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An Integrated Approach to Understand Relationships Between Shallow Water Benthic Community Structure and Ecosystem Function SERDP Project SI-1335

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FINAL REPORT

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Strategic Environmental Research and Development Program

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFDM	ash free dry mass
AN	Anacostia
ANOVA	Analysis of Variance
AP or APG	Aberdeen Proving Ground
API	abundance of pollution indicative species
APS	abundance of pollution sensitive species
BB5	percent biomass below than 5 cm
B-IBI	Benthic Index of Biotic Integrity
BPI	Biomass of pollution indicative species
BPS	Biomass of pollution sensitive species
C:N	carbon to nitrogen ratio
CB	Chesapeake Bay
CBNERR	Chesapeake Bay National Estuarine Research Reserve
CBP	Chesapeake Bay Program
CC	Canal Creek
CCA	chromium copper arsenate
CH	Chisman Creek
Chl a or chla	Chlorophyll a
cm	centimeter
DDF	percent abundance of deep deposit feeders
DIC	dissolved inorganic carbon
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DM	dry mass
DNR	denitrification
DNRA	dissimilatory nitrate reduction to ammonium
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	Department of Defense
DON	dissolved organic nitrogen
DQ	Dames Quarter Creek
EMAP	Environmental Monitoring and Assessment Program
ER	Elizabeth River
ER-M	effects-range median
FE	Fort Eustis
g	grams
GPP	gross primary production

H'	Shannon-Wiener species diversity index
HM	high mesohaline
i.d.	inner diameter
IEI	Index of Environmental Integrity
J'	species evenness
KCl	potassium chloride
Kd	light attenuation coefficient
L	liter
LA or LAFB	Langley Air Force Base
LM	low mesohaline
LSM	Least Squares Mean
m	meter
MAIA	Middle Atlantic Integrated Assessment Program
MB	Monie Bay
MCCDC	Marine Corps Combat Development Command
MCLs	maximum contaminant levels
MDE	Maryland Department of the Environment
MDNERR	Maryland National Estuarine Research Reserve
MDS	multiple dimensional scaling
mg/L	milligrams per liter
mL	milliliter
MLOE	Multiple Lines of Evidence
MLW	mean low water
mmol	millimole
NASA LaRC	National Aeronautics and Space Administration Langley Research Center
NAVFAC	Naval Facilities Engineering Command Headquarters
NEM	net ecosystem metabolism
nf	near-field stratum
ng/L	nanograms per liter
NH_4^+	ammonium
NOx	nitrate+nitrite
NPL	National Priorities List
OH	oligohaline
P/R	gross primary production to respiration ratio
PAHs	polyaromatic hydrocarbons
PAX	Patuxent Naval Air Station
PC	principal component
PCA	Principal Components Analysis
PCBs	polychlorinated biphenyls
PCO	percent abundance of carnivores and omnivores

PCP	pentachlorophenol
PG	Pagan River
PO	polyhaline
POC	particulate organic carbon
ppm	parts per million
ppt	parts per thousand
PX	Patuxent Naval Air Station
QT	Quantico
R	respiration
ROC	Region of Concern
RQ	respiratory quotient
S	species richness
SA	Sarah Creek
SAV	submerged aquatic vegetation
SERDP	Strategic Environmental Research and Development Program
SH	Sweet Hall Marsh
SQO	Sediment Quality Objective
ST	Thorntons Creek
TCE	trichloroethylene
TDN	total dissolved nitrogen
TeCA	tetrachloroethane
TF	tidal freshwater
TN	total particular nitrogen
TOC	total organic carbon
TSS	total suspended solids
U.S. EPA or USEPA	U.S. Environmental Protection Agency
ug/L or µg/L	micrograms per liter
uM or µM	micromolar
µm	micrometer
umol or µmol	micromole
VADEQ	Virginia Department of Environmental Quality
VOCs	volatile organic compounds
VP-BI	Virginian Province Benthic Index
VSS	volatile suspended solids
WC	water column

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The authors thank the Strategic Environmental Research and Development Program (SERDP) for the financial assistance that enabled us to undertake this project. Appreciation for technical assistance is extended to Mr. Bradley Smith and Dr. Jeffrey Marqusee, SERDP Executive Directors, former and present, and Drs. Robert Holst and John Hall, Sustainable Infrastructure Program Managers, former and present, and to the HydroGeoLogic, Inc., staff for their administrative assistance. This research was conducted by the Schaffner and Anderson labs: Dr. Hyun Sig Lim, David Gillett, Bill Metcalfe, Leandra Lockwood, Alice Brylawski, Treda Smith, Shanay Butler, Jennifer Stanhope, Betty Neikirk, Hunter Walker, Frank Parker, Amber Hardison, Jessica Burshell, Floret Parker, and Bryan May. The research would also not be possible without the assistance of the NAVFAC and military base personnel by granting us access to the bases, helping us to identify study sites, and providing site information, including: Kim Parker Brown, Andrew Gutberlet (NAVFAC), Dr. Terry Bashore, David Wiker (Langley Air Force Base); Kyle Rambo, Kevin Weinelt (Patuxent Naval Air Station); James Dolan, Terry Sanders, Tim Christensen (Fort Eustis); Chuck Grimm, Ruth Zolock, Kristine Stein (Quantico); Dr. Jim Bailey, Steve Wampler, Todd Beser (Aberdeen Proving Ground). We are especially grateful to Dr. Terry Bashore, the project COR, who provided liaison between the Schaffner/Anderson labs and military personnel, as well as significant assistance and guidance in this project. We also would like to thank the Chesapeake Bay National Estuarine Research Reserve and Maryland National Estuarine Research Reserve for granting us access to Sweet Hall Marsh and Monie Bay, respectively.

EXECUTIVE SUMMARY

Human activities along our nation's coasts often lead to habitat modification, pollution, and overexploitation of living resources in coastal and estuarine waters (U.S. Commission on Ocean Policy 2004). Coastal areas are the most developed regions of the United States. In addition to recreational and leisure activities, these areas support commercial fishing, aquaculture, shipping, and defense activities. Numerous human activities can have detrimental effects on biodiversity and the provision of ecosystem services that support and sustain human populations. Given their proximity to the land and human population centers, nearshore estuarine ecosystems are especially vulnerable. Effective management can be improved with a better understanding of relationships between ecological integrity and human pressures in these ecosystems (National Estuary Program 2007).

Ecologists, coastal managers, and policy-makers are working together to develop better ways to measure and manage human effects on estuarine and coastal ecosystems. Management strategies can be framed in the context of human actions (*pressure* or *stressor*), resulting effects on community structure and ecosystem functions (*state or condition*), and management *response* (Figure 1, Fairweather 1999, Begon et al. 2006, Whitall et al. 2007).

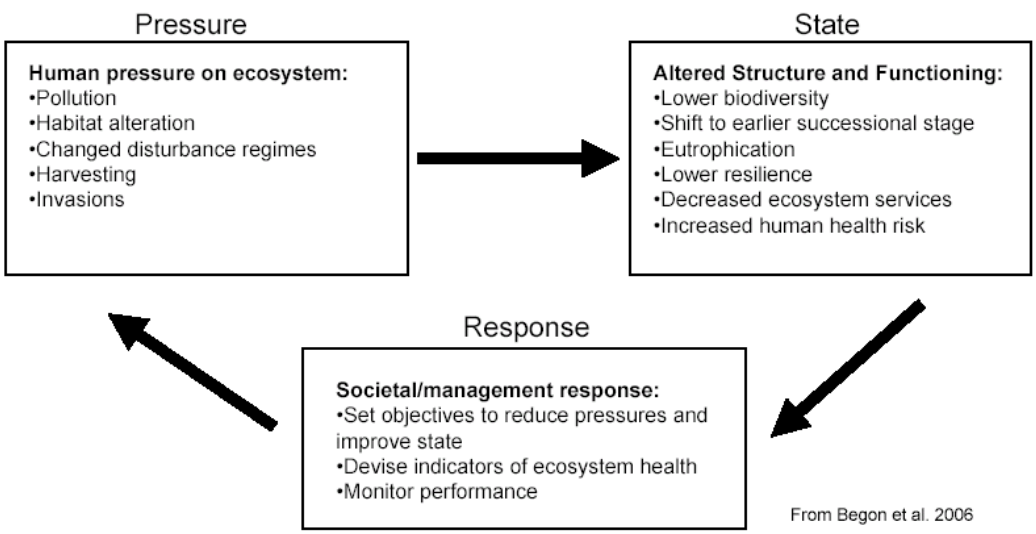


Figure 1. Relationship between human pressure, ecosystem state, and management responses.

Defense activities along estuarine shorelines present both unique and common stressors that impact ecosystem sustainability. Department of Defense (DoD) installations along estuarine shorelines affect and are influenced by regional activities in the watershed that influence the overall health or integrity of the ecosystem. Local activities also influence an installation's nearshore zone. As stated by SERDP in 2001, "Through implementation of the Clean Water Act, it is the responsibility of Federal land management agencies, to protect and restore the quality of public waters under their jurisdiction." DoD needs to "work with other stakeholders to improve the science and technology to control non-point source pollution and to improve estimates of the magnitude and sources of non-point source pollution." One way to do this is to increase the use of biological indicators and other metrics as a preferred method for determining the condition of aquatic ecosystems.

The approach of using environmental and biotic indicators to help set priorities for action and to determine when management strategies have been successful is growing. The National Coastal Assessment, for example, uses a suite of indicators including a water quality index (including dissolved oxygen, chlorophyll a, nitrogen, phosphorus, and water clarity), sediment quality index (including sediment toxicity, sediment contaminants, and sediment total organic carbon [TOC]), benthic index, coastal habitat index, and a fish tissue contaminants index (U.S. EPA 2005 National Coastal Condition Report, http://www.epa.gov/owow/oceans/nccr/2005). Similar indicators have been used for the National Estuary Program's Coastal Condition Assessment (National Estuary Program 2007). The State of California is developing methods that can be used to assess whether sediment quality at a specific location meets a defined goal or Sediment Quality Objective (SQO). Their approach, which is designed to detect risks associated with contaminated sediments, is based on the use of multiple lines of evidence (MLOE), with specific indicators, such as sediment contaminant concentrations, benthic community composition and bioassays forming the basis for the decision-making process.

Objectives of Study

For the study described in this report, our major objective is to couple detailed investigations of benthic community structure and metrics of habitat condition with studies of ecosystem function in order to better understand relationships among military activities, integrity of benthic communities, and the ability of shallow waters of the Chesapeake Bay estuarine system to provide important ecological services such as nutrient cycling and food web support.

Our specific objectives were to (1) use the Benthic Index of Biotic Integrity (B-IBI) to assess benthic community integrity in shallow water habitats at sites spanning a range of salinities and stressor types and including representative stressors of DoD installations of the Chesapeake Bay region; (2) determine how metrics of ecosystem function vary along gradients of impairment both within and across salinity regimes; and (3) elucidate relationships among B-IBI metrics (including biodiversity, abundance, biomass, pollution sensitivity, trophic complexity, and more), food web structure, metabolic processes (including primary production and respiration), and nitrogen cycling along gradients of impairment. These measurements represent key features or processes of benthic systems that are important to understanding stressor effects on food web structure, water and sediment quality. We focused on benthic processes because they are of high relevance and importance in nearshore habitats.

Overarching Hypotheses

The major hypothesis guiding our investigations is that the B-IBI approach, which uses metrics based on macrobenthic community structure, predicts significant changes in shallow water estuarine food web structure and ecosystem functional processes that are important for ecosystem sustainability. Subhypotheses are shown in Figure 2.

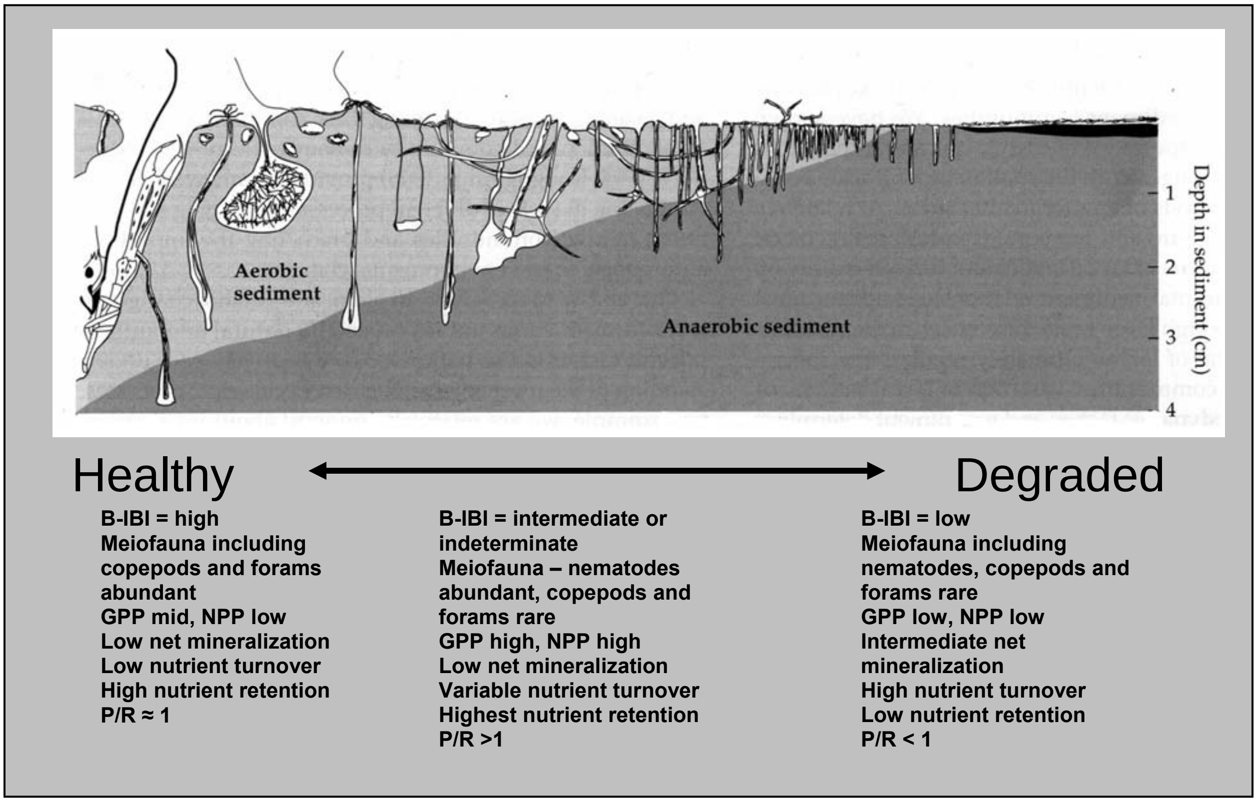


Figure 2. Expected relationships between the Benthic Index of Biotic Integrity (B-IBI) and other measures of community structure and function. Specific working hypotheses are based on previous work of Odum 1985, Green and Montagna 1996, Peterson et al. 1996, Weisberg et al. 1997, Carman et al. 2000, Emmerson et al. 2001, Alden et al. 2002, and Cairns 2003.

Sampling Sites and Methods

Investigations of benthic community structure (microbes, meio- and macro-invertebrates) and ecosystem function (primary and secondary production, respiration, nutrient cycling, food web structure) were conducted at eleven primary sites and two secondary sites in Chesapeake Bay during 2003-2005. Field data were collected at shallow water euphotic sites adjacent to selected military installations (“unclassified”, with respect to environmental condition), at paired non-DoD sites that had high environmental quality (“reference”), sites deemed to be highly influenced by anthropogenic activities (“degraded”), and two additional “unclassified”, but non-DOD sites that were sampled for macrofauna and meiofauna in 2003. End-member sites were selected to maximize stressor gradients associated with human activities. The end-member sites were selected such that DoD installations were expected to have intermediate overall environmental quality based on the available historic water quality and sediment data.

Primary sites sampled during 2003 were in lower Chesapeake Bay, including Langley Air Force Base (LAFB) on Back River, Thorntons Creek, a sub-tributary of Mobjack Bay, representing a reference site, and a highly degraded site in the southern branch of the Elizabeth River (ER). Secondary sites included Chisman Creek, which is located in a sub-tributary of the Poquoson River, north of the Back River, and Sarah Creek, a sub-tributary of the York River. Both were considered intermediate in condition to the reference and degraded sites. In 2004, study sites were located in the lower and mid-Chesapeake Bay, and included Fort Eustis on the James and Warwick Rivers, Patuxent Naval Air Station at the mouth of the Patuxent River, and their paired reference and degraded sites of Monie Bay and the Pagan River, respectively. In 2005, study sites were located in tidal freshwater and included Aberdeen Proving Ground at the head of Chesapeake Bay, Quantico Marine Corps Base on the Potomac River, and their paired reference and degraded sites of Sweet Hall Marsh in the Pamunkey River and the Anacostia River, respectively. Two of our degraded study sites (Elizabeth, Anacostia) were in tributaries given a "Region of Concern" designation for chemical contamination by the Chesapeake Bay Program (1999) and one site (Pagan) has an impaired waters 303(d) listing since 1996 (Chesapeake Bay Foundation 1996). The reference sites were located within National Estuarine Research Reserves (Monie Bay, Sweet Hall), or in an area otherwise deemed to have relatively low human impact (Thorntons Creek).

The sites we studied had demonstrable gradients in water and sediment quality from relatively pristine conditions found at National Estuarine Research Reserve sites to highly impacted urban estuaries at Norfolk, VA and Washington, DC. DoD installations generally had intermediate environmental conditions, in terms of the regional water and local sediment quality parameters measured, which did not include sediment contaminants. We did include measures of sediment toxicity in 2003. Only the ER near-field site had significant sediment toxicity.

Results and Recomendations

Stressor Gradients

Relative to identifying stressor gradients at regional and local scales, our major results and recommendations are:

- Regional water quality and local environmental setting interact to influence local sediment quality. Labile organic matter accumulated in muddy, depositional habitats, but not in sandy habitats, which were exposed to greater physical energy from waves and currents.
- While some effects of regional eutrophication (e.g. sediment organic enrichment) will be greater in protected muddy nearshore habitats relative to exposed, sandy nearshore habitats, other effects (e.g. shift to autotrophic system) may be greater in sandy habitats if light is more readily available. This differential response of benthic habitats to regional water quality impairments should be taken into account when designing monitoring and restoration programs.

Benthic Index of Biotic Integrity (B-IBI)

Results of benthic macrofauna studies generally supported the overarching hypotheses for this study:

- The Benthic Index of Biotic Integrity (B-IBI) was useful for detecting gradients of water and sediment quality impairment, within and across major habitat types and salinity regimes.
- The B-IBI and component metric results demonstrate that impairment gradients are stronger in near-field than far-field habitats, consistent with water and sediment quality metrics such as organic enrichment and sediment toxicity (2003 only). Sediment associated stressors acted to degrade benthic communities locally.
- The B-IBI is useful for detecting effects of multiple stressors acting together on benthos. However, results presented for the Elizabeth River near-field study site demonstrate that the B-IBI is influenced by stressor interactions (e.g. sediment contaminants and eutrophication).
- For areas where both contaminants and eutrophication are likely to determine environmental conditions, we recommend that a Multiple Lines of Evidence (MLOE) approach be used to assess environmental quality. See for example: http://www.swrcb.ca.gov/bptcp/sediment.html

Meiofauna as Indicators of Environmental Quality

Results of the benthic meiofauna studies did not follow the originally proposed hypotheses.

- Meiofauna identified to major taxa were of limited use in understanding the environmental conditions of the shallow water high mesohaline to tidal freshwater habitats we studied. The estuary may represent an ecotone that separates meiofauna populations of marine and freshwater systems, leaving a depauperate community at intermediate salinities.
- Increased taxonomic detail in the study of meiofauna, which was beyond the scope of this project, would likely strengthen the relationship between meiofauna community structure and habitat quality by illustrating species-specific sensitivities that are undetectable at higher taxonomic levels, much like macrofaunal communities.

Benthic Secondary Production as an Indicator of Environmental Quality

Secondary production of macrofauna was useful for linking environmental quality and benthic community structure to the provision of ecosystem services.

- Secondary production of macrofauna decreased with decreasing habitat quality in habitats where organic matter or contaminants accumulated in the sediment (i.e., near-field sites). Secondary production was decoupled from local habitat quality in those environments where organic matter and contaminants did not accumulate (i.e., far-field sites).
- Our results failed to show a strong linkage between secondary production of tidal freshwater macrofauna and habitat quality, regardless of major habitat type. Stressors that were not captured in our data may more important to controlling production in tidal freshwater (e.g., presence of invasive SAV, episodic salinity intrusion, or sedimentation).

- Estimates of secondary production can be made relatively easily once benthic community data have been assembled, are valuable for assessing food web support of higher trophic levels, and can be used to demonstrate the value of nearshore regions as essential fish habitat.

Responses of Ecosystem Process Rates to Estuarine Gradients and Impairments

Results of ecosystem process studies generally supported the hypotheses for this study.

- Across the entire estuarine gradient of the Chesapeake Bay, nitrogen loading and light availability played an essential role in determining benthic ecosystem function.
- The primary responses that differentiated sites along the estuarine gradient were associated with sediment autotrophy (GPP, P/R, sediment chlorophyll a).
- All ecosystem process rates measured, except for mineralization, responded to site impairment (status, condition).
- However, the local response of a process rate to a stressor such as nutrient enrichment varied depending upon regional light availability, sediment type (stratum), and salinity.
- Benthic microalgal – mediated nutrient uptake may buffer the effect of nutrient enrichment provided that sufficient light is available.
- Across the estuarine gradient from high mesohaline to tidal fresh waters in the Chesapeake Bay, there was a shift:
    - From net benthic autotrophy to net heterotrophy, and
    - From primary production in the benthos to the pelagic zone.

Relationships Between Benthic Integrity and Ecosystem Function

The estuarine nearshore region supports highly productive benthic communities. As a result, function in these areas is strongly influenced by benthic processes. An assessment of relationships between structure and function of shallow water habitats has been used to quantify the impacts of human activities on biodiversity, benthic condition, important functional processes, and the provision of ecological services. This holistic approach shows that:

- Consistent with our initial hypotheses, benthic community condition was optimal in habitats with balanced or autotrophic conditions as reflected in GPP, NEM, respiration, and P/R, as long as the sediments were not toxic.
- Major habitat types, position along the estuarine gradient, and factors related to regional water quality were the most useful predictors of environmental quality, biodiversity, and ecosystem function at the sites we studied. Local stressors may, however, interact with and modulate the effects of regional water quality impairments.
- Benthic microalgae, which due to light availability are most abundant in shallow, nearshore waters, may serve to buffer the benthic community from the full effects of local sediment impairment associated with toxic sediments. This finding has implications for restoration activities:
    - First, reductions in nutrient loadings or increases of turbidity that result in lower benthic primary production could lead to a collapse of shallow water food webs in areas with toxic sediments, much as is seen in deeper waters where light is not available.

- Conversely, cleaning up toxic sediments without controls on regional water quality will likely make effects of sediment impairments due to eutrophication more prominent.

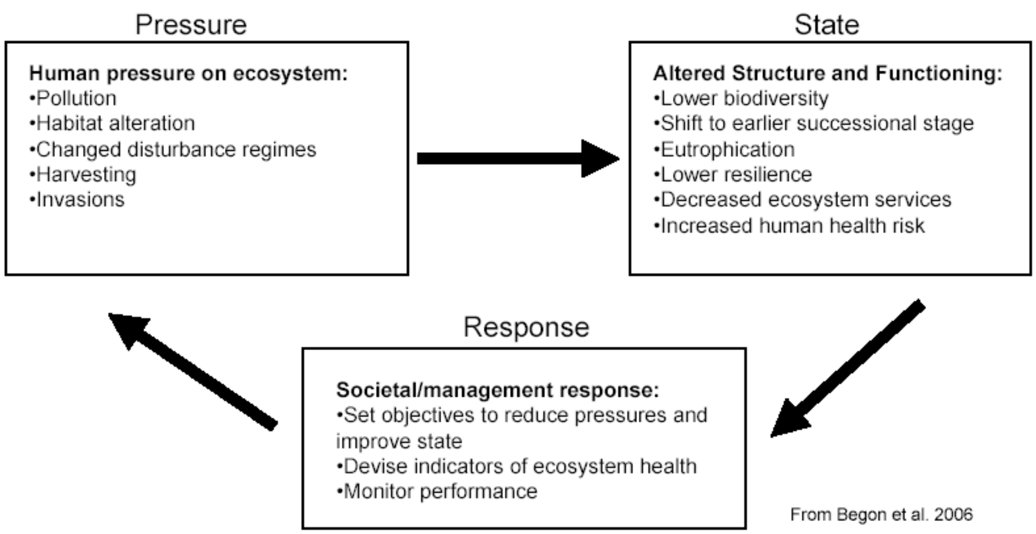
Ecosystem Responses to DOD Activities

Although DoD activities along the shorelines of the Chesapeake Bay create some unique stressors for nearshore habitats, the DoD sites we studied generally had intermediate environmental conditions relative to the range observed within representative Chesapeake Bay shallow water habitats. The major patterns we observed in community structure, benthic condition, and ecosystem processes were concordant with a priori classifications of sites based on position along the estuarine gradient, historic regional water quality and land use, and major habitat types.

1. CONTEXT

Human activities along our nation's coasts often lead to habitat modification, pollution, and overexploitation of living resources in coastal and estuarine waters (U.S. Commission on Ocean Policy 2004). Coastal areas are the most developed regions of the United States. In addition to recreational and leisure activities, these areas support commercial fishing, aquaculture, shipping, and defense activities. Numerous human activities can have detrimental effects on biodiversity and the provision of ecosystem services that support and sustain human populations. Given their proximity to the land and human population centers, nearshore estuarine ecosystems are especially vulnerable. Effective management can be improved with a better understanding of relationships between ecological integrity and human pressures in these ecosystems (National Estuary Program 2007).

Ecologists, coastal managers, and policy-makers are working together to develop better ways to measure and manage human effects on estuarine and coastal ecosystems. Management strategies can be framed in the context of human actions (*pressure* or *stressor*), resulting effects on community structure and ecosystem functions (*state or condition*), and management *response* (Figure 1, Fairweather 1999, Begon et al. 2006, Whitall et al. 2007).



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2. OBJECTIVES

The major objective of this project is to couple detailed investigations of benthic community structure and metrics of habitat condition with studies of ecosystem function in order to better understand relationships among military activities, integrity of benthic communities, and the ability of shallow waters of the Chesapeake Bay estuarine system to provide important ecological services such as nutrient cycling and food web support.

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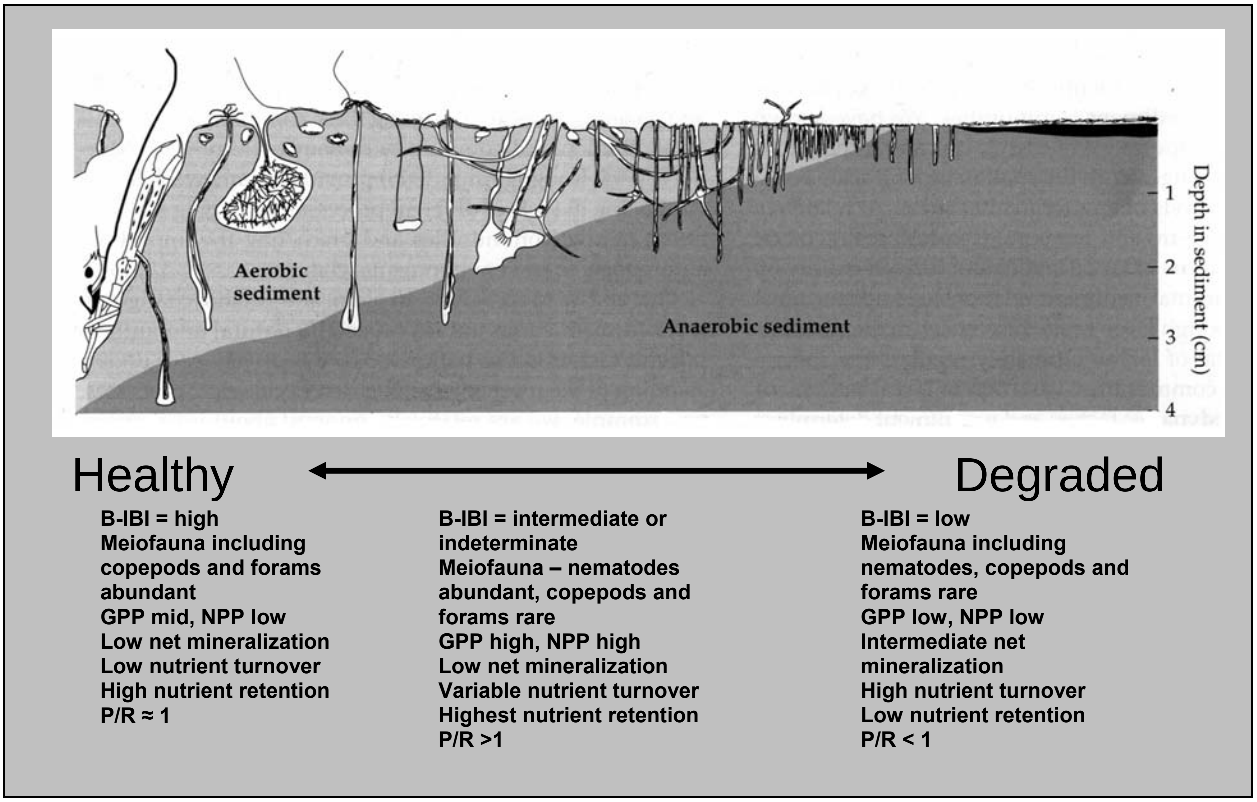
The major hypothesis guiding our investigations is that the B-IBI approach, which uses metrics based on macrobenthic community structure, predicts significant changes in shallow water estuarine food web structure and ecosystem functional processes that are important for ecosystem sustainability (Figure 2). Improved understanding of the relationships between structure and function in these shallow water areas will lead to better management of key resources and the preservation of critical ecological services, such as trophic support of fisheries and protection of water quality.



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3. BACKGROUND

3.1 The Benthic Index of Biotic Integrity

Benthic invertebrates are used as biotic indicators of estuarine and marine environmental status and trends globally. Benthic invertebrate-based indicators have been included in every major federally funded monitoring program since the early 1990s. In the Chesapeake Bay region, the Benthic Index of Biotic Integrity (B-IBI), which is based on benthic community structure, has been successfully used to identify regional and local water and sediment quality impairments (Ranasinghe et al. 1994, Dauer et al. 2000) and physical habitat disturbance (Schaffner et al. 1996). The B-IBI allows scientists and managers to compare the relative condition of benthic invertebrate assemblages across major habitat types and salinity regimes. It combines several benthic community measures into a single number that represents overall benthic community condition. Community measures that are components of the B-IBI include species abundance, biomass, the Shannon diversity index, the abundance and biomass of pollution-indicative species, and the abundance and biomass of pollution-sensitive species.

While the B-IBI approach is robust and sensitive (Alden et al. 2002, Ranasinghe et al. 2002), its relationship to important functional attributes of shallow water ecosystems, such as primary and secondary productivity, nutrient cycling, and food web structure, has not been investigated. Elucidating relationships between the B-IBI, which is based on the structure of benthic invertebrate communities, and ecosystem function will enhance our ability to manage and restore human-transformed ecosystems, especially in shallow water habitats where benthic processes regulate the provision of key ecological service functions such as nutrient cycling and food web linkages.

3.2 Benthic Meiofauna as Indicators of Environmental Condition and as Key Components of Estuarine Food Webs

Meiofauna, composed primarily of nematodes, harpacticoid copepods and foraminiferans, are important components of shallow water estuarine ecosystems. These taxa play important roles in estuarine food web dynamics because they provide a link between microalgae and detrital food sources and juvenile fish that utilize estuarine nursery habitats. Similar to the macrofauna, pollutant effects on meiofauna have been shown to depend on pollutant types, taxon, exposure levels and field conditions (Coull and Chandler 1992). Green and Montagna (1996) suggested the use of a ratio of nematodes (the more tolerant taxa): harpacticoid copepods (the more sensitive taxa) as a means of assessing contaminant impacts on meiofaunal community structure.

The important effects of contaminants on meiofaunal community structure and the implications for key benthic processes such as primary production and nutrient flux are demonstrated in the results of studies by Carman and colleagues (Carman et al. 1996, 1997, 2000). They have shown that contamination of salt marsh sediments by diesel fuel, a relatively toxic petroleum compound, resulted in high mortality of benthic harpacticoid copepods in experimental mesocosms. Associated with reduced abundances of copepods, reduced grazing on benthic microalgae resulted in algal blooms at the sediment-water interface. The resultant increase in algal biomass limited the efflux of ammonium from the sediments, despite enhanced rates of microbial remineralization of organic matter. The shift from grazing control to nutrient control in the system was accompanied by an increase in the ratio of chlorophyll *a* to phaeophytin, a degradation compound formed when microalgae are grazed.

3.3 A Synthetic Model of Benthic Community Response to Contamination

Although meiofauna and macrofauna may differ somewhat in their responses to impairment gradients, recent studies suggest that some generalities are emerging. Peterson et al. (1996) reviewed the literature on benthic community responses to pollution in marine environments. Their findings indicate that macroinfaunal and meiofaunal communities exhibit repeatable patterns of response to sedimentary contamination generally detectable at high taxonomic levels (even phyla). As they state, "These responses appear to be jointly driven by intrinsic physiological and ecological characteristics of higher taxa, such that crustaceans (especially amphipods and harpacticoid copepods) and echinoderms are sensitive to toxics whereas polychaetes, oligochaetes, and nematodes (especially non-selective deposit-feeders) are enhanced by organic enrichment." This suggests a means of isolating different causal mechanisms in studies of pollution involving both toxicant and nutrient or organic loading effects.

3.4 Microbial Processes

Numerous studies, as in Hansen and Kristensen (1997), Carman et al. (2000), and Middelburg et al. (2000), have shown strong interactions among macrofauna, meiofauna, benthic microbial metabolism, and nutrient cycling and transport. Moreover, benthic microbial processes are more easily measured than macro- or meiofaunal abundance, particularly in shallow water environments, and are highly relevant to overall ecosystem function. The benthic microbial community, including both autotrophic and heterotrophic components, of estuaries plays a critical role in ecosystem function by regulating organic matter production, diagenesis, and nutrient transformations within sediments and exchanges of oxygen and nutrients with the overlying water column. Microbial-dominated benthic processes have significant implications for eutrophication, nutrient removal, hypoxia, and contaminant transport and degradation, as well as food web support of higher trophic levels (Capone 2001, Middelburg et al. 2000, Nixon et al. 1995, Reay et al. 1995, Sundback et al. 2000). For example, reports suggest that up to 50% of the dissolved inorganic nitrogen (DIN) load to an estuary may be removed by denitrification (Seitzinger 1987); however recent reports suggests that alternative bacterial nitrate removal processes may be more important than denitrification in estuaries (Burgin and Hamilton 2007), and in shallow euphotic systems, benthic microalgal-mediated uptake often exceeds denitrification (Sundback et al. 2006).

Depending upon sediment type, salinity, and water residence time, benthic heterotrophic and autotrophic microorganisms may: (1) convert nitrate to N_2 by denitrification (DNR), a process by which nitrogen is removed from the ecosystem; (2) convert nitrate to ammonium by dissimilatory nitrate reduction to ammonium (DNRA), a process which conserves nitrogen in the ecosystem; (3) remove organic nitrogen from sediments by the coupled processes of mineralization, nitrification, and denitrification; (4) regenerate inorganic nutrients from organic particulates; (5) regulate dissolved oxygen (DO) in surface sediments and bottom water; and (6) immobilize nutrients by production of benthic microalgal and bacterial biomass (Fenchel et al. 1998; Joye and Anderson 2008). These processes are susceptible to a wide variety of disturbances, including changes in salinity, light availability, DO, and inputs of nutrients and organic matter including toxicants and heavy metals (An and Joye 2001, Slater and Capone 1984, Sundback et al. 2000, Rysgaard et al. 1999, Carman et al. 2000, Cloern 2001). Multiple stressors may produce greater than additive effects (Breitburg et al. 1999).

Depending on the type of contaminant, microbial processes may be either enhanced or inhibited (Capone and Bauer 1992). For example, monoaromatic hydrocarbons can be degraded by aerobic respiration or by denitrification (Hutchins 1991). Autotrophic nitrifiers reportedly can potentially degrade a wide variety of anthropogenic pollutants, including trichloroethylene (TCE), chloroethane, benzene, halogenated aliphatics, and dimethylether (Kowalchuk and Stephen 2001). In the presence of toluene, rates of degradation of TCE are increased; however these two contaminants act synergistically to inhibit both ammonium and nitrite oxidation processes essential to support growth of nitrifiers (Fuller and Scow 1997). Thus, in the presence of TCE and toluene ammonium will accumulate in sediments, increasing the probability of fluxes to overlying water. Ammonium oxidizers also exhibit sensitivity to surfactants such as linear alkylbenzene sulfonates, which affect growth and metabolism, as well as ammonium oxidation (Brandt et al. 2001). Heavy metal mixtures, including cadmium, cobalt, cesium, and strontium, have been shown to affect the structure of autotrophic nitrifier communities and also cause accumulation of ammonium in soils (Stephen et al. 1999).

When sediment organic concentrations are high and when the water column is stratified, hypoxic or anoxic conditions will result due to the occurrence of microbial respiration. The low DO conditions may further reduce microbial remineralization of sediment organic matter, causing accumulation of sulfides, increased retention of nitrogen, and result in a negative feedback loop with decreased production by microalgae (Cloern 2001). Microbial metabolism and resulting DO concentrations will also control rates of detoxification of organics such as halogenated compounds. The activities of benthic macro- and meiofauna have been shown to strongly influence microbial processes such as respiration and nutrient cycling; for example by bioturbation (Hansen and Kristensen 1997), and by meiofaunal grazing of microalgal or bacterial biomass (Sundback et al. 1996). Carman at al. (2000) showed that algal blooms in salt marshes contaminated by diesel fuel resulted from reduced grazing by meiofaunal copepods and ultimately led to nitrogen limitation of microbial processes.

Two stressors that are predicted to increase in magnitude across the Chesapeake Bay estuarine gradient are nutrient loading, especially nitrogen, and decreased light availability, due to total suspended solids, including phytoplankton, sediment, and detrital particulates. Predicted responses to increased nitrogen loads to the water column include increased primary production (eutrophication) (Nixon et al. 1986, Boynton et al. 1996), increased nutrient and organic enrichment of sediment, increased benthic respiration resulting in sediment and bottom water hypoxia/anoxia, and a shift in dominance from benthic to pelagic autotrophs (Duarte, 1995, Joye and Anderson 2008, McGlathery et al. 2007, Valiela et al. 1997). Although these hypothesized responses to nutrient stress have been shown to develop in controlled mesocosm experiments, they have not been well supported in studies under in situ conditions, especially in shallow water systems (Nixon et al. 2001). In addition, it is not clear whether multiple stressors, including nutrient enrichment, decreased light availability, and disturbances such as toxics will produce greater or lesser than additive responses.

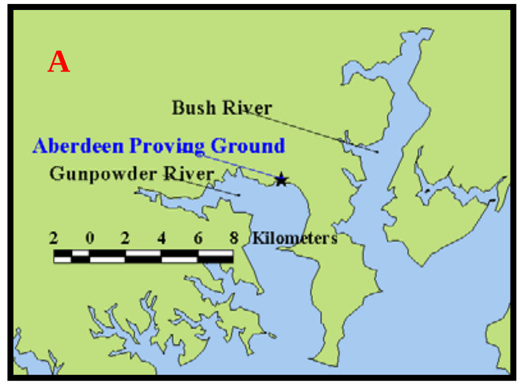
4. MATERIALS AND METHODS

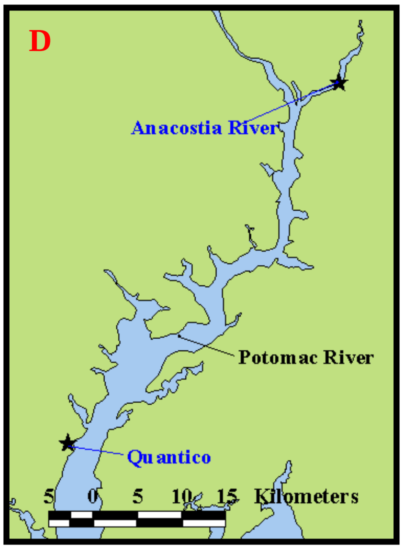
4.1 Overview of Approach

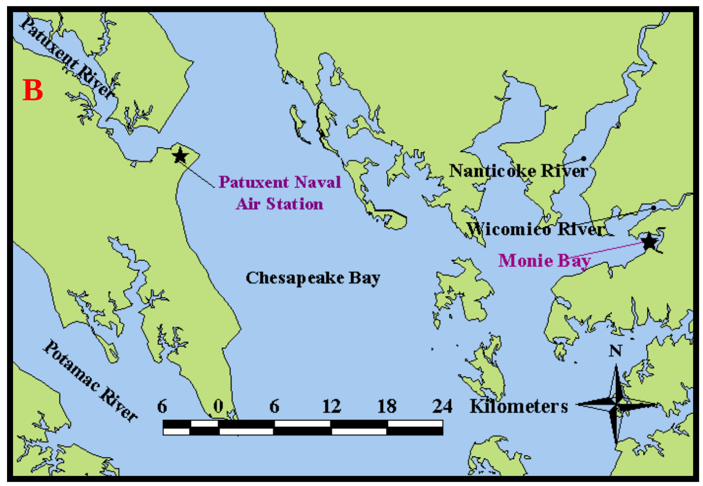
Detailed investigations of benthic community structure and ecosystem function were conducted at eleven primary sites and two secondary sites in Chesapeake Bay. Field data were collected at shallow water euphotic sites adjacent to selected military installations ("unclassified", with respect to environmental condition), at paired non-DoD sites that had high environmental quality ("reference"), sites deemed to be highly influenced by anthropogenic activities ("degraded"), and two additional "unclassified", but non-DOD sites that were sampled for macrofauna and meiofauna in 2003. End-member sites were selected to maximize stressor gradients associated with human activities. The end-member sites were selected such that DoD installations were expected to have intermediate overall environmental quality based on the available historic water quality and sediment data (see below). It is important to note that we did not have sediment contaminant data for most of the sites studied and as a result we could not use that information to array our sites.

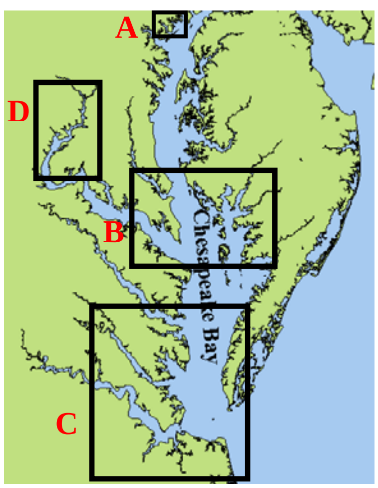
During any one sampling season we were constrained by the number of sites that could be visited. We therefore restricted our investigations to a single salinity regime in order to ensure that differences in salinity and other natural environmental factors had minimal effects on observed relationships between structure and function. Sites within our polyhaline/high mesohaline salinity regime (hereafter termed "**high mesohaline**") typically had historic salinity ranges between 12 and 20 ppt. When we sampled during summer 2003, all sites were high mesohaline (12-18 ppt). Our low mesohaline and oligohaline sites (hereafter termed "**low mesohaline**"), sampled during 2004, had salinities ranging between 0.5 and 12 ppt. **Tidal freshwater** sites had salinities less than 0.5 ppt and were sampled in 2005. All sampling was conducted during mid-summer, which is the index period for the B-IBI approach.

Primary sites sampled during 2003 were in lower Chesapeake Bay, including Langley Air Force Base (LAFB) on Back River; Thorntons Creek, a sub-tributary of Mobjack Bay, representing a relatively pristine reference site, and a highly impacted site in the southern branch of the Elizabeth River (ER) (Figure 3). Secondary sites included Chisman Creek (CH), which is located in a sub-tributary of the Poquoson River, north of the Back River, and Sarah Creek (SA), a sub-tributary of the York River. SA and CH lie along the impairment gradient defined by the end-member sites located in the Elizabeth River and Thorntons Creek. In 2004, study sites were located in the lower and mid-Chesapeake Bay, and included Fort Eustis on the James and Warwick Rivers, Patuxent Naval Air Station (PAX) at the mouth of the Patuxent River, and their paired pristine reference and degraded sites of Monie Bay and the Pagan River, respectively. In 2005, study sites were located in tidal freshwater (0-0.5 ppt) and included Aberdeen Proving Ground (APG) at the head of Chesapeake Bay, Quantico Marine Corps Base on the Potomac River, and their paired reference and degraded sites of Sweet Hall Marsh in the Pamunkey River and the Anacostia River, respectively. Degraded sites were in areas documented to have high levels of environmental degradation by other investigators (noted below).









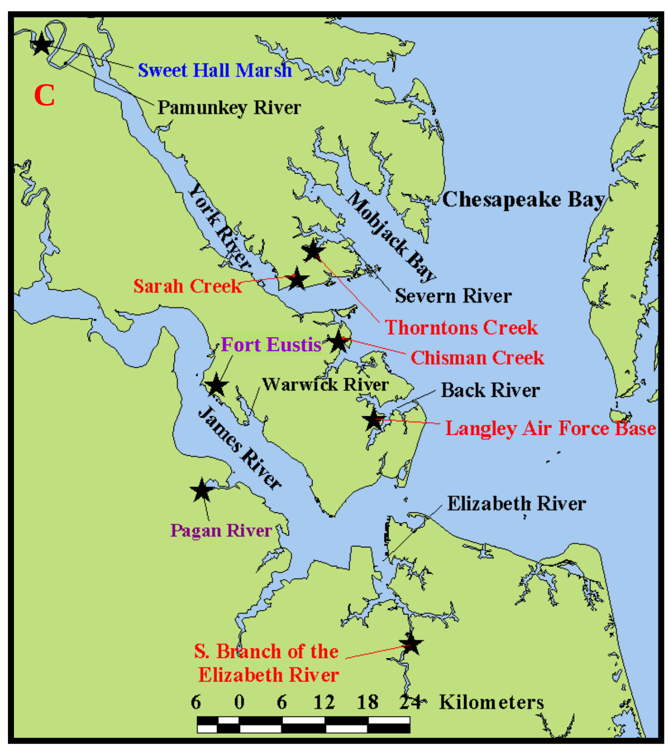


Figure 3. Map of the Chesapeake Bay and sites sampled in high mesohaline (in red), low mesohaline (in purple), and tidal freshwater (in blue) salinity regimes.

Candidate reference and degraded sites were identified using the Chesapeake Bay Program (CBP), U.S. Environmental Protection Agency (U.S. EPA) Environmental Monitoring and Assessment Program (EMAP), and Middle Atlantic Integrated Assessment Program (MAIA) databases. Reference sites were chosen in areas that are not greatly influenced by point source or concentrated non-point loadings and were expected to have very low concentrations of sediment contaminants (Dauer et al. 2000). Prior to initiating our field sampling programs, each potential site was visited to determine salinity, bathymetry, sediment grain size, organic and chlorophyll *a* content, physical exposure, tidal regime, and presence of oyster reefs or submerged aquatic vegetation. The character of soft sediments relative to other bottom types and the spatial extent of the proposed sampling sites (shallow subtidal, ≤ 1 m at mean low water (MLW)) were determined. In addition, any available benthic community or environmental data for the region of the candidate sampling sites were also considered.

After final selection, each study site was stratified into two major habitat types: (1) **Near-field stratum** - protected, muddy tidal marsh creek in relative close proximity to potential sources of pollutants in surface runoff and groundwater base flow; and (2) **Far-field stratum** - open water area with sandy sediments, higher tidal flushing, more potential for wave exposure, and less potential for direct impacts of pollutants in surface runoff and groundwater. Boundaries for these strata were determined based on potential impacts from the adjacent watershed and after consultation with Natural Resources and Restoration or Environmental staff at each military site. Sampling stations were randomly allocated within the strata (near-field and far-field) at each site. Random sampling within each stratum and sampling along gradients of impairment allowed us to address questions concerning the effects of stratum, classification status, and salinity on the parameters we measured.

Sampling was conducted in mid-summer because it is the index period for the B-IBI and is also a period of high rates of biological activities that determine function. Data on macrofaunal community composition and abundance collected at each station were used to compute B-IBIs, which were compared to other measures of structure and function (i.e., primary production, respiration, nutrient flux, mineralization, and denitrification rates), determined at the same sites at which B-IBI data were collected.

4.2 Study Sites

DoD installation study sites, located adjacent to Chesapeake Bay and its tributaries, were selected based upon their position along the salinity gradient and extent and type of impairments expected. Non-military sites were chosen to represent relatively pristine (reference) and degraded conditions, bracketing the degree of impairment expected at military sites within the same salinity regime. Preliminary site characterization was conducted to ensure that military and non-military sites were of similar habitat type and physical characteristics and met criteria described in section 4.2.1. For the high mesohaline sites, Thorntons Creek was identified as an appropriate reference site since it is relatively pristine with comparable sediment types, physical characteristics, and exposure as LAFB and the ER. The Atlantic Wood site in the Southern Branch of the Elizabeth River was selected to represent the degraded end-member site for comparison to LAFB because previous studies have shown that the sediments in the region are highly contaminated with PAHs and metals (Walker et al. 2004, Conrad and Chishom-Brause 2004). The ER is also listed as a "Region of Concern" for chemical contamination by the Chesapeake Bay Program (CBP 1999).

For the low mesohaline sites (2004), Monie Bay, Md, which is part of the Maryland National Estuarine Research Reserve system and the Deal Island Wildlife Management Area, was identified as a relatively pristine reference site for comparison to Fort Eustis and PAX. The Pagan River was selected to represent the degraded end-member. The Pagan River was placed on the impaired waters 303(d) list in 1996 due to discharge associated with two meat-packing plants on the Pagan's shoreline (Chesapeake Bay Foundation 1996). Although the plants were subsequently connected to the Hampton Roads Sanitation District sewage treatment system, leaks from previously used direct discharge pipes have been reported as recently as spring 2006 (VA DEQ 2006).

For the tidal freshwater sites (2005), the Sweet Hall Marsh site on the Pamunkey River, VA was selected as a reference site for comparison to APG and Quantico. This site is part of the Chesapeake Bay National Estuarine Research Reserve System and has been used as a study site by investigators at the Virginia Institute of Marine Science for over a decade (Neubauer et al. 2005). The Anacostia River, which originates in Maryland and flows into Washington, D.C., was selected as the degraded end-member site because it is known to be highly contaminated by metals and organics from stormwater runoff and combined stormwater and sewer overflow and is listed as a "Region of Concern" for chemical contamination by the Chesapeake Bay Program (CBP 1999).

4.2.1 Criteria for Reference Site Selection

Study sites along known stressor gradients were selected using a three-step process for comparison to the military installations. First, we identified potentially suitable areas by matching chemical-physical characteristics to sampling sites at the military installations. Using existing databases such as the CBP Monitoring Program database, EPA's EMAP and MAIA databases, and VA DEQ's surface water quality monitoring database, we considered the following parameters: salinity, sediment type (grain size, organic content), physical exposure, and tidal regime. We also examined CBP historical (1993-2002) water column nutrient concentrations and DO levels from monitoring stations near the sites to assess potential impairment. Second, we obtained additional information on the suitability of these sites by crosschecking previously computed B-IBIs for collections made in each region, if available. These data were obtained from Dr. Dan Dauer, Department of Biology, Old Dominion University, Norfolk VA, and Dr. Roberto Llansó, VERSAR Inc., Springfield, VA, who are the PIs responsible for maintaining the B-IBI data in the CBP bay-wide benthic database. Over the last 10 years they have computed B-IBIs for hundreds of stations around the Bay as part of the CBP monitoring program. If B-IBI data for a region that included our proposed sites were not available, we used other indices of benthic and environmental health obtained from the U.S. EPA's EMAP and MAIA databases. Finally, the reference sites were also evaluated based on the following criteria: (1) sites were eliminated if they were in highly developed watersheds or near known point sources of discharge, and (2) water column DO was consistently high (80% of observations above 5 ppm).

For delineating far-field and near-field strata, we examined pre-existing benthic and environmental data and visited the sites to conduct preliminary field characterizations (e.g., salinity, bathymetry, sediment grain size, organic content, benthic chlorophyll, and physical exposure). The far-field stratum was defined as an open water area with sandy sediments (≤ 40% silt-clay) and subject to higher physical energy than the near-field strata. The near-field stratum was defined as a physically protected, tidal creek with muddy sediments (> 40% silt-clay). The far- and near-field strata at the reference and degraded sites were matched as closely as possible to those at the military sites.

4.2.2 Detailed Site Descriptions

High Mesohaline (2003) Sites:

Langley Air Force Base (LAFB): LAFB/National Aeronautics and Space Administration Langley Research Center (NASA LaRC) is located in lower Chesapeake Bay in Hampton, Virginia and consists of two federal facilities. Salinities in the region fall within a range typical for the lower Chesapeake Bay, ranging from high mesohaline to low polyhaline (≥ 12 to 20 ppt or higher). LAFB covers 3,152 acres, has been an airfield and aeronautical research center since 1917, and is the home base for the First Fighter Wing. Impacts on adjacent tidal waters are from a suite of physical and chemical disturbances. NASA LaRC consists of 787 acres and is a research facility that conducts numerous operations in nearly 200 buildings and 40 wind tunnels. Wastes generated at LAFB include petroleum, oils and lubricants, fuels, solvents, paints, pesticides, photographic chemicals, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and heavy metals. Wastes generated at NASA LaRC include waste oils, solvents, paint wastes, pesticides and rinse waters, photographic wastes, scrap materials, used batteries, and printed circuit board plating wastes. PCBs and polychlorinated terphenyls were used in hydraulic systems, electrical equipment, compressors, and casting operations. There are more than 40 sources of possible contamination at the two facilities. The complex is surrounded by wetland areas, including the Plum Tree National Wildlife Refuge. Tabbs Creek, which is located between LAFB and NASA, is contaminated with PCBs and PCTs; areas in the creek upstream of Worley Road Bridge were dredged in the late 1990's, and an extensive area of brackish wetland was restored downstream of the bridge. The watershed for LAFB consists primarily of low to medium intensity development (33%), forests and woodlands (27%), and developed open space (22%) (Metcalfe 2005). The nearby Back River historically has supported commercial and recreational crab, oyster, clam, and fin fishing. Its two branches form a tidal estuary that empties into the Chesapeake Bay.

Thorntons Creek: Thorntons Creek is a tributary to the Severn River of Mobjack Bay in Gloucester County, VA and is located near the mouth of the York River in the lower Chesapeake Bay. Gloucester County, a rural area that is predominantly forested with agriculture as the second largest land use (Comprehensive Coastal Inventory Program 1997), has a population of about 35,000 (U.S. Census Bureau 2000). Thorntons Creek, a shallow, muddy creek with an average depth at MLW <1.5 m, is surrounded by marsh, residential, and agricultural land and is considered relatively pristine of the sites that were suitable for comparison with LAFB. The watershed for Thorntons Creek consists primarily of forests and woodlands (76%) and farmland (17%) (Metcalfe 2005).

