Chapter 4.3

Dissolved oxygen status and trends in the Maryland Coastal Bays

Catherine Wazniak[1], Carol McCollough[1], Brian Sturgis[2]

[1]Maryland Department of Natural Resources, Tidewater Ecosystem Assessment, Annapolis, MD 21401
[2]United States Department of the Interior, National Park Service, Assateague Island National Seashore, Berlin, MD 21811

Abstract
Although the Coastal Bays are shallow lagoons that typically do not stratify, low dissolved oxygen (DO) concentrations were observed in some areas. Daytime measurements showed infrequent dissolved oxygen concentrations below 5 mg/L during the summer at some locations. Diel data from continuous monitors showed oxygen values less than 5 mg/L frequently in tributaries (20-60% of the time), but less often in the open bays. DO concentrations below 3 mg/L were observed infrequently by monthly daytime sampling, however diel sampling results revealed more pervasive and lengthy conditions of such extreme low DO events, often occurring at night and early morning.

Introduction
Eutrophication and it's impacts to living resources was identified in the Maryland Coastal Bays Characterization Report as the most pressing environmental issue facing Maryland's Coastal Bays. As a result, the Scientific and Technical Advisory Committee (STAC) recommended that the initial focus of the monitoring plan be on nutrient and sediment inputs to the Coastal Bays and their impacts on living resources (Wazniak 1999). DO concentration in water is often used to gauge the overall health of the aquatic environment and is needed to maintain suitable fisheries habitat. Concentrations often vary with depth, and the lowest values are found near the bottom. When excessive amounts of algae die and sink to the bottom. The process of algal decomposition by bacteria consumes oxygen. The resulting low levels of oxygen that result can impair the feeding, growth and reproduction of aquatic life in the bays. Animals that cannot move about easily may die. Fish and crabs generally detect and avoid areas with low DO. Oxygen concentrations that trigger avoidance (around 5 mg/L for most species) tend to be two to three times higher than lethal DO levels.

Daytime DO measurements are problematic in a non-stratified embayment. Because the Coastal Bays are shallow and generally well-mixed bays, low DO typically does not persist for long periods of time and cannot usually be detected by daytime measurement alone. Also, exceedingly high daytime DO levels that result from phytoplankton blooms often surpass threshold levels, and then plummet at night as photosynthesis ceases and respiration continues. Daily oxygen fluctuations in the Coastal Bays vary between one and six mg/L/day depending on season and chlorophyll abundance (Wazniak 2002). Minimum DO levels occur in the early to mid-morning, and monitoring programs typically collect samples hours later, between 9 a.m. and 2 p.m. Other factors that may impact the use of daytime DO as a primary indicator of eutrophic impacts include naturally low DO in areas with extensive marshes (especially at ebb tide) and areas of abundant benthic algae. Additionally, some areas have high sediment oxygen demand which contributes to low water column oxygen.

Maryland state water quality criteria require a minimum DO concentration of 5 mg/L at all times (Code of Maryland, COMAR, 1995). This water quality standard is needed for the following aquatic target species in the Coastal Bays: hard clam (*Mercenaria mercenaria*), alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), white perch (*Morone americana*) and striped bass (*Morone saxatilis*). Blue crabs (*Callinectes sapidus*), bay anchovies (*Anchoa mitchelli*); alewife and blueback herring juveniles need a minimum of 3 mg/L DO. More tolerant species such as spot (*Leiostomus xanthurus*) and Atlantic menhaden (*Brevoortia tyrannus*) need a minimum of 2 mg/L and 1.1 mg/L, respectively, before significant mortalities occur (Funderburk *et al.* 1991). While these species may survive at such low oxygen values, they will not grow or reproduce.

Data Sets

Oxygen concentrations at fixed sampling stations were monitored monthly during the day by the DNR, the National Park Service, Assateague Island National Seashore (ASIS), and volunteers with MCBP (DNR 2014a and 2014b, ASIS 2001) (Maryland Department of Natural Resources 2014).

Continuous monitors have been operated by DNR at five sites between 2007 and 2013, and by ASIS at two sites between 2009 and 2013. Continuous monitors collect data at 15-minute intervals.

During August 2010, a single oxygen profile was collected at 25 fixed sites for U.S. Environmental Protection Agency's (EPA) National Coastal Condition Assessment (NCCA).

Management Objective: To maintain suitable fisheries (all benthic community) habitat.

DO Indicator 1: Minimum of 5 mg/L during diurnal (day)
DO Indicator 2: Minimum of 3 mg/L at any time

Analyses

Status Analyses:

1. Fixed Monitoring Data: A 98th percentile dissolved oxygen value was determined for the summer season (June through September) for rolling three-year periods from 2007-2013 for each fixed station monitoring station (Figure 4.3.1). The Maryland Coastal Bays Scientific and Technical Advisory Committee (STAC) developed threshold values based on living resources indicators (see Management Objective above). Based on these criteria, attainment categories were determined (Table 4.2.1). Each calculated value was compared to its category cut-off values using the non-parametric Wilcoxon sign-rank test. Those values that were significantly different at p=0.01 from both category cutoffs were considered statistically significant overall.

2. Continuous Monitoring Data: DO concentrations from continuous monitors were

analyzed annually for the percent time the concentrations fell below the 5 and 3 mg/L thresholds.

3. National Coastal Condition Assessment (NCCA) 2010 data: During August 2010, one visit was made to each of 25 stations (Figure 4.3.2), providing a snapshot of water quality conditions. Bottom DO values were placed into STAC attainment categories (Table 4.3.1).

4. Total Maximum Daily Load (TMDL) analyses: Percent time dissolved oxygen failed the 5mg/L threshold (June – August).

Trend Analysis:

Trends were not determined for oxygen due to the temporal variability of sample collection. The time of day when measurements were taken was not consistent within or among sampling programs.

Figure 4.3.1 Location of fixed station monitoring sites for Maryland Department of Natural Resources, Assateague Island National Seashore and Maryland Coastal Bays Volunteer monitoring programs.

