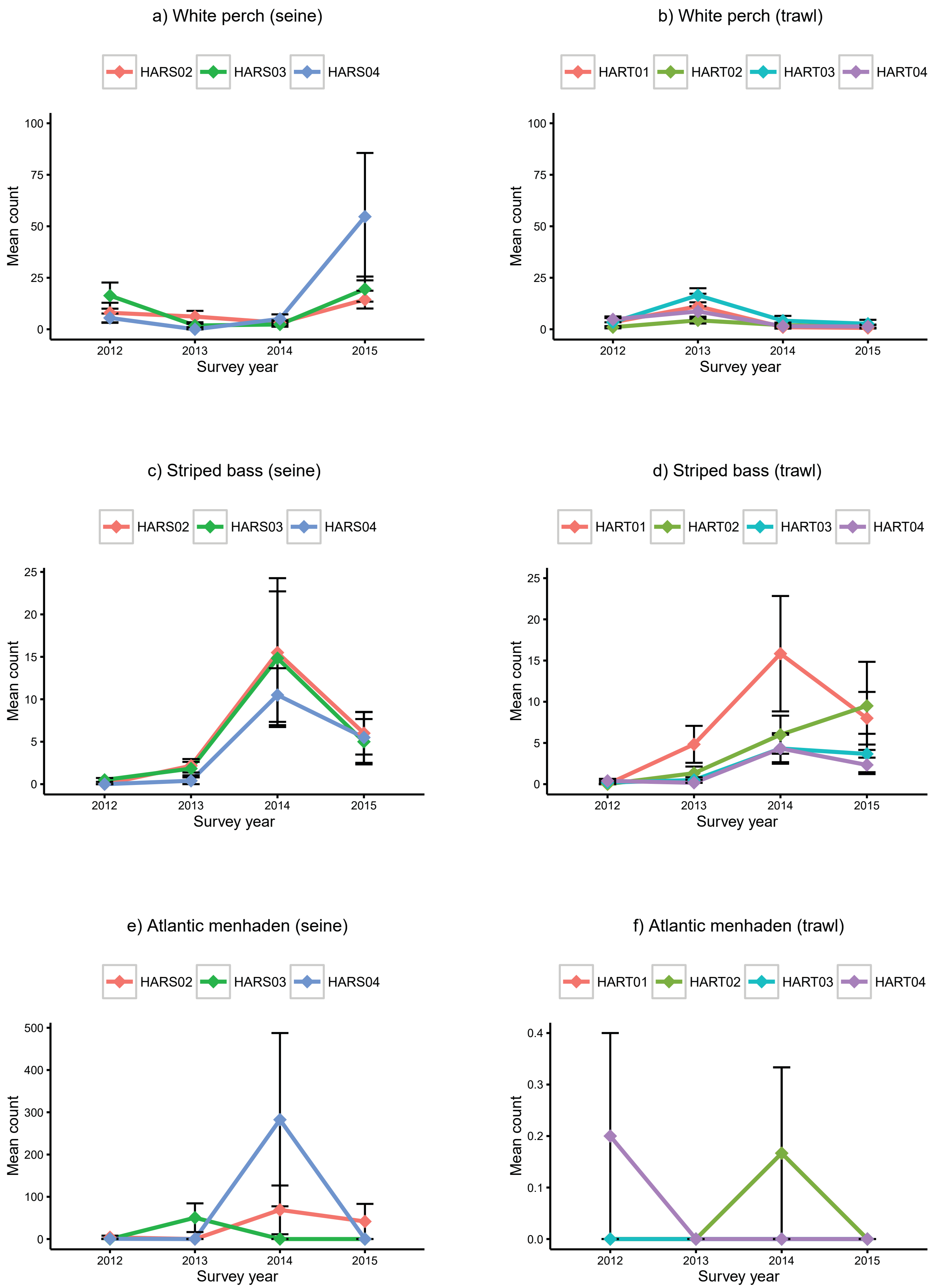

Figure 7.17. Mean (±SE) counts of white perch (a,b), striped bass (c,d) and Atlantic menhaden (e,f) in FHEP seine and trawl surveys in Harris Creek from 2012-2015. White perch and striped bass include juveniles and adults combined.

western most site in Harris Creek having higher mean abundance of juveniles (Figure 7.18). In contrast, a higher proportion of small and harvestable adults were sampled in the trawl gear (Figure 7.19). The majority of observed striped bass across all sites and in both gears were juveniles.

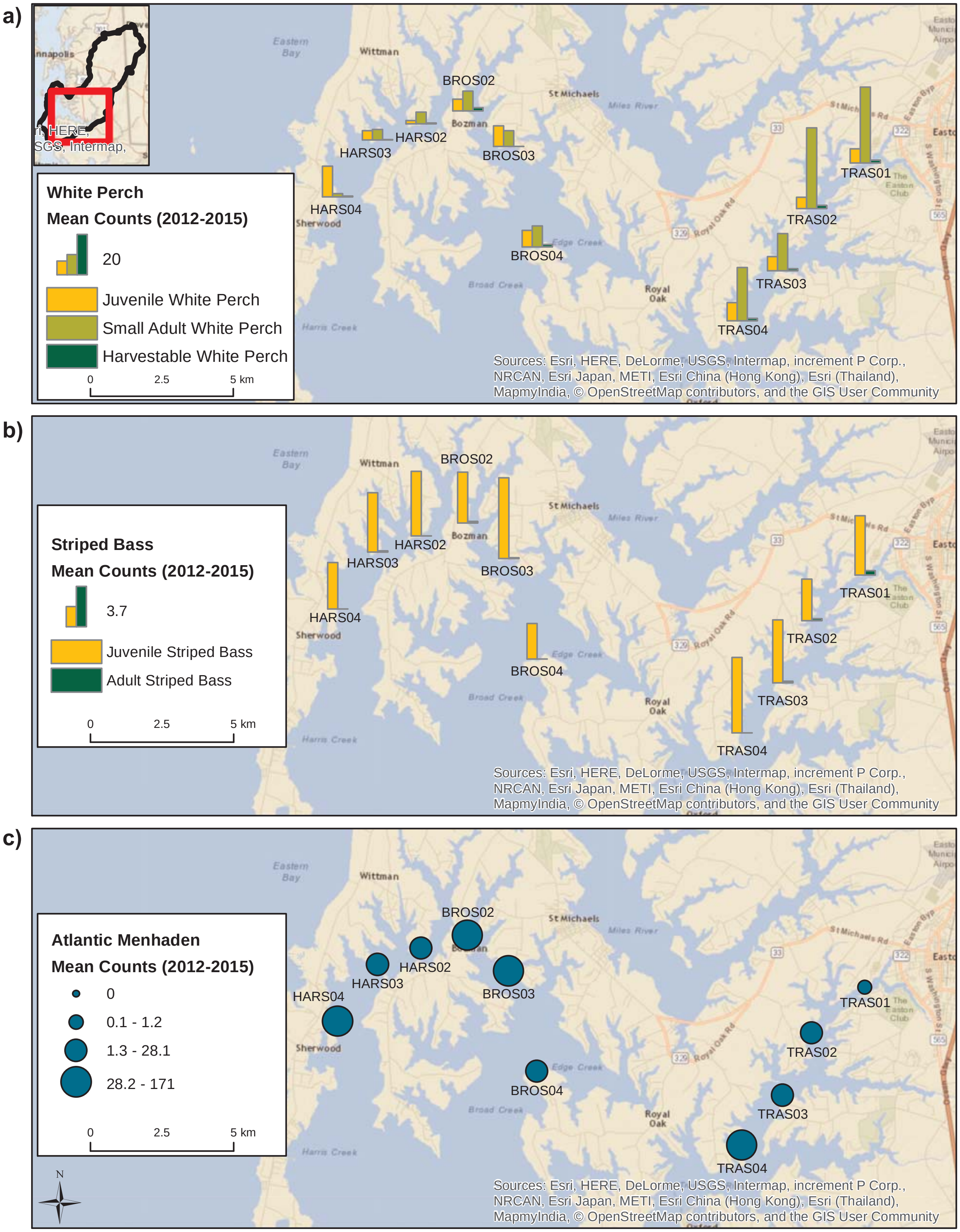

Figure 7.18. Mean counts of a) juvenile, small adult, and harvestable adult white perch, b) juvenile and adult striped bass, and c) Atlantic menhaden in FHEP seine surveys from 2012-2015. For a) and b), the tallest bar in the legend represents mean counts of 20 and 3.7 fish, respectively.

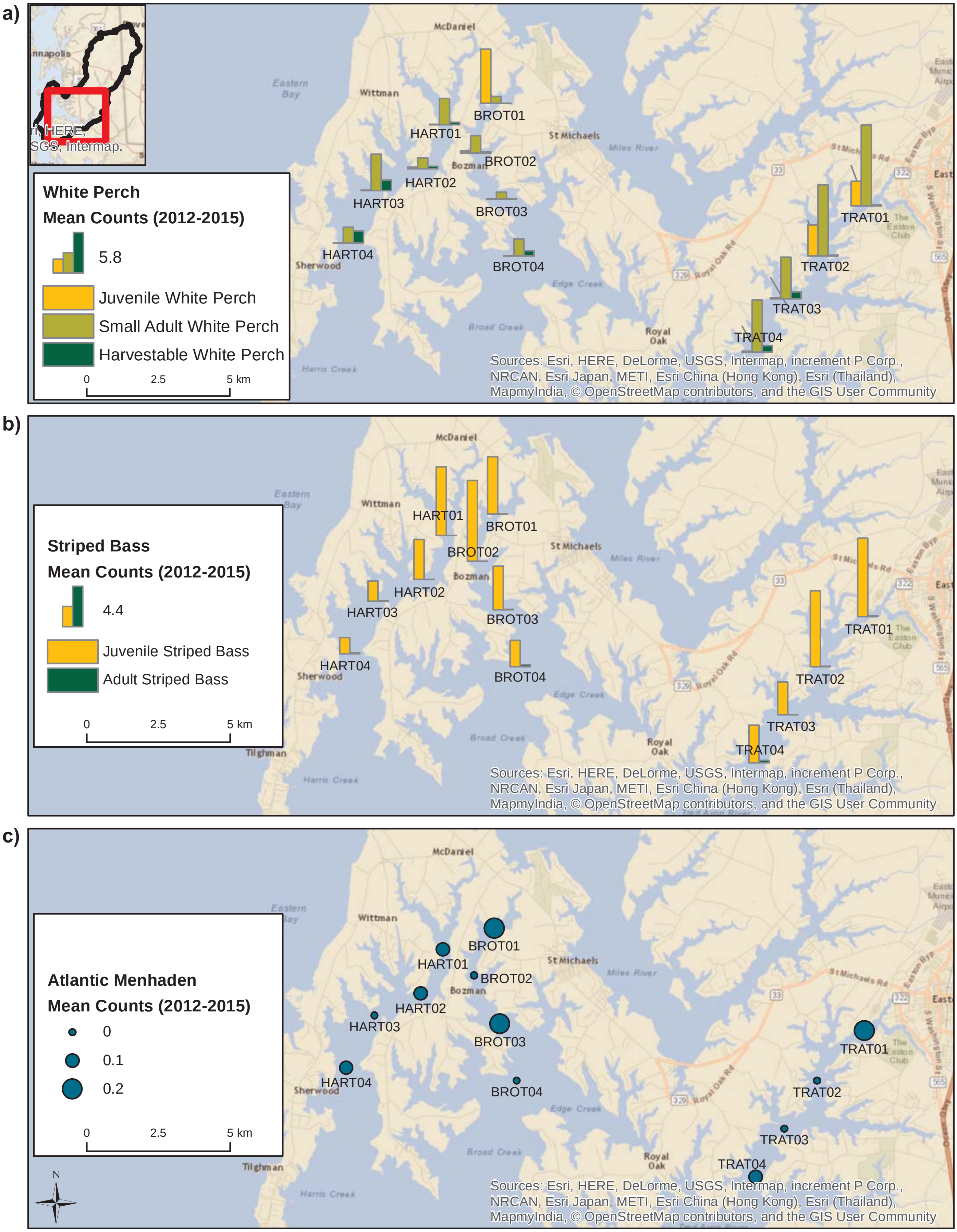

Figure 7.19. Mean counts of a) juvenile, small adult, and harvestable adult white perch, b) juvenile and adult striped bass, and c) Atlantic menhaden in FHEP trawl surveys from 2012-2015. For a) and b), the tallest bar in the legend represents mean counts of 5.8 and 4.4 fish, respectively.

Maryland Biological Stream Survey
The Maryland Biological Stream Survey (MBSS) has sampled 130 sites within the Choptank HFA from 1996-2014.

There was no significant trend in the Fish-IBI score at the Skeleton Creek sentinel site (F=0.616, p=0.449). The IBI score fluctuated between the "Fair" and "Poor" range, with a couple scores at the lower end of the "Good" range (Figure 7.20a). There was a significant increase in fish species richness (F=21.83, p<0.001), with the first three years in the time series exhibiting lower richness values compared to the later years (Figure 7.20b). There was no significant trend in total fish abundance (F=1.432, p=0.257; Figure 7.20c).

Of the 105 surveys with a Fish IBI score, approximately half were classified as "Good", 24% were classified as "Fair", 11% were classified as "Poor", and 15% were classified as "Very Poor." Sites in the "Very Poor" category included those located near Easton, Preston, and in the Little Choptank, as well as scattered throughout the Upper Choptank (Figure 7.21).

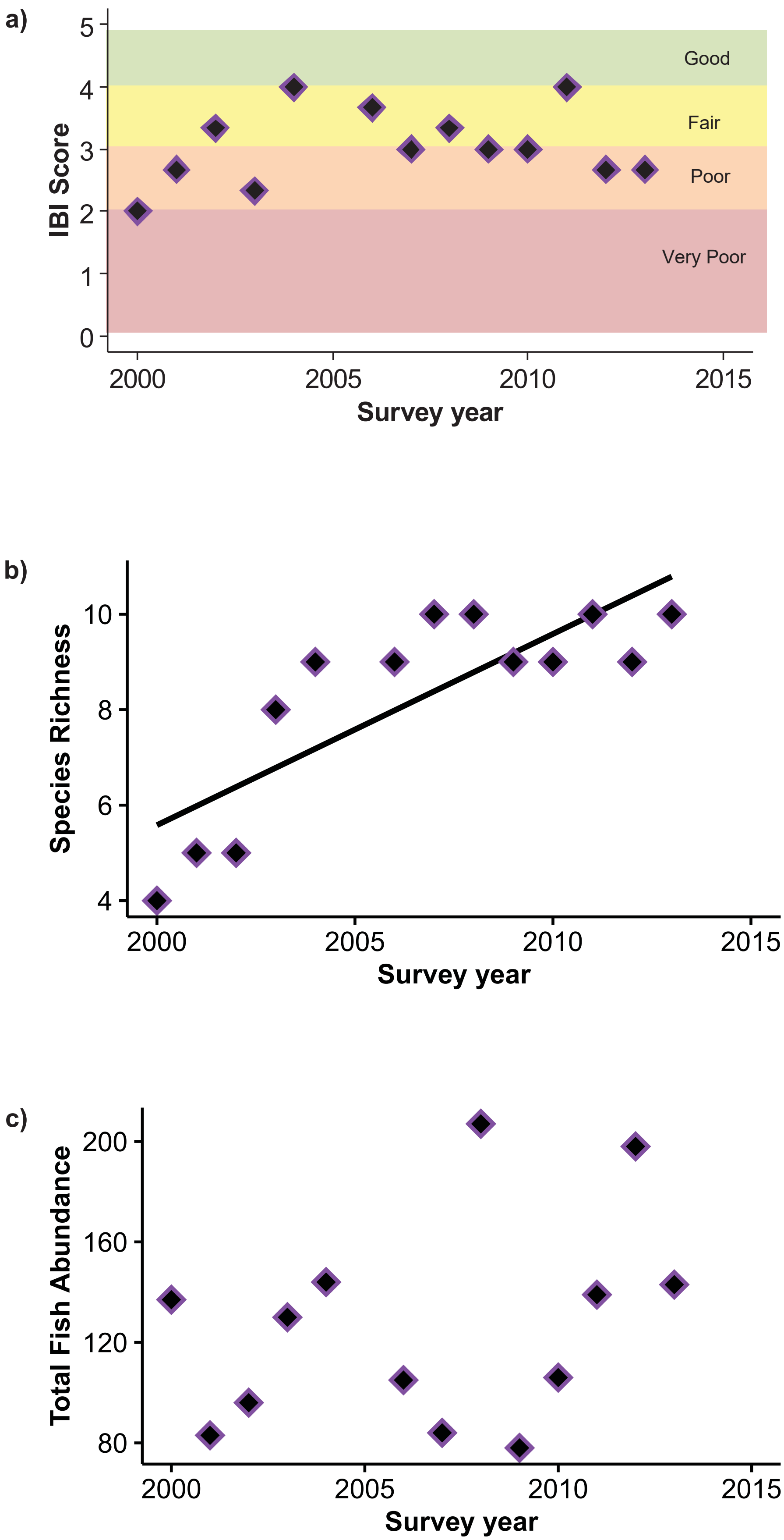

Figure 7.20. a) Fish-IBI score, b) total species richness, and c) total fish abundance over time at sentinel site at Skeleton Creek.

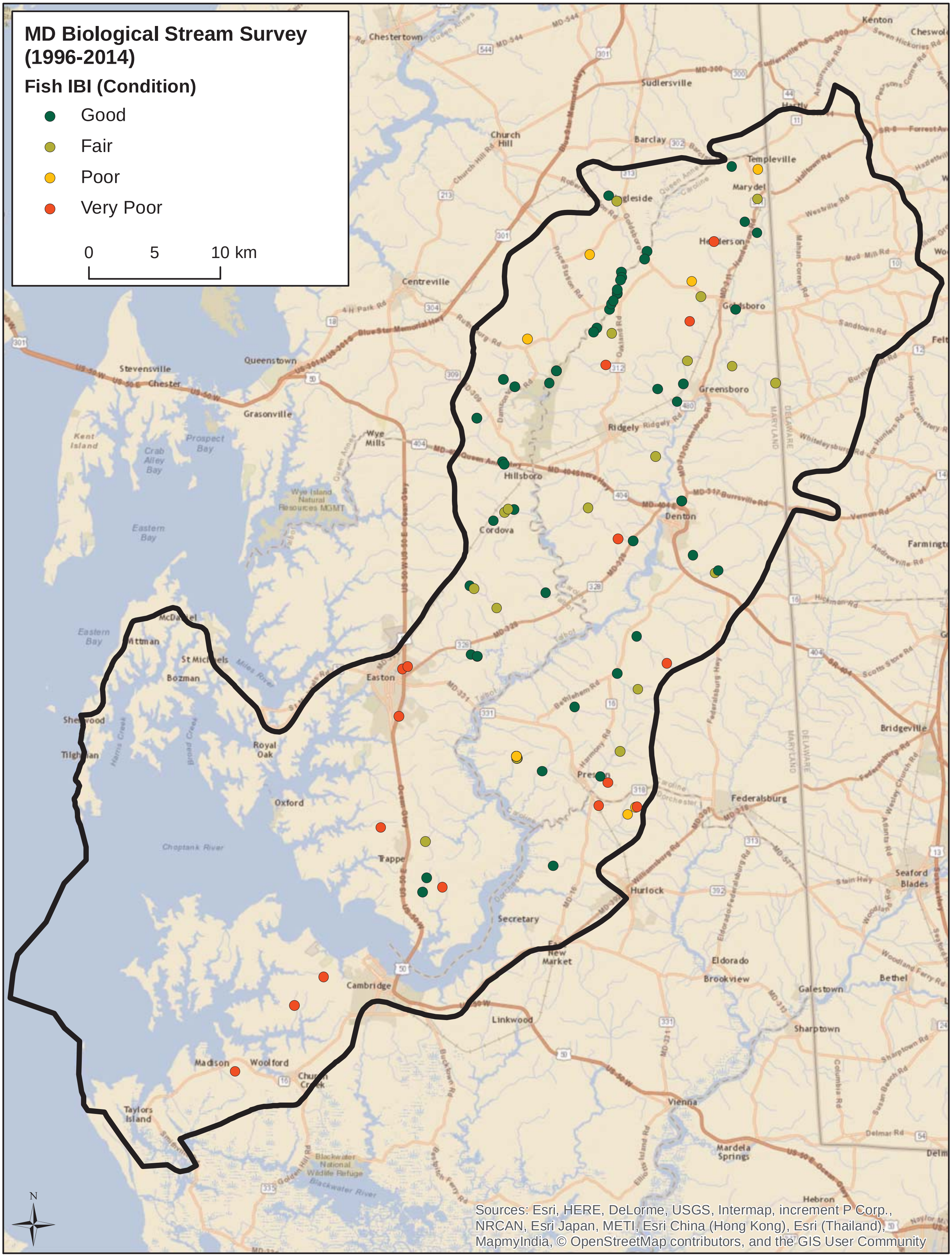

Figure 7.21. Fish index of biotic integrity (F-IBI) as measured by the Maryland Biological Stream Survey in the Choptank River complex.

Commercial Fisheries Data

Commercial landings of striped bass are largely from the Choptank reporting area, with a smaller amount coming from the Little Choptank (Figure 7.22). Although there was significant variability over time, there was a significant decreasing trend in striped bass landings in the Choptank ($F = 15.62$, $p<0.001$), but not in the Little Choptank ($F = 1.081$, $p=0.306$). Cyclic patterns were also apparent for white perch (Figure 7.23) but there was a significant increase in landings in both the Choptank ($F = 6.56$, $p=0.012$), and Little Choptank ($F = 16.81$, $p<0.001$) over time. The overall decrease in striped bass landings in the Choptank is likely attributed to changes in management of the fishery, which has become stricter over time. An Atlantic-wide decline in landings and juvenile recruitment during the 1970s led to the passage of new regulations, including a five-year moratorium on striped bass harvest in Maryland in 1985 (ASFMC, 2016). The Chesapeake Bay stock was declared restored in 1995, and current regulatory measures, which include minimum size limits and quotas, are updated regularly based on the latest stock information (ASFMC, 2016).

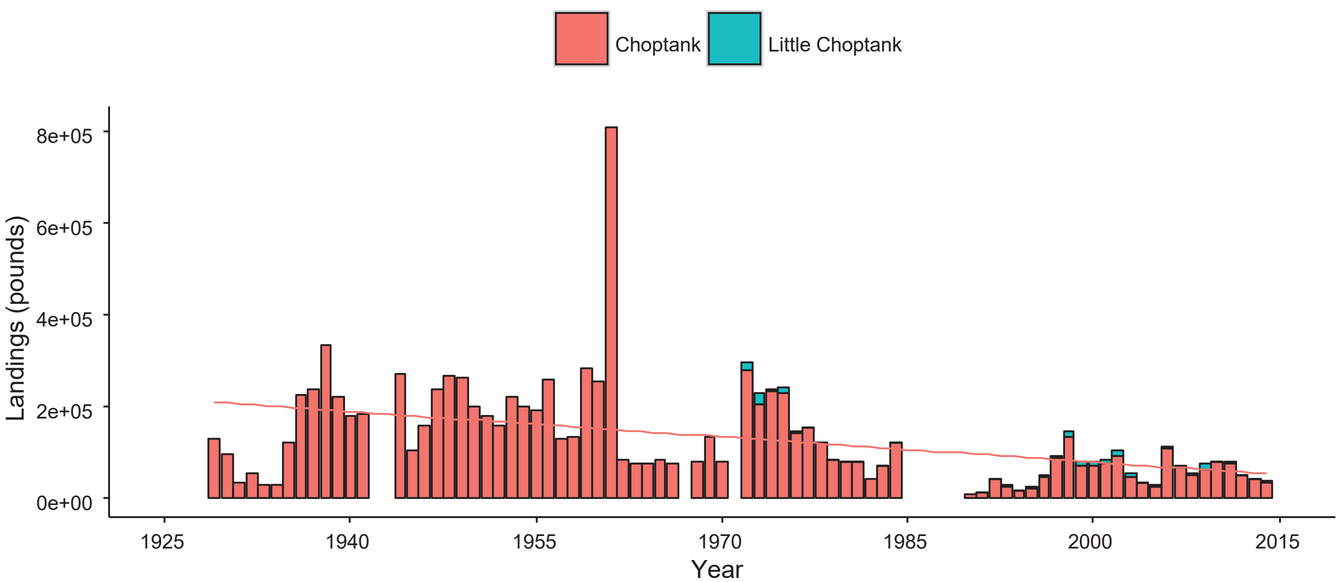

Figure 7.22. Reported striped bass landings in the Choptank (NOAA code 037) and Little Choptank (NOAA code 053) rivers from 1929-2014 and 1972-2014, respectively. Linear regression trend lines are overlayed for the Choptank data only, as no significant trend was present in the Little Choptank.

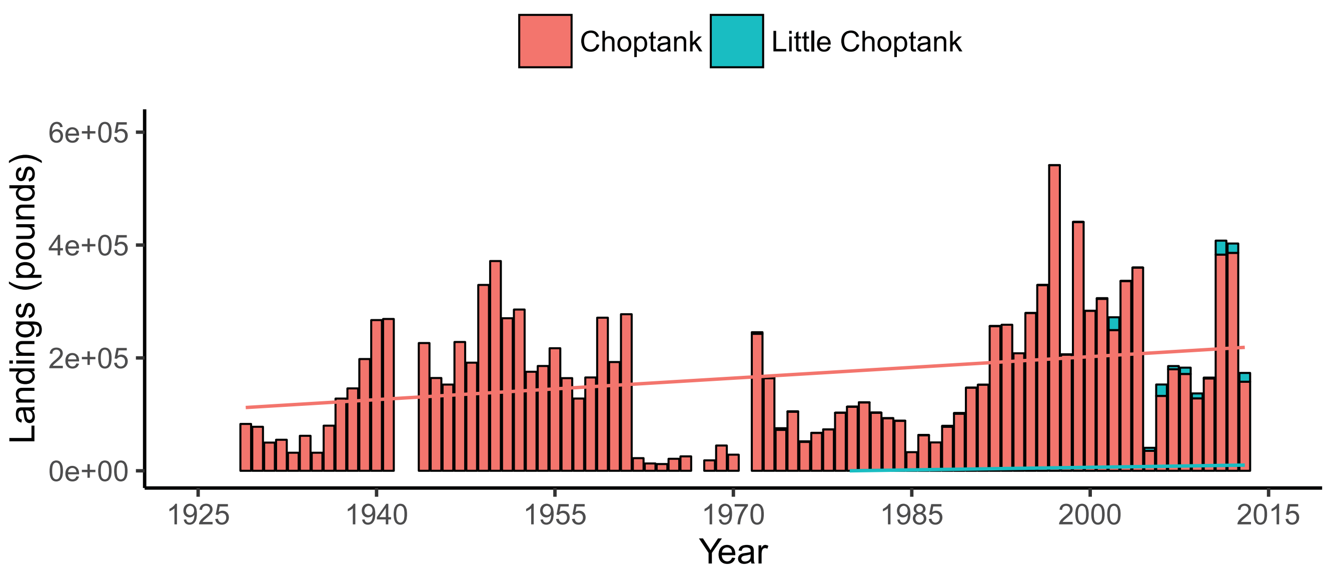

Figure 7.23. Reported white perch landings in the Choptank (NOAA code 037) and Little Choptank (NOAA code 053) rivers from 1929-2014 and 1972-2014, respectively. Linear regression trend lines are overlayed on the data.

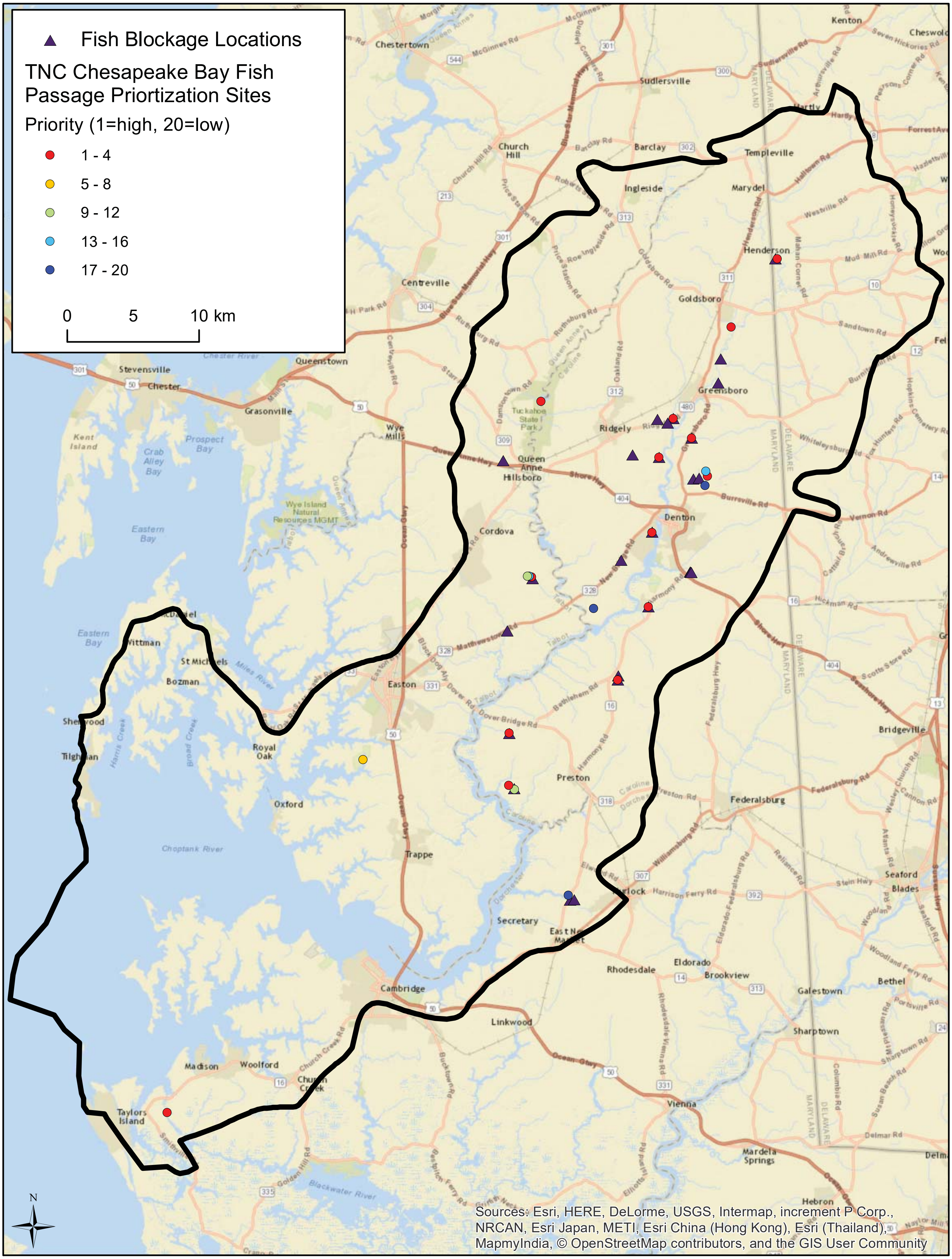

Figure 7.24. Fish blockage locations (Source: Maryland iMap) and The Nature Conservancy's fish passage prioritization sites for the diadromous fish scenario (Martin and Apse, 2013).

Fish Blockage Locations and TNC Fish Passage Prioritization

Out of a total of 2,144 fish passage prioritization sites in the TNC database, 22 were located in the Choptank HFA (Figure 7.24). Approximately a third of these were of the highest priority for diadromous fishes (i.e., priority rank = 1), and were located in close proximity to identified fish blockage locations.

CURRENT ACTIVITIES AND DATA GAPS

Work to identify fish spawning habitat in the Chesapeake Bay, including the Choptank, is ongoing. Many watersheds have undergone considerable development since the original statewide maps of spawning habitat were produced, and icthyoplankton surveys continue to be conduced by MD DNR to characterize the presence/absence of eggs/larvae, and to determine the relationship between spawning activity and watershed development (MD DNR, 2013, 2014). In addition, as previously mentioned, work is ongoing by scientists at SERC to characterize river herring spawning habitats.

The intensity of fish community sampling varies over the Choptank HFA, with the Middle-Lower Choptank mainstem, Tred Avon River, and Harris and Broad Creeks receiving the majority of the effort. The Little Choptank is relatively less characterized than other parts of the Choptank-Little Choptank River complex. There are advantages and disadvantages to various fish gears that are used in the Choptank surveys. Seines, which are deployed in the only long-term dataset (MD DNR Striped Bass Juvenile Seine Survey), are limited to shallow, nearshore environments. Conversely, trawls must be used in deeper offshore areas.

As an extension of work that was recently completed in six other Chesapeake watersheds (Leight et al., 2014, 2015), NOAA's Cooperative Oxford Lab (COL) is conducting additional monitoring and characterization of the Tred Avon River and Kings Creek. Fish abundance will be estimated by seine and otter trawl surveys, and individual fish will be sampled to measure a suite of parameters related to fish health, including fish body fat index, external fish parasites, fish macrophage aggregates, and fish disease. This work will provide additional insight on overall ecosystem health.

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Chapter 8: Oysters

INTRODUCTION

The eastern oyster (*Crassostrea virginica*) has long been a key component of the Choptank estuarine ecosystem, and has contributed to the local and regional economy. Oysters provide reef habitat where other species aggregate, as well as a food source for estuarine fishes and invertebrates. They have been harvested first by Native Americans, and from the Colonial 1600s up to the present day. At the scale of an individual organism, oysters play a role in linking pelagic and benthic food webs by making available a portion of the organic material they filter as dense, mucus-bound deposits, which are consumed by other species (Newell, 1988). At the population and ecosystem scale, oysters can play a "bottom-up" role in mitigating the adverse effects of estuarine eutrophication by filtering organic and inorganic particles and limiting turbidity and phytoplankton blooms. This can enable greater light penetration through the water column, and benefit other components of the estuarine ecosystem, such as submerged aquatic vegetation (SAV) (Kennedy, 1991), which provides valuable habitat for fish, crabs, and other species. At the same time, oysters can be adversely impacted by the secondary effects of eutrophication, such as hypoxia. Therefore, the relationship between oyster populations and water quality is complex and depensatory: healthy oyster populations can provide a net benefit to water quality, but are adversely affected by poor water quality. Chesapeake Bay oyster populations are a small fraction (often cited as 1%) of historic levels throughout the greater Chesapeake Region. Based on landings data, since 2013 oyster harvest has increased to approximately 2.5% of historic levels. Even still, at current population levels oysters no longer provide the level of ecosystem services that they once did. The historic decline of oyster populations in the Choptank HFA parallels that in the greater Chesapeake, and has been attributed to many factors, including overharvest, pollution and sedimentation, altered hydrology and salinity, habitat loss, and oyster diseases, such as Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*). These trends are not unique to the Chesapeake, but have been observed in many other estuarine ecosystems over a parallel time period (zu Ermgassen et al., 2012).

Chesapeake Bay oyster. Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory

CHOPTANK OYSTER DISTRIBUTION

Historic Oyster Habitat

Mapping Chesapeake Bay oyster bars dates back to the early 1900s when Charles C. Yates mapped 769 natural oyster bars over six years (1906-1912) resulting in what is now well known as the Yates Survey (Yates, 1911, 1913). Areas were mapped and documented with their bars names, representing a total area of 872 km². However, the Yates Survey was conducted to define regulatory boundaries, not necessarily to map all oyster habitat, so comparisons between the Yates Survey and modern habitat surveys are not warranted. Efforts for mapping oyster bars continued in Chesapeake Bay to complete a historic oyster bottom digital map in 1997 by the Maryland Department of Natural Resources (MD DNR) (Smith et al., 1997) representing oyster bars surveyed from 1906 to 1977. The total area of the historic oyster bars was 1,335 km² representing 1,105 oyster bars (MD iMAP, 2016a), of which 202 oyster bars occur in the Choptank Habitat Focus Area (HFA). These sites represent 184 km² which is 14% of Chesapeake Bay historic oyster bars (Figure. 8.1).

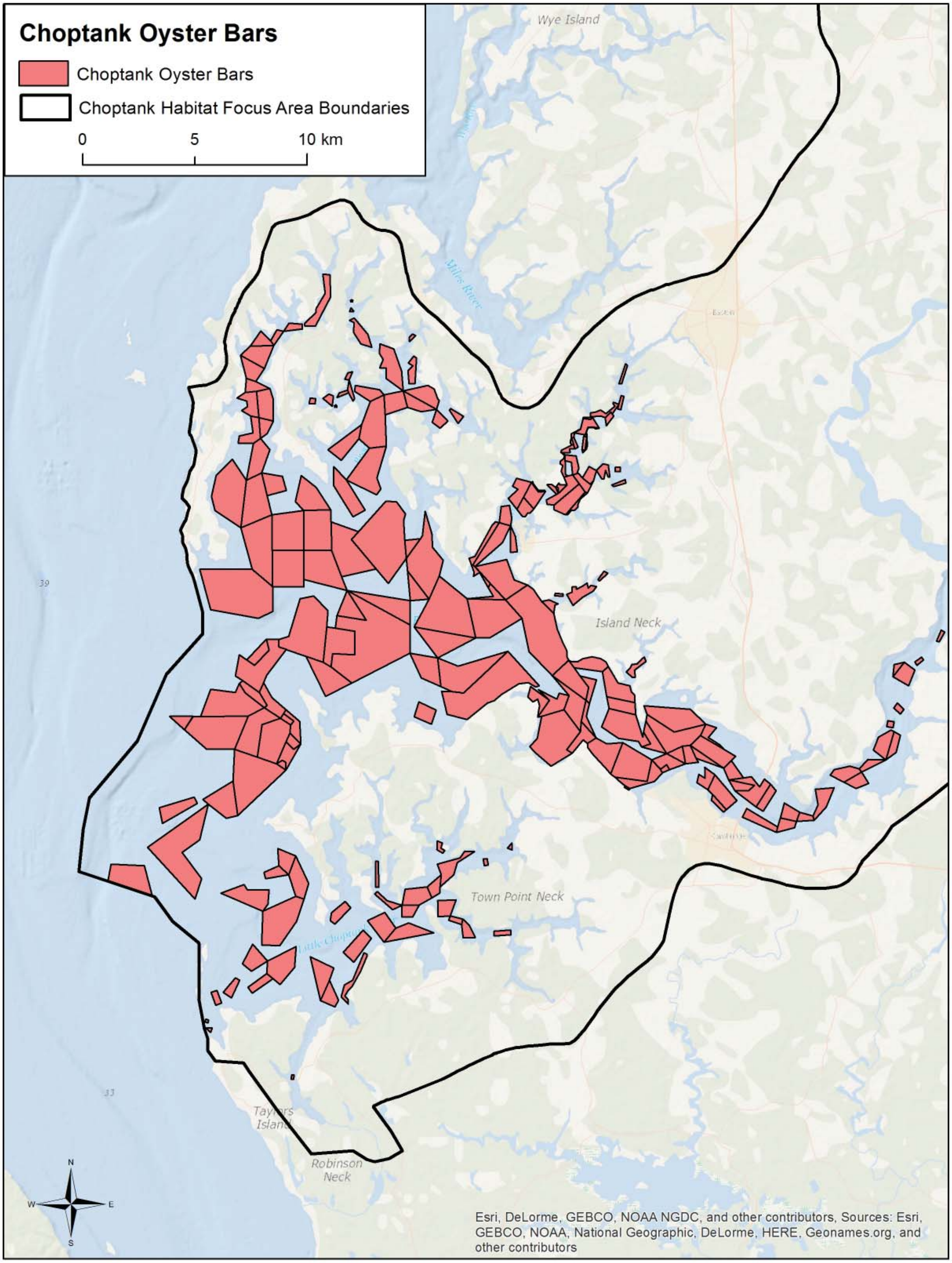

Figure 8.1. Choptank historic oyster bars locations based on MD DNR spatial data file (Smith et al., 1997) with a total area of 187.68 km² (46,377.75 acres).