Elizabeth River (ER): The ER is located in the Norfolk-Portsmouth metropolitan region and discharges into the James River in the lower Chesapeake Bay. The highly industrialized Southern Branch of the ER, with high mesohaline to polyhaline waters, had the highest percentage of degraded benthic bottom (B-IBI values less than 3.0) of all the branches of the ER (Dauer 2000). Of sites studied, 44% of the bottom was severely degraded (B-IBI values less than 2.0). The Southern Branch has several Superfund sites, including the Atlantic Wood Industries, Inc. in Portsmouth, VA. The Atlantic Wood site was a 47.5-acre wood preserving facility in operation from 1926 to 1991 that used creosote and pentachlorophenol (PCP) wood-treating processes and stored chromium copper arsenate (CCA)-treated wood (Lockheed Martin 2002, VADEQ unpublished). Waste at the site includes creosote-contaminated soil from leaking aboveground storage tanks (removed in 1986), 20,000 cubic feet of land-filled creosote, and PCP contaminated wood-chips. PCP, arsenic, and chromium have been measured in nearby surface waters. The watershed for the Southern Branch of the Elizabeth River consists primarily of low to medium intensity development (40%), woodlands and forests (20%), developed open space (18%), and farmland (16%) (Metcalfe 2005). The Elizabeth River Atlantic Woods site served as a highly degraded end member for the 2003 sampling program.

Sarah Creek (SA): SA, a sub-tributary of the lower York River, is bordered by residential and agricultural development along the shoreline of the headwaters with a large marina for recreational boaters located near its mouth. Many of the houses along its shorelines have residential septic systems. Tributyltin (10-40 ng/L) has been detected in the water column annually between 1986 and 1996 near the mouth and is likely associated with sediments in greater concentrations. Muddy sediment in the headwater region is organically-enriched (elevated carbon and nitrogen content). The watershed for Sarah Creek consists primarily of woodlands and forests (46%), farmland (31%), and developed open space (12%) (Metcalfe 2005).

Chisman Creek (CH): The headwaters of CH border a previous EPA Superfund site that has undergone remediation. The CH Superfund Site holds an estimated 500,000 tons of fly ash from Virginia Power's Yorktown Power Station in underground borrow pits. Heavy metals, arsenic, beryllium, chromium, copper, molybdenum, and selenium were found to have leeched from the pits, contaminating groundwater, surface water, sediments, and soil. The site was included on the National Priorities List (NPL) on September 1, 1983. EPA conducted a five-year review in 1996 and determined that the remedial actions were operating properly (NPL Fact Sheet - CHISMAN CREEK). The watershed for Chisman Creek consists primarily of woodlands and forests (62%), farmland (17%), and developed open space (9%) (Metcalfe 2005).

Low Mesohaline (2004) Sites:

Fort Eustis: Fort Eustis occupies approximately 8,300 acres in southeastern Virginia on the James River, within the city of Newport News. Warwick River, a tributary to the James River, borders the eastern side of Fort Eustis and has salinities ranging from tidal freshwater to mesohaline. Fort Eustis is owned and operated by the U.S. Department of the Army and is located on the western side of a low-lying peninsula formed by the York River and the James River estuaries. This peninsula is approximately 30 miles upstream of the confluence of the James River and the Chesapeake Bay in tidal mesohaline water (approximately 1 m tidal range). The James River is a major commercial fishing and recreational resource; it is the third largest tidal tributary of the Chesapeake Bay and the most productive estuary in Virginia. Impacts on adjacent waters at this site result from both physical and chemical disturbances. The site began operations in 1918 as a training center known as Camp Abraham Eustis. In 1946, Fort Eustis became the Transportation Corps Training Center. In 1988, the U.S. Army Toxic and Hazardous Materials Agency identified 34 potential waste sources at Fort Eustis. The sources include unlined landfills, pesticide storage areas, firefighting training areas, maintenance shops, and range and impact areas resulting from anti-aircraft training activities.

Patuxent River Naval Air Station (PAX): PAX is located at the mouth of the Patuxent River in the mesohaline, mid-Chesapeake Bay area. Tidal range is approximately 0.3 m. It is a 6,400 acres naval facility with a work force of approximately 17,500 personnel. The facility is directly adjacent to the city of Lexington Park with a population of 13,000. Impacts on adjacent waters are from a suite of physical and chemical disturbances. Surface water contamination has occurred primarily due to drainage from two sanitary landfills and from a pesticide rinse area. One landfill was closed in 1974, and the other in 1994. The pesticide rinse area generated 300 – 400 gallons of contaminated water per day from 1962 until the late 1970's. Drainage from the pesticide rinse area has impacted two fishing areas on the facility, and the state of Maryland has issued a fish advisory for ponds on the base. Hazardous materials that may potentially impact Chesapeake Bay include pesticides, sewage treatment sludge, spent oil absorbents, paints, antifreeze, and hospital wastes.

Monie Bay: Monie Bay is a relatively small embayment located on the eastern shore of the mesohaline, mid-Chesapeake Bay area in Somerset County; its eastern half is part of the Maryland National Estuarine Research Reserve (MDNERR). Land cover in the watershed is predominantly forest (46%) and wetlands (32%), followed by agriculture (19%) and development (2%) (Maryland Department of Planning 1994). Tidal range is approximately 0.6 m and water depth averages less than 2 m. Little Creek, one of three tidal creeks in the MDNERR portion of Monie Bay, is surrounded by marsh (63%) and forest (35%) with minimal residential development (1%) and agriculture (1%) (Apple et al. 2004).

Pagan River: The Pagan River, an oligohaline to mesohaline, tidally-influenced tributary of the James River (1 m tidal range), is located approximately 6 km downriver from Fort Eustis and 24 km from the mouth of the James River. Two major point sources on the Pagan River were wastewater discharges from two meat-processing plants, Gwaltney and Smithfield Packing, in the town of Smithfield, Virginia. These discharges were discontinued by 1997 when the plants were connected to the Hampton Roads Sanitation District sewage system (June 24, 1996 and August 3, 1997, respectively) (Kuo 1999). The plants slaughter and process approximately 4.6 million hogs annually. The Virginia Department of Conservation and Recreation ranked the Pagan River watershed as high priority for potential non-point source pollution (VADEQ 2004). The Pagan River is listed on Virginia's (VA) 303(d) Impaired Waters List for exceedances of

VA's water quality standards for fecal coliform bacteria and dissolved oxygen, and fish tissue criteria for PCBs (VADEQ 2004).

Tidal Freshwater (2005) Sites:

<u>Aberdeen Proving Ground (APG):</u> APG is located in the upper reaches of Chesapeake Bay with salinity ranging from fresh (spring) to oligohaline (summer). Impacts on marine systems are primarily from runoff of hazardous materials. The Edgewood (EA) area has been placed on the National Priorities List of hazardous waste sites. This 13,000 acres area includes Gunpowder Neck, Pooles Island, Carroll Island, and Graces Quarters. EA is surrounded by the Gunpowder and Bush Rivers and the Chesapeake Bay, which have a mean tidal range of approximately 0.4 m. EA was used for the development and testing of chemical agent munitions. From 1917 to the present, activities at the EA included chemical research, manufacture of chemical agents, and testing, storage, and disposal of toxic materials. The EA has large areas of land and water and numerous buildings that are contaminated or suspected of contamination. Substances disposed of in the area include significant quantities of napalm, white phosphorus, and chemical agents. On-site surface waters include rivers, streams, and wetlands. Groundwater sampling has identified various metals, volatile organic compounds (VOCs), and chemical warfare agent degradation products. Soil contamination sampling has identified various VOCs, metals, and unexploded ordnance in surface and subsurface soils. Surface water sampling has identified various metals, phosphorus, and VOCs. The area is a designated habitat for bald eagles.

<u>Quantico Marine Corps Base:</u> The Marine Corps Combat Development Command site (MCCDC) is a 56,000-acre military training facility located in Quantico, Virginia, about 35 miles south of Washington, D.C., with approximately 5 km (3 miles) of shoreline along the tidal freshwater portion of the Potomac River (mean tidal range of 0.4 m). Numerous streams and creeks, including Chopawamsic Creek, Little Creek, and Quantico Creek, bisect the installation and lead to the Potomac River. Impacts on the river include drainage of hazardous materials as well as inputs of sediment due to physical disturbances. A total of 261 potentially contaminated sites have been identified, prioritized, and are systematically being investigated. The "Old Landfill", which was the primary landfill for the base from the 1920s until 1971, covers about 25 acres and has 8 acres located along the west bank of the Potomac River. Operations at the Old Landfill and Defense Reutilization and Marketing Office (DRMO) have led to PCB and pesticide contamination of soils, groundwater and sediments in the Potomac River.

<u>Sweet Hall Marsh:</u> Sweet Hall Marsh is a tidal freshwater marsh on the Pamunkey River that drains into the York River estuary and is located 35 km upriver from West Point, VA. Mean tidal range is approximately 0.9 m. The 353-hectare marsh, dominated by *Peltandra virginica* (arrow arum), is part of the Chesapeake Bay National Estuarine Research Reserve (CBNERR), which conducts water quality and meteorological monitoring at this site. Land cover in the Pamunkey River watershed is predominantly undeveloped with 65% forested and 6% wetlands, followed by 27% agriculture and grasslands and <2% developed (Neubauer et al. 2002).

<u>Anacostia River:</u> The Anacostia River is a tidal freshwater river (0.9 m tidal range) that flows from Maryland (Prince George's County) into Washington, DC for approximately 13.5 km (8.4 miles) to the Potomac River. The Anacostia watershed is heavily urbanized (65% developed) with a high percentage of impervious surfaces (33%), leading to greater stormwater runoff and combined sewer and stormwater overflows (Maryland Department of Planning 1994). River sediments are contaminated with multiple trace metals (e.g., Cu, Cr, Cd, Hg, Pb, and Zn), polycyclic aromatic hydrocarbons (PAHs), PCBs, DDT, DDE, and total chlordanes, of which concentrations were found to be generally higher near sewer and stormwater outfalls (Wade et al. 1994, Velinsky et al. 1994). The Anacostia River is one of three sites in the Chesapeake Bay listed as "Regions of Concern" for chemical contamination (CBP, 1999) and is listed on Maryland's 303(d) Impaired Waters List, category 5, for pathogen impairment due to fecal coliform exceedances (MDE 2004).

4.3 Within-Site Field Sampling Design

Random station selection is most appropriate for evaluating the status of benthic community integrity relative to diverse and diffuse activities in the adjacent watershed (Gibson et al. 2000). At nine randomly selected stations (0.5 – 0.75 m MLW) in each near- and far-field stratum, sediment samples were collected using: (1) large acrylic cores (13.3 cm i.d. by 40 cm) (18 cores total per site); and (2) medium acrylic cores (5.7 cm i.d. by 30 cm) (18 cores total per site). The large cores were used for the following analyses: sediment/water nutrient fluxes, primary production, respiration, denitrification, sediment chlorophyll *a*, phaeophytin, sediment grain size distribution, and parameters for determination of B-IBI scores. The medium cores were used for determinations of the following sediment parameters: bulk density, organic content, exchangeable nutrients, total particulate nitrogen (TN), and particulate organic carbon (POC). Sediment samples were also collected with 24 small acrylic cores per stratum (5.7 cm i.d. by 20 cm), in which two cores were taken at the same nine stations and six were taken at an additional randomly selected station within each stratum (6 cores at the 10th station; 48 cores total per site). The small cores were used to determine mineralization rates. Concurrent with sampling at each stratum, we measured water column DO, salinity, pH, and temperature with a YSI datasonde at approximately 0.5 m water depth and light attenuation within the water column with a LiCor 2 PAR sensor. Water samples were also collected in triplicate for nutrient analyses. Samples were collected at low tide to ensure consistency in measurements.

Ten stations per stratum at each site were randomly selected along the shoreline and sampled in July-August. The protocol required that sediment collected for the multiple experiments be unvegetated, in order to allow for the computation of the B-IBI, which is calibrated only for unvegetated habitats and to reduce variability and confounding factors; however Quantico far- and near-field sites high densities of submerged aquatic vegetation (SAV) in their shallow waters and the APG near-field site had some vegetation present. To examine the potential effects of the SAV, we collected three cores with SAV at each of these sites and the remainder of the cores in unvegetated areas between the SAV stems. Quantico's far-field site in the Embayment had extensive, dense mats of *Hydrilla verticillata* covering the majority of the area (Figure 4), and to avoid the SAV, we collected in shallower water depths than usual (<0.5 m) for the unvegetated cores. Quantico's near-field was also dominated by *H. verticillata*, while at APG *Elodea canadensis* and *H. verticillata* were most abundant. SAV beds (predominantly *Vallisneria americana* and *Myriophyllum spicatum*) were also found at APG's far-field site but at depths greater than our sampling sites.

Figure 4. Dense mats of *Hydrilla verticillata* covered the majority of area at Quantico's far-field site in the Embayment

4.4 Environmental Parameters

Water samples collected in triplicate from each stratum were filtered (Gelman Supor, 0.45 µm) and frozen until analyzed for dissolved inorganic phosphorus (DIP), DIN, dissolved organic carbon (DOC), and dissolved organic nitrogen (DON) using the methods listed in Table 1. Water column chlorophyll a and phaeophytin were determined as described by Shoaf and Lium (1976). Five mL water samples were filtered through 25 mm filters (Whatman GFF) and extracted for 24 hours at room temperature in the dark in 8 mL of a DMSO/acetone mixture (45% acetone, 45% DMSO, 10% deionized water, 0.1% diethylamine by volume). Samples were analyzed using a Turner Designs Fluorometer, Model 10-AU. Total suspended solids (TSS) and volatile suspended solids (VSS) were determined in triplicate by filtering a known volume of sample (~200-500 mL, depending on levels of suspended matter in sample) through pre-weighed, combusted GF/F filters (0.7 µM Ahlstrom Corp.) followed by drying at 50ºC to constant weight. For VSS, filters were then muffled for five hours at 500ºC.

After completion of flux experiments, each of the 18 large cores was subsampled for determinations of grain size distribution, chlorophyll a, and phaeophytin content. Sediment for grain size distribution analysis (11.5 cm depth) was collected using a pre-cut 60 mL syringe. After homogenizing the extruded sample, a 15-20 g subsample was weighed out and sieved (63 µm sieve), washing silt and clay fractions into a graduated cylinder. After 24 hours, pipette analysis was performed to determine clay (4 phi) and silt (8 phi) fractions of the sample. Dry weights of the aliquots were determined for calculation of percent sand, silt, and clay (modification of Plumb, 1981).

Table 1. Analytical techniques for nutrients.

Analyses	Methods	References	EPA Method
Nitrate, Nitrite	Cadmium reduction/diazotization	Lachat auto analyzer[1] (Smith and Bogren 2001, revised 2002)	353.4
Ammonium	Phenol Hypochlorite method	Lachat auto analyzer (Liao 2001, revised 2002)	349.0
Total dissolved nitrogen (TDN)	Alkaline persulfate digestion in sealed ampoules	Koroleff 1983	
Dissolved organic nitrogen (DON)	= TDN-(ammonium+nitrate+nitrite)		
Dissolved organic carbon (DOC)	680°C catalytically-aided combustion oxidation/non-dispersive infrared detection	Shimadzu TOC-V analyzer	415.3
Dissolved inorganic phosphorus (phosphate)	Molybdate method	Lachat auto analyzer (Knepel and Bogren 2001, revised 2002)	365.5

[1] The Lachat auto analyzer (QuikChem 8000 Automated Ion Analyzer, Lachat Instruments, Loveland, CO) is a continuous flow automated analytical system that complies with US Environmental Protection Agency (EPA) standards.

Sediment (top 3 cm) for determinations of chlorophyll a and phaeophytin content was sampled in triplicate using a pre-cut 5 mL Fortuna syringe (1.1 cm i.d.) and subdivided into 3 depth sections: 0-1, 1-2, and 2-3 cm. Triplicate samples from each of the three depth sub-sections were composited in a centrifuge tube and frozen (as soon as possible) for a minimum of 24 hours in a dark environment to prevent breakdown of chlorophyll. Within one month, the samples were processed by adding 15 mL extractant (45% methanol, 45% acetone, 10% DI water by volume), vortexing and sonicating for 30 seconds each, and freezing for an additional 24 hours (Neubauer et al. 2000). Following extraction, samples were centrifuged, filtered (Gelman PTFE, 0.45 μM), and analyzed using a Shimadzu UV-1601 spectrophotometer before and after acidification by addition of 0.15 mL 10% HCl to each sample. Chlorophyll a and phaeophytin concentrations were calculated using the equations of Lorenzen (1967).

Medium acrylic cores were used to collect sediment to a depth of 25 cm in the field. Each core was sectioned at 0-2, 2-5, 5-15, and 15-25 cm depth intervals and sub-sections were cut into quarters. One quarter was used for determination of bulk density and percent organic content. It was placed in a pre-weighed foil envelope and weighed before and after being (1) dried at 50°C to constant weight for bulk density determination and (2) combusted in a muffle oven at 500°C for 5 hours for percent organic content determination. For determinations of POC and TN, a second quarter section was placed in a foil envelope, dried at 50°C to constant weight, and ground with a mortar and pestle. POC and TN were analyzed by standard methods using a Fisions CHN analyzer (Model EA1108) after removing inorganic carbon with 10% HCl. Acetanilide was used as a standard. Elemental analysis results were reported as percent C and percent N by weight and C/N molar ratios. For determinations of sediment exchangeable nutrients, the third quarter section was extracted in 2M potassium chloride (KCl), shaken for 1 hour, centrifuged, filtered (Gelman Supor, 0.45 µm), and frozen until analyzed. DIN and DIP were determined in the samples using a Lachat auto analyzer (Table 1).

4.5 Flux and Ecosystem Metabolism Studies

Large sediment cores (as previously described), sampled to a depth of 25 cm at the nine randomly selected stations within each of two strata, were used for concurrent determinations of primary production, respiration, nutrient fluxes, and denitrification rates. Additionally, three water blanks were taken from each stratum (large cores filled with water collected from each stratum and site) to distinguish water column from sediment processes. Power analyses of primary production measured at coastal sites along the Delmarva Peninsula have shown that a sample size of nine allows us to be 75% certain of detecting a 30% difference in primary production/respiration between samples at α=0.05. When measuring nutrient fluxes, this same number of cores allows us to detect a 100% difference between NH_4^+ fluxes and a 75% difference between NO_x fluxes.

Flux and metabolism experiments were performed in a temperature and light-controlled environmental chamber adjusted to the ambient water column temperature (25-26°C) of the sites studied. After returning from the field and prior to starting the incubations, cores were uncapped and immersed overnight in the dark in water collected from each site. During this time, water within the cores was constantly mixed and aerated. Flux experiments were initiated the next morning by capping the cores with clear acrylic lids under water in large tanks (Figure 5). To determine the net exchange of nutrients and oxygen between the sediment and overlying water, water samples were collected at regular intervals over two 4 to 5 hour periods, first in the dark followed by incubation in the light (saturating irradiance of 400 µE m^{-2} s^{-1}). The cores were

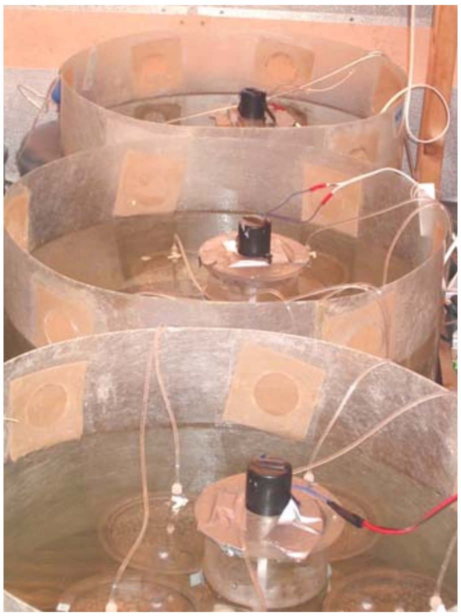


Figure 5. Incubation of large sediment cores for flux and ecosystem metabolism experiments.

connected to a reservoir system so that water removed during sampling was replaced with water from the respective stratum and site. Dissolved oxygen concentrations in the sampled water were measured using a galvanic oxygen sensor (Orion). Changes in DO in the light and dark were used for determinations of rates of ecosystem metabolism, including respiration, gross primary production, and net ecosystem metabolism. Water samples taken concurrently with the DO measurements were filtered (Gelman Supor, 0.45 µm) and frozen until analyzed for DIP, DIN, DOC, and DON. Net uptake or release of nutrients from sediment was determined from changes in nutrient concentrations during the same incubation periods. Denitrification was determined during dark incubations at 1.5 h intervals by measuring N_2/Ar ratios in water samples preserved with mercuric chloride using a membrane inlet mass spectrometer at the University of Maryland, Horn Point laboratory as described by Kana et al. (1998). After completion of flux experiments, cores were processed for macrofauna, meiofauna, sediment chlorophyll, and grain size distribution.

For calculating sediment respiration (R), net sediment ecosystem metabolism (NEM), and gross primary production (GPP), a respiratory quotient (RQ) of 1 was assumed (1 mmol DO equals 1 mmol dissolved inorganic carbon (DIC)). Sediment DO and nutrients fluxes were corrected for DO and nutrient uptake or release in the water column. The sediment metabolism and daily nutrient flux equations follow:

$$R = F_d * 24 \text{ hrs}$$

$$NEM = (F_l * h_l) + (F_d * h_d)$$

$$GPP = NEM - R$$

$$\text{Daily nutrient flux} = (F_l * h_l) + (F_d * h_d)$$

F_d represents hourly flux in the dark
F_l represents hourly flux in the light
h_l represents hours of light
h_d represent hours of dark

4.6 Gross N-Mineralization

Following completion of the nutrient flux and ecosystem metabolism measurements and as described in Section 4.3, 24 small cores (25.5 cm^2) per stratum were taken for mineralization measurements. The small cores were taken to a depth of 10 cm. The sample number was based on power analyses using gross mineralization data collected from shallow coastal waters on the ocean-side of Virginia's Delmarva Peninsula. We determined that in order to observe with 80% certainty at α=0.1 a difference of 75% between mineralization rates, it was necessary to perform 12 replicate measurements for each stratum at each site at time (t) = 0 and t = final. Following collection, the cores were uncapped and immersed in site-specific water and held overnight in the dark with constant mixing and aeration. Incubations, performed in the dark in a temperature-controlled incubator (Figure 6) (25ºC), were conducted for 24 hours for mineralization.

Figure 6. Small sediment core used for mineralization with magnetic spinner inside core (left). Small sediment cores placed around large magnetic spinner in temperature-controlled incubator (right).

^{15}N-NH_4^+ was injected for determination of mineralization using the isotope pool dilution technique as described by Anderson et al. (1997). At the beginning and conclusion of the incubations, sediments in the cores were extracted with two volumes of 2 M KCl; the extractant was filtered (Gelman Supor, 0.45 µm), and the filtrate frozen until analyzed. NH_4^+ in extracts from the mineralization experiment was trapped by diffusion onto acidified filters, as described by Brooks et al. (1989). Previous studies have shown that trapping efficiencies exceed 90%. Samples were analyzed for ^{15}N enrichment at the University of California at Davis' stable isotope facility. Rates of gross mineralization were calculated using a model described by Wessel and Tietema (1992).

4.7 Benthic Macroinvertebrates

Following completion of the nutrient flux and ecosystem metabolism measurements and subsampling of the cores for collection of meiofauna and sediment for other determinations (as previously described), the large cores (surface area approximately 130 cm^{-2} after subsamples were removed) were divided into two depth horizons (0-5, >5 cm). Each sample was gently washed over a 500 µm mesh screen using ambient seawater. The material retained on the screen was transferred to a labeled jar and fixed with 10% buffered formalin in seawater with a small quantity of Rose Bengal stain, which aids in subsequent sorting. Fixed samples were washed with fresh water, and organisms separated from debris and sorted into major taxa using a binocular dissecting microscope. Organisms were then transferred to 2% buffered formalin and subsequently identified to the lowest possible taxonomic level (usually species) and counted. Fragments without heads were eliminated from the counts but included in biomass determinations. Ash free dry mass (AFDM) biomass was determined for each species by drying the organisms to a constant weight at 60°C followed subtraction of the ash content determined by ashing samples in a muffle furnace at 550 °C for four hours.

Calculation of the B-IBI: We followed the standard methods originally described in Weisberg et al. (1997), as detailed in Llansó (2002), and summarized below. Our methods deviated from theirs in three ways. We used the cores described above, not a Young grab sampler, our samples were incubated for 24 hours prior to the time we processed them, and we subsequently stored our samples in 2% formalin rather than 70% ethanol. As previous investigations have indicated that the B-IBI approach is relatively insensitive to sampling methods (Weisberg et al. 1997), we did not attempt to correct for the differences in sampling gear. Sample storage in formalin rather than ethanol will result in less loss of alcohol-soluble fats and lipids over time, resulting in more representative biomass estimates.

The B-IBI is based on observations about macrofauna, which indicate benthic community condition. Taxa that are not usually retained on a 500 µm mesh screen (e.g., nematodes, copepods, and ostracods) are eliminated from the data. Data sets must be standardized by applying uniform naming conventions. Taxa that are not sampled quantitatively or that are not truly indicative of sediment conditions are retained in the data sets but excluded from the B-IBI calculations. These taxa include benthic algae, fish, pelagic invertebrates, and some epifauna, especially colonial forms. A list of the currently omitted Chesapeake Bay organisms is available online (http://baybenthos.versar.com/DsgnMeth/Analysis.htm).

The B-IBI was designed to account for variability in benthic community composition due to changes in major estuarine habitats. Metrics and thresholds were derived for each of the seven major habitat types, based on salinity and sediment types, in Chesapeake Bay. Before metrics can be calculated, a sample must be assigned to one of five salinity classes: tidal freshwater, oligohaline, low mesohaline, high mesohaline, and polyhaline. These classes were defined according to a modified Venice System for the classification of marine waters (Symposium on the Classification of Brackish Waters 1958). Within the high mesohaline and polyhaline classes, a sample must be further assigned to one of two sediment classes according to the percent silt-clay content of the sample. Table 2 shows the resulting habitats into which samples are classified.

Table 2. Habitat classification used for the Chesapeake Bay Benthic Index of Biotic Integrity.

Habitat Class	Bottom Salinity (ppt)	Silt-clay (<62 µm) (% by wt.)
Tidal freshwater (TF)	0 – 0.5	na
Oligohaline (OH)	$\geq$ 0.5 - 5	na
Low mesohaline (LM)	$\geq$ 5 - 12	na
High Mesohaline (HM) sand	$\geq$ 12 - 18	$\leq$ 40
High Mesohaline (HM) mud	$\geq$ 12 - 18	> 40
Polyhaline (PO) sand	$\geq$ 18	$\leq$ 40
Polyhaline (PO) mud	$\geq$ 18	> 40

Metrics used in the calculation of the B-IBI are those of Weisberg et al. (1997), except for the tidal freshwater and oligohaline habitats. Metrics for these two habitats were developed in Alden et al. (2002). The metric selection process was based on Mann-Whitney U tests for differences in means between the reference and the degraded sites of the index development data sets, and on consistency with ecological principles (Weisberg et al. 1997). Not all the metrics are used in all habitats. Table 3 shows metric usage by habitat. For lists of taxa included in the various categories (e.g. pollution indicative), see Llansó (2002).

Table 3. B-IBI metrics used for each major habitat.

Metric	**Habitat Class**						
	TF	**OL**	**LM**	**HM sand**	**HM mud**	**PO sand**	**PO mud**
Shannon-Weiner species diversity index			X	X	X	X	X
Total abundance	X	X	X	X	X	X	X
Total biomass			X	X	X	X	X
Pollution indicative taxa (% abundance)	X	X	X	X			
Pollution sensitive taxa (% abundance)		X		X		X	
Pollution indicative taxa (% biomass)					X	X	X
Pollution sensitive taxa (% biomass)			X		X		X
Carnivores and omnivores (% abundance)		X		X	X		X
Deep-deposit feeders (% abundance)	X					X	
Tolerance score	X	X					
Tanypodini to Chironomidae (% abundance ratio)		X					
Biomass > 5 cm (%)			X		X		
No. taxa > 5 cm (%)							X

The scoring of metrics to calculate the B-IBI is done by comparing the value of a metric from the sample of unclassified sediment quality to thresholds established from reference data distributions. These thresholds were established as the 5th (or 95th, see below) and 50th (median) percentile values of reference sites for each metric-habitat combination. Reference sites were those that showed no chemical contaminant impact or significant low dissolved oxygen events (see Weisberg et al. 1997).

For the following metrics:

- Shannon-Wiener species diversity index ($H' = -\sum_i p_i \log(p_i)$)
- Percent abundance of pollution-sensitive taxa
- Percent biomass of pollution-sensitive taxa
- Percent abundance of carnivore and omnivores
- Percent abundance of deep-deposit feeders (polyhaline sand habitat)
- Percent biomass of organisms found >5cm below the sediment-water interface
- Percent number of taxa found >5cm below the sediment-water interface

a score of 1 is assigned to a metric if the value of the metric for the sample being evaluated is below the 5th percentile of corresponding reference values, a score of 3 is assigned for values between the 5th percentile and the median, and a score of 5 is assigned for values above the median. For any metric, a score of 1 indicates impaired conditions. A maximum score of 3 is assigned for the pollution-sensitive taxa metric if the overall abundance in a sample is low (i.e., below the lower abundance threshold). This is done to avoid high scores due to the presence of a few organisms of pollution sensitive species found among a small number of organisms within a sample.

An upper threshold corresponding to the 95th percentile of reference sites is used for the following metrics:

- Percent abundance of pollution-indicative taxa
- Percent biomass of pollution-indicative taxa
- Percent abundance of deep-deposit feeders (tidal freshwater habitat)
- Tolerance Score
- Tanypodini to Chironomidae percent abundance ratio

This is done because the direction of the response for these metrics is such that higher percentages are expected in degraded sites than in reference sites. For these metrics, the scoring is reversed so that a score of 1 is assigned for values above the 95th percentile, a score of 3 is assigned for values between the 95th percentile and the median, and a score of 5 is assigned for values below the median. No score is assigned to the Tanypodini to Chironomidae percent abundance ratio metric if there are no chironomids in the sample (the ratio cannot be calculated). Likewise, no score is assigned to the Tolerance Score metric if none of the species for which there are tolerance values are present in the sample.

Abundance and biomass respond bimodally to pollution (Pearson and Rosenberg 1978). An increase in abundance and/or biomass of organisms is expected at polluted sites when stress from pollution is moderate, such as at sites where there is organic enrichment of the sediment. A decrease in the abundance and biomass of organisms is expected at sites with high degrees of stress from pollution. Therefore, for these two metrics, an upper threshold corresponding to the 95th percentile of reference sites was established in addition to the lower threshold corresponding to the 5th percentile. For total species abundance and total biomass, a score of 1 is assigned if the value of these metrics for the sample being evaluated is below the 5th percentile or above the 95th percentile of corresponding reference values, a score of 3 is assigned for values between the 5th and 25th or between the 75th and 95th percentiles, and a score of 5 is assigned for values between the 25th and 75th percentiles. Table 4 shows the thresholds used to score each metric of the Chesapeake Bay B-IBI. The B-IBI index value for a sample is computed by averaging the scores of the individual metrics.

Table 4. Threshold values used to score biocriteria (metrics) of the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI).

	Scoring Criteria		
	5	**3**	**1**
Tidal Freshwater (≤ 0.5 ppt)			
Abundance (# m^{-2})	≥1,050-4,000	800-1050 or ≥ 4,000-5500	<800 or ≥5500
Abundance of pollution-indicative taxa (%)	≤39	39-87	>87
Abundance of deep deposit feeders (%)	≤70	70-95	>95
Tolerance Score	≤8	8-9.35	>9.35
Oligohaline (≥ 0.5 – 5 ppt)			
Abundance (# m^{-2})	≥450-3,350	180-450 or ≥3,350-4,050	<180 or ≥4050
Abundance of pollution-indicative taxa (%)	≤27	27-95	>95
Abundance of pollution-sensitive taxa (%)	≥26	0.2-26	<0.2
Abundance of carnivores and omnivores (%)	≥35	15-35	<15
Tolerance Score	≤6	6-9.05	>9.05
Tanypodini to Chironomidae abundance ratio (%)	≤17	17-64	>64
Low Mesohaline (≤ 5 - 12 ppt)			
Shannon-Weiner Diversity	≥2.5	1.7-2.5	<1.7
Abundance (# m^{-2})	≥1,500-2,500	500-1,500 or ≥2,500-6,000	<500or ≥6,000
Biomass (g DW m^{-2})	≥5-10	1-5 or >10-30	<1 or ≥30
Abundance of pollution-indicative taxa (%)	≤10	10-20	>20
Biomass of pollution-sensitive taxa (%)	≥80	40-80	<40
Biomass > 5 cm below the sediment-water interface (%)	≥80	10-80	<10
High Mesohaline – Mud (≥ 12 - 18 ppt, > 40% silt-clay)			
Shannon-Weiner Diversity	≥3.0	2.0-3.0	<2.0
Abundance (# m^{-2})	≥1,500-2,500	1,000-1,500 or ≥2,500-5,000	<1,000 or ≥5,000
Biomass (g DW m^{-2})	≥2-10	0.5-2 or ≥10-50	<0.5 or ≥50
Biomass of pollution-indicative taxa (%)	≤5	5-30	>30
Biomass of pollution-sensitive taxa (%)	≥60	30-60	<30
Abundance of carnivores and omnivores (%)	≥25	10-25	<10
Biomass > 5 cm below the sediment-water interface	≥60	10-60	<10

Table 4, continued. Threshold values used to score biocriteria (metrics) of the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI).

	Scoring Criteria		
	5	**3**	**1**
High Mesohaline – Sand ($\geq$ 12 - 18 ppt, $\leq$ 40% silt-clay)			
Shannon-Weiner Diversity	$\geq$3.2	2.5-3.2	<2.5
Abundance (# m^{-2})	$\geq$1,500-3,000	1,000-1,500 or $\geq$3,000-5,000	<1,000 or $\geq$5,000
Biomass (g DW m^{-2})	$\geq$3-15	1-3 or $\geq$15-50	<1 or $\geq$50
Abundance of pollution-indicative taxa (%)	$\leq$10	10-25	>25
Abundance of pollution-sensitive taxa (%)	$\geq$40	10-40	<10
Abundance of carnivores and omnivores (%)	$\geq$35	20-35	<20
Polyhaline – Mud ($\geq$ 18 - 30 ppt, > 40% silt-clay)			
Shannon-Weiner Diversity	$\geq$3.3	2.4-3.3	<2.4
Abundance (# m^{-2})	$\geq$1,500-3,000	1,000-1,500 or $\geq$3,000-8,000	<1,000 or $\geq$8,000
Biomass (g DW m^{-2})	$\geq$3-10	0.5-3 or $\geq$10-30	<0.5 or $\geq$30
Biomass of pollution-indicative taxa (%)	$\leq$5	5-20	>20
Biomass of pollution-sensitive taxa (%)	$\geq$60	30-60	<30
Abundance of carnivores and omnivores (%)	$\geq$40	25-40	<25
Number of taxa > 5 cm below the sediment-water interface (%)	$\geq$40	10-40	<10
Polyhaline – Sand ($\geq$ 18 - 30 ppt, $\leq$ 40% silt-clay)			
Shannon-Weiner Diversity	$\geq$3.5	2.7-3.5	<2.7
Abundance (# m^{-2})	$\geq$3,000-5,000	1,500-3,000 or $\geq$5,000-8,000	<1,500 or $\geq$8,000
Biomass (g DW m^{-2})	$\geq$5-20	1-5 or $\geq$20-50	<1 or $\geq$50
Biomass of pollution-indicative taxa (%)	$\leq$5	5-15	>15
Abundance of pollution-sensitive taxa (%)	$\geq$50	25-50	<25
Abundance of deep deposit feeders (%)	$\geq$25	10-25	<10

4.8 Benthic Meioinvertebrates

Meiofaunal community structure was used to elucidate potential impacts of disturbance on shallow water benthic food webs. Meiofauna exert top down control on benthic processes by feeding on primary producers, bacteria, and detritus. They also serve as major sources of food for higher trophic levels. In conjunction with the SERDP-funded study, William Metcalfe (M.S. program) completed a study of meiofauna community structure at the 2003 sites and two additional sampling sites of SA and CH (Metcalfe 2005).

Methods used by Metcalfe (2005) were similar to those being used in this report. The additional sites were visited once during 2003, within 2-3 weeks of the completion of sampling for the SERDP-funded project and within the index period for the B-IBI. Cores from SA and CH were processed in the field on the day of sampling as they were not used for flux studies.

Following completion of the core incubation and flux measurements, the large cores were sub-sampled for meiofauna using a 5 mL Fortuna syringe (1.1 cm i.d.) to 5 cm depth. Samples were washed using stacked 500 µm and 63 µm screens followed by a final rinse on a 63 µm screen. The 500 µm screen retained larger debris and macrofauna, while the 63 µm screen retained meiofauna, detritus, and fine sediment. This fine material was transferred to a pre-labeled 50 mL centrifuge tube for subsequent processing. Ludox –AM®, a colloidal silica (or silica sols) made by DuPont was used to form an isopycnic density gradient within the centrifuge tube. After addition of the Ludox, samples were centrifuged at 2000 rpm for 15 minutes. Supernatant was decanted onto a 63 µm sieve to isolate and capture suspended organisms. These samples were washed into prelabeled 100 mL beakers with 20-30 mL of 3% formalin in filtered buffered seawater stained with rose bengal, and immediately processed or stored in a refrigerator. Organisms in each sample were sorted to major taxonomic groups (polychaetes, oligocheates, copepods, mites, ostracods, forams, bivalves, nematodes, turbellarians) using a dissecting microscope and enumerated.

4.9 Secondary Production and Food Web Structure

Macrofaunal secondary production in soft-sediment habitats was used to elucidate potential impacts of disturbance on shallow water benthic food webs. Macrofauna also exert top down control on benthic processes by feeding on primary producers, bacteria, and detritus and serve as major sources of food for higher trophic levels. Doctoral student David Gillett (in progress) analyzed macrobenthic data from all SERDP sites (2003-2005) as well as the secondary sites added for 2003.

Methods used by Gillett (in progress) were the same as those used for the main study. Macrobenthic production at all of the sites studied was empirically estimated using the measured species-specific biomass data. For the oligohaline through high-mesohaline salinity regimes, production was estimated using the equations of Edgar (1990) (eq 1), where b is biomass of a given taxa in µg AFDM m^{-2}, t is temperature in °C, and P is production in mg AFDM m^{-2} d^{-1}. Given the distinct faunal differences in tidal freshwater (see Appendix A), the production equation of Morin and Bourassa (1992) (eq 2) was used to empirically estimate production, where *b* is annual biomass in g dry mass (DM) m^{-2}, *m* is mean individual biomass in mg DM, *t* is temperature in °C, and *P* is production in g DM m^{-2} y^{-1}. These estimates of annual DM production were then converted to annual AFDM using equations 3 and 4 for non-bivalves and bivalves, respectively.

$$\log_{10}P = -2.31 + 0.80*\log_{10}b + 0.89*\log_{10}t \qquad \text{(eq. 1)}$$

$$\log_{10}P = -0.75 + 1.01*\log_{10}B - 0.34*\log_{10}M + 0.037*T \qquad \text{(eq. 2)}$$

$$\text{AFDM } P = -0.00005 + 0.8198*\text{DM } P \text{ (non-bivalves)} \qquad \text{(eq. 3)}$$

n=272; r^2=0.992; p<0.0001

$$\text{AFDM } P = 0.0013 + 0.05137*\text{DM } P \text{ (bivalves)} \qquad \text{(eq. 4)}$$

n=88; r^2=0.999; p<0.0001

4.10 Data Analysis

Preliminary analyses of all data (means, standard errors) were completed using Excel. PRIMER 6 was used to calculate macrofauna diversity, species richness and evenness, conduct multiple dimensional scaling (MDS) ordination of taxa data, and conduct Principal Components Analysis (PCA) of environmental, macrofaunal metrics, and ecosystem function variables. StatView 5.0 for Windows was used to perform linear regressions and one-way ANOVA analyses on ecosystem process data. Tukey's test was used to evaluate pair-wise comparisons after a significant ANOVA; differences significant at p=0.05. SAS 9.1 was used to conduct 3-way ANOVA on macrofaunal metrics and ecosystem process measurements for main effects of stratum, status, and salinity regime, and Least Squares Means post-hoc analyses. Non-normal data were transformed as necessary prior to ANOVA analyses.

5. RESULTS AND ACCOMPLISHMENTS

5.1 Preliminary Site Characterization and Stratum Selection

5.1.1 Historical Water Quality

Historical water quality data from a 10-year period (1993-2002), or a shorter time based on available data, were evaluated for candidate study sites to assess potential impairment and assist in site selection for the study (Table 5). Both regional and local water quality were analyzed. "Regional" water quality stations are located in major tributaries of Chesapeake Bay, generally in channel regions, and are considered to be representative of regional water quality. "Local" stations are located in minor tributaries, generally adjacent to the study sites, and are considered to be representative of local water quality. Tables 5-11 provide the general statistics for the following water quality parameters: dissolved oxygen, salinity, temperature, ammonium, nitrate + nitrite, phosphate, and chlorophyll a.

5.1.2 High Mesohaline Sites

For sites studied in 2003, regional water quality data indicated that they had similar historic salinity conditions, with median values of 20.6 to 22.8 ppt; thus, they are categorized as being located in historically polyhaline waters (salinity range of 18-30 ppt) (Tables 6, 7). We conducted our evaluations during a relatively wet year (2003) and the actual salinities measured at all sites were in the high mesohaline range (12-18 ppt). At all stations, with the exception of YRK-R (Sarah Creek), the percent of DO measurements above 5 mg/L was greater than 80%. However, at the local station for Sarah Creek, SAR-L, all DO values were above 5 mg/L. The Elizabeth River had the highest observed water column nutrient concentrations, followed by Sarah Creek, suggesting that they are degraded relative to the other 2003 sites described in this report. Local stations generally had higher nutrient concentrations than regional stations, due to their location farther upriver and closer to potential nutrient sources.

Langley Air Force Base: No B-IBI data were available for the Back River, but the EPA EMAP Virginian Province Benthic Index (VP-BI) scores for two stations in the main stem of the Back River were 2.4 and 1.7 (EPA EMAP database, http://www.epa.gov/emap; Paul et al. 1999), wherein a positive score indicates healthy benthic conditions and a negative one indicates degraded conditions (Paul et al. 1999). After consultation with the LAFB Natural Resources and Restoration staff, we conducted preliminary field characterization (e.g., salinity, temperature, sediment grain size, bulk density, organic and nutrient contents, exposure, benthic chlorophyll) at five candidate sites in shallow waters (0.5 – 0.75 m MLW) adjacent to LAFB in June 2003 (Figure 7). The data are presented in Table 12 and Figure 8. Tabbs Creek and an area in the Northwest Branch of the Back River (site C) were identified as suitable near- and far-field strata, respectively. Tabbs Creek is a shallow tidal creek <1 m at MLW with muddy sediments and is bordered by a *Spartina* spp.-dominated marsh. A golf course is located at the head of the creek. Dredging of soils contaminated with PCBs and PCTs along Tabbs Creek, upriver of the sampling stations, occurred in 1999-2000 along with extensive restoration of intertidal brackish

Table 5. Historical regional water quality station information. "Regional" water quality stations are located in major tributaries of Chesapeake Bay, generally in channel regions, and are considered to be representative of regional water quality. "Local" stations are located in minor tributaries, generally adjacent to the study sites, and are considered to be representative of local water quality. Ten years of historic data (1/93 to 12/02 or when data were available during this time period) from the Chesapeake Bay Program (CBP) water quality database (http://www.chesapeakebay.net/data/index.htm) and Virginia Department of Environmental Quality (VADEQ) surface water quality monitoring database (http://www.deq.virginia.gov/watermonitoring/monitoring.html).

Data Code	Site	Waterbody; regional or local	Station #	Source	Inclusive Dates	Surface (S) or Bottom (B) Water
MJB-R	Thorntons Creek	Mobjack Bay, regional	WE4.1	CBP	1/93-12/02	B, except chla
POQ-R	Chisman Creek	Poquoson River, regional	WE4.3	CBP	1/93-12/02	B, except chla
BCK-R	Langley AFB	Back River, Regional	WE4.4	CBP	1/93-12/02	B, except chla
YRK-R	Sarah Creek	York River, regional	LE4.3	CBP	1/93-12/02	B, except chla
ER-R	Elizabeth River	Elizabeth River, regional	LE5.6	CBP	1/93-12/02	B, except chla
CHI-L	Chisman Creek	Chisman Creek, local	widely pier	VADEQ	1/97-11/02	Not available
SAR-L	Sarah Creek	Sarah Creek, local	mouth	VADEQ	1/97-11/02	Not available
ER-L	Elizabeth River	Elizabeth River, local	SBE5	CBP	1/93-12/02	B, except chla
MON-R	Monie Bay	Nanticoke River, regional	EE3.1	CBP	1/93-12/02	B, except chla
PAX-R	Patuxent NAS	Patuxent River, regional	LE1.4	CBP	1/93-12/02	B, except chla
FTE-R	Fort Eustis	James River, regional	LE5.1	CBP	1/93-12/02	B, except chla
MON-LF	Monie Bay, far	Monie Bay, local	site 1	Apple et al. 2004	4/00-1/02	S
MON-LN	Monie Bay, near	Monie Bay, local	site 4	Apple et al. 2004	4/00-1/02	S
WAR-LN	Fort Eustis, near	Warwick River, local	2WWK003.98	VADEQ	1/96-11/02	S
PAG-LF	Pagan, far	Pagan River, local	2PGN000.00	VADEQ	2/93-11/02	S
PAG-LN	Pagan, near	Pagan River, local	2PGN005.46	VADEQ	2/93-11/02	S
PAM-R	Sweet Hall Marsh	Pamunkey River, regional	TF4.2	CBP	1/93-12/02	B, except chla
GPR-R	Aberdeen Proving Ground	Gun Powder River (Upper CB), regional	WT2.1	CBP	1/93-12/02	B, except chla
POT-R	Quantico	Potomac River, regional	TF2.4	CBP	1/93-12/02	B, except chla
UPOT-R	Anacostia	Upper Potomac River, regional	TF2.1	CBP	1/93-12/02	B, except chla
QT-LN	Quantico, near	Chopawamsic Creek, local	1ACHO003.65	VADEQ	1/93-12/00	S
AN-LN	Anacostia, near	Anacostia River, local	ANA08	CBP	1/97-12/02	S
AN-LF	Anacostia, far	Anacostia River, local	ANA14	CBP	1/99-12/02	S

Table 6. Historical regional water quality data for the 2003 high mesohaline sites. All parameters are for bottom water except chlorophyll a (CHL-a), which is for surface water. CBP ROC=Chesapeake Bay Program Region of Concern.

Station Code	**MJB-R**	**POQ-R**	**BCK-R**	**YRK-R**	**ER-R**
Parameter / Site	Thorntons	Chisman	LAFB	Sarah	Elizabeth
CBP ROC? 0=no, 1=yes	0	0	0	0	1
DO (mg/L) (%>5mg/L)	96.55	99.16	98.25	71.55	84.48
DO (mg/L) MEDIAN	8.69	8.80	8.89	7.10	7.30
DO (mg/L) MEAN	8.67	8.82	8.96	6.89	7.54
DO (mg/L) 75th percentile	10.62	10.65	10.48	9.00	9.10
DO (mg/L) 25th percentile	6.78	6.99	7.39	4.33	5.80
SAL (PPT) MEDIAN	20.53	20.68	20.59	23.30	22.70
SAL (PPT) MEAN	19.82	20.07	19.97	22.92	22.91
SAL (PPT) 75th percentile	22.03	22.29	22.19	24.90	24.70
SAL (PPT) 25th percentile	18.36	18.58	18.41	20.80	21.50
TEMP (C) MEDIAN	16.47	16.58	16.84	15.56	16.01
TEMP (C) MEAN	15.80	16.09	16.27	15.25	15.65
TEMP (C) 75th percentile	24.44	24.53	24.43	22.80	22.60
TEMP (C) 25th percentile	8.30	8.68	8.87	8.31	9.15
NH4 (uM) MEDIAN	0.68	0.66	0.69	3.18	5.86
NH4 (uM) MEAN	1.26	1.12	0.97	4.90	7.02
NH4 (uM) 75th percentile	1.29	1.20	1.07	5.98	10.86
NH4 (uM) 25th percentile	0.40	0.40	0.40	1.75	2.86
NO3+NO2 (uM) MEDIAN	0.22	0.18	0.17	1.25	3.64
NO3+NO2 (uM) MEAN	1.62	0.93	0.62	2.24	4.92
NO3+NO2 (uM) 75th percentile	0.93	0.63	0.35	3.57	7.14
NO3+NO2 (uM) 25th percentile	0.09	0.09	0.08	0.50	1.20
PO4 (uM) MEDIAN	0.08	0.09	0.08	0.43	0.67
PO4 (uM) MEAN	0.12	0.13	0.09	0.56	0.87
PO4 (uM) 75th percentile	0.16	0.17	0.15	0.69	1.28
PO4 (uM) 25th percentile	0.03	0.04	0.03	0.23	0.33
CHL-a (ug/L) MEDIAN	7.64	6.78	5.84	6.40	7.81
CHL-a (ug/L) MEAN	8.07	7.49	6.80	7.98	9.35
CHL-a (ug/L) 75th percentile	10.15	10.25	9.13	10.10	12.00
CHL-a (ug/L) 25th percentile	4.49	3.59	3.12	4.36	4.60

Table 7. Historical local water quality data for the 2003 high mesohaline sites. For CHI-L and SAR-L stations, the detection limits were 2.86 uM and 3.57 uM for NH_4^+ and NO_3^-+NO_2^-, respectively.

Station code	**CHI-L**	**SAR-L**	**ER-L**
Parameter / Site	Chisman	Sarah	Elizabeth
DO (mg/L) (%>5mg/L)	93.44	100.00	72.88
DO (mg/L) MEDIAN	7.81	7.39	6.57
DO (mg/L) MEAN	8.09	8.09	6.59
DO (mg/L) 75th percentile	9.70	9.29	8.37
DO (mg/L) 25th percentile	6.38	6.45	4.92
SAL (PPT) MEDIAN	20.70	20.76	18.48
SAL (PPT) MEAN	20.08	20.53	17.91
SAL (PPT) 75th percentile	22.70	22.85	20.96
SAL (PPT) 25th percentile	18.35	18.70	15.77
TEMP (C) MEDIAN	15.39	23.12	19.44
TEMP (C) MEAN	16.01	20.35	19.62
TEMP (C) 75th percentile	23.89	26.05	26.58
TEMP (C) 25th percentile	9.20	14.88	13.58
NH4 (uM) MEDIAN	2.86	2.86	20.35
NH4 (uM) MEAN	5.01	4.78	21.55
NH4 (uM) 75th percentile	5.00	4.29	28.73
NH4 (uM) 25th percentile	2.86	2.86	14.11
NO3+NO2 (uM) MEDIAN	3.57	3.57	16.71
NO3+NO2 (uM) MEAN	3.63	3.95	18.49
NO3+NO2 (uM) 75th percentile	3.57	3.57	25.65
NO3+NO2 (uM) 25th percentile	3.57	3.57	9.66
PO4 (uM) MEDIAN	0.50	0.03	0.99
PO4 (uM) MEAN	0.49	0.03	1.28
PO4 (uM) 75th percentile	0.67	0.04	1.77
PO4 (uM) 25th percentile	0.33	0.02	0.48
CHL-a (ug/L) MEDIAN	10.63	13.26	3.95
CHL-a (ug/L) MEAN	15.30	12.34	7.22
CHL-a (ug/L) 75th percentile	13.19	16.87	10.13
CHL-a (ug/L) 25th percentile	6.03	8.33	2.03

Table 8. Historical regional water quality data for the 2004 low mesohaline sites. All parameters are for bottom water except chlorophyll a (CHL-a), which is for surface water. CBP ROC=Chesapeake Bay Program Region of Concern.

Station code	**MON-R**	**PAX-R**	**FTE-R**
Parameter / Site	Monie	PAX	Fort Eustis/ Pagan
CBP ROC? 0=no, 1=yes	0	0	0
DO (mg/L) (%>5mg/L)	85.84	77.97	100.00
DO (mg/L) MEDIAN	8.00	8.45	8.14
DO (mg/L) MEAN	8.05	7.95	8.55
DO (mg/L) 75th percentile	10.10	10.65	10.10
DO (mg/L) 25th percentile	6.10	5.65	6.61
SAL (PPT) MEDIAN	16.29	14.73	6.60
SAL (PPT) MEAN	15.47	14.18	6.67
SAL (PPT) 75th percentile	17.66	16.56	10.20
SAL (PPT) 25th percentile	13.86	12.17	3.00
TEMP (C) MEDIAN	14.50	14.05	17.60
TEMP (C) MEAN	14.95	14.69	17.16
TEMP (C) 75th percentile	23.80	23.08	24.83
TEMP (C) 25th percentile	7.10	6.43	9.49
NH4 (uM) MEDIAN	2.86	1.43	2.78
NH4 (uM) MEAN	5.06	3.20	4.32
NH4 (uM) 75th percentile	6.48	3.84	4.30
NH4 (uM) 25th percentile	0.95	0.64	1.20
NO3+NO2 (uM) MEDIAN	0.00	4.12	10.75
NO3+NO2 (uM) MEAN	0.00	10.06	14.70
NO3+NO2 (uM) 75th percentile	0.00	14.70	24.29
NO3+NO2 (uM) 25th percentile	0.00	0.98	5.21
PO4 (uM) MEDIAN	0.13	0.11	0.77
PO4 (uM) MEAN	0.18	0.18	0.82
PO4 (uM) 75th percentile	0.21	0.22	1.03
PO4 (uM) 25th percentile	0.10	0.08	0.63
CHL-a (ug/L) MEDIAN	9.27	8.04	5.25
CHL-a (ug/L) MEAN	10.83	10.15	7.05
CHL-a (ug/L) 75th percentile	13.21	11.36	8.68
CHL-a (ug/L) 25th percentile	6.48	5.71	3.33

Table 9. Historical local water quality data for the 2004 low mesohaline sites. For PAG-LF and PAG-LN stations, non-detect values were set at 1.43 uM and 1.79 uM for NH_4^+ and $NO_3^-+NO_2^-$, respectively. For WAR-LN, non-detect values were set at 1.43 uM and 0.71 uM for NH_4^+ and $NO_3^-+NO_2^-$, respectively.

Station code	**MON-LF**	**MON-LN**	**WAR-LN**	**PAG-LF**	**PAG-LN**
Parameter / Site	Monie, Far	Monie, Near	Fort Eustis, Near	Pagan, Far	Pagan, Near
DO (mg/L) (%>5mg/L)	NA	NA	82.05	96.36	75.44
DO (mg/L) MEDIAN	NA	NA	7.17	8.40	7.48
DO (mg/L) MEAN	NA	NA	7.85	8.41	7.47
DO (mg/L) 75th percentile	NA	NA	9.90	9.68	9.42
DO (mg/L) 25th percentile	NA	NA	5.52	6.78	5.04
SAL (PPT) MEDIAN	11.30	11.10	10.95	13.50	9.00
SAL (PPT) MEAN	12.35	11.74	10.85	13.28	8.83
SAL (PPT) 75th percentile	14.10	12.65	14.80	16.85	12.80
SAL (PPT) 25th percentile	11.00	10.40	6.85	9.95	4.50
TEMP (C) MEDIAN	22.00	21.50	15.91	17.50	14.60
TEMP (C) MEAN	18.91	18.42	16.06	16.91	17.01
TEMP (C) 75th percentile	25.60	24.88	24.07	23.98	23.64
TEMP (C) 25th percentile	13.00	12.80	8.99	11.06	11.84
NH4 (uM) MEDIAN	1.67	2.51	2.86	2.86	7.14
NH4 (uM) MEAN	1.96	2.17	4.22	4.19	11.58
NH4 (uM) 75th percentile	2.41	3.21	6.25	5.89	13.75
NH4 (uM) 25th percentile	0.98	0.97	1.43	1.43	2.86
NO3+NO2 (uM) MEDIAN	5.56	1.96	1.43	5.00	17.14
NO3+NO2 (uM) MEAN	7.76	4.23	1.47	9.09	62.67
NO3+NO2 (uM) 75th percentile	13.80	7.80	1.43	13.75	98.39
NO3+NO2 (uM) 25th percentile	0.24	0.38	0.71	1.79	3.12
PO4 (uM) MEDIAN	0.02	0.04	1.33	2.00	4.33
PO4 (uM) MEAN	0.04	0.32	1.43	2.36	10.01
PO4 (uM) 75th percentile	0.05	0.08	1.67	3.00	14.67
PO4 (uM) 25th percentile	0.01	0.01	1.00	1.33	2.00
CHL-a (ug/L) MEDIAN	12.34	6.71	16.16	9.52	26.45
CHL-a (ug/L) MEAN	14.30	7.72	15.70	13.70	29.25
CHL-a (ug/L) 75th percentile	16.78	9.45	21.39	14.56	39.68
CHL-a (ug/L) 25th percentile	7.15	5.50	8.89	4.28	14.17

Table 10. Historical regional water quality data for the 2005 tidal freshwater sites. All parameters are for bottom water except chlorophyll a (CHL-a), which is for surface water. CBP ROC=Chesapeake Bay Program Region of Concern.

