Contents

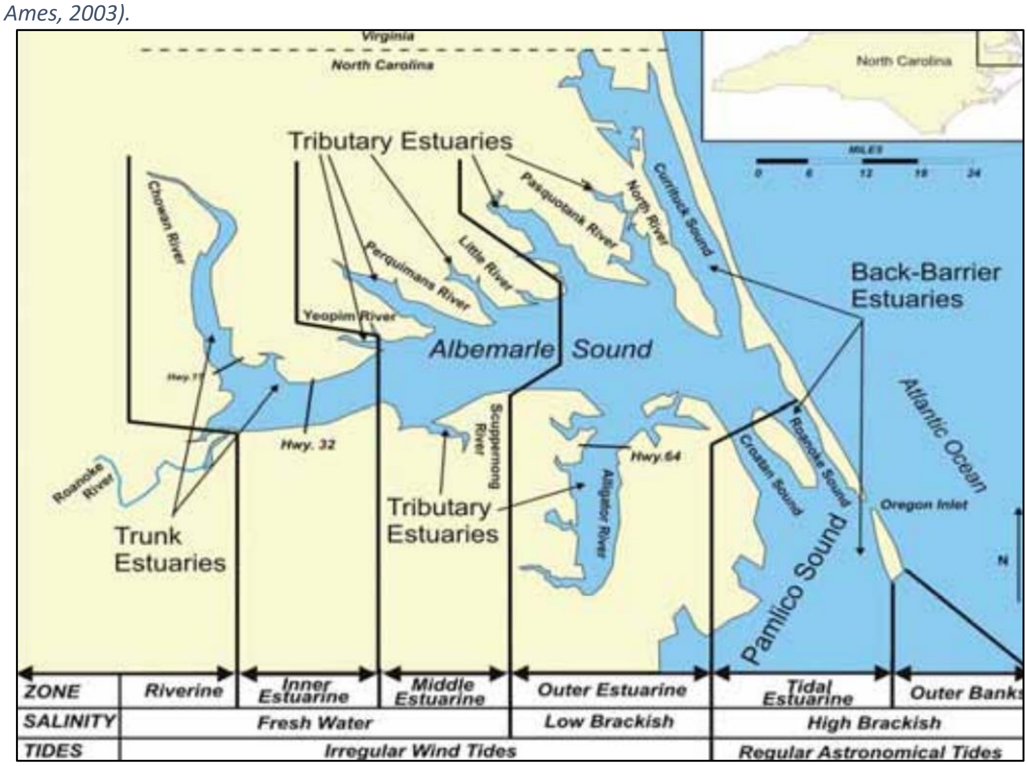
Chapter 6 Albemarle Sound Overview

6.1 Overview

The Albemarle Sound is part of the Albemarle-Pamlico Estuarine System in Northeastern North Carolina. It is the second largest estuarine system in the United States, following the Chesapeake Bay. In recognition of the numerous benefits provided by the Albemarle and Pamlico Sounds, the United States Congress designated the Albemarle-Pamlico Estuarine System an “estuary of national significance” in 1987. That same year, the Albemarle-Pamlico Estuarine Study (APES) was among the first of 28 National Estuary Programs established by the EPA through amendments to the Clean Water Act (CWA). Upon adoption of its first Comprehensive Conservation Management Plan (CCMP) in 1994, the program became known as the Albemarle-Pamlico National Estuary Program (APNEP) and it broadened its mission to include applied conservation, management, and engagement initiatives to protect natural resources within the region. In 2012, the program was formally renamed and identified as a Partnership, reflecting the importance of coordinated and integrated efforts for protecting and restoring the estuarine ecosystem in the region.

The Albemarle Sound and nearby tributaries comprise shallow, low salinity, high turbidity estuary covering 2,330 square kilometers with greater than 800 kilometers of shoreline (Moorman et al., 2014). The Chowan and Roanoke rivers flow in from the west to form the Albemarle Sound behind the barrier islands. Many of smaller streams drain coastal-area swamps into the Albemarle Sound, including the Yeopim, Perquimans, Little, Pasquotank, and North rivers along the northern shore of the sound and the Scuppernong and Alligator rivers southern shore of the sound (Moorman et al., 2014). Riggs and Ames (2003) divided the estuarine zones in the Albemarle Sound into an Inner Estuarine, Middle Estuarine, Outer Estuarine, and Tidal Estuarine areas (Figure 6-1).

Figure 6-1 The Albemarle Sounds divided into different estuarine zones based on salinity gradients and dominant tidal processes (Riggs and Ames, 2003).



The Albemarle Sound is connected to the Atlantic Ocean through the Roanoke and Croatan sounds which connect to the Oregon Inlet. There is little tidal exchange and the movement of the water in the sound is primarily drive by wind tides (Moorman et al., 2014). This also results in freshwater imparting a direct influence on the water quality in the Albemarle Sound area (NCDENR, 1991). Drainage canals have been implemented in the Albemarle Sound areas to allow the land to be used for agriculture, silviculture, and other types of development to offset the relatively high rainfall, flat terrain, and naturally high water table (NCDENR, 1991). These drainage canals pose the potential to cause water problems from runoff of bacteria, nutrients, pesticides, and sediment associated with land use in the region (Heath, 1975). In the Albemarle-Pamlico Estuary environmental stress can be seen in the form of declining fisheries, algal blooms, closure of shellfish waters, loss of historical submerged aquatic vegetation beds, and degradation of wetlands, fish and upland habitats (US EPA, 2001).

The 2016 National Land Cover Database (NLCD) is used to understand the dominant land-use types throughout the watershed and is used to infer possible sources of pollutants that can contribute to water quality issues. Several of the watersheds monitored by the surface water ambient monitoring system (AMS) capture water quality conditions associated with high agricultural land use practices in the Pasquotank River Basin (Table 6-1). Specifically, the Little River watershed (HUC 0301020505) has the highest percentage of total agricultural land use in the Pasquotank River Basin at approximately 55 percent; however, above the AMS station (M3500000; Little River at Old US-17) the agricultural land use is closer to 69 percent of the watershed (Table 6-1).

Table 6-1 Percentage of land cover for several watersheds draining to the Albemarle Sound at the river basin scale, HUC 10 scale and station specific watershed scale. (Data Source: 2016 National Land Cover Database and USGS StreamStats).

Land Cover Type	Pasquotank Basin (NC Portion)	Perquimans River 0301020503	Perquimans River at M5000000	Little River 0301020505	Little River at M3500000	Pasquotank River 0301020507	Pasquotank River at M2750000	Edenton Bay 0301020501	Kendrick Creek at M6920000	Bull Bay/ Scuppernong River 0301020502	Scuppernong River at M6980000
Agriculture	19.9%	45.0%	45.3%	**55.4%**	**68.8%**	41.7%	29.0%	29.7%	47.9%	35.5%	46.8%
Barren Land	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
Developed	3.4%	3.8%	3.4%	4.7%	5.3%	7.2%	5.2%	4.7%	4.1%	2.7%	2.3%
Forest	5.1%	11.5%	13.4%	6.8%	8.0%	6.9%	9.5%	13.2%	12.6%	6.0%	2.5%
Grassland/ Shrub	0.7%	1.2%	1.8%	0.7%	0.8%	0.8%	1.2%	2.1%	2.5%	0.6%	0.7%
Open Water	37.4%	11.9%	0.6%	14.4%	0.3%	11.0%	2.6%	29.6%	1.4%	15.1%	19.4%
Wetland	33.1%	26.5%	35.6%	18.0%	16.7%	32.4%	52.4%	20.6%	31.4%	40.0%	28.3%

The National Water-Quality Assessment Project in agricultural areas was the first national-scale study by the USGS to address nutrients in agricultural landscapes using standardized methods, and combines ecological effects and nutrient processing (Munn et al., 2018). As part of this study, *Understanding the Influences of Nutrients on Stream Ecosystems in Agricultural Landscapes* was published. This study was conducted in “the Central Columbia-Yakima River Basins in eastern Washington (Columbia Plateau); the Upper Snake River Basin (Snake River) of southeastern Idaho and northeastern Nevada; in Central Nebraska; the Ozark Highlands in Arkansas, Missouri, and Oklahoma (Ozarks); the Upper Mississippi River Basins in Minnesota and Wisconsin (Upper Mississippi); the White River and Great and Little Miami River Basins of Indiana and Ohio (White-Miami); the Delmarva Peninsula (Delmarva); and the Georgia Coastal Plain (Georgia Coastal) that also includes part of Alabama and Florida.” (Munn et al., 2018). This study suggests six implications for management of agricultural streams (Munn et al., 2018):

(1) “Algal and invertebrate communities were altered under increasing nutrient concentrations, negatively influencing biological condition in streams. Managers should consider strategies that take advantage of the wide variety of tools available to reduce nutrient inputs to streams. Furthermore, multiple taxonomic groups (i.e., algae, invertebrates) should be used in stream assessments because assessments that rely on a single biological community may not accurately reflect the health of a stream.” (chapter 6 – Munn et al., 2018)

(2) “Elevated nutrient concentrations do not always result in nuisance levels of aquatic vegetation in agricultural streams; therefore biological assessments are necessary to correctly identify the overall condition of a stream. While streams with elevated nutrient concentrations may not reflect local biological impairment, they can still be an important source of nutrients to downstream receiving waters.” (chapter 5 – Munn et al., 2018)

(3) “Stream habitat plays an important role in determining biological communities in agricultural streams; therefore, it is important to include stream habitat assessments in nutrient programs to determine the relative influence of habitat and nutrients on biological conditions.” (chapter 6 – Munn et al., 2018)

(4) “Limiting the amount of agricultural land along stream buffers can improve algal and invertebrate community condition; therefore, maintaining or improving riparian buffers is an important tool that managers can use for enhancing agricultural streams.” (chapter 6 – Munn et al., 2018)

(5) “Natural loss of nitrogen in streams is diminished by agricultural practices; therefore enhancing the ability of an agricultural stream to naturally transform nutrients should be part of any nutrient management strategy. Increasing natural loss of nitrogen can be done by protecting or restoring the physical complexity of a stream, which will benefit the local stream health, as well as downstream receiving waters impacted by nutrient loading.” (chapter 4 – Munn et al., 2018)

(6) “Complex modeling improves our understanding of regional differences in how invertebrate communities respond to interactions of land use, habitat, and nutrients. Tools like Structural Equation Modeling provide insight into the factors most likely influencing the biological condition of streams, and hence can help optimize management strategies for specific regions.” (chapter 6 – Munn et al., 2018)

Management agencies in the Albemarle Sound include: North Carolina Department of Environment Quality which includes the Albemarle - Pamlico National Estuary Partnership (APNEP), Division of Coastal Management (DCM), Division of Marine Fisheries (DMF), Division of Water Resources (DWR); the North Carolina Division of Parks and Recreation; the North Carolina Forest Service; the North Carolina Wildlife Resources Commission; the Virginia Department of Environmental Quality (VADEQ), which includes the Virginia Department of Game and Inland Fisheries, Virginia Department of Forestry, and Virginia Department of Conservation and Recreation; the U.S. Department of the

Interior, which includes the U.S. Fish and Wildlife Service (USFWS) and National Park Service (NPS); and the U.S. Environmental Protection Agency (USEPA) (Moorman et al., 2014). More information about water quality initiatives and funding can be found in Chapter 8 of this basin plan.

6.2 Data Availability and Parameters of Interest

6.2.1 Water Quality Monitoring

The Division of Water Resources (DWR) Ambient Monitoring System (AMS) program has continued to sample five stations in the Albemarle Sounds proper (Table 6-2, Table 6-2)

D999500C – Albemarle Sound near Edenton mid-channel (formally a Chowan R. basin station)

D999500N – Albemarle Sound near Edenton north shore (formally a Chowan R. basin station)

D999500S – Albemarle Sound near Edenton south shore (formally a Chowan R. basin station)

M610000C – Albemarle Sound between Harvey Point and Mill Point mid-channel

M390000C – Albemarle Sound near Frog Island mid-channel

Prior to 2014, there were nine stations across the Albemarle Sound; however, due to staffing shortages, resource issues, and/or extreme weather conditions over the years, the Albemarle Sound stations were reduced, and current monitoring stations have not always been monitored (Table 6-2 and Table 6-2). Monitoring inconsistencies present a limitation when interpreting the water quality data and these inconsistencies should be taken into consideration when reviewing the water quality data. The Albemarle Sound is listed on the 303(d) list of impaired water for dioxin in fish tissue, copper, and elevated pH (Table 6-3)

Table 6-2 Ambient Monitoring Stations in Albemarle Sound Watershed.

Station ID	Station Location	Active Date	County	Stream AU#	Stream Classification
Albemarle Sound Proper					
D999500C	ALBEMARLE SOUND NR EDENTON MID CHANNEL	1997-Present	Washington	26	B, NSW
D999500N	ALBEMARLE SOUND NR EDENTON N SHORE	1997-Present	Chowan	26-1	C, NSW
D999500S	ALBEMARLE SOUND NR EDENTON S SHORE	1997-Present	Chowan	30	SB
M610000C	ALBEMARLE SOUND BETWEEN HARVEY PT AND MILL PT MID CHANNEL	1997-Present	Tyrrell	30	SB
M610000N	ALBEMARLE SOUND BETWEEN HARVEY PT AND MILL PT N SHORE	1997-2014	Perquimans	30	SB
M610000S	ALBEMARLE SOUND BETWEEN HARVEY PT AND MILL PT S SHORE	1997-2014	Tyrrell	30	SB
M390000C	ALBEMARLE SOUND NR FROG ISLAND MID CHANNEL	1997-Present	Tyrrell	30	SB
M390000N	ALBEMARLE SOUND NR FROG ISLAND N SHORE	1997-2014	Camden	30	SB
M390000S	ALBEMARLE SOUND NR FROG ISLAND S SHORE	1997-2014	Tyrrell	30	SB

Station ID	Station Location	Active Date	County	Stream AU#	Stream Classification
North Shore Pasquotank River Basin Watershed					
M5000000	PERQUIMANS RIV AT SR 1336 AT HERTFORD	1968-Present	Perquimans	30-6-(3)	SC
M3500000	LITTLE RIV AT SR 1367 AT WOODVILLE	1973-Present	Pasquotank	30-5-(1)	C, Sw
M2750000*	PASQUOTANK RIV AT ELIZABETH CITY	1968-2014	Camden	30-3-(12)	SB
M2490000	PASQUOTANK RIV AT MOUTH OF CHARLES CRK AT ELIZABETH CITY	2015-Present	Camden	3-3-(7)	SC
South Shore Pasquotank River Basin Watershed					
M6920000	KENDRICK CRK AT SR 1300 AT MACKEYS	1982-Present	Washington	30-9-(2)	SC
M6980000	SCUPPERNONG RIV AT SR 1105 NR COLUMBIA	1997-Present	Tyrrell	30-14-4-(1)	C, Sw
M7175000	ALLIGATOR RIV AT US 64 NR ALLIGATOR	1982-Present	Tyrrell	30-16-(7)	SC, Sw, ORW
M6930000	RAMS DEEP CRK AT SR 1303 NR SCUPPERNONG	2013-2014	Washington	30-14-2	C, Sw
Mouth of Roanoke River					
N9700000	ALBEMARLE SOUND AT BATCHELOR BAY NR BLACK WALNUT	1974-Present	Washington	30	SB
Mouth of Chowan River					
D9490000	CHOWAN RIVER AT US 17 AT EDENHOUSE	1969-Present	Bertie	25c	B, NSW
Note: Ambient Monitoring Stations with a letter as the eighth digit indicates a spatial location in context of other stations (i.e. N = North, C = Center, and S = South) *Station was relocated please refer to Chapter 3 for details					

Table 6-3 Impaired waters in the Albemarle Sound proper.

AU Name	AU Number	Stream Class	Parameter of Interest	303d Listing Year
Albemarle Sound	26	B;NSW	Dioxin Fish Tissue Advisory (Advisory, FC, NC)	2010
Albemarle Sound	30b	SB	Copper (3 µg/l, AL, SW)	2008
Albemarle Sound	30c1	SB	Copper (3 µg/l, AL, SW)	2008
Albemarle Sound	30c2a	SB	Copper (3 µg/l, AL, SW)	2008
Albemarle Sound	30c2a	SB	pH (8.5, AL, SW)	2018
Albemarle Sound	30c2b	SB	Copper (3 µg/l, AL, SW)	2008

Figure 6-2 Ambient Monitoring Stations and 2018 Integrated Report Ratings. Station M2750000 (Pasquotank River) was relocated upstream to the present location in 2015.

6.5.2 Ammonia

Ammonia ($NH3 + NH4^+$; reported as ammonia) is the nutrient parameter most often found at low concentrations (at or below detection levels) in our natural aquatic ecosystems in North Carolina. Ammonia is readily utilized by the algal communities, especially in highly productive environments. This form of nitrogen is also converted to nitrite and nitrate by nitrifying bacteria which results in transient values in surface water (Harned and Davenport, 1990). Ammonia concentrations in the Albemarle Sound have remained fairly stable since 2002. Most measurements have been below 0.04 mg/L and annual average values are near the practical quantitation limit (PQL) which have varied over time (Table 6-4). Overall, the Albemarle Sound displays relatively similar ammonia concentrations from the western to the eastern sides of the sound and from north to south sides of the sound (Figure 6-3 and Table 6-5). Although ammonia concentrations have remained relatively low in the Albemarle Sound proper, Kendrick's Creek (M6920000) and Scuppernong River (M6980000) on the southern shoreline, as well as the Little River (M3500000) and Pasquotank River (M2750000) on the northern shoreline have elevated ammonia levels (Figure 6-4, Figure 6-5 and Table 6-5).