Recent Oyster Habitat

NOAA's Chesapeake Bay Office recently developed a digital map of the benthic habitat bay-wide adapting the Coastal and Marine Ecological Classification Standard (CMECS) Substrate Component (SC), where oyster habitats were identified. The map relied mainly on Maryland Bay Bottom Survey (MBBS) conducted by MD DNR (1974-1983) and the Acoustic Survey by Maryland Geological Survey and NOAA Chesapeake Bay Office (2003-2014) (MD iMAP, 2016b).

Oysters in the Choptank River. Photo credit: NOAA/OHC NOAA Chesapeake Bay Office

The total area surveyed in the Chesapeake Bay was 11,324 km², and of this 931 km² were oyster habitats. This area is further classified by origin, anthropogenic (man-made) and biogenic (natural) using the CMECS. Bay wide, anthropogenic origin oyster habitats had an area of 21.61 km² of which only 0.085 km² was classified as anthropogenic oyster reefs (size ≥ 4,096 millimeters), while the rest were mainly anthropogenic oyster rubble (4,096 millimeters > size > 64 millimeters) (21.08 km²). On the other hand the biogenic oyster habitats had an area of 749.96 km² of which only 1.54 km² were classified as biogenic oyster reefs (size ≥ 4,096 millimeters) and the rest were mainly biogenic oyster rubble (4,096 millimeters > size > 64 millimeters). In the Choptank basin oyster habitats (anthropogenic and biogenic) were estimated to cover an area of 75.55 km² (Figure 8.2). This represents 9.8% of the total area of Maryland Chesapeake Bay oyster habitats. Anthropogenic oyster habitats were 12.72 km² of which only 2,349 m² were classified as anthropogenic oyster reef and the rest were mainly anthropogenic oyster rubble. Meanwhile the biogenic oyster habitats were 52.96 km² of which only 0.91 km² were classified as biogenic oyster reefs and the rest were biogenic oyster rubble.

When comparing historic and recent oyster habitat it is important to consider the difference in scale of measurement. This is evident between Figures 8.1 and 8.2 where the latter is more detailed using a finer scale. It is also important to remember that the historic surveys and modern surveys were conducted for different purposes using different methods, so comparisons of the results are not warranted.

CHOPTANK OYSTER MANAGEMENT

Historic Overview

Management of oysters in Maryland's Chesapeake Bay dates back to the year 1820, when the Maryland legislature enacted the first oyster law prohibiting both dredging in the state and transporting oysters with ships not owned by Maryland residents (Kennedy and Breisch, 1983). Ten years later the One-Acre Planting Law was enacted, allowing Maryland citizens to plant and grow oysters on one acre of barren bottom water, promoting oyster culture as a management tool. Over the 19th century, more laws were passed and different management measures were established to manage oysters, including seasonal closures, size limits, licensing, and leasing for oyster culture. Oyster production peaked in 1884 at 15 million bushels, but these management measures did not prevent the subsequent decline of oyster populations and harvest.

With the beginning of the twentieth century oyster culture was encouraged, expanding acres for lease to reach 500 acres via the Haman Oyster Culture Law (1906) and the Price Campbell Bill (1912). New management measures were also developed, such as a fuel tax on work boats and shell tax from the packing houses, to fund the planting program. Controversy over leasing increased and conflicts between the oyster fishermen and the oyster culture communities arose. The Shepherd Bill (1914) was enacted, which limited

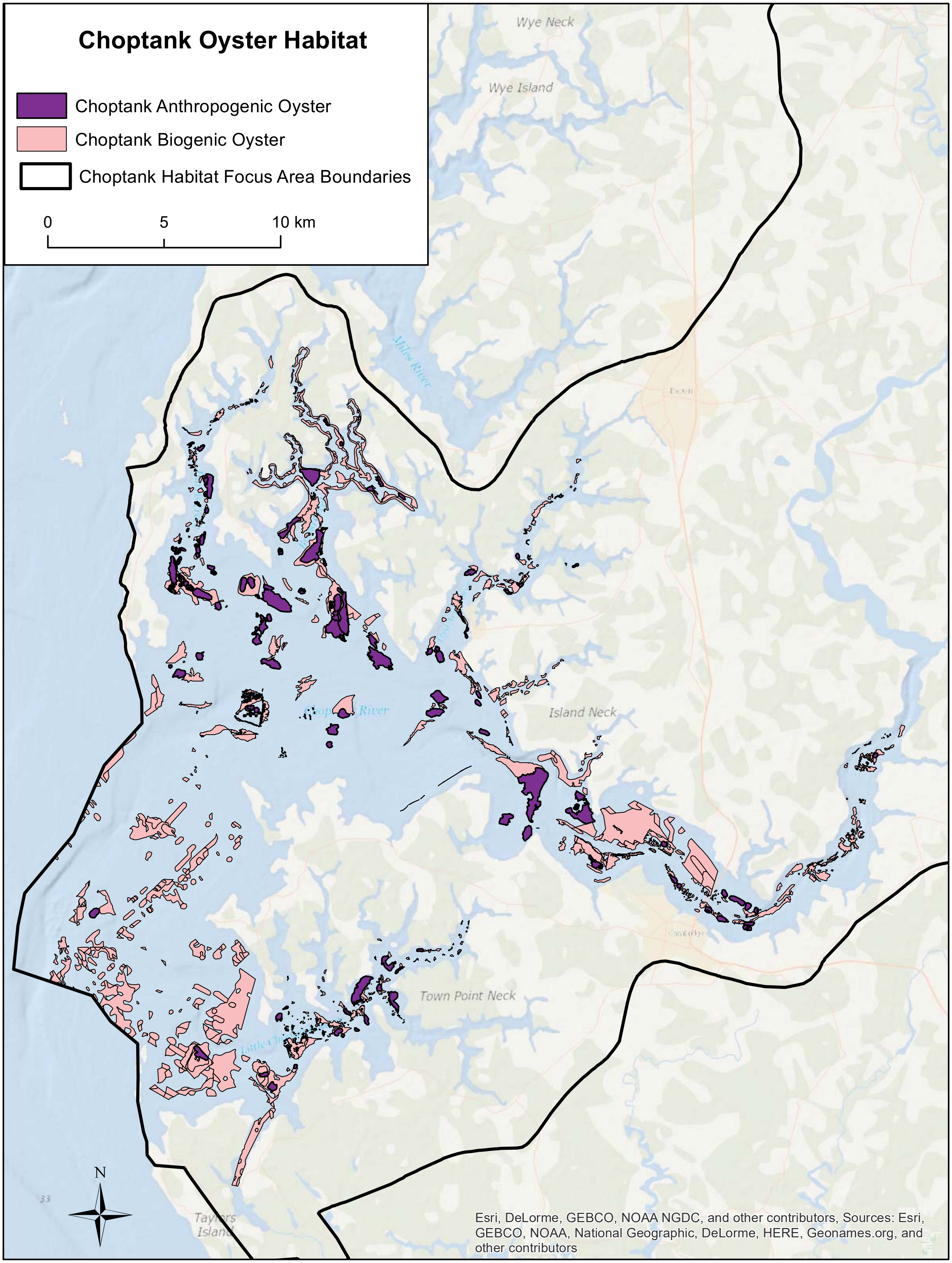

Figure 8.2. Choptank anthropogenic and biogenic reefs with a total area of 12.72 km² and 52.96 km² respectively.

the expansion of the oyster leasing. Additionally, the Maryland Conservation Commission was developed in 1916 (a predecessor of the MD DNR) and for the first time Reserve Areas were used as a tool to manage Chesapeake Bay oysters.

An Oyster Management Plan was developed in 1943 and another adopted in 1948, both with the aim to increase oyster production (Kennedy and Breisch, 1983). The plans were not fully implemented and did not achieve their objectives. However, they did lead to the establishment of an annual oyster seed and shell planting program as a management practice to maintain oyster fisheries.

Recent Management Efforts

In recent decades, The management of oyster populations has become no less complex, with the emergence of challenges such as oyster diseases, seasonal hypoxia (lack of oxygen), flood events resulting in high freshwater inflow, and climate change effects. As a result, a series of oyster management plans and agreements (CBP, 1989, 1994, 2000, 2004) for the Chesapeake Bay were developed and adopted by local states (MD, VA, PA, DC) and the Chesapeake Bay Commission. The main objective of these plans was to protect, restore and enhance the oyster resources for long term ecological and economic benefits. These plans addressed oyster problems such as: 1) declining harvest due to overfishing; 2) recruitment; 3) disease mortality; 4) low production from leased grounds; 5) habitat degradation; 6) shellfish sanitation problems; 7) market stability; and 8) repletion efforts.

One of the most important outcomes of these plans is using the oyster sanctuaries (25% of the remaining oyster bar habitat) as a management tool. According to MD DNR, “sanctuaries are areas where the wild harvest of oysters is prohibited” (MD DNR, 2010). They are areas where oyster populations are expected to increase in size and in density, producing disease resistant oysters which will function as key spawners and also enhance the ecosystem services in the Bay.

More recently President Obama issued Executive Order 13508 in May 2009 for protecting and restoring the Chesapeake Bay watershed (FLCCB, 2010). As a result the Federal Leadership Committee for the Chesapeake Bay developed a strategy to restore the watershed. One of the main outcomes of this strategy was to “restore native oyster habitat and populations in 20 tributaries out of 35 to 40 candidate tributaries by 2025” (U.S. EPA, 2010). Restoration goals and metrics have been further refined to evaluate the success of these efforts (CBP, 2011). In the most recent Chesapeake Bay Program Watershed Agreement (CBP, 2014) the stated oyster restoration goal was to restore native oyster habitat and population in 10 tributaries by 2025 and ensure their protection.

Within the Choptank HFA (NOAA/CBO, 2015a), establishment of “oyster sanctuaries” is one of the main management measures (MD DNR, 2010). There are 13 oyster sanctuaries and two oyster reserves in the Choptank River watershed covering an area of 177.29 km^2 (43,809 acres)(Figure 8.3), of which Harris Creek, Tred Avon and Little Choptank sanctuaries represent 42% and were selected for restoration projects (MIORW, 2013, 2015a, b). Public Oyster Fisheries Areas were also established in the Choptank watershed, covering an area of 151.94 km^2 (37,545 acres) (Figure 8.3).

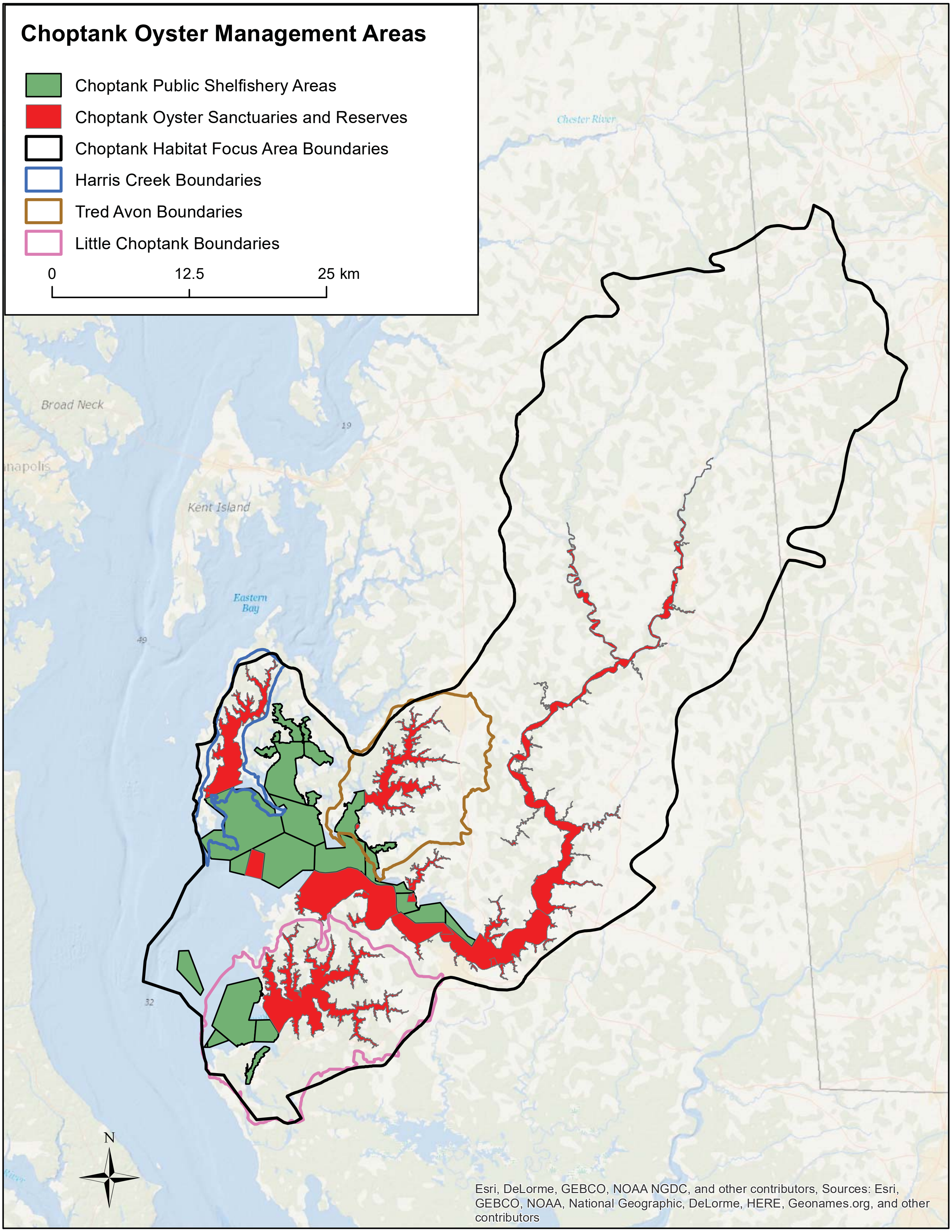

Figure 8.3. Choptank oyster management areas with public fisheries areas in green 159.94 km² (37,545 acres) and oyster sanctuaries in red 177.29 km² (43,809 acres).

CHOPTANK OYSTER RESTORATION

Oyster restoration projects have been taking place in the Choptank HFA for over 50 years (Figure 8.4). Methods have evolved and practices have changed over time. Most recently, large scale oyster restoration projects have been initiated in Harris Creek, the Tred Avon River, and the Little Choptank River, consistent with the goals of the recent Chesapeake Bay Watershed Agreement (CBP, 2014). In addition to their inherent value, restored oyster populations may provide ecosystem benefits such as improved water quality (Cerco and Noel, 2005), and serve as habitat for fish, crabs, and other species (NOAA/CBO, 2016a).

Harris Creek

In addition to being designated as an Oyster Sanctuary by the State of Maryland in 2010, Harris Creek is the site of the world's largest oyster restoration effort. The State of Maryland, US Army Corps of Engineers, and the U.S. Department of Commerce (U.S. DOC), National Oceanic and Atmospheric Administration (NOAA), along with local groups and not for profit organizations have partnered to restore 1.53 km² of oyster reef within the sanctuary (MIORW, 2013). Restoration began in 2012, with 89,031 m² (22 acres) of reef constructed with substrate and seeded, and 356,123 m² (88 acres) receiving seed only. The restoration plan identifies an additional 789,137 m² (195 acres) of constructed reef substrate, and 279,233 m² (69 acres) to receive seed only, over a period of years. Figure 8.5 shows the historic and recent planting areas in Harris Creek. When the restoration plan was drafted (MIORW, 2013), monitoring indicated that only 12,141 m² (3 acres) of oyster reef habitat in Harris Creek already met the target density of 50+ oysters/m². At the time that our benthic habitat data was collected, we measured 2.18 km² (539 acres) of man-made (anthropogenic) reef and 2.20 km² (544 acres) of natural (biogenic) reef (Figure 8.6). Recent monitoring results from twelve reef sites in Harris Creek suggest substantial success towards the pre-established metrics for oyster density, biomass, and multiple year classes (NOAA/CBO, 2016b).

Oyster restoration monitoring work. Photo credit: NOAA/NCCOS Cooperative Oxford Laboratory

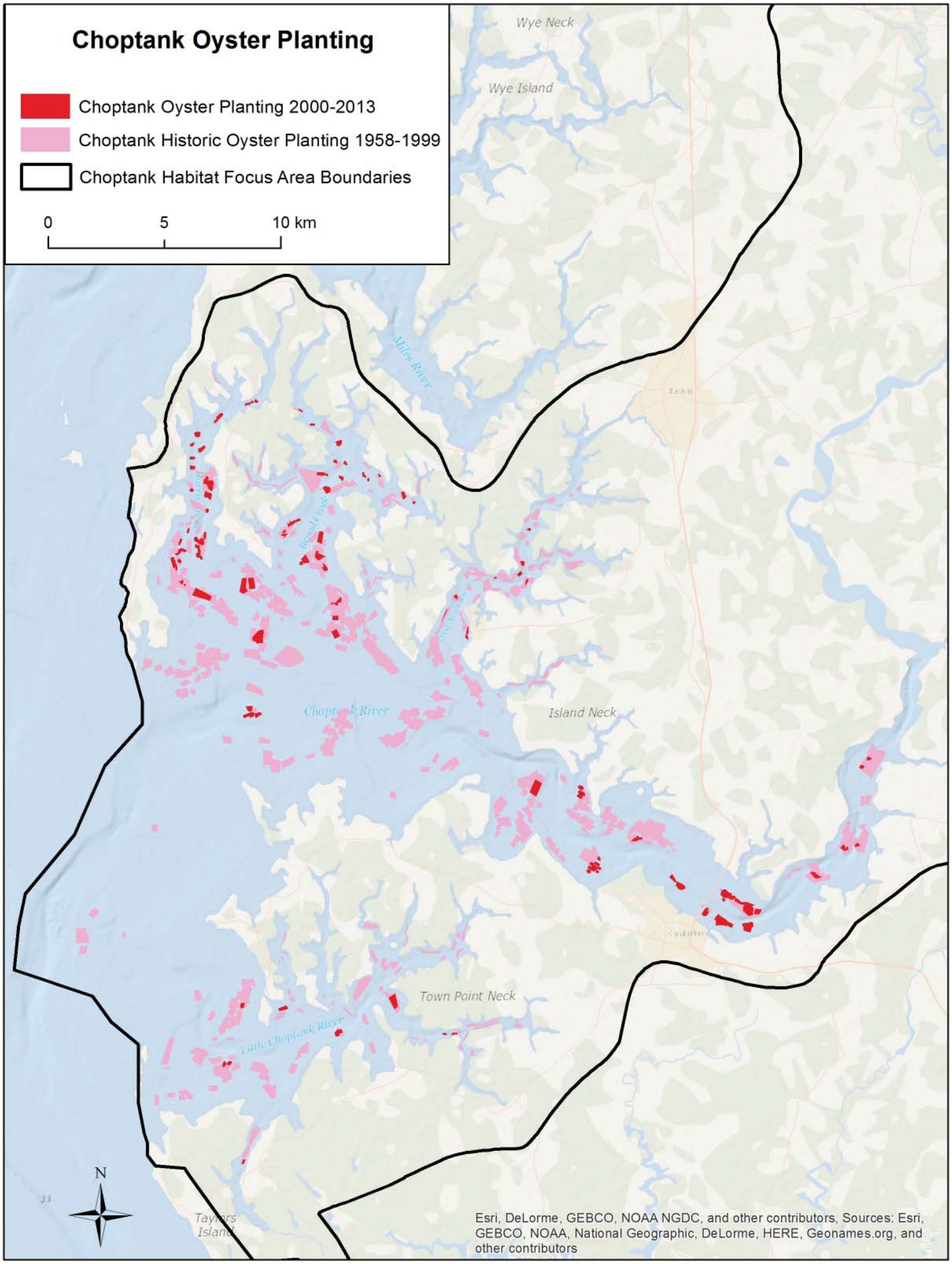

Figure 8.4. Choptank oyster planting locations with historic (1958-1999) planting of 75.33 km² (18,615 acres) and from 2000 to present is 9.69 km² (2,395 acres).

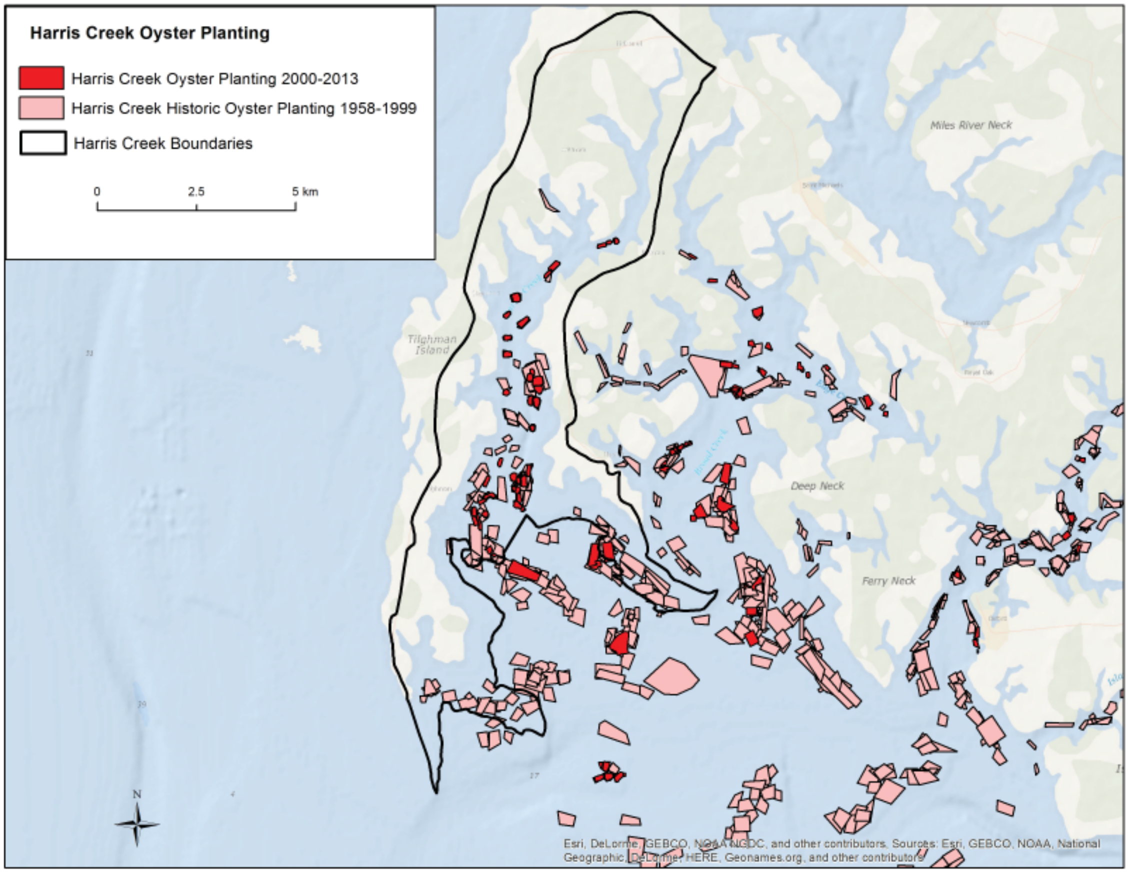

Figure 8.5. Harris Creek oyster planting with historic (1958-1999) oyster planting area of 8.37 km² (2,068 acres) and oyster planting area from 2000 to 2013 is 2.71km² (670 acres).

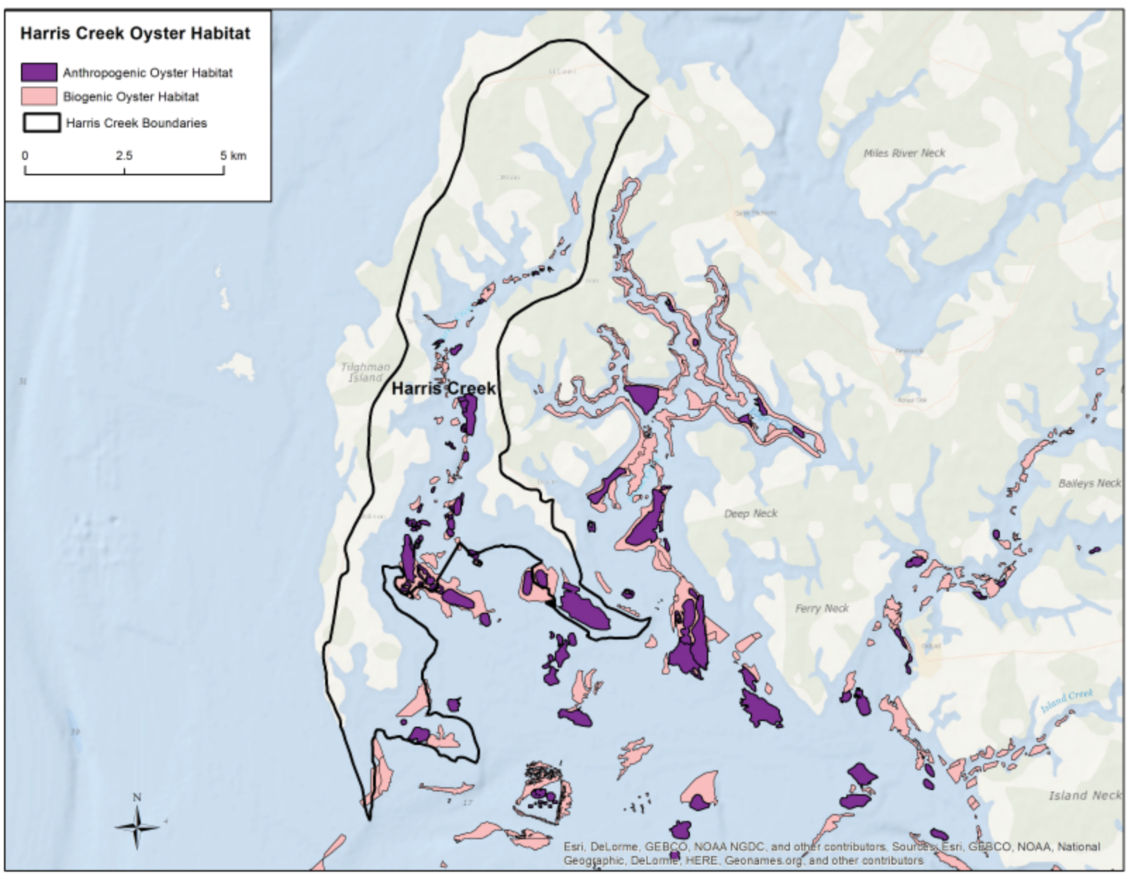

Figure 8.6. Harris Creek anthropogenic oyster reef with total area of 2.18 km² (539 acres) and biogenic oyster reef total area of 2.20 km² (544 acres).

Tred Avon

In addition to being designated as an Oyster Sanctuary, the tidal Tred Avon River was also selected as a restoration site by the Maryland Interagency Oyster Restoration Workgroup (MIORW, 2015b). Historic surveys of the Tred Avon River identified 11.51 km² (2,844 acres) of oyster reef habitat within the sub-watershed. A recent analysis identified 1.02 km² (251 acres) of "restorable" habitat based on multiple criteria. The draft restoration plan recommends restoration of 0.60 km² (147 acres) over a period of years, with 0.34 km² (84 acres) of reef requiring both substrate and seed, and 63 acres receiving seed only. Figure 8.7 shows the historic and recent restoration effort in the Tred Avon River. At the time that our benthic habitat data was collected, we measured 0.39 km² (96 acres) of man-made (anthropogenic) reef and 2.50 km² (618 acres) of natural (biogenic) reef in the tidal Tred Avon River and Island Creek (Figure 8.8)

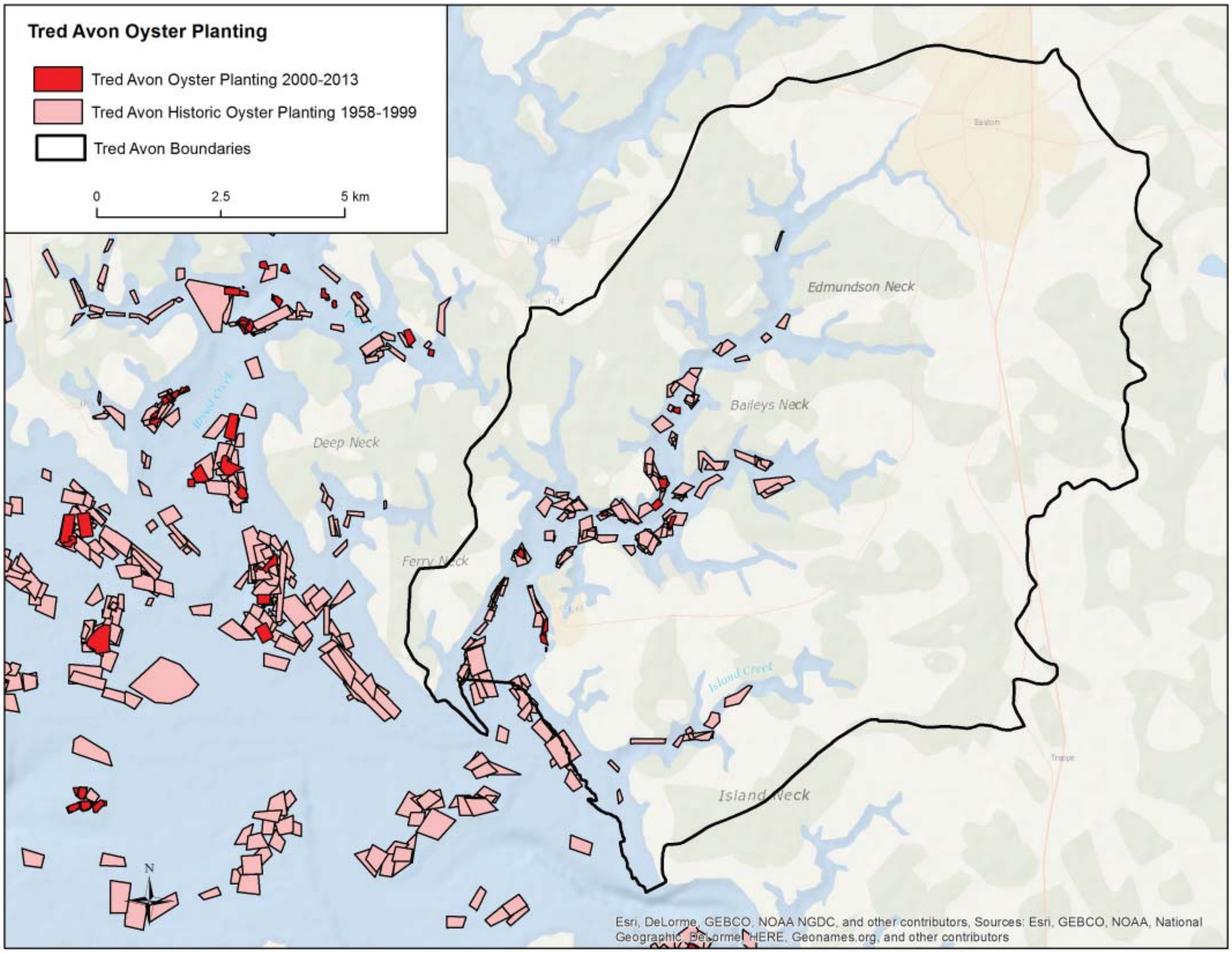

Figure 8.7. Tred Avon and Island Creek oyster planting with historic (1958-1999) total area of 6.54 km² (1,616 acres) and from 2000 to 2013 is 0.19 km² (47 acres).

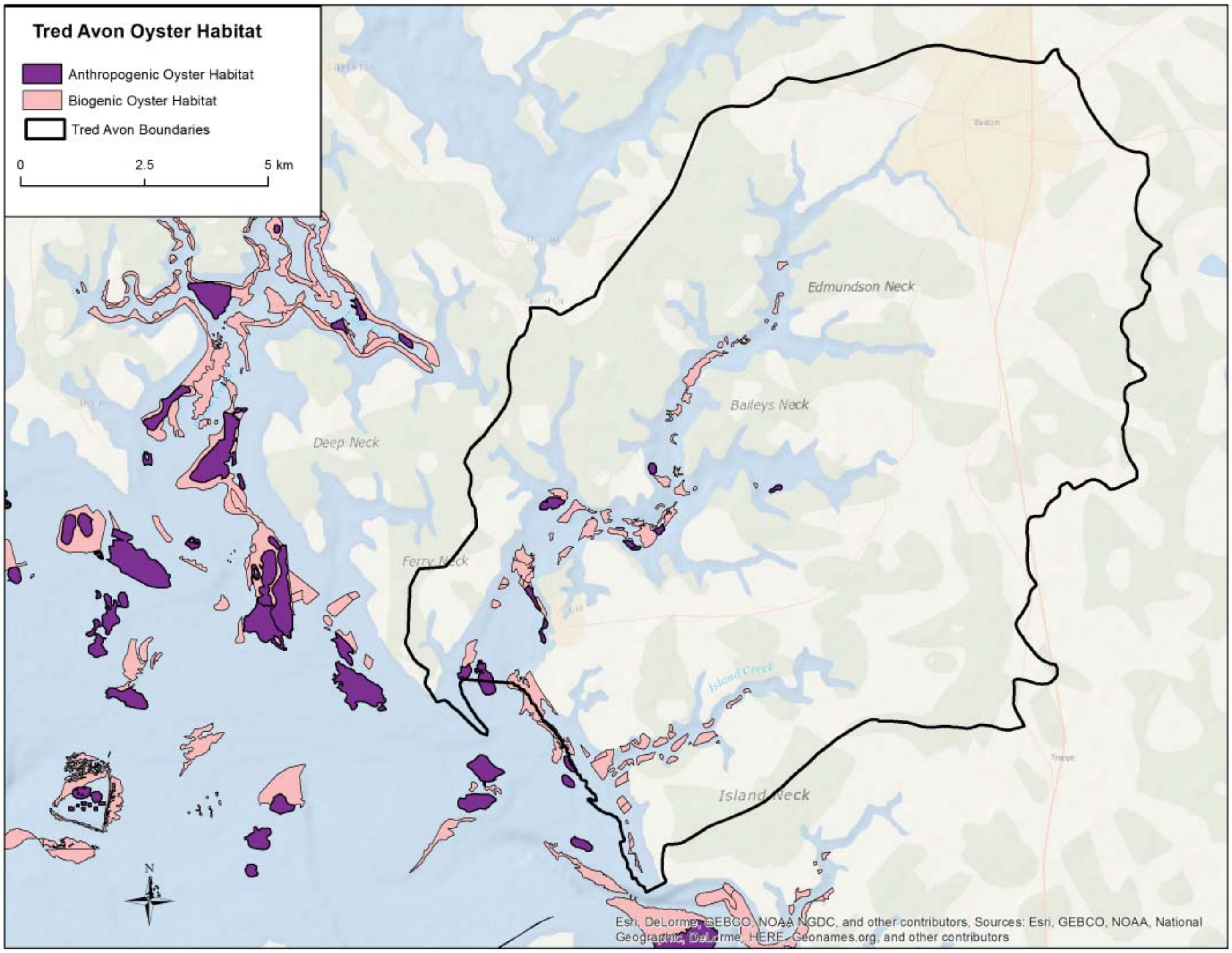

Figure 8.8. Tred Avon and Island Creek anthropogenic reefs with a total area of 0.39 km² (96 acres) and biogenic reefs total area is 2.50 km² (618 acres).

Little Choptank

In addition to being designated as an Oyster Sanctuary, the tidal Little Choptank River was also selected as a restoration site by the Maryland Interagency Oyster Restoration Workgroup (MIORW, 2015a). Historic surveys of the Little Choptank identified 17.19 km² (4,2448 acres) of oyster reef habitat. A recent analysis identified 2.77 km² (685 acres) of potentially restorable oyster reef habitat based on multiple criteria. The restoration plan recommends restoration of 1.78 km² (440 acres) over a period of years, with 1.05 km² (260 acres) of reef requiring both substrate and seed, and 0.55 km² (137 acres) receiving seed only. However, 174,015 m² (43 acres) of habitat in the Little Choptank already meet the target density of 50+ oysters/m². Figure 8.9 shows the historic and recent restoration effort in the Little Choptank. At the time that our benthic habitat data was collected, we measured 1.52 km² (356 acres) of man-made (anthropogenic) reef and 13.50 km² (3,336 acres) of natural (biogenic) reef in the tidal Little Choptank River (Figure 8.10)

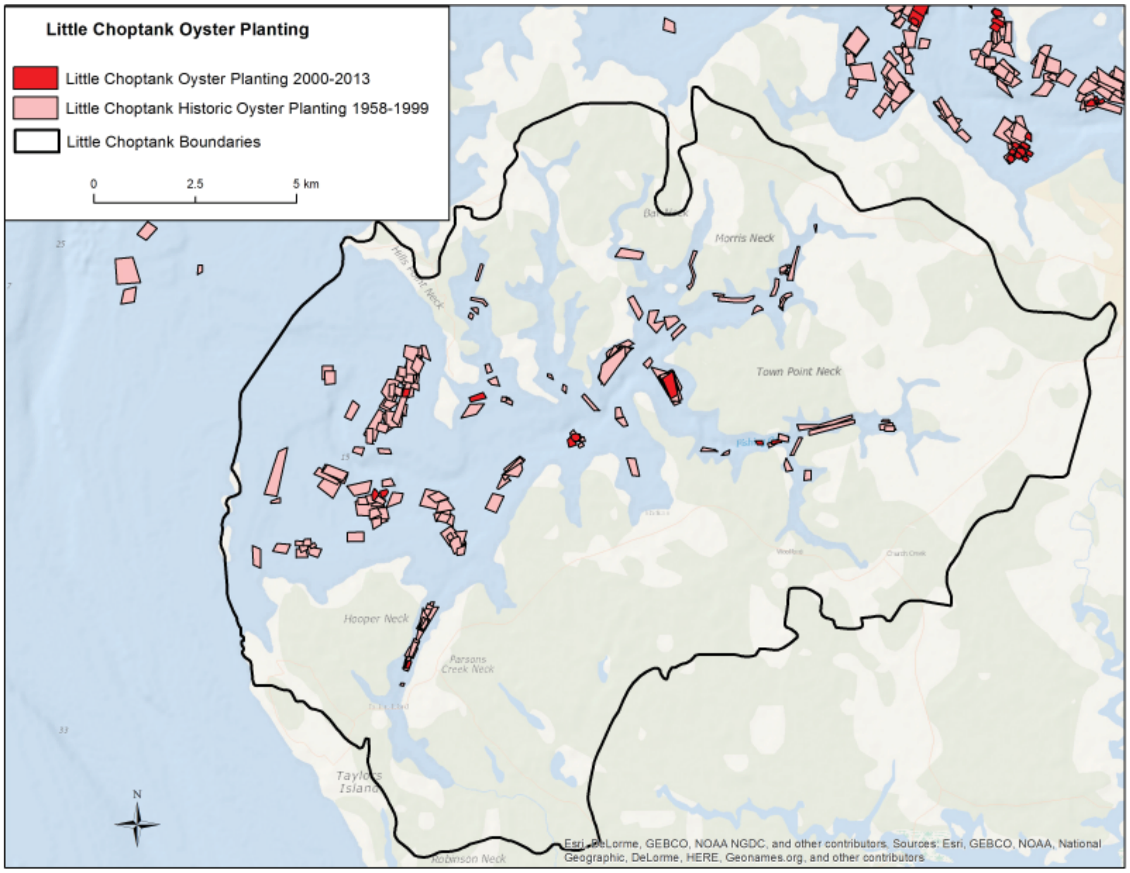

Figure 8.9. Little Choptank oyster planting with historic (1958-1999) total area of 12.54 km² (3,099 acres), and area of oyster planting from 2000 to 2013 of 0.46 km² (114 acres).