Station code	**PAM-R**	**GPR-R**	**POT-R**	**UPOT-R**
Parameter / Site	Sweet Hall	APG	Quantico	Anacostia
CBP ROC? 0=no, 1=yes	0	0	0	0
DO (mg/L) (%>5mg/L)	86.32	98.15	99.16	98.33
DO (mg/L) MEDIAN	7.40	9.85	8.80	8.80
DO (mg/L) MEAN	7.82	9.58	9.06	9.10
DO (mg/L) 75th percentile	9.50	11.40	11.50	11.03
DO (mg/L) 25th percentile	5.93	7.70	7.00	7.00
SAL (PPT) MEDIAN	0.00	1.90	0.00	0.00
SAL (PPT) MEAN	0.16	2.27	0.56	0.00
SAL (PPT) 75th percentile	0.08	3.56	0.60	0.00
SAL (PPT) 25th percentile	0.00	0.16	0.00	0.00
TEMP (C) MEDIAN	17.08	15.97	15.28	15.43
TEMP (C) MEAN	17.06	15.65	15.80	14.95
TEMP (C) 75th percentile	25.22	24.78	24.35	24.43
TEMP (C) 25th percentile	9.90	7.38	6.40	6.63
NH4 (uM) MEDIAN	2.64	1.07	7.43	8.96
NH4 (uM) MEAN	2.80	3.01	8.84	11.28
NH4 (uM) 75th percentile	3.43	4.23	12.25	15.59
NH4 (uM) 25th percentile	1.86	0.57	4.21	5.25
NO3+NO2 (uM) MEDIAN	18.07	11.64	87.14	121.04
NO3+NO2 (uM) MEAN	16.96	33.38	87.58	123.92
NO3+NO2 (uM) 75th percentile	23.57	60.73	118.50	151.84
NO3+NO2 (uM) 25th percentile	7.50	1.29	51.86	102.14
PO4 (uM) MEDIAN	0.67	0.20	0.90	0.70
PO4 (uM) MEAN	0.75	0.23	0.91	0.76
PO4 (uM) 75th percentile	0.83	0.33	1.20	0.93
PO4 (uM) 25th percentile	0.50	0.11	0.61	0.46
CHL-a (ug/L) MEDIAN	2.60	14.49	6.98	4.86
CHL-a (ug/L) MEAN	4.07	17.76	11.90	10.46
CHL-a (ug/L) 75th percentile	5.86	25.42	15.40	14.52
CHL-a (ug/L) 25th percentile	1.16	7.16	3.34	2.16

Table 11. Historical local water quality data for the 2005 tidal freshwater sites. For QT-LN station, the detection limits were 2.86 uM and 3.57 uM for NH_4^+ and NO_3^-+NO_2^-, respectively.

Station code	**QT-LN**	**AN-LN**	**AN-LF**
Parameter / Site	Quantico, Near	Anacostia, Near	Anacostia, Far
DO (mg/L) (%>5mg/L)	97.50	71.43	72.92
DO (mg/L) MEDIAN	8.80	7.00	6.70
DO (mg/L) MEAN	8.94	6.96	6.87
DO (mg/L) 75th percentile	10.85	9.20	9.13
DO (mg/L) 25th percentile	7.38	4.80	4.68
SAL (PPT) MEDIAN	NA	0.00	0.00
SAL (PPT) MEAN	NA	0.00	0.00
SAL (PPT) 75th percentile	NA	0.00	0.00
SAL (PPT) 25th percentile	NA	0.00	0.00
TEMP (C) MEDIAN	14.04	15.72	15.87
TEMP (C) MEAN	13.95	15.00	16.20
TEMP (C) 75th percentile	20.83	24.98	24.60
TEMP (C) 25th percentile	7.98	8.85	9.08
NH4 (uM) MEDIAN	2.86	19.64	18.54
NH4 (uM) MEAN	3.52	20.99	19.76
NH4 (uM) 75th percentile	3.57	28.87	25.17
NH4 (uM) 25th percentile	2.86	10.77	13.66
NO3+NO2 (uM) MEDIAN	3.57	44.04	42.46
NO3+NO2 (uM) MEAN	8.43	49.03	46.04
NO3+NO2 (uM) 75th percentile	5.00	60.00	56.32
NO3+NO2 (uM) 25th percentile	3.57	31.78	32.30
PO4 (uM) MEDIAN	0.33	0.50	0.45
PO4 (uM) MEAN	0.57	0.59	0.53
PO4 (uM) 75th percentile	0.67	0.75	0.77
PO4 (uM) 25th percentile	0.33	0.27	0.26
CHL-a (ug/L) MEDIAN	NA	11.05	13.70
CHL-a (ug/L) MEAN	NA	15.14	18.89
CHL-a (ug/L) 75th percentile	NA	21.23	28.06
CHL-a (ug/L) 25th percentile	NA	5.93	4.98

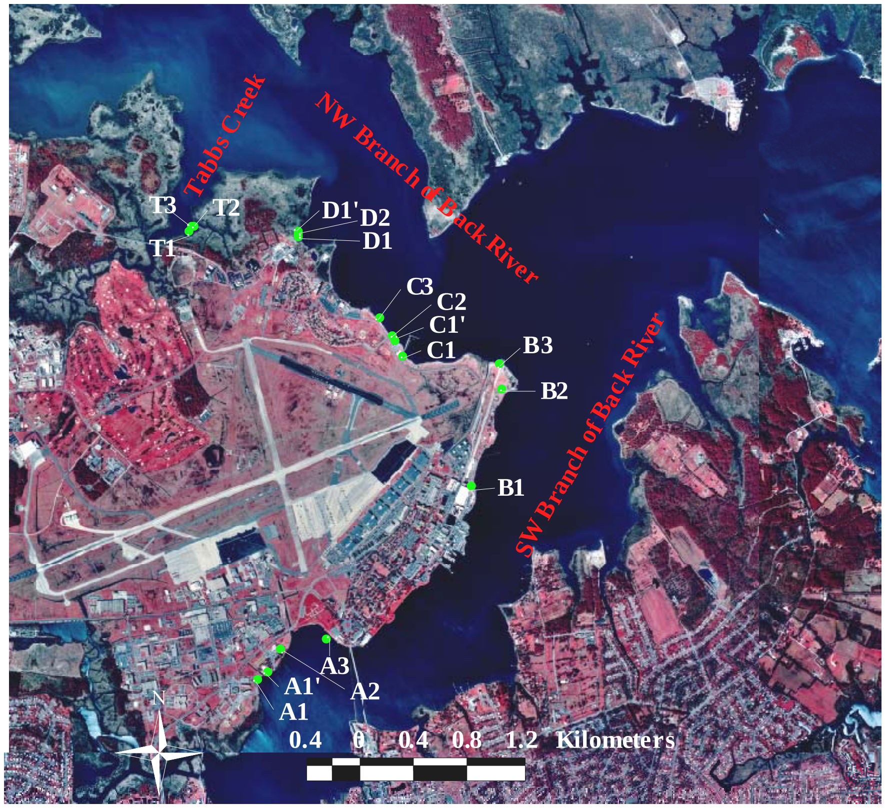


Figure 7. Preliminary field characterization locations at the Langley AFB. Sites A to D are located in the Back River. T is in Tabbs Creek.

Table 12. Temperature, salinity, and % mud content (from top 11.5 cm) of sediment from the Langley AFB's preliminary field characterization sites. NA, data not collected.

Sample	Temp (°C)	Salinity (ppt)	% Mud
A1	24.5	15	33.09
A1'	24.1	15.1	61.78
A2	24.5	15	49.55
A3	24.5	15.3	30.55
B1	23.9	15.6	1.17
B1'	24	15.5	13.69
B2	24.2	15.8	9.61
B3	23.9	15.8	10.65
C1	25.8	15.8	2.85
C1'	25.6	15.8	7.64
C2	25.6	15.8	5.55
C3	25.1	15.7	6.23
D1	24.9	15.8	28.25
D1'	25.1	16.1	9.07
D2	24.9	15.8	12.54
Tabbs 1	27.7	12.9	NA
Tabbs 2	28.1	12.8	NA
Tabbs 3	27.8	13.7	NA

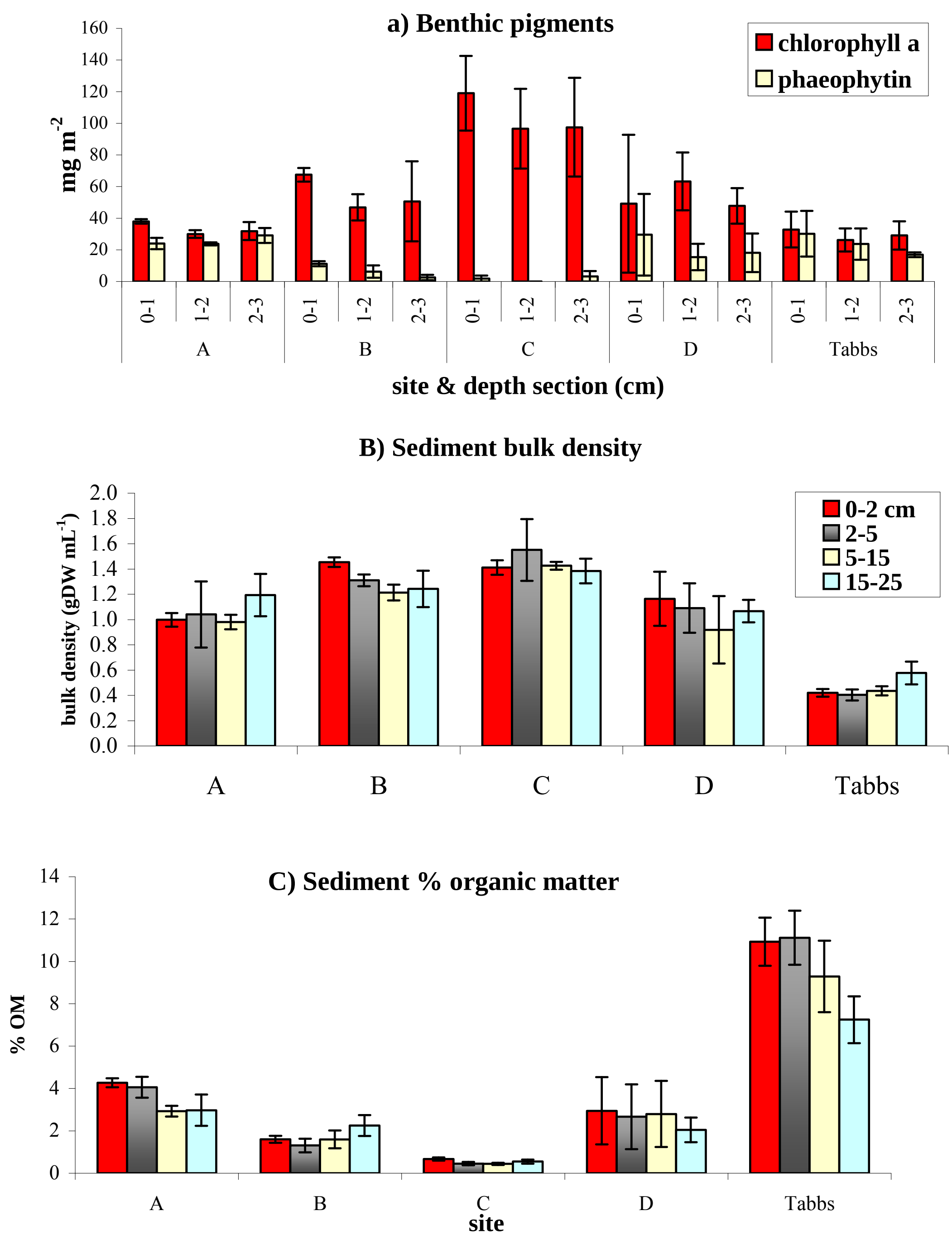


Figure 8. Langley AFB's preliminary site characterization: A) Mean benthic pigments by depth section, B) mean sediment bulk density by depth section, and C) mean % organic matter of sediment by depth section. Error bars represent standard errors (n=3).

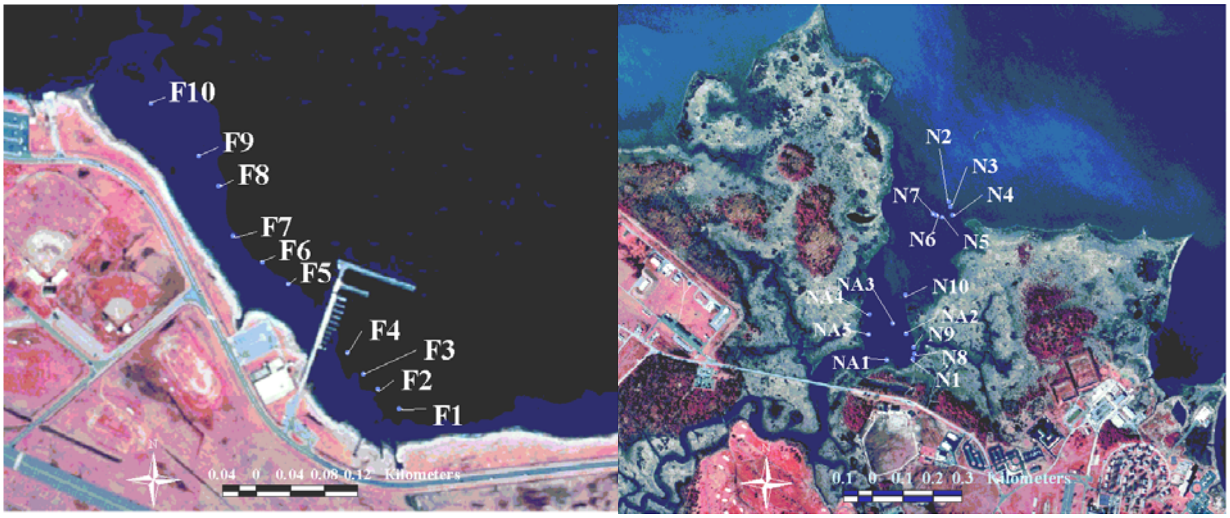


Figure 9. Location of sampling stations in far-field (left) and near-field (right) strata at the Langley AFB. Additional sediment cores for B-IBI analyses were collected at stations NA1 to NA5 in August 2003.

wetlands in areas close to our near-field sampling sites. The far-field site is an exposed, open water area with sandy sediments and nearby seagrass (*Zostera marina*) beds. Figure 9 shows the location of the ten stations in each stratum that were randomly selected along the shoreline for the summer study.

Thorntons Creek: The Mobjack Bay, near Thorntons Creek, is relatively pristine compared to many areas in the Chesapeake Bay, based on an evaluation of the Index of Environmental Integrity (IEI) scores (USEPA 2002). The IEI is an aggregation of indicator data for eutrophication, sediment contamination, and benthic condition, with a value of 5 representing good condition, 3 fair, and 1 poor. Mobjack Bay had an overall IEI score of 3.6, which was higher than scores for 14 other Chesapeake Bay sites studied in the report. In sediment samples (top 5 cm) collected at four locations in Thorntons Creek, mud content (silt-clay) varied from 27 to 73% and organic matter content ranged from 5.7 to 14.5%. Based on these characteristics, Thorntons Creek was deemed a satisfactory match to serve as the pristine reference near-field site for the LAFB site. A sandy area in the Southwest Branch of the Severn River was identified as an appropriate far-field site because it has similar physical characteristics and exposure as that of the far-field site in LAFB (Figure 10). Figure 11 shows the randomly selected sampling stations at each stratum.

Elizabeth River: For the near-field stratum site in the Southern Branch, we identified a shallow, muddy inlet with relatively low physical disturbance adjacent to the Atlantic Wood facility (Figure 12). The inlet is contaminated with polycyclic aromatic hydrocarbons (PAHs) and creosote (Lockheed Martin 2002). Water runoff from the Atlantic Wood facility drains to the inlet via two storm water outfalls and direct surface water runoff. Fish and benthic invertebrates in laboratory toxicity tests demonstrated acute toxicity to sediments from the

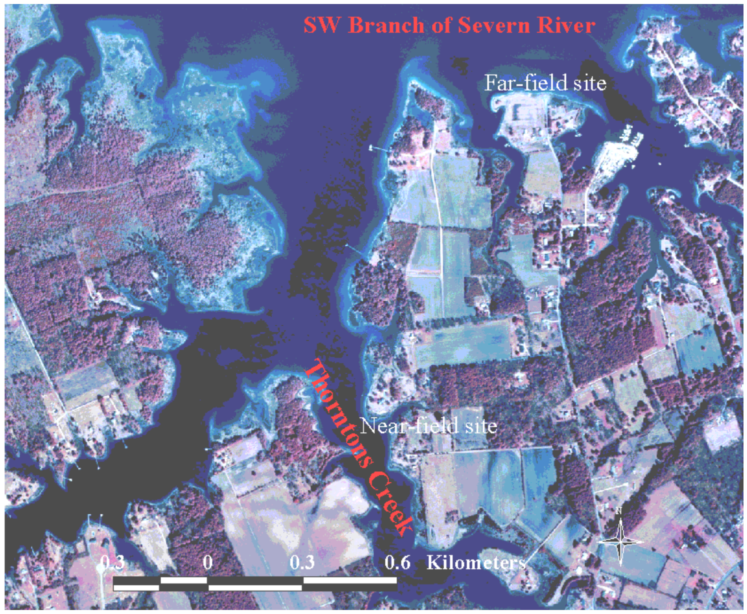


Figure 10. Far- and near-field strata in Thorntons Creek and the Southwestern Branch of Severn Creek.

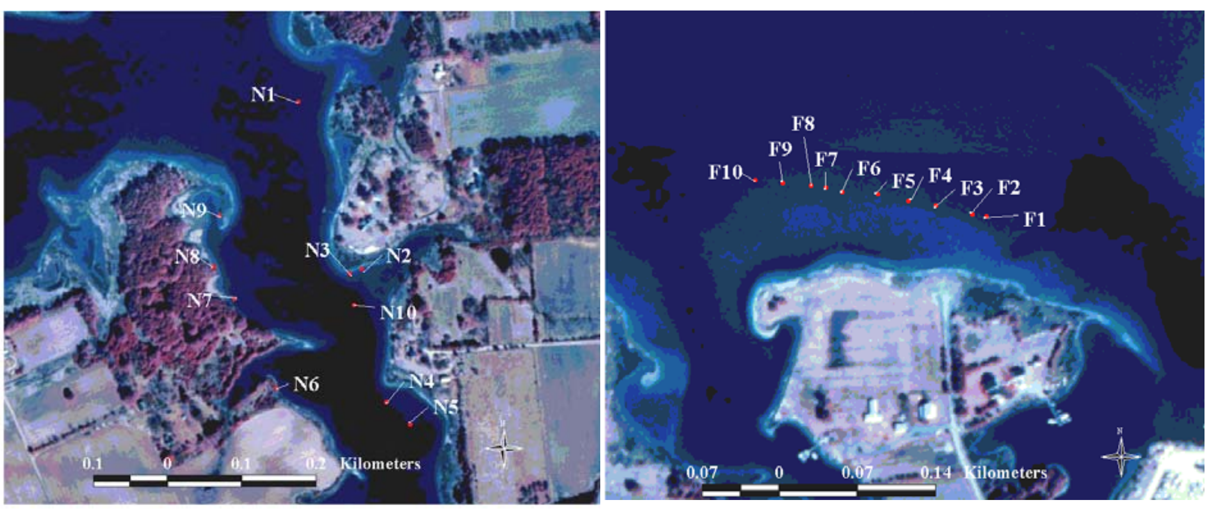


Figure 11. Location of sampling stations in far-field (right) and near-field (left) strata at Thorntons Creek and the Southwestern Branch of Severn River.

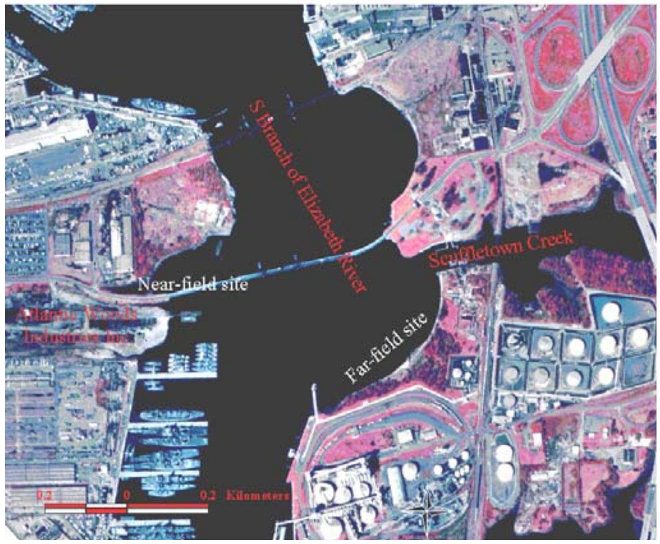


Figure 12. Far- and near-field strata in the Southern Branch of the Elizabeth River.

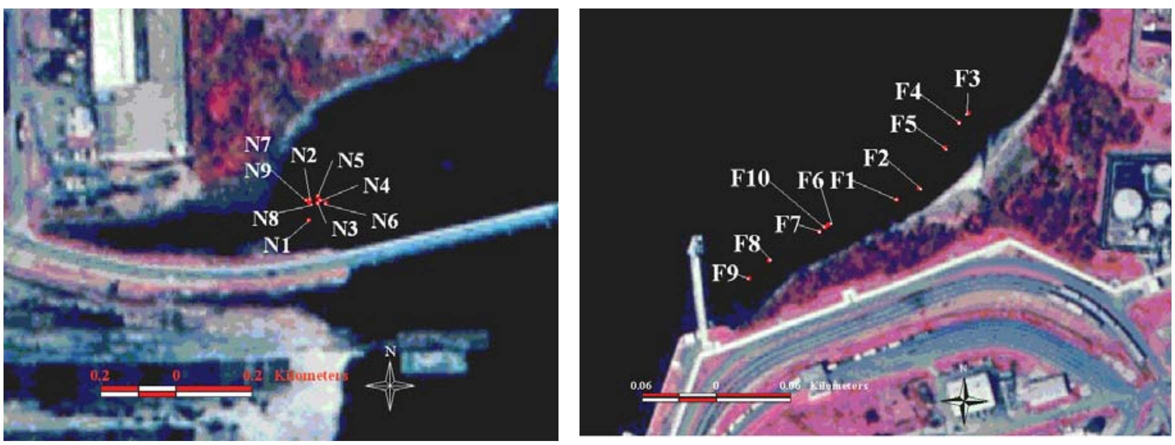


Figure 13. Location of sampling stations in far-(right) and near-field (left) strata at the Southern Branch of the Elizabeth River.

vicinity of Atlantic Wood. There are significantly fewer taxa of benthic macroinvertebrates in the Atlantic Wood area compared to a York River reference area. A sample collected near Atlantic Wood in deep water (14 m) had a B-IBI score of 2.0 (Dauer 2000). A sandy, exposed area at the mouth of Scuffletown Creek was identified as the far-field stratum site (Figure 12). The creek, which is across from Atlantic Wood, is a proposed location for sediment contaminant removal and other restoration activities. Dauer (2000) randomly sampled Scuffletown Creek in 1999; B-IBI values in the sandy area, with mud content ranging from 9.6 to 18.5%, varied from 2.3 to 3.7. Figure 13 shows the location of randomly selected sampling stations at each stratum.

5.1.3 Low Mesohaline Sites

The four sites studied in 2004 are located in oligohaline to low mesohaline waters (salinity range of 0.5-12 ppt), with the historic regional median salinity ranging from 6.6 to 15.7 ppt (Table 8). Median salinity at the local stations ranged from 9.0 to 13.5 ppt (Table 9). The Pagan River and Fort Eustis shared the same regional water quality station (FTE-R) located on the James River. At all stations, the percent of DO measurements above 5 mg/L was greater than 80%, except for PAX-R (Patuxent) and PAG-LN (Pagan) suggesting greater eutrophication at these stations. Total N concentrations, especially for nitrate + nitrite, were highest for the Fort Eustis and Pagan River stations, especially PAG-LN, which is an upriver monitoring station close to a former meat-processing plant discharge point (discontinued in 1997). Even with the discontinued wastewater discharges, observed nutrient concentrations remained relatively high.

Fort Eustis: B-IBI scores in the James River in the vicinity of Fort Eustis varied between 2.2 to 5 (10 stations; mean of 3.1), suggesting diverse benthic conditions from moderately degraded to healthy (CBP-benthic unpublished). The EPA EMAP VP-BI scores for four stations in the James River near Fort Eustis ranged between 0.1 to 1.17, where positive scores indicate relatively healthy benthic conditions (USEPA unpublished, Paul et al. 1999). At the mouth of the Warwick River, a B-IBI score of 2.7 and EMAP VP-BI score of -0.82 indicated degraded benthic conditions (CBP-benthic unpublished, USEPA unpublished).

After consultation with the Fort Eustis Natural Resources and Restoration staff, we conducted preliminary field characterization at ten candidate sites in shallow waters (0.5 – 0.75 m MLW) of the James and Warwick Rivers adjacent to Fort Eustis in April 2004 (Figure 14). The data are presented in Table 13 and Figure 15 North Anzio Beach (NA) and an area in the Warwick River (site W1) were identified as suitable far- and near-field strata, respectively. North Anzio Beach is an exposed, open water area on the James River where military exercises are conducted in the intertidal zone and on the beach. Adjacent to site W1 on the Warwick River are a landfill (53.5 acres) and a small tidal creek that drains Browns Lake. From 1951 to 1972, the landfill reportedly received municipal solid waste, construction debris, garbage, miscellaneous refuse (e.g., paints, oils, pesticide and herbicide containers), and infectious waste contaminated with pathogens. The following compounds were detected in the groundwater, but below their respective Maximum Contaminant Levels (MCLs): chloroform, chlorobenzene, 1,4-dichlorobenzene, naphthalene, and carbon disulfide (Malcolm Pirnie 1998). The following compounds and metals were detected, but below their MCLs: bis(2-Ethylhexyl)phthalate, barium, cadmium, and zinc. Figure 16 shows the randomly selected stations in each stratum where field samples were collected during the summer.

Patuxent Naval Air Station: B-IBI scores in the Patuxent River near the PAX area varied between 1.7 to 3.8 (7 stations; mean of 2.8) and EPA EMAP VP-BI scores for three stations near PAX were –0.22, -0.31, and 1.85, indicating both degraded and intermediate benthic health (CBP-benthic unpublished, USEPA unpublished). We conducted preliminary field characterization at six candidate sites in creeks and basins located on the military installation in May 2004, based upon information and recommendations from the PAX Natural Resources and Restoration staff (Figure 17). Benthic pigment, sediment bulk density, and percent organic matter data are shown in Table 14 and Figure 18. We made many attempts to

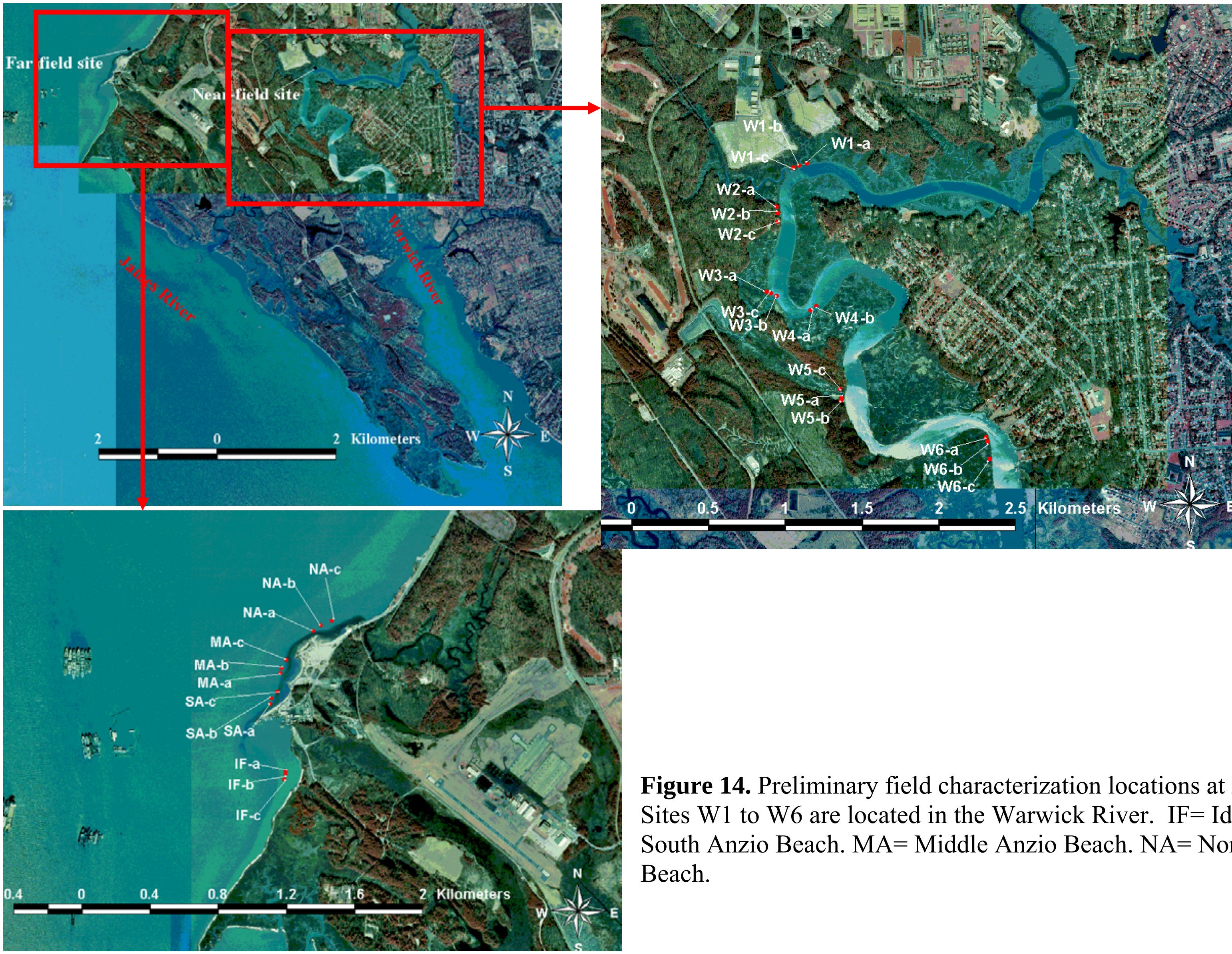


Figure 14. Preliminary field characterization locations at Fort Eustis. Sites W1 to W6 are located in the Warwick River. IF= Idle Fleet; SA= South Anzio Beach. MA= Middle Anzio Beach. NA= North Anzio Beach.

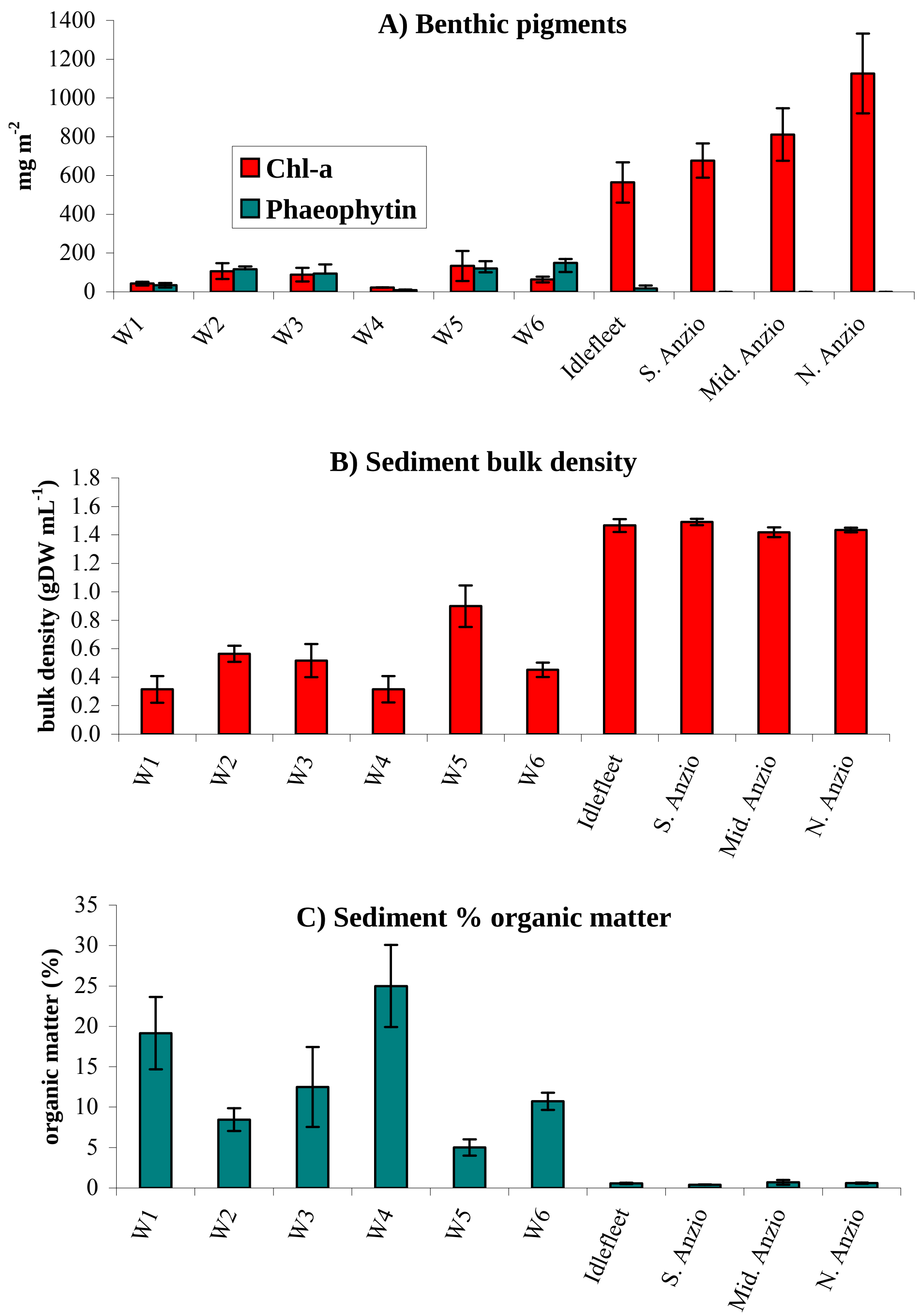
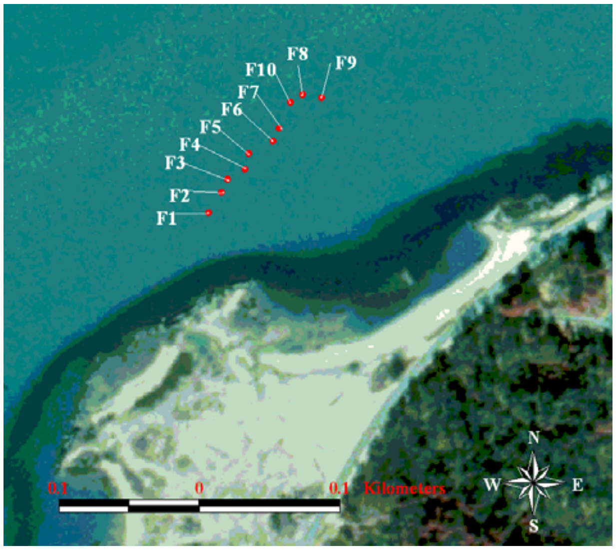


Figure 15. Fort Eustis' preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth). Error bars represent standard errors.

Table 13. Temperature, salinity, and % mud content (from top 11.5 cm) of sediment from the Fort Eustis' preliminary field characterization sites. Salinity was likely lower than normal due to precipitation during days prior to sampling day.

Site	Temp (C)	Salinity (ppt)	Replicate	% Mud
W1	18.7	1.2	A	96.9
			B	98.9
			C	98.5
W2	19.6	1.5	A	67
			B	81.2
			C	36.3
W3	19.2	1.6	A	87.6
			B	65.4
			C	26.6
W4	19.3	1.8	A	96.7
			B	83.3
W5	19.6	2.8	A	53.4
			B	75
			C	31.4
W6	20	3.6	A	69.8
			B	89
			C	81.1
IF	19.6	1.8	A	0.6
			B	0
			C	0
SA	20.9	1.5	A	2.3
			B	0.2
			C	0.4
MA	21.1	1.5	A	25.5
			B	0
			C	1.2
NA	21.1	1.5	A	4.5
			B	0.3
			C	0



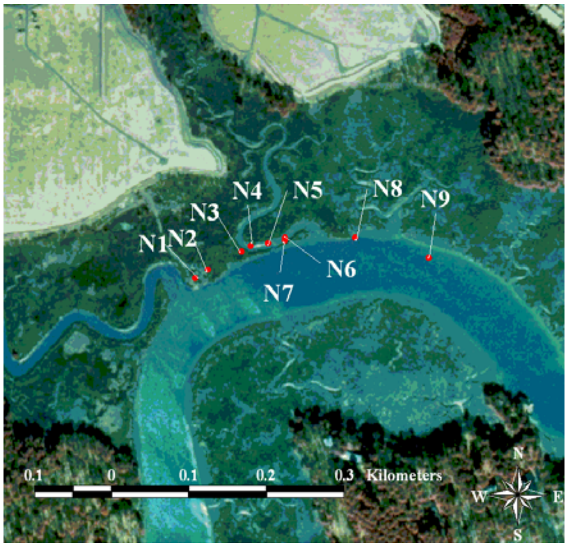


Figure 16. Location of sampling stations in far-field (left) and near-field (right) strata at Fort Eustis on the James River and Warwick River, respectively.

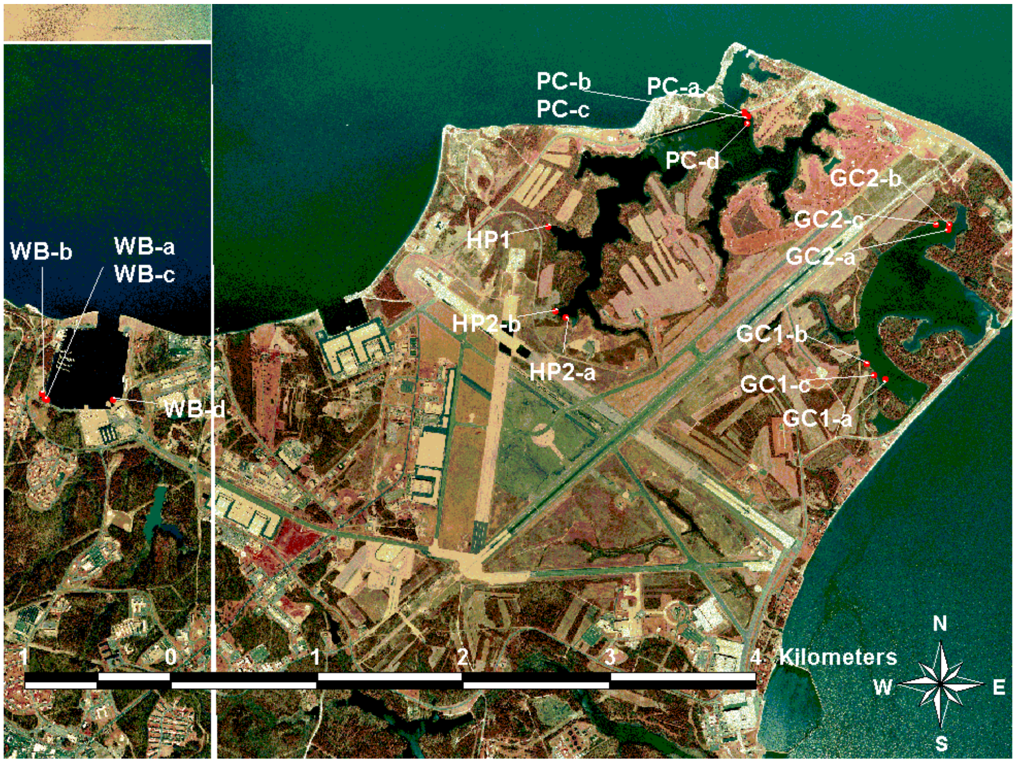


Figure 17. Preliminary field characterization locations at PAX. WB= West Basin. HP= Harpers Creek. PC= Pearsons Creek. GC= Goose Creek.

Table 14. Temperature, salinity, and % mud content (from top 11.5 cm) of sediment from PAX's preliminary field characterization sites.

Site	Temp (C)	Salinity (ppt)	Replicate	% Mud
WB	17.4	10.2	A	0
			B	3.2
			C	0.7
HP1	19.3	9.3	A	21.0
			B	28.9
HP2	18.5	8.2	A	21.9
			B	27.7
PC	23.3	9.8	A	2.6
			B	3.9
			C	3.4
			D	4.6
GC1	21.3	11	A	95.0
			B	81.9
			C	48.2
GC2	23.1	11.2	A	98.1
			B	88.7
			C	77.7

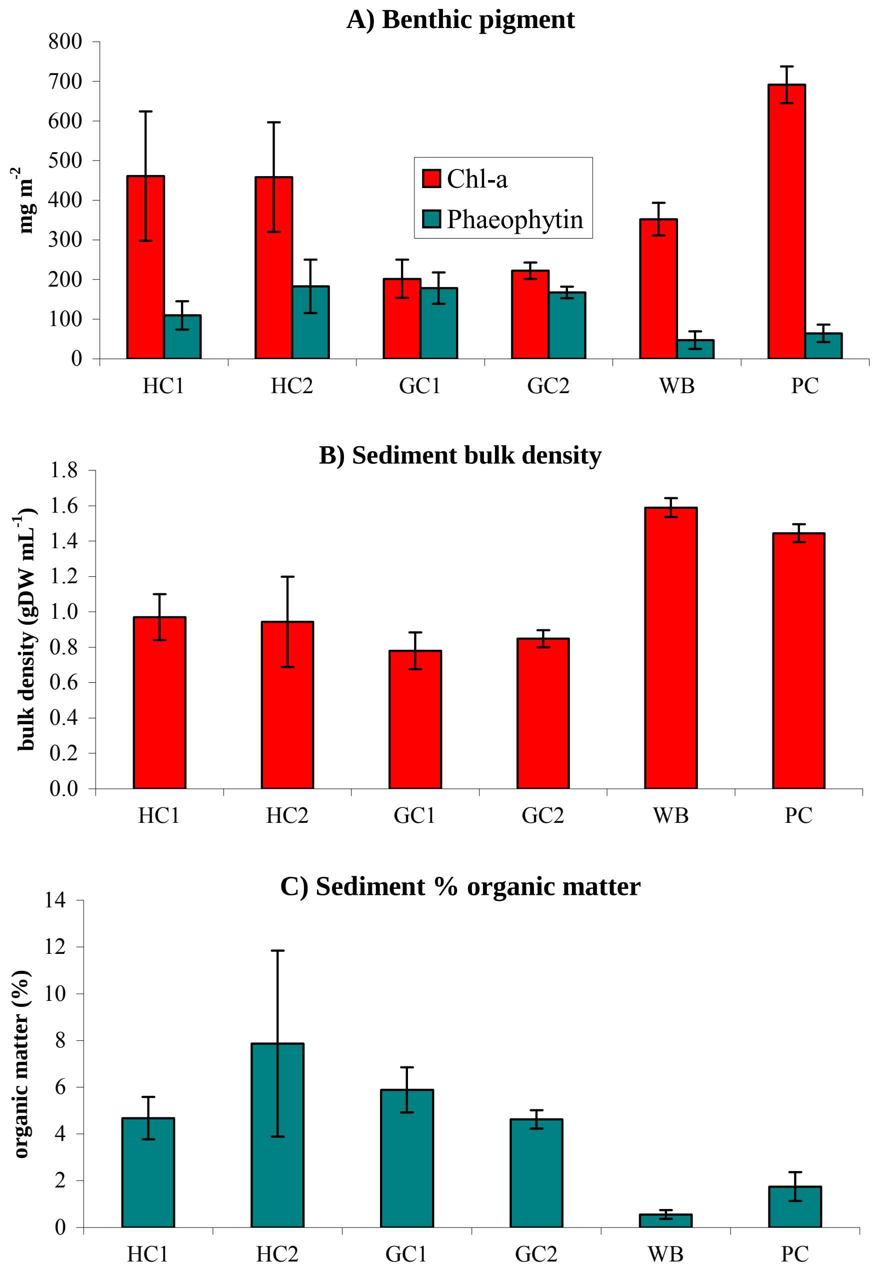


Figure 18. PAX's preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth). Error bars represent standard errors.

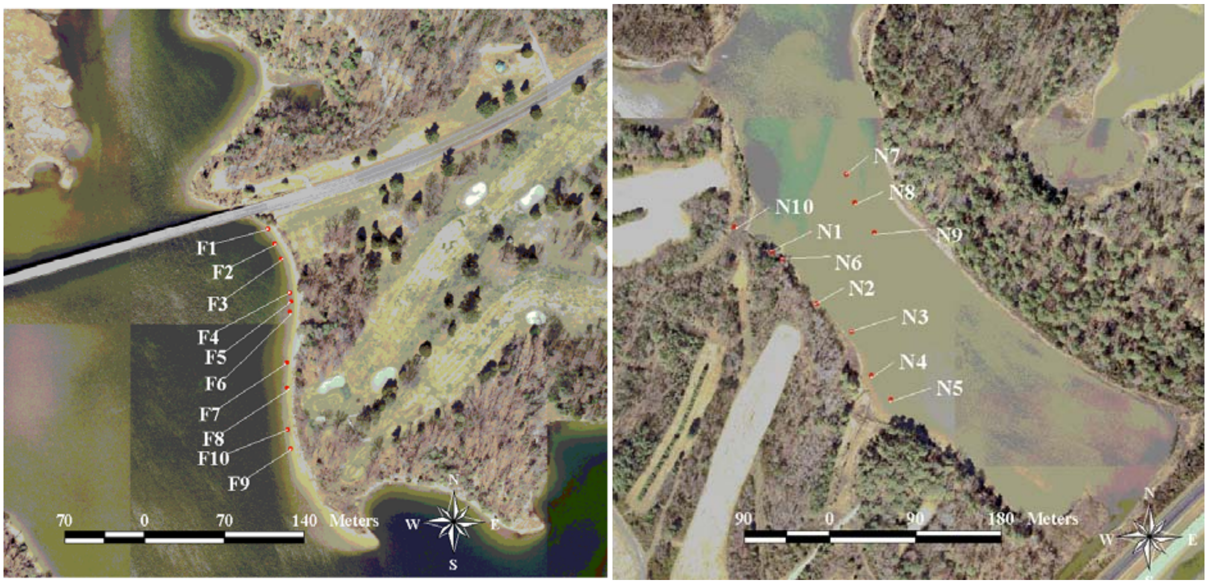


Figure 19. Location of sampling stations in far-field (left) and near-field (right) strata at PAX in Pearsons Creek and Goose Creek, respectively.

find far-field sites along the exposed shoreline, however the sediment grain size was too large (e.g., large pebbles, gravel), making it difficult to collect sediment cores; therefore we sampled within areas that were less physically exposed and had lower tidal energy than typical far-field sites. Pearson Creek (PC) and Goose Creek (GC1) were identified as suitable far- and near-field strata, respectively. Pearson Creek is a tidal (tidal range about 0.3 m), mostly enclosed creek with one inlet located slightly north of the sampling site. The site is adjacent to a golf course, with potential nutrient and pesticide impacts. Goose Creek is a protected tidal creek and is mostly enclosed with the inlet far from the near-field sampling site. Goose Creek receives storm water drainage from airfields; campgrounds and a temporary landfill are adjacent to the sampling site. Figure 19 shows the location of the randomly selected sampling stations at each stratum.

Monie Bay: B-IBI scores in open waters of Monie Bay ranged from 3.3 to 4 (7 stations; mean of 3.6), indicating intermediate to healthy benthic conditions (CBP-benthic unpublished). The high percentage of forest and marsh land use in the watershed and intermediate to healthy B-IBI scores suggest that Monie Bay is relatively pristine compared to many areas in the Chesapeake Bay and is an appropriate reference site for PAX and Fort Eustis. Based upon preliminary measurements of water column characteristics, sediment photosynthetic pigments, bulk density, and organic content conducted at four shallow water candidate sites (Figure 20, data presented in Table 15 and Figure 21), we identified a sandy, exposed area near the mouth of Dames Quarter Creek (DQ) as an appropriate far-field site. Site LC1 in Little Creek, a sub-tributary to Monie Bay, was surrounded by *Spartina alterniflora* and *S. cynosoroides* marsh, and was determined to be a suitable reference near-field site. Location of the 10 randomly selected sampling stations in each stratum is shown in Figure 22.

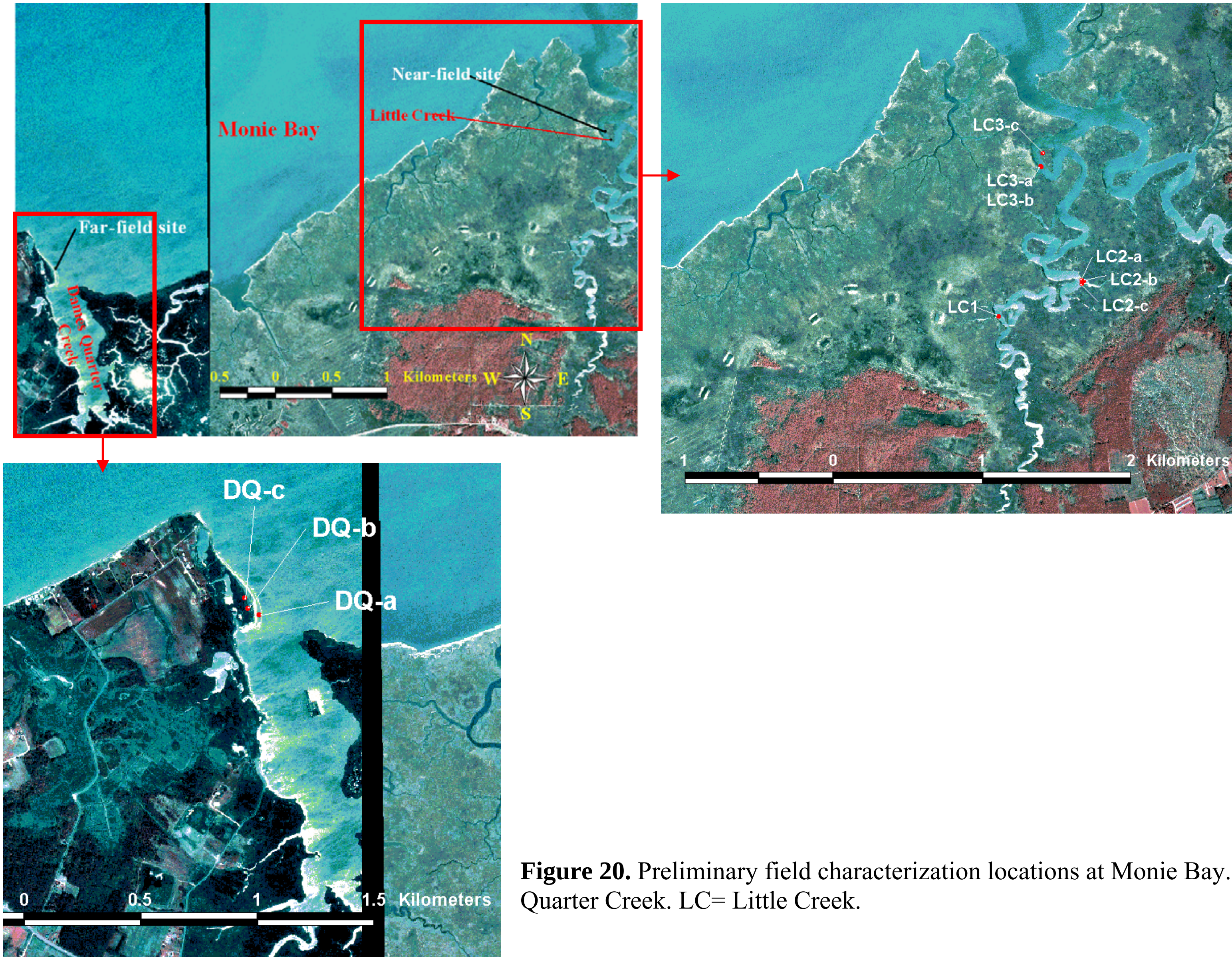


Figure 20. Preliminary field characterization locations at Monie Bay. DQ= Dames Quarter Creek. LC= Little Creek.

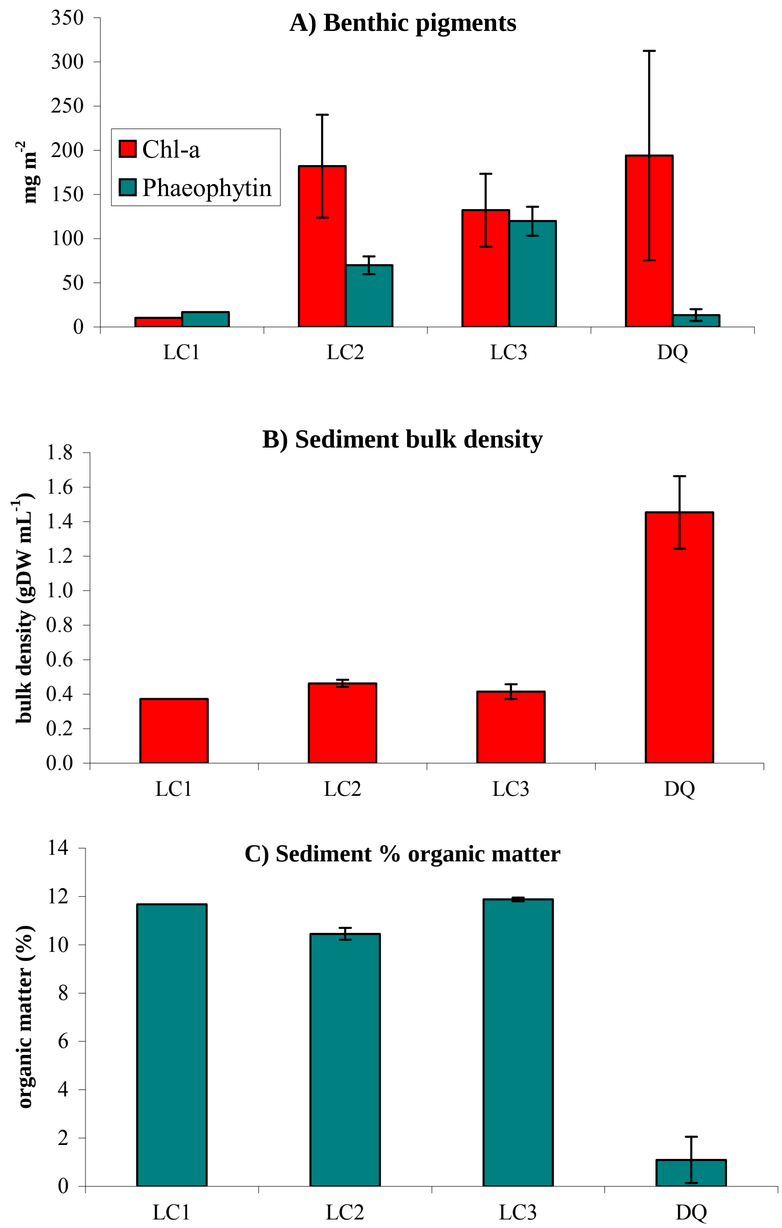


Figure 21. Monie Bay's preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth). Error bars represent standard errors.