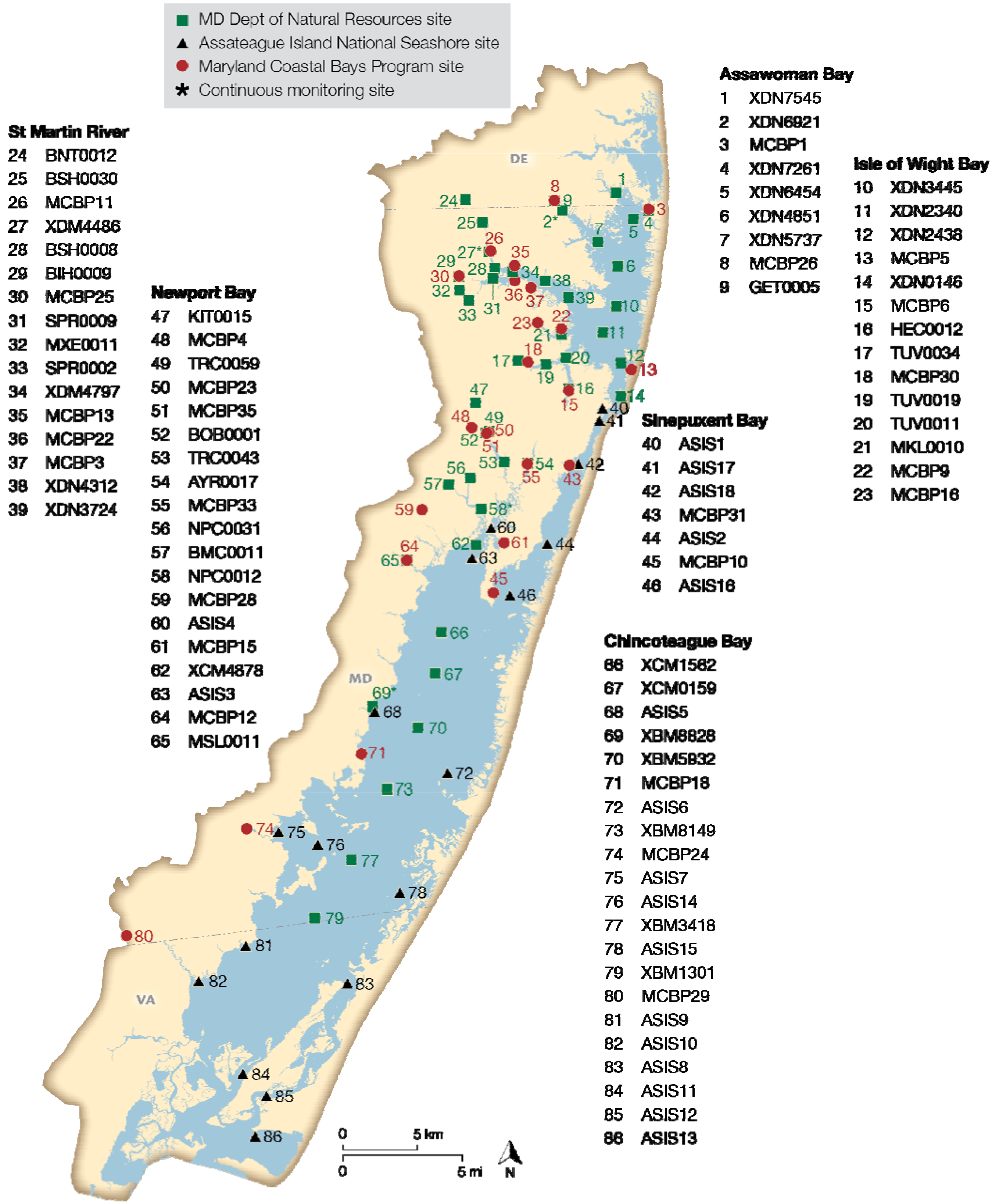

Figure 4.3.2 Location of 2010 National Coastal Condition Assessment and Maryland Coastal Bays benthic sampling sites.

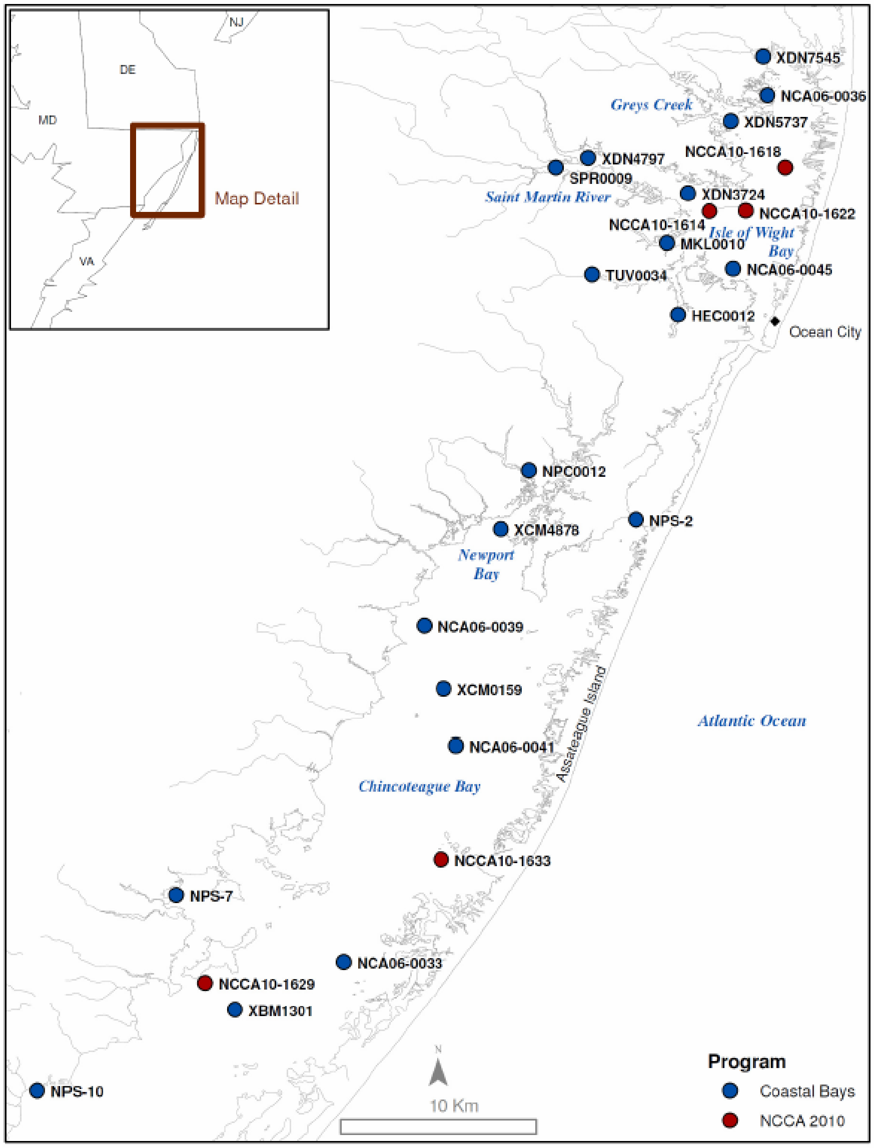

Table 4.3.1 Category values for dissolved oxygen concentration in the Maryland Coastal Bays. Bolded values are living resources and dissolved oxygen indicator values.