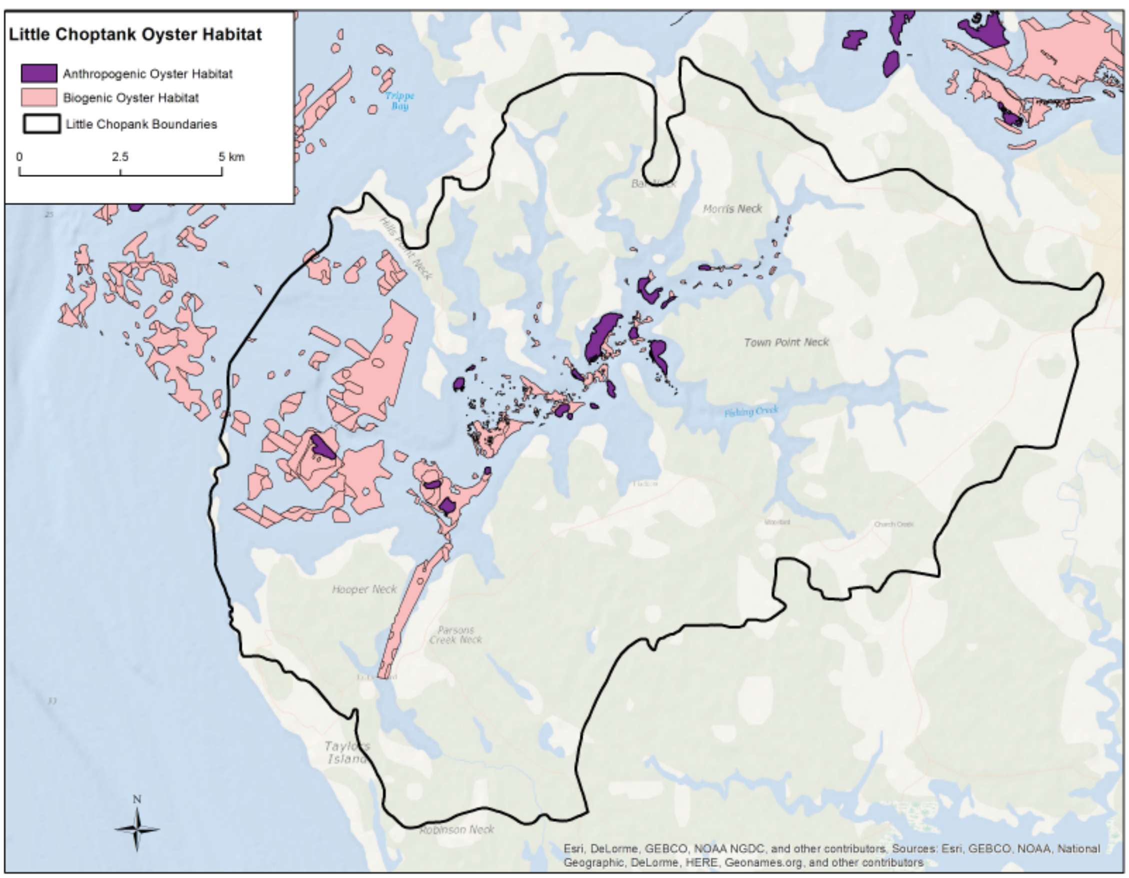

Figure 8.10. Little Choptank anthropogenic reef with total area of 1.52 km² (356 acres) and biogenic reef with total area of 13.50 km² (3,336 acres).

OYSTER MONITORING AND ASSESSMENT

Because of their long-standing prominence in Chesapeake fisheries, vital statistics of oyster populations have been monitored and reported on an annual basis for many decades. Maryland's Annual Fall Oyster Survey has been conducted for 75 years (1939-2014), providing consistent time-series data on the status of oyster populations (Tarnowski, 2015). Some of the sites sampled annually are called "key bars" based on sampling protocol, and some are also known as "disease bars" because they are monitored for oyster diseases, including Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*). The Maryland bay-wide monitoring program includes 264 sites, with eleven of these in the Choptank HFA, listed in Table 8.1 and mapped in Figure 8.11. Parameters monitored by the MD DNR at specific sites include:

- Spatfall Intensity Index
- Total Observed Mortality
- Biomass Index
- Dermo disease prevalence and mean intensity, reported for "disease bars"
- MSX disease prevalence, reported for "disease bars"
- Annual harvest, reported by tributary/sub-estuary

Other monitoring programs report on other vital parameters. A cooperative program of MD DNR and Virginia Institute of Marine Sciences (VIMS) developed estimates of oyster population abundance on a per-tributary (sub-estuary) scale from 1994 to 2006 (Greenhawk et al., 2007; VIMS, 2015). At restoration sites in Harris Creek and the Little Choptank, specific parameters are being monitored by University of Maryland scientists to assess progress and assist future efforts (Paynter et al., 2014; Chesapeake Conservancy, 2015). NOAA's Chesapeake Bay Office has incorporated many of the monitored parameters into an "Oyster Decision Support Tool", for online display and analysis of data (NOAA/CBO, 2015c).

Table 8.1. Eleven MD DNR monitoring sites for annual oyster population status report (Tarnowski, 2015) in the Choptank HFA. Sites are designated as "key" and/or "disease" bars based on the parameters monitored, and some fall within a designated oyster sanctuary.

Waterbody	Site Name	Longitude	Latitude	Notes
Choptank River	Cooks Point	-76.284105	38.650878	Key Bar, Disease Bar, Sanctuary
	Royston	-76.245194	38.685425	Key Bar, Disease Bar
	Lighthouse	-76.186172	38.654660	Disease Bar
	Sandy Hill	-76.117063	38.596414	Key Bar, Disease Bar, Sanctuary
	Oyster Shell Point	-76.002097	38.588184	Disease Bar, Sanctuary
Harris Creek	Tilghman Wharf	-76.321632	38.705571	Key Bar, Disease Bar
	Eagle Point	-76.307490	38.731062	Key Bar
Broad Creek	Deep Neck	-76.247963	38.733933	Key Bar, Disease Bar
Tred Avon River	Double Mills	-76.138159	38.731290	Key Bar, Disease Bar, Sanctuary
Little Choptank River	Cason	-76.245345	38.531022	Key Bar, Disease Bar, Sanctuary
	Ragged Point	-76.295802	38.533805	Key Bar, Disease Bar

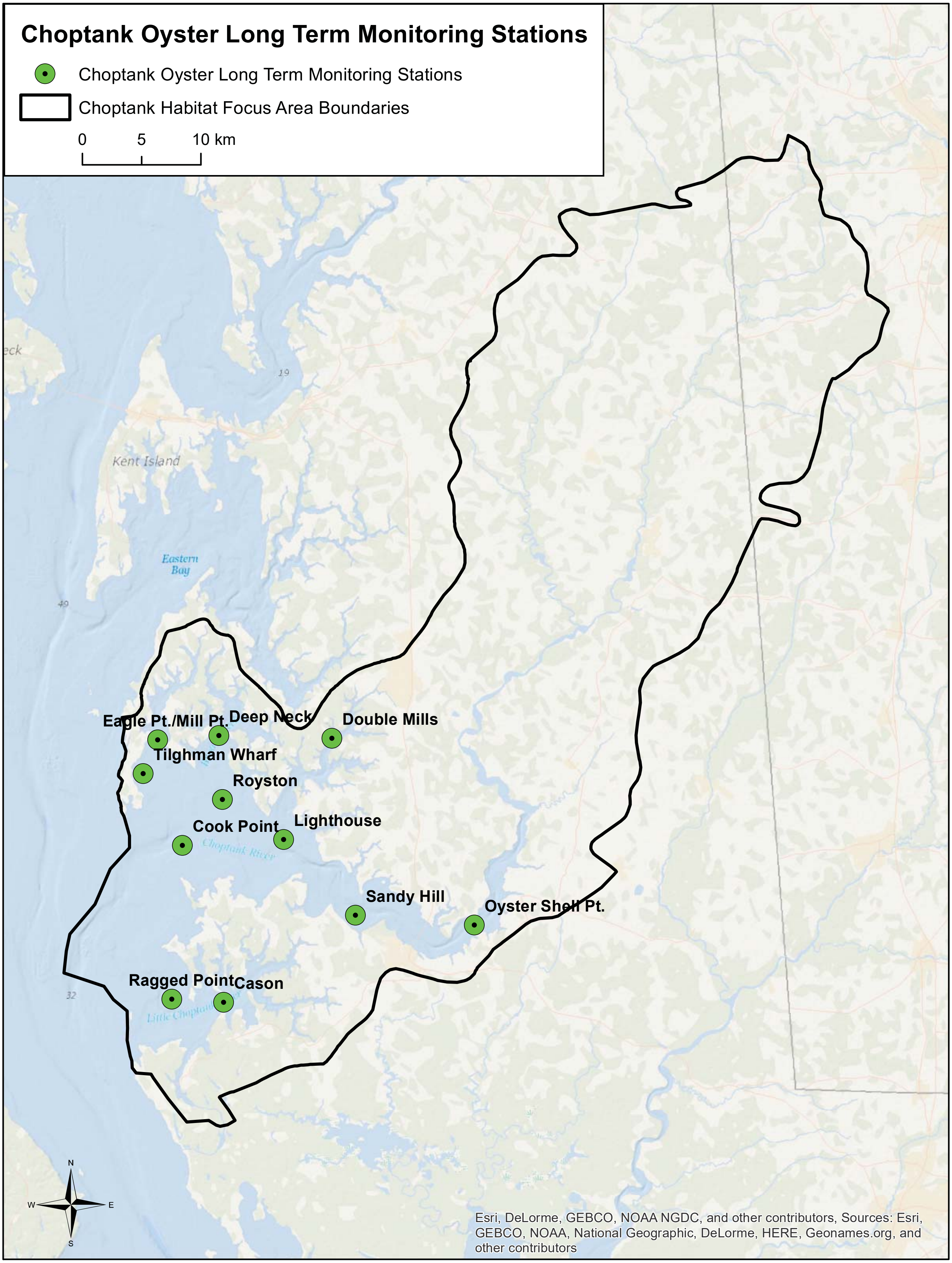

Figure 8.11. Eleven long-term oyster monitoring sites in the Choptank HFA (Tarnowski, 2015; Smith et al., 1997).

Choptank Oyster Monitoring

Oyster Spatfall Index and Recruitment

The Oyster Spatfall Index is one of the vital parameters monitored annually by the MD DNR Fall Survey (Tarnowski, 2015), measured as number of juvenile oysters (spat) which have set upon oyster shell, per bushel of shell sampled. It provides a useful measure of successful reproduction, or recruitment, to future years of growth. Spatfall is influenced by many environmental variables as well as the number of spawning adult oysters, and is therefore highly variable between years and location. Figure 8.12 depicts the inter-annual variability in spatfall, using numbers averaged across nine “key bar” sampling stations in the greater Choptank HFA. Even when data are averaged among locations, the high inter-annual variability is evident. Recruitment in 2014 was below long-term averages, but follows high recruitment years in 2010 and 2012.

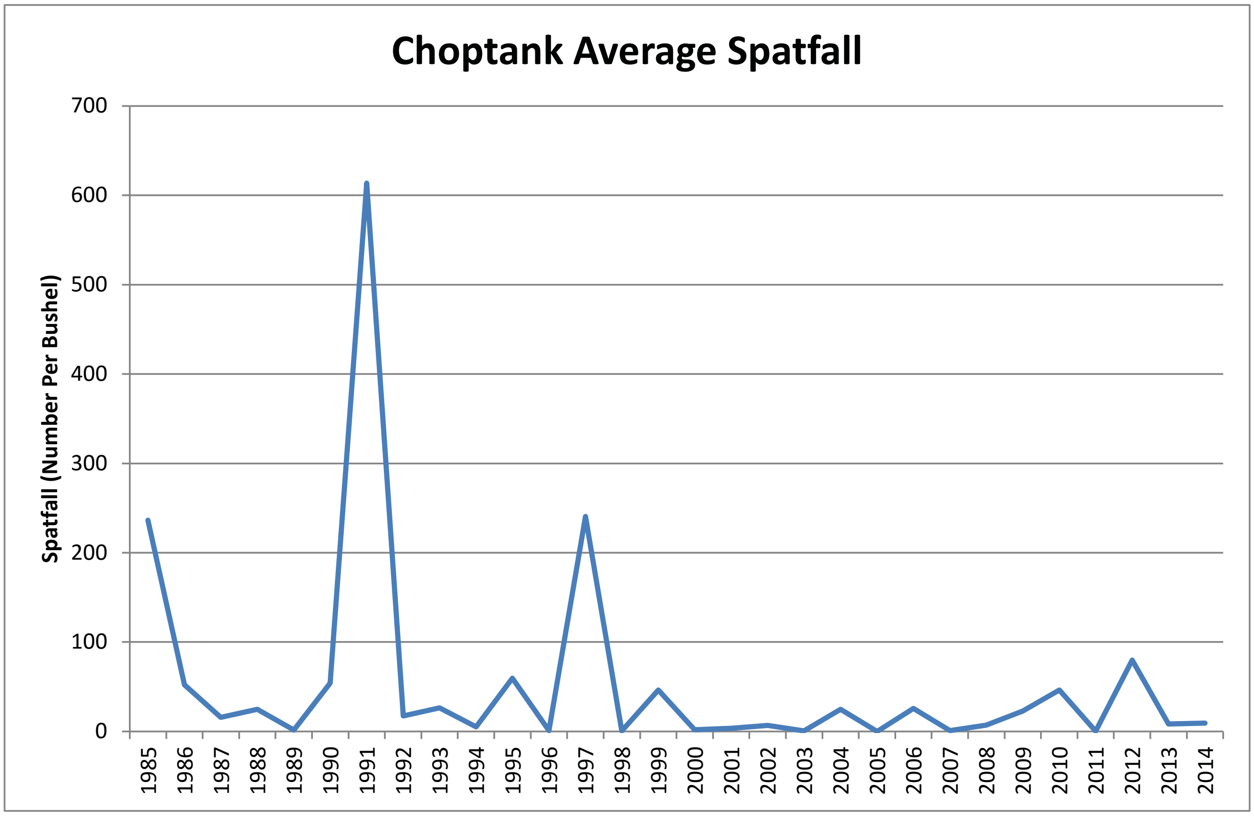

Figure 8.12. Shows average oyster spatfall (average number of spatfall per bushel) from 9 oyster bars (3 in the Lower and Outer Choptank River, 2 at Harris Creek, 2 at Little Choptank, 1 at Tred Avon River, and 1 at Broad Creek) in the Choptank from 1985 to 2014 (Tarnowski, 2015).

Recruitment success varies among locations as well as years. Figure 8.13 depicts the spatfall index for five sub-estuaries of the Choptank HFA, with both spatial and temporal variability evident from 1985 to 2014 (Tarnowski, 2015). High-recruitment years tend to coincide in each of the areas, but in any given year it will vary among locations. In the high-recruitment year of 2012, the highest measured spatfall was in Broad Creek, whereas the Little Choptank had the highest measured spatfall in 1991. When compared with other locations in the greater Chesapeake, a pattern of spatial and temporal variability emerges. In any given year, recruitment is higher or lower among locations throughout the Bay, but with high variability among locations. High recruitment generally leads to higher landings three to four years later, as oysters grow to harvestable size.

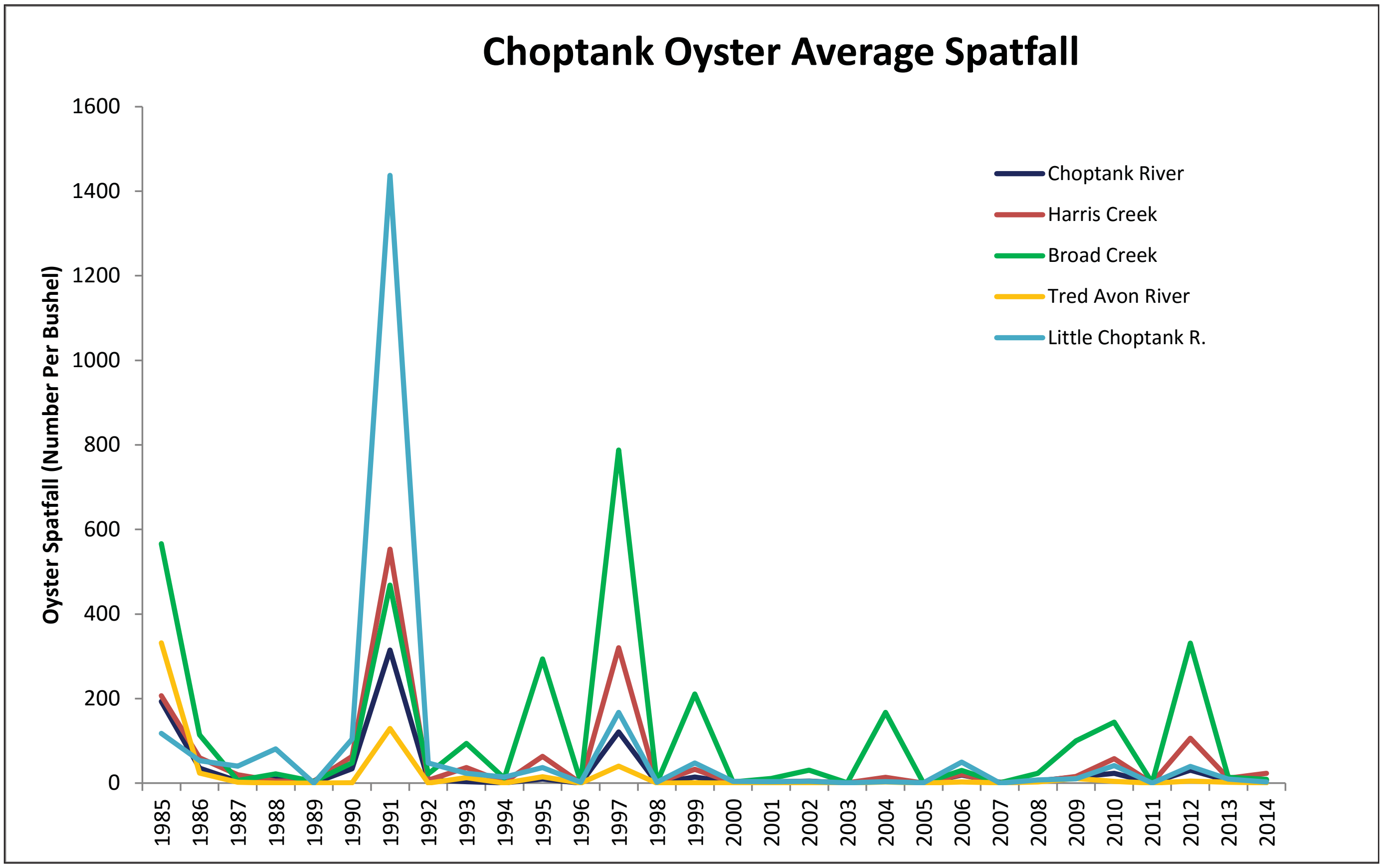

Figure 8.13. Average oyster spatfall (number of spatfall per bushel) at different Choptank sub-watersheds from 1985 to 2014 (Tarnowski, 2015).

Oyster Diseases and Mortality

Throughout its range, the eastern oyster is susceptible to many infectious diseases and parasites which can cause mortality of individuals, and adverse impacts on the growth and reproduction of populations. Causative agents include viruses, bacteria, fungi, and protozoans (Ford and Tripp, 1996). For some diseases, the etiological agents are still unknown. In the Choptank HFA, two of the major diseases affecting oysters are Dermo, caused by protozoan *Perkinsus marinus*, and MSX, caused by protozoan *Haplosporidium nelsoni*. In some years, either or both of these diseases can infect oysters in the Choptank and increase natural mortality in populations. These two diseases are monitored by the MD DNR's annual oyster survey, by sampling 30 oysters from locations known as "disease bars", ten of which are within the Choptank HFA. Dermo is assessed for both prevalence within a sample (reported as percent infected), and intensity (reported on a numeric scale from 0 to 7) (Tarnowski, 2015). Both pathogens are affected by environmental conditions including temperature and salinity, so the prevalence and effects of these diseases are highly variable between years and locations. Ideal conditions for Dermo are temperatures from 25 to 30 degrees C and salinities greater than 15 ppt, and MSX is intolerant of salinities below 10 ppt (Ford and Tripp, 1996). Because of its intolerance of low salinities, MSX tends to be more prevalent in the Choptank region during dry years, with higher than average salinities, whereas it may be more continually present in higher salinity areas of the Lower Chesapeake.

Figure 8.14 depicts the annual prevalence of Dermo in the Choptank HFA, averaged across ten "disease bar" sample locations from 1990 to 2014 (Tarnowski, 2015). Annual average prevalence varies from 26% in 2005, to 98% in 2002. Figure 8.15 illustrates the spatial variation among Choptank sub-estuaries. Dermo prevalence is high in all areas in some years (e.g., 2001-2002), but since 2008 is apparently much lower in Harris Creek than in the other areas. The assessed intensity of Dermo infections also varies among years and locations. When assessed on a 0-7 scale and averaged across the ten "disease bars" in the Choptank region (Figure 8.16), it varies from 4.1 in 2001 to 0.7 in 2005. Among sub-estuaries, Dermo intensity has been higher in all locations in some years (e.g., 2000-2002), but apparently lower in Harris Creek from 2008 to 2014 (Figure 8.17).

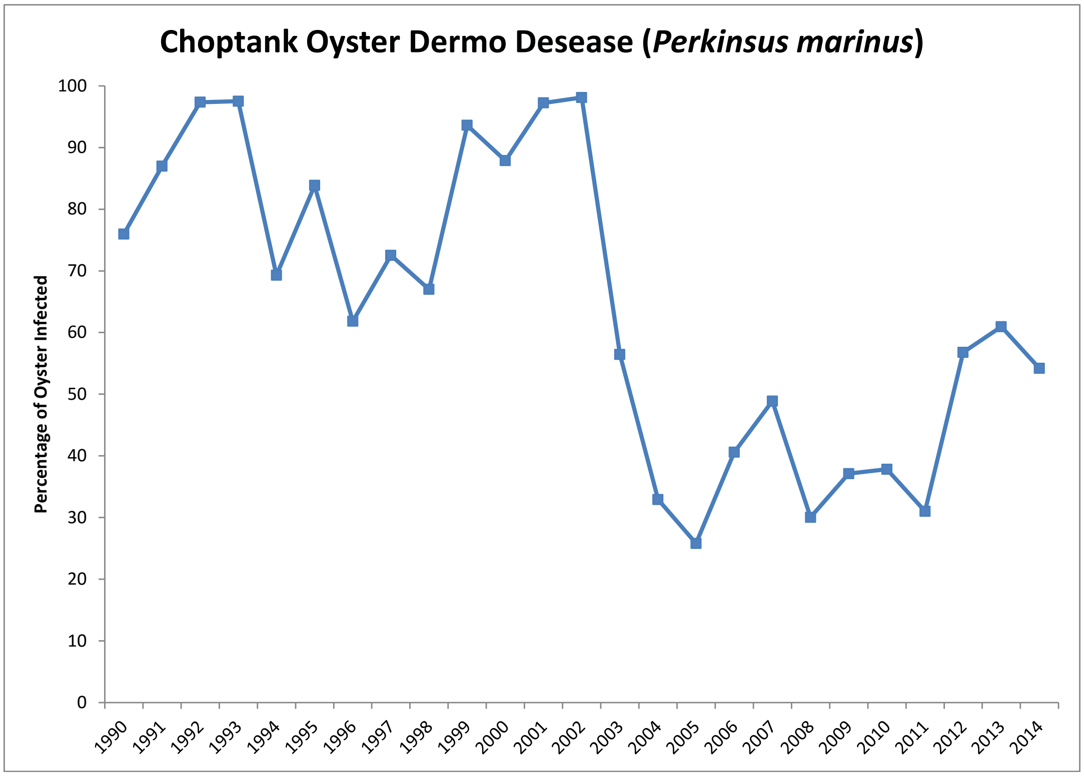

*Figure 8.14. The average percentage for oyster infected with Dermo disease (*Perkinsus marinus*) from 10 oyster bars (5 at the Lower and Outer Choptank River, 2 at Little Choptank, 1 at Harris Creek, 1 at Broad Creek, and 1 at Tred Avon River) in the Choptank from 1990 to 2014 (Tarnowski, 2015).*

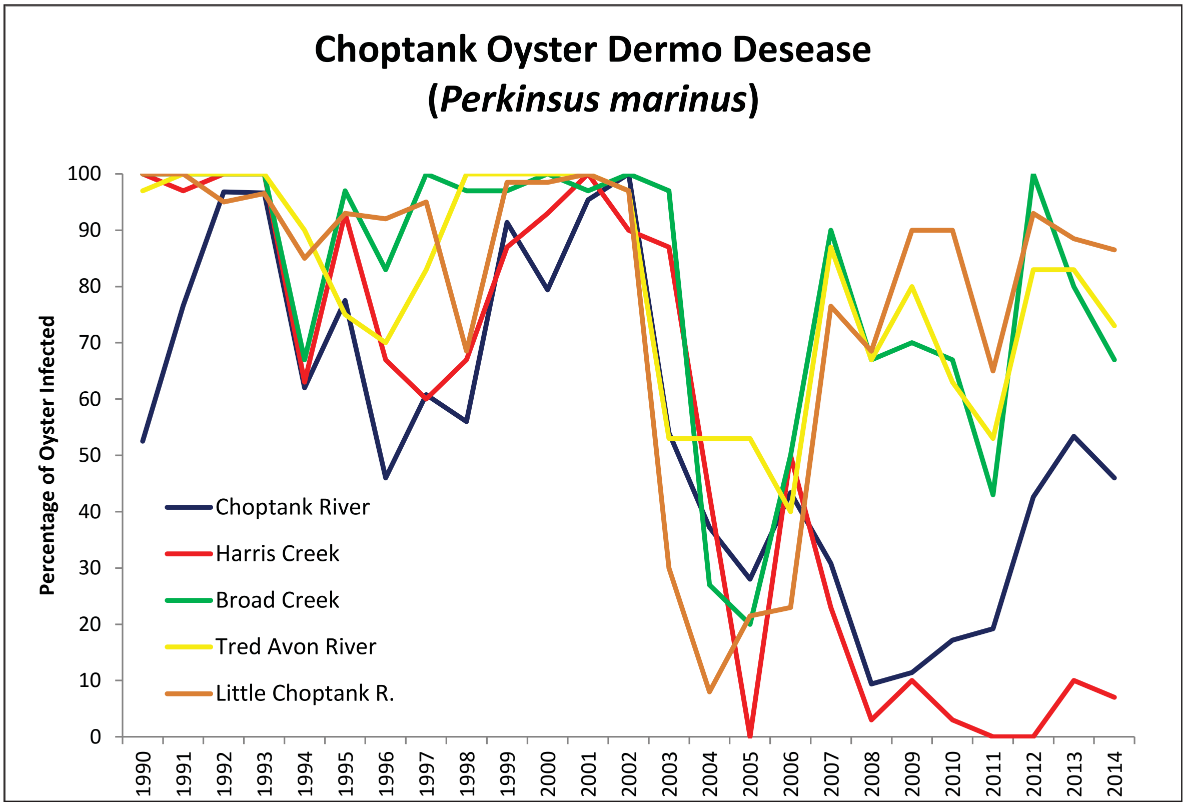

*Figure 8.15. The percentage of oysters infected with Dermo disease (*Perkinsus marinus*) at different Choptank sub-watersheds from 1990 to 2014 (Tarnowski, 2015).*

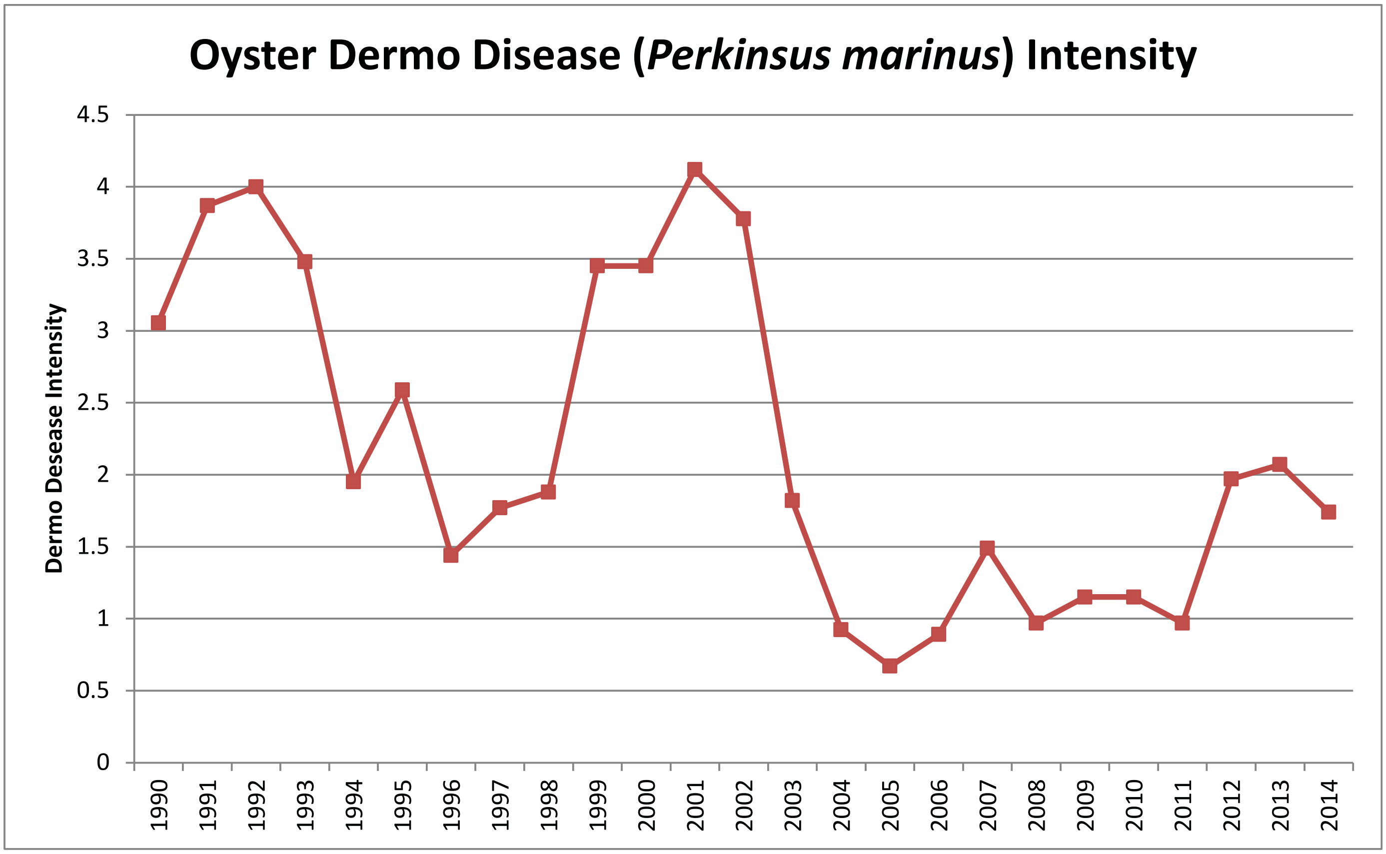

*Figure 8.16. Average oyster infection intensity (0-7) with Dermo disease (*Perkinsus marinus*) from 10 oyster bars (5 at the Lower and Outer Choptank River, 2 at Little Choptank, 1 at Harris Creek, 1 at Broad Creek, and 1 at Tred Avon River) in the Choptank from 1990 to 2014 (Tarnowski, 2015).*

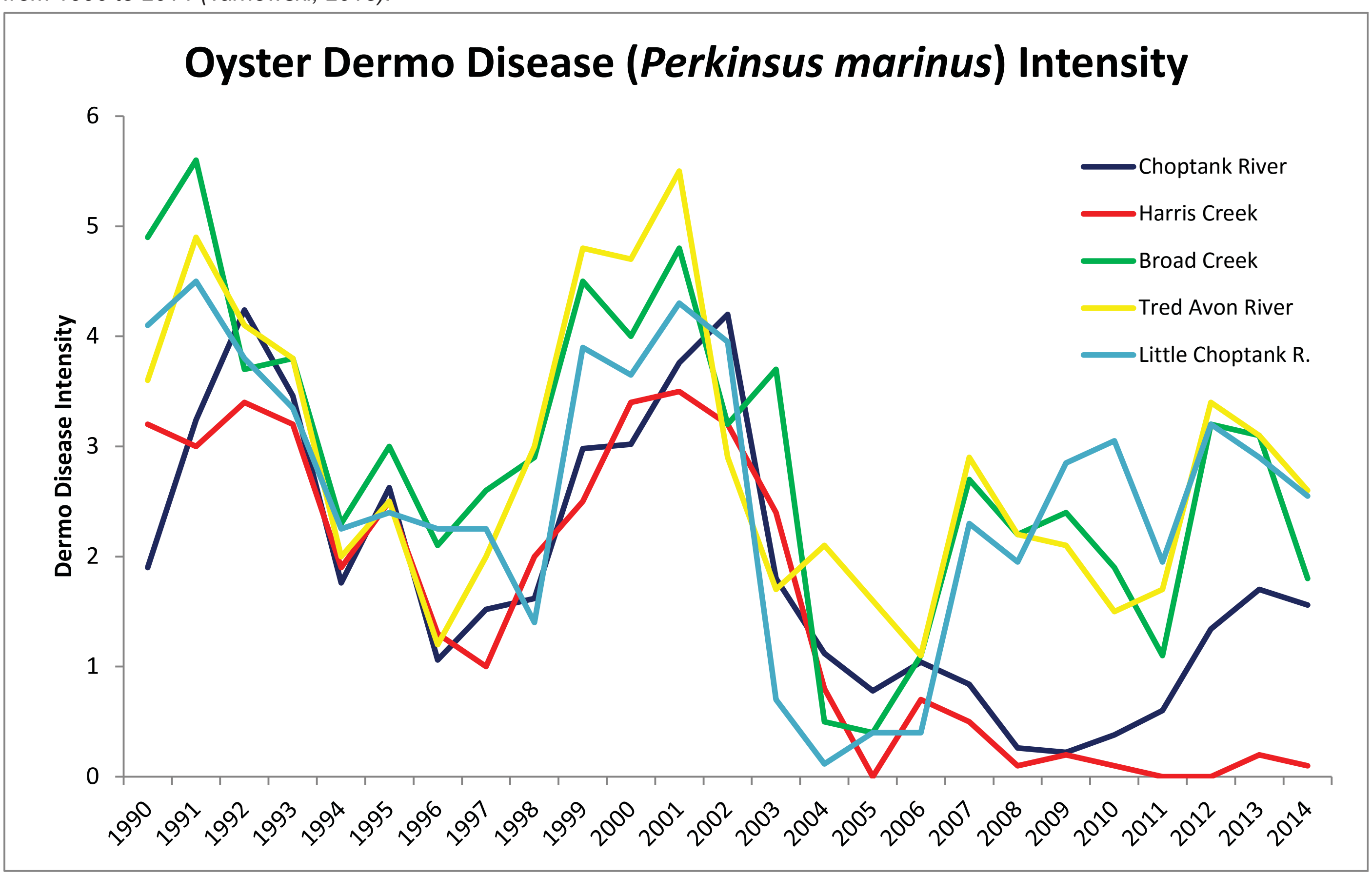

*Figure 8.17. Oyster average infection intensity for Dermo disease (*Perkinsus marinus*) at different Choptank sub-watersheds from 1990 to 2014 (Tarnowski, 2015).*

The protozoan causing MSX disease, *Haplosporidium nelsoni*, is more strongly associated with high salinity conditions than is the Dermo pathogen (Ford and Tripp, 1996). Therefore, MSX in the Choptank region is less prevalent, and generally peaks only in dry years with less freshwater inflow and higher estuarine salinities. Figure 8.18 depicts the annual prevalence of MSX in the Choptank HFA, averaged across ten "disease bar" sample locations from 1990 to 2014 (Tarnowski, 2015). Prevalence has been very low since 2011, but there are notable peaks in 2009, 2002 (peak of a four-year epizootic from 2001-2004), and 1992. In the years when MSX is prevalent, it appears to affect the higher salinity areas such as the Little Choptank, adjacent to the Chesapeake mainstem, more than lower salinity tributaries such as the Tred Avon (Figure 8.19).

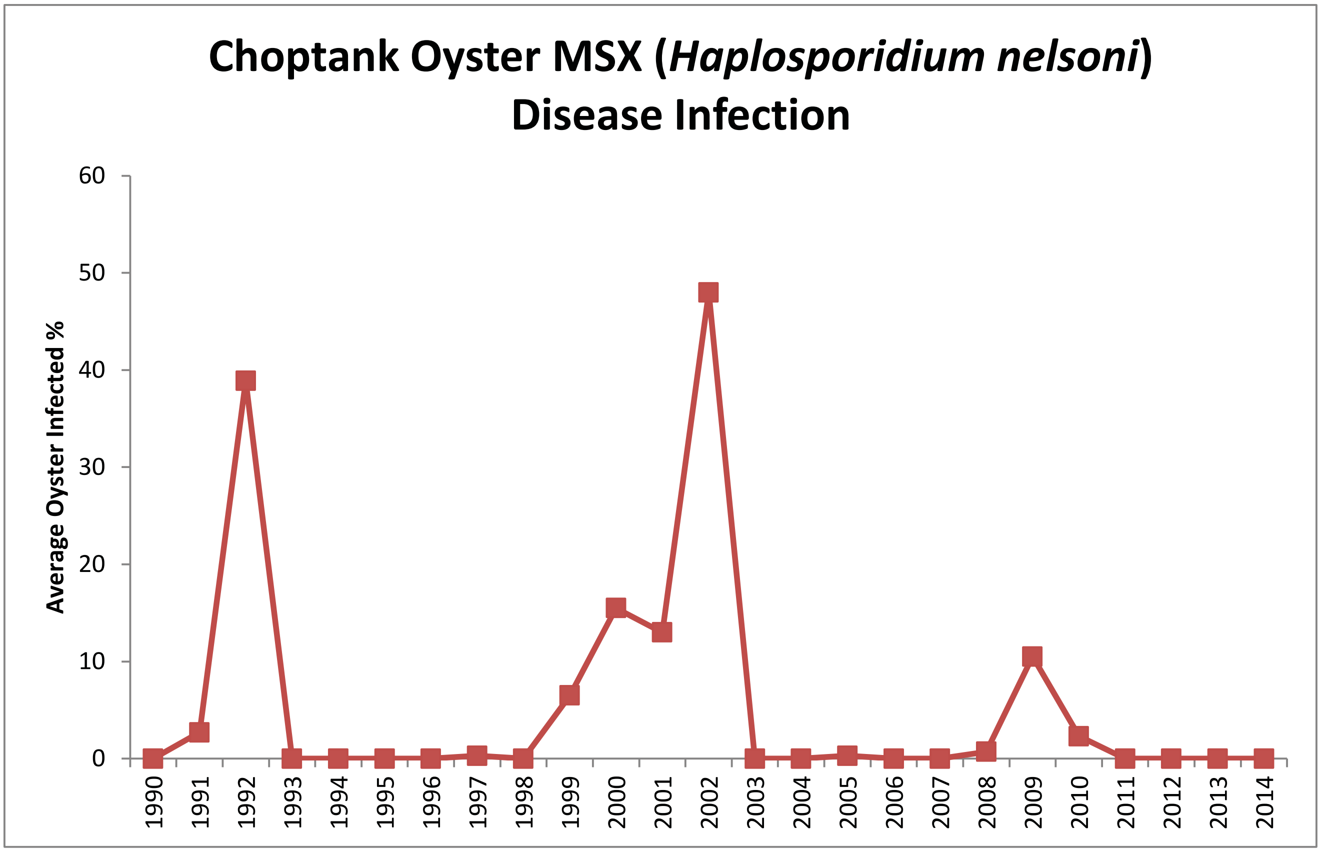

*Figure 8.18. The average percentage for oyster infected with MSX disease (*Haplosporidium nelsoni*) from 10 oyster bars (5 at the Lower and Outer Choptank River, 2 at Little Choptank, 1 at Harris Creek, 1 at Broad Creek, and 1 at Tred Avon River) in the Choptank from 1990 to 2014 (Tarnowski, 2015).*

Although MSX is only sporadically significant in the Choptank region, both MSX and Dermo contribute substantially to natural mortality. Figure 8.20 depicts annual natural mortality in the Choptank HFA, averaged across sample locations from 1985 to 2014 (Tarnowski, 2015). The inter-annual variability of mortality ranging from 4% to 9% over the past ten years (2005-2014) is dwarfed by the marked mortality event of 2002, when the average annual mortality peaked at 86% at ten sites in the Choptank region and was estimated at 58% for the Maryland portion of the Chesapeake Bay (Tarnowski, 2015) (Figures 8.20 and 8.21). Much of this mortality can be attributed to Dermo and MSX, which peaked at 98% and 48% prevalence (respectively) in the Choptank HFA in that year. Diseases are not the only factors contributing to natural mortality. In waters of the upper Chesapeake, where salinities are typically at the lower portion of the oyster's optimal range, flood events can drop salinities to well below optimum for extended periods of time. In other areas, periodic low DO conditions can affect mortality and growth.

