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2021 Water Quality Monitoring Program for Tidal Creeks in Calvert County, Maryland

Final Report

Prepared for the Calvert County Board of County Commissioners

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Executive Summary

Our monitoring work is divided between measurements in the Mill Creek system that have been ongoing since 1987 and more recent efforts to document water quality conditions in a larger set of Calvert County tidal creeks. Below, we offer an executive summary for each of these components. Both precipitation and river discharge influence tidal water quality and are described below as they apply to both sampling programs.

Precipitation and River Flow/Discharge
Precipitation and river discharge patterns exert substantial influence on water quality conditions in many estuaries, including those considered in this monitoring program, because they help deliver sediments and nutrients from land to tidal waters.

Precipitation: The March through September 2021 average precipitation of 0.136 inches per day is very close to the long-term year average (Fig 3.1 A). The 2021 peak precipitation month was in June with 0.25 inches per day or 7.59 inches total for the month. But February, July and August all had over 0.15 inches of rainfall per day. December was the driest month with 0.01 inches per day.

River Discharge: The Patuxent River January-September 2021 mean flow was 391 cubic feet per second or cfs (measured at Bowie, MD), which was lower than the 35 year average of 417 cfs. Discharge rates in 2021 were highest in February and March, which is a typical seasonal pattern and consistent with the high precipitation in February.

MILL CREEK SUB-ESTUARY MONITORING PROGRAM

Yearly Monitoring Measurements
Water column temperature, salinity, dissolved oxygen, clarity and chlorophyll-*a* concentrations were measured at 10 fixed stations on 9 cruises during the spring and summer of 2021.

This report examines the patterns of Patuxent River flow, local precipitation, chlorophyll-*a* concentrations and water column stratification in concert with long-term trends of bottom water dissolved oxygen concentration and algal blooms. We have also included the 2021 MDE fecal coliform data from this area, Maryland Department of Health and Mental Hygiene and Calvert County Health Department data concerning water-related infections, and presence/absence data of sea nettles.

Temperature, Salinity and Dissolved Oxygen

Temperature: Both bottom and surface water temperatures increased from a range of 19-23°C measured during the May 18 cruise to a range of 27-31°C recorded during the July 15 cruise. Surface water temperatures were typically higher than bottom temperatures, due to solar heating, and all stations had comparable temperatures (within 2 to 6 degrees Celsius).

Salinity: For most stations, salinity increased through the season, with bottom salinities slightly greater than or equal to surface salinities. Measurements on August 10th were slightly lower throughout the creek, and likely connected to localized precipitation in the basin.

Water Column Stratification: Stratification strength in the 2021 season was generally less than or equal to a difference of 1.5 sigma-t units between surface and bottom water, which is indicative of vertically well-mixed water. However, there were 10 instances of higher stratification with differences greater than 1.5 sigma-t units which occurred in late June/early July. By comparison, there 9 instances in both 2019 and 2020.

Dissolved Oxygen: In 15 instances, bottom water dissolved oxygen concentrations were below 2.0 mg L^{-1} during the 2021 study (8% of all surface and bottom water samples). Concentrations below 2.0 mg L^{-1} are considered very hypoxic and are stressful to organisms. Bottom water dissolved oxygen saturation levels less than 50% saturation were observed 53% of the time (48 out of 90 bottom water observations).

Water Column Chlorophyll-a: Average active chlorophyll-a levels were 16.32 µg L^{-1} in 2021, which is lower than the long-term mean (18.5 µg L^{-1}) of the five representative stations. A total of 11 samples indicated bloom conditions in 2021, which we consider to be concentrations greater than 20 µg L^{-1}.

Water Column Clarity
Water column clarity and light penetration are very important parameters contributing to the growth of submerged aquatic vegetation (SAV). SAV not only provides food, oxygen, nursery areas and shelter for Bay animals, but can trap sediment and nutrients, and slow erosion, thus further clearing the water.

The Mill Creek sub estuary is located in the mesohaline portion (salinity 5.0 to 18.0) of the Bay. We used calculated light attenuation coefficients (which are quantitative indicators of how cloudy the water is) measured at each station to compute the depth where 15% of surface light is available, which is the minimum needed for submerged aquatic vegetation growth. These values ranged from 0.89 to 3.49 meters during 2021, which is an improvement over 2020 because light in 2021 reached a deeper depth, thus expanding potential areas for growth. The average water depth is 3.1 m, meaning that there were many stations with sufficient light for SAV growth during the 2021 sampling period.

Shellfish and Swimming Safety Review
We reviewed 2007-2021 MDE fecal coliform data for this drainage basin (Table 4.9). Local waters had three instances of not meeting the quality standards for shellfish harvesting: values less than 70 MPN per 100 mLs of water (MPN = most probable number). During 2021, the highest value recorded was 240 MPN/100 mL in October at station 09-04-109A. Even though the bacteria standards are being met most of the time, MDE will keep this area closed to shellfish harvesting due to oyster sanctuary status and shoreline activities and the intensity of boating activities, increasing the potential for overboard discharge of

untreated sewage. The U.S. EPA regulatory concentration for closure of swimming areas is greater than 200 MPN fecal coliforms per 100 mL.

In addition, the Calvert County Health Department provided information related to non-cholera *Vibrio* infections for Maryland and Calvert County. In 2021, 48 confirmed cases of *Vibrio* were reported in Maryland, with an additional 47 probable cases. Calvert County had two confirmed cases. Compared to 2020, 2021 had 17% fewer confirmed and more than double the probable cases. Calvert County counts have remained low.

Long-Term Trends
A subset of five representative stations (stations 2, 6, 7, 9 and 15) are used to investigate long-term trends in Solomons Harbor from 1987 to 2021.

Dissolved Oxygen: Average 2021 bottom-water dissolved oxygen concentrations (4.14 mg/L) were on the lower end of the spectrum observed in this monitoring program with a long-term annual average of 4.27 mg L^{-1}. A possible decline in bottom water dissolved concentrations over the long-term is suggested in the time series. Even though anoxic conditions (dissolved oxygen concentrations of zero milligrams per liter) have never been observed, hypoxic conditions (less than 2.0 mg L^{-1}) are observed frequently enough to continue monitoring these trends. Solomons Harbor continues to experience periods of hypoxia that may impair habitat suitability for some organisms.

Chlorophyll-a: Concentrations of active chlorophyll-*a* serve as a measure of the size of algal populations in the water column. The 2021 surface mean active chlorophyll-*a* concentration decreased from last year's average of 23.03 µg L^{-1} to 18.10 µg L^{-1}. This yearly average is comparable to the 1987-2021 average concentration of 18.50 µg L^{-1}.

Algal Blooms: During the 2021 sampling season, 10 algal blooms were observed at the 5 inter-annual comparison stations. A bloom is defined here as chlorophyll-*a* concentration greater than 20 µg L^{-1}. The average across all stations is 11.6 blooms per year.

CALVERT COUNTY TIDAL TRIBUTARIES MONITORING PROGRAM

The 2021 Calvert County creek monitoring program included stations in Patuxent River creeks and Western Shore Chesapeake Bay creeks. The lower Patuxent River creeks (Hellen's Creek, St. Leonard Creek, Island Creek, and Hungerford Creek), the upper Patuxent River creeks (Battle Creek, Hunting Creek and Hall Creek), the Western Shore Chesapeake Bay creeks (Fishing Creek, Plum Point Creek, Flag Harbor, and Parkers Creek) were sampled in June, July and August. A total of 32 stations were sampled in these creek systems.

More hypoxic conditions in the bottom water were found in the lower Patuxent River creeks with 12 instances of dissolved oxygen concentrations < 2 mg L^{-1} (almost double those documented in 2020), where St. Leonard Creek samplings made up 9 of these instances. The upper creeks had three instances of hypoxia in Battle Creek. The Western

Shore saw five cases of hypoxia in Fishing Creek in July and on all sampling dates in Parkers Creek. Algal blooms were common occurrences in all of the Calvert County.

Summary and Conclusions

- Monitoring of Mill Creek estuarine system has been conducted since 1987 (no 1989 data collection), providing a 35 year record of water quality conditions in the county. In addition, three creeks in the lower Patuxent have been monitored for thirteen years (2009-2021), one creek in the lower Patuxent has been monitored for ten years (2012-2021), three upper Patuxent creeks have been monitored for twelve years (2010-2021), three Western Shore creeks have been monitored for eleven years (2011-2021), and Parkers Creek has been monitored for nine years (2013-2021).

- In terms of bottom water oxygen and chlorophyll-a concentrations, overall water quality of the Mill Creek system appears to be slowly degrading over time although both bottom water oxygen and surface chlorophyll levels improved slightly in 2021.

- Monitoring of Calvert County tributaries continues to build our database for detecting change and response to watershed based restoration efforts. The prevalence of hypoxia in the lower Patuxent creeks and the widespread algal blooms across all sampled tributary sites suggests there is room for improvements to local water quality.

- In 2021, many of the Calvert Creeks (those outside Mill Creek) had conditions that were close to long-term averages for water clarity, dissolved oxygen, and chlorophyll-*a.* There do not appear to be any long-term trends in the creeks, except for degrading trends in some creeks for dissolved oxygen (St. Leonard, Battle Creek, Parkers Creek).

Recommendations

- Continue to monitor the Mill Creek sub-estuarine system so that both negative and positive trends in water quality can be clearly documented. The emergence of long-term degradation in this system might require further investigation.

- Continue to gather basic data in the Patuxent River and Chesapeake Bay tributaries of Calvert County. We recommend continued monitoring in each area to capture differences between years associated with local climate variability, with implementation of Best Management Practices, and to identify hot spots for water quality change. For example, St. Leonard's Creek has degrading oxygen conditions.

- Continue to support planning and eventual implementation of sewer upgrades, BMPs, installation of enhanced nutrient removal (ENR) septic systems, riparian and other vegetative buffer zones, and encourage the use of pump-out facilities by boaters.

- Continue to interpret conditions in the Calvert Creeks within the context of adjacent Patuxent River conditions, e.g. CBL Pier and along the estuary.

- Consider working with the Chesapeake Bay Program water quality modeling team, who is working on new and improved assessment models for shallow waters.

1 Introduction

As development adjacent to coastal and estuarine waters increases so does the risk that water quality of these areas will degrade. Water quality degradation is a concern not only in the large estuaries, such as Chesapeake Bay, but also in the smaller coves and tributary rivers adjoining these estuaries. In many cases these areas can be considered small estuaries or sub-estuaries. They are subjected to similar natural and anthropogenic influences as the larger estuaries. However, due to their smaller size and restricted flushing, the potential for dilution of pollutants is limited and the potential for algal blooms and general water quality deterioration is enhanced.

Located within the Dowell, Drum Point, Lusby, Olivet and Solomons portion of southern Calvert County, Maryland, the Mill Creek sub-estuarine system includes St. John's Creek, Mill Creek, Back Creek, The Narrows and Solomons Harbor. It is identified as a smaller sub-estuarine system. The number of houses and town houses surrounding the Mill Creek system is increasing, as are the numbers of boat slips and the amount of shore-line hardening within the Mill Creek system. Additionally, many forms of recreation enjoyed by the local population and by visitors are becoming increasingly popular.

The aquatic resources and the population growth in this area must be managed to preserve this system for the use and enjoyment of future generations. In response to these management concerns, the Calvert County Board of County Commissioners provides the University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory (UMCES CBL) with funding to monitor water quality conditions in the Mill Creek system. Past monitoring grants were awarded in 1987-1988 and 1990-2016. In 2017, the funding method changed, and we responded to an RFP and were awarded funding to continue monitoring. This was renewed for the 2021 monitoring year.

The focal point of these studies was to measure the variables that best indicate stress to an estuarine system due to increased development and recreational activity. In the early years of this program, variables measured included particulate and dissolved nutrients, chlorophyll-*a*, fecal coliform concentrations, temperature, water column clarity, dissolved oxygen concentrations and salinity. Particulate and dissolved nutrients are no longer measured at these sites.

In addition to sampling the Mill Creek system, at the request of the Calvert County Commissioners, the 2009 water quality monitoring program expanded to include 10 new stations in 3 tributaries located in the lower Patuxent River estuary, all south of Broomes Island: 3 stations in Hellen's Creek, 4 stations in Saint Leonard Creek and 3 stations in Island Creek. In 2010, the water quality monitoring program expanded again to include 9 new stations in 3 tributaries in the upper Patuxent River estuary: 3 stations in Battle Creek, 3 stations in Hunting Creek, and 3 stations in Hall Creek. Monitoring efforts increased once again in 2011 to include 8 new stations in 3 tributaries of the Chesapeake Bay western shore: 3 stations in Fishing Creek, 3 stations in Plum Point Creek, and 2 stations in Flag Harbor; and 2 stations in Hungerford Creek were added to the lower Patuxent Creeks sampling regime. The 2013 monitoring effort added Parkers Creek. All stations were sampled 3 times yearly, once in June, July, and August.

At all stations (including the historical 10 stations in the Mill Creek sub-estuarine system), we tracked important water quality variables to determine changes in key indices between years. Surface and bottom water temperature, salinity, dissolved oxygen, and water clarity were measured. Water samples were collected, filtered and analyzed for total and active chlorophyll-*a* concentration.

The effects and long-term trends of Patuxent River flow (otherwise referred to as discharge), precipitation, Mill Creek system chlorophyll-*a* concentrations and the influence of water column stratification on bottom water dissolved oxygen levels were also examined.

2 Sampling Procedures

It is important to remember for any analyses comparing data across years in Solomons Harbor or Mill Creek that 2020 measurements were delayed and missed sampling in May and early June. This has the potential to impact metrics like averages. Wherever possible, we have highlighted 2020 in a contrasting color to remind the reader of this impact of the Covid-19 pandemic. Fortunately, we were able to resume sampling in June and avoid impact to the Calvert Creeks dataset.

2.1 Station Locations and Sampling Frequency

Table 2.1, 2.2 & Figure 2.1, 2.2, 2.3

Water column data were collected at ten fixed stations in the Mill Creek system on nine different cruises that ran from May 18 to September 7.

As in previous years, sampling stations were distributed throughout the Mill Creek system to ensure coverage of the area. Four stations were positioned along Mill Creek (stations 3, 4, 6, and 7); two along St. John's Creek (stations 8 and 9) and two located in Back Creek (stations 15 and 17). One station was located in The Narrows (station 11) and one at the mouth of the Mill Creek system (station 2). Data from stations 2 and 11 provide insight into the influence of the Patuxent River on water quality conditions in the Mill Creek system.

Table 2.1 Location and average depth of the 2021 sampling sites in the Mill Creek system.

Station Number	Station Name	Average Depth (meters)	Latitude (Decimal Degrees)	Longitude
2	Boat Shop	5.0	38.32182	-76.45015
3	Bow Cove	4.6	38.32995	-76.45046
4	Pancake Point	4.5	38.33389	-76.44801
6	Cole's Creek	2.3	38.33863	-76.43253
7	Ranch Club	1.4	38.34437	-76.42726
8	Hutchin's Cove	2.7	38.33965	-76.44782
9	Lore's Creek	0.9	38.35033	-76.44876
11	Pilot Transfer Station	3.4	38.32369	-76.45905
15	Calvert Marina	3.6	38.33084	-76.45820
17	Solomon's Landing	2.8	38.33722	-76.46079

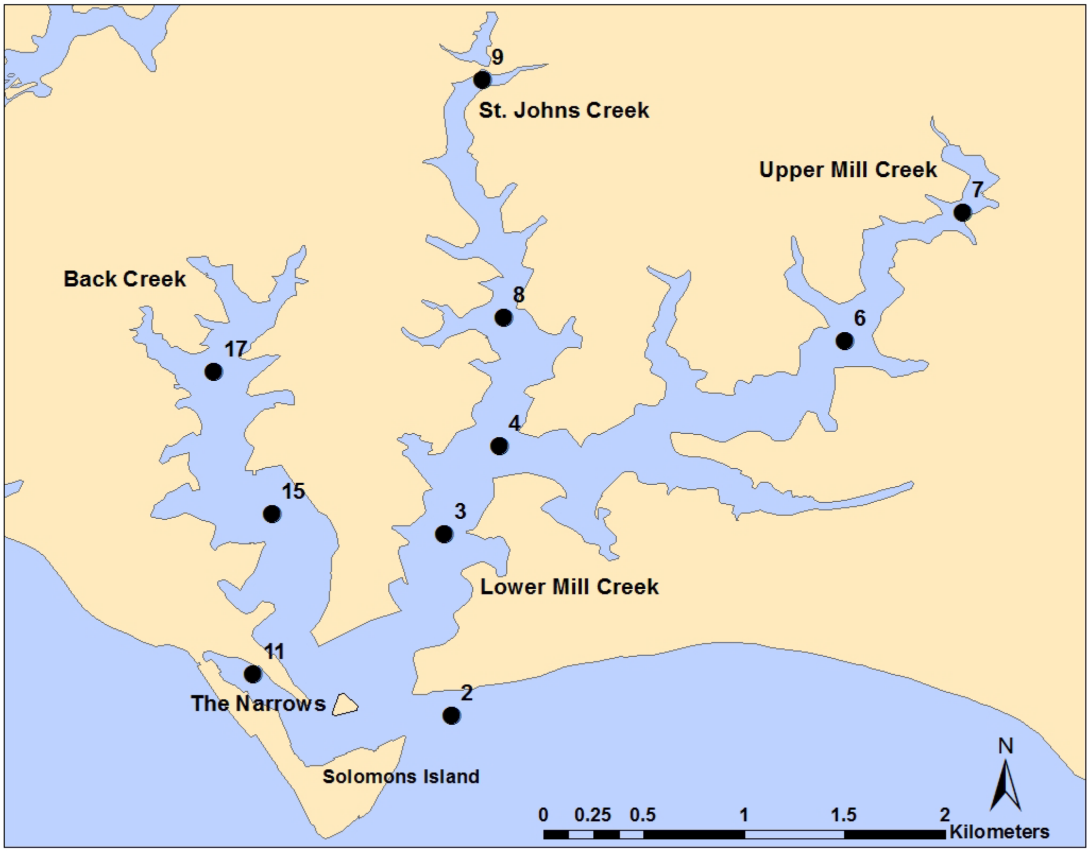


Figure 2.1 Map of the 2021 sampling sites in the Mill Creek system.

Water column data were collected at: 9 fixed stations in the upper Patuxent River creeks, 12 fixed stations in the lower Patuxent River creeks and 11 fixed stations in the Western Shore Calvert County creeks on three monthly cruises in June, July and August (Table 2.2, Figures. 2.2 and 2.3).

The Mill Creek system, lower Patuxent River and Battle Creek sampling cruises were conducted aboard the R/V Pisces, a 25-ft CBL research vessel. The remaining upper Patuxent River and Western Shore cruises were conducted from the Sourpuss, a 13-ft CBL Boston Whaler, except for Parker's Creek, Plum Point Creek, and Fishing Creek stations which were sampled via canoe. Flag Harbor continued to be sampled off the dock. Sampling methods were similar to those of the other creeks in this monitoring program.

Table 2.2 Location and average depth of the 2021 sampling sites in the 4 lower Patuxent, 3 upper Patuxent River Creeks and 3 Western Shore Creeks.

Station	Average Depth meters	Latitude	Longitude
		Decimal Degrees	
Lower Patuxent			
SLC-1	5.2	38.3918	-76.4930
SLC-2	4.2	38.4075	-76.4868
SLC-3	3.3	38.4212	-76.4887
SLC-4	1.6	38.4357	-76.4840
HLN-1	3.7	38.3608	-76.4773
HLN-2	3.4	38.3665	-76.4750
HLN-3	1.4	38.3740	-76.4687
IC-1	3.2	38.4135	-76.5433
IC-2	2.7	38.4193	-76.5400
IC-3	1.3	38.4288	-76.5417
HNG-1	2.1	38.3531	-76.4656
HNG-2	1.0	38.3568	-76.4599
Upper Patuxent			
BAT-1	3.8	38.4521	-76.5992
BAT-2	2.4	38.4584	-76.5960
BAT-3	1.5	38.4734	-76.5981
HUN-1	2.3	38.5645	-76.6520
HUN-2	2.4	38.5684	-76.6339
HUN-3	1.4	38.5745	-76.6252
HAL-1	3.8	38.6886	-76.6899
HAL-2	4.6	38.6927	-76.6878
HAL-3	2.0	38.6922	-76.6776
Western Shore			
FSH-1	4.1	38.6905	-76.5379
FSH-2	2.4	38.6842	-76.5485
FSH-3	1.6	38.6785	-76.5580
PLM-1	1.0	38.6161	-76.5142
PLM-2	1.2	38.6194	-76.5149
PLM-3	1.1	38.6147	-76.5170
FLG-1	2.1	38.4636	-76.4731
FLG-2	1.8	38.4623	-76.4736
WR	1.1	38.5373	-76.5182
MC	1.6	38.5357	-76.5232
BS	1.1	38.5324	-76.5419

SLC = Saint Leonard's Creek
HLN = Hellen's Creek
IC = Island Creek
HNG = Hungerford Creek

BAT = Battle Creek
HUN = Hunting Creek
HAL = Hall Creek

FSH = Fishing Creek
PLM = Plum Point Creek
FLG = Flag Harbor
WR = Warrior's Rest (Parkers)
MC = Mini Creek (Parkers)
BS = Bridge Spur (Parkers)

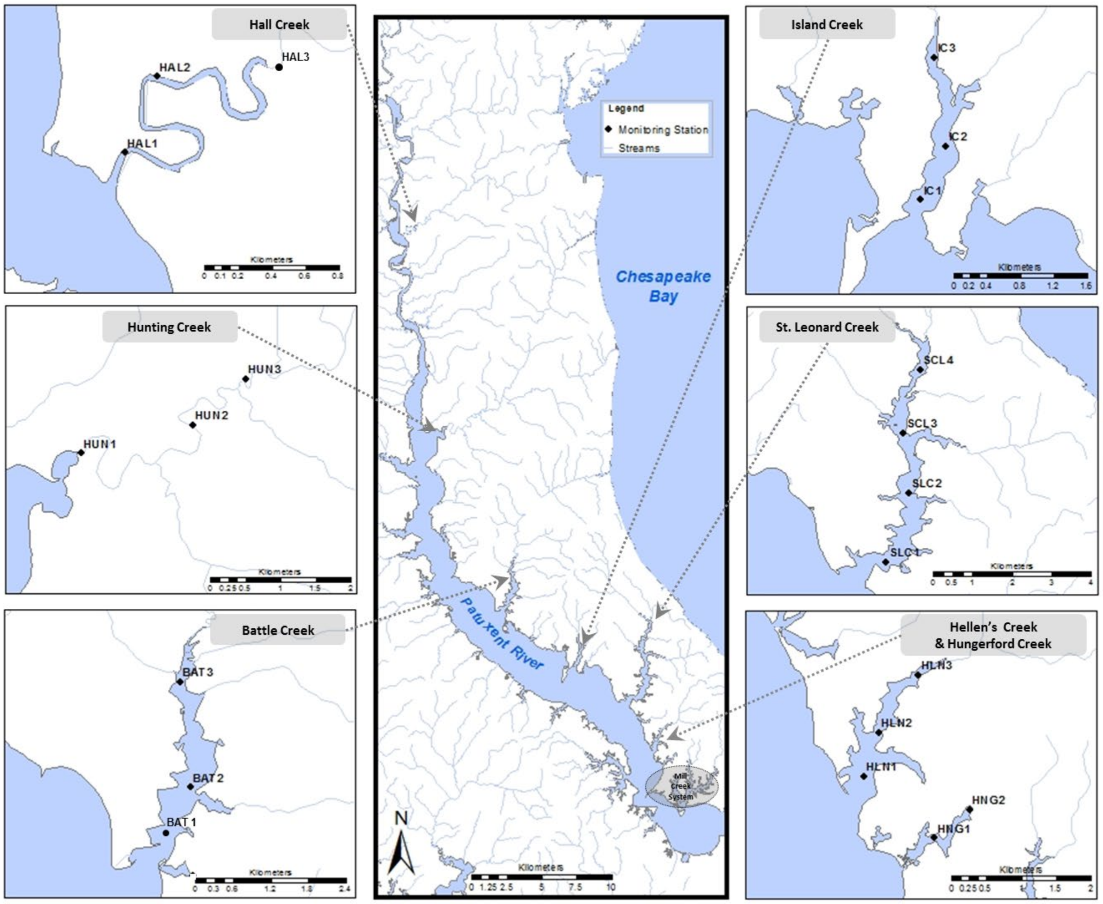


Figure 2.2. Maps of the 2021 sampling sites in Hall, Hunting, Battle, Island, St. Leonard, Hellen's, and Hungerford Creeks.

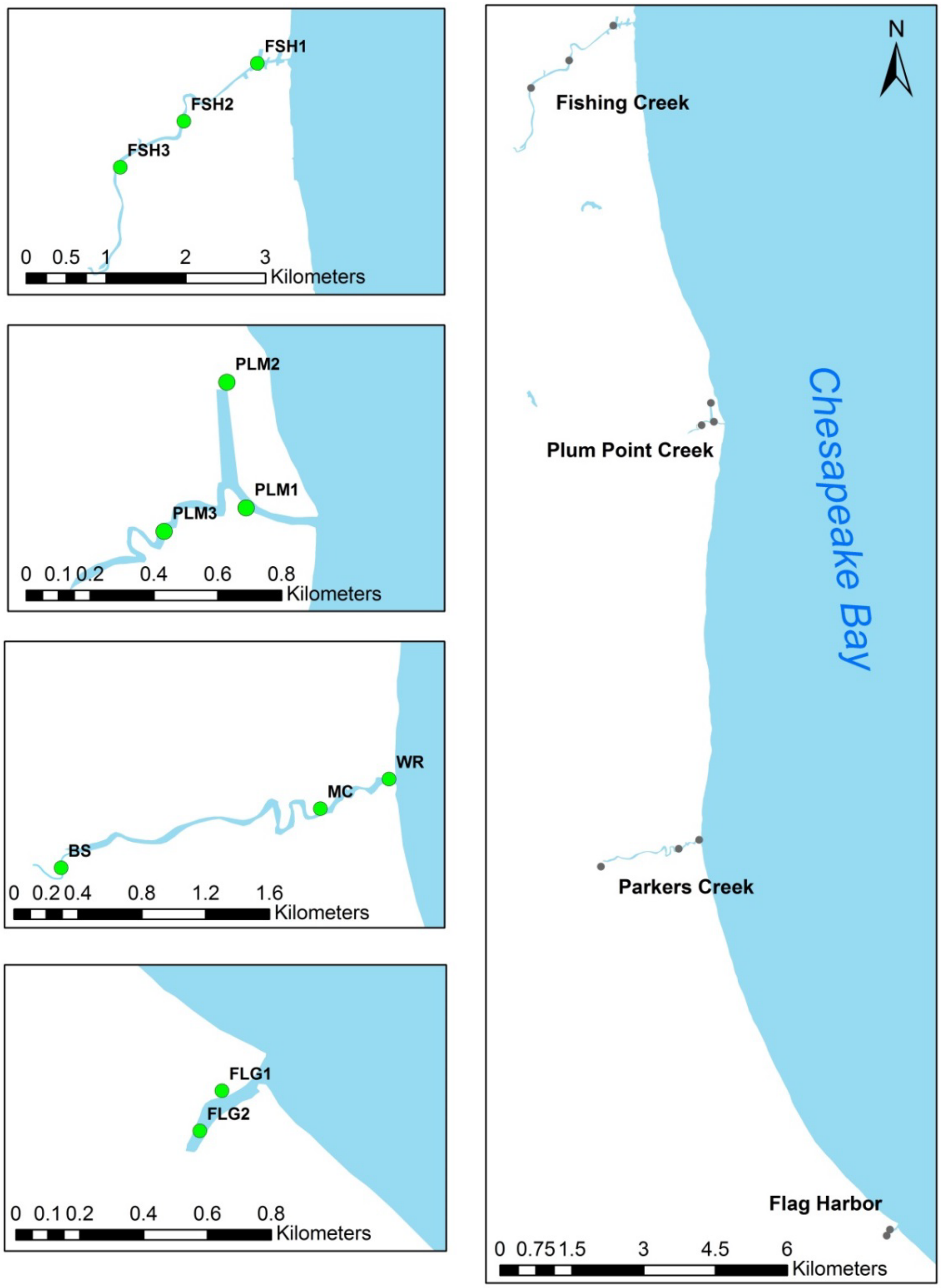


Figure 2.3 Maps of the 2021 sampling sites in Fishing Creek, Plum Point Creek, Parkers Creek, and Flag Harbor.