Category	**Dissolved oxygen values for category**
Better than living resources objective	> 7 mg/L
Meets living resources objective	6 - 7 mg/L
Borderline living resources objective	**5 - 6 mg/L**
Living resources threatened	**3 - 5 mg/L**
Does not meet objectives	< 3 mg/L

Results: Status of dissolved oxygen

Figure 4.3.3 The status of dissolved oxygen in the Maryland Coastal Bays (2001-2013).

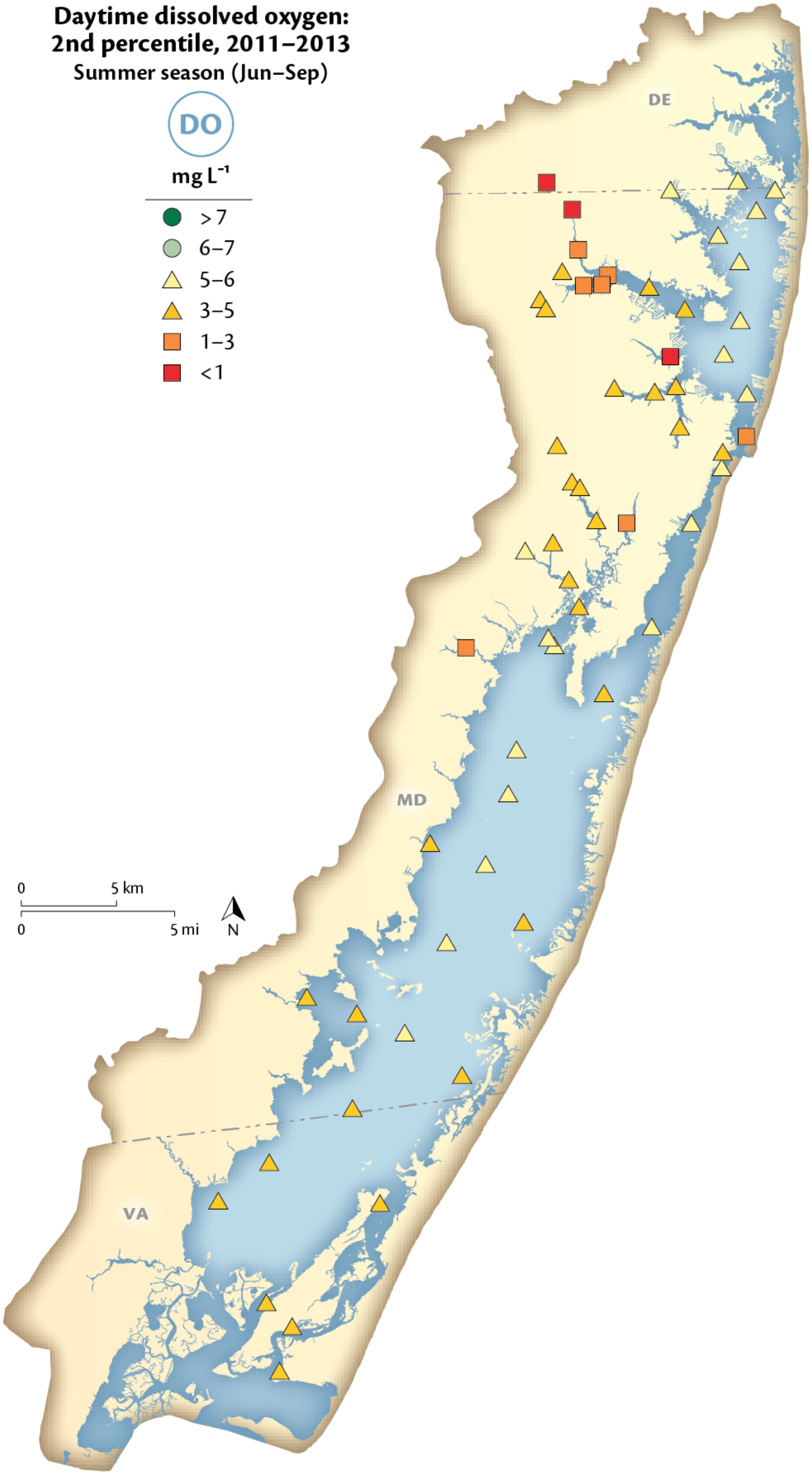

Table 4.3.2 Annual percent of time summer dissolved oxygen (June – September) threshold levels were not met (e.g. failure) at continuous monitoring stations in the Maryland Coastal Bays (2007 – 2013).

	Station	Threshold Level	2007	2008	2009	2010	2011	2012	2013
Greys Creek	XDN6921	DO<5	NS	31.5%	43.1%	43.9%	44.9%	33.7%	48.1%
		DO<3	NS	9.6%	18.4%	17.8%	18.0%	8.6%	18.8%
Bishopville Prong	XDM4486	DO<5	48.9%	39.6%	50.5%	40.7%	55.8%	43.8%	49.2%
		DO<3	24.7%	15.0%	24.6%	16.1%	26.4%	18.2%	27.3%
Turville Creek	TUV0021	DO<5	42.4%	NS	NS	NS	NS	NS	NS
		DO<3	13.1%	NS	NS	NS	NS	NS	NS
Newport Creek	NPC0012	DO<5	42.2%	30.6%	38.8%	39.3%	41.8%	28.7%	21.3%
		DO<3	11.1%	4.5%	7.3%	7.8%	10.2%	2.6%	0.5%
Public Landing	XBM8828	DO<5	14.5%	18.4%	9.2%	15.9%	18.6%	16.4%	10.9%
		DO<3	0.3%	0.6%	0.7%	1.2%	0.4%	0.1%	0.6%
Sinepuxent at bridge	ASIS TG1	DO<5	NS	NS	43.6%	43.7%	28.0%	24.3%	5.2%
		DO<3	NS	NS	6.2%	12.6%	4.9%	0.2%	0.02%
Tingle Island	ASIS TG2	DO<5	NS	NS	45.4%	31.2%	30.1%	11.5%	1.3%
		DO<3	NS	NS	9.2%	8.7%	1.8%	0.6%	0.1%

NS – not sampled

Assawoman Bay

Fixed Station Status: All stations are borderline or fail the minimum living resources threshold (5 mg/L) (Table 4.3.3).

