# *Monie Bay NERR Site Literature Review and Synthesis*

## Final Report

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## (1) Background

The National Estuarine Research Reserve (NERR) System is a network of protected areas established by the Coastal Zone Management Act of 1972 for long-term research, education and stewardship (NOAA 2003). This partnership program between NOAA and the coastal states of the US protects estuarine land and water to provide essential habitat for wildlife and research reserves for scientific inquiry. Monie Bay, which is a tributary of Tangier Sound located in the southeastern portion of Chesapeake Bay, is one of three sites that form the Maryland Chesapeake Bay NERR System (NERR 2004). Although the Monie system is generally not as well-studied as other Maryland NERR sites, several recent research projects associated with this system provide detailed information on Monie's tidal marshes, estuarine waters, and human ecology. Most of the recent Monie Bay research was conducted in support of several NERR Graduate Research Fellows, as well as monitoring studies by other researchers from Salisbury University and UMCES Horn Point Laboratory and University of Maryland College Park. In addition, routine and specialized habitat, wildlife monitoring studies have been conducted in this area by various agencies of the state of Maryland Department of Natural Resources.

Although considerable information may be presently available to describe the Monie Bay ecosystem and its watershed, these data have not been compiled and analyzed to provide an integrated description of the estuarine system. Several reports and student theses have presented limited background information in support of particular studies; however, these are all far from comprehensive. NOAA NERR regulations call for the development of *Site Profiles* for each NERR to review the state of knowledge about that site and to identify research and monitoring needs to be addressed in the future studies (J. Bortz, personal communication). This is a vitally important activity needed for defining key research questions and for providing background to support future research endeavors at this site. At present, sufficient resources are not available for producing a complete synthesis of data and information pertaining to the Monie Bay NERR. The present report is, however, designed to provide an initial step toward that goal. Here we review all published and unpublished data and reported information that we could obtain describing the Monie Bay system. This report provides a brief review of key relevant information. In support of this report, we also provide an annotated bibliography of some fifty research papers, theses, reports and websites pertaining to Monie Bay NERR and the region in which it is situated. We also provide hard and electronic copies of all documents located in our search.

## (2) Physical Environment

Monie Bay is a small embayment with little freshwater input located near the mouth of the Wicomico River south of the Nanticoke River. Its tidal channels have maximum water depths of ~ 2 m, with tidal ranges of ~0.3 m and salinities generally ranging from 7-17 psu (Ward et al. 1998). The Monie NERR site is situated in a region of low-lying terraces composed primarily Parsonburg Sands with interbedded clays and shell beds, ranging in age from Miocene to Late Pleistocene (Ward et al. 1998). The region's soils are part of a sequence of alluvial sands and marsh beds to the east, and Holocene Marsh Deposits overlap the lowland Quaternary Deposits on the eastern side of the Delmarva Peninsula containing Monie Bay proper. This western side of the peninsula is broad lowland with surface elevations ranging from 0-10 m above sea level that are extensively dissected with bay flats and broad valley bottoms. Monie Bay estuary is bordered by tidal marsh deposits of the Holocene Age, which extend east from the Chesapeake Bay and Tangier Sound across this coastal lowland into the central Delmarva Peninsula (NERR 2004). Monie Bay soils are generally classified as tidal marsh soils, containing sands, clay, and sulfurous peaty muck (**Table 1**). Most of the upland portions of the site are in the Othello-Portsmith association comprised of poorly-drained silt loams overlying silty-clay loam subsoils (Matthews and Hall 1966).

The climatic conditions at Monie NERR are humid and semi-continental, with mild winters and hot summers. Prevailing winds are from the west such that the Atlantic Ocean influences weather patterns only occasionally, as with periodic northeaster storms.

The average growing season length is ~230 days in the Monie watershed, and average annual rainfall is ~ 46 inches, with summer being the rainy season. Average monthly minimum temperature is 9°F in February, and average monthly maximum is 98oF in July. Annual minimum and maximum temperatures are 5 and 97°F (Matthews and Hall 1966).

There are seven major aquifers underlying the Monie NERR region (**Fig. 1**). The first of these is the *Surficial Aquifer*, which has limited capacity and is generally soft and acidic with high nitrate concentrations in areas near farming. The *Pocomoke Aquifer,* which is present only in the SE part of the region, has elevated concentrations of iron and manganese. The *Manokin Aquifer* is the principal source of water for human use in Maryland's Somerset County, which is the site of Monie NERR. It has highly variable water quality ranging from relatively soft water low in solutes to the south and east to hard water high in chlorides toward Chesapeake Bay. Water in the Deal Island/Monie NERR area has chloride concentrations exceeding USEPA standards. The *Paleocene* and *Potomac Aquifers* supply water to major towns and cities in Somerset and other counties along the Bay. Model analyses suggested that projected increases in human water use in the region could encounter salinity problems within 50 years.

The chemical character of natural water in the *Surficial Aquifer* is controlled primarily by the chemical properties of precipitation, in combination with mineral dissolution and biological activity in the aquifer (Hamilton et al. 1993). Like precipitation and natural ground water are moderately acidic (pH ~ 5.8), and concentrations of dissolved constituents are low because the *Surficial Aquifer* consists mostly of relatively insoluble quartz sand. The high permeability of soils increases ground-water-flow rates and reduces contact and reaction time between water and aquifer minerals. Nitrate concentrations, derived from nitrification of ammonia in inorganic fertilizers and manure, is the dominant anion in agricultural areas, with concentrations ranging from 0.4 to 48 mg N $l^{-1}$ (median = 8.2 mg N $l^{-1}$). Nitrate concentrations exceeded the USEPA maximum for drinking water (10 mg N $l^{-1}$) in ~ 33 % of the 185 water samples (**Table 2**). Effects of agricultural activities on ground water quality are not limited to the near-surface parts of the aquifer underlying farm fields but are common at or near the base of the aquifer, 25-

35 m land surface. Elevated concentrations of nitrate in deep ground water reflect recharge through distant agricultural or residential land rather than through agricultural or residential land directly around a well (e.g., Shedlock et al. 1999). Nitrate concentrations are minimal or less than the laboratory reporting limit in ground water beneath agricultural or residential areas underlain by fine sand, clay, silt, peat, and other organic matter (Hamilton et al. 1993). Recent studies suggest that forest buffers could help reduce nitrate input to ground waters in the region (e.g., Speiran et al. 1997).

### (3) Human Uses and Activities

The Monie Bay NERR is situated near the southwestern edge of Somerset County on the Chesapeake Bay coast. Somerset County is a very rural and economically depressed region of Maryland. As of the 2000 Census, the county population was 24,747 people living at an average density of one person per 9 acres (Somerset 1998, 2002). The per capita personal income was $17,360 in 1999 (MD DBED. 2002, US Dept. of Commerce. 2001), which is just over half the overall value for the state of Maryland ($32,517). Although farming, agriculture, fishing and forestry accounted for 22% of jobs in 1970, this declined to only 17% by 1995. The closing of seafood and produce processing plants during this period caused manufacturing employment to drop from 24% to 7% of all jobs. Meanwhile, service and government jobs have increased from 18% to 29% during this same time period (Urban Research 1998).

The region was first surveyed by the state of Maryland in 1662 along major rivers in the south and west for settlers leaving Virginia, primarily for religious reasons. Proprietary Manors (6000 acres each) were laid out in 1674 for Lord Baltimore’s use. The boarders of Somerset County were disputed with Virginia and the “Lower Three Counties of Pennsylvania” (now Delaware) between the mid 1600s and 1700s. By 1742 there were 9-10 designated Somerset “Hundreds” (a medieval English term indicating subunits within a county). Among these was the Monie Hundred, which increased in size by >3-fold by 1783 (Lyons 2004).

Modern land-use in Somerset County is comprised by ~30% farmland and ~42% forests, and ~28% undeveloped wetlands. Nearly 15% of the County's land area is part of State or federal recreation and wildlife management areas, primarily along the waterfront (Urban Research 1998). Watersheds for the three primary tidal creeks that drain and define the Monie Bay NERR site have different mixes of land-use (Fig. 2). Little Creek watershed has 35% forested land, 63% marshland, 1% farmland, and 1% residential, while Little Monie Creek and Monie Creek have similar land-use distributions with, respectively, 52% and 58% forested land, 20% and 16% marshland, 25% and 23% farmland, and 3% residential land (Apple et al. 2004). Oblique angle aerial photographs (Fig. 3a, b) illustrate the dominance of marshlands surrounding Monie Creek near its mouth, while forest and farming land-uses dominate the upper reaches of the creek watershed.

## (4) Terrestrial Ecology: Forests and Wildlife

Various groups in Maryland Department of Natural Resources conduct routine surveys of forests, other plants and wildlife on annual scales. Unfortunately, results of these surveys are not readily available for examination and analysis. We were able to obtain hard copies of the 2004-2005 annual reports for Furbearer, rabbit and squirrel (Colona 2005), for Deer (Hotton et al. 2005), and for Wild turkey and Upland game birds (Long 2005). Furbearer data are based on informal bowhunter surveys, while other mammal surveys were based on harvest rates. Somerset County has relatively high rates of otter harvest; however, the population estimates for other small mammals were not organized by county, and few clear time trends were evident between surveys conducted in 2002-2003 and 2003-2004. Harvest rates for deer and turkey for the 2004-2005 season were relatively high in Somerset County, particularly when calculated on a per human capita basis. Extensive breeding bird surveys (USGS 2006) in Somerset County indicate a diversity of song birds using the region for habitat. The 2004 Bald eagle nesting surveys reveal that Somerset County has a relatively abundant population. Plant and wildlife habitat management surveys have been done for Somerset County (Ludwig et al.1987), and Irish Grove has been designated a "natural heritage area" in the county.

Unfortunately, this review was unable to find any scientific data describing the natural history of plant and animal populations, or dynamic community interactions in forested or field upland habitats in Somerset County's natural or managed lands. Similarly, we found no data describing any aspects of the terrestrial ecology of the upland watersheds of the Monie Bay NERR site. This underscores a major gap in our understanding of this Monie ecosystem.

### (5) Tidal Marshes

In contrast to the complete absence of information on upland ecosystems, the tidal wetland marshes of Monie Bay and the surrounding areas have been relatively well studied during the last decade. Plant biomass in Monie marshes is generally dominated by *Spartina alterniflora*; however, *S. patens* and *Juncus roemerianus* are also important in many sites (**Fig. 4**). Quantitative samples at most Monie sites indicate 5-8 plant species making up the marsh community (Jones et al. 1997, Stribling and Cornwell 1997). Plant diversity tends to be higher Little Creek marshes which are relatively unaffected by agricultural inputs, while plant biomass tends to be greater in Monie Creek marshes which are heavily affected farmland runoff (Jones et al. 1997); similarly, plant tissue nutrient levels tend to be higher in the marshes from the agricultural watershed. Growth of above ground biomass for *S. alterniflora* was significantly increased by experimental nutrient (N & P) fertilization in spring in the marshes of both Little Creek and Monie Creek; however, no responses were evident with fall fertilization (Jones et al. 1997). Porewater profiles of ammonium and phosphate concentrations in Monie NERR marshes show strong seasonal trends that follow plant growth cycles (**Fig. 5**) and generally higher concentrations in agriculturally influenced marshes (Cornwell et al. 1994, Stribling and Cornwell 2001). Porewater nutrient concentrations are also controlled by plant processes that influence the sediment biogeochemistry at these sites (Stribling et al. 2006).

Surveys of stable isotopes of carbon and sulfur suggest that sources of organic matter production in Monie Bay NERR marshes and tidal creeks are relatively balanced, with C4 marsh plants (e.g., *S. alterniflora*), C3 marsh plants (e.g., *J. roemerianus*), phytoplankton and benthic algae all contributing to the organic carbon budget (Stribling and Cornwell 1997). This finding is in contrast to earlier work in higher salinity marshes, where C4 plant production tended to dominate the detrital carbon pools. Furthermore, studies of isotopic signatures of consumer animals in the marsh system, including shrimp, crabs, snails, and fish, suggest that marsh plants make substantial contribution to the diets of these animals (Stribling and Cornwell 1997), in contrast to previous findings in higher salinity systems where algae appeared to be the dominant food. These are important findings despite the fact that seasonal variations in marsh plant signatures for stable sulfur isotopes may slightly cloud these interpretations (Stribling et al. 1998).

A series of studies have examined rates of sediment accretion and the stability of marsh area in the Monie Bay NERR system. Sediment accretion rates over various time scales (~30 years, ~100 years, and ~200 years) were determined using $^{137}$Cs, $^{210}$Pb, and pollen geochronologies. System integrated long-term vertical accretion rates have averaged about 3.0mm/yr for the last two centuries (**Fig. 6**), which is similar to the rate of marsh submergence for the area over the last half century recorded by tide-gauges (Kearney et al. 1994). However, there is considerable spatial variability in these rates (ranging from 0.15 to 0.63 mm/yr) within the Monie system (Fig. 6). The delicate balance between sediment accretion rates and sea level rise emphasizes the susceptibility of marshes such as those at Monie to substantial loss through erosion (Stevenson et al. 1988). Natural compaction processes and disturbance by storms can lead to extensive marsh loss, with interior ponding often appearing as an intermediate phase in marsh erosion (Kearney et al. 1988). The marshes at the Monie Bay research Reserve are composed of three sedimentary environments; (1) high wave energy bay bank marshes characterized by low organic coarse-grained storm over-wash deposits overlying finer-grained marsh sediments; (2) low energy tidal channel bank deposits composed of moderately organic fine-grained sediments; and (3) organic rich fine-grained black marsh sediments (Ward et al. 1988). Although Monie Bay marshes appear to be relatively stable over the last several decades (Ward et al. 1988), inputs of terrestrial sediments to Monie marshes are relatively limited compared to riverine marshes along the Nanticoke River, making Monie Bay marshes more susceptible to long term erosion (Ward et al. 1998).

Coupling sediment accretion rates with measurements of nutrient content of accumulation particulate matter suggests tidal marsh including those at Monie may serve as major sinks for N and P burial (Zelenke and Cornwell 1996). Measurements at Monie Bay and Jug Bay NERR sites suggest that these marshes trap 35% of the nitrogen and 81% of the phosphorus inputs from the surrounding watershed (**Table 3**). If these nutrients were not trapped in marsh sediments, they would otherwise be recycled, exported, or buried in the subtidal sediments of the estuary. Relatively high denitrification rates measured in Monie and Jug Bay marsh sediments (~60 μmol N $m^{-2}$ $h^{-1}$) with high seasonal variability suggests that an additional 10% of the fall line nitrogen may be removed from the estuary via this biogeochemical transformation.

## (6) Estuarine Ecology

Relatively recent studies have provided substantial new information about the estuarine ecology of the tidal creeks and embayments connected to the tidal marsh and upland habitats of the Monie Bay NERR site. Three substantial tidal creeks (Monie Crk, Little Monie Crk, and Little Crk) penetrate into the Monie system (Fig. 2) through the marshes near their mouths into the forested and agricultural lands near their freshwater sources (**Fig. 7**). These tidal creeks empty into an outer bay which connects drainage from Monie, as well as Wicomico and Nanticoke Rivers, to Chesapeake Bay proper. The three tidal creeks and adjacent outer bay form an integrated Monie estuarine system, the plankton ecology of which has been relatively well studied during the last decade.

A 2-year (1994-1995) water quality monitoring effort in the Monie Bay tidal ecosystem indicated that Little Monie Creek (LMC) and Little Creek (LC) were similar with respect to salinity, temperature, and water volume (Jones et al. 1994, 1998). However, spring flow reduced salinities in the upper reaches of LMC relative to values in LC. Nutrient concentrations generally declined from the upper reaches of the tidal creeks to the open bay water because of dilution and biogeochemical processing (**Fig. 8**). LMC had higher nutrient and phytoplankton chlorophyll-*a* concentrations than LC, and this difference was attributed to differences in the watersheds of the two creeks. LMC and Monie Creek (MC) were consistently higher in TSS, dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP), and chlorophyll-*a* than LC throughout the study period, with greatest difference in DIP. In general, nutrient levels followed a consistent gradient where MC>LMC>>LC, with MC and LMC being very close. Based on a transect in LMC from headwaters to the open bay, agricultural runoff nearly doubles the concentration of total nitrogen (TN) and total phosphorus (TP) along the creek axis. TP concentrations in LMC were four-fold higher than that of LC, and TN was elevated two- to three-fold. Salinity values were lowest in the late winter to early spring (February-April) and highest in summer and fall; values in MC were consistently lower than LMC and LC (which are similar). Nitrate concentrations were extremely low most of the year (i.e., June - November, <2 μM). However, an early spring peak (~50 μM) occurred in February, then gradually declined through April (**Fig. 9**). Concentrations were highest in LMC, then MC, and did not change substantially throughout the year in LC. Ammonium concentrations peaked in December and again in March in all creeks; otherwise values were low (Jones et al. 1998).

A recent dissertation study investigated the factors regulating spatial and temporal variability of bacterioplankton carbon metabolism in the Monie Bay estuarine ecosystem (Apple et al. 2004, 2006, Apple 2005). Results suggest that differences in land-use and landscape characteristics in the study site (Monie Bay) drive intra- and inter-creek environmental gradients in salinity, nutrients, and dissolved organic matter (DOM) quality and quantity (**Fig. 8, 9**). A 2-yr study (2000-2002) revealed that bacterioplankton metabolism was generally stimulated system-level nutrient enrichment, and that these responses were modulated by differences in salinity distribution among tidal creeks. Water temperature and organic matter quality exerted the strongest influence on carbon metabolism. Bacterioplankton production (BP), respiration (BR) and total carbon consumption (BCC)) all exhibited significant positive temperature dependence. Different strength of temperature effects on BP and BR resulted in the negative temperature dependence of bacterioplankton growth efficiency (BGE = BP/[BP+BR]). Dissolved organic matter also influenced carbon metabolism, with higher BCC and BGE generally associated with DOM of greater lability. Data analyses suggested that the energy content and lability of DOM may be more important than nutrient content or dissolved nutrients alone in determining the magnitude and variability of BGE. Values of BCC and BGE may be further modulated by the abundance, proportion, and individual metabolism of highly-active cells. Observed salinity effects on single-cell bacterial activity suggest that other cellular-level properties and phylogenetic composition may also be important factors. In general, the variability of bacterioplankton carbon metabolism in the Monie NERR estuarine system reflects a complex response to a wide range of environmental and biological factors, of which temperature and DOM quality appear to be the most important. Furthermore, this research reveals fundamental differences in both cellular and community-level metabolic processes when freshwater and marine endmembers of estuaries are compared that may contribute to the variability in bacterioplankton carbon metabolism within and among estuarine systems (Apple 2005).

There is little scientific information regarding benthic plants and animals, fish, water birds and trophic relationships in the Monie Bay estuarine ecosystem. However, a few studies provide limited data that lend some insights into the structure of this ecosystem. In an effort to assess the habitat quality of the shallow portions of the Monie Bay Reserve, replicate sediment cores were randomly collected (2 Aug 2004) in two locations to determine the abundance and composition of the macrobenthic faunal community. Comparative analysis of benthic faunal at a muddy low-energy environments of tidal creeks were distinctly different from the community sampled in a nearby sandy, high-energy environment. The muddy site's macrobenthic community was numerically dominated by the tubificid oligochaetes *Tubificoides heterochaetus* and *T. brownae* and by the aorid amphipod *Leptocheirus plumulosus*. In contrast, over 75% of the biomass of the community was represented by the single tellinid bivalve species, *Macoma balthica*. At the sandy site, the macrobenthic community was numerically dominated by the venerid bivalve *Gemma gemma*, ostracods, and by nemerteans. The largest biomass components of the macrobenthic community in this habitat were the polychaetes *Glycera dibranchiate* and *Marenzellaria viridis*. The tellinid bivalve *M. balthica* was also important at this site.

## (7) Ecosystem Biogeochemistry

Studies of biogeochemical processes have been conducted as part of marsh and estuarine studies in Monie NERR during the last two decades; however, there have been only a few attempts to analyze these data in the context of whole Monie Bay ecosystem.

Various studies of the Monie Bay ecosystem have demonstrated strong ecological effects of differences in nutrient loading associated with different land-uses in the watersheds of three tidal creeks (e.g., Jones et al. 1998, Apple et al. 2004). These nutrient enrichment effects on the plankton community are related to enrichment of both phytoplankton and marsh autotrophs and the associated enhancement of organic matter lability and nutritional value (Apple 2005). Stable isotopic analyses suggest that marine and brackish water marsh plants, benthic/epiphytic algae and phytoplankton all contribute to the total ecosystem production of the marsh-tidal creek system and that vascular plants and algae both contributed substantially to the diets of estuarine consumer animal populations (Stribling and Cornwell 1997). Biogeochemical processes in marsh sediments can strongly modify the fate and effects of allochthonous and autochthonous organic matter and associated nutrients and sulfide (Stribling et al. 2002).

The marshes of Monie Bay system are large sinks for suspended sediments derived from both watershed/river sources and from marine sources in the lower reaches. In general, rates of sediment accumulation are sufficient to balance the relative rise in sea level in this coastal region (Kearney et al. 1988, Stevenson et al. 1988, Ward et al. 1998). Variablity in sediment sources and physical disturbance due to storm activity contribute to heavy erosion and marsh loss under some conditions, making the Monie system potentially vulnerable to major habitat loss. On the other hand, particulate forms of nitrogen and phosphorus that are part of the TSS load tend to be trapped in marsh sediments creating a major nutrient sink that tends to mitigate eutrophication trends in the estuary (e.g., Cornwell et al. 1992). Furthermore, denitrification in marsh sediments represents another sink for nitrogen pollution entering the marsh-estuary complex (e.g., Merrill and Cornwell 2000). Although these studies provide an initial analysis of ecosystem level biogeochemical processes, further studies are needed to integrate ecological studies in the watershed, marsh and estuarine habitats.

## (8) Resources Management

An integrated resource management plan for Monie Bay NERR and/or for the surrounding region appears to be lacking. A few scientific studies and monitoring programs, which were oriented toward environmental management questions, are described below. The state of Maryland has a shellfish monitoring program which may collect information on relative abundance and recruitment of oysters and clams in the Monie Bay system; however, we were able to obtain information only on the fecal coliform contamination at shellfish monitoring stations. In the most recent survey, all three monitoring stations in the Monie NERR system had *E. coli* levels that were below the criterion for closure of shellfish harvest operations (Table 4). Waterbird surveys conducted at the nearby Deal Island Wildlife Management Area in the early 1980s (Walbeck et al. 1990) revealed that impoundment ponds generally had higher densities of birds than did mosquito control ponds (Table 5). Tidal marshes at Monie, Deal Island and the surrounding region have been invaded by the non-native reed species *Phragmites australis*, particularly in disturbed areas. A recent investigation using the Monie Bay NERR and two other areas as study sites (Hunter et al. 2006) compared abundance of the killifish, *Fundulus heteroclites*, in tidal creeks adjacent to natural marsh stands and near *P. australis* stands in initial, early and late stages of invasion. In general, relative fish abundance (catch per unit effort) was highest at the natural marsh sites and declined with stage of *P. australis* invasion from initial to late (Fig. 10).

## (8) Research Needs

During the last 10-20 years there have been a range of scientific studies of particular aspects of the Monie Bay NERR system; however, there is much that remains to be done. To our knowledge there is essentially no scientific information describing or analyzing the upland habitats of the reserve's watershed. Trees, grasses, and herbaceous plants and their associations have not been studied. Soil and groundwater biogeochemistry have not been described for forests, natural fields or agricultural plots in the region. Atmospheric inputs to the watershed are unknown, as are ecological processes that regulate gas exchange between watershed and overlying atmosphere. The water circulation of tidal creeks and open bays of the Monie system have not been measured or modeled, and there is not information on water residence times in the three creek systems. Basic information on marsh plant ecology and sediment biogeochemistry is available; however, little is known about marsh interactions with the watershed and estuary. Although the water quality of the tidal creeks has been reasonably well described and bacterioplankton metabolism has been studied in detail, little is know about phytoplankton and zooplankton dynamics and interactions. Plankton food webs are poorly understood as is the role of marsh production in regulating them. The dynamics of benthic fauna and submersed aquatic plants are virtually unknown in this system as are the interactions between these communities and the adjacent marshes. Fish and bird communities of Monie NERR system are also not well described nor are the food webs that support them. Finally, an integrative understanding of Monie Bay NERR as an ecosystem is totally lacking, where system level biogeochemical cycles, food webs and community dynamics are not well described nor are the interactions between processes at ecosystem, community and population levels. The ecological services and economic value of the Monie Bay system are not well understood, and the socioeconomic impact of the reserve is poorly described.

### (9) Recommendations for Enhancing the Monie NERR Site

This report represents a very small step toward the crucial goal of integrating all information related to the Monie Bay NERR site and defining a clear plan for research and monitoring. Although the list of tasks needed to enhance the Monie NERR site is long, we will focus on a few key points in this final section of the report.

- **Comprehensive information compilation and synthesis**. This report represents the first effort to provide a compilation and integration of information related to the Monie Bay NERR system. Although we believe that we have successfully located and compiled most existing and relevant information, DNR and other state agencies need to collaborate on an effort to uncover and release for broad distribution any internal documents that may exist. We have only scratched the surface in terms of integrating the existing information and defining the logical research priorities. The next step should be to develop a formal site profile for this NERR site.

- **Meetings of researchers and managers.** We strongly recommend that DNR and the NERR managers organize a series of meetings that bring together researchers and managers who have knowledge and interest in the Monie Bay NERR system. This process should begin as soon as possible.

- **On-site manager.** Progress in the development of the Monie Bay NERR system has been impeded by the absence of an on-site reserve manager with a vested interest in the growth and development of this system. The hiring of such a formal manager should be a high priority toward the goal of bringing life to Monie Bay NERR.

- **On-site research support facilities.** To encourage more researchers to use Monie as a study site and to facilitate the conducting of experimental studies, NOAA and DNR need to create a well-appointed on-site research support building. This building should have room for equipment storage, as well as basic wet and dry laboratory facilities and overnight accommodations for graduate students.

- **Monitoring program.** A basic monitoring program including water quality and key biological variables needs to be initiated as soon as possible. These routine data are needed to detect changes in the Monie system in response to climate and anthropogenic factors and to provide context for research projects. Such monitoring programs are a basic component for all other NERR sites across the country. The existence of on-site manager and research facilities will make this goal feasible.

- **Social anthropology of the region.** A recent report (Power and Paolisso 2005) analyzes results of an assessment of socio-cultural needs of the local community in relation to the Monie Bay NERR site. The study uses methods of environmental anthropology including carefully designed surveys of the local human community to identify and analyze explicit cultural-ecological knowledge of stakeholder groups and to provide recommendations for MD DNR regarding expansion of scientific and education outreach that engages the local community. The project proposes five cultural models for marshes such as those of Monie: (1) marshes as recreation, (2) marsh as filter, (3) marsh as buffer, (4) marsh as protection, and marsh as heritage. The project recommends several courses of action to improve the linkage in Monie NERR between scientific understanding, natural resources, and human community. (a) The local community is strongly supportive of scientific research at Monie NERR, and there was strong interest in a continuing series of informal talks presented in the region given by scientists, watermen, and farmers. (b) The community expressed interest in developing tourism based on the ecology and heritage of the region. (c) There was a very strong interest in development of a place to focus outreach activity at Monie NERR, such as visitor center or museum. There was associated interest in establishing and maintaining nature trails, boardwalks, and self-guided tour; however, the strongest point was the need for a visitor center, where people from the community could meet, hear talks and discuss related issues. (d) Many local folks expressed interested in volunteering to work at and support a Monie NERR facility.

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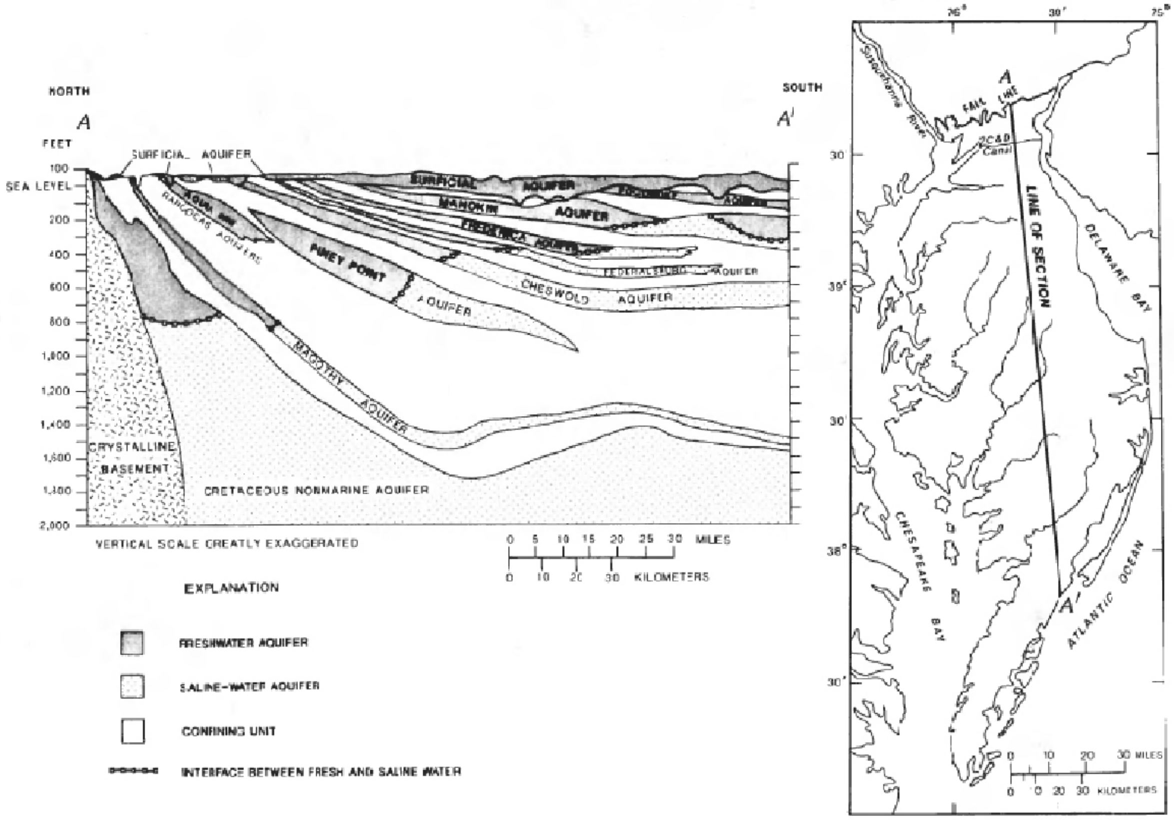
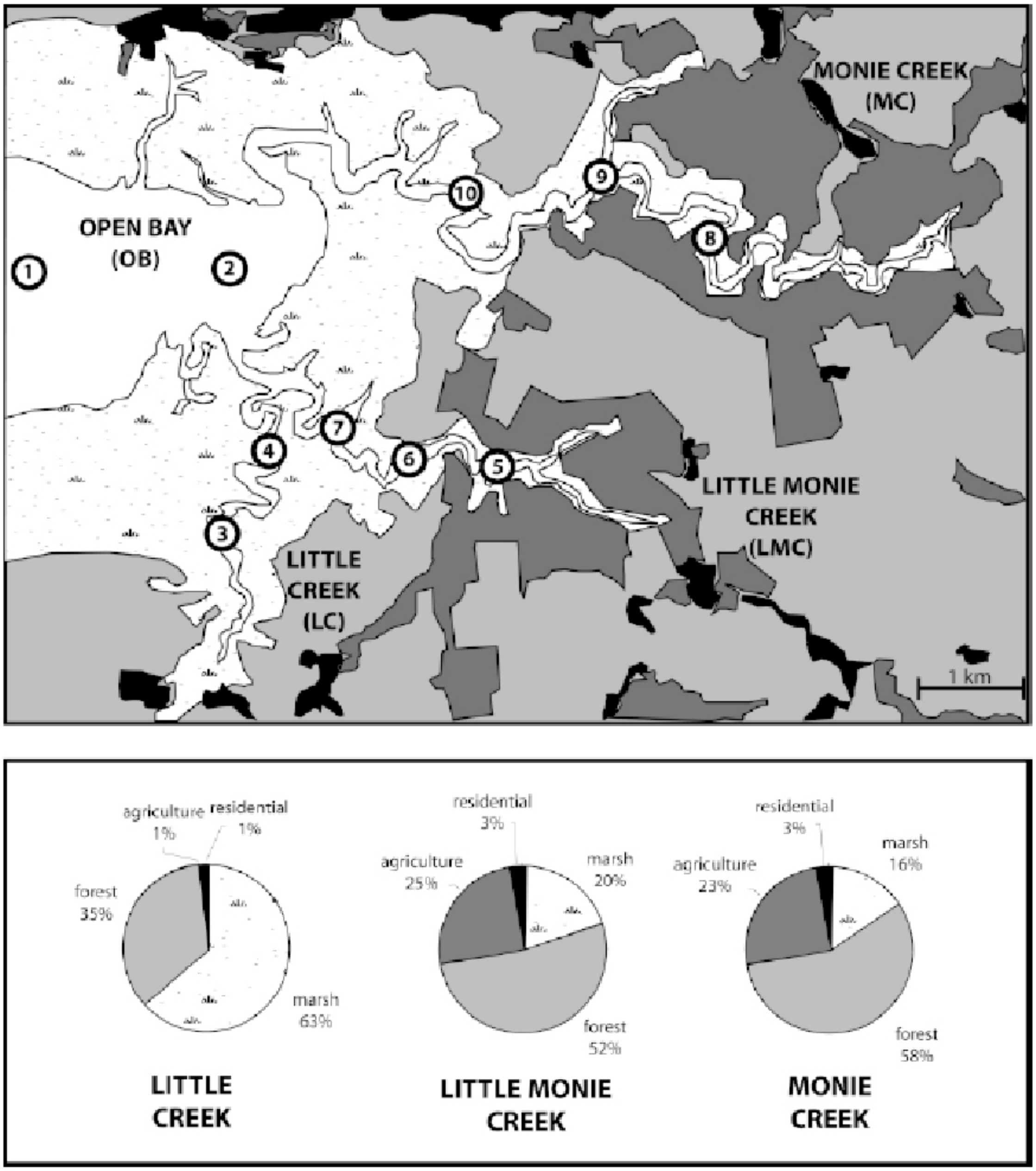


Hydrogeologic section across the Delmarva Peninsula.

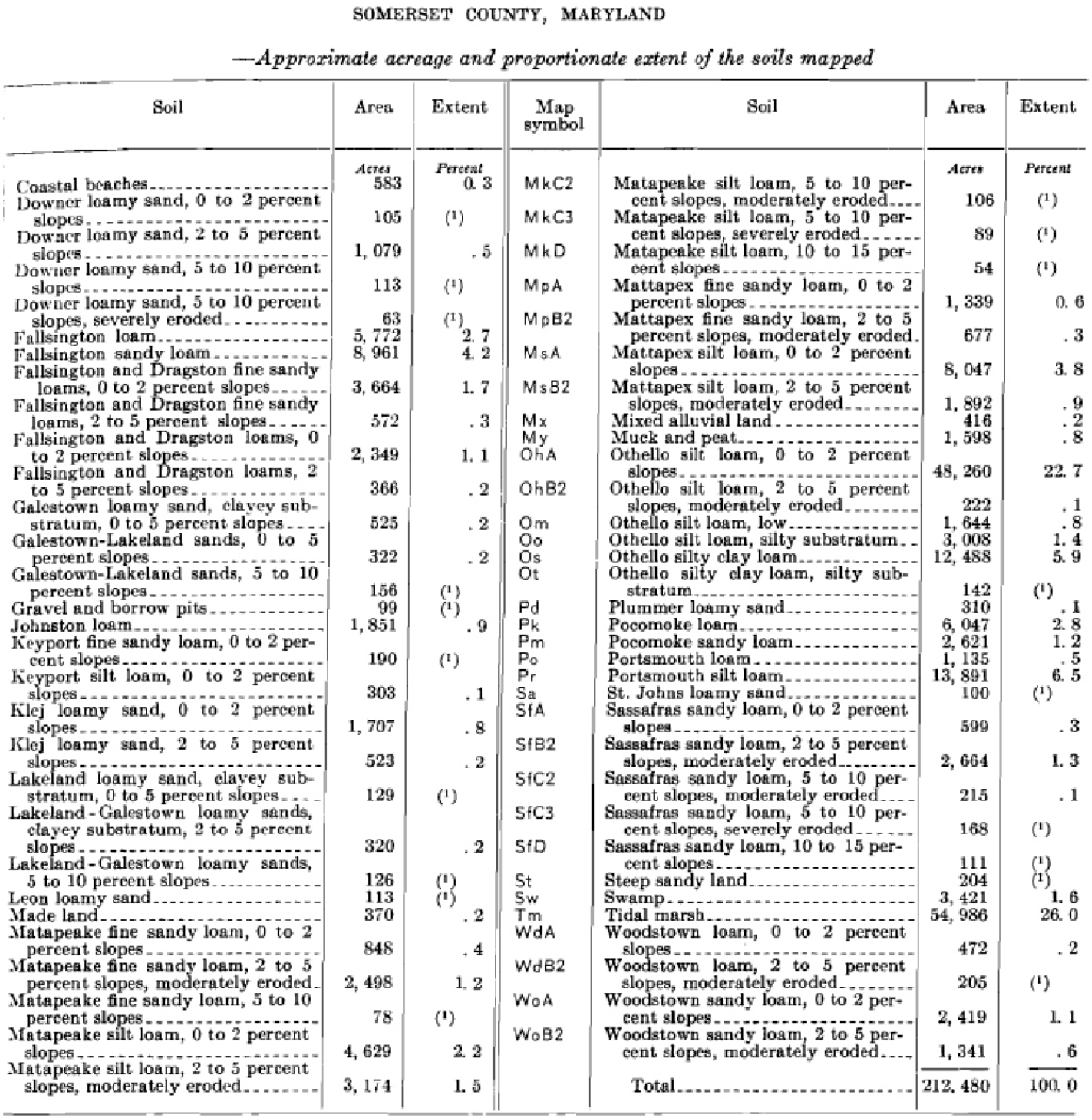
(Hamilton et al. 1993)

Figure 1. Vertical section across Delmarva Peninsula showing the locations and distributions of major aquifers (Hamilton et al. 1993).



Monie Bay National Estuarine Research Reserve System with location and number of each sampling station (upper panel) and proportion of each watershed attributed to one of four land-use categories (lower panel).

Figure 2. Watershed land-use and water sampling stations for experimental tidal creeks of Monie Bay NERR. Note the similarities in land use distribution between LMC and MC watersheds, and the absence of agricultural in LC watershed (Apple et al. 2004).



SOMERSET COUNTY, MARYLAND

*—Approximate acreage and proportionate extent of the soils mapped*

| Map symbol | Soil | Area | Extent |
|---|---|---|---|
| | | *Acres* | *Percent* |
| | Coastal beaches | 583 | 0.3 |
| | Downer loamy sand, 0 to 2 percent slopes | 105 | (1) |
| | Downer loamy sand, 2 to 5 percent slopes | 1,079 | .5 |
| | Downer loamy sand, 5 to 10 percent slopes | 113 | (1) |
| | Downer loamy sand, 5 to 10 percent slopes, severely eroded | 63 | (1) |
| | Fallsington loam | 5,772 | 2.7 |
| | Fallsington sandy loam | 8,961 | 4.2 |
| | Fallsington and Dragston fine sandy loams, 0 to 2 percent slopes | 3,664 | 1.7 |
| | Fallsington and Dragston fine sandy loams, 2 to 5 percent slopes | 572 | .3 |
| | Fallsington and Dragston loams, 0 to 2 percent slopes | 2,349 | 1.1 |
| | Fallsington and Dragston loams, 2 to 5 percent slopes | 366 | .2 |
| | Galestown loamy sand, clayey substratum, 0 to 5 percent slopes | 525 | .2 |
| | Galestown-Lakeland sands, 0 to 5 percent slopes | 322 | .2 |
| | Galestown-Lakeland sands, 5 to 10 percent slopes | 156 | (1) |
| | Gravel and borrow pits | 99 | (1) |
| | Johnston loam | 1,851 | .9 |
| | Keyport fine sandy loam, 0 to 2 percent slopes | 190 | (1) |
| | Keyport silt loam, 0 to 2 percent slopes | 303 | .1 |
| | Klej loamy sand, 0 to 2 percent slopes | 1,707 | .8 |
| | Klej loamy sand, 2 to 5 percent slopes | 523 | .2 |
| | Lakeland loamy sand, clayey substratum, 0 to 5 percent slopes | 129 | (1) |
| | Lakeland-Galestown loamy sands, clayey substratum, 2 to 5 percent slopes | 320 | .2 |
| | Lakeland-Galestown loamy sands, 5 to 10 percent slopes | 126 | (1) |
| | Leon loamy sand | 113 | (1) |
| | Made land | 370 | .2 |
| | Matapeake fine sandy loam, 0 to 2 percent slopes | 848 | .4 |
| | Matapeake fine sandy loam, 2 to 5 percent slopes, moderately eroded | 2,498 | 1.2 |
| | Matapeake fine sandy loam, 5 to 10 percent slopes | 78 | (1) |
| | Matapeake silt loam, 0 to 2 percent slopes | 4,629 | 2.2 |
| | Matapeake silt loam, 2 to 5 percent slopes, moderately eroded | 3,174 | 1.5 |
| MkC2 | Matapeake silt loam, 5 to 10 percent slopes, moderately eroded | 106 | (1) |
| MkC3 | Matapeake silt loam, 5 to 10 percent slopes, severely eroded | 89 | (1) |
| MkD | Matapeake silt loam, 10 to 15 percent slopes | 54 | (1) |
| MpA | Mattapex fine sandy loam, 0 to 2 percent slopes | 1,339 | 0.6 |
| MpB2 | Mattapex fine sandy loam, 2 to 5 percent slopes, moderately eroded | 677 | .3 |
| MsA | Mattapex silt loam, 0 to 2 percent slopes | 8,047 | 3.8 |
| MsB2 | Mattapex silt loam, 2 to 5 percent slopes, moderately eroded | 1,892 | .9 |
| Mx | Mixed alluvial land | 416 | .2 |
| My | Muck and peat | 1,598 | .8 |
| OhA | Othello silt loam, 0 to 2 percent slopes | 48,260 | 22.7 |
| OhB2 | Othello silt loam, 2 to 5 percent slopes, moderately eroded | 222 | .1 |
| Om | Othello silt loam, low | 1,644 | .8 |
| Oo | Othello silt loam, silty substratum | 3,008 | 1.4 |
| Os | Othello silty clay loam | 12,488 | 5.9 |
| Ot | Othello silty clay loam, silty substratum | 142 | (1) |
| Pd | Plummer loamy sand | 310 | .1 |
| Pk | Pocomoke loam | 6,047 | 2.8 |
| Pm | Pocomoke sandy loam | 2,621 | 1.2 |
| Po | Portsmouth loam | 1,135 | .5 |
| Pr | Portsmouth silt loam | 13,891 | 6.5 |
| Sa | St. Johns loamy sand | 100 | (1) |
| SfA | Sassafras sandy loam, 0 to 2 percent slopes | 599 | .3 |
| SfB2 | Sassafras sandy loam, 2 to 5 percent slopes, moderately eroded | 2,664 | 1.3 |
| SfC2 | Sassafras sandy loam, 5 to 10 percent slopes, moderately eroded | 215 | .1 |
| SfC3 | Sassafras sandy loam, 5 to 10 percent slopes, severely eroded | 168 | (1) |
| SfD | Sassafras sandy loam, 10 to 15 percent slopes | 111 | (1) |
| St | Steep sandy land | 204 | (1) |
| Sw | Swamp | 3,421 | 1.6 |
| Tm | Tidal marsh | 54,986 | 26.0 |
| WdA | Woodstown loam, 0 to 2 percent slopes | 472 | .2 |
| WdB2 | Woodstown loam, 2 to 5 percent slopes, moderately eroded | 205 | (1) |
| WoA | Woodstown sandy loam, 0 to 2 percent slopes | 2,419 | 1.1 |
| WoB2 | Woodstown sandy loam, 2 to 5 percent slopes, moderately eroded | 1,341 | .6 |
| | Total | 212,480 | 100.0 |

(Matthews et al. 1966)

Table 1. Areal cover and elative importance of different soil types in Somerset County, Maryland (Matthews et al. 1966).

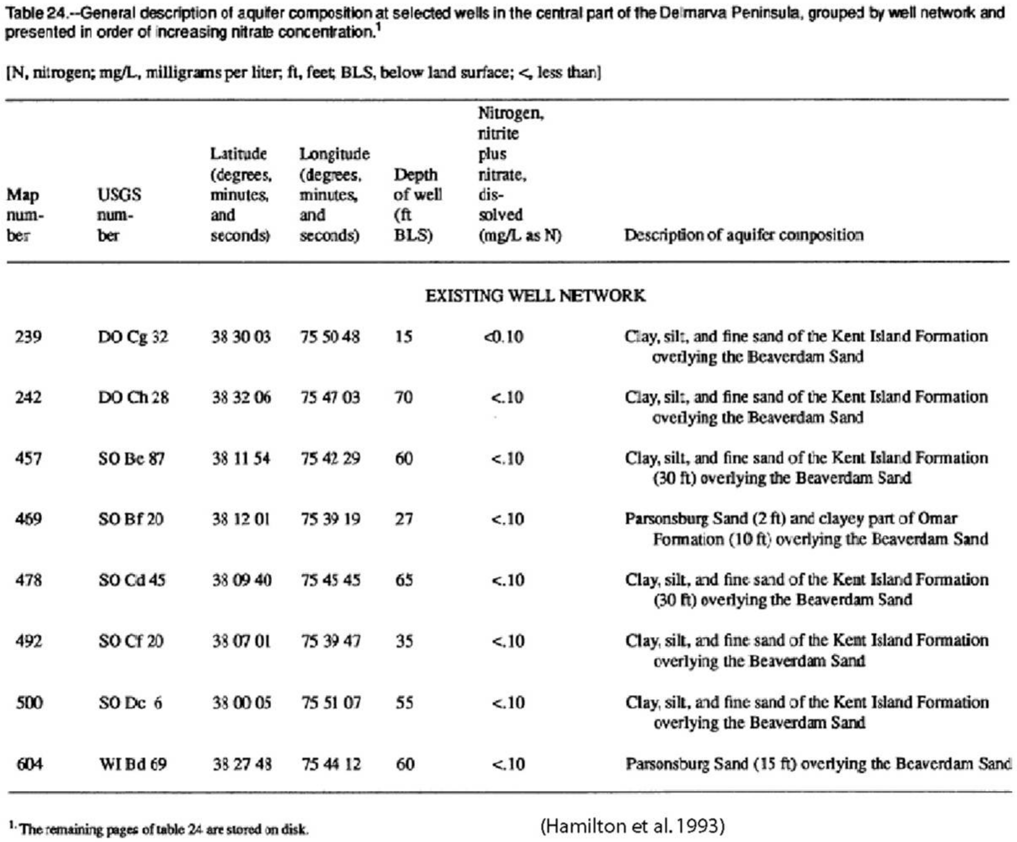


Table 24.--General description of aquifer composition at selected wells in the central part of the Delmarva Peninsula, grouped by well network and presented in order of increasing nitrate concentration.[1]

[N, nitrogen; mg/L, milligrams per liter; ft, feet; BLS, below land surface; <, less than]

| Map number | USGS number | Latitude (degrees, minutes, and seconds) | Longitude (degrees, minutes, and seconds) | Depth of well (ft BLS) | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | Description of aquifer composition |
|---|---|---|---|---|---|---|
| | | | EXISTING WELL NETWORK | | | |
| 239 | DO Cg 32 | 38 30 03 | 75 50 48 | 15 | <0.10 | Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand |
| 242 | DO Ch 28 | 38 32 06 | 75 47 03 | 70 | <.10 | Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand |
| 457 | SO Bc 87 | 38 11 54 | 75 42 29 | 60 | <.10 | Clay, silt, and fine sand of the Kent Island Formation (30 ft) overlying the Beaverdam Sand |
| 469 | SO Bf 20 | 38 12 01 | 75 39 19 | 27 | <.10 | Parsonsburg Sand (2 ft) and clayey part of Omar Formation (10 ft) overlying the Beaverdam Sand |
| 478 | SO Cd 45 | 38 09 40 | 75 45 45 | 65 | <.10 | Clay, silt, and fine sand of the Kent Island Formation (30 ft) overlying the Beaverdam Sand |
| 492 | SO Cf 20 | 38 07 01 | 75 39 47 | 35 | <.10 | Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand |
| 500 | SO Dc 6 | 38 00 05 | 75 51 07 | 55 | <.10 | Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam Sand |
| 604 | WI Bd 69 | 38 27 48 | 75 44 12 | 60 | <.10 | Parsonsburg Sand (15 ft) overlying the Beaverdam Sand |

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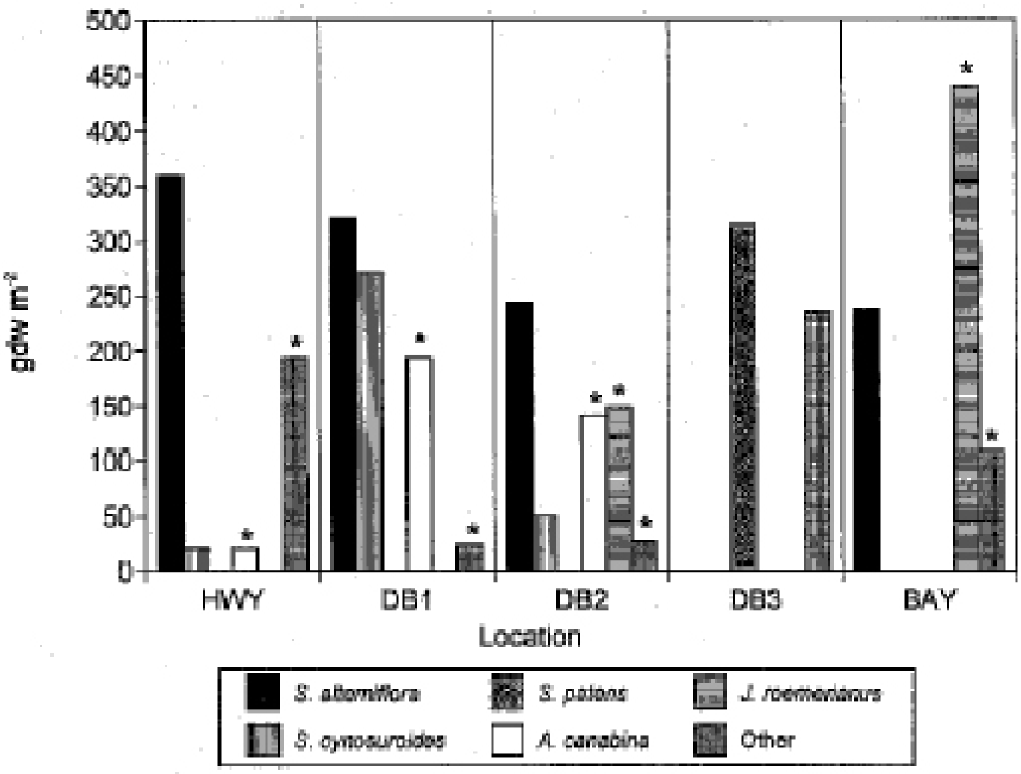
[1] The remaining pages of table 24 are stored on disk.

(Hamilton et al. 1993)

Table 2. Groundwater concentrations of nitrate and aquifer composition at sampling sites across Delmarva Peninsula. Note that well number 457 is in the Monie Creek watershed.

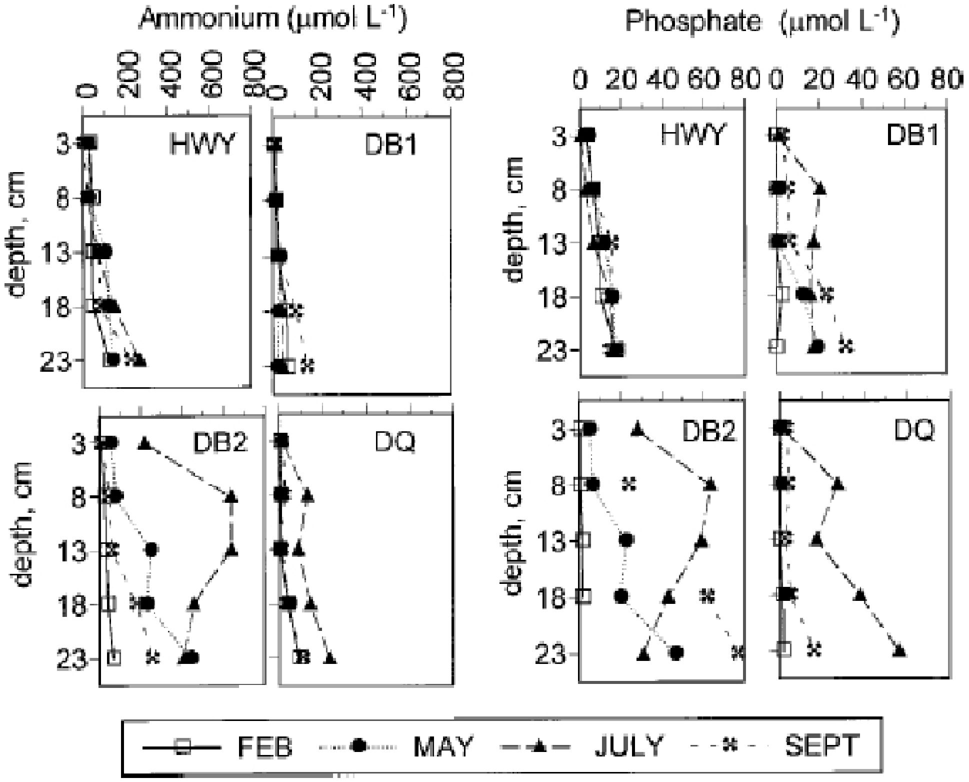
Figure 3a: Oblique aerial view of lower Monie Creek showing tidal creek surrounded by marshes at the lower end and by forests and farms further upstream.

Figure 3b: Oblique aerial view of upper Monie Creek showing forest and farms.



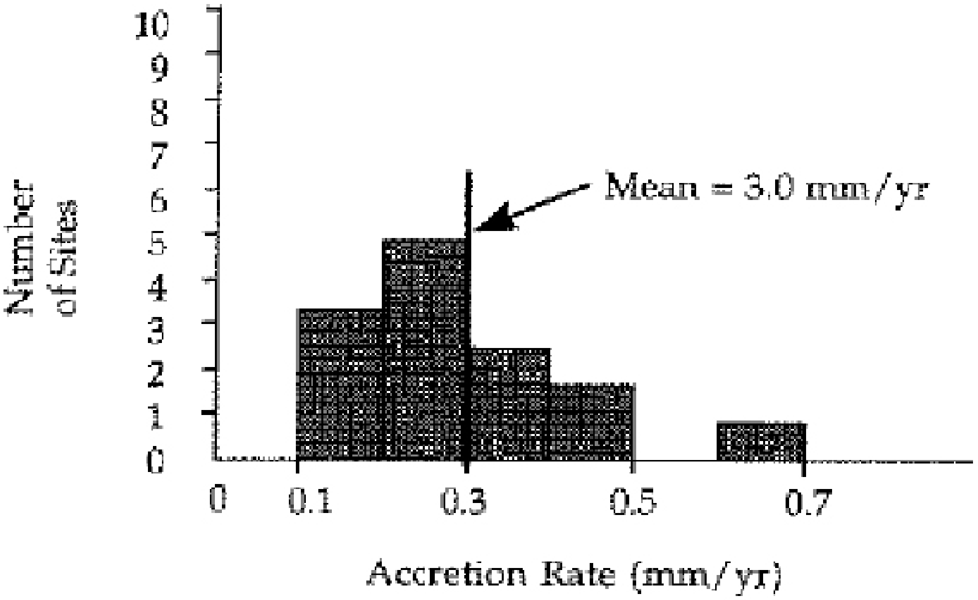
Plant species composition and peak standing crop for the marsh study sites. Bars representing C3 species are marked *. !

Figure 4. Biomass of major plant species in tidal marshes at five tidal creek stations. Stations are located along the length of Monie Creek from the head of tide (HWY) to the middle area (DB1-3) to the mouth connecting it to Monie Bay (BAY); stations DB1-3 are on a transect from tidal creek to upland (Stribling & Cornwell 1997).



Depth profiles of porewater ammonium and phosphate for months encompassing the growing season.

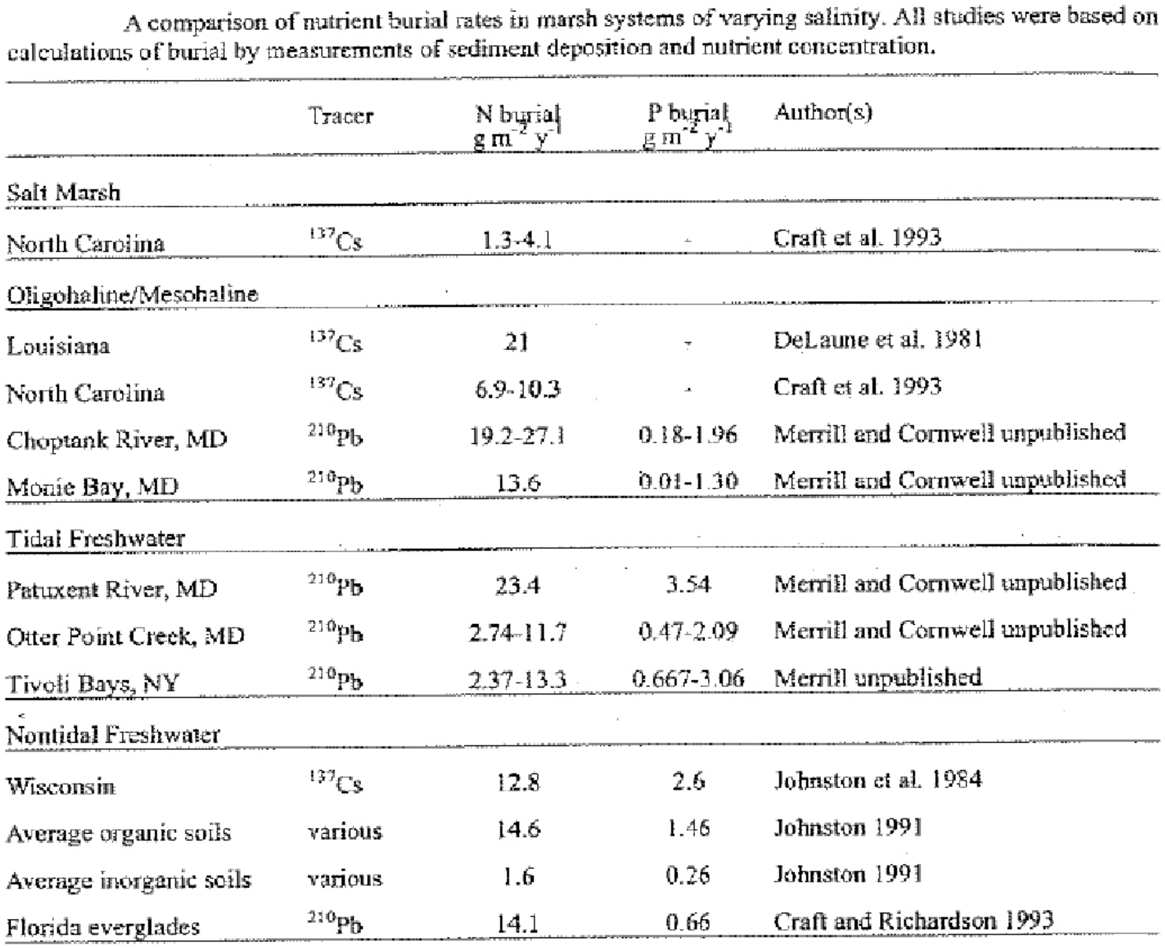
Figure 5. Vertical profiles of porewater ammonium and phosphate in tidal marsh sediments during growing season. Stations are as noted in Fig. 4 except DQ is from Dames Quarters marsh at the SW edge of Monie Bay (Stribling and Cornwell 2001).



Histogram showing the range of long-term accretion rates determined for all sites sampled in Monie Bay.

(Kearney et al. 1994)

Figure 6. Frequency distribution of sediment accretion rates measured in Monie Bay NERR site tidal marshes (Kearney et al. 1994).



A comparison of nutrient burial rates in marsh systems of varying salinity. All studies were based on calculations of burial by measurements of sediment deposition and nutrient concentration.

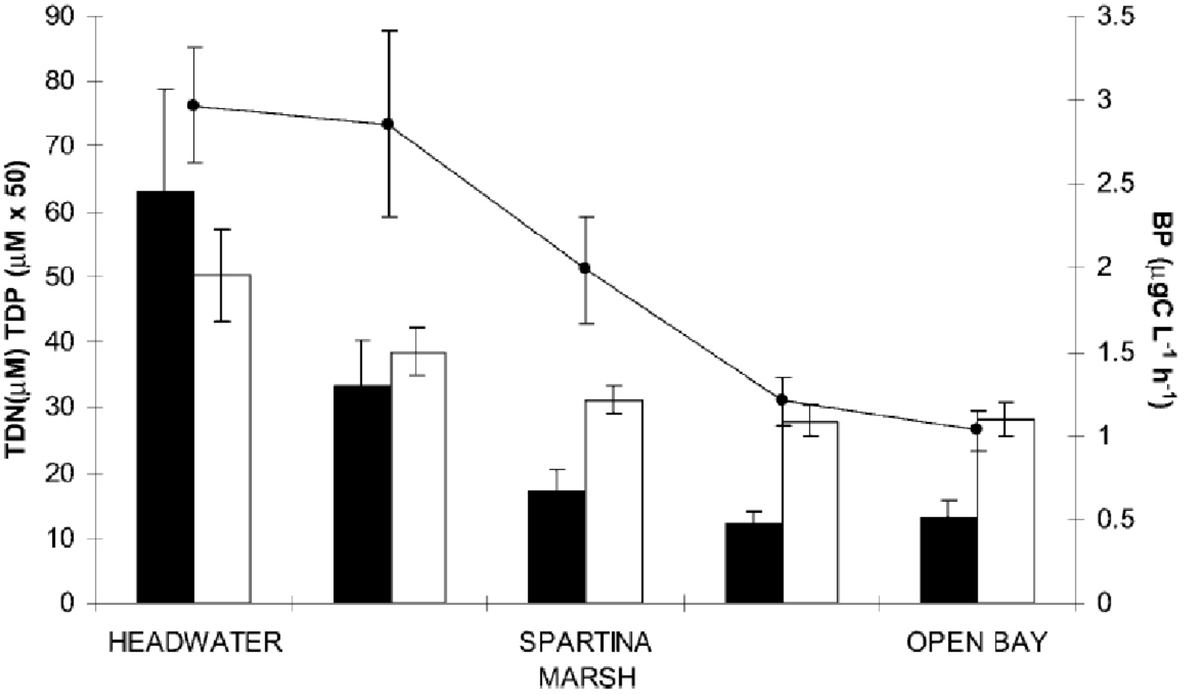
| | Tracer | N burial g m$^{-2}$ y$^{-1}$ | P burial g m$^{-2}$ y$^{-1}$ | Author(s) |
|---|---|---|---|---|
| Salt Marsh | | | | |
| North Carolina | $^{137}$Cs | 1.3-4.1 | - | Craft et al. 1993 |
| Oligohaline/Mesohaline | | | | |
| Louisiana | $^{137}$Cs | 21 | - | DeLaune et al. 1981 |
| North Carolina | $^{137}$Cs | 6.9-10.3 | - | Craft et al. 1993 |
| Choptank River, MD | $^{210}$Pb | 19.2-27.1 | 0.18-1.96 | Merrill and Cornwell unpublished |
| Monie Bay, MD | $^{210}$Pb | 13.6 | 0.01-1.30 | Merrill and Cornwell unpublished |
| Tidal Freshwater | | | | |
| Patuxent River, MD | $^{210}$Pb | 23.4 | 3.54 | Merrill and Cornwell unpublished |
| Otter Point Creek, MD | $^{210}$Pb | 2.74-11.7 | 0.47-2.09 | Merrill and Cornwell unpublished |
| Tivoli Bays, NY | $^{210}$Pb | 2.37-13.3 | 0.667-3.06 | Merrill unpublished |
| Nontidal Freshwater | | | | |
| Wisconsin | $^{137}$Cs | 12.8 | 2.6 | Johnston et al. 1984 |
| Average organic soils | various | 14.6 | 1.46 | Johnston 1991 |
| Average inorganic soils | various | 1.6 | 0.26 | Johnston 1991 |
| Florida everglades | $^{210}$Pb | 14.1 | 0.66 | Craft and Richardson 1993 |

(Merril & Cornwell 2000)

Table 3. Estimates of burial rates for total nitrogen and phosphorus in tidal marshes of Monie Bay NERR and other tidal and non-tidal sites nation-wide (Merril & Cornwell 2000).

Figure 7a: Monie Creek as seen from bridge.

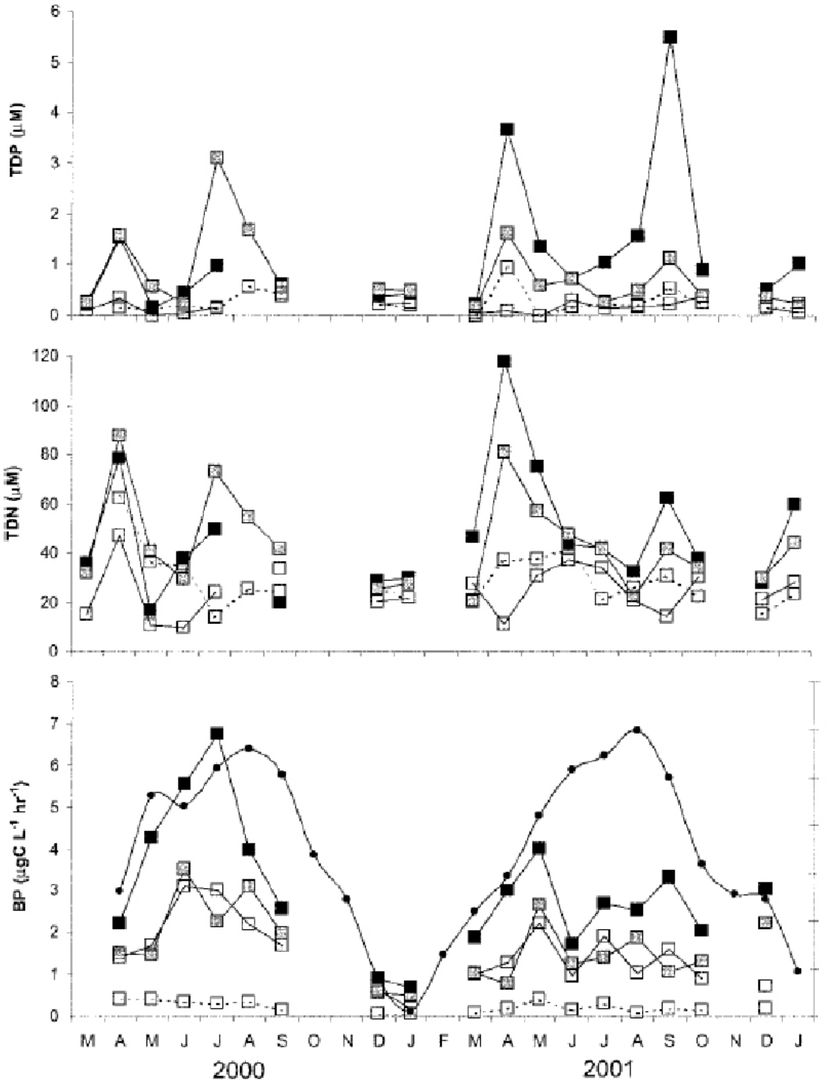
Figure 7b: Monie Creek tributary showing narrow swath of marshes bordering tidal creek surrounded by forested lands.



Transect of ambient nutrient concentrations (total dissolved phosphorus [TDP] and total dissolved nitrogen [TDN]) and total bacterial production (BP) along the axis of agriculturally impacted Little Monie Creek (LMC) and open bay (OB; each point represents 2-year mean ± SE, $n$=21).

(Apple et al. 2004)

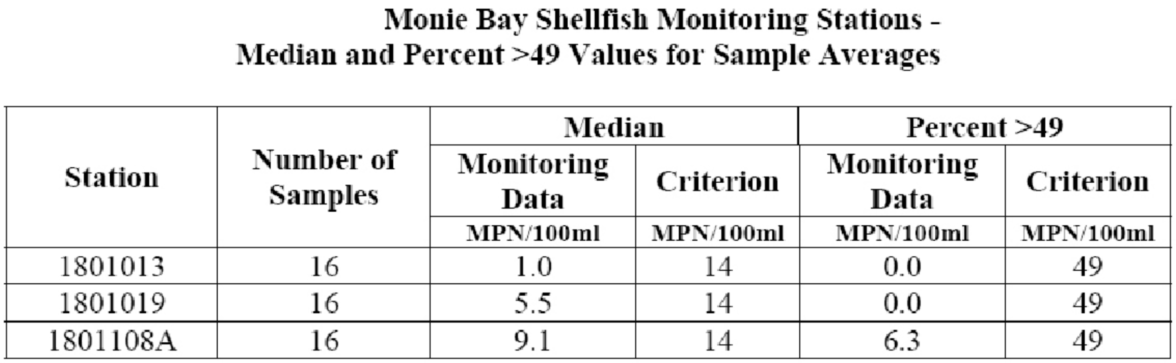
Figure 8. Axial distributions for annual mean concentrations of total dissolved nitrogen and phosphorus (TDN, TDP, white and black bars) and bacterioplankton production (BP, points) in Little Monie Creek (Apple et al. 2004).



Two-year seasonal variability in total dissolved phosphorus (TDP), total dissolved nitrogen (TDN), total bacterial production (BP), and temperature (TEMP) among the sub-systems of Monie Bay.

(Apple et al. 2004)

Figure 9. Mean seasonal variations in TDP (upper), TDN (middle) and BP plus temperature (lower) in Monie Creek (grey square), Little Monie Creek (black square), Little Creek (white square, solid line) and open Bay (white square, dotted line). See Fig. 8 legend for meaning of abbreviations (Apple et al. 2004).

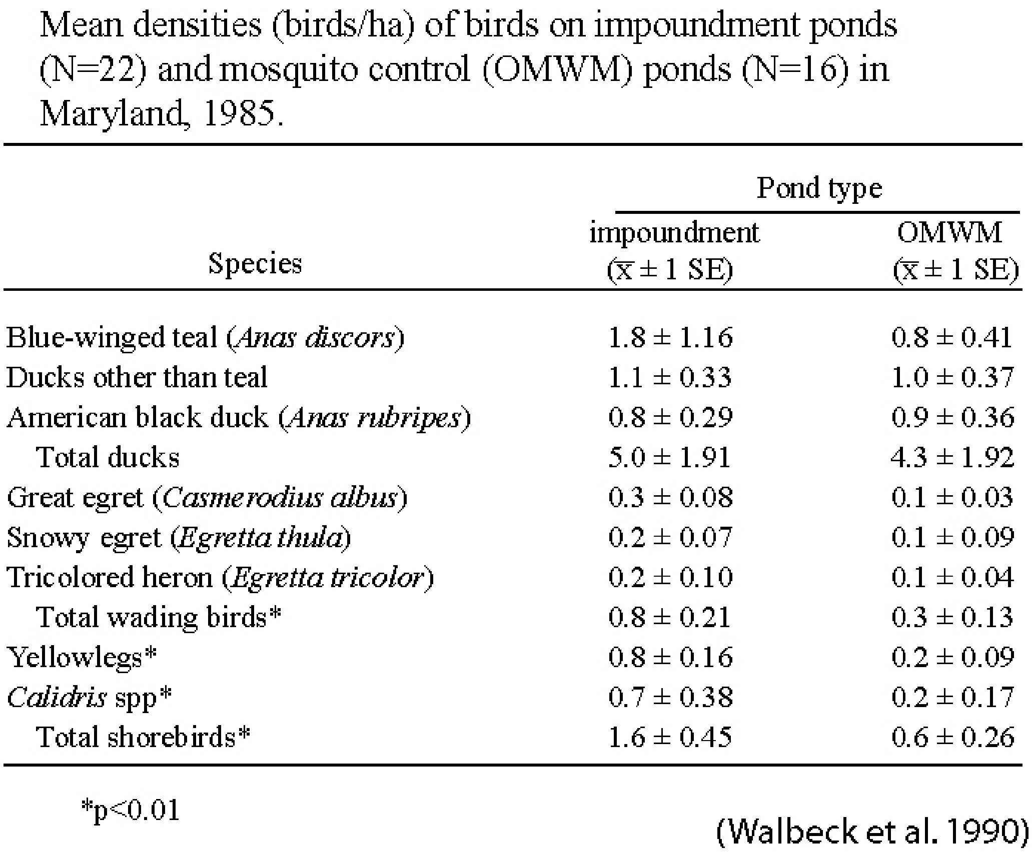


**Monie Bay Shellfish Monitoring Stations -**
**Median and Percent >49 Values for Sample Averages**

| Station | Number of Samples | Median | | Percent >49 | |
|---|---|---|---|---|---|
| | | Monitoring Data | Criterion | Monitoring Data | Criterion |
| | | MPN/100ml | MPN/100ml | MPN/100ml | MPN/100ml |
| 1801013 | 16 | 1.0 | 14 | 0.0 | 49 |
| 1801019 | 16 | 5.5 | 14 | 0.0 | 49 |
| 1801108A | 16 | 9.1 | 14 | 6.3 | 49 |

(MDE 2005)

Table 4. Bacterial pollution (*E. coli* relative abundance) at shellfish monitoring stations in Monie Bay NERR site (MDE 2005).



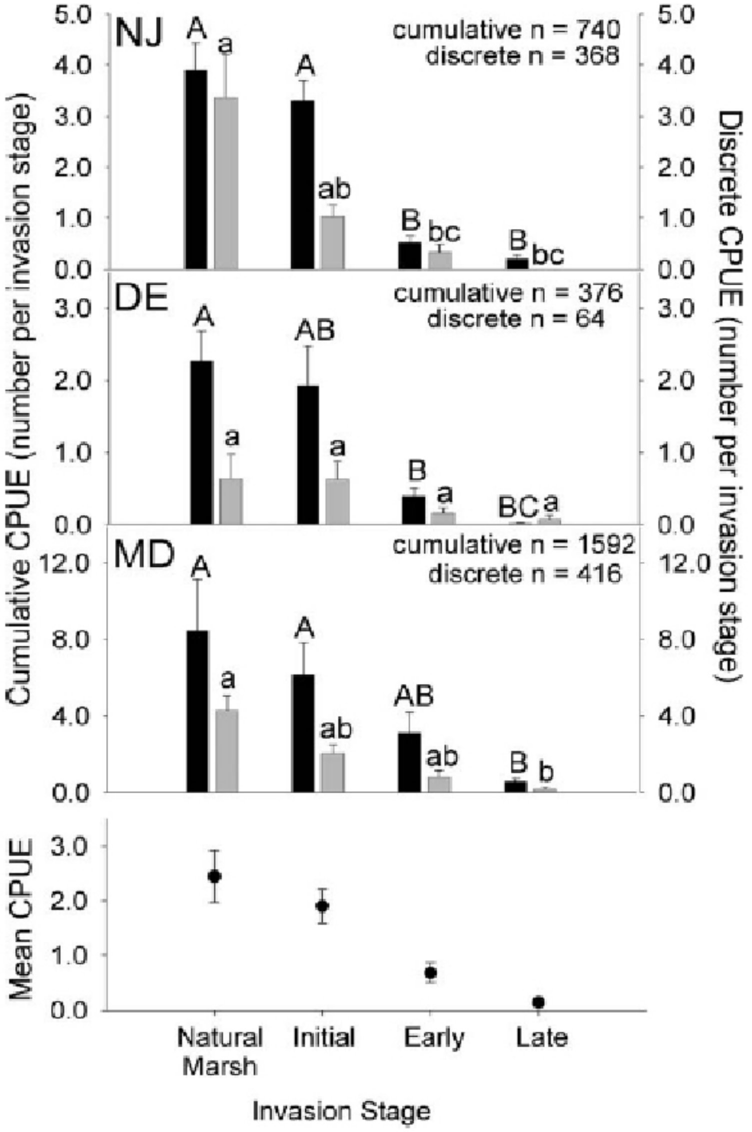
Mean densities (birds/ha) of birds on impoundment ponds (N=22) and mosquito control (OMWM) ponds (N=16) in Maryland, 1985.

| Species | Pond type | |
|---|---|---|
| | impoundment ($\bar{x} \pm 1$ SE) | OMWM ($\bar{x} \pm 1$ SE) |
| Blue-winged teal (*Anas discors*) | 1.8 ± 1.16 | 0.8 ± 0.41 |
| Ducks other than teal | 1.1 ± 0.33 | 1.0 ± 0.37 |
| American black duck (*Anas rubripes*) | 0.8 ± 0.29 | 0.9 ± 0.36 |
| Total ducks | 5.0 ± 1.91 | 4.3 ± 1.92 |
| Great egret (*Casmerodius albus*) | 0.3 ± 0.08 | 0.1 ± 0.03 |
| Snowy egret (*Egretta thula*) | 0.2 ± 0.07 | 0.1 ± 0.09 |
| Tricolored heron (*Egretta tricolor*) | 0.2 ± 0.10 | 0.1 ± 0.04 |
| Total wading birds* | 0.8 ± 0.21 | 0.3 ± 0.13 |
| Yellowlegs* | 0.8 ± 0.16 | 0.2 ± 0.09 |
| *Calidris* spp* | 0.7 ± 0.38 | 0.2 ± 0.17 |
| Total shorebirds* | 1.6 ± 0.45 | 0.6 ± 0.26 |

*p<0.01

(Walbeck et al. 1990)

Table 5. Mean densities of water birds on impoundment and mosquito control ponds at Deal Island Wildlife Management Area near Monie Bay NERR (Walbeck et al. 1990).



Mean catch per unit effort (CPUE, number per invasion stage ±1 standard error) of *Fundulus heteroclitus* by invasion stage for (NJ), (DE), and (MD) all study locations during 2004. Abundance for cumulative samples (collection after a 2–4 wk soak period) is shown with black bars; abundance for discrete samples (collection after 1 daytime high tide) is shown with white bars. Significant differences in average catch per unit effort among invasion stages are shown for cumulative samples (upper case letters) and discrete samples (lower case letters). Columns with the same letters are not significantly different.

(Hunter et al. 2006)

Figure 10. Comparative study of relative abundances of killifish (*Fundulus heteroclites*) in tidal creeks adjacent to tidal marshes with 4 levels of invasion by the non-native species, (*Phragmites australis*) at Monie Bay NERR (MD) and two other sites.