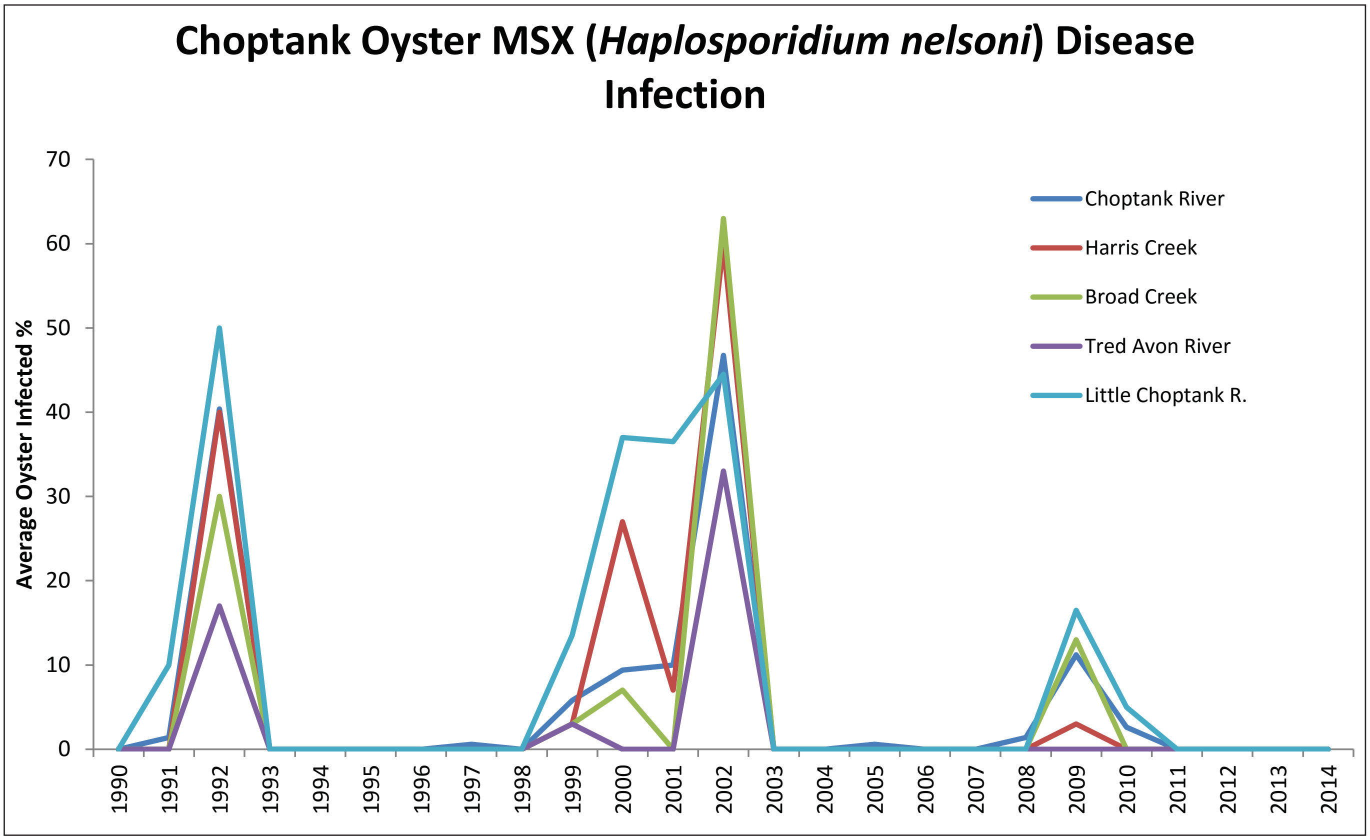

*Figure 8.19. Percentage of oysters infected with MSX disease (*Haplosporidium nelsoni*) at different Choptank sub-watersheds from 1990 to 2014 (Tarnowski, 2015).*

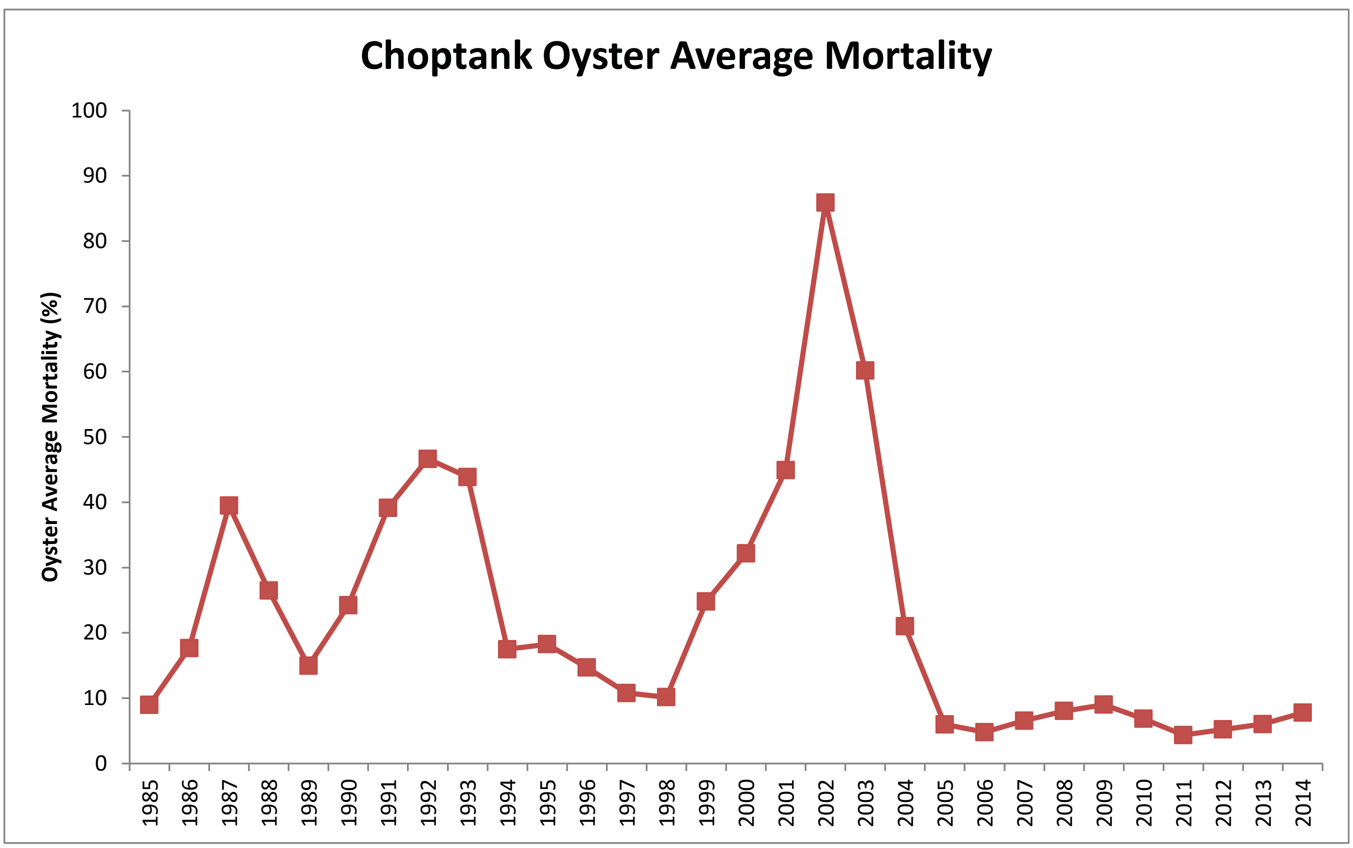

Figure 8.20. The average percentage for oyster mortality from 10 oyster bars (5 at the Lower and Outer Choptank River, 2 at Little Choptank, 1 at Harris Creek, 1 at Broad Creek, and 1 at Tred Avon River) in the Choptank from 1990 to 2014 (Tarnowski, 2015).

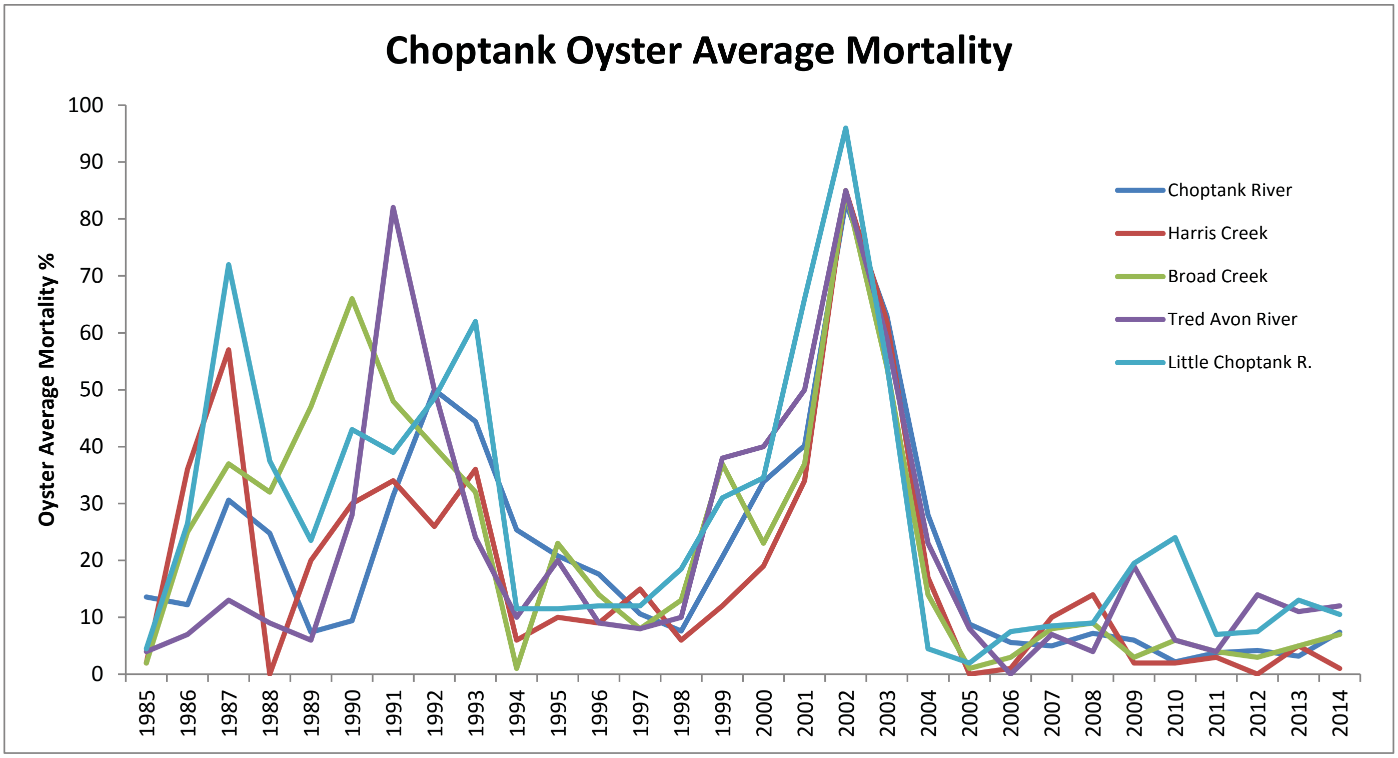

Figure 8.21. Percentage of oyster mortality at different Choptank sub-watersheds from 1990 to 2014 (Tarnowski, 2015).

HARVEST OF OYSTERS

Because of the importance of oysters in the early economy and cultural life of Maryland, their fisheries have been the subject of state legislation and political management as early as the 1820s. The harvest of oysters in Maryland peaked in the late 1800s to meet growing demand, following the depletion of oyster populations in southern New England (Kennedy and Breisch, 1983). Bay-wide harvest levels are now at a small fraction of their peak, often cited as around 1% (NOAA/CBO, 2015b). The long term trend in the Choptank region generally parallels that of the greater Chesapeake, although the Choptank remains one of the major oyster harvesting regions in Maryland's portion of the Chesapeake Bay. From 1985 to 2014, the Choptank (including tributaries and Little Choptank) accounted for approximately 32% of the harvest from Maryland's Chesapeake Bay (Tarnowski, 2015).

Figure 8.22 illustrates the temporal trend in oyster landings from the Choptank region, including tributaries (Harris Creek, Broad Creek, Tred Avon River) and Little Choptank River. The recent increase in landings 2013-2014 is likely associated with the strong recruitment (spatfall) year of 2010. Similar trends can be discerned in the 1980s and 90s, where high spatfall contributes to higher harvest in subsequent years.

Landings in sub-estuaries with more waters open to harvest (e.g., Broad Creek) are higher than landings where a large proportion of the sub-estuary is designated as oyster sanctuary (e.g., Harris Creek) (Figure 8.23).

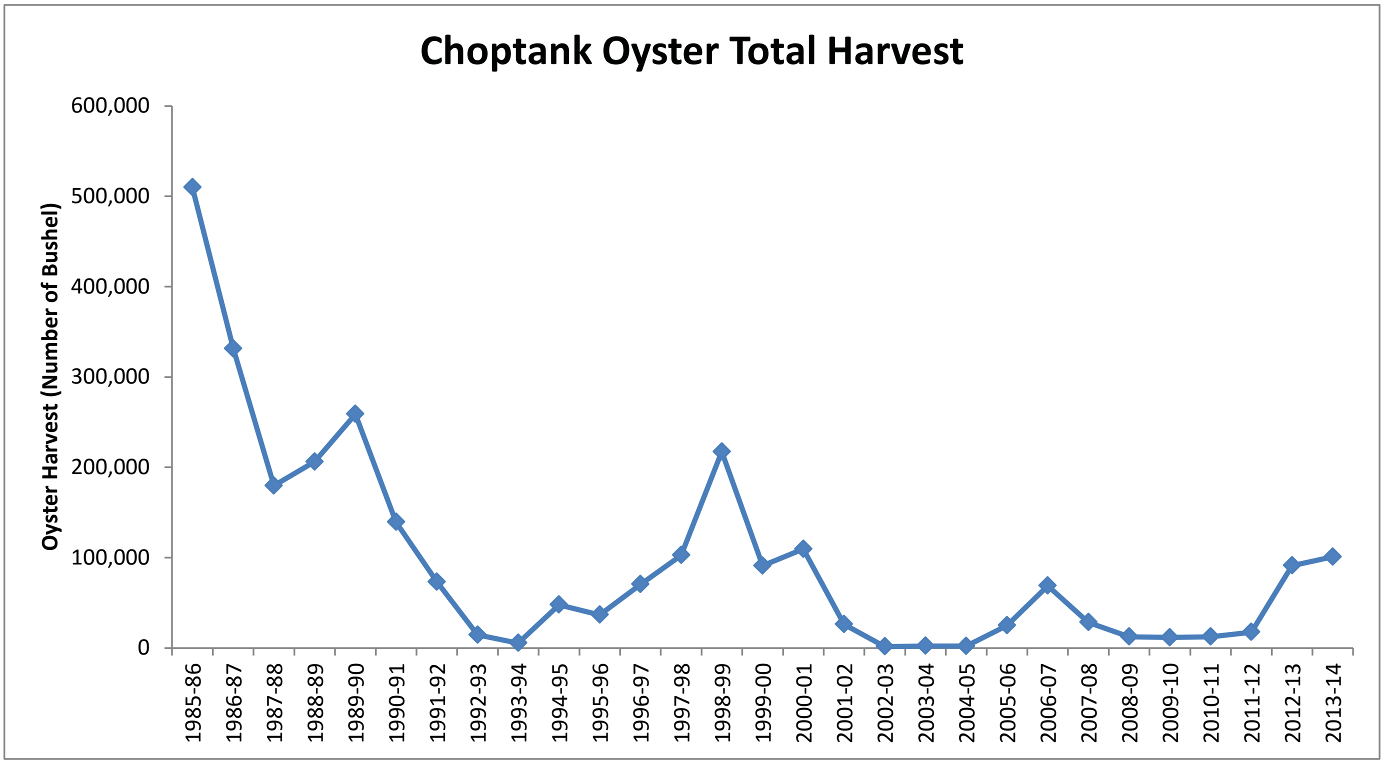

Figure 8.22. The total oyster harvest (number of bushels) for Choptank River from 1985 to 2014 (Tarnowski, 2015).

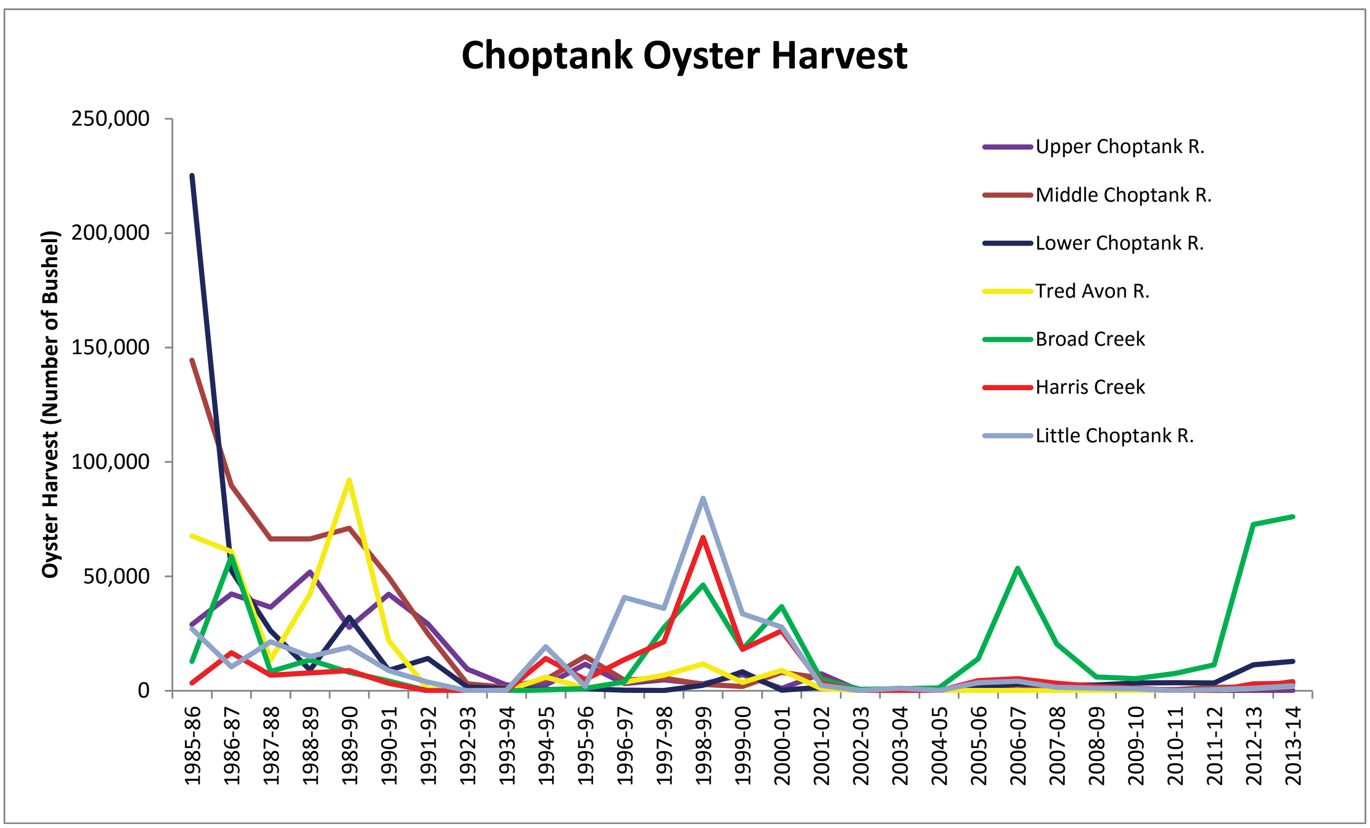

Figure 8.23. Oyster harvest (number of bushels) for Choptank sub-watersheds from 1995 to 2014 (Tarnowski, 2015).

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Appendix A

Table A.1. The status (2014) of the Choptank water quality indicators and the linear trend analysis results for 1984-2014. Data for the long term monitoring stations of the Choptank River, Chesapeake Bay Program.

Parameter	Station	Mean	Status 2014	Trend 1984-2014		
				Status	R^2	p
DO mg/l	Outer Choptank EE2.1	6.987	Meet	NT	NT	NT
	Little Choptank EE2.2	5.543	Meet	NT	NT	NT
	Upper Choptank ET5.0	7.300	Meet	NT	NT	NT
	Middle Choptank ET5.1	6.761	Meet	MB DEC	0.1679	0.022
	Lower Choptank ET5.2	6.293	Meet	NT	NT	NT
	Tuckahoe Creek TUK0181	7.283	Meet	NT	NT	NT
BDO mg/l	Outer Choptank EE2.1	5.625	Meet	NT	NT	NT
	Little Choptank EE2.2	0.425	Fail	NT	NT	NT
	Upper Choptank ET5.0	NA	NA	NT	NT	NT
	Middle Choptank ET5.1	6.500	Meet	DEC	0.2233	0.0073
	Lower Choptank ET5.2	5.300	Meet	NT	NT	NT
TN mg/l	Outer Choptank EE2.1	0.679	Meet	NT	NT	NT
	Little Choptank EE2.2	0.650	Meet	NT	NT	NT
	Upper Choptank ET5.0	1.803	Fail	NT	NT	NT
	Middle Choptank ET5.1	2.431	Fail	INC	0.35065	0.0004
	Lower Choptank ET5.2	0.997	Fail	NT	NT	NT
CHLA µg/l	Outer Choptank EE2.1	9.465	Meet	INC	0.265	0.0005
	Little Choptank EE2.2	9.635	Meet	MB INC	0.1884	0.0166
	Upper Choptank ET5.0	2.544	Meet	NT	NT	NT
	Middle Choptank ET5.1	11.995	Meet	DEC	0.3091	0.0012
	Lower Choptank ET5.2	15.182	Fail	INC	0.3465	0.0005
SECCHI Disk meter	Outer Choptank EE2.1	1.440	Fail	DEC	0.2513	0.0041
	Little Choptank EE2.2	1.358	Fail	DEC	0.3168	0.0012
	Upper Choptank ET5.0	NA	NA	NT	NT	NT
	Middle Choptank ET5.1	0.333	Fail	NT	NT	NT
	Lower Choptank ET5.2	0.909	Fail	DEC	0.3509	0.0004
Water T ºC	Outer Choptank EE2.1	13.725	NA	DEC	0.6208	<0.0001
	Little Choptank EE2.2	13.591	NA	NT	NT	NT
	Upper Choptank ET5.0	14.363	NA	NT	NT	NT
	Middle Choptank ET5.1	15.683	NA	DEC	0.2852	0.002
	Lower Choptank ET5.2	14.158	NA	DEC	0.0451	0.0001
Salinity ppt	Outer Choptank EE2.1	11.929	NA	NT	NT	NT
	Little Choptank EE2.2	12.698	NA	NT	NT	NT
	Upper Choptank ET5.0	0.000	NA	NT	NT	NT
	Middle Choptank ET5.1	0.515	NA	MB DEC	0.1239	0.0488
	Lower Choptank ET5.2	9.188	NA	NT	NT	NT

NT=No Trend; MB DEC=Maybe Decreasing ($0.01<p<0.05$); DEC=Decreasing ($p\leq0.01$); INC= Increasing ($p\leq0.01$); and MB INC=Maybe Increasing ($0.01<p<0.05$).

Table A.2. The status (2014) of the Choptank total phosphorus and total suspended solids and the linear trend analysis results for 1985-1997 and 1999-2014.

Parameter	Station	Mean	Status 2014	Trend 1985-1987			Trend 1999-2014		
				Status	R^2	p	Status	R^2	p
TP mg/l	Outer Choptank EE2.1	0.023	Meet	MB DEC	0.3247	0.0266	NT	NT	NT
	Little Choptank EE2.2	0.022	Meet	DEC	0.5353	0.0029	NT	NT	NT
	Upper Choptank ET5.0	0.072	Fail	NT	NT	NT	NT	NT	NT
	Middle Choptank ET5.1	0.100	Fail	NT	NT	NT	NT	NT	NT
	Lower Choptank ET5.2	0.036	Meet	NT	NT	NT	NT	NT	NT
TSS mg/l	Outer Choptank EE2.1	5.500	Meet	MB INC	0.3139	0.0298	NT	NT	NT
	Little Choptank EE2.2	5.354	Meet	MB INC	0.3112	0.0382	NT	NT	NT
	Upper Choptank ET5.0	2.809	Meet	NT	NT	NT	MB DEC	0.2564	0.0453
	Middle Choptank ET5.1	23.833	Fail	NT	NT	NT	NT	NT	NT
	Lower Choptank ET5.2	9.108	Meet	INC	0.6328	0.0004	NT	NT	NT

NT=No Trend; MB DEC=Maybe Decreasing ($0.01<p<0.05$); DEC=Decreasing ($p\leq0.01$); INC= Increasing ($p\leq0.01$); and MB INC=Maybe Increasing ($0.01<p<0.05$).

Appendix B

Table B.1. Evaluation for the water quality indicator parameters for Choptank River 2014. Data for the long term monitoring stations of the Choptank River, Chesapeake Bay Program.

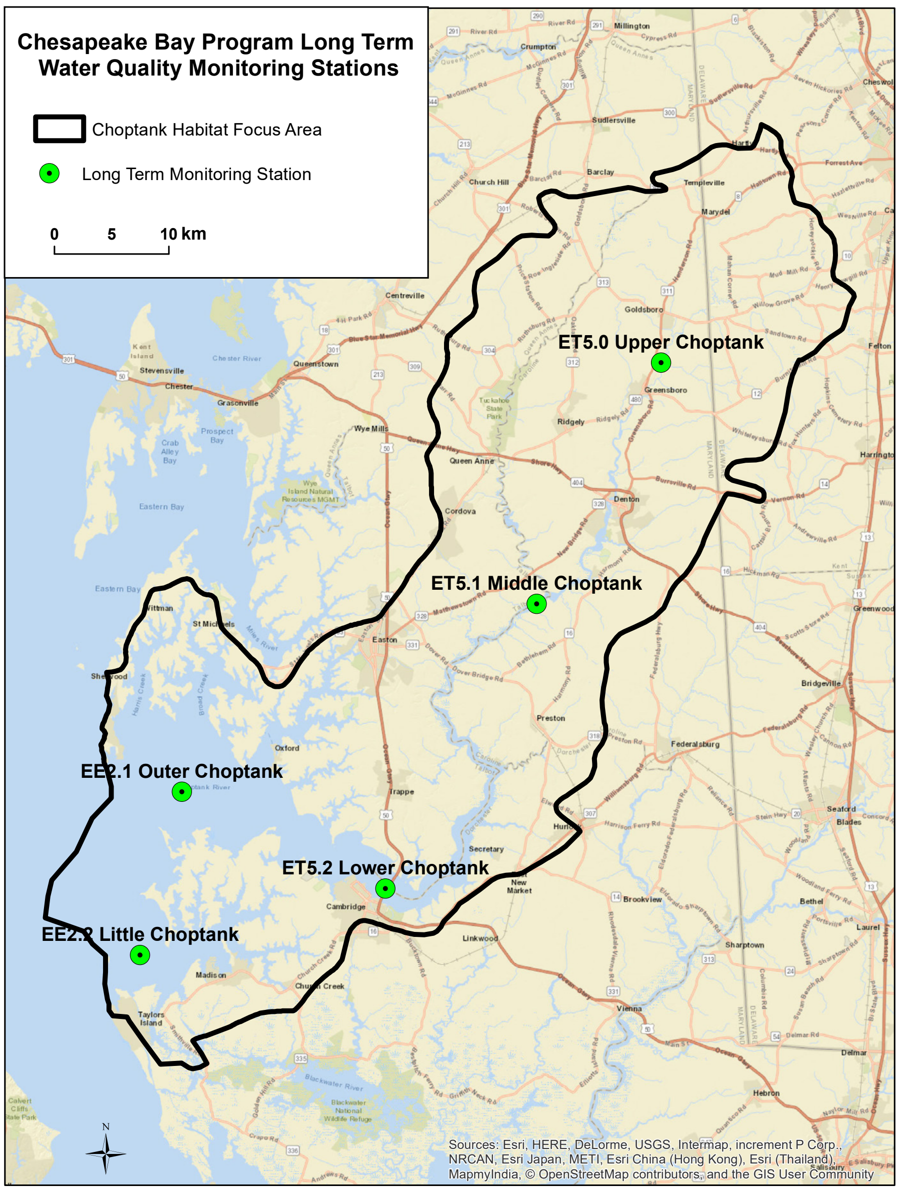
Station	DO mg/l		BDO mg/l		TN mg/l		TP mg/l		CHLA µg/l		SECCHI Disk m		TSS mg/l	
	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014	Mean	Status 2014
Outer Choptank EE2.1	6.988	Meet	5.625	Meet	0.680	Fail	0.023	Meet	9.465	Meet	1.440	Fail	5.500	Meet
Little Choptank EE2.2	5.543	Meet	0.425	Fail	0.650	Meet	0.022	Meet	9.635	Meet	1.358	Fail	5.354	Meet
Lower Choptank ET5.2	6.294	Meet	5.300	Meet	0.998	Fail	0.036	Meet	15.183	Fail	0.909	Fail	9.108	Meet
Middle Choptank ET5.1	6.762	Meet	6.500	Meet	2.431	Fail	0.100	Fail	11.996	Meet	0.333	Fail	23.833	Fail
Upper Choptank ET5.0	7.300	Meet	NA	NA	1.804	Fail	0.072	Fail	2.544	Meet	NA	NA	2.809	Meet
Tuckahoe Creek TUK0181	7.283	Meet	NA	NA	4.047	Fail	0.149	Fail	NA	NA	NA	NA	12.720	Meet

Appendix C

The following materials present detailed information for the Chesapeake Bay Program's long term water quality monitoring program. Information is presented both inter-annually and on a monthly basis in order to enable assessment of trends across seasonal variations. The parameters included are Dissolved Oxygen (DO), Total Nitrogen (TN), Total Phosphorus (TP) and Chlorophyll *a* (CHLA).

Each figure has two graphs showing the concentration of individual parameters charted across months and years and color coded to established water quality criteria. The first graph is a level plot and the second is a 3-dimensional version of the same data.

The measurements for each parameter by month and then tracking trend over time is shown. A Generalized Additive Mixed Model (GAMM) was used in order to assess trend over time while accounting for seasonal variation. The main reference used for the GAMM was the book written by Simon N. Wood (2006) Generalized Additive Models: An Introduction with R, Chapman and Hall/CRC, New York, pp. 392. Analytic software used was the R-package mgcv developed by Simon Wood. The graphic packages used were lattice and latticeExtra. These R-packages were obtained from CRAN.R-project.org. The SAS package was used to manipulate the data.

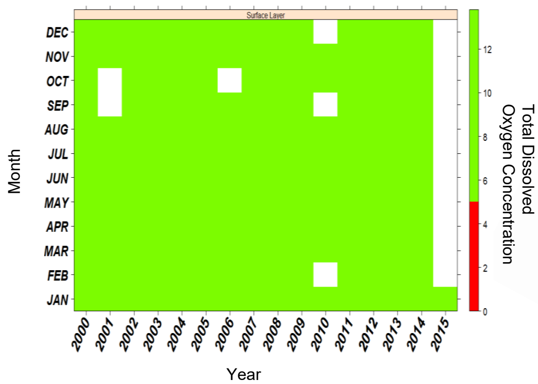


Map of the Chesapeake Bay Program's Long Term Water Quality Monitoring Stations.

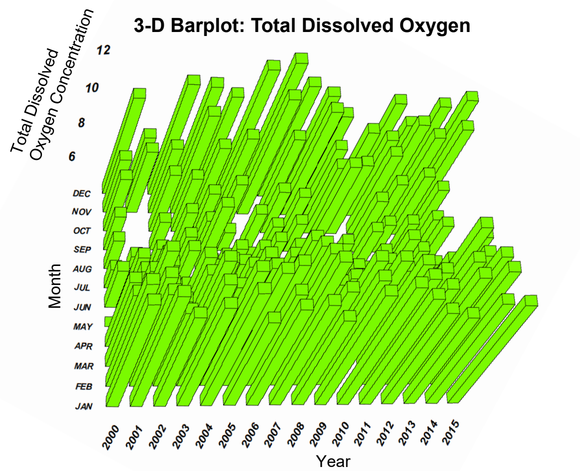
Parameter: Dissolved Oxygen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: DO F01

Key Summarization:
Low levels of dissolved oxygen have consistently occurred during summer months, but levels have remained above 5 mg/l during all months and over all years.

Level Plot: Dissolved Oxygen



3-D Barplot: Total Dissolved Oxygen



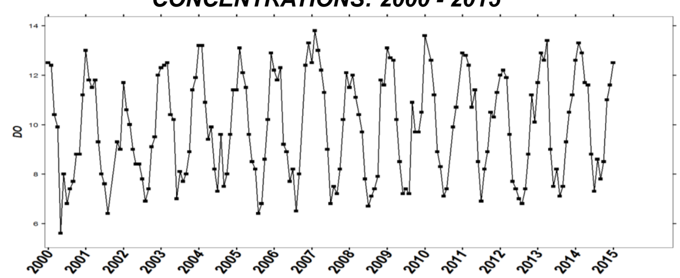
LEGEND FOR SURFACE DISSOLVED OXYGEN CONCENTRATIONS
WHITE Is No Sample
RED is Low (< 5 mg/l)
GREEN Is Good (> 5 mg/l)

Figure C.1. Monthly surface dissolved oxygen (mg/l) at Little Choptank station EE2.2.

Parameter: Total Dissolved oxygen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface

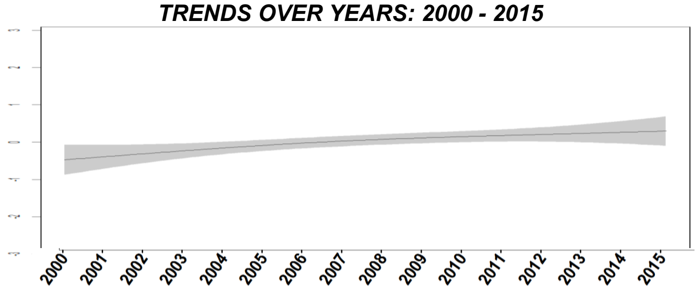
Analytical Summarization:
Dissolved oxygen concentrations increased slightly over the years 2000 – 2015 for the surface layer at the Little Choptank station EE2.2

TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



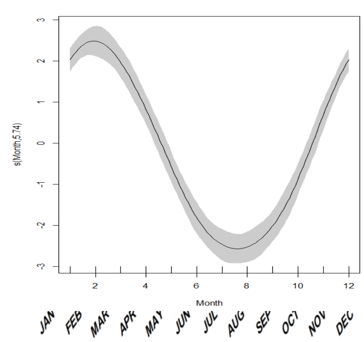
Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

TOTAL DISSOLVED OXYGEN TRENDS OVER YEARS: 2000 - 2015



Estimated Dissolved oxygen concentrations over cumulative months (2000 – 2015)

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

Figure C.2. Surface total dissolved oxygen (mg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

Parameter: Dissolved Oxygen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: DO F01

Key Summarization:
Low levels of dissolved oxygen have consistently occurred during summer months.

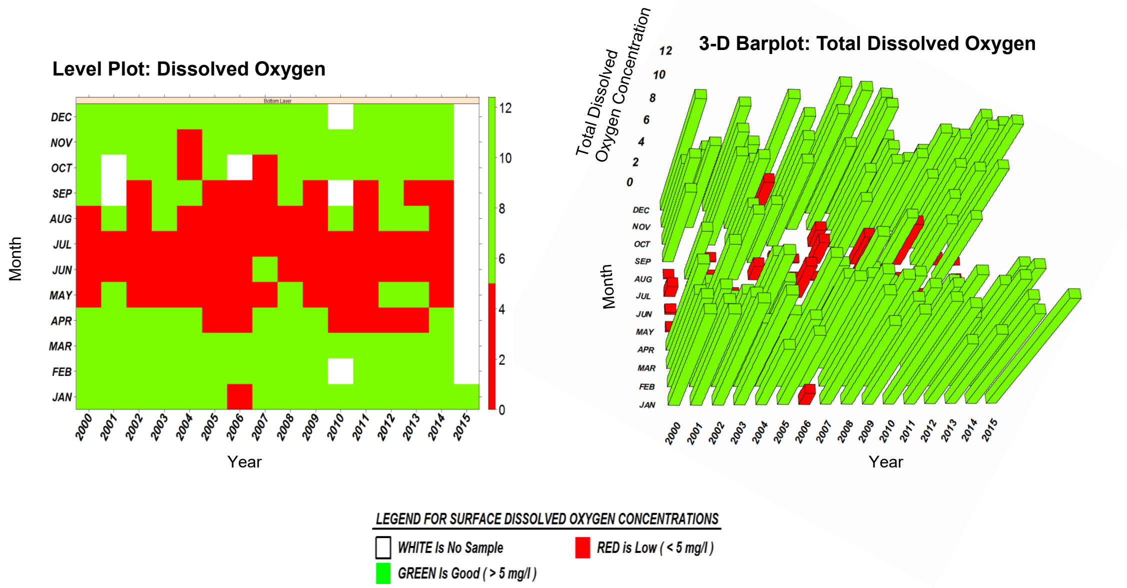
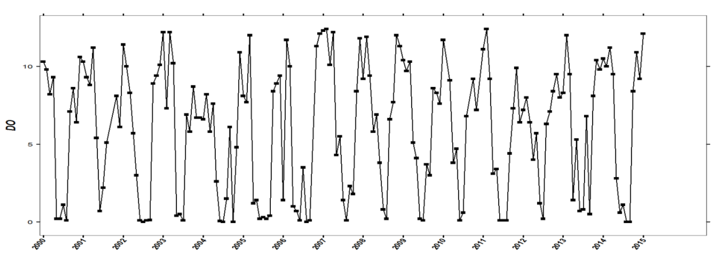


Figure C.3. Monthly bottom dissolved oxygen (mg/l) at Little Choptank station EE2.2.

Parameter: Total Dissolved Oxygen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom

TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015

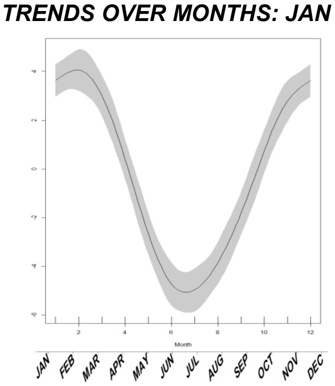


Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

NO DISSOLVED OXYGEN TRENDS OVER YEARS: 2000 - 2015

Analytical Summarization:
Dissolved oxygen concentrations have not displayed any significant trend over the years 2000 – 2015 in the bottom layer at the Little Choptank station EE2.2

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

Figure C.4. Bottom total dissolved oxygen (mg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface
Time Span: 2000 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained greater that 0.6 mg/l over all months and years.