Table 4.3.3 Rolling three year assessment of 98th percentile of dissolved oxygen (mg/L) during the summer months (June-Sept) in Assawoman Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Greys Creek	M26			0.6	0.6	0.6
	GET0005	1.3	1.3	2.7	2.7	3.5
Fenwick Ditch	XDN7261	4.6	4.4	4.0	4.0	4.0
	MCBP 1		3.7	3.7	**3.7**	3.8
Assawoman Bay	XDN4851	5.2	5.2	5.0	5.0	4.7
	XDN5737*	5.1	5.0	4.5	4.5	4.5
	XDN6454	4.0	4.0	4.0	4.4	4.0
	XDN7545*	3.9	3.9	3.8	3.8	3.8

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring Status: The continuous monitoring station on Grey's Creek failed the oxygen living resource threshold (3 mg/L) between 9.6 and 18.8% of the time during the summer months between 2007 and 2013. DO concentrations fell below the threatened threshold (5 mg/L) between 31 and 48% of the time.

Table 4.3.4 Annual summer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring site in Assawoman Bay

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
XDN6921 Grey's Creek	**DO<5**	NS	31.5%	43.1%	43.9%	44.9%	33.7%	48.1%
	DO<3	NS	9.6%	18.4%	17.8%	18.0%	8.6%	18.8%

National Coastal Condition Assessment status: During the 2010 NCCA, all stations in Assawoman Bay were sampled mid-day, when oxygen values are expected to reach their highest. Yet, all stations failed the diurnal minimum living resources threshold (5 mg/L), even at depths of 1 m or less (NCA06-0036, XDN7545).

Table 4.3.5 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, in Assawoman Bay

Station	Date	Time	Depth (m)	Bottom DO
XDN7545	2-Aug	11:13	1.0	3.47
NCA06-0036	2-Aug	13:06	0.7	4.32
XDN5737	2-Aug	14:00	1.5	4.49
NCCA10-1618	2-Aug	14:47	1.3	4.83

Total Maximum Daily Load Status: The TMDL analysis of the growing season all sites except one failed the threshold >5% of the time. When just the summer months were analyzed this increased significantly (31-47%) (Table 4.3.21).

St. Martin River

Fixed Station Status: All stations were borderline or failed the living resources threshold (5 mg/L) during all analysis periods. No station passed this threshold during the two most recent analysis periods.

Table 4.3.6 Rolling three year results for the 98th percentile of dissolved oxygen (mg/L) in St. Martin River (June- September).

Area	STATION	07-09	08-10	09-11	10-12	11-13
Bishopville Prong	BNT0012	4.3	4.3	3.1	3.1	3.1
	BSH0030	0.3	0.3	0.1	0.1	0.1
	MCBP 11			3.1	2.7	2.7
	XDM4486	1.8	2.6	0.1	0.1	0.1
	BSH0008	2.4	3.0	1.2	1.2	1.2
Spring Branch	MXE0011	4.2	4.2	4.0	4.0	4.0
	BIH0009	4.7	4.9	4.7	4.7	4.7
	MCBP 25			5.0	4.5	4.5
	SPR0009*	0.5	0.5	0.5	2.0	2.0
	SPR0002	2.1	2.1	2.1	2.1	1.6
St. Martin River	MCBP 13			4.8	4.8	0.1
	XDM4797*	2.7	2.7	2.7	2.9	1.0
	MCBP 22		5.4	3.7	3.7	3.7
	MCBP 3		5.4	3.5	3.5	3.5
	XDN4312	3.8	3.8	3.3	3.3	2.3
	XDN3724*	3.2	4.0	4.0	4.5	4.5

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring Status: Over the 7-year period, the continuous monitoring station on Bishopville Prong failed the living resources diurnal DO threshold (5 mg/L) between 39 and 56% of the time (2008 and 2011, respectively). Failure relative to the minimum threshold of 3 mg/L ranged from 15 to 27% of the time, (2008 and 2013, respectively). There is no pattern of improvement or deterioration in oxygen conditions measured by continuous monitoring.

Table 4.3.7 Annual summer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring site in the St. Martin River

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
XDM4486 Bishopville Prong	**DO<5**	48.9%	39.6%	50.5%	40.7%	55.8%	43.8%	49.2%
	DO<3	24.7%	15.0%	24.6%	16.1%	26.4%	18.2%	27.3%

National Coastal Condition Assessment status: In contrast to the picture painted by the 3-year status values, one-time measurements of summer DO at three stations during 2010 all passed the living resources threshold of 5 mg/L. Such distinct differences demonstrate the risk of using single samples to characterize a parameter that is highly variable on daily and seasonally temporal scales. At St. Martin River stations, DO attainment as measured by NCCA is completely reversed compared to 3-year status, with the upstream stations appearing to be in better condition than the station at the river mouth, which is a misleading depiction of DO. Continuous monitoring data available for that date and time shows a DO of 8.44 mg/L (130% saturation). The entire daily range, however shows DO declining below 5 mg/L at 04:45 (4.98 mg/L) with a minimum of 3.76 mg/L (55.3% saturation) at 07:30. Oxygen concentrations remained below 5 mg/L until 10:00, for a total of 5.25 hours.

Table 4.3.8 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, in the St. Martin River.

Area	Station	Date	Time	Depth (m)	Bottom DO
Spring Branch	SPR0009	4-Aug	13:00	0.8	6.36
St. Martin River	XDM4797	4-Aug	13:30	1.0	7.52
	XDN3724	4-Aug	12:27	1.5	5.03

Total Maximum Daily Load Status: The TMDL analysis of the growing season revealed all of the sites in the St Martin River failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed this increased significantly (30-66%) (Table 4.3.21).

Isle of Wight Bay

Fixed Station Status: The open bay sites closest to Ocean City Inlet (XDN0146, XDN2438) consistently achieved the living resources threshold (5 mg/L), probably due to the influence of cool, oxygenated ocean water. Two additional open bay sites (XDN2340, MCBP34) also achieved this threshold during most analysis periods. All tributary stations consistently failed the threshold of 5 mg/L, and MCBP16, MKL0010, MCBP30, and MCBP6 also consistently failed the minimum dissolved oxygen threshold of 3 mg/L. MKL0010 is a deep station, which has a negative effect on oxygen compared to shallower stations.

Table 4.3.9 Rolling three year results of the 98th percentile of dissolved oxygen (mg/L) in Isle of Wight Bay (June- September) compared to the percent failure of the Total Maximum Daily Load standard of 5mg/L (June- August) during 2011-2013.