The sources of the higher ammonia concentrations in these watersheds draining to the Albemarle Sound need to be investigated further. These watersheds are dominated by agricultural and wetland land cover types (Table 6-1). In 2014, the Little River had the highest annual average instream ammonia concentration of 0.378 mg/L (Table 6-5). The Pasquotank River ammonia concentration increased substantially starting in 2015, however the overall annual average concentrations is lower than those in the Little River, Kendrick Creek and Scuppernong River (Figure 6-4 and Figure 6-5). The change in the Pasquotank River at M2750000 is likely due to relocating the stations from the open water (boat monitored) location downstream of Elizabeth City January 2015. This change put the stations in a narrower stretch of the riverine/estuarine system, closer to both point and nonpoint sources of pollutants. The Elizabeth City wastewater treatment plant discharge is about 1 mile upstream of the US-158 bridge. A majority of the ammonia values greater than 1 mg/L between 2000 and 2019 occurred during the months of mid-May through early October. The Division of Water Resources currently does not have an instream ammonia standard.

Table 6-4 Nutrient reporting levels or PQL (Practical Quantitation Limit) by date.

Parameter	Reporting Level by Date* (mg/L)				
	Pre-2001	3/13/2001 to 3/29/2001	3/30/2001 to 7/24/2001	7/25/2001 to 2/28/2009	3/01/2009 to Present
NH_3	0.01	0.50	0.20	0.01	0.02
TKN	0.10	1.00	0.60	0.20	0.20
NO_2+NO_3	0.01	0.50	0.15	0.01	0.02
TP	0.01	0.50	0.10	0.02	0.02

*In early 2001, the DWQ Laboratory Section reviewed its internal Quality Assurance/Quality Control (QA/QC) programs and analytical methods. This effort resulted in a marked increase in reporting levels for certain parameters. New analytical equipment and methods were subsequently acquired to establish new lower reporting levels and more scientifically supportable quality assurance. As a result, the reporting levels quickly dropped back down to at or near the previous reporting levels.

Table 6-5 Average and maximum nutrient concentrations for the year 2014 at stations in the Pasquotank River basin. The year 2014 was the last year nutrients were collected at the northern (N) and southern (S*) stations in the Albemarle Sound; these five stations are no longer monitored on a routine basis. (Note: The 2014 highest recorded values are in red.)*

Station ID	Station Location (2014)	Ave. NH_3 mg/L	Max NH_3 mg/L	Ave. NOx mg/L	Max NOx mg/L	Ave. TKN mg/L	Max TKN mg/L	Ave. TP mg/L	Max TP mg/L	Ave. Chl *a* µg/L	Max Chl *a* µg/L
Albemarle Sound Proper - 2014											
D999500**N*** Western Section	Albemarle Sound nr Edenton North Shore	0.023	0.03	0.105	0.28	0.530	0.72	0.056	0.07	ND	ND
D999500**C** Western Section	Albemarle Sound nr Edenton Mid-Channel	0.025	0.04	0.128	0.38	0.449	0.61	0.051	0.08	11	25
D999500**S** Western Section	Albemarle Sound nr South Shore	0.024	0.04	0.119	0.25	0.458	0.53	0.045	0.07	ND	ND
M610000**N*** Middle Section	Albemarle Sound nr North Shore	0.020	0.02	0.030	0.10	0.575	0.67	0.036	0.07	ND	ND
M610000**C** Middle Section	Albemarle Sound Mid-Channel	0.020	0.02	0.043	0.11	0.600	0.72	0.035	0.07	18	30
M610000**S*** Middle Section	Albemarle Sound nr South Shore	0.020	0.02	0.061	0.21	0.619	0.86	0.032	0.05	ND	ND
M390000**N*** Eastern Section	Albemarle Sound nr Frog Island North Shore	0.020	0.02	0.022	0.04	0.700	0.96	0.039	0.07	ND	ND
M390000**C** Eastern Section	Albemarle Sound nr Mid-Channel	0.020	0.02	0.020	0.02	0.705	0.90	0.037	0.08	**26**	50
M390000**S*** Eastern Section	Albemarle Sound nr South Shore	0.020	0.02	0.025	0.06	0.688	0.93	0.031	0.06	ND	ND
North Shore Pasquotank River Basin Watershed - 2014											
M5000000	Perquimans River	0.100	0.57	0.498	1.90	1.168	1.80	0.131	0.23	13	48
M3500000	Little River	**0.378**	**2.10**	0.239	1.20	**1.692**	**3.60**	**0.323**	**0.58**	ND	ND
M2750000	Pasquotank River nr Elizabeth City	0.040	0.08	0.120	0.33	1.144	1.40	0.070	0.12	21	37
South Shore Pasquotank River Basin Watershed - 2014											
M6920000	Kendrick Creek	0.108	0.37	**0.993**	**3.90**	1.159	1.70	0.072	0.12	15	**70**
M6980000	Scuppernong River	0.212	0.70	0.864	1.80	1.492	2.30	0.138	0.25	6	30
M7175000	Alligator River at US 64	0.022	0.04	0.053	0.12	0.797	1.00	0.025	0.04	16	36
Mouth of Roanoke River - 2014											
N9700000 Western Section	Albemarle Sound at Batchelor Bay	0.029	0.06	0.130	0.28	0.441	0.66	0.045	0.06	11	28

The number of samples collected in 2014 for each parameter ranged between 8 and 12 samples;
ND = No Data available;
***** = Last year station was assessed;
Red bolded numbers are the highest recorded maximum and yearly average values for each parameter.

Figure 6-3 Annual Mean Ammonia Readings from the Albemarle Sound. Blue Color Bars Are Stations Located Near the Western Side of the Sound, Green Color Bars Are Stations Located Near the Center of the Sound, and Purple Are Stations Located Near the Eastern Side of the Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

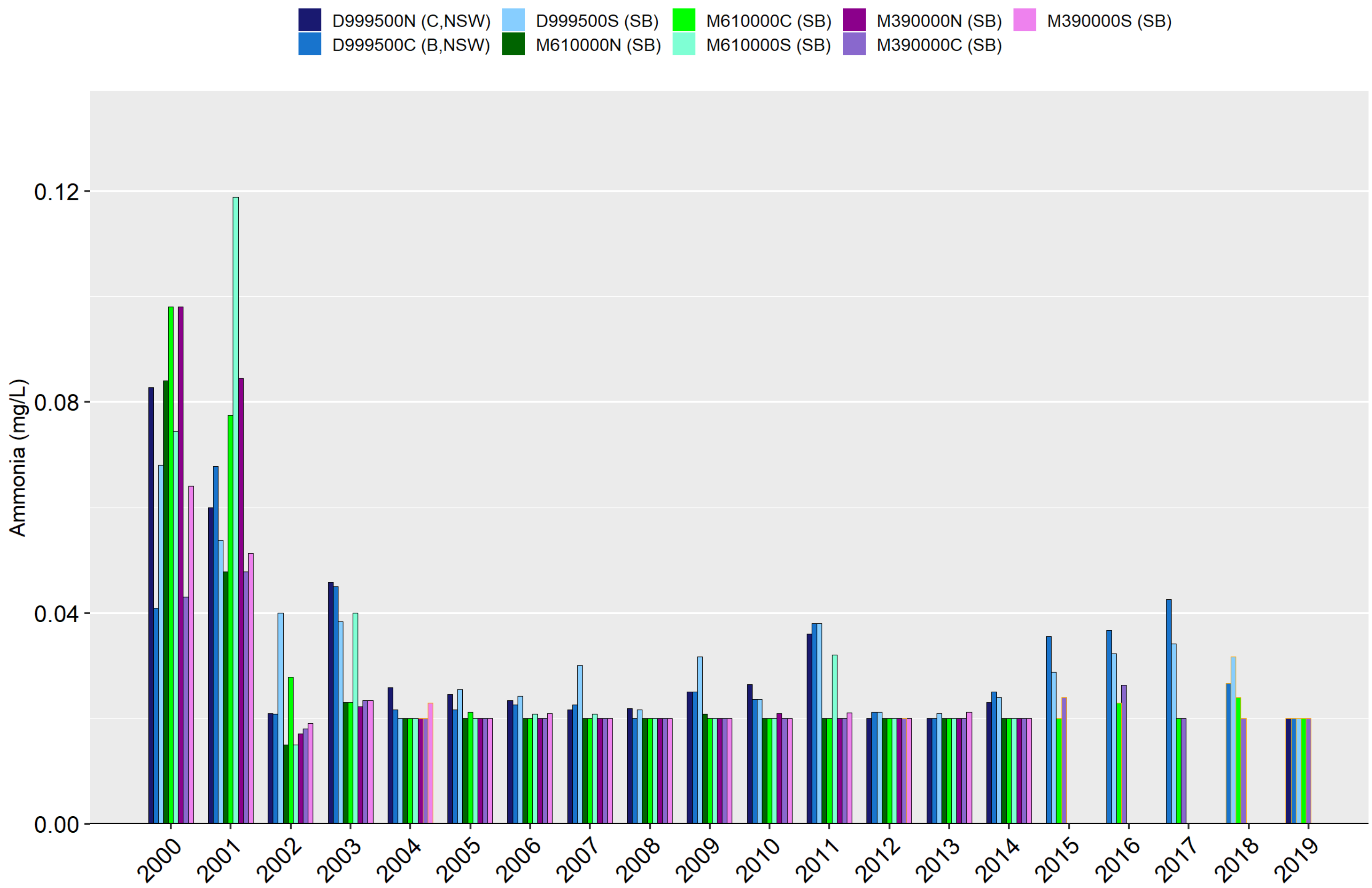


Figure 6-4 Annual Mean Ammonia Readings from the Northern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

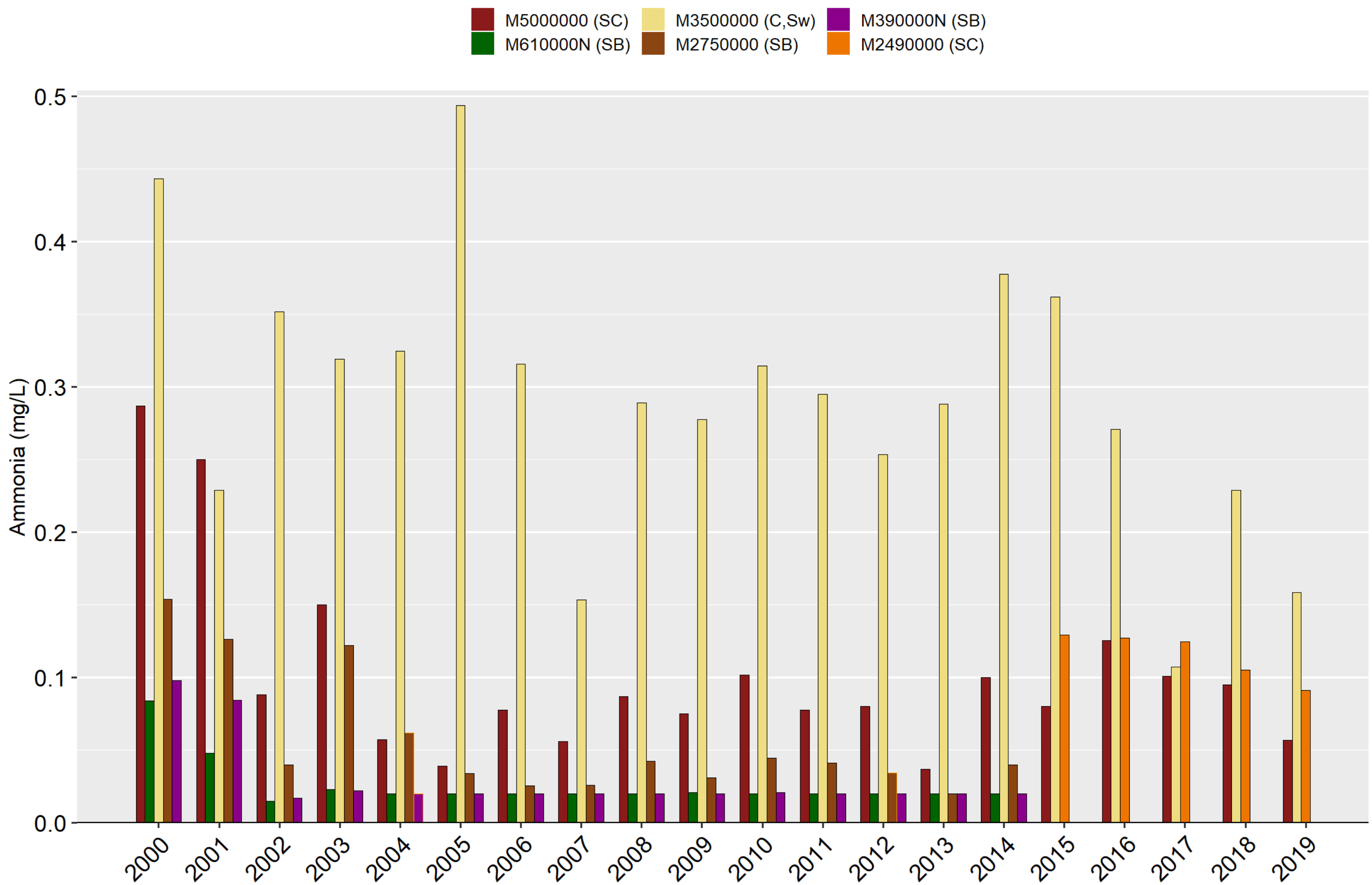
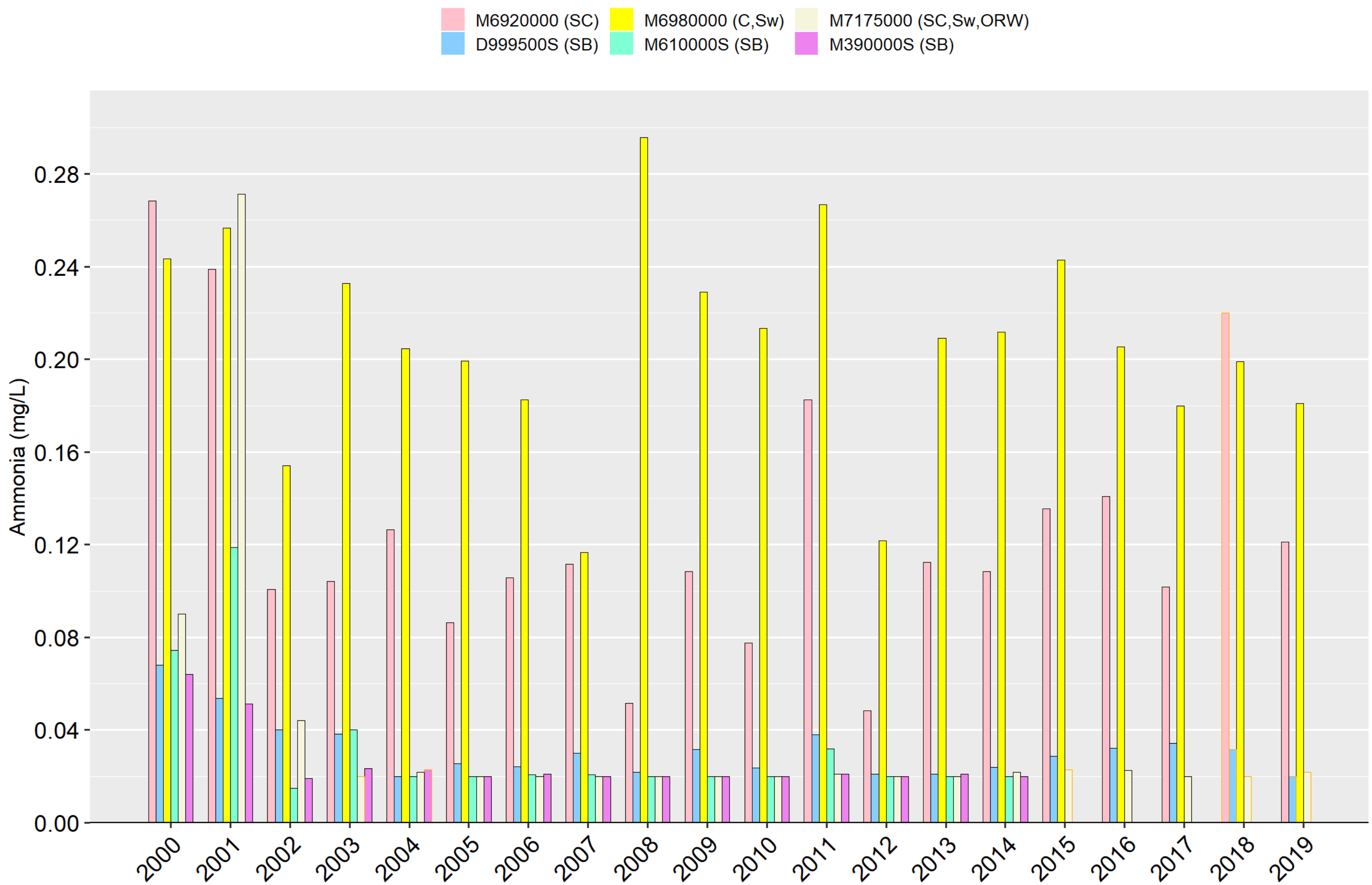


Figure 6-5 Annual Mean Ammonia Readings from the Southern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.



6.5.3 Nitrate and Nitrite (NOx)

Nitrate and nitrite (NOx) can be found in both terrestrial and aquatic ecosystems. However, nitrite contributes little to the total nitrogen concentration, due to the fact that it is generally unstable in surface water (Munn et al., 2018). Nitrate is useful for aquatic plants and organisms, but excess amounts can result in eutrophication of a water system. Nitrate sources include, but are not limited to, wastewater treatment plants, septic systems, agriculture, and stormwater.