2.2 Water Quality Observations

Water column temperature, conductivity, salinity and dissolved oxygen were measured at each station using a submersible water quality monitoring instrument (YSI model 6600, 6920, or Exo2). Surface (0.5 meters) and bottom (0.5 meters above the sediment surface) measurements were taken at each site. Water clarity was measured using a Secchi disk. Beginning in 2015, light levels were collected with a LI-COR photosynthetically active radiation (PAR) sensor at the surface and at various water depths. Weather and sea-state conditions including air temperature, percent cloud cover, wind speed and direction, total water depth and wave height were recorded.

2.3 Chlorophyll-*a* Analyses

Samples of near-surface and near-bottom water were collected for chlorophyll-*a* analysis in separate, sample rinsed, 500mL dark polyethylene jugs using a small submersible pump (Rule model 1500). For each depth, aliquots of 50 to 100 mL were immediately filtered through a 0.7 µm glass fiber filter, wrapped in a labeled foil packet, then stored in a dark, iced cooler. After the cruise, the samples were immediately transported to the CBL Nutrient Analytical Services Laboratory (NASL) and frozen. Analyses of all samples were conducted by NASL using the standard operating protocols described in Keefe et al. (2004).

3 Precipitation Patterns and River Flow

3.1 Precipitation

Figure 3.1 A&B

To understand the water quality in the Mill Creek system and other Calvert County creeks it is critical to consider spring and summer precipitation. This section describes when and how materials enter the system from the surrounding land and from the Patuxent River. Conditions during 2021 are described and long-term trends are evaluated.

In general, the level of precipitation provides an index of the potential amount of nitrogen and phosphorus (as well as other materials), which could enter the Mill Creek system and tidal creeks as diffuse source run-off. While there is not a simple relationship between precipitation and diffuse source nutrient loading (Summers 1989), loading generally increases in proportion to precipitation. As a result, nutrient loads to the Mill Creek system and tidal creeks can be expected to be larger in wet than in dry years. The magnitude of river flow reflects the intensity of rainfall. Since river water is ultimately of terrestrial origin, it is responsible for the import of a significant amount of nutrients to the estuary (Kemp and Boynton 1992). This supply of nutrients can then generate spring and summer algal blooms, create increased water turbidity, and lead to low DO conditions.

The relationship between river flow and algal biomass has been documented in a number of estuaries (Nichols and Cloern 1985; Malone et al. 1988; Christian et al. 1991; Kemp and Boynton 1992). Typically, with increased river input, the amount of nutrients imported to the system increases and therefore the potential for more intense algal blooms increases.

Furthermore, decay of an algal bloom and its subsequent sinking to the bottom can stimulate bacteria which draw down dissolved oxygen and decrease habitat quality for fish, seagrass, and other organisms. Work in the Chesapeake Bay (Wainger et al. 2016) has provided intriguing evidence that local water quality in sub-estuaries like the creeks monitored here are more likely to be influenced by surrounding smaller watersheds, rather than larger scale trends in the mainstem. This was reinforced in recent years (2011-2020) as chlorophyll-*a* declined slightly in the nearby Patuxent River and mainstem of Chesapeake Bay, but increased in Solomons Harbor (Testa et al. 2018; Chesapeake Bay Program Trends tool; this report).

Average daily precipitation has been collected in the Mill Creek system (measured at a NOAA station located at CBL) for the period of March through September which includes the sampling dates of the Mill Creek system studies as well as springtime conditions that can impact nutrient inputs. This pattern also serves as an indicator of precipitation affecting other Calvert Creek tidal systems included in our monitoring program. Data can be downloaded here:

https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00188405/detail

Total 2021 rainfall was 42.33 inches, very close to the long term average. The May through September 2021 average precipitation of 0.14 inches per day is the same as the long-term annual average, which includes the months March to September to account for freshwater flow that influences early summer conditions (Fig 3.1 A). The 2021 peak precipitation month was June with 0.25 inches per day or 7.59 inches total for the month followed by February (0.20 inches/day, 5.66 inches total) and July (0.16 inches/day, 4.92 inches total). December was the driest month with a cumulative total of 0.43 inches and a daily average of 0.01 inches.

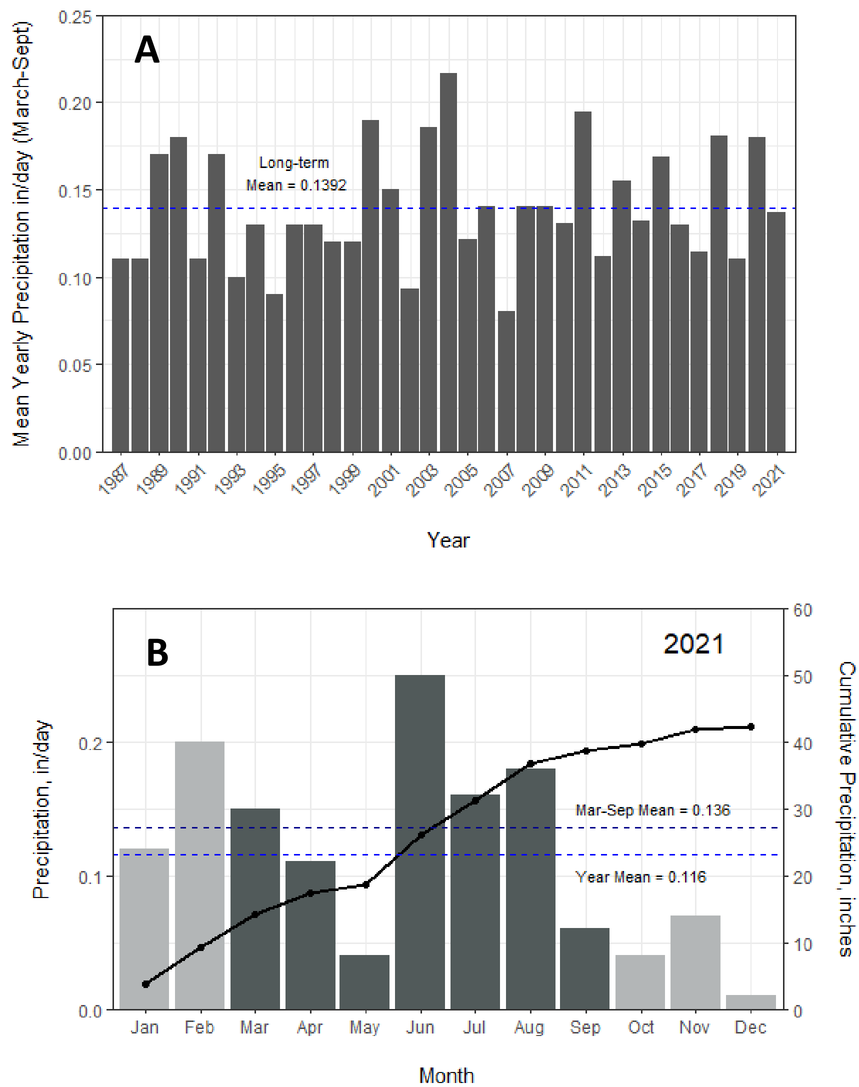
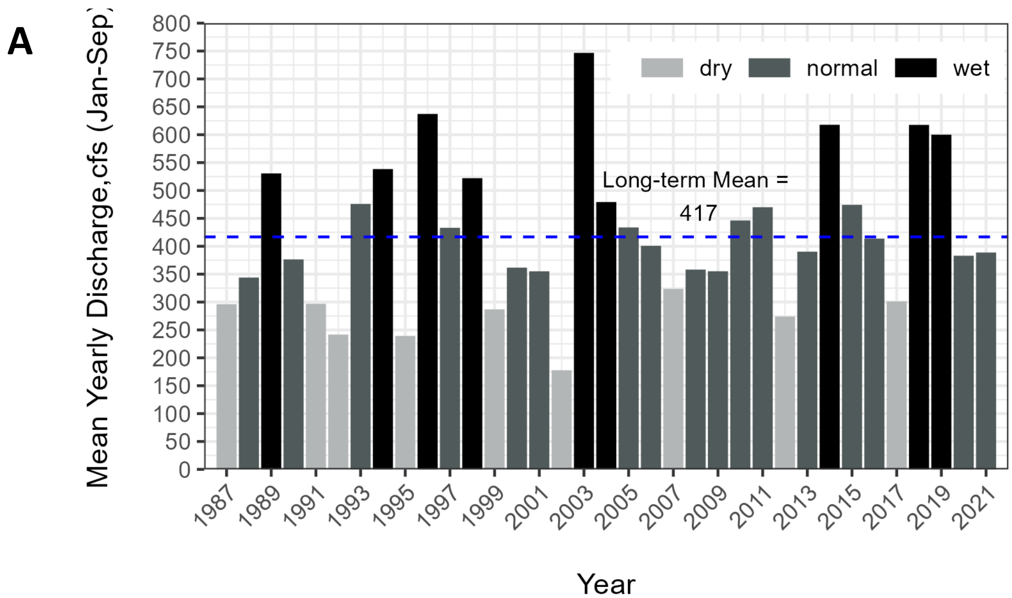


Figure 3.1 A&B Bar graphs showing (A) the mean daily seasonal precipitation (March through September) for 1987 to 2021 and (B) the mean daily precipitation by month (bars) in 2021 and cumulative precipitation (solid line). The darker bars indicated the months used for the seasonal precipitation in (A). The dashed horizontal lines indicate average or daily precipitation, as indicated.

3.2 River Flow

Figure 3.2 A&B

In the past, spring river discharge has been reported, but some years have had wetter summers including 2018 and therefore we now report the January-September discharge from 1987-2021. Mean Patuxent River flow for each month was obtained from a discharge gauge at station 01594440 Patuxent River at Bowie, MD, maintained by the United States Geological Survey (USGS). This river discharge affects tidal creeks located on the Patuxent side of the Calvert County peninsula, as well as the Mill Creek system and Solomons Harbor. The 25th and 75th percentile were determined from 1987-2020 to classify wet and dry years (Kimmel et al. 2009), which are highlighted in Figure 3.2A.



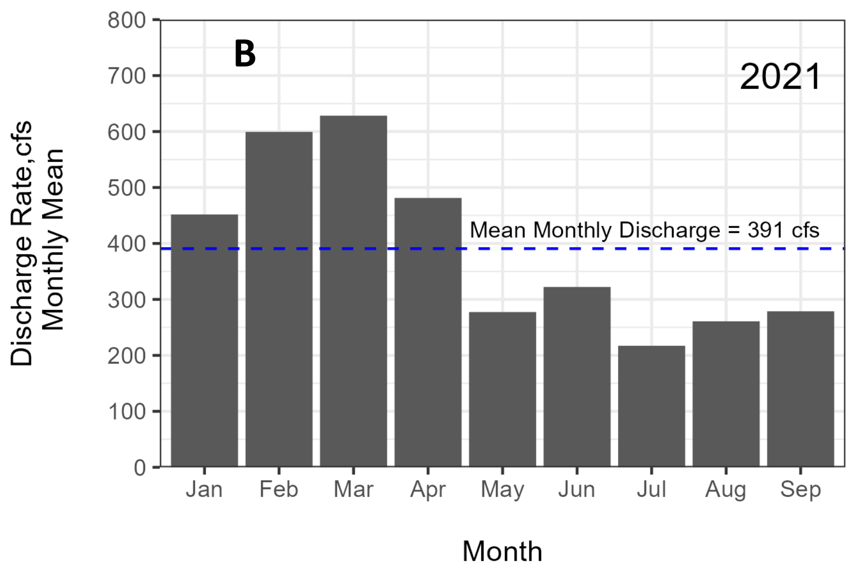


Figure 3.2 A&B Bar graphs showing (A) Patuxent River mean January through September flow 1987 to 2021, with darker bars representing wet years and lighter bars representing dry years and the (B) mean monthly flow for 2021. Average flows during the history of the study are indicated in (A), while the monthly average for 2021 is indicated in (B).

The January-September 2021 mean monthly flow, 391 cubic feet per second (cfs), was lower than the 35 year mean (417 cfs) and was a normal year based on discharge rates. Rates were highest in February and March. Precipitation measured at CBL and river discharge measured at Bowie, MD do not always covary, reflecting the fact that precipitation that falls in the upper Patuxent watershed may be different from that in Calvert County. Precipitation and associated river discharge in the early part of the year (February to April) typically deliver the nutrients that support chlorophyll-*a* in both spring and summer, but large summer discharges can also stimulate blooms more immediately.

4 Mill Creek Sub-estuary: Water Quality Results and Discussion

All water quality data collected during the 2021 monitoring study in the Mill Creek sub-estuarine system are listed in Appendix I by station and date.

4.1 Temperature and Salinity

4.1.1 *Temperature*

Table 4.1, Figure 4.1 & 4.2

Table 4.4.1 Surface and bottom water temperature ranges (°C). ****measurements in 2020 were impacted by the Covid-19 pandemic***

Year		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Surface	L	22.6	16.9	18.1	18.7	17.2	18.1	17.2	20.3	20.6
	H	29.9	31.2	29.5	28.3	29.1	32.0	30.6	31.7	30.0
Bottom	L	21.6	16.9	17.9	18.2	17.1	17.6	17.4	19.1	18.5
	H	29.2	29.6	29.5	28.3	29.1	30.6	30.2	31.3	29.9
Year		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Surface	L	17.0	21.2	22.4	16.6	19.2	20.8	21.7	23.1	18.9
	H	28.6	29.6	30.7	30.3	30.9	31.2	31.7	30.8	30.6
Bottom	L	16.9	17.9	19.2	16.1	18.6	20.0	19.2	22.6	18.8
	H	29.1	29.5	30.3	30.2	30.7	30.6	31.4	30.4	29.34

Surface water temperatures ranged from 18.9°C (station 2, May) to 30.6 °C (station 9, July 15). The bottom water temperature ranged from 18.8°C (station 2, May 18) to 29.34°C (station 7 and 7, Aug 24). Note that surface water temperatures were higher in 2020 because our late sampling, omitting the cooler conditions in May), biased these numbers to higher values.

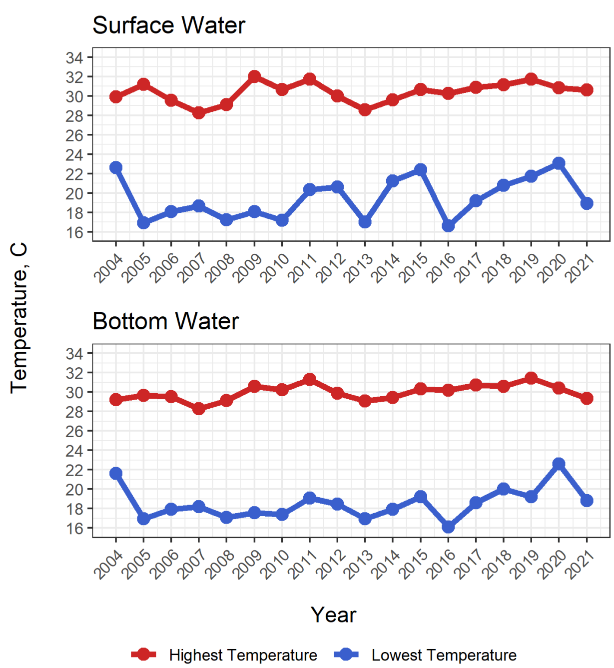


Figure 4.1 Historical surface and bottom water temperatures (°C).

Both bottom and surface water temperatures increased from a range of 19-23□□C measured during the May 18 cruise to a range of 27-31□□C recorded during the July 15 cruise. For the past five years, minimum temperatures measured in both the bottom and surface of the water column have increased, suggesting a narrower range of temperatures.

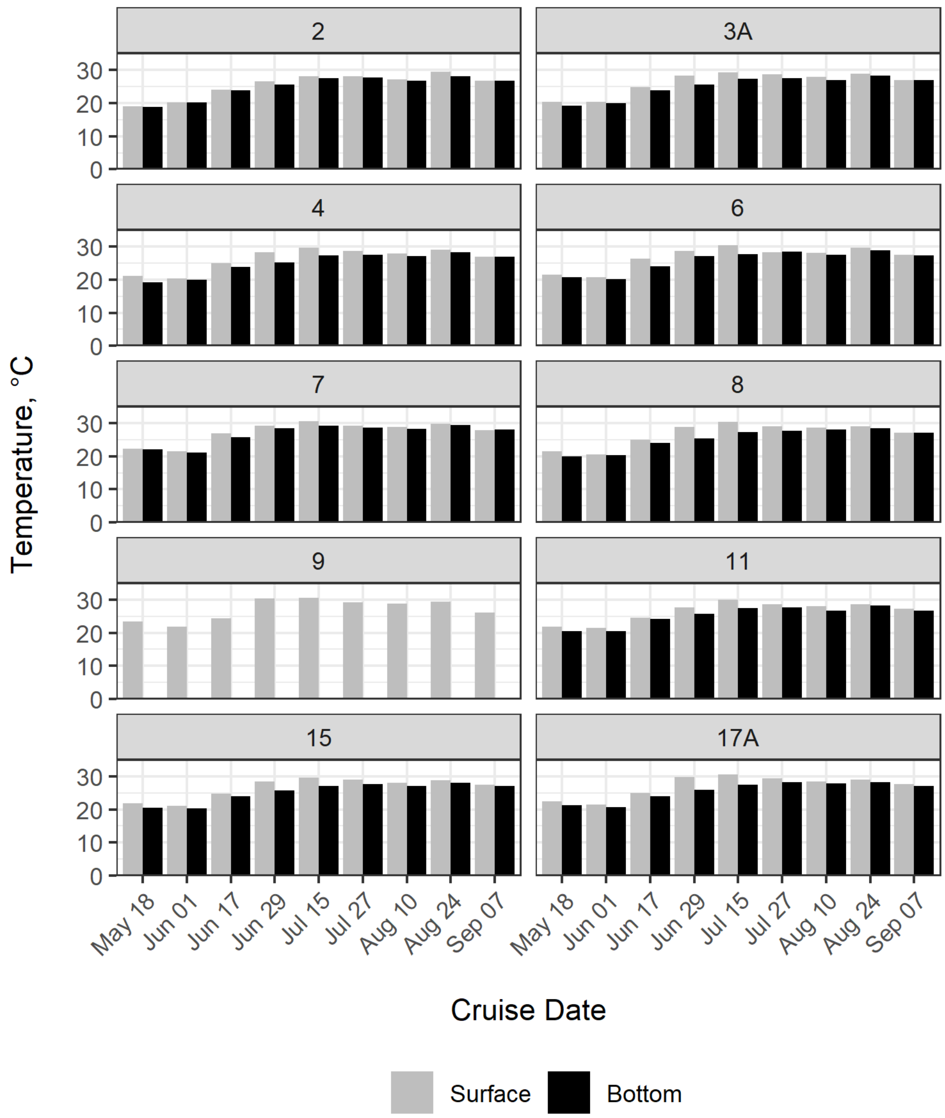


Figure 4.2 Bar graphs of surface and bottom water temperature measured at each station from May 18 through September 7, 2021. Note that bottom data was not collected for station 9, Lore's Point, due to the shallow depth (~1 m or less).

Looking at these data spatially across the 10 stations, we observed a typical seasonal pattern of warming temperatures. In general, the warmest values are found at stations 8 and 6, which were ~0.5 degrees Celsius warmer than other stations.

4.1.2 ***Salinity***

Table 4.2, Figure 4.3 & 4.4

The minimum salinity values for surface and bottom water in 2021 were higher than typical years. Regional river flow in 2021 was normal. The average difference between surface and bottom salinities was 0.64.

Surface water salinity ranged from 9.41 (station 7, August 10) to 13.39 (station 2, Sept 7). Bottom water salinity ranged from 10.97 (station 7, June 1) to 13.69 (station 4, Sept 7).

Table 4.4.2 Surface and bottom water salinity ranges in the Mill Creek System. **Measurements in 2020 were impacted by the Covid-19 pandemic*

Year		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Surface	L	6.1	5.05	9.8	9.1	6.4	9.7	9.2	4.0	11.4
	H	11.9	14.7	14.9	15.2	14.0	14.2	17.2	13.3	15.1
Bottom	L	7.9	8.3	10.4	9.7	7.8	10.8	10.2	4.5	11.7
	H	12.4	14.8	15.3	15.9	14.3	14.4	17.5	13.5	15.5
Year		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Surface	L	7.5	6.7	8.9	6.7	4.7	3.5	2.3	8.0	9.4
	H	14.2	13.7	14.2	16.4	12.5	9.9	12.3	13.1	13.4
Bottom	L	8.8	7. 8	11.3	11.5	10.0	6.6	3.6	10.2	11.0
	H	14.4	13.8	14.2	16.4	13.3	10.9	12.5	13.7	13.7

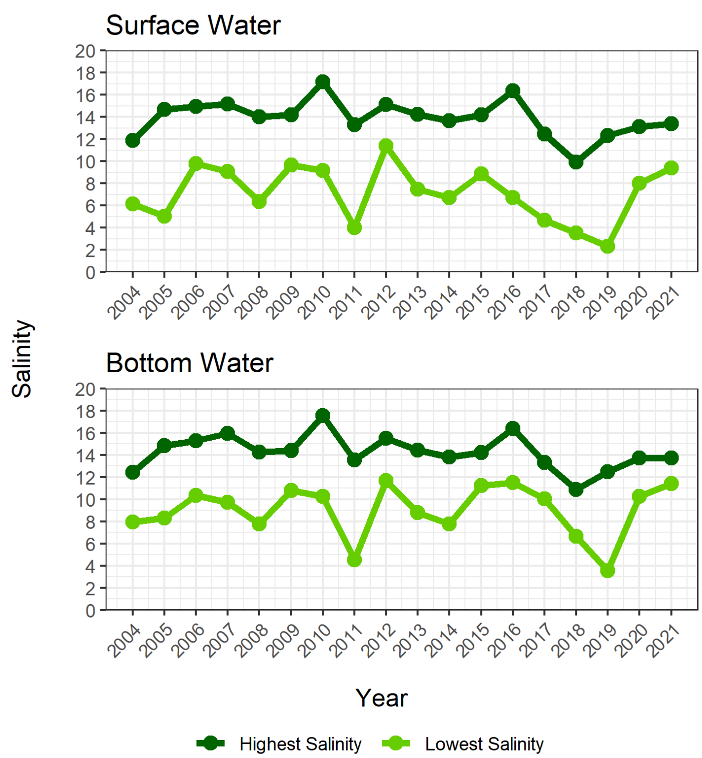


Figure 4.3 Historical surface and bottom water salinity in the Mill Creek System.

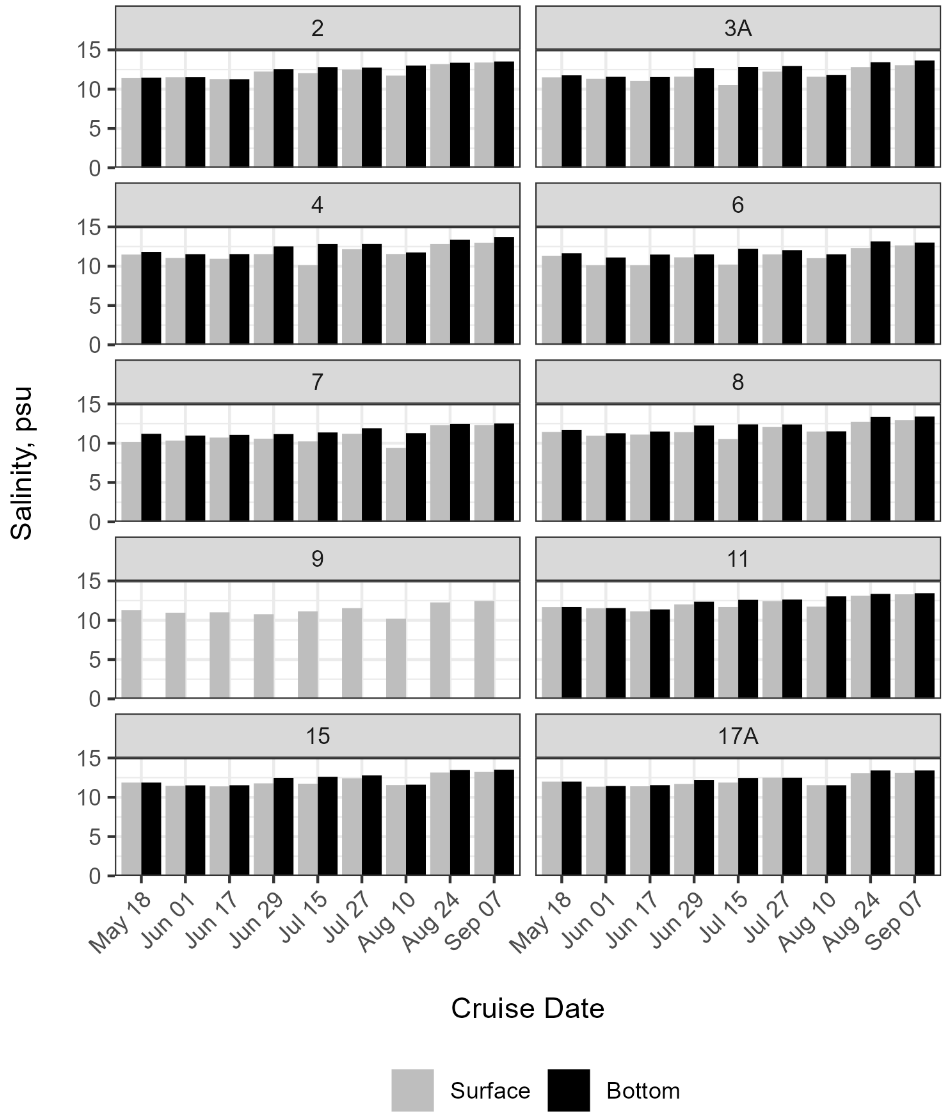


Figure 4.4 Bar graphs of surface and bottom water salinity values measured at each station in the Mill Creek System from May 18 through September 7, 2021

Not surprisingly, the freshest stations were documented at the inland stations 7 and 9 for St. Johns and Upper Mill Creeks. The highest salinity stations within Solomons Harbor are sometimes higher than at the mouth to the Patuxent (station 2). This is likely a consequence of higher residence times and opportunities for evapotranspiration that can increase local salinities.

4.1.3 Stratification Strength

Figure 4.5

Sigma-t (specific gravity of water computed using water temperature and salinity) of the surface and bottom waters was calculated for each station and sampling date. The difference between surface and bottom sigma-t values provides an indication of the stratification strength of the water column. Stratification in an estuary indicates the layering of water of differing densities, where strong layering can prevent oxygen delivery to bottom water. Density differences result from water of varying temperature and salinity conditions, where cold, high salinity waters are denser than fresh, warm waters. Waters stratify when density differences are not overwhelmed by other physical forces, like wind, tides, or currents.