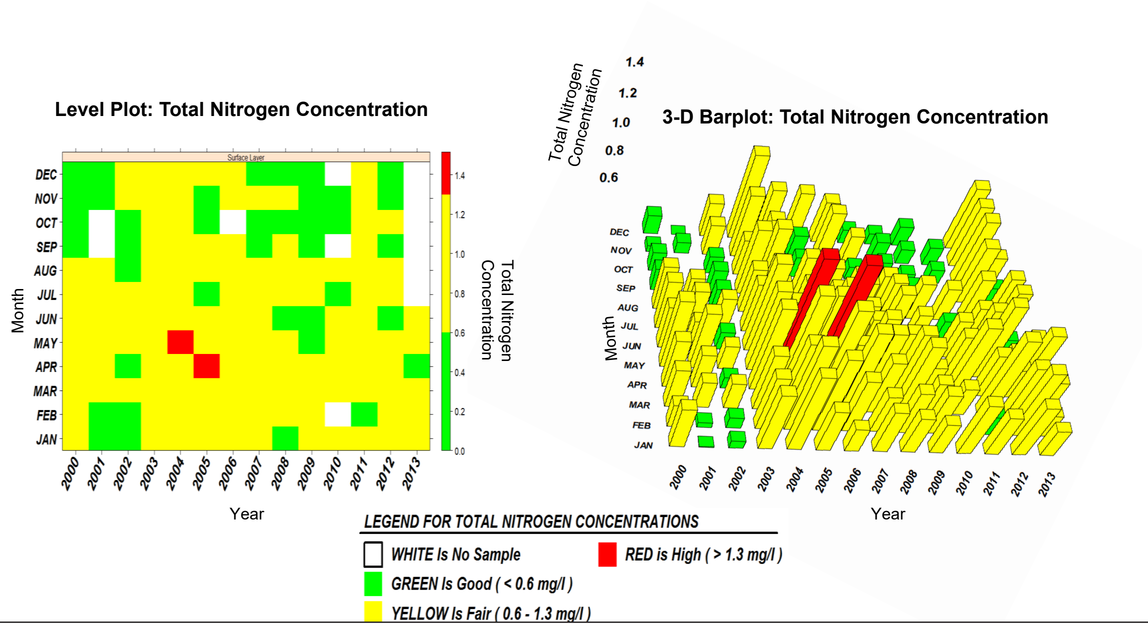
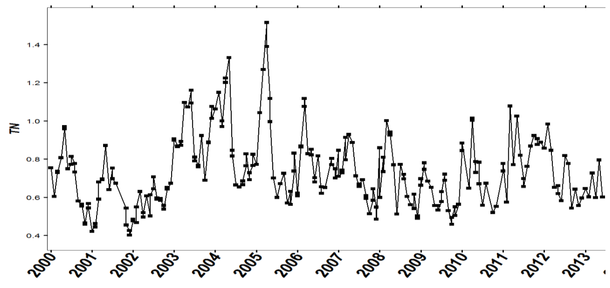


Figure C.5. Monthly surface total nitrogen (mg/l) at Little Choptank station EE2.2.

Parameter: Total Nitrogen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface

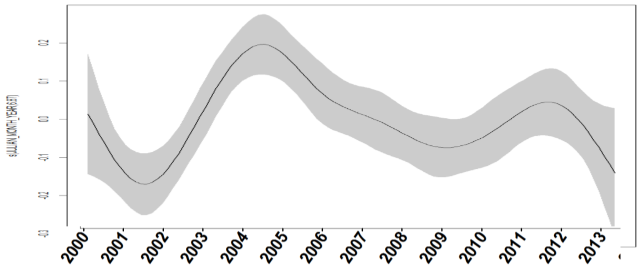
Analytical Summarization:
Total nitrogen concentrations were elevated during the years 2003 – 2005, but since appear to be in a downtrend in the surface layer at the Little Choptank station EE2.2

TOTAL NITROGEN CONCENTRATIONS: 2000 - 2013



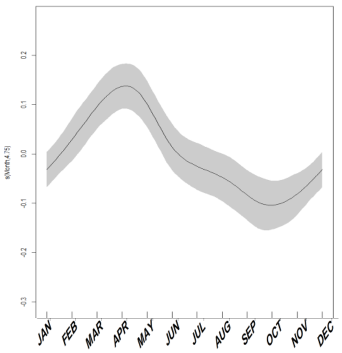
Total nitrogen concentrations over cumulative months (2000 – 2013)

TOTAL NITROGEN TRENDS OVER YEARS: 2000 - 2013



Estimated total nitrogen trends over cumulative months (2000 – 2013)

TOTAL NITROGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

Figure C.6. Surface total nitrogen (mg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom
Time Span: 2000 – 2013
Parameter Method: TN D03

<u>Key Summarization:</u>
Total nitrogen concentrations have been greater that 0.6 mg/l in winter and summer over all years. Concentrations have been decreasing since 2010.

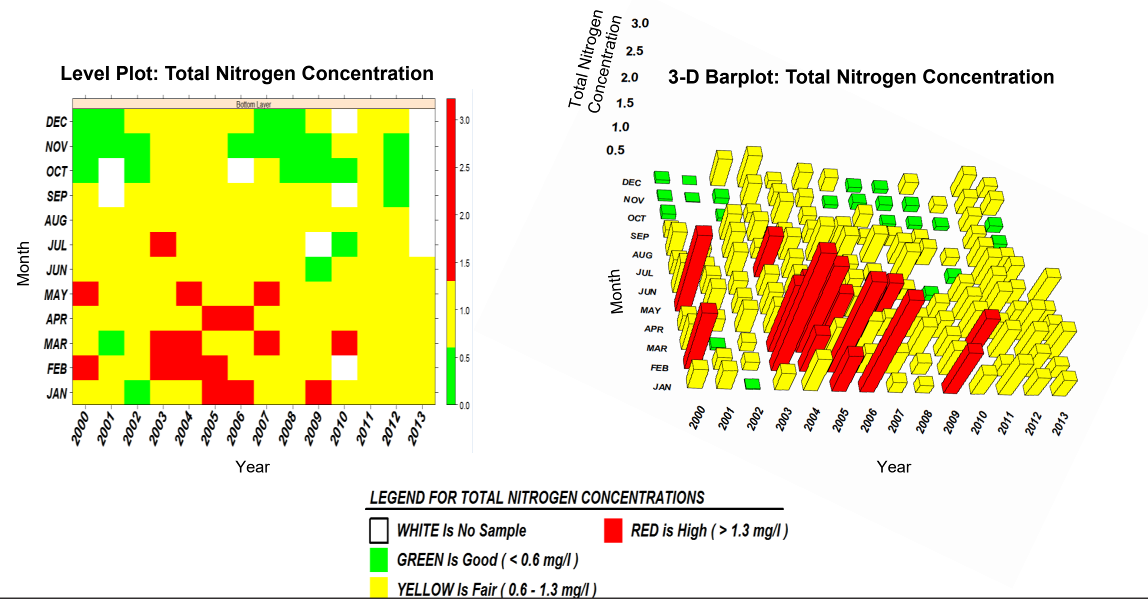
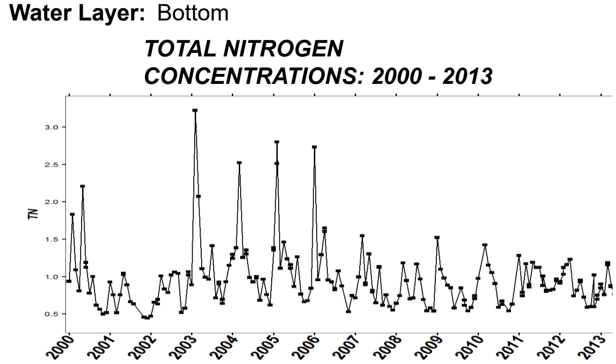


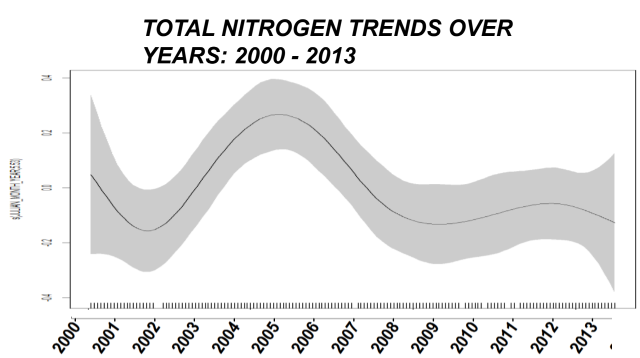
Figure C.7. Monthly bottom total nitrogen (mg/l) at Little Choptank station EE2.2.

Parameter: Total Nitrogen (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom

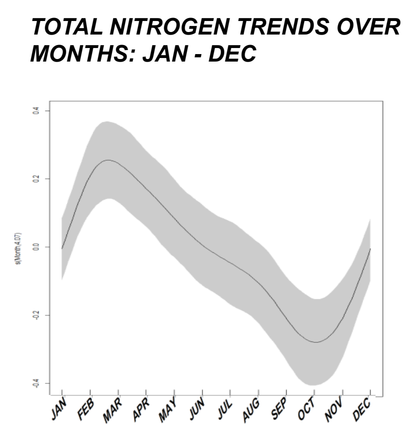
<u>Analytical Summarization:</u>
Total nitrogen concentrations were elevated during the years 2003 – 2006, but since 2006 appear to be in a downtrend in the bottom layer at the Little Choptank station EE2.2



Total nitrogen concentrations over cumulative months (2000 – 2013)



Estimated total nitrogen trends over cumulative months (2000 – 2013)



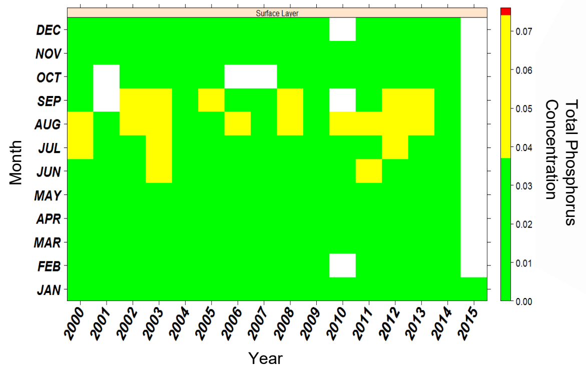
Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

Figure C.8. Bottom total nittrogen (mg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

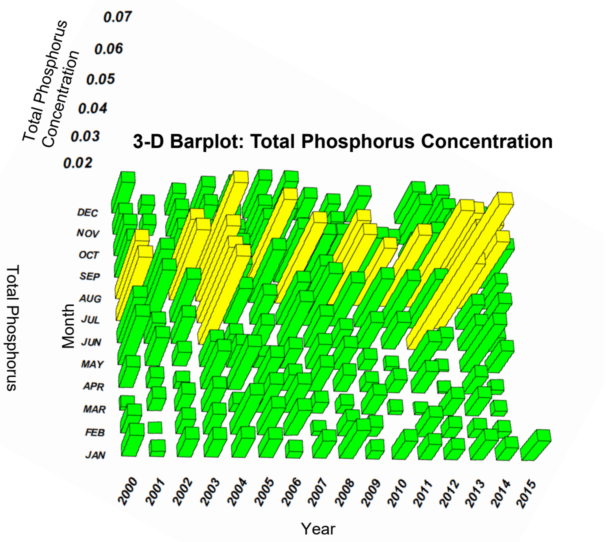
Parameter: Total Phosphorus (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: TP DO1

<u>Key Summarization:</u>
Total phosphorus concentrations have generally remained greater than 0.037 mg/l during summer over the years.

Level Plot: Total Phosphorus Concentration



3-D Barplot: Total Phosphorus Concentration



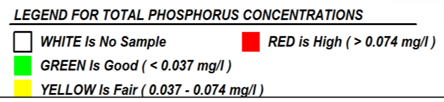
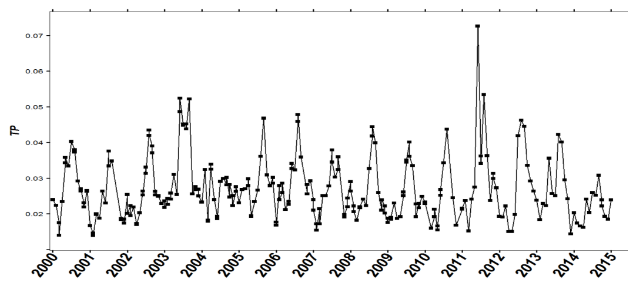


Figure C.9. Monthly surface total phosphorus (mg/l) at Little Choptank station EE2.2.

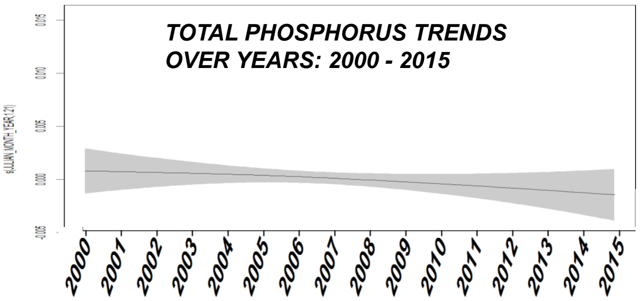
Parameter: Total Phosphorus (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface

<u>Analytical Summarization:</u>
Total phosphorus concentrations were elevated in 2003 and 2011-2013, but since 2003 have been in a significant downtrend in the surface layer at the Little Choptank station EE2.2

TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015

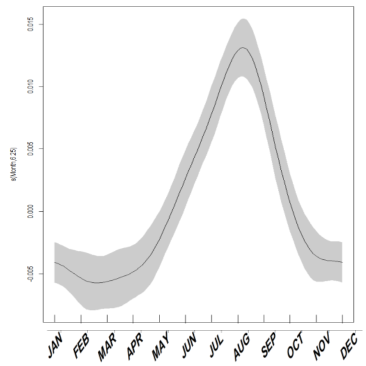


Total phosphorus concentrations over cumulative months (2000 – 2015)



Estimated total phosphorus trend over cumulative months (2000 – 2015)

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



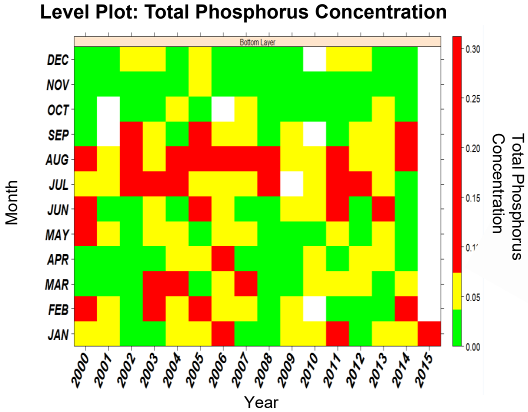
Estimated annual cycle of total phosphorus Jan – Dec (2000 - 2015)

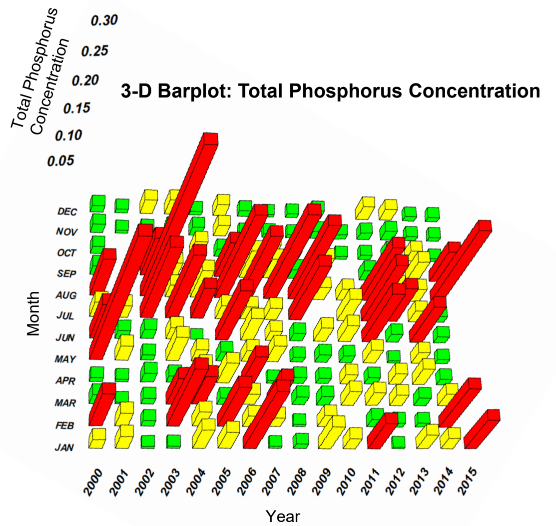
Figure C.10. Surface total phosphorus (mg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

Parameter: Total Phosphorus (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: TP DO1

Key Summarization:
Total phosphorus concentrations have occurred greater than 0.074 mg/l many times during winter, spring, and summer over the years.

Level Plot: Total Phosphorus Concentration





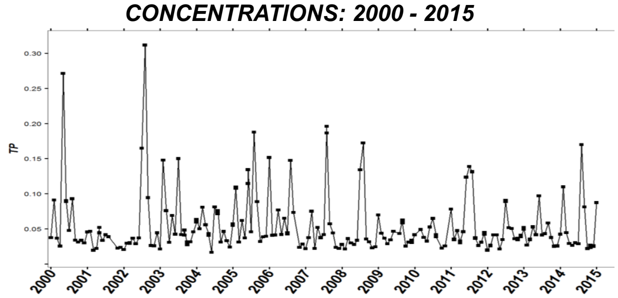
LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS
- *WHITE Is No Sample*
- *RED is High (> 0.074 mg/l)*
- *GREEN Is Good (< 0.037 mg/l)*
- *YELLOW Is Fair (0.037 - 0.074 mg/l)*

Figure C.11. Monthly bottom total phosphorus (mg/l) at Little Choptank station EE2.2.

Parameter: Total Phosphorus (mg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom

Analytical Summarization:
Total phosphorus concentrations have not displayed any significant trend from 2000 – 2015 in the bottom layer at the Little Choptank station EE2.2

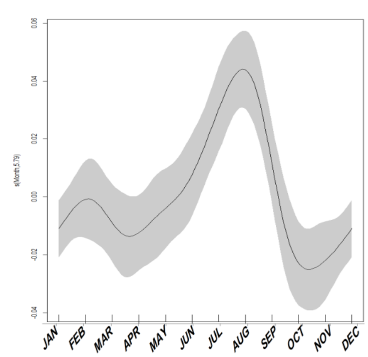
TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015



Total phosphorus concentrations over cumulative months (2000 – 2015)

NO TOTAL PHOSPHORUS TRENDS OVER YEARS: 2000 - 2015

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



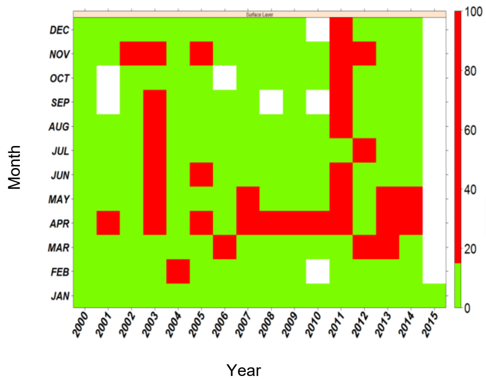
Estimated annual cycle of total phosphorus Jan – Dec (2000 - 2015)

Figure C.12. Bottom total phosphorus (mg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

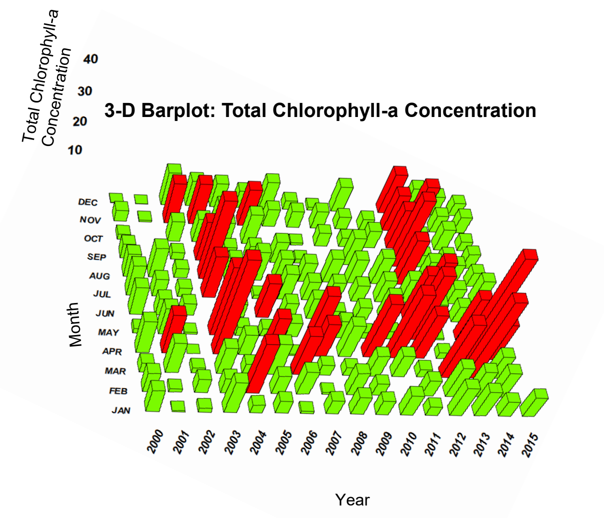
Parameter: Chlorophyll-a (µg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: CHLA L01

Key Summarization:
Chlorophyll-a concentrations are increasing through the years, and elevated during spring months.

Level Plot: Total Chlorophyll-a Concentration



3-D Barplot: Total Chlorophyll-a Concentration



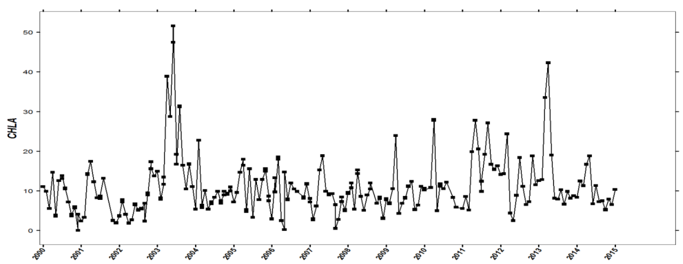
LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS
WHITE Is No Sample
RED is High (> 15 ug/l)
GREEN Is Good (< 15 ug/l)

Figure C.13. Monthly surface total chlorophyll-a (µg/l) at Little Choptank station EE2.2.

Parameter: Total Chlorophyll-a (µg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Surface

Analytical Summarization:
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the surface layer at the Little Choptank station EE2.2

TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC

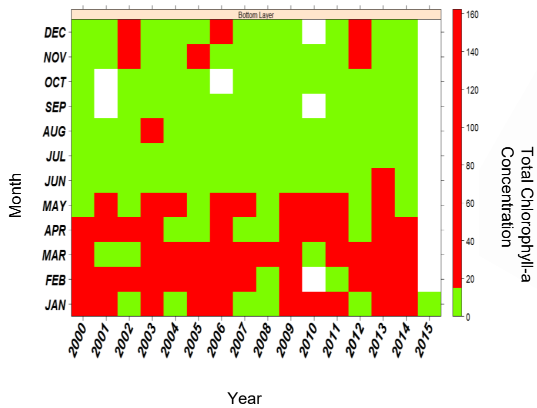
Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

Figure C.14. Surface total chlorophyll-a (µg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

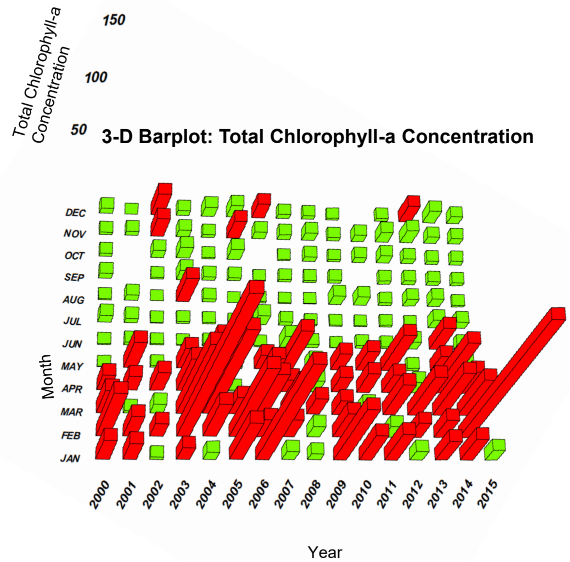
Parameter: Chlorophyll-a (µg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: CHLA L01

<u>Key Summarization:</u>
Chlorophyll-a concentrations are increasing through the years, and elevated during spring months.

Level Plot: Total Chlorophyll-a Concentration



3-D Barplot: Total Chlorophyll-a Concentration



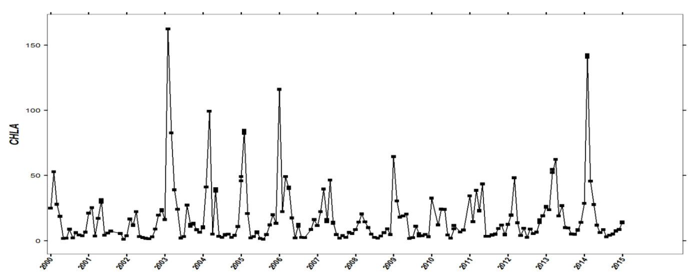
LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS
WHITE Is No Sample
RED is High (> 15 ug/l)
GREEN Is Good (< 15 ug/l)

Figure C.15. Monthly bottom total chlorophyll-a (µg/l) at Little Choptank station EE2.2.

Parameter: Total Chlorophyll-a (µg/l)
Location: Little Choptank River Station EE2.2
Water Layer: Bottom

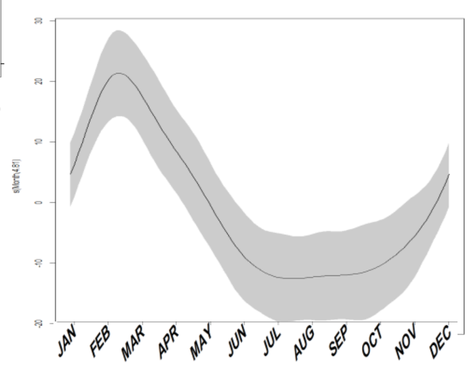
<u>Analytical Summarization:</u>
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the bottom layer at the Little Choptank station EE2.2

TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

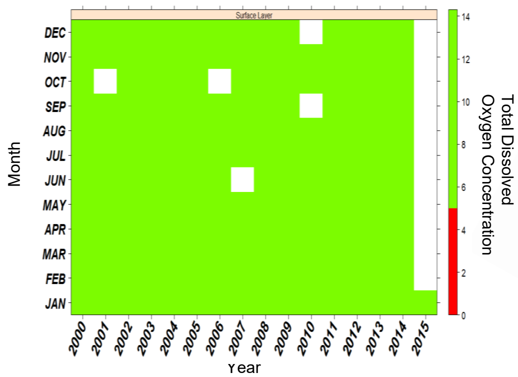
Estimated total chlorophyll-a trends over cumulative months (2000 – 2015)

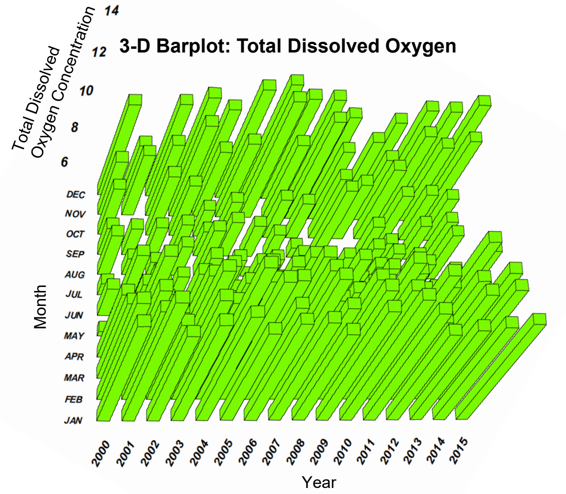
Figure C.16. Bottom total chlorophyll-a (µg/l) at Little Choptank station EE2.2 trend over time adjusted for seasonal variation.

Parameter: Dissolved Oxygen (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: DO F01

Key Summarization:
Low levels of dissolved oxygen have consistently occurred during summer months, but levels have remained above 5 mg/l during all months and over all years.

Level Plot: Dissolved Oxygen





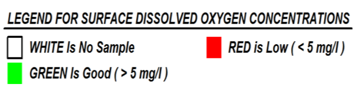
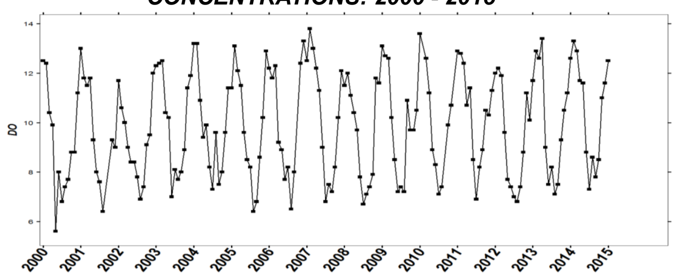


Figure C.17. Monthly surface dissolved oxygen (mg/l) at Outer Choptank station EE2.1.

Parameter: Total Dissolved oxygen (mg/l)
Location: Outer Choptank River Station EE2.2
Water Layer: Surface

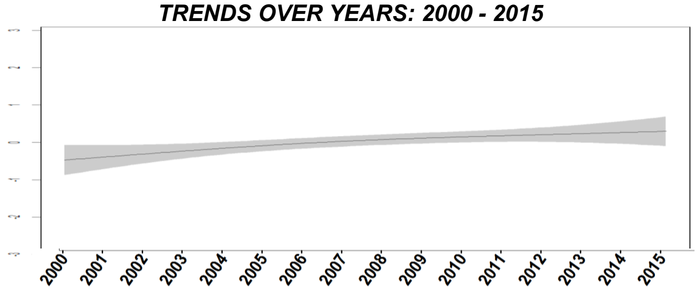
Analytical Summarization:
Dissolved oxygen concentrations increased slightly over the years 2000 – 2015 for the surface layer at the Outer Choptank station EE2.2

TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



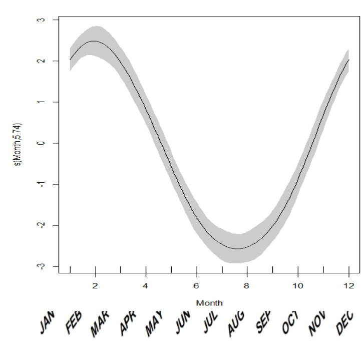
Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

TOTAL DISSOLVED OXYGEN TRENDS OVER YEARS: 2000 - 2015



Estimated Dissolved oxygen concentrations over cumulative months (2000 – 2015)

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



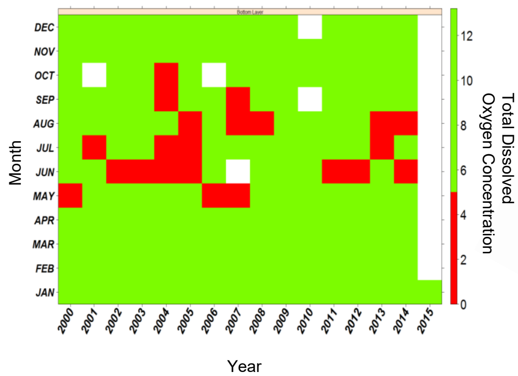
Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

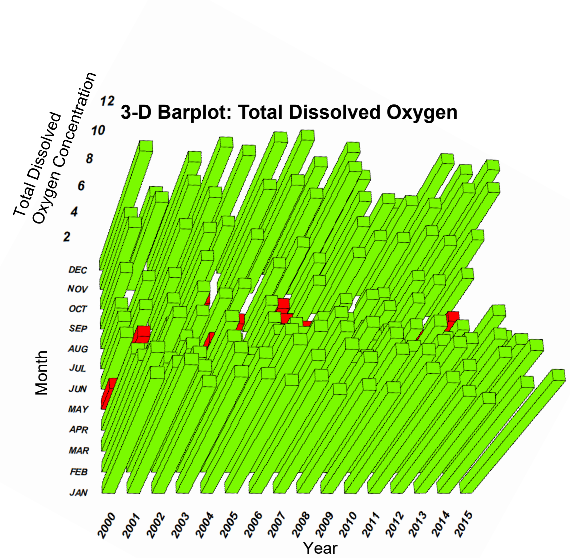
Figure C.18. Surface total dissolved oxygen (mg/l) at Outer Choptank station EE2.2 trend over time adjusted for seasonal variation.

Parameter: Dissolved Oxygen (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: DO F01

<u>Key Summarization:</u>
Low levels of dissolved oxygen have consistently occurred during summer months.

Level Plot: Dissolved Oxygen





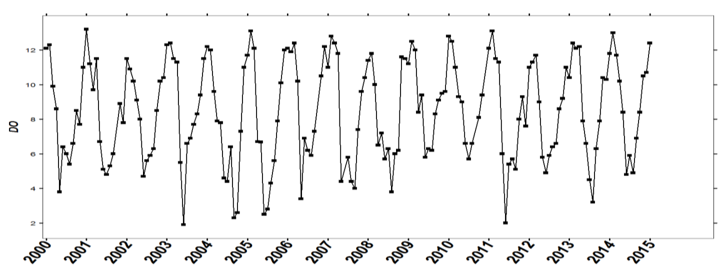
LEGEND FOR SURFACE DISSOLVED OXYGEN CONCENTRATIONS
WHITE Is No Sample
RED is Low (< 5 mg/l)
GREEN Is Good (> 5 mg/l)

Figure C.19. Monthly bottom dissolved oxygen (mg/l) at Outer Choptank station EE2.1.

Parameter: Total Dissolved oxygen (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom

<u>Analytical Summarization:</u>
Dissolved oxygen concentrations increased slightly over the years 2000 – 2015 for the surface layer at the Outer Choptank station EE2.1

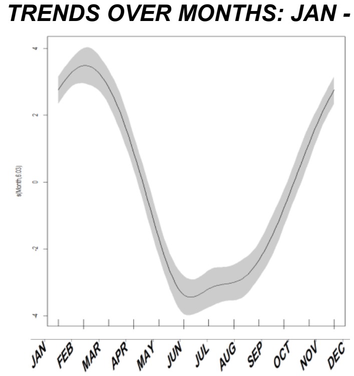
TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

NO DISSOLVED OXYGEN TREND OVER YEARS: 2000 - 2015

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

Figure C.20. Bottom total dissolved oxygen (mg/l) at Outer Choptank station EE2.1 trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Surface
Time Span: 2000 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained greater that 0.6 mg/l over all months and years.

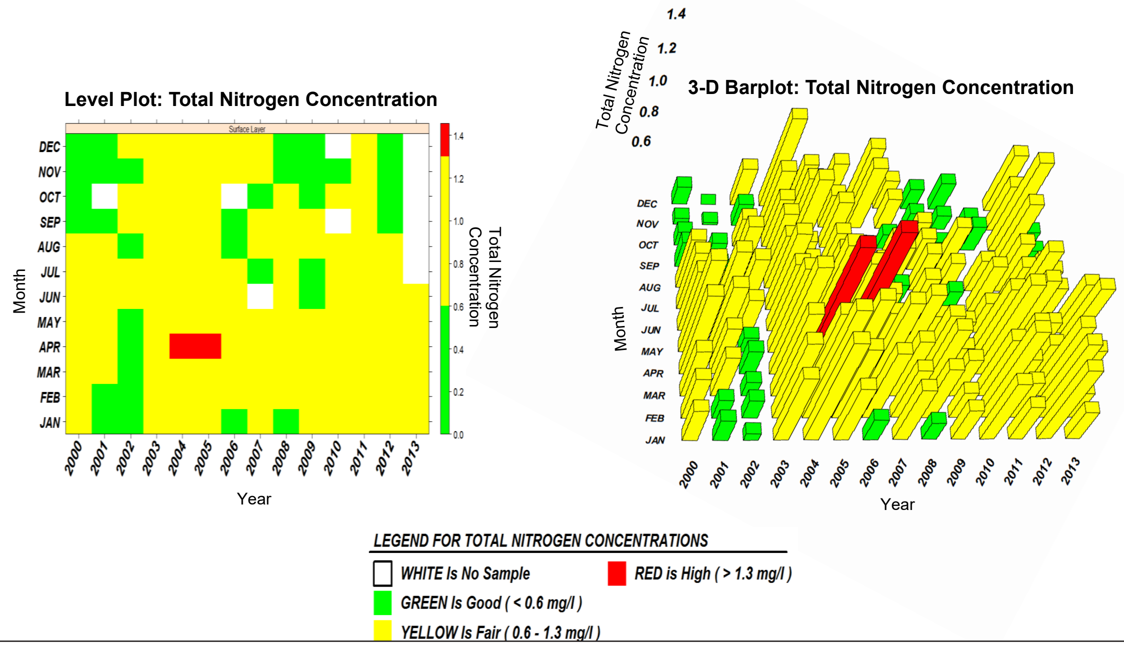
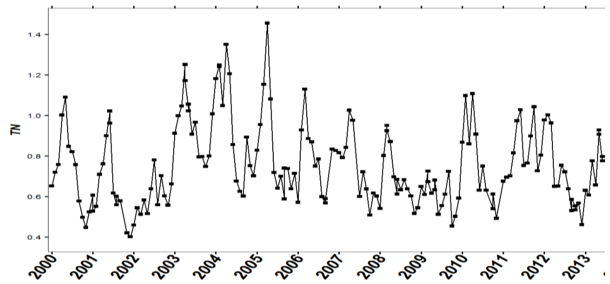


Figure C.21. Monthly surface total nitrogen (mg/l) at Outer Choptank station EE2.1.

Parameter: Total Nitrogen (mg/l)
Location: Outer Choptank River Station E
Water Layer: Surface

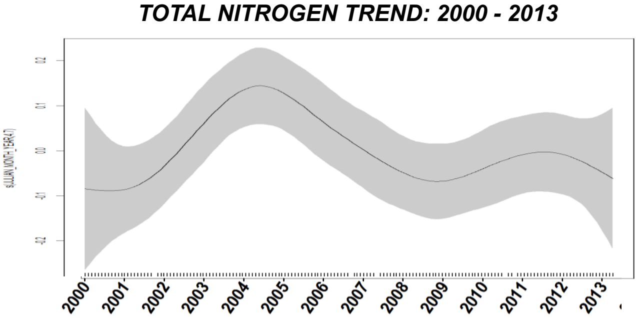
Analytical Summarization:
Total nitrogen concentrations were elevated during the years 2003-2005, but since 2005 appear to be in a down trend in the surface layer at the outer Choptank station EE2.1

TOTAL NITROGEN CONCENTRATIONS: 2000 - 2013



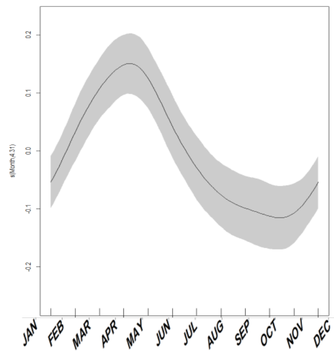
Total nitrogen concentrations over cumulative months (2000 – 2013)

TOTAL NITROGEN TREND: 2000 - 2013



Estimated total nitrogen trends over cumulative months (2000 – 2013)

TOTAL NITROGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

Figure C.22. Surface total nitrogen (mg/l) at Outer Choptank station EE2.1. trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom
Time Span: 2000 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained greater that 0.6 mg/l over all months and years.