Overall, NOx concentrations appear to decline as the Albemarle Sound is observed from west to east; with the highest concentrations observed on the western side of the sound near the confluence of the Chowan and Roanoke rivers. Biological uptake in the western and central portions of the Albemarle Sound likely contributes to the reduction in the nitrate concentration in the eastern portion which on average are at the practical quantitation limit or detection limit of 0.02 mg/L (Table 6-4 and Table 6-5). The highest zone of biological productivity in the sound varies greatly depending on several physical factors such as surface water flow velocity as well as wind and storm events. The Albemarle Sound is known to be more of a wind driven system than a gravitational tidal system (Moorman et al., 2014).

Tributaries contributing elevated levels of NOx include Kendrick's Creek (M6920000) and Scuppernong River (M6980000) on the southern shoreline and the Perquimans River (M5000000), Little River (M3500000) and Pasquotank River (M2750000) on the northern shoreline (Figure 6-7 and Figure 6-8). These NOx concentrations range from 0.01 to 7.1 mg/L between 2000 and 2019. Kendrick Creek had the highest 2014 yearly average of 0.99 mg/L with a maximum reading of 3.90 mg/L (Table 6-5). Since 2015, elevated NOx concentrations were observed in Kendrick Creek (M6920000) and the Scuppernong (M6980000) rivers during all months of the year. There was also a substantial increase in NOx concentration seen in the Pasquotank River since 2015 (Figure 6-7). This is likely due to the change in the station location upstream near Elizabeth City in January 2015 where there has likely been less biological uptake at that point in the system. The DWR will work with the county Soil and Water Conservation Districts and local stakeholders to identify potential sources and work to implement nutrient reducing BMPs in these subwatersheds. The DWR currently does not have an ecosystem health surface water NOx standard. There is a human health NOx standard in water supply waters (WS-I though WS-V) of 10 mg/L which is intended to protect against infant methemoglobinemia or blue baby syndrome.

Figure 6-6 Annual Mean Nitrate plus Nitrite Readings from the Albemarle Sound. Blue Color Bars Are Stations Located Near the Western Side of the Sound, Green Color Bars Are Stations Located Near the Center of the Sound, and Purple Are Stations Located Near the Eastern Side of the Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

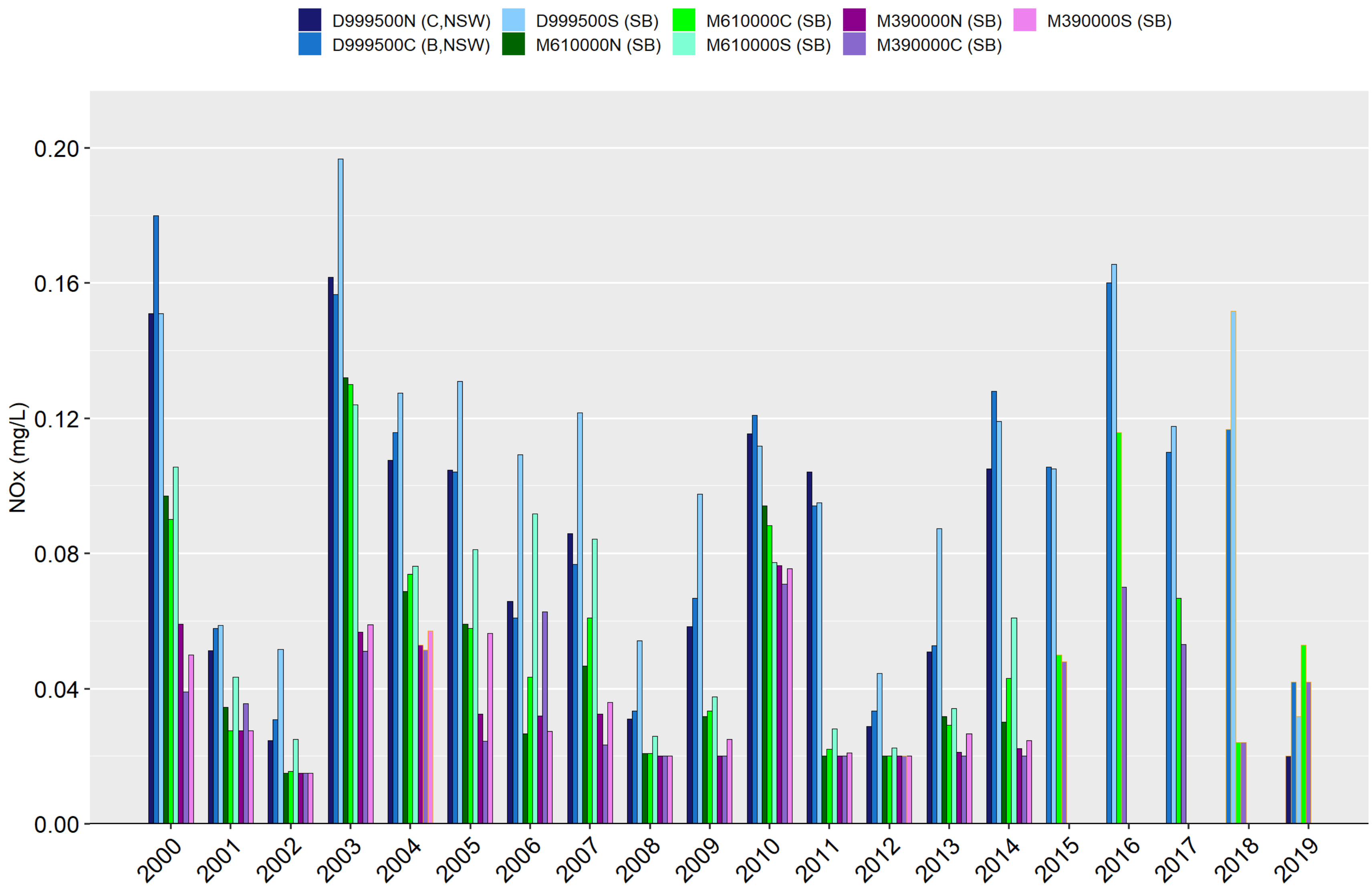


Figure 6-7 Annual Mean Nitrate plus Nitrite Readings from the Northern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

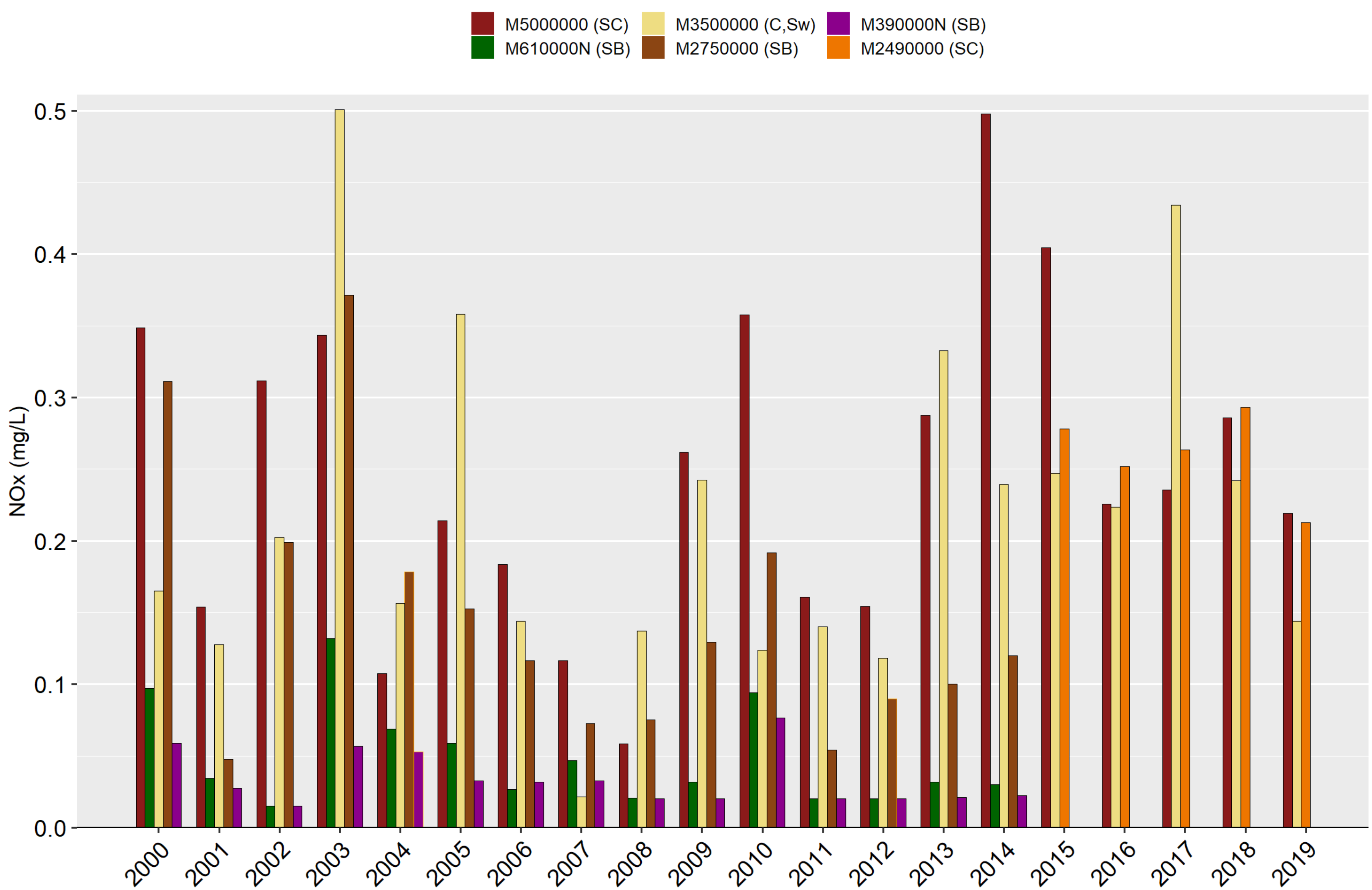
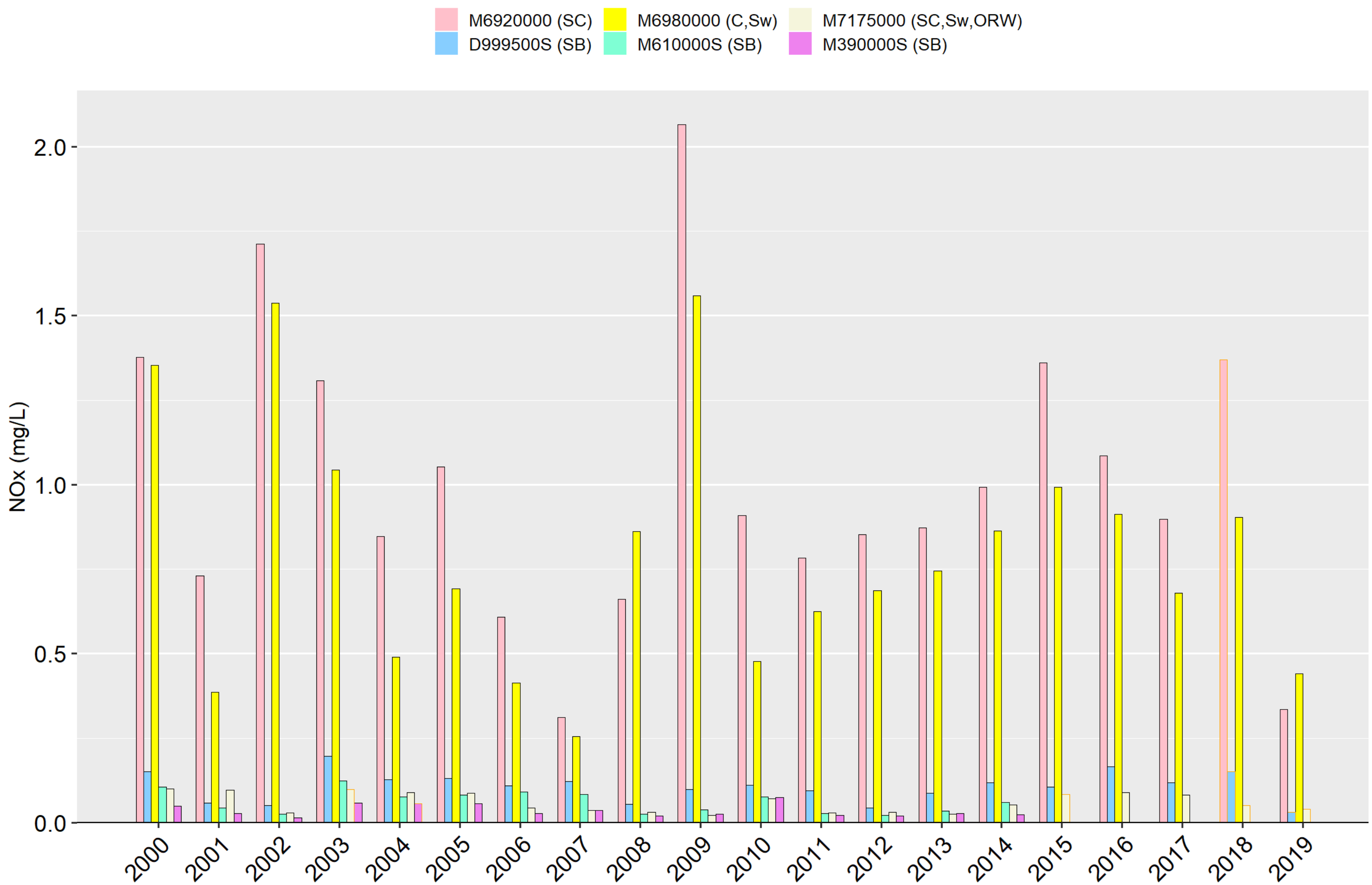


Figure 6-8 Annual Mean Nitrate plus Nitrite Readings from the Southern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.



6.5.4 Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl Nitrogen (TKN) is ammonia/ammonium nitrogen + organic nitrogen. “Organic nitrogen (mostly from plant material and organic matter) can exist in considerable proportions and contribute substantially to concentration of total nitrogen in streams.” (Munn et al., 2018). Increase in TKN concentrations often coincide with increases in biological productivity in these systems. The TKN signature in the Albemarle Sound increases as the sound is viewed from west to east (Figure 6-9 and Table 6-5). The most recent 10 years on record (2010 – 2019) displayed this pattern more frequently and with a larger range of TKN concentrations between the east and west (Figure 6-9). The instream concentration of TKN is also increasing overtime which is similar to many areas across the state (Figure 6-10). This increase is likely related to an increase in algal productivity discussed later in this chapter.

Similar to many of the other nutrient contributing tributaries, the Perquimans River (M5000000), Little River (M3500000), and Pasquotank River (M2750000) on the northern shoreline and Kendrick’s Creek (M6920000) and Scuppernong River (M6980000) on the southern shoreline have higher average TKN concentrations compared to the Albemarle Sound (Figure 6-11, Figure 6-12, and Table 6-5). In 2014, the Little River had the highest yearly average and maximum concentration of 1.69 and 3.60 mg/L TKN, respectively (Table 6-5). However, the data in the Little River does not indicate that the instream TKN concentration has increased over time in this watershed (Figure 6-13)

Figure 6-9 Annual Mean Total Kjeldahl Nitrogen Readings from the Albemarle Sound. Blue Color Bars Are Stations Located Near the Western Side of the Sound, Green Color Bars Are Stations Located Near the Center of the Sound, and Purple Are Stations Located Near the Eastern Side of the Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