Stratification strength in the 2021 season was generally less than or equal to a difference of 1.5 sigma-t units between surface and bottom water for both stations and sampling times, which is indicative of weak stratification strength, or in other words, well-mixed water. However, there were 10 instances of higher stratification with differences greater than 1.5 sigma-t units compared to 14 instances in 2018 and 9 instances in both 2019 and 2020. In particular, sampling on June 28th and July 15th documented high stratification conditions, which may correspond to local rainfall events. We are interested in stratification because it can create conditions where a) bottom waters are not replenished with oxygen from mixing with the atmosphere and b) phytoplankton in the surface waters can become nutrient limited when nitrogen and phosphorus recycled in sediments is not mixed upward to the surface. These stronger density differences may help to explain the higher salinity values as well, as density gradients can increase estuarine circulation and thereby cause greater entrainment of higher salinity Patuxent waters to Solomons Harbor.

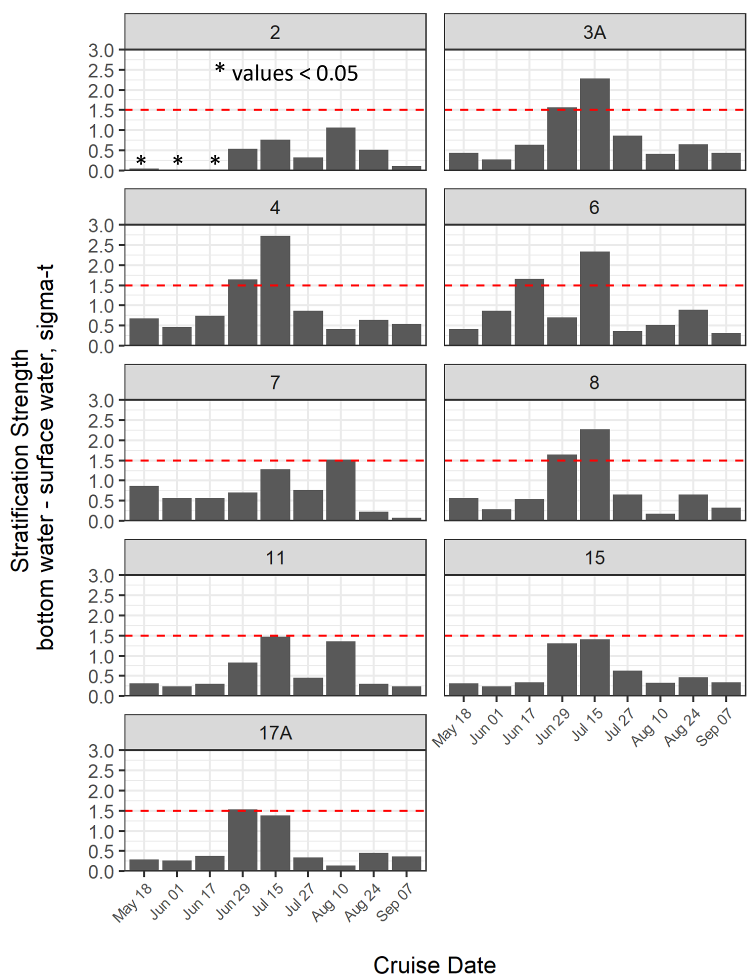


Figure 4.5 Bar graphs of water column stratification represented as the difference between surface and bottom water sigma-t values calculated for each Mill Creek station from May 18 through

September 7, 2021. Stratification strength below 1.5 (dashed line) indicates well mixed water. Note that due to shallow depths, stratification for Lore Creek could not be calculated.

4.2 Dissolved Oxygen

Table 4.3 & 4.4, Figure 4.6 & 4.7A

The dissolved oxygen concentration of surface waters ranged from 2.58 milligrams per liter (mg L^{-1}) (station 9, Sept 7) to 11.15 mg L^{-1} (station 6, May 18). Bottom water dissolved oxygen concentrations ranged from 0.16 mg L^{-1} (station 15, Aug 24) to 9.90 mg L^{-1} (station 6, May 18).

Table 4.4.3 Historical surface and bottom water oxygen concentration ranges (mg L^{-1}) in the Mill Creek System. SW= surface water. BW = bottom water.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
SW Min	0.79	1.86	2.10	2.12	2.77	3.04	2.81	1.86	2.81
SW Max	10.10	11.92	9.47	8.32	8.89	15.06	8.66	14.42	10.16
BW Min	0.18	0.30	1.18	0.88	0.98	0.31	2.10	0.26	1.90
BW Max	7.31	9.56	7.91	6.99	8.17	9.51	9.02	13.93	8.92
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
SW Min	1.76	2.11	2.53	1.78	2.15	2.46	2.51	1.59	2.58
SW Max	8.92	11.13	8.85	8.50	9.54	9.74	8.95	8.41	11.15
BW Min	0.44	0.77	0.36	1.21	0.76	0.39	0.38	0.49	0.16
BW Max	8.77	10.05	9.11	7.70	9.00	8.59	7.56	7.28	9.9

Fifteen of the bottom water dissolved oxygen concentrations were below 2.0 mg L^{-1} during the 2021 study (see figure 4.7 A for historical comparisons). Levels below 2.0 mg L^{-1} are considered hypoxic and are very stressful to organisms. The percent of hypoxic readings during the drier years (e.g. 2002, 2012) have been typically low relative to the wetter years (e.g. 2003), but this has not always been the case in the last decade. The year 2018 was a wet year and saw a high amount of hypoxia, while 2017 was a drier year and saw high hypoxia percentages as well. Based on discharge, 2021 was considered a normal but below-average year with more frequent occurrences of hypoxia.

Table 4.4.4 Percent hypoxic readings in the bottom water (<2.0 mg L^{-1}) in the Mill Creek System.

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
8%	31%	25%	24%	10%	11%	17%	13%	0%	21%
2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
3%	10%	10%	9%	6%	23%	28%	13%	16%	17%

True anoxic conditions (0.00 mg L^{-1} dissolved oxygen) have not been recorded on the sampling dates of any Mill Creek system cruise. It may be that only high frequency monitoring will record any short-term (less than 2 weeks in duration) anoxic events if they do occur as water column respiration processes that consume oxygen typically peak in the night and pre-dawn hours.

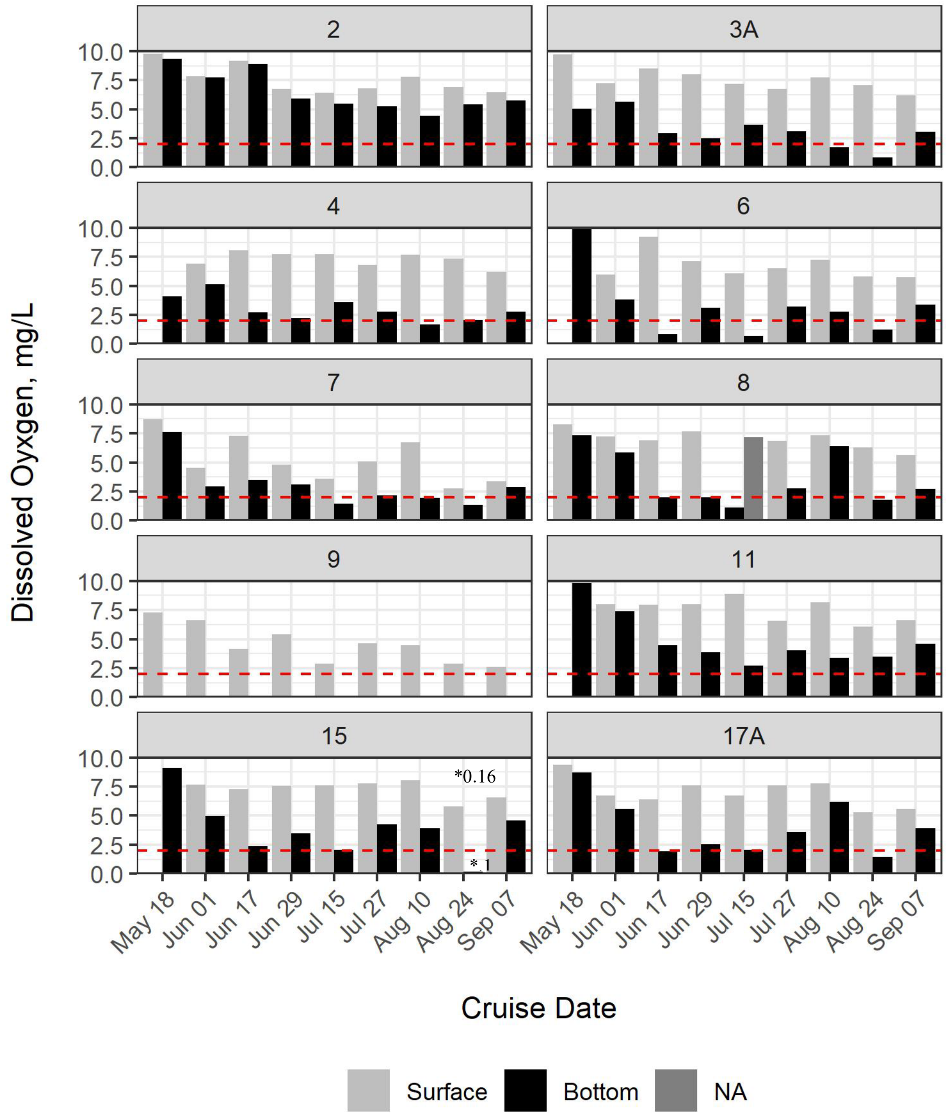


Figure 4.6 Bar graphs of surface and bottom water dissolved oxygen concentrations measured at each Mill Creek station from May 18 through September 7, 2021. Values below 2 mg L^{-1} (dashed line) are consided hypoxic. ND represents no data available. Note that bottom data was not recorded for station 9 due to shallow depth (~1 or less).

The data in Figure 4.6 show that some of the stations are more vulnerable to low dissolved oxygen than others. Bottom water at stations 2 and station 11 was not hypoxic in 2021, while station 6 had several instances where values were extremely low.

4.2.1 ***Dissolved Oxygen Saturation Levels***

Table 4.5 & Figure 4.7B

Oxygen from the air dissolves in the water column in proportion to water temperature and salinity. When oxygen dissolved in water is in equilibrium with that in air, the water is 100% saturated with dissolved oxygen. Oxygen is replenished in water by direct exchange with air at the surface and through the efforts of photosynthesizing phytoplankton in the water column releasing oxygen to the water. The amount of oxygen that water can hold is a function of temperature and salinity, with higher temperatures and salinities meaning the water can hold less dissolved oxygen. Respiration by organisms in the water and in the mud, as well as some chemical processes, consumes oxygen in the water, causing the oxygen content to fall below the 100% saturation level.

Bottom water dissolved oxygen saturation levels less than 50% saturation were observed 53% of the time (48 out of 90 observations). This is similar to prior years.

Table 4.4.5 Percent bottom water dissolved oxygen saturation levels less than 50%, by year.

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
32%	65%	50%	44%	36%	36%	54%	32%	31%	58%
2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
16%	30%	39%	39%	30%	57%	58%	42%	51%	53%

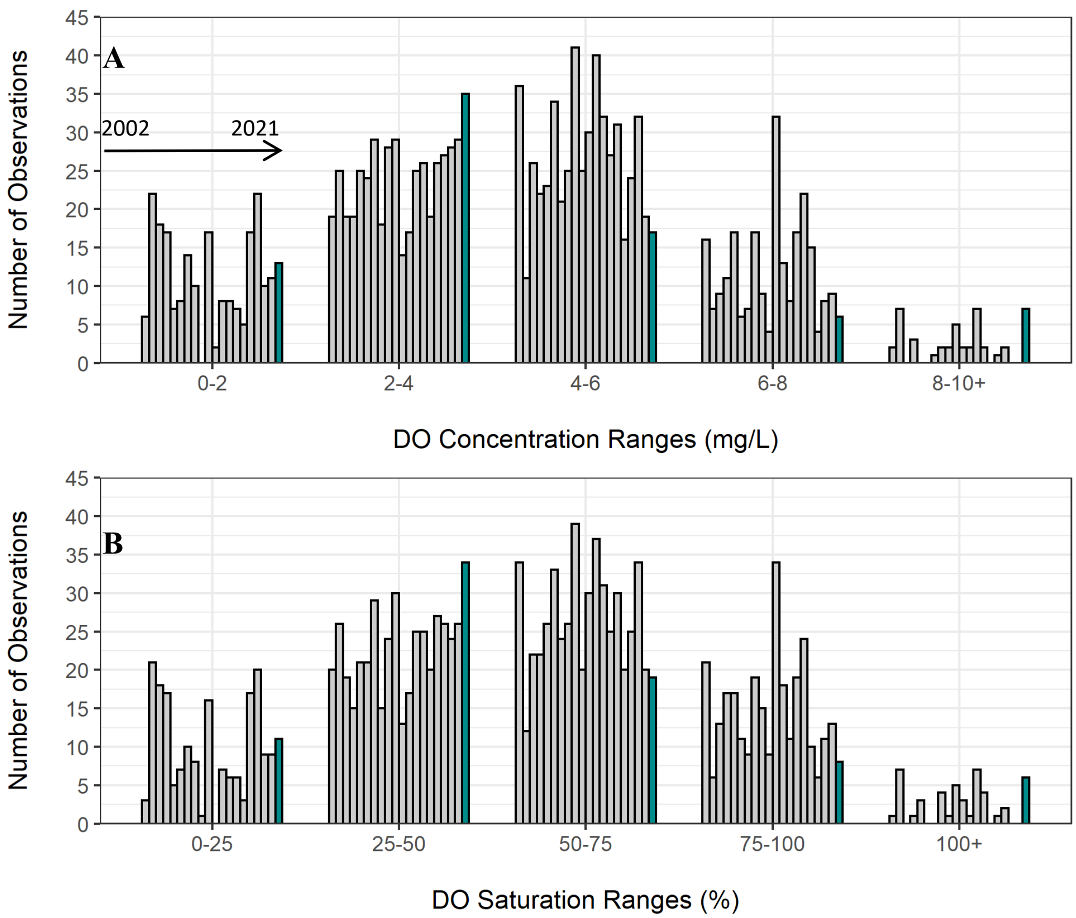


Figure 4.7 A & B Bar graphs comparing the distribution of bottom water dissolved oxygen (A) and bottom water percent oxygen saturation (B) observations, 2002-2021 from right to left in each category. The green/dark bars represent 2021.

4.3 Active Chlorophyll-*a*

Table 4.6 & 4.7 & Figure 4.8

Active chlorophyll-*a* concentration serves as a measure of water-column algal community densities. Total chlorophyll-*a* measurements include phaeophytin, a chlorophyll degradation product. Active chlorophyll-*a* concentrations in surface waters ranged from 5.58 micrograms per liter (µg L^{-1}) (station 6, June 1) to 63.09 µg L^{-1} (station 9, May 18). Bottom water concentrations ranged from 5.11 µg L^{-1} (station 15, Aug 24) to 49.86 µg L^{-1} (station 7, June 29).

Table 4.4.6 Historical surface and bottom active chlorophyll-*a* (µg L^{-1}) ranges in Mill Creek.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
Surface	5-88	4-225	5-57	4-64	5-91	4-78	3-72	6-207	8-33
Bottom	3-42	3-42	2-68	5-47	3-53	6-58	5-242	4-118	3-121
Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Surface	6-66	5-86	5-39	4-45	3-73	3-166	7-66	6-99	6-63
Bottom	5-56	6-108	6-55	6-91	7-37	2 -39	6-129	5-87	5-50

Concentrations greater than 20 µg L^{-1} indicate the presence of an algal bloom (severe bloom concentrations in the Patuxent River have exceeded 300 µg L^{-1}). Fortunately, the average concentrations in 2021 were lower than in recent years.

Table 4.4.7 Average surface active chlorophyll-*a* (µg L^{-1}) concentrations in the Mill Creek System.

2004	2005	2006	2007	2008	2009	2010	2011	2012
20.46	17.64	16.69	19.97	15.63	15.59	17.51	29.25	14.25
2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
16.13	18.47	15.87	13.49	16.63	21.51	20.48	21.06	15.04

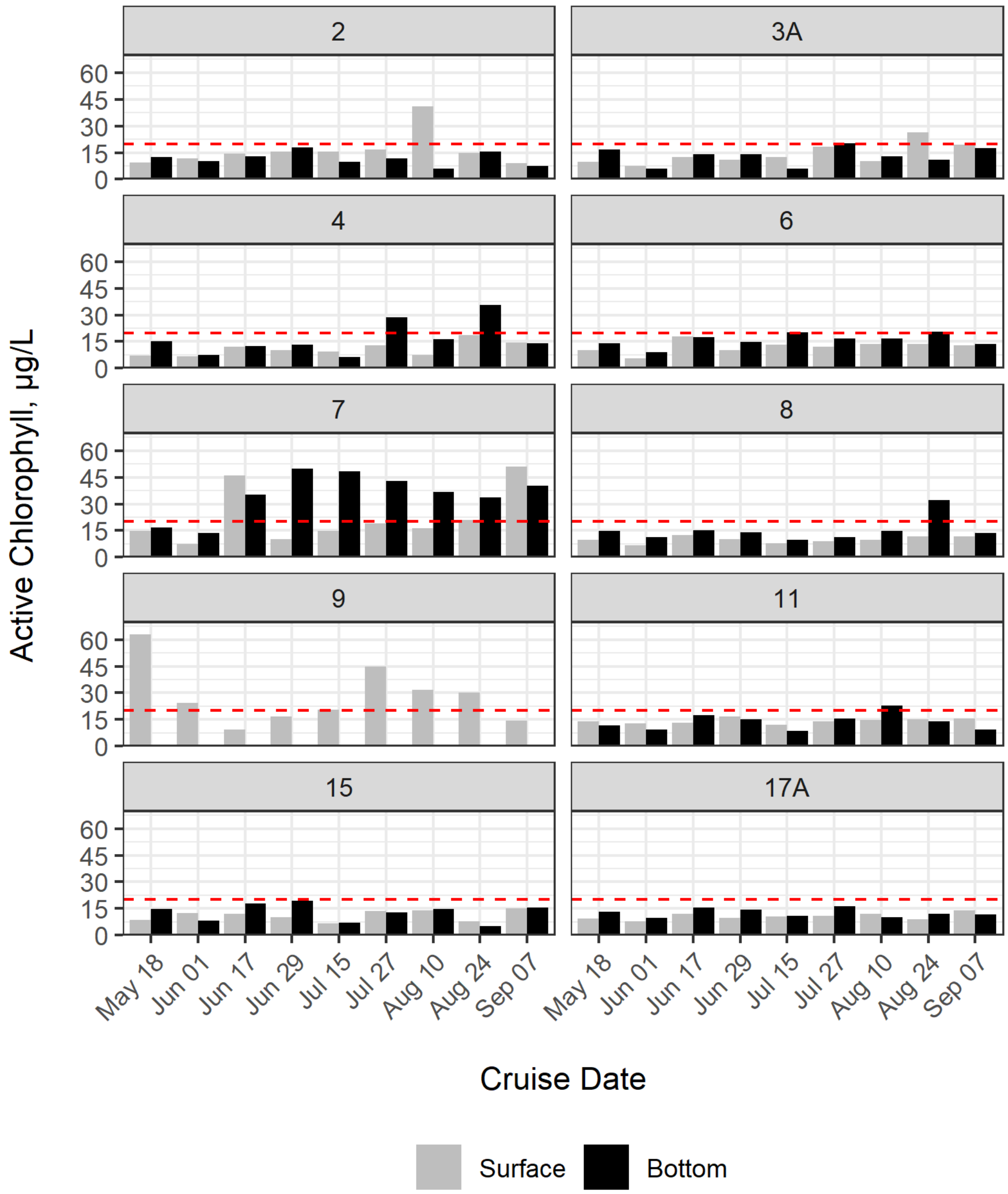


Figure 4.8 Bar graphs of surface and bottom water active chlorophyll-*a* values for each station in Mill Creek from May 18 through September 7, 2021. Values above 20 ug L^{-1} (dashed line) are considered blooms. Bottom data was not collected for station 9, Lore's Creek (depth 1 m or less).

In 2021, stations 7 and 9 had relatively higher concentrations than other stations throughout the summer with multiple blooms. Station 9 also exhibited one date of extremely high concentrations (>60 µg L^{-1}) on May 18th. In general, the other stations had lower chlorophyll levels but most had blooms at least one time. This is a pattern we have documented in several of the past recent years.

4.4 Water Column Clarity

4.4.1 ***Secchi Disk Readings***

Table 4.8 & Figure 4.9

Water clarity was measured using a Secchi disk to document the depth at which the water clarity diminishes. The highest 2021 Secchi disk measurement (indicating the clearest water) was 1.9 meters measured at station 17A on June 1. The lowest 2021 recording was 0.4 meters at station 7 on May 18. Station 9 had the lowest average readings during all cruises (0.65 meters).

Table 4.4.8 Historical Secchi disk ranges (lowest to highest clarity) in the Mill Creek System.

Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Secchi Range	0.5-2.0	0.2-2.0	0.4-1.7	0.4-1.8	0.3-2.2	0.3-2.0	0.4-2.1	0.2-1.5	0.5-1.8
Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Secchi Range	0.4-1.6	0.3-1.4	0.2-1.8	0.35- 2.0	0.35- 1.8	0.45-1.6	0.35-1.6	0.2-1.4	0.4-1.9

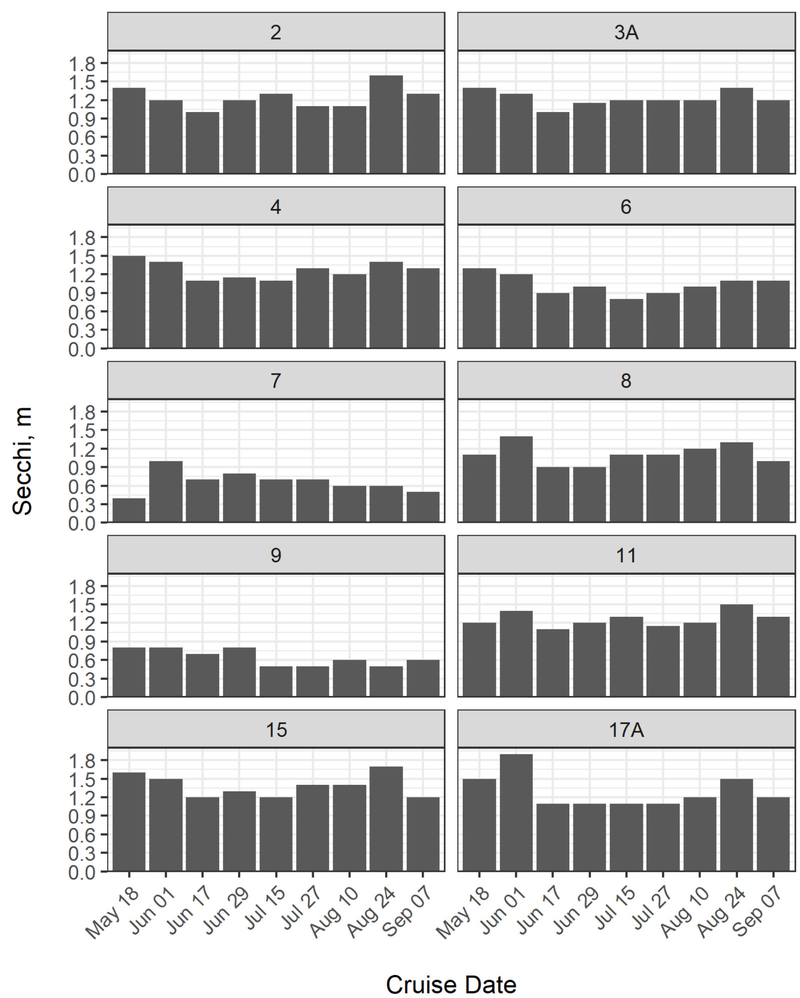


Figure 4.9 Bar graphs of water column Secchi disk measurements for each station in the Mill Creek System from May 18 throughout September 7, 2021.

When examining differences temporally, the highest average Secchi disk readings over all stations were on June 1 (1.31 m). The monitoring cruise on June 17 averaged the lowest Secchi disk readings basin-wide with an average of 0.97 meters. This aligns with our observation of SAV in the Solomons Harbor system in May, followed by its disappearance later in the summer.

4.4.2 *Light Penetration using Light Attenuation (Kd)*

Figure 4.10

Water column clarity and light penetration are very important parameters contributing to the growth and habitat suitability for submerged aquatic vegetation (SAV). SAV not only provides food, oxygen, nursery areas and shelter for Bay animals, but can trap sediment and slow erosion, thus further clearing the water. In this way, SAV beds serve as "engineers" that establish better water quality in their vicinity to self-support their own growth.

Potential SAV habitat can be quantified by measuring the clarity of water and associated areas of Bay bottom that have enough light to support SAV growth. We quantify water clarity by estimating a number that quantifies how fast light disappears when we lower a light sensor into the water column. This number is called the light attenuation coefficient, where low values represent clear water. The Mill Creek sub estuary is located in the mesohaline (salinity of 5.0 to 18.0) portion of the Bay. The goal in this area is to restore SAV to depths of one meter, requiring a light attenuation coefficient of $\leq 1.5\ m^{-1}$ (Kemp et al. 2004)

This extinction or light attenuation coefficient (Kd) has been calculated based on the Secchi disk depth using the following equation: Kd = 1.43/Secchi disk depth (Keefe et al. 1976). For the past five years, Kd was also calculated with the light profiles by finding the exponential fit to light vs. depth. A Secchi disk measures only one point in the water and relies on human eyesight, so it does not represent the full picture of light attenuation in the water column. With the light profiles, multiple reference points are used for Kd calculations and are more accurate. For the most part, calculations of water clarity made from Secchi disks and light profiles are similar, but there are times where there are larger differences.

We can use these calculations of Kd to determine the depth that sufficient light penetrates for both algal growth (1% of surface light) and SAV growth (at 15% of surface light) (Kemp, 2004). Using the Kd values estimated with Secchi depth, the depth at which light penetration is sufficient for algal growth (the euphotic zone) ranged from a low of 1.29 meters (Station 7 on May 18) to 6.12 meters (Station 17a on June 1). The seasonal average light attenuation allowed for 1% penetration to 3.26 meters.

Using the Kd values from the light profile data suggests that light penetration sufficient for algal growth existed at depth ranges from 1.32 meters (Station 9 on May 18) to 5.88 meters (Station 15 on May 18), with a seasonal average depth to 1% light penetration of 2.95 meters. Regardless of method, light for algal growth was present on average throughout much of the water column on most sampling dates since the mean depth of the Mill Creek system is a just over 3.0 meters.