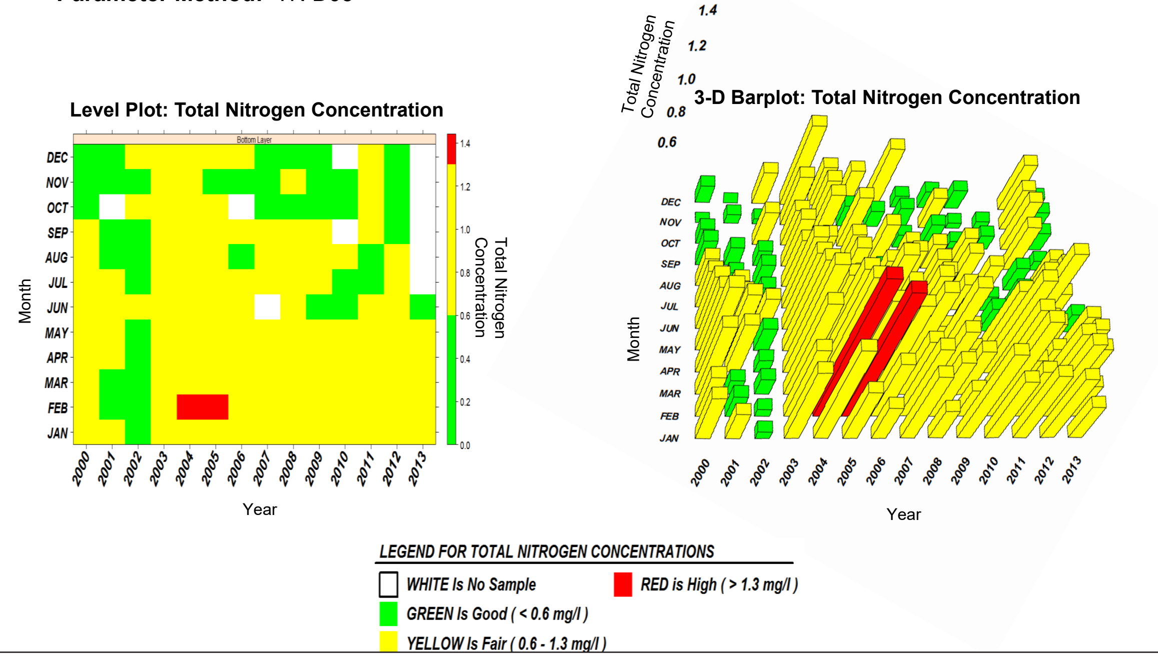
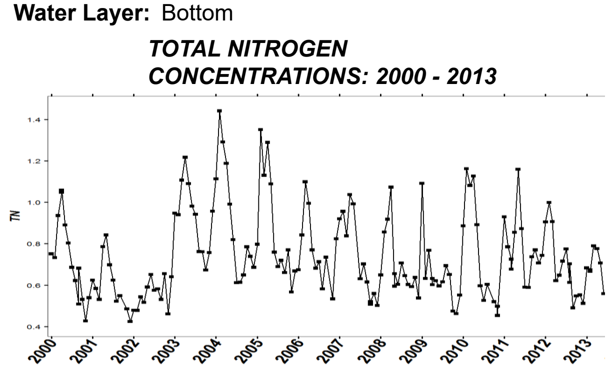


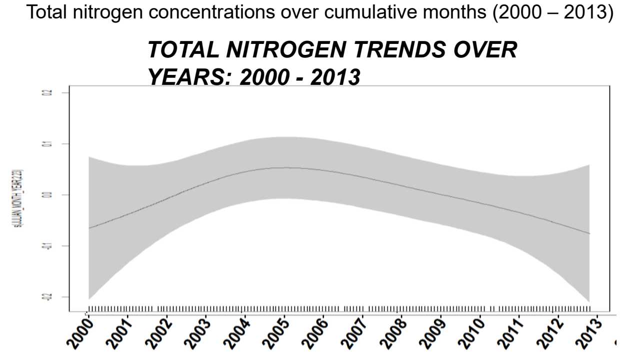
Figure C.23. Monthly bottom total nitrogen (mg/l) at Outer Choptank station EE2.1.

Parameter: Total Nitrogen (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom

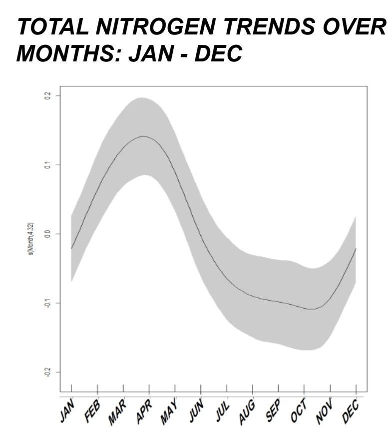
Analytical Summarization:
Total nitrogen concentrations were elevated during the years 2003 – 2006, but since 2006 appear to be in a downtrend in the bottom layer at the Outer Choptank station EE2.1



Total nitrogen concentrations over cumulative months (2000 – 2013)



Estimated total nitrogen trends over cumulative months (2000 – 2013)



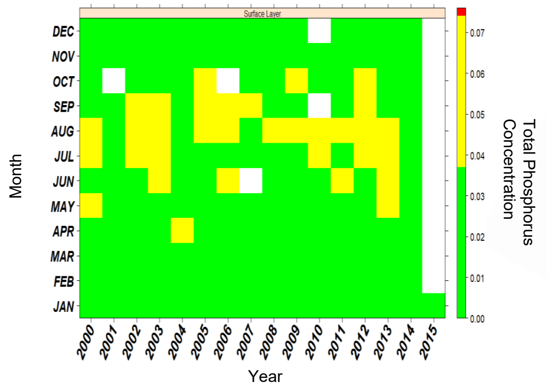
Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

Figure C.24. Bottom total nitrogen (mg/l) at Outer Choptank station EE2.1 trend over time adjusted for seasonal variation.

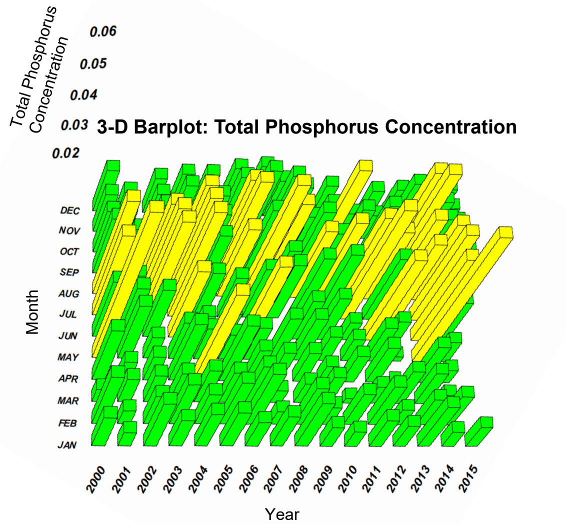
Parameter: Total Phosphorus (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: TP DO1

<u>Key Summarization:</u>
Total phosphorus concentrations have generally remained greater than 0.037 mg/l during summer and early fall over the years.

Level Plot: Total Phosphorus Concentration



3-D Barplot: Total Phosphorus Concentration



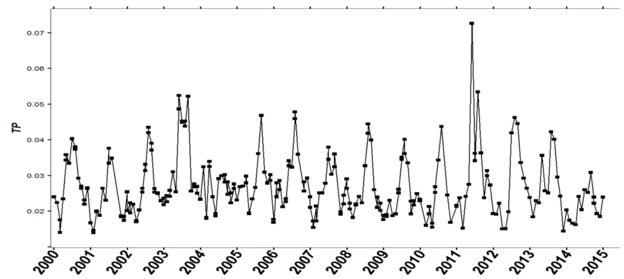
LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS
- *WHITE Is No Sample*
- *RED is High (> 0.074 mg/l)*
- *GREEN Is Good (< 0.037 mg/l)*
- *YELLOW Is Fair (0.037 - 0.074 mg/l)*

Figure C.25. Monthly surface total phosphorus (mg/l) at Outer Choptank station EE2.1.

Parameter: Total Phosphorus (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Surface

<u>Analytical Summarization:</u>
Total phosphorus concentrations have not displayed any significant trends over the years 2000-2015 in the surface layer at the outer Choptank station EE2.1

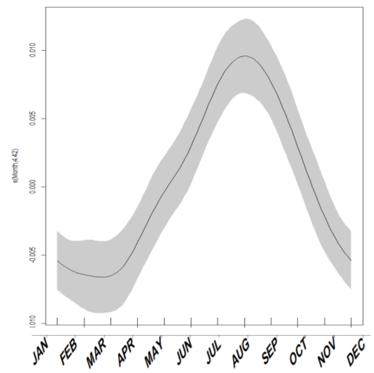
TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015



Total phosphorus concentrations over cumulative months (2000 – 2015)

NO TOTAL PHOSPHORUS TRENDS OVER YEARS: 2000 - 2015

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



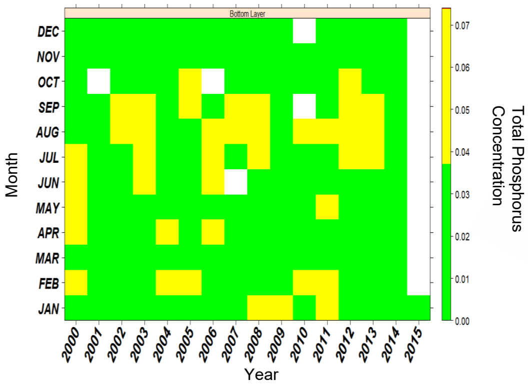
Estimated annual cycle of total phosphorus Jan – Dec (2000 - 2015)

Figure C.26. Surface total phosphorus (mg/l) at Outer Choptank station EE2.1 trend over time adjusted for seasonal variation.

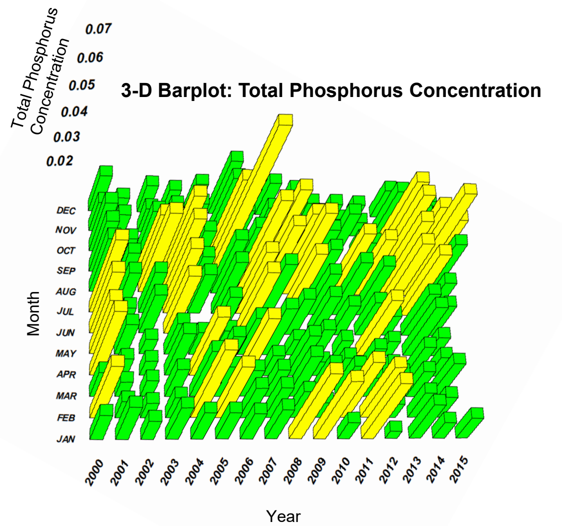
Parameter: Total Phosphorus (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: TP DO1

<u>Key Summarization:</u>
Total phosphorus concentrations have generally remained greater than 0.037 mg/l during winter, spring, summer and early fall over the years.

Level Plot: Total Phosphorus Concentration



3-D Barplot: Total Phosphorus Concentration



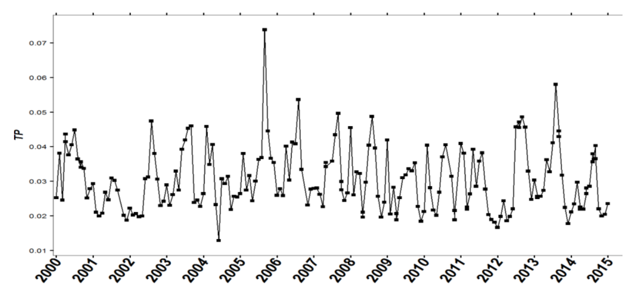
LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS
- ***WHITE Is No Sample***
- ***RED is High (> 0.074 mg/l)***
- ***GREEN Is Good (< 0.037 mg/l)***
- ***YELLOW Is Fair (0.037 - 0.074 mg/l)***

Figure C.27. Monthly bottom total phosphorus (mg/l) at Outer Choptank station EE2.1.

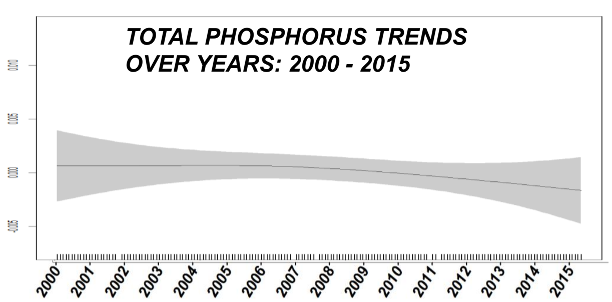
Parameter: Total Phosphorus (mg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom

<u>Analytical Summarization:</u>
Total phosphorus were elevated during the years 2005, 2012 and 2013, but appear to be in a downtrend in the bottom layer at the outer Choptank station EE2.1

TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015

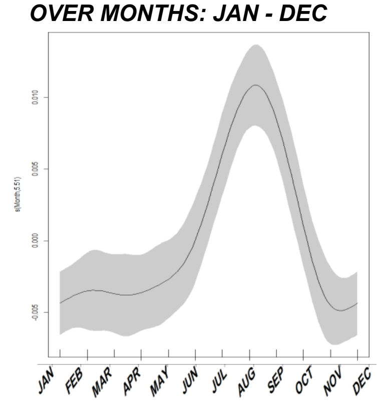


Total phosphorus concentrations over cumulative months (2000 – 2015)



Estimated phosphorus concentrations over cumulative months (2000 – 2015)

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



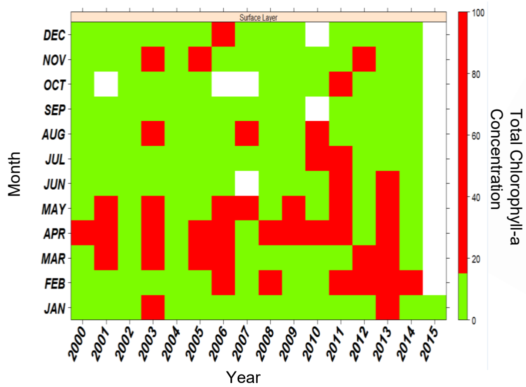
Estimated annual cycle of total phosphorus Jan – Dec (2000 - 2015)

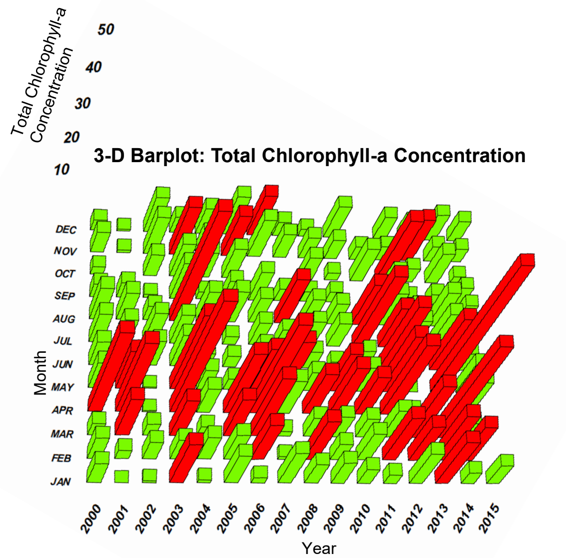
Figure C.28. Bottom total phosphorus (mg/l) at Outer Choptank station EE2.1. trend over time adjusted for seasonal variation.

Parameter: Chlorophyll-a (µg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: CHLA L01

<u>Key Summarization:</u>
Chlorophyll-a concentrations are very high during winter and early spring months.

Level Plot: Total Chlorophyll-a Concentration





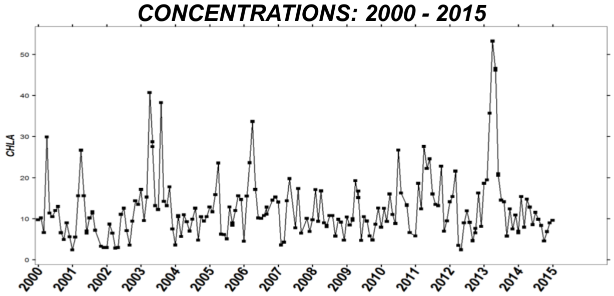
LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS
- *WHITE Is No Sample*
- *RED is High (> 15 ug/l)*
- *GREEN Is Good (< 15 ug/l)*

Figure C.29. Monthly surface total chlorophyll-a (µg/l) at Outer Choptank station EE2.1.

Parameter: Total Chlorophyll-a (µg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Surface

<u>Analytical Summarization:</u>
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the surface layer at the Outer Choptank station EE2.1

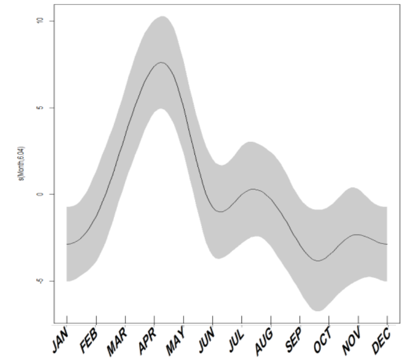
TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC

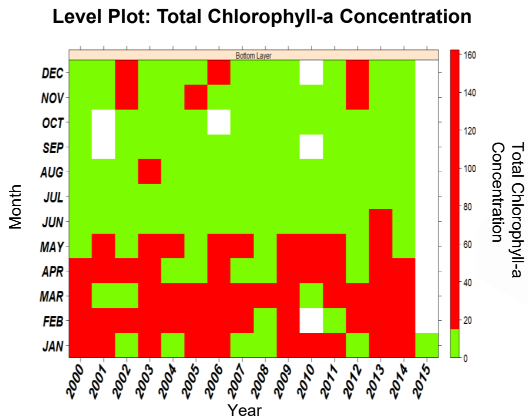


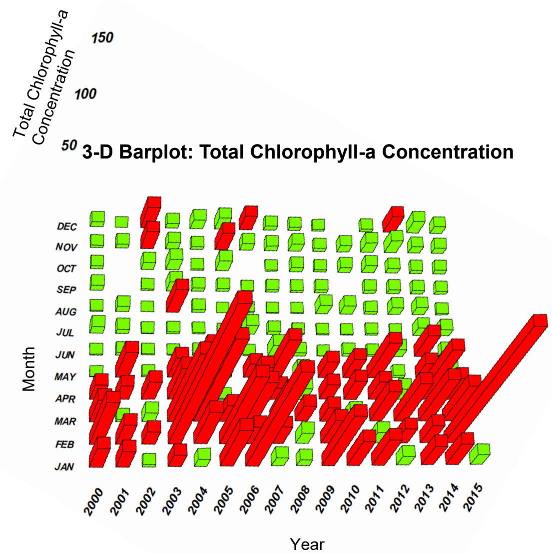
Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

Figure C.30. Surface total chlorophyll-a (µg/l) at Outer Choptank station EE2.1 trend over time adjusted for seasonal variation.

Parameter: Chlorophyll-a (µg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: CHLA L01

Key Summarization:
Chlorophyll-a concentrations are very high during winter and early spring months.





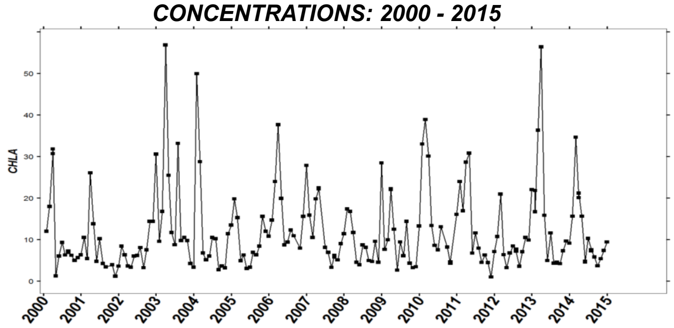
LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS
- *WHITE Is No Sample*
- *RED is High (> 15 ug/l)*
- *GREEN Is Good (< 15 ug/l)*

Figure C.31. Monthly bottom total chlorophyll-a (µg/l) at Outer Choptank station EE2.1.

Parameter: Total Chlorophyll-a (µg/l)
Location: Outer Choptank River Station EE2.1
Water Layer: Bottom

Analytical Summarization:
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the bottom layer at the Outer Choptank station EE2.1

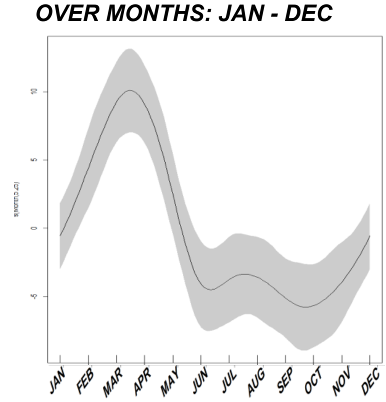
TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

Figure C.32. Bottom total chlorophyll-a (µg/l) at Outer Choptank station EE2.1 trend over time adjusted for seasonal variation.

Parameter: Dissolved Oxygen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: DO F01

Key Summarization:
Low levels of dissolved oxygen have consistently occurred during summer months, but levels have remained greater than 5 mg/l over all months and years.

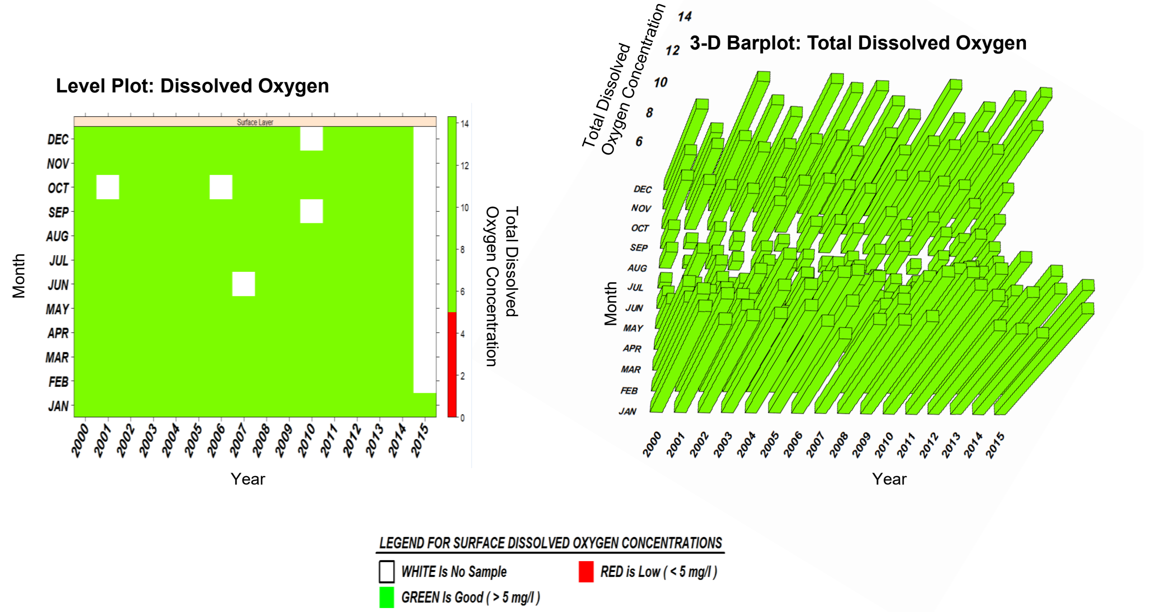
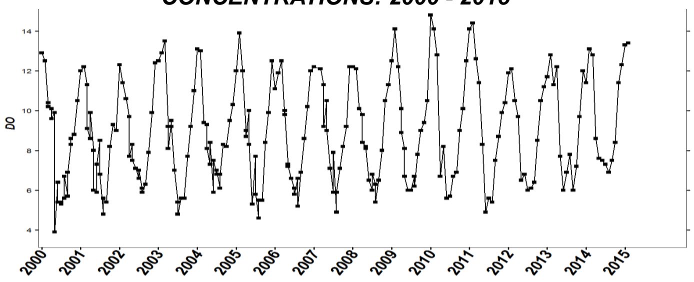


Figure C.33. Monthly surface dissolved oxygen (mg/l) at Lower Choptank station ET5.2.

Parameter: Total Dissolved oxygen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface

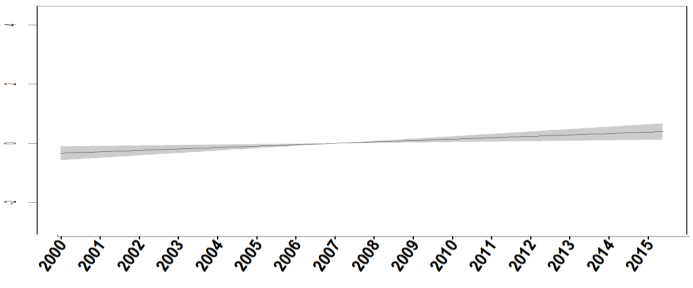
Analytical Summarization:
Dissolved oxygen concentrations have increased over the years 2000 – 2015 for the surface layer at the Lower Choptank station ET5.2

TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



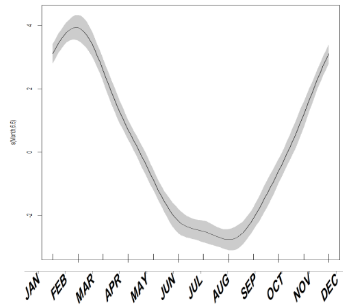
Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

DISSOLVED OXYGEN TREND OVER YEARS: 2000 - 2015



Estimated dissolved oxygen trend over cumulative months (2000 – 2015)

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

Figure C.34. Surface total dissolved oxygen (mg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

Parameter: Dissolved Oxygen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: DO F01

<u>Key Summarization:</u>
Low levels of dissolved oxygen have consistently occurred during summer months.

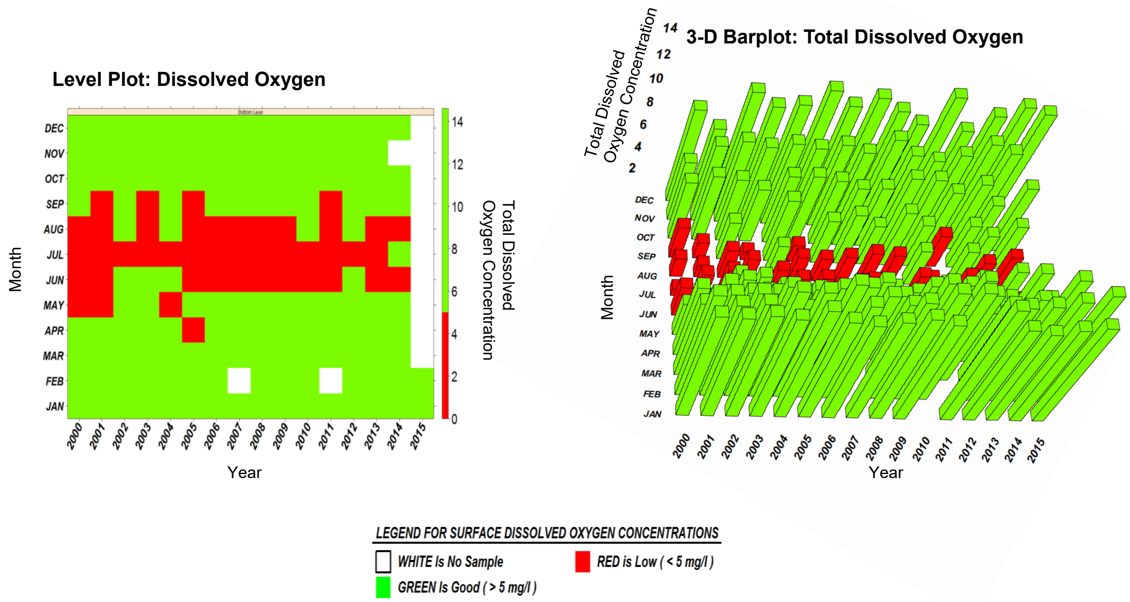
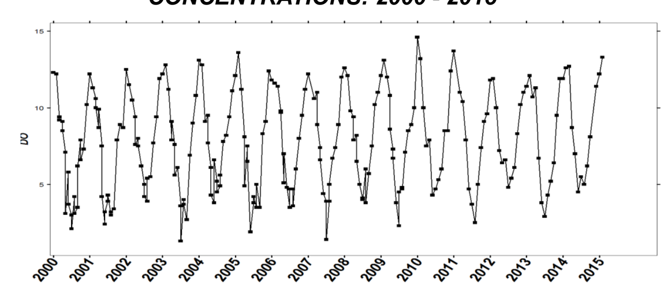


Figure C.35. Monthly bottom dissolved oxygen (mg/l) at Lower Choptank station ET5.2.

Parameter: Total Dissolved oxygen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom

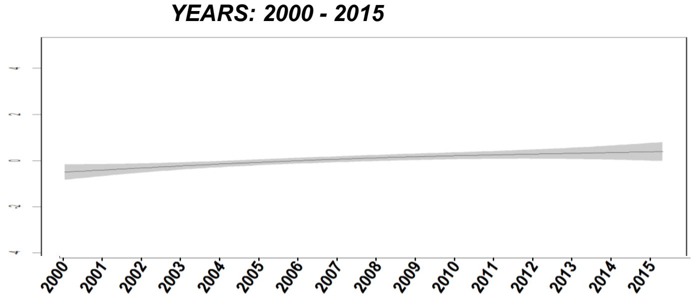
<u>Analytical Summarization:</u>
Dissolved oxygen concentrations have increased slightly but significantly over the years 2000 – 2015 for the bottom layer at the Lower Choptank station ET5.2

TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



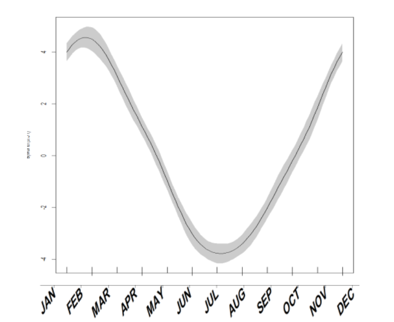
Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

DISSOLVED OXYGEN TREND OVER YEARS: 2000 - 2015



Estimated dissolved oxygen trends over cumulative months (2000 – 2015)

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

Figure C.36. Bottom total dissolved oxygen (mg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface
Time Span: 2000 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained under 1.3 mg/l during winter and spring for many years.

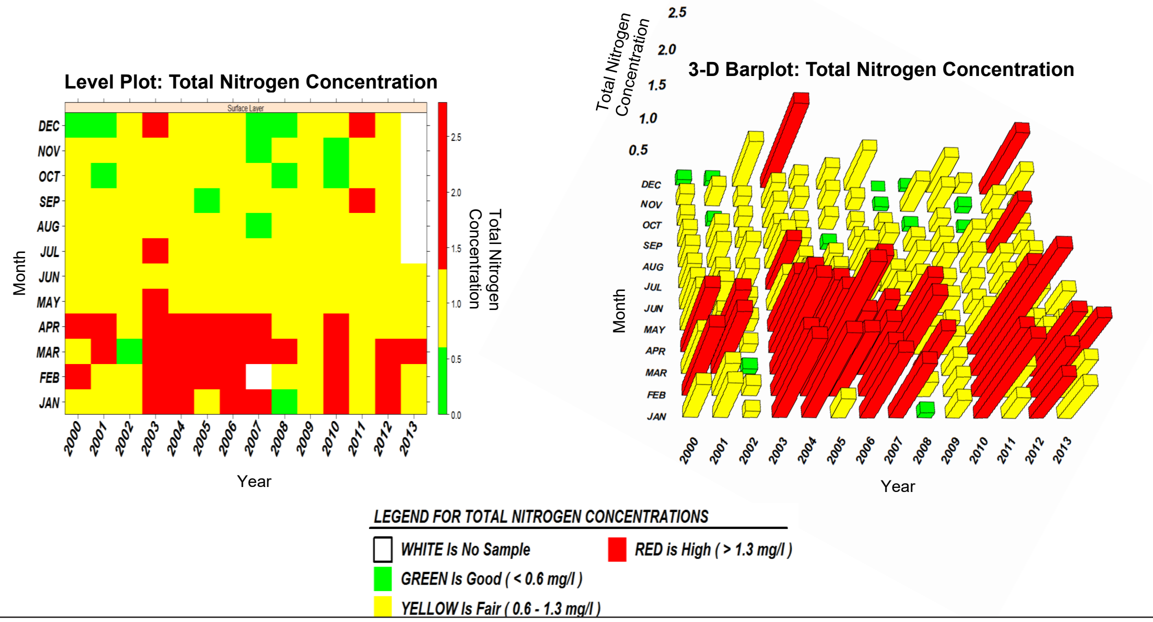
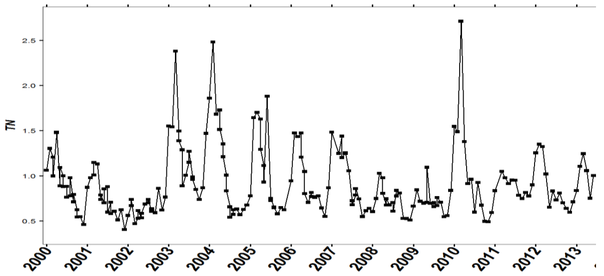


Figure C.37. Monthly surface total nitrogen (mg/l) at Lower Choptank station ET5.2.

Parameter: Total Nitrogen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom

Analytical Summarization:
Total nitrogen concentrations have not displayed any significant trend over the years 2000 to 2013 in the bottom layer at the Lower Choptank station ET5.2

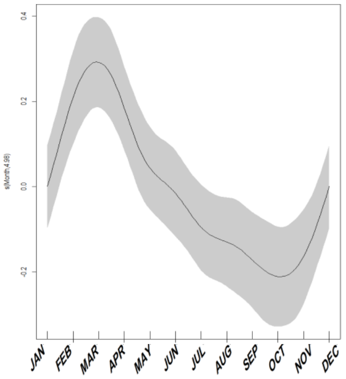
TOTAL NITROGEN CONCENTRATIONS: 2000 - 2013



Total nitrogen concentrations over cumulative months (2000 – 2013)

NO TOTAL NITROGEN TRENDS OVER YEARS: 2000 - 2013

TOTAL NITROGEN TRENDS OVER MONTHS: JAN - DEC

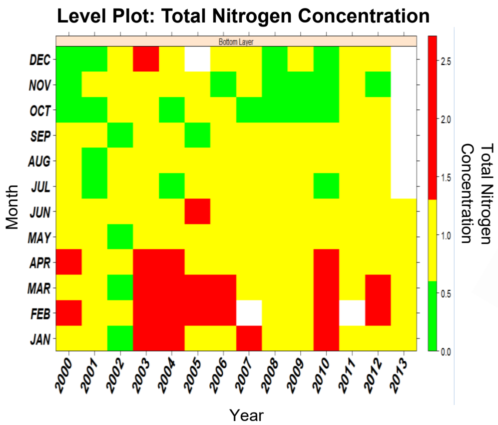


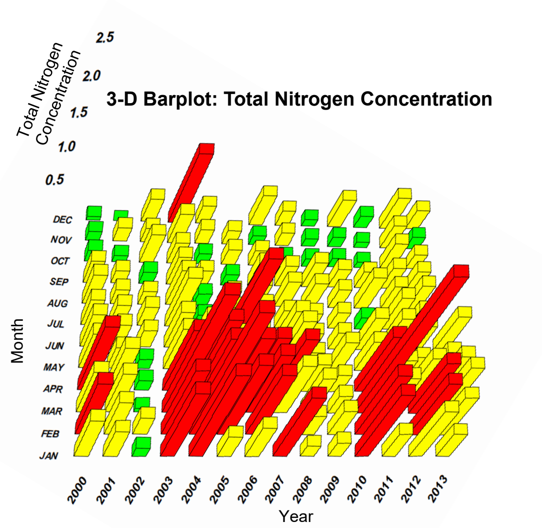
Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

Figure C.38. Bottom total nitrogen (mg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom
Time Span: 2000 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained greater than 0.6 mg/l during winter and spring for many years.





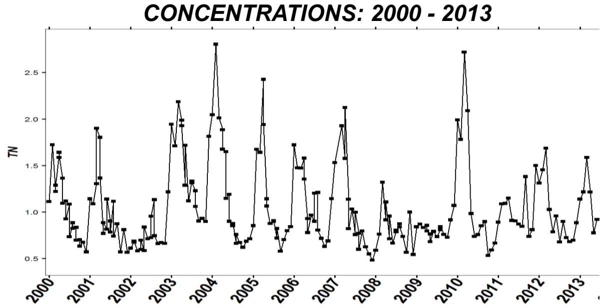
LEGEND FOR TOTAL NITROGEN CONCENTRATIONS
WHITE Is No Sample
RED is High (> 1.3 mg/l)
GREEN Is Good (< 0.6 mg/l)
YELLOW Is Fair (0.6 - 1.3 mg/l)

Figure C.39. Monthly bottom total nitrogen (mg/l) at Lower Choptank station ET5.2.

Parameter: Total Nitrogen (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface

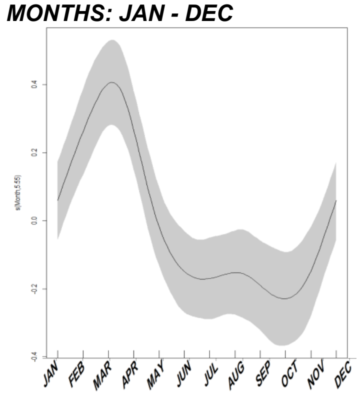
Analytical Summarization:
Total nitrogen concentrations have not displayed any significant trend over the years 2000 to 2013 in the surface layer at the Lower Choptank station ET5.2

TOTAL NITROGEN CONCENTRATIONS: 2000 - 2013



Total nitrogen concentrations over cumulative months (2000 – 2013)

TOTAL NITROGEN TRENDS OVER MONTHS: JAN - DEC



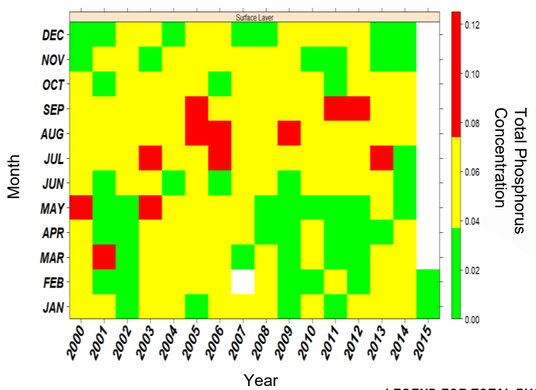
Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

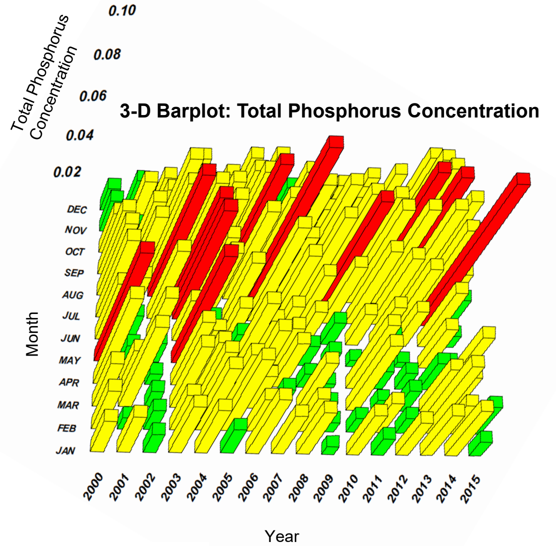
NO TOTAL NITROGEN TRENDS OVER YEARS: 2000 - 2013

Figure C.40. Surface total nitrogen (mg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

Parameter: Total Phosphorus (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: TP DO1

Key Summarization:
Total phosphorus concentrations have generally remained greater than 0.037 mg/l during all seasons over all years. Total concentrations greater than 0.074 mg/l have occurred during the summer for some years.





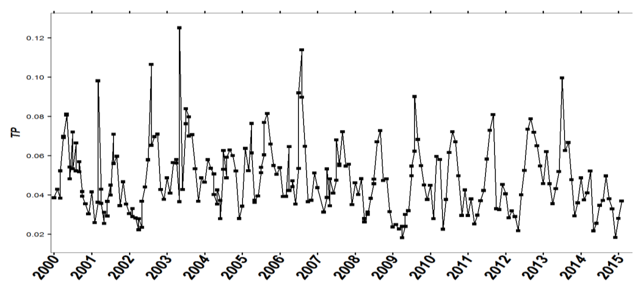
LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS
- WHITE Is No Sample
- RED is High (> 0.074 mg/l)
- GREEN Is Good (< 0.037 mg/l)
- YELLOW Is Fair (0.037 - 0.074 mg/l)

Figure C.41. Monthly surface total phosphorus (mg/l) at Lower Choptank station ET5.2.