Table 15. Temperature, salinity, and % mud content (from top 11.5 cm) of sediment from Monie Bay's preliminary field characterization sites.

Site	Temp (C)	Salinity (ppt)	Replicate	% Mud
LC1	25.6	9.1		79.2
LC2	24.9	9.2	A	60.7
			B	67.1
			C	85.9
LC3	25.6	6.5	A	93.6
			B	94.6
			C	94.7
DQ	25.9	10	A	1.6
			B	1.7
			C	0.8

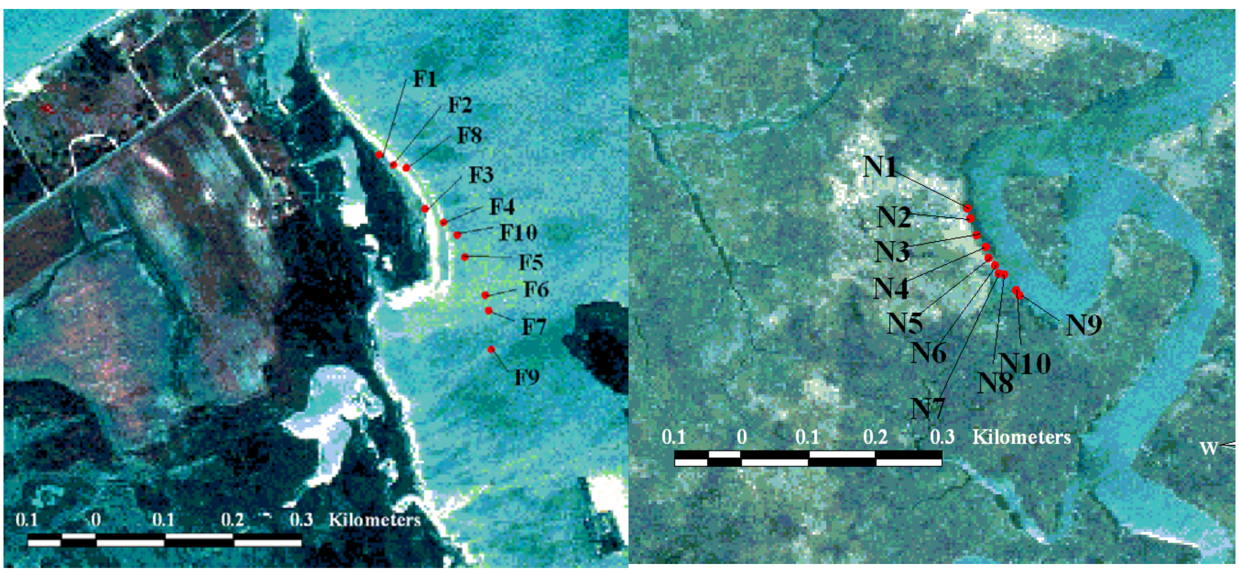


Figure 22. Location of sampling stations in far-field (left) and near-field (right) strata at Monie Bay and Little Creek, respectively.

Pagan River: B-IBI scores for two stations in the deeper subtidal regions of Pagan River were 1.3 and 1.7 (collected in Sept 1998), indicating degraded benthic conditions (CBP-benthic unpublished). The low B-IBI scores and high water column nutrient concentrations suggest that the Pagan River is degraded relative to the other 2004 sites described in this report. We conducted preliminary site characterization at six candidate sites in the Pagan River (Figure 23) and data are presented in Table 16 and Figure 24. Site 1, near one former wastewater discharge point and adjacent to a predominantly *S. cynosoroides* marsh, was selected as an appropriate near-field site, with physical-chemical characteristics that match the military sites. Located at the mouth of the Pagan River, site 5 was identified as a suitable far-field site. Figure 25 shows the sampling stations were that randomly selected in each stratum.

5.1.4 Tidal Freshwater Sites

Analysis of historic regional and local water quality data for the 2005 sites indicated that they were all located in historically tidal freshwater/oligohaline waters (tidal freshwater: 0-0.5 ppt, oligohaline: 0.5-5 ppt), with median values of 0-1.9 ppt (Tables 10, 11). All the regional stations had the percentage of DO measurements above 5 mg/L greater than 80%, however the local Anacostia stations (AN-LN, AN-LF) had lower percentages close to 70%. The Anacostia regional water quality station (UPOT-R) had the highest nitrogen concentration, with a median NO_3^-+NO_2^- concentration of 121.0 uM, suggesting poor water quality in this area. PAM-R and GPR-R (Sweet Hall Marsh and APG regional stations) had the lowest median nitrogen concentrations.

Aberdeen Proving Ground (APG): B-IBI scores in waters surrounding APG including Gunpowder River, Bush River, and Chesapeake Bay varied from 1.0 to 4.2, with a mean of 2.9 (42 stations), suggesting diverse benthic conditions (CBP-benthic unpublished). Specifically in the Gunpowder River near potential study sites, B-IBI scores were 1.8, 2.3, 2.3, and 3.4. The EPA EMAP VP-BI scores around APG ranged between -1 to 2.0 (10 stations), with 70% of the scores negative (Paul et al. 1999, USEPA 2002). With the assistance of APG's Directorate of Safety, Health, and Environment staff, we conducted preliminary field characterization at five candidate sites in shallow waters (0.5 – 0.75 m MLW) of the Gunpowder River and Spesutie Narrows in May 2005 (Figure 26). As a safety precaution, we avoided areas with known unexploded ordnance. The data are presented in Table 17 and Figure 27. We eliminated Spesutie Narrows as a sampling site since it was difficult to collect sediment samples due to historic marsh root mats in shallow waters, rocky sediment, or high biomass of water lilies. Canal Creek (CC) and an area in the Gunpowder River at the mouth of Reardon Inlet (site GP2) were identified as suitable near- and far-field strata, respectively. Canal Creek is a tidal creek surrounded by marshes; vegetation includes *Peltandra virginica*, *Spartina cynosoroides*, and cattail. Most of APG's chemical-manufacturing and munitions-filling plants were found in the Canal Creek area and were eventually demolished or abandoned after World War II (Phelan et al. 2001). These plants generated organic solvent wastes (e.g., tetrachloride (CT), 1,1,2,2-tetrachloroethane (TeCA), trichloroethane (TCE)) used as decontaminating or cleaning agents; on-site disposal of demolition materials from these plants further contaminated the Canal Creek aquifer. Phelan et al. (2001) estimated that approximately 0.84 kg per day of VOCs are

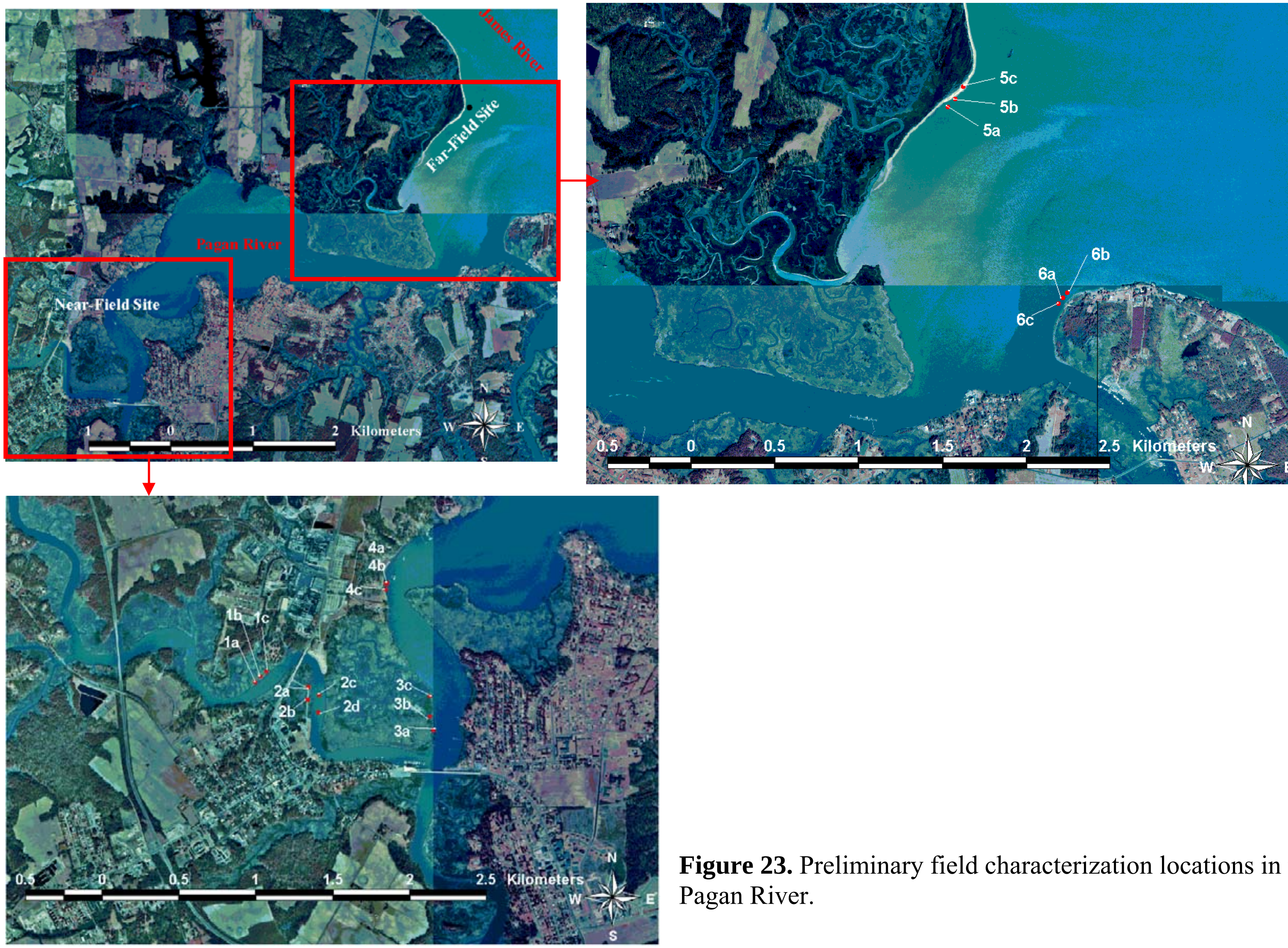


Figure 23. Preliminary field characterization locations in the Pagan River.

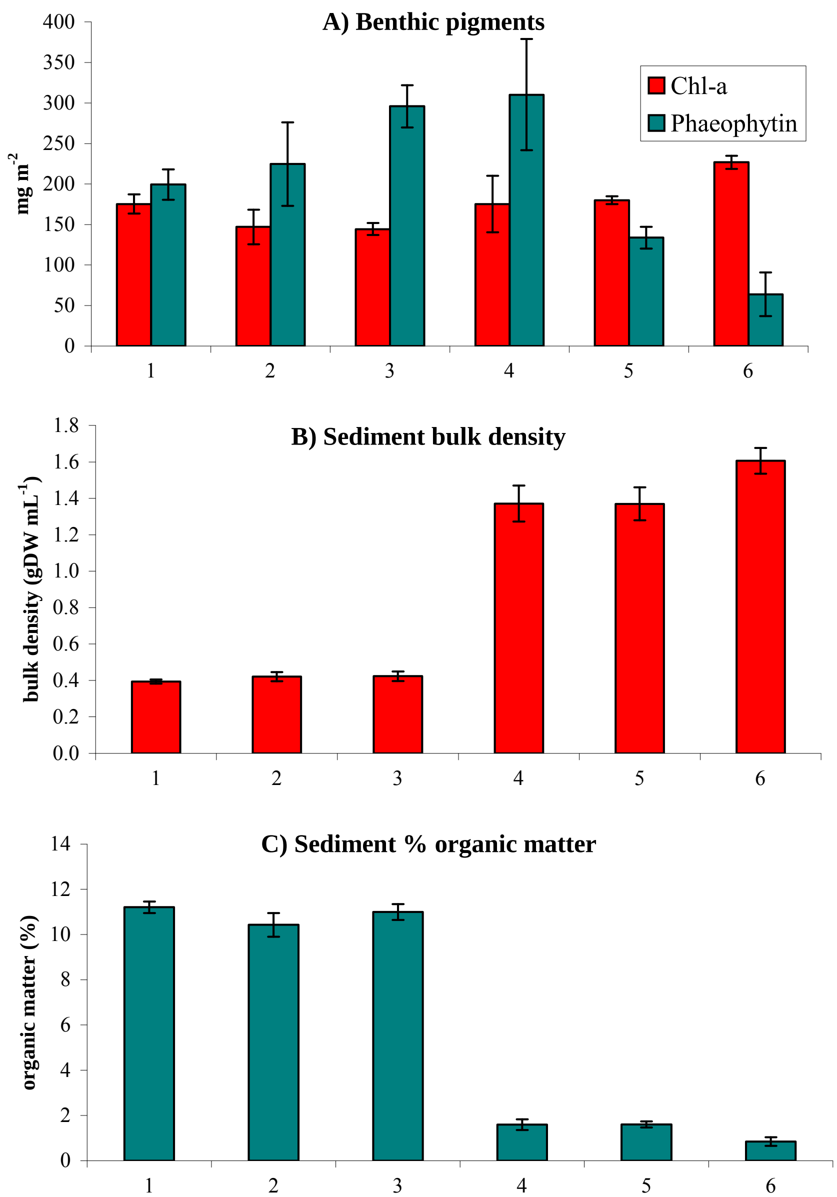


Figure 24. Pagan River's preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth). Error bars represent standard errors.

Table 16. Temperature, salinity, and % mud content (from top 11.5 cm) of sediment from the Pagan River's preliminary field characterization sites. Salinity was likely lower than normal due to precipitation during days prior to sampling day.

Site	Temp (C)	Salinity (ppt)	Replicate	% Mud
			A	89.4
1	24.4	3.6	B	87.4
			C	96.0
			A	83.8
2	24.8	4.0	B	93.6
			C	90.5
			D	98.8
			A	81.1
3	24.7	5.5	B	81.8
			C	92.0
			A	6.9
4	25.4	6.5	B	20.3
			C	8.4
			A	12.1
5	29.1	10.7	B	17.7
			C	13.1
			A	6.5
6	28.5	10.7	B	2.8
			C	10.4

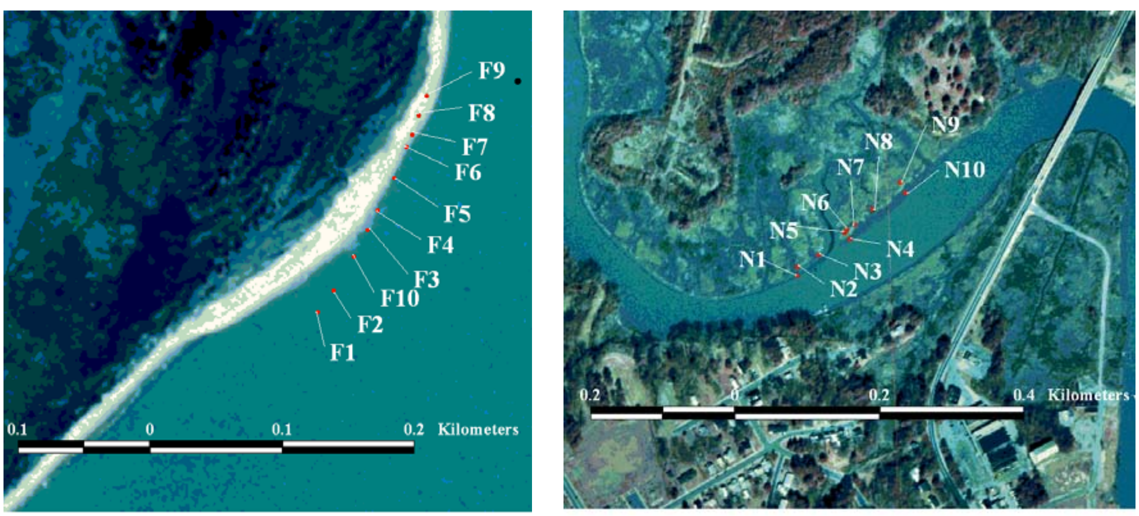
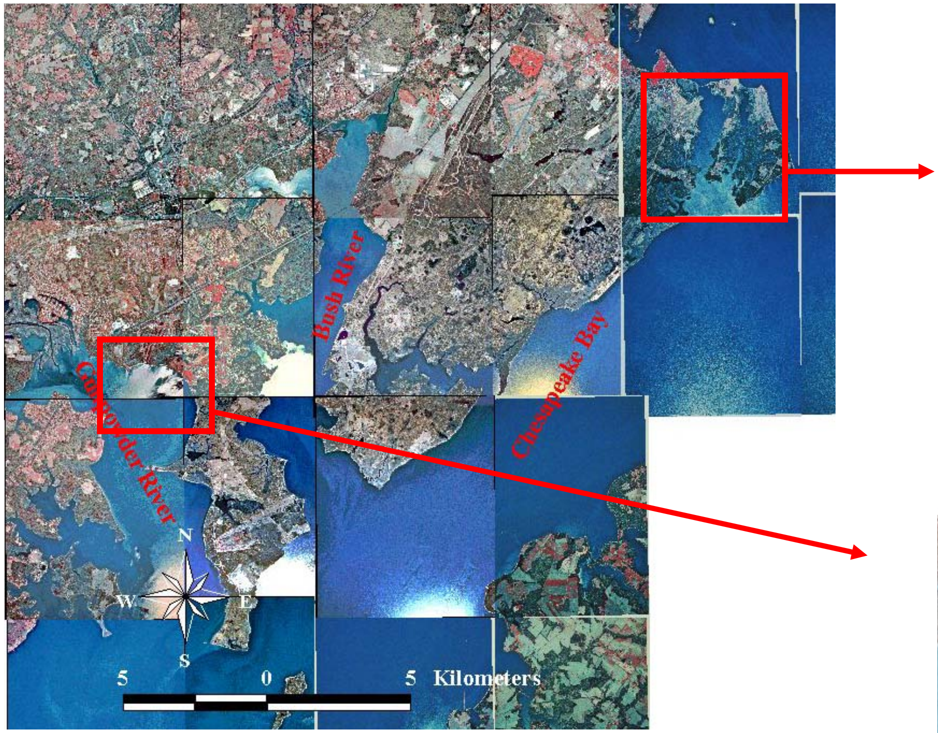


Figure 25. Location of sampling stations in far-field (left) and near-field (right) strata at the Pagan River.



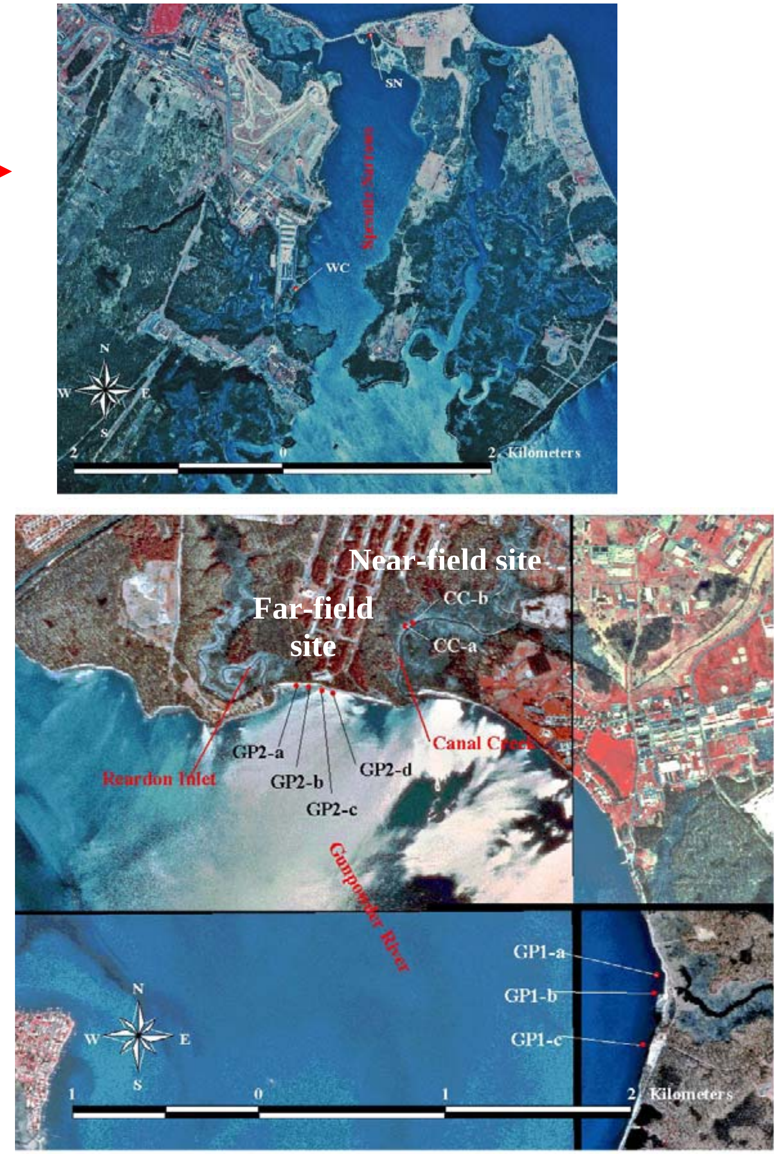


Figure 26. Preliminary field characterization locations at Aberdeen Proving Ground. GP=Gunpowder River; CC=Canal Creek; WC=Woodrest Creek; SN=Spesutie Narrows.

Table 17. Temperature, salinity, and % mud content (from top 11.5 cm) of sediment from the preliminary field characterization at Aberdeen Proving Ground, Quantico, Sweet Hall Marsh, and Anacostia River.

Site	Temp (C)	Salinity (ppt)	%Mud
Aberdeen Proving Ground			
GP1	16.6	0.2	<25
GP2	17.2	0.2	<25
CC	17.4	0.2	>75
WC	17.4	0.2	>25
SN	18.9	0.2	>75
Quantico			
CH	17.4	0.2	>75
EMB1	16.6	0.2	variable
EMB3	16.5	0.2	variable
ISL	18.9	0.2	<25
Sweet Hall Marsh			
SH1	24.6	0.1	<25
SH2	25.4	0.2	>75
Anacostia River			
NKL	19.1	0.2	variable
PEP1	19.3	0.2	variable
PEP2	20.1	0.2	>75
BR	19.6	0.2	<25

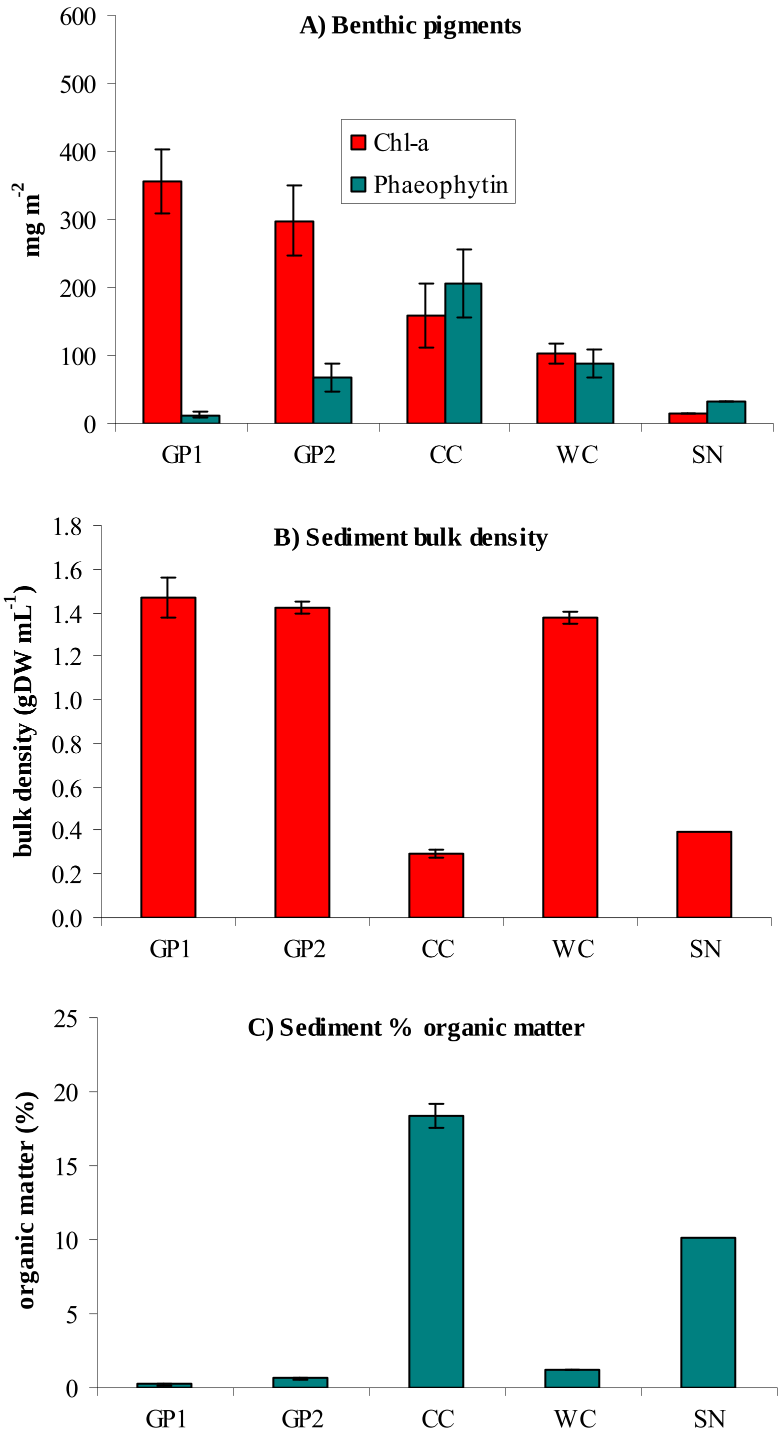


Figure 27. Aberdeen Proving Ground's preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth). Error bars represent standard errors.

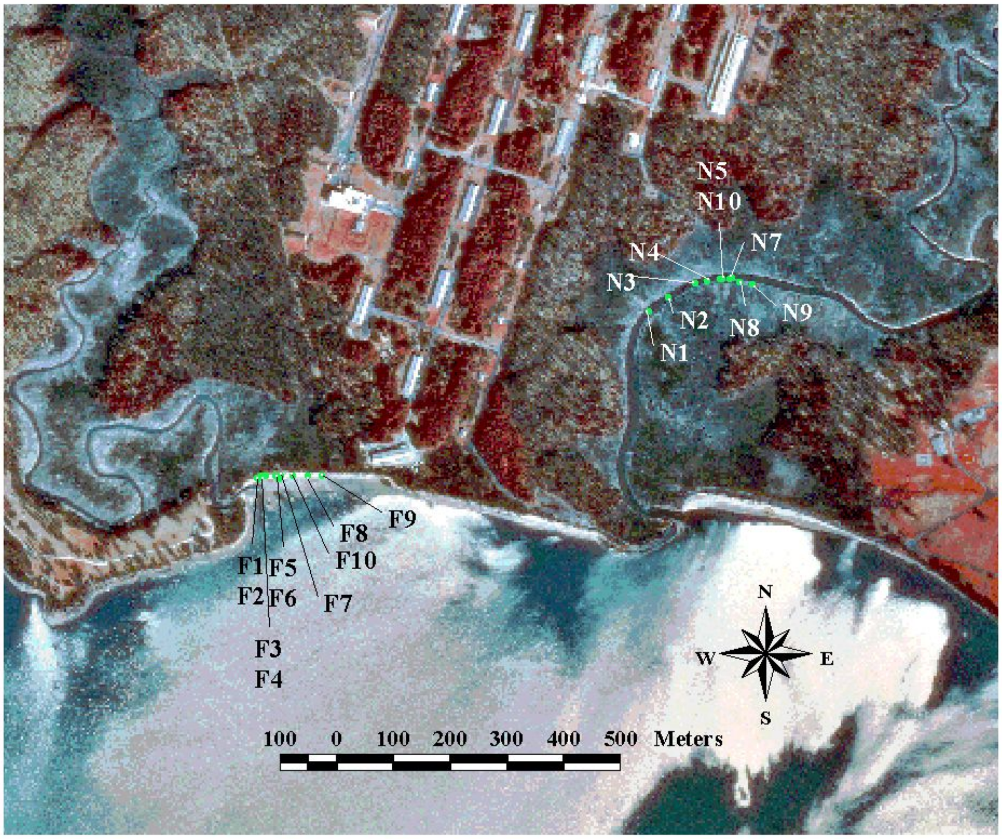


Figure 28. Location of sampling stations in far-field (left) and near-field (right, Canal Creek) strata at Aberdeen Proving Ground.

discharged from Canal Creek to Gunpowder River. The far-field site is located between the mouths of Reardon Inlet and Canal Creek on Gunpowder River and is an exposed, open water area with small sandy beach. Figure 28 shows the location of ten sampling locations in each stratum for the study conducted in the summer.

Quantico: B-IBI scores in the Potomac River near Quantico varied from 2 to 5 (7 stations; mean=2.9) and EPA EMAP VP-BI scores were –0.1, 0.4, and 0.4, indicating varied benthic conditions from degraded to healthy (CBP-benthic unpublished, Paul et al. 1999, USEPA 2002). Based upon information and recommendations from the Quantico Natural Resources and Environmental Affairs staff and Naval Facilities Engineering Command Headquarters (NAVFAC) staff, we conducted preliminary field characterization at four candidate sites in Chopawamsic Creek and the Potomac River in May 2005 (Figure 29). Water column characteristics, benthic pigment, sediment bulk density, and percent organic matter data are shown in Table 17 and Figure 30. We attempted to find far-field sites along the exposed shoreline, however the sediment grain size was too large (e.g., large pebbles, gravel), making it difficult to collect sediment cores; therefore we sampled within the "Embayment" area off the Potomac River that is somewhat protected by Chopawamsic Island. Chopawamsic Creek and an area off the island in the Embayment (ISL site) were identified as suitable near- and far-field strata, respectively. Chopawamsic Creek is a tidal, shallow, mostly enclosed creek with one channelized inlet at its mouth. The near-field site is located in the northeastern portion of the creek adjacent to a marsh, south of Russell Road and Caitlin Road near a former rifle range (Site 20) (Tetra Tech NUS, Inc, 2004). PAHs and inorganic metals (e.g., Sb, Cu, Pb, As) have been found in the marsh sediments, likely from surface water runoff from the range. The Embayment, a shallow inlet with depths of 0.3-2 m, is adjacent to an airfield and Site 4 Old Landfill, which was found to be a source of PCBs, pesticides, petroleum hydrocarbons, and metal discharges to the Potomac River (Battelle 2004). The Mainside Sewage Treatment Plant and numerous stormwater outfalls also discharge into the Embayment. Location of sampling stations in each stratum is shown in Figure 31.

Sweet Hall Marsh: B-IBI scores in the Pamunkey River near Sweet Hall Marsh were 3, 3, 3, and 3.8 and EPA EMAP VP-BI scores ranged from 0.14 to 1.57 (5 stations; mean=0.79), suggesting intermediate to healthy benthic conditions (CBP-benthic unpublished, Paul et al. 1999, USEPA 2002). The relatively undeveloped watershed, low nutrient concentrations, and generally healthy benthic condition suggest that Sweet Hall Marsh is relatively pristine compared to many oligohaline areas in the Chesapeake Bay and is an appropriate reference site for APG and Quantico. We conducted preliminary site characterization in June 2005 (Figure 32, data presented in Table 17 and Figure 33) and identified a sandy, open water area across from Sweet Hall Marsh as an appropriate far-field site (site SH1). Site SH2, located in a small creek draining the marsh, was determined to be a suitable reference near-field site. Figure 34 shows the location of the randomly selected stations sampled in each stratum for the summer study.

Anacostia River: The mean B-IBI score in the Anacostia River was 2.8 (19 stations; range 1.7-4.0) and EPA EMAP VP-BI scores were –2.18, 0.11, 0.24, indicating variable benthic conditions from degraded to healthy (McGee and Pinkney 2002, Paul et al. 1999). Compared to the other 2005 sites described in the report, the Anacostia River possessed a highly urbanized watershed, had low water column DO concentrations, high water column $NO_3^-+NO_2^-$ concentrations, and relatively low benthic condition scores, demonstrating greater degradation relative to the other sites. Based upon measurements of water column characteristics and sediment photosynthetic pigments, grain size, bulk density, and organic content conducted at five shallow water candidate sites (Figure 35, data presented in Table 17, Figure 36), we selected site PEP2 as a suitable near-field site and BR as the far-field site. PEP2 is a shallow water, mud flat area near the PEPCO Power Generator plant and BR is a sandy outcrop located in front of a former stormwater outfall south of the Anacostia Park boat ramp. B-IBI scores near these sites were 1.7 and 2.3 (McGee and Pinkney 2002). Figure 37 shows the location of the sampling stations in each stratum.

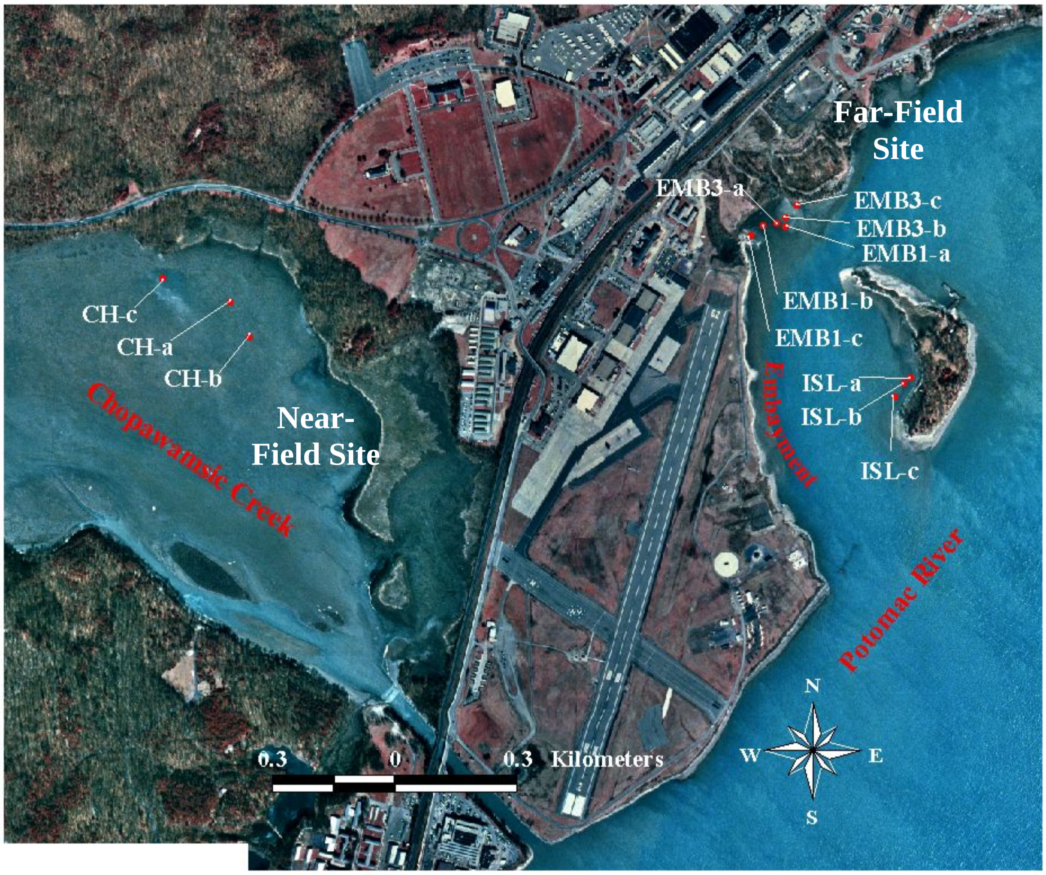


Figure 29. Preliminary field characterization locations at Quantico. CH= Chopawamsic Creek; EMB= Embayment; ISL=island.

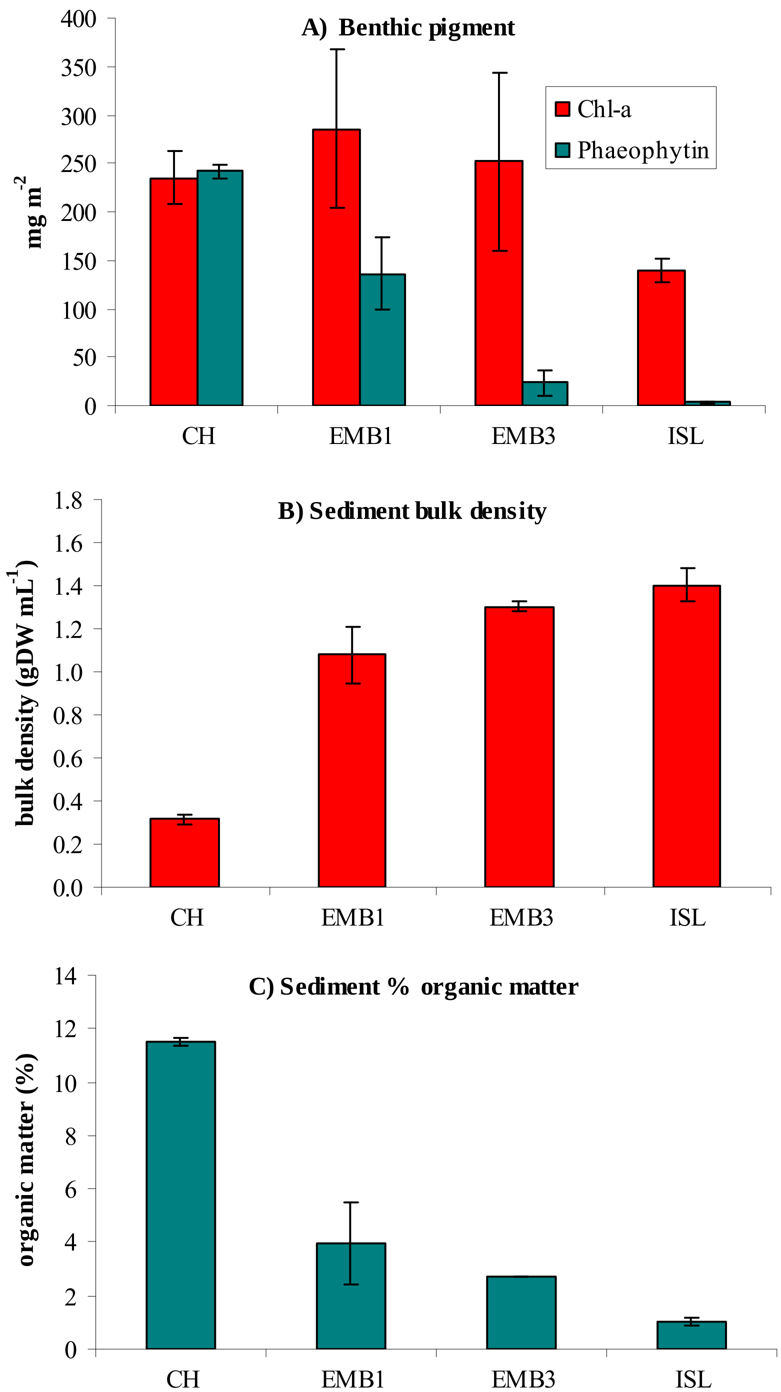


Figure 30. Quantico's preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth). Error bars represent standard errors.

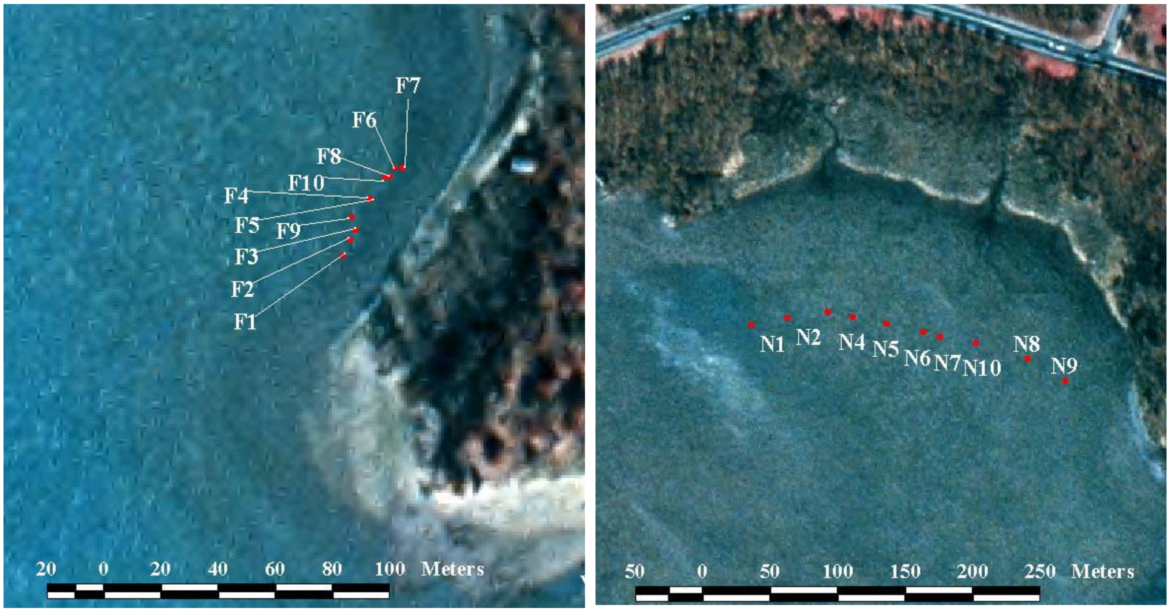


Figure 31. Location of sampling stations in far-field (left) and near-field (right) strata at Quantico in the Embayment and Chopawamsic Creek, respectively.

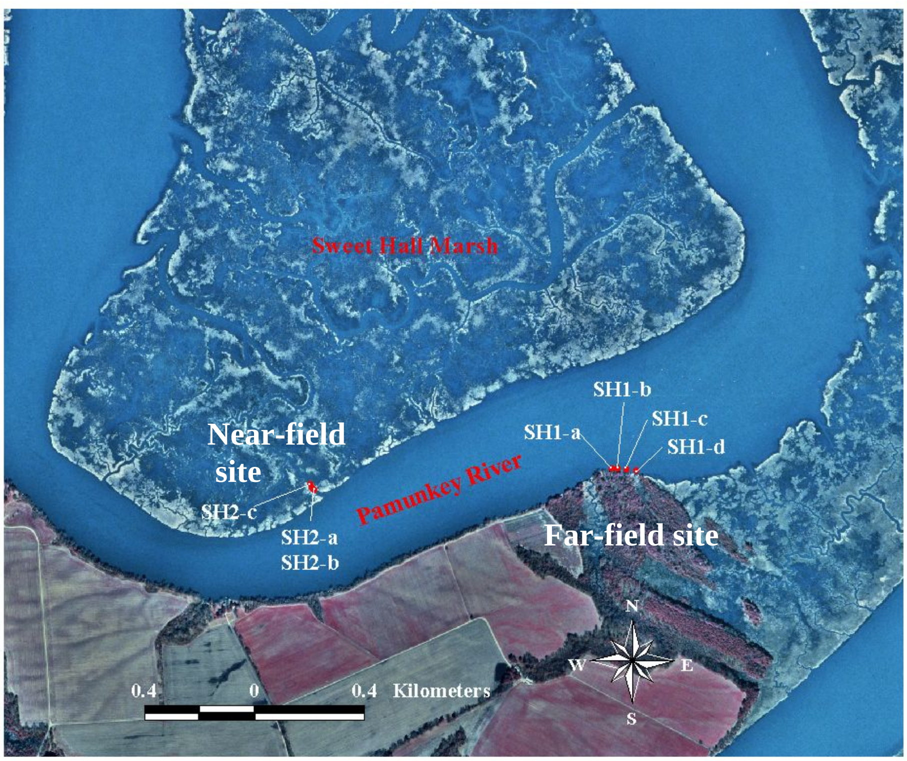


Figure 32. Preliminary field characterization locations at Sweet Hall Marsh on the Pamunkey River.

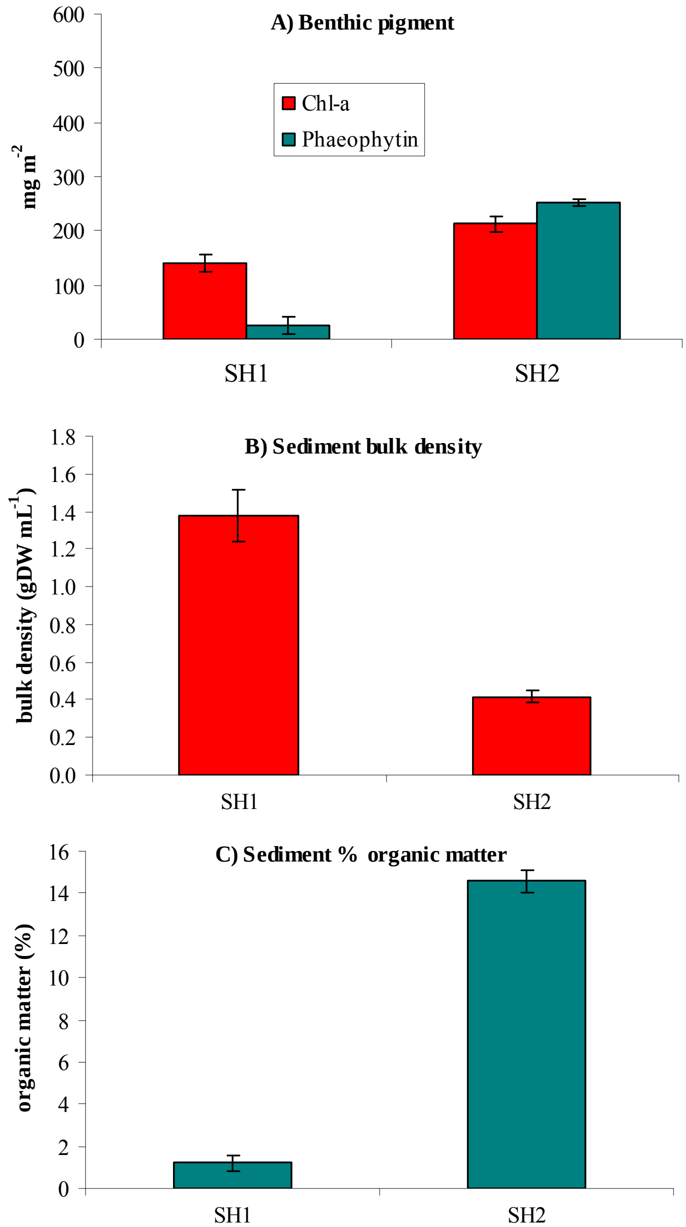


Figure 33. Sweet Hall Marsh's preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth). Error bars represent standard errors.

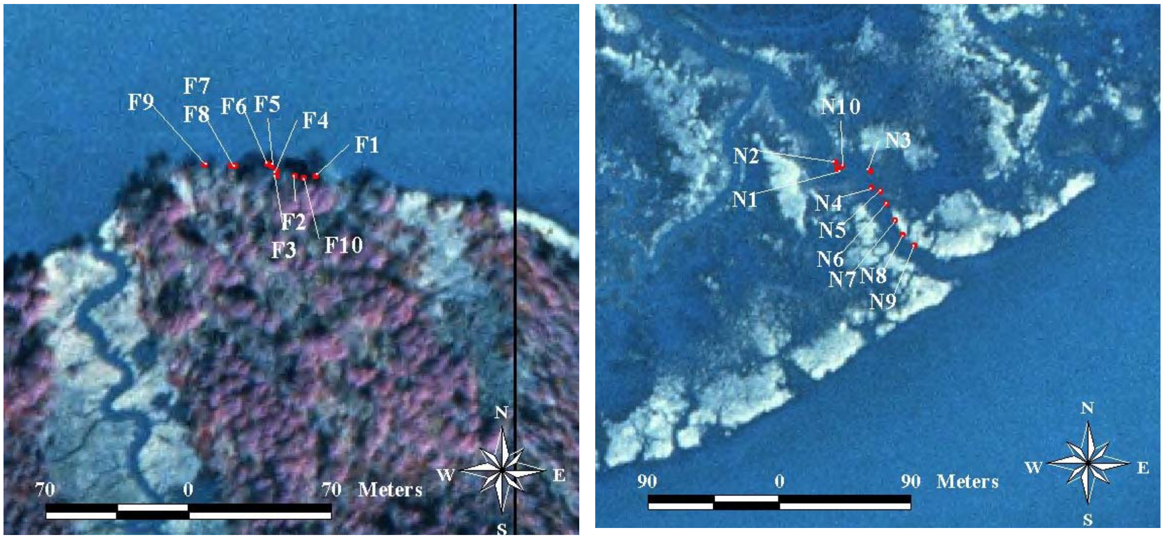


Figure 34. Location of sampling stations in far-field (left) and near-field (right) strata at Sweet Hall Marsh in the Pamunkey River.

Figure 35. Preliminary field characterization locations at the Anacostia River. NKL=North Kingman Lake; SKL=South-side of Kingman Lake; PEP=near Pepco; BR= boat ramp.

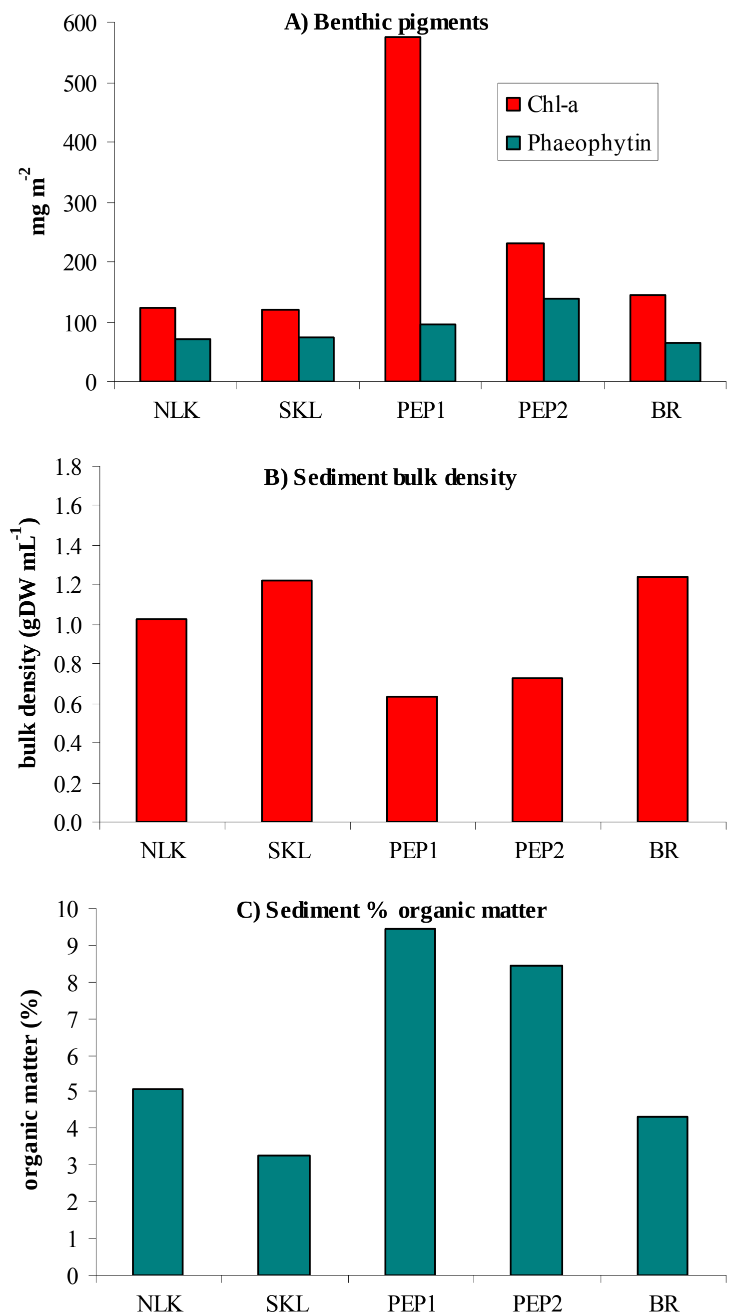


Figure 36. Anacostia River's preliminary site characterization: A) Mean total benthic pigments (3 cm depth), B) mean sediment bulk density (10 cm depth), and C) mean sediment % organic matter (10 cm depth).

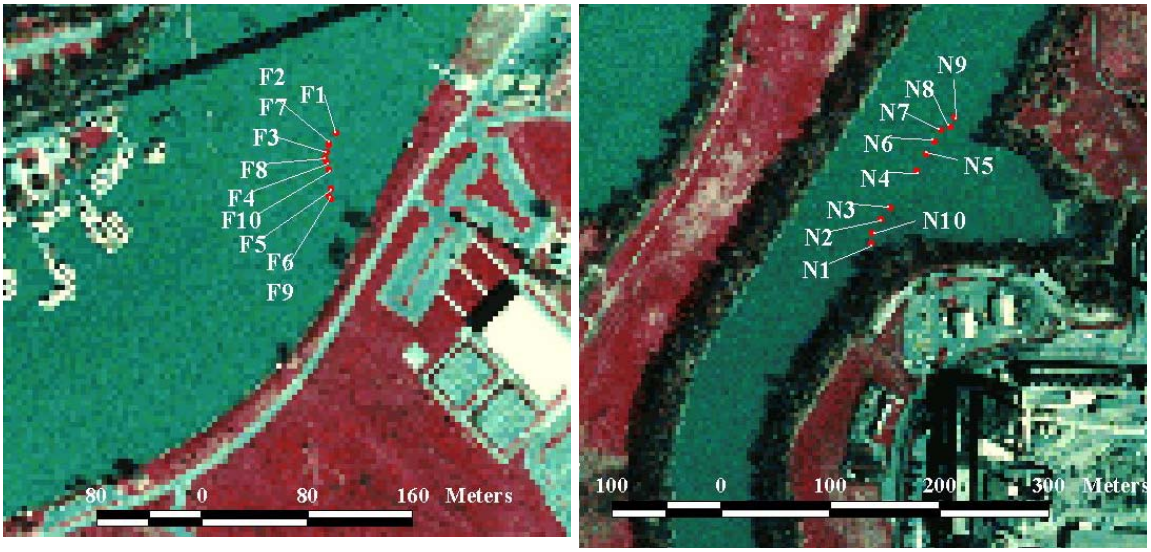


Figure 37. Location of sampling stations in far-field (left) and near-field (right) strata at the Anacostia River.