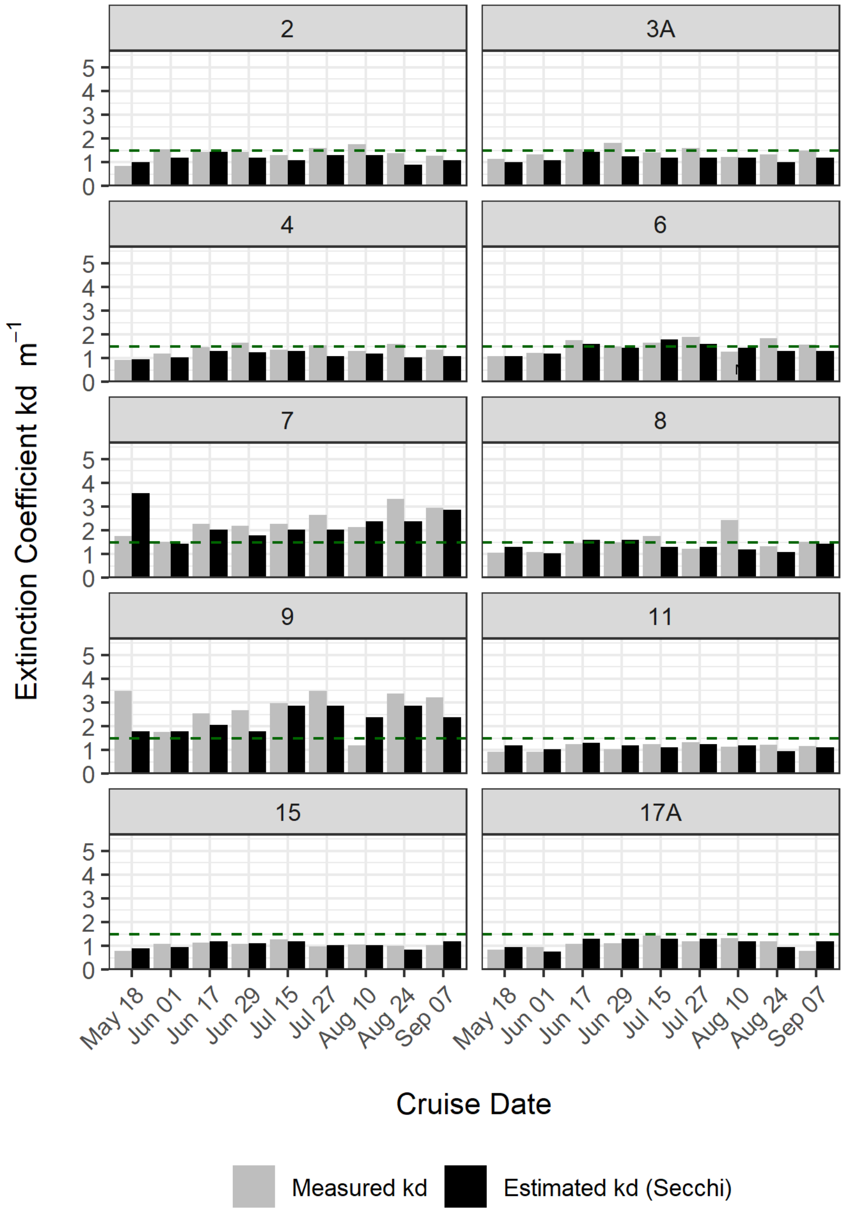


Figure 4.10 Bar graphs of light attenuation measurements (Kd) for each station in the Mill Creek System from May 18 through September 7, 2021, using the estimates of Kd with the Secchi depths and Kd from light profiles. The dashed line in each graph indicates the CBP restoration goal of Kd = 1.5 m^{-1}. ND represents no data available.

During the sampling season, the depth of 15% light penetration sufficient for SAV growth ranged from 0.53 meters to 2.52 meters with an average penetration of 1.34 meters with Kd estimated with Secchi disk depth. With the light profile calculations, these depths ranged from 0.54 to 2.42 meters with an average penetration of 1.22 meters. Light sufficient for SAV growth was not available for many of the deeper stations in the Mill Creek system, as found in previous years.

4.5 Seafood and Swimming Safety Monitoring

4.5.1 *Bacterial Contamination*

Figure 4.11 & Table 4.9

During the presentation of the 2006 report to the Calvert County Board of County Commissioners, the issue was raised concerning bacterial contamination of waters in the Mill Creek system. Additionally, the question was raised regarding seafood consumption advisories in the Solomons vicinity. Our water quality monitoring program does not measure fecal coliform bacteria. However, the Maryland Department of Environment produces monthly reports.

MDE has three monitoring stations in the Mill Creek system for classifying shellfish (oyster/clam) harvesting waters along with a sanitary survey. Figure 4.4.11 depicts a total of 4 stations of interest: Station 005B, a reference Station located off of Sandy Point in the Patuxent River; Station 015A, near station 2 (Boat Shop); Station 109A, in Mill Creek at the mouth of Saint John's Creek near station 4 (Pancake Point); and station 104 in Back Creek, near station 15 (Calvert Marina).

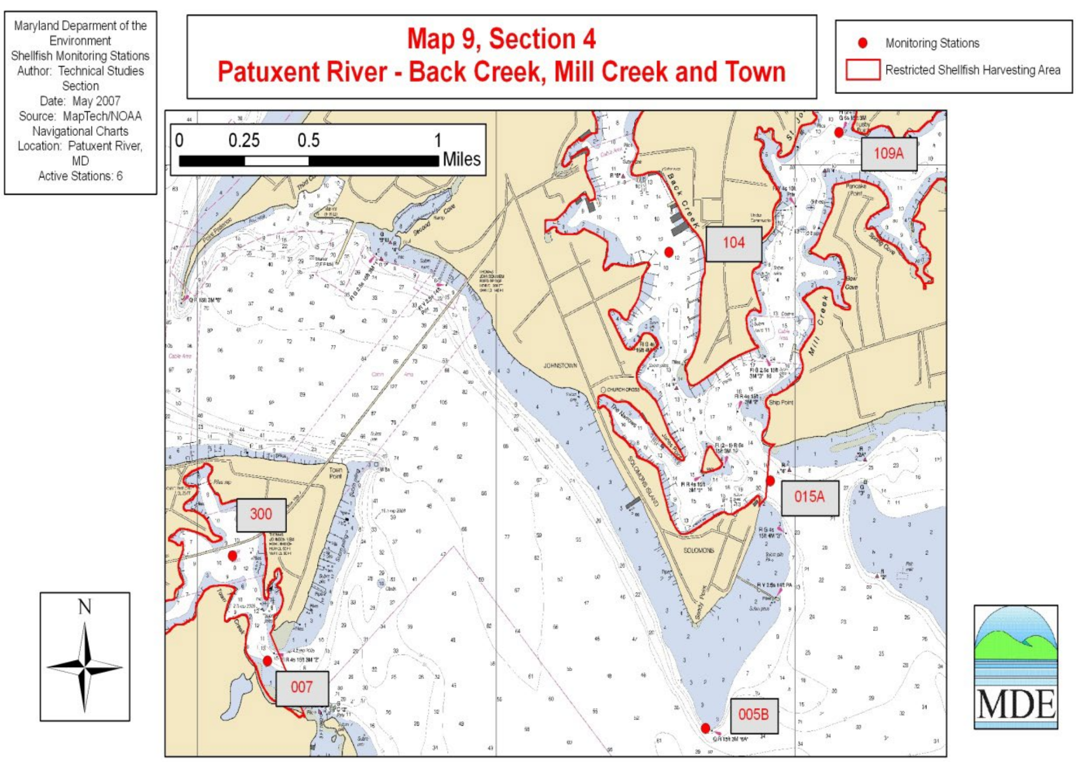


Figure 4.11 Map of the Maryland Department of the Environment (MDE) shellfish monitoring stations in the Mill Creek System

Fecal coliform is the indicator used for classifying shellfish waters. Water quality standards for shellfish harvesting require that fecal coliform numbers be ≤ 70 MPN/100 mL (MPN = most probable number per 100 milliliters of water). To read more, please refer to the following web site: http://bcn.boulder.co.us/basin/data/BACT/info/FColi.html

Table 4.4.9 displays the January-December 2021 fecal coliform sample analyses. Note that the peaks in MPN/100 mL do not always coincide with a rain event. The averages for 2007-2021 for each station are listed. The highest value recorded for 2021 was 240 MPN/100 mL at station 109A (Pancake Point).

Table 4.4.9 Fecal coliform counts from a reference station located in the Patuxent River and three stations in the Mill Creek System in 2021. The averages for each station for 2007 through 2021 are listed. Numbers greater than 70 MPN/100 mL are highlighted. Stations that experienced rainfall within 24 hours of sampling are starred (*).

Station ID	Sample Date	Fecal Coliform MP/100mL	Rain	Station ID	Sample Date	Fecal Coliform MP/100mL	Rain
09-04-005B	1/11/2021	1		**09-04-015A**	1/11/2021	1	
	3/4/2021	1			3/4/2021	1	
	4/12/2021	1	*		4/12/2021	15	*
	5/10/2021	1	*		5/10/2021	23	*
	8/16/2021	1	*		8/16/2021	23	*
	9/13/2021	1			9/13/2021	23	
	9/29/2021	1			9/29/2021	1	
	10/13/2021	1	*		10/13/2021	43	*
	10/26/2021	1	*		10/26/2021	43	*
	10/26/2021		*		10/26/2021		*
	12/2/2021	1			12/2/2021	1	

Long Term Average		Long Term Average	
2007	5	2007	8
2008	1	2008	45
2009	1	2009	5
2010	5	2010	20
2011	4	2011	35
2012	3	2012	15
2013	2	2013	51
2014	2	2014	7
2015	2	2015	95
2016	2	2016	50
2017	2	2017	7
2018	3	2018	4
2019	7	2019	16
2020	11	2020	77
2021	1	2021	17.4

Station ID	Sample Date	Fecal Coliform MP/100mL	Rain
09-04-104	1/11/2021	1	
	3/4/2021	1	
	4/12/2021	75	*
	5/10/2021	43	*
	8/16/2021	93	*
	9/13/2021	39	
	9/29/2021	43	
	10/13/2021	43	*
	10/26/2021	43	*
	10/26/2021		*
	12/2/2021	9.1	

Long Term Average	
2007	27
2008	37
2009	44
2010	33
2011	103
2012	22
2013	14
2014	20
2015	25
2016	39
2017	48
2018	14
2019	31
2020	161
2021	39.01

Station ID	Sample Date	Fecal Coliform MP/100mL	Rain
09-04-109A	1/11/2021	1	
	3/4/2021	1	
	4/12/2021	9.1	*
	5/10/2021	3.6	*
	8/16/2021	43	*
	9/13/2021	7.3	
	9/29/2021	23	
	10/13/2021	23	*
	10/26/2021	240	*
	12/2/2021	1	

Long Term Average	
2007	11
2008	12
2009	4
2010	131
2011	50
2012	43
2013	8
2014	26
2015	47
2016	77
2017	30
2018	12
2019	31
2020	146
2021	35.2

Stations 09-04-005B and 09-044-015A met water quality standards but stations 09-09-104 and 09-04-109A had at least 1 instance where fecal coliform counts did not fall within water quality standards. Even though the bacteria standards are largely achieved, as in past years, MDE closed the entire area to shellfish harvesting, initially due to shoreline activities and the intensity of boating activities, all of which increase the potential for overboard discharge of untreated sewage and other sources of contamination. Since 2010, DNR has declared Mill Creek waters oyster sanctuaries, so no harvesting would be allowed regardless of water quality conditions.

4.5.2 *Fish and Shellfish Advisories*

Table 4.10

MDE monitors contaminants in fish and shellfish in Maryland waters. While data specific to the Mill Creek system are not available, data for the Patuxent River and Chesapeake Bay are available and outlined in Table 4.10. Additional information can be found at this website:

http://mde.maryland.gov/programs/Marylander/fishandshellfish/Pages/fishconsumptionadvisory.aspx

Shellfish information can be found at this website:

http://mde.maryland.gov/programs/Marylander/fishandshellfish/Pages/shellfishmaps.aspx

The public can also call MDE (410-537-3906), the USFDA at 1-888-SAFEFOOD, or the Calvert County Health Department at 410-535-3922 for additional information.

Table 4.10 Table of MDE fish advisory recommended consumption by species for the Patuxent River and Chesapeake Bay. Adapted from: https://mde.maryland.gov/programs/Marylander/fishandshellfish/Documents/Maryland_Fish_Advisories.pdf

Species	Waterbody	Recommended Meals per month (for general population)
American Eel	Patuxent River	3
Blue Crab Meat	Patuxent River	No restrictions
Blue Crab Mustard	Patuxent River	Eat Sparingly
Channel Catfish	Patuxent River	2
Spot	Chesapeake Bay and Tributaries	5
Striped Bass >28 inches	Chesapeake Bay and Tributaries	1 (all meat) / No restrictions (if no dark meat or belly fat)
Striped Bass <28 inches	Chesapeake Bay and Tributaries	3 (all meat) / No restrictions (if no dark meat or belly fat)
White Perch	Patuxent River	No restrictions

4.5.3 *Swimming Safety*

MDE does not monitor for swimming safety, but they do work closely with the local health departments who determine where beach monitoring should occur. No beaches in the Mill Creek system are monitored by Calvert County. They do monitor a beach at Drum Point on the Chesapeake Bay side. The website to the Calvert County Health Department Public Beach Monitoring is:

http://www.calverthealth.org/community/environmentalhealthservices/cp_publicbeach.htm

For more information, also go to the Maryland Healthy Beach website:

http://www.marylandhealthybeaches.com/

The bacteria indicator used for beach monitoring in estuarine waters is *enterococci*. U.S. EPA regulations state that waters used for Class 1 primary contact (including such activities as swimming, rafting, and kayaking) shall not have fecal coliform counts above 200 fecal coliforms per 100 mL. Waters used for Class 2 secondary contact (non-primary contact waters, including, but not limited to, fishing and other streamside or lakeside recreation) should not have fecal coliform counts above 2000 fecal coliforms per 100 mL.

4.5.4 ***Cases of* Vibrio *Species Infection***

Figure 4.12

We include Maryland and Calvert County case counts of *Vibrio*. With data supplied by the Maryland Department of Mental Health and Hygiene, we can now report state and county cases of *Vibrio* since 2005. The 2021 data were supplied by Nichole Klecz, RN, Disease Surveillance and Response, Calvert County Health Department and Sophia Wozny, Emerging Infections Program unit, Maryland Department of Health.

Vibrio species are natural inhabitants of sea water. Noncholera *Vibrio* infections are classified into two groups: those that require salt water for growth and those that do not require salt water. The prevalence of noncholera *Vibrio* infections in the United States have increased in recent years. The combination of increased water temperature and salinity where shellfish are harvested may contribute to the increased contamination rates of shellfish.

Most *Vibrio* infections are associated with the consumption of contaminated shellfish. However, *Vibrio* can also cause severe skin infections in an open area of skin exposed to warm salt water.

All *Vibrio* species are reportable in Maryland. In 2021, 48 cases were confirmed, with 47 probable cases. Two confirmed cases and 1 probable case were reported in Calvert County. In 2020, 56 confirmed cases of *Vibrio* were reported in Maryland, with an additional 20 probable cases. Probable cases have been higher since 2017, due to the change in case definition.

https://wwwn.cdc.gov/nndss/conditions/vibriosis/case-definition/2012/

Case reports in years before 2017 only had a few probable cases. Figure 4.12 ignores probable cases before 2017. Compared to 2020, 2021 had ~16% increase in confirmed cases and unlike the previous years, probable cases were approximately equal to the confirmed cases. Assessments with previous years is difficult as probable cases have risen with the definition change.

Since *Vibrio* species are normally found in the Chesapeake Bay and rivers, it is important not to swim if you have an open skin wound or a compromised immune system. All open skin areas should be evaluated by a health care provider if showing signs and symptoms of infection such as redness, soreness, swelling or drainage. Also, to avoid becoming ill by consuming a *Vibrio* species, you should only eat cooked shellfish. For more information go to the Center for Disease Control website about *Vibrio*:

https://www.cdc.gov/vibrio/

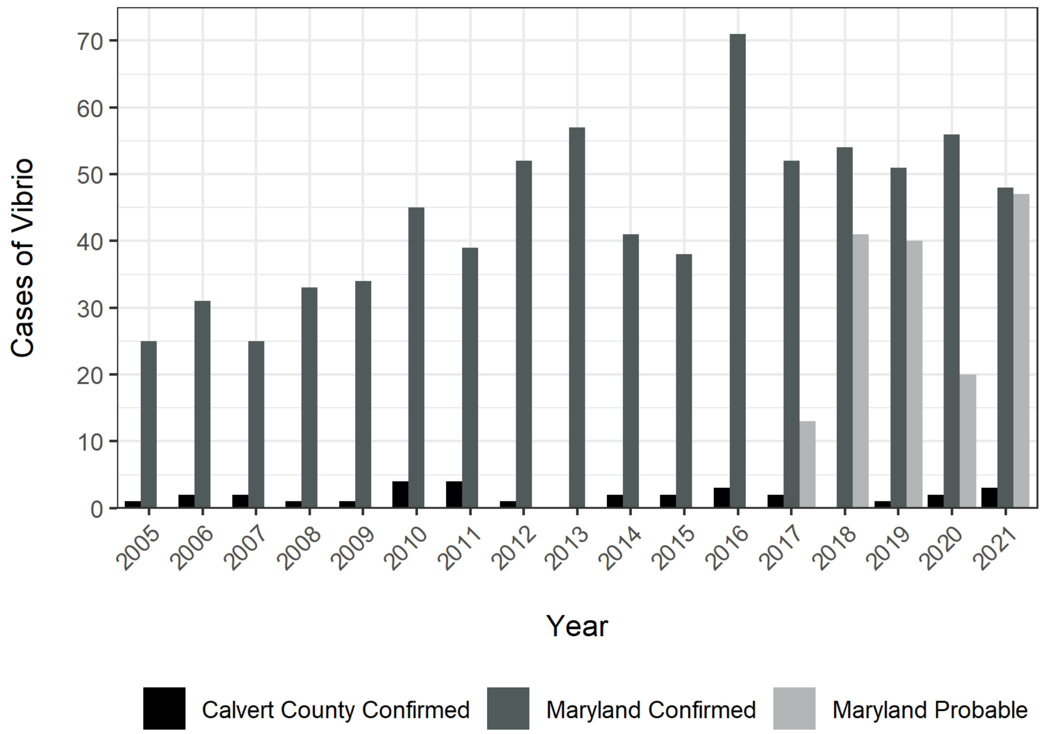


Figure 4.12 Case counts of *Vibrio* in Calvert County and the State of Maryland for 2005-2021, with probable cases since 2017. Bars represent the total number of cases involving all non-cholera *Vibrio* infections.

4.6 Sea Nettle Monitoring: Presence /Absence in the Mill Creek Estuary

Figure 4.13

Sea nettles (*Chrysaora quinquecirrha*), are one of the dominant species of jellyfish in Chesapeake Bay. They have three distinct life stages; an adult medusa stage, a juvenile ephyra stage (immature medusa) and a sessile polyp stage. The medusa stage is the umbrella-shaped, free-swimming form that spawns. Combined egg and sperm of male and female medusae produce a larval form (planula) that swims until it is cued to settle. Once attached to substrate, the planula metamorphoses into a sessile polyp. The polyp produces a stack of many small sea-nettles or ephyra through a process called strobilation. Sea nettle polyps can also reproduce asexually through budding and are the overwintering stage that persists through harsher conditions by encysting, while the medusa stage only exists in warmer summer months, and die off every year.

Polyps attach to hard substrate in shallow water, and release 8-10 ephyrae per polyp. The release of ephyrae coincides with the increasing water temperatures as spring approaches summer (Loeb 1972). Ephyrae continue to grow into their medusae form, which are usually noted in highest abundances in July and August. Sea nettle abundance varies greatly from year to year. Research has shown interannual variation to be explained by flow (Cargo and King 1990), ctenophore abundance, oyster restoration efforts (Breitburg and Burrell 2014; Breitburg and Fulford 2006) climate effects (Purcell 2005), and others.

In 2021, sea nettles were not present on May 18 and June 1 cruises (Fig. 4.13) but were present on all remaining cruises for the season. In years with more sea nettles, the abundances of nettles (both ephyrae and medusae) were highest in upper creeks and coves (Breitburg and Burrell 2014). During late June to early August, there is an increase in dispersal likely due to advection and periodic pulses of ephyrae releasement that continuously contribute juveniles to the creeks and coves, with reduced occurrences beginning in September.

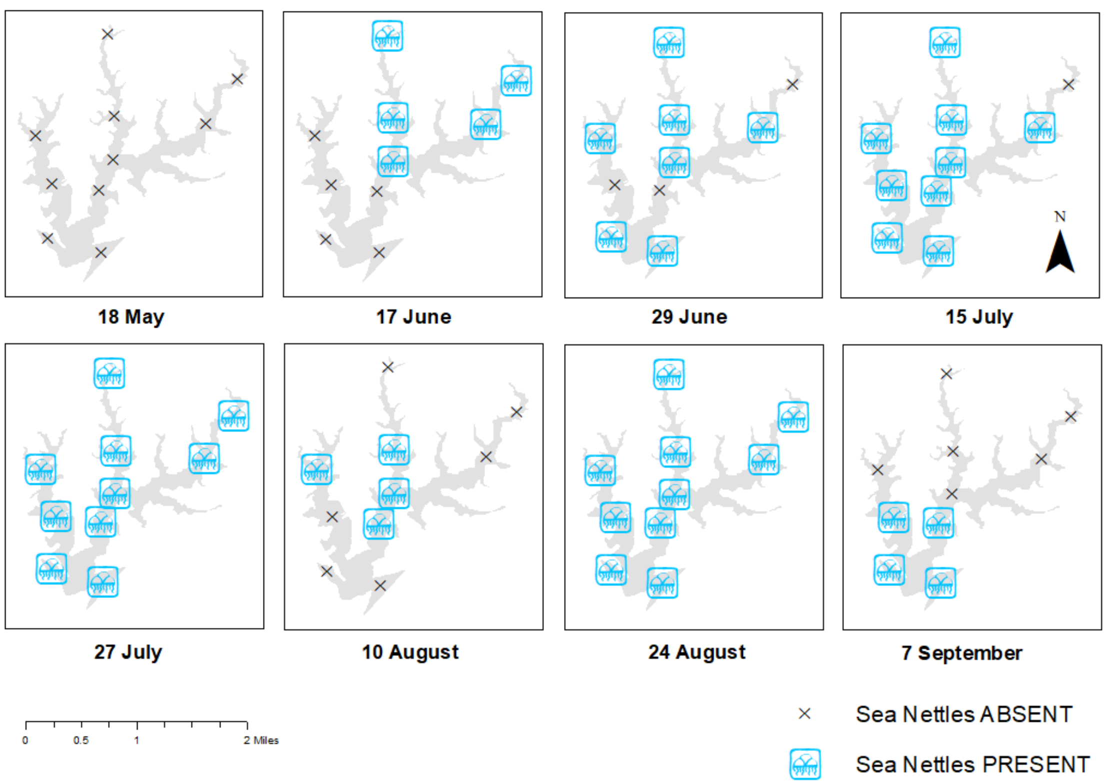


Figure 4.13 Map of the Mill Creek estuary showing presence or absence of Sea Nettles during the 2021 cruises.

5 Mill Creek Sub-estuarine System Long Term Water Quality Trends

To determine if trends were evident in Mill Creek system water quality conditions, we examined data from 5 representative stations: 2-Boat Shop (Mill Creek system mouth), 6-Coles Creek (mid Mill Creek), 7-Ranch Club (upper Mill Creek), 9-Lore's Creek (upper St. John's Creek), and 15-Calvert Marina (mid Back Creek). Two variables were examined, and these included bottom water dissolved oxygen concentrations and surface water active chlorophyll-*a* concentrations. These variables are good indicators of the water quality status of estuarine systems.

Due to Covid restrictions in 2020, two cruises that were usually conducted in mid-May and early-June did not occur. To determine if the reduced sampling effort would impact the long-term trends, averages were computed both with and without the 2020 data. Exclusion of the 2020 data resulted in less than 1% difference in long-term averages for dissolved oxygen, chlorophyll-a, and number of algal blooms. As such, 2020 data was included in the long-term analysis for determining water quality trends.

5.1 Dissolved Oxygen

Figure 5.1 & 5.3A

The average bottom water dissolved oxygen concentrations for these stations for the summer periods for 1987, 1990-2021 are summarized in Figure 5.1. Prior to 2010 bottom water DO was not measured at station 9; bottom DO was not measured at station 9 in 2021 due to shallow depths (~1 m or less). The average long-term bottom water dissolved oxygen concentration is 4.27 mg L^{-1}**.** Bottom-water dissolved oxygen concentrations in 2021 were higher than the previous four years (2017-2020) with an annual average of 4.14 mg L^{-1}. Even though anoxic conditions (dissolved oxygen concentrations of zero milligrams per liter) have never been observed, hypoxic conditions (less than 2.0 mg L^{-1}) are observed frequently enough to continue monitoring these trends. Ranking mean bottom water dissolved oxygen concentrations for all years with existing data creates the following pattern from high (better) to low (worse).

2012>1991>1997>2002>1992>1994>2001>2010>2009>1998>2014>2013>2016>1996>2000>2006>
1999>2015>1995>1990>**2021**>2011>1987>2019>2005>1993>2007>2004>2008>2018>2017>2020>2003

The regression in Figure 5.1 visually indicates that average bottom water dissolved oxygen may be declining (worsening trend) during the years the system has been monitored. However, at this point the relationship is not statistically significant. This year, dissolved oxygen lay above the regression line.

5.1 Chlorophyll-*a*

Figure 5.2 & 5.3B

Surface active chlorophyll-*a* concentration means for stations 2, 6, 7, 9, and 15 from 1987 through 2021 are depicted in Figure 5.2. Ranking mean surface water active chlorophyll-*a* concentration for all years with existing data creates the following pattern from low (better) to high (worse):

1991<1992<1995<1999<2002<2000<1997<1993<1987<2012<2016<2001<1994<2006<2015<2005<**2021**<2013
<1990<2009<2008<2017<1996<2014<2018<2004<2010<2007<2020<1998<2019<2011<2003

The surface mean active chlorophyll-*a* concentration of 18.10 µg L^{-1} in 2021 was lower than the 2020 average of 23.03 µg L^{-1}. This yearly average is slightly lower than the 1987-2020 average concentration of 18.50 µg L^{-1} and is equivalent to the long-term median

(18.10 µg L^{-1}). The highest observed average yearly concentration, 45.21 µg L^{-1}, occurred in 2003, an especially wet year, and was more than twice as high as the long-term average.

The regression in Figure 5.2 indicates that average surface water active chlorophyll-*a* may be increasing over the years. This trend is statistically significant. The upward trend can be expressed as a decadal change of about 2.5 µg L^{-1} chlorophyll-*a* every 10 years. While this is a small change, it seems to be progressive and that is reason for concern. In 1987, average chlorophyll-*a* concentration was about 14 µg L^{-1}, well below what is considered to be a bloom concentration (> 20 µg L^{-1}). For the past 15+ years, annual average concentrations are much closer or even above the bloom concentration threshold. Increased algal blooming leads to less water clarity and to less well oxygenated bottom waters.

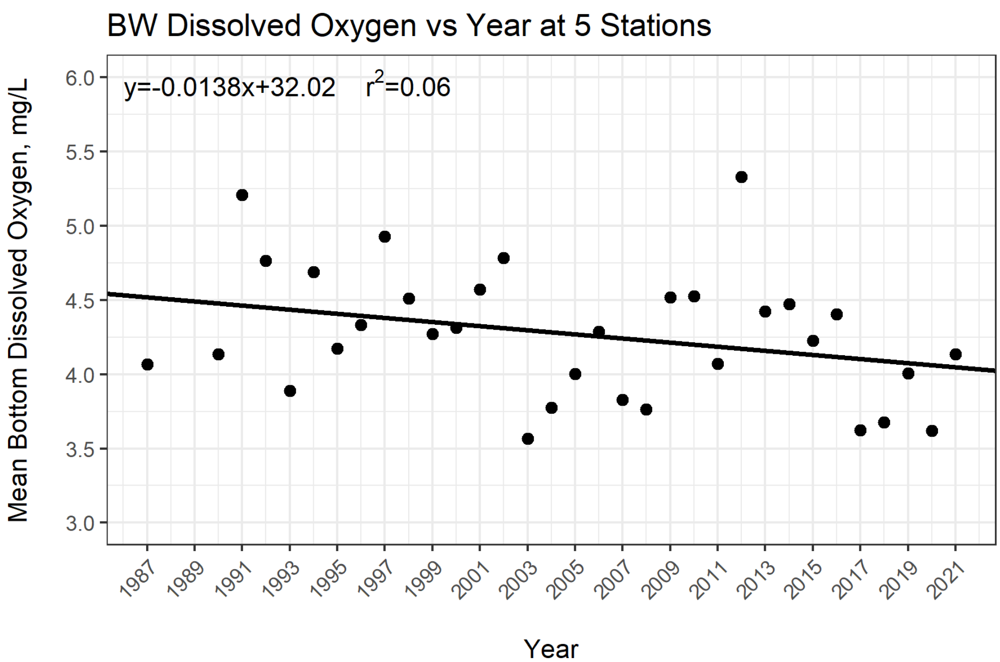


Figure 5.1 Possible trends in average bottom water dissolved oxygen in the Mill Creek System using the 5 inter-annual comparison stations. The solid line indicates a slight downward trend but it is not statistically significant (p = 0.06) at generally accepted probability levels.

