# Linking Monie Bay watershed land use to $\delta^{15}N$ in tissues of the native eastern oyster, *Crassostrea virginica*

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Monie Bay component of Chesapeake Bay, MD National Estuarine Research Reserve

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**Abstract**

Deleterious effects of nitrogen loading from anthropogenic sources, e.g. fertilizer and manure runoff as well as sewage effluents, are well documented in Chesapeake Bay. The Monie Bay component of the Chesapeake Bay National Estuarine Research Reserve in Maryland acts as a natural laboratory to detect septic nitrogen. Monie Bay contains creeks similar in hydrographic conditions but differ in adjacent land use. This land use configuration allows comparisons of nitrogen sources from poultry farm runoff (Little Monie Creek), crop agriculture (Monie Creek), and a sub-watershed dominated by wetlands and forests (Little Creek). Stable nitrogen isotopes ($\delta^{15}N$) from deployments of the eastern oyster, *Crassostrea virginica*, were analyzed to discern spatial and temporal patterns of nitrogen sources, as influenced by land use. *C. virginica* $\delta^{15}N$ values were highest (13.72 ‰) in the open bay and lowest (11.61 ‰) furthest upstream Little Creek. Unexpectedly, sewage/septic sources were inferred to come into Monie Bay, likely from the more populated Wicomico River watershed, rather than from terrestrial sources within Monie Bay's watershed. Overall, water quality was generally poorer than expected, given the rural and 'pristine' characteristics of this component of the National Estuarine Research Reserve System. Identifying nutrient sources can focus nutrient management for this system.

**Keywords:** biological indicators, stable nitrogen isotopes, *Crassostrea virginica*, nitrogen source, land use, sewage/septic, Monie Bay

**Introduction**

The declining water quality of Chesapeake Bay due to excessive nutrient loading has been well documented (Kemp et al., 2005). Annual terrestrial nitrogen inputs to the Chesapeake Bay and several of its tributaries ranged from a six- to eight-fold load increase over inputs in pre-colonial times (Boynton et al. 1995). Non-point sources deliver about half the annual total nitrogen and phosphorus loads to the Patuxent River and 60-70% of the total nitrogen and phosphorous loads to the mainstream Chesapeake Bay and the Potomac River (Boynton et al. 1995). Spatially explicit distinctions between nutrient inputs from agricultural fertilizers and from sewage or manure effluents provide evidence necessary to target nutrient reduction management endeavors from the most important local sources. This research develops the eastern oyster, *Crassostrea virginica*, as a biological indicator of nitrogen source capable of distinguishing between fertilizers and biologically processed wastes. Further, this research establishes a link between oyster tissue isotopes and land use within the Monie Bay component of the Maryland Chesapeake Bay National Estuarine Research Reserve.

*Monie Bay, Chesapeake Bay National Estuarine Research Reserve*

Somerset County is overall comprised of ~30% farmland and ~42% forests and ~28% undeveloped wetlands (Figure 1a). Nearly 15% of this land is State or Federal recreation and wildlife management areas. Tree farms are also abundant in this county. Located within this county, Monie Bay, part of the National Estuarine Research Reserve System, is a tributary of Tangier Sound (see Figure 1b). Monie Bay can act as a natural laboratory to link land use to aquatic processes because the area includes three tidal creeks differing only by the surrounding land use. This land configuration allows for direct comparisons of nitrogen sources from poultry

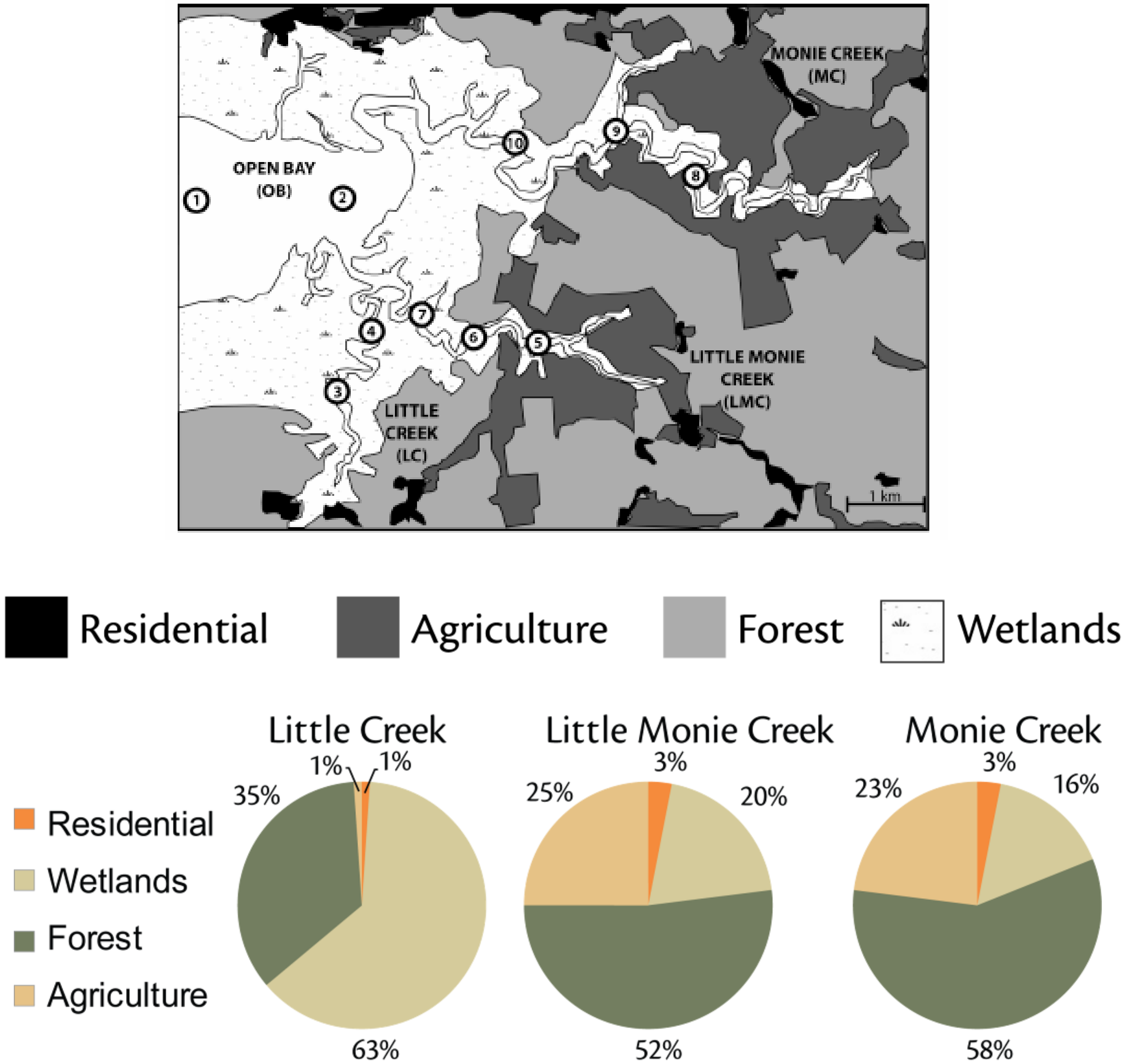


**Figure 1a**: Map of Monie Bay component of the Chesapeake Bay National Estuarine Research Reserve in Maryland, a tributary of Tangier Sound, off of Chesapeake Bay. Replicate sampling locations and surrounding land uses for each of the three creeks within Monie Bay are circled in the upper panel and charted in the lower panel respectively. (Apple et al, 2004)


**Figure 1b**. Satellite imagery depicts Monie Bay, its watershed and portions of Lower Wicomico River watershed. Shaded region indicates Monie Bay component of Chesapeake Bay, Maryland National Estuarine Research Reserve and monitoring stations are shown and labeled.

farm runoff (Little Monie Creek), crop agriculture (Monie Creek, near the border of the estuarine reserve), and a sub-watershed dominated by wetlands and forests (Little Creek). Though not within the scope of this report, future comparisons will extend into portions of the Wicomico River, whose mouth also flows into Monie Bay, and where effluents from waste water treatment plants near the towns of Salisbury, Delmar, and Fruitland are discharged. Local land uses adjacent to each of the creeks entering Monie Bay have previously been shown to be linked to the aquatic ecology of the system, driving intra- and inter-creek environmental gradients in salinity, nutrients, and dissolved organic matter quality and quantity (Apple et al. 2004).

Dominant marsh plants in Monie include *Spartina alterniflora*, *S. patens*, and *Juncus roemerianus*, in total comprised of 5-8 plant species and diversity tending to be higher around Little Creek and biomass greater around Monie Creek (Jones et al. 1997, Stribling and Cornwell 1997). Previous carbon and sulfur stable isotope studies indicate these marsh plants substantially contribute to consumers' diets (with potential temporal variation), with a balance between C4 (e.g. *Spartina alterniflora*) and C3 (e.g. *J. roemerianus*) marsh plants, phytoplankton and benthic algae (Stribling and Cornwell 1997). Consumers and macrobenthic communities include tubificid oligochaetes *Tubificoides heterochaetus* and *T. brownae*, the aorid amphipod *Leptocheirus plumulosus*, the tellinid bivalve *Macoma balthica* and the venerid bivalve *Gemma gemma*, ostracods, and nemerteans, as well as the polychaetes *Glycera dibranchiate* and *Marenzellaria viridis* (Kemp, 2006). Blue crabs, *Callinectes sapidus*, and mud crabs *Panopeus herbstii* have also been observed.

Marsh accretion is delicately balanced with sea-level rise (Stevenson et al. 1988), with average vertical accretion rates 3.0 mm $y^{-1}$ for the last 200 years (Kearney et al. 1994), but ultimately the marsh may be susceptible to long-term erosional forces. Monie Bay marshes are comprised of three sedimentary environments: 1) high wave energy bay bank marshes, 2) low energy tidal channel bank deposits, and 3) organic rich fine-grained black marsh sediments (Ward et al. 1988). Porewater $NH_4^+$ and $PO_4^-$ concentration profiles seasonally follow plant growth patterns and are generally higher in agriculturally influenced marshes (Cornwell et al 1994, Stribling and Cornwell 2001). Sediment accretion rates and nutrient contents suggest that Monie tidal marshes may serve as sinks for N and P burial (Zelenke and Cornwell 1996), trapping 35% of nitrogen and 81% of phosphorus inputs from the surrounding watershed. An additional 10% may be removed from the estuary via denitrification, a biogeochemical transformation, which has been measured (with high seasonal variability) at ~60 µmol N $m^{-2}$ $h^{-1}$ in sediments (Merrill and Cornwell, 2000). Due to this ecosystem service of nitrogen removal, Monie Bay and its tidal marsh creeks may be excellent locations to study nitrogen source with biological indicators.

The Monie Bay watershed is also an ideal location to test the ability of native oysters (*Crassostrea virginica)* to act as biological indicator using stable nitrogen isotopes due to the very rural characteristics of this watershed within Somerset County. Somerset County is home to 24,747 people, which roughly 9 acres for every person or 0.12 people/acre or 0.30 people/hectare (See Figures 2a, 2b. US Department of Commerce, 2001). Due to this low population density, there are few septic systems within the watershed. Meanwhile, the nearby Lower Wicomico River watershed contains the urban center of Salisbury, and contains over twice the population density and a corresponding order of magnitude more septic systems, as well as three wastewater treatment plants, which are absent in Monie Bay watershed. Nitrogen discharge loads in 2005 from the Salisbury, Delmar, and Fruitland, wastewater treatment plants were near 500,000 lbs N year$^{-1}$, 20,000 lbs N year$^{-1}$, and 10,000 lbs N year$^{-1}$ respectively (Figures 3a, 3b, 3c Maryland

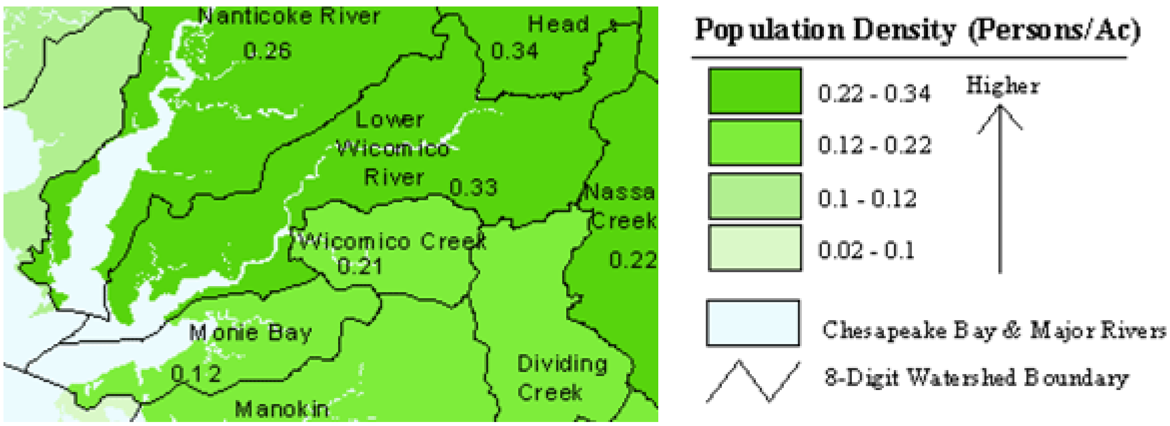


**Figure 2a:** Population density in Monie Bay watershed and surrounding watersheds. While generally rural, Monie Bay watershed in Somerset County has very low population density, particularly as compared to nearby Lower Wicomico River watershed, which contains the towns of Salisbury and Fruitland. (Modified from Maryland Department of Natural Resources, 1999a)

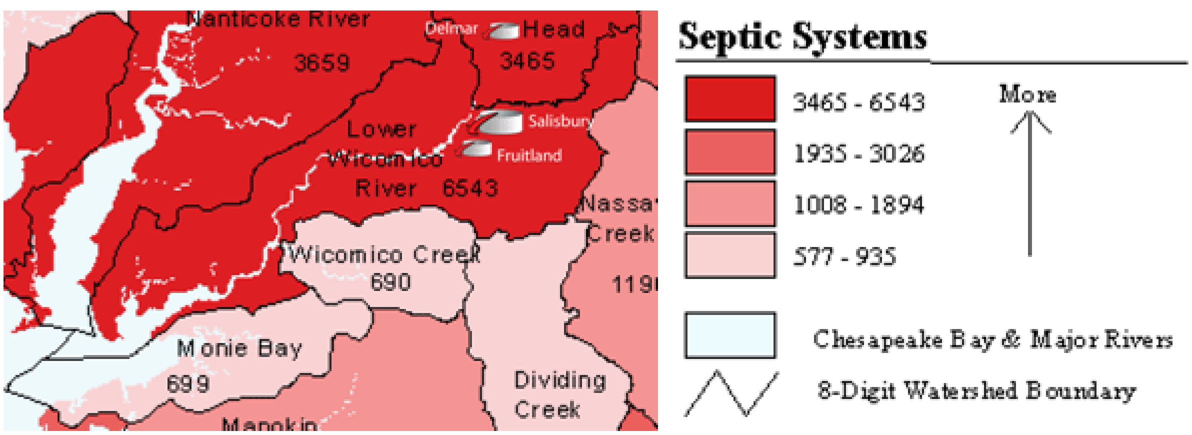


**Figure 2b:** Septic systems and wastewater treatment plants in Monie Bay watershed and surrounding watersheds. Due to the rural nature of the Monie Bay watershed, there are relatively few septic systems in place. The four sub-watersheds of the Wicomico River have an order of magnitude more septic systems, as well as three sewage treatment plants. (Modified from Maryland Department of Natural Resources, 1999b)

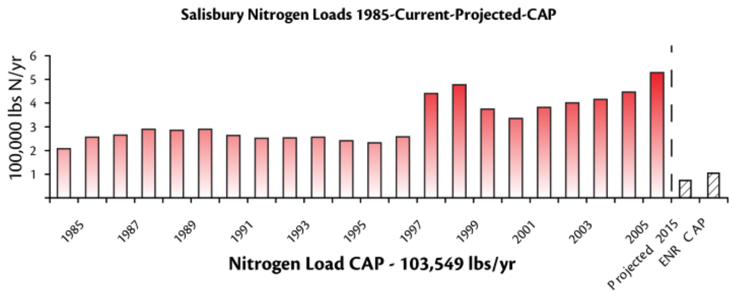


**Figure 3a:** Historical and projected nitrogen loads in 100,000 lbs N year$^{-1}$ to Wicomico River from Salisbury Wastewater Treatment Plant (Modified from Maryland Department of the Environment, 2007a).

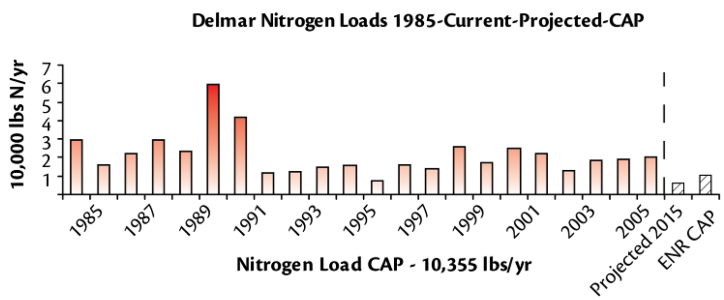


**Figure 3b:** Historical and projected nitrogen loads in 10,000 lbs N year$^{-1}$ to Wicomico River from Delmar Wastewater Treatment Plant (Modified from Maryland Department of the Environment, 2007b).

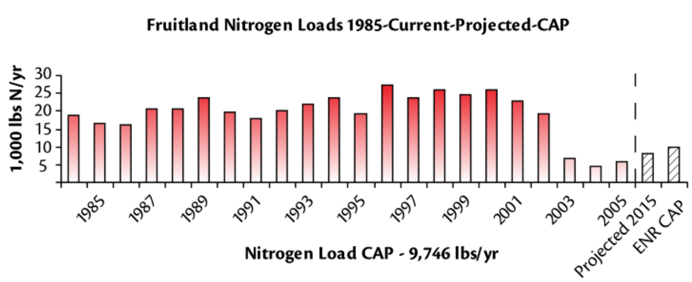


**Figure 3c:** Historical and projected nitrogen loads in 1,000 lbs N year$^{-1}$ to Wicomico River from Fruitland Wastewater Treatment Plant (Modified from Maryland Department of the Environment, 2007c).

Department of Environment, 2007a,b,c). Overall, relatively low levels of nitrogen loading from septic and wastewater treatment plants within the Monie Bay watershed potentially allow direct identification of nitrogen source in each creek and can thus link the oyster biological indicator with this nitrogen source. Developing the bioindicator can be done by analyzing stable nitrogen isotopes in the oyster tissues.

*Previous water quality monitoring*

Water quality monitoring in 1994-1995 indicated that Little Monie Creek and Little Creek were similar with respect to salinity, temperature, and water volume, while spring flows freshened the upper portions of Little Monie Creek as compared to Little Creek. Nutrient concentrations declined from the upper reaches downstream due to dilution and biogeochemical processing (Apple et al. 2004). Little Creek had lower nutrient and phytoplankton chlorophyll *a* concentrations due to differences in their watersheds. Little Monie Creek and Monie Creek were higher in total suspended solids, dissolved inorganic nitrogen, and dissolved inorganic phosphorus and chlorophyll *a* than Little Creek. Generally, nutrient concentrations were highest in Monie Creek, with Little Monie Creek slightly lower concentrations and Little Creek had much lower concentrations. Agricultural runoff has been implicated in nearly doubling total nitrogen and total phosphorous in Little Monie Creek. Nitrate concentrations peaked (~50 μM) in February, declined by April, and were extremely low the rest of the year. The nitrogen concentrations were highest in Little Monie Creek, then Monie Creek and did not vary temporally in Little Creek. Ammonium peaked in December and March in all creeks, but was low the rest of the year (Jones et al. 1997). Salinity varied temporally, being lowest until early spring and highest in summer and fall, and spatially in that Monie Creek was freshest.

*Stable nitrogen isotope techniques and biological indicators*

Nitrogen stable isotope analysis ($\delta^{15}N$) is increasingly being used to identify nitrogen sources, and has been effectively applied using seagrass, macroalgae, molluscs and fish (Udy and Dennison, 1997, Costanzo et al, 2001, McKinney et al, 2001, Schlacker and Carruthers, 2001, McKinney et al., 2002). Identification of nitrogen sources using indicator species is based on the relative ratio of isotopic nitrogen ($^{15}N$) to standard nitrogen ($^{14}N$) in their tissues as compared to a recognized standard. That is, the $\delta\, ^{15}N(‰) = (R_{sample}/R_{standard} - 1) * 10^3$. Here, R is defined as the atomic $^{15}N/^{14}N$ ratio. The standard reference used is atmospheric $N_2$, which has a $^{15}N$ abundance of 0.3663% (Junk and Svec 1958, Sweeny et al. 1978, Mariotti 1983, Costanzo et al. 2001).

The relative ratios of $\delta^{15}N$ can potentially be used to distinguish between fertilizer and sewage sources. Nitrogen fertilizer is mainly produced through the process of fixing atmospheric nitrogen. Therefore, agricultural runoff has a $\delta^{15}N$ signal of zero, which is close to that of the atmosphere, which is zero. Meanwhile, sewage and animal wastes have a higher $\delta^{15}N$ value (Costanzo et al. 2001). This happens for two reasons. First, organisms preferentially metabolize the lighter $^{14}N$ over $^{15}N$ so that they excrete a higher percentage of ingested $^{15}N$ as compared to $^{14}N$. Second, sewage contains a higher concentration of urea than fertilizer. Urea becomes more basic when hydrolyzed, which favors a conversion into ammonia. Ammonia, a volatile compound, is easily lost to the atmosphere. During volatilization, the difference in atomic weight between $^{14}N$ and $^{15}N$ becomes apparent. The lighter $^{14}N$ is more easily volatilized so the remaining ammonia fraction is relatively enriched with $^{15}N$. Ultimately, this remainder is either taken up by plants and algae or converted into highly water-soluble nitrates via microbial processes (Costanzo et al. 2001). Figure 4 depicts nitrogen isotope pathways and the theoretical signal strengths of the relative ratios of isotopic nitrogen between inputs from crop fertilizers and those from poultry manure runoff in a conceptual diagram.

Molluscs, particularly oysters, are advantageous as biological indicators over species from other taxonomic groups because they are sessile organisms that can integrate nitrogen over time in a single individual. Furthermore, oysters can provide a time-integrated history of nitrogen sources (see Figure 5) because different oyster tissues turn over at different rates, as Moore (2003) found for the Sydney rock oyster (*Saccostrea commercialis*). Eastern oysters are euryhaline suspension filter feeders that derive nitrogen from a variety of spatially variable ultimate sources including microorganisms, phytoplankton, detritus and inorganic particles (Langdon and Newell 1996, Newell and Langdon 1996). Transplanted molluscs, even species with slower growth rates than *Crassostrea virginica*, have previously been shown to reflect the isotope signature of the host location after deployment (Dattagupta, 2004). This report seeks to validate *C. virginica* as a monitoring tool to distinguish among biologically available nitrogen sources. The natural abundance of stable nitrogen isotopes in *C. virginica* muscle, gills, and mantle tissues were analyzed to test three hypotheses: 1) $\delta^{15}N$ values in *C. virginica* tissues initially grown in different tributaries, with different initial $\delta^{15}N$ values converge after deployment at each deployment station; 2) analysis of *C. virginica* tissue $\delta^{15}N$ values after deployment can distinguish between nitrogen sources and thus the eastern oyster can be developed as a biological indicator; and 3) oysters grown in Little Monie Creek will have higher $\delta^{15}N$ than those grown in Little Creek or in Monie Creek.

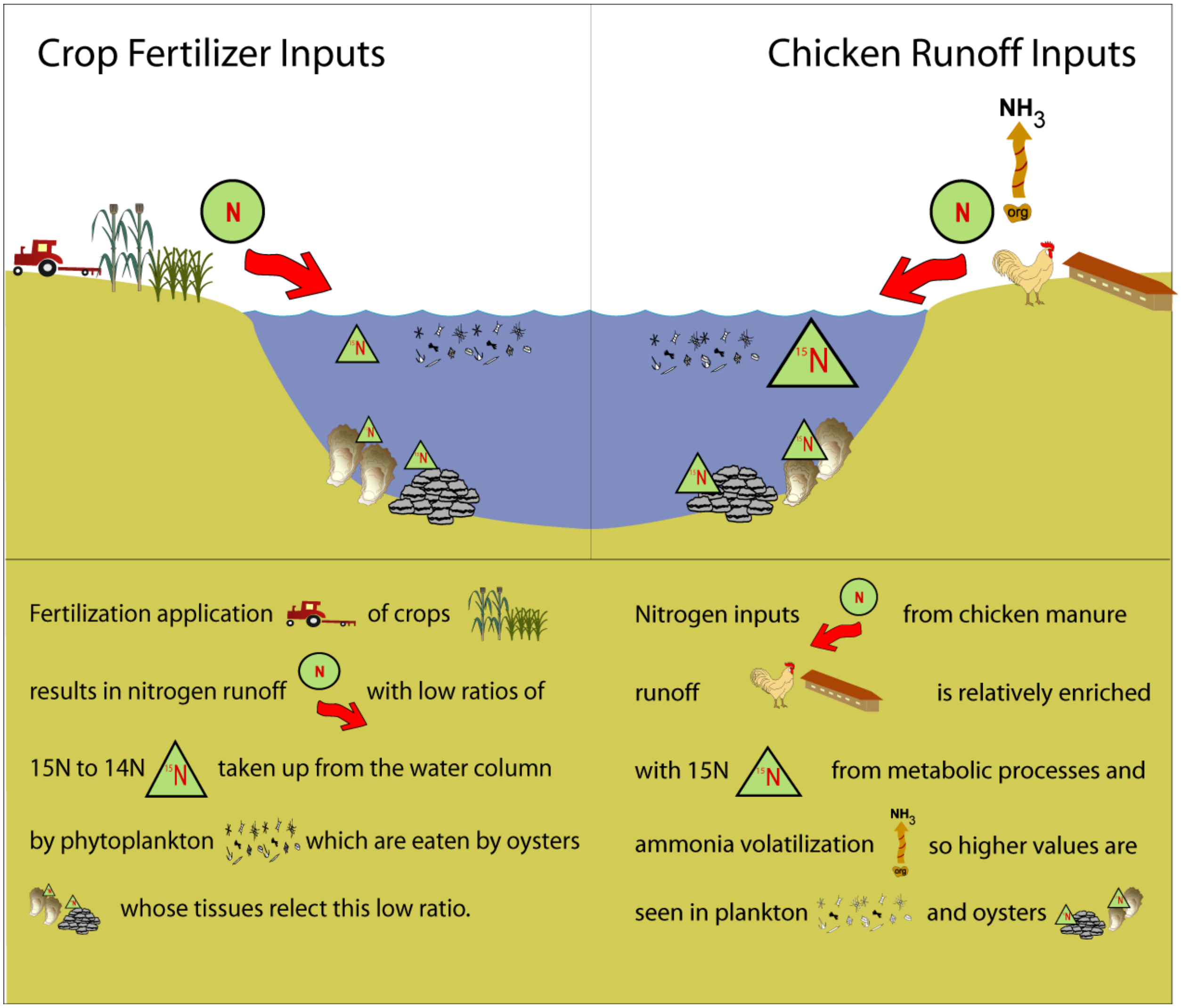


**Figure 4:** Conceptual diagram of the nitrogen fractionation patterns for agricultural fertilizer sources vs. poultry manure runoff inputs. Note the larger $\delta^{15}N$ symbols atop the oysters in the poultry runoff scenario indicate the higher expected relative ratios of $\delta^{15}N$ from this source.