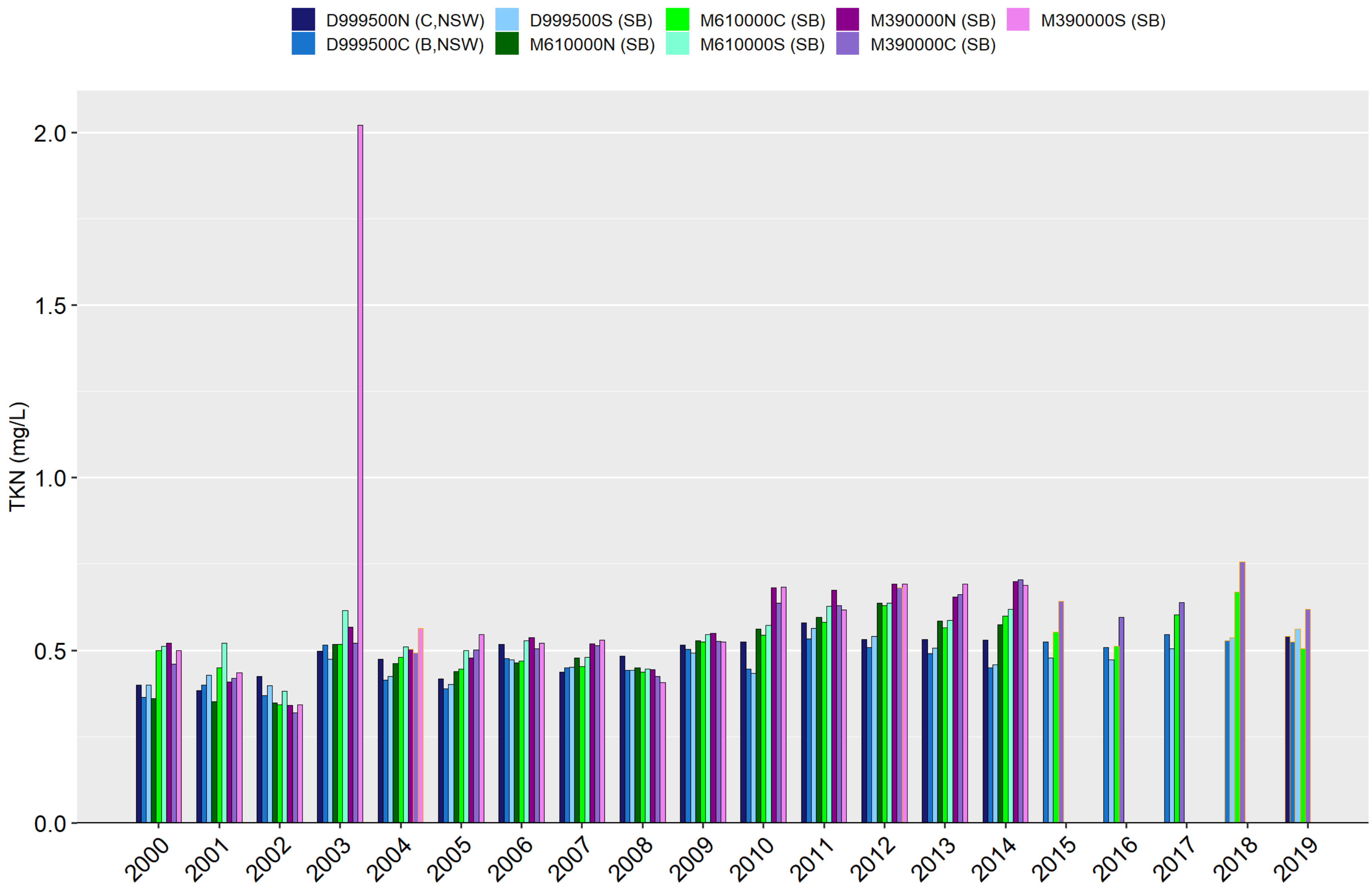
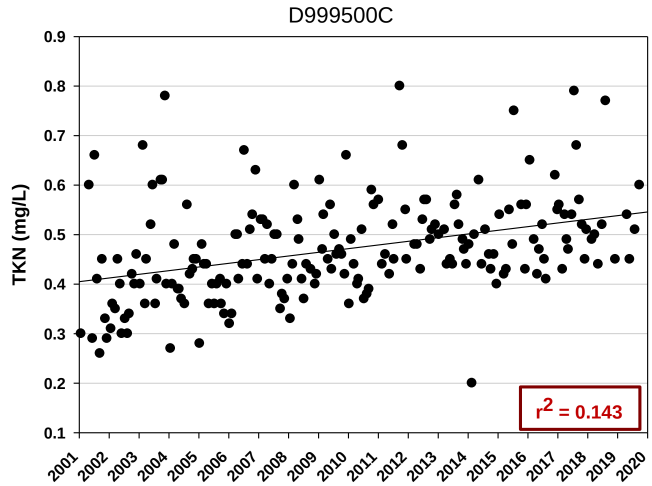
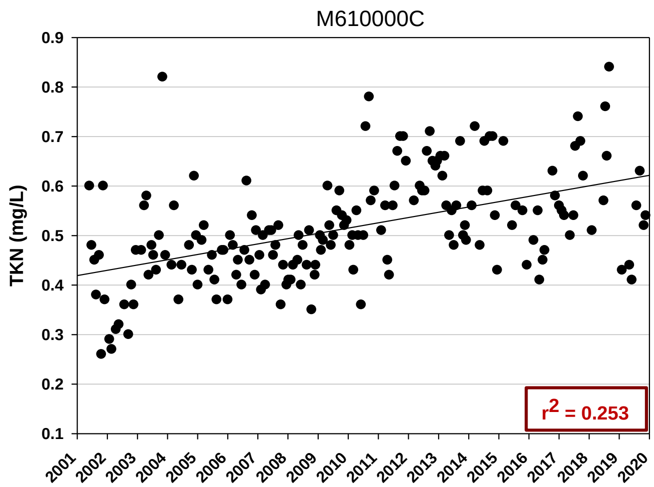


Figure 6-10 Monthly Total Kjeldahl Nitrogen at the Three Center Channel Albemarle Sound Stations Between 2001 and 2019. D999500C in the Western Albemarle Sound, M610000C in the Central Portion of the Albemarle Sound and M390000C in the Easter Portion of the Albemarle Sound. A Simple Regression Line was Plotted in Sigma Plot and the r^2 Value Reported on the Graph in Red.





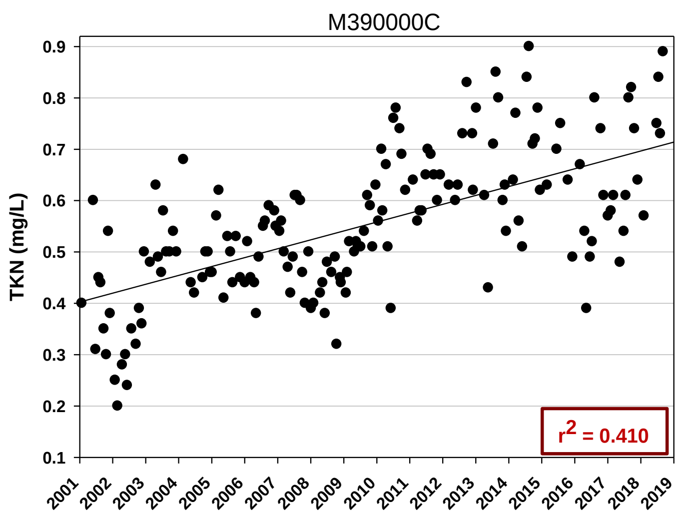


Figure 6-11 Annual Mean Total Kjeldahl Nitrogen Readings from the Northern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

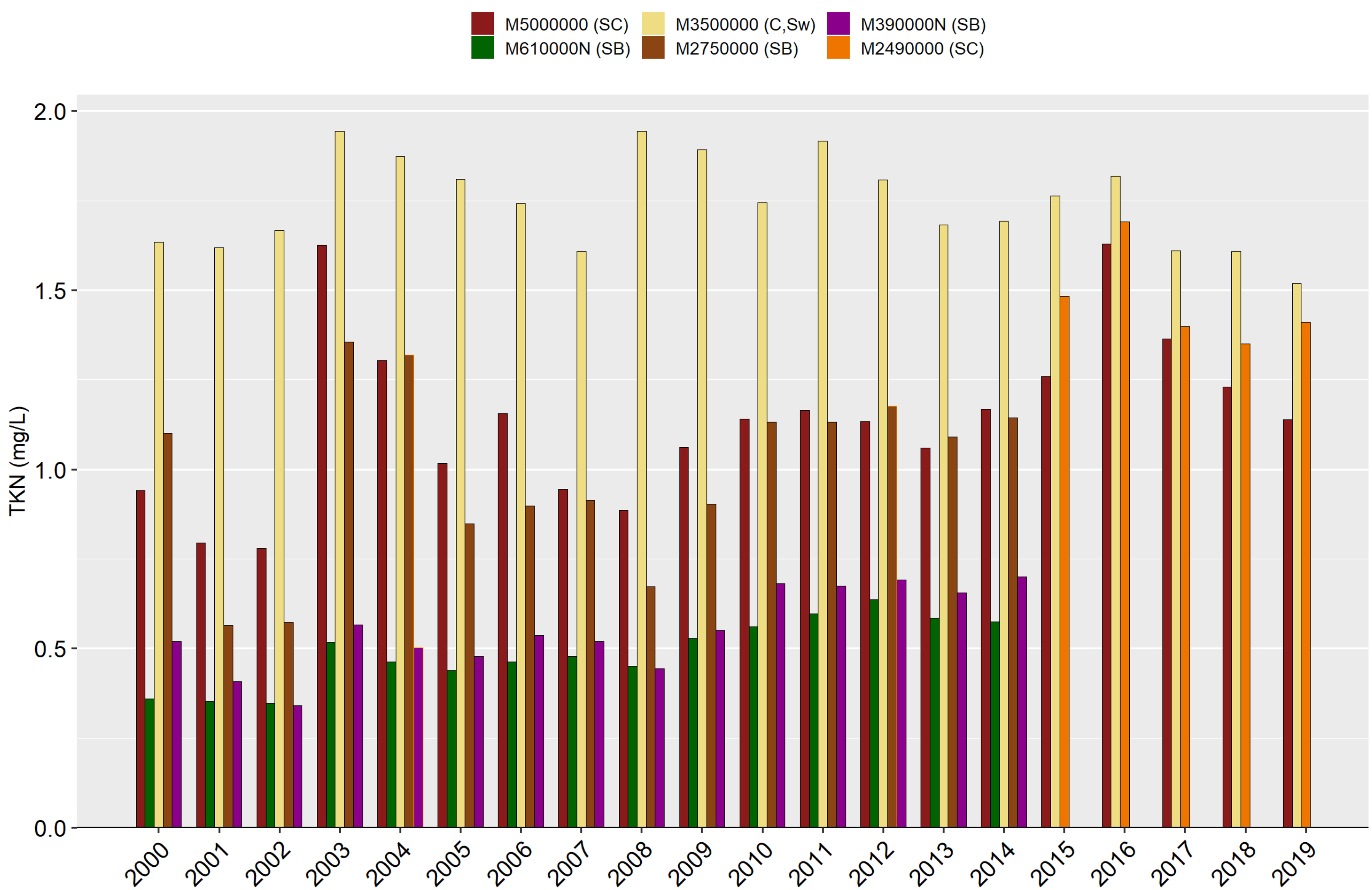


Figure 6-12 Annual Mean Total Kjeldahl Nitrogen Readings from the Southern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

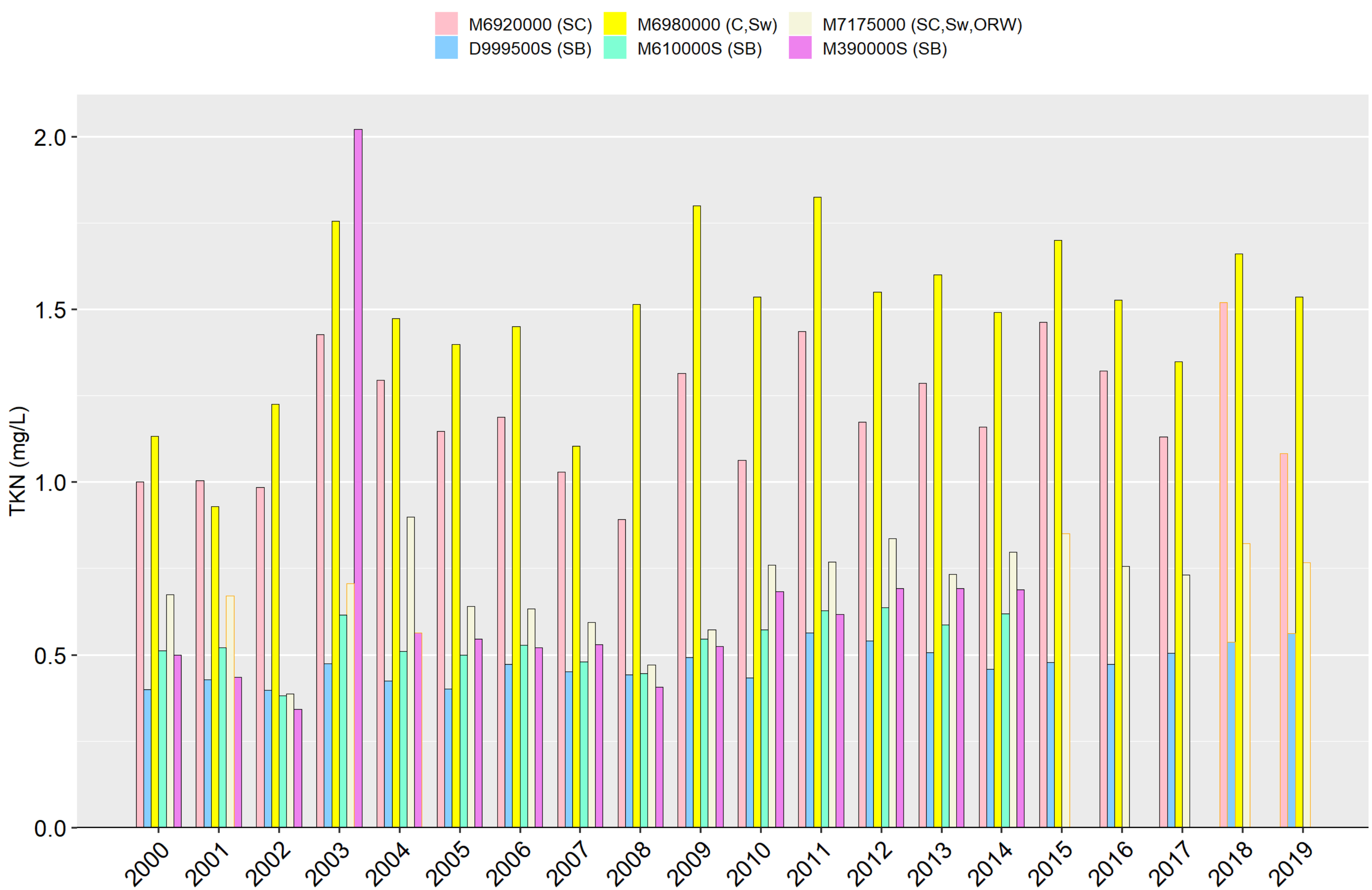
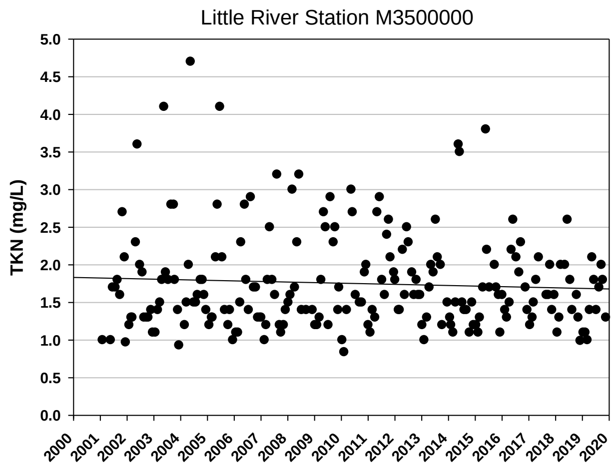


Figure 6-13 Monthly Total Kjeldahl Nitrogen at the Little River M3500000 Stations Between 2001 and 2019 with a Simple Regression Line Plotted Showing no Major Change Over the Time Period Assessed.



6.5.5 Phosphorus

Phosphorus is an essential nutrient for healthy plant and animal populations; however elevated values in surface water can cause algal blooms and aquatic plants growth (USGS, 1999). Concentrations of phosphorus in streams can often exceed the level necessary for excessive plant growth (USGS, 1999). Although phosphorus may be present in a stream, many forms of phosphorus are bound in soil particles and large proportions are transported to streams from eroded soil during high runoff triggered by precipitation and/or irrigation (USGS, 1999). Sources of phosphorus include, but are not limited to: effluent from wastewater treatment plants, agriculture operations, and stormwater. Low concentrations of phosphorus in freshwater have been found to limit aquatic plant growth; however excessive aquatic plan growth and eutrophication in freshwater can occur at concentrations greater than 0.1 mg/L (USGS, 1999).

Overall, the Albemarle Sound has relatively low phosphorus concentrations which generally decrease in concentration from west to east and north to south (Figure 6-14). Interestingly, the annual mean phosphorus concentrations from the Perquimans River (M5000000), and the Little River (M3500000), on the northern shoreline were consistently greater than 0.1 mg/L (Figure 6-15). There was a substantial increase in the Pasquotank River (M2750000) phosphorus concentration starting in 2015 when the station was moved and the annual mean phosphorus concentration has also remained above 0.1 mg/L.

Of the monitored streams in the Pasquotank River basin, the annual mean phosphorus concentrations observed in the Little River (M3500000) are the most concerning (Figure 6-15). In 2014, the Little River annual mean was 0.32 mg/L with a recorded maximum that year of 0.58 mg/L (Table 6-5). The southern shoreline annual mean phosphorus concentrations are lower than the Little River, but values were often elevated above 0.1 mg/L in the Scuppernong (M6980000) and Kendrick Creek (M6920000) for the past ten years of record (2010 – 2019) (Figure 6-16). In 2014, the annual mean concentrations were 0.14 and 0.07 mg/L respectively (Table 6-5). These tributaries drain predominately agricultural lands with an extensive network of drainage ditches which likely carry a lot of phosphorus-laden sediments. BMPs to reduce runoff and keep soil and nutrients out of the ditch networks and streams would help to reduce the instream phosphorus concentrations. DWR does not currently have an instream phosphorus standard.