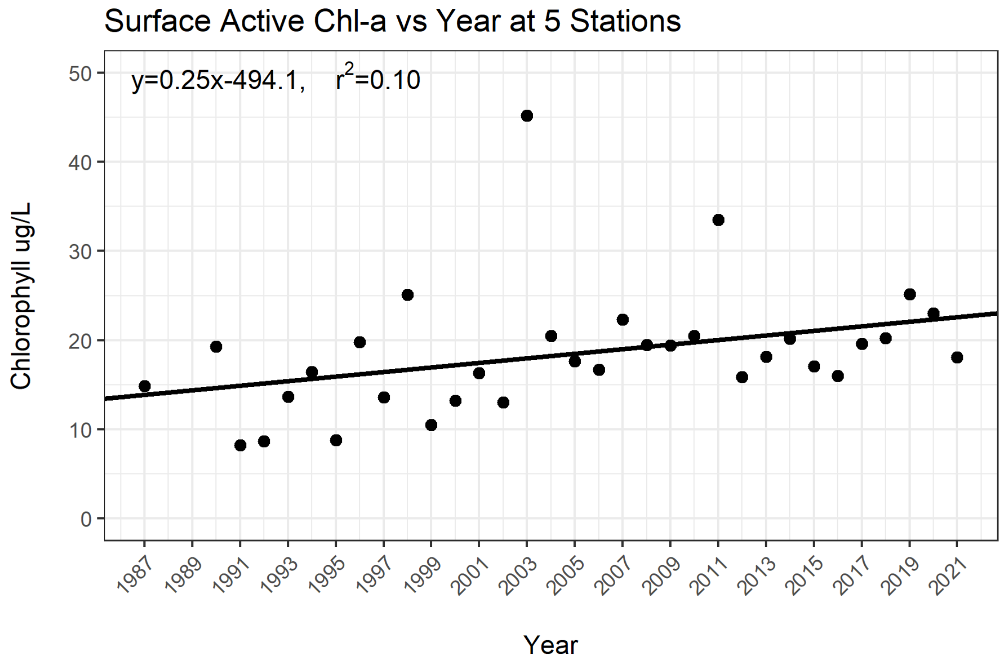


Figure 5.2 Trends in averaged surface water chlorophyll-*a* in the Mill Creek System using the 5 inter-annual comparison stations. The upward trend is statistically significant ($p<0.05$).

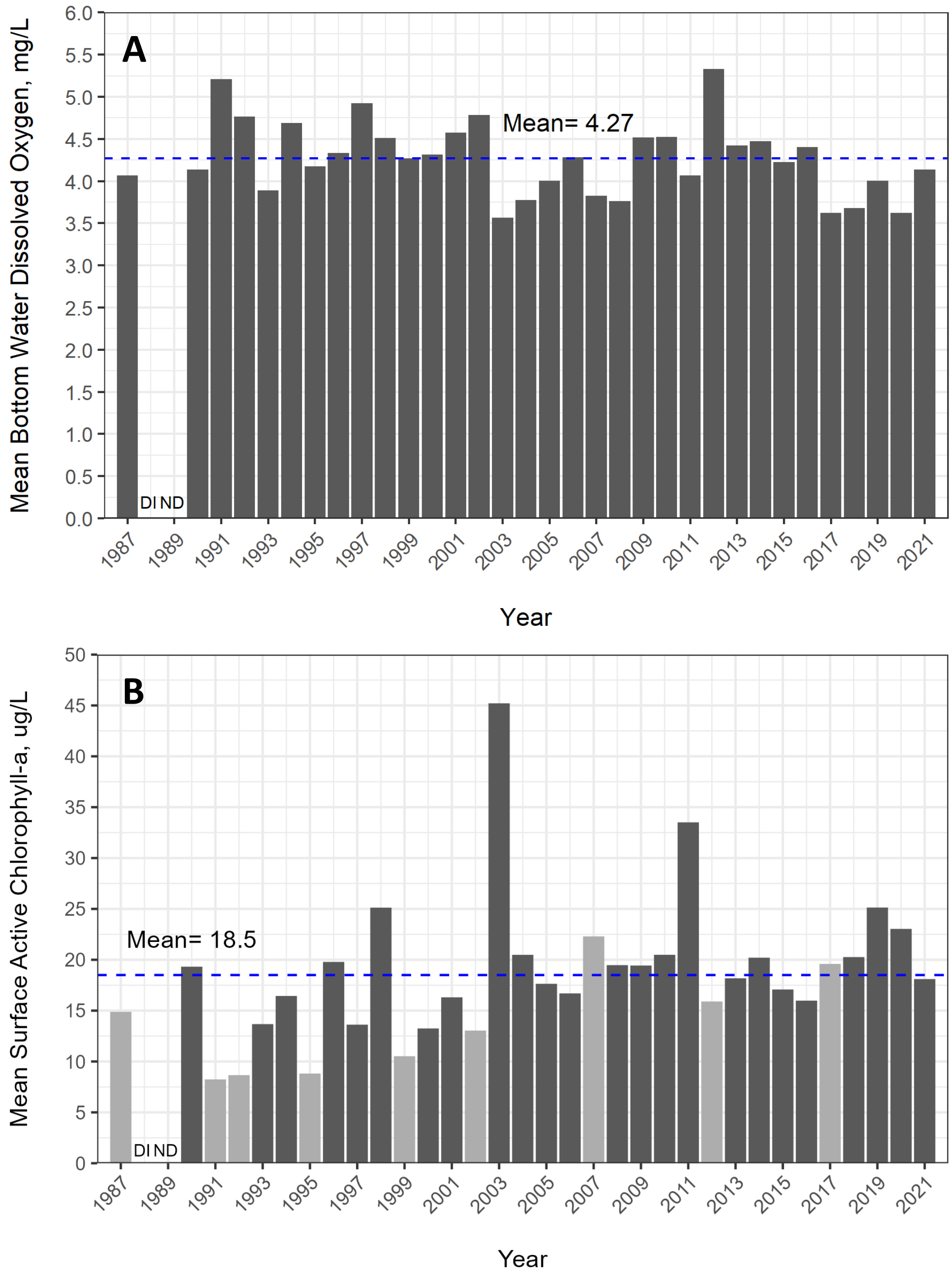


Figure 5.3 A&B Bar graphs of (A) bottom water mean dissolved oxygen concentrations at the inter-annual comparison sites (stations 2, 6, 7, 9 (historical) and 15) from 1987 through 2021, and (B) mean surface water active chlorophyll-*a* concentrations at the inter-annual comparison sites (stations 2, 6, 7, 9 and 15) from 1987 through 2021. In graph B, the dry years based on river discharge are indicated by the lighter bars. DI = Data set for 1988 was incomplete. ND = Study was not funded during 1989.

5.2 Algal Blooms

Figure 5.4

For this program, an algal bloom is defined as any concentration of active chlorophyll-*a* greater than 20 □g L^{-1}. Occurrences of algal blooms at the five inter-annual comparison stations were averaged. This year produced 10 blooms ranging from 20.52 to 63.09 □g L^{-1}, placing 2021 as the 9th best bloom year out of 19 levels. In comparison, the 1999 study recorded zero blooms, while 2003 produced the study maximum of 29 blooms. Ranking occurrences of algal blooms since 1987 gives the following pattern from lowest (better) to highest (worse) number of blooms:

1999<1995<2002<1991=1992<2005<2012<1993=1997=2000<1987=1990=2013<2006=**2021***<2009<
1994=2001=2015=2016<1996=2008=2014=2017=2020<2004=2010<2018<2019<1998<2007<2011<2003

In general, algal bloom rankings track with active chlorophyll-*a* rankings.

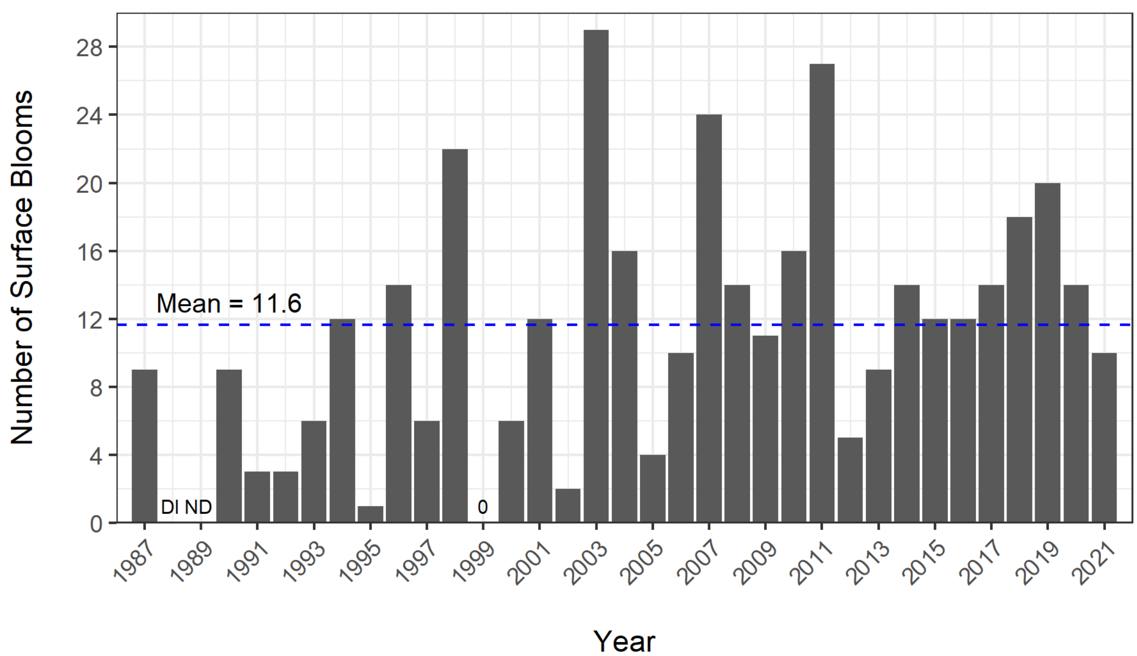


Figure 5.4 Bar graph of surface chlorophyll-*a* blooms in the Mill Creek System at the inter-annual comparison stations 2, 6, 7, 9 and 15 from 1987 through 2021. Note that chlorophyll-*a* concentrations measuring greater than 20 µg L^{-1} were defined as blooms. DI = Data set for 1988 was incomplete. ND = No study was funded in 1989.

6 Calvert County Tidal Tributaries: Water Quality Monitoring Results & Discussion

Our monitoring since 2009 in a number of tidal creeks along the Patuxent and Western Chesapeake shores of Calvert County is building into a robust database of water quality measurements. Here we outline results from 2021 and begin to provide some context for these measurements within the framework of the up to thirteen years of data now available for interpretation.

6.1 Lower Patuxent River Tributaries

Twelve stations located in four lower Patuxent river tributaries were examined three times in 2021 (June, July and August) to capture summer water quality conditions in these systems. The stations were located in 4 creeks in the lower Patuxent River estuary, all south of Broomes Island and all in Calvert County. Included were: 3 stations in Hellen's Creek, 4 stations in Saint Leonard Creek, 3 stations in Island Creek and 2 stations in Hungerford Creek.

All water quality data collected during the 2021 monitoring study in the Lower Patuxent River Tributaries are listed in Appendix II by station and date.

6.1.1 *Water Column Clarity using Secchi Disk Readings*

Figure 6.1

The Lower Patuxent tributary Secchi disk measurements were comparable in magnitude to the Mill Creek system, ranging from 0.4 to 1.4 meters. In general, the most upper stations (i.e., higher station numbers) in each creek had lower clarity compared to the downstream stations. Secchi Disk depth generally declined as the summer progressed.

6.1.2 *Dissolved Oxygen*

Figure 6.2

In the Lower Patuxent Tributaries, surface water dissolved oxygen concentrations ranged from 3.98 to 8.98 mg L^{-1}. Bottom water concentrations ranged from 0.11 to 7.38 mg L^{-1}. Hypoxic conditions were measured 11 times in 2021, with 9 of these cases occurring in St. Leonard Creek. Nine of the eleven hypoxic readings from 2020 also occurred in St. Leonard Creek.

As a part of the Chesapeake Bay Program, water quality criteria have been developed for dissolved oxygen concentration in estuarine waters. The criterion (30 day average) is 5.0 mg L^{-1} for shallow water systems such as those in the Patuxent creeks and Solomons Harbor. Oxygen levels in the lower Patuxent tributaries fell below this minimum criteria at least one time over the summer in the bottom water at all 12 stations, and in the surface waters of the uppermost station (IC3) of Island Creek on two occasions. Bottom water concentrations fell below a more severe threshold of 2.0 mg L^{-1} in bottom water of Hellen's Creek and St. Leonard Creek.

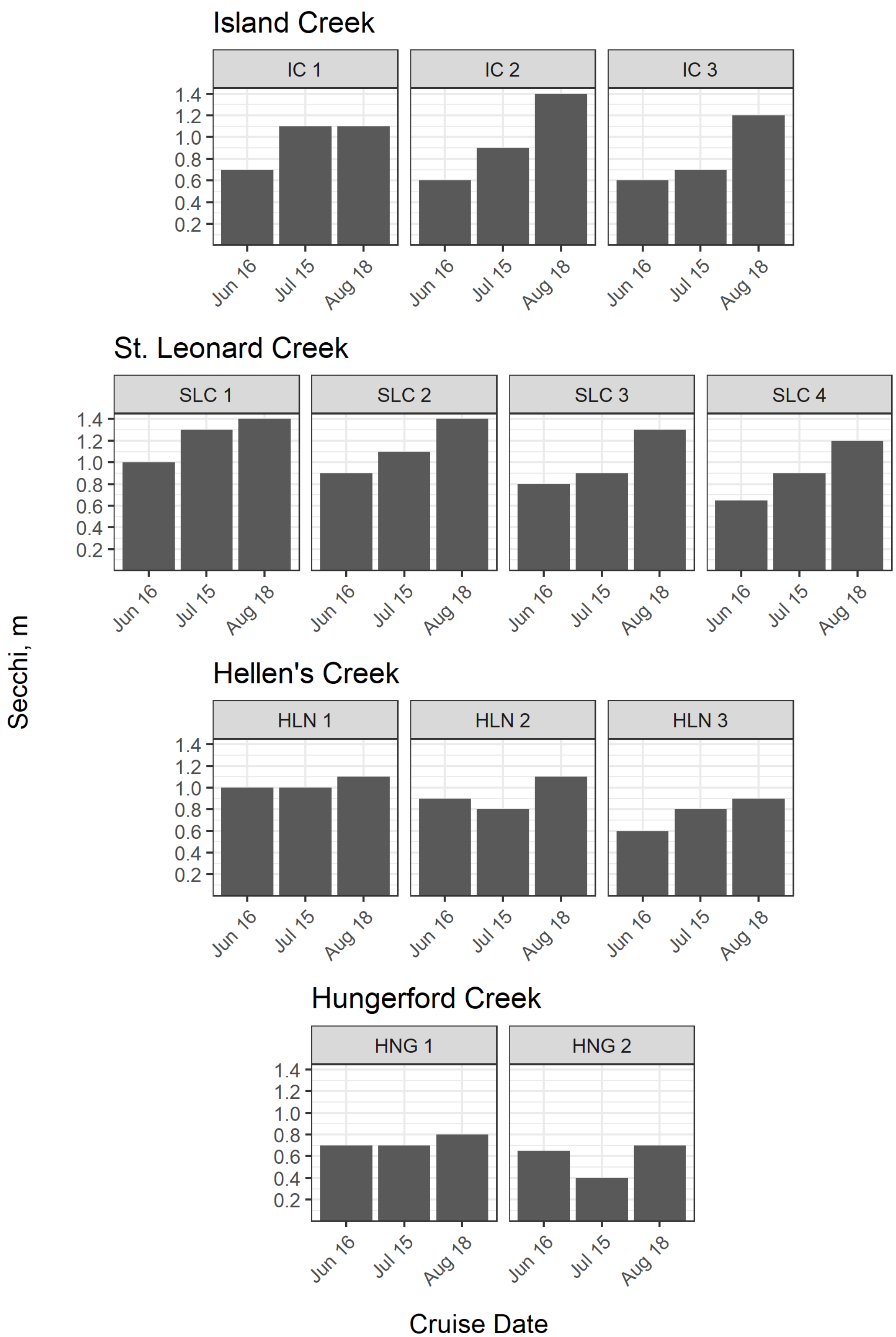


Figure 6.1 Bar graphs of water column Secchi disk measurements for each station from June, July and, August 2021.

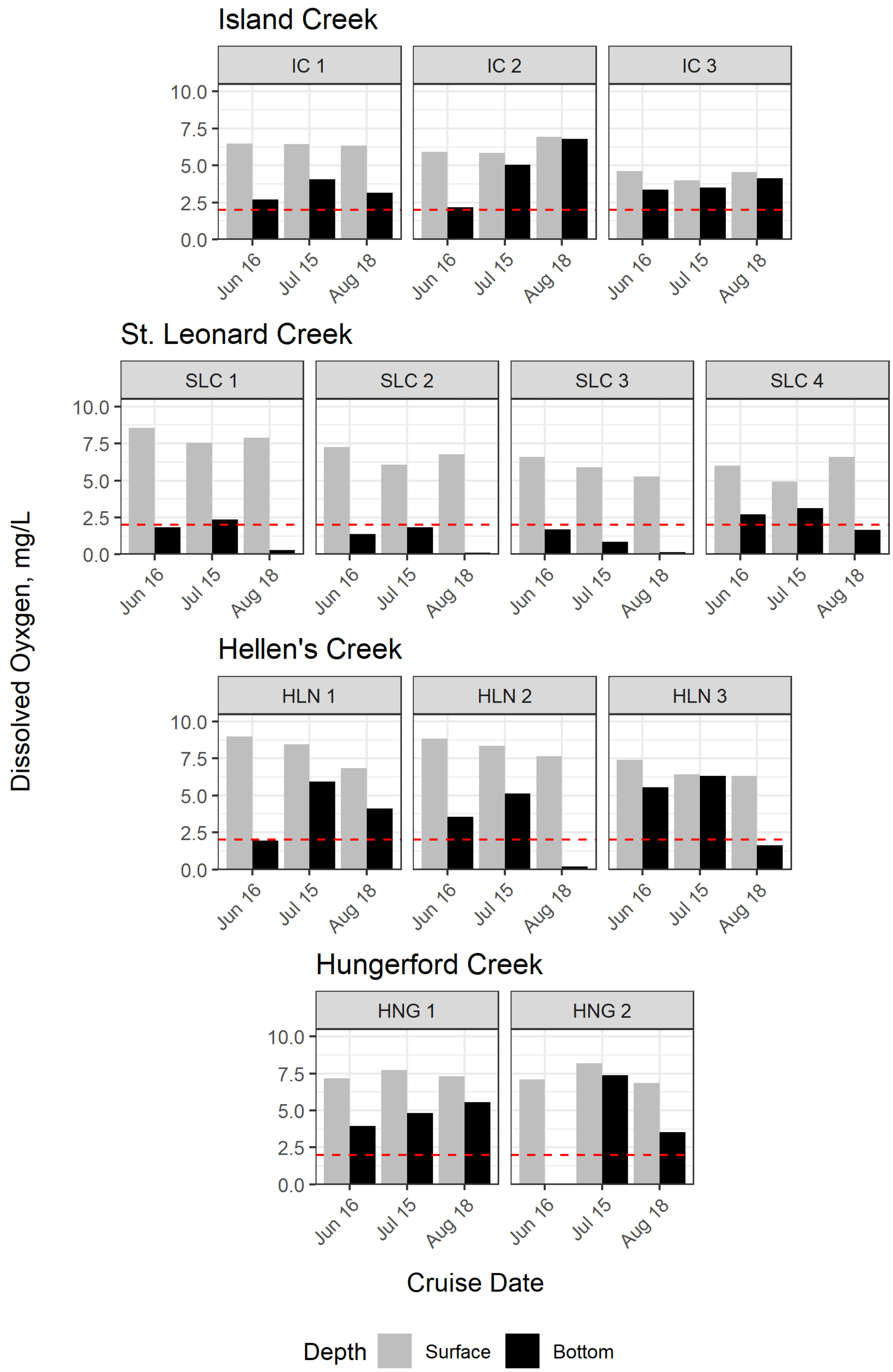


Figure 6.2 Bar graphs of surface and bottom water dissolved oxygen measurements for each station from June, July and, August 2021. Values below 2 mg L^{-1} (dashed line) are considered hypoxic.

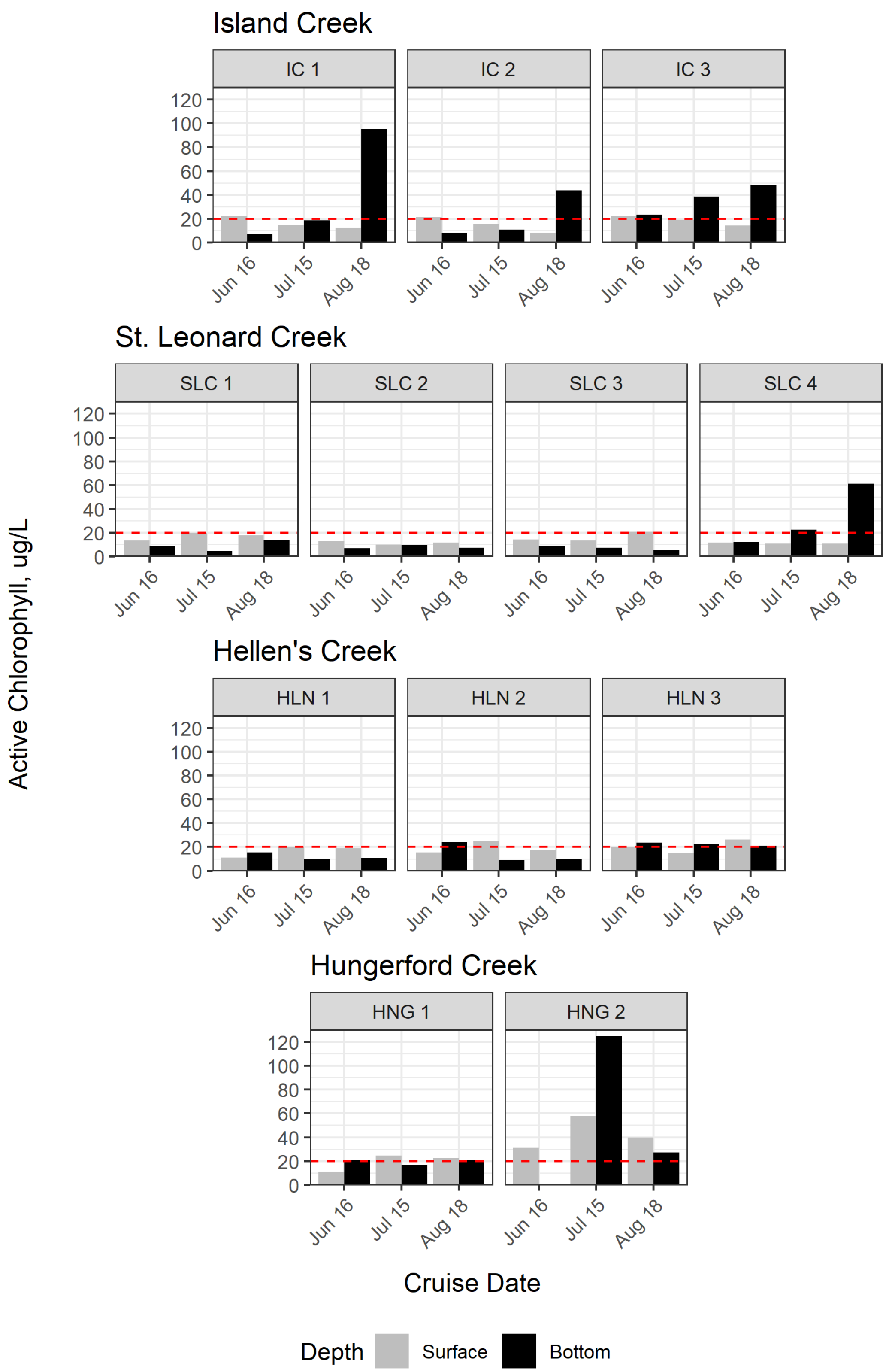


Figure 6.3 Bar graphs of surface and bottom water active chlorophyll-*a* measurements for each station from June, July and August 2021. Values above 20 ug L^{-1} (dashed line) are considered blooms.

6.1.3 Active Chlorophyll-a

Figure 6.3

Surface water active chlorophyll-*a* concentrations ranged from 8.24 to 58.18 µg L^{-1}. Bottom water concentrations ranged from 4.96 to 124.91 µg L^{-1}. The highest surface and bottom concentrations measured occurred at HNG-2 on July 15. There were 12 surface blooms recorded (concentrations greater than 20 µg L^{-1} Chl-A) in 2021, compared to the 20 blooms in 2020. Most of the blooms occurred at Hungerford Creek. Hellens Creek and Island Creek also experienced multiple blooms.

6.2 Upper Patuxent River Tributaries

Nine stations located in three upper Patuxent river creeks were examined three times (June, July and August) during 2021, to catch the peak of summer conditions in these systems. The stations were located in 3 creeks in the upper Patuxent River estuary, all north of Broomes Island and all in Calvert County and these included 3 stations in Battle Creek, 3 stations in Hunting Creek and 3 stations in Hall Creek. As in 2012-2020, Battle Creek was sampled with the Lower Patuxent creeks, while Hall and Hunting Creeks were usually sampled the same day. All water quality data collected during the 2021 monitoring study in the Upper Patuxent River tributaries are listed in Appendix II by station and date.

6.2.1 *Water Column Clarity using Secchi Disk Readings*

Figure 6.4

The tidal creek Secchi disk readings were generally lower than the Mill Creek system and the lower Patuxent tidal creeks, ranging from 0.3 to 0.9 meters. Readings from both Hall Creek and Hunting Creek were the lowest of the upper creeks, ranging between 0.3 m and 0.5 m and averaging 0.4 m, while Battle Creek had a higher average of 0.7 m. Secchi disk readings in the range of 0.3 to 0.9 m are not supportive of SAV growth. We should note that water clarity in the mainstem of the Patuxent River is also poor in the vicinity of these creeks, where both the creeks and the mainstem Patuxent are flanked by extensive tidal marshes that export light-attenuating materials to the creeks.

6.2.2 *Dissolved Oxygen*

Figure 6.5

Surface water dissolved oxygen concentrations ranged from 2.65 to 7.33 mg L^{-1}. Bottom water concentrations ranged from 1.52 to 6.67 mg L^{-1}. Overall, surface DO was comparable to the Mill Creek system and the lower Patuxent. As in previous years, Hall Creek exhibited a well-mixed water column, with similar surface and bottom DO values and concentrations that suggest equilibrium with the atmosphere. Hall Creek was characterized by small DO fluctuations both spatially and temporally in contrast to those observed in many of the lower Patuxent creeks and in areas of the Mill Creek system. Battle Creek had surface DO that was typically above 5.0 mg L^{-1} over the summer (except July 16 at BAT 3), but all BC stations had one concentration below the more severe 2.0 mg L^{-1} at some point during summer 2021. DO concentrations at all Hall Creek stations and at Hunting Creek 3 (HUN-3) increased slightly between June and July and then fell below 5.0 mg L^{-1} by August. However, DO concentrations at HUN-1 increased over the summer while HUN-3 decreased to below the 5.0 m L^{-1} threshold.

6.2.3 ***Active Chlorophyll-a***

Figure 6.6

Surface water active chlorophyll-*a* concentration ranged from 10.55 to 50.1 µg L^{-1}, and bottom water readings ranged from 11.62 to 38.82 µg L^{-1}, and did not vary substantially over the summer. There were 20 surface blooms measured across all three creeks (> 20 µg L^{-1}). Surface and bottom water chlorophyll were often comparable, with a few exceptions in Battle Creek and Hunting Creek 1 (HUN-1).

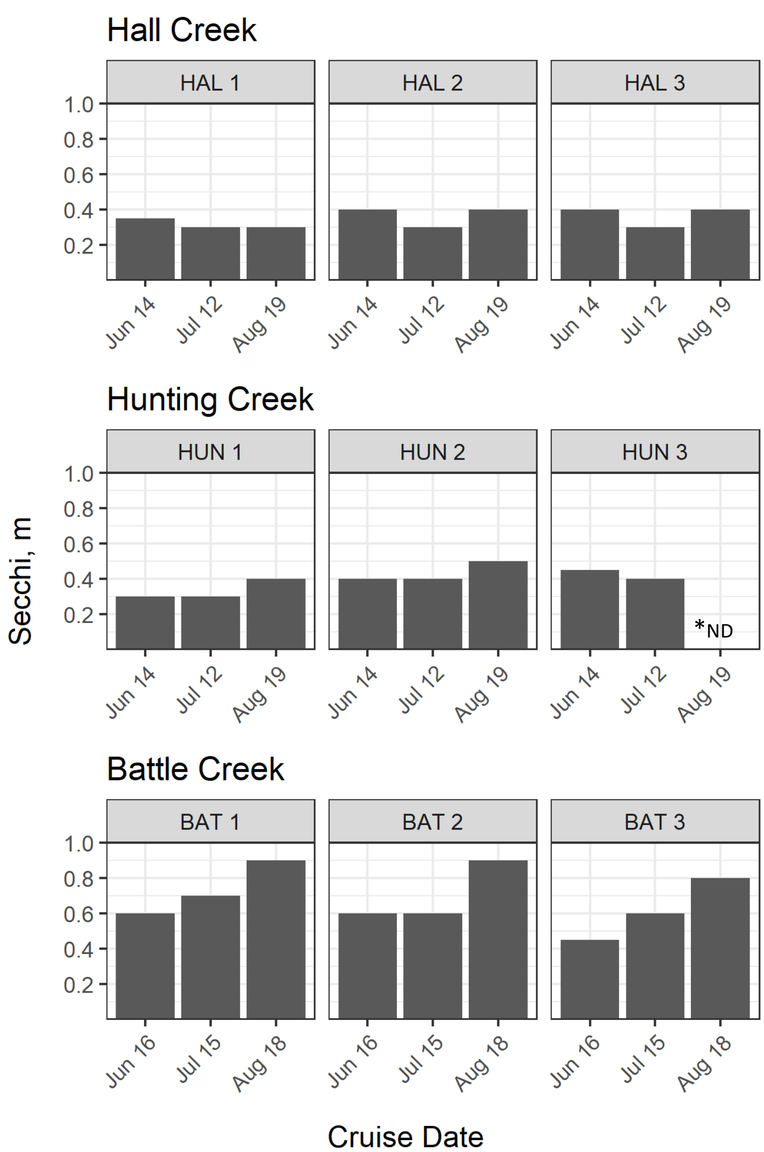


Figure 6.4 Bar graphs of water column Secchi disk measurements for each station from June, July, and August 2021. ND indicates no data.

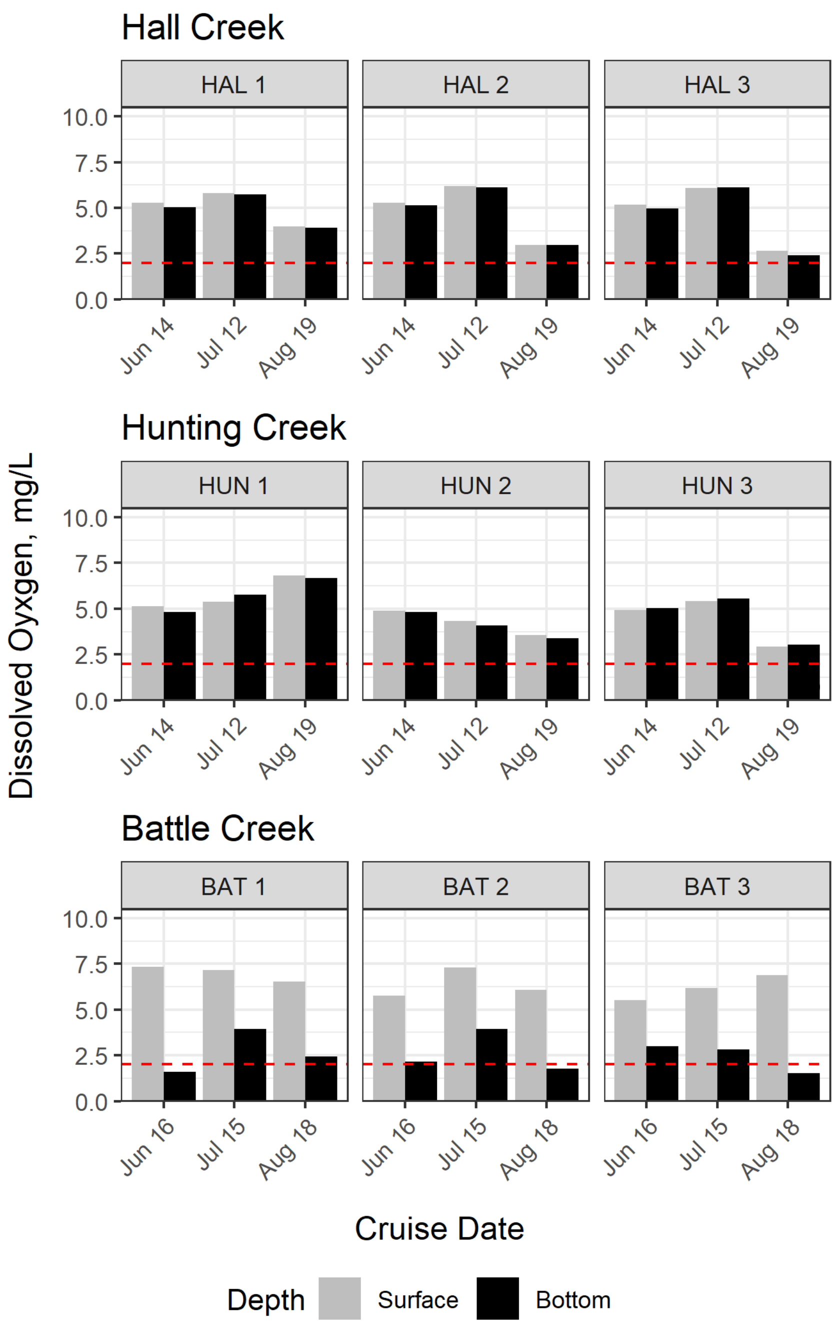


Figure 6.5 Bar graphs of surface and bottom water dissolved oxygen measurements for each station from June, July, and August 2021. Values below 2 mg L^{-1} (dashed line) are considered hypoxic.

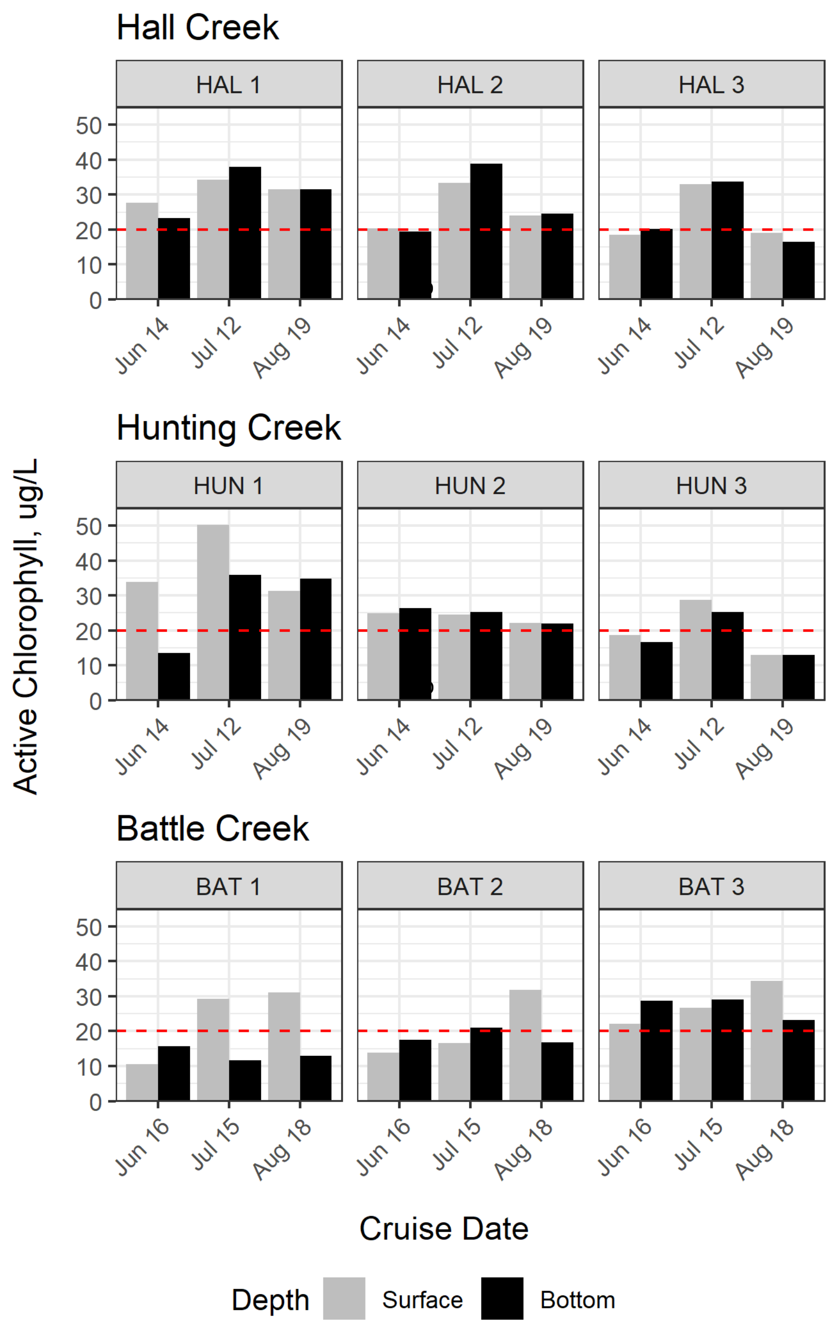


Figure 6.6 Bar graphs of surface and bottom water active chlorophyll-*a* measurements for each station from June, July, and August 2021. Values above 20 ug L^{-1} (dashed line) are considered blooms.

6.3 Chesapeake Bay Western Shore Tributaries

Eleven stations located in four Chesapeake Bay Western shore tributaries were examined three times (June, July, and August) during 2021, to measure summer water quality conditions in these systems. The stations were located in 4 creeks on the Chesapeake Bay Western shore in Calvert County including 3 stations in Fishing Creek, 3 stations in Plum Point Creek, 3 stations in Parkers Creek and 2 stations in Flag Harbor.

All water quality data collected during the 2021 monitoring study in the Western Shore tributaries are listed in Appendix II by station and date.

6.3.1 *Water Column Clarity using Secchi Disk Readings*

Figure 6.7

The tributary Secchi disk readings (0.4 – 1.1 m) were comparable to those of the Upper Patuxent tributaries (0.3 – 0.9 m) which is not sufficient to support healthy SAV communities in most circumstances. Water clarity in 2021 was variable between the stations and throughout the season, and was slightly higher than the range of 0.25 to 0.8 meters measured in 2020.

6.3.2 *Dissolved Oxygen*

Figure 6.8

Surface water dissolved oxygen concentrations ranged from 1.96 to 8.87 mg L^{-1}. Bottom water concentrations ranged from 0.07 to 7.82 mg L^{-1}. Oxygen conditions below 5.0 mg L^{-1}) occurred at all sites at some point during summer. Surface DO in Fishing Creek declined as the summer progressed all stations but remained above the threshold for hypoxia (< 2.0 mg/L). However, bottom DO in the two upstream stations reach near anoxic levels in July and rebounded to just above the hypoxia threshold in August. DO in Plum Point Creek also generally declined as the summer progressed, but surface waters were typically well oxygenated and bottom waters did not become hypoxic. Flag Harbor had high surface water DO compared to other creeks with a drop to near hypoxic concentrations at the upstream station in July. At the two downstream stations of Parker's Creek, DO increased from June to July and remained at similar levels in September. Surface DO at the upstream station decreased in general over the summer with a dip to below the hypoxic threshold in July and bottom water were well below and reached near anoxic conditions (0 mg/L) in September.

6.3.3 *Active Chlorophyll-a*

Figure 6.9

Surface water active chlorophyll-*a* concentration ranged from 0.76 to 58.25 µg L^{-1}. Bottom water readings ranged from 6.44 to 113.5 µg L^{-1}; only one station (PLM3) was above 60 µg L^{-1}. There were 15 surface blooms (greater than 20 µg L^{-1}). Chlorophyll was high at Plum Point Creek and Flag Harbor relative to Fishing Creek and Parker's Creek, where Fishing Creek had dependably low chlorophyll.

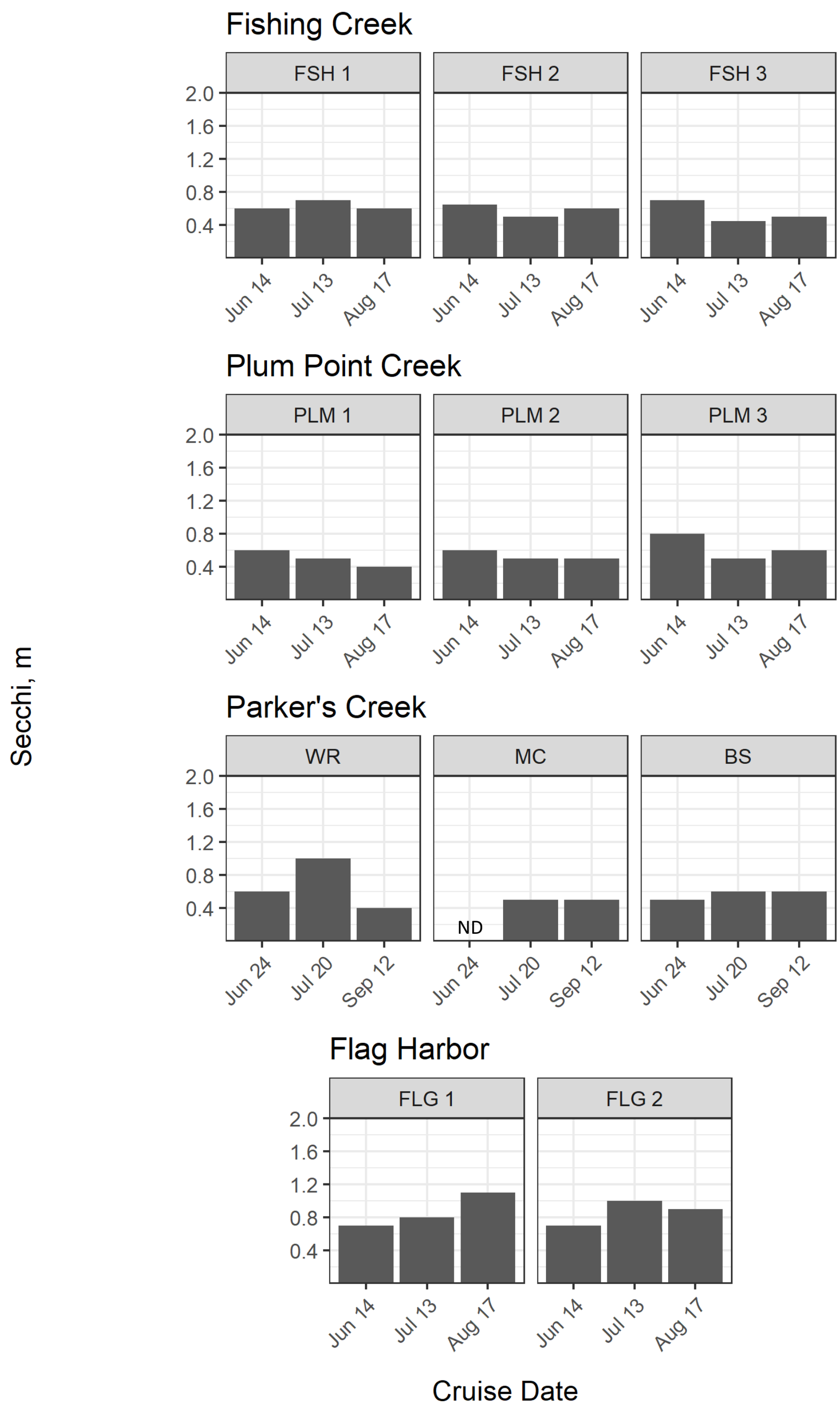


Figure 6.7 Bar graphs of Western Shore water column Secchi disk measurements for each station from June, July, and August 2021. ND indicates no data.

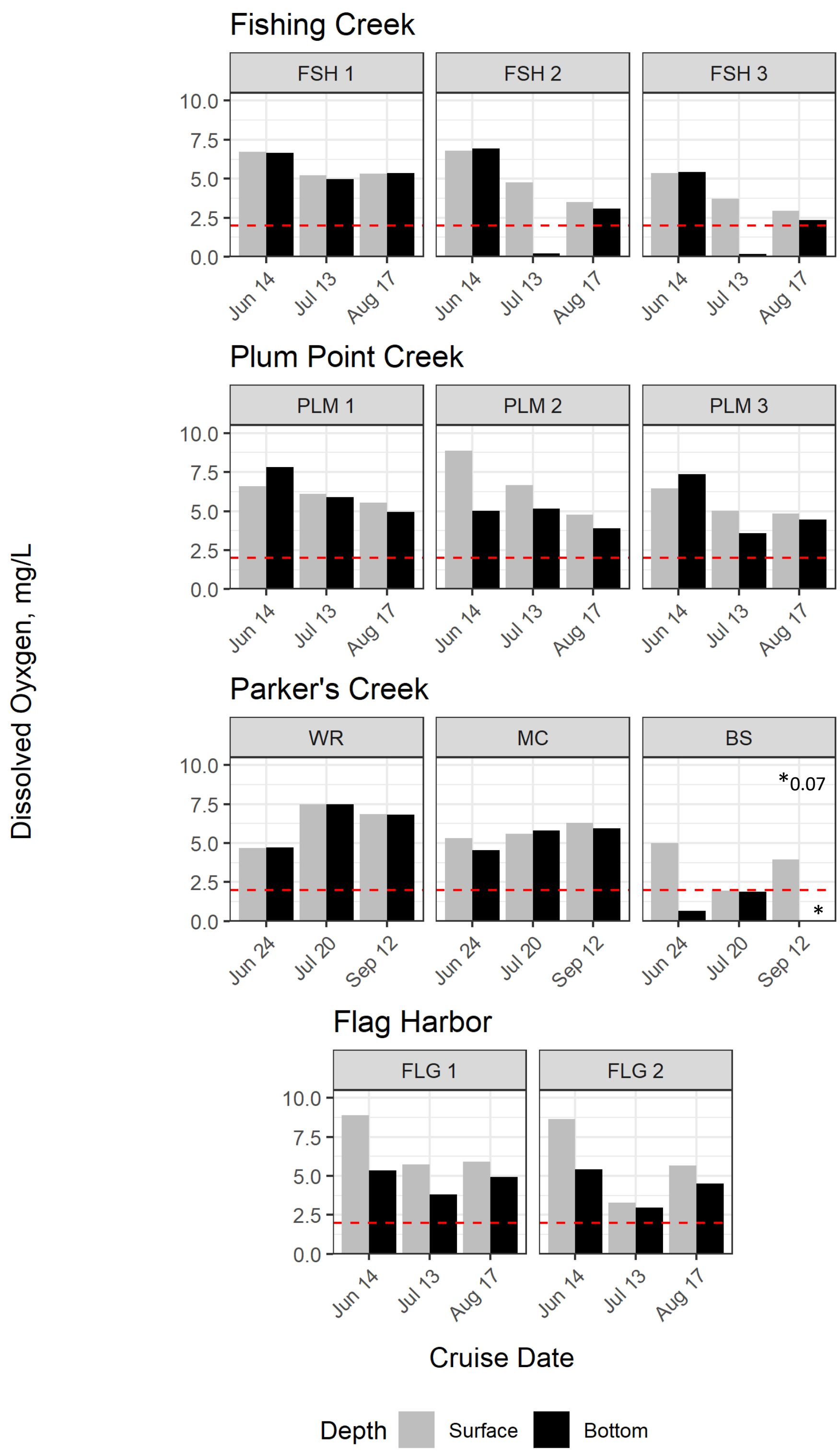


Figure 6.8 Bar graphs of Western Shore surface and bottom water dissolved oxygen measurements for each station from June, July, August and September 2021. Values below 2 mg L^{-1} (dashed line) are considered hypoxic.

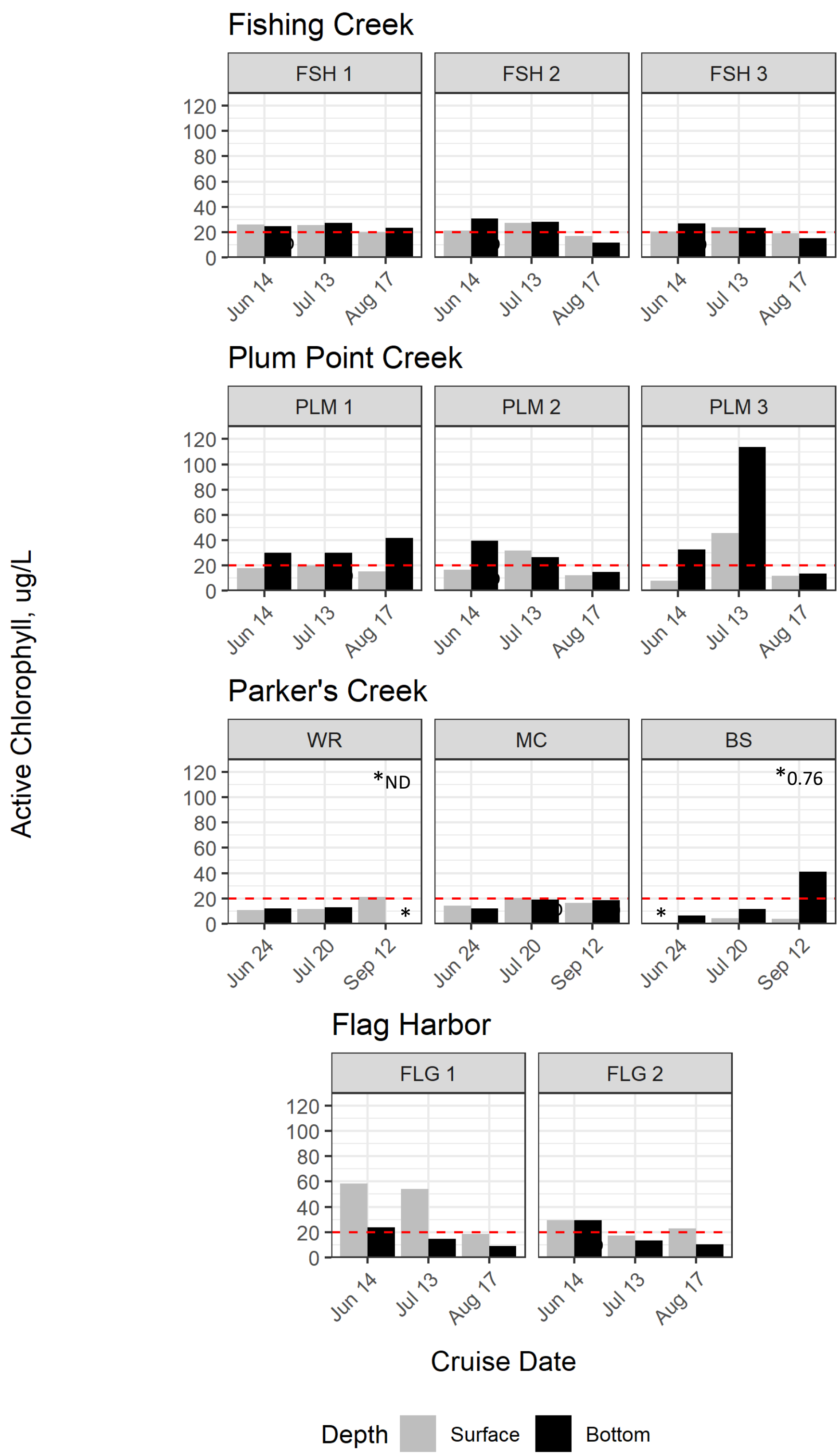


Figure 6.9 Bar graphs of Western Shore surface and bottom water active chlorophyll-*a* measurements for each station from June, July, August, and September 2021. Values above 20 ug L^{-1} (dashed line) are considered blooms. ND represents no data available.

7 Calvert County Tidal Tributaries: Inter-annual Comparisons

The monitoring scheme for shallow water environments (near-shore waters and small tributaries) adopted by the EPA Chesapeake Bay Program involves a rotation of sampling locations that are maintained three consecutive years of sampling at a given location. This 3-year scheme is meant to be long enough to capture the high degree of variability in water quality typically associated with estuarine ecosystems caused by inter-annual (and inter-seasonal) differences in weather conditions. For example, in dry years (or dry seasons) freshwater flow and associated nutrient, sediment and organic matter loads from the adjacent landscape are generally reduced while the opposite is the case during wet years. The three-year sampling schedule is an attempt to capture at least a portion of this variability and thus arrive at an average "water quality status" for each location.

In contrast, the Calvert County Monitoring Program takes a longer-term monitoring approach that is advisable because identification of trends in water quality is a central issue rather than just establishing a water quality status for various locations. The lower Patuxent Creeks (Island Creek, St Leonard Creek and Hellen's Creek) have been monitored for thirteen summer seasons (2009-2021). The upper Patuxent River creeks (Battle Creek, Hunting Creek and Hall Creek) have been monitored for twelve summer seasons. The Chesapeake Bay Western shore creeks have been monitored for eleven summer seasons and Hungerford Creek (lower Patuxent) has been monitored for ten seasons. Parkers Creek (western shore) has been monitored for nine years as a part of this program. Here we present average tributary conditions during summer (June, July, and August) for each sampling year and long-term tributary averages of the water quality collected in each tributary.

7.1 Lower Patuxent Tributary Comparisons

7.1.1 *Water Column Clarity using Secchi Disk Readings*

Figure 7.1

Summer average water clarity, as indicated by Secchi disk depth in the Patuxent Creek systems were relatively stable between years. Water clarity was generally insufficient for SAV growth in the majority of years in the Patuxent creeks. In recent years, there has been notable SAV growth in the spring period in Mill Creek and some lower Patuxent creeks, but this SAV is a species known as *Zannichellia,* which grows in spring and senesces and disappears before our sampling typically begins. Over the years of sampling, Hungerford Creek had the minimum average Secchi Disk depth across creeks with an average of 0.57 m, while St. Leonard Creek had the maximum average at 0.97 m. Lower Patuxent creeks had slightly higher clarity in 2021 than in 2020 and compared to the long-term averages. In thirteen years of sampling, the minimum (poor water clarity) Secchi disk measurement was 0.2 m on a few occasions in different creeks. The maximum (better water clarity) measurement was 1.5 m in St. Leonard Creek.

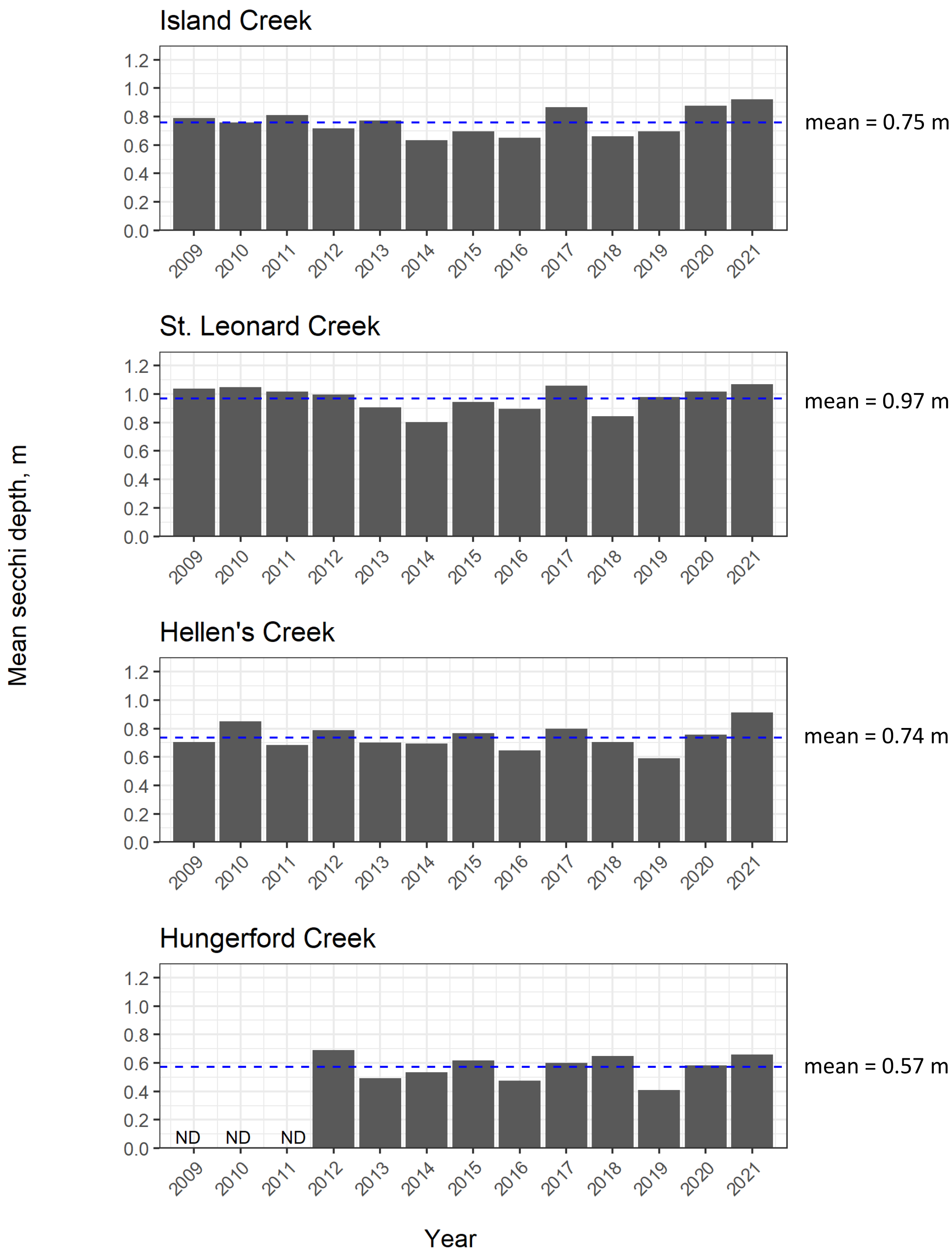


Figure 7.1 Bar graphs indicating summer mean water clarity as Secchi disk depths in the lower Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2009-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.

7.1.2 ***Dissolved Oxygen***

Figure 7.2

In all of the creeks average bottom DO was below long-term averages in 2021 and lower than 2020 levels except for St. Leonard Creek, which was well below average the long term average (2.63 mg L^{-1}) for the creek and similar to 2020 levels. Concentrations of DO less than 2.0 mg L^{-1} are very stressful to most organisms and should be considered dangerously low levels, and the average bottom water DO in St. Leonard Creek was below this limit in 2010, 2014, 2015, 2018, 2019, 2020, and 2021. For the lower Patuxent tributary monitoring time-series, Hungerford has the highest average bottom water DO at 5.43 mg L^{-1}. The minimum (worse conditions) bottom water DO measurement was recorded in August of 2021 at Helens Creek (0.11 mg L^{-1}); similar low levels (0.17-0.18 mg L^{-1}) were found in St. Leonards Creek on the same date. The maximum (better conditions) measurement (8.98 mg L^{-1}) was also recorded at Hellen's Creek, in June of 2021.

7.1.3 ***Active Chlorophyll-a***

Figure 7.3

Average surface water chlorophyll-*a* concentrations for 2021 were lower than long term average for all creeks. From 2018 to 2019, the chlorophyll-*a* increased in all the creeks, but in 2020 dropped back down to 2018 levels. In 2021, levels remain below the long-term means with St. Leonards Creek concentrations similar to the 2020 average. Island Creek and Hellen's Creek averages dropped below the 2020 average while surface water chlorophyll-*a* was higher than the 2020 average for Hungerford Creek. The long term average in the surface water chlorophyll-*a* in Island, Hellen's, and Hungerford Creeks was above 20 µg L^{-1}, which is the concentration used to define an algal bloom. Hellen's Creek had the highest long term average due to an algae bloom in 2011 (131 µg L^{-1}). The time-series minimum (better conditions) surface water chlorophyll-*a* measurement was 4.96 µg L^{-1} in Saint Leonard Creek, occurring in July of 2021, while the maximum (worse conditions) measurement was 946 µg L^{-1} in Hellen's Creek in 2011. There are no significant trends over time in chlorophyll in any of the creeks.

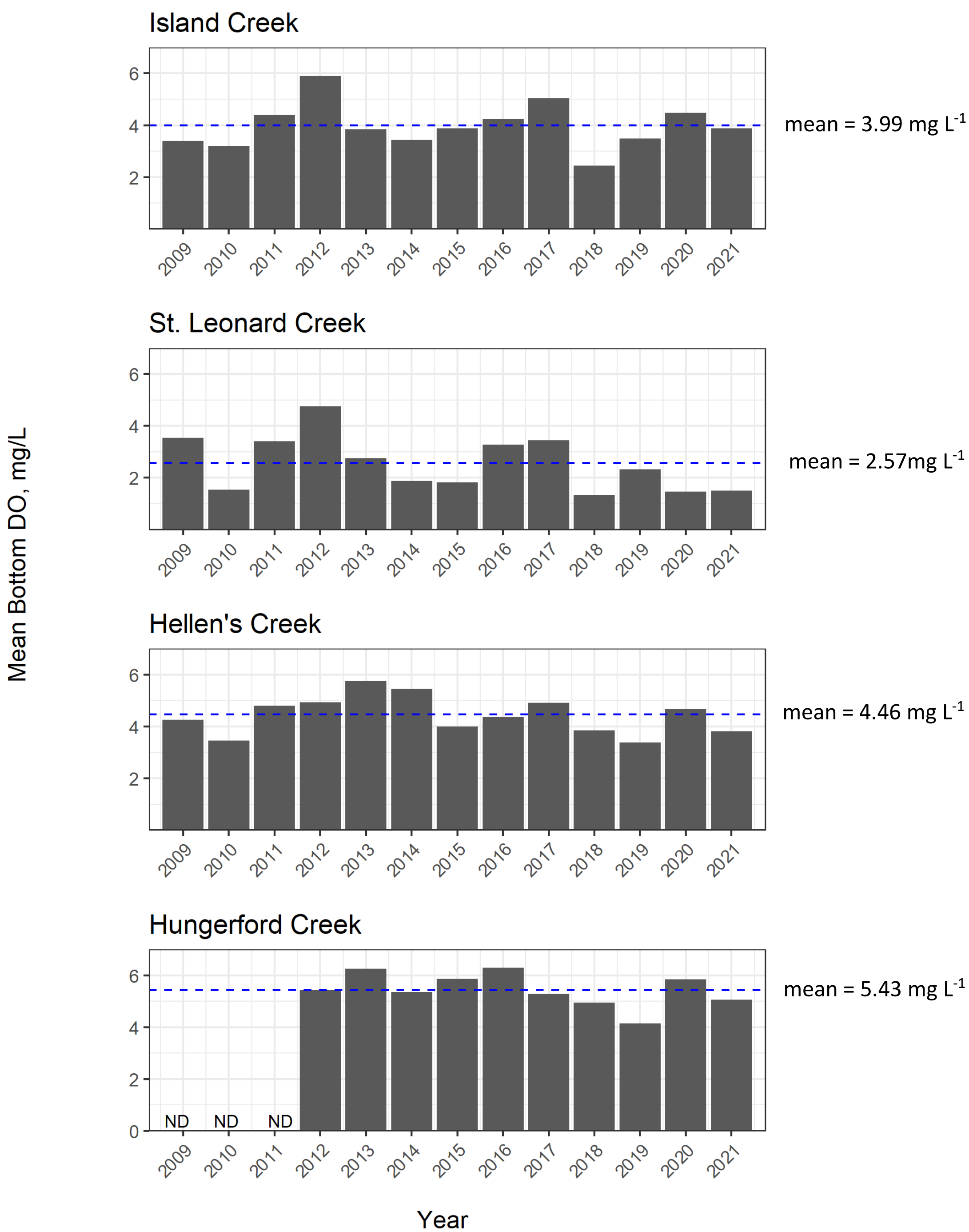


Figure 7.2 Bar graphs indicating summer mean bottom water DO concentration (mg L^{-1}) in the lower Patuxent River creeks. Comparisons are made between data collected during summer periods of 2009-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.

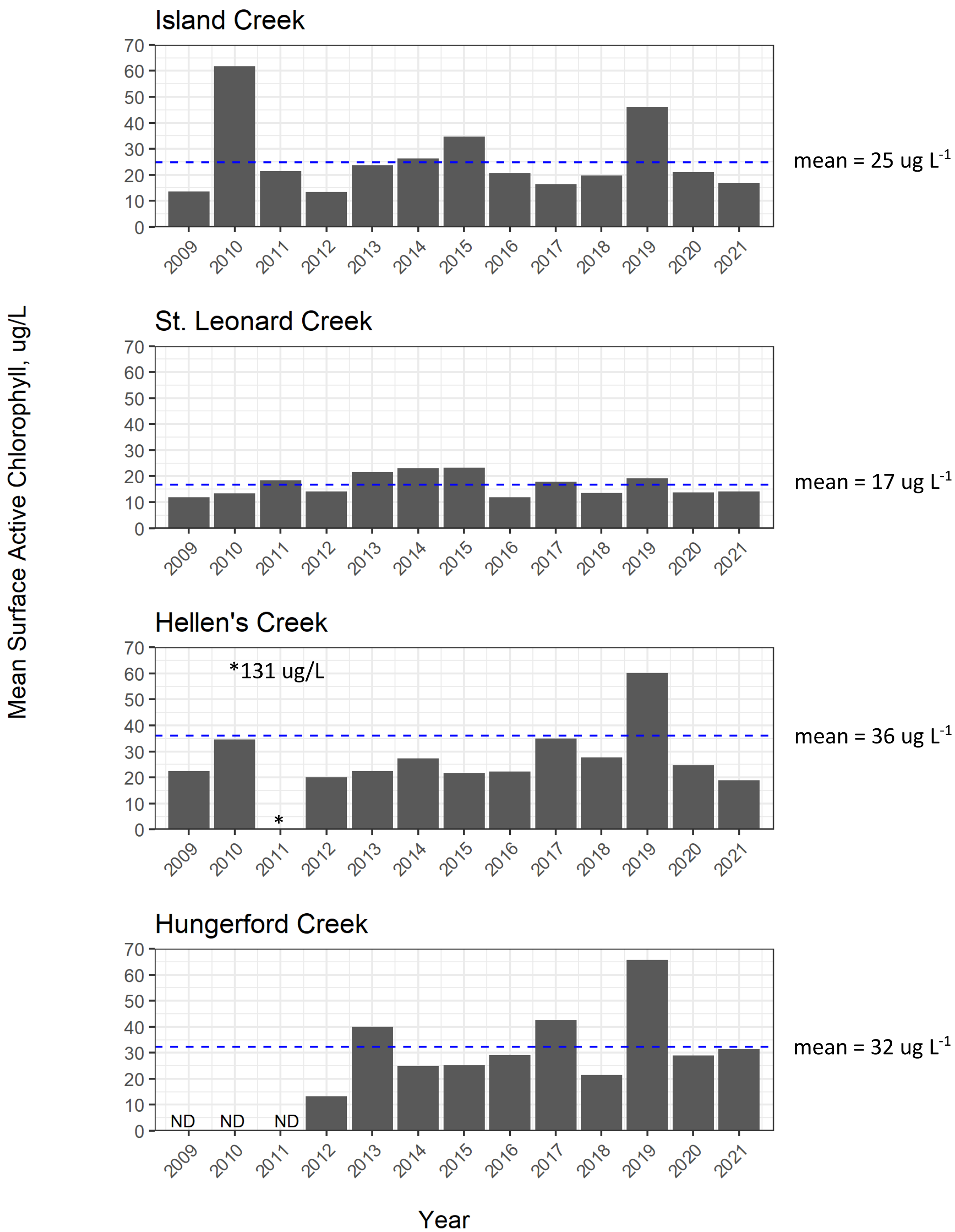


Figure 7.3 Bar graphs indicating summer mean surface water chlorophyll-*a* concentration in the lower Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2009-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.

7.2 Upper Patuxent Tributary Comparisons

7.2.1 *Water Column Clarity using Secchi Disk Readings*

Figure 7.4

The year 2021 was the 12th year of monitoring the upper Patuxent Creeks. Yearly summer average water clarity for these tributaries was lower than in the lower Patuxent Creeks, ranging from about 0.1 to 1.4 m over the time series. These measurements indicate poor water clarity and would not normally be associated with SAV communities. However, these creeks are quite shallow and thus enough light can reach the bottom so that some SAV species are able to grow in these turbid but shallow waters. In addition, some of these freshwater SAV species are canopy forming types and because a portion of the plant grows along the surface of the water adequate light is available. Water clarity decreased in Hall Creek over the time series, but appears to have somewhat stabilized since 2017. Water clarity in Hunting and Battle Creeks fluctuated around their respective long-term average, with 2021 being slightly above the long-term average. In twelve years of sampling, the minimum (poor water clarity) Secchi disk measurement was 0.1 m in Hunting Creek in 2019. The maximum (better water clarity) measurement was 1.4 m in Hall Creek in 2010.

7.2.2 *Dissolved Oxygen*

Figure 7.5

Average bottom water dissolved oxygen concentrations in the upper Patuxent creeks were fair to good. All creeks had average bottom water concentrations above 2 mg L^{-1}. Bottom water DO levels in Hall Creek decreased in 2021 to below the long-term average (5.32 mg/L) and were similar to the lower averages recorded in 2010, 2016 and 2017. Despite these drops an overall increase has occurred in Hall Creek since 2010. An overall increase has occurred in the bottom waters of Hunting Creek over the time series although levels in 2021 decreased from 2020 to below the long-term mean. DO in Battle Creek has decreased since 2011, with the lowest measurement (2.58 mg/L) occurring in 2021. The time-series minimum (worse conditions) bottom water DO measurement was 0.92 mg L^{-1} in Battle Creek in 2015. The maximum (better conditions) measurement was 9.04 mg L^{-1} in Hall Creek in 2014.

7.2.3 *Active Chlorophyll-a*

Figure 7.6

Average concentrations in Hall and Battle Creeks were at or slightly higher than their long-term averages while average concentration in Hunting Creek in 2021 was below the long-term mean. There appears to be a slight upward trend in chlorophyll in all three creeks, but these trends are not significant. The time-series minimum (better conditions) surface water chlorophyll-*a* measurement was 4.54 µg L^{-1} in Hall Creek in 2010. The maximum (worse conditions) measurement was 195 µg L^{-1} in Hunting Creek in 2020.

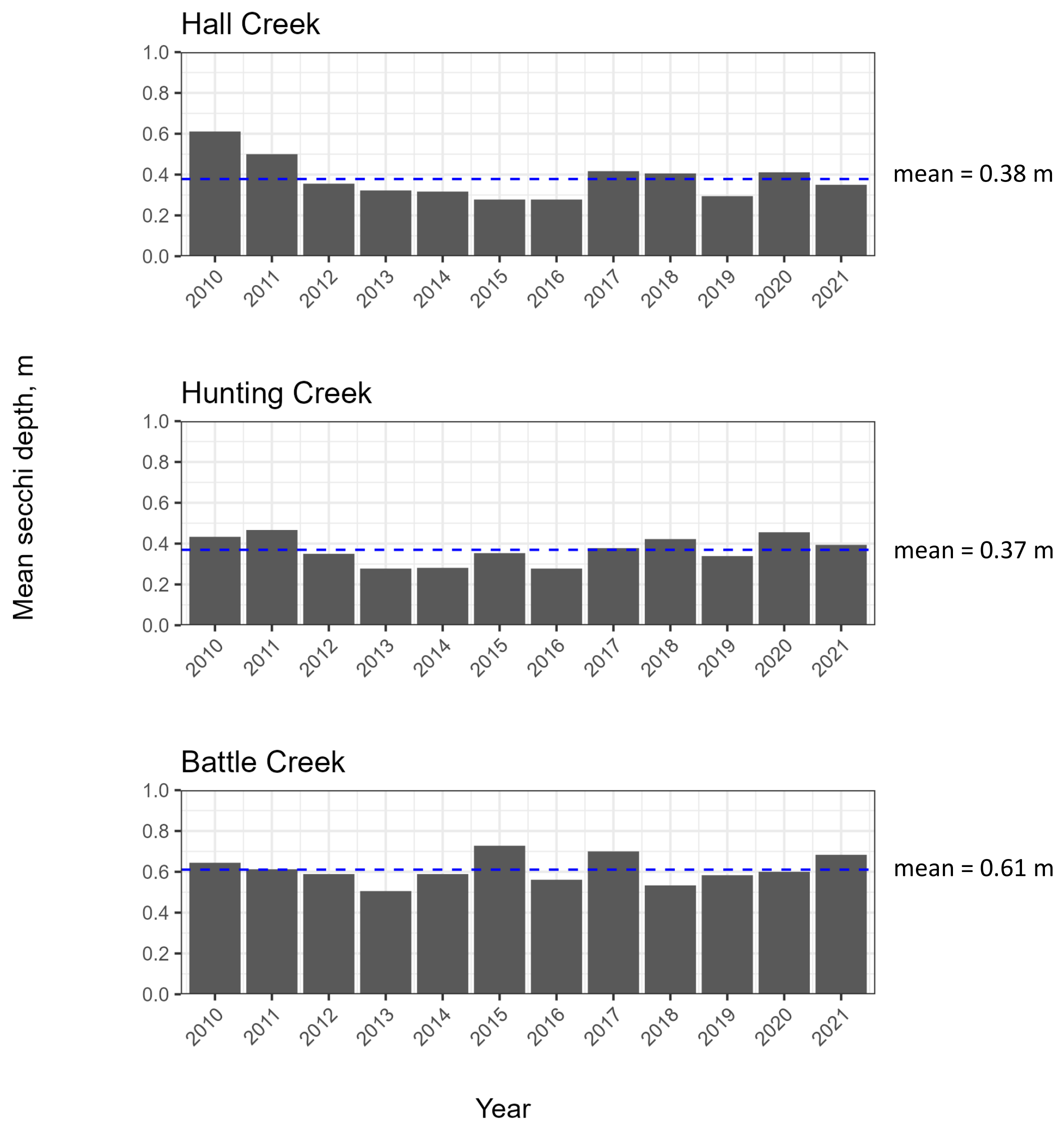


Figure 7.4 Bar graphs indicating summer mean water clarity as Secchi disk depths in the upper Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2010-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average.

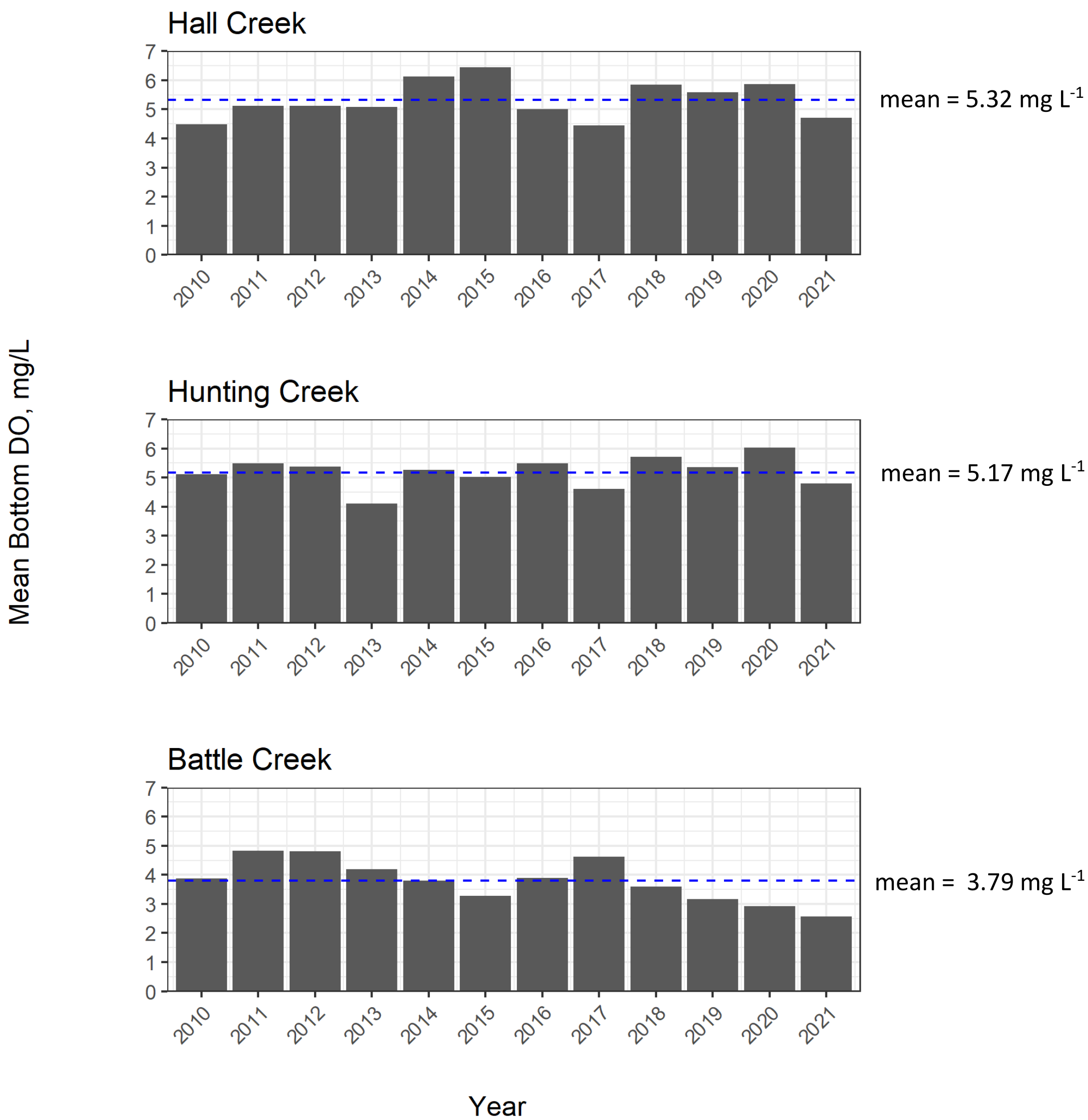


Figure 7.5 Bar graphs indicating summer mean bottom water DO concentration in the upper Patuxent River Creeks. Comparisons are made between data collected during summer periods of 2010-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average.

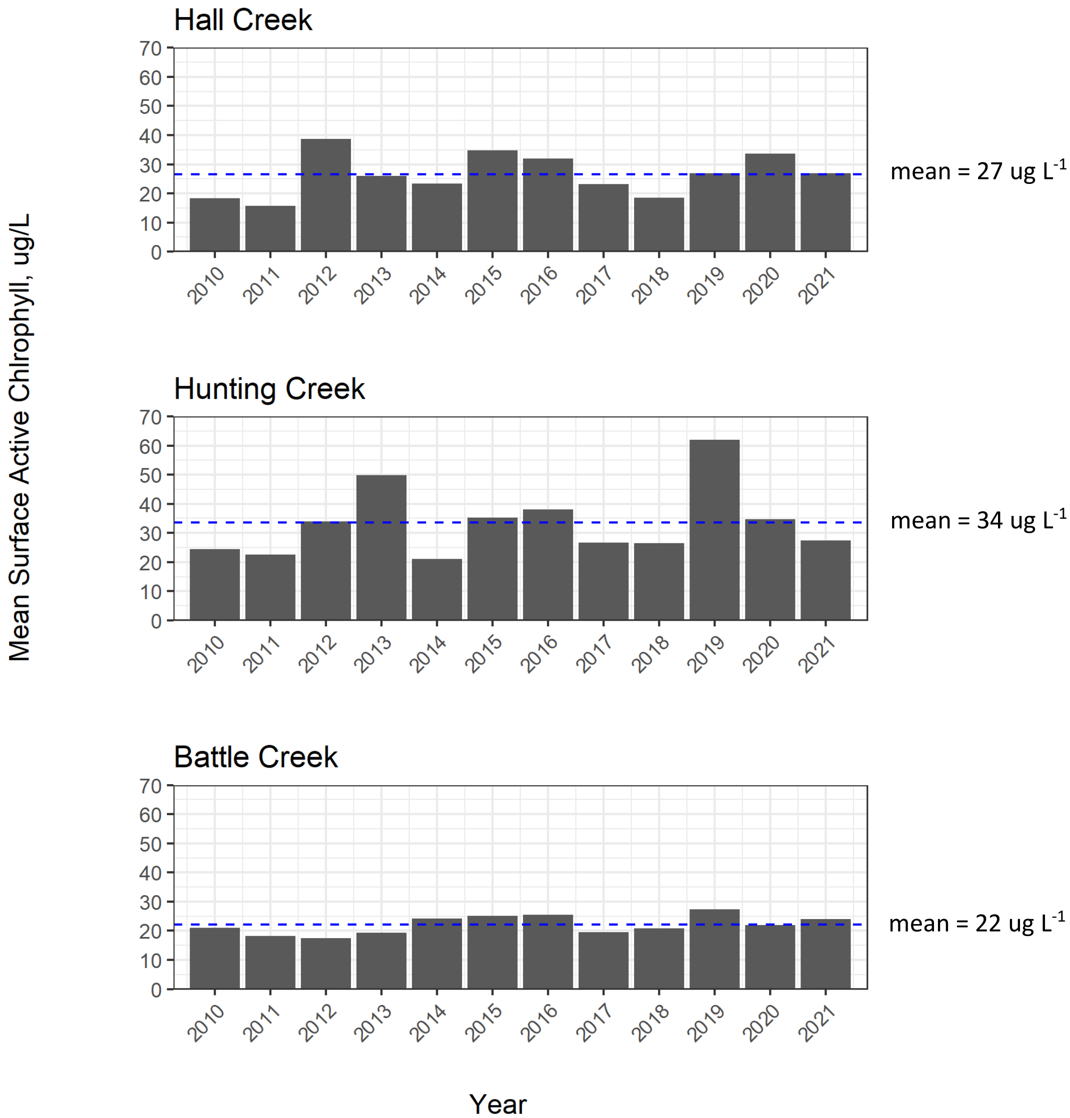


Figure 7.6 Bar graphs indicating summer mean surface water chlorophyll-*a* concentration in the upper Patuxent River creeks. Comparisons are made between data collected during summer periods of 2010-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average.

7.3 Chesapeake Bay Western Shore Tributary Comparisons

7.3.1 *Water Column Clarity using Secchi Disk Readings*

Figure 7.7

The 2021 summer marked the eleventh year of monitoring the many of the Western Shore creeks and the ninth year of monitoring Parkers Creek. Average water clarity over these years ranged from 0.36 to 0.99 m with 2021 averages approximately the same or slightly higher than long-term average for each of the creeks. These measurements indicate poor water clarity and would not normally be associated with SAV communities. Over the past five years average water clarity appears to relatively stable. Clarity was higher in Flag Harbor than the other three creeks. The time-series minimum (poor water clarity) Secchi disk measurement was 0.05 m in Parkers Creek in 2014. The maximum (better water clarity) measurements were 1.6 m in Flag Harbor in 2015 and in Fishing Creek in 2018.

7.3.2 *Dissolved Oxygen*

Figure 7.8

Average bottom water dissolved oxygen concentrations in the Western Shore creeks were at or below the long-term means in 2021 except for Plum Point, which was higher than long-term averages. 2021 levels were higher in all creeks compared to 2020 with the exception of Flag Harbor, where DO concentrations increased. All creeks were above 2 mg L^{-1} but below the desired oxygen concentration of 5 mg L^{-1} for these environments. The time-series minimum (worse conditions) bottom water DO measurement was 0.07 mg L^{-1} in Parkers Creek in 2021. The maximum (better conditions) measurement was 10.26 mg L^{-1} in Parkers Creek in 2016.

7.3.3 *Active Chlorophyll-a*

Figure 7.9

In 2021, average surface water chlorophyll-*a* concentration in these creeks were lower than long-term averages (2011-2021) and typically greater than those associated with bloom conditions (>20 µg L^{-1}), with the exception of Parkers Creek. Parkers Creek has the lowest long-term average chlorophyll-*a* (15 ug L^{-1}) exhibiting small fluctuations over time; 2021 concentrations decreased from 2020, remaining below the long-term average, and were the lowest since 2016. The time-series minimum (better conditions) surface water chlorophyll-*a* measurement was 0.23 µg L^{-1} in Parkers Creek in 2013. The maximum (worse conditions) measurement was 177.6 µg L^{-1} in Plum Point Creek in 2018.

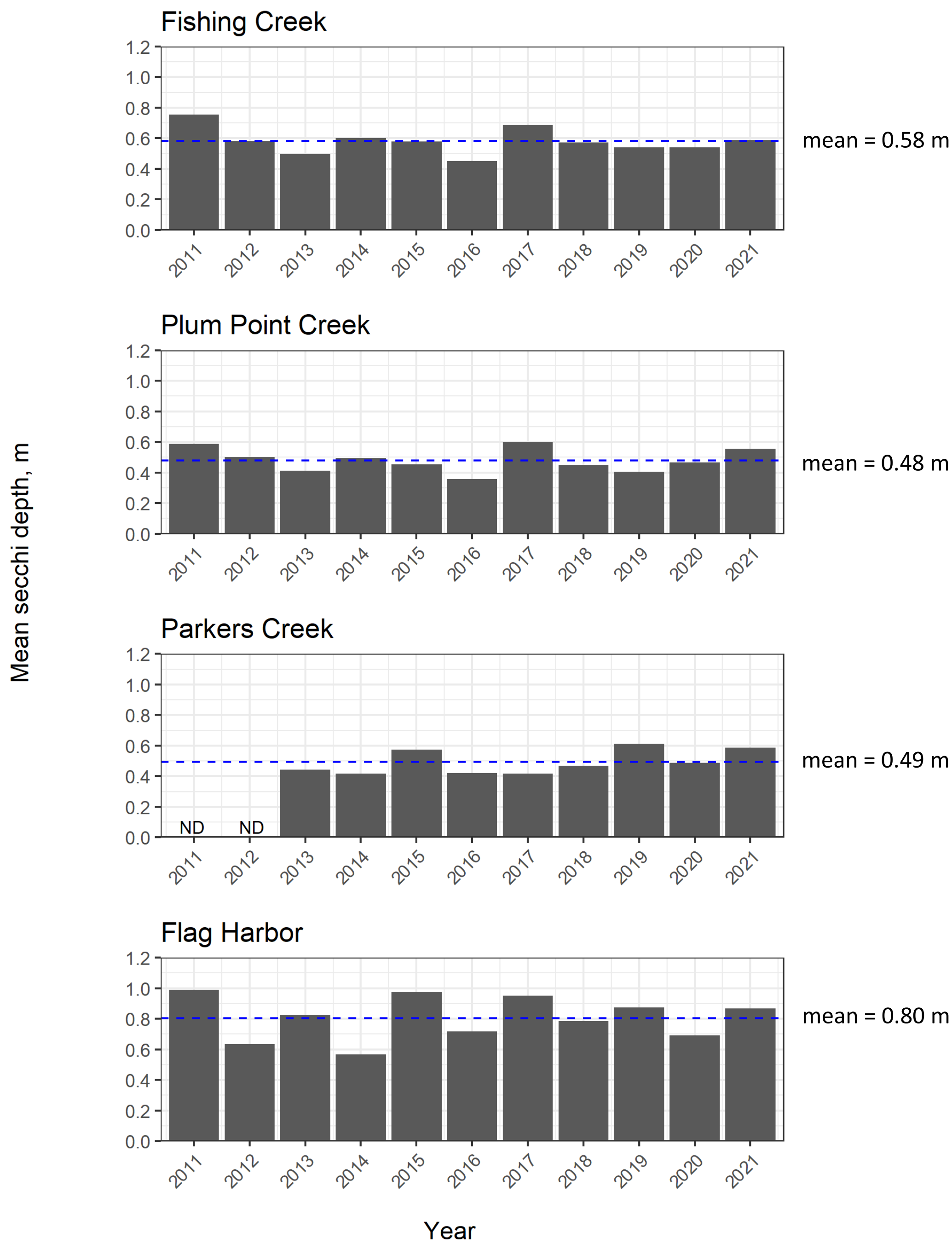


Figure 7.7 Bar graphs indicating summer mean water clarity as Secchi disk depths in the Western Shore creeks. Comparisons are made between data collected during summer periods of 2011-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.

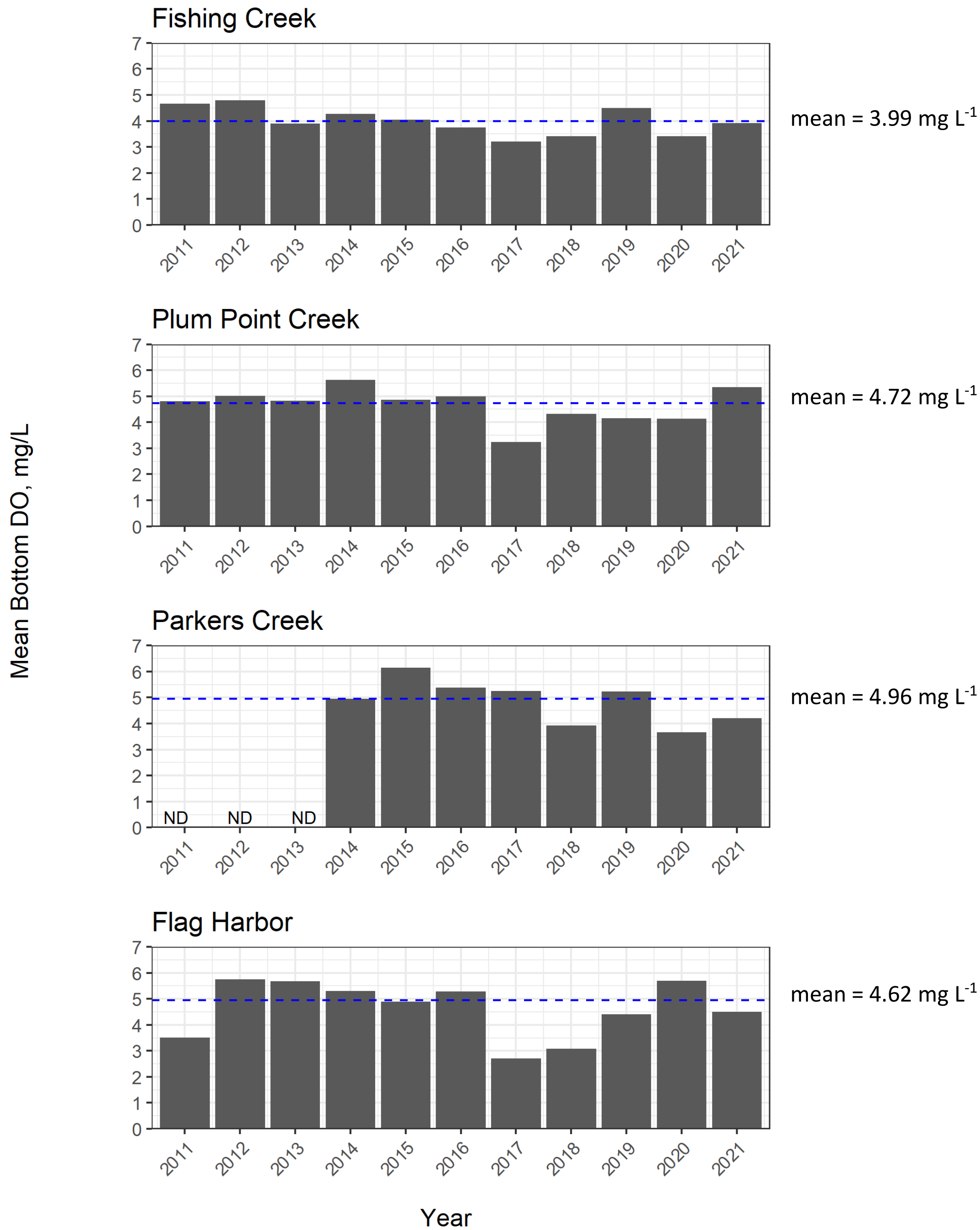


Figure 7.8 Bar graphs indicating summer average bottom water DO concentration in the Western Shore creeks. Comparisons are made between data collected during summer periods of 2011-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates no data available (2013) or the tributary was not sampled these years (2011-2012).

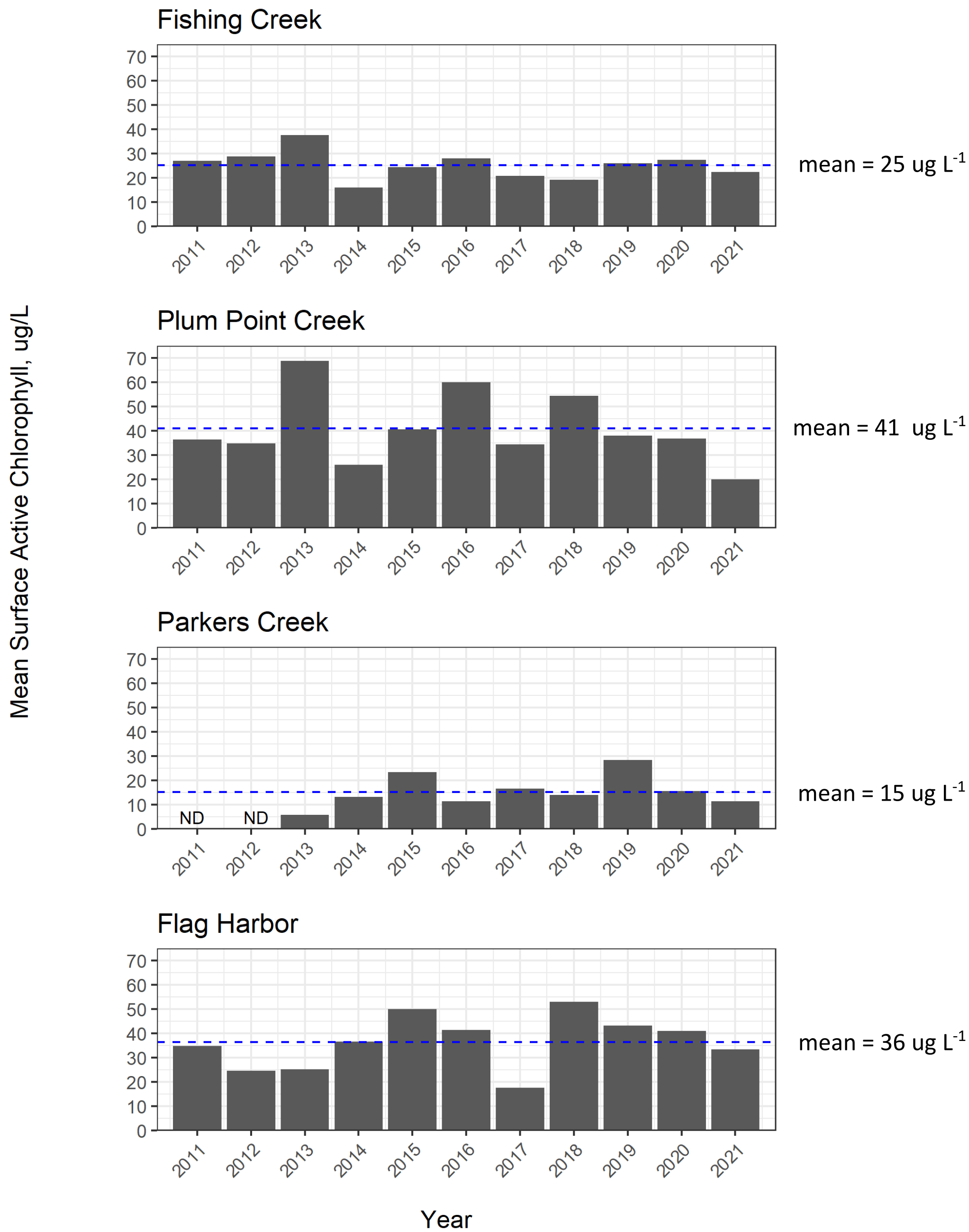


Figure 7.9 Bar graphs indicating summer mean surface chlorophyll-*a* concentration in the Western Shore Creeks. Comparisons are made between data collected during summer periods of 2011-2021. Data presented are averaged across tributary sampling stations and for each sampling year. The dashed line represents the long term tributary average. ND indicates tributary was not sampled these years.

8 Tidal Creek Trends Compared to Mainstem Stations Trends

The Chesapeake Bay Program (CBP) has a long-term monitoring program of the Chesapeake Bay and its tributaries. In the Patuxent River and the western Bay surrounding Calvert County, there are 9 stations that have been monitored from 1985-present by the Maryland Department of Natural Resources as a part of this program. The smaller tributaries have been monitored by CBL from ~2010-2021 with a higher resolution of 29 stations.

CBP uses statistical techniques called "Generalized Additive Models" (GAMs) to quantitatively assess trends over time in the monitoring data. Here we ran this model on the same years (2013 to 2021) and months (June – Aug) for both the Calvert Creek (CBL) and the CBP stations specifically for Secchi depth, surface chlorophyll, and bottom water dissolved oxygen to compare these smaller systems versus the larger adjoining systems. GAMs also gives us an understanding of how all of these systems have changed with time. Monitoring of the most recently added creek began in 2013, the starting year for the time series analysis.

8.1 Secchi Depth

Figure 8.1

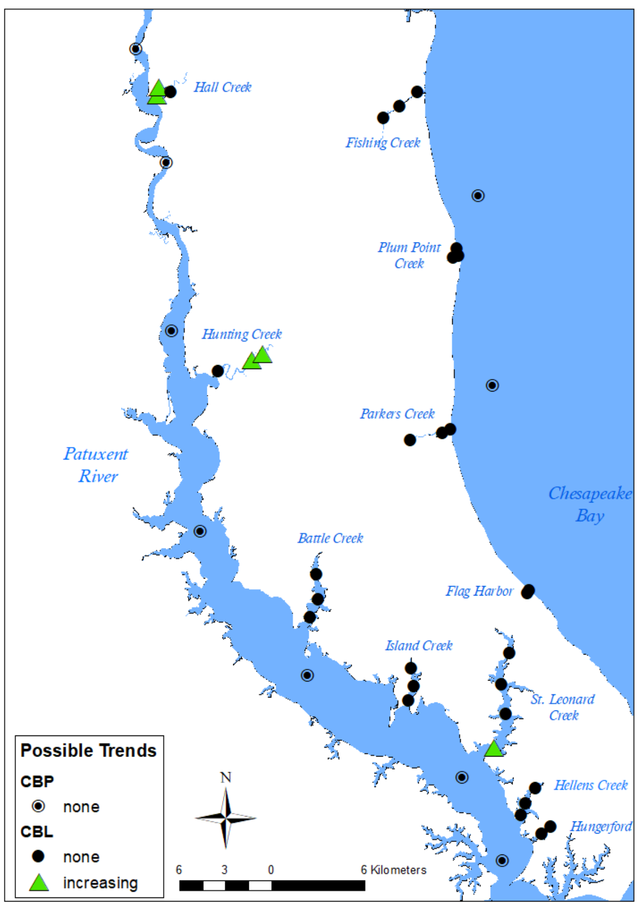


Figure 8.1 Possible trends for Secchi disk depth for the summer months ~2013-2021.

Most stations exhibited "no trend" for Secchi disk depth in the time series. Two Hall Creek stations saw improving trends, as well as two stations in Hunting Creek.

8.2 Chlorophyll-*a*

Figure 8.2

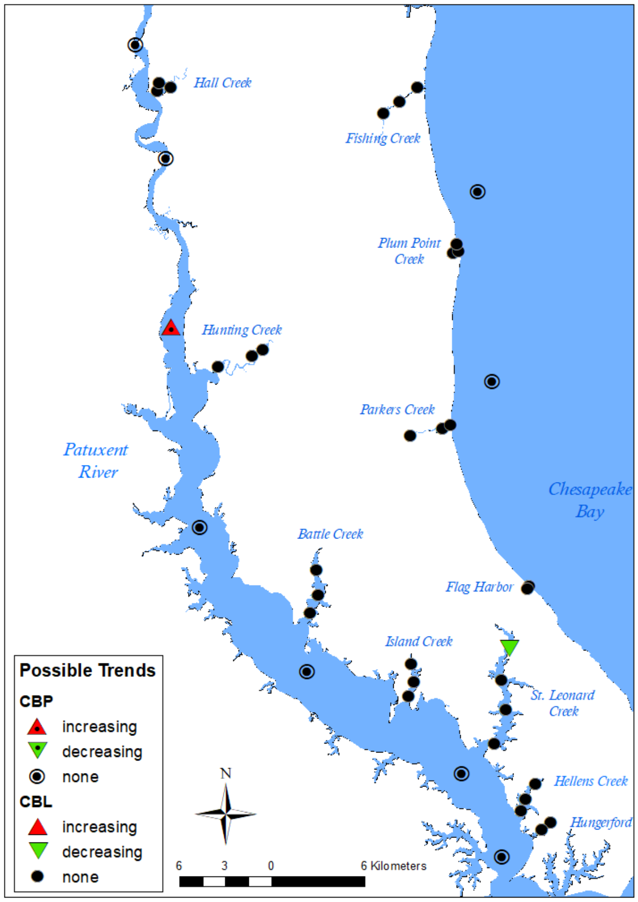


Figure 8.2 Possible trends for surface chlorophyll-*a* for the summer months ~2013-2021.

Most stations showed "no trend" for chlorophyll concentrations. The upstream station at St. Leonards Creek exhibited an improving trend. One CBP station near Hunting Creek exhibited a degrading trend. Note that a decrease in chlorophyll concentrations indicates improving conditions and increase indicates degrading conditions.

8.3 Dissolved Oxygen

Figure 8.3

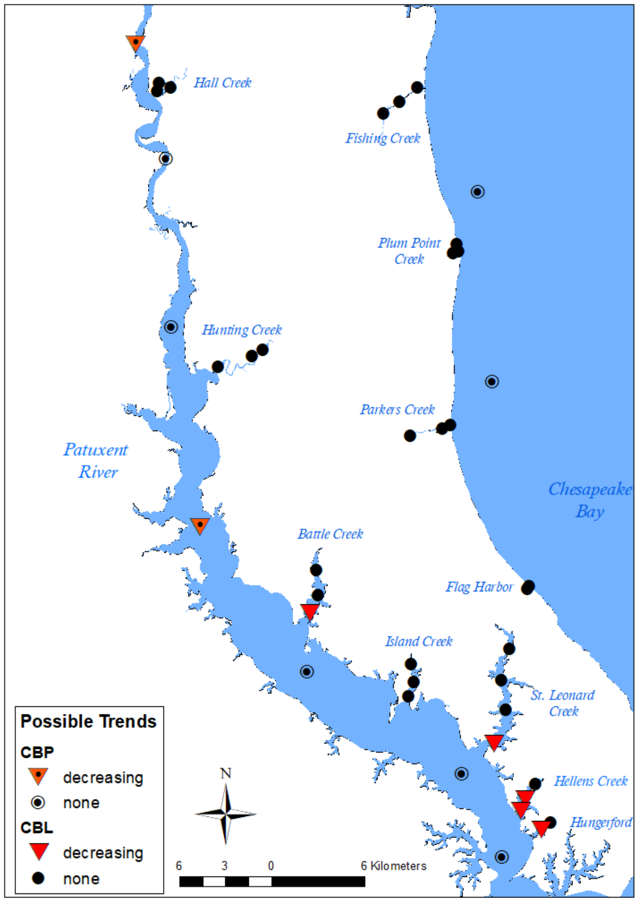


Figure 8.3 Possible trends for bottom DO for the summer months ~2013-2021. Note that surface DO trends are shown for stations MC and WR (Parkers Creek) and PLM3 (Plum Point Creek) due to their shallow depth.

Most stations exhibited no trend for increasing or decreasing bottom dissolved oxygen (DO). However, two CBP stations (upper and mid Patuxent) experienced a degrading trend as well as five CBL stations in the downstream areas of Battle Creek, St. Leonard Creek, Hellen's Creek, and Hungerford Creek. No improving trends were demonstrated.

Note that due to consistently shallow depths (~1m or less), that trend analysis for stations MC and WR in Parkers Creek and station PLM-3 in Plum Point Creek were conducted on 0.5 m depth water DO rather than bottom water.

The overall finding of the trend analysis is that the majority of CBL and CPB sites are not demonstrating significant change over the past 9 years for water clarity (secchi depth), dissolved oxygen, or chlorophyll concentrations.

References

Boynton, W.R., J.D. Hagy, J.C. Cornwell, W.M. Kemp, S.M. Greene, M.S. Owens, J.E. Baker, and R.K. Larsen. 2008. Nutrient budgets and management actions in the Patuxent River Estuary, Maryland. *Estuaries and Coasts* 31(4): 623-651.

Breitburg, D.L. and R.S. Fulford. 2006. Oyster-sea nettle interdependence and altered control within the Chesapeake Bay ecosystem. *Estuaries and Coasts* 29(5): 776-784.

Breitburg, D. and R. Burrell. 2014. Predator-mediated landscape structure: seasonal patterns of spatial expansion and prey control by Chrysaora quinquecirrha and Mnemiopsis leidyi. *Mar. Ecol. Prog. Ser*. 510:183-200.

Cargo, D.G. and D.R. King. 1990. Forecasting the abundance of the sea nettle, Chrysaora quinquecirrha, in the Chesapeake Bay. *Estuaries and Coasts* 13(4): 486-491.

Christian, R.R., J.N. Boyer and D.W. Stanley. 1991. Multi-year distribution patterns of nutrients within the Neuse River estuary, North Carolina. *Mar. Ecol. Prog. Ser.* 71: 259-274.

Keefe, C.W., D.A. Flemer and D.H. Hamilton. 1976. Seston distribution in the Patuxent River estuary. *Chesapeake Science* 17(1): 56-59.

Keefe, C.W., K.L. Blodnikar, W.R. Boynton, C.A. Clark, J.M. Frank et al. 2004. Nutrient Analytical Services Laboratory Standard Operating Procedures. Special Publication Series No. SS-80-04-CBL. University of Maryland Center for Environmental Studies. 65 pp.

Kemp, W.M., R. Batuik, R. Bartleson, P. Bergstrom, V. Carter et al. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: Water quality, light regime, and physical-chemical factors. *Estuaries and Coasts* 27(3): 363-377.

Kemp, W.M. and W.R. Boynton. 1992. Benthic pelagic interactions: Nutrient and Oxygen dynamics. pp. 149-221. In: D.E. Smith, M. Leffler and G, Mackiernan (eds.). *Oxygen Dynamics in the Chesapeake Bay: A Synthesis of Recent Research*. Maryland Sea Grant College. College Park, MD.

Kimmel, D.G., W.D. Miller, L.W. Harding, E.D. Houde, and M.R. Roman. 2009. Estuarine ecosystem response captured using a synoptic climatolgy. *Estuaries and Coasts*. 32(3): 403-409.

Loeb, M.J. 1972. Strobilation in the Chesapeake Bay sea nettle Chrysaora quinquecirrha. I. The effects of environmental temperature changes on strobilation and growth. Journal of Experimental Zoology.

Malone, T.C., L.H. Crocker, S.E. Pike and B.W. Wendler. 1988. Influences of river flow on the dynamics of phytoplankton production in a partially stratified estuary. *Mar. Ecol. Prog. Ser*. 48: 235-249.

Tillmans, L. 2016. Personal Communication. R.N., Disease Surveillance and Response. Calvert County Health Department. Prince Frederick, MD.

Nichols, F.H. and J.E. Cloern. 1985. Time scales and mechanisms of estuarine variability, a synthesis from studies of San. Francisco Bay. *Hydrobiologia* 129: 229-237.

Orth, R. J., W. C. Dennison, J. S. Lefcheck, C. Gurbisz, M. Hannam, J. Keisman, J. B. Landry, K. A. Moore, R. R. Murphy, C. J. Patrick, J. Testa, D. E. Weller, and D. J. Wilcox. 2017. Submersed aquatic vegetation in Chesapeake Bay: sentinel species in a changing world. *Bioscience* 67:698-712. doi:10.1093/biosci/bix058

Purcell, J.E. 2005. Climate effects on formation of jellyfish and ctenophore blooms: a review. *Journal of the Marine Biological Association of the United Kingdom.* 85: 461-476.

Summers, R.M. 1989. Point and non-point source nitrogen and phosphorus loading to the northern Chesapeake Bay. Maryland Department of the Environment, Water Management Administration, Chesapeake Bay and Special Projects Program. Baltimore, MD.

United States Geological Survey. 2021. Stream Flow Data for Site #01594440: Patuxent River Near Bowie, MD. http://waterdata.usgs.gov/nwis/

Wainger, L., H. Yu, K. Gazenski, and W. Boynton. 2016. The relative influence of local and regional environmental drivers of algal biomass (chlorophyll-*a)* varies by estuarine location. *Estuarine, Coastal and Shelf Science* 178: 65-76.