A Planning Estimate for an Oyster Reef Restoration Enhanced Denitrification Rate Based on Harris Creek Data

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Rationale and Approach

The restoration of oyster communities has a net positive benefit with regard to nitrogen removal via microbial denitrification (Newell et al. 2005, Kellogg et al. 2013, Humphries et al. 2016). While many studies suggest denitrification may be assessed with reef-adjacent sediments (Smyth et al. 2015), other studies, including published work at Harris Creek (MD), suggest that the best measurement of oyster-related biogeochemical fluxes require consideration of the whole community (Kellogg et al. 2013, Caffrey et al. 2016, Jackson et al. 2018).

Recently, private oyster aquaculture practices related to assimilated nitrogen (N) and phosphorus (P) in the tissue of harvested oysters were approved as best management practices (BMPs) by the Chesapeake Bay Program (CBP) Partnership (Cornwell et al. 2016). These oyster BMPs are now available to help jurisdictions meet their N and P reduction goals outlined in the Chesapeake Bay TMDL. With the option of oyster tissue being credited by the USEPA Chesapeake Bay Program, both Maryland and Virginia governments are now working towards implementation of oyster BMPs. In summer 2019 the Oyster BMP Expert Panel will submit a new report that suggests that denitrification and assimilation of nitrogen and phosphorus in oyster biomass associated with oyster reef restoration are viable best management practices. Approval will be considered by fall 2019.

With watershed implementation plans being developed in summer 2019, the urgent need for information on reef denitrification has been identified. This report is a section being incorporated into a much larger data and analysis report of denitrification in Harris Creek. To advance the use of this data the goal of this report is to:

- Provide a synopsis of the data developed via NOAA and other funding in Harris Creek
- **Provide a defensible and conservative areal rate of enhanced denitrification related to N reduction from oyster reef restoration suitable for planning of watershed implementation plans.**

Overall, the estimate of 57 lbs N per acre per year (based on an eligible crediting timeframe of 184 days from measured values) is recommended for planning purposes. This estimate can be applied toward various oyster reef restoration projects in Maryland and Virginia, but only for planning purposes. It should not be used for crediting purposes, since site-specific estimates are needed to address variability (Oyster BMP Expert Panel in draft).

Data Sources

Scientists from VIMS and UMCES have carried out measurements of denitrification in Harris Creek from 2014-2017 and are completing a comprehensive report of the biogeochemical assessment of restored oyster reefs. The data used here will be described in detail in the report and will be publicly available before 2020. Note that all samples were collected from "seed only" reefs on which the only restoration activity was the planting of spat on shell directly on the bottom. Although we assume here that similar rates occur on reefs restored with a shell or stone base beneath the spat on shell, direct measurements are needed to determine whether this is an appropriate assumption. However, for planning purposes, the N reduction estimates presented in this document can be used in these situations. The NCBO-funded program made measurements in 135 incubation trays encompassing all seasons; this analysis uses spring, summer and fall measurements from 2015-2017 (n = 121).

Calculation Approach

To calculate net enhancement of denitrification associated with oyster reef restoration, we subtracted mean measured seasonal fluxes for sediments (i.e. background denitrification rates) from those for restored oyster reefs. Given the seasonal variability in denitrification rates, it is not recommended to extrapolate the hourly seasonal rates to the full annual timeframe of 365 days without data from all seasons (Spring, Summer, Fall, and Winter). The dataset for the planning estimate only captures the timeframe from May-October; therefore, the seasonal net hourly rates were scaled up to a total of 184 days (May 1 thru October 31) to represent the annual net denitrification enhancement using appropriate information on number of days and average day length. This estimate is conservative because it assumes no enhanced denitrification for any other days of the year.

The steps in our calculations were as follows:

1. Assign an oyster tissue biomass category based on dry weight (DW) to each flux value. Categories used were low (<75 g DW m^{-2}), medium (75 - 225 g DW m^{-2}), and high (> 225 g DW m^{-2}; Figure 1) based on summer data (June-August).
2. Calculate average seasonal (Spring: May, Summer: June-August, Fall: September-October) reef denitrification rates (µmol N m^{-2} h^{-1}) within each biomass category using Harris Creek data collected in 2015-2017. For seasons in which data were collected in multiple years, means were calculated within each year (Table 1) and then these values were averaged across years (Table 2). All seasons and years included data from both dark and illuminated fluxes.
3. Calculate average seasonal (Spring: May, Summer: June-August, Fall: September-October) sediment denitrification rates (µmol N m^{-2} h^{-1}) using Harris Creek data collected in 2014-2016. For seasons in which data were collected in multiple years, means were calculated within each year (Table 1) and then these values were averaged across years. All seasons and years included data from both dark and illuminated fluxes.
4. For each *season x biomass x light* level combination, subtract seasonal average sediment rates from reef rates from Table 1 to determine the dark and light enhancement of denitrification in µmol N m^{-2} h^{-1} (Table 2).

5. Extrapolate to daily rates (µmol N m^{-2} d^{-1}) by multiplying the resulting values from step 4 by the appropriate average number of daytime and nighttime hours based on data for 2016 from the United States Naval Observatory (http://aa.usno.navy.mil/data/docs/Dur_OneYear.php/) and summing the totals for each season (Table 2).
6. Calculate the net denitrification enhancement during the eligible crediting timeframe based on measured values (May-October; 184 days) by multiplying the daily rates from Step 5 by the eligible crediting days in the season and summing the results to get an estimate in µmol N m^{-2} 184 d^{-1} for each oyster tissue biomass category that can be used to represent the annual nitrogen reduction per year (Table 2).
7. To convert the enhanced net denitrification rate from µmol N m^{-2} y^{-1} to lbs N $acre^{-1}$ y^{-1}, divide by 1,000,000 micromoles to convert to moles, multiply by 14.0067 to convert moles to grams (molecular weight of N equals 14.0067 g mol^{-1}), divide by 453.592 to convert grams (g) into pounds (lbs), and lastly multiply by 4046.86 to convert square meters (m^2) to acres (Table 2).

Results

The data from all years were parsed into three oyster tissue biomass classes based on tissue dry weight (DW) per square meter: low (<75 g DW m^{-2}), medium (75 - 225 g DW m^{-2}), and high (> 225 g DW m^{-2}). Mean oyster tissue biomass in these categories varied by year and ranged from 16-37 g DW m^{-2} (low), 111-158 g DW m^{-2} (medium) and 349-370 g DW m^{-2} (high; Figure 1). Note that for all years, the means for the **low** biomass category fall between the threshold (15 g DW m^{-2}) and target (50 g DW m^{-2}) restoration biomass categories identified by the Oyster Metrics Working Group (2011).

For restored reefs with low biomass, we observe average dark rates of 84, 210 and 42 μmol m^{-2} h^{-1} for spring, summer and fall conditions; illuminated rates were 142, 227 and 38 μmol N m^{-2} h^{-1} in spring, summer and fall (Table 1). While the sediment rates are much lower than reef rates (Table 1), they are nevertheless an important correction to reef rates. Of particular note are the observations that 1) diminished sediment denitrification in the light has an important effect on this calculation and 2) the annual benefit for enhanced denitrification is dominated by summer rates, and 3) there is a positive relationship between oyster biomass and denitrification rates but the slope of the relationship tends to be less than one.

If we follow the usual approach of subtracting background sediment denitrification from reef rates (i.e. Kellogg et al. 2013), we can estimate rates of enhanced denitrification for the three biomass classes (Table 2). The summation of the average spring, summer and fall data yields an enhanced denitrification rate of 57 (low biomass), 79 (medium biomass), and 160 (high biomass) lbs N $acre^{-1}$ y^{-1} (Table 2). While the medium and high biomass categories results are also presented; it is not expected that these would be used for planning purposes unless there are oyster tissue biomass data from the site demonstrating average levels above 75 g m^{-2}.

Conclusions

The most conservative estimate for nitrogen removal via denitrification comes from the low biomass estimate of 57 lbs N $acre^{-1}$ y^{-1} (based on 184-day timeframe of measured values). This rate is a conservative estimate because it assumes negligible denitrification enhancement from November through April and low rates of off-site transport of biodeposits which might be denitrified in other Harris Creek environments. These rates are lower than those based on modeling efforts (Kellogg et al. 2018); the estimate of 206 lbs N acre^{-1} y^{-1} from the model includes the whole year, not just the warm months of May thru October.

For the purposes of using this data for a preliminary estimate of enhanced denitrification in watershed implementation plans, we suggest the best available knowledge at this time yields an annual rate of 57 lbs N acre^{-1} y^{-1}. This is based on an aggregation of data from different reefs in Harris Creek and is based on the most detailed study of restored reef environments that has been carried out up to this point in time. Biomass changes are likely to have an effect on the trajectory of reef denitrification, but the current estimate is appropriate for extrapolation to the whole Harris Creek restoration area, and is appropriate as a starting point for other restoration sites.

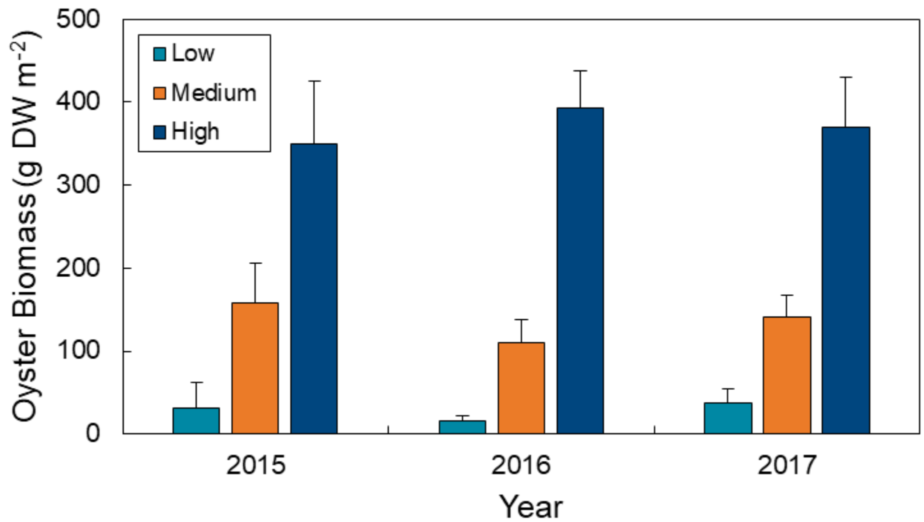

Figure 1. Biomass class definition for denitrification analysis. The data used here are from summer tray incubations used for the determination of oyster biomass and do not include the accumulation of shell and organisms other than oysters.

Table 1. Seasonally explicit estimation of denitrification rates (μmol m^{-2} h^{-1}) for the different biomass categories (low: <75 g DW m^{-2}; medium: 75 - 225 g DW m^{-2}; high: > 225 g DW m^{-2}) within year and across years for light and dark incubations. The timeframe of measured values included three seasons (Spring: May, Summer: June-August, Fall: September-October). Shaded upper left corner indicates seasonal averages that included more than one year. The diminishment of sediment denitrification rates with illumination is commonly observed in shallow water sediments (Risgaard-Petersen 2003).

			Dark Reef Denitrification Rates				Light Reef Denitrification Rates			
Oyster Tissue Biomass Category	**Sampling Season**	**Sampling Year**	**n**	**Average N_2-N Flux witin Year (μmol m^{-2} h^{-1})**	**StdDev of Average N_2-N Flux within Year (μmol m^{-2} h^{-1})**	**Seasonal Average N_2-N Flux Across Years (μmol m^{-2} h^{-1})**	**n**	**Average of N_2-N Flux (μmol m^{-2} h^{-1})**	**StdDev of N2-N Flux (μmol m^{-2} h^{-1})**	**Seasonal Average N_2-N Flux Across Years (μmol m^{-2} h^{-1})**
Low	Spring	2015	2	84	93	84	2	142	102	142
	Summer	2015	16	202	182	210	12	235	265	227
		2016	6	152	99		6	156	73	
		2017	12	275	182		12	290	224	
	Fall	2015	2	0	0	42	2	1	75	38
		2016	7	84	87		7	74	75	
Medium	Summer	2015	6	373	252	336	7	278	144	276
		2016	6	230	83		6	182	46	
		2017	12	407	222		12	368	109	
	Fall	2015	4	18	21	96	3	83	79	89
		2016	6	175	113		6	95	120	
High	Spring	2015	4	396	184	396	6	676	225	676
	Summer	2015	14	361	162	384	15	320	128	384
		2016	6	267	81		6	299	61	
		2017	12	525	254		12	532	178	
	Fall	2015	1	23		122	1	82		137
		2016	5	221	165		5	192	80	
Sediment (Background)	Spring	2015	10	26	24	26	12	2	65	2
	Summer	2015	12	88	74	88	11	17	37	17
	Fall	2014	12	43	27	55	12	23	20	38
		2016	12	66	36		12	54	39	

Table 2. Calculation spreadsheet to determine the net denitrification reef enhancement in lbs per acre per year for the oyster tissue biomass categories (low: <75 g DW m^{-2}; medium: 75 - 225 g DW m^{-2}; high: > 225 g DW m^{-2}). The enhanced dark and light denitrification reef rates are the corresponding areal reef rates minus the rates in Harris Creek sediments from Table 1 (the average was used for seasons with more than one measurement across years). The daily denitrification reef enhancement is calculated by multiplying the enhanced dark and light denitrification rates by their corresponding mean hours per day and summing the results. The seasonal net denitrification reef enhancement in lbs per acre per year (based on eligible crediting days of 184) is calculated by multiplying the daily rate by the eligible crediting days and dividing by 1,000,000 micromoles to convert to moles, multiplying by 14.0067 to convert moles to grams (molecular weight of N equals 14.0067 g mol^{-1}), dividing by 453.592 to convert grams (g) into pounds (lbs), and lastly multiplying by 4046.86 to convert square meters (m^2) to acres. The sum of the seasonal net denitrification enhancement rates determines the annual total net denitrification reef enhancement (lbs N $acre^{-1}$ y^{-1}) of the oyster tissue biomass categories for nitrogen reduction planning purposes. The means for the **low** biomass category fall between the threshold (15 g DW m^{-2}) and target (50 g DW m^{-2}) restoration biomass categories identified by the Oyster Metrics Working Group (2011).

	Enhanced Dark Denitrification Reef Rate (µmol m^{-2} h^{-1})			**Enhanced Light Denitrification Reef Rate (µmol m^{-2} h^{-1})**		
Oyster Tissue Biomass Category	***Spring***	***Summer***	***Fall***	***Spring***	***Summer***	***Fall***
Low	58	122	-13	140	210	0
Medium		248	41		259	51
High	370	296	67	674	367	99
Mean hours per day	9.7	9.7	12.2	14.3	14.3	11.8
	Daily Denitrification Reef Enhancement (µmol m^{-2} d^{-1})			**Denitrification Reef Enhancement during Measured Timeframe (µmol m^{-2} 184 d^{-1})**		
Oyster Tissue Biomass Category	***Spring***	***Summer***	***Fall***	***Sum of Season x Eligible Crediting Days***		
Low	2,558	4,183	-160	454,425		
Medium		6,112	1,096	629,202		
High	13,218	8,115	1,980	1,277,154		
Eligible Crediting Days	31	92	61	184		
	Net Denitrification Reef Enhancement (lbs $acre^{-1}$ y^{-1})					
Oyster Tissue Biomass Category	***Spring***	***Summer***	***Fall***	***Annual Total Based on 184 Eligible Crediting Days***		
Low	10	48	-1	**57**		
Medium		70	8	79		
High	51	93	15	160		

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