Figure 6-14 Annual Mean Phosphorus Readings from the Albemarle Sound. Blue Color Bars Are Stations Located Near the Western Side of the Sound, Green Color Bars Are Stations Located Near the Center of the Sound, and Purple Are Stations Located near the Eastern Side of the Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

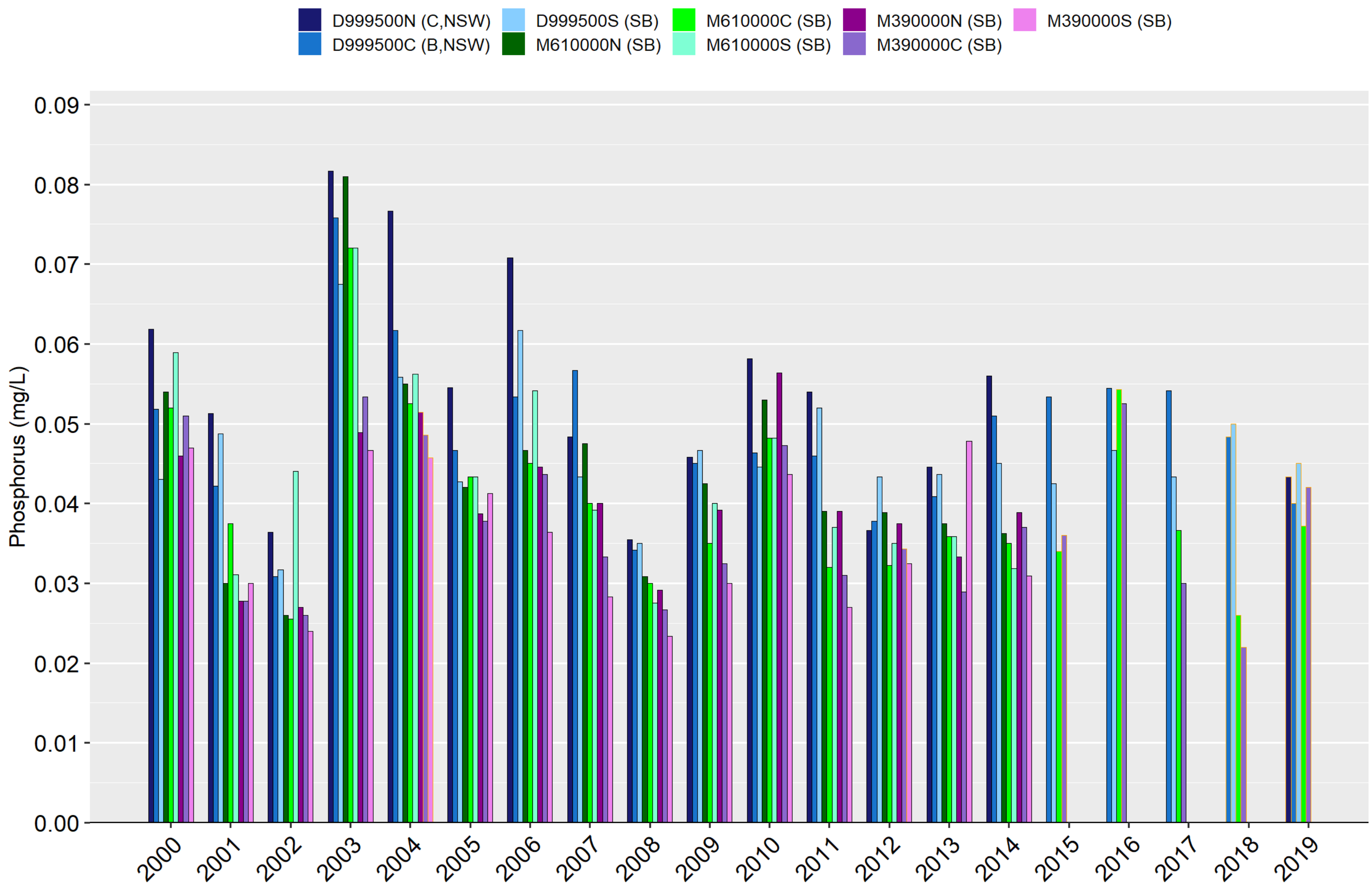


Figure 6-15 Annual Mean Phosphorus Readings from the Northern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.

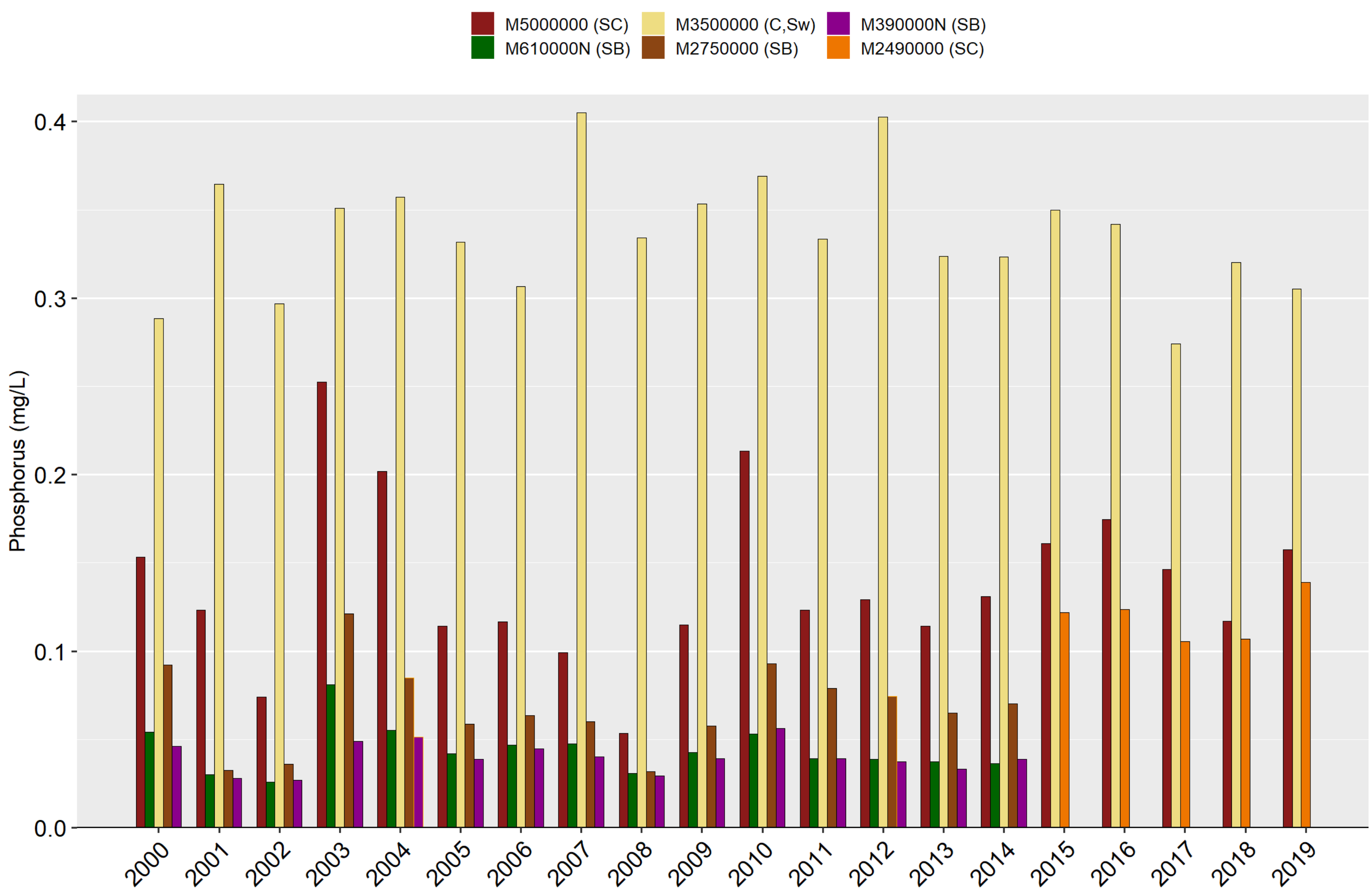
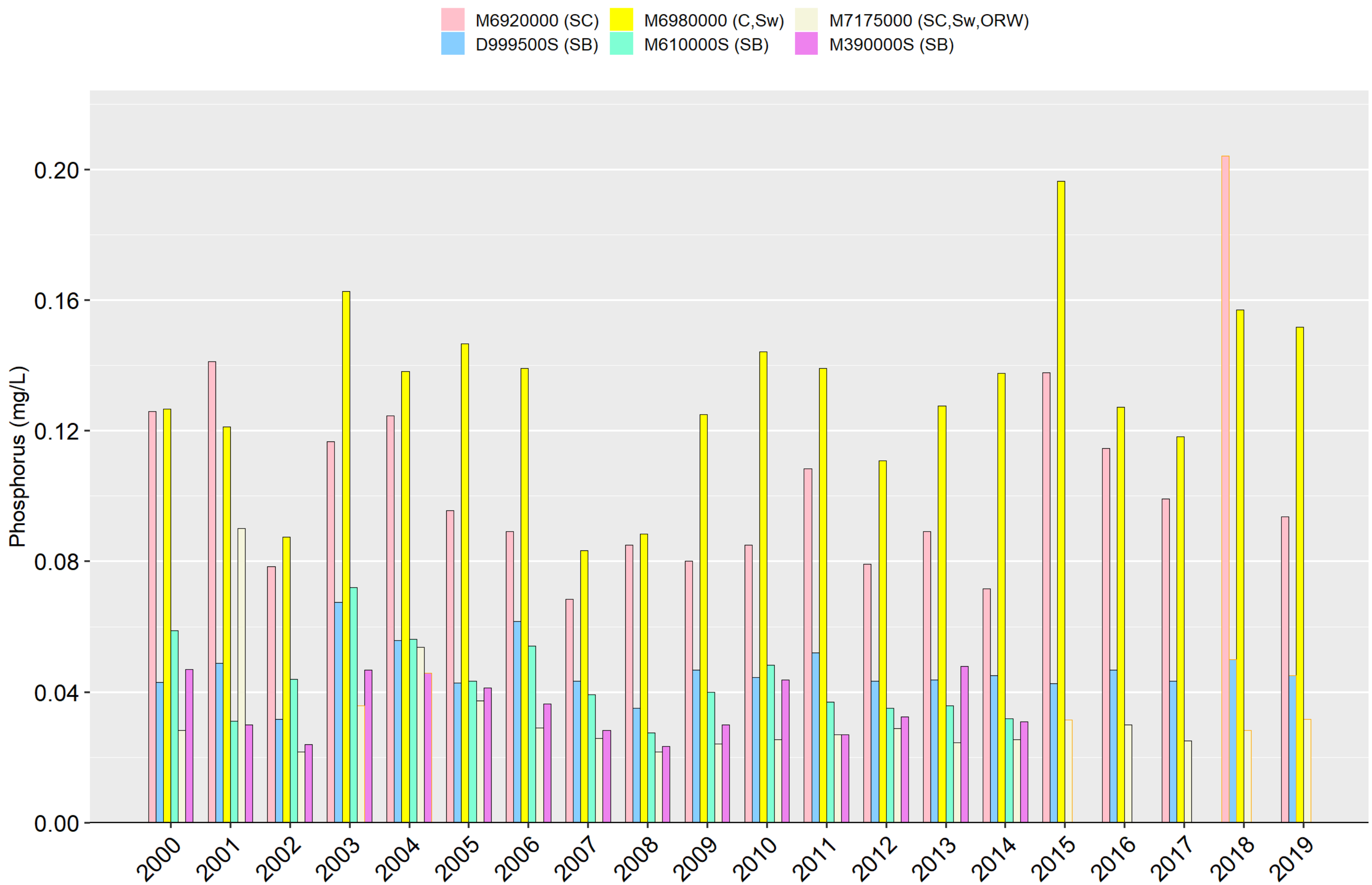


Figure 6-16 Annual Mean Phosphorus Readings from the Southern Shoreline of the Albemarle Sound. Orange Outlines Around the Bars Indicate Annual Means that have Less than Eight Measurements.



6.6 Chlorophyll *a* and pH

Chlorophyll *a* is an algal pigment that is used as a surrogate for measuring how biologically productive an aquatic ecosystem is at a specific point in time. Algae is the base of the food chain and is a required component of a healthy aquatic ecosystem. However, nutrient over-enrichment can lead to over production of algae (eutophication), resulting in the formation of algal blooms with elevated chlorophyll *a* concentrations. As part of the algal bloom development and photosynthetic process, the uptake of carbon dioxide results in a corresponding increase in pH levels. This corresponding shift in the ambient pH is often used to indicate the presence of an algal bloom at an ambient monitoring station. Photosynthesis is the process in which plants/algae utilize energy from the sun, carbon dioxide and water to produce food they need to grow and reproduce. Photosynthesis also releases oxygen back into the water.

Chlorophyll *a* monitoring in the Albemarle Sound proper has mainly occurred at the three center channel stations (D999500C, M610000C, M390000C) and on occasion at other locations, mainly in response to algal blooms or special studies. The Albemarle Sound is a very unique system in that it remains fairly fresh (low salinity) due to the volume of freshwater draining to the sound and the restriction of high salinity water from the ocean due to the barrier islands limiting direct ocean inputs. This results in a wide range of algal species potentially present and is highly influenced by the riverine systems draining to it such as the many tributaries in the Pasquotank River basin as well as the large river basin systems like the Chowan and Roanoke rivers. The state of North Carolina currently has an instream chlorophyll *a* standard of 40 µg/L that applies to all the tributaries and the Albemarle Sound. The DWR is currently in the process of evaluating the need for instream nitrogen and phosphorus surface water standards in this system. As part of this Nutrient Criteria Development Plan (NCDP) process, the division will also assess if the current standard for the nutrient response variables such as chlorophyll *a* is appropriate and protective of the uses in Albemarle Sound. There is a Scientific Advisory Council (SAC) that is advising the division on these efforts. See the NCDP discussion later in this chapter for more details. There is some concern that the 40 µg/L standard is not protective of this unique aquatic habitat and the most sensitive species in this system (such as submerged aquatic vegetation (SAV) and threatened and endangered fish species).

Table 6-6 Yearly Mean and Maximum Recorded Chlorophyll a Concentration at the Three Albemarle Sound Center Channel Stations and the Western Station in Batchelor Bay (N9700000) for the Years Between 2014 and 2019.

	Western Albemarle Sound						Central Albemarle S.			Eastern Albemarle S.		
	N9700000			D999500C			M610000C			M390000C		
	Mean (µg/L)	Max (µg/L)	n	Mean (µg/L)	Max (µg/L)	n	Mean (µg/L)	Max (µg/L)	n	Mean (µg/L)	Max (µg/L)	n
2014	11	28	10	11	25	10	18	30	10	26	50	10
2015	7	20	9	14	81	9	14	19	5	17	31	5
2016	4	11	9	6	19	9	8	13	7	16	46	8
2017	8	32	12	14	55	12	19	32	9	18	36	10
2018	10	39	6	11	26	6	21	29	5	27	32	5
2019	20	28	6	18	26	5	15	33	7	19	40	5
n - equivalent to the number of samples collected each year. The yearly mean is influenced by the number of samples collected and in what season or month they are collected in.												

The yearly mean chlorophyll *a* concentration generally increases from west to east similar to the TKN nitrogen signature presented above (Table 6-5 and Table 6-6). Algal blooms which result in elevated chlorophyll *a* concentrations occur throughout the Albemarle Sound. Algal bloom formation depends on many different physical and chemical factors. Stream flow velocities and weather patterns play an important role in determining where and how algal blooms form in the Albemarle Sound.

Figure 6-17 Algal growth in the Little River.

Chlorophyll *a* and the associated pH levels have generally increased at each of the center channel stations since 2001 with more frequent violation of the 40 µg/L chlorophyll *a* standard, as well as, pH standards of 8.5 (in class SB waters (M610000C and M390000C)) and 9.0 (in class B waters (D999500C)) (Figure 6-18).

Portions of the Albemarle Sound are listed on the 303(d)/Impaired Waters List due to the elevated pH levels (Table 6-3). The pH levels at M610000C and M390000C are becoming a concern as the recorded values during the summer months continue to show a response to nutrient over enrichment (Figure 6-18 and Figure 6-19). The peak pH and chlorophyll *a* concentrations between 2017 and 2019 generally occurred between July and September (Figure 6-19).

The northern and southern watershed tributaries are also responding to excess nutrient concentrations as seen by the elevated levels of chlorophyll *a* concentrations within these systems (Figure 6-20, Figure 6-22 and Table 6-7).

The location of the ambient monitoring station and the river or stream flow dynamics can also play an important role in the chlorophyll *a* response at these specific stations. If the streams are fast moving, the amount of chlorophyll *a* response is often limited due to the stream flow velocity, while streams that are slower moving or widen into a more estuarine system often allow for greater bloom dynamics to occur. The chlorophyll *a* concentrations have significantly increased at the Pasquotank River (M2750000) and Alligator River (M7175000) stations (Figure 6-18 and Figure 6-20). The Pasquotank River station was moved upstream near Elizabeth City in 2015 (Figure 6-21). Both locations show an increase in the overall chlorophyll *a* concentrations over the time period they were sampled (Figure 6-20). The Little River at M3500000 has not been consistently monitored for chlorophyll *a* over the years and is much further up in the watershed than the other northern tributary stations (Figure 6-20 and Figure 6-22). The yearly mean concentration and maximum readings were lower in 2018 and 2019 than the other two northern tributaries (Table 6-7). There have been many reported algal blooms occurring in the Little River system over the last several years (Appendix VI, Figure 6-17). DWR should continue to monitor M3500000 for chlorophyll *a* and when resources are available and should consider sampling this system downstream in the saltwater (SB) section of the river to better assess the impact of nutrients to this system as a whole. Chlorophyll *a* is consistently elevated at certain times of the year in the Perquimans River (M5000000), Kendrick Creek (M6920000) and Scuppernong River (M6980000) stations (Figure 6-20, Figure 6-22, and Table 6-7). The 2019 yearly mean chlorophyll *a* concentration in the Scuppernong River (M6980000) doubled over the previous five year means (Table 6-7). As previously mentioned, all of the northern and southern tributary watersheds drain mostly agricultural lands (Table 6-1). The Pasquotank River basin as a whole is showing increasing chlorophyll *a* as result of all the nutrient sources. Additional monitoring closer to the mouths of these river systems is recommended as time and resources allow in order to understand the overall impact these watersheds are having on the Albemarle Sound proper.

Figure 6-18 The AMS Chlorophyll a and Associated pH Levels at the Three Center Channel Albemarle Sound Stations with a Simple Regression Line with the r-squared (r^2) Value. The Red Line denotes the 40 µg/L Chlorophyll a Standard or pH 8.5 or 9.0 Standard. Any Monthly Record Above these Standards are Violating the NC Surface Water Quality Standard. (Note: pH standard in class B waters is 9.0 and in SB waters is 8.5; A single chlorophyll a *data point was removed from the analysis at station M610000C (March 27, 2003; Chl a = 360 µg/L). The extreme data point could not be confirmed, however, the corresponding parameters such as pH, DO, TKN or turbidity do not support such an extreme chlorophyll* a *concentration. See Appendix VI-I for additional station data.)*

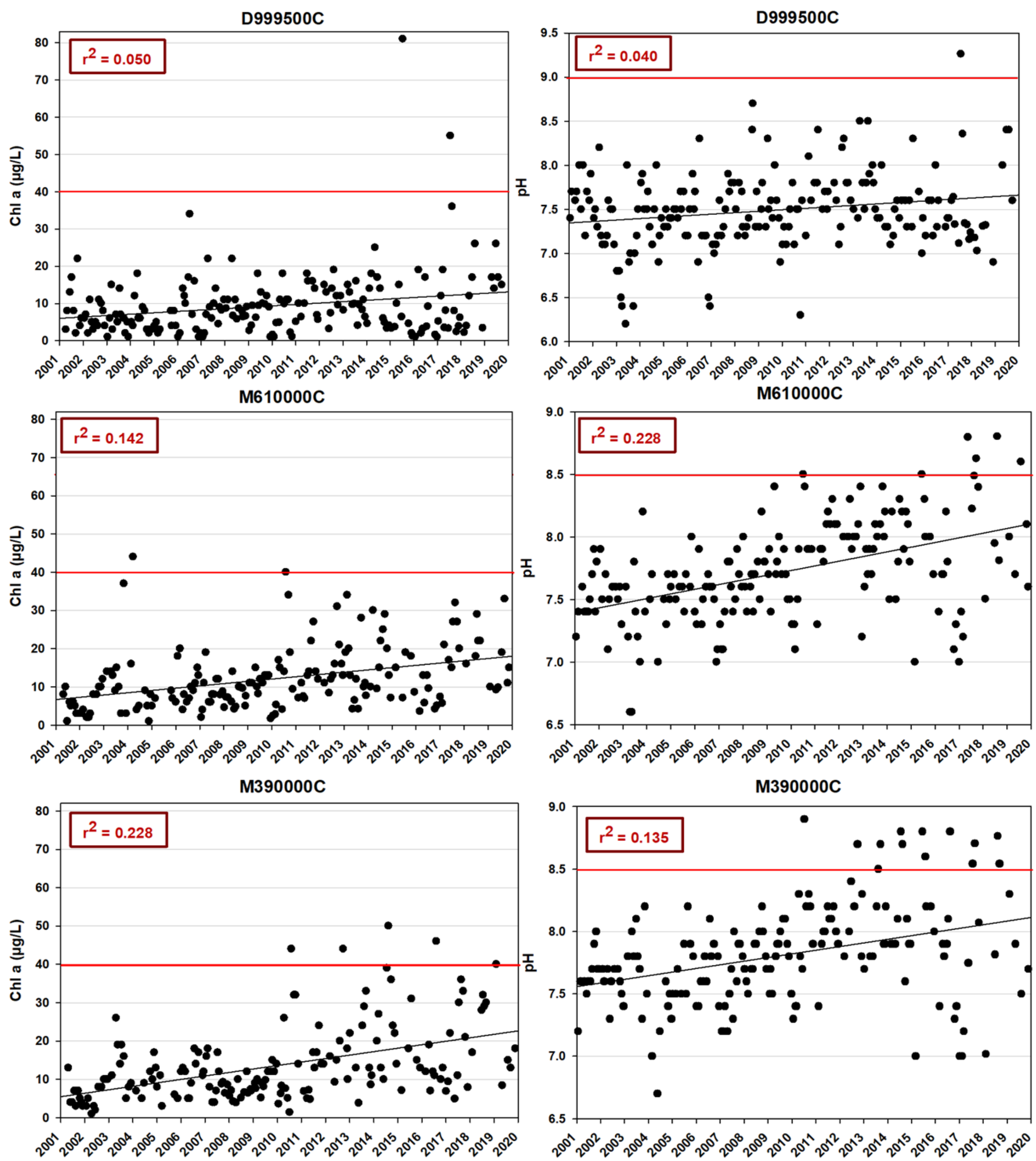


Figure 6-19 Ambient Monitoring Chlorophyll a and pH concentrations by month for 2017-2019. Concentrations Generally Increase During the Summer Months when Biological Productivity is at its Highest. Note: Monitoring did not occur each month at each station over this specific time period. There were no samples collected in April or December for any of these three years.

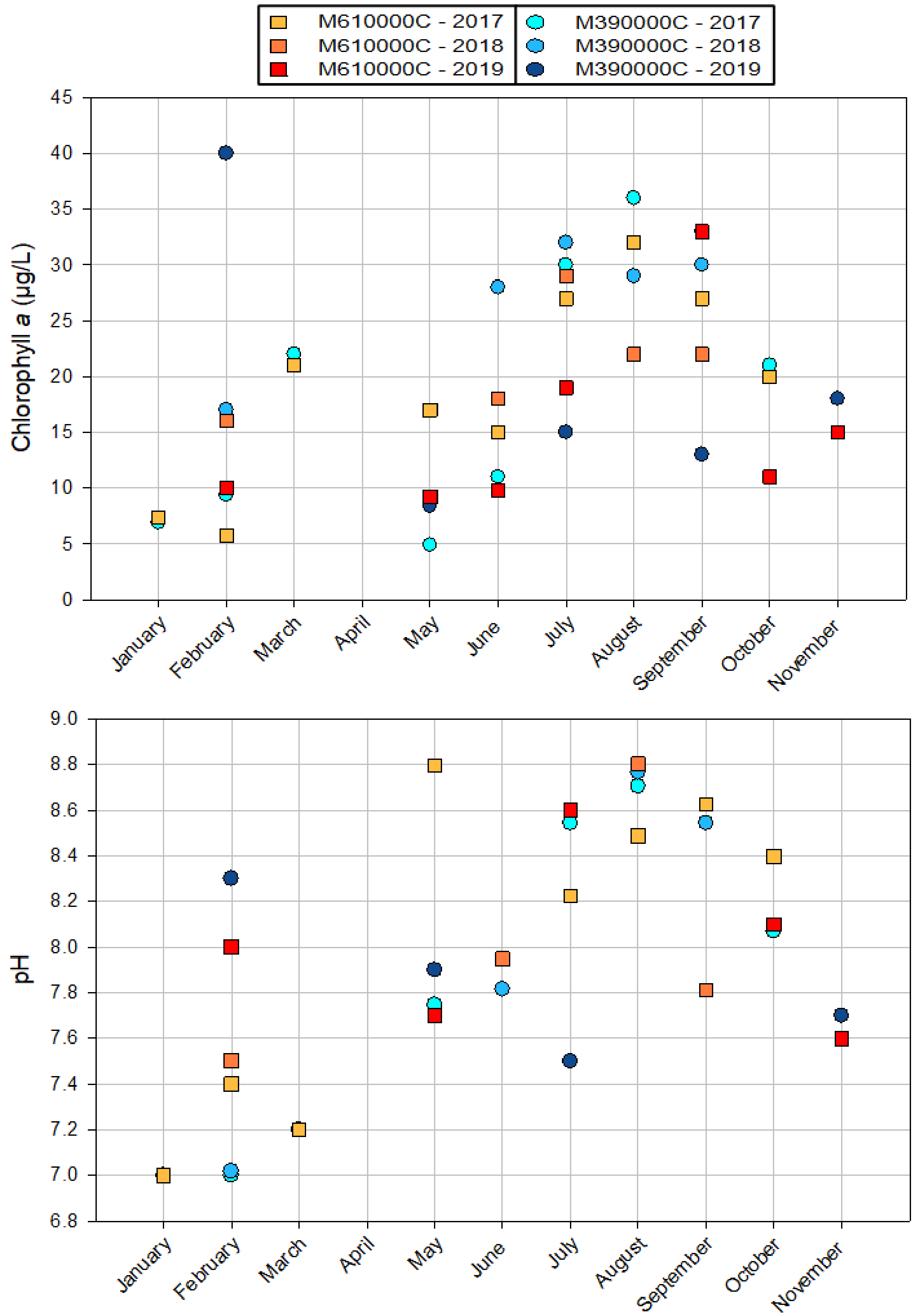


Figure 6-20 Chlorophyll a *Concentrations at the Ambient Monitoring Stations in the Northern Tributaries Draining to the Albemarle Sound. A Simple Regression Line and the r^2 Value. The Red Line denotes the 40 µg/L Chlorophyll a Standard. Any Monthly Record Above these Standards are Violating the NC Surface Water Quality Standard. Stations include, Perquimans River (M5000000), Little River (M3500000; not consistently monitored) and Pasquotank River (M2750000; Station moved starting January 2015).*

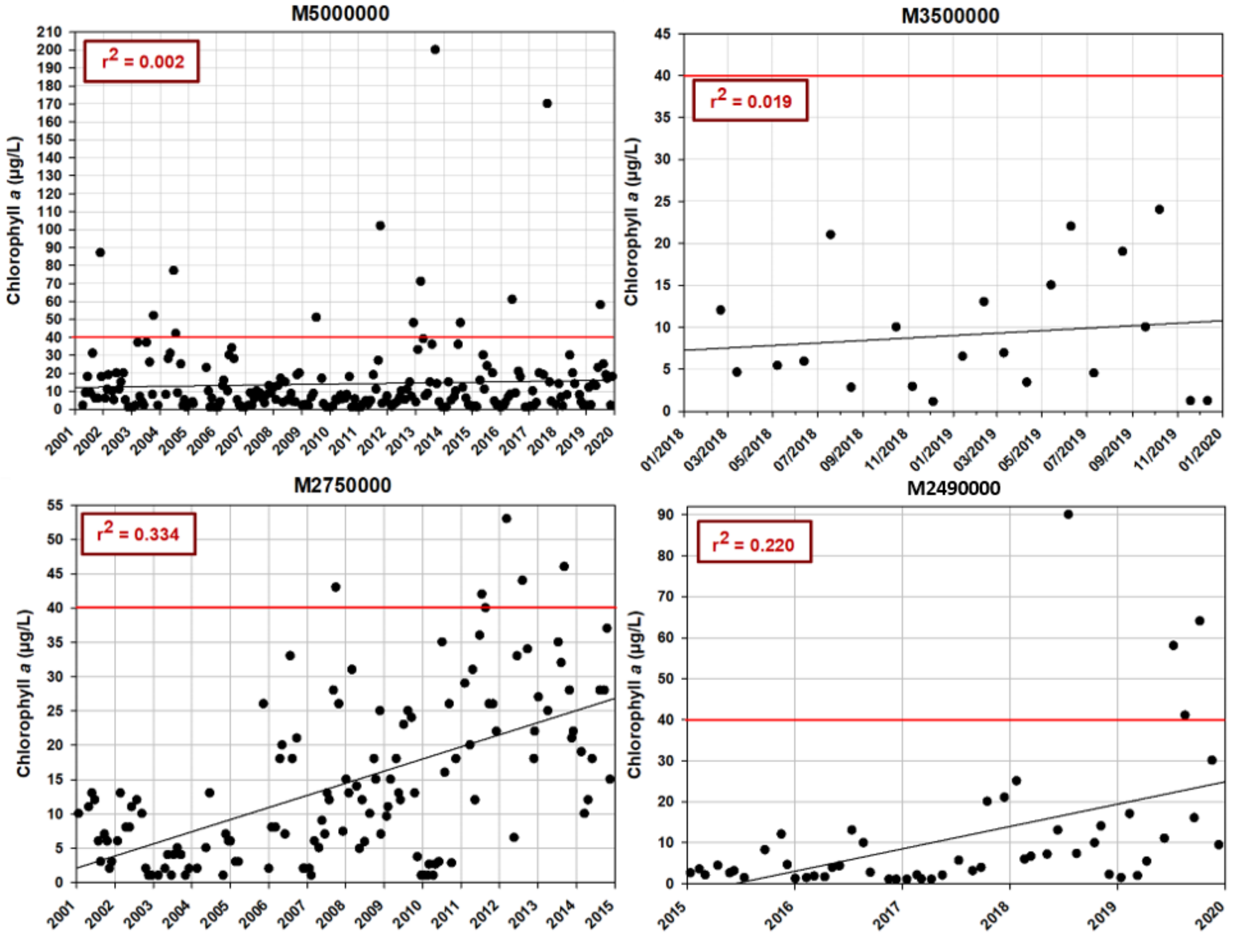


Figure 6-21 A Map of the Pasquotank River Basin Northern Tributary Stations to Demonstration Watershed Station Locations and Size of River System at Point of Monitoring.

Figure 6-22 Chlorophyll a *Concentrations at the Ambient Monitoring Stations in the Southern Tributaries Draining to the Albemarle Sound and a Corresponding Station Map. A Simple Regression Line and r^2 Value. The Red Line denotes the 40 µg/L Chlorophyll a Standard. Any Monthly Record Above these Standards are Violating the NC Surface Water Quality Standard. Stations include, Kendrick Creek (M6920000), Scuppernong River (M6980000) and Alligator River (M7175000).*

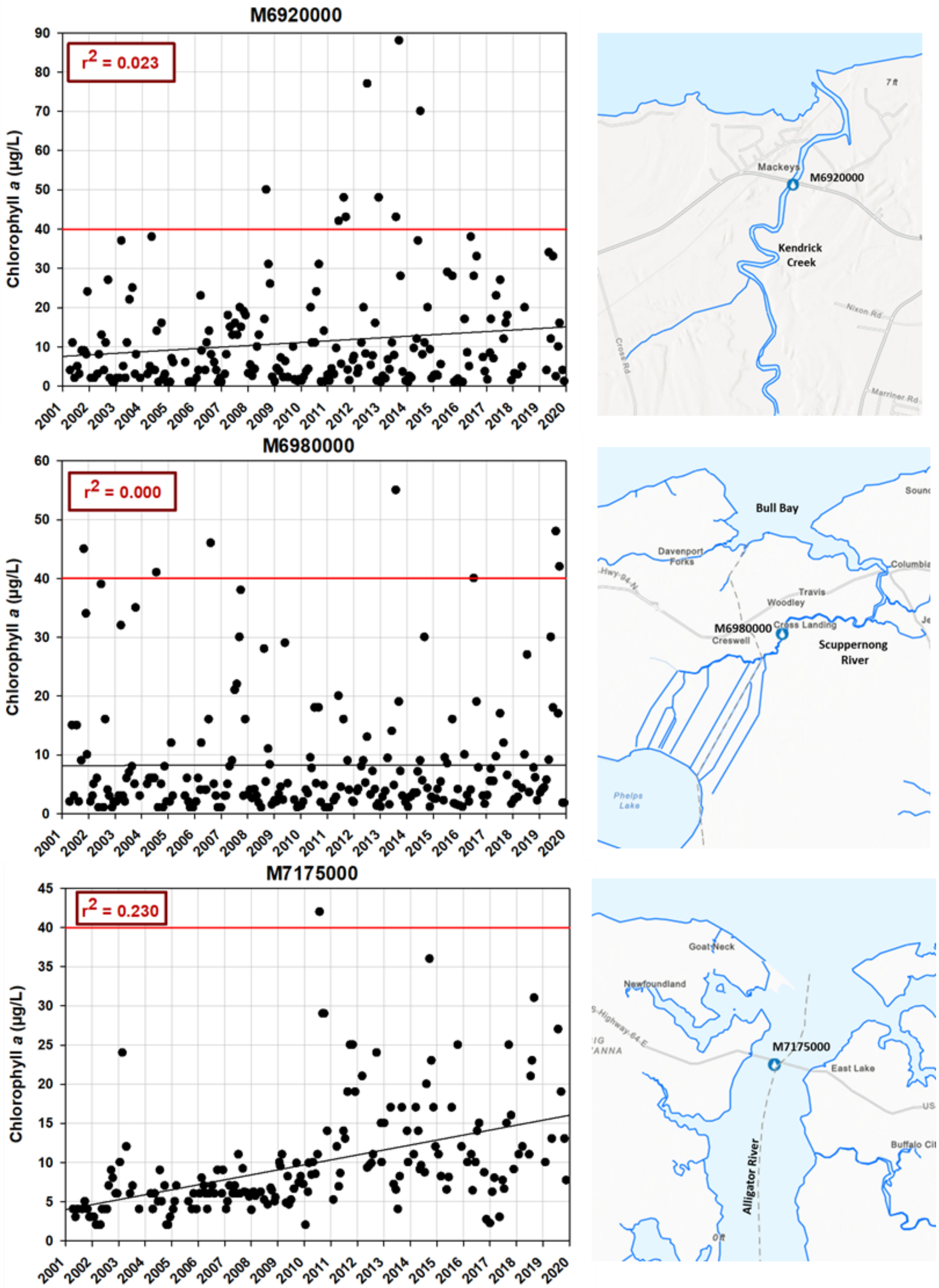


Table 6-7 Yearly Mean and Maximum Recorded Chlorophyll a Concentration at the Northern and Southern Tributaries to the Albemarle Sound for the Years Between 2014 and 2019.

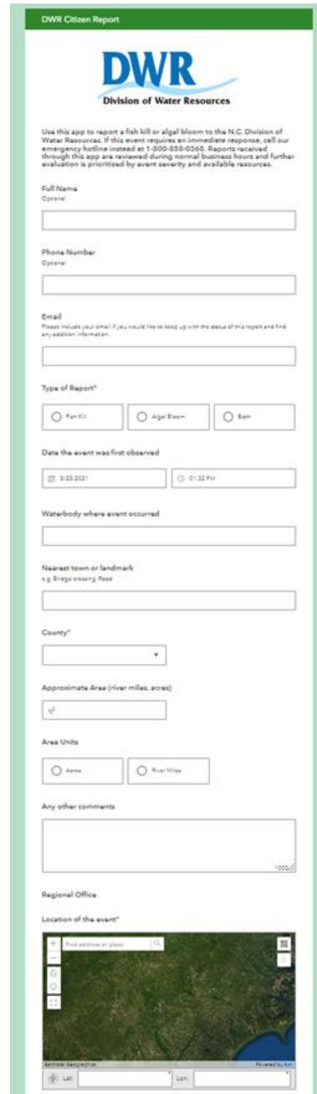
Northern Pasquotank River Basin Tributaries									
	Perquimans River M5000000			Little River M3500000			Pasquotank River M2750000*		
	Mean (µg/L)	Max (µg/L)	n	Mean (µg/L)	Max (µg/L)	n	Mean (µg/L)	Max (µg/L)	n
2014	13	48	11	ND			21*	37	8
2015	10	30	11	ND			5	12	10
2016	12	61	11	ND			4	13	11
2017	**25**	**170**	10	ND			6	21	10
2018	11	30	10	7	21	9	18	**90**	10
2019	17	58	12	**11**	**24**	12	**23**	64	11
Southern Pasquotank River Basin Tributaries									
	Kendrick Creek M6920000			Scuppernong River M6980000			Alligator River M7175000		
	Mean (µg/L)	Max (µg/L)	n	Mean (µg/L)	Max (µg/L)	n	Mean (µg/L)	Max (µg/L)	n
2014	**15**	**70**	12	6	30	12	**16**	**36**	11
2015	8	29	9	5	16	11	13	25	7
2016	14	38	10	9	40	11	10	15	8
2017	13	27	10	8	17	9	10	25	10
2018	7	20	5	7	27	10	18	31	6
2019	13	34	9	**16**	**48**	12	15	27	6

n is equivalent to the number of samples collected each year. The yearly mean is influenced by the number of samples collected and in what season or month they are collected in.
Red numbers are the highest yearly mean and maximum recorded reading for each station over this time period.
ND = No data collected for chlorophyll *a* during that year.
*M2750000 open water station (In 2015, station relocated and renamed M2490000).

6.7 Algal Blooms

Changes in nutrient concentrations have been directly related to change in algal communities; yet there is a lack of consistent response due to interaction of streamflow, light conditions, water temperature, and grazing by invertebrates and fish (Munn et al., 2018). Excess nutrients in a river system can also "often leads to taste and odor issues in drinking water supplies, increased treatment costs for drinking water, toxic algal blooms, oxygen depletion, fish kills, decreases in the aesthetic value of the source-water bodies, and an overall decline in ecosystem health." (Moorman, 2014).

Hall and Paerl (2020) applied flow estimates to many of the Albemarle Sound tributaries including the Scuppernong and Kendrick Creek which allows for nutrient loading calculations. Their work was coupled with an evaluation of the "likelihood of increases from each [nutrient] source in causing recent blooms and trends in trophic status in the Chowan River and Albemarle Sound" (Hall and Paerl, 2020). Their work concluded that "Given the high concentrations and more rapid increases in total N loads from the coastal plain streams that were assessed, and the fact that such streams constitute about a quarter of the total watershed of Albemarle Sound, it is possible that the smaller, and largely unassessed, coastal plain streams contribute up to forty-five percent of N and P loads to Albemarle Sound." (Hall and Paerl, 2020). Their work also found " The trend in elevated algal productivity that has precipitated the current harmful algal bloom problem is likely associated with the long-term trend of increasing total N [nitrogen] concentration with a slope of about 0.01- 0.02 mg/L/y." (Hall and Paerl, 2020).



In the Pasquotank River basin, there have been multiple occurrences of algal blooms in the Albemarle Sound and associated tributaries including the Little River, Perquimans River, and Pasquotank River (Appendix VI). Our understanding of algal blooms throughout this basin is limited due to the inaccessibility of a large portion of the Albemarle Sound and limited monitoring that occurs for such a vast area. The number of blooms reported or identified as part of the AMS program were 4 in 2015, 2 in 2016, 7 in 2017, 3 in 2018, and 7 in 2019 (Table 6-8 (2018 and 2019 information); see Appendix VI for full table of blooms). Many of the algae samples collected at the stations in the Albemarle Sound and tributaries have proportionally high cyanobacteria cell counts (example Figure 6-23)

DWR's Ecosystem Branch developed an algal toxin program in 2018 and began monitoring algal blooms for *microcystin* toxin in the Chowan and Pasquotank River basins in late 2018 (Table 6-8). The division is still developing the capacity to analyze algal blooms around the state and is hoping to expand the program to include other algal toxins as resources allow. None of the 2018 or 2019 Pasquotank River Basin blooms had detectable toxin concentrations above the WHO recreational moderate risk level (10 µg/L Microcystin), however there were cyanobacteria (bluegreen algae) cell counts and chlorophyll *a* concentrations within the associated moderate risk level (Cyanobacteria (cells/mL) 20,000-100,000; Microcystin-LR (µg/L) 10-20; Chlorophyll *a* (µg/L) 10-50 (WHO 1999 Guidelines).

Many of the bluegreen algae species identified have the ability to produce microcystin toxin and are classified as potentially Harmful Algal Blooms (HAB)). DEQ and DHHS issued several press release regarding several algal bloom events in 2018 and 2019. The press releases urged the public to avoid contact with the blooms in order to eliminate the risks associated with exposure to *microcystin* and other algal toxins (Link to July 3, 2019 DEQ advisory). For more information on algal blooms go to our Algal Blooms webpage. A DWR algal bloom reporting application has been developed for the public and local stakeholders to use to report algal blooms and provide documentation on the geographic location, possible extent and attach a photographs of the event (DWR Citizen Report link). Local reporting of algal bloom events will help the division understand the magnitude and extent of the issues and concerns in this watershed.

Little River algal bloom near Nixonton Community in Elizabeth City. Photo by Rodney Johnson

Table 6-8 Bloom Events in 2018 and 2019 with Associated Microcystin Toxin Concentrations, Chlorophyll a Concentrations, and Dominate Algal Group Identification and Quantification (This is a subset of the available data, full 2015-2019 DWR Pasquotank River Basin Algal Bloom in Appendix VI).

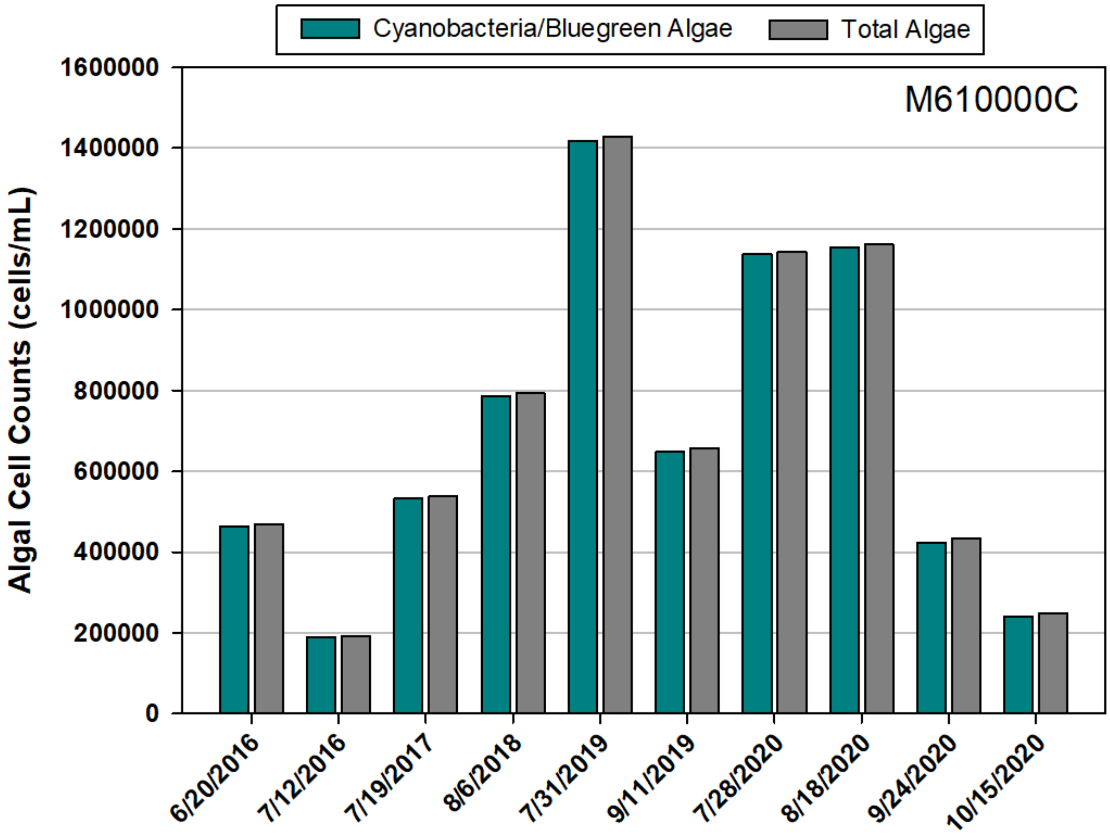
Location	Date	Micro-cystin µg/L	Chl a µg/L	Cell Density+ cells/mL	Cell Density+ units/mL	Biovolume mm^3/m^3	Algal Group/ Dominant Taxa	County
Albemarle Sound M390000C	6/28/2018	ND	28	T-865,000 C-860,000	T-85,000	T-5,500	CYA Dolichospermum	Tyrrell
Albemarle Sound M390000C	8/6/2018	0.4U	29	T-1,624,000 C-1,620,000	T-140,000	T-8,300	CYA Dolichospermum, Pseudanabaena	Tyrrell
Albemarle Sound M610000C	8/6/2018	0.4	22	T-793,000 C-787,000	T-79,000	T-5,300	CYA Dolichospermum	Tyrrell
Perquimans River	6/5/2019	0.4	131		T-14,000	T-15,000	CYA Dolichospermum	Perquimans
Sutton Creek (to Perquimans R)	6/12/2019	0.44	86		T-139,000	T-19,000	CYA, BAC Choococcus, centric diatoms	Hertford
Little River	7/2/2019	0.4U	ND		T-125,000	T-45,000	CYA Dolichospermum, Cylindrospermopsis	Pasquotank
Albemarle Sound M610000C	7/31/2019	ND	19	T-1,429,000 C-1,418,000	T-108,000	T-7,100	CYA Chroococcus, Pseudanabaena	Tyrrell
Manns Harbor	8/29/2019	ND	9.4		T-53,000	T-3,000	CYA Planktolyngbya	Dare
Albemarle Sound M610000C	9/11/2019	ND	33	T-657,000 C-648,200	T-66,000	T-5,000	CYA Chroococcus, Pseudanabaena	Tyrrell
Pasquotank River M2750000	10/8/2019	ND	ND	T-421,000 C-406,000	T-26,000		CYA Pseudanabaena, Dolichospermum	Pasquotank

WHO (World Health Organization): Recreational guideline of 10 ug/L indicating moderate probability of acute health effects from recreational exposure;
+ T=Total Algae & C=Cyanobacteria/Bluegreen Algae;
ND = No data available (data sheet found, but no analytical data this specific parameter found;
CYA = Cyanobacteria Algal Group (Cyanobacteria is also known as bluegreen algae)

Pasquotank River Basin algal bloom.

Photo by Rodney Johnson.

Figure 6-23 Algal Counts at Station M610000C in the Albemarle Sound. (Cyanobacteria Represents the Largest Portion of the Overall Algal Population).



6.8 Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) are rooted aquatic vascular plants that grow in estuarine and marine environments forming vast habitat beds underwater. In North Carolina, SAV occurs coastwide, including the sounds and rivers of the Albemarle-Pamlico Estuarine System, but not beyond the extent of the outer banks (Figure 6-24 and Figure 6-25; DEQ, 2021; Ferguson and Wood, 1994). There are two distinct groups of SAV habitats in NC that are distributed according to the estuarine salinity. One group thrives in fresh and low salinity riverine waters (<10 ppt), referred to as low salinity SAV or underwater grasses, and includes species such as Redhead grass (*Potamogeton perfoliatus*), Wild celery (*Vallisneria Americana*), and Sago pondweed (*Stuckenia pectinate*), etc. The second group occurs in moderate to high (>10 ppt) salinity estuarine waters of the bays, sounds, and tidal creeks, referred to as high salinity SAV or seagrasses, and includes three species, temperate eelgrass (*Zostera marina*), tropical shoal grass (*Halodule wrightii*), and cosmopolitan widgeon grass (*Ruppia maritima*). These SAV beds provide critical habitat for nursery and feeding for fish, shellfish, and wading birds (Ferguson and Wood, 1994; DEQ, 2021).

There have been many efforts over the last 40 years to map the distribution of SAV along the NC coast and it is estimated that the known historic extent of SAV (1981-2015) covers approximately 191,155 acres, of which 12,872 acres are in the Albemarle/Chowan system (Figure 6-24 and Figure

6-25; DEQ, 2021). Low salinity SAV has historically been found in the shallow portions of the lower Chowan River up to about Colerain and along the shorelines of the Albemarle Sound (Figure 6-25; DEQ, 2021). "The primary factors controlling SAV distribution are water depth, sediment composition, wave energy, and the penetration of light through the water column" (DEQ, 2021); Goldsborough and Kemp, 1988).

SAV is a sensitive bioindicator of environmental health and can become stressed due to eutrophication and other environmental conditions which reduces water clarity such as algal blooms and sedimentation (DEQ, 2021). The current extent of SAV in the Pasquotank River basin is unknown, but a significant decline in native grass species has been documented in the Albemarle Sound through recent hydroacoustic surveys (Speight H., 2020). This is likely due to the decline in the water quality resulting in a reduction in the water clarity.

SAV in North Carolina also includes an invasive non-native species known as Hydrilla (*Hydrilla verticillata)*. This invasive aquatic plant species was identified in the Albemarle Sound and Chowan regions through local efforts by the Chowan Edenton Environmental Group, Chowan Soil and Water Conservation District, and NC Sea Grant (Riddle, 2015). Their work aimed to survey and reduce the presence of Hydrilla appears to have been successful (CEEG, personal communication 2020). The effort to eliminate Hydrilla succeeded through the formation of the Hydrilla Citizen Science Project.

The Coastal Habitat Protection Plan (CHPP), which is a requirement of the 1997 NC Fisheries Reform Act (G.S. 143B-279.8), has a legislative goal of long-term enhancement of coastal fisheries by addressing habitat and water quality needs of fishery species. The CHPP aims to identify threats and recommend management actions to protect and restore habitats critical to North Carolina's coastal fishery resources. The CHPP is reviewed every five years, and the 2021 CHPP Amendment is currently underway and projected be adopted in by the end of 2021. The 2021 CHPP Amendment is focusing on five priority issues, one being "submerged aquatic vegetation protection and restoration through water quality improvements". An SAV issue paper has been drafted and included recommended actions to be considered by three commissions (EMC, CRC, MFC) when the full 2021 CHPP amendment is presented for final approval. Many of these direct the EMC to develop several criteria and water quality standards through the Nutrient Criteria Development Plan (NCDP) process, using SAV as an endpoint with the specific goal of protection and restoration. More information on the 2021 Amendment and earlier versions of the CHPP can be found here.

Figure 6-24 Known historic extent of SAV in North Carolina, mapped from 1981 to 2015. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981 (DEQ, 2021).

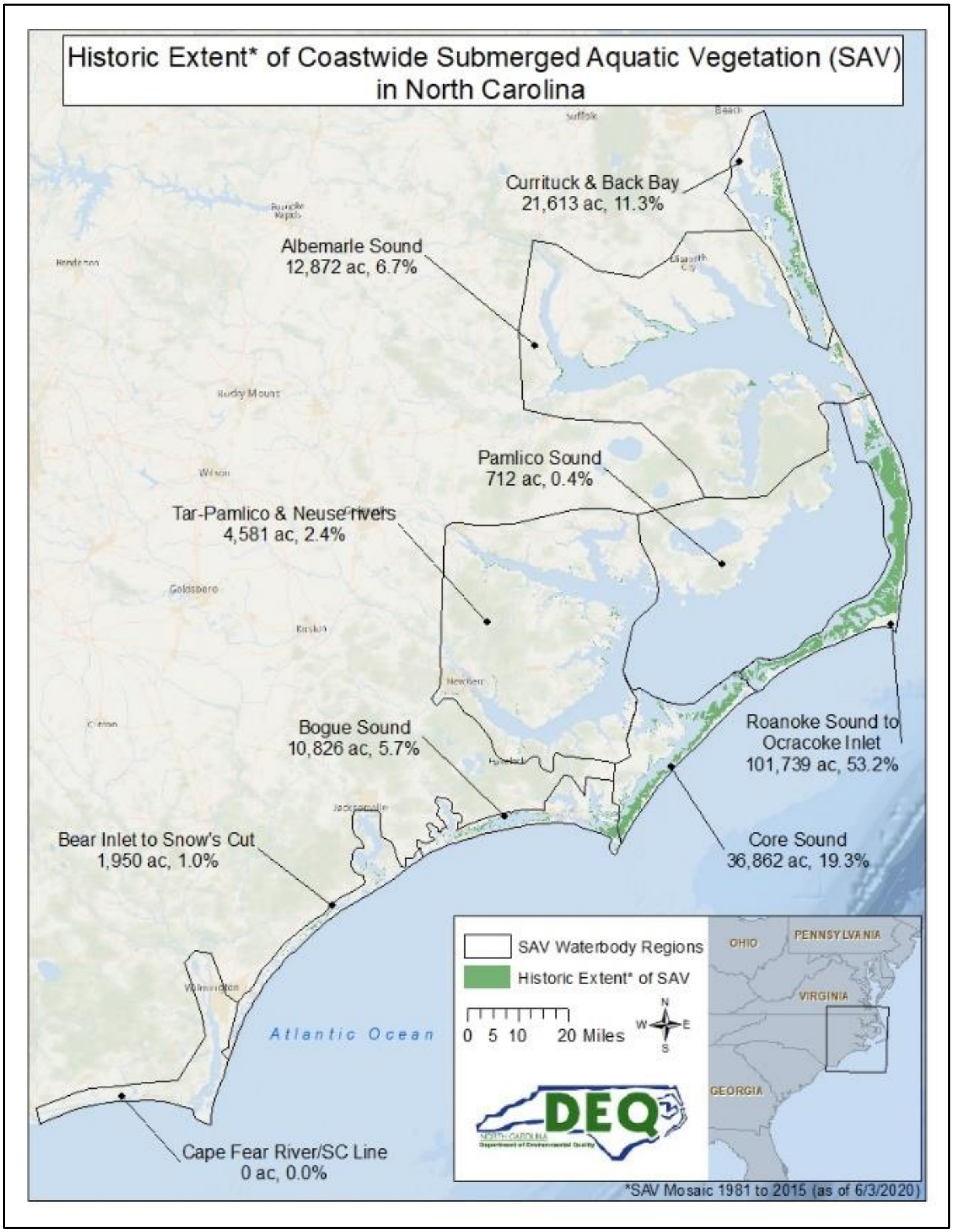
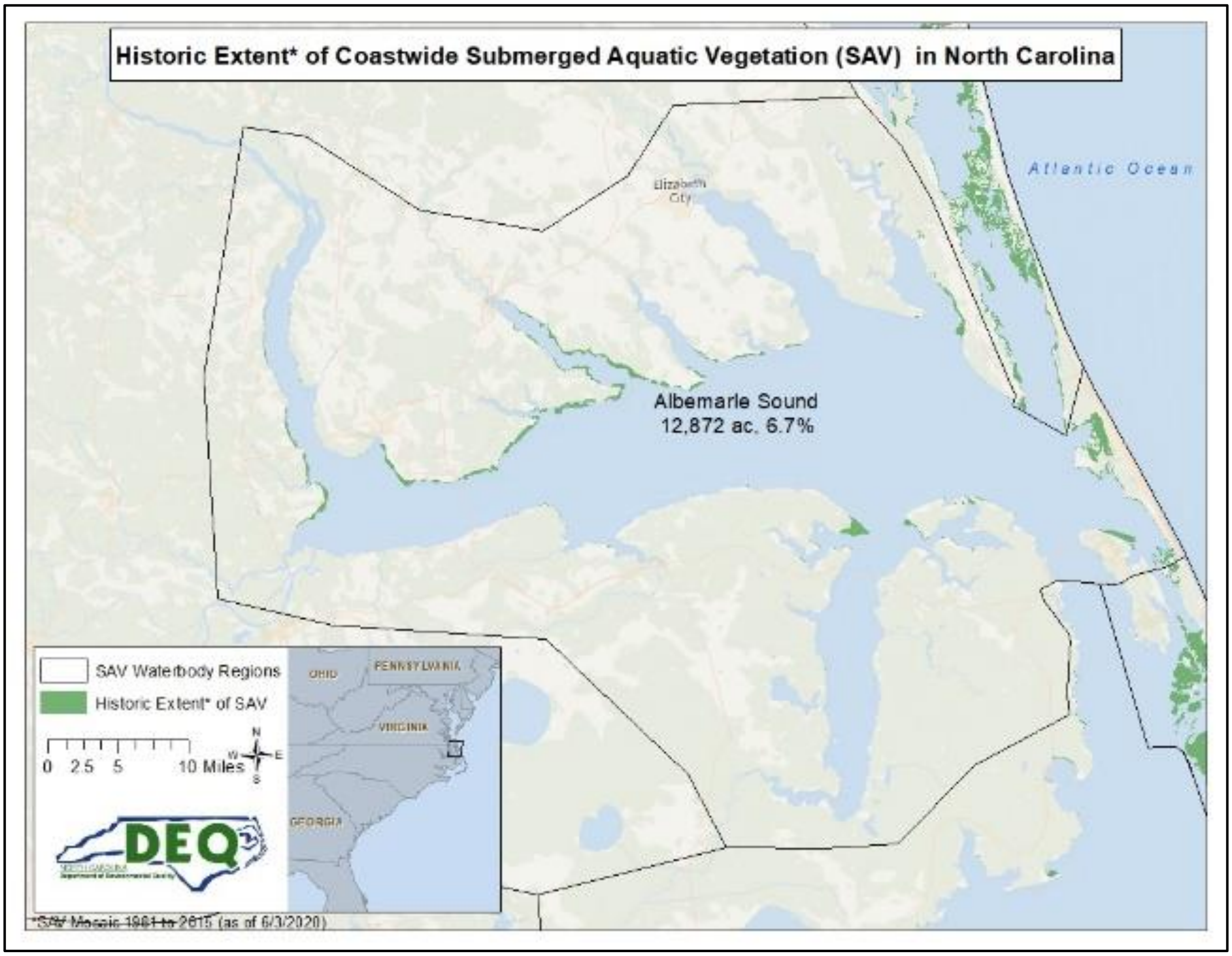


Figure 6-25 Known historic extent of SAV in NC, mapped from 1981 to 2015 in Albemarle Sound. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981 (DEQ, 2021).



6.9 Current and Proposed Actions and Recommendations

6.9.1 Nutrient Criteria Development Plan

In 2001, the US EPA strongly encouraged every state to develop nutrient criteria if states did not currently have site specific criteria in place to protect waterbodies from nutrient over enrichment (eutrophication) issues. In 2014, NC developed a Nutrient Criteria Development Plan (NCDP) which laid out the approach NC would take to achieve this requirement. The goal is to develop scientifically defensible criteria based primarily on the linkage between nutrient concentrations and protection of designated uses. The EPA-approved North Carolina NCDP identified three specific waterbody types and prioritized the development of criteria in three pilot watersheds. These watersheds were identified as possibly experiencing impacts from excess nutrients and were chosen in order to facilitate appropriate management actions by the division based on any new criteria developed. The specific waterbody type and pilot watersheds were:

1.) Reservoir and Lakes – High Rock Lake in the Yadkin-Pee Dee River basin;
2.) Rivers and Streams – Central portion of the Cape Fear River in the Cape Fear River basin;
3.) Estuaries - Albemarle Sound in the Pasquotank River basin.

The NCDP was approved by the EPA in 2014 which was followed by the development of a 12-member Science Advisory Council (SAC). The SAC is composed of experts in the areas specifically related to water quality, nutrient response variables, nutrient management, and point and non-point nutrient abatement and is meant to help provide scientific guidance to the division for the development of appropriate nutrient related criteria. The first NCDP meeting was held on May 6, 2015 with the focus on developing criteria for High Rock Lake.

During this same time period, the Albemarle-Pamlico National Estuary Partnership (APNEP), guided by their Comprehensive Conservation Management Plan (CCMP) to maintain ecological integrity in the estuary by ensuring that "nutrients and pathogens do not harm species that depend on the water", evaluated nutrient-related criteria and determine additional data and research needs in order to fulfill the mandate. The Albemarle Sound Nutrient Criteria Development Workgroup consisted of subject-matter experts/scientist, resource agency staff, environmental groups, municipal and concerned citizens, which met nine times between August 2014 and September 2016. The group successfully secured resources for several targeted initiatives, identified additional research needs and developed list of criteria proposals for parameters including pH, DO, chlorophyll *a*, nitrogen, and phosphorus. While the group did not come to consensus on criteria recommendations, priority research efforts were identified. (Proceedings of the Albemarle Sound Nutrient Criteria Development Workgroup: Phase I, February 8, 2018 document https://files.nc.gov/apnep/documents/files/past-committees/Albemarle-Sound-Report_combined.pdf)

In 2019, as result of the ongoing algal blooms in the Chowan River, DWR modified the NCDP to pair the Albemarle Sound and Chowan River waterbodies for development of numeric nutrient criteria. This will allow for a more holistic nutrient criteria development strategy for the watershed since the Chowan River directly influence the condition of the Albemarle Sound. EPA approved the modification in May 2019 and the Albemarle/Chowan SAC NCDP kick off meeting was held on October 30, 2019.

To develop an appropriate numeric nutrient criterion for any waterbody, many steps must occur prior to this determination. These initial steps minimally include, identification of designated uses to protect, which response variable (i.e. chlorophyll a, pH, DO, water clarity, phytoplankton) is affected by nitrogen or phosphorus concentrations or loading, and which is the most sensitive species or use for a specific parameter under consideration.

The DWR has worked with the SAC to identify the designated use in need of protection, developed a list of the most sensitive organism to consider throughout this process and currently is in the process of determining the appropriate response variables to assess in the Chowan River and Albemarle Sound. Depending on needs for additional research and continued availability of staff resources, the goal is to complete adoption of nutrient criteria for the Chowan River/Albemarle Sound by January 2024. For more information see the NCDP webpage https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/nutrient-criteria-development-plan.

6.9.2 Proposed Actions and Recommendations

DWR proposes the following actions and recommendations to address nutrients in the Pasquotank River basin.

- Reevaluate appropriate nutrient-related criteria and assessment protocols in the Albemarle Sound.
  - DWR will continue to work with the Nutrient Criteria Development Plan (NCDP) Scientific Advisory Council (SAC) to develop appropriate protective criteria (which could be response and/or causal variables) for the Chowan River and Albemarle Sound. This may include modifications to current criteria such as chlorophyll *a* and/or the development of an instream nitrogen and/or phosphorus criterion, which could result in the need for nutrient reductions to meet a new criterion. There is some debate as to whether the 40 µg/L level for chlorophyll *a* is an appropriate criteria level to protect the designated uses of the Albemarle Sound, including aquatic life and recreational uses. For more information on this process see the Nutrient Criteria Development Plan (NCDP) webpage.
  - Continue to support the development of water quality criteria and standards through the NCPD process using SAV as an endpoint with the specific goal of protection and restoration.
- Reevaluate monitoring needs throughout the basin for water quality assessment purposes and algal bloom response.
  - The Albemarle Sound and most of the rivers draining to the sound are not listed as impaired for nutrient-related parameters despite clear indications that use of the water has been affected. There is a need to better characterize the instream water quality conditions. The current monitoring schema does not appear to appropriately capture the magnitude, frequency, or the geographic extent of the ongoing water quality problems in the region. A review of the Pasquotank River basin AMS program is needed to ensure the program is capturing the algal blooms, algal toxin production, nutrients and physical characteristics needed to understand current water quality conditions and algal bloom development (e.g., dissolved fractions of N and P, algal limiting constituents, sediment recycling, nutrient source identification, river flow, sample locations, algal bloom response time, etc.).
  - Develop/expand local capacity to monitor for algal blooms and algal toxins. Pasquotank and Chowan River systems are far from the DWR regional and central offices. Blooms shift quickly and swift response is needed in order to capture a bloom in progress. A local entity in the region would be better positioned to monitor the situation (County health department, special monitoring group, citizen scientist organizations, others).
  - Expand local education and outreach on algal blooms and improve local stakeholder digital bloom reporting.
  - Support research and use of new monitoring techniques and technology to improve understanding of algal blooms in the hard to reach sections of the Chowan and Albemarle Sound region (e.g., remote sensing/satellite imagery, drones, etc.).
  - Expand/initiate groundwater quality monitoring in the Pasquotank River basin to understand the contribution nutrients from baseflow and nonpoint nutrient sources.

- Track health-related algal events, including closures and advisories.

- *Riparian Buffers:*
    - Consider financial incentives (i.e., grants or tax credits) to promote strategic preservation or restoration of riparian areas.
    - Consider implementation of nonpoint source management strategies (e.g., buffer rules) analogous to those in other nutrient-impaired watersheds.
    - Use existing state and federal cost share programs to identify ways to maximize voluntary implementation of buffers, filter strips, or other effective nutrient reducing BMPs on agricultural lands.
- Administration, Communication, and Public Relations:
    - Consider accepting third-party algal reporting as a separate layer on the NC algal bloom tracker. Already underway at county level with active community participation.
    - Contribute to community education and local forums on this topic.
    - Coordinate and facilitate semi-annual meetings between state agencies, local agencies, and stakeholders to discuss water quality and quantity concerns.

6.9.3 Nutrient Related Research Needs

DWR has identified the following research needs for the Pasquotank River basin.

- Research in determining if the Pasquotank River basin system is nitrogen or phosphorus limited.
    - Conduct bioassays throughout the Pasquotank River basin including the Albemarle Sound to understand response of algae to nitrogen and phosphorus.
- Research into nutrient source identification
    - Conduct research into the role of nitrogen fixation as a source of new nitrogen into the Albemarle Sound.
    - DWR has identified a pattern of increasing TKN concentrations in the Pasquotank River basin as well as in other river basins across the state. The reason for this basinwide shift in increasing organic nitrogen concentrations is not known. There is a need, however, to understand the sources of the organic nitrogen to the Pasquotank River system and across the state of NC.
    - There is a critical need for technology that can distinguish a specific nitrogen signature in order to identify a specific source such as agricultural animal types, domestic waste or a background forest/sediment signature. DWR encourages researchers to continue to work toward a method viable to use on a large-scale system. Using bioassays, assess algal growth responses to specific organic nitrogen sources, as these are increasing as part of the N load to the Pasquotank River basin system. This would assist in the development of appropriate best management practices to reduce the load of organic nitrogen into the system.
    - It is recommended that research be conducted to better establish and understand the relationship between groundwater and surface water in eastern North Carolina. Such understanding would provide for more accurate assessment of surface water impairments

resulting from groundwater discharges and enable the state to make sound permitting judgments and recommendations to better protect ground and surface water quality.

- Scientific Research for Streamflow
    - Currently there is a lack of available stream flow data throughout the Pasquotank River basin. DWR has identified a need for bi-directional instream flow data that would allow for loading estimates and better understand of nutrient cycling in the coastal creeks, rivers, and the sound. Research needs include identification of appropriate tools, monitoring locations and data assessment to improve the overall understanding of the Pasquotank River basin system and enhance future management decisions.

References

Babbitt B., Groat C. G., 1999. The Quality of Our Nation's Waters Nutrients and Pesticides. Accessed: https://pubs.usgs.gov/circ/1999/1225/report.pdf

Ferguson R. L., and L. L. Wood. 1994. Rooted vesicular aquatic beds in the Albemarle-Pamlico estuarine system. Albemarle-Pamlico Estuarine Study

Goldsborough, W. J., and W. M. Kemp. 1988. Light responses of submersed macrophytes: implication for survival in turbid waters. Ecology, Vol. 69, No. 6:1775-1786.

Hall N., Paerl H., 2020. Quantitative Evaluation of Changing Nutrients Sources to the Albemarle Sound System. Final Report to the Albemarle Commission. Accessed: albcom_report_hall_paerl_10feb2020.pdf (albemarlercd.org)

Harned D. A., Davenport M. S., 1990. Water-Quality Trends and Basin Activates and Characteristics for the Albemarle-Pamlico Estuarine System, North Carolina Virginia. U. S. Geological Survey Report 90-398.

Heath R. C., 1975. Hydrology of the Albemarle-Pamlico Region, North Carolina, - a preliminary report on the impact of agricultural developments: U.S. Geological Survey Water Resources Investigations 9-75Moorman M., Kolb K. R., Supak S., 2014. Estuarine Monitoring Programs in the Albemarle Sound Study Area, North Carolina. Accessed: https://pubs.usgs.gov/of/2014/1110/pdf/ofr2014-1110.pdf

Munn, M.D., Frey, J.W., Tesoriero, A.J., Black, R.W., Duff, J.H., Lee, Kathy, Maret, T.R., Mebane, C.A., Waite, I.R., Zelt, R.B., 2018, Understanding the influence of nutrients on stream ecosystems in agricultural landscapes: U.S. Geological Survey Circular 1437, 80 p., https://doi.org/10.3133/cir1437.

North Carolina Department of Environment, Health, and Natural Resources, United States Environmental Protection Agency/National Estuary Program, Sea Grant College Program, Water Resources Research Institute of the University of North Carolina, 1991. Status and Trends Report of the Albemarle Pamlico Estuarine Study. Accessed: https://files.nc.gov/apnep/documents/files/apes/9101.pdf

NC Department of Environmental Quality (DEQ). 2021. North Carolina Coastal Habitat Protection Plan Amendment 1. http://portal.ncdenr.org/web/mf/habitat/chpp/07-2020-chpp

Riddle N., 2015. Naturalist's Notebook: Evicting an Invader: Reducing the Spread of Hydrilla. Coastwatch.

Riggs S. R., Ames D. P., North Carolina Sea Grant College Program, and North Carolina. Division of Coastal Management., 2003. Drowning the North Carolina Coast: Sea-Level Rise and Estuarine Dynamics North Carolina Sea Grant. Accessed: http://core.ecu.edu/geology/riggs/DROWNING%20The%20NC%20Coast.pdf

Speight, H., 2020. Submerged Aquatic Vegetation in a low-visibility low-salinity estuary in North Carolina: Identifying temporal and spatial distributions by sonar and local ecological knowledge. Doctoral Dissertation, East Carolina University, Greenville, NC.

US EPA. 2001. Albemarle-Pamlico Estuary Program. Accessed: https://nepis.epa.gov/Exe/ZyPDF.cgi/200050E1.PDF?Dockey=200050E1.PDF

United States Geological Survey (USGS), 1999. The Quality of Our Nation's Waters Nutrients and Pesticides. Accessed: https://pubs.usgs.gov/circ/1999/1225/report.pdf