Planning Estimates for Oyster Reef Restoration BMPs Related to Nitrogen and Phosphorus Assimilation Based on Harris Creek Data and Draft Recommendations from the Oyster BMP Expert Panel

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Rationale and Approach

Oysters present in an oyster reef restoration setting can sequester (store) nitrogen (N) and phosphorus (P) in their tissue and shell by assimilation of these nutrients from filtration of organic matter (e.g., algae, phytoplankton, etc.; Kellogg et al. 2013). This process results in removal of excess nitrogen and phosphorus that may have otherwise been remineralized and therefore available in the water column for additional biological growth. In January 2018, the U.S. EPA concluded that pollutants sequestered from the water column by in-water best management practices (BMPs) could legally be counted towards the TMDL pollutant reduction goals.[1]

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 U.S. EPA 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 assimilation of N and P in oyster biomass and nitrogen removal from enhanced denitrification related to oyster reef restoration are viable BMPs. Oyster reef restoration practices refers to planting oysters (e.g., spat-on-shell [SOS], single oysters), substrate (e.g., shell, stone), or both directly on the bottom to enhance oyster biomass in areas where harvesting is not permitted (e.g., sanctuaries). Approval of the oyster reef restoration BMPs will be considered by fall 2019.

Assimilated N and P in live oysters (tissue and shell) from oyster reef restoration practices is a form of permanent removal from the water column when the total live oyster biomass post-restoration is more than the pre-restoration baseline (Oyster BMP Expert Panel second report in draft). On reefs, individual

[1] The Oyster BMP Expert Panel's February 1, 2018 update to the Chesapeake Bay Program Partnership's Water Quality Goal Implementation Team that includes the U.S. EPA's legal opinion concerning in-water BMPs and sequestration of nitrogen and phosphorus, https://oysterrecovery.org/wp-content/uploads/2015/10/Update-on-Oyster-BMP-Expert-Panel-2nd-Report_2-1-18_Final.pdf.

oysters will die and new oysters will grow. Throughout this process, N and P are continuously stored (e.g., assimilation, burial) and released (dissolution, denitrification). The total live oyster tissue and shell biomass above the pre-restoration baseline represents the measurable reduction of nitrogen and phosphorus from the water column.

With watershed implementation plans being developed in summer 2019, the urgent need for information on the amount of N and P assimilated in the tissue and shell of oyster reefs has been identified. This report provides broad estimates for the potential amount of N and P sequestered by oyster reef restoration projects based on data collected in Harris Creek three years post-restoration. To advance the use of these BMPs for planning of watershed implementation plans, the goal of this report is to:

- **Provide defensible and conservative estimates of live oyster tissue and shell biomass and corresponding N and P reduction effectiveness that would be representative of expected levels post-restoration after three years based on real data.**

Concerning the reduction effectiveness estimates related to the assimilation of N and P in the tissue and shell of live oysters on restored reefs (hereafter, oyster reef restoration-assimilation estimates) presented in this report, the baseline for the live oyster biomass is assumed to be zero for both tissue and shell. However, in real world application, there is usually a low level of live oyster tissue and shell biomass at the site before the oyster reef restoration activity. Since these estimates are only being used for planning purposes, a baseline of zero is sufficient. However, for crediting purposes, the pre-restoration baseline for live oyster tissue and shell biomass would need to be evaluated from available *in situ* data since the BMP is based on an enhancement of oyster biomass after the implementation of a restoration activity (i.e., planting hatchery-produced SOS, shell or alternative substrate, or both; Oyster BMP Expert Panel second report in draft).

Overall, the oyster reef restoration-assimilation estimates of 24 lbs. nitrogen and 4 lbs. phosphorus per acre per year for a maximum of three years are recommended for planning purposes (Table 1). These estimates include the N and P sequestered in both oyster tissue and shell and, for planning purposes only, can be applied broadly toward various oyster reef restoration projects in Chesapeake Bay where restoration activities have occurred post 2009 (timeframe established by CBP Management Board).[2] These estimates were derived from oyster density and shell height data from Harris Creek three years post-restoration collected during the Oyster Monitoring and Assessment Program sampling operations on restored reefs that used a shell-base (NOAA 2018). While oyster densities above 100

[2] June 15, 2016 CBP Special Management Board Session, https://www.chesapeakebay.net/what/event/oyster_bmp_policy_issues_special_management_board_session

oysters per square meter were observed in Harris Creek, these were at sites that used stone-related substrate, such as granite or fossilized shell. Given that a different sampling technique was used at the stone-base sites versus the shell-base sites (divers instead of patent tongs) it is unclear whether the higher densities are a result of the type of substrate activity or method of sampling. Therefore, to be conservative, only the shell-base sites were used to calculate the N and P reduction estimates for BMP planning. Site-specific analyses would likely produce higher estimates of N and P reduction.

Table 1. The oyster reef restoration-assimilation estimates for BMP planning purposes. The restoration activity (i.e., treatment) involved creating a shell-base by planting spat-on-shell (SOS) on mixed shell or planting SOS only. For the SOS only sites, oyster shell was used as the shell base. Estimates include the amount of nitrogen or phosphorus assimilated (sequestered) in the combined tissue and shell biomass of live oysters based on oyster size measurements (i.e., shell heights) and oyster densities from 2017/2018 Harris Creek data three years post-restoration. The Oyster BMP Expert Panel's recommended Chesapeake Bay-wide regression equations (in draft) were used to convert measured shell heights to tissue and shell dry weight biomass. The average nitrogen (tissue: 8.2%, shell: 0.2%) and phosphorus (tissue: 0.9%, shell: 0.04%) percent contents were used to calculate the amount sequestered in the live oyster tissue and shell biomass (tissue percent contents approved by CBP, Cornwell et al. 2016; shell percent contents in draft). Estimates can be applied for a total of three years on acres where substrate (shell or alternative substrate, such as granite or stone) and/or hatchery-produced SOS were planted.

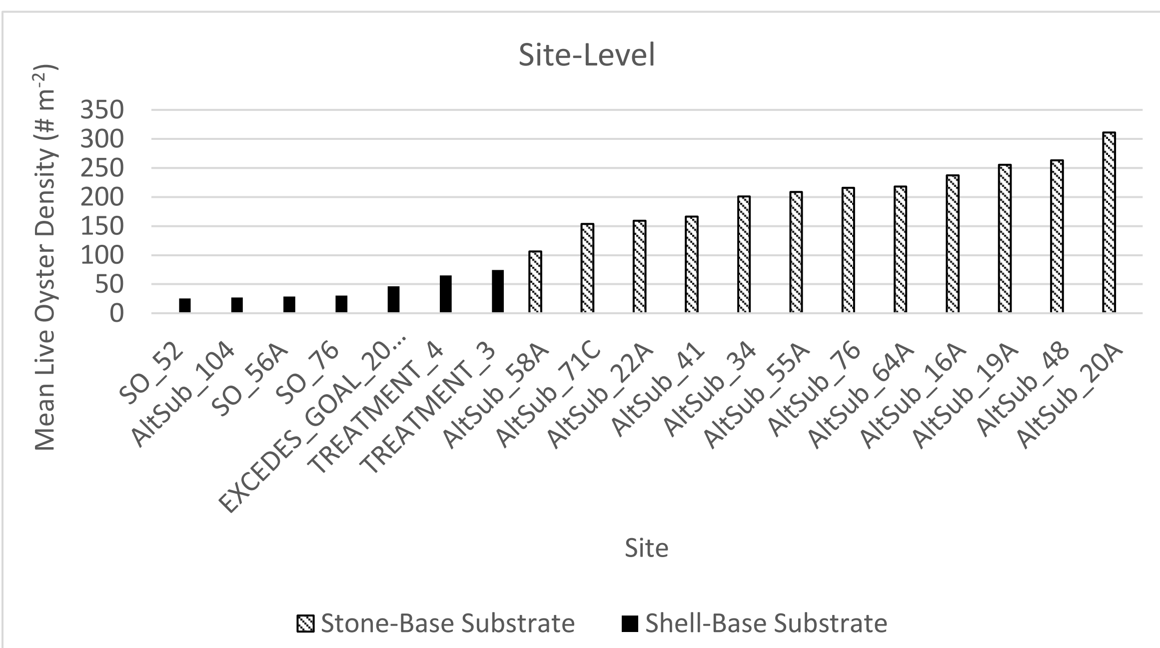
Oyster Reef Restoration-Assimilation Estimates for Planning		
Live Oyster Tissue + Shell Reduction Effectiveness	**lbs $acre^{-1}$ $year^{-1}$ (max duration = 3 years)**	
Treatment Category	**Nitrogen**	**Phosphorus**
Shell-Base + SOS n = 7 sites Mean Live Density = 42 oysters m^{-2}	**24**	**4**

The annual estimates can be applied for a total of three years, since the data represents three years post-restoration. As more post-restoration data becomes available beyond three years, this credit duration could be re-evaluated and adjusted accordingly. Overall, the combined live oyster tissue and shell biomass results in a total reduction of 74 lbs. N and 12 lbs. P per acre over the course of three years. The data and description of the calculation methods are described in their respective sections below.

Data Sources

Shell height and oyster density data used to derive the oyster reef restoration-assimilation estimates were collected from restored reefs in Harris Creek and are described fully in NOAA 2018. The oyster reef restoration effort in Harris Creek includes the planting of hatchery-produced oyster SOS on different substrate types. Oyster Monitoring and Assessment Program sampling operations occurred between fall 2017 and spring 2018. Data were collected from 19 oyster reef restoration sites where the planting of hatchery-produced SOS occurred. Data from restoration sites in Harris Creek (NOAA 2018) showed that the highest oyster densities were found on stone-base reefs (106 - 311 oysters m^{-2}, n = 12 sites), followed by shell-base reefs (n = 7 sites; Figure 1). Four to 16 samples were taken from each site. Sampled acres included 31 acres from the shell-base reefs and 60 acres from the stone-base reefs. Sampling methods differed between the substrate types with patent tongs being used at the shell-base reef sites and divers at the stone-base reef sites. Given the skewed results from the different treatment types (shell-base versus stone-base substrate), only the oyster densities from the shell-base sites were used for the N and P reduction analyses (mean = 42 live oysters m^{-2}) to produce conservative estimates for BMP planning purposes. The mean percent distribution of oyster sizes grouped by large (> 76 mm), small (40-75 mm), and spat (< 40 mm) was approximately 44, 33, and 23%, respectively at the shell-base sites.

Figure 1. Mean live oyster densities at the site level from the Oyster Monitoring and Assessment Program data collected in Harris Creek during 2017 and 2018 (NOAA 2018). Shell-base substrate sites (n = 7 sites, total of 31 acres) included mixed shell and spat-on-shell (SOS) only using oyster shell. Stone-base substrate sites (n = 12 sites, total of 61 acres) included the use of granite plus mixed shell, granite only, and stone-like fossil shell. Sampling included four to 16 samples per site representing one to 25 acres.



The Oyster BMP Expert Panel are drafting recommendations on Chesapeake Bay-wide regression equations that can be used to convert oyster shell heights to tissue and shell dry weights (g m^{-2}) for oysters on restored reefs. The tissue and shell datasets includes oyster data from several studies in Chesapeake Bay. These data are fully described in the report that the Oyster BMP Expert Panel is near in completing. While the report has not been released yet, the panel has reached consensus on the shell height to tissue and shell dry weight regression equations and the mean percent N and P contents in oyster tissue and shell.

Briefly, the Panel used a compiled dataset of oyster shell heights and tissue and shell dry weights (DW) from multiple Chesapeake Bay studies and locations representing different seasons (Fall, Winter, Spring, and Summer) and habitats (i.e., mesohaline and polyhaline environments in the upper, mid, and lower bay and tributaries) to develop the following shell height to tissue and shell dry weight regression equations.

Shell height to tissue dry weight:

$$W = 0.00037 * L^{1.83359}$$

where *W*=tissue dry weight in grams (g) and *L*= shell height in millimeters (mm).

Shell height to shell dry weight:

$$W = 0.00147 * L^{2.3964}$$

where *W*=shell dry weight in grams (g) and *L*= shell height in millimeters (mm).

The oyster tissue regression analysis included a total of 6,888 oysters from eight studies (four published and four unpublished sources) from 22 locations in Chesapeake Bay. The oyster shell regression analysis included a total of 4,296 oysters from six studies (two published and four unpublished sources) from 11 locations in Chesapeake Bay.

The panel previously established the mean percent N and P contents in oyster tissue in the first report approved by the CBP Partnership (Cornwell et al. 2016):

Mean Percent Nitrogen Content in Oyster Tissue = 8.2%

Mean Percent Phosphorus Content in Oyster Tissue = 0.9%

The panel draft recommendations will include the following mean percent N and P contents in oyster shell (Oyster BMP Expert Panel second report in draft):

Mean Percent Nitrogen Content in Oyster Shell = 0.2%

Mean Percent Phosphorus Content in Oyster Shell = 0.04%

Overall, for the mean percent N content in shell, the Panel used six reported values from five studies (three sites from two studies in Chesapeake Bay and three general waterbody averages along the Atlantic Coast). For the percent P content, the Panel used three reported site values from two studies in Chesapeake Bay. These data are fully described in the panel's near completed draft report.

Calculation Approach

To calculate N and P sequestration related to oyster reef restoration projects, we first need to determine the average tissue and shell biomass of live oysters in pounds per acre (lbs $acre^{-1}$). Oyster tissue and shell biomass were calculated using the following steps:

1. The individual oyster tissue and shell dry weights in grams (g) were determined by applying the individual measured oyster shell height measurements in millimeters (mm) with the corresponding shell height to dry weight regression equation (see Data Source section above).
2. To calculate the mean oyster tissue and shell biomass in grams per square meter (g m^{-2}), first sum the individual tissue and shell dry weights in grams at the site level. Then divide by the total measured oysters at the site level to determine the tissue and shell dry weight in grams per oyster. Next multiply by the mean live oyster density (number of oysters m^{-2}) to determine the oyster tissue and shell biomass in g m^{-2} at the site-level. Lastly, take the average of the site biomass to determine the mean oyster tissue and shell biomass (g m^{-2}) at the treatment level (i.e., shell-base substrate; Table 2). These values are converted to pounds per acre (lbs $acre^{-1}$) by multiplying by 4046.86 m^2 and dividing by 453.592 g (Table 3).

Once the mean live oyster tissue and shell biomass in lbs $acre^{-1}$ are known, then the N and P reduction effectiveness can be calculated using the following steps:

3. Multiply the mean live oyster biomass (lbs $acre^{-1}$; Table 3) by the corresponding nitrogen and phosphorus percent contents in tissue (8.2 and 0.9%, respectively) and shell (0.02 and 0.004%, respectively). The total N and P reduction is the sum of the tissue and shell estimates (Table 3).
4. Divide the total N and P reduction estimates in Table 3 by three (the duration of the BMP) to determine the combined tissue + shell live oyster reduction effectiveness in lbs per acre per year (lbs $acre^{-1}$ $year^{-1}$) shown in Table 1.

Results

The data demonstrated a mean live oyster tissue and shell biomass of approximately 45 and 2300 g m^{-2}, respectively, three years post-restoration (Table 2). The mean live oyster tissue biomass is in line with the expected live oyster tissue restoration target of 50 g m^{-2} (Oyster Metrics Workgroup 2011). For management use, these biomass values were converted to lbs $acre^{-1}$ (Table 3). Applying the percent N and P contents to the mean live oyster tissue and shell biomass produces the N and P reduction estimates in Table 3. The total N reduction (tissue plus shell) was approximately 74 lbs $acre^{-1}$. The total P reduction (tissue plus shell) was 12 lbs $acre^{-1}$ (Table 3). Using the combined tissue and shell estimates from Table 3 and dividing by the duration of three years produces the annual oyster reef restoration-assimilation estimates of 24 lbs. N and 4 lbs. P per acre per year (up to three years) for planning purposes (Table 1).

Table 2. Calculation of mean live oyster tissue and shell biomass (g m^{-2}) for the shell-base plus spat-on-shell (SOS) treatment category based on Harris Creek data collected during 2017 and 2018 three years post-restoration activity (NOAA 2018). The shell-base sites included one mixed shell site plus SOS. There were six sites where SOS were only planted. The mean live oyster density (# m^{-2}) at the treatment level is the average of the mean oyster densities observed at the seven shell-base sites. The total live oysters measured is the sum of the measured oysters from the seven shell-base sites. The mean live oyster tissue and shell biomass in grams per square meter (g m^{-2}) are calculated by applying the individual measured oyster shell heights with the Oyster BMP Expert Panel's recommended shell height to dry weight equations (see Data Source section), dividing by the total live oysters measured at the site level, multiplying by the mean live oyster density at the site level, and then taking the average at the treatment level.

Treatment Category	Mean Live Oyster Density (# oysters m^{-2})	Total Live Oysters Measured	Mean Live Oyster Tissue Biomass (g m^{-2})	Mean Live Oyster Shell Biomass (g m^{-2})
Shell-Base + SOS **n = 7 sites**	42	2315	45	2301

Table 3. The nitrogen (N) and phosphorus (P) reduction for the treatment category in pounds per acre (lbs $acre^{-1}$). The mean live oyster tissue and shell biomass in grams per square meter (g m^{-2}) from Table 2 are converted to lbs acre-1 by multiplying by 4046.86 m^2 and dividing by 453.592 g. The N and P reduction is then calculated by multiplying the mean live oyster tissue and shell biomass in lbs $acre^{-1}$ by their corresponding percent N and P contents in tissue (8.2 and 0.9%, respectively) and shell (0.02 and 0.004%, respectively). The total N and P reduction is the sum of the tissue and shell estimates. Table 1 shows the total reduction adjusted to annual estimates.

	lbs $acre^{-1}$							
	Mean Live Oyster Biomass		Nitrogen Reduction			Phosphorus Reduction		
Treatment Category	**Tissue**	**Shell**	**Tissue**	**Shell**	**Total**	**Tissue**	**Shell**	**Total**
Shell-Base + SOS **n = 7 sites** **Mean Live Density = 42 oysters m^{-2}**	401.48	20529.08	32.92	41.06	**73.98**	3.61	8.21	**11.82**

Conclusions

The N and P reduction effectiveness for the oyster reef restoration-assimilation BMPs are driven by oyster tissue and shell biomass. Data from Harris Creek provided the largest dataset to determine conservative planning estimates that reflect potential oyster tissue and shell biomass three years post restoration. While these planning estimates can be applied more broadly for other restoration projects in the Chesapeake Bay, they should not be used to calculate the N and P reduction for crediting purposes. Oyster densities, and consequently, tissue and shell biomass, can vary quite significantly depending on the restoration activity and location. Therefore, for crediting purposes, site-specific data should be acquired to determine the oyster tissue and shell biomass following the Oyster BMP Expert Panel's recommendations (in draft). Also, it is important to note that, while these estimates were derived using Harris Creek data, they do not necessarily reflect the current biomass in Harris Creek since only the shell-base site data were used and the data were from 2017 and 2018 sampling. For site-specific estimates, the most current monitoring data should be used to determine the oyster tissue and shell biomass.

The most conservative planning estimates for N and P reduction via combined oyster tissue and shell assimilation comes from the shell-base substrate treatment sites: approximately 24 lbs. N and 4 lbs. P per acre per year. These planning estimates can apply for a max duration of three years since it is unknown at this time whether there are additional increases in oyster tissue and shell biomass beyond three years post restoration. Six year post restoration data will be available from Harris Creek and could be evaluated to assess whether there are further increases in oyster tissue and shell biomass and adjustments to the planning estimates could be made accordingly.

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