Parameter: Total Phosphorus (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface

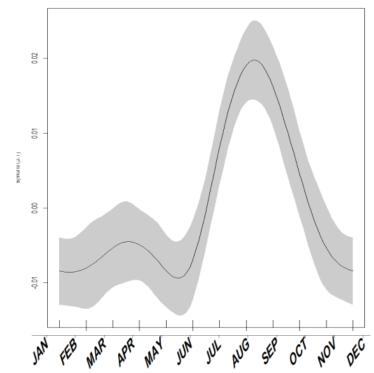
Analytical Summarization:
Total phosphorus concentrations have not displayed any significant trend over the years 2000 – 2015 in the surface layer at the lower Choptank station ET5.2

TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015



Total phosphorus concentrations over cumulative months (2000 – 2015)

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total phosphorus Jan – Dec (2000 - 2015)

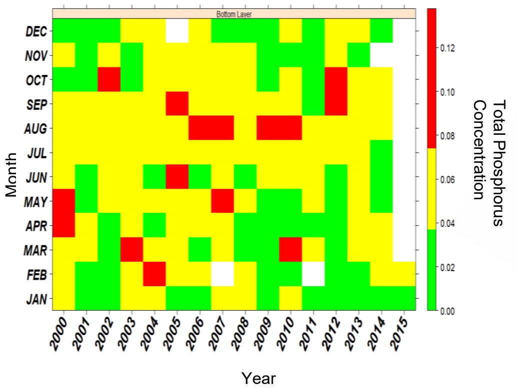
NO PHOSPHORUS TRENDS OVER YEARS: 2000 - 2015

Figure C.42. Surface total phosphorus (mg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

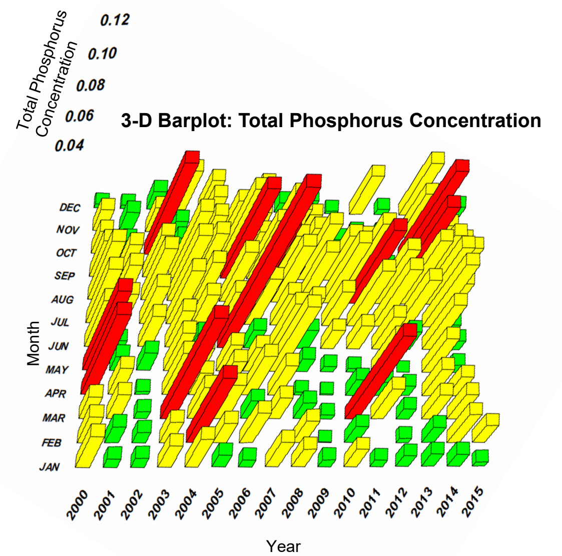
Parameter: Total Phosphorus (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: TP DO1

Key Summarization:
Total phosphorus concentrations have generally remained greater than 0.037 mg/l during all seasons over all years.

Level Plot: Total Phosphorus Concentration



3-D Barplot: Total Phosphorus Concentration



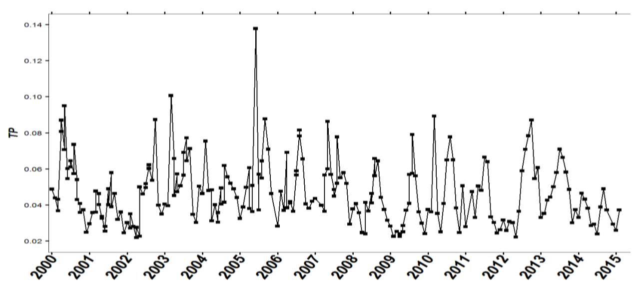
LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS
- *WHITE Is No Sample*
- *RED is High (> 0.074 mg/l)*
- *GREEN Is Good (< 0.037 mg/l)*
- *YELLOW Is Fair (0.037 - 0.074 mg/l)*

Figure C.43. Monthly bottom total phosphorus (mg/l) at Lower Choptank station ET5.2.

Parameter: Total Phosphorus (mg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom

Analytical Summarization:
Total phosphorus concentrations have not displayed any significant trend over the years 2000 – 2015 in the surface layer at the lower Choptank station ET5.2

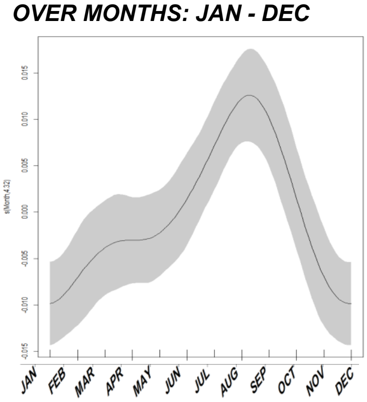
TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015



Total phosphorus concentrations over cumulative months (2000 – 2015)

NO TOTAL PHOSPHORUS TRENDS OVER YEARS: 2000 - 2015

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



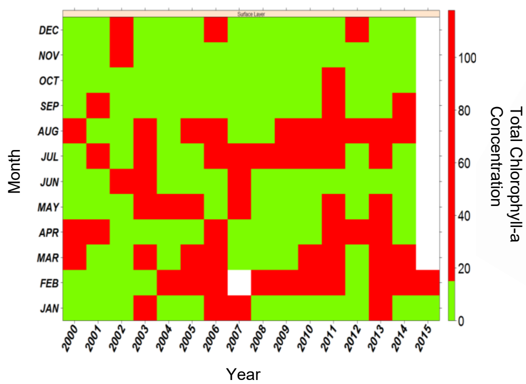
Estimated annual cycle of total phosphorus Jan – Dec (2000 - 2015)

Figure C.44. Bottom total phosphorus (mg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

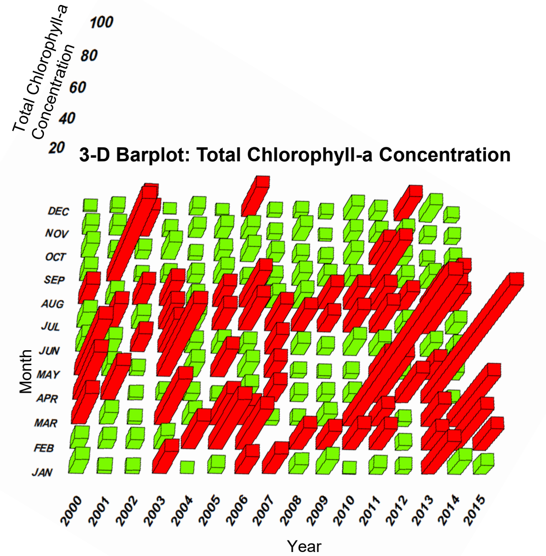
Parameter: Chlorophyll-a (µg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: CHLA L01

Key Summarization:
Chlorophyll-a concentrations have been increasing during winter, spring and summer since 2010.

Level Plot: Total Chlorophyll-a Concentration



3-D Barplot: Total Chlorophyll-a Concentration



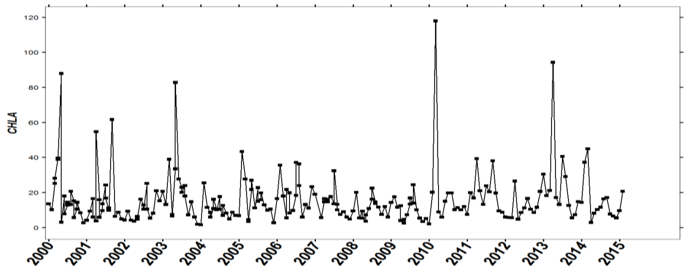
LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS
WHITE Is No Sample
RED is High (> 15 ug/l)
GREEN Is Good (< 15 ug/l)

Figure C.45. Monthly surface total chlorophyll-a (µg/l) at Lower Choptank station ET5.2.

Parameter: Total Chlorophyll-a (µg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Surface

Analytical Summarization:
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the surface layer at the Lower Choptank station ET5.2

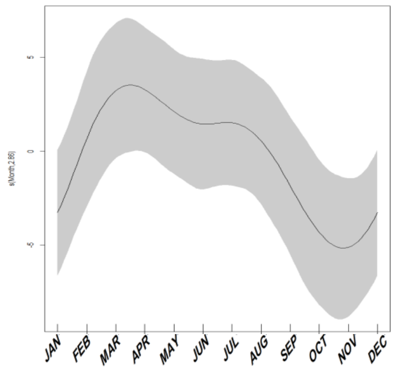
TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC



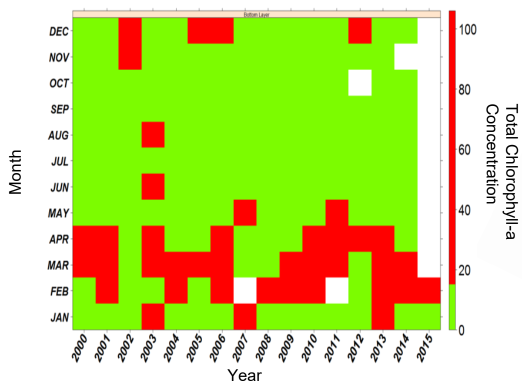
Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

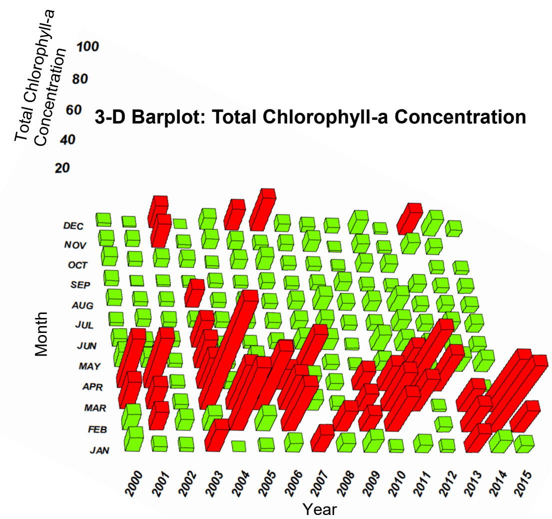
Figure C.46. Surface total chlorophyll-a (µg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

Parameter: Chlorophyll-a (µg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: CHLA L01

Key Summarization:
Chlorophyll-a concentrations are high during winter and spring months.

Level Plot: Total Chlorophyll-a Concentration





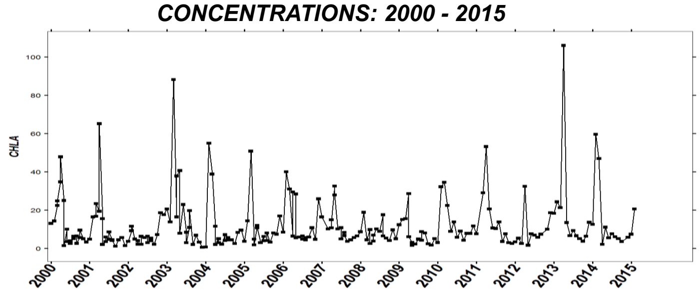
LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS
WHITE Is No Sample *RED is High (> 15 ug/l)*
GREEN Is Good (< 15 ug/l)

Figure C.47. Monthly bottom total chlorophyll-a (µg/l) at Lower Choptank station ET5.2.

Parameter: Total Chlorophyll-a (µg/l)
Location: Lower Choptank River Station ET5.2
Water Layer: Bottom

Analytical Summarization:
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the bottom layer at the Lower Choptank station ET5.2

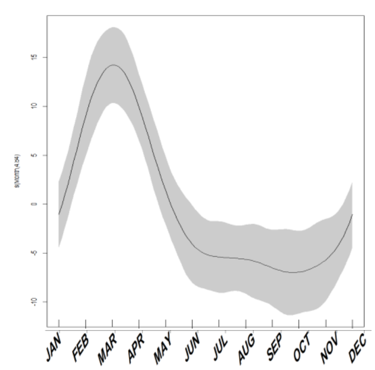
TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC



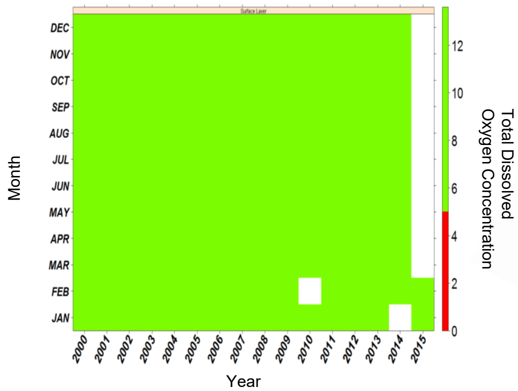
Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

Figure C.48. Bottom total chlorophyll-a (µg/l) at Lower Choptank station ET5.2 trend over time adjusted for seasonal variation.

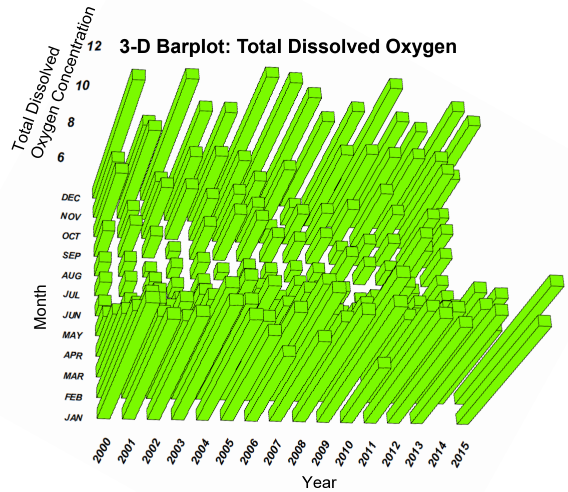
Parameter: Dissolved Oxygen (mg/l)
Location: Middle Choptank River Station ET5.0
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: DO F01

Key Summarization:
Low levels of dissolved oxygen have consistently occurred during summer months. Levels have remained above 4 mg/l during all months and years.

Level Plot: Dissolved Oxygen



3-D Barplot: Total Dissolved Oxygen



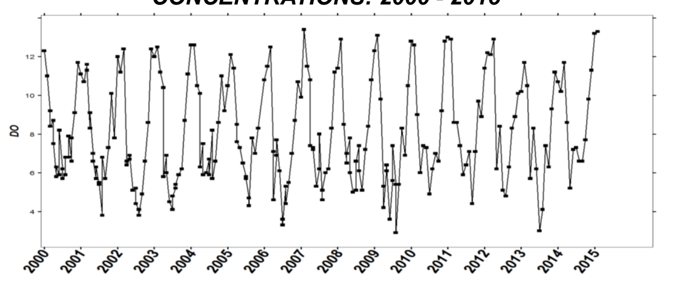
LEGEND FOR SURFACE DISSOLVED OXYGEN CONCENTRATIONS
WHITE Is No Sample
RED is Low (< 5 mg/l)
GREEN Is Good (> 5 mg/l)

Figure C.49. Monthly surface dissolved oxygen (mg/l) at Middle Choptank station ET5.0.

Parameter: Total Dissolved Oxygen (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Surface

Analytical Summarization:
Dissolved oxygen concentrations have not displayed any significant trends over the years 2000 to 2015 in the surface layer at the middle Choptank station ET5.1

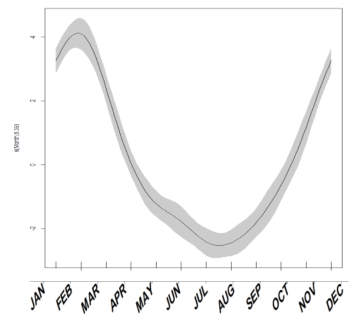
TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

NO DISSOLVED OXYGEN TREND OVER YEARS: 2000 - 2015

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC

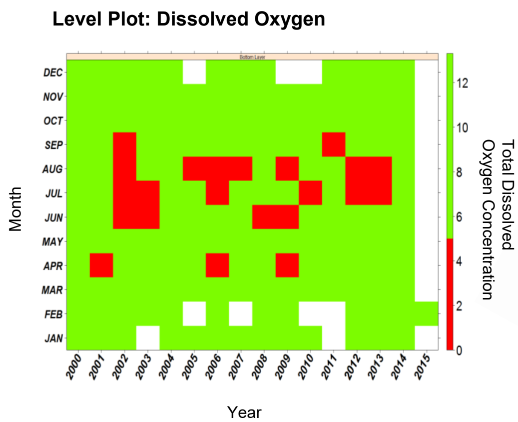


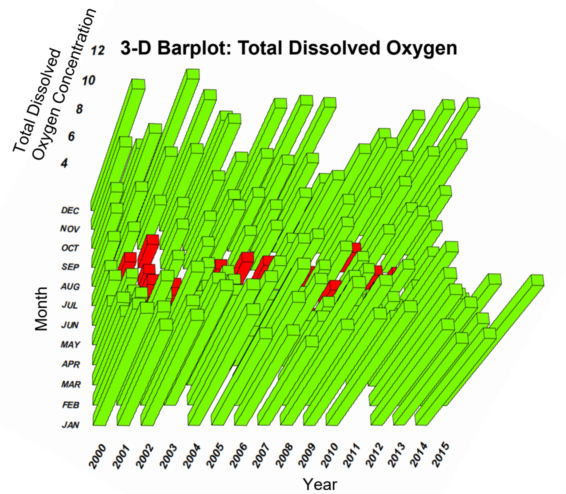
Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

Figure C.50. Surface dissolved total oxygen (mg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

Parameter: Dissolved Oxygen (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: DO F01

Key Summarization:
Low levels of dissolved oxygen have consistently occurred during summer months.





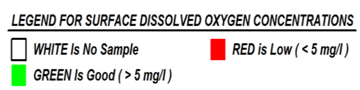
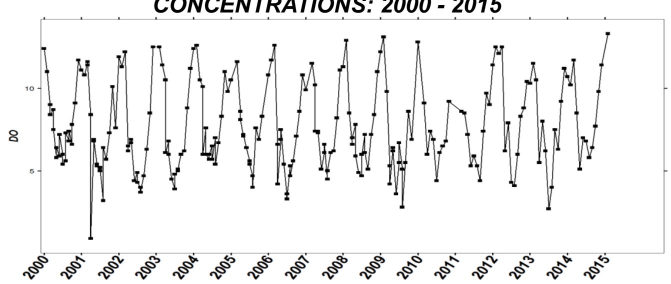


Figure C.51. Monthly bottom dissolved oxygen (mg/l) at Middle Choptank station ET5.1.

Parameter: Total Dissolved Oxygen (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom

Analytical Summarization:
Dissolved oxygen concentrations have not displayed any significant trends over the years 2000 to 2015 in the bottom layer at the middle Choptank station ET5.1

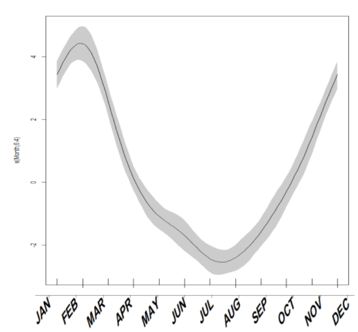
TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

NO DISSOLVED OXYGEN TREND OVER YEARS: 2000 - 2015

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

Figure C.52. Bottom total dissolved oxygen (mg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Surface
Time Span: 2000 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained greater than 1.3 mg/l over winter, spring, early summer and late fall for all years.

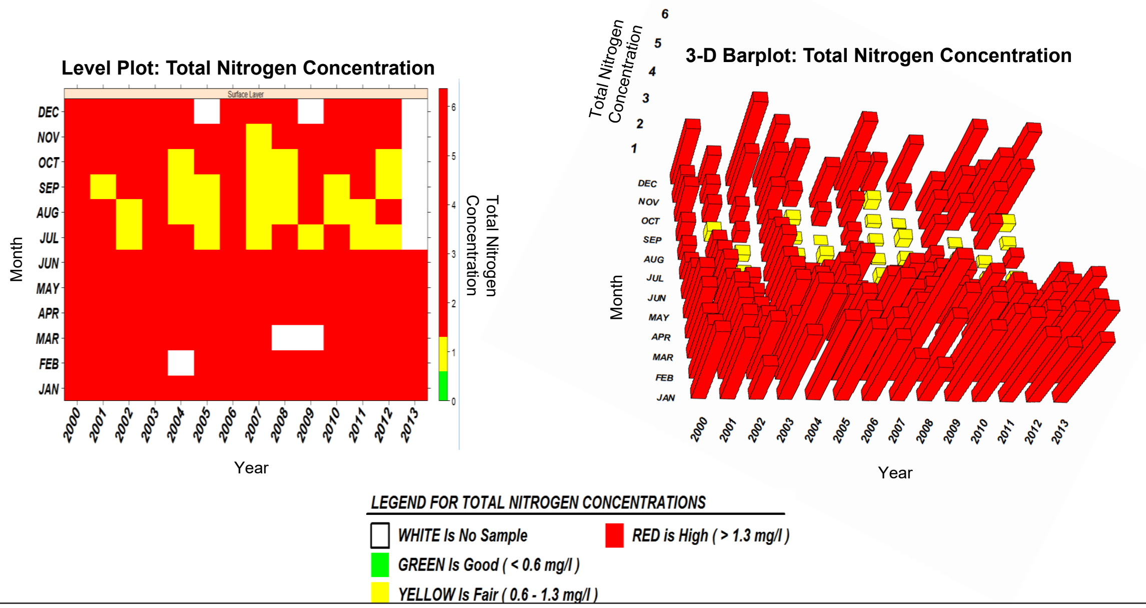
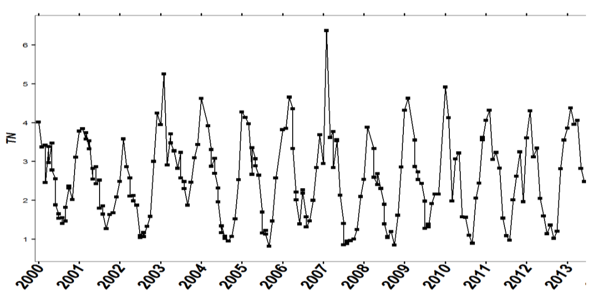


Figure C.53. Monthly surface total nitrogen (mg/l) at Middle Choptank station ET5.1.

Parameter: Total Nitrogen (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Surface

TOTAL NITROGEN CONCENTRATIONS: 2000 - 2013

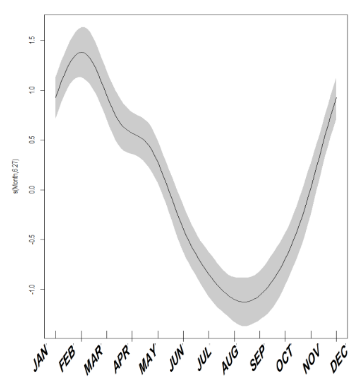


Total nitrogen concentrations over cumulative months (2000 – 2013)

NO NITROGEN TREND OVER YEARS: 2000 - 2013

Analytical Summarization:
Total nitrogen concentrations have not displayed any significant trend over the years 2000 – 2013 in the surface layer at the Middle Choptank station ET5.1

TOTAL NITROGEN TRENDS OVER MONTHS: JAN - DEC



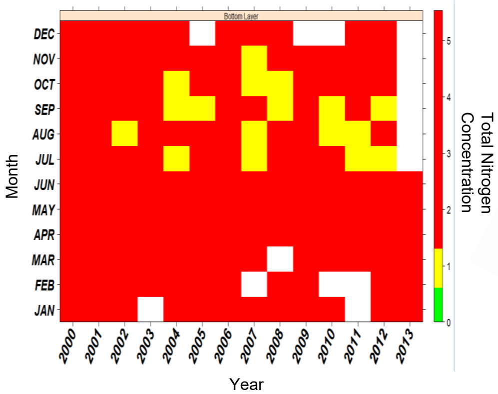
Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

Figure C.54. Surface total nitrogen (mg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

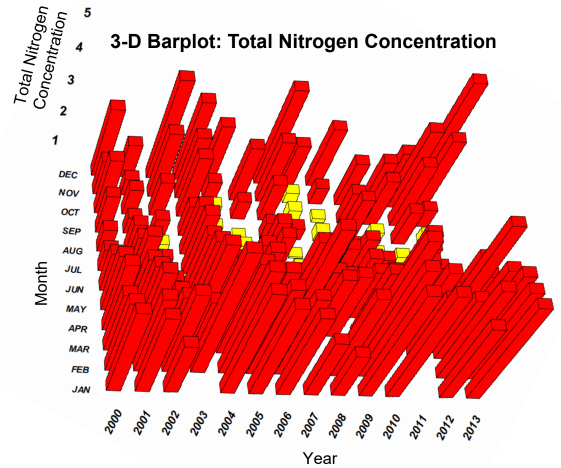
Parameter: Total Nitrogen (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom
Time Span: 2000 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained greater than 1.3 mg/l over winter, spring, early summer and late fall for all years.

Level Plot: Total Nitrogen Concentration



3-D Barplot: Total Nitrogen Concentration



LEGEND FOR TOTAL NITROGEN CONCENTRATIONS

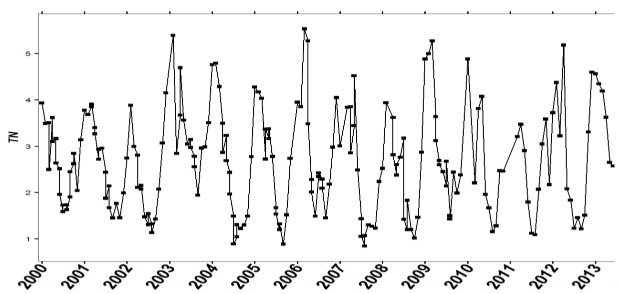
- *WHITE Is No Sample*
- *RED is High (> 1.3 mg/l)*
- *GREEN Is Good (< 0.6 mg/l)*
- *YELLOW Is Fair (0.6 - 1.3 mg/l)*

Figure C.55. Monthly bottom total nitrogen (mg/l) at Middle Choptank station ET5.1.

Parameter: Total Nitrogen (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom

Analytical Summarization:
Total nitrogen concentrations have not displayed any significant trend over the years 2000 – 2013 in the bottom layer at the Middle Choptank station ET5.1

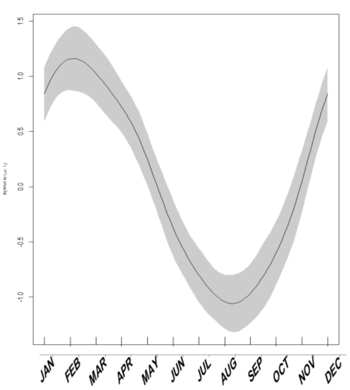
TOTAL NITROGEN CONCENTRATIONS: 2000 - 2013



Total nitrogen concentrations over cumulative months (2000 – 2013)

NO NITROGEN TREND OVER YEARS: 2000 - 2013

TOTAL NITROGEN TRENDS OVER MONTHS: JAN - DEC



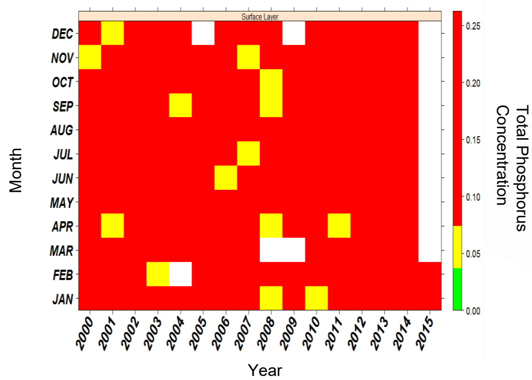
Estimated annual cycle of total nitrogen from Jan – Dec (2000 - 2013)

Figure C.56. Bottom total nitrogen (mg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

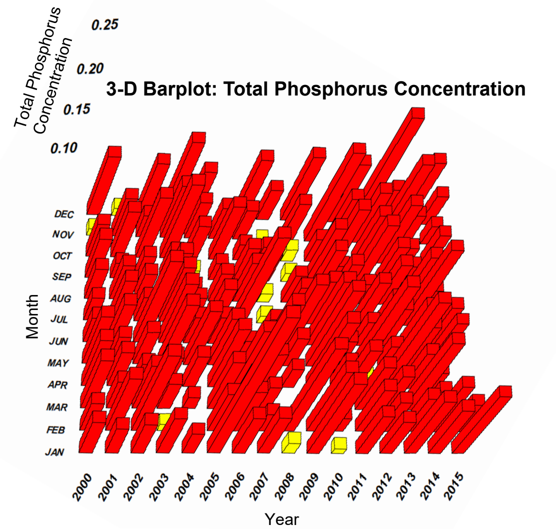
Parameter: Total Phosphorus (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: TP DO1

Key Summarization:
Total phosphorus concentrations have generally remained greater than 0.074 mg/l during all seasons over the years.

Level Plot: Total Phosphorus Concentration



3-D Barplot: Total Phosphorus Concentration



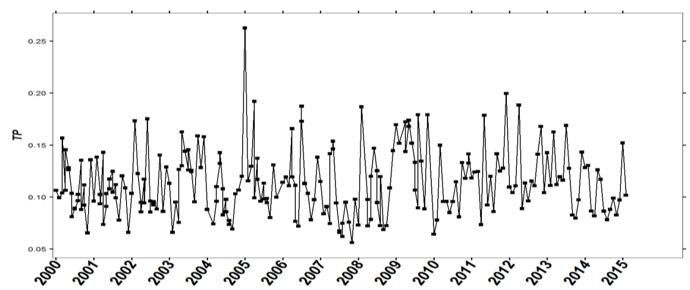
LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS
- *WHITE Is No Sample*
- *RED is High (> 0.074 mg/l)*
- *GREEN Is Good (< 0.037 mg/l)*
- *YELLOW Is Fair (0.037 - 0.074 mg/l)*

Figure C.57. Monthly surface total phosphorus (mg/l) at Middle Choptank station ET5.1.

Parameter: Total Phosphorus (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Surface

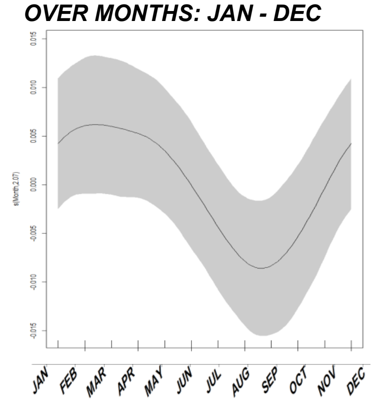
Analytical Summarization:
Total phosphorus concentrations have not displayed any significant trends over the years 2000-2015 in the surface layer at the Middle Choptank station ET5.1

TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015



Total phosphorus concentrations over cumulative months (2000 – 2015)

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total phosphorus Jan – Dec (2000 - 2015)

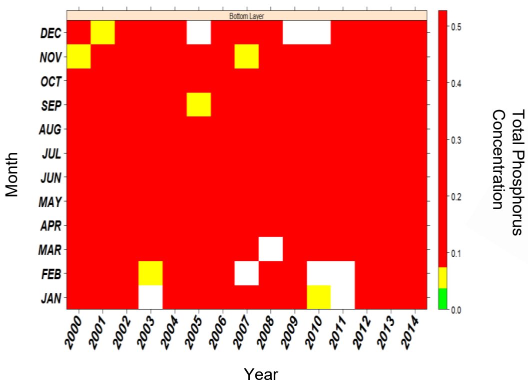
NO TOTAL PHOSPHORUS TRENDS OVER YEARS: 2000 - 2015

Figure C.58. Surface total phosphorus (mg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

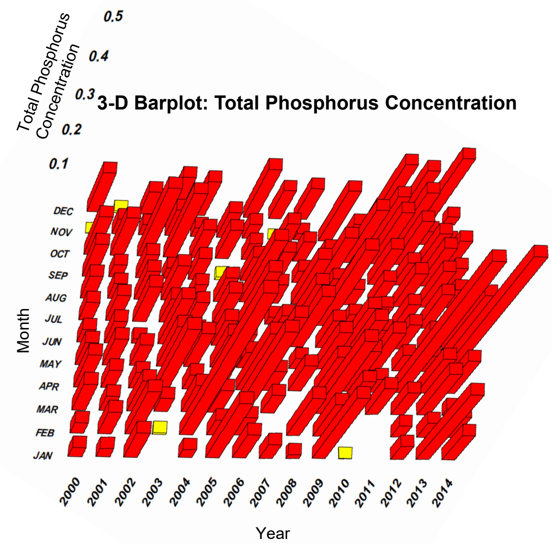
Parameter: Total Phosphorus (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: TP DO1

Key Summarization:
Total phosphorus concentrations have generally remained greater than 0.074 mg/l during all seasons over the years.

Level Plot: Total Phosphorus Concentration



3-D Barplot: Total Phosphorus Concentration



LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS

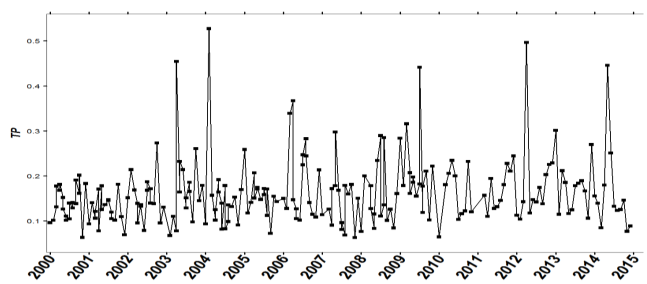
- *WHITE Is No Sample*
- *RED is High (> 0.074 mg/l)*
- *GREEN Is Good (< 0.037 mg/l)*
- *YELLOW Is Fair (0.037 - 0.074 mg/l)*

Figure C.59. Monthly bottom total phosphorus (mg/l) at Middle Choptank station ET5.1.

Parameter: Total Phosphorus (mg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom

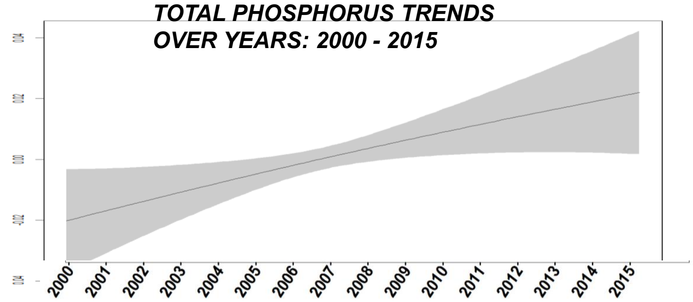
Analytical Summarization:
Total phosphorus concentrations have not displayed any significant trends over the years 2000-2015 in the bottom layer at the Middle Choptank station ET5.1

TOTAL PHOSPHORUS CONCENTRATIONS: 2000 - 2015



Total phosphorus concentrations over cumulative months (2000 – 2015)

TOTAL PHOSPHORUS TRENDS OVER YEARS: 2000 - 2015



Estimated total phosphorus trends over cumulative months (2000 – 2015)

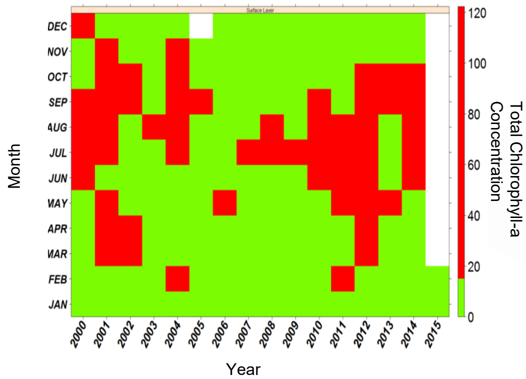
NO TOTAL PHOSPHORUS TREND OVER MONTHS: JAN - DEC

Figure C.60. Bottom total phosphorus (mg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

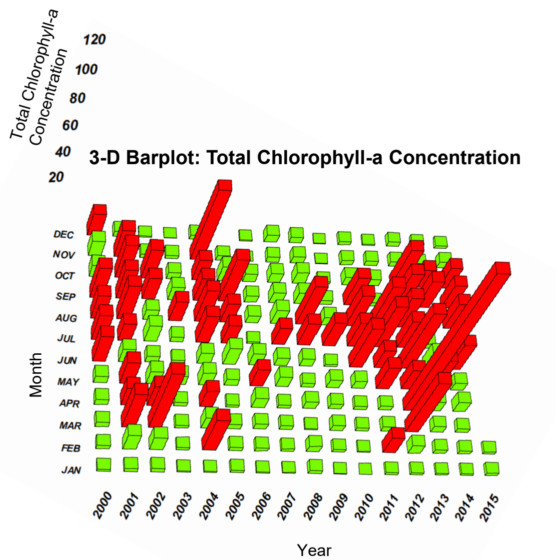
Parameter: Chlorophyll-a (µg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: CHLA L01

Key Summarization:
Chlorophyll-a concentrations have been increasing in summer and fall since 2010.

Level Plot: Total Chlorophyll-a Concentration



3-D Barplot: Total Chlorophyll-a Concentration



LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS

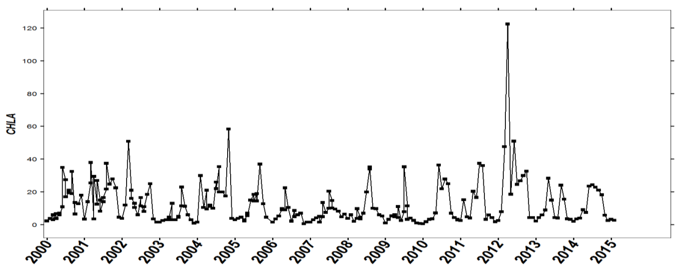
- *WHITE Is No Sample*
- *RED is High (> 15 ug/l)*
- *GREEN Is Good (< 15 ug/l)*

Figure C.61. Monthly surface total chlorophyll-a (µg/l) at Middle Choptank station ET5.1.

Parameter: Total Chlorophyll-a (µg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Surface

Analytical Summarization:
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the surface layer at the Middle Choptank station ET5.1

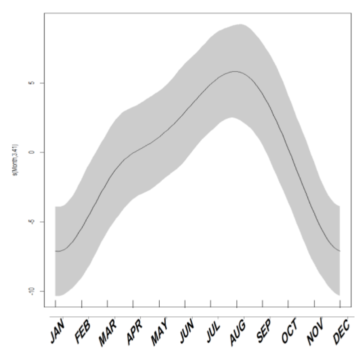
TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC



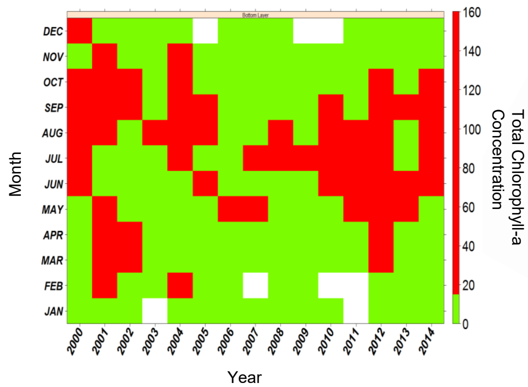
Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

Figure C.62. Surface total chlorophyll-a (µg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

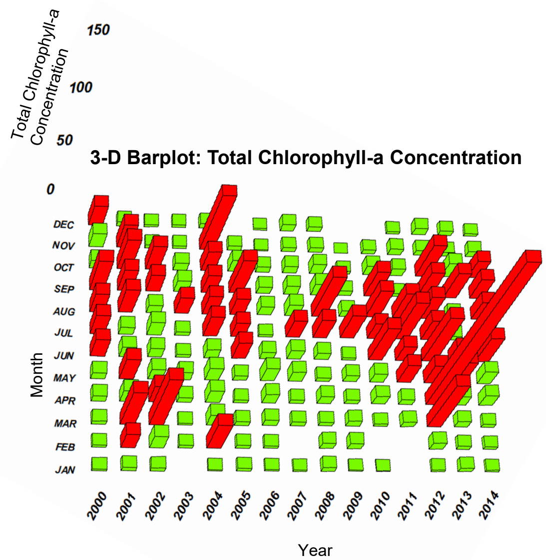
Parameter: Chlorophyll-a (µg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom
Time Span: 2000 – 2015
Parameter Method: CHLA L01

<u>Key Summarization:</u>
Chlorophyll-a concentrations have been increasing in summer and fall since 2010.

Level Plot: Total Chlorophyll-a Concentration



3-D Barplot: Total Chlorophyll-a Concentration



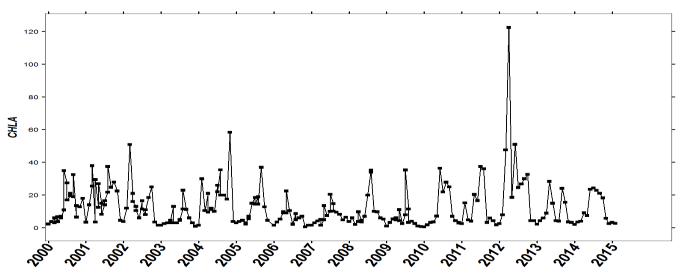
LEGEND FOR CHLOROPHYLL-A CONCENTRATIONS
- *WHITE Is No Sample*
- *RED is High (> 15 ug/l)*
- *GREEN Is Good (< 15 ug/l)*

Figure C.63. Monthly bottom total chlorophyll-a (µg/l) at Middle Choptank station ET5.1.

Parameter: Total Chlorophyll-a (µg/l)
Location: Middle Choptank River Station ET5.1
Water Layer: Bottom

<u>Analytical Summarization:</u>
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2014 in the bottom layer at the Middle Choptank station ET5.1

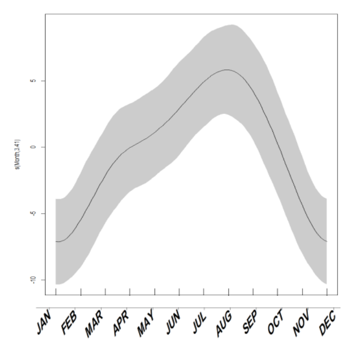
TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

TOTAL CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC



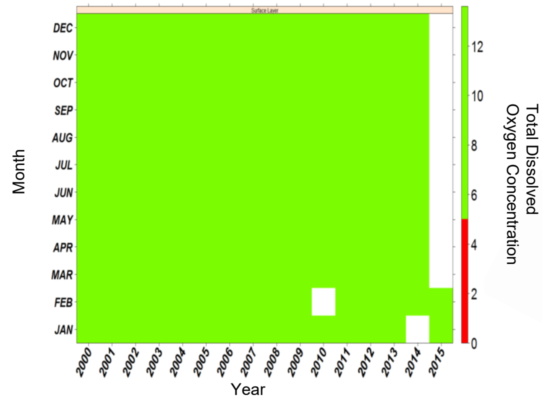
Estimated annual cycle of total chlorophyll-a from Jan – Dec (2000 - 2015)

Figure C.64. Bottom total chlorophyll-a (µg/l) at Middle Choptank station ET5.1 trend over time adjusted for seasonal variation.

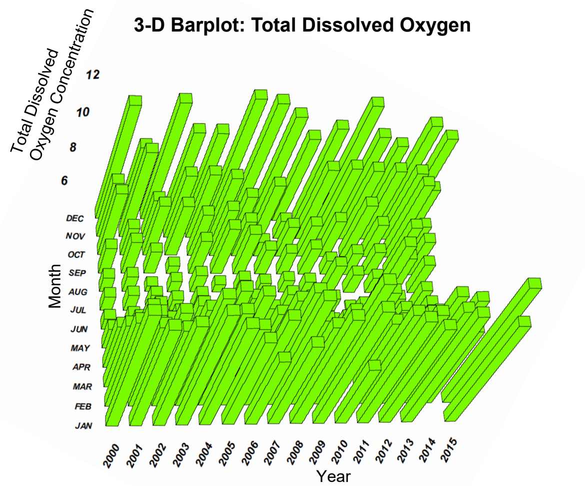
Parameter: Dissolved Oxygen (mg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: DO F01

Key Summarization:
Low levels of dissolved oxygen have consistently occurred during summer months. but levels have remained above 5 mg/l during all months and over all years.

Level Plot: Dissolved Oxygen



3-D Barplot: Total Dissolved Oxygen



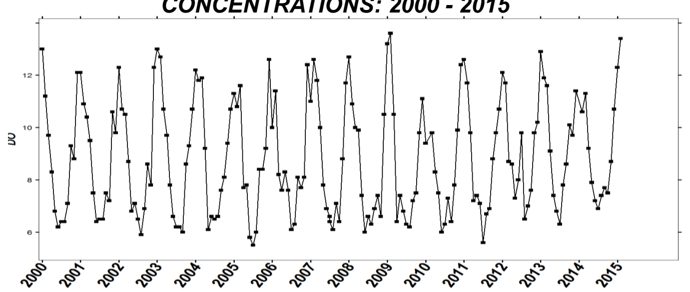
LEGEND FOR SURFACE DISSOLVED OXYGEN CONCENTRATIONS
WHITE Is No Sample
RED is Low (< 5 mg/l)
GREEN Is Good (> 5 mg/l)

Figure C.65. Monthly surface dissolved oxygen (mg/l) at Upper Choptank station ET5.0.

Parameter: Total Dissolved oxygen (mg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface

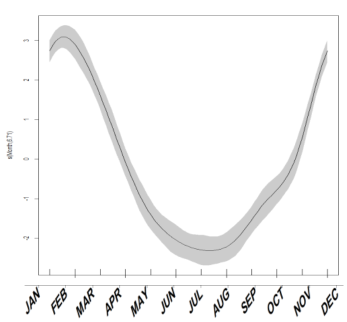
Analytical Summarization:
Dissolved oxygen concentrations have not displayed any significant trends over the years 2000 to 2015 in the surface layer at the Upper Choptank station ET5.0

TOTAL DISSOLVED OXYGEN CONCENTRATIONS: 2000 - 2015



Total Dissolved oxygen concentrations over cumulative months (2000 – 2015)

TOTAL DISSOLVED OXYGEN TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total Dissolved oxygen from Jan – Dec (2000 - 2015)

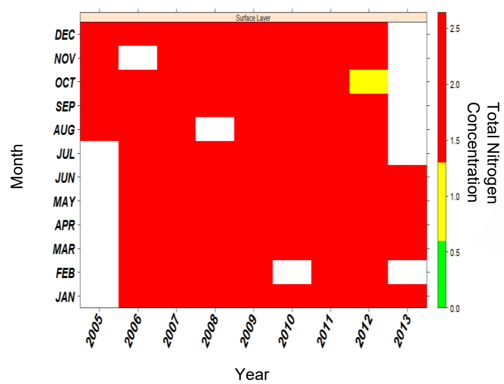
NO DISSOLVED OXYGEN TREND OVER YEARS: 2000 - 2015

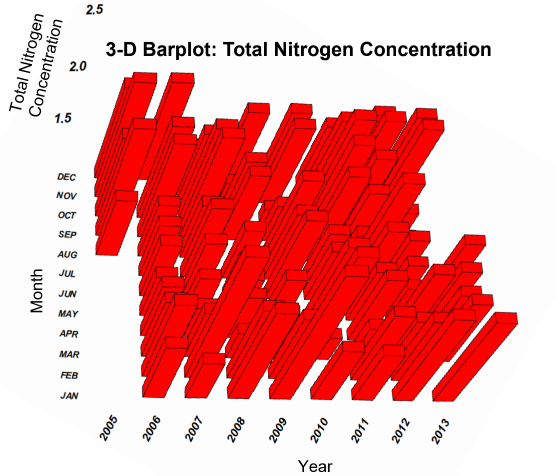
Figure C.66. Surface total dissolved oxygen (mg/l) at Upper Choptank station ET5.0 trend over time adjusted for seasonal variation.

Parameter: Total Nitrogen (mg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface
Time Span: 2005 – 2013
Parameter Method: TN D03

Key Summarization:
Total nitrogen concentrations have generally remained greater than 1.3 mg/l over winter, spring, early summer and late fall for all years since 2005. Total nitrogen was first lab analyzed with method D03 starting in 2005 at this station.

Level Plot: Total Nitrogen Concentration





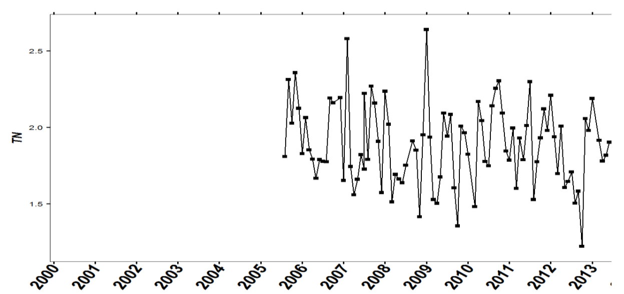
LEGEND FOR TOTAL NITROGEN CONCENTRATIONS

- WHITE Is No Sample
- RED is High (> 1.3 mg/l)
- GREEN Is Good (< 0.6 mg/l)
- YELLOW Is Fair (0.6 - 1.3 mg/l)

Figure C.67. Monthly surface total nitrogen (mg/l) at Upper Choptank station ET5.0.

Parameter: Total Nitrogen (mg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface

TOTAL NITROGEN CONCENTRATIONS: 2005 - 2013

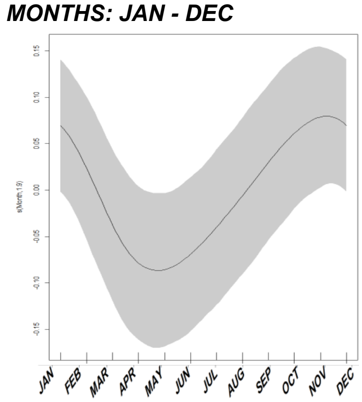


Total nitrogen concentrations over cumulative months (2000 – 2013)

NO NITROGEN TREND OVER YEARS: 2005 - 2013

Analytical Summarization:
Total nitrogen concentrations have not displayed any significant trend over the years 2005 – 2013 in the surface layer at the Upper Choptank station ET5.0

TOTAL NITROGEN TRENDS OVER MONTHS: JAN - DEC



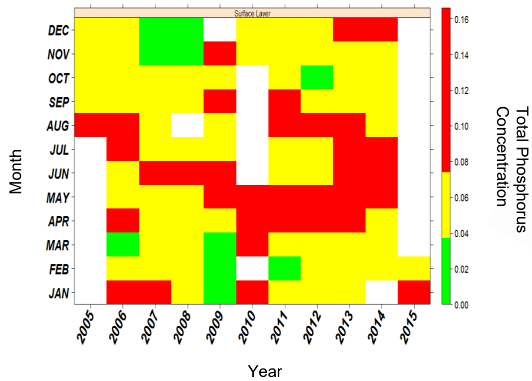
Estimated annual cycle of total nitrogen from Jan – Dec (2005 - 2013)

Figure C.68. Surface total nitrogen (mg/l) at Upper Choptank station ET5.0 trend over time adjusted for seasonal variation.

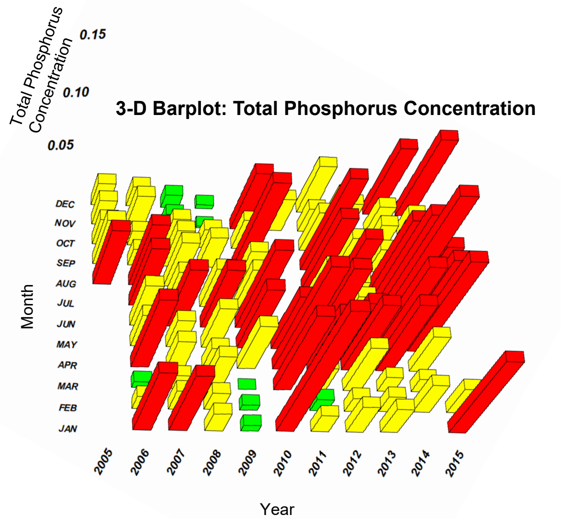
Parameter: Total Phosphorus (mg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface
Time Span: 2005 – 2015
Parameter Method: TP DO1

Key Summarization:
Total phosphorus concentrations have generally remained greater than 0.074 mg/l many times during spring and summer over all years. Total Phosphorus measurements did not start until the year 2005 at this station.

Level Plot: Total Phosphorus Concentration



3-D Barplot: Total Phosphorus Concentration



LEGEND FOR TOTAL PHOSPHORUS CONCENTRATIONS

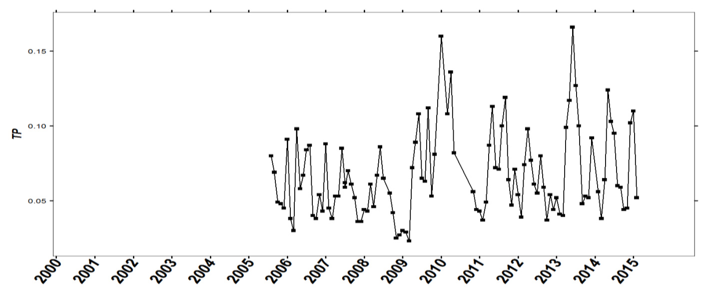
- *WHITE Is No Sample*
- *RED is High (> 0.074 mg/l)*
- *GREEN Is Good (< 0.037 mg/l)*
- *YELLOW Is Fair (0.037 - 0.074 mg/l)*

Figure C.69. Monthly surface total phosphorus (mg/l) at Upper Choptank station ET5.0.

Parameter: Total Phosphorus (mg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface

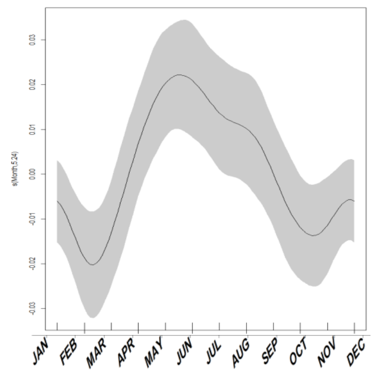
Analytical Summarization:
Total phosphorus concentrations have not displayed any significant trends over the years 2005-2015 in the surface layer at the upper Choptank station ET5.0

TOTAL PHOSPHORUS CONCENTRATIONS: 2005 - 2015



Total phosphorus concentrations over cumulative months (2005 – 2015)

TOTAL PHOSPHORUS TRENDS OVER MONTHS: JAN - DEC



Estimated annual cycle of total phosphorus Jan – Dec (2005 - 2015)

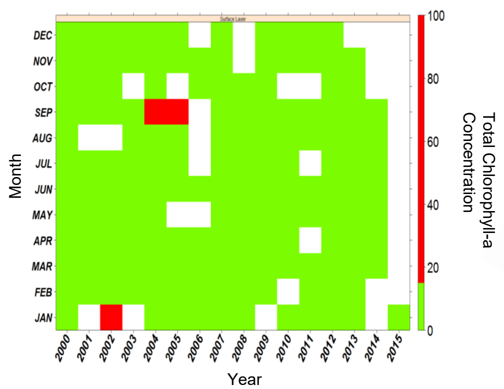
NO TOTAL PHOSPHORUS TRENDS OVER YEARS: 2005 - 2015

Figure C.70. Surface total phosphorus (mg/l) at Upper Choptank station ET5.0 trend over time adjusted for seasonal variation.

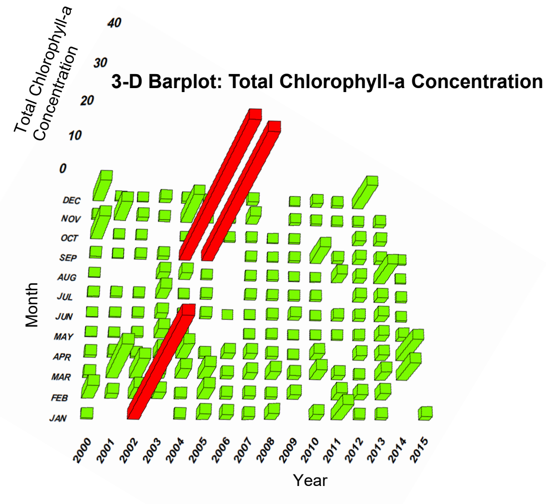
Parameter: Chlorophyll-a (µg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface
Time Span: 2000 – 2015
Parameter Method: CHLA L01

Key Summarization:
No consistent patterns in chlorophyll-a concentrations over years or months. Levels have remained below 46 µg/l over all months and years.

Level Plot: Total Chlorophyll-a Concentration



3-D Barplot: Total Chlorophyll-a Concentration



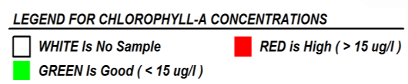
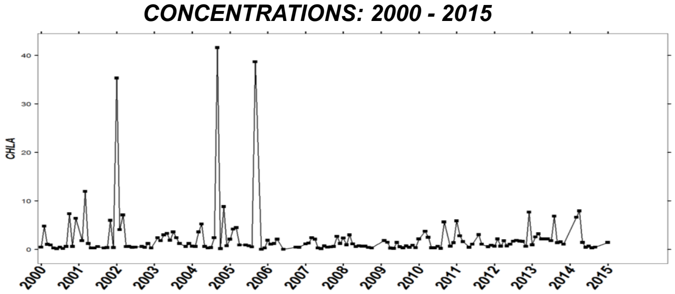


Figure C.71. Monthly surface total chlorophyll-a (µg/l) at Upper Choptank station ET5.0.

Parameter: Total Chlorophyll-a (µg/l)
Location: Upper Choptank River Station ET5.0
Water Layer: Surface

Analytical Summarization:
Chlorophyll-a concentrations have not displayed any significant trend over the years 2000-2015 in the surface layer at the Upper Choptank station ET5.0

TOTAL CHLOROPHYLL-A CONCENTRATIONS: 2000 - 2015



Total chlorophyll-a concentrations over cumulative months (2000 – 2015)

NO CHLOROPHYLL-A TRENDS OVER MONTHS: JAN - DEC

NO CHLOROPHYLL-A TRENDS OVER YEARS: 2000 - 2015

Figure C.72. Surface total chlorophyll-a (µg/l) at Upper Choptank station ET5.0 trend over time adjusted for seasonal variation.

Appendix D

Table D.1. The Mid-shore Riverkeeper Conservancy stations and monitoring segment locations.

No.	Station Code	Monitoring Segment	Latitude	Longitude
1	BC01	Broad Creek	38.779496	-76.256291
2	BC02	Broad Creek	38.767571	-76.251522
3	BC03	Broad Creek	38.768922	-76.2276
4	BC04	Broad Creek	38.748783	-76.238982
5	BC05	Broad Creek	38.739262	-76.21474
6	BC06	Broad Creek	38.746838	-76.257196
7	BC07	Broad Creek	38.725481	-76.248446
8	BC08	Broad Creek	38.72165	-76.270805
9	BC09	Broad Creek	38.70641	-76.237356
10	CR01	Outer Choptank	38.66781998	-76.28974915
11	CR02	Outer Choptank	38.6152	-76.3232
12	CR03	Outer Choptank	38.63852	-76.24812
13	CR04	Outer Choptank	38.6237	-76.20382
14	CR05	Outer Choptank	38.66085	-76.20523
15	CR06	Lower Choptank	38.62783	-76.15525
16	CR07	Lower Choptank	38.60123	-76.10792
17	CR08	Lower Choptank	38.58813	-76.06233
18	CR09	Lower Choptank	38.57048	-76.03632
19	CR10	Lower Choptank	38.59577	-75.98228
20	CR11	Lower Choptank	38.63037	-75.97865
21	CR12	Lower Choptank	38.64958	-75.95595
22	CR13	Middle Choptank	38.67568	-75.95468
23	CR14	Middle Choptank	38.69628	-75.98223
24	CR15	Middle Choptank	38.72342	-76.01237
25	CR16	Middle Choptank	38.73477	-76.00153
26	CR17	Middle Choptank	38.77408	-75.96775
27	CR18	Middle Choptank	38.805509	-75.909069
28	CR19	Upper Choptank	38.823608	-75.865945
29	CR20	Upper Choptank	38.889477	-75.837719
30	CR21	Upper Choptank	38.971202	-75.799689
31	HC01	Harris Creek	38.811938	-76.259082
32	HC02	Harris Creek	38.794411	-76.269523
33	HC03	Harris Creek	38.778783	-76.28849
34	HC04	Harris Creek	38.763377	-76.30441
35	HC05	Harris Creek	38.744844	-76.306852
36	HC06	Harris Creek	38.728214	-76.30662
37	IC1	Broad Creek	38.701991	-76.221998
38	LI1	Island Creek	38.6775833	-76.10745
39	LI2	Island Creek	38.66905	-76.13335
40	LI3	Island Creek	38.6615667	-76.1477
41	LI4	La Trappe Creek	38.63645	-76.108733
42	LI5	La Trappe Creek	38.64425	-76.11085
43	LI6	La Trappe Creek	38.65165	-76.093983
44	TA1	Tred Avon River	38.767188	-76.096369
45	TA2	Tred Avon Creek	38.758611	-76.117092
46	TA3	Tred Avon Creek	38.736772	-76.130328
47	TA4	Tred Avon Creek	38.708618	-76.143437
48	TA5	Tred Avon Creek	38.703391	-76.169897
49	TA6	Tred Avon Creek	38.684441	-76.178466
50	TR1	Tuckahoe Creek	38.831583	-75.914351
51	TR2	Tuckahoe Creek	38.872936	-75.944127
52	TR3	Tuckahoe Creek	38.916835	-75.94463

Appendix E

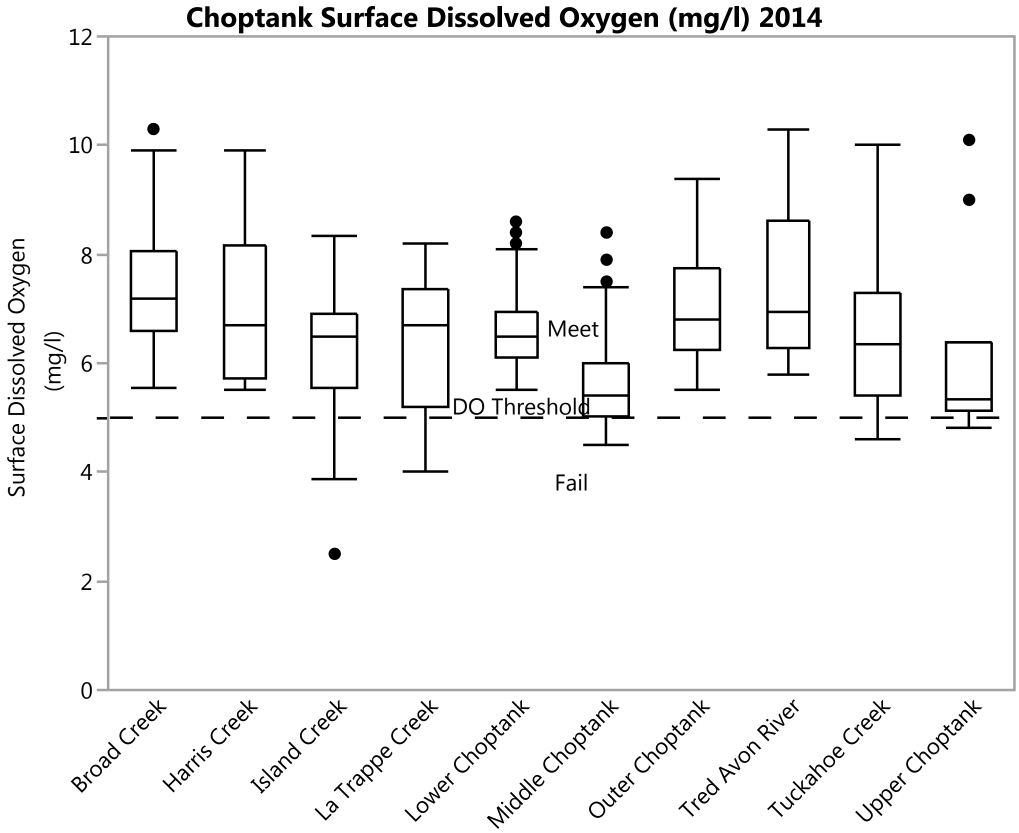


Figure E.1. Box plot of surface water dissolved oxygen (mg/l) for Choptank River monitoring segments 2014.

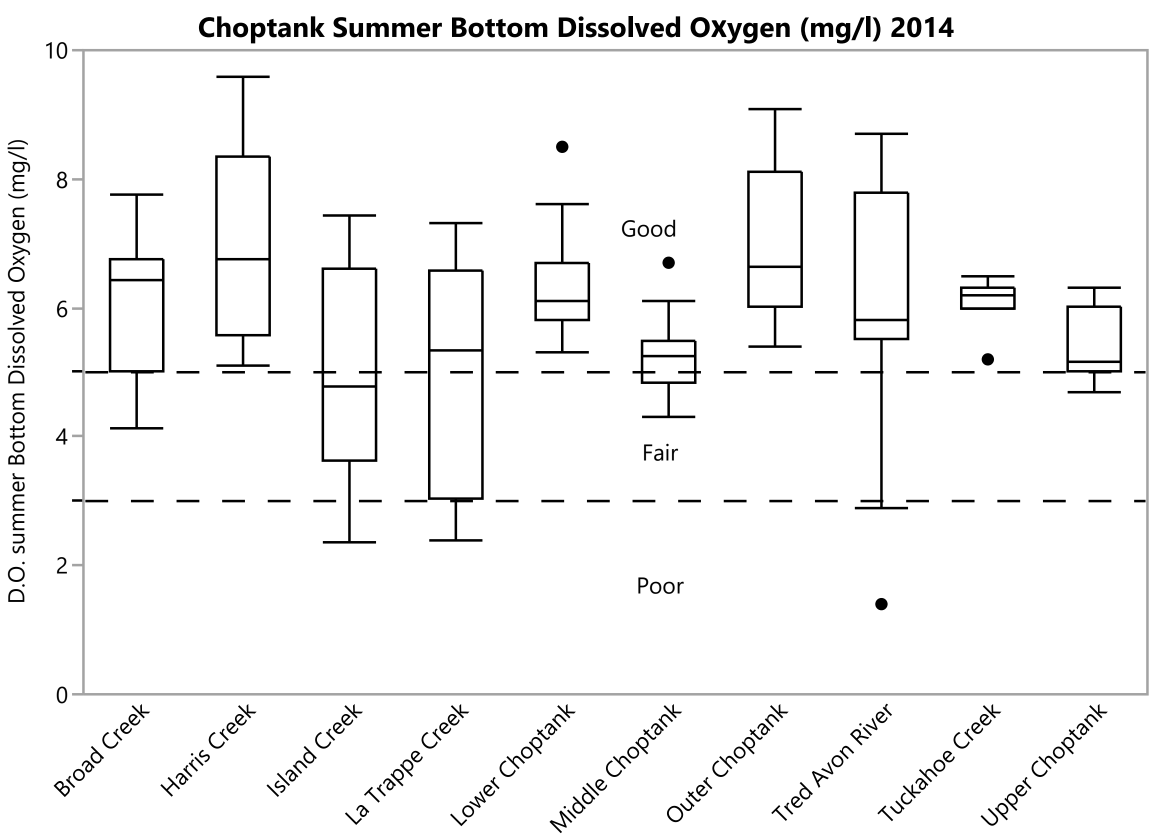


Figure E.2. Box plot of summer bottom dissolved oxygen (mg/l) for Choptank River monitoring segments 2014.

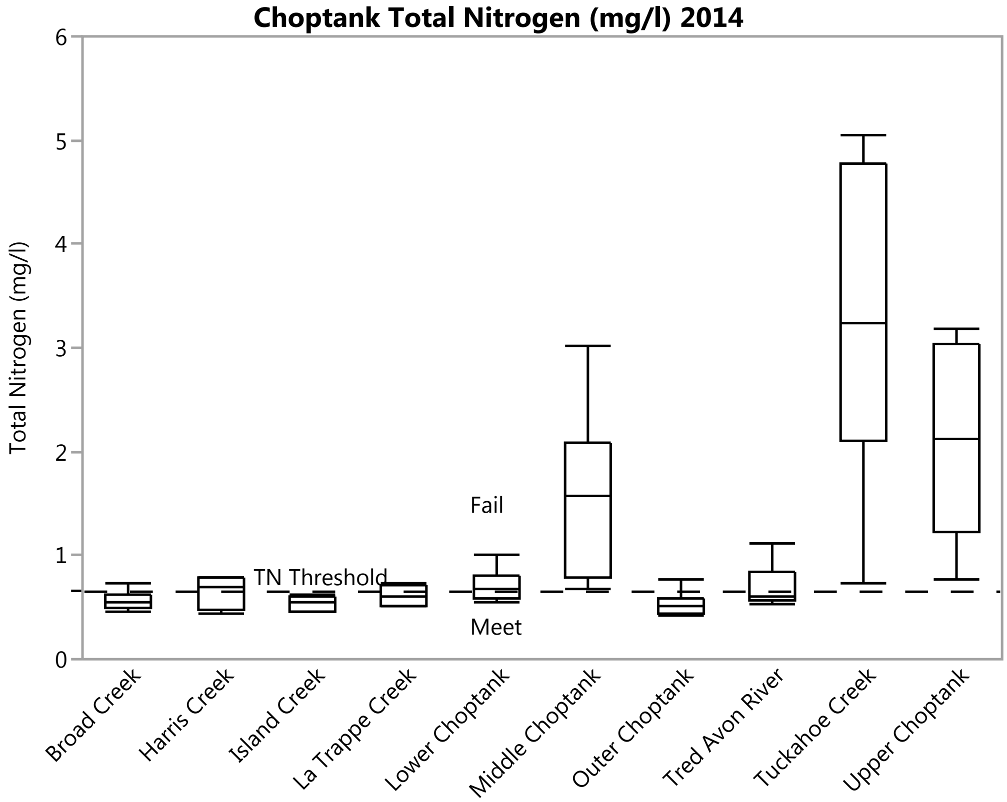


Figure E.3. Box plot of total nitrogen (mg/l) for Choptank River monitoring segments 2014.

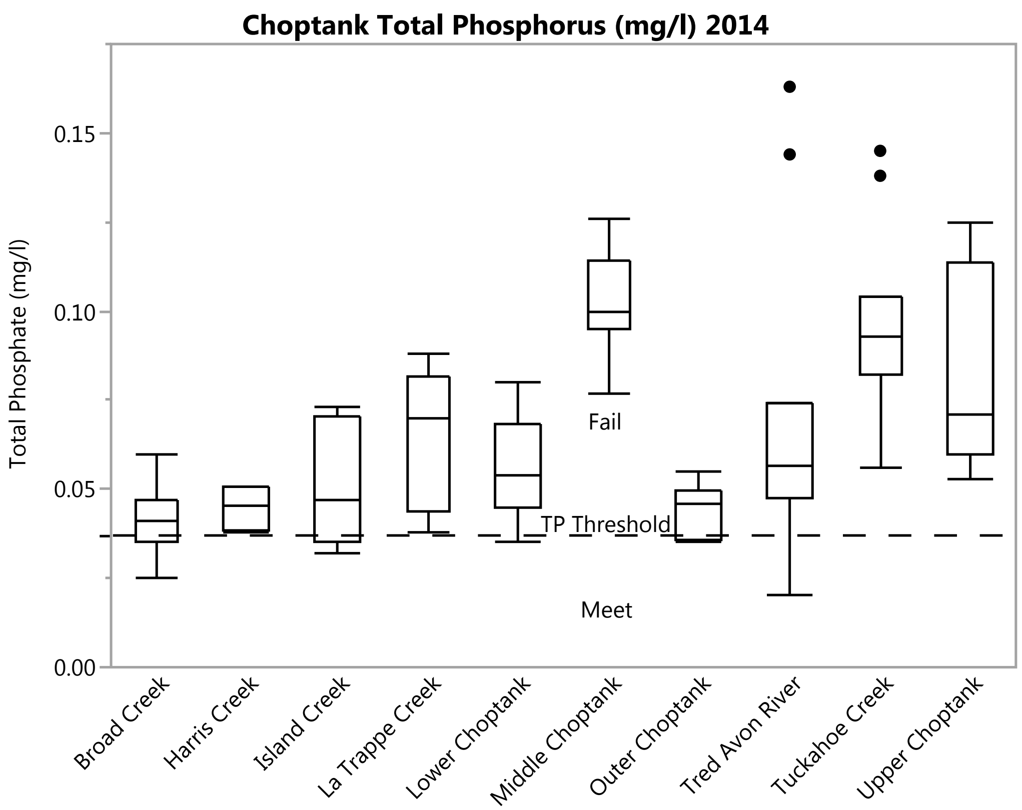


Figure E.4. Box plot of total phosphorus (mg/l) for Choptank River monitoring segments 2014.

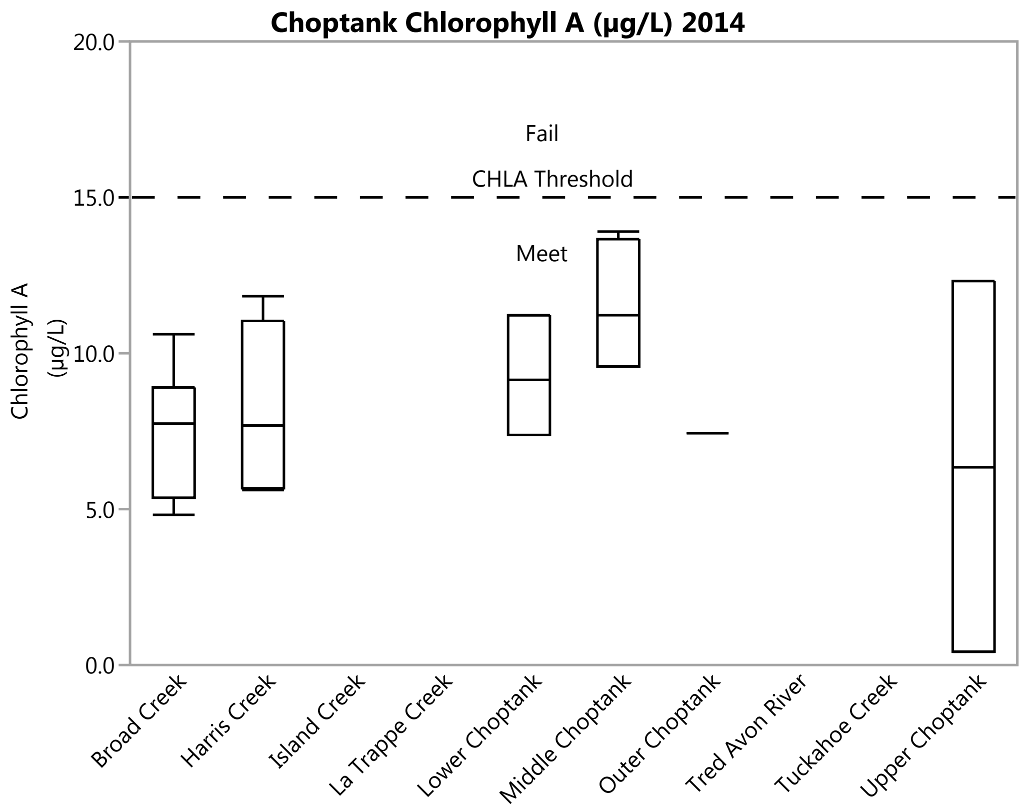


Figure E.5. Box plot of chlorophyll a (µg/l) for Choptank River monitoring segments 2014.

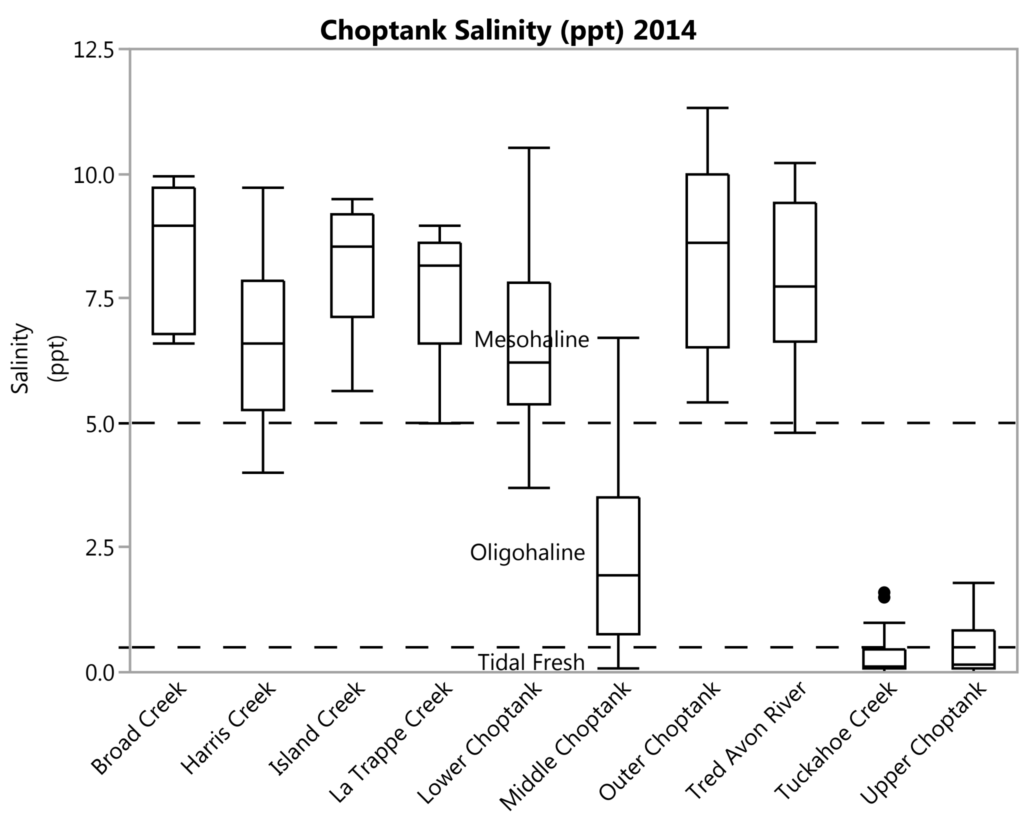


Figure E.6. Box plot of salinity (ppt) for Choptank River monitoring segments 2014.

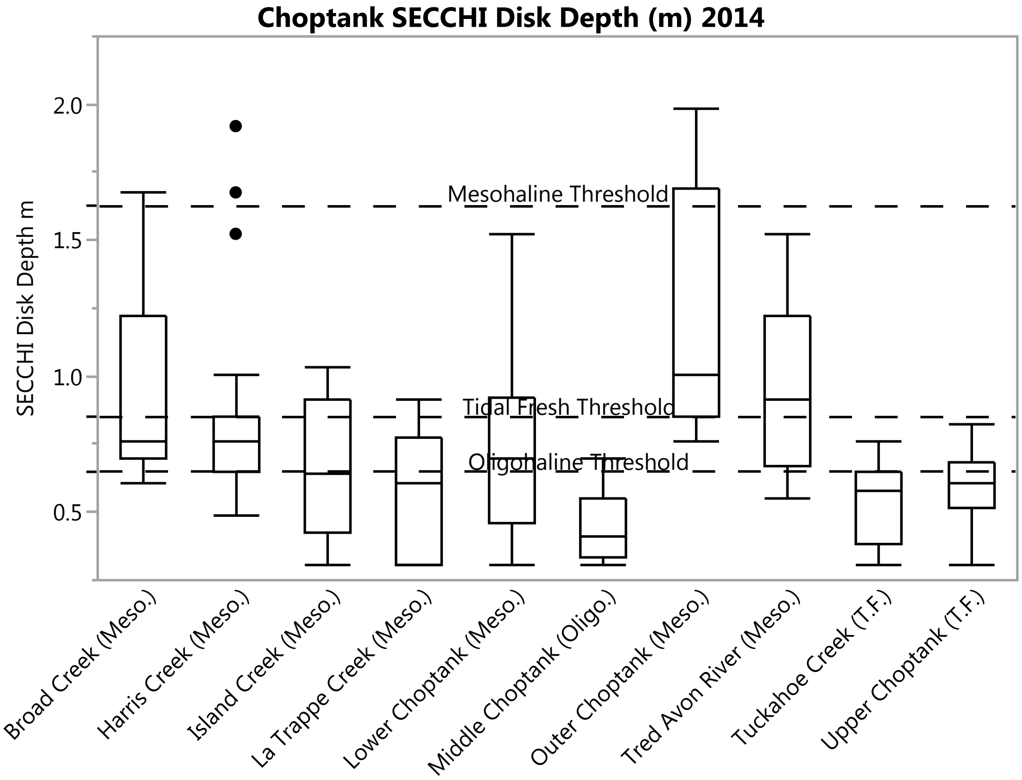


Figure E.7. Box plot of SECCHI disk depth (m) for Choptank River monitoring segments 2014.

U.S. Department of Commerce

Penny Pritzker, *Secretary*

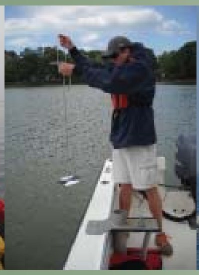
National Oceanic and Atmospheric Administration

Kathryn Sullivan, *Under Secretary for Oceans and Atmosphere*

National Ocean Service

Russell Callender, *Assistant Administrator for National Ocean Service*





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