5.2 Water Quality

Concurrent with measurements of benthic ecosystem process rates and community structure, water quality at each site and stratum was characterized by measuring salinity, concentrations of NH_4^+, NO_x, and DIP, and light attenuation coefficient at low tide. Results are shown in Table 18. For the high mesohaline sites, concentrations of all nutrients were far greater at ER than at the other sites. On the other hand, total suspended solids and chlorophyll a were highest at both far-field and near-field stations at LAFB. The lowest chlorophyll a concentration observed was in water from the near-field site in the ER, even though this site had the highest nutrient concentrations observed. For the low mesohaline sites, concentrations of all nutrients were highest in the Pagan River, the site chosen as the disturbed end member site. Pagan River water also had the highest loads of total suspended solids (TSS) but lower concentrations of chlorophyll a relative to the other sites studied, as one might expect given the high TSS load and accompanying increase in light attenuation (K_d) (decreased light availability). The low chlorophyll a and high K_d at the Monie Bay near-field site is typical of very narrow and shallow tidal channels cutting through marshes. The high chlorophyll a concentrations observed at the Fort Eustis near-field site indicates a high degree of eutrophication within the Warwick River, which is adjacent to Fort Eustis. For the tidal freshwater sites the disturbed end member site, Anacostia, had the highest NO_x and NH_4^+ concentrations, while Quantico had the lowest. The high concentrations of chlorophyll a found at far-field sites in Quantico and Anacostia are symptomatic of eutrophied conditions. Although nutrient concentrations were high in the Anacostia River, chlorophyll a concentrations were low at the near-field site perhaps due either to high light attenuation or to phosphorous limitation.

5.3 Sediment Characterization

In order to determine how benthic ecosystem function and community structure vary along gradients of impairment, it was necessary to assess the degree of natural variability that exists in physical and chemical properties of sediments from sites and strata within and between salinity regimes. To characterize the sediments we measured sediment bulk density, grain size, organic content, extractable nutrients, C and N content, chlorophyll a, and phaeophytin pigments

At each sampling site, sediment cores to a depth of 25 cm were taken at both near- and far-field stations, sectioned, and analyzed for bulk density, organic content, extractable inorganic nutrients, total organic carbon (TOC), and total nitrogen (TN) content. Sediment cores were also taken to a depth of 11.5 cm for grain size distribution analysis.

For the high mesohaline study sites, bulk density of sediments was generally similar at the far-field stations and did not vary with depth down to 25 cm (Figure 38). At the high mesohaline near-field stations, bulk density was lowest at ER sites and highest at the Thorntons Creek site. Bulk density did not appear to vary systematically with depth at any of the sites. At the PAX site bulk density increased with depth, although this variation was not clearly observed at the other low mesohaline sites (Figure 39). For the tidal freshwater sites, bulk density also increased with depth at the Sweet Hall Marsh and Quantico sites (Figure 40). An inter-site

Table 18. Mean (± SE) water column salinity, nutrients, chlorophyll a, total suspended solids (TSS), and light attenuation coefficient (K_d) at all study sites. ND=not detectable.

Site	stratum	Salinity (ppt)	NO_X (μM)	NH_4^+ (μM)	PO_4^{3-} (μM)	Chl *a* (μg L^{-1})	TSS (mg L^{-1})	K_d (m^{-1})
High Meoshaline (2003) Sites								
Thorntons	Far	17.80	ND	ND	0.19 ± 0.003	20.11 ± 0.96	26.00 ± 0.27	na
Thorntons	Near	17.08	ND	ND	0.17 ± 0.01	20.91 ± 1.95	22.00 ± 0.23	3.72
Langley	Far	18.88	0.06 ± 0.01	0.20 ± 0.02	0.20 ± 0.01	34.19 ± 0.67	86.67 ± 5.44	4.40
Langley	Near	17.31	0.02 ± 0.01	0.18 ± 0.06	0.31 ± 0.01	28.53 ± 1.47	71.47 ± 1.33	4.10
Elizabeth	Far	15.74	18.12 ± 0.04	36.37 ± 0.16	1.72 ± 0.02	22.99 ± 0.93	10.20 ± 1.22	2.64
Elizabeth	Near	15.81	18.05 ± 0.08	37.67 ± 0.08	1.79 ± 0.01	10.57 ± 0.26	9.93 ± 0.29	2.51
Low Mesohaline (2004) Sites								
Monie Bay[a]	Far	10.37	ND	0.31 ± 0.02	0.03 ± 0.004	23.20 ± 0.65	60.07 ± 4.82	3.35
Monie Bay[a]	Near	7.27	0.62 ± 0.01	3.55 ± 0.03	0.19 ± 0.004	9.99 ± 1.11	45.70 ± 0.29	6.46
PAX	Far	10.78	1.39 ± 0.02	0.35 ± 0.02	0.07 ± 0.002	22.35 ± 0.05	20.03 ± 0.39	1.10
PAX	Near	11.62	0.04 ± 0.01	0.35 ± 0.02	0.11 ± 0.01	14.22 ± 1.84	36.27 ± 3.58	2.49
Fort Eustis[a]	Far	5.80	0.04 ± 0.02	0.24 ± 0.03	0.07 ± 0.01	32.91 ± 3.46	25.67 ± 2.03	2.51
Fort Eustis[a]	Near	2.85	0.16 ± 0.05	0.42 ± 0.03	0.12 ± 0.02	115.63 ± 2.27	45.33 ± 2.03	3.93
Pagan	Far	12.33	2.09 ± 0.02	1.10 ± 0.06	0.72 ± 0.001	32.32 ± 2.08	99.70 ± 4.23	4.20
Pagan[b]	Near	0.11	10.31 ± 0.15	6.14 ± 0.04	0.82 ± 0.01	10.23 ± 1.26	76.00 ± 1.28	7.17
Tidal Freshwater (2005) Sites								
Sweet Hall	Far	0.90	0.40 ± 0.01	0.27 ± 0.00	0.35 ± 0.00	17.62 ± 0.54	31.57 ± 3.43	2.94
Sweet Hall	Near	1.10	0.44 ± 0.07	12.32 ± 2.04	0.13 ± 0.03	21.77 ± 2.16	79.78 ± 0.63	2.35
Quantico[c]	Far	0.16	0.09 ± 0.02	0.28 ± 0.02	0.16 ± 0.01	60.93 ± 4.06	21.16 ± 3.54	1.25
Quantico	Near	0.14	0.17 ± 0.01	0.43 ± 0.06	0.37 ± 0.01	6.13 ± 0.47	10.98 ± 1.46	1.36
APG[d]	Far	0.03	18.19 ± 0.98	2.13 ± 0.07	0.13 ± 0.03	3.96 ± 0.72	42.93 ± 10.17	2.31
APG[d]	Near	0.00	8.01 ± 0.36	1.27 ± 0.05	0.71 ± 0.03	2.89 ± 0.25	31.98 ± 0.56	3.09
Anacostia	Far	0.12	30.00 ± 0.23	21.08 ± 0.24	0.22 ± 0.02	54.81 ± 1.42	22.88 ± 1.03	3.53
Anacostia	Near	0.11	34.91 ± 0.28	22.08 ± 0.40	0.20 ± 0.00	13.57 ± 0.53	35.58 ± 3.13	8.06

[a] Heavy precipitation occurred the day before sampling, which may have caused the water to be more turbid and have lower salinity than usual.

[b] Heavy precipitation occurred during the week before sampling, which may have caused the water to be more turbid and have lower salinity than usual.

[c] Dense mats of SAV *(Hydrilla verticillata)* covered the entire far-field area. Water samples and light attenuation measurements were taken in an area with less dense SAV mats.

[d] Heavy precipitation occurred prior to sampling at APG. High water discharge from Reardon Inlet caused water to be very turbid at the far-field site; water samples and light attenuation measurements were taken away from the site outside the wrack line created by debris from the high discharge.

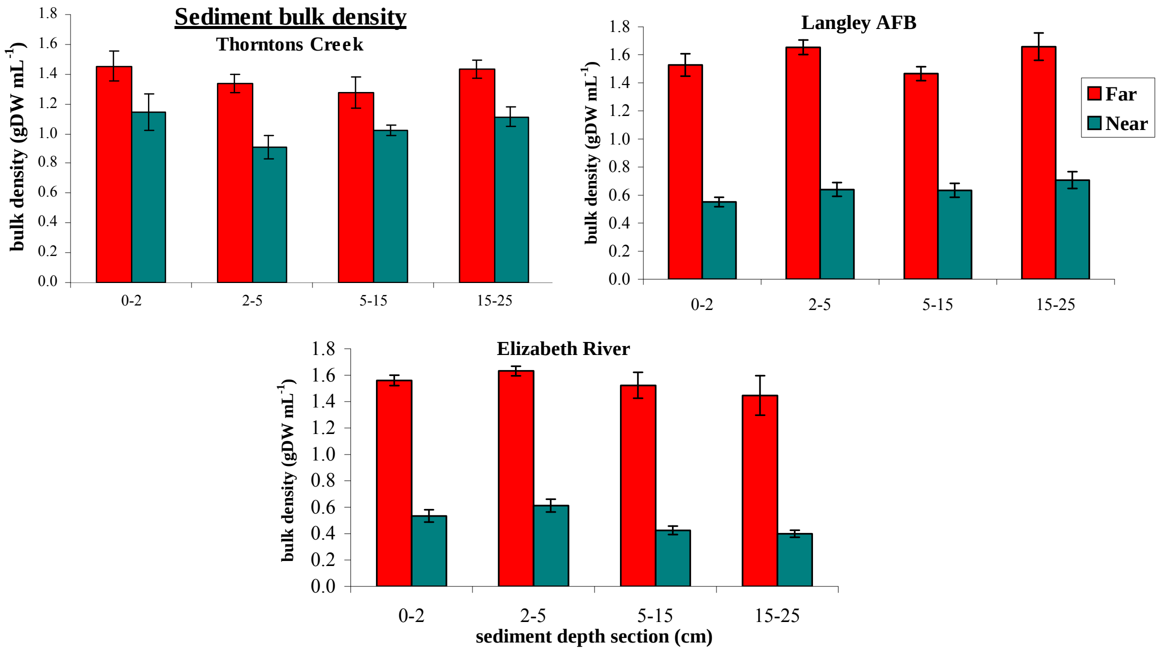


Figure 38. Mean sediment bulk density by depth section and stratum site at Thorntons Creek, Langley AFB, and Elizabeth River. Error bars represent standard errors.

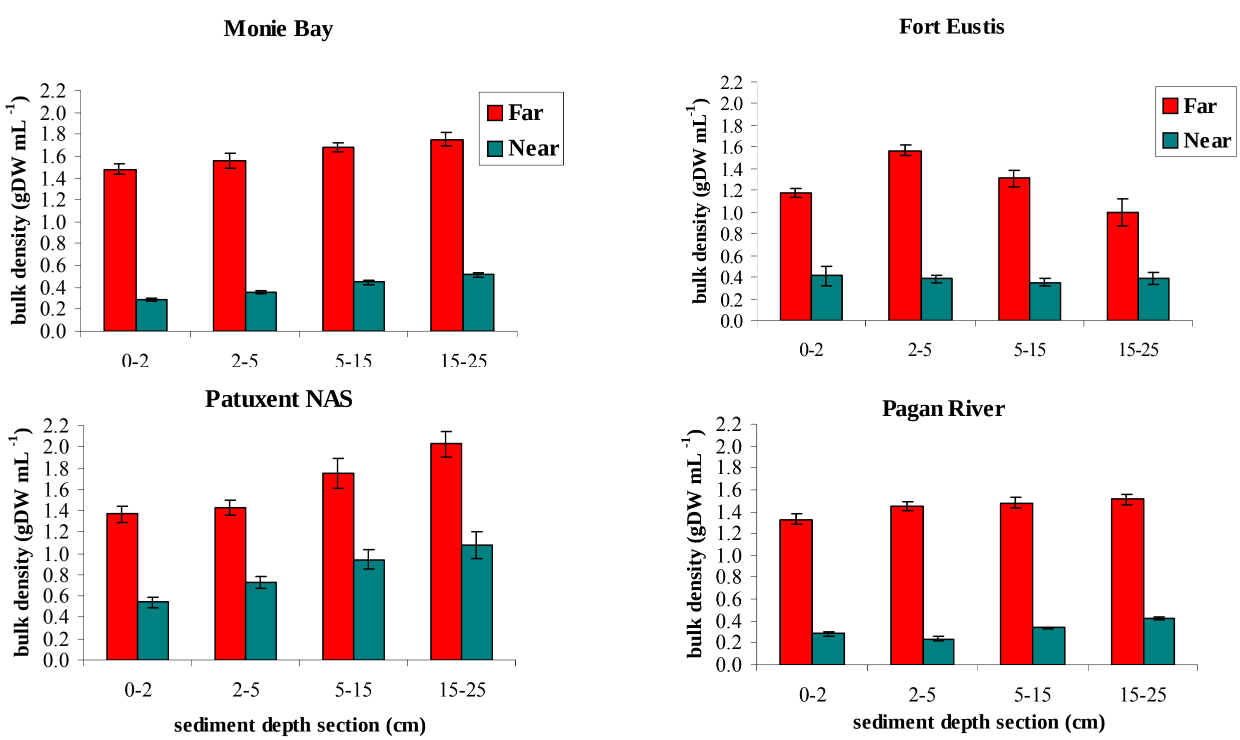


Figure 39. Mean sediment bulk density by depth section and stratum at Monie Bay, PAX, Fort Eustis, and the Pagan River. Error bars represent standard errors.

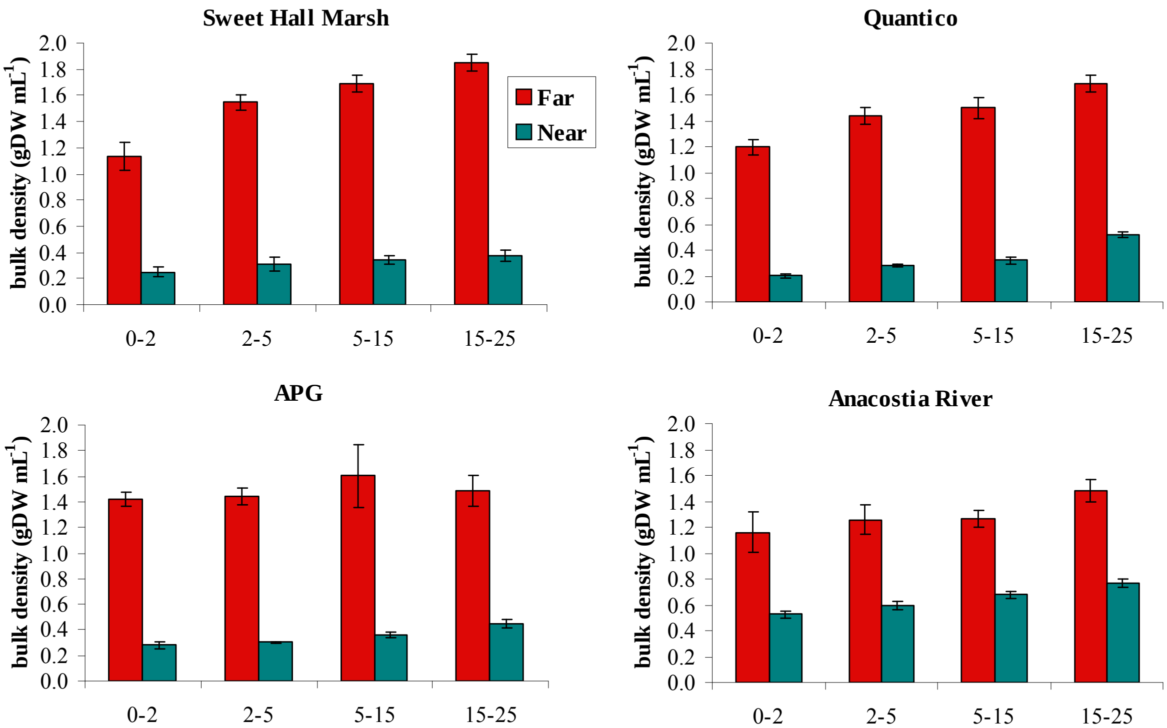


Figure 40. Mean sediment bulk density by depth section and stratum at Sweet Hall Marsh, Quantico, APG, and the Anacostia River. Error bars represent standard errors.

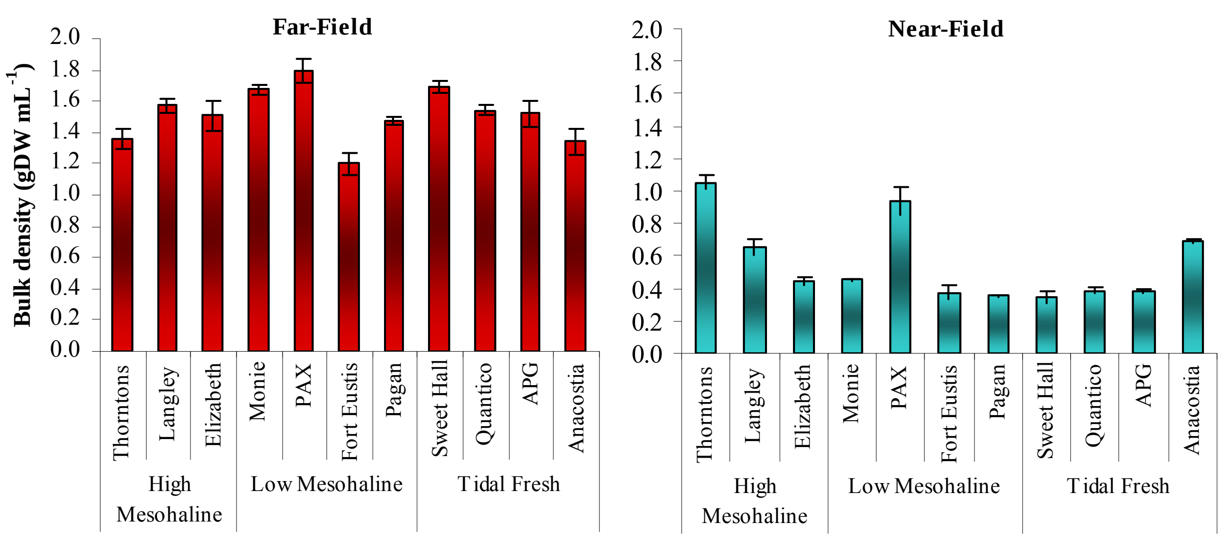


Figure 41. Mean depth averaged (over 25 cm) sediment bulk density at far- and near-field strata for all sites. Error bars represent standard errors. 2003=high mesohaline; 2004=low mesohaline; 2005=tidal freshwater salinity regimes.

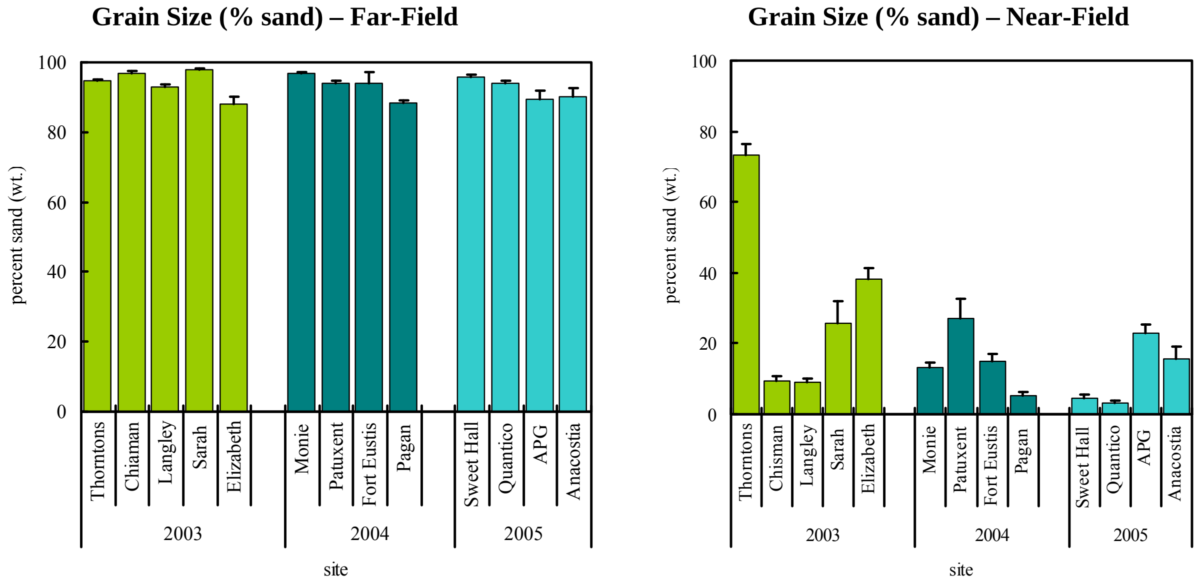


Figure 42. Sediment grain size distribution (11.5 cm depth), given as percent sand by weight, for benthic cores taken at far- and near-field strata for all sites, including Chisman and Sarah Creeks. The sand fraction includes detrital materials such as woody debris and shell. Error bars represent standard errors. 2003=high mesohaline; 2004=low mesohaline; 2005=tidal freshwater salinity regimes.

comparison of depth averaged bulk density over the 25 cm demonstrates that bulk density was highest at far-field stations and lowest at near-near stations for all the study sites (Figure 41). Bulk density was generally similar within a stratum.

As would be expected based on bulk density, near-field stations had lower percentages of sand than far-field stations for all sites, although Thorntons near-field site had higher sand content than the other high mesohaline near-field stations (Figure 42). Near-field stations were generally characterized by muddy sediments (< 40% sand), while far-field stations generally had 90% or more sand content.

Sediment organic content was highest at near-field stations for all years (Figures 43-46). For the high mesohaline sites, ER near- and far-field sediments were enriched in organic content relative to LAFB and Thorntons Creek sediments (Figure 43). Organic content declined with depth in LAFB near-field stations, but this variation was not apparent at the other sites. For the low mesohaline sites in general, there was no consistent organic content pattern with depth. (Figure 44). The organic content of the sediments at the Patuxent River near-field stations was markedly less than that observed at the other low mesohaline sampling stations. Fort Eustis and Pagan near-field sites had the highest organic content (Figures 44 and 46). For the tidal freshwater sites, organic content declined with depth at near-field but not far-field sites (Figure 45). Anacostia far-field stations were enriched in organic content relative to the other tidal freshwater far-field stations (Figure 45 and 46). APG and Sweet Hall Marsh near-field sediments had the highest organic enrichment. Along the Chesapeake Bay salinity gradient, organic content was relatively constant at far-field sites, however, it generally increased with decreasing salinity at near-field sites (Figure 46).

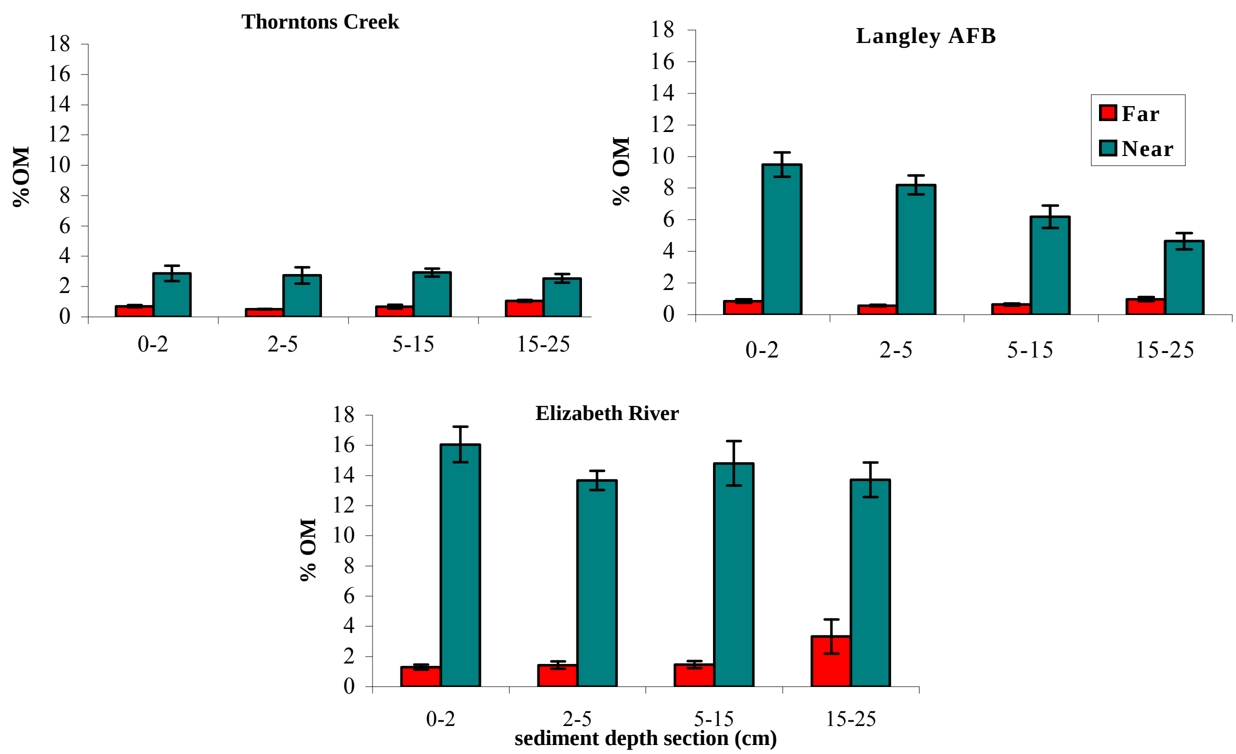


Figure 43. Mean sediment % organic matter by depth section and stratum site at Thorntons Creek, Langley AFB, and Elizabeth River. Error bars represent standard errors.

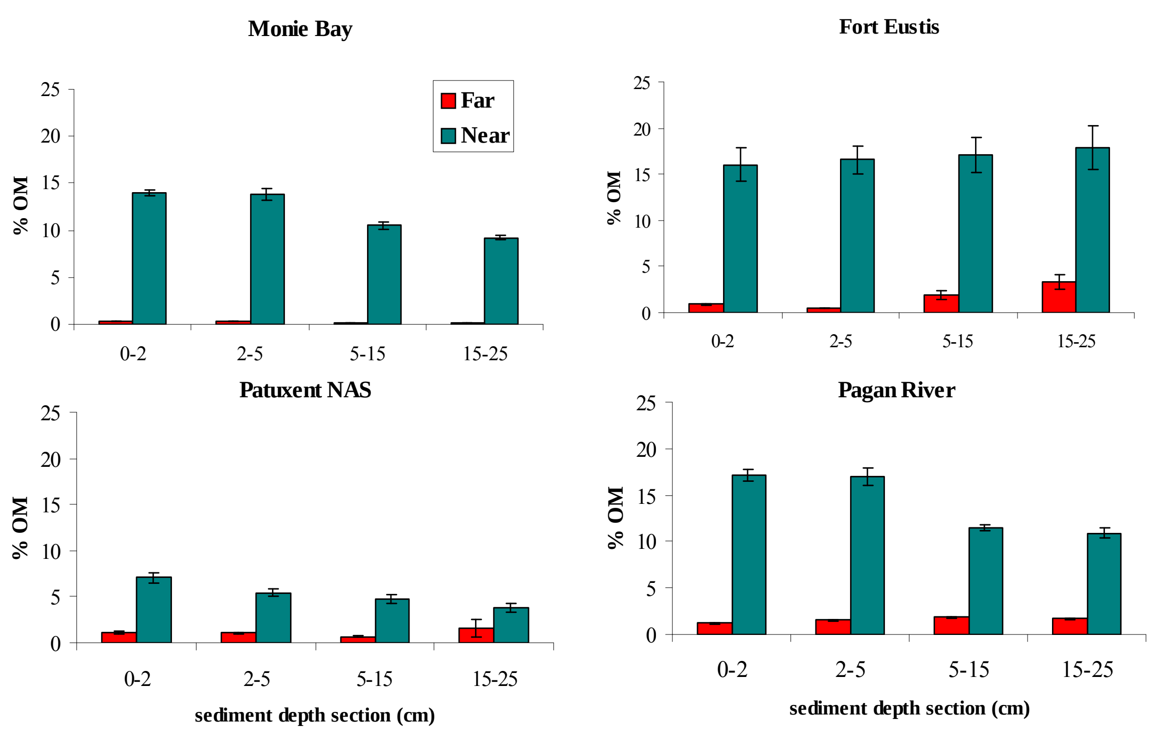


Figure 44. Mean sediment % organic matter by depth section and stratum at Monie Bay, PAX, Fort Eustis, and the Pagan River. Error bars represent standard errors

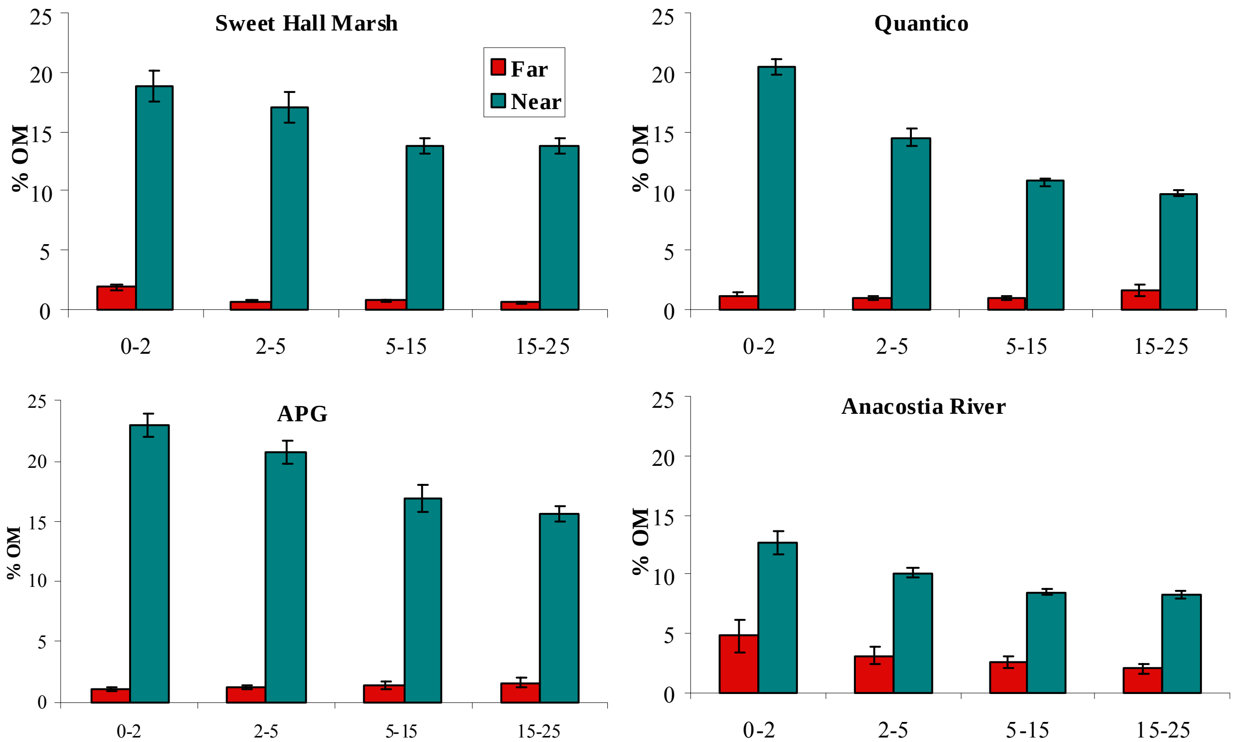


Figure 45. Mean sediment % organic matter by depth section and stratum at Sweet Hall Marsh, Quantico, APG, and the Anacostia River. Error bars represent standard errors.

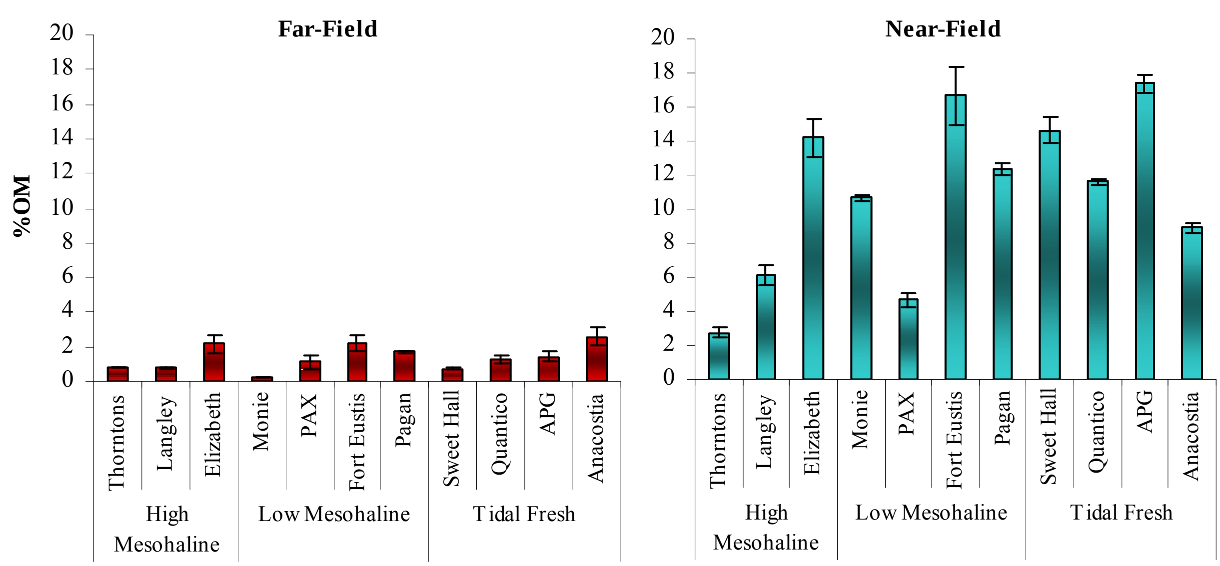


Figure 46. Mean depth averaged (over 25 cm) sediment bulk density at far- and near-field strata for all sites. Error bars represent standard errors. 2003=high mesohaline; 2004=low mesohaline; 2005=tidal freshwater salinity regimes.

Extractable sediment NH_4^+, NOx, and PO_4^{3-} concentrations at the near-field sites were higher than at the far-field sites (Figure 47). NH_4^+ was the predominant nitrogen species found in the sediment, indicating reducing conditions. For the high mesohaline sites, the Elizabeth River (degraded) site had the highest sediment nutrient concentrations, followed by LAFB then Thorntons Creek (reference). For the low mesohaline sites, PAX near-field stations had the lowest sediment NH_4^+ concentrations, while Fort Eustis and Pagan River near-field sites had the highest concentrations. The degraded end member Anacostia River site had the highest sediment NH_4^+ concentrations compared to other tidal freshwater sites. Sediment NH_4^+ concentrations generally increased along the Chesapeake Bay estuarine gradient from high to low salinity (from 2003 to 2005). Within a salinity regime, the sites classified a priori as degraded generally had the highest sediment nutrient concentrations.

Similar to the sediment extractable nutrients and organic content, sediment TOC and TN content were higher at the near-field sites (Figure 48). TOC and TN were highest at the Elizabeth River near-field site among the high mesohaline study sites. For the low mesohaline sites, the Fort Eustis near-field site had the highest TOC and TN, while PAX near-field had the lowest. Interestingly although Anacostia had the highest sediment nutrients, its TN content was the lowest among the tidal freshwater sites. The low TN, organic and chlorophyll a contents in the Anacostia sediments relative to the other near-field tidal freshwater sites suggest that conditions at the near-field Anacostia site inhibited sediment autotrophy and, thus, accumulation of organic matter. APG near-field site had the highest TOC and TN, followed by Sweet Hall and Quantico near-field sites. The sediment molar C/N ratio was determined for all sites. Sites with high organic enrichment, such as near-field sites compared to far-field sites, tended to have higher C/N values, suggesting the presence of detrital material. At specific near-field sites, such as Elizabeth River, Fort Eustis, and Anacostia, with C/N> 20, the organic matter present is likely to be refractory and less susceptible to decomposition.

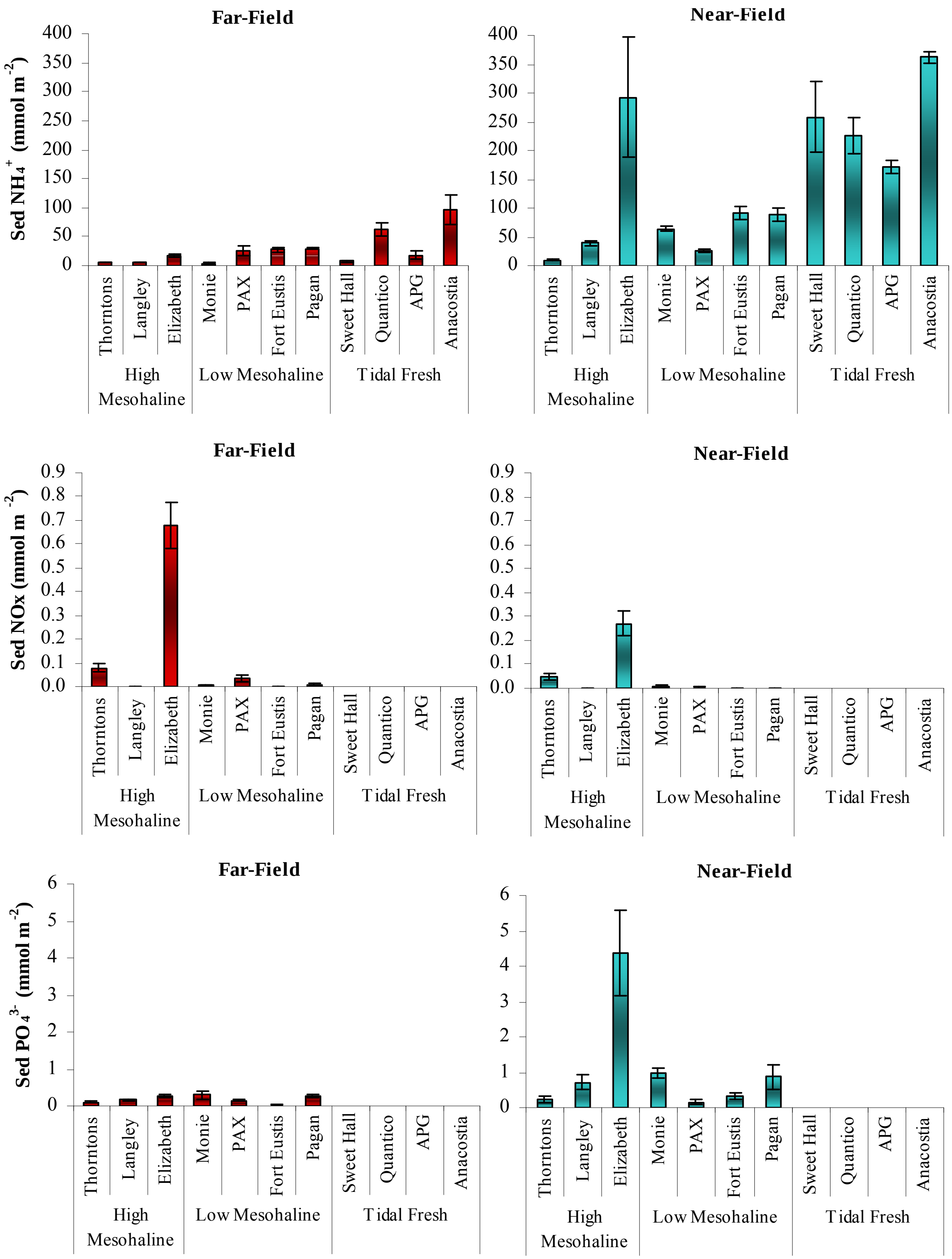


Figure 47. Mean depth averaged (over 25 cm) sediment extractable nutrients at far- and near-field strata for all sites. Error bars represent standard errors. It was not possible to analyze for PO_4^{3-} in the 2005 samples because of severe iron interference. 2003=high mesohaline; 2004=low mesohaline; 2005=tidal freshwater salinity regimes.

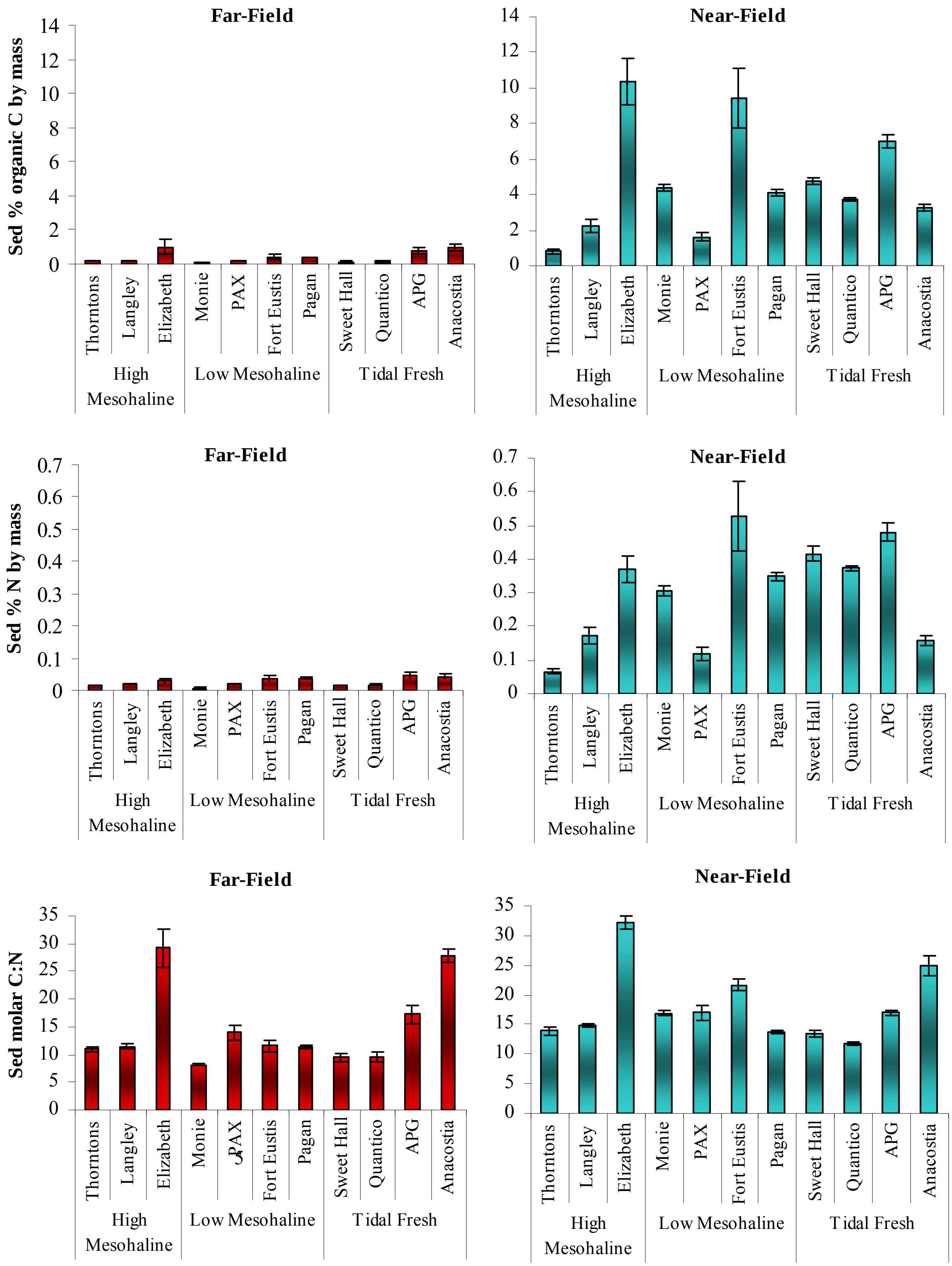


Figure 48. Mean depth averaged (over 25 cm) sediment % total organic carbon, total nitrogen, and molar C:N ratio at far- and near-field strata for all sites. Error bars represent standard errors. 2003=high mesohaline; 2004=low mesohaline; 2005=tidal freshwater salinity regimes.

Both chlorophyll a and phaeophytin pigments were analyzed in 1 cm depth sections down to 3 cm at far-field and near-field stations at all sites. Pigment content varied strongly between sites, strata, and with depth at each station (Figures 49-53). At all sites, far-field stations had greater chlorophyll a content than near-field stations. Chlorophyll a generally declined with depth, although a significant percentage of the total chlorophyll was found in the 2-3 cm depth interval. In all the sites, phaeophytin was a minor component of pigment content in sediments of the far-field stations but was generally similar in concentration to chlorophyll a or higher at the near-field stations (Figures 49-51). This indicates that detrital material was an important component of the organic matter found in sediments at near-field but not far-field stations. At all near-field sites, pigment concentration did not vary much with depth, likely due to the activity of bioturbating macrofauna.

Specifically for the high mesohaline sites, phaeophytin was higher in the near-field than the far-field stations at both the ER and Thorntons Creek sites (Figure 49). In the ER sediments, most of the photosynthetic pigment in the near-field stations was in the form of phaeophytin, a pigment that characterizes degraded chlorophyll typically found in detrital material. Sediments taken from both near- and far-field stations in the Pagan had lower levels of total chlorophyll a but higher concentrations of phaeophytin compared to all other low mesohaline sites, reflecting the high turbidity and high light attenuation at those stations as well as the high detrital content of the sediments (Figure 50). PAX and Fort Eustis far-field sites had the highest chlorophyll a among the low mesohaline sites, suggesting greater light availability. The Anacostia River far-field site had much lower levels of chlorophyll a compared to the other tidal freshwater sites (Figure 51). The high phaeophytin observed in the near-field Sweet Hall Marsh site was expected since sampling was performed in a narrow tidal creek surrounded by marsh. An inter-site comparison across the Chesapeake Bay estuarine gradient demonstrated higher chlorophyll a in far-field than in near-field sites, highest chlorophyll a in far-field low mesohaline sites, and a trend of decreasing chlorophyll a with decreasing salinity at near-field sites (Figures 52 and 53).

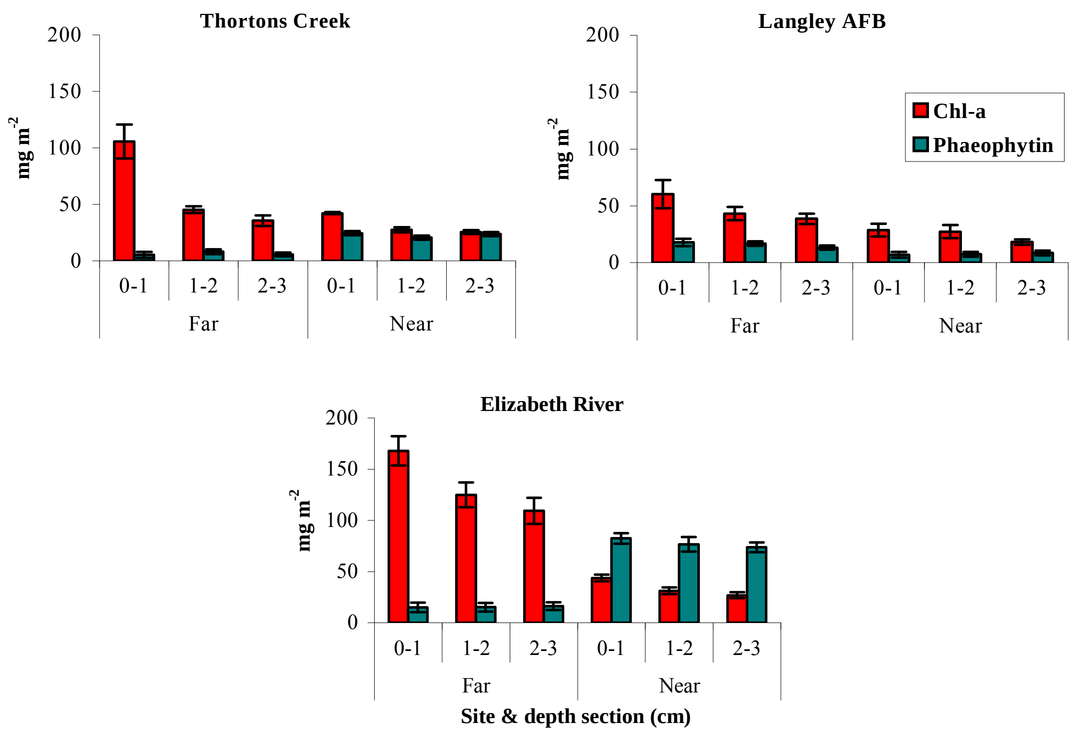


Figure 49. Mean benthic chlorophyll a and phaeophytin concentrations by sediment depth section and stratum site at Thorntons Creek, Langley AFB, and Elizabeth River. Error bars represent standard errors.

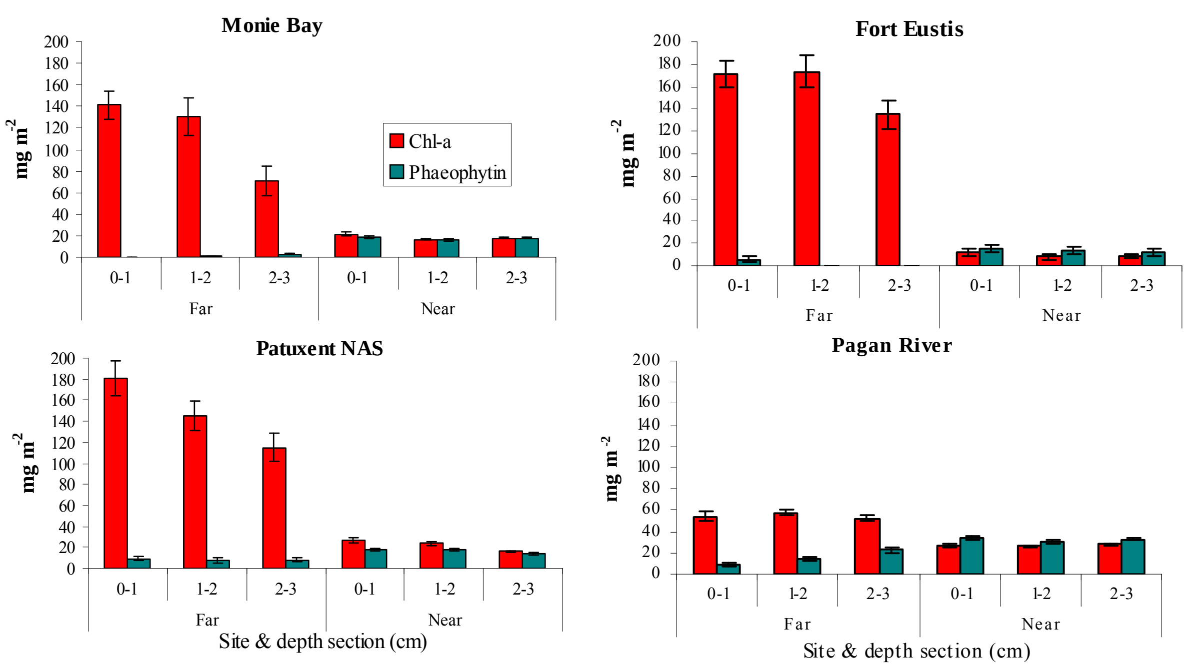


Figure 50. Mean benthic chlorophyll a and phaeophytin concentrations by sediment depth section and stratum site at Monie Bay, PAX, Fort Eustis, and the Pagan River. Error bars represent standard errors.

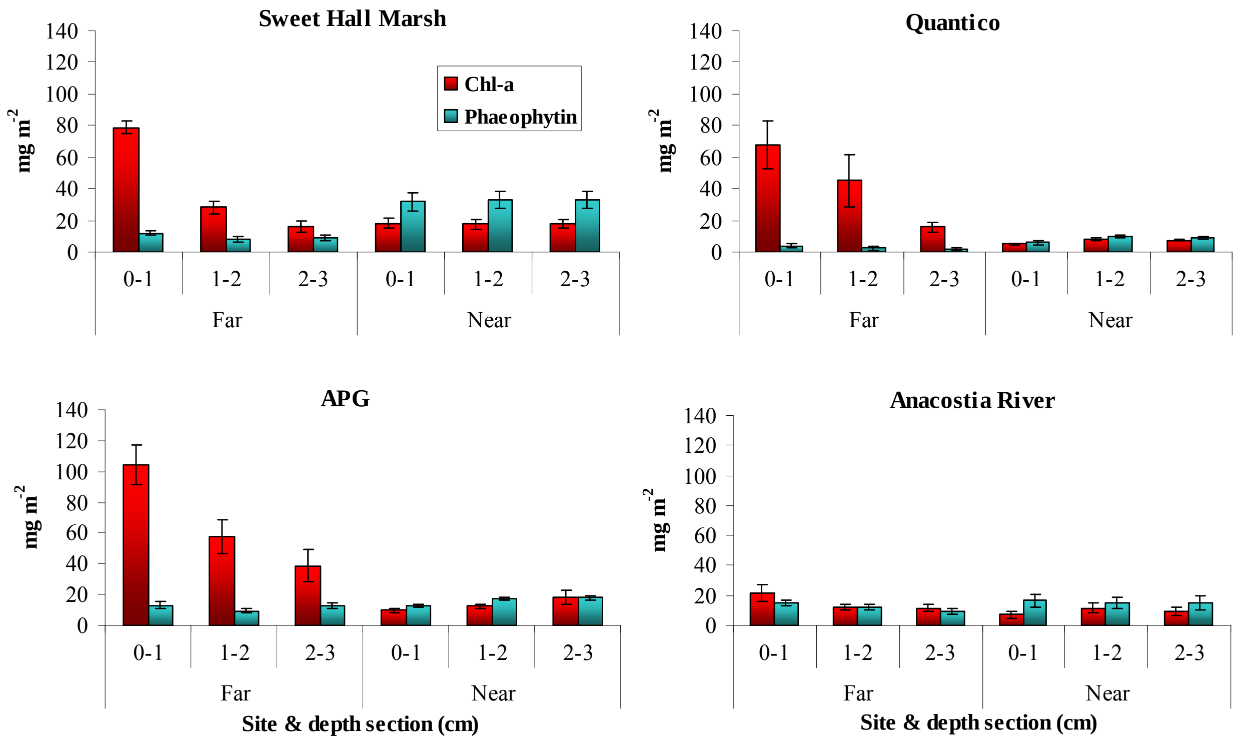


Figure 51. Mean benthic chlorophyll a and phaeophytin concentrations (mg m^{-2}) by sediment depth section and stratum site at Sweet Hall Marsh, Quantico, APG, and the Anacostia River. Error bars represent standard errors.

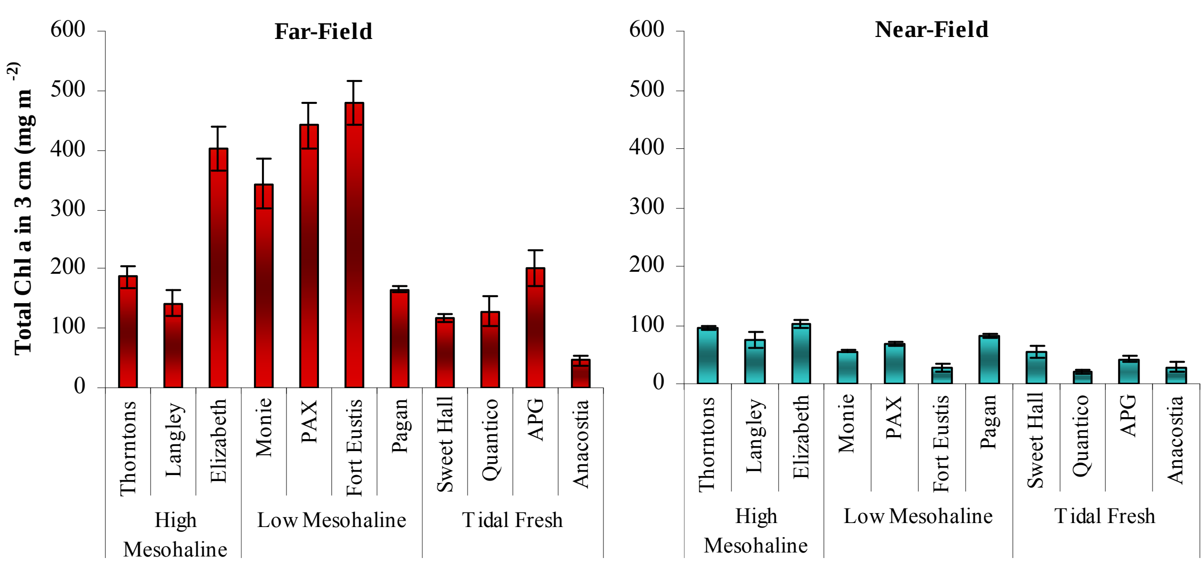


Figure 52. Mean total chlorophyll a in 3 cm of sediment at far- and near-field strata for all sites. Error bars represent standard errors. 2003=high mesohaline; 2004=low mesohaline; 2005=tidal freshwater salinity regimes.