Area	STATION	07-09	08-10	09-11	10-12	11-13
Manklin Creek	MCBP 16		2.3	1.9	1.9	1.9
	MKL0010*	0.1	0.1	**0.1**	**0.1**	**0.1**
	MCBP 9		3.4	3.1	0.9	0.9
Turville Creek	MCBP 34		5.9	5.9	5.9	
	TUV0034*	4.4	**4.4**	3.7	3.4	3.4
	MCBP 30			2.8	2.8	2.8
	TUV0019	4.0	4.0	4.0	4.1	4.3
	TUV0011	**4.6**	4.6	4.6	3.5	3.5
Herring Creek	HEC0012*	4.4	4.4	3.7	3.7	3.7
	MCBP 6			2.7	2.6	1
Isle of Wight Bay	XDN3445	4.6	4.6	4.6	5.3	3.4
	XDN2340	4.3	5.0	5.0	5.3	5.3
	MCBP 5			3.7	3.7	3.7
	XDN2438	5.8	6.0	5.6	5.6	5.6
	XDN0146	5.3	5.3	6.1	5.1	5.1

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blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring status: A continuous monitor was deployed in this segment, in Turville Creek, only during 2007. The 5 and 3 mg/L criteria were not met 42% and 13% of the time (Table 4.3.10).

Table 4.3.10 Annual summer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring sites in Isle of Wight Bay

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
TUV0021 Turville Creek	**DO<5**	42.4%	NS	NS	NS	NS	NS	NS
	DO<3	13.1%	NS	NS	NS	NS	NS	NS

NS – not sampled

National Coastal Condition Assessment status: Instantaneous DO measurements collected during 2010 again show very different results from full-season and continuous monitoring. Upstream and open bay sites appear little different from one-another, with the site closest to Ocean City Inlet (NCA06-0045) exceeding the living resources diurnal threshold (5 mg/L), showing the mitigating influence of the ocean on DO. In contrast, 3-year 98th percentiles show that upstream sites consistently fail one or both thresholds. This one time assessment does not reveal the same low oxygen problem that is shown by more routine monitoring (Table 4.3.9).

Table 4.3.11 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, assessment in Isle of Wight Bay

Area	Station	Date	Time	Depth (m)	Mean DO
Manklin Creek	MKL0010	4-Aug	11:41	0.8	5.58
Turville Creek	TUV0034	4-Aug	18:15	2.5	4.34
Herring Creek	HEC0012	4-Aug	10:27	0.5	4.05
Isle of Wight Bay	NCCA10-1614	3-Aug	8:01	1.3	4.63
	NCCA10-1614	7-Sep	12:30	1.6	5.55
	NCCA10-1622	2-Aug	17:26	1.0	4.20
	NCA06-0045	4-Aug	8:50	2.7	6.17

<u>TMDL Status</u>: The total maximum daily load analysis of the growing season results showed half of the sites in Isle of Wight Bay failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (17-74%) (Table 4.3.21).

Sinepuxent Bay

<u>Fixed Station Status</u>: Until the 2010-12 analysis period, no site met the living resources threshold of >5 mg/L. Four sites never met it during any analysis period. All but one site (MCBP10 – South Point Landing) did meet the instantaneous minimum threshold of threemg/l (Figure 4.3.3 and Table 4.3.12). Improvements have occurred at sites well within the bay (ASIS 2, ASIS17, ASIS18), but the continued failure of ASIS 1, close to Ocean City Inlet and XDN0146, is puzzling.

Table 4.3.12 Rolling three-year assessment of summer (June – Sept) dissolved oxygen (mg/L) in Sinepuxent Bay (98th percentile).

STATION	07-09	08-10	09-11	10-12	11-13
ASIS 16	4.6	4.6	4.6	4.1	4.0
MCBP 10	0.3	0.3	0.3	1.5	1.5
ASIS 2*	5.0	4.6	4.6	4.6	5.3
MCBP 31		4.1	3.6	3.6	3.6
ASIS 18	4.8	4.8	4.8	5.4	5.5
ASIS 17	4.9	4.9	4.9	5.0	**5.7**
ASIS 1	4.8	4.4	4.4	4.2	4.2

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blank cells have no data for that timeframe
* sampled during 2010 NCCA

<u>Continuous monitoring Status</u>: ASIS maintains a continuous monitor at a tide gauge station near the Verrazano Narrows Bridge. Data available from 2009-13 shows that the

site failed the 3 mg/L criterion less than 10% of the time in all years except 2010, when it failed 12.6% of the time (Table 4.3.13). Failure at the 5 mg/L criterion was more frequent, about 43% in 2009-10, but improved markedly in 2011-12 with failure between 24 and 28% time (Table 4.3.13). Encouragingly, in 2013 failure improved to only 5.2% of the time.

Table 4.3.13 Annual summer (June-September) dissolved oxygen threshold (either 3 or 5 mg/L) percent failure at continuous monitoring sites in Sinepuxent Bay (ASIS Tide Station 1 near the Verrazano Bridge).

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
ASIS TS1	DO<5	NS	NS	43.6%	43.7%	28.0%	24.3%	5.2%
	DO<3	NS	NS	6.2%	12.6%	4.9%	0.2%	0.02%

NS – not sampled

National Coastal Condition Assessment status: At station ASIS 2, the instantaneous DO measured during 2010 was well above the living resources threshold of 5 mg/L, but again, the measurement was collected during the mid-afternoon when DO concentrations are expected to be at a high point on the diurnal cycle. This was better oxygen value compared to the fixed station three year analyses (Table 4.3.12) showing a single data point may not capture low oxygen in non-stratified systems.

Table 4.3.14 2010 National Coastal Condition Assessment instantaneous dissolved oxygen in Sinepuxent Bay.

Station	Date	Time	Depth (m)	Mean DO
ASIS-2	4-Aug	16:00	1.8	6.94

Total Maximum Daily Load Status: The TMDL analysis of the growing season dissolved oxygen revealed two out of five sites in Sinepuxent Bay failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (13-15%) (Table 4.3.21).

Newport Bay

Fixed Station Status: With the exception of Beaverdam Creek (BMC0011) and the mouth of Newport Creek (A3), all sites consistently failed the > 5 mg/L threshold (Table 4.3.15).

Marshall Creek (MSL0011), the head of Trappe Creek (MCBP 23), and the mouth of Newport Creek (MCBP 15) failed the instantaneous minimum of 3 mg/L threshold. Marshall Creek is one of the deepest stations sampled and stratifies. The station at the mouth of Newport Creek is within a marsh embayment that may receive poor exchange with the mainstem creek.

The Ayers Creek sites are co-located. During the most recent 3-year analysis periods, both sets of measurements consistently failed the instantaneous minimum of 3 mg/L threshold (Figure 4.3.3).

Table 4.3.15 Three-year 98-percentile of dissolved oxygen (mg/L) in Newport Bay.

Area	STATION	07-09	08-10	09-11	10-12	11-13
Trappe Creek	KIT0015	2.9	2.9	3.8	3.8	4.4
	BOB0001	1.5	4.5	4.3	4.3	4.3
	MCBP 4			5.1	2.8	2.5
	MCBP 23	0.9	0.9	0.9	1.7	1.5
	TRC0059	2.4	3.1	4.4	4.1	4.1
	MCBP 35	1.4	3.0	3.4	3.4	3.4
	TRC0043	3.1	4.0	4.0	4.0	4.8
Ayers Creek	AYR0017	3.8	3.9	3.9	2.7	2.7
	MCBP 33	2.1	2.1	1.7	1.7	1.5
Newport Creek	BMC0011	**6.4**	6.3	6.3	5.9	5.9
	NPC0031	3.1	3.6	3.0	3.0	3.0
	NPC0012*	3.6	3.6	3.6	4.7	4.8
	ASIS 4	4.8	4.7	4.6	4.6	4.6
	MCBP 15	0.1	0.5	0.5	1.1	1.2
Newport Bay	XCM4878*	3.8	3.8	3.9	3.9	4.6
	ASIS 3	4.7	4.8	4.8	5.0	5.0
Bassett Creek	MCBP 28	4.6	4.6	1.2	1.2	1.2
Marshall Creek	MSL0011	1.8	1.8	1.8	2.4	2.4
	MCBP 12	0.9	0.9	0.1	0.1	0.1

bold values are significantly different from boundary values.
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring status: Data available from the continuous monitor at Newport Creek (2007-2013) shows that the site failed the 3mg/L criterion less than 10% of the time in all years except 2011 (Table 4.3.16) Failure at the 5 mg/L criterion was more frequent, varied between 21-42% with the lowest failure rate in 2013.

Table 4.3.16 Percent failure of summer (June-September) dissolved oxygen, DO, thresholds in Newport Creek (2007-2013).

Area	Station	Threshold	2007	2008	2009	2010	2011	2012	2013
Newport Creek	NPC0012	DO<5	42.2%	30.6%	38.8%	39.3%	41.8%	28.7%	21.3%
		DO<3	11.1%	4.5%	7.3%	7.8%	10.2%	2.6%	0.5%

National Coastal Condition Assessment status: The sampling in 2010 occurred at only two stations in Newport Bay. Rolling 3-year status analyses show both of these stations consistently failing the living resources threshold (5 mg/L) during all analysis periods, but the single event samples collected for NCCA show DO exceeding the highest threshold (>7 mg/L) (Table 4.3.17). These data provide strong evidence that instantaneous measurements of oxygen do not provide accurate measures of ecosystem condition.

Table 4.3.17 2010 NCCA instantaneous dissolved oxygen, DO, in Newport Bay

Area	Station	Date	Time	Depth (m)	Mean DO
Newport Creek	NPC0012	5-Aug	16:45	0.4	10.45
Newport Bay	XCM4878	3-Aug	13:15	1.6	7.05

Total Maximum Daily Load Status: The TMDL analysis of the growing season demonstrated three quarters of the sites in Newport Bay failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (13-55%) (Table 4.3.21).

Chincoteague Bay

Fixed Station Status: Open bay sites tended to meet the living resources (5 mg/L) and instantaneous minimum (3 mg/L) thresholds. All nearshore stations except MCBP18 failed the living resources threshold (Table 4.3.18). The single tributary station (MCBP29), located at the dam on Big Mill Pond, failed all thresholds, and showed that Big Mill Pond was a source of poorly oxygenated water to Swan Gut.

Table 4.3.18 Three-year 98th percentile of dissolved oxygen (mg/L) in Chincoteague Bay.

Area	STATION	07-09	08-10	09-11	10-12	11-13
Maryland	XCM1562	5.0	4.7	4.7	4.7	5.3
	XCM0159*	5.2	4.7	4.7	4.7	5.4
	ASIS 5	4.2	4.2	4.2	4.5	4.5
	XBM5932	5.5	5.6	5.6	5.6	**5.5**
	MCBP 18			5.3	5.2	5.2
	ASIS 6	4.2	4.2	4.2	4.6	4.9
	XBM8149	5.4	4.6	4.6	4.6	5.4
	MCBP 24			3.8	3.8	3.8
	ASIS 7*	4.6	4.0	3.8	3.8	3.8
	ASIS 14	4.8	4.7	4.7	4.7	4.9
	XBM3418	5.4	5.4	5.2	5.2	5.2
	ASIS 15	5.0	4.4	4.4	4.4	4.5
	MCBP 27			3.7	3.7	3.7
	XBM1301*	5.4	5.3	5.0	5.0	4.8
	MCBP 29		0.9	0.9	0.9	
Virginia	ASIS 9	4.1	4.6	4.6	4.7	4.8
	ASIS 10*	4.7	3.5	3.5	3.5	4.7
	ASIS 8	4.2	4.2	4.2	4.2	**4.5**
	ASIS 11	4.9	4.6	4.6	4.6	4.8
	ASIS 12	3.7	3.5	3.5	3.5	4.8
	ASIS 13	4.8	5.4	4.7	4.7	4.5

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring status: The continuous monitoring station at Tingles Island was active only during the last five years of the report period. Dissolved oxygen failed the living resources threshold (5 mg/L) between 1.3 and 45.4% of the time (Table 4.3.19). On a positive note, the failure rate has declined annually through the entire period. Similarly, the failure rate for the instantaneous minimum threshold declined over the entire period, from 9.2% of the time to 0.1%. Public Landing failed the living resources DO threshold (5 mg/L) between 9.2 and 18.6% of the time (2009 and 2011, respectively) (Table 4.3.19). Failure relative to the minimum threshold of 3 mg/L ranged from 0.1 to 1.2% of the time, (2012 and 2010, respectively).

Table 4.3.19 Annual summer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring stations in Chincoteague Bay

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
ASIS TG2 Tingles Island	DO<5	NS	NS	45.4%	31.2%	30.1%	11.5%	1.3%
	DO<3	NS	NS	9.2%	8.7%	1.8%	0.6%	0.1%
XBM8828 Public Landing	DO<5	14.5 %	18.4%	9.2%	15.9%	18.6%	16.4%	10.9%
	DO<3	0.3%	0.6%	0.7%	1.2%	0.4%	0.1%	0.6%

NS – not sampled

National Coastal Condition Assessment status: NCCA sampling in 2010 occurred at 9 stations in Chincoteague Bay. All stations met the living resources threshold (5 mg/L) for these single time samples, and three (NCA06-0041, XCM0159, ASIS10) exceeded the seagrass objective (Table 4.3.20). This is consistent with the conmon data, which show that meeting or exceeding the threshold is more likely than failure in Chincoteague Bay. These data provide strong evidence that instantaneous measurements of oxygen do not provide accurate measures of ecosystem condition.

Table 4.3.20 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, in Chincoteague Bay

Area	Station	Date	Time	Depth (m)	Mean DO
Maryland	NCA06-0039	3-Aug	14:11	1.7	6.60
	XCM0159	3-Aug	18:20	2.0	7.36
	NCA06-0041	3-Aug	15:09	2.0	7.35
	NCCA10-1633	3-Aug	16:35	1.3	6.50
	ASIS 7	5-Aug	11:29	0.9	6.10
	NCA06-0033	5-Aug	10:44	1.6	6.18
	NCCA10-1629	5-Aug	12:27	1.0	6.46
	XBM1301	5-Aug	9:30	1.8	6.10
Virginia	ASIS 10	5-Aug	14:04	1.0	7.13

Total Maximum Daily Load Status: The TMDL analysis of the growing season approximately half of the sites failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (9-31%) (Table 4.3.21).

Table 4.3.21 Total Maximum Daily Load, TMDL, analysis- 2001-2004 vs 2011-2013 water quality monitoring data indicating the percent of time dissolved oxygen levels are not meeting the TMDL endpoint of 5 mg/L (all oxygen readings from profile data used). Red box indicates greater failure rate in more recent period (2011-2013) compared with TMDL analysis (2001-2004).

Sub-basin	Station Name	Growing season (May-Oct) % > Threshold		Summer (June-August) % > Threshold	
Assawoman Bay		2001-2004	**2011-2013**	2001-2004	**2011-2013**
	GET0005	16.7	**17.6**	16.7	47.6
	XDN4851	6	**5.6**	9.1	11.1
	XDN5737	32.1	**3.3**	23.5	5.8
	XDN6454	8.8	**17**	14.7	33.3
	XDN7261	26.2	**16.2**	19.2	31.3
	XDN7545	36.9	**20.4**	39.3	40.7
St. Martin River	BSH0008	44.2	**35.5**	57.1	**56.1**
	BSH0030	25	**38.9**	25	**66.7**
	SPR0002	12.2	**32.5**	16.7	**55**
	SPR0009	25	**22.2**	39.1	**35.7**
	XDM4486	42.1	**50**	47.1	**68**
	XDM4797	27.7	**27**	39.1	**39.1**
	XDN3724	13.2	**13.9**	22.2	**29.8**
	XDN4312	35	**19.6**	51.7	**38.8**
Isle of Wight Bay	TUV0011	45.9	**7.5**	45.5	**16.8**
	TUV0019	25	**16.7**	41.7	**22.2**
	TUV0034	17.4	**44.4**	18.4	**46**
	MKL0010	65.5	**48.1**	74.3	**74.4**
	XDN0146	0	**0**		**0**
	XDN2340	1.4	**0**		**0**
	XDN2438	0	**0**		**0**
	XDN3445	29.5	**0.9**	25	**1.9**
Newport Bay	AYR0017	8.3	**11.1**	16.7	**25.4**
	BMC0011	0	**0**	?	**0**
	BOB0001	8.3	**16.7**	8.3	**20.6**
	KIT0015	4.2	**12.5**	8.3	**25**
	MSL0011	54.2	**38.9**	75	**55.6**
	NPC0012	41.7	**11.1**	58.3	**12.7**
	NPC0031	29.2	**27.8**	25	**31.7**
	TRC0043	4.3	**5.6**	9.1	**12.7**
	TRC0059	25	**16.7**	25	**20.6**
	XCM4878	10.3	**2.8**	13	**5.6**
	ASIS 3	4.4	**1.4**	5.6	**0**
	ASIS 4	10.8	**18.2**	18.8	**12.7**
Sinepuxent Bay	ASIS 1	8.9	**8.2**	15	**13.1**
	ASIS 2	0	**0**	0	**0**
	ASIS 16	2	**14.4**	5	**15.6**
	ASIS 17	0	**0**	0	**0**
	ASIS 18	0	**0**	0	**0**
Chincoteague Bay, MD	XBM1301	1.4	**5.6**	2.7	**11.1**
	XBM3418	4.3	**0**	8.3	**0**
	XBM5932	0	**0**		**0**
	XBM8149	8.7	**0**	16.7	**0**
	XCM0159	6.5	**0**	12.5	**0**
	XCM1562	5.9	**0**	11.1	**0**
Chincoteague Bay, VA	ASIS 5	0	**18.2**	0	**26.5**
	ASIS 6	0	**4**	0	**0**
	ASIS 7	17.1	**20.4**	35.7	**31.2**

	ASIS 8	10.5	**16.7**	25	**21.3**
	9	8.9	**10.5**	22.2	**9.7**
	10	2.4	**15.5**	5.9	**11.1**
	11	1.6	**4.6**	4.5	**8.7**
	12	0	**5**	0	**9.8**
	13	5.1	**6.6**	4	**10.4**
	ASIS 14	9.3	**1.4**	22.2	**0**
	ASIS 15	9.6	**5.6**	23.8	**12.7**

Summary
Although the Coastal Bays are shallow lagoons, which typically do not stratify, low oxygen values were frequently found in some areas. Daytime measurements show that DO falls below 5 mg/L during the summer months throughout bays and their tributaries, with the exceptions mainly at open bay sites. Areas that have <5 mg/L dissolved oxygen during the day likely provide extremely stressful habitat at night, when respiration in the absence of photosynthesis synergistically reduces oxygen values even further.

Dissolved oxygen indicators can be problematic in an unstratified, shallow system especially when relying primarily on daytime measurements (which can be highly variable). Diel data showed that DO is frequently less than the 5 mg/L threshold in the tributaries (40 – 60% of the time in Turville Creek and Bishopville Prong). Possible causes of observed low DO values include respiration of large algae blooms (responding to high nutrient availability); bloom decay; high sediment oxygen demand from organically enriched sediments in many areas (Wells and Conkwright 1999; UMCES 2004); decay of macroalgae, seagrasses, and/or marsh vegetation; and poor circulation.

As demonstrated by the use of continuous monitoring data, when sampling frequency and spatial coverage increases, the understanding of oxygen conditions in the Coastal Bays improves. Even where only daytime measurements of DO are practical, increasing frequency and examining seasonal differences provides a more robust insight into dissolved oxygen. This is evident by comparing one-time samples collected during late summer for National Coastal Condition Assessment once every five years, to 3-year medians collected during all four summer months (increasing frequency). NCCA samples show that DO concentrations can meet or exceed thresholds, and appear to represent adequate or good conditions, while more frequent sampling, demonstrates that oxygen fails criteria at a majority of sampling sites within the Coastal Bays.

When comparing continuous monitoring data to the spatially more robust fixed monthly station data, the continuous monitoring data provides a more nuanced picture of dissolved oxygen conditions. Continuous monitoring ites overlap fixed sites at two locations, XDM4486 in St. Martin River and TS1/A2 in Sinepuxent Bay, allowing direct comparison. In St. Martin River, continuous monitoring data show that the minimum threshold (3 mg/L) failure occurs only 15-27% of the time at a specific site, while spatially more robust monthly sampling indicates that on a system-wide basis DO fails the minimum threshold during all analysis periods. In Sinepuxent Bay the continuous monitoring data shows minimum threshold (3 mg/L) failure between 0.02% and 12.6%. The living resources threshold was not met between 5.2% and 43.7% of the time. The failure rate declined annually for both thresholds. The fixed station shows improvement and met the living resources threshold during the last analysis period (2011-13), but failed this threshold during all other periods. Similar results are shown in comparisons among continuous monitor and monthly measurements in Assawoman Bay, where the continuous monitoring site is within 0.75 Km of a fixed site (XDN6921, GET0005 respectively). Here, continuous monitoring data show that the minimum threshold (3 mg/L) failure occurs only 10-19% of the time, while monthly sampling indicated that the fixed site DO fails the minimum threshold during all but the most recent analysis period. During 2011-13 the fixed site failed the living resources threshold (5 mg/L), while the continuous monitoring showed failure between 34-48% of the time during those years. Where conditions are typically good, analyses of fixed station data based on the 98th percentile will find those DO values that do fail the thresholds, and may paint a much poorer picture than the conditions that actually exist.

Next Steps

During 2012, a study was undertaken to begin development of a time-of-day calibration model for Coastal Bays long term fixed monthly monitoring stations in order to adjust DO to a fixed and comparable time of day so that spatial patterns and long term trends may be more accurately assessed. Typically, oxygen levels are assessed against a criterion with a failure allowance to account for natural variability. The criterion is set at 5.0 mg/L and the failure rate is computed for observed DO for a sequence of times of day. As expected, the frequency of falling below 5.0 tends to decrease with increasing time of day for observed DO. It is clear that observations taken during mid and late day do not reflect the stress that is experienced due to low DO in the water column in the early morning.

Continuous monitoring technologies implemented over the last decade provide high frequency datasets (observations every 15 minutes) that reveal new insights on short temporal DO patterns, including diel cycles. Typical diel patterns in the Coastal Bays reveal that the lowest DO and greatest stress to aquatic fauna occurs in the early morning. As the DO producing chlorophyll of phytoplankton are activated by sunlight, DO concentrations rise through the day to reach a zenith in mid or late afternoon. As sunlight wanes and respiration continues, DO decreases to a minimum in the early morning of the following day when the cycle begins again. On observing this cycle, it becomes apparent that it is difficult to discern spatial patterns of DO in the fixed station data because observations at different stations are taken at different times. Thus the difference in DO between two station observations is partly due to change in location and partly due to the progression of DO in its diel cycle.

This study attempted to model the diel cycle of DO as a function of numerous variables to obtain estimates of the diel cycle that could be used to adjust DO observations taken at any time of day to reflect the DO at a time of day associated the greatest DO stress. The results are mixed, which indicates that improvement is needed before the method can be generally applied. The evidence of bias that emerged from the validation study indicates that the true diel cycle has systematic departures from the trigonometric model that was employed. Thus one avenue for improvement might be to replace the trigonometric model with something like a spline function that would have greater flexibility in attempting to mimic the diel cycle. Another approach that might be explored would use day-specific diel trends to make the diel adjustment, rather than a diel-cycle predicted based on day specific attributes such as photosynthetically active radiation (PAR), temperature, turbidity, and chlorophyll. That is, a smoothing model applied to the diel trend observed at a Con-Mon site contemporaneous to the fixed station observations could be used to make the diel adjustment. A third area of improvement might be to explore a modeling approach that would identify days with a very weak diel cycle. Weak diel cycles may be related to phytoplankton bloom changes, such as succession or termination. In this study weak diel cycle days were essentially excluded by removing all days where the diel cycle model had r-square less than 0.7. It is likely that some of the poor performance is due to applying a diel cycle model to days where diel cycle is weak.

References

Assateague Island National Seashore (ASIS). 2001. Quality Assurance Project Plan for Assateague Island National Seashore's Water Quality Monitoring Program Chemical and Physical Properties. November 2001. B. Sturgis and C. Zimmerman Editors. 97 pages

COMAR (Code of Maryland Regulations). 1995. Code of Maryland Regulations: 26.08.02.03 – Water Quality Criteria Specific to Designated Uses. Maryland Department of the Environment. Baltimore, Maryland.

Funderburk, SL., S.J. Jordan, J.A. Milhursky, and D. Riley. 1991. Habitat Requirements for Chesapeake Bay Living Resources. Second Edition. Prepared by the Chesapeake Bay Program Habitat Objectives Workgroup of the Living Resources Subcommittee.

Maryland Department of Natural Resources. 2014a. Quality Assurance Project Plan for the Maryland Department of Natural Resources Chesapeake Bay Water Quality Monitoring Program - Chemical and Physical Properties Component for the period July 1, 2013 - June 30, 2014. B. Cole and T. Parham Editors. 32 pages.

Maryland Department of Natural Resources. 2014b. Quality Assurance Project Plan for the Maryland Department of Natural Resources Chesapeake Bay Shallow Water Quality Monitoring Program for the period July 1, 2014 – June 30, 2015. 96 pages.

UMCES. 2004. Monitoring of sediment oxygen and nutrient exchanges in Maryland's Coastal Bays in support of TMDL development. Draft Report. Maryland Department of the Environment, Baltimore, Maryland.

Wazniak, C.E. 2002. Dissolved oxygen in the Coastal Bays. Maryland Department of Natural Resources, 8 pp.

Wazniak, C.E. 1999. Eutrophication monitoring plan. Appendix A of the Maryland Coastal Bays Comprehensive Conservation Management Plan. Maryland Coastal Bays Program. Berlin, MD.

Wells, D.V, and R. Conkwright. 1999. The Maryland Coastal Bays Sediment Mapping Project - Physical and chemical characteristics of the shallow sediments: Synthesis Report and Atlas, Md. Dept. of Natural Resources, Maryland Geological Survey, Coastal & Estuarine Geology Program File Report 99-5, *HTML*-format on CD-ROM