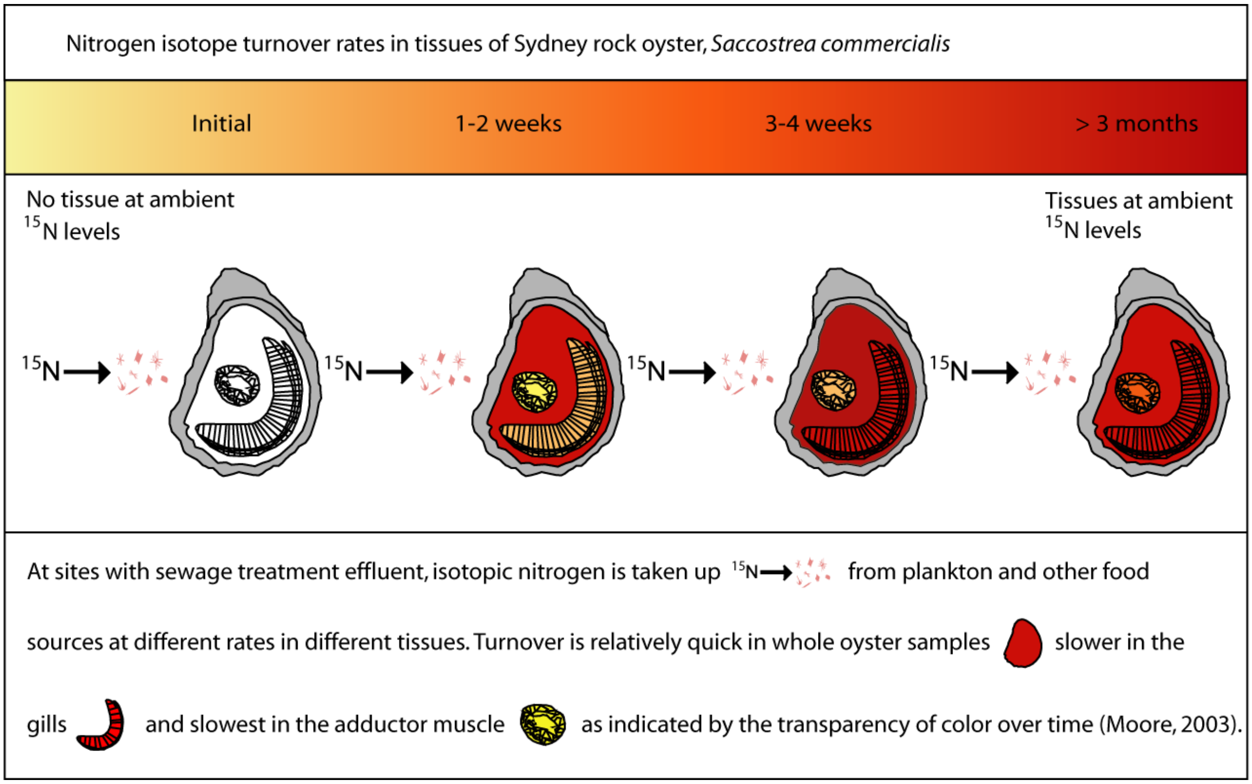


**Figure 5**: Nitrogen turnover rates in tissues from Sydney rock oysters (*Saccostrea commercialis*) vary by tissue, and thus provide a time-integrated history of nitrogen as each tissue becomes saturated with fractionated nitrogen (Moore 2003).

## Materials and Methods

### *Water Quality Monitoring*

Fortnightly, a suite of hydrographic conditions (e.g. salinity, temperature, dissolved oxygen concentration and saturation, pH, conductivity, and Secchi depth) were monitored using standard YSI field probe. At each station, a liter of water was sampled and kept on ice during transport to the laboratory, where it was prepared for chemical analyses, including total and dissolved nitrogen and phosphorus, total suspended solids, total volatile solids and chlorophyll *a*. Water samples were prepared at Horn Point Laboratory for analysis by contractors for DNR.

### *Water Quality Index*

Overall system health was assessed by combining several variables considered critical for seagrass and benthic communities into a single-value Water Quality Index (WQI) in a manner similar to Wazniak et al. (2007). Levels of total nitrogen (TN), total phosphorous (TP), chlorophyll *a*, and dissolved oxygen in the bottom layer were considered for assessment (Baden et al. 1990, Pihl et al. 1991, Pihl et al., 1992, Dennison et al. 1993, Stevenson et al. 1993, Smith and Dauer 1994, Valdes-Murtha 1997, Ritter and Montagna 1999, and Lea et al. 2003). For each parameter, if a site met the biologically relevant threshold value indicated in Table 1, it received a score of one; otherwise it received a score of zero. A single-value WQI was calculated for each site within each creek and the Open Bay by averaging the resulting scores for each of the four parameters. A WQI of 1 would indicate all metrics were met, that of 0 would indicate none were, and an intermediate score would mean that some metrics were met. For example, on June 22, 2006 site MB1, in the open bay, had 0.76 mg N $L^{-1}$ and so received a 0 for TN, had

| **Management Objective** | **Water Quality Indicator** | **Reference Value** |
|---|---|---|
| Maintain seagrass | Chlorophyll *a* | Chl *a* < 15 μg $L^{-1}$ |
| Maintain seagrass | Total phosphorus | TP < 1.2 μM OR TP < 0.037 mg $L^{-1}$ |
| Maintain seagrass | Total nitrogen | TN < 46 μM OR TN < 0.65 mg $L^{-1}$ |
| Maintain benthic communities | Bottom dissolved oxygen | DO > 5.0 mg $L^{-1}$ |

**Table 1.** Table of management objectives together with water quality indicators and reference values to determine the status of the objectives (Wazniak et al., 2007)

0.0674 mg P $L^{-1}$ for TP and so received a 0, 12.0 µg $L^{-1}$ chlorophyll *a* earning it a 1, and 6.83 mg $L^{-1}$ attaining a 1 for dissolved oxygen and an overall WQI score of 0.5.

*Oyster Deployment, Sampling, and Analysis*

Oyster spat on shell were deployed in June 2006 in Monie Bay at the 10 sampling stations: two open bay sites, two sites in Little Creek, and three each in Little Monie Creek and Monie Creek (recall Figure 1a). At each station, two ¾ inch mesh bags, each containing 20 oyster spat on shell, were anchored with three bricks and suspended 1.5 feet off the bottom using a marked buoy to minimize sediment smothering. Each bag contained oysters initially grown in one of two Chesapeake Bay tributaries (the South River and the Severn River) such that both source tributaries were represented by transplants at each of the ten sampling stations. A sample size of 5 oysters was determined to optimize isotope standard errors and preparation efforts using statistical techniques described by Bros and Cowell (1987, Figure 6). Oyster mortality was correctly assumed to be overestimated at 40%, so the initial number of oysters deployed exceeded sampling demands. Fouling organisms and trapped sediments were removed from mesh bags fortnightly or as needed to maintain water flows throughout the deployment period. Sites were accessed using a small research vessel housed by Deale Island National Wildlife Management Area near Monie Bay.

Oyster samples were collected in October 2006. Individually, five sampled oysters were dissected to obtain the adductor muscle, gills, and mantle. Each tissue was oven-dried overnight at 60˚C and ground with mortar and pestle into a powder, which was packed in tin capsules for sample analysis. Capsules were weighed so %N and molar C:N could be calculated for analysis.

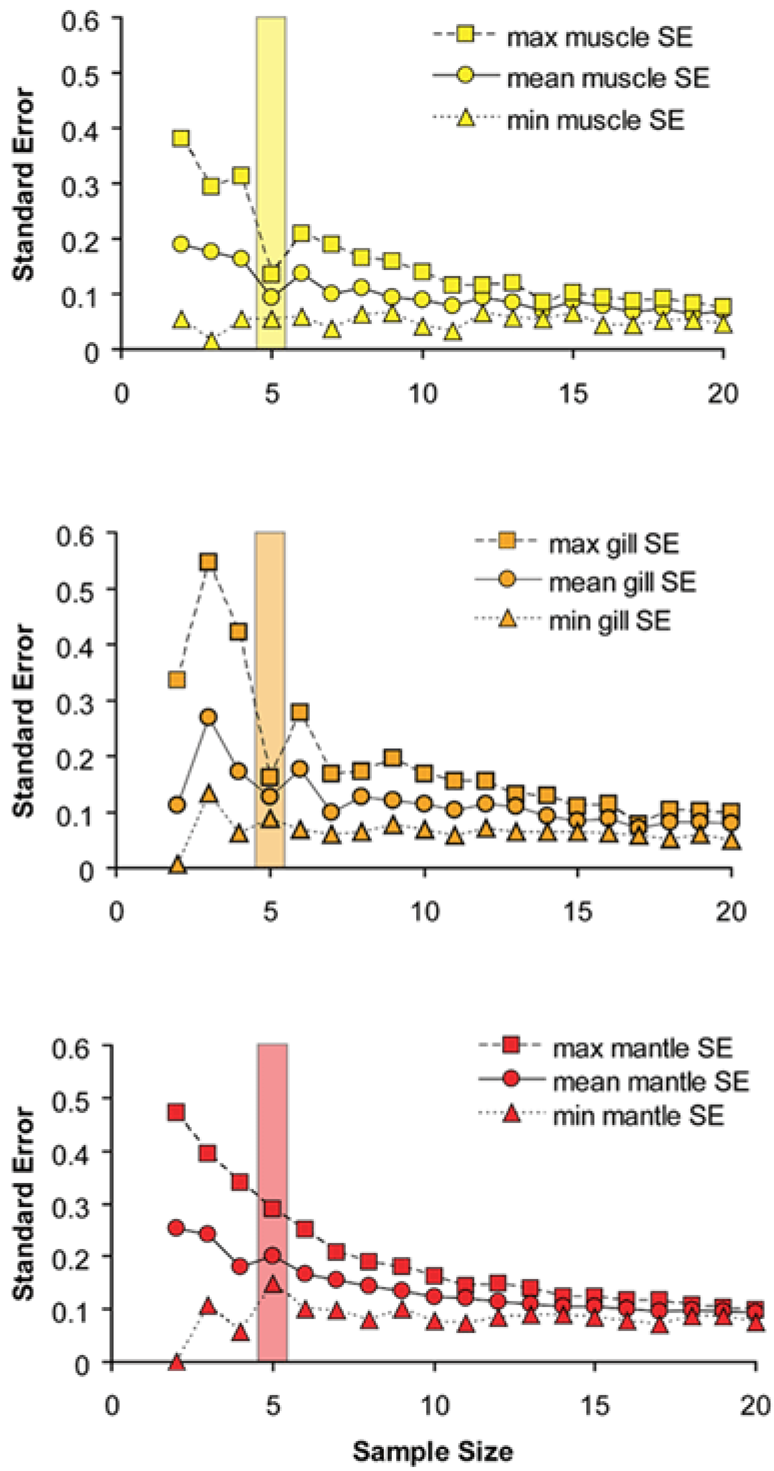


**Figure 6**. Optimum sample size was determined to be 5 oysters by examining the decline in standard error as sampling size increased for each tissue. Methods used detailed in Bros and Cowell (1987).

$\delta^{15}N$ analysis from the prepared tissue powder was conducted by University of California Davis Stable Isotope Facility using a continuous flow Isotope Ratio Mass Spectrometer (IRMS).

## Results

### *Precipitation*

2006 had a very dry spring, wet early summer, and mainly dry late summer punctuated by heavy but sporadic rain events, for example on July 5-6, 2006 (Figure 7). Oyster deployments, indicated by the shaded area, were during late summer through fall. Since oyster tissue turnover rates are on the order of weeks rather than days, the overall impact of precipitation pulses on tissue $\delta^{15}N$ values should be muted, as there is a time and opportunistic lag between a precipitation event, resulting terrestrial nutrient runoff, incorporation of these nutrients by phytoplankton, and lastly the ingestion and incorporation of this nitrogen via plankton pathway into oyster tissues.

### *Physical and Chemical Water Quality Monitoring*

Water temperatures warmed over the course of the summer, with warmest temperatures coinciding with a 1.62 inch precipitation event on July 5 followed by a 3.28 inch event on July 6, 2006 (Figure 8a). This rain event decreased surface salinities to their lowest point for the summer at each creek. All creeks exhibited similar temperatures but the Open Bay was the saltiest and had highest bottom layer oxygen levels due to exchange with Tangier Sound and Chesapeake Bay while Monie Creek was always fresher than the other creeks, likely due to higher flow volume (Figure 8b). After an early July rainfall event, increases in concentrations of bottom layer dissolved oxygen (Figures 8c, 8d), total nitrogen (Figure 8e), total phosphorus (Figure 8f), and

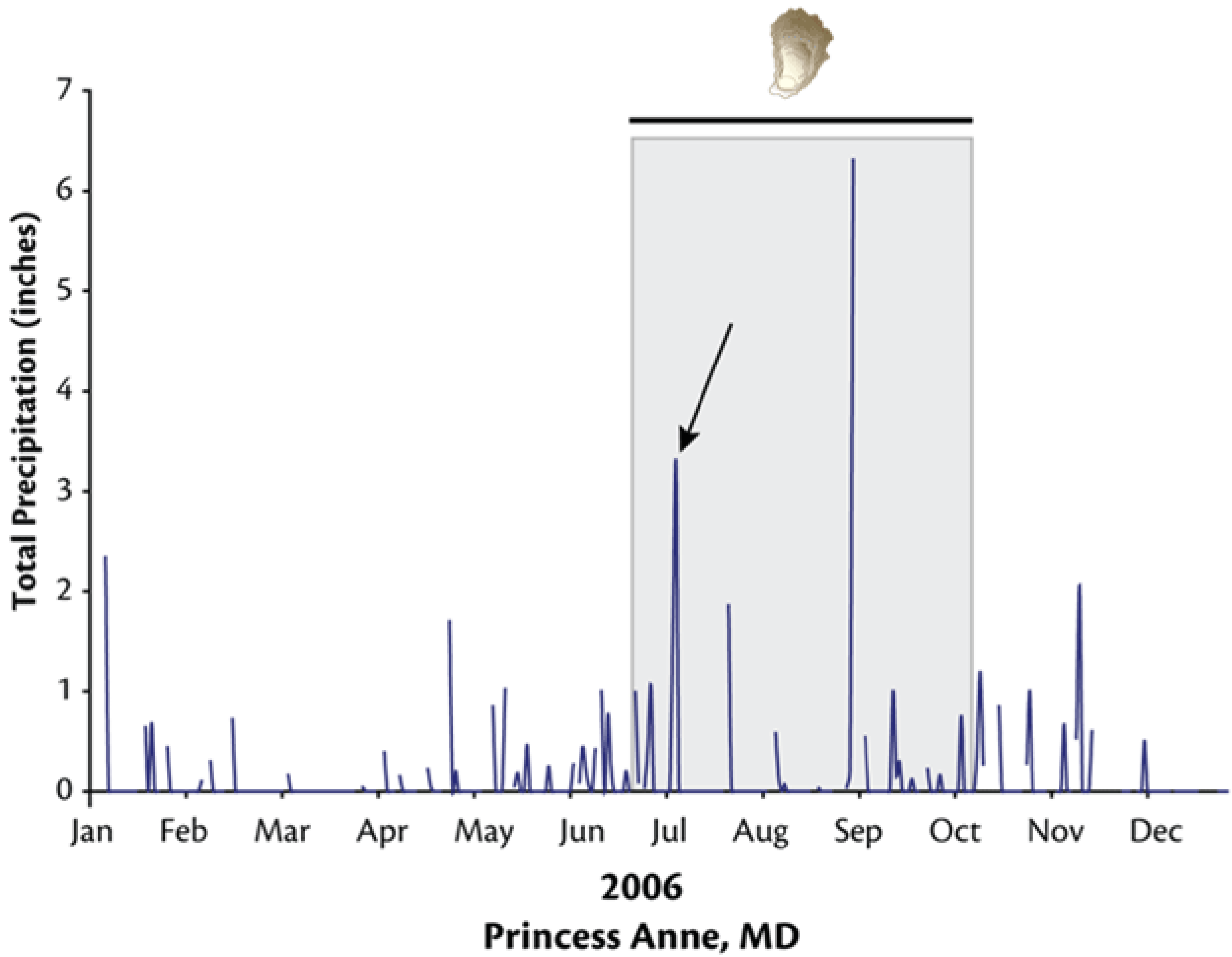


**Figure 7:** Daily total precipitation record for Princess Anne, MD (Data received from the Office of the State Climatologist, Department of Atmospheric and Oceanic Science, University of Maryland, College Park, 2007). Duration of oyster deployment period is shaded in grey and denoted with the line and oyster above it.

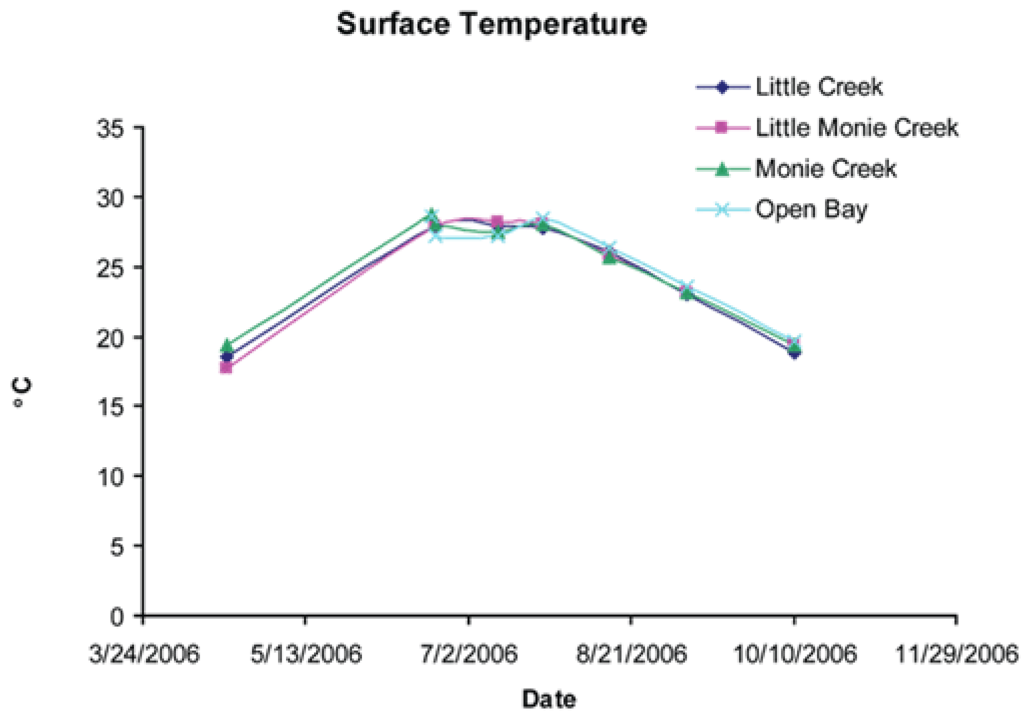


**Figure 8a:** Temporal patterns of surface temperature averaged for each creek.

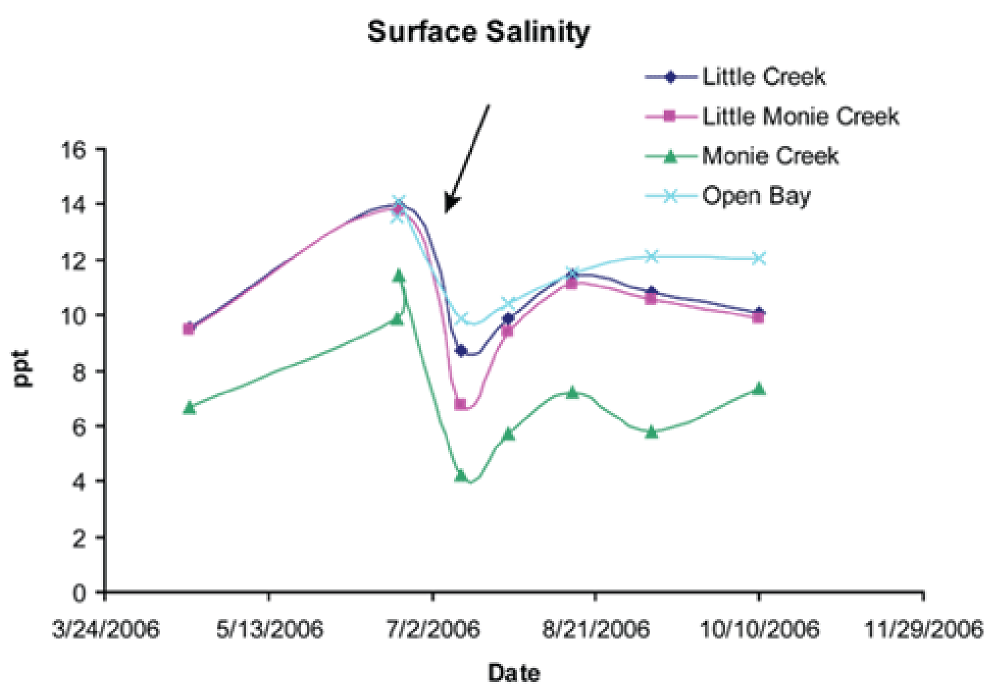


**Figure 8b:** Temporal patterns of surface salinity averaged for each creek. Arrow indicates July 6, 2006 precipitation event.

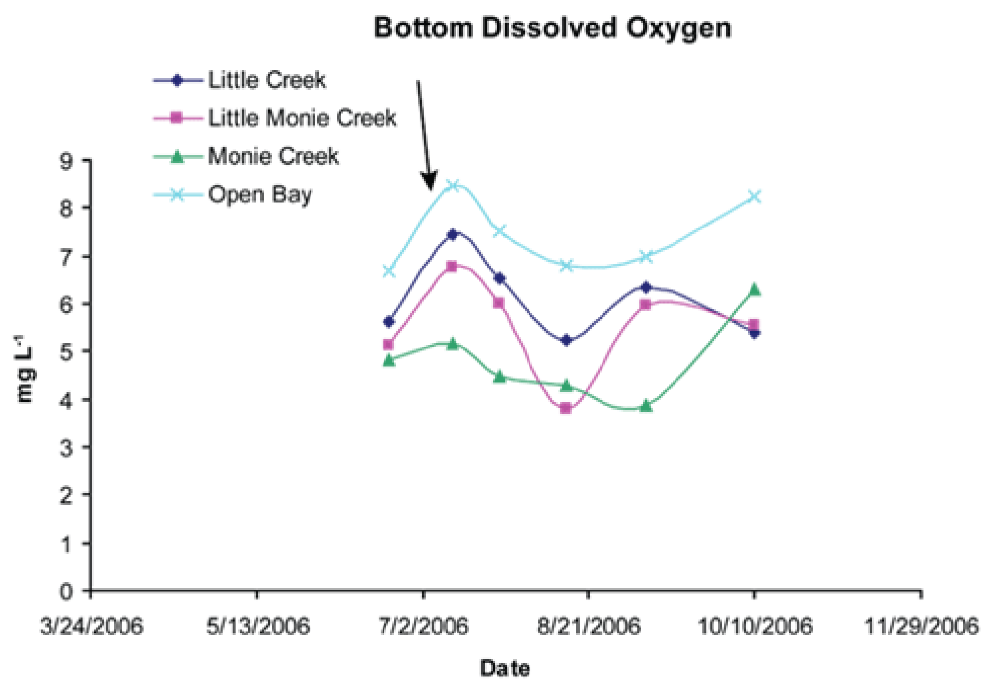


**Figure 8c:** Temporal patterns of bottom layer dissolved oxygen concentrations. Arrow indicates July 6, 2006 precipitation event.

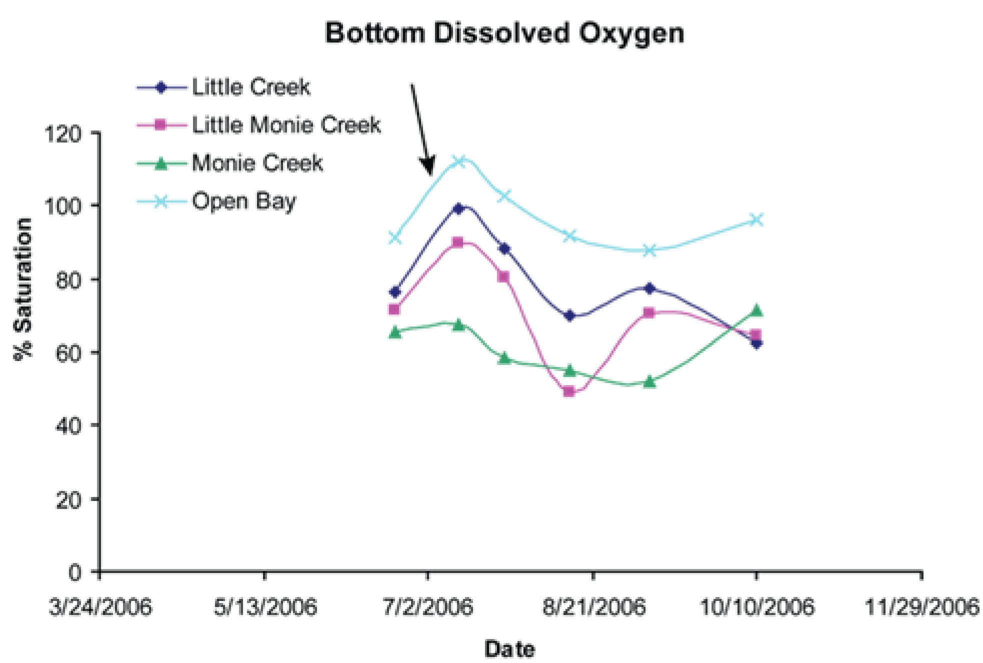


**Figure 8d:** Temporal patterns of bottom layer dissolved oxygen percent saturation. Arrow indicates July 6, 2006 precipitation event.

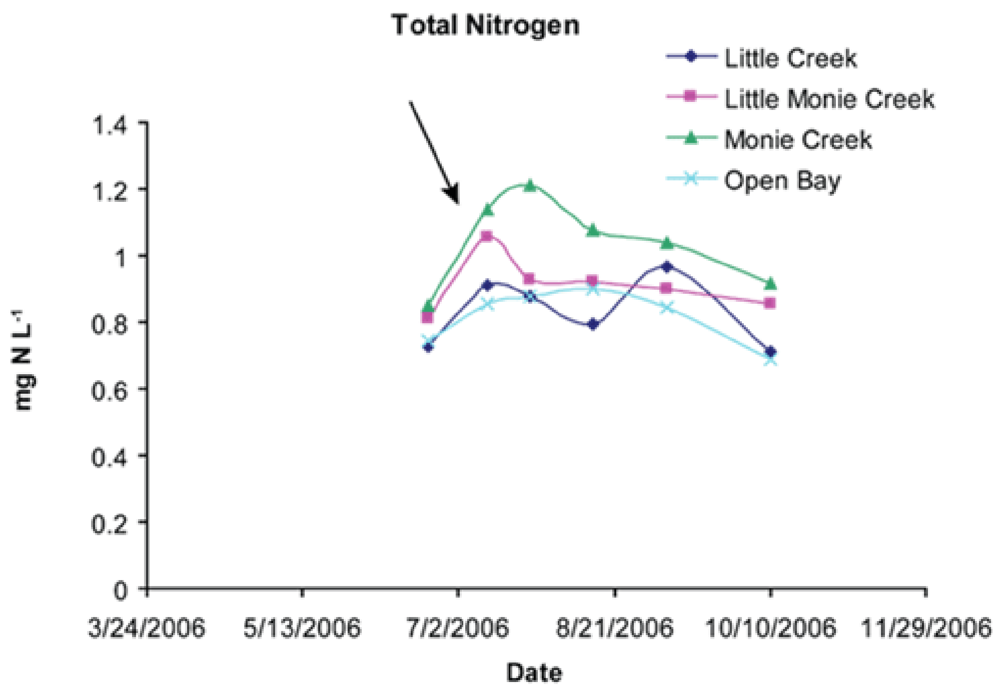


**Figure 8e:** Temporal patterns of total nitrogen. Arrow indicates July 6, 2006 precipitation event.

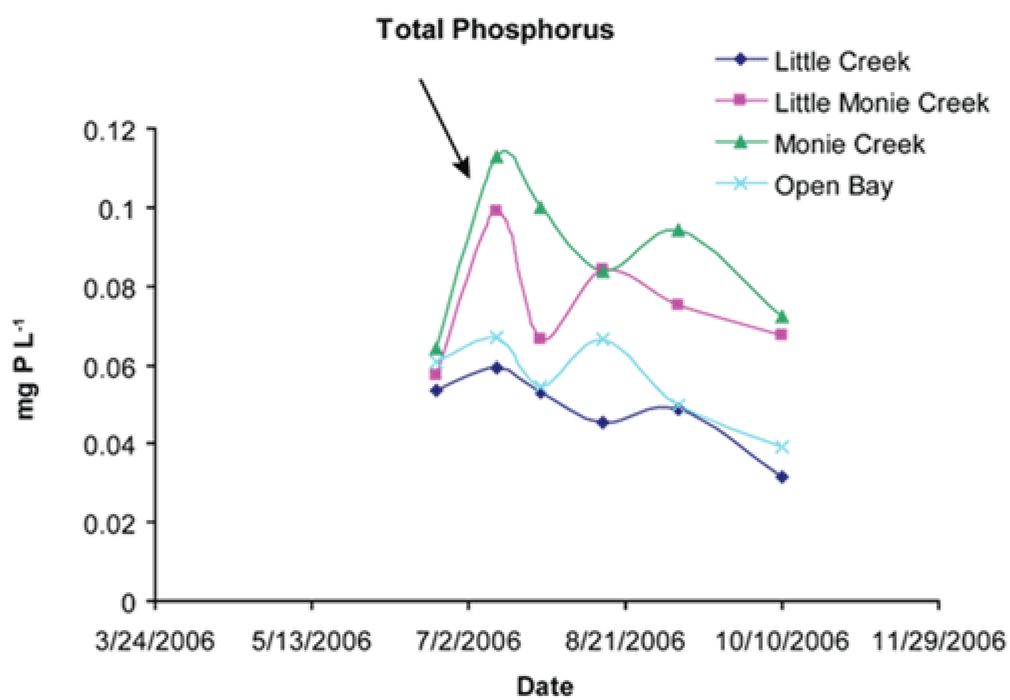


**Figure 8f:** Temporal patterns of total phosphorus. Arrow indicates July 6, 2006 precipitation event.

chlorophyll *a* (Figure 8g) were observed. Meanwhile, the combined nitrate/nitrite (Figure 8h) increased in Monie Creek and the Open Bay, while nitrite (Figure 8i) declined overall.

Spatial patterns were also observed between creeks. Little Creek and Little Monie Creek were generally similar over the course of the monitoring season. Monie Creek was generally more extreme than the other creeks, having higher concentrations of total nitrogen (Figure 8e) and phosphorus (Figure 8f), chlorophyll *a* (Figure 8g), while having lower salinities, dissolved oxygen (Figures 8b, 8c,8d), and total suspended solids (Figure 8j) but not total volatile solids (Figure 8k). Dissolved nutrients such as ammonium (Figure 8l), nitrite (Figure 8i), combined nitrite and nitrate (Figure 8h), and phosphate (Figure 8m), peaked in different creeks at different times throughout the summer, with no clear patterns emerging. Peak values at intermediate distances from station MB1 was sometimes, but not always followed by the water quality parameters that comprise the WQI. Though TN overall increased with distance from station MB1, within creeks, it was highest at either end of the creek, suggesting nitrogen loads from both terrestrial and external sources (Figure 9a). Total phosphorus and chlorophyll *a* generally increased with distance from MB1 (Figure 9b, Figure 9c), but dissolved oxygen decreased (Figure 9d).

Temporal patterns emerged for total nutrients (Figures 8e and 8f) and chlorophyll *a* (Figure 8g), with differently timed peaks and changes in nutrient concentrations over the course of the summer monitoring period. Both total nitrogen (Figure 8e) and total phosphorus (Figure 8f) increased over the course of the summer in Monie Creek and Little Monie Creek, while in Little Creek and the Open Bay total nitrogen remained stable overall and total phosphorus actually decreased. Though chlorophyll *a* had successive peaks in July and September, levels

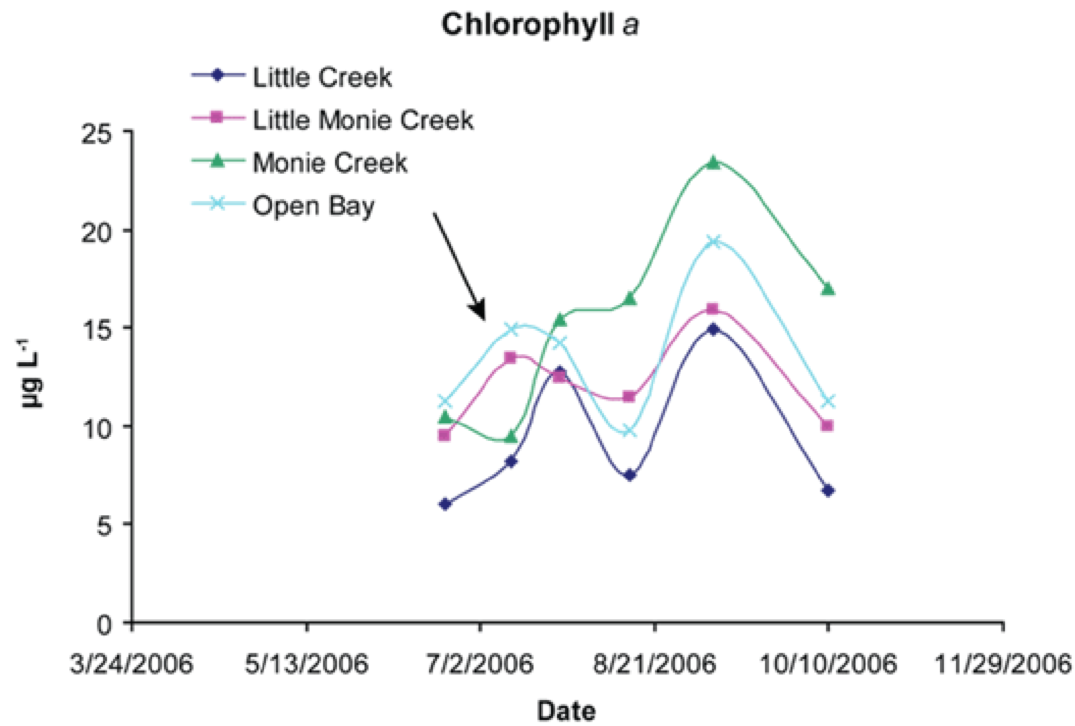


**Figure 8g:** Temporal patterns of chlorophyll *a*. Arrow shows July 6, 2006 precipitation event.

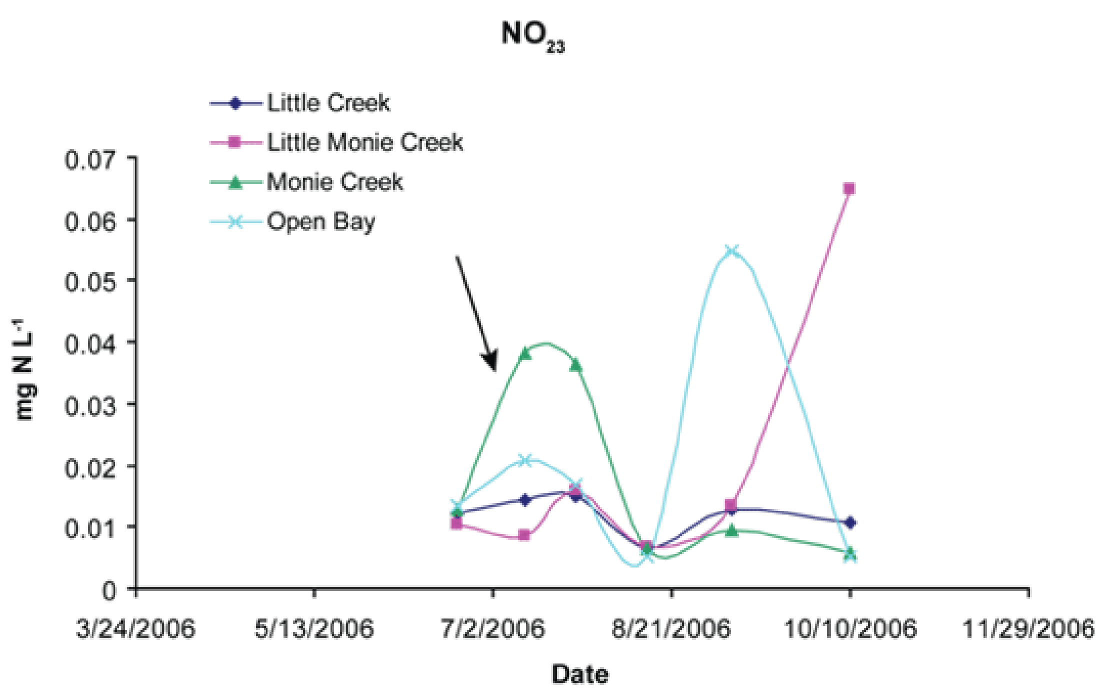


**Figure 8h:** Temporal patterns of combined nitrite/nitrate averaged for each creek. Arrow indicates July 6, 2006 precipitation event.

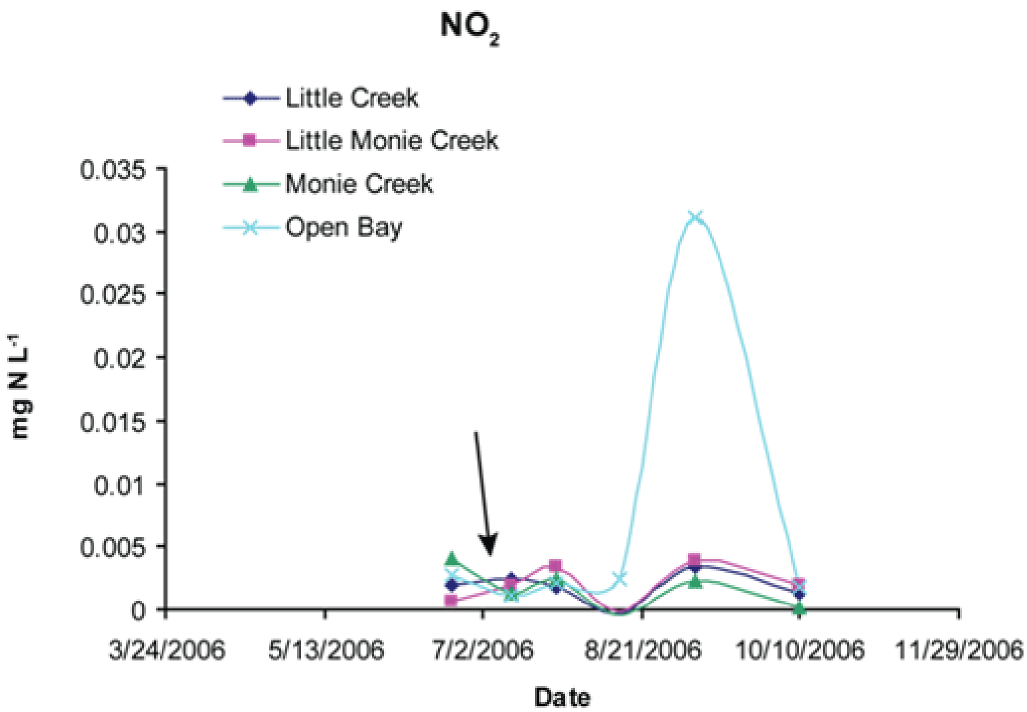


**Figure 8i:** Temporal patterns of nitrite. Arrow indicates July 6, 2006 precipitation event.

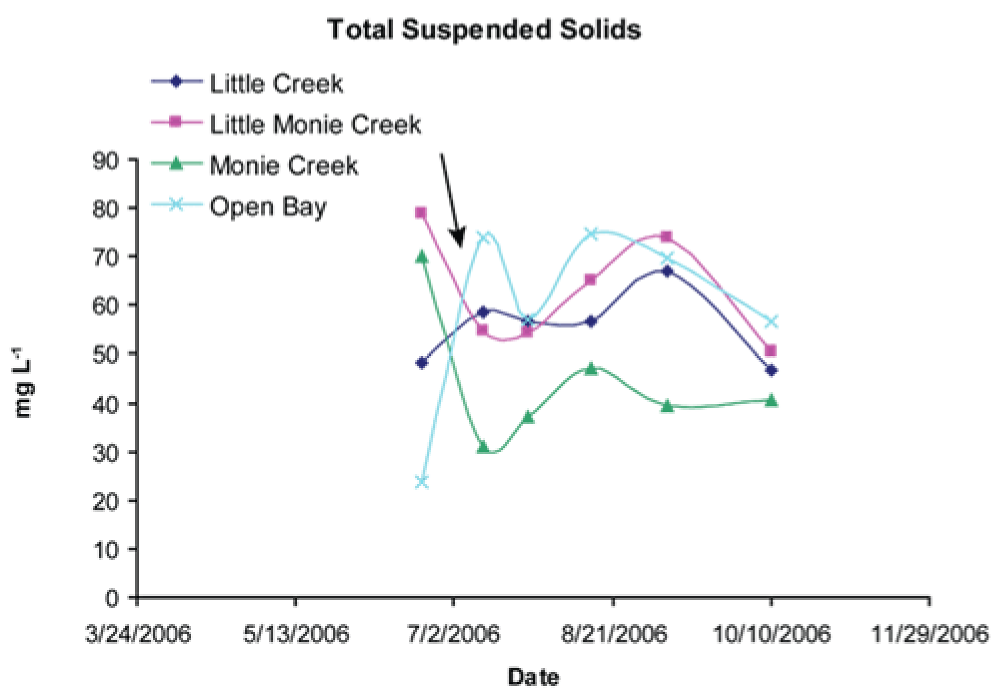


**Figure 8j:** Temporal patterns of total suspended solids averaged for each creek. Arrow indicates July 6, 2006 precipitation event.

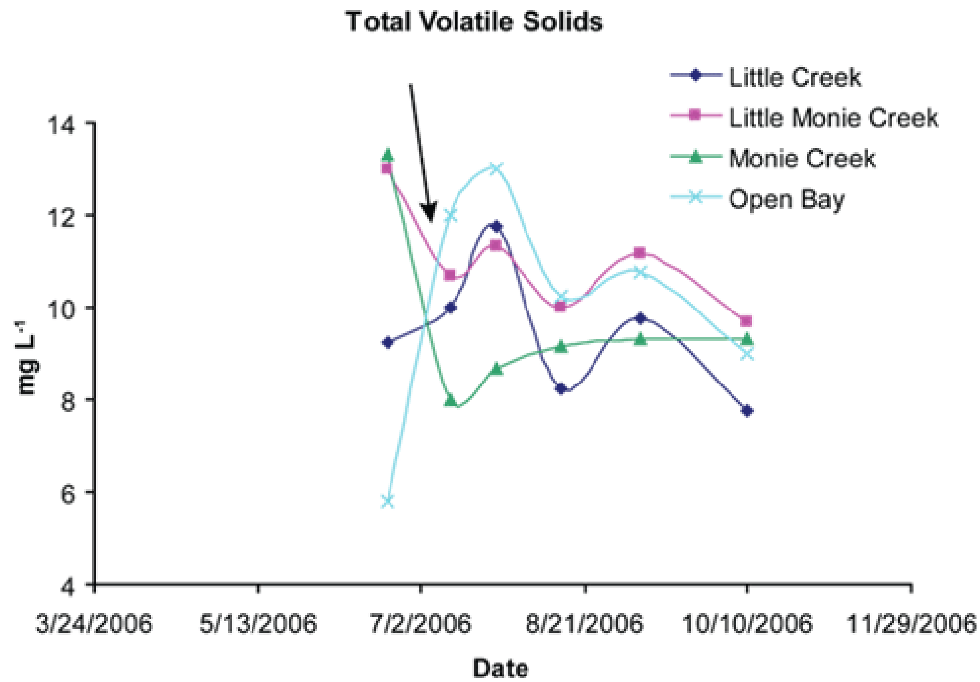


**Figure 8k:** Temporal patterns of total volatile solids. Arrow shows July 6, 2006 precipitation event.

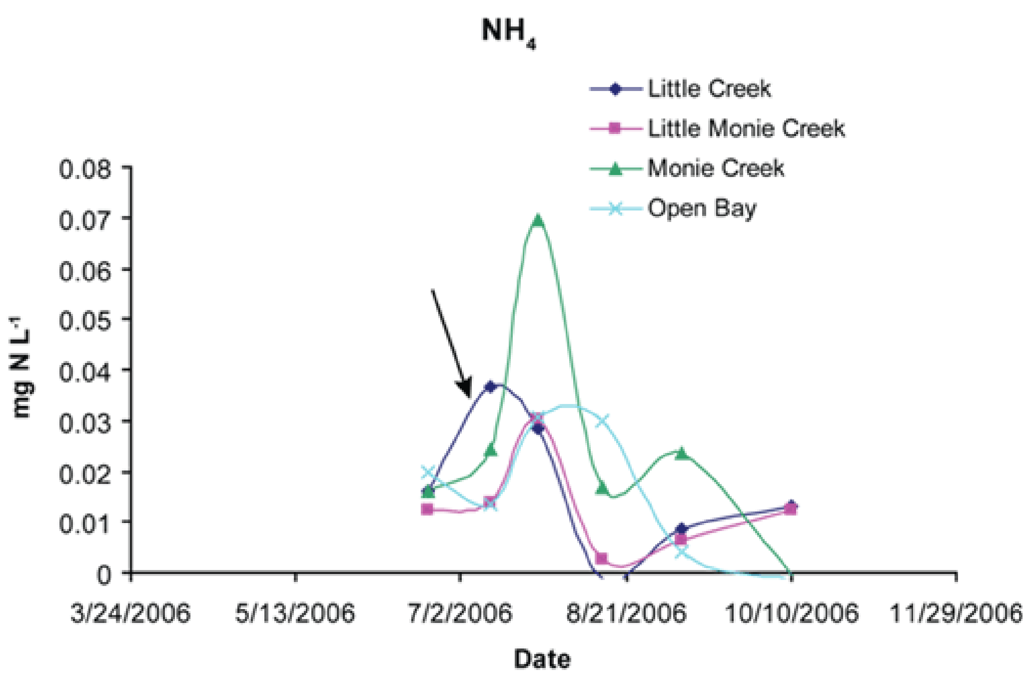


**Figure 8l:** Temporal patterns of ammonium. Arrow indicates July 6, 2006 precipitation event.

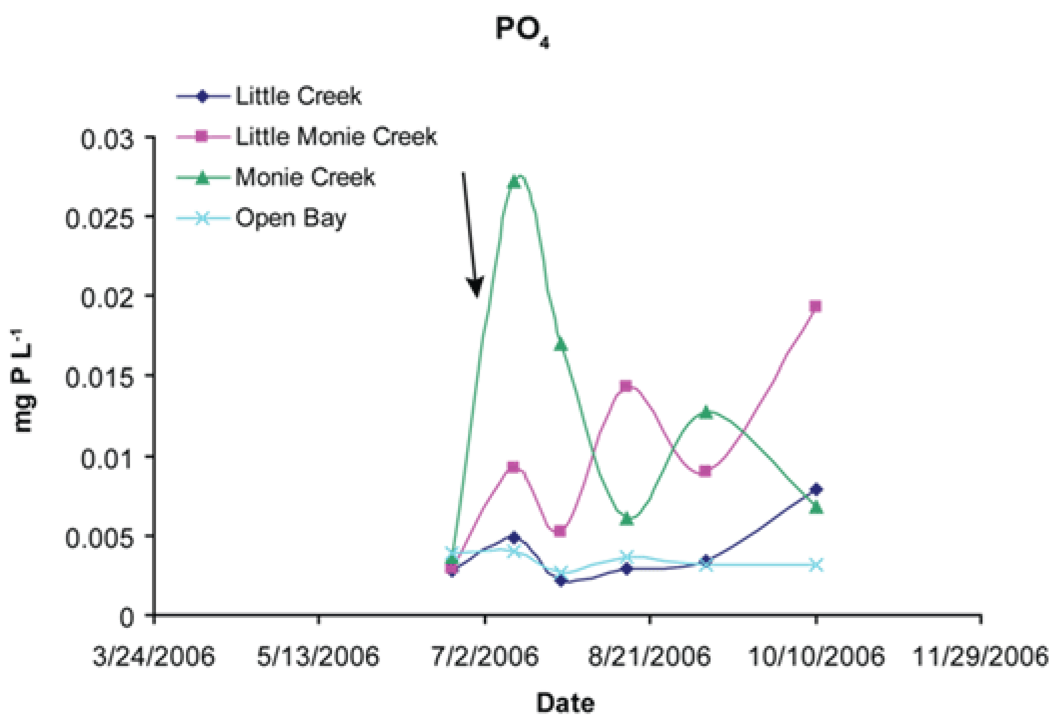


**Figure 8m:** Temporal patterns of phosphate averaged for each creek. Arrow indicates July 6, 2006 precipitation event.

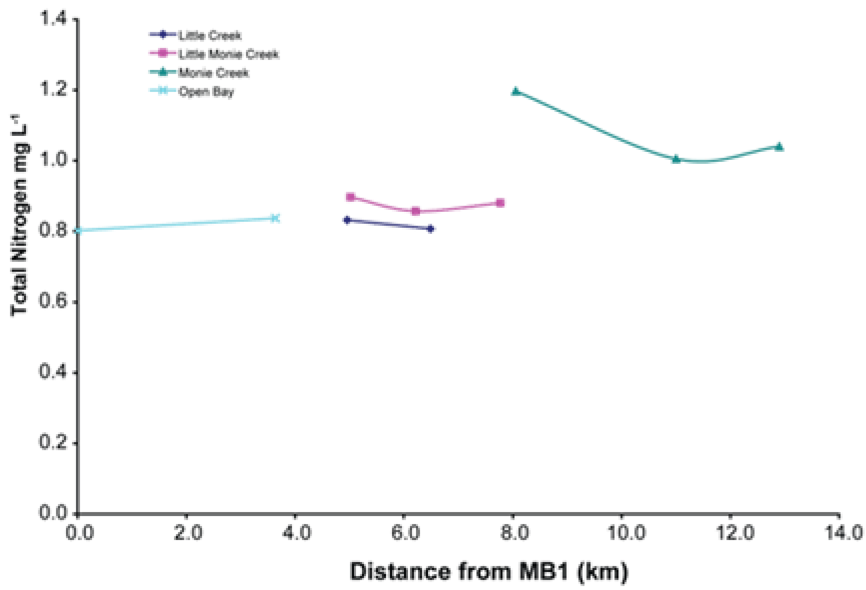


**Figure 9a.** Total nitrogen (mg $L^{-1}$) as related to distance from station MB1, in the Open Bay. TN is lowest at intermediate distances from MB1, suggesting nitrogen sources from both outside Monie Bay and from terrestrial sources.

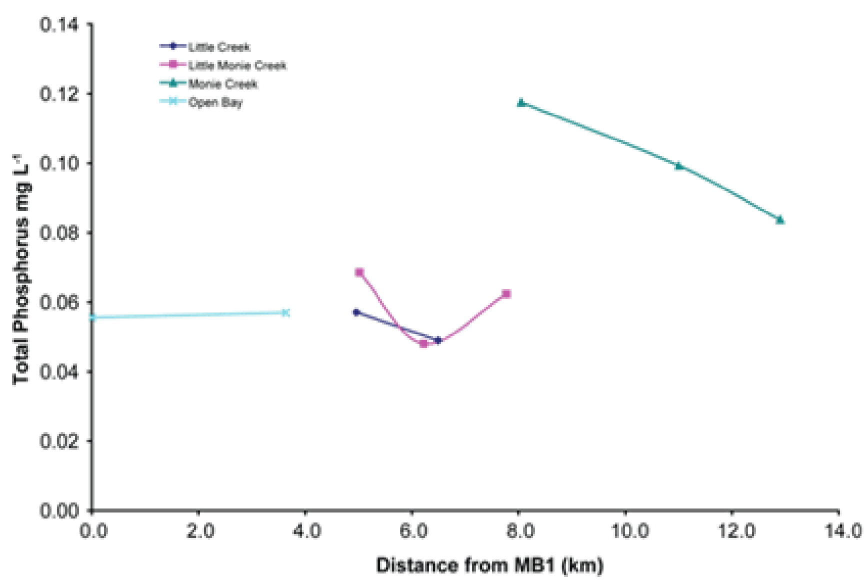


**Figure 9b** Total phosphorus (mg $L^{-1}$) as related to distance from station MB1, in the Open Bay. TP is lowest at intermediate distances from MB1, suggesting phosphorus sources from both outside Monie Bay and from terrestrial sources.

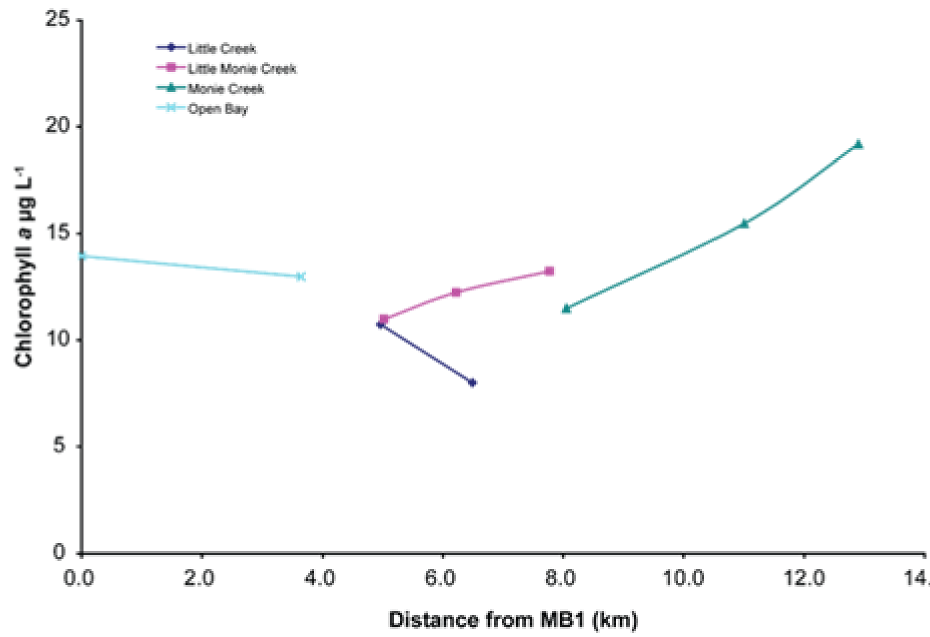


**Figure 9c**. Chlorophyll *a* (µg $L^{-1}$) as related to distance from station MB1, in the Open Bay. Chlorophyll is lowest at intermediate distances from MB1, suggesting that nutrients from both outside Monie Bay and from terrestrial sources are available for plankton growth.

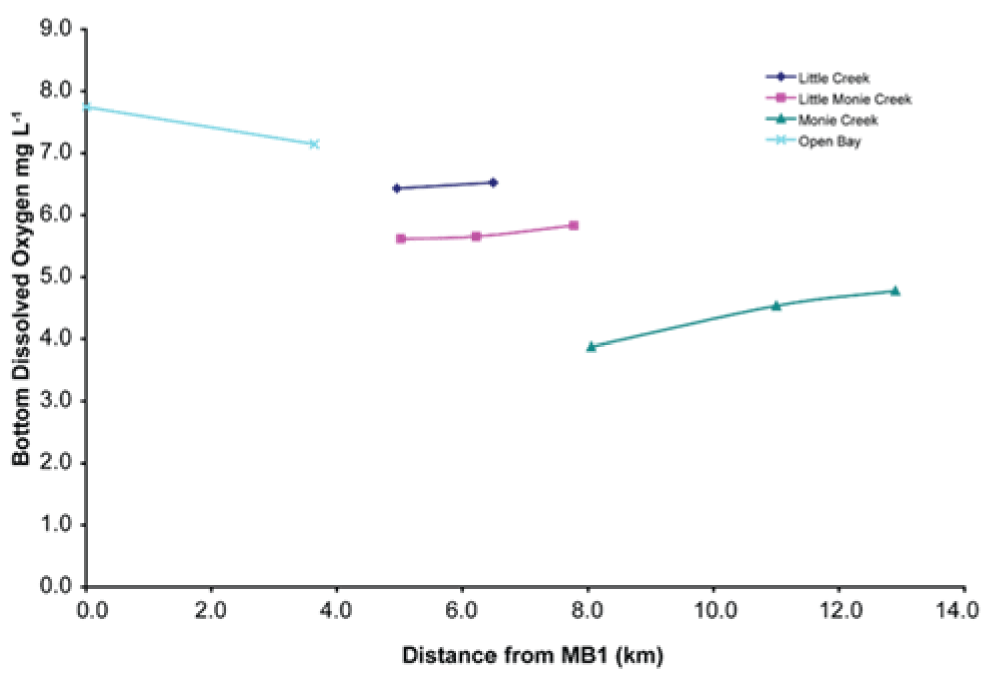


**Figure 9d.** Bottom layer dissolved oxygen (mg $L^{-1}$) as related to distance from station MB1, in the Open Bay. Oxygen decreases away from MB1.

were similar at the end of the monitoring period to those at the beginning of the monitoring period for all but Monie Creek, which increased.

Concentrations of total suspended solids (Figure 8j) and total volatile solids (Figure 8k) peaked in late summer. Total suspended solids generally peaking in August – September, and total volatile solids generally peaked in July. However, total volatile solids remained fairly constant at around 8.67-9.33 mg/L in Monie Creek. Though phosphate (Figure 8m) generally did not fluctuate in the Open Bay, it peaked for all creeks. Extreme but decreasing peaks were found in Monie Creek in July and September. Lesser but increasing peaks were found in Little Monie Creek in August and October. Temporal patterns for various forms of dissolved nitrogen (Figures 8h, 8i, and 8l) were generally inconsistent between creeks.

Water quality monitoring identified a potential for non-conservative mixing within the creeks, based on the relationship between total nitrogen and salinity, a conservative tracer. Non-conservative mixing potentially indicates the presence of biological nutrient cycling, such as microbially-mediated denitrification or other biogeochemical transformation processes, since nitrogen is not linearly diluted with increasing amounts of freshwater, as is a conservative tracer, such as salinity. The mixing diagram (Figure 10) data points generally fall below the line linking the total nitrogen data points at both salinity extremes, indicating non-conservative mixing in these creeks. Thus, there is potential for net denitrification, and this microbially-mediated process has been implicated in elevating oyster isotope values in Maryland's Coastal Bays (personal observation, unpublished data) and so must be accounted for in the framework for interpreting oyster isotope values as related to nitrogen source.

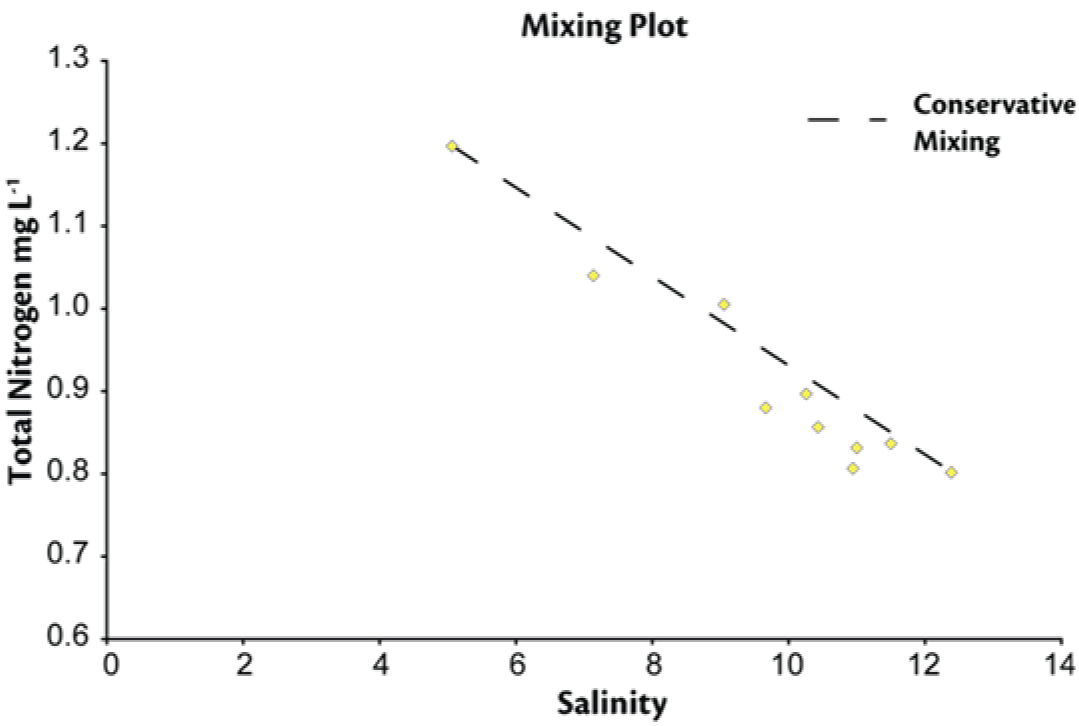


**Figure 10**: Mixing diagram indicates potential non-conservative mixing of total nitrogen due to lack of fit with the linear relationship found between total nitrogen and a conservative tracer, salinity. Potential net denitrification may explain why most of the stations fall below this linear relationship.

*Water Quality Index*

Both temporal and spatial trends in the water quality index were immediately apparent. Table 2 displays the calculation of the WQI, including relevant nutrient values, attainment of threshold value for each of the four water quality parameters, and the overall WQI score for each site. Over the monitoring period, the WQI was best in the Open Bay and Little Creek, likely due to water residence time and location within the Deale Island Wildlife Management Area, respectively (Table 2). Temporally, WQI decreased during late summer and increased in fall for each creek. However, the Open Bay was best when all creeks were worst (Figure 11).

Monie Creek had the worst overall WQI, and Little Monie Creek was intermediate. As noted earlier, Monie Creek often displayed extreme values of nutrients, as compared to the other creeks and the Open Bay, and Monie Creek generally had the highest chlorophyll *a*, since it was generally over 15 $\mu g\ L^{-1}$ (Figure 11). Little Creek generally had the lowest chlorophyll *a*, and was always under this threshold value. More specifically, WQI was best at MB2, further inshore within the Open Bay, and worst at MB8, the upstream station in Monie Creek. WQI increased (an improvement) to peak values at intermediate distances from MB1 (Figure 12), and was worst furthest from MB1, in Monie Creek. Overall, these spatial patterns suggest that factors contributing to degraded water quality are coming from both terrestrial sources, but also from outside Monie Bay. The nearby Wicomico River is potentially a nitrogen source to Monie Bay.

Open Bay did not follow the same trends as the creeks, likely due to inputs from Monie Creek and exchange with Tangier Sound. Temporal variation was greatest at MB2, and least at MB3. Variation increased going downstream at Little Monie Creek, and increased in Little Creek and the Open Bay, but patterns were unclear at Monie Creek (Table 3). Overall, this temporal

| | Mean Measured Values | | | | Mean Attainment | | | | Mean Proportion of Attainment |
|---|---|---|---|---|---|---|---|---|---|
| Site | TN (mg N $L^{-1}$) | TP (mg P $L^{-1}$) | chl *a* | bottom DO mg $L^{-1}$ | TN | TP | chl | DO | Water Quality Index |
| Open Bay | | | | | | | | | |
| MB1 | 0.80 | 0.056 | 13.95 | 7.75 | 0.00 | 0.00 | 0.50 | 1.00 | 0.38 |
| MB2 | 0.84 | 0.057 | 12.98 | 7.15 | 0.17 | 0.17 | 0.83 | 1.00 | 0.54 |
| Little Creek | | | | | | | | | |
| MB3 | 0.86 | 0.048 | 8.00 | 5.66 | 0.00 | 0.17 | 1.00 | 0.83 | 0.50 |
| MB4 | 0.81 | 0.049 | 10.73 | 6.53 | 0.00 | 0.17 | 0.67 | 0.83 | 0.42 |
| Little Monie Creek | | | | | | | | | |
| MB5 | 1.01 | 0.099 | 13.23 | 4.54 | 0.00 | 0.00 | 0.67 | 0.17 | 0.21 |
| MB6 | 0.90 | 0.069 | 12.23 | 5.62 | 0.00 | 0.00 | 0.83 | 0.83 | 0.42 |
| MB7 | 0.83 | 0.057 | 10.98 | 6.43 | 0.00 | 0.00 | 0.83 | 0.83 | 0.42 |
| Monie Creek | | | | | | | | | |
| MB8 | 1.20 | 0.117 | 19.18 | 3.88 | 0.00 | 0.00 | 0.33 | 0.17 | 0.13 |
| MB9 | 1.04 | 0.084 | 15.47 | 4.77 | 0.00 | 0.00 | 0.33 | 0.33 | 0.17 |
| MB10 | 0.88 | 0.062 | 11.48 | 5.83 | 0.00 | 0.00 | 0.83 | 0.83 | 0.42 |

**Table 2:** Calculation of mean Water Quality Index (WQI) for each station over the monitoring period, showing mean measurements for each parameter, mean attainment, and calculated WQI.

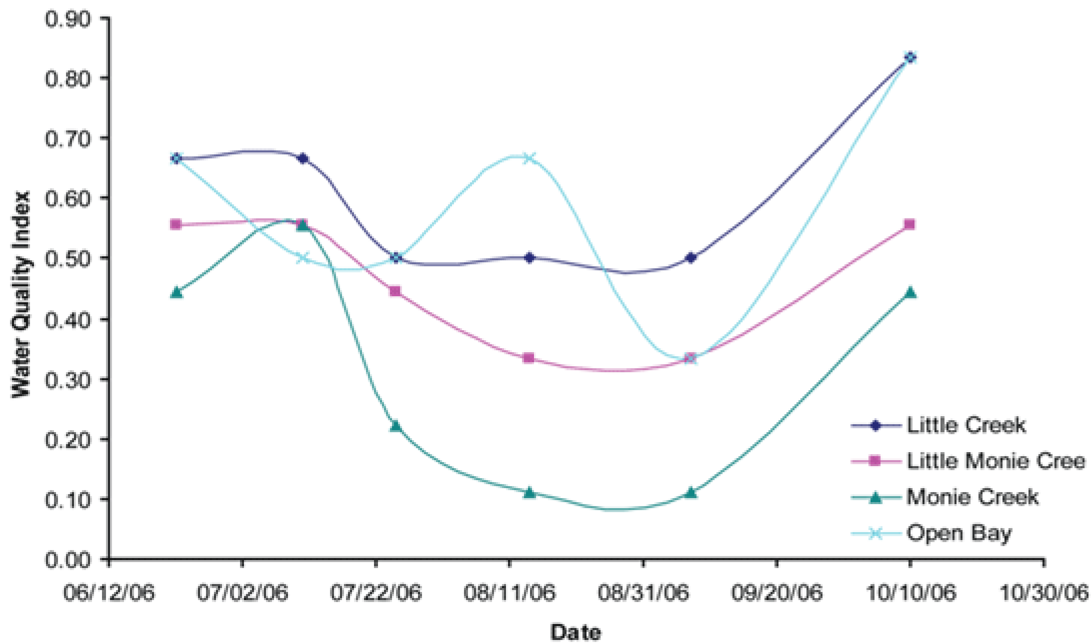


**Figure 11**: Temporal trends in the Water Quality Index (WQI)

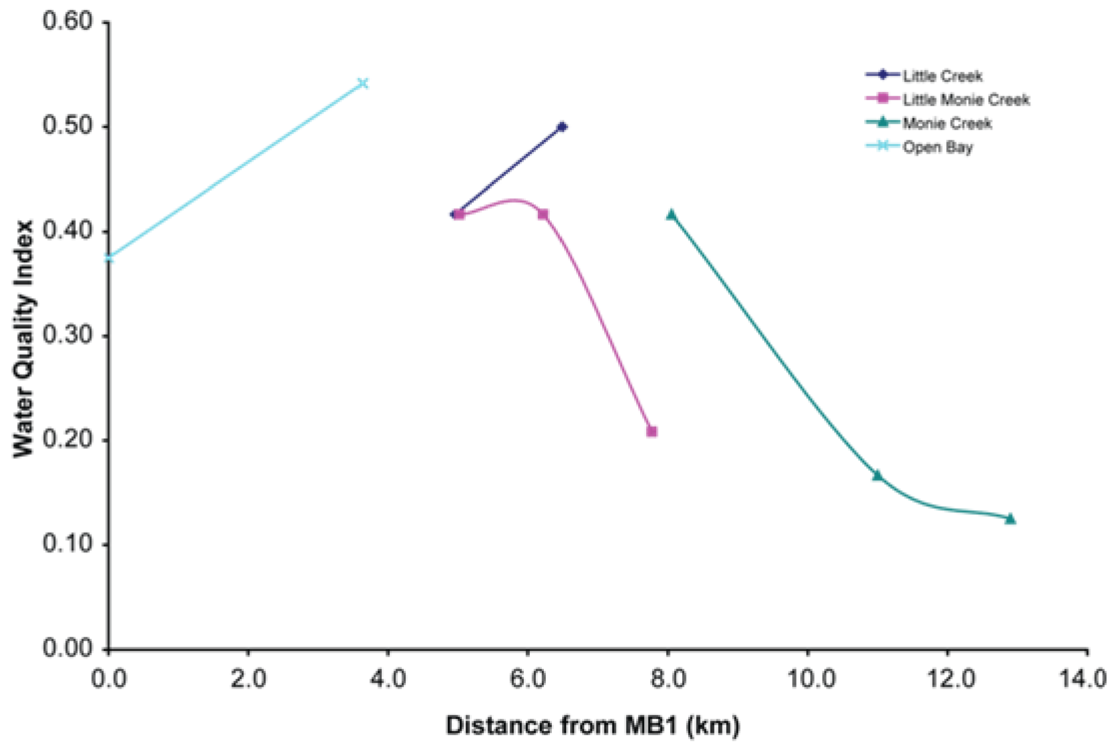


**Figure 12.** Water Quality Index (WQI) as related to distance from station MB1, in the Open Bay. WQI is highest at intermediate distances from MB1, indicating that Water Quality closest to Wicomico River and terrestrial sources of nitrogen have poorest water quality.

| | Standard Error for Measured Values | | | | Standard Error of Attainment | | | | Standard Error for WQI |
|---|---|---|---|---|---|---|---|---|---|
| | TN (mg N $L^{-1}$) | TP (mg P $L^{-1}$) | chl *a* | bottom DO mg $L^{-1}$ | TN | TP | chl *a* | DO | Water Quality Index |
| Open Bay | | | | | | | | | |
| MB1 | 0.02 | 0.004 | 1.61 | 0.34 | 0.00 | 0.00 | 0.22 | 0.00 | 0.06 |
| MB2 | 0.06 | 0.006 | 1.70 | 0.33 | 0.17 | 0.17 | 0.17 | 0.00 | 0.10 |
| Little Creek | | | | | | | | | |
| MB3 | 0.05 | 0.004 | 1.14 | 0.30 | 0.00 | 0.17 | 0.00 | 0.17 | 0.00 |
| MB4 | 0.04 | 0.004 | 1.90 | 0.49 | 0.00 | 0.17 | 0.21 | 0.17 | 0.08 |
| Little Monie Creek | | | | | | | | | |
| MB5 | 0.05 | 0.011 | 1.46 | 0.42 | 0.00 | 0.00 | 0.21 | 0.17 | 0.04 |
| MB6 | 0.03 | 0.005 | 0.89 | 0.45 | 0.00 | 0.00 | 0.17 | 0.17 | 0.05 |
| MB7 | 0.04 | 0.004 | 1.74 | 0.53 | 0.00 | 0.00 | 0.17 | 0.17 | 0.05 |
| Monie Creek | | | | | | | | | |
| MB8 | 0.09 | 0.016 | 3.28 | 0.61 | 0.00 | 0.00 | 0.21 | 0.17 | 0.06 |
| MB9 | 0.06 | 0.006 | 1.98 | 0.32 | 0.00 | 0.00 | 0.21 | 0.21 | 0.08 |
| MB10 | 0.04 | 0.003 | 1.31 | 0.47 | 0.00 | 0.00 | 0.17 | 0.17 | 0.05 |

**Table 3:** Calculation of standard errors for the Water Quality Index (WQI) for each station over the monitoring period, showing standard error for the mean measurements for each parameter, mean attainment, and calculated WQI.

variation is largely due to increasing and later decreasing levels of chlorophyll *a*, though fluctuations in bottom layer dissolved oxygen also play some role.

### *Different Sources of Oysters*

Potential effects of originating tributary on final $\delta^{15}N$ values after deployment were investigated. Mean initial $\delta^{15}N$ values of oyster tissue isotopes from the two different source tributaries, the South River and the Severn River, significantly differed. Figure 13 indicates the relationship between the $\delta^{15}N$ from all tissues dissected from oysters initially grown at these two sources. $\delta^{15}N$ in oyster tissues from the Severn River varies linearly (with a slope of 1.0 and an $R^2$ of 0.73) with $\delta^{15}N$ in oyster tissues originating in the South River. Thus, the initial source of oyster had no effect on the ultimate $\delta^{15}N$ value after deployment. Deploying oysters is a valid method to identify local $\delta^{15}N$ values at the host site because isotopes in tissues converge to ambient conditions over the deployment period. The ability to deploy oysters in specified locations adds to the practical utility of the oyster as a bioindicator. Deployment, rather than opportunistic sample collection at the site of interest, is necessary to identify $\delta^{15}N$ patterns where no local beds of oysters exist currently.

### *Correlation with land use areas*

Terrestrial sources and loads of nitrogen vary by land use, so the relationship between oyster isotope values and land use was examined. The analysis focused on the muscle tissue because this tissue is the slowest to turnover, thus integrating over the longest period of time, and least likely to be biased by pulsed precipitation and resulting nutrient loads. Additionally, analysis was limited to stations furthest upstream in each of the creeks (MB8 in Monie Creek,

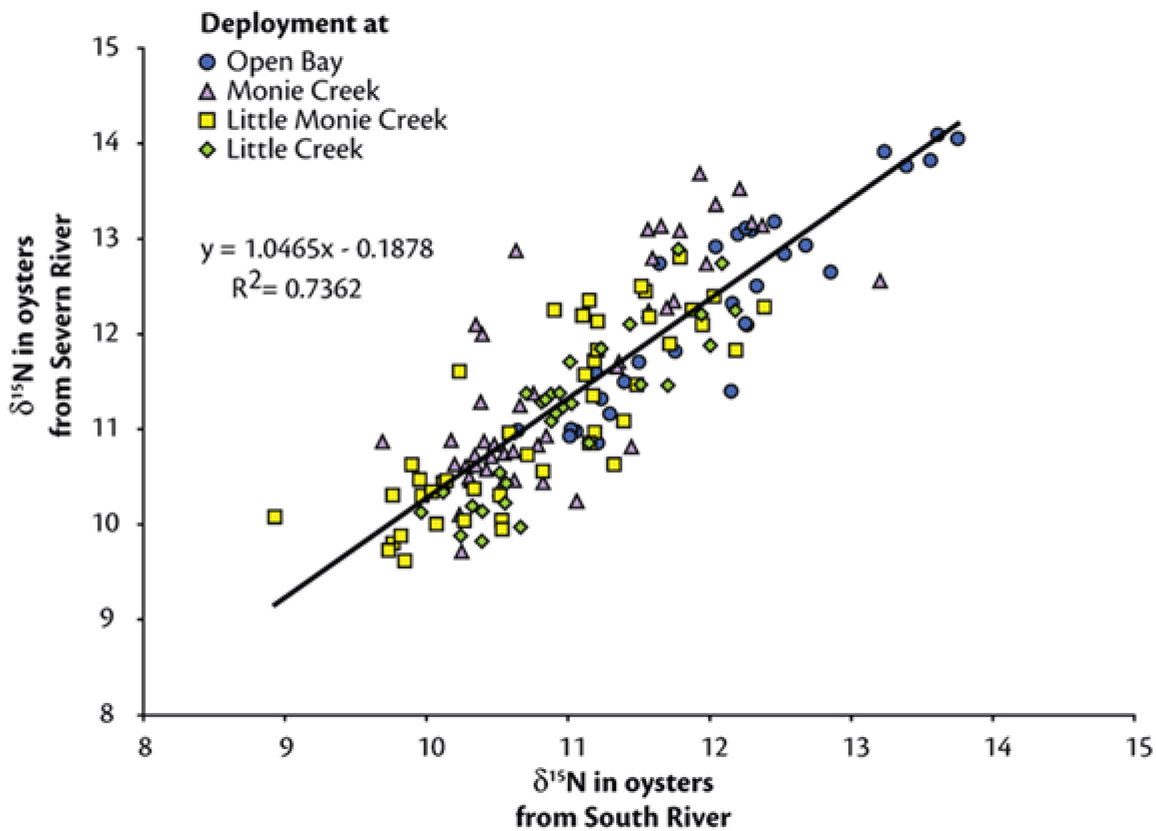


**Figure 13:** Relationship of $\delta^{15}N$ values (all three tissues) from oysters originating in different sources The tight fit of $\delta^{15}N$ from these two sources to each other indicates that oyster tissue $\delta^{15}N$ reached ambient isotope conditions, and the originating source of oysters does not affect the ultimate isotope signal found after deployment.

MB 5 in Little Monie Creek, and MB3 in Little Creek) to capture events that solely occur due to terrestrial influence. It is necessary to minimize any potential impact that gradients (including salinity) or tidal inputs of nutrients, plankton, etc. might have along the creek axis. The site furthest upstream is likely to be the best predictor of the terrestrially derived nitrogen for each creek. Oyster muscle $\delta^{15}N$ was found to increase as the percentage of the sub-watershed was covered with residential, agriculture, and forest, and was inversely related to the percentage of marshland. Table 4 lists the linear relationships and presents $R^2$ values for each of these single-variable relationship models. Using forward selection model building, Table 5 indicates that the two-variable model which includes percent cover of both forest and marsh is significantly related to oyster muscle $\delta^{15}N$ and explains nearly 53% of the variation. Accordingly, combined forest and marsh cover 72% and 74% of the Little Monie Creek and Monie Creek sub-watersheds, respectively.

*Oyster isotopes*

Several clear patterns emerged from oyster tissue $\delta^{15}N$. Oyster muscle always had higher $\delta^{15}N$ values than either the gill or the mantle, which were did not significantly differ (Figure 14). This pattern was consistent across creeks and individual stations, so only patterns found in the muscle tissue will be discussed specifically. Interesting spatial patterns of oyster muscle $\delta^{15}N$ emerge, though no temporal variability in tissue-specific $\delta^{15}N$ can be assessed because oysters were collected only at the end of the study period. Unexpectedly, the highest $\delta^{15}N$ values were found in the Open Bay (12.88 ± 0.923 ‰), rather than in the creeks. Mean $\delta^{15}N$ in Monie Creek (12.39 ± 0.685‰) is slightly higher than Little Creek (11.87 ± 0.466‰) or Little Monie Creek (11.89 ± 0.452‰, see Figure 15a). Lowest values of $\delta^{15}N$ were found at intermediate distances

| **Variable** | **Slope** | **Intercept** | **$R^2$** |
| --- | --- | --- | --- |
| % residential | 0.1342 | 11.738 | 0.274 |
| % agriculture | 0.0102 | 11.885 | 0.210 |
| % marsh | -0.0067 | 12.271 | 0.345 |
| % forest | 0.0179 | 11.186 | 0.520 |

**Table 4:** Relationship between *Crassostrea virginica* muscle $\delta^{15}N$ and percentage landuse.

| **Variable** | **Number of Variables** | **Partial $R^2$** | **Model $R^2$** | **C(p)** | **F** | **P** |
|---|---|---|---|---|---|---|
| Forest | 1 | 0.2830 | 0.2830 | 15.1195 | 11.05 | 0.0025 |
| Marsh | 2 | 0.2462 | 0.5292 | 3.00000 | 14.12 | 0.0008 |

**Table 5:** Summary of forward selection model building

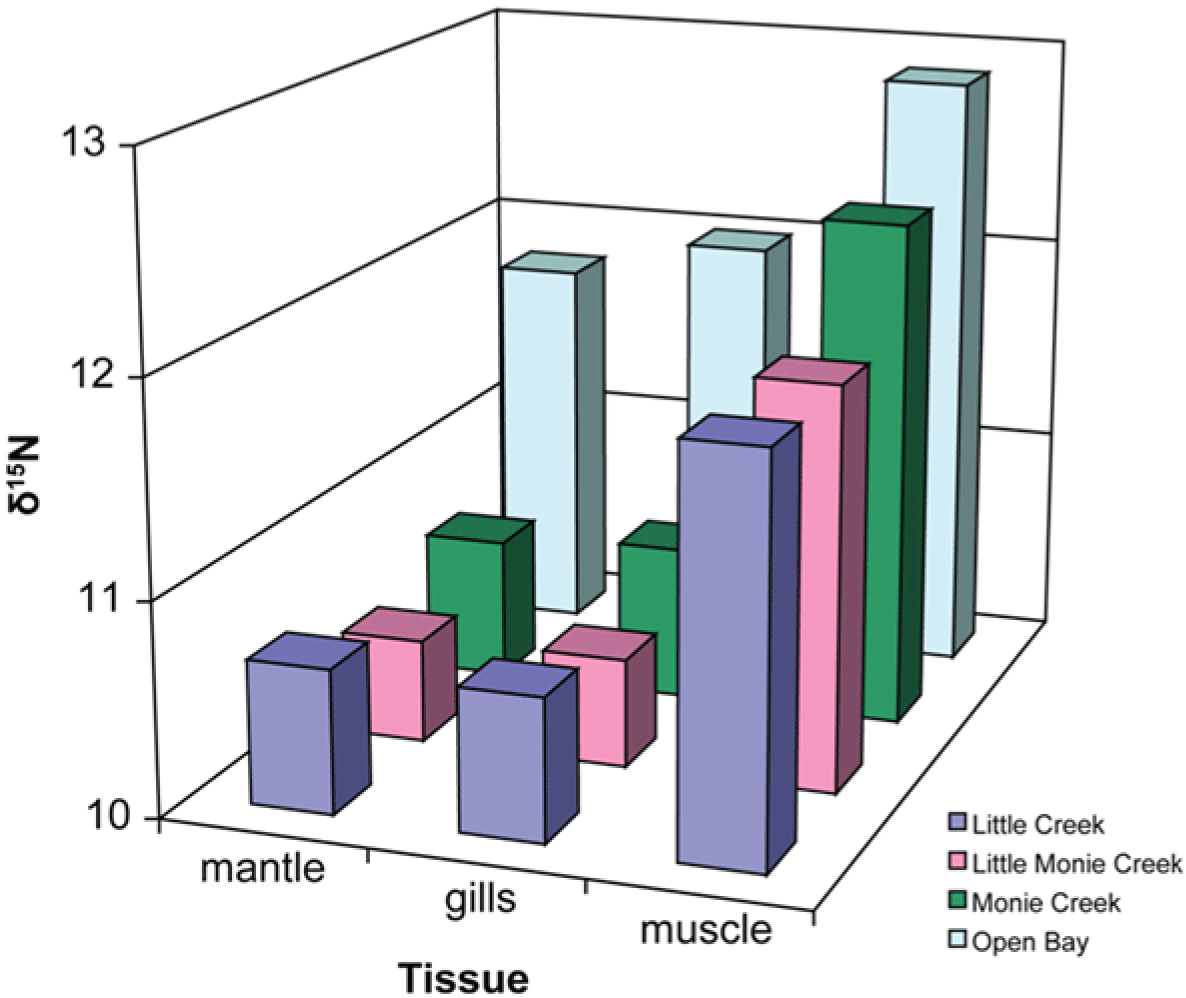


**Figure 14.** Patterns of $\delta^{15}N$ were found between tissues. In *Crassostrea virginica*, muscle tissue was always found to have higher $\delta^{15}N$ values than either the mantle or the gills, which did not significantly differ in Monie Bay.

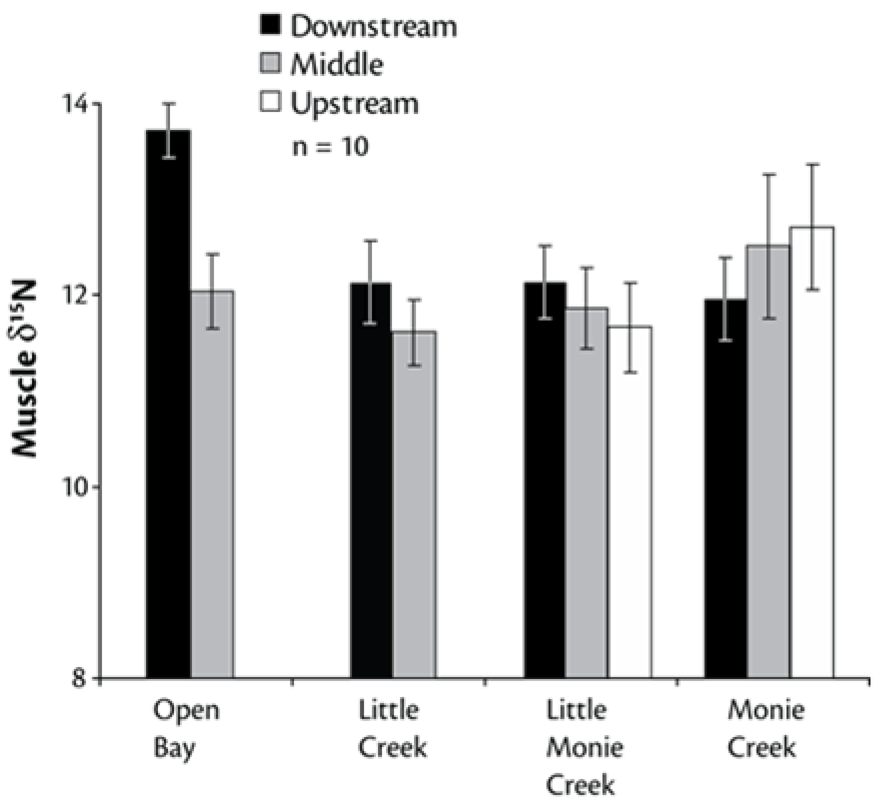


**Figure 15a:** $\delta^{15}N$ values in muscle tissues of oysters deployed at Monie Bay and its creeks. Distances from the mouth of each creek and Monie Bay are separated by color, where black is closest to the mouth, grey is intermediate distance and white is furthest. Standard error bars are shown, which include minimal variation due to the two oyster sources, which are not considered here.

from station MB1, and increased again heading upstream Monie Creek (Figure 15b). Accordingly, $\delta^{15}N$ decreases going upstream along the creek axis in Little Creek and Little Monie Creek, but increases along the Monie Creek axis. Spatial patterns of oyster muscle suggest two sources of sewage/septic nitrogen inputs to Monie Bay; from terrestrial sources upstream in Monie Creek, and coming into Monie Bay from outside, likely from Wicomico River. A terrestrial source of nitrogen to Monie Creek could explain why this creek has higher $\delta^{15}N$ values than the other two creeks and why $\delta^{15}N$ decreases downstream, rather than upstream, as $\delta^{15}N$ does in Little Monie Creek and Little Creek.

Little Monie Creek was predicted to have highest $\delta^{15}N$ due to poultry runoff within the Little Monie Creek sub-watershed, but overall this land use appears to have little ultimate effect on oyster $\delta^{15}N$, as it may not be the dominant source of nitrogen to the system. Monie Creek may have the highest levels of $\delta^{15}N$ due to nearby terrestrial sources of septic.

Several relationships between monitored nutrients and $\delta^{15}N$ in oyster tissues were also apparent. For example, increases in $\delta^{15}N$ were found to be dramatic with nitrite in all creeks and linearly in the Open Bay (Figure 16a). Meanwhile, $\delta^{15}N$ was inversely related to ammonium (Figure 16b) in all creeks and with total nitrogen (Figure 16c) and total phosphorus (Figure 16d) in Monie Creek (but not the other creeks). No clear patterns emerged for phosphate, combined nitrite/nitrate, total suspended solids, or total volatile solids.

There is a strong relationship between oyster muscle $\delta^{15}N$ and water quality index. Note that station MB5 is an outlier, because while water quality is poor, due to proximity to high nutrient loads from terrestrial sources, $\delta^{15}N$ is low because this terrestrial nitrogen is not derived from sewage/septic sources. Rather, sewage/septic nitrogen are diluted upon arrival from downstream and external sources. Removal of MB5 dramatically improves $R^2$ values from 0.41

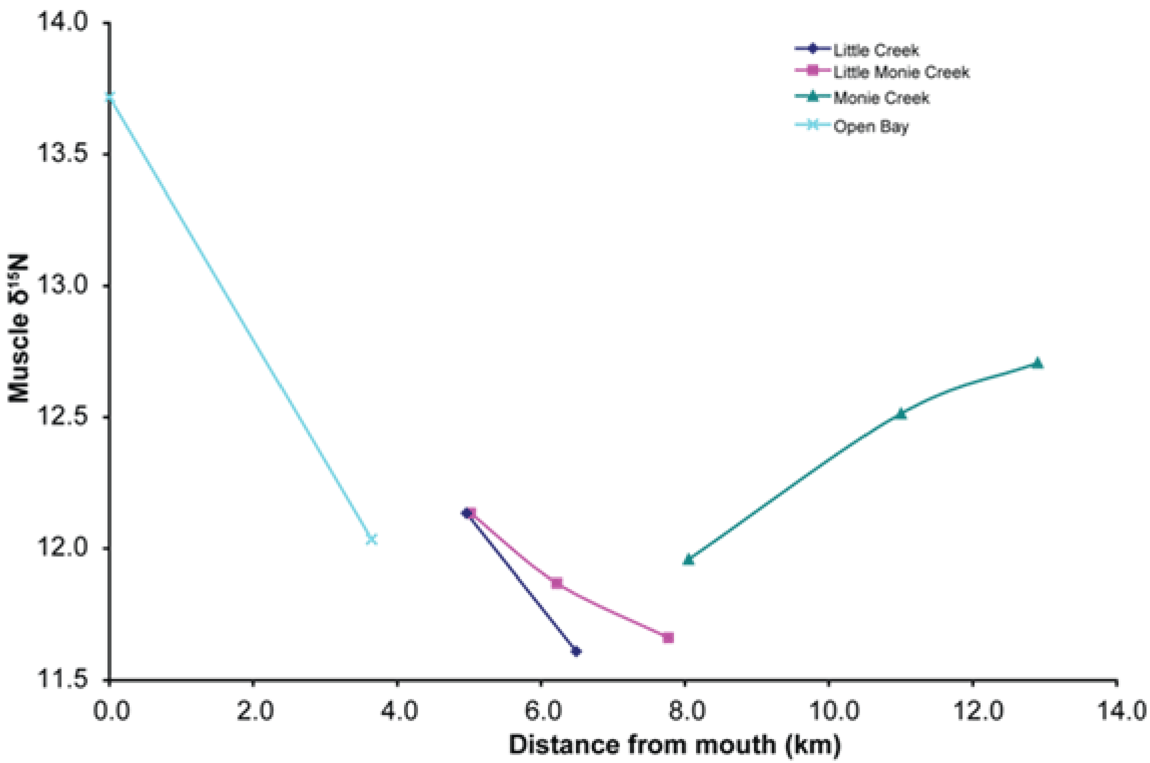


**Figure 15b:** $\delta^{15}N$ values in muscle tissues of oysters deployed at Monie Bay and its creeks. $\delta^{15}N$ is lowest at intermediate distances from station MB1. This suggests there are two sources of sewage/septic nitrogen to Monie Bay and its creeks: entering the Open Bay (potentially from Wicomico River) and entering Monie Creek from terrestrial sources. Open Bay $\delta^{15}N$ values are higher than in Monie Creek, suggesting sewage/septic is a more important source in this area.

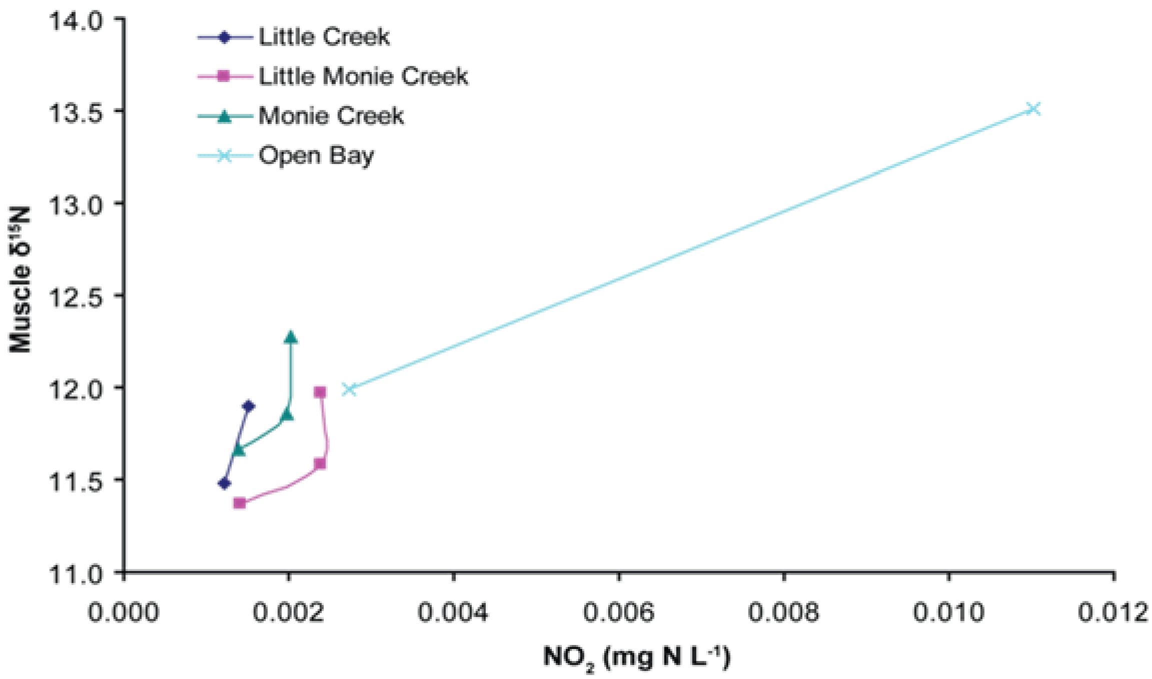


**Figure 16a**. Dramatic increases in $\delta^{15}N$ were found with small increases of nitrite in the creeks, while $\delta^{15}N$ increased over larger increases of nitrite in the Open Bay.

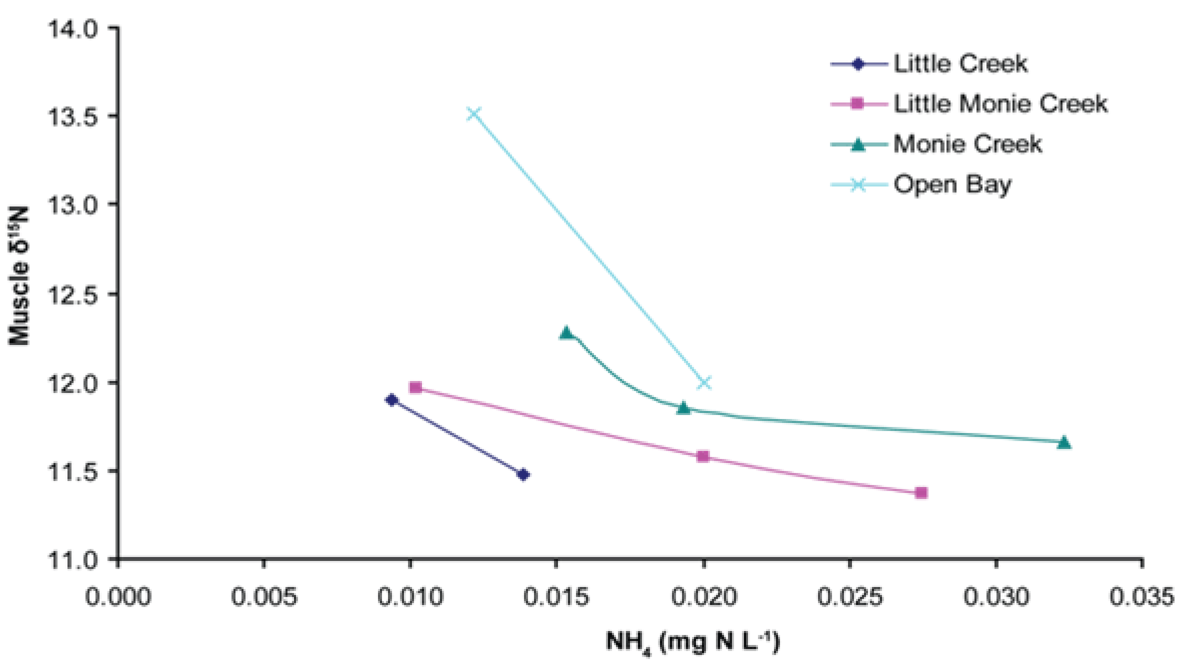


**Figure 16b**. Oyster muscle $\delta^{15}N$ was inversely related to ammonium levels.

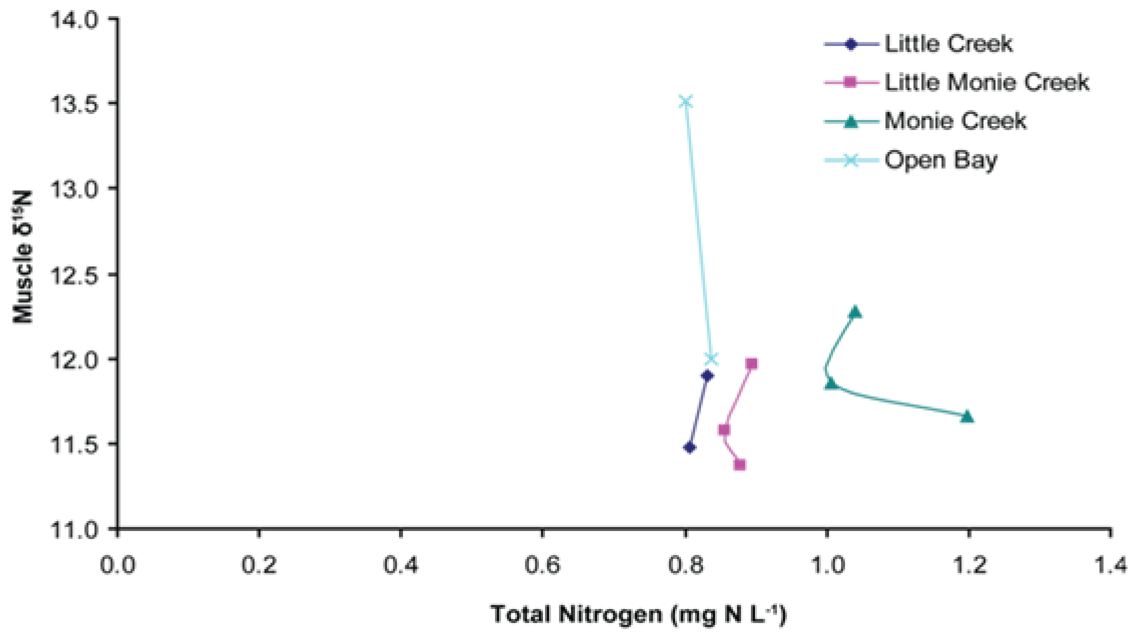


**Figure 16c**. Oyster muscle $\delta^{15}N$ decreased with total nitrogen in Monie Creek, but not the other creeks.

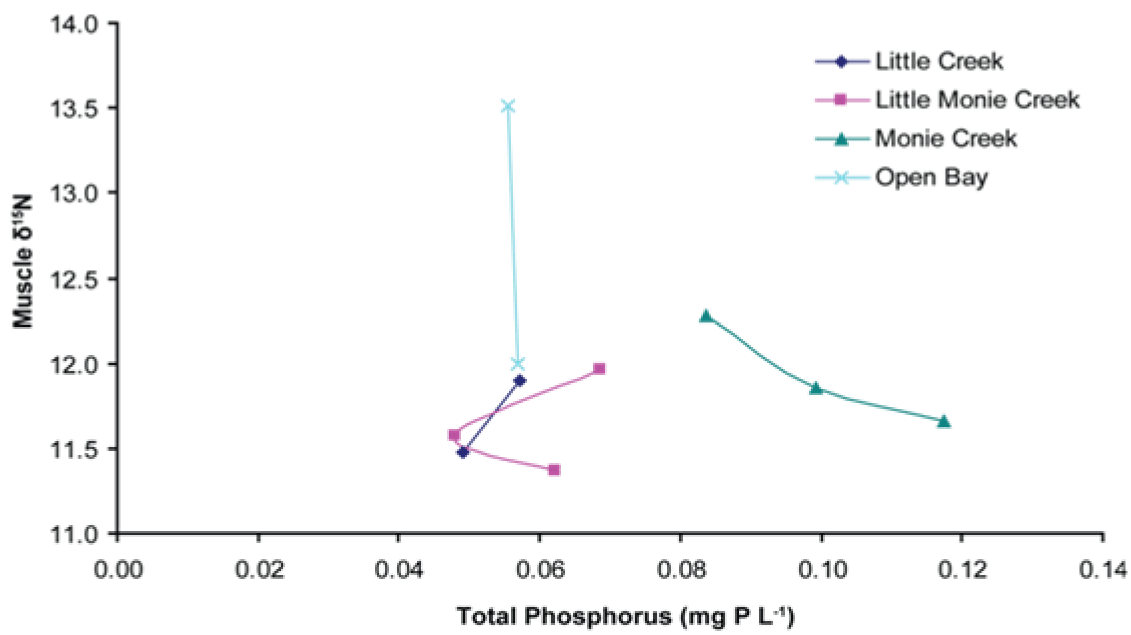


**Figure 16d**. Oyster muscle $\delta^{15}N$ decreased with total phosphorus in Monie Creek, but not the other creeks.

to 0.89 (Figures 17a, 17b). Overall, $\delta^{15}N$ can largely be explained by variations in the water quality index, and thus ultimately by total nitrogen, total phosphorus, chlorophyll *a*, and dissolved oxygen. Areas closer to 'pristine' are located in the lower right of these plots, having high water quality index values and low $\delta^{15}N$ values.

**Discussion**

One of the major findings from this research is that the native eastern oyster, *Crassostrea virginica*, can serve as a deployable biological indicator of nitrogen source and distribution, regardless of originating oyster source. The ability to deploy biological indicators makes the native eastern oyster a useful tool to identify spatial patterns in aquatic systems where local populations of oysters are not currently extant. Secondly, as a biological indicator, the eastern oyster relates land use to nitrogen sources available in the aquatic system. Establishing a link between land use and oyster $\delta^{15}N$ values is important because it helps identify origins of nitrogen sources. Finally, spatial patterns of nitrogen sources emerged, both between creeks and along the creek axes. Spatial patterns can help identify areas of concern and can help to focus nutrient reduction management efforts on the relevant nitrogen source, either sewage/septic or agricultural fertilizers. Ultimately, oyster stable isotopes relate well to overall water quality, and so can be used as an overall biological indicator of ecosystem health.

Both *Crassostrea virginica* muscle $\delta^{15}N$ and water quality index values indicate two sources of nitrogen to the Monie Bay system; one smaller source arriving from terrestrial sources (likely to be septic) along Monie Creek, and a larger source external to Monie Bay. Oyster muscle tissue $\delta^{15}N$ values along the creek axis for Little Monie Creek and Little Creek suggest that these oysters have access to sewage and septic sources of nitrogen that enters Monie Bay

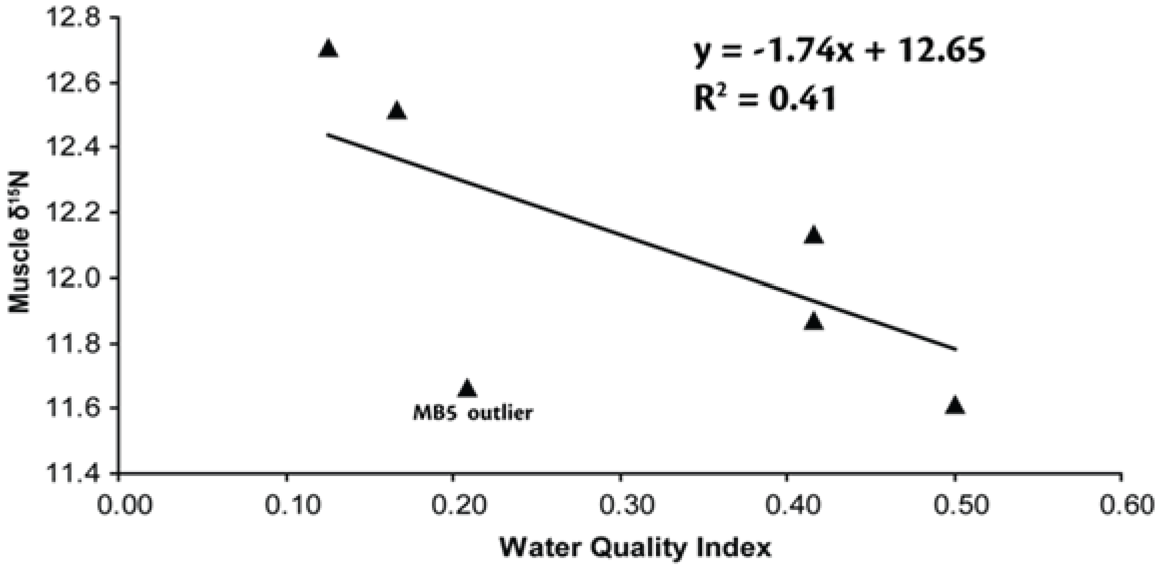


**Figure 17a**. Over all sites, there is a strong relationship between *Crassostrea virginica* muscle $\delta^{15}N$ and water quality index (WQI).

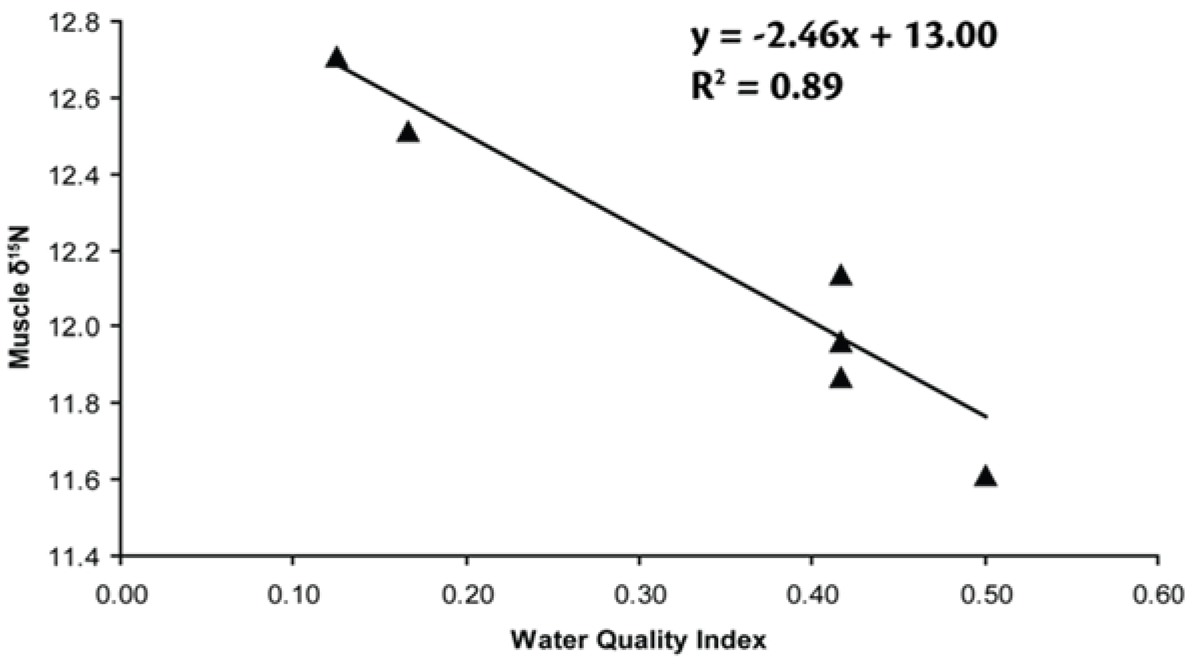


**Figure 17b**. The relationship between *Crassostrea virginica* muscle $\delta^{15}N$ and water quality index (WQI) is stronger after removing the MB5 outlier.

and these creeks from the mouth, rather than being diluted and dispersed downstream, as would a terrestrial source. The nearest sewage and septic sources of nitrogen are the Salisbury, Delmar, and Fruitland wastewater treatment plants, which currently input substantial nitrogen loads into the Wicomico River, and are slated for enhanced nitrogen removal upgrades by 2015 (Maryland Department of the Environment, 2007a,b,c). The sewage and septic nitrogen detected in the creeks of Monie Bay are potentially due to these sources of nitrogen.

Calibration and extension of the oyster's indicator capabilities regarding nitrogen sources may be effected by modeling oyster isotope physiology and cycling. A STELLA model based upon 2006 Monie Bay fieldwork, the collected land use datasets, and 2006 oyster isotope values could be developed to predict oyster isotope values at each field station for 2007. For each station, the STELLA model could be validated by additional oyster deployment. Redeployment of oysters over multiple years at the same locations in Monie Bay offsets inter-annual variability and bias. This STELLA model would refine deployment logistics such as duration and timing for other applied monitoring purposes. Further, when linked with land use data it would allow generalizations and predictions of nitrogen source to be made for other estuarine systems, including other components of the National Estuarine Research Reserve System.

Indication of sewage and septic inputs to Monie Bay from external sources fits with results from other hazardous material monitoring. Dorabawila and Gupta (2005) observed concentrations of the endocrine disruptor estradiol (E2) in Monie Bay at 2.3 ng $L^{-1}$. Note that concentrations as low as 1 ng $L^{-1}$ can induce vitellogenin production in male fish (Dorabawila and Gupta, 2005). E2 is commonly transported to estuarine ecosystems via effluents from wastewater treatment plants.

Future research could verify if the sewage/septic nitrogen sources detected in Monie Bay and its creeks have similar signals as the Wicomico River. Additional oyster deployments in Monie Bay creeks and the Wicomico River could potentially identify if the Wicomico River is indeed the source of nitrogen to Monie Bay. A continuation of the pattern of increasing $\delta^{15}N$ in oyster tissues towards and up the Wicomico River would implicate this river as a source.

Wherever sewage and septic sources of nitrogen ultimately arrive from, results presented here suggest Monie Bay acts as a nitrogen sink, rather than a nitrogen source. In general, oligohaline marshes such as Monie Bay can act as sinks of nitrogen and phosphorous in the short term by denitrification, and in the long-term by sediment burial of organic matter and marsh accretion. Preliminary results from mixing plots presented in this study suggest non-conservative mixing potentially due to net denitrification. Yet sediment denitrification rates in Monie Bay and its creeks have not been reported in the literature previously. Nutrient burial, calculated by multiplying sediment burial rate (g $m^{-2}$ $y^{-1}$) by nutrient concentration (mg $g^{-1}$) in a core sample, has been found to be lower in Monie Bay than in the upper marshes of the Patuxent River (Merrill and Cornwell, 2000). Future studies could also quantify sediment denitrification rates in this area and ultimately identify if Monie Bay and its tidal creeks act as a sink for nitrogen from the Wicomico River.

In addition to identifying spatial patterns and resolving source vs. sink issues, temporal integration is one of the major benefits of using the eastern oyster as a biological indicator of nitrogen sources. Sporadically pulsed precipitation events during the oyster deployment duration should have minimal impact on the overall resulting tissue $\delta^{15}N$ values. Evidence of this was found in another related study in the Maryland Coastal Bays, where oyster tissues identified spatial patterns differently than macroalgae deployed within the same regions. By integrating over longer periods of time than the macroalgae, pulsed nutrient events (due to the roughly dozen precipitation events during the deployment period) identified with the *Gracilaria* were muted in *Crassostrea* (Fertig et al., 2006). Oysters deployed in Maryland's Coastal Bays identified spatial patterns despite the precipitations the frequent precipitation So in Maryland's Coastal Bays, there were more frequent rain events and the oysters were still able to identify spatial patterns due to their lengthy deployment duration, and in Monie Bay, there were fewer (but stronger) precipitation events that should have muted effects on the $\delta^{15}N$ value, especially given the even lengthier oyster deployment duration in Monie Bay and its creeks.

*Management Implications*

Ultimately, preserving the Monie Bay component of the National Estuarine Research Reserve and the Deale Island Wildlife Management Area are not enough to keep Monie Bay and its creeks in pristine condition. Exchange with other watersheds, potentially including the Lower Wicomico River sub-watershed, is clear. Therefore, a broader scope of management is necessary to protect this resource for recreation, research, and other management uses. Furthermore, a broader research scope may be necessary to understand complex interchanges between Monie Bay and nearby watersheds.

Within the confines of the Monie Bay component of the Chesapeake Bay National Estuarine Research Reserve, it is important to continue research efforts to ultimately understand the important factors driving nutrient sources, sinks, transport, and exchange mechanisms. Monitoring will be increasingly important to provide data to assess Monie Bay ecosystem health and focus pertinent management nutrient reduction efforts. Yet, these efforts must be coordinated and kept in context of the external sources mentioned earlier, which potentially add much larger amounts of nutrients to the system than internal sources.

Ultimately, *Crassostrea virginica* is potentially a simple yet powerful spatial and temporal indicator of biologically incorporated nitrogen sources. As a tool for environmental management, validating the performance of oysters as an indicator and developing detailed methodologies is the first step towards the incorporation of this new biological indicator into large, currently existing monitoring programs. Generally, biological indicators focus nutrient reduction strategies and monitor the effectiveness of management actions. Specifically, the eastern oyster provides a temporally-integrated approach to identifying sewage and septic sources of nitrogen, as compared to those derived from agricultural fertilizers. The research in the Monie Bay component of the Chesapeake Bay, MD National Estuarine Research Reserve presented here benefits other NERRS sites and coastal areas by adding a component to water quality and ecosystem health monitoring programs that is often missed. Applied regionally, oysters provide spatially explicit baseline dataset of biologically important nitrogen sources.

Results from regional monitoring programs are often complex and are aided by readily interpreted communication tools. Acting as a communications tool, eastern oysters are a regional symbol of the Chesapeake Bay’s declining water quality. They are an intuitive indicator of nutrient inputs, facilitating effective communication of subsequent monitoring results. Results and analysis resulting from this research will be relayed through various formats, including public presentations, newsletters, and other general communications products published through the Integration and Application Network at the University of Maryland Center for Environmental Science in addition to the conventional scholarly or academic journals.

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## Appendix 1: Water Quality Monitoring Data

| Date | Time | Site | Secchi depth (m) | Total depth (m) | Surface salinity (ppt) | Bottom salinity (ppt) | Surface $O_2$ mg $L^{-1}$ | Surface $O_2$ % saturation | Bottom $O_2$ mg $L^{-1}$ | Bottom $O_2$ % saturation | Surface conductivity | Bottom conductivity | Surface temperature (°C) | Bottom temperature (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22-Jun-06 | 12:53 PM | MB1 | 0.4 | 2.7 | 14.4 | 14.4 | 7.25 | 93.7 | 6.83 | 92.2 | 24.52 | 24.53 | 26.7 | 26.7 |
| 22-Jun-06 | 2:28 PM | MB10 | 0.6 | 2.7 | 12.9 | 12.9 | 5.11 | 70.3 | 5.19 | 70.2 | 22.64 | 22.60 | 27.7 | 27.6 |
| 22-Jun-06 | 12:36 PM | MB2 | 0.3 | 1.7 | 13.8 | 13.8 | 6.87 | 91.2 | 6.55 | 89.9 | 24.17 | 24.16 | 27.8 | 27.7 |
| 22-Jun-06 | 12:10 PM | MB3 | 0.5 | 0.9 | 13.9 | 13.9 | 5.78 | 75.3 | 5.43 | 73.2 | 24.26 | 24.26 | 27.7 | 27.7 |
| 22-Jun-06 | 12:27 PM | MB4 | 0.6 | 0.9 | 14.0 | 14.0 | 6.47 | 89.4 | 5.78 | 79.1 | 24.51 | 24.50 | 28.0 | 27.9 |
| 22-Jun-06 | 1:19 PM | MB5 | 0.6 | 2.5 | 13.4 | 13.5 | 4.58 | 63.8 | 4.35 | 60.2 | 23.82 | 23.83 | 28.3 | 28.3 |
| 22-Jun-06 | 1:12 PM | MB6 | 0.5 | 1.9 | 13.9 | 13.9 | 5.58 | 76.6 | 5.20 | 74.2 | 24.35 | 24.33 | 27.8 | 27.8 |
| 22-Jun-06 | 1:06 PM | MB7 | 0.5 | 1.6 | 13.9 | 13.9 | 5.90 | 81.2 | 5.80 | 79.8 | 24.33 | 24.34 | 27.7 | 27.7 |
| 22-Jun-06 | 2:06 PM | MB8 | 0.6 | 2.7 | 10.1 | 10.2 | 5.35 | 73.9 | 4.67 | 62.7 | 18.37 | 18.40 | 28.3 | 27.8 |
| 22-Jun-06 | 2:15 PM | MB9 | 0.7 | 2.3 | 11.3 | 11.2 | 4.87 | 69.5 | 4.56 | 63.1 | 20.23 | 20.15 | 27.9 | 27.6 |
| 11-Jul-06 | 5:37 PM | MB1 | 0.3 | 2.3 | 10.6 | 10.6 | 8.58 | 116.1 | 8.74 | 115.6 | 18.60 | 18.63 | 26.9 | 26.9 |
| 11-Jul-06 | 3:34 PM | MB10 | 0.5 | 2.9 | 7.5 | 8.5 | 7.35 | 99.3 | 7.41 | 97.5 | 13.74 | 15.36 | 27.3 | 27.2 |
| 11-Jul-06 | 5:57 PM | MB2 | 0.3 | 1.5 | 9.1 | 9.1 | 8.20 | 108.9 | 8.16 | 108.6 | 16.43 | 16.43 | 27.6 | 27.6 |
| 11-Jul-06 | 4:11 PM | MB3 | 0.4 | 1.3 | 8.3 | 8.4 | 6.97 | 93.3 | 6.99 | 92.8 | 15.12 | 15.21 | 27.8 | 27.7 |
| 11-Jul-06 | 4:26 PM | MB4 | 0.5 | 2.8 | 9.1 | 9.5 | 7.84 | 105.0 | 7.89 | 105.5 | 16.74 | 17.10 | 28.1 | 27.7 |
| 11-Jul-06 | 4:49 PM | MB5 | 0.3 | 2.3 | 4.3 | 4.3 | 6.42 | 85.2 | 6.38 | 84.1 | 8.41 | 8.30 | 28.8 | 28.8 |
| 11-Jul-06 | 5:07 PM | MB6 | 0.4 | 1.7 | 7.1 | 7.1 | 6.58 | 88.3 | 6.56 | 87.5 | 13.24 | 13.23 | 28.1 | 28.1 |
| 11-Jul-06 | 5:16 PM | MB7 | 0.4 | 0.7 | 8.8 | 8.8 | 7.35 | 98.5 | 7.30 | 97.7 | 16.01 | 16.04 | 27.8 | 27.8 |
| 11-Jul-06 | 2:45 PM | MB8 | 0.4 | 0.6 | 0.9 | 1.2 | 3.44 | 46.1 | 3.07 | 39.3 | 20.20 | 23.97 | 27.6 | 27.0 |
| 11-Jul-06 | 3:22 PM | MB9 | 0.5 | 2.9 | 4.3 | 4.4 | 5.72 | 74.3 | 5.04 | 65.0 | 8.24 | 8.33 | 27.5 | 27.1 |
| 25-Jul-06 | 4:36 PM | MB1 | 0.7 | 2.7 | 11.1 | 11.6 | 8.45 | 115.5 | 7.36 | 100.3 | 19.99 | 20.70 | 28.3 | 27.8 |
| 25-Jul-06 | 2:45 PM | MB10 | 0.7 | 3.0 | 9.0 | 8.9 | 6.31 | 83.4 | 6.48 | 86.2 | 16.23 | 16.32 | 27.8 | 27.8 |
| 25-Jul-06 | 4:55 PM | MB2 | 0.6 | 1.7 | 9.7 | 9.8 | 8.04 | 109.3 | 7.70 | 104.9 | 17.81 | 17.81 | 28.6 | 28.4 |
| 25-Jul-06 | 3:15 PM | MB3 | 0.7 | 2.0 | 9.7 | 9.8 | 6.15 | 80.0 | 5.81 | 78.2 | 17.51 | 17.47 | 27.6 | 27.6 |
| 25-Jul-06 | 3:27 PM | MB4 | 0.7 | 1.0 | 10.1 | 10.0 | 7.25 | 97.1 | 7.27 | 98.3 | 18.16 | 18.11 | 28.0 | 28.0 |
| 25-Jul-06 | 3:44 PM | MB5 | 0.7 | 2.0 | 8.5 | 8.8 | 5.31 | 74.2 | 4.93 | 68.2 | 15.65 | 15.89 | 28.1 | 27.6 |
| 25-Jul-06 | 4:01 PM | MB6 | 0.5 | 2.1 | 9.7 | 9.8 | 6.15 | 79.0 | 5.99 | 80.6 | 17.54 | 17.54 | 27.9 | 27.7 |
| 25-Jul-06 | 4:18 PM | MB7 | 0.4 | 1.4 | 10.0 | 10.1 | 7.01 | 98.5 | 7.04 | 92.3 | 18.15 | 18.16 | 28.1 | 28.0 |
| 25-Jul-06 | 2:00 PM | MB8 | 0.4 | 2.4 | 2.9 | 3.1 | 3.29 | 42.6 | 3.18 | 40.8 | 5.67 | 5.80 | 28.2 | 28.0 |
| 25-Jul-06 | 2:24 PM | MB9 | 0.5 | 2.7 | 5.2 | 5.2 | 3.69 | 50.9 | 3.84 | 48.1 | 9.81 | 9.84 | 27.9 | 28.0 |
| 14-Aug-06 | 12:06 PM | MB1 | 0.7 | 2.2 | 12.0 | 12.0 | 7.62 | 101.3 | 7.16 | 94.3 | 20.65 | 20.65 | 26.2 | 26.2 |
| 14-Aug-06 | 11:22 AM | MB10 | 0.7 | 2.5 | 9.2 | 9.3 | 4.42 | 57.5 | 4.32 | 56.6 | 15.99 | 16.16 | 25.5 | 25.8 |
| 14-Aug-06 | 1:55 PM | MB2 | 0.4 | 1.5 | 11.0 | 10.9 | 6.97 | 92.8 | 6.41 | 89.2 | 19.19 | 19.08 | 26.6 | 26.6 |
| 14-Aug-06 | 1:25 PM | MB3 | 0.7 | 1.1 | 11.5 | 11.5 | 5.64 | 78.2 | 5.64 | 78.9 | 19.84 | 19.88 | 26.3 | 26.3 |
| 14-Aug-06 | 1:42 PM | MB4 |  | 0.7 | 11.4 | 11.4 | 5.01 | 69.5 | 4.82 | 60.5 | 19.53 | 19.46 | 25.9 | 25.7 |
| 14-Aug-06 | 12:37 PM | MB5 | 0.7 | 1.5 | 10.9 | 10.9 | 3.75 | 48.2 | 3.46 | 43.8 | 18.71 | 18.68 | 26.1 | 25.9 |
| 14-Aug-06 | 12:51 PM | MB6 | 0.6 | 1.7 | 11.1 | 11.2 | 4.09 | 53.6 | 3.55 | 44.4 | 18.93 | 18.93 | 25.6 | 25.0 |
| 14-Aug-06 | 1:04 PM | MB7 | 0.7 | 2.3 | 11.3 | 11.4 | 4.61 | 60.5 | 4.43 | 58.6 | 19.31 | 19.41 | 25.7 | 25.5 |
| 14-Aug-06 | 10:48 AM | MB8 | 0.5 | 1.7 | 5.3 | 5.3 | 4.36 | 56.5 | 4.15 | 53.0 | 9.59 | 9.61 | 25.8 | 25.8 |
| 14-Aug-06 | 11:04 AM | MB9 | 0.5 | 0.7 | 7.1 | 7.1 | 4.17 | 55.1 | 4.39 | 55.2 | 12.58 | 12.55 | 25.8 | 25.8 |
| 7-Sep-06 | 11:32 AM | MB1 | 0.6 | 2.5 | 12.5 | 12.6 | 7.89 | 99.1 | 7.62 | 94.4 | 20.20 | 20.10 | 23.4 | 22.9 |
| 7-Sep-06 | 11:10 AM | MB10 | 0.6 | 2.5 | 8.6 | 8.8 | 5.66 | 72.0 | 5.07 | 64.8 | 14.17 | 14.42 | 23.2 | 22.6 |
| 7-Sep-06 | 1:19 PM | MB2 | 0.5 | 2.3 | 11.8 | 11.7 | 8.15 | 105.5 | 6.32 | 80.7 | 19.29 | 18.79 | 23.7 | 23.5 |
| 7-Sep-06 | 11:59 AM | MB3 | 0.7 | 1.8 | 10.1 | 10.1 | 5.05 | 63.9 | 5.14 | 63.3 | 16.36 | 16.40 | 22.7 | 22.6 |
| 7-Sep-06 | 12:10 PM | MB4 | 0.6 | 2.0 | 11.5 | 11.5 | 7.13 | 95.3 | 7.52 | 91.2 | 18.78 | 18.77 | 23.3 | 23.3 |
| 7-Sep-06 | 12:36 PM | MB5 | 0.6 | 2.0 | 8.7 | 8.7 | 4.09 | 50.8 | 3.74 | 32.7 | 14.39 | 14.37 | 23.0 | 22.9 |
| 7-Sep-06 | 12:47 PM | MB6 | 0.5 | 2.3 | 11.2 | 11.3 | 5.90 | 75.8 | 6.07 | 78.5 | 18.21 | 18.24 | 23.0 | 22.9 |
| 7-Sep-06 | 1:08 PM | MB7 | 0.5 | 4.0 | 11.7 | 11.7 | 8.02 | 99.1 | 8.05 | 99.9 | 19.10 | 19.11 | 23.6 | 23.5 |
| 7-Sep-06 | 10:46 AM | MB8 | 0.4 | 1.8 | 3.1 | 3.4 | 6.50 | 79.4 | 1.95 | 36.8 | 5.43 | 5.92 | 23.5 | 22.5 |
| 7-Sep-06 | 10:59 AM | MB9 | 0.5 | 1.5 | 5.6 | 5.6 | 4.86 | 59.4 | 4.63 | 54.3 | 9.41 | 9.48 | 22.6 | 22.5 |
| 10-Oct-06 | 11:22 AM | MB1 | 1.0 | 2.6 | 12.4 | 13.3 | 8.92 | 104.2 | 8.78 | 102.6 | 18.36 | 19.31 | 19.3 | 18.9 |
| 10-Oct-06 | 2:25 PM | MB10 | 0.9 | 2.9 | 10.0 | 10.0 | 6.70 | 76.7 | 6.53 | 75.5 | 14.96 | 14.97 | 18.9 | 18.7 |
| 10-Oct-06 | 11:49 AM | MB2 | 1.1 | 1.3 | 11.7 | 11.8 | 7.81 | 93.6 | 7.73 | 89.7 | 17.59 | 17.57 | 20.0 | 19.4 |
| 10-Oct-06 | 12:15 PM | MB3 | 1.2 | 1.5 | 9.1 | 9.5 | 5.38 | 60.7 | 4.92 | 57.7 | 13.77 | 13.83 | 18.7 | 17.5 |
| 10-Oct-06 | 12:38 PM | MB4 | 1.3 | 2.2 | 11.0 | 11.0 | 6.16 | 74.0 | 5.87 | 67.4 | 16.31 | 16.21 | 19.0 | 18.4 |
| 10-Oct-06 | 1:00 PM | MB5 | 0.9 | 1.7 | 8.5 | 8.5 | 4.77 | 56.6 | 4.35 | 48.5 | 12.95 | 13.08 | 19.6 | 19.0 |
| 10-Oct-06 | 1:13 PM | MB6 | 1.0 | 1.0 | 9.8 | 9.8 | 7.33 | 85.6 | 6.32 | 71.7 | 14.80 | 14.79 | 19.4 | 19.3 |
| 10-Oct-06 | 1:24 PM | MB7 |  | 0.7 | 11.4 | 11.5 | 6.73 | 78.4 | 5.96 | 73.8 | 17.05 | 17.02 | 19.2 | 19.0 |
| 10-Oct-06 | 1:57 PM | MB8 | 0.6 | 1.5 | 4.9 | 5.3 | 7.71 | 84.9 | 6.25 | 70.2 | 7.83 | 8.18 | 20.3 | 18.5 |
| 10-Oct-06 | 2:14 PM | MB9 | 0.7 | 2.2 | 7.2 | 7.3 | 6.09 | 70.6 | 6.18 | 69.2 | 10.99 | 11.12 | 18.8 | 18.7 |

| Date | Time | Site | Total Nitrogen (mg N L$^{-1}$) | $NO_2$ (mg N L$^{-1}$) | $NO_{23}$ (mg N L$^{-1}$) | $NH_4$ (mg N L$^{-1}$) | Total Phosphorus (mg P L$^{-1}$) | $PO_4$ (mg P L$^{-1}$) | Total Suspended Solids (mg L$^{-1}$) | Total Volatile Solids (mg L$^{-1}$) | Chlorophyll a | Phaeophytin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22-Jun-06 | 12:53 PM | MB1 | 0.76 | 0.0018 | 0.0134 | 0.011 | 0.0674 | 0.0043 | 21.6 | 5.2 | 12 | -1.5 |
| 22-Jun-06 | 2:28 PM | MB10 | 0.84 | 0.0007 | 0.008 | 0.006 | 0.0603 | 0.0036 | 78.5 | 13.5 | 7.5 | 1.9 |
| 22-Jun-06 | 12:36 PM | MB2 | 0.73 | 0.0038 | 0.0135 | 0.029 | 0.0538 | 0.0034 | 26 | 6.4 | 10.5 | -2.1 |
| 22-Jun-06 | 12:10 PM | MB3 | 0.76 | 0.0007 | 0.0128 | 0.006 | 0.0508 | 0.0026 | 80.5 | 13 | 6 | -0.7 |
| 22-Jun-06 | 12:27 PM | MB4 | 0.7 | 0.0033 | 0.0114 | 0.027 | 0.068 | 0.0031 | 18 | 5.5 | 6 | -0.7 |
| 22-Jun-06 | 1:19 PM | MB5 | 0.86 | 0.0003 | 0.0108 | 0.017 | 0.0621 | 0.0032 | 73.5 | 12 | 9 | 3.6 |
| 22-Jun-06 | 1:12 PM | MB6 | 0.79 | 0.0004 | 0.0125 | 0.01 | 0.0549 | 0.0022 | 76 | 12 | 10.5 | -3.1 |
| 22-Jun-06 | 1:06 PM | MB7 | 0.79 | 0.0014 | 0.0079 | 0.01 | 0.0567 | 0.0033 | 87.5 | 15 | 9 | -1.6 |
| 22-Jun-06 | 2:06 PM | MB8 | 0.88 | 0.0044 | 0.0172 | 0.023 | 0.0701 | 0.0032 | 62 | 14 | 10.5 | 4.2 |
| 22-Jun-06 | 2:15 PM | MB9 | 0.83 | 0.0072 | 0.0129 | 0.019 | 0.0613 | 0.0042 | 69.5 | 12.5 | 13.5 | 4.3 |
| 11-Jul-06 | 5:37 PM | MB1 | 0.86 | 0.0018 | 0.0337 | 0.016 | 0.0653 | 0.0041 | 70 | 11.5 | 17.9 | 0.9 |
| 11-Jul-06 | 3:34 PM | MB10 | 0.86 | 0.0018 | 0.0121 | 0.015 | 0.0652 | 0.0036 | 47 | 9.5 | 9 | 1.5 |
| 11-Jul-06 | 5:57 PM | MB2 | 0.86 | 0.0004 | 0.0078 | 0.011 | 0.0683 | 0.0039 | 78 | 12.5 | 12 | -0.4 |
| 11-Jul-06 | 4:11 PM | MB3 | 0.94 | 0.0045 | 0.0153 | 0.062 | 0.0609 | 0.0053 | 58.5 | 10 | 7.5 | -0.1 |
| 11-Jul-06 | 4:26 PM | MB4 | 0.88 | 0.0005 | 0.0132 | 0.011 | 0.0576 | 0.0043 | 58.5 | 10 | 9 | 0.4 |
| 11-Jul-06 | 4:49 PM | MB5 | 1.22 | 0.0003 | 0.0098 | 0.008 | 0.1433 | 0.0184 | 44.5 | 10 | 19.4 | 2.5 |
| 11-Jul-06 | 5:07 PM | MB6 | 0.96 | 0.003 | 0.0095 | 0.021 | 0.0815 | 0.0056 | 53.5 | 10 | 12 | -0.4 |
| 11-Jul-06 | 5:16 PM | MB7 | 0.98 | 0.0027 | 0.0066 | 0.012 | 0.0724 | 0.0036 | 66.5 | 12 | 9 | 0.4 |
| 11-Jul-06 | 2:45 PM | MB8 | 1.43 | 0.0008 | 0.0831 | 0.042 | 0.178 | 0.0643 | 12.5 | 5.5 | 10.5 | 2.1 |
| 11-Jul-06 | 3:22 PM | MB9 | 1.12 | 0.0014 | 0.0193 | 0.016 | 0.0975 | 0.0139 | 34 | 9 | 9 | 1.5 |
| 25-Jul-06 | 4:36 PM | MB1 | 0.77 | 0.0019 | 0.015 | 0.022 | 0.0525 | 0.0028 | 60 | 12.5 | 16.4 | -0.7 |
| 25-Jul-06 | 2:45 PM | MB10 | 0.93 | 0.0017 | 0.013 | 0.056 | 0.0632 | 0.0026 | 54.5 | 11 | 13.5 | -0.9 |
| 25-Jul-06 | 4:55 PM | MB2 | 0.99 | 0.0023 | 0.0189 | 0.039 | 0.0564 | 0.0026 | 54.5 | 13.5 | 12 | 0.6 |
| 25-Jul-06 | 3:15 PM | MB3 | 0.89 | 0.002 | 0.0162 | 0.025 | 0.0526 | 0.0024 | 67 | 12 | 10.5 | 1 |
| 25-Jul-06 | 3:27 PM | MB4 | 0.87 | 0.0017 | 0.0136 | 0.032 | 0.0532 | 0.002 | 56.5 | 11.5 | 15 | -6.6 |
| 25-Jul-06 | 3:44 PM | MB5 | 0.97 | 0.0033 | 0.0178 | 0.049 | 0.0823 | 0.0096 | 47.5 | 9.5 | 15 | -0.3 |
| 25-Jul-06 | 4:01 PM | MB6 | 0.93 | 0.0053 | 0.0154 | 0.023 | 0.0606 | 0.0039 | 55 | 12.5 | 12 | -0.4 |
| 25-Jul-06 | 4:18 PM | MB7 | 0.89 | 0.0017 | 0.0147 | 0.019 | 0.0565 | 0.0024 | 61 | 12 | 10.5 | -2.1 |
| 25-Jul-06 | 2:00 PM | MB8 | 1.46 | 0.0027 | 0.086 | 0.119 | 0.149 | 0.0409 | 17 | 5.5 | 16.4 | -0.7 |
| 25-Jul-06 | 2:24 PM | MB9 | 1.26 | 0.0027 | 0.03 | 0.034 | 0.0877 | 0.0074 | 40.5 | 9.5 | 16.4 | 2.4 |
| 14-Aug-06 | 12:06 PM | MB1 | 0.84 | 0.0019 | 0.0044 | 0.019 | 0.0572 | 0.0033 | 60.5 | 9.5 | 10.5 | 0 |
| 14-Aug-06 | 11:22 AM | MB10 | 1.01 | -0.0001 | 0.0074 | 0.027 | 0.0679 | 0.0067 | 49.5 | 8.5 | 12 | 1.6 |
| 14-Aug-06 | 1:55 PM | MB2 | 0.96 | 0.0029 | 0.0058 | 0.041 | 0.076 | 0.0041 | 88.5 | 11 | 9 | 1.5 |
| 14-Aug-06 | 1:25 PM | MB3 | 0.83 | -0.0002 | 0.0044 | -0.002 | 0.0468 | 0.0028 | 61 | 9 | 7.5 | -0.1 |
| 14-Aug-06 | 1:42 PM | MB4 | 0.76 | -0.0003 | 0.009 | 0 | 0.0437 | 0.003 | 52.5 | 7.5 | 7.5 | -2.2 |
| 14-Aug-06 | 12:37 PM | MB5 | 0.98 | 0.0001 | 0.0085 | 0.003 | 0.1123 | 0.0253 | 73.5 | 11 | 12 | 0.6 |
| 14-Aug-06 | 12:51 PM | MB6 | 0.96 | -0.0004 | 0.0054 | -0.003 | 0.083 | 0.012 | 59.5 | 9 | 12 | -1.5 |
| 14-Aug-06 | 1:04 PM | MB7 | 0.82 | -0.0002 | 0.0066 | 0.008 | 0.0577 | 0.0057 | 62 | 10 | 10.5 | -4.2 |
| 14-Aug-06 | 10:48 AM | MB8 | 1.16 | -0.0011 | 0.0059 | 0.006 | 0.0989 | 0.0044 | 42.5 | 9.5 | 22.4 | 3.7 |
| 14-Aug-06 | 11:04 AM | MB9 | 1.07 | -0.0002 | 0.0057 | 0.018 | 0.0848 | 0.007 | 49 | 9.5 | 15 | 4.9 |
| 7-Sep-06 | 11:32 AM | MB1 | 0.82 | 0.0565 | 0.0994 | 0.006 | 0.0498 | 0.003 | 70.5 | 10 | 17.9 | -1.2 |
| 7-Sep-06 | 11:10 AM | MB10 | 0.89 | 0.0043 | 0.0146 | 0.064 | 0.0671 | 0.0078 | 47.5 | 8 | 16.4 | -0.7 |
| 7-Sep-06 | 1:19 PM | MB2 | 0.87 | 0.0057 | 0.0109 | 0.002 | 0.0497 | 0.0032 | 69 | 11.5 | 20.9 | 0 |
| 7-Sep-06 | 11:59 AM | MB3 | 1.02 | 0.0054 | 0.0252 | 0.004 | 0.0476 | 0.0038 | 66 | 9.5 | 12 | -1.5 |
| 7-Sep-06 | 12:10 PM | MB4 | 0.91 | 0.0015 | 0.0007 | 0.013 | 0.0495 | 0.0031 | 68 | 10 | 17.9 | -4.3 |
| 7-Sep-06 | 12:36 PM | MB5 | 1.03 | 0.0044 | 0.0204 | 0.012 | 0.0999 | 0.0199 | 61.5 | 10.5 | 12 | -0.4 |
| 7-Sep-06 | 12:47 PM | MB6 | 0.89 | 0.0043 | 0.0084 | 0.001 | 0.0702 | 0.0036 | 86.5 | 12.5 | 16.4 | -1.8 |
| 7-Sep-06 | 1:08 PM | MB7 | 0.78 | 0.0031 | 0.0112 | 0.006 | 0.0551 | 0.0035 | 73.5 | 10.5 | 19.4 | -2.7 |
| 7-Sep-06 | 10:46 AM | MB8 | 1.15 | 0.0012 | 0.008 | 0.006 | 0.1169 | 0.0174 | 34.5 | 10.5 | 29.9 | 5.7 |
| 7-Sep-06 | 10:59 AM | MB9 | 1.08 | 0.0011 | 0.0058 | 0.001 | 0.0985 | 0.013 | 38 | 9.5 | 23.9 | 5.4 |
| 10-Oct-06 | 11:22 AM | MB1 | 0.76 | 0.0022 | 0.003 | -0.001 | 0.0411 | 0.0031 | 54.5 | 9 | 9 | -1.6 |
| 10-Oct-06 | 2:25 PM | MB10 | 0.75 | 0.0001 | 0.0074 | -0.003 | 0.0501 | 0.0046 | 48.5 | 9 | 10.5 | -3.1 |
| 10-Oct-06 | 11:49 AM | MB2 | 0.62 | 0.0013 | 0.0076 | -0.002 | 0.0373 | 0.0032 | 58.5 | 9 | 13.5 | -9.3 |
| 10-Oct-06 | 12:15 PM | MB3 | 0.7 | 0.002 | 0.0136 | 0.026 | 0.0294 | 0.0129 | 43.5 | 7 | 4.5 | -2.4 |
| 10-Oct-06 | 12:38 PM | MB4 | 0.72 | 0.0006 | 0.0079 | 0 | 0.0337 | 0.003 | 60 | 8.5 | 9 | -4.8 |
| 10-Oct-06 | 1:00 PM | MB5 | 0.98 | 0.0035 | 0.1283 | 0.027 | 0.0956 | 0.0388 | 46.5 | 10 | 12 | -2.5 |
| 10-Oct-06 | 1:13 PM | MB6 | 0.85 | 0.0018 | 0.0684 | 0.009 | 0.061 | 0.0156 | 47 | 9 | 10.5 | -4.2 |
| 10-Oct-06 | 1:24 PM | MB7 | 0.73 | 0.0004 | 0.008 | 0.001 | 0.045 | 0.0037 | 58.5 | 10 | 7.5 | -2.2 |
| 10-Oct-06 | 1:57 PM | MB8 | 1.11 | 0.0004 | 0.0066 | -0.002 | 0.094 | 0.0077 | 34.5 | 10.5 | 25.4 | 1.8 |
| 10-Oct-06 | 2:14 PM | MB9 | 0.89 | 0 | 0.0031 | 0.004 | 0.0726 | 0.0082 | 38.5 | 8.5 | 15 | -0.3 |

## Appendix 2: Oyster Tissue Isotopes

| Id | Distance | Creek | Station | Source | Tissue | δ15N | δ13C | % N | % C | C:N ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Downstream | Little Creek | 4 | South R. | Gills | 10.81 | -27.20 | 9.21 | 35.99 | 4.55 |
| 2 | Downstream | Little Creek | 4 | South R. | Gills | 10.97 | -27.19 | 9.29 | 40.58 | 5.09 |
| 3 | Downstream | Little Creek | 4 | South R. | Gills | 10.88 | -27.49 | 8.71 | 39.37 | 5.27 |
| 4 | Downstream | Little Creek | 4 | South R. | Gills | 10.88 | -26.83 | 9.42 | 40.03 | 4.95 |
| 5 | Downstream | Little Creek | 4 | South R. | Gills | 10.92 | -27.25 | 9.34 | 40.18 | 5.02 |
| 6 | Downstream | Little Creek | 4 | South R. | Muscle | 12.18 | -25.52 | 12.86 | 41.43 | 3.76 |
| 7 | Downstream | Little Creek | 4 | South R. | Muscle | 11.78 | -25.75 | 13.32 | 42.81 | 3.75 |
| 8 | Downstream | Little Creek | 4 | South R. | Muscle | 12.00 | -24.96 | 12.27 | 38.57 | 3.67 |
| 9 | Downstream | Little Creek | 4 | South R. | Muscle | 12.09 | -25.56 | 12.58 | 41.03 | 3.80 |
| 10 | Downstream | Little Creek | 4 | South R. | Muscle | 11.44 | -25.85 | 12.21 | 39.58 | 3.78 |
| 11 | Downstream | Little Creek | 4 | South R. | Mantle | 10.71 | -20.59 | 9.58 | 44.88 | 5.46 |
| 12 | Downstream | Little Creek | 4 | South R. | Mantle | 10.84 | -27.23 | 9.62 | 40.18 | 4.87 |
| 13 | Downstream | Little Creek | 4 | South R. | Mantle | 10.94 | -27.13 | 8.77 | 39.38 | 5.24 |
| 14 | Downstream | Little Creek | 4 | South R. | Mantle | 11.03 | -26.95 | 9.47 | 38.67 | 4.76 |
| 15 | Downstream | Little Creek | 4 | South R. | Mantle | 11.15 | -27.24 | 9.24 | 41.20 | 5.20 |
| 16 | Downstream | Little Creek | 4 | Severn R. | Gills | 11.29 | -27.02 | 10.05 | 41.70 | 4.84 |
| 17 | Downstream | Little Creek | 4 | Severn R. | Gills | 11.23 | -27.07 | 10.48 | 42.64 | 4.75 |
| 18 | Downstream | Little Creek | 4 | Severn R. | Gills | 11.37 | -27.01 | 10.43 | 42.52 | 4.75 |
| 19 | Downstream | Little Creek | 4 | Severn R. | Gills | 11.08 | -27.34 | 9.94 | 42.98 | 5.04 |
| 20 | Downstream | Little Creek | 4 | Severn R. | Gills | 11.17 | -27.55 | 9.47 | 42.93 | 5.28 |
| 21 | Downstream | Little Creek | 4 | Severn R. | Muscle | 12.25 | -25.70 | 13.38 | 42.36 | 3.69 |
| 22 | Downstream | Little Creek | 4 | Severn R. | Muscle | 12.89 | -25.33 | 13.56 | 43.40 | 3.73 |
| 23 | Downstream | Little Creek | 4 | Severn R. | Muscle | 11.88 | -26.07 | 12.89 | 42.58 | 3.85 |
| 24 | Downstream | Little Creek | 4 | Severn R. | Muscle | 12.74 | -25.63 | 13.02 | 41.71 | 3.73 |
| 25 | Downstream | Little Creek | 4 | Severn R. | Muscle | 12.10 | -25.74 | 13.61 | 43.09 | 3.69 |
| 26 | Downstream | Little Creek | 4 | Severn R. | Mantle | 11.38 | -27.00 | 10.53 | 42.45 | 4.70 |
| 27 | Downstream | Little Creek | 4 | Severn R. | Mantle | 11.31 | -26.85 | 9.85 | 40.15 | 4.75 |
| 28 | Downstream | Little Creek | 4 | Severn R. | Mantle | 11.38 | -26.99 | 11.22 | 43.59 | 4.53 |
| 29 | Downstream | Little Creek | 4 | Severn R. | Mantle | 11.27 | -26.66 | 10.65 | 40.08 | 4.39 |
| 30 | Downstream | Little Creek | 4 | Severn R. | Mantle | 10.86 | -27.66 | 9.13 | 42.87 | 5.47 |
| 31 | Middle | Little Creek | 3 | South R. | Gills | 10.56 | -28.32 | 9.95 | 33.76 | 3.96 |
| 32 | Middle | Little Creek | 3 | South R. | Gills | 10.40 | -6.96 | 9.56 | 48.39 | 5.90 |
| 33 | Middle | Little Creek | 3 | South R. | Gills | 10.67 | -27.45 | 10.46 | 35.58 | 3.97 |
| 34 | Middle | Little Creek | 3 | South R. | Gills | 9.96 | -27.98 | 10.30 | 35.58 | 4.03 |
| 35 | Middle | Little Creek | 3 | South R. | Gills | 10.32 | -19.41 | 9.76 | 45.91 | 5.48 |
| 36 | Middle | Little Creek | 3 | South R. | Muscle | 11.94 | -16.93 | 13.63 | 45.81 | 3.92 |
| 37 | Middle | Little Creek | 3 | South R. | Muscle | 11.01 | -26.85 | 13.11 | 38.14 | 3.39 |
| 38 | Middle | Little Creek | 3 | South R. | Muscle | 11.23 | -9.12 | 13.40 | 46.45 | 4.04 |
| 39 | Middle | Little Creek | 3 | South R. | Muscle | 11.51 | -17.61 | 13.71 | 46.53 | 3.96 |
| 40 | Middle | Little Creek | 3 | South R. | Muscle | 11.70 | -24.73 | 12.68 | 43.82 | 4.03 |
| 41 | Middle | Little Creek | 3 | South R. | Mantle | 10.39 | -28.59 | 9.66 | 44.35 | 5.35 |
| 42 | Middle | Little Creek | 3 | South R. | Mantle | 10.24 | -28.58 | 9.12 | 44.62 | 5.70 |
| 43 | Middle | Little Creek | 3 | South R. | Mantle | 10.56 | -27.48 | 10.40 | 41.78 | 4.68 |
| 44 | Middle | Little Creek | 3 | South R. | Mantle | 10.12 | -28.04 | 9.68 | 43.50 | 5.24 |
| 45 | Middle | Little Creek | 3 | South R. | Mantle | 10.52 | -28.26 | 9.59 | 43.38 | 5.27 |
| 46 | Middle | Little Creek | 3 | Severn R. | Gills | 10.43 | -23.53 | 10.05 | 45.81 | 5.32 |
| 47 | Middle | Little Creek | 3 | Severn R. | Gills | 10.14 | -27.18 | 9.74 | 44.44 | 5.32 |
| 48 | Middle | Little Creek | 3 | Severn R. | Gills | 9.97 | -28.59 | 10.19 | 40.28 | 4.61 |
| 49 | Middle | Little Creek | 3 | Severn R. | Gills | 10.13 | -28.38 | 9.30 | 42.94 | 5.38 |
| 50 | Middle | Little Creek | 3 | Severn R. | Gills | 10.19 | -28.23 | 9.29 | 42.11 | 5.29 |
| 51 | Middle | Little Creek | 3 | Severn R. | Muscle | 12.21 | -26.57 | 13.70 | 44.66 | 3.80 |
| 52 | Middle | Little Creek | 3 | Severn R. | Muscle | 11.71 | -26.37 | 13.44 | 34.28 | 2.97 |
| 53 | Middle | Little Creek | 3 | Severn R. | Muscle | 11.85 | -26.57 | 14.13 | 44.67 | 3.69 |
| 54 | Middle | Little Creek | 3 | Severn R. | Muscle | 11.47 | -27.02 | 12.95 | 37.17 | 3.35 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 55 | Middle | Little Creek | 3 | Severn R. | Muscle | 11.46 | -26.51 | 12.22 | 44.18 | 4.22 |
| 56 | Middle | Little Creek | 3 | Severn R. | Mantle | 9.82 | -28.60 | 10.13 | 33.61 | 3.87 |
| 57 | Middle | Little Creek | 3 | Severn R. | Mantle | 9.88 | -28.73 | 9.60 | 38.88 | 4.72 |
| 58 | Middle | Little Creek | 3 | Severn R. | Mantle | 10.22 | -22.37 | 9.66 | 44.14 | 5.33 |
| 59 | Middle | Little Creek | 3 | Severn R. | Mantle | 10.34 | -28.57 | 8.89 | 44.07 | 5.78 |
| 60 | Middle | Little Creek | 3 | Severn R. | Mantle | 10.54 | -28.04 | 10.39 | 44.44 | 4.99 |
| 61 | Downstream | Little Monie Creek | 7 | South R. | Gills | 10.23 | -27.69 | 9.06 | 43.35 | 5.58 |
| 62 | Downstream | Little Monie Creek | 7 | South R. | Gills | 11.12 | -26.96 | 9.81 | 40.98 | 4.87 |
| 63 | Downstream | Little Monie Creek | 7 | South R. | Gills | 11.10 | -27.31 | 9.25 | 41.59 | 5.25 |
| 64 | Downstream | Little Monie Creek | 7 | South R. | Gills | 11.39 | -26.79 | 10.43 | 41.27 | 4.62 |
| 65 | Downstream | Little Monie Creek | 7 | South R. | Gills | 11.32 | -27.20 | 9.05 | 43.51 | 5.61 |
| 66 | Downstream | Little Monie Creek | 7 | South R. | Muscle | 12.18 | -25.58 | 12.93 | 42.10 | 3.80 |
| 67 | Downstream | Little Monie Creek | 7 | South R. | Muscle | 11.79 | -25.47 | 13.14 | 42.71 | 3.79 |
| 68 | Downstream | Little Monie Creek | 7 | South R. | Muscle | 11.95 | -25.03 | 13.85 | 42.89 | 3.61 |
| 69 | Downstream | Little Monie Creek | 7 | South R. | Muscle | 12.39 | -25.41 | 13.19 | 41.20 | 3.64 |
| 70 | Downstream | Little Monie Creek | 7 | South R. | Muscle | 11.52 | -25.39 | 14.15 | 42.70 | 3.52 |
| 71 | Downstream | Little Monie Creek | 7 | South R. | Mantle | 11.19 | -26.83 | 10.91 | 41.78 | 4.47 |
| 72 | Downstream | Little Monie Creek | 7 | South R. | Mantle | 11.18 | -26.61 | 10.63 | 40.49 | 4.44 |
| 73 | Downstream | Little Monie Creek | 7 | South R. | Mantle | 11.15 | -27.29 | 9.27 | 40.92 | 5.15 |
| 74 | Downstream | Little Monie Creek | 7 | South R. | Mantle | 11.15 | -27.17 | 9.80 | 41.03 | 4.88 |
| 75 | Downstream | Little Monie Creek | 7 | South R. | Mantle | 10.59 | -27.14 | 8.86 | 41.46 | 5.46 |
| 76 | Downstream | Little Monie Creek | 7 | Severn R. | Gills | 11.61 | -26.66 | 10.19 | 40.98 | 4.69 |
| 77 | Downstream | Little Monie Creek | 7 | Severn R. | Gills | 11.57 | -26.54 | 10.04 | 39.55 | 4.59 |
| 78 | Downstream | Little Monie Creek | 7 | Severn R. | Gills | 12.20 | -26.74 | 10.41 | 40.78 | 4.57 |
| 79 | Downstream | Little Monie Creek | 7 | Severn R. | Gills | 11.09 | -27.10 | 9.71 | 40.40 | 4.85 |
| 80 | Downstream | Little Monie Creek | 7 | Severn R. | Gills | 10.63 | -27.50 | 8.82 | 40.71 | 5.38 |
| 81 | Downstream | Little Monie Creek | 7 | Severn R. | Muscle | 11.83 | -25.21 | 12.94 | 40.63 | 3.66 |
| 82 | Downstream | Little Monie Creek | 7 | Severn R. | Muscle | 12.80 | -25.59 | 13.07 | 41.77 | 3.73 |
| 83 | Downstream | Little Monie Creek | 7 | Severn R. | Muscle | 12.10 | -25.68 | 13.08 | 42.70 | 3.81 |
| 84 | Downstream | Little Monie Creek | 7 | Severn R. | Muscle | 12.28 | -25.85 | 12.20 | 43.84 | 4.19 |
| 85 | Downstream | Little Monie Creek | 7 | Severn R. | Muscle | 12.50 | -25.38 | 12.01 | 43.12 | 4.19 |
| 86 | Downstream | Little Monie Creek | 7 | Severn R. | Mantle | 10.97 | -26.78 | 10.14 | 37.78 | 4.34 |
| 87 | Downstream | Little Monie Creek | 7 | Severn R. | Mantle | 11.35 | -17.91 | 10.93 | 45.43 | 4.85 |
| 88 | Downstream | Little Monie Creek | 7 | Severn R. | Mantle | 10.86 | -27.38 | 9.66 | 40.11 | 4.84 |
| 89 | Downstream | Little Monie Creek | 7 | Severn R. | Mantle | 12.35 | -26.85 | 10.32 | 40.60 | 4.59 |
| 90 | Downstream | Little Monie Creek | 7 | Severn R. | Mantle | 10.96 | -27.54 | 7.89 | 41.92 | 6.20 |
| 91 | Middle | Little Monie Creek | 6 | South R. | Gills | 10.34 | -27.93 | 10.12 | 38.53 | 4.44 |
| 92 | Middle | Little Monie Creek | 6 | South R. | Gills | 10.14 | -27.86 | 9.71 | 42.00 | 5.04 |
| 93 | Middle | Little Monie Creek | 6 | South R. | Gills | 10.54 | -27.70 | 10.23 | 35.51 | 4.05 |
| 94 | Middle | Little Monie Creek | 6 | South R. | Gills | 9.90 | -28.04 | 9.68 | 38.50 | 4.64 |
| 95 | Middle | Little Monie Creek | 6 | South R. | Gills | 10.83 | 7.91 | 10.85 | 49.12 | 5.28 |
| 96 | Middle | Little Monie Creek | 6 | South R. | Muscle | 11.57 | -4.43 | 14.74 | 47.23 | 3.74 |
| 97 | Middle | Little Monie Creek | 6 | South R. | Muscle | 11.21 | -26.23 | 13.57 | 39.24 | 3.37 |
| 98 | Middle | Little Monie Creek | 6 | South R. | Muscle | 12.03 | -26.29 | 13.43 | 43.81 | 3.80 |
| 99 | Middle | Little Monie Creek | 6 | South R. | Muscle | 11.21 | -26.29 | 11.99 | 43.27 | 4.21 |
| 100 | Middle | Little Monie Creek | 6 | South R. | Muscle | 11.88 | -25.85 | 12.30 | 42.90 | 4.07 |
| 101 | Middle | Little Monie Creek | 6 | South R. | Mantle | 9.95 | -28.22 | 8.62 | 34.46 | 4.66 |
| 102 | Middle | Little Monie Creek | 6 | South R. | Mantle | 10.27 | -25.30 | 8.68 | 43.93 | 5.90 |
| 103 | Middle | Little Monie Creek | 6 | South R. | Mantle | 10.71 | -21.68 | 9.63 | 44.23 | 5.36 |
| 104 | Middle | Little Monie Creek | 6 | South R. | Mantle | 10.04 | -28.26 | 9.00 | 33.42 | 4.33 |
| 105 | Middle | Little Monie Creek | 6 | South R. | Mantle | 10.52 | -27.62 | 9.48 | 41.94 | 5.16 |
| 106 | Middle | Little Monie Creek | 6 | Severn R. | Gills | 10.37 | -27.31 | 9.74 | 43.85 | 5.25 |
| 107 | Middle | Little Monie Creek | 6 | Severn R. | Gills | 10.46 | -28.22 | 9.18 | 38.08 | 4.84 |
| 108 | Middle | Little Monie Creek | 6 | Severn R. | Gills | 9.95 | -27.78 | 9.82 | 35.46 | 4.21 |
| 109 | Middle | Little Monie Creek | 6 | Severn R. | Gills | 10.63 | -27.74 | 10.38 | 43.25 | 4.86 |

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|---|---|---|---|---|---|---|---|---|---|
| 110 | Middle | Little Monie Creek | 6 | Severn R. | Gills | 10.56 | -27.68 | 10.75 | 43.47 | 4.71 |
| 111 | Middle | Little Monie Creek | 6 | Severn R. | Muscle | 12.18 | -25.81 | 13.39 | 40.39 | 3.52 |
| 112 | Middle | Little Monie Creek | 6 | Severn R. | Muscle | 12.13 | -26.08 | 13.33 | 34.51 | 3.02 |
| 113 | Middle | Little Monie Creek | 6 | Severn R. | Muscle | 12.40 | -25.40 | 13.54 | 36.41 | 3.13 |
| 114 | Middle | Little Monie Creek | 6 | Severn R. | Muscle | 11.83 | -26.05 | 12.78 | 40.06 | 3.65 |
| 115 | Middle | Little Monie Creek | 6 | Severn R. | Muscle | 12.26 | -26.14 | 12.41 | 43.65 | 4.10 |
| 116 | Middle | Little Monie Creek | 6 | Severn R. | Mantle | 10.47 | -27.40 | 9.93 | 33.77 | 3.97 |
| 117 | Middle | Little Monie Creek | 6 | Severn R. | Mantle | 10.04 | -27.79 | 9.50 | 38.75 | 4.76 |
| 118 | Middle | Little Monie Creek | 6 | Severn R. | Mantle | 10.73 | -27.62 | 9.62 | 39.00 | 4.73 |
| 119 | Middle | Little Monie Creek | 6 | Severn R. | Mantle | 10.34 | -28.43 | 8.27 | 33.73 | 4.75 |
| 120 | Middle | Little Monie Creek | 6 | Severn R. | Mantle | 10.31 | -28.06 | 8.76 | 42.27 | 5.63 |
| 121 | Upstream | Little Monie Creek | 5 | South R. | Gills | 9.76 | -28.73 | 9.85 | 35.27 | 4.18 |
| 122 | Upstream | Little Monie Creek | 5 | South R. | Gills | 9.76 | -16.86 | 9.52 | 45.73 | 5.60 |
| 123 | Upstream | Little Monie Creek | 5 | South R. | Gills | 9.82 | -29.08 | 8.77 | 41.23 | 5.48 |
| 124 | Upstream | Little Monie Creek | 5 | South R. | Gills | 10.12 | -28.67 | 10.63 | 43.51 | 4.77 |
| 125 | Upstream | Little Monie Creek | 5 | South R. | Gills | 9.73 | -28.71 | 10.41 | 44.05 | 4.94 |
| 126 | Upstream | Little Monie Creek | 5 | South R. | Muscle | 11.18 | -26.51 | 14.75 | 43.88 | 3.47 |
| 127 | Upstream | Little Monie Creek | 5 | South R. | Muscle | 11.49 | -26.54 | 14.18 | 43.21 | 3.55 |
| 128 | Upstream | Little Monie Creek | 5 | South R. | Muscle | 11.72 | -26.66 | 13.89 | 42.77 | 3.59 |
| 129 | Upstream | Little Monie Creek | 5 | South R. | Muscle | 11.55 | -26.59 | 14.39 | 43.89 | 3.56 |
| 130 | Upstream | Little Monie Creek | 5 | South R. | Muscle | 10.91 | -26.77 | 13.37 | 43.30 | 3.78 |
| 131 | Upstream | Little Monie Creek | 5 | South R. | Mantle | 10.07 | -28.21 | 9.84 | 44.09 | 5.23 |
| 132 | Upstream | Little Monie Creek | 5 | South R. | Mantle | 8.93 | -28.57 | 9.30 | 31.69 | 3.97 |
| 133 | Upstream | Little Monie Creek | 5 | South R. | Mantle | 9.85 | -28.37 | 10.59 | 42.40 | 4.67 |
| 134 | Upstream | Little Monie Creek | 5 | South R. | Mantle | 10.53 | -28.94 | 9.09 | 42.70 | 5.48 |
| 135 | Upstream | Little Monie Creek | 5 | South R. | Mantle | 9.97 | -29.20 | 8.50 | 42.73 | 5.86 |
| 136 | Upstream | Little Monie Creek | 5 | Severn R. | Gills | 10.31 | -28.80 | 8.84 | 41.55 | 5.48 |
| 137 | Upstream | Little Monie Creek | 5 | Severn R. | Gills | 9.80 | -29.38 | 8.51 | 42.74 | 5.86 |
| 138 | Upstream | Little Monie Creek | 5 | Severn R. | Gills | 9.88 | -16.60 | 8.45 | 46.00 | 6.35 |
| 139 | Upstream | Little Monie Creek | 5 | Severn R. | Gills | 10.43 | -28.92 | 9.43 | 42.57 | 5.27 |
| 140 | Upstream | Little Monie Creek | 5 | Severn R. | Gills | 9.73 | -28.80 | 9.94 | 42.25 | 4.95 |
| 141 | Upstream | Little Monie Creek | 5 | Severn R. | Muscle | 11.71 | -26.61 | 9.66 | 42.29 | 5.11 |
| 142 | Upstream | Little Monie Creek | 5 | Severn R. | Muscle | 11.47 | -26.78 | 13.62 | 43.18 | 3.70 |
| 143 | Upstream | Little Monie Creek | 5 | Severn R. | Muscle | 11.90 | -26.38 | 12.39 | 43.98 | 4.14 |
| 144 | Upstream | Little Monie Creek | 5 | Severn R. | Muscle | 12.45 | -26.83 | 12.26 | 43.79 | 4.16 |
| 145 | Upstream | Little Monie Creek | 5 | Severn R. | Muscle | 12.25 | -26.15 | 13.04 | 41.65 | 3.72 |
| 146 | Upstream | Little Monie Creek | 5 | Severn R. | Mantle | 10.00 | -29.39 | 7.88 | 35.69 | 5.28 |
| 147 | Upstream | Little Monie Creek | 5 | Severn R. | Mantle | 10.08 | -27.62 | 8.20 | 43.06 | 6.12 |
| 148 | Upstream | Little Monie Creek | 5 | Severn R. | Mantle | 9.62 | -29.74 | 7.02 | 39.07 | 6.49 |
| 149 | Upstream | Little Monie Creek | 5 | Severn R. | Mantle | 10.04 | -29.21 | 8.44 | 41.03 | 5.67 |
| 150 | Upstream | Little Monie Creek | 5 | Severn R. | Mantle | 10.30 | -29.11 | 8.43 | 41.32 | 5.71 |
| 151 | Downstream | Monie Creek | 10 | South R. | Gills | 10.63 | -28.35 | 9.49 | 43.05 | 5.29 |
| 152 | Downstream | Monie Creek | 10 | South R. | Gills | 10.35 | -28.23 | 9.78 | 42.85 | 5.11 |
| 153 | Downstream | Monie Creek | 10 | South R. | Gills | 10.42 | -28.03 | 9.63 | 41.53 | 5.03 |
| 154 | Downstream | Monie Creek | 10 | South R. | Gills | 9.69 | -28.35 | 9.06 | 43.72 | 5.63 |
| 155 | Downstream | Monie Creek | 10 | South R. | Gills | 10.30 | -28.02 | 9.91 | 43.04 | 5.07 |
| 156 | Downstream | Monie Creek | 10 | South R. | Muscle | 11.57 | -17.82 | 9.49 | 44.70 | 5.50 |
| 157 | Downstream | Monie Creek | 10 | South R. | Muscle | 11.34 | -26.11 | 13.46 | 38.01 | 3.29 |
| 158 | Downstream | Monie Creek | 10 | South R. | Muscle | 11.75 | -26.01 | 14.12 | 42.14 | 3.48 |
| 159 | Downstream | Monie Creek | 10 | South R. | Muscle | 11.70 | -26.06 | 13.47 | 42.77 | 3.70 |
| 160 | Downstream | Monie Creek | 10 | South R. | Muscle | 11.98 | -26.14 | 12.16 | 43.23 | 4.14 |
| 161 | Downstream | Monie Creek | 10 | South R. | Mantle | 10.20 | -28.57 | 8.62 | 42.33 | 5.72 |
| 162 | Downstream | Monie Creek | 10 | South R. | Mantle | 10.34 | -28.28 | 9.71 | 43.09 | 5.17 |
| 163 | Downstream | Monie Creek | 10 | South R. | Mantle | 10.25 | -27.94 | 9.51 | 39.01 | 4.78 |
| 164 | Downstream | Monie Creek | 10 | South R. | Mantle | 10.18 | -28.25 | 9.41 | 42.03 | 5.21 |

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|---|---|---|---|---|---|---|---|---|---|---|
| 165 | Downstream | Monie Creek | 10 | South R. | Mantle | 10.48 | -28.40 | 8.37 | 43.33 | 6.04 |
| 166 | Downstream | Monie Creek | 10 | Severn R. | Gills | 12.88 | -28.01 | 7.81 | 36.33 | 5.43 |
| 167 | Downstream | Monie Creek | 10 | Severn R. | Gills | 12.10 | -20.09 | 11.04 | 44.93 | 4.75 |
| 168 | Downstream | Monie Creek | 10 | Severn R. | Gills | 10.57 | -27.97 | 9.77 | 40.89 | 4.88 |
| 169 | Downstream | Monie Creek | 10 | Severn R. | Gills | 10.87 | -27.65 | 10.60 | 41.35 | 4.55 |
| 170 | Downstream | Monie Creek | 10 | Severn R. | Gills | 10.49 | -28.03 | 9.01 | 43.08 | 5.58 |
| 171 | Downstream | Monie Creek | 10 | Severn R. | Muscle | 12.24 | -26.20 | 10.27 | 34.52 | 3.92 |
| 172 | Downstream | Monie Creek | 10 | Severn R. | Muscle | 11.66 | -25.87 | 13.56 | 42.20 | 3.63 |
| 173 | Downstream | Monie Creek | 10 | Severn R. | Muscle | 12.34 | -25.67 | 13.27 | 41.61 | 3.66 |
| 174 | Downstream | Monie Creek | 10 | Severn R. | Muscle | 12.27 | -25.93 | 13.42 | 43.09 | 3.74 |
| 175 | Downstream | Monie Creek | 10 | Severn R. | Muscle | 12.74 | -25.73 | 13.82 | 43.69 | 3.69 |
| 176 | Downstream | Monie Creek | 10 | Severn R. | Mantle | 10.63 | -28.67 | 8.01 | 36.78 | 5.35 |
| 177 | Downstream | Monie Creek | 10 | Severn R. | Mantle | 10.73 | -28.22 | 9.90 | 42.73 | 5.03 |
| 178 | Downstream | Monie Creek | 10 | Severn R. | Mantle | 9.71 | -28.11 | 10.03 | 41.93 | 4.87 |
| 179 | Downstream | Monie Creek | 10 | Severn R. | Mantle | 10.88 | -27.92 | 9.92 | 43.13 | 5.07 |
| 180 | Downstream | Monie Creek | 10 | Severn R. | Mantle | 10.84 | -27.96 | 9.97 | 40.94 | 4.79 |
| 181 | Middle | Monie Creek | 9 | South R. | Gills | 10.41 | -27.71 | 9.93 | 41.55 | 4.88 |
| 182 | Middle | Monie Creek | 9 | South R. | Gills | 10.62 | -27.89 | 10.19 | 42.01 | 4.81 |
| 183 | Middle | Monie Creek | 9 | South R. | Gills | 10.66 | -27.89 | 10.03 | 42.69 | 4.96 |
| 184 | Middle | Monie Creek | 9 | South R. | Gills | 10.23 | -28.03 | 10.39 | 43.85 | 4.92 |
| 185 | Middle | Monie Creek | 9 | South R. | Gills | 10.46 | -27.79 | 10.23 | 44.11 | 5.03 |
| 186 | Middle | Monie Creek | 9 | South R. | Muscle | 11.59 | -25.70 | 13.37 | 41.77 | 3.64 |
| 187 | Middle | Monie Creek | 9 | South R. | Muscle | 11.65 | -25.60 | 13.65 | 42.11 | 3.60 |
| 188 | Middle | Monie Creek | 9 | South R. | Muscle | 12.30 | -25.71 | 13.36 | 42.64 | 3.72 |
| 189 | Middle | Monie Creek | 9 | South R. | Muscle | 11.93 | -25.15 | 14.18 | 42.53 | 3.50 |
| 190 | Middle | Monie Creek | 9 | South R. | Muscle | 11.79 | -25.46 | 13.38 | 41.98 | 3.66 |
| 191 | Middle | Monie Creek | 9 | South R. | Mantle | 10.85 | -28.63 | 8.41 | 42.30 | 5.87 |
| 192 | Middle | Monie Creek | 9 | South R. | Mantle | 10.31 | -27.60 | 9.74 | 41.05 | 4.92 |
| 193 | Middle | Monie Creek | 9 | South R. | Mantle | 10.39 | -28.69 | 8.17 | 42.74 | 6.10 |
| 194 | Middle | Monie Creek | 9 | South R. | Mantle | 10.61 | -27.50 | 10.30 | 41.76 | 4.73 |
| 195 | Middle | Monie Creek | 9 | South R. | Mantle | 10.38 | -27.91 | 9.76 | 42.11 | 5.03 |
| 196 | Middle | Monie Creek | 9 | Severn R. | Gills | 10.87 | -28.03 | 9.64 | 42.26 | 5.11 |
| 197 | Middle | Monie Creek | 9 | Severn R. | Gills | 10.46 | -28.34 | 9.95 | 41.55 | 4.87 |
| 198 | Middle | Monie Creek | 9 | Severn R. | Gills | 11.25 | -27.45 | 9.91 | 41.91 | 4.93 |
| 199 | Middle | Monie Creek | 9 | Severn R. | Gills | 10.10 | -27.98 | 10.33 | 42.81 | 4.83 |
| 200 | Middle | Monie Creek | 9 | Severn R. | Gills | 10.71 | -28.09 | 9.73 | 43.44 | 5.20 |
| 201 | Middle | Monie Creek | 9 | Severn R. | Muscle | 12.80 | -25.55 | 14.08 | 42.09 | 3.49 |
| 202 | Middle | Monie Creek | 9 | Severn R. | Muscle | 13.14 | -25.23 | 13.80 | 42.92 | 3.63 |
| 203 | Middle | Monie Creek | 9 | Severn R. | Muscle | 13.17 | -25.23 | 14.12 | 43.43 | 3.59 |
| 204 | Middle | Monie Creek | 9 | Severn R. | Muscle | 13.68 | -24.75 | 13.87 | 42.78 | 3.60 |
| 205 | Middle | Monie Creek | 9 | Severn R. | Muscle | 13.09 | -24.99 | 13.80 | 42.35 | 3.58 |
| 206 | Middle | Monie Creek | 9 | Severn R. | Mantle | 10.93 | -27.83 | 9.70 | 42.01 | 5.05 |
| 207 | Middle | Monie Creek | 9 | Severn R. | Mantle | 10.46 | -28.56 | 9.44 | 42.49 | 5.25 |
| 208 | Middle | Monie Creek | 9 | Severn R. | Mantle | 12.00 | -27.83 | 8.49 | 40.11 | 5.51 |
| 209 | Middle | Monie Creek | 9 | Severn R. | Mantle | 10.77 | -27.61 | 10.01 | 41.42 | 4.83 |
| 210 | Middle | Monie Creek | 9 | Severn R. | Mantle | 11.29 | -28.33 | 8.84 | 42.77 | 5.64 |
| 211 | Upstream | Monie Creek | 8 | South R. | Gills | 10.82 | -27.62 | 11.54 | 43.99 | 4.45 |
| 212 | Upstream | Monie Creek | 8 | South R. | Gills | 11.45 | -27.04 | 11.49 | 44.66 | 4.53 |
| 213 | Upstream | Monie Creek | 8 | South R. | Gills | 10.55 | -27.58 | 10.63 | 45.35 | 4.98 |
| 214 | Upstream | Monie Creek | 8 | South R. | Gills | 10.76 | -27.43 | 10.25 | 42.88 | 4.88 |
| 215 | Upstream | Monie Creek | 8 | South R. | Gills | 10.52 | -27.34 | 11.09 | 42.53 | 4.47 |
| 216 | Upstream | Monie Creek | 8 | South R. | Muscle | 11.56 | -25.58 | 12.42 | 37.03 | 3.48 |
| 217 | Upstream | Monie Creek | 8 | South R. | Muscle | 13.20 | -24.74 | 13.28 | 42.48 | 3.73 |
| 218 | Upstream | Monie Creek | 8 | South R. | Muscle | 12.21 | -24.59 | 14.61 | 43.50 | 3.47 |
| 219 | Upstream | Monie Creek | 8 | South R. | Muscle | 12.04 | -25.22 | 14.27 | 42.87 | 3.50 |

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|---|---|---|---|---|---|---|---|---|---|---|
| 220 | Upstream | Monie Creek | 8 | South R. | Muscle | 12.37 | -24.87 | 13.88 | 43.30 | 3.64 |
| 221 | Upstream | Monie Creek | 8 | South R. | Mantle | 10.79 | -27.94 | 10.35 | 44.54 | 5.02 |
| 222 | Upstream | Monie Creek | 8 | South R. | Mantle | 10.28 | -27.56 | 9.78 | 42.48 | 5.07 |
| 223 | Upstream | Monie Creek | 8 | South R. | Mantle | 11.36 | -28.14 | 7.84 | 42.94 | 6.39 |
| 224 | Upstream | Monie Creek | 8 | South R. | Mantle | 10.35 | -27.90 | 9.18 | 44.68 | 5.68 |
| 225 | Upstream | Monie Creek | 8 | South R. | Mantle | 11.06 | -27.46 | 10.34 | 45.17 | 5.09 |
| 226 | Upstream | Monie Creek | 8 | Severn R. | Gills | 10.44 | -27.46 | 11.66 | 43.83 | 4.38 |
| 227 | Upstream | Monie Creek | 8 | Severn R. | Gills | 10.82 | -27.54 | 10.62 | 44.35 | 4.87 |
| 228 | Upstream | Monie Creek | 8 | Severn R. | Gills | 10.74 | -27.73 | 10.87 | 44.12 | 4.73 |
| 229 | Upstream | Monie Creek | 8 | Severn R. | Gills | 11.38 | -27.42 | 10.45 | 44.62 | 4.98 |
| 230 | Upstream | Monie Creek | 8 | Severn R. | Gills | 10.37 | -27.45 | 10.17 | 42.15 | 4.83 |
| 231 | Upstream | Monie Creek | 8 | Severn R. | Muscle | 13.10 | -25.19 | 14.53 | 43.49 | 3.49 |
| 232 | Upstream | Monie Creek | 8 | Severn R. | Muscle | 12.56 | -25.63 | 14.50 | 42.99 | 3.46 |
| 233 | Upstream | Monie Creek | 8 | Severn R. | Muscle | 13.52 | -24.37 | 14.97 | 43.47 | 3.39 |
| 234 | Upstream | Monie Creek | 8 | Severn R. | Muscle | 13.36 | -24.53 | 14.40 | 43.32 | 3.51 |
| 235 | Upstream | Monie Creek | 8 | Severn R. | Muscle | 13.14 | -24.99 | 14.26 | 42.74 | 3.50 |
| 236 | Upstream | Monie Creek | 8 | Severn R. | Mantle | 10.83 | -28.31 | 8.09 | 41.69 | 6.01 |
| 237 | Upstream | Monie Creek | 8 | Severn R. | Mantle | 10.61 | -28.47 | 9.03 | 43.98 | 5.68 |
| 238 | Upstream | Monie Creek | 8 | Severn R. | Mantle | 11.71 | -28.49 | 7.67 | 44.68 | 6.80 |
| 239 | Upstream | Monie Creek | 8 | Severn R. | Mantle | 10.62 | -27.59 | 9.62 | 41.80 | 5.07 |
| 240 | Upstream | Monie Creek | 8 | Severn R. | Mantle | 10.24 | -27.88 | 9.66 | 41.82 | 5.05 |
| 241 | Bay | Open Bay | 1 | South R. | Gills | 12.85 | -25.04 | 10.17 | 41.04 | 4.71 |
| 242 | Bay | Open Bay | 1 | South R. | Gills | 12.20 | -24.87 | 10.14 | 40.67 | 4.68 |
| 243 | Bay | Open Bay | 1 | South R. | Gills | 12.53 | -25.22 | 9.81 | 40.19 | 4.78 |
| 244 | Bay | Open Bay | 1 | South R. | Gills | 12.29 | -24.85 | 9.60 | 40.31 | 4.90 |
| 245 | Bay | Open Bay | 1 | South R. | Gills | 12.68 | -24.84 | 11.01 | 40.65 | 4.31 |
| 246 | Bay | Open Bay | 1 | South R. | Muscle | 13.75 | -23.51 | 14.27 | 42.35 | 3.46 |
| 247 | Bay | Open Bay | 1 | South R. | Muscle | 13.56 | -23.11 | 14.18 | 42.84 | 3.52 |
| 248 | Bay | Open Bay | 1 | South R. | Muscle | 13.39 | -23.29 | 14.13 | 43.16 | 3.56 |
| 249 | Bay | Open Bay | 1 | South R. | Muscle | 13.61 | -23.41 | 13.72 | 41.73 | 3.55 |
| 250 | Bay | Open Bay | 1 | South R. | Muscle | 13.23 | -23.41 | 13.93 | 42.53 | 3.56 |
| 251 | Bay | Open Bay | 1 | South R. | Mantle | 12.26 | -25.63 | 9.32 | 43.67 | 5.46 |
| 252 | Bay | Open Bay | 1 | South R. | Mantle | 12.04 | -25.39 | 9.92 | 41.74 | 4.91 |
| 253 | Bay | Open Bay | 1 | South R. | Mantle | 12.46 | -25.05 | 8.87 | 39.39 | 5.18 |
| 254 | Bay | Open Bay | 1 | South R. | Mantle | 12.33 | -25.13 | 9.79 | 38.14 | 4.54 |
| 255 | Bay | Open Bay | 1 | South R. | Mantle | 12.26 | -24.87 | 10.24 | 41.35 | 4.71 |
| 256 | Bay | Open Bay | 2 | South R. | Gills | 11.50 | -27.14 | 9.71 | 40.22 | 4.83 |
| 257 | Bay | Open Bay | 2 | South R. | Gills | 11.40 | -27.24 | 9.87 | 43.27 | 5.11 |
| 258 | Bay | Open Bay | 2 | South R. | Gills | 10.65 | -27.46 | 8.95 | 40.99 | 5.34 |
| 259 | Bay | Open Bay | 2 | South R. | Gills | 11.23 | -27.24 | 10.32 | 41.97 | 4.74 |
| 260 | Bay | Open Bay | 2 | South R. | Gills | 11.29 | -27.67 | 9.40 | 43.13 | 5.35 |
| 261 | Bay | Open Bay | 2 | South R. | Muscle | 12.25 | -25.51 | 13.44 | 41.42 | 3.59 |
| 262 | Bay | Open Bay | 2 | South R. | Muscle | 11.64 | -25.43 | 13.45 | 42.52 | 3.69 |
| 263 | Bay | Open Bay | 2 | South R. | Muscle | 11.76 | -25.49 | 13.44 | 43.23 | 3.75 |
| 264 | Bay | Open Bay | 2 | South R. | Muscle | 12.15 | -25.49 | 14.02 | 42.86 | 3.56 |
| 265 | Bay | Open Bay | 2 | South R. | Muscle | 12.16 | -25.10 | 14.60 | 43.72 | 3.49 |
| 266 | Bay | Open Bay | 2 | South R. | Mantle | 11.19 | -27.30 | 9.21 | 40.74 | 5.16 |
| 267 | Bay | Open Bay | 2 | South R. | Mantle | 11.21 | -27.06 | 9.66 | 41.87 | 5.05 |
| 268 | Bay | Open Bay | 2 | South R. | Mantle | 11.05 | -27.40 | 9.46 | 42.64 | 5.26 |
| 269 | Bay | Open Bay | 2 | South R. | Mantle | 11.02 | -27.14 | 10.05 | 42.22 | 4.90 |
| 270 | Bay | Open Bay | 2 | South R. | Mantle | 11.01 | -27.28 | 9.87 | 41.33 | 4.89 |
| 271 | Bay | Open Bay | 1 | Severn R. | Gills | 12.65 | -19.91 | 9.24 | 43.79 | 5.53 |
| 272 | Bay | Open Bay | 1 | Severn R. | Gills | 13.05 | -25.14 | 9.75 | 40.83 | 4.88 |
| 273 | Bay | Open Bay | 1 | Severn R. | Gills | 12.84 | -25.21 | 9.24 | 40.66 | 5.13 |
| 274 | Bay | Open Bay | 1 | Severn R. | Gills | 13.09 | -24.93 | 9.84 | 38.80 | 4.60 |

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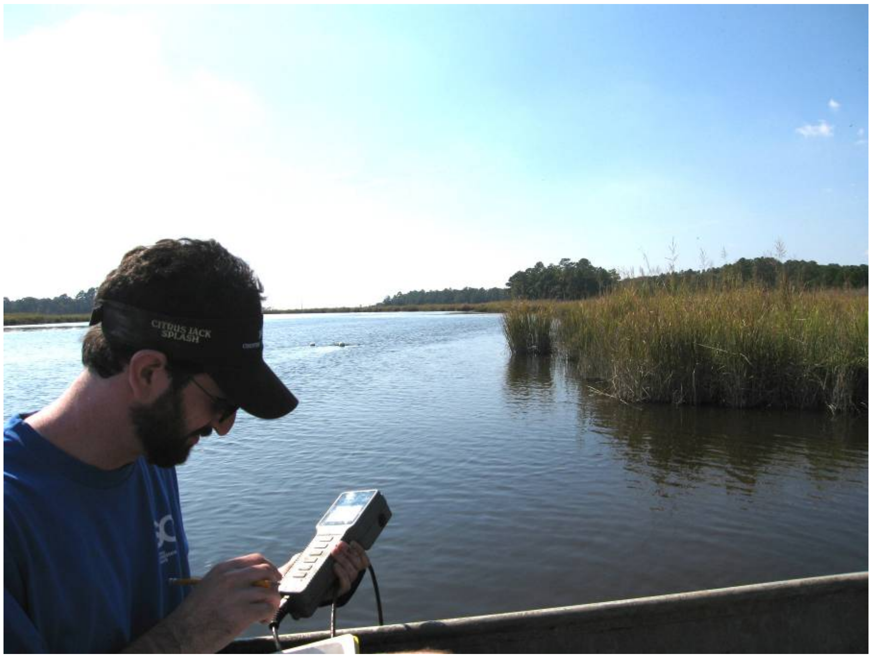
|---|---|---|---|---|---|---|---|---|---|
| 275 | Bay | Open Bay | 1 | Severn R. | Gills | 12.93 | -25.33 | 9.57 | 40.73 | 4.96 |
| 276 | Bay | Open Bay | 1 | Severn R. | Muscle | 14.05 | -23.19 | 13.60 | 41.61 | 3.57 |
| 277 | Bay | Open Bay | 1 | Severn R. | Muscle | 13.82 | -23.17 | 13.38 | 42.40 | 3.70 |
| 278 | Bay | Open Bay | 1 | Severn R. | Muscle | 13.76 | -23.34 | 14.11 | 42.63 | 3.52 |
| 279 | Bay | Open Bay | 1 | Severn R. | Muscle | 14.09 | -23.45 | 13.46 | 41.68 | 3.61 |
| 280 | Bay | Open Bay | 1 | Severn R. | Muscle | 13.91 | -23.74 | 13.89 | 42.11 | 3.53 |
| 281 | Bay | Open Bay | 1 | Severn R. | Mantle | 12.10 | -24.73 | 8.82 | 39.92 | 5.28 |
| 282 | Bay | Open Bay | 1 | Severn R. | Mantle | 12.92 | -25.51 | 8.42 | 39.95 | 5.54 |
| 283 | Bay | Open Bay | 1 | Severn R. | Mantle | 13.18 | -24.66 | 10.08 | 39.18 | 4.53 |
| 284 | Bay | Open Bay | 1 | Severn R. | Mantle | 12.50 | -25.12 | 9.92 | 40.02 | 4.70 |
| 285 | Bay | Open Bay | 1 | Severn R. | Mantle | 13.11 | -25.14 | 10.26 | 40.08 | 4.56 |
| 286 | Bay | Open Bay | 2 | Severn R. | Gills | 11.71 | -27.13 | 10.89 | 44.72 | 4.79 |
| 287 | Bay | Open Bay | 2 | Severn R. | Gills | 11.50 | -27.38 | 10.30 | 43.26 | 4.90 |
| 288 | Bay | Open Bay | 2 | Severn R. | Gills | 10.99 | -27.41 | 10.35 | 42.51 | 4.79 |
| 289 | Bay | Open Bay | 2 | Severn R. | Gills | 11.32 | -27.67 | 9.95 | 42.38 | 4.97 |
| 290 | Bay | Open Bay | 2 | Severn R. | Gills | 11.16 | -27.21 | 9.85 | 41.52 | 4.92 |
| 291 | Bay | Open Bay | 2 | Severn R. | Muscle | 12.11 | -25.54 | 14.43 | 43.73 | 3.54 |
| 292 | Bay | Open Bay | 2 | Severn R. | Muscle | 12.74 | -25.51 | 14.41 | 44.09 | 3.57 |
| 293 | Bay | Open Bay | 2 | Severn R. | Muscle | 11.82 | -25.95 | 13.33 | 42.23 | 3.69 |
| 294 | Bay | Open Bay | 2 | Severn R. | Muscle | 11.40 | -25.91 | 14.24 | 46.48 | 3.81 |
| 295 | Bay | Open Bay | 2 | Severn R. | Muscle | 12.32 | -25.66 | 13.55 | 41.94 | 3.61 |
| 296 | Bay | Open Bay | 2 | Severn R. | Mantle | 11.60 | -28.10 | 9.85 | 43.68 | 5.17 |
| 297 | Bay | Open Bay | 2 | Severn R. | Mantle | 10.85 | -28.32 | 8.15 | 44.14 | 6.32 |
| 298 | Bay | Open Bay | 2 | Severn R. | Mantle | 10.98 | -27.32 | 10.13 | 41.74 | 4.80 |
| 299 | Bay | Open Bay | 2 | Severn R. | Mantle | 11.00 | -27.52 | 10.10 | 44.72 | 5.16 |
| 300 | Bay | Open Bay | 2 | Severn R. | Mantle | 10.93 | -27.85 | 9.85 | 44.00 | 5.21 |

**Appendix 3: Photos**

Tidal marshes found along the creeks

Forests are backdrop to marshes along the creeks




Measuring hydrographic conditions and water quality. Photo: Emily Benson

Deploying oysters in mesh bags. Photo: Julie Bortz

Residences utilizing septic are located close to station MB8, marked by buoys

Little Monie Creek

Oyster cages were heavily fouled in some stations, though not all.

Oysters collected after deployment