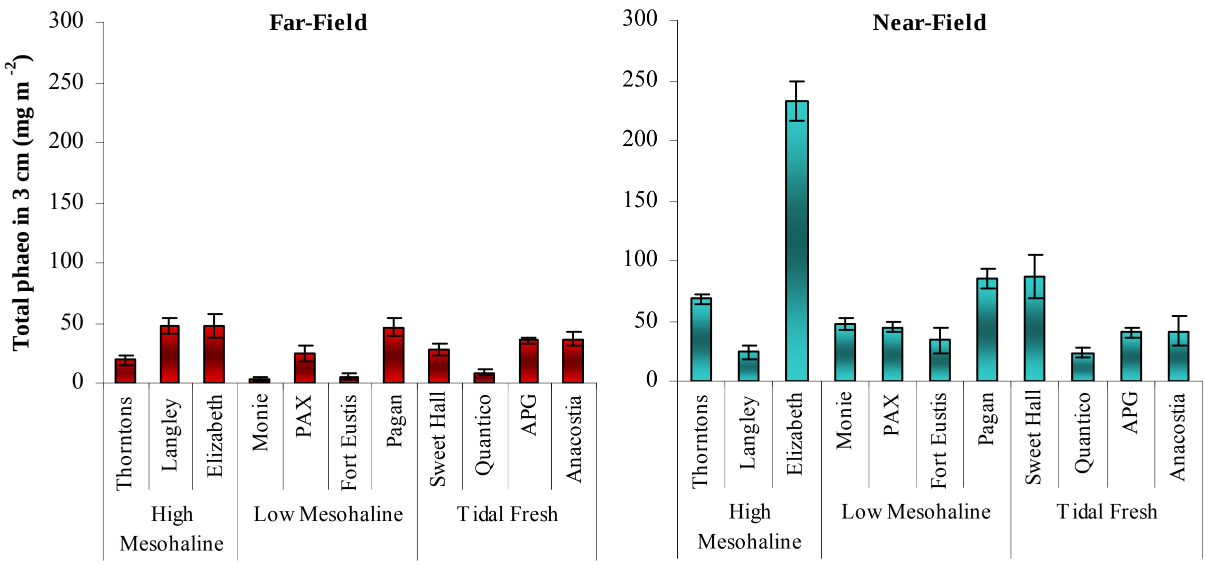


Figure 53. Mean total phaeophytin in 3 cm of sediment at far- and near-field strata for all sites. Error bars represent standard errors. 2003=high mesohaline; 2004=low mesohaline; 2005=tidal freshwater salinity regimes.

5.4 Gradients of Environmental Impairment

Principal Components Analysis (PCA) of historical regional and local water quality data and Chesapeake Bay Region of Concern status demonstrates that our study areas are arrayed along gradients of environmental impairment (Figure 54). Study areas selected a priori as highly degraded end-members (shown in red in the figure) had high water column dissolved nutrients (bottom water for regional stations). This includes the Elizabeth River (ER), Pagan River (PG), and Anacostia River (AN), and two of our study areas (ER and AN) are located within tributaries that have been given the Region of Concern (ROC) designation by the Chesapeake Bay Program, due to the high degree of urbanization, and presence of high levels of sediment contaminants throughout these systems. In contrast, our reference sites were selected to be in areas of minimal human activity and low regional nutrient loadings. Two of our study areas, Sweet Hall and Monie Bay are part of the National Estuarine Research Reserve system and represent some of the most pristine habitats within the Chesapeake Bay ecosystem. Our Severn River/Thorntons Creek study area, which was used as the reference area for the lower estuary sampling in 2003, is located in a region that is dominated by forest and woodlands (Table 20, from Metcalfe 2005). Regional nutrient concentrations for the Sweet Hall study region were relatively high (Figure 54, Table 18), reflecting the general conditions observed in the tidal freshwater reaches of the Chesapeake Bay ecosystem. We did not have access to local water quality data for the Sweet Hall study region.

High scores on principal component (PC) 1, which accounted for 58.8% of the variance in the data, were associated with low nutrient concentrations and high environmental quality (estuarine reserves). PC2 (18.1% of variance) separated sites based on the dominant form of nutrient present in bottom waters annually. Sites with positive scores on PC2 had high nitrate and nitrite concentrations in bottom waters, while sites with negative scores on PC2 had the highest phosphate concentrations. Sites characterized by high dissolved ammonium concentrations had intermediate scores on PC2. PC3 accounted for a small amount of variance (11.8%) and separated sites based on both status and nutrient concentrations.

In the Chesapeake Bay ecosystem, as in many other shallow coastal and estuarine regions, high nutrient loading in the water column leads to eutrophication, which is defined as an accumulation of organic matter (Nixon 1995). Eutrophication has a multitude of direct and indirect effects (Cloern 2001). For benthic habitats, one of the primary effects is the enhanced probability of hypoxia or anoxia in bottom waters due to high respiration fueled by high primary production. This is common in deep water when stratification precludes effective physical mixing of oxygen from the surface to the bottom. Eutrophication also leads to sediment organic enrichment due to the enhanced deposition or in situ production of organic matter or increased loadings of organic matter from anthropogenic sources. Depositional nearshore habitats may serve as effective repositories for labile allocthonous and autochthonous organic matter due to the limitations on rates of organic matter degradation in sediments. The multitude of effects of organic enrichment has on benthic communities, via changes in factors such as sediment chemistry and food web dynamics, have been well-studied. Results of previous studies formed the basis for the hypotheses that guided this study (see Background).

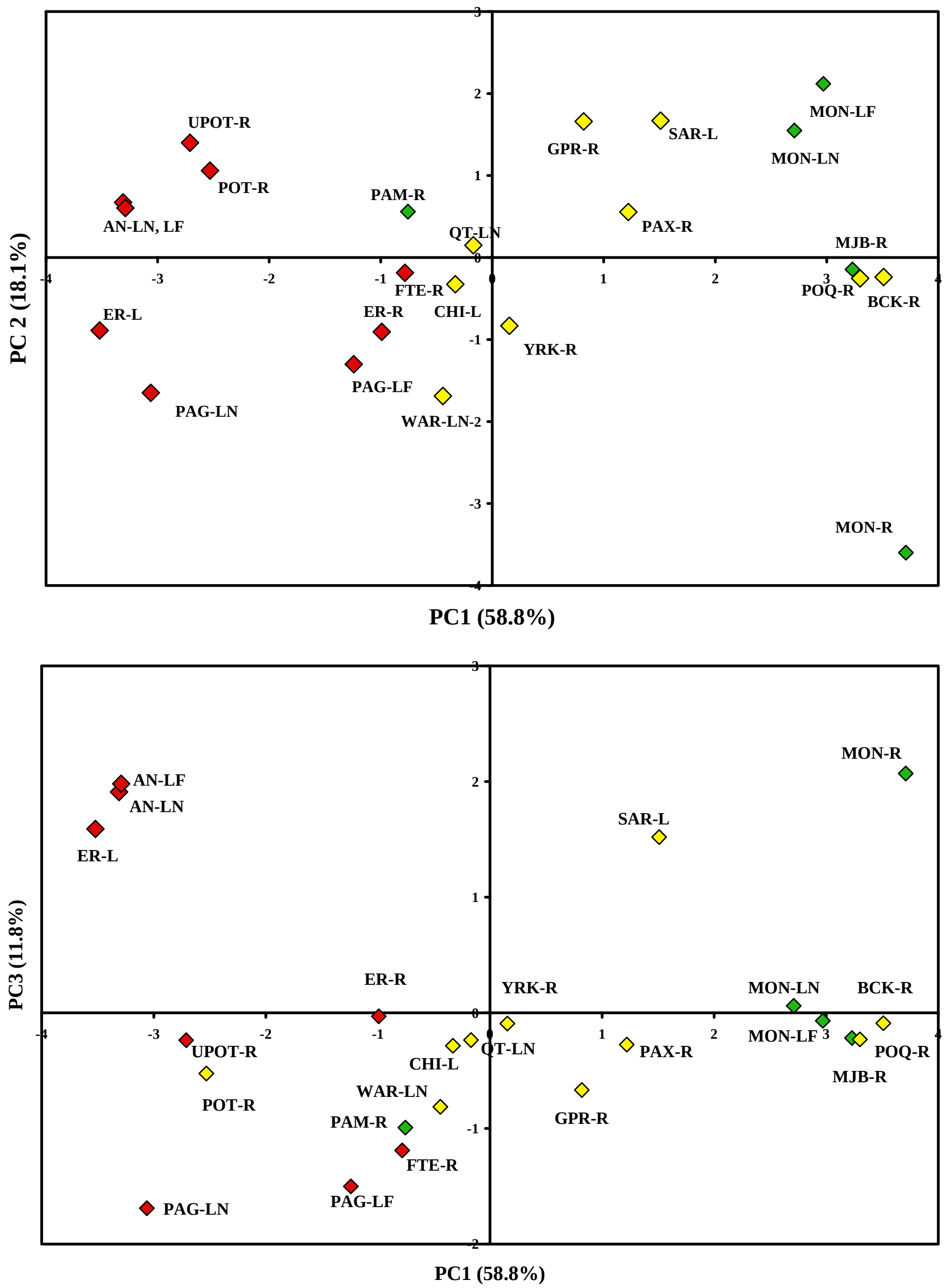


Figure 54. PCA ordinations of regional and local environmental quality indicators. Relationships between environmental indicators and principal components 1-3 are given in Table 19. Site codes are listed in Table 5. For additional information refer to text.

Table 19. Coefficients of environmental indicator eigenvectors for principal components 1-3. For additional information on data used, refer to methods.

Variable	**PC1**	**PC2**	**PC3**
Annual dissolved NH_4, lower quartile	-0.351	0.180	0.342
Annual dissolved NH_4, upper quartile	-0.284	-0.285	0.334
Annual dissolved NH_4, median	-0.357	-0.036	0.380
Annual dissolved NO_x, lower quartile	-0.324	0.416	-0.108
Annual dissolved NO_x, upper quartile	-0.301	0.366	-0.247
Annual dissolved NO_x, median	-0.321	0.436	-0.185
Annual dissolved PO_4, lower quartile	-0.349	-0.227	-0.229
Annual dissolved PO_4, upper quartile	-0.267	-0.441	-0.407
Annual dissolved PO_4, median	-0.334	-0.336	-0.323
Status	-0.258	-0.174	0.445

Table 20. Watershed land use information for our high mesohaline study regions determined using GIS as part of a companion study by Metcalfe 2005.

Study region	**% developed high intensity**	**% developed medium intensity**	**% developed low intensity**	**% developed open space**	**% natural barren**	**% farmland**	**% woodlands**	**% forest**
Chisman Creek	0.3	1.8	6.3	9.0	3.7	17.1	4.6	57.2
Elizabeth River	4.8	12.3	28.3	18.1	1.2	15.6	6.3	13.5
Langley AFB	3.9	11.2	21.9	21.9	1.1	13.0	9.0	18.0
Sarah Creek	0.4	2.5	5.3	12.0	2.7	30.7	6.1	40.4
Thorntons Creek	0.2	0.5	1.3	2.4	2.7	17.2	24.1	56.1

Consistent with our initial hypotheses, as reflected in our experimental design, we found significant relationships between the organic content of surface sediments (0-5 cm) measured as total nitrogen (TN), sediment grain size (a reflection of hydrodynamic/depositional regime) and regional water quality (Table 21). Sediment nitrogen content, for both near-field and far-field strata, and within the far-field stratum, is primarily a function of sediment clay content. For the high mesohaline sites, regional DIN is a better predictor of sediment nitrogen content than clay content.

The relationship between particle-reactive contaminant inventories and sediment grain size has been well-documented in many previous studies. Concentrations of persistent contaminants (metals, PCBs, PAHs) tend to be higher in depositional sheltered habitats that are floored by fine grained sediments, relative to exposed habitats that are floored by sandy sediments. Although we did not measure sediment contaminants during this study, Metcalfe (2005) used a standard amphipod bioassay to measure sediment toxicity for the sites we visited in 2003. He found significant acute sediment toxicity only at the Elizabeth River near-field site. In contrast, sediments from the Elizabeth River far-field site, and all other sites we sampled were not significantly different. Although the areas we sampled in the Elizabeth River are only 100s of meters apart and are within the same regional water mass, only the near-field site had elevated sediment organic matter and sediment toxicity. Water quality impairments are regional in the Elizabeth due to water mixing, while the sediment quality impairments we observed within the region were localized to the area with fine sediments.

Table 21. Regressions of total nitrogen (TN) versus clay and historic regional dissolved inorganic nitrogen (DIN) concentration. na=not applicable; ns=not significant; HM=high mesohaline; LM=low mesohaline, ol=oligohaline; tf=tidal freshwater.

Regression Models	Stratum	n	f	*p*	r^2	A (clay)	B (DIN)	C
Mean TN (all)	na	26	38.06	<0.0001	0.768	0.0086	0	0.0144
Mean TN (strata)	Near	13	2.04	ns				
	Far	13	24.17	0.0001	0.828	0.0015	0.0003	0.014
Mean TN (salinity)	hm	10	19.68	0.0013	0.849	0.0093	0.0113	-0.0533
	lm	5	114.58	0.0087	0.991	0.0128	-0.0055	0.0132
	ol	3	1618.37	0.0158	0.999	0.008	0	-0.0074
	tf	8	5.83	0.0494	0.7	0.0829	0.0082	0.0082

5.5 Using Benthic Community Indicators to Assess Environmental Condition

A major objective of our study was to evaluate and characterize the ecological integrity of representative nearshore habitats of DoD installations of Chesapeake Bay, using benthic macroinfaunal and meiofaunal communities as key indicators of environmental condition. To accomplish this objective, we used detailed investigations of sites arrayed along gradients of impairment associated with watershed development and activities, sediment contamination, and eutrophication to elucidate relationships among human activities and benthic community structure indicators. We also examined relationships between environmental impairment and macroinfaunal secondary production, an important ecosystem process that supports productivity of higher trophic levels.

The primary ecological indicator used in this study is the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI, Weisberg et al. 1997). This multimetric index has been used for over a decade to characterize benthic macroinfauna community condition of Chesapeake Bay and as a general index of estuarine health. The B-IBI has previously been successfully applied to elucidate regional and local water and sediment quality impairments (e.g. Dauer et al. 2000, Ranasinghe et al. 2002, Llanso et al. 2003) and physical habitat disturbance (e.g. Schaffner et al. 1996) in subtidal areas of the major tributaries and main bay. Application of the B-IBI in the shallow nearshore waters of the bay ecosystem has been very limited (Bilkovic et al. 2006, Dauer et al. 2008), and previous investigations have not examined the performance of the B-IBI against gradients of impairment established a priori based on other environmental indicators such as water and sediment quality or land use.

Our sampling design allowed us to consider how local habitat characteristics may act to modulate the effects of regional stressors, and alternatively, how some stressor effects are highly localized. We also examined patterns of response for the individual metrics that comprise the B-IBI, as well as other aspects of benthic community structure. This approach provides insights regarding the ability of the B-IBI to detect changes in benthic community condition along defined impairment gradients and it's response to specific stressors types.

5.5.1 The Benthic Index of Biotic Integrity

The strong effects of the estuarine salinity gradient on benthic community structure and bottom types on community structure make it challenging to assess ecological integrity in estuarine environments. The B-IBI developed for Chesapeake Bay is actually seven multimetric indexes developed specifically for the major salinity and sediment regimes of Chesapeake Bay. During the development of the CB B-IBIs, the scoring thresholds for each of the metrics used to calculate a given B-IBI (e.g. high mesohaline sand) were calibrated to so that results are comparable across salinity regimes and bottom types. This is key to using the B-IBI as a management tool because it allows assessments and comparisons of the effects of sediment and water quality impairments on benthic biota throughout the estuary.

We hypothesized that, within each major salinity regime, mean B-IBI would be significantly lower at degraded sites relative to reference sites, due to water and sediment quality impairments. The B-IBI approach also allowed us to make comparisons among habitat types within a salinity regime (mud versus sand) and across salinity regimes (e.g. high mesohaline vs. tidal freshwater). We expected to find consistent relationships for mean B-IBI among major salinity regimes and between major habitat (sediment) types given similar degrees of environmental impairment.

We used three-way ANOVA to examine the main effects of stratum (near-field mud, far-field sand), status (reference, unclassified, degraded), and salinity regime (high mesohaline, low mesohaline/oligohaline, tidal freshwater) on mean B-IBI (Figure 55). We found highly significant effects of stratum, status and salinity regime, and significant interactions. Least Squares Means post-hoc analyses allowed us to further explore the two-way interaction effects, which are discussed below. When significance is indicated, but a p-value is not given, the threshold is $p < 0.05$.

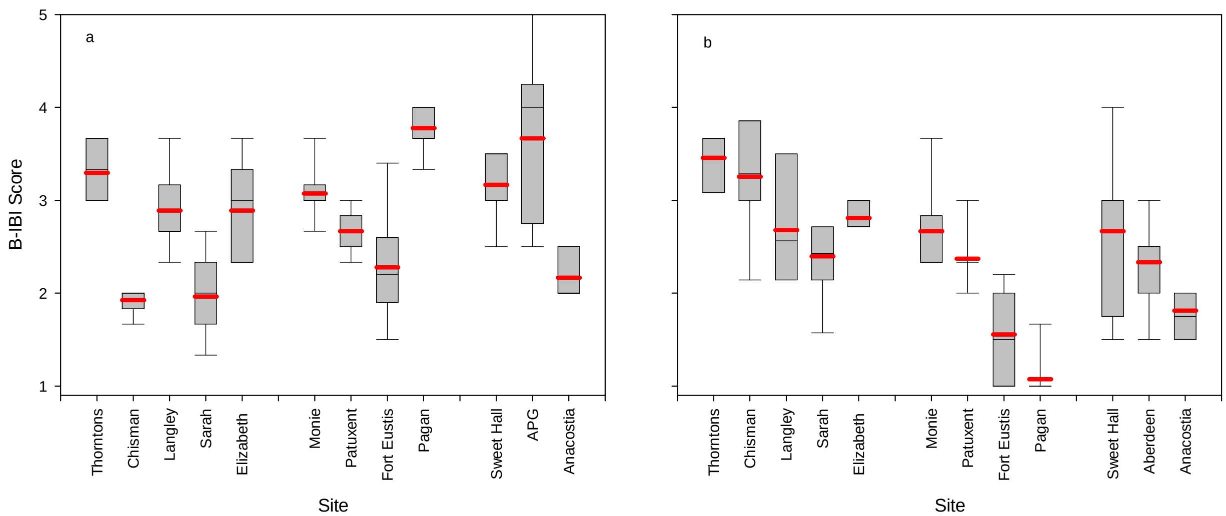


Figure 55. Benthic Index of Biotic Integrity by stratum, major salinity regime, and site. Shown are the means (red line), as well as the median, quartiles and deciles based on 8 or 9 samples for far-field (a) and near-field (b) strata.

The patterns we observed for main effects on the B-IBI (Table 22) were largely consistent with our initial hypotheses. Far-field sites had significantly higher mean B-IBIs than near-field sites. Reference sites had higher mean B-IBIs than sites with unclassified condition or degraded sites, which were not significantly different. Mean B-IBIs were significantly higher for the high mesohaline sites relative to low mesohaline and tidal freshwater sites, which were not significantly different.

The interaction of main effects **stratum and status** was also significant ($F = 11.7$, $p < 0.0001$). For the near-field stratum there were significant differences among sites based on status (reference>unclassified>degraded). For the far-field stratum there were significant differences between reference and unclassified (reference>unclassified) and degraded and

Table 22. Summary of the three-way ANOVAs of B-IBI and other select macrofauna metrics with the parameter evaluated, number of samples (n), model p-value, model r^2, the F-statistic and degrees of freedom (model, error), the probability for each of the main effects, significant interactions terms, and the least square means contrasts for the main effects. Least squares means are arranged left to right for highest to lowest. Similarity of least squares mean values for stratum, status and salinity occur when (1) values overlap in columns, or (2) co-occur in the same row. **FF** = far-field, **NF** = near-field, **R** = reference, **U** = unclassified, **D** = degraded, **HM** = high-mesohaline, **LM** = low-mesohaline, **TF** = tidal freshwater.

parameter	n	model p-value	model R^2	F	df	stratum p-value	status p-value	salinity p-value	inter-action	stratum effect		status effect			salinity regime effect		
bibi	218	<0.0001	0.602	18.11	17, 194	<0.0001	<0.0001	<0.0001	all	FF		R			HM		
											NF		U	D		TF	LM
abundance	212	<0.0001	0.756	35.43	17, 194	<0.0001	<0.0001	<0.0001	all	NF		D			LM		
											FF		U	R		TF	
																	HM
biomass	212	<0.0001	0.517	12.2	17, 194	0.0019	<0.0001	<0.0001	all	FF		D			LM	HM	
											NF		U				TF
														R			
H' diversity	212	<0.0001	0.657	21.88	17, 194	<0.0001	<0.0001	<0.0001	all	FF		R			HM		
											NF		U			LM	
														D			TF
Species Richness (S)	212	<0.0001	0.576	10.62	17, 194	ns	<0.0001	<0.0001	str*sta, sta*sal, str*sta* sal	FF	NF	R			LM	HM	
													U				TF
														D			

Table 22, continued

parameter	n	model p-value	model R^2	F	df	stratum p-value	status p-value	salinity p-value	inter-action	stratum effect		status effect			salinity regime effect		
J' Evenness	212	<0.0001	0.700	25.36	17, 194	<0.0001	0.0089	<0.0001	all	FF		R	U		HM		
											NF		U	D		TF	
																	LM
% abundance indicative	212	<0.0001	0.811	48.92	17, 194	<0.0001	<0.0001	<0.0001	all	NF	FF	U	D	R	TF	LM	HM
% biomass indicative	212	<0.0001	0.642	20.53	17, 194	<0.0001	<0.0001	<0.0001	all	NF	FF	U			TF		
													D	R		LM	HM
% abundance sensitive	212	<0.0001	0.687	41.12	17, 194	<0.0001	<0.0001	<0.0001	all	FF	NF	R	D	U	HM	LM	
% biomass sensitive	212	<0.0001	0.401	12.57	17, 194	<0.0001	ns	ns	all	FF	NF	R	U	D	LM	HM	
% biomass > 5 cm	212	<0.0001	0.521	12.48	17, 194	<0.0001	0.0193	0.0005	all	FF	NF	D	U	R	LM	HM	TF
% abundance carnivores/ omnivores	212	<0.0001	0.686	24.96	17, 194	<0.0001	0.0507	0.0006	all	FF	NF	U	D		HM	TF	
														R			LM
% abundance deep deposit	212	<0.0001	0.771	38.43	17, 194	<0.0001	<0.0001	<0.0001	all	NF	FF	D	R		TF	LM	HM
														U			

unclassified (degraded>unclassified) sites, which suggests that the unclassified sites were more impacted than the sites classified a priori as degraded. For reference sites, the mean B-IBIs were not significantly different for far-field and near-field, but the B-IBIs at far-field sites with unclassified and degraded status were significantly higher than the B-IBIs at near-field sites with unclassified and degraded status. This is consistent with our finding that regional water quality impairments promote sediment organic enrichment at near-field, but not far-field sites.

The interaction of main effects **stratum and salinity** was significant ($F = 27.5$, $p < 0.0001$). When sites were classified by stratum, salinity regime was significant for near-field (high mesohaline>tidal freshwater>low mesohaline/oligohaline), but not far-field sites. This suggests that the lowest overall habitat quality is in the fine grained sediments of the middle estuary, a pattern previously observed in the deeper waters of the bay and many of its tributaries (Dauer et al. 2000). Within both the low mesohaline and tidal freshwater salinity regimes, far-field abundance was significantly greater than near-field abundance.

The interaction of main effects **status and salinity** was significant ($F = 11.08$, $p < 0.0001$). Within a major salinity regime, all but degraded and reference sites sampled in the low mesohaline salinity regime were significantly different (degraded=reference>unclassified). Patterns in abundance were reversed for the high mesohaline (reference>unclassified>degraded) relative to tidal freshwater (degraded>unclassified>reference). When sites were classified by status, salinity regime was important, but the rank order of abundance was different for each salinity regime: reference (low mesohaline/oligohaline>high mesohaline>tidal freshwater); unclassified (low mesohaline/oligohaline>tidal freshwater >high mesohaline); degraded (tidal freshwater>low mesohaline/oligohaline>high mesohaline).

Based on the results presented in Section 5.4, we examined relationships between mean B-IBIs and two nutrient-related indicators that are indicative of environmental condition- median annual water column dissolved inorganic nitrogen concentration (DIN) and sediment percent total nitrogen (TN). Neither variable alone or together explained a significant amount of the variation in B-IBI across all sites. Annual DIN and sediment nitrogen together predicted B-IBI for high meso- to oligohaline near-field sites better than either variable alone (Table 23). We found no significant relationships between B-IBI and DIN or TN for high meso- to oligohaline far-field sites, or near- or far-field sites in tidal freshwater.

Some site specific results are worth noting here and will be discussed further below. The B-IBI is not calibrated for habitats with submerged aquatic vegetation, so we were unable to include the Quantico sites in our B-IBI analyses. We have included discussion of our findings for the Quantico sites in a separate section below. Our Elizabeth River near-field study site had higher than expected mean B-IBI given the poor water quality of the region and the high sediment toxicity documented for the site (Metcalfe 2005). Consideration of the behavior of individual metrics at this site provides some insights regarding the factors contributing to this pattern (see below). Our Fort Eustis far-field site had lower than expected mean B-IBI based on regional water quality, and also was not expected to have sediment quality impairments based on the sediment grain size. Thus, we cannot rule out the possibility that this site was impacted by physical disturbance associated with military operations (tanks) in the nearshore region of our study area.

Table 23. Regression models for mean B-IBI by site versus annual median dissolved inorganic nitrogen (DIN) in the water column and sediment % total nitrogen (TN) in the 0-5 cm. ns=not significant. For stratum: nf = near-field, ff = far-field. For salinity: hm = high mesohaline, lm = low mesohaline, ol = oligohaline and tf = tidal freshwater.

Regression Model	**stratum**	**salinity**	**n**	r^2	***p***	**A**	**B**	**C**
Mean BIBI =								
A*TN +B*DIN + C	nf	all	13		ns			
	ff	all	13		ns			
	nf	hm,lm,ol	9	0.72	0.0224	-1.647	-0.094	3.551
	ff	hm,lm,ol	9		ns			
	nf	tf	4		ns			
	ff	tf	4		ns			
Mean B-IBI =								
A*DIN + C	nf	all	13		ns			
	ff	all	13		ns			
	nf	hm,lm,ol	9	0.65	0.008	-0.117		3.218
	ff	hm,lm,ol	9		ns			
	nf	tf	4		ns			
	ff	tf	4		ns			
Mean B-IBI =								
A*TN + C	nf	all	13		ns			
	ff	all	13		ns			
	nf	hm,lm,ol	9	0.45	0.0478	0.016		2.571
	ff	hm,lm,ol	9		ns			
	nf	tf	4		ns			
	ff	tf	4		ns			

5.5.2 Individual Metrics Comprising the B-IBI

Multimetric approaches for measuring ecological integrity are useful for detecting diverse suites of stressors and measuring impacts in systems receiving multiple stressors (Newman and Clements 2008). During the development phase of the Chesapeake Bay B-IBIs, individual metrics were selected to reflect characteristics of life history, productivity, pollution sensitivity and food web structure. Many of these metrics are also of general interest in describing benthic community structure.

We used three-way ANOVA and Least Squares Means post-hoc analyses to examine the effects of stratum (near-field, far-field), status (reference, unclassified, degraded), and salinity regime (high mesohaline, low mesohaline/oligohaline, tidal freshwater) on abundance, biomass, species diversity (H'), species richness (S), evenness (J'), percent abundance and biomass of pollution indicative taxa (as defined for the B-IBI), percent abundance and biomass of pollution indicative taxa (as defined for the B-IBI), percent biomass found below 5 cm, percent abundance of carnivores and omnivores and percent deep deposit feeders. Relationships among sites based on the full suite of macrofauna-based metrics are further explored for major habitats (strata) within each major salinity regime using PCA.

<u>Abundance</u>

Macroinfaunal abundance varied over three orders of magnitude across all samples collected (Figure 56). The highest abundances were at the low mesohaline/oligohaline near-field sites (Monie, Patuxent, Fort Eustis and Pagan) and at the Anacostia site (tidal freshwater, both strata). At all other sampling sites, abundance was typically less than 250 individuals per 130 cm^2, with low spatial variability within a given stratum at each site.

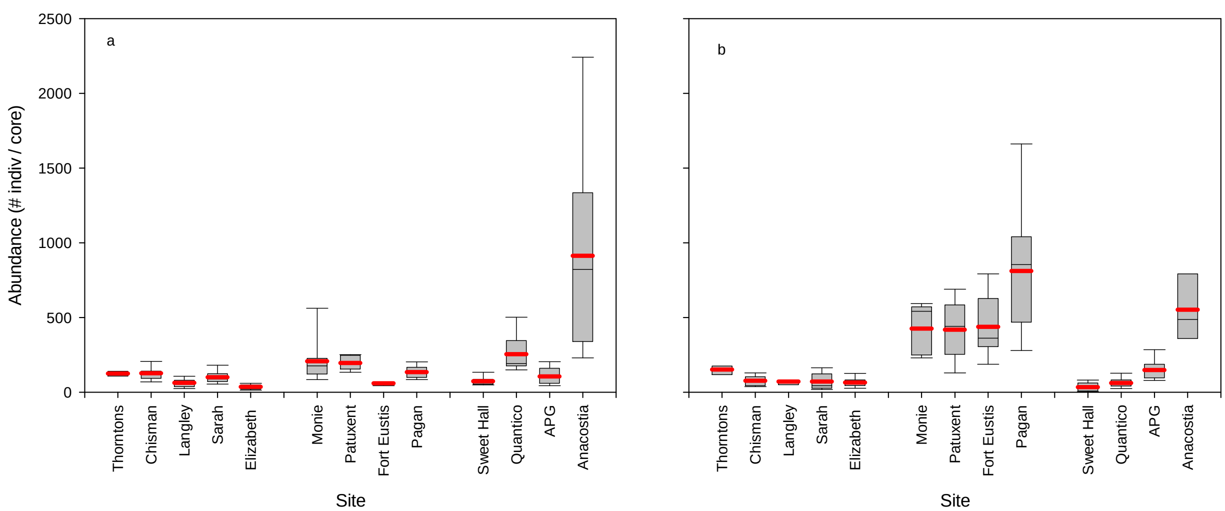


Figure 56. Number of individuals by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

Abundance is included as a metric for all seven of the CB B-IBIs. The patterns we observed for main effects on abundance were largely consistent with our initial hypotheses (Table 22). Near-field sites had significantly higher abundance than far-field sites. Degraded sites had higher abundance than sites with unclassified condition or reference condition, which were not significantly different. Abundance was significantly different among salinity regime (low mesohaline/oligohaline>tidal freshwater>high mesohaline).

The interaction of main effects **stratum and status** was significant ($F = 5.6$, p 0.0042). For the near-field stratum there were significant differences among sites based on status (degraded >unclassified>reference). For the far-field stratum there were significant differences between degraded and unclassified (degraded>unclassified) sites. For reference sites, abundance was not significantly different for far-field and near-field, but at sites with unclassified and degraded status, abundance at near-field sites was significantly higher compared to far-field sites. This is consistent with our finding that regional water quality impairments are associated with sediment organic enrichment at near-field, but not far-field sites, and the hypothesis that organic enrichment results in a shift towards a benthic community comprised of small, opportunistic species with characteristically high abundance.

The interaction of main effects **stratum and salinity** was significant ($F = 44.4$, $p <0.0001$). When sites were classified by stratum, salinity regime was significant for both the near-field (tidal freshwater>low mesohaline/oligohaline>high mesohaline) and far-field (tidal freshwater, low mesohaline/oligohaline>high mesohaline) sites. Within the high mesohaline salinity regime, near- and far-field sites were not significantly different. Salinity regime was significant for low mesohaline/oligohaline, where near-field sites had greater abundance than far-field sites. The interactions was also significant in tidal freshwater (far-field>near-field).

The interaction of main effects **status and salinity** was significant ($F = 58.96$, $p < 0.0001$). Within a major salinity regime, all but degraded and reference sites sampled in the low mesohaline/oligohaline salinity regime were significantly different (degraded=reference>unclassified). Patterns in abundance were reversed for the high mesohaline (reference>unclassified>degraded) relative to tidal freshwater (degraded>unclassified>reference). When sites were classified by status, salinity regime was significant for all comparisons, but the rank order of abundance was different for each salinity regime: reference (low mesohaline/oligohaline>high mesohaline>tidal freshwater); unclassified (low mesohaline/oligohaline>tidal freshwater >high mesohaline); degraded (tidal freshwater>low mesohaline/oligohaline>high mesohaline).

<u>Biomass</u>

Biomass ranged from less than 10 to more than 1000 mg per core and was one of the most variable biological metrics measured (Figure 57). High and variable biomass within a site/stratum was associated with the presence of bivalves, such as *Macoma* spp and *Tagelus plebius* in the mesohaline regions, *Rangia cuneata* in the oligohaline and unionids in tidal freshwater.

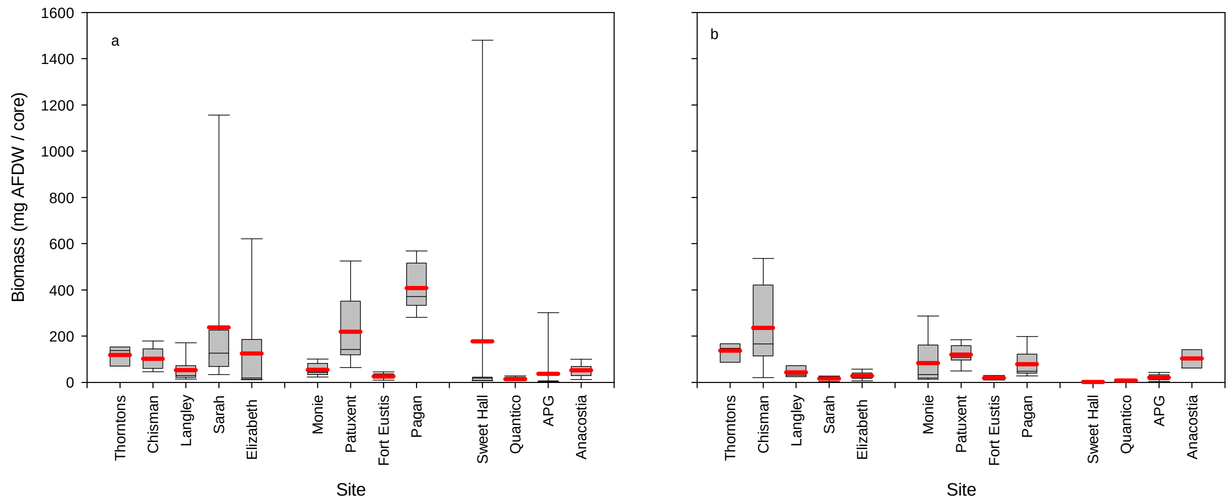


Figure 57. Total biomass by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

The patterns we observed for main effects on biomass were largely consistent with our initial hypotheses (Table 22). Near-field sites had significantly higher biomass than far-field sites. Sites of different status had significantly different biomass (degraded>unclassified>reference). This ordering suggests that eutrophication, which can stimulate benthic biomass if there is no associated DO stress, was the primary stressor at our sites. We would not expect elevated biomass at degraded sites relative to reference sites if sediment contaminants were the primary stressor. Biomass was significantly greater for low mesohaline/oligohaline and high mesohaline sites relative to tidal freshwater sites.

The interaction of main effects **stratum and status** was significant ($F = 3.2$, p 0.044). For the near-field stratum there were significant differences between degraded and reference sites (degraded >reference). For the far-field stratum biomass was highest at the degraded sites (degraded>reference=unclassified). For sites of unclassified condition, biomass was not significantly different for far-field and near-field, but at sites with reference and degraded status, biomass at far-field sites was significantly higher compared to near-field sites. Biomass at our sites was typically dominated by suspension or surface feeding bivalves. Thus our results suggest that in shallow water habitats, where dissolved oxygen stress is reduced, eutrophication expressed primarily as changes in water quality rather than sediment quality is not detrimental and may be beneficial for bivalves. Schaffner et al. (2002) previously made a similar observation for the Chesapeake Bay system overall.

The interaction of main effects **stratum and salinity** was not significant.

The interaction of main effects **status and salinity** was significant ($F = 15.78$, $p < 0.0001$). For the high mesohaline, the reference site had higher biomass than unclassified and degraded sites, which were not significantly different. For both the low mesohaline/oligohaline and tidal freshwater, sites with degraded condition had higher biomass than sites with unclassified and reference condition, which were not significantly different. Status had significant effects on biomass within each salinity regime: reference (high mesohaline>low mesohaline>tidal freshwater); unclassified (high mesohaline=low mesohaline>tidal freshwater); degraded (low mesohaline>tidal freshwater>high mesohaline).

Species Diversity (H')

For all sites visited, H' diversity ranged between 1.5 and 3.5 for the far-field sites and from <1 to 3 for the near-field sites (Figure 58). An overall trend of decreasing diversity with decreasing salinity was apparent for the far-field sites we studied, which is consistent with the general pattern often observed in estuaries. In contrast, diversity at our near-field sites dropped at our mid-salinity sites and then increased again in tidal freshwater. While this pattern may suggest a relatively high level of impairment at fine-grained sites within the middle reaches of the estuary, other explanations also seem plausible, such as intense predation by predators "squeezed" out of hypoxic or anoxic deepwater habitats of the middle estuary.

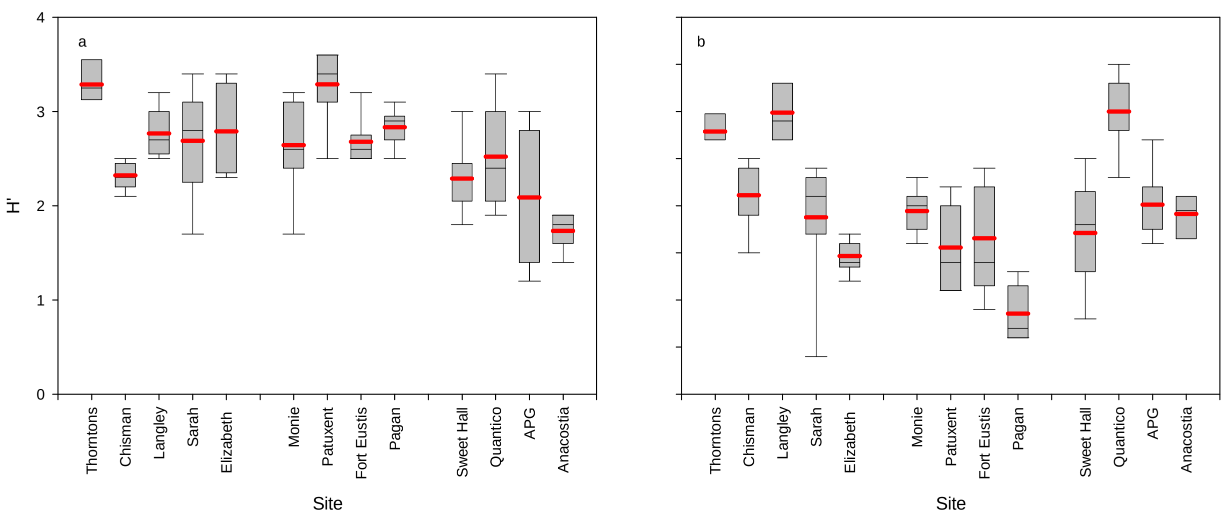


Figure 58. Shannon (H") diversity by stratum, salinity regime and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

Although the diversity metric is not used to compute the CB B-IBIs for tidal freshwater and oligohaline habitat classes, we compared this metric among all of the strata, status and salinity combinations represented in our study because diversity is an aspect of community structure that may also affect ecosystem function.

The patterns we observed for main effects on H' were largely consistent with our initial hypotheses (Table 22). Far-field sites had significantly higher H' than near-field sites. H' was significantly different among sites of different status (reference>unclassified>degraded) and from different salinity regimes (high mesohaline>low mesohaline>tidal freshwater).

The interaction of main effects **stratum and status** was significant ($F = 10.62$, $p < 0.0001$). There were significant differences in H’ among sites based on status (reference >unclassified>degraded) for the near-field, but not the far-field. H’ was significantly different for far-field and near-field for reference (far-field>near-field), unclassified (far-field>near-field) and degraded sites (far-field>near-field). These results are consistent with our finding that regional water quality impairments are associated with sediment organic enrichment at near-field, but not far-field sites, and our hypothesis that organic enrichment results in a shift towards a benthic community comprised of small, opportunistic species with characteristically high abundance.

The interaction of main effects **stratum and salinity** was significant ($F = 33.77$, $p < 0.0001$). When sites were classified by stratum, salinity regime was significant for both the near-field (high mesohaline>tidal freshwater>low mesohaline) and far-field (high mesohaline=low mesohaline>tidal freshwater) sites. Within the high mesohaline and low mesohaline/oligohaline salinity regimes, near- and far-field sites were significantly different (far-field>near-field).

The interaction of main effects **status and salinity** was significant ($F = 4.91$, $p = 0.0009$). Within high mesohaline, the reference site had higher H’ compared to other sites, while the degraded site had the lowest H’ (reference>unclassified>degraded). For the low mesohaline/oligohaline sites, reference and unclassified conditions were not significantly different, but had higher H’ than the degraded site. Status did not affect H’ in tidal freshwater. H’ decreased with the salinity gradient for reference sites (high mesohaline>low mesohaline>tidal freshwater). For sites with unclassified condition, tidal freshwater had significantly lower H’ relative to high mesohaline and low mesohaline/tidal freshwater sites. For degraded sites, H’ was highest at high mesohaline sites (high mesohaline>low mesohaline=tidal freshwater).

<u>Species Richness (S)</u>

Average Species Richness (S), as the number of species per core, ranged between 10 and 20 for far-field sites and from less than 5 to more than 20 for near-field sites, with complex patterns associated with stratum, status and salinity (Figure 59). Although S is not used to compute the CB B-IBIs, we compared this metric among all of the strata, status and salinity combinations represented in our study because richness is a component of species diversity and an aspect of community structure that may also affect ecosystem function.

The patterns we observed for main effects on S were consistent with our initial hypotheses, assuming that sites with higher salinity and better environmental quality will have greater species richness (Table 22). Overall, far- and near-field sites were not significantly different with respect to species richness, which is not surprising because species richness in an estuarine setting is expected a priori to be controlled primarily by salinity regime and disturbance. Richness was significantly different among sites of different status (reference>unclassified>degraded), with the effects being most pronounced in the mesohaline near-field sites and the high mesohaline far-fields sites, and from different salinity regimes (low mesohaline=high mesohaline>tidal freshwater). Species richness was higher than we expected

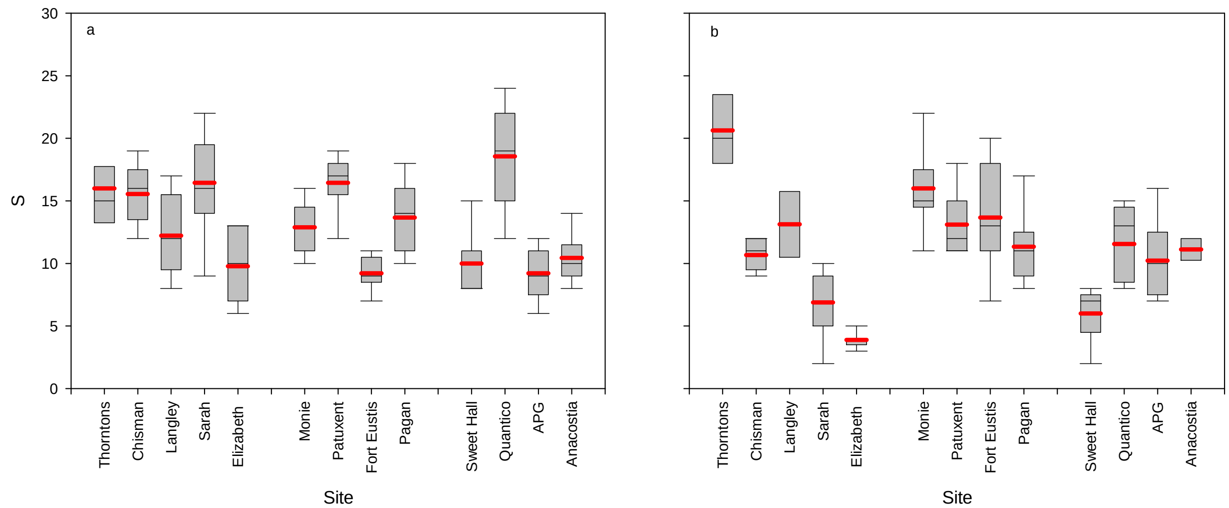


Figure 59. Species Richness (S) by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

for the low mesohaline/oligohaline sites in both far- and near-field settings, but this may be an artifact of computing richness on a per core basis.

The interaction of main effects **stratum and status** was significant (F = 5.25, p = 0.0060). There were expected differences in S among sites based on status (reference >unclassified>degraded) for the near-field, and the far-field (reference>degraded). Species richness was not different between far-field and near-field for reference and unclassified sites, but was different at degraded sites (far-field>near-field). These results suggest that species richness is a sensitive measure of condition over the full estuarine salinity gradient and that it may be useful for discriminating local versus regional impairments, e.g. patterns for high mesohaline far- and near-field sites (Figure 59).

The interaction of main effects **stratum and salinity** for species richness was not significant.

The interaction of main effects **status and salinity** was significant (F = 25.37, p <0.0001), but the trends generally supported our hypothesis. Within high mesohaline, the reference site had higher richness compared to other sites and the degraded site was lowest (reference>unclassified>degraded). Within the low mesohaline and tidal freshwater regions, sites were not different. For sites differing by status, S decreased with the salinity gradient for reference sites (high mesohaline>low mesohaline>tidal freshwater). For sites classified as degraded, high mesohaline was lower relative to tidal freshwater and low mesohaline/oligohaline sites. For unclassified sites, species richness was also lowest at high mesohaline sites (low mesohaline=tidal freshwater>high mesohaline). These trends are consistent with previous findings that the species found in poly- and high mesohaline regions of the estuary are more sensitive to environmental quality relative to species at lower salinities and tidal freshwater, which are typically more resilient.

Species Evenness (J')

The distribution of individuals among species (J') varied by stratum, salinity, and environmental status of the sites (Figure 60). Mean J' ranged between 0.5 and 0.9 for far-field sites and 0.3 and 0.9 for near-field sites. Although J' is not used to compute the CB B-IBIs, we compared this metric among all of the strata, status and salinity combinations represented in our study because evenness is a component of species diversity and an aspect of community structure that may also affect ecosystem function.

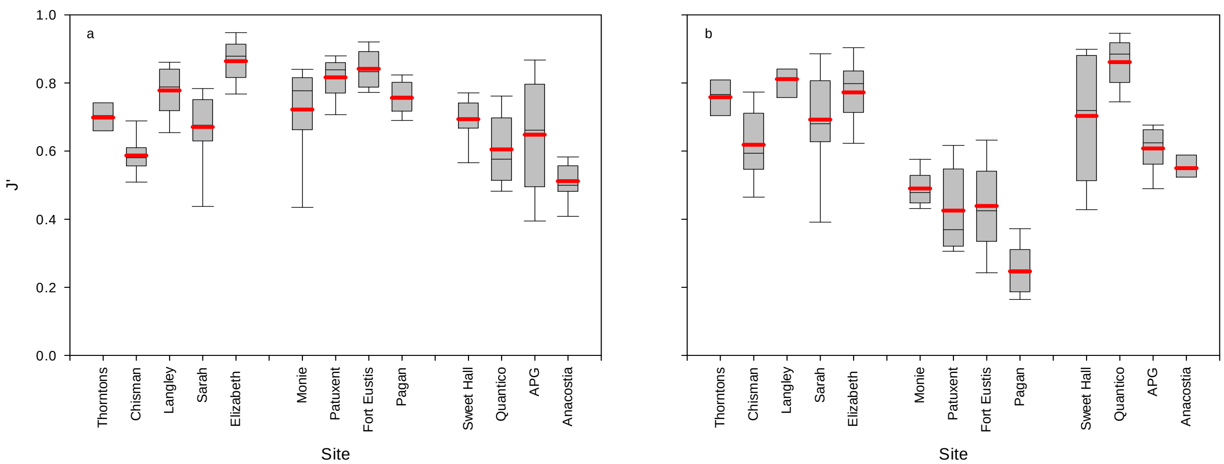


Figure 60. Evenness (J') by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25^{th} and 75^{th} quartiles, and the error bars span the 10^{th} to the 90^{th} deciles.

The patterns we observed for main effects on J' were consistent with our initial hypotheses, assuming that sites with higher environmental quality have higher evenness associated with lower dominance of the community by opportunistic species (Table 22). Far-field sites had significantly higher J' than near-field sites. J' was significantly different among sites of different status in the direction expected (reference>degraded), which is consistent with our predictions. Based on our major hypothesis, we would expect J' to be lowest when communities are degraded. Thus, our finding of highest J' in the high mesohaline (high mesohaline>tidal freshwater>low mesohaline) is concordant with the pattern for the B-IBI.

The interaction of main effects **stratum and status** was significant (F = 5.95, p = 0.0031). There were significant differences in J' among sites based on status (reference >unclassified>degraded) for the near-field, but not the far-field, with the strongest gradient observed in the low mesohaline. J' was significantly different for far-field and near-field (far-field>near-field) for reference, unclassified, and degraded sites. These results are consistent with our finding that regional water quality impairments are associated with sediment organic enrichment at near-field, but not far-field sites, and our hypothesis that organic enrichment results in a shift towards a benthic community comprised of small, opportunistic species with characteristically high abundance, which results in lower evenness overall. At the Elizabeth River study site, the near-field in particular, the community was so degraded that extremely low species richness (Figure 59) caused evenness and diversity (Figure 58) to be higher than expected.

The interaction of main effects **stratum and salinity** was significant ($F = 74.93$, $p < 0.0001$). When sites were classified by stratum, salinity regime was significant for both the near-field (high mesohaline>tidal freshwater>low mesohaline) and far-field (low mesohaline=high mesohaline>tidal freshwater) sites. Within the low mesohaline/oligohaline salinity regime, near- and far-field sites were significantly different (far-field>near-field), while near- and far-field sites were not significantly different for the high mesohaline and tidal freshwater sites.

The interaction of main effects **status and salinity** was significant ($F = 14.17$, $p < 0.0001$). Within high mesohaline, the degraded site had higher J' compared to other sites (degraded>reference=unclassified). In part this is because the degraded Elizabeth River near-field site had only five species. For the low mesohaline/oligohaline sites, reference and unclassified conditions were not significantly different, but had higher J' than the degraded site, as expected. Status significantly affected J' in tidal freshwater consistent with expectations (reference>unclassified>degraded). J' decreased with the salinity gradient for unclassified sites (high mesohaline>low mesohaline>tidal freshwater). For sites classified as degraded, high mesohaline had significantly higher J' relative to tidal freshwater and low mesohaline/oligohaline sites. For reference sites, J' was highest at high mesohaline and tidal freshwater sites (high mesohaline=tidal freshwater>low mesohaline).

Pollution Indicative Species

Pollution indicative species of the Chesapeake Bay have been identified using expert judgment, which is informed by information on life history and previously published relationships with environmental variables (Weisburg et al. 1997). Percent abundance of pollution indicative species (API) is used to calculate the CB B-IBIs for tidal freshwater, oligohaline, low mesohaline, and high mesohaline sand, while percent biomass of pollution indicative species (BPI) is used to compute the CB B-IBIs for high mesohaline mud. The patterns we observed for API and BPI (Figures 61, 62, Table 22) were not consistent with an hypothesis of increased importance of pollution indicative taxa at degraded sites relative to reference sites within the major CB habitat classes noted above, as was demonstrated during the development and validation of the B-IBI approach (Weisburg et al. 1997, Alden et al. 2002). These results may be due to low site replication, variability among samples within stratum at a given site, lack of effects, a combination of these factors, or other factors not accounted for in our sampling design.

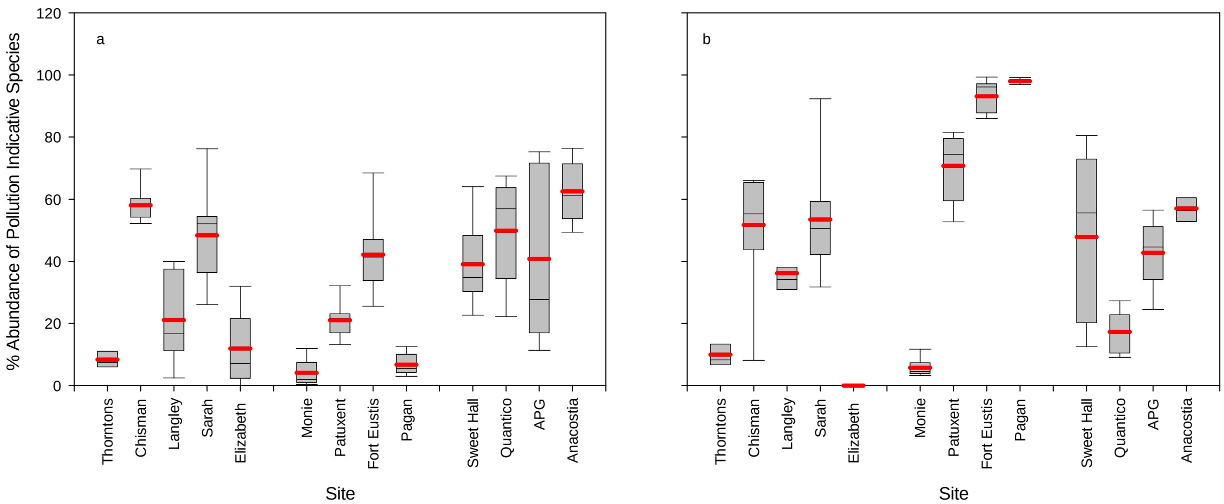


Figure 61. Percent abundance of pollution-indicative species by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

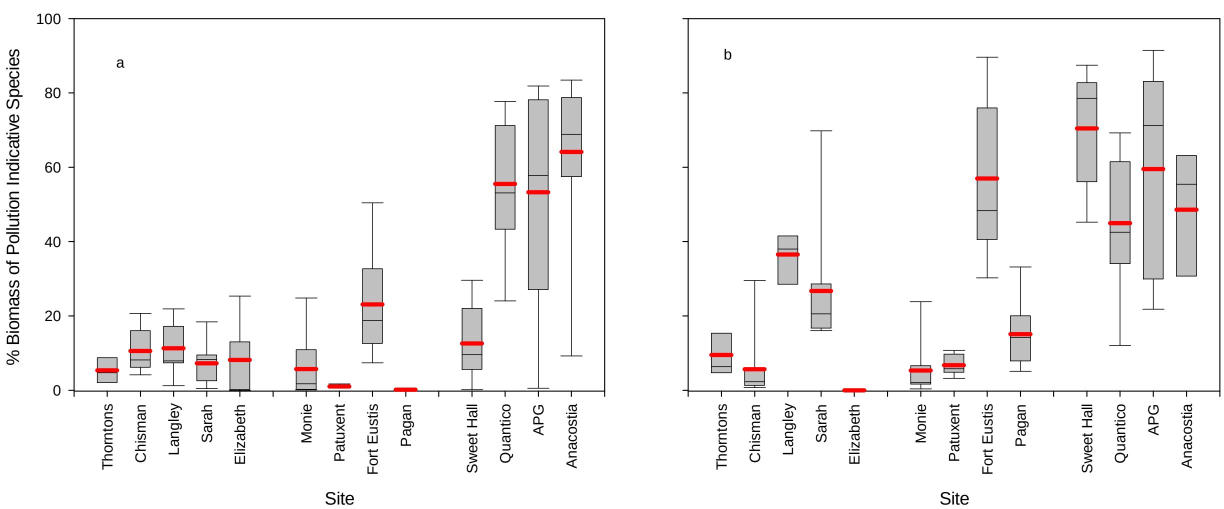


Figure 62. Percent biomass of pollution-indicative species by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

Pollution Sensitive Species

Pollution sensitive species of the Chesapeake Bay have been identified using expert judgment, which is informed by information on life history and previously published relationships with environmental variables (Weisburg et al. 1997). Percent abundance of pollution sensitive species (APS) is used to calculate the CB B-IBIs for oligohaline and high mesohaline sand, while percent biomass of pollution sensitive species (BPS) is used to compute the CB B-IBI for high mesohaline mud. No sensitive species have been defined for tidal freshwater. The patterns we observed for APS and BPS (Figures 63, 64, Table 22) were not consistent with an hypothesis of increased importance of pollution sensitive taxa at reference sites relative to degraded sites within the major CB habitat classes noted above, as was demonstrated during the development and validation of the B-IBI approach (Weisburg et al. 1997, Alden et al. 2002). This may be due to low site replication, variability among samples within stratum at a given site, lack of effects, a combination of these factors, or other factors not accounted for in our sampling design.

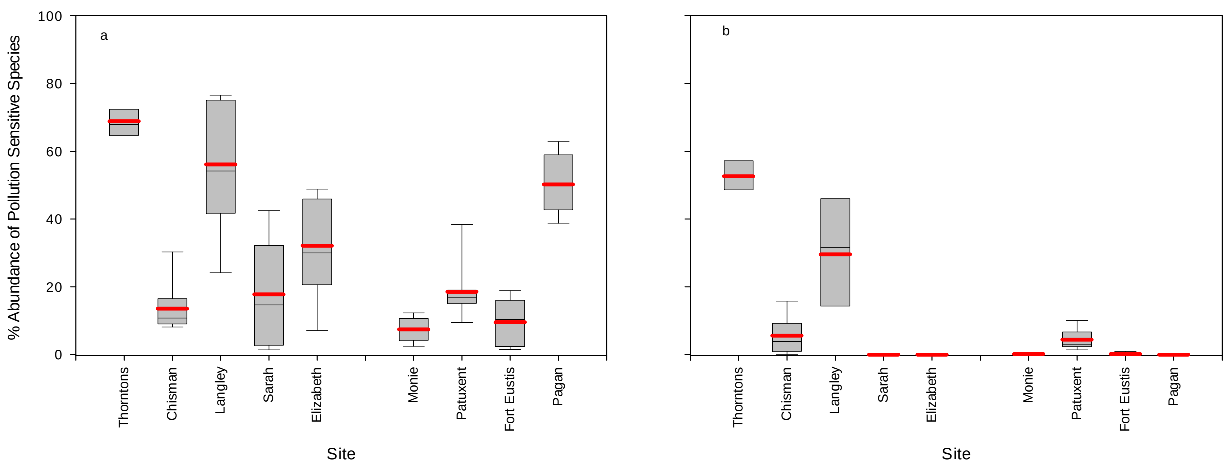


Figure 63. Percent abundance of pollution-sensitive species by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

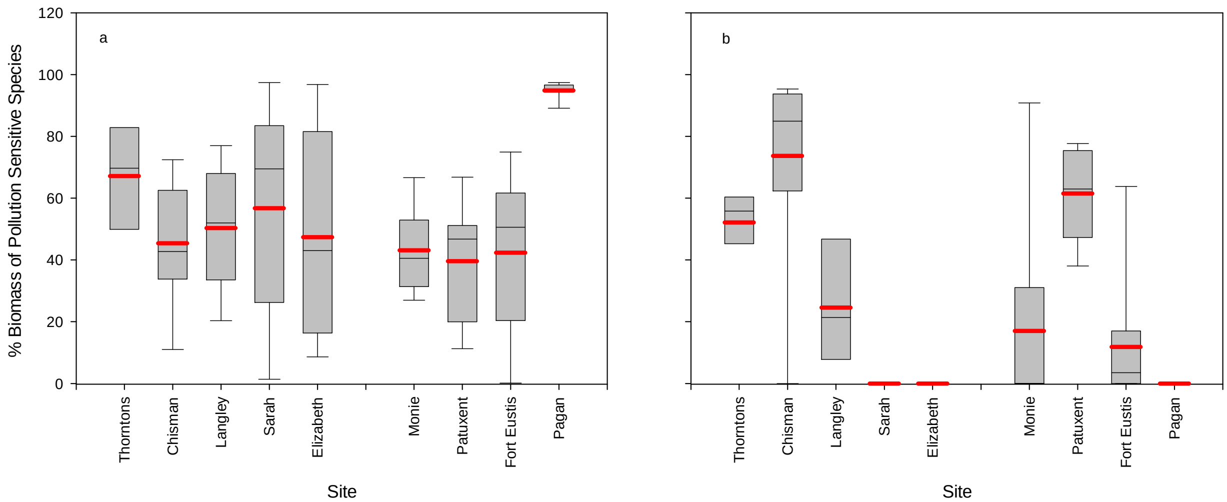


Figure 64. Percent biomass of pollution-sensitive species by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

<u>Percent Biomass > 5 cm</u>

Percent biomass below than 5 cm (BB5) in the sediment should be greatest when a community has high integrity, because it will contain large, long-lived species, which reside deeper in the sediment than short-lived opportunistic species. This pattern has been observed in a variety of marine environments, but the patterns have not been as clear for estuaries. As a result, BB5 is used to calculate the CB B-IBIs only for low mesohaline and high mesohaline mud (Weisburg et al. 1997, Alden et al. 2002). We found complex relationships of BB5 as a function of stratum, status, and salinity (Figure 65, Table 22). This may be due to low site replication, variability among samples within stratum at a given site, lack of effects, a combination of these factors, or other factors not accounted for in our sampling design. For example, the ER near-field site, where sediment toxicity was a major stressor, was depauperate of long-lived infauna including infaunal bivalves, while the PG near-field site, where eutrophication was likely the major stressor, had relatively high BB5 due to the presence of infaunal bivalves.

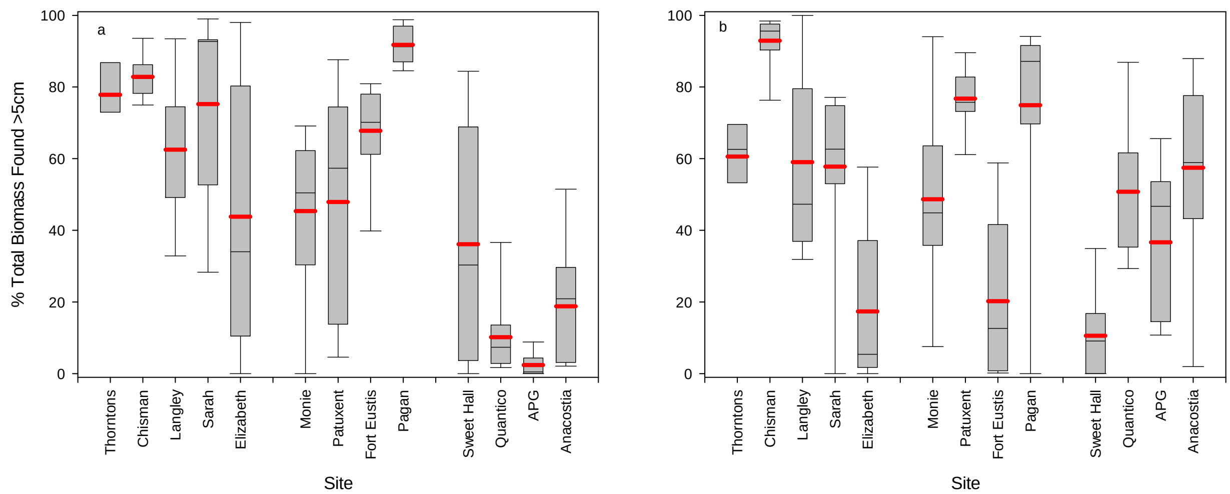


Figure 65. Percent of biomass at >5 cm by stratum, salinity regime and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

<u>Percent Abundance Carnivores and Omnivores</u>

The percent abundance of carnivores and omnivores (PCO) is used as an indicator of trophic structure with the assumption that a higher percentage is associated with high quality habitats and is indicative of more trophic complexity (Weisburg et al. 1997). PCO is used to calculate the CB B-IBIs for oligohaline and high mesohaline mud and sand based on its ability to successfully delimit reference from degraded conditions in those habitat classes (Weisburg et al. 1997, Alden et al. 2002). We found very complex relationships for PCO as a function of stratum, status, and salinity (Figure 66, Table 22). This may be due to low site replication, variability among samples within stratum at a given site, lack of effects, a combination of these factors, or other factors not accounted for in our sampling design. The patterns observed do not support the initial hypothesis. Most notably, we measured a relatively high PCO at the ER near-field site, which has highly degraded environmental conditions, and low PCO at the reference site sampled the same year. The ER near-field site had very few infauna and virtually lacked deposit feeders. Thus, the elevated PCO there appears to reflect a highly altered food web.

<u>Percent Abundance Deep Deposit Feeders</u>

The percent abundance of deep deposit feeders (DDF) is an indicator of higher environmental quality in the polyhaline region of CB estuary because most DDFs found there are longer-lived, head down deposit feeders such as maldanid polychaetes (Weisburg et al. 1997). The reverse is the case in tidal freshwater where deep dwelling oligochaetes are key indicators of environmental degradation (Alden et al. 2002). DDF is used to calculate the CB B-IBIs for tidal freshwater (and polyhaline sand, not included in this study) based on its ability to successfully delimit reference from degraded conditions in those habitat classes (Weisburg et al. 1997, Alden et al. 2002). We found complex patterns for DDF as a function of stratum, status, and salinity (Figure 67, Table 22). This may be due to low site replication, variability among samples within stratum at a given site, lack of effects, a combination of these factors, or other factors not accounted for in our sampling design.

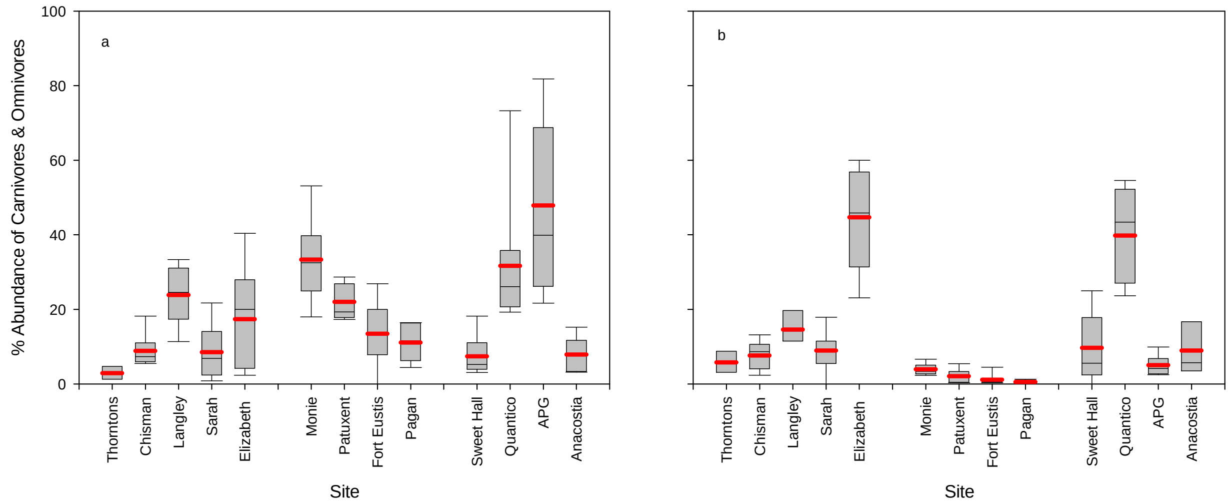


Figure 66. Percent abundance of carnivores and omnivores by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

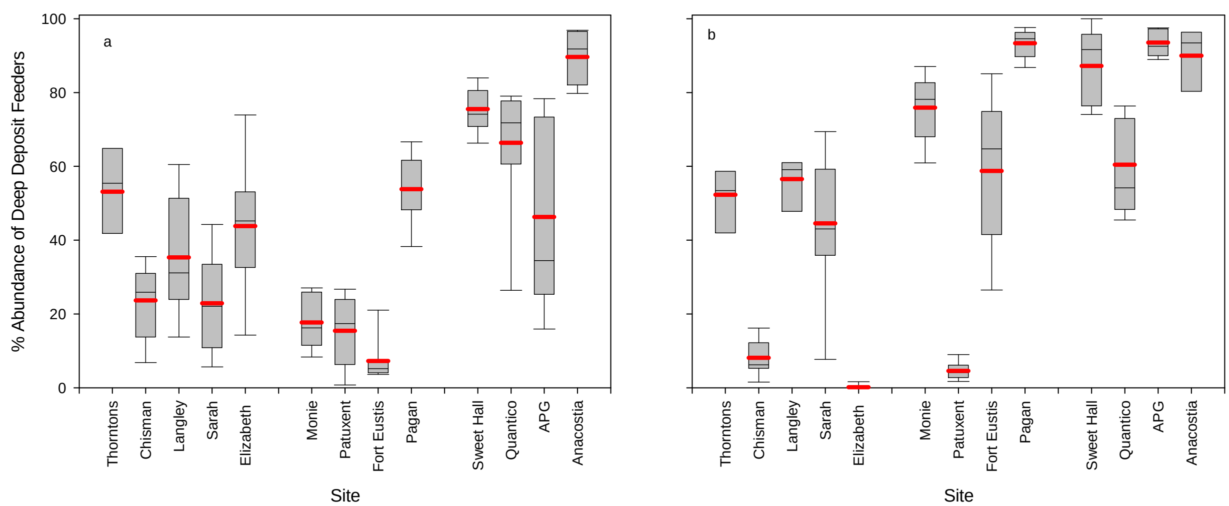


Figure 67. Percent abundance of deep deposit feeders by stratum, salinity regime, and site for far-field (a) and near-field (b) strata. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

5.5.3 Principal Components Analyses of Macrofaunal Metrics

Principal Components Analysis (PCA) was used to explore relationships among macrofauna metrics and to determine which metrics were most important for distinguishing sites on the basis of status. Based on the findings presented above, we performed these analyses within strata and major salinity regimes.

For **high mesohaline near-field sites**, the first three principal components accounted for 82.6% of the variance in the ordination of macrofauna metrics (Table 24). PC1 arrayed stations consistent with the a priori status classifications (Figure 68). Collections from the degraded Elizabeth River site were depauparate, and were characterized primarily by a relatively high percentage of organisms classified as carnivores or omnivores. Only five species were collected at this site (Appendix A), and none of them were classified as pollution sensitive or pollution indicative. PC2 reflected gradients in the % biomass and abundance of pollution indicative species, and evenness. PC3 further defined relationships among stations based on the same variables that were important on PC2 (Table 24).

Table 24. Coefficients of the eigenvectors for principal components 1-3 for near-field sites in the high mesohaline region of the estuary, based on macrofauna. Metrics used to calculate the B-IBI are given in italics.

Near-field		**coefficients**	
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	40	21.9	20.6
Abundance Carnivores/Omnivores (%)	0.278	-0.156	-0.447
Abundance – Pollution Indicative Species (%)^{hms}	0.034	0.149	0.609
Biomass - Pollution Indicative Species (%)^{hmm}	-0.033	0.558	0.197
Species Evenness - J'	-0.071	0.208	-0.532
Biomass - Pollution Sensitive Species (%)^{hmm}	-0.293	-0.383	0.22
Abundance Deep Deposit Feeders (%)	-0.297	0.451	-0.035
Abundance ($\log_{10}(x+1)$)	-0.312	-0.188	-0.068
Biomass ($\log_{10}(x+1)$)	-0.313	-0.427	0.082
Abundance – Pollution Sensitive Species (%)^{hms}	-0.391	0.115	-0.141
Species Diversity - H' ($\log_2$)	-0.429	0.135	-0.162
Species Richness (no. of species)	-0.458	-0.007	-0.013
^{hmm}high mesohaline mud only, ^{hms}high mesohaline sand only (used for Thorntons Creek near-field)			

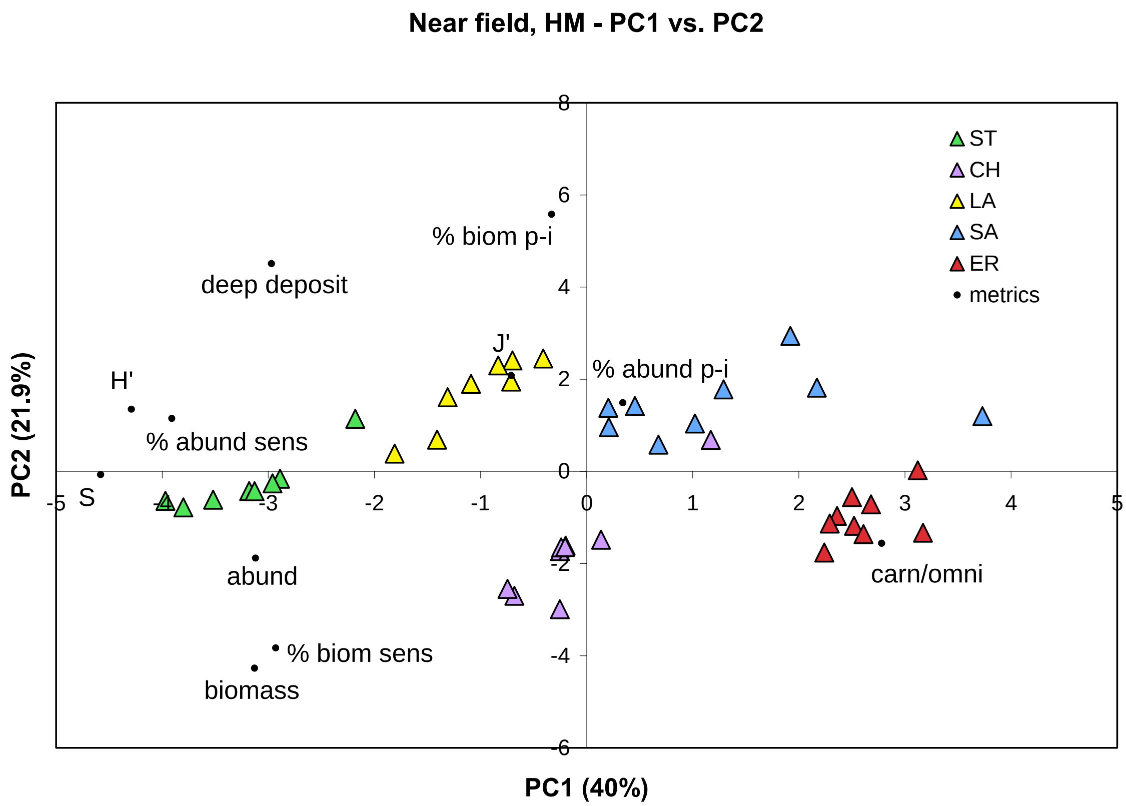


Figure 68. PCA ordinations of macrofaunal metrics for high mesohaline, near-field sites. Relationships between macrofaunal metrics and principal components 1-3 are given in Table 24. Coefficients of the eigenvectors (x10) are used to show the relative relationships and weightings of each variable (metric) in ordination space. For additional information refer to text.

For **high mesohaline far-field sites**, the first three principal components accounted for 79.3% of the variance in the ordination of macrofauna metrics (Table 25). There was less distinction of stations on the basis of classification status relative to the near-field sites. PC1 arrayed stations primarily on the basis of abundance (Figure 69). Collections with high positive scores on PC1 had high percent abundance of pollution indicative species, and high total abundance. These stations also had high species richness, which is influenced by high abundance. Negative scores on PC1 were associated with high percent abundance of pollution sensitive species, high percent abundance of carnivore/omnivore, higher species diversity, and a higher percent abundance of deep deposit feeders. The relative abundances of pollution sensitive or pollution indication species was again reflected in scores on PC2 of the variation. PC3 arrayed stations based on trophic structure and diversity.

Table 25. Coefficients of the eigenvectors for principal components 1-3 for far-field sites in the high mesohaline region of the estuary, based on macrofauna. Metrics used to calculate the B-IBI are given in italics.

Far-field	**coefficients**		
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	36.8	27.2	25.3
Abundance – Pollution Indicative Species (%)	0.447	0.330	-0.126
Abundance ($\log_{10}$(x+1))	0.414	-0.243	0.071
Species Richness (no. of species)	0.375	-0.287	-0.288
Biomass ($\log_{10}$(x+1))	0.228	-0.362	-0.237
Biomass - Pollution Indicative Species (%)	0.005	0.235	0.148
Biomass - Pollution Sensitive Species (%)	0.005	-0.464	-0.127
Abundance Deep Deposit Feeders (%)	-0.180	-0.275	0.405
Species Diversity - H' ($\log_2$)	-0.199	-0.269	-0.504
Abundance – Pollution Sensitive Species (%)	-0.216	-0.407	0.380
Abundance Carnivores/Omnivores (%)	-0.254	0.183	-0.401
Species Evenness - J'	-0.503	0	-0.281

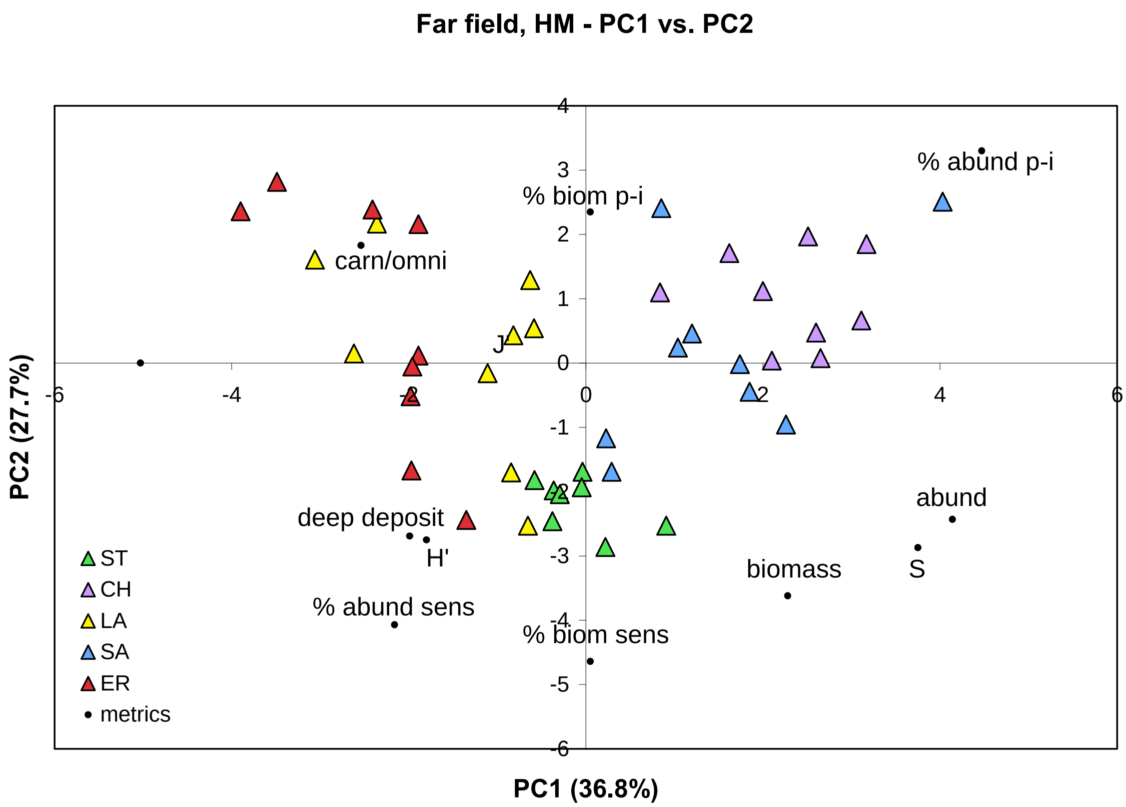


Figure 69. PCA ordinations of macrofaunal metrics for high mesohaline far-field sites. Relationships between macrofaunal metrics and principal components 1-3 are given in Table 25. Coefficients of the eigenvectors (x10) are used to show the relative relationships and weightings of each variable (metric) in ordination space. For additional information refer to text.

For **low mesohaline and oligohaline near-field sites**, the first three principal components accounted for 79.2% of the variance in the ordination of macrofauna metrics (Table 26). PC1 arrayed stations according to status, with the reference and unclassified sites generally having lower or more negative scores on PC1 relative to the degraded sites. Total abundance and percent abundance of pollution indicative species was high for the degraded site (Pagan River), while species diversity (H'), richness (S), evenness (J') and trophic complexity were greater at the reference site (Monie Bay) (Figure 70). PC2 reflected changes in the abundance and biomass of pollution sensitive species, and total biomass, which is often dominated by pollution sensitive species. Biomass of pollution indicative species was an important variable on PC3 (not shown).

For **low mesohaline and oligohaline far-field sites**, the first three principal components accounted for 82.9% of the variance in the ordination of macrofauna metrics (Table 27). The ordination comparing PC1 and PC2 delineates stations on the basis of a priori status, but the factors accounting for the spatial relationships are complex and the observed patterns do not support some of our major hypotheses (Figure 71). Collections from the Pagan River (degraded) site had high percent abundance and biomass of pollution sensitive species due to relatively high abundances of bivalves (Appendix A). Biomass and the percent abundance of deep deposit feeders were also high at this site. In contrast, the reference site (Monie Bay) had higher abundance, richness, species diversity, and percent abundance of carnivores/omnivores. The unclassified Patuxent site was intermediate to the reference and degraded sites, while the Fort Eustis site was differentiated on the basis of the highest percent abundance and biomass of pollution indicative species. PC3 (not shown) differentiated stations mostly on the basis of diversity and evenness.

Table 26. Coefficients of the eigenvectors for principal components 1-3 for near-field sites in the low mesohaline/oligohaline region of the estuary, based on macrofauna. Metrics used to calculate the B-IBI are given in italics.

Near-field	**coefficients**		
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	38.9	24	16.3
Abundance – Pollution Indicative Species (%)	0.336	0.149	0.378
Abundance ($\log_{10}(x+1)$)	0.324	0.077	-0.387
Abundance Deep Deposit Feeders (%)	0.263	-0.355	-0.326
Biomass - Pollution Indicative Species (%)	0.149	-0.288	0.525
Biomass ($\log_{10}(x+1)$)^{lm}	0.007	0.513	-0.299
Biomass - Pollution Sensitive Species (%)^{lm}	-0.178	0.476	0.047
Abundance – Pollution Sensitive Species (%)^{ol}	-0.249	0.409	0.236
Species Richness (no. of species)	-0.266	-0.175	-0.318
Abundance Carnivores/Omnivores (%)^{ol}	-0.395	-0.118	-0.209
Species Evenness - J'	-0.426	-0.163	0.174
Species Diversity - H' ($\log_2$)^{lm}	-0.435	-0.188	0.043

^{lm}low mesohaline only, ^{ol}oligohaline only

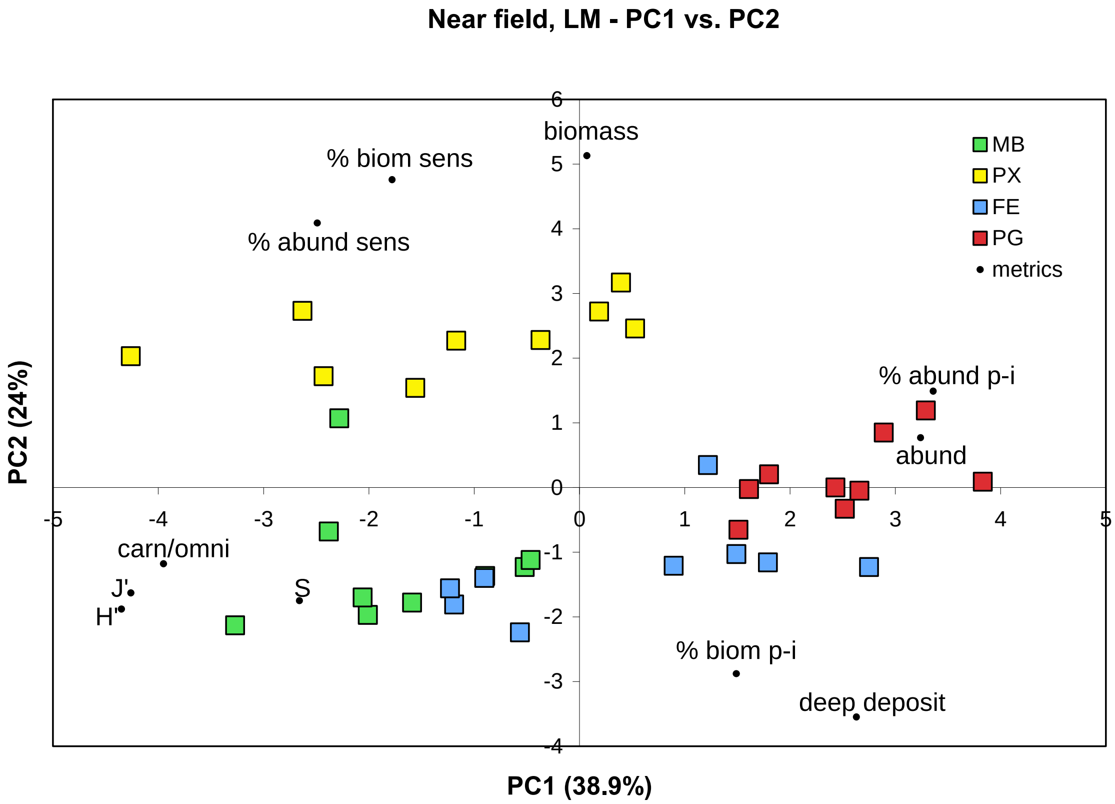


Figure 70. PCA ordinations of macrofaunal metrics for low mesohaline and oligohaline near-field sites. Relationships between macrofaunal metrics and principal components 1-3 are given in Table 26. Coefficients of the eigenvectors (x10) are used to show the relative relationships and weightings of each variable (metric) in ordination space. For additional information refer to text.

Table 27. Coefficients of the eigenvectors for principal components 1-3 for far-field sites in the low mesohaline/oligohaline region of the estuary, based on macrofauna. Metrics used to calculate the B-IBI are given in italics.

Far-field	**coefficients**		
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	45.2	21.8	15.9
Biomass ($\log_{10}(x+1)$)[lm]	0.461	-0.013	-0.154
Abundance Deep Deposit Feeders (%)	0.358	-0.283	-0.075
Biomass - Pollution Sensitive Species (%)[lm]	0.334	-0.418	0.105
Abundance – Pollution Sensitive Species (%)[ol]	0.279	-0.276	-0.109
Species Richness (no. of species)	0.236	0.337	-0.194
Abundance ($\log_{10}(x+1)$)	0.217	0.354	0.251
Species Diversity - H' ($\log_2$)[lm]	0.098	0.270	-0.688
Abundance Carnivores/Omnivores (%)[ol]	-0.068	0.517	0.159
Species Evenness - J'	-0.111	-0.026	-0.534
Abundance – Pollution Indicative Species (%)	-0.27	-0.159	-0.238
Biomass - Pollution Indicative Species (%)	-0.517	-0.253	-0.077
[lm]low mesohaline only, [ol]oligohaline only			

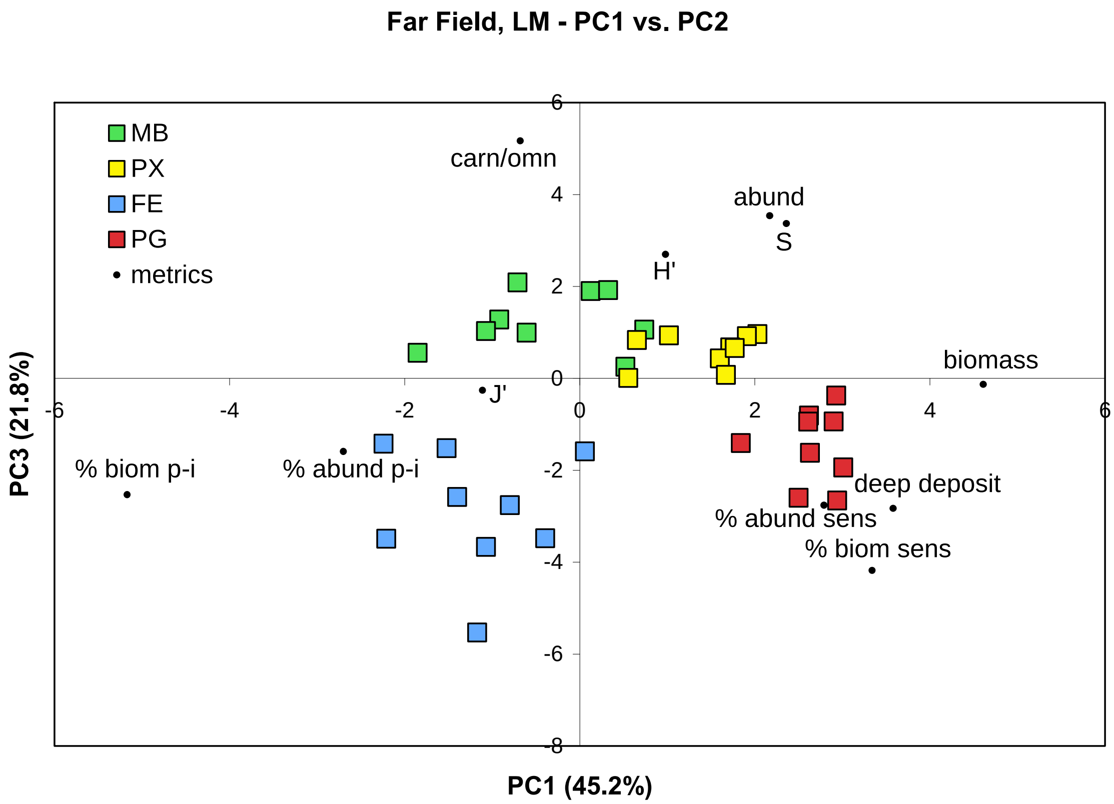


Figure 71. PCA ordinations of macrofaunal metrics for the low mesohaline to oligohaline far-field sites. Relationships between macrofaunal metrics and principal components 1-3 are given in Table 27. Coefficients of the eigenvectors (x10) are used to show the relative relationships and weightings of each variable (metric) in ordination space. For additional information refer to text.

For **tidal freshwater near-field sites**, the first three principal components accounted for 85.7% of the variance in the ordination of macrofauna metrics (Table 28). PC1 clearly differentiated between the Quantico and the other sites (Figure 72). The presence of the invasive plant *Hydrilla,* which formed extremely dense beds at Quantico may account for these patterns. The sediments under *Hydrilla* had higher diversity, higher evenness, and a higher percentage of species classified as carnivores or omnivores. The deep deposit feeding oligochaete *Limnodrilus hoffmeisteri*, which is also a key pollution indicative species, was absent or rare at the Quantico near-field site. PC2 arrayed stations according to status, with the Anacostia (degraded) site distinguished mostly by having higher biomass and abundance. Many of the stations at Sweet Hall (reference) were depauperate. PC3 (not shown) accounted for only 10.6% of the variance, with the most important variable being tolerance score, which did not distinguish stations based on status. There is further discussion of the Quantico site in a later section.

For **tidal freshwater far-field sites**, the first three principal components accounted for 76.6% of the variance in the ordination of macrofauna metrics (Table 29). PC1 arrayed station according to total abundance, as well as the percent abundance and biomass of pollution indicative species (positive scores on PC1) versus high diversity, evenness, and percent abundance of carnivores or omnivores (negative scores on PC1), while species richness (S) and tolerance score were more important on PC2 (Figure 73). Both Aberdeen and Sweet Hall far-field sites had relatively low total abundance of macrofauna and had negative scores on PC1, while the stations in the Anacostia had high abundance. As a result of the very low abundances at Sweet Hall, the species richness and diversity were also low. The species collected at Sweet Hall also had the highest tolerance scores, which is the reverse of what was expected a priori. PC3 (not shown) further distinguished stations on the basis of overall abundance as well as the biomass of pollution indicative species.

Table 28. Coefficients of the eigenvectors for principal components 1-3 for near-field sites in the tidal freshwater region of the estuary, based on macrofauna metrics. Those metrics used to calculate the B-IBI are given in italics.

Near-field	**coefficients**		
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	47.2	27.8	10.6
Abundance Deep Deposit Feeders (%)	0.412	-0.054	-0.162
Abundance – Pollution Indicative Species (%)	0.389	0.019	0.12
Biomass - Pollution Indicative Species (%)	0.217	-0.326	-0.339
Abundance ($\log_{10}$(x+1))	0.211	0.514	-0.066
Tolerance Score	0.184	-0.023	0.834
Biomass ($\log_{10}$(x+1))	0.183	0.517	0.177
Species Richness (no. of species)	-0.142	0.517	-0.245
Species Diversity - H' ($\log_2$)	-0.404	0.226	-0.043
Species Evenness - J'	-0.409	-0.189	0.17
Abundance Carnivores/Omnivores (%)	-0.412	0.063	0.149

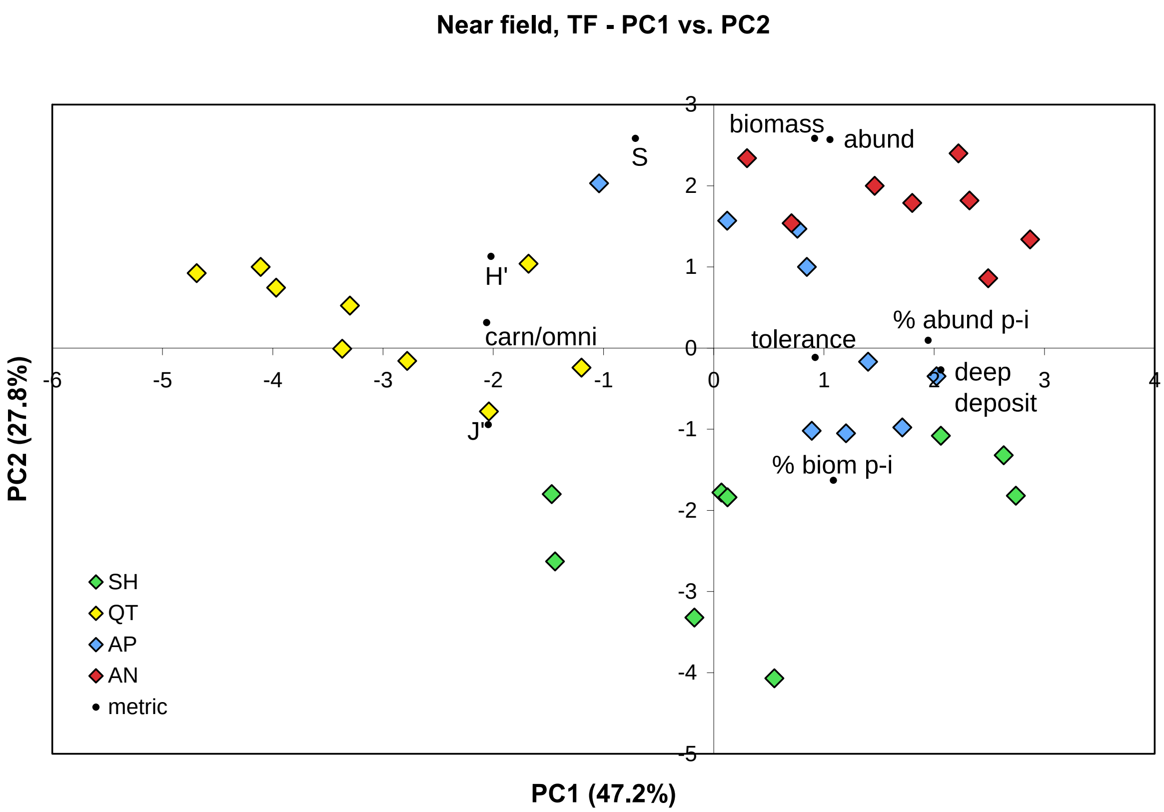


Figure 72. PCA ordinations of macrofaunal metrics for tidal freshwater near-field sites. Relationships between macrofaunal metrics and principal components 1-3 are given in Table 28. Coefficients of the eigenvectors (x5) are used to show the relative relationships and weightings of each variable (metric) in ordination space. For additional information refer to text.

Table 29. Coefficients of the eigenvectors for principal components 1-3 for far-field sites in the tidal freshwater region of the estuary, based on macrofauna. Metrics used to calculate the B-IBI are given in italics.

Far-field		**coefficients**	
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	42.9	18.2	15.6
Abundance – Pollution Indicative Species (%)	0.44	0.026	-0.139
Abundance Deep Deposit Feeders (%)	0.412	0.053	0.303
Biomass - Pollution Indicative Species (%)	0.282	0.272	-0.51
Abundance ($\log_{10}(x+1)$)	0.265	0.456	0.081
Biomass ($\log_{10}(x+1)$)	0.148	0.031	0.604
Tolerance Score	0.089	-0.514	0.033
Species Richness (no. of species)	-0.085	0.585	0.081
Abundance Carnivores/Omnivores (%)	-0.341	0.063	-0.409
Species Diversity - H' ($\log_2$)	-0.388	0.32	0.21
Species Evenness - J'	-0.428	-0.012	0.199

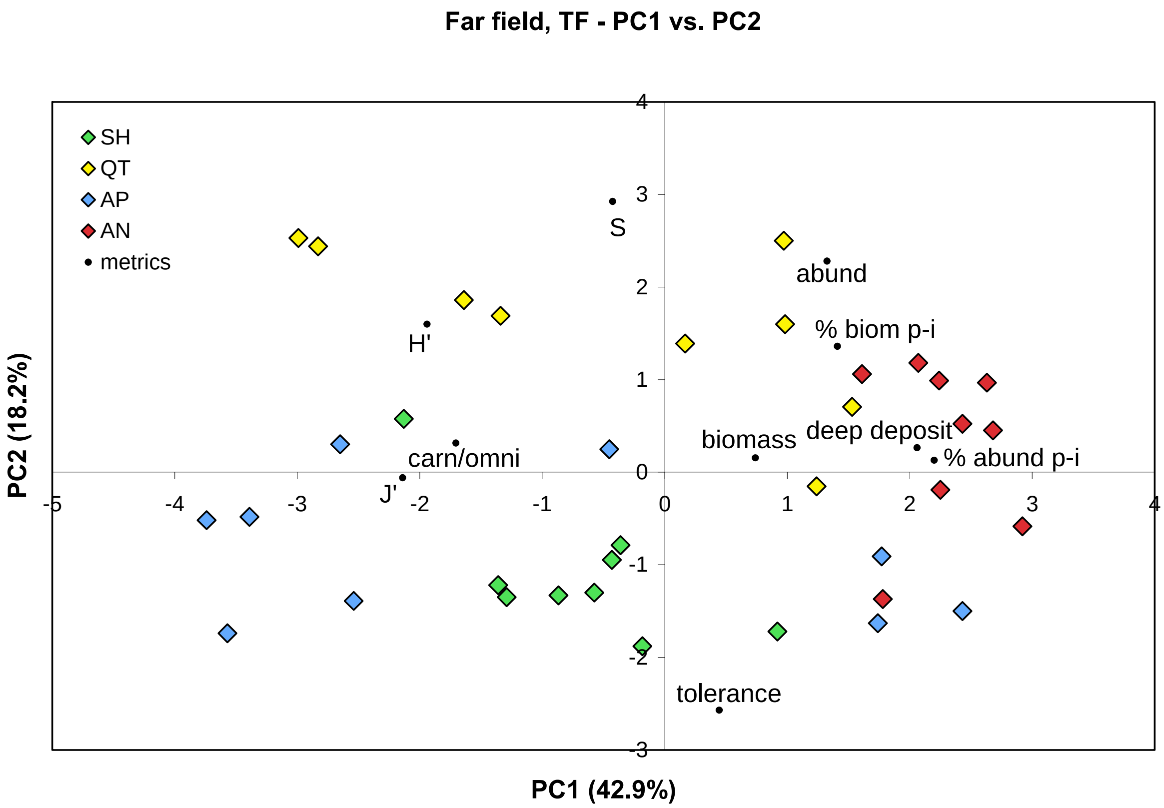


Figure 73. PCA ordinations of macrofaunal metrics for the tidal freshwater far-field sites. Relationships between macrofaunal metrics and principal components 1-3 are given in Table 29. Coefficients of the eigenvectors (x5) are used to show the relative relationships and weightings of each variable (metric) in ordination space. For additional information refer to text.

5.5.4 Quantico – A Vegetated Habitat Where the B-IBI Is Not Calibrated

Most of the shallow water estuarine habitat (≤ 1 m) surrounding the Quantico Marine Reserve is covered by dense meadows of submerged aquatic vegetation (SAV); primarily the invasive *Hydrilla verticillata*. These meadows included the two areas that were selected as near-field (Chopawamsic Creek) and far-field (Potomac River embayment) strata for our study. The presence of the SAV created some unique problems for the analysis of the environmental quality of the area. The primary tool for our analysis of the benthic community data in this study was the Chesapeake Bay B-IBI, which is not calibrated for application in vegetated or otherwise structured habitats (Weisburg et al. 1997). Three dimensional structures like SAV alter the composition, abundance, and biomass of the of the macrobenthic community in an area compared to similar or adjacent non-vegetated habitats (Marsh 1970, Orth 1973, Mason 1998), as they provide substrate for sessile epifauna to grow on, shelter for more mobile fauna, and an additional source of organic matter for fauna to feed on beyond microphytobenthos and phytoplankton. Additionally, dense beds of SAV can have negative effects on the benthic community by creating diel hypoxic conditions and altering the sediment structure with their dense networks of roots and rhizomes.

We examined the performance of the B-IBI and component metrics in *H. verticillata* beds in both the near- and far-field strata at Quantico as a means of demonstrating the limitations of the B-IBI in this type of habitat and comparing the component metrics to other measures of habitat quality (i.e., regional water quality or sediment organic content). A non-metric multiple dimensional scaling (MDS) ordination of Bray-Curtis similarity values of the species data in the near- and far-field strata of the freshwater sites shows a clear distinction between the four sites in both strata (Figure 74).

One of the benefits of the Chesapeake Bay B-IBI is that beyond the comparisons and analysis of the grand score (the mean of the component metrics for a given site), the component metrics can be analyzed independently (Weisberg et al. 1997, Llansó 2002). Within the tidal freshwater portions of Chesapeake Bay, four component metrics are used to calculate the B-IBI: abundance (# m^{-2}), % abundance of pollution indicative taxa, % abundance of deep deposit feeders, and tolerance score (Alden et al. 2002, Llansó 2002). Principal component analysis (PCA) was used to investigate the distribution of the freshwater sites based upon the B-IBI metrics used to compute the tidal freshwater B-IBI and their scores.

The first two principal components of the near-field metrics PCA accounted for 83.2% of the variation and the far-field analysis accounted for 90.4% of the variation. The first two principal components of the PCA based upon the B-IBI scores accounted for 78.9% of the variation in the near-field stations and 76.5 % in the far-field stations. Quantico stations had relatively low overall abundance, abundance of pollution indicative taxa, abundance of deep deposit feeders, and tolerance score (Figure 75a), which translate into relatively high B-IBI component scores compared to the other sites (Figure 76a). In comparison, the PCA of the far-field B-IBI component metrics (Figure 75b) and scores (Figure 76b) places the Quantico stations among the stations from Anacostia River and Sweet Hall Marsh; all with relatively high overall abundance, abundance of pollution indicative taxa, abundance of deep deposit feeders, and

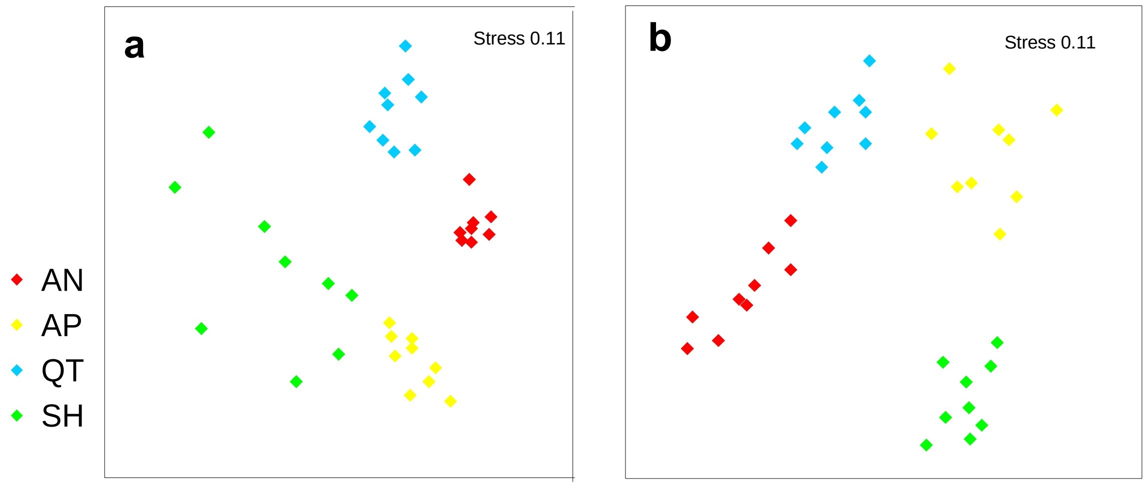


Figure 74. Non-metric MDS ordination of macrobenthic community Bray-Curtis similarity values among samples collected in the near-field (**a**) and far-field strata (**b**) of the tidal freshwater sites. Species abundance data used in the analysis were square root transformed. **AN** = Anacostia River, **AP** = Aberdeen Proving Ground, **QT** = Quantico, and **SH** = Sweet Hall Marsh.

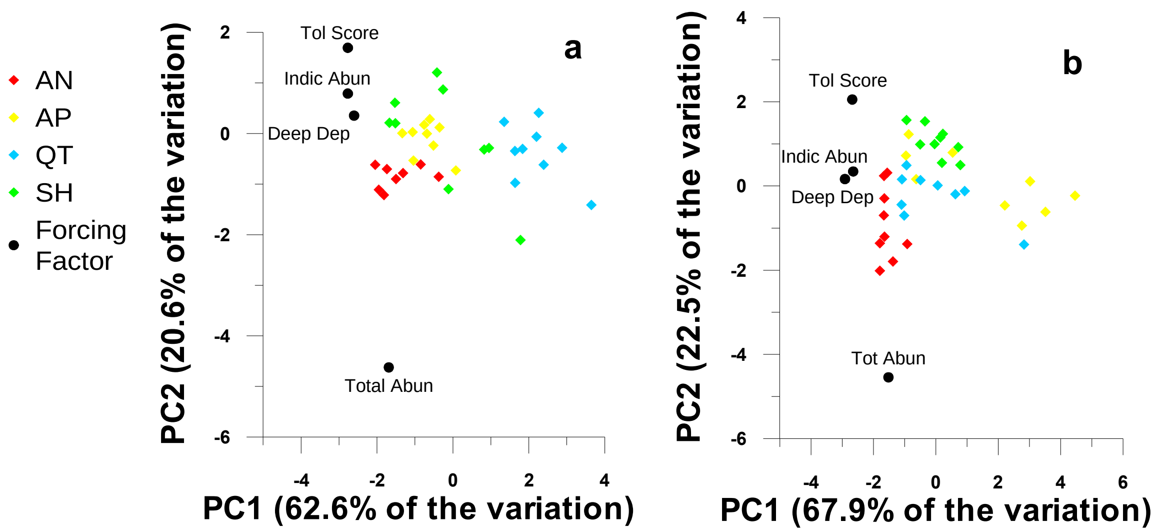


Figure 75. Principal component analysis among metrics used to calculate the B-IBI in the tidal freshwater sites at the near-field (**a**) and far-field (**b**) stations, with individual samples arrayed along PC1 and PC2. The black circles represent the general direction of the forcing factors that comprise PC1 and PC2. **Tot Abun** = $\log_{10}$ total abundance (# indv m^{-2}), **Indic Abun** = % abundance of pollution indicative taxa, **Deep Dep** = % abundance of deep deposit feeders, and **Tol Score** = mean tolerance score of species in the community. All metrics were normalized by subtracting the mean value from each measured value before analysis.

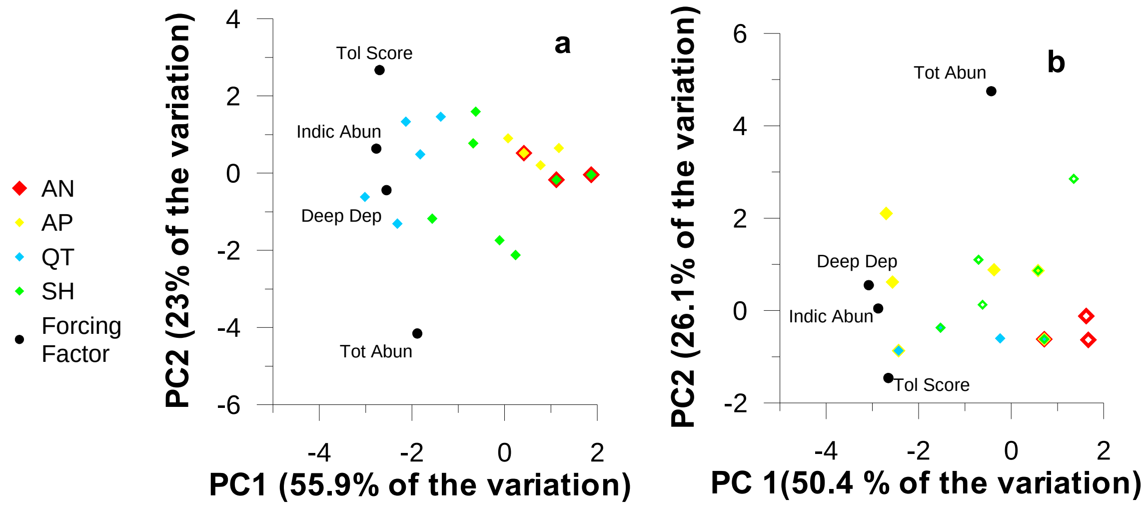


Figure 76. Principal component analysis among constituent scores calculated in the assessment of the tidal freshwater sites with the B-IBI at the near-field (**a**) and far-field (**b**) stations, with individual samples arrayed along PC1 and PC2. The black circles represent the general direction of the forcing factors that comprise PC1 and PC2. **Tot Abun** = total abundance score, **Indic Abun** = % abundance of pollution indicative taxa score, **Deep Dep** = % abundance of deep deposit feeders score, and **Tol Score** = community tolerance score. All metrics were normalized by subtracting the mean value from each measured value before analysis.

tolerance scores. There was less differentiation of the far-field sites when the metric values are converted to scores (Figure 76b), similar to the comparisons of the grand B-IBI scores (Section 5.5.3).

The separation of the Quantico stations in the MDS analyses indicates that the macrobenthic community there was different from the other tidal freshwater sites. This is further supported by the relatively high B-IBI values, both in the grand score (4.1 in the near-field and 2.8 in far-field, see Section 5.5.3) and in the component metrics; indicating a relatively non-degraded habitat. At almost all of the other sites that were sampled, B-IBI values followed a similar pattern to the sediment and water column nitrogen concentration; illustrating the strong link between macrobenthic community integrity and eutrophication/excessive organic matter accumulation in the sediments. This pattern did not hold true for the Quantico stations, particularly the near-field, where the macrobenthic community had high B-IBI scores indicating high quality habitat, but there was also high concentrations of nitrogen in the water column and sediments, suggesting the presence of degraded habitat conditions.

Two metrics used to compute the tidal freshwater B-IBI (% deep deposit feeders, % abundance of pollution indicative taxa) are influenced by the presence of tubificid oligochaetes, which are typically considered to be indicative of pollution. The large, deeply burrowing tubificid oligochaete *Limnodrilus hoffmeisteri* is of particular importance because it is the only pollution indicative taxon of note and can reach very high abundances in organically enriched freshwater habitats (Alden et al. 2002). *Limnodrilus hoffmeisteri* was virtually absent at Quantico compared to two other sites with comparable water and sediment quality (APG, Anacostia) (Figure 77). We suspect that the presence of the *H. verticillata*, with their dense network of roots and rhizomes, was a mechanical deterrent to the burrowing of *L. hoffmeisteri*.

The data we collected suggests that *H. verticillata* can have a variety of effects on the resident benthic community. Results presented in Section 5.5.3 demonstrate that the infauna associated with the *H. verticillata* habitat were more diverse than those associated with unvegetated areas and that the community also had a higher proportion of carnivores or omnivores. At the same time, there may be exclusion of some species from specialized niches. The dependence of the B-IBI on species that may be negatively or positively related to the presence of structured habitat, like these SAV beds has not been evaluated. Thus, the B-IBI must be calibrated based on healthy vegetated habitats before it is used to interpret environmental conditions in the presence of *H. verticillata*.

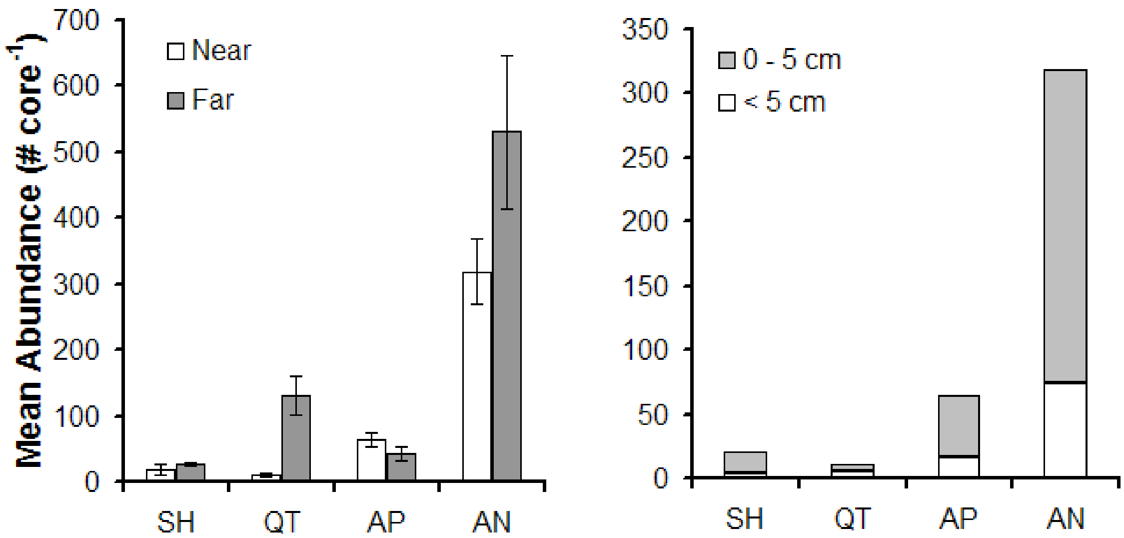


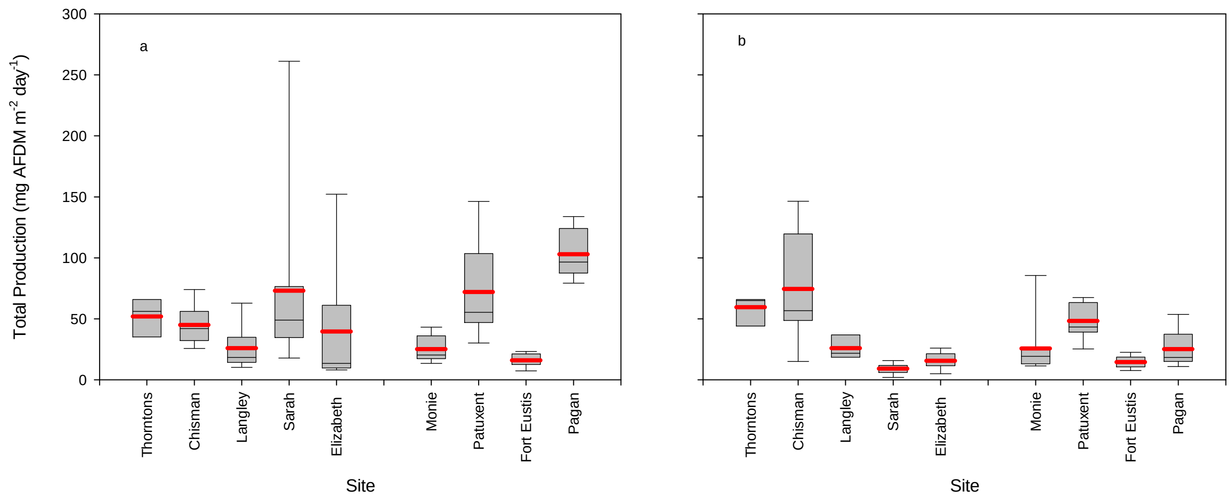
Figure 77. Mean abundance of the tubificid oligochaete *Limnodrilus hoffmeisteri* at the near- and far-field strata of the tidal freshwater sites (left). Error bars are ± 1 standard error of the mean. Mean abundance 0-5 cm below the sediment surface and >5 cm below the sediment surface of *L. hoffmeisteri* in the near-field stations of the tidal freshwater sites (right). **AN** = Anacostia River, **AP** = Aberdeen Proving Ground, **QT** = Quantico, and **SH** = Sweet Hall Marsh.

5.5.5 Secondary Production

Macrobenthic invertebrates are a key part of the estuarine food web. They feed on primary producers, bacteria, and detritus and also serve as a major source of food for higher trophic levels. Elucidating the relationships between secondary production and environmental disturbance will help us to better understand the relationships between structure and function in coastal ecosystems.

Macrobenthic secondary production represents the rate at which the macrobenthic community adds new biomass. This production is supported by primary production via grazing by consumers, and is, in turn, available for consumption by predators (Diaz and Schaffner 1990, Tumbiolo and Downing 1994). We estimated secondary production for this study because it represents a key ecological function of shallow water habitats. These highly productive areas serve as important nurseries for juvenile crabs and fish.

For sites sampled in the lower to mid-estuary (high mesohaline, low mesohaline, and oligohaline salinity regimes), macrobenthic production was compared using a 3-way analysis of variance (ANOVA) among *a priori* stratum (habitat), status, and salinity regime with $\alpha = 0.05$. For the upper estuary, freshwater sites, production differences were analyzed between the strata and habitat status using a 2-way ANOVA with $\alpha = 0.05$. Separate analyses had to be used due to the different equations applied, which result in different production units: day^{-1} for the saline sites and $year^{-1}$ for the freshwater sites. The community production in the saline sites was further divided into bivalve and non-bivalve production to help separate the influence of lifespans, which are typically multi-year for bivalves, but annual for other components of the community. For both data sets, differences based on stratum, status, and salinity were assessed using post-hoc, Least Squares Mean (LSM) comparisons with an α value of 0.05. All production data were $\log_{10}$ transformed to reduce the heteroskedacity of the model residuals. To relate specific aspects of habitat quality and macrobenthic production, a series of linear regressions were made between the production estimates and a variety of quality metrics, including the Chesapeake Bay B-IBI, Shannon-Weiner Species Diversity (H’), and sediment organic matter (% nitrogen used as a proxy).



There was considerable variation in the pattern of macrobenthic production across all of the high mesohaline to oligohaline sites that were sampled, even when the production was partitioned into the bivalve and non-bivalve portions of the community (Figures. 78-80). There was a significant difference in the total secondary production between strata (F = 13.44, p = 0.0003), as well as significant interactions between stratum and status (F = 4.03, p = 0.0197) and year and status (F = 14.29, p <0.0001) (Table 30). Differences between strata accounted for 25% of the variance in the total community production model, the strata*status interaction accounted for 15%, and the salinity*status interaction accounted for the remaining 53%. Overall, production was greater in the far-field strata than the near-field (Table 30), but within a given status classification the differences were not always significant. Within the near-field strata, production was greater at reference sites relative to unclassified or degraded sites, which were similar. There were no differences in production based on status for the far-field. There were significant differences based on status within the high-mesohaline (reference>unclassified>

Figure 78. Total community secondary production in the far-field (a) and near-field (b) stations of the saline sites. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

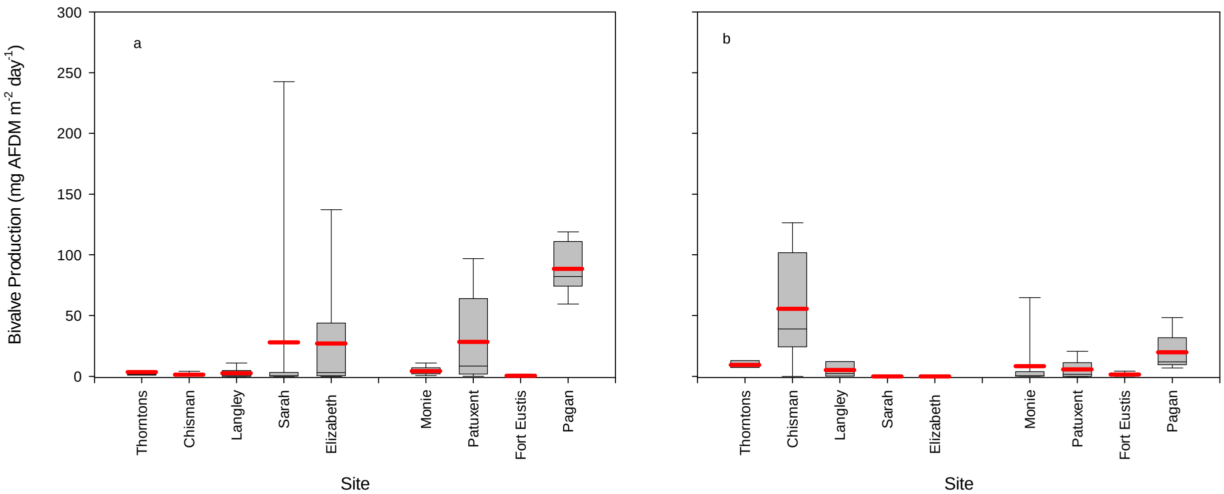


Figure 79. Bivalve secondary production in the far-field (a) and near-field (b) stations of the saline sites. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

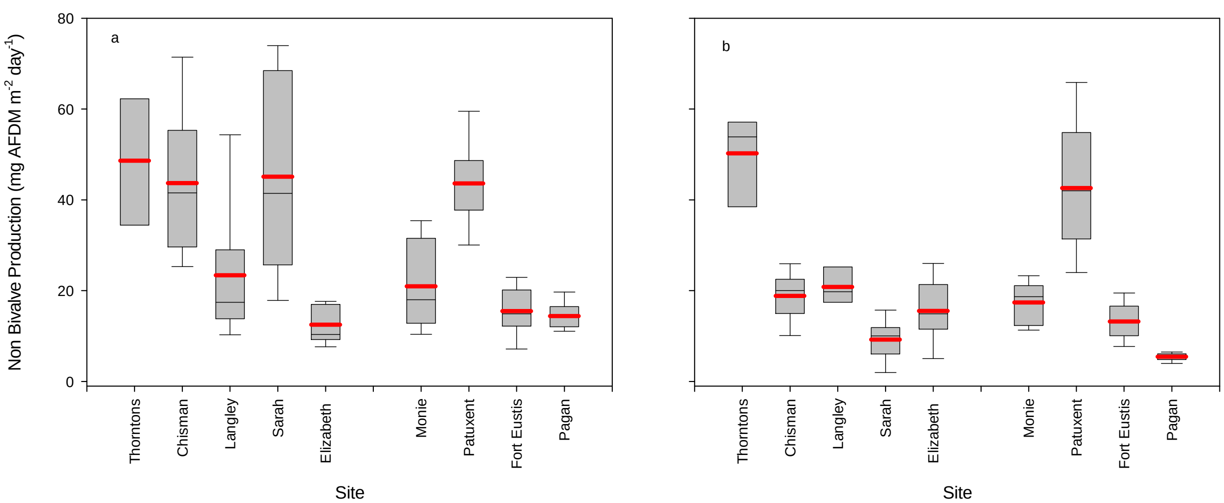


Figure 80. Non-bivalve secondary production in the far-field (a) and near-field (b) stations of the saline sites. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

Table 30. Summary of the 3-way and 2-way ANOVAs of secondary production, with the parameter evaluated, the number of samples, the model *p* value, model r^2, F-statistic, degrees of freedom (model, total), the *p* values for the individual treatment variables, significant interaction terms, and least square means contrasts. The least square means variables are in order from largest to smallest and if they are on they are on the same line the treatment levels were not significantly different at an $\alpha = 0.05$. **str** = stratum, **sta** = status, **sal** = salinity regime, **FF** = far-field, **NF** = near-field, **R** = reference, **U** = unclassified, **D** = degraded, **HM** = high-mesohaline, and **LM** = low-mesohaline.

Parameter	**n**	**model *p*-value**	**model r^2**	**F**	**df**	**Stratum *p*-value**	**status *p*-value**	**salinity *p*-value**	**interaction**	**stratum effect**	**status effect**	**salinity regime effect**
Log_{10} Total Community Production (mg AFDM m^{-2} d^{-1}) Saline Sites	165	<0.0001	0.258	6.77	8, 156	0.0003	0.9182	0.3194	str*sta sal*sta	FF NF	R U D	HM LM
Log_{10} Bivalve Production (mg AFDM m^{-2} d^{-1}) Saline Sites	165	<0.0001	0.350	10.49	8, 156	0.0426	0.0018	<0.0001	str*sta sal*sta	FF NF	D R U	LM HM
Log_{10} Non-Bivalve Production(mg AFDM m^{-2} d^{-1}) Saline Sites	165	<0.0001	0.510	14.50	11, 153	0.0004	<0.0001	<0.0001	sal*sta str*sal*sta	FF NF	R U D	HM LM
Log_{10} Total Community Production (g AFDM m^{-2} y^{-1}) Freshwater Sites	53	<0.0001	0.802	38.16	5, 47	0.0669	<0.0001		str*sta	FF NF	D U R	

degraded), but in the low-mesohaline production was higher in the degraded sites than the unclassified and reference sites, which were similar to each other.

The results of the ANOVA for the non-bivalve macrobenthos showed significant differences among strata ($F = 13.14$, $p = 0.0004$), status ($F = 37.07$, $p < 0.0001$), and salinity regime ($F = 24.68$, $p < 0.0001$), as well as significant interactions between salinity and status ($F = 12.01$, $p < 0.0001$) and the 3-way interaction of strata, salinity, and status classification ($F = 5.02$, $p = 0.0003$) (Table 30). Strata differences accounted for 8% of the variation in the non-bivalve ANOVA model, salinity differences accounted for 15%, and status classification accounted for 46%, with the interactions of salinity*status and strata*salinity*status accounting for 15% and 16%, respectively. Production was higher in far-field than the near-field, greater in the high mesohaline sites than the low–mesohaline/oligohaline, and reference sites had higher production than unclassified, which were greater than degraded (Table 30). The pattern of production among sites of different status was not consistent across salinity regimes. In the high mesohaline production was greatest at the reference site (reference>unclassified>degraded), while the unclassified sites had the greatest amount of production in the low mesohaline/oligohaline (unclassified=reference>degraded).

For bivalves, there were significant differences in production among sites based on stratum ($F = 4.18$, $p = 0.0426$), status ($F = 10.77$, $p < 0.0001$) and salinity regime ($F = 10.10$, $p = 0.0018$). Differences between strata accounted for 1% of the model variance, status for 24%, and salinity accounted for 6%, Additionally, the interactions between stratum and status ($F = 9.23$, $p = 0.0002$) and salinity regime and status ($F = 19.22$, $p < 0.0001$) were significant and accounted for 22% and 46% of the variation in the model, respectively. Production was greater for far-field relative to near-field sites and greater for the high mesohaline relative to low – mesohaline/oligohaline sites. Overall, bivalve production was greater at degraded sites than at reference and unclassified sites, which were equivalent, but there were interactions with stratum and salinity regime. There were no differences in production by status within the near-field or among the high mesohaline sites. Within the far-field strata or within the low-mesohaline salinity regime, bivalve production was higher at degraded relative to unclassified and reference sites, which were equivalent,

Among the freshwater sites (Figure 81), there were significant differences in total community macrobenthic production among sites based on status ($F = 75.70$, $p < 0.0001$) but not stratum ($F = 3.52$, $p = 0.0669$). Production was highest at the degraded sites, followed by the unclassified, and reference sites (Table 30). As with the saline sites, there were significant stratum*status interactions ($F = 17.88$, $p < 0.0001$). For the near-field, production was greatest at the degraded site and lowest at the reference site (degraded>unclassified>reference). For the far-field, production was greatest at the degraded site, and lower at the reference and unclassified sites, which were similar (Figure 81). Differences in production among sites separated by status accounted for 79% of the modeled variance in the ANOVA and the interaction term accounted for 19% of the variance.

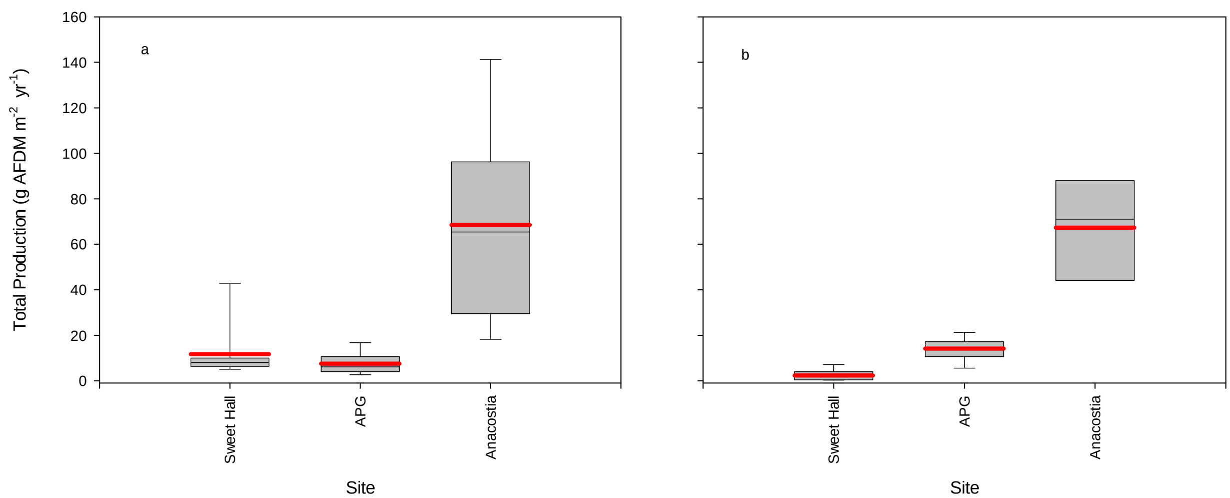


Figure 81. Total community secondary production in the far-field (a) and near-field (b) stations of the freshwater sites. The red line represents the mean, the black line the median, the shaded area spans 25th and 75th quartiles, and the error bars span the 10th to the 90th deciles.

In the high-mesohaline through oligohaline sites, there were significant (p <0.0001) positive linear relationships between non-bivalve secondary production and habitat quality, expressed as B-IBI score, Shannon-Weiner Diversity (H'), and sediment nitrogen concentration, in the near-field strata. The models accounted for 36-43% of the variation in the production data (Figure 82a-c). Conversely, there were no significant trends of bivalve secondary production with habitat quality in the near-field strata of the saline sites, accounting for less than 4% of the variation in the production data (Figure 83a-c).

For the far-field, there was no relationship between non-bivalve production, sediment nitrogen and Shannon-Weiner Diversity (H'), and a weak negative relationship with the B-IBI, accounting for only 0.05% of the variation (Figure 82d-f). There was also no consistent pattern of bivalve production and habitat quality in the far-field strata, with a positive relationship between production and habitat quality expressed as B-IBI score and Shannon-Weiner Diversity, but a negative relationship with habitat quality expressed as sediment nitrogen content (Figure 83d-f).

There were mixed patterns of total macrobenthic production and habitat quality in the near-field stratum of the freshwater sites. There was a significant negative relationship between production and habitat quality expressed as B-IBI score that accounted for 21% of the variation (Figure 84a), a positive relationship when expressed as sediment nitrogen content that accounted for 37% of the variation (Figure 84c), and no relationship when expressed as Shannon-Wiener Diversity (Figure 84b). There were also conflicting results in the patterns of the far-field macrobenthic community production, where production was positively related to habitat quality as Shannon-Wiener Diversity (Figure 84e), but negatively related to habitat quality expressed as B-IBI Score and sediment nitrogen (Figure 84d & f).

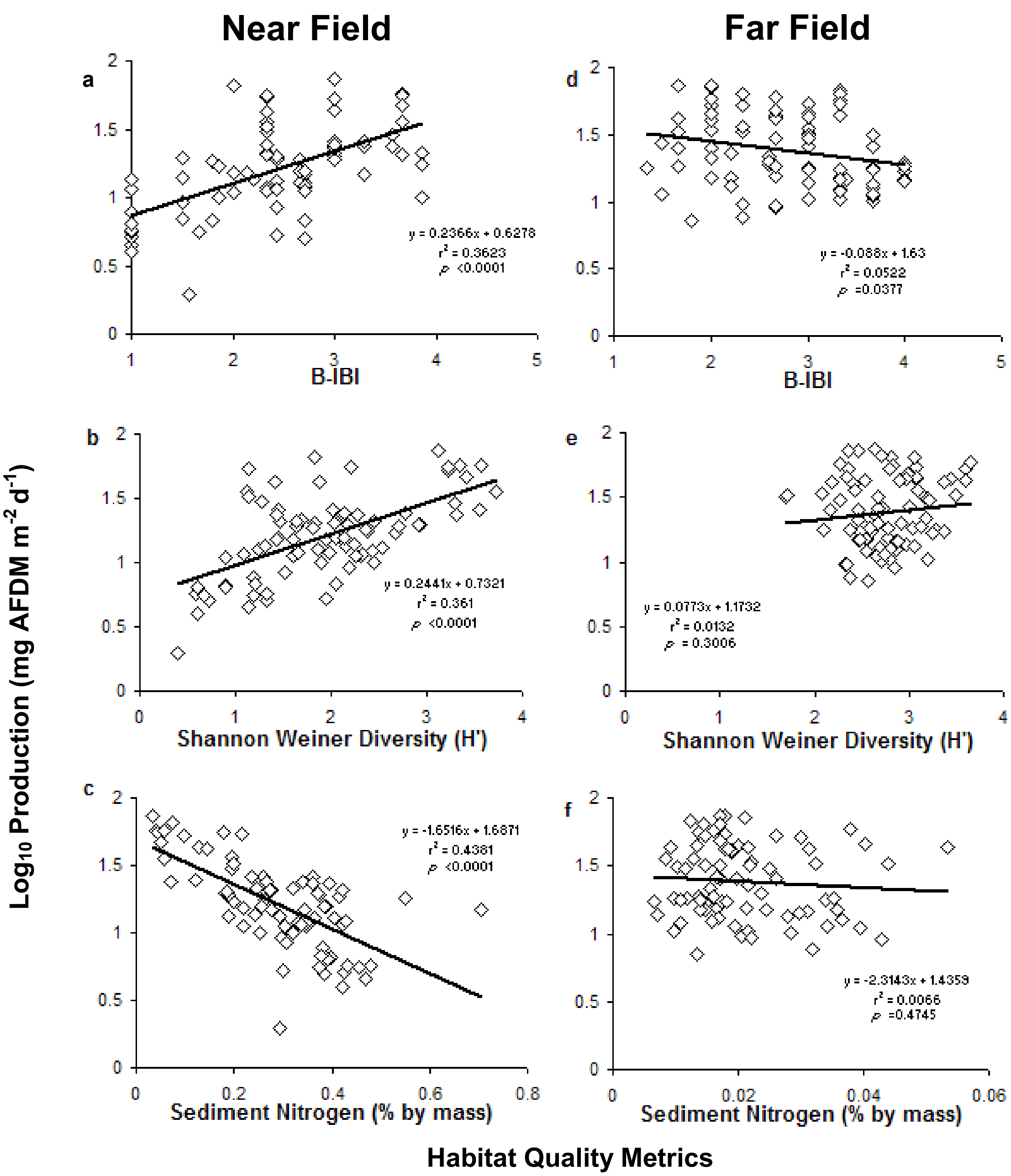


Figure 82. Linear relationships of $\log_{10}$ transformed secondary production of the non-bivalve portion of the macrobenthic community to three indicators of benthic habitat quality in the near-field (**a-c**) and far-field strata (**d-f**) of the saline sites. Note that low B-IBI and Shannon-Weiner Diversity scores correspond to low quality habitats, but that low sediment nitrogen concentrations correspond to high quality habitats.

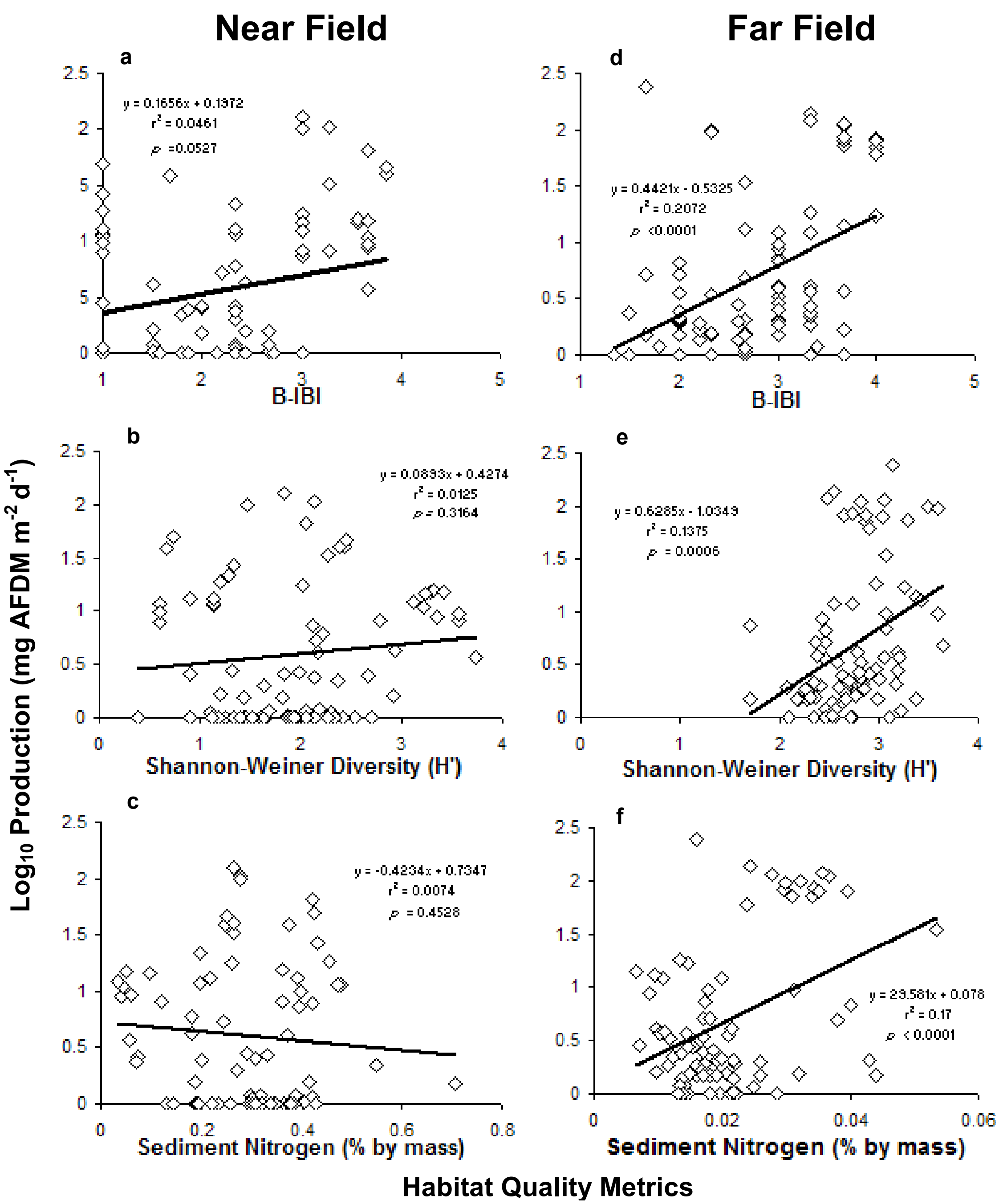


Figure 83. Linear relationships of $\log_{10}$ transformed bivalve secondary production to three indicators of benthic habitat quality in the near-field (**a-c**) and far-field strata (**d-f**) of the saline sites. Note that low B-IBI and Shannon-Weiner Diversity scores correspond to low quality habitats, but that low sediment nitrogen concentrations correspond to high quality habitats.

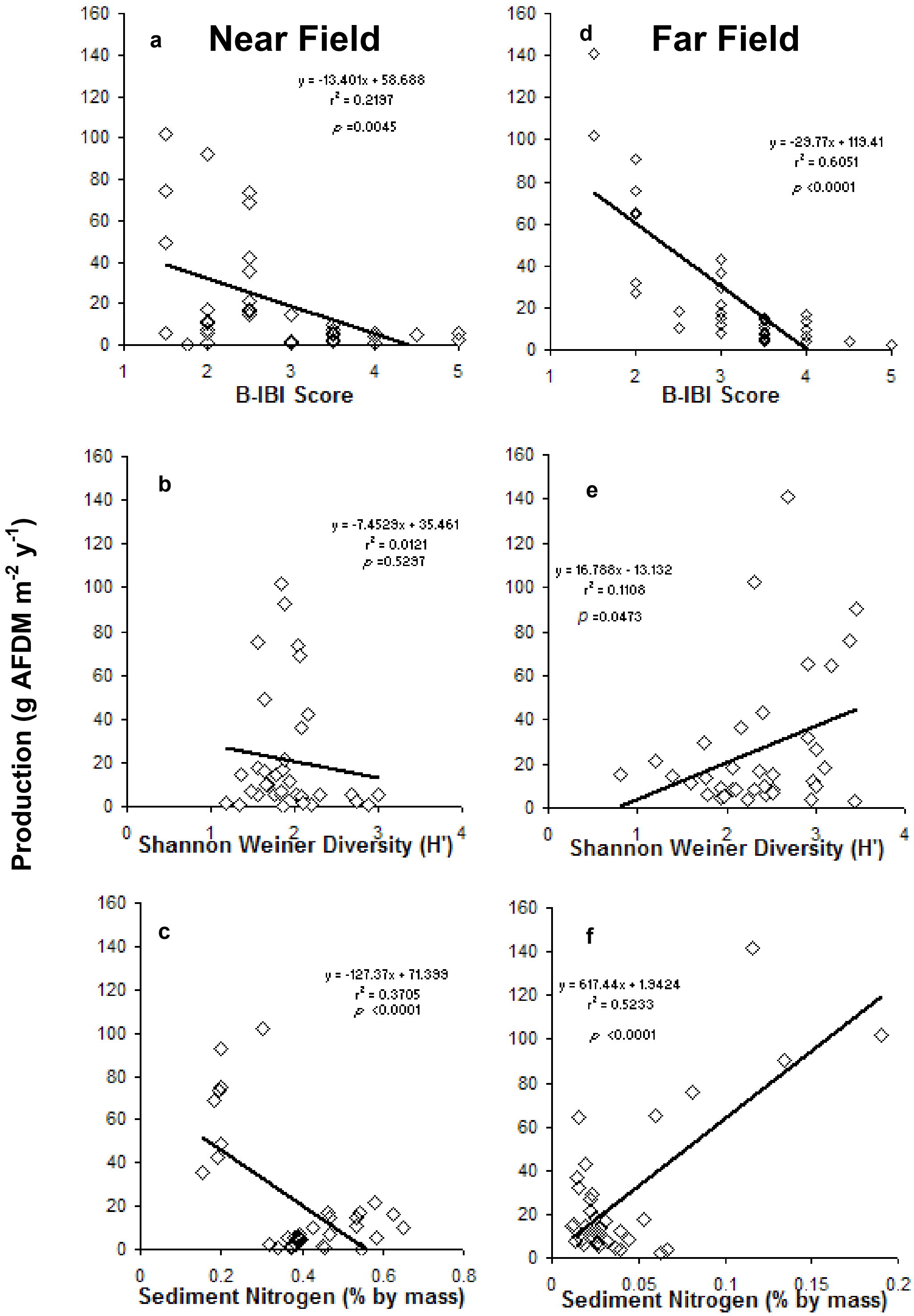


Figure 84. Linear relationships of $\log_{10}$ transformed secondary production of the total macrobenthic community to three indicators of benthic habitat quality in the near-field (**a-c**) and far-field strata (**d-f**) of the freshwater sites. Note that low B-IBI and Shannon-Weiner Diversity scores correspond to low quality habitats, but that low sediment nitrogen concentrations correspond to high quality habitats.

Secondary production is a complex, integrative measure of, among other things, a population's response to environmental conditions, food supply, and age-distribution (Crisp 1984). Interpretation of secondary production patterns can become even more complex when they are treated at the community-level; integrating the responses of multiple taxa that likely have differing lifespans, feeding styles, and reproductive modes. Secondary production data are vital though, to understand the trophic functioning of an ecosystem and provide information on the movement of energy and material in ecosystems, which cannot be determined from abundance and biomass measures alone (Diaz and Schaffner 1990, Tumbiolo and Downing 1994, Gillett et al. 2005).

As with many of the other macrobenthic metrics noted above, there were distinctly different patterns of macrobenthic production in the shallow water habitats of the meso- to oligohaline estuary versus the tidal freshwater reaches. The environmental setting of the near-field sites - muddy, depositional, and relatively quiescent - as compared to the relatively sandy, exposed far-field sites, was consistently important in accounting for the differences in production at the saline sites.

More specifically, the differences of how eutrophication and excessive organic matter accumulation in the sediments impact the near- and far-field strata appears to greatly influence the production of the macrobenthic community and which taxa are most productive at the different sites. Relatively large values of community secondary production can be a product of either an accumulation of biomass in larger, longer-lived organisms (e.g., Walker and Tenore 1984, Diaz and Schaffner 1990, Thompson and Schaffner 2001) or a community composed of smaller taxa with a high turnover rate (e.g., Martinet et al. 1993, Gillett et al. 2005). In the Chesapeake Bay sites that were sampled during this study, high production values were primarily related to those sites with the larger organisms instead of organisms with a high turnover rate. In the high-mesohaline through oligohaline sites, this translates into large bivalves, whereas in the freshwater sites, the large organisms were primarily oligochaetes.

Within the saline sites, the near-field strata experienced significant reductions of secondary production of non-bivalves with decreased habitat quality measured with the B-IBI, H' diversity, and sediment nitrogen content. There were similar trends for the bivalves, but due to the paucity of bivalves in the near-field strata that we sampled as part of the project none of these trends were significant. The loss of the long-lived taxa, like the bivalves, from the near-field sites is an indication of the degraded habitat.

These patterns illustrate a considerable loss in ecosystem function: a reduction of organic matter for subsequent economically, socially, and ecologically important finfish and crustaceans. That it was only manifest in the near-field stratum of areas with regional-scale eutrophication and excessive nutrient inputs further illustrates the fundamental differences in the strata discussed elsewhere. As noted earlier, the primary insults along the gradient of habitat quality we sampled were eutrophication and excessive input of organic matter to the sediment, but without hypoxia due the shallow depth of the sites that were sampled. Organic matter inputs and accumulation in the sediment will be greater in the near-field sites because of the reduced flushing and higher mud content of the sediments compared to the far-field strata noted above (section 5.3). As such, it is not surprising that patterns were less evident in the non-bivalve macrofauna of the far-field strata in the saline sites. The more exposed nature of the far-field sites (e.g., greater wave action, episodic storm impacts) likely affects the macrobenthic community negatively, especially the soft-bodied, non-bivalve taxa (e.g., Emerson 1989), but not in a way that is accounted for by the B-IBI, H', or sediment nitrogen composition.

Conversely, the production of bivalves in the far-field seemed to respond positively to greater inputs of organic matter to the systems (measured as sediment nitrogen content). This opposite effect to that seen in the near-field sites is likely due to differences in the sediment composition, water circulation, and magnitude of organic matter in the two strata noted above (section 5.3). The coarser-grained sands of the far-field retain less organic material, which in turn, prevents the accumulation of reduced compounds (e.g., ammonia or sulfides) that are harmful to most macrobenthic fauna. Benthic primary production was similar to that in the near-field, and together with phytoplankton provided an abundant amount of labile organic matter for the macrobenthos to consume. The sum result is that filter- and sediment interface-feeding fauna, like the tellinid bivalves that dominate the biomass of the far-field sites, realize the benefits of increased microphytobenthic and planktonic production, but are not exposed to the negative build up of reduced compounds in the sediment, as happens in the muddier near-field sites.

5.5.6 Meiofauna

Benthic meiofauna are important components of coastal and estuarine ecosystems, grazing on microalgae and bacteria and influencing primary production, nutrient cycling, and other benthic metabolic processes (Carman et al. 1996, 1997, 2000, Manini et al. 2000, Pinckney et al. 2003). Additionally, benthic meiofauna may be a common prey item for macrofauna and juvenile benthivoric nekton, facilitating energy and nutrient transfer to higher trophic levels (Coull et al. 1995, Aarnio et al. 1996, Street et al. 1998, Kovac et al. 2001, French et al. 2001, Leguerrier et al. 2003). Previous investigations have suggested that meiofauna and macrofauna may show similar responses to disturbances (Coull & Chandler, 1992, Peterson et al. 1996, Warwick et al. 1990, Schratzberger et al. 2001). There is very little data on meiofauna of Chesapeake Bay. To our knowledge, this is the first general survey along the estuarine salinity gradient.

Nematodes, copepods, Foraminifera, copepod nauplii, ostracods, polychaetes, turbellarians, and mites comprised the dominant meiofauna taxa (Appendix B). There were markedly lower abundances of all meiofauna with decreasing salinity through the estuary (Figure 85) for both strata. Nematodes were the dominant meiofauna taxa collected at all sites (Figure 86). Densities were highest at SA near-field and lowest by an order of magnitude in the near-field stratum of the ER, FE, PG sites, as well as all of the freshwater sites. Nematodes are considered to be pollution resistant and their absence from the ER near-field site is assumed to be a reflection of the high sediment toxicity at the study site (Metcalfe 2005). Copepods, which were assumed to be pollution sensitive, were the second most abundant meiofaunal taxon at the near- and far-field sites across all of the different salinity regimes, with highest densities at LA and CH (Figure 87). Foraminifera, also expected to be pollution sensitive based on previous studies, were abundant taxa some of the high-mesohaline sites, though they were relatively absent at the lower salinity sites (Figure 88). As noted earlier, there were a variety of other taxa collected, but they were relatively rare compared to these groups (Appendix B).

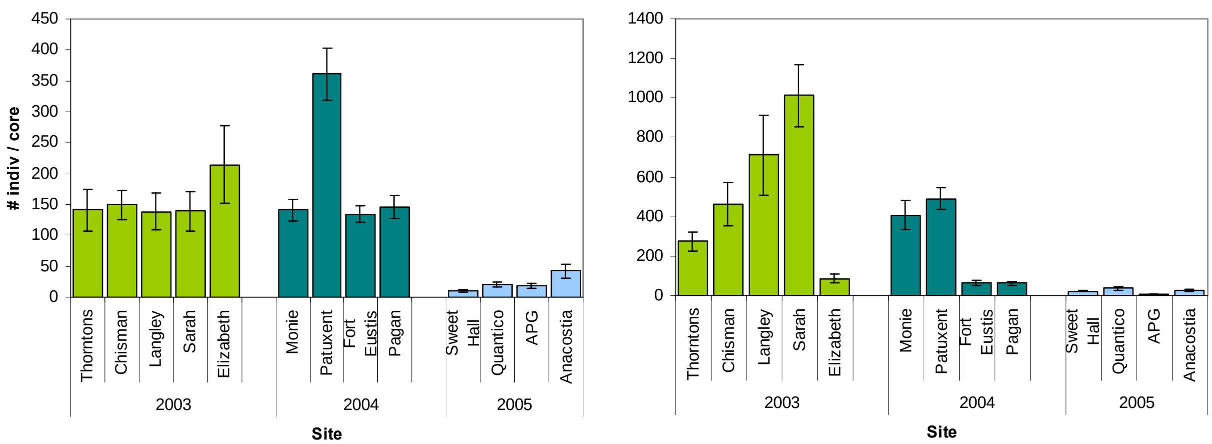


Figure 85. Mean abundance of meiofauna for far- and near- field strata by major salinity regime and site. Shown are the means and standard errors based on 8 or 9 samples for far-field (left) and near-field (right) strata.

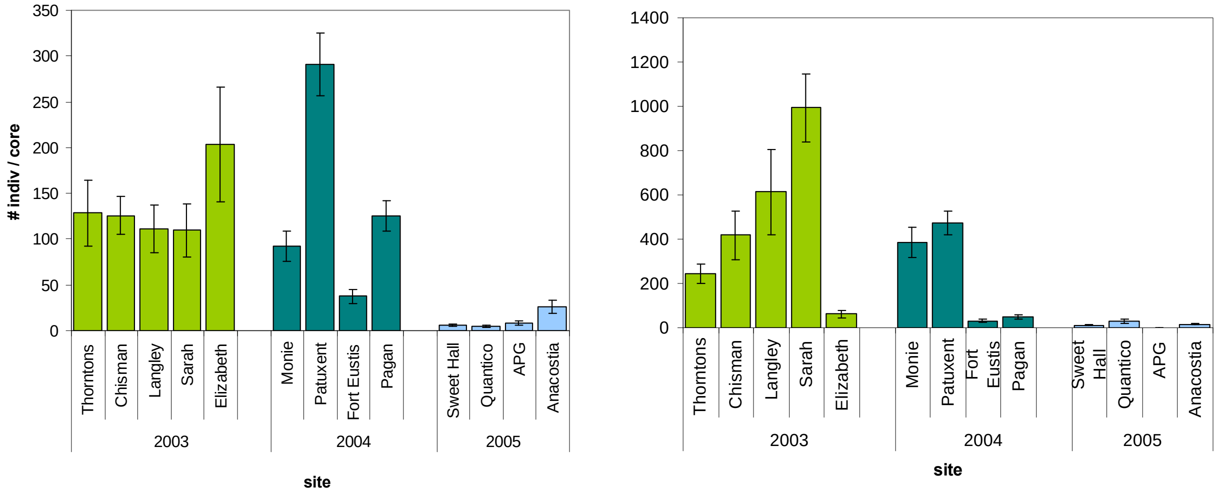


Figure 86. Mean abundance of nematodes for far- and near- field strata by major salinity regime and site. Shown are the means and standard errors based on 8 or 9 samples for far-field (left) and near-field (right) strata.

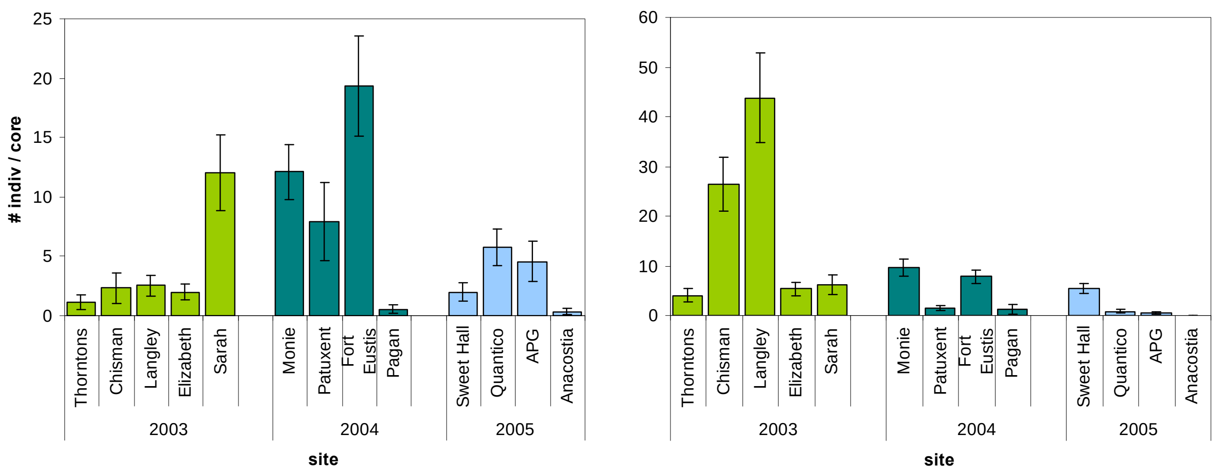


Figure 87. Mean abundance of copepods for far- and near- field strata by major salinity regime and site. Shown are the means and standard errors based on 8 or 9 samples for far-field (left) and near-field (right) strata.

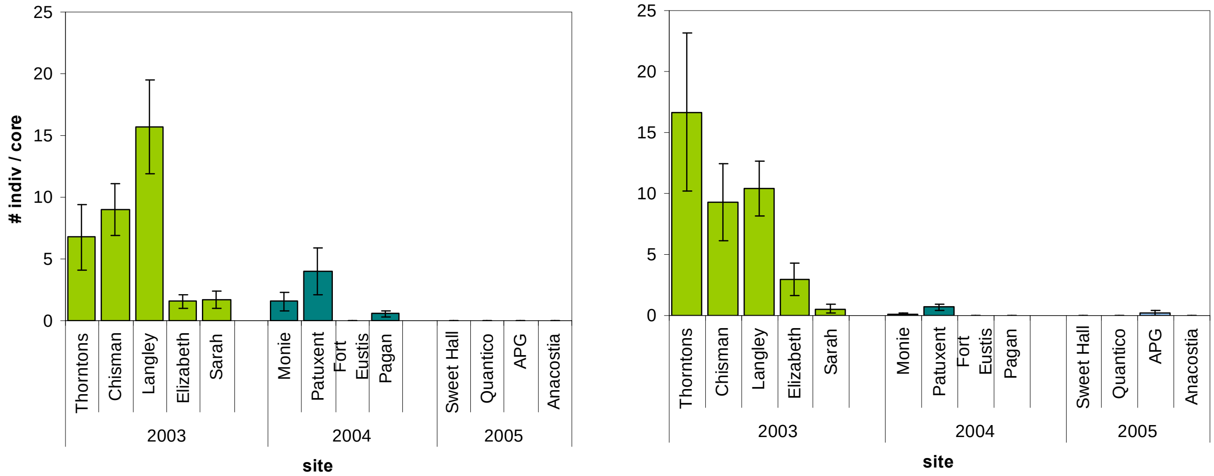


Figure 88. Mean abundance of forams for far- and near- field strata by major salinity regime and site. Shown are the means and standard errors based on 8 or 9 samples for far-field (left) and near-field (right) strata.

Green and Montagna (1996) have suggested the use of a ratio of nematodes (the more tolerant taxa) to harpacticoid copepods (the more sensitive taxa) as a means of assessing contaminant impacts on meiofaunal community structure. Across the sites we studied, we found no compelling evidence that this ratio is useful for identifying gradients of impairment associated primarily with eutrophication on benthic meiofauna assemblages (Figure 89). At most sites the ratio was 100 or less, but a few sites had very high ratios (SA near-field, PAX near-field). At SA this was driven by high nematode abundance (Figure 86), while at PAX it was driven by low copepod abundance (Figure 87). One of the lowest ratios we measured was at the ER near-field site, which had high sediment toxicity and very low overall meiofauna abundance (Figure 85).

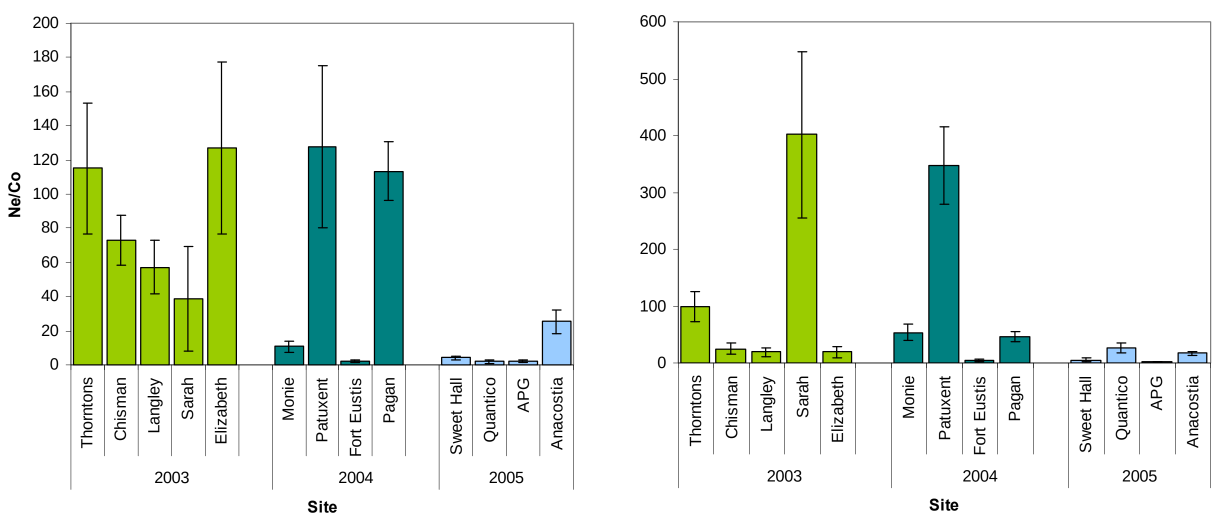


Figure 89. The ratio of nematodes to copepods for far- and near- field strata by major salinity regime and site. Shown are the means and standard errors based on 8 or 9 samples for far-field (left) and near-field (right) strata.

We considered the ratio of nematodes to forams, which are also considered relatively sensitive and therefore useful as indicators of environmental quality (Metcalfe 2005). As for the Ne:Co ratio, there were no obvious patterns relating the gradient of impairment identified a priori or via the B-IBI approach (Figure 90).

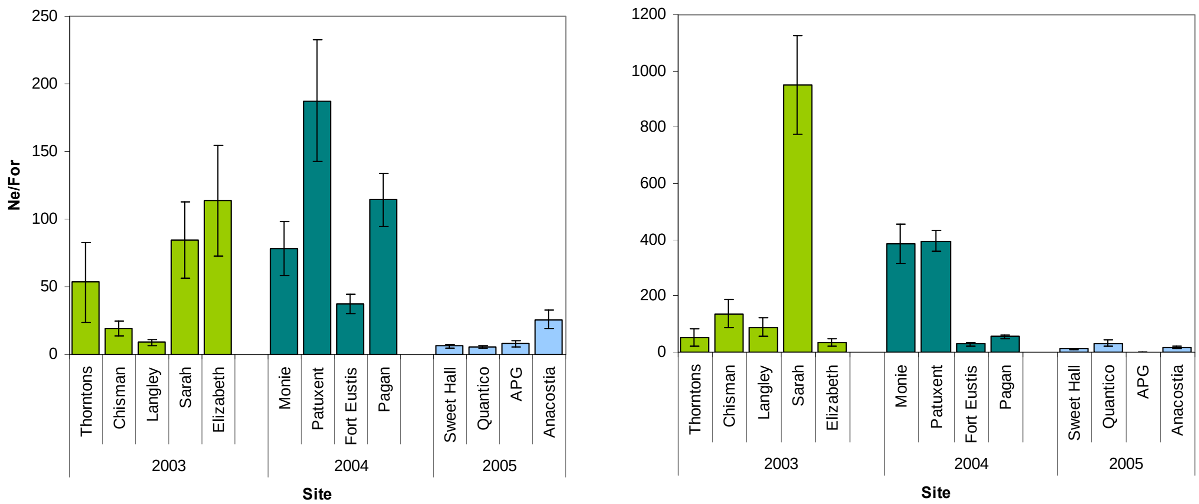


Figure 90. The ratio of nematodes to Foraminifera for far- and near- field strata by major salinity regime and site. Shown are the means and standard errors based on 8 or 9 samples for far-field (left) and near-field (right) strata.

Meiofaunal community composition

Given the low overall abundances of meiofauna in the low mesohaline to tidal freshwater regions, we restricted the community analyses of meiofauna to the high-mesohaline sites. Non-metric Multi-Dimensional Scaling (MDS) Ordination was used to evaluate relationships in community composition of meiofauna among sites and strata.

Within the MDS ordination of the meiofauna in the high-mesohaline near-field stations, the two most impaired sites (SA and ER), based on regional water quality, sediment TN and sediment toxicity, formed distinct end-member clusters within ordination space (Figure 91). Other stations were arrayed between these clusters, with separation based primarily on stratum. There was some separation of the far from the near-field sites, but within the far-field grouping there was little structure in the meiofaunal community similarities in relation to habitat status.

Linking Meiofauna Community Structure to Environmental Variables and the B-IBI

To investigate the relationship of meiofaunal community structure to environmental quality, two approaches were taken: 1) Meiofaunal community composition was compared to a suite of historical environmental characteristics, as well as parameters measured concurrently with the meiofauna (e.g., benthic chlorophyll, sediment grain size, sediment organic matter content) using the biological-environmental linkage procedure of PRIMER-E (Clarke and Warwick 2001); and 2) A series of linear regressions were calculated between the Chesapeake Bay B-IBI and the abundance of the most abundant meiofauna taxa and the ratio of nematodes to copepods (sensu Raffaelli and Mason 1981).

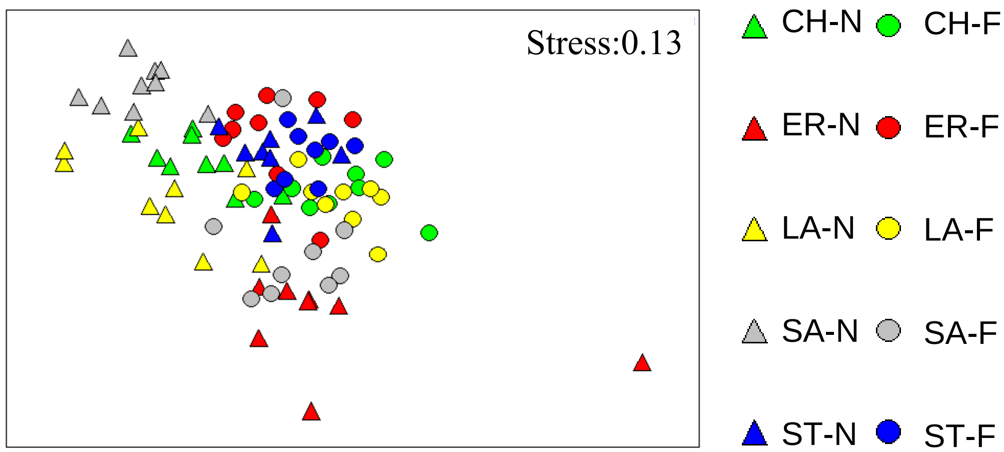


Figure 91. Ordination plots of non-metric Multi-dimensional Scaling of square root transformed meiofauna abundance data from high mesohaline sites. Taxa included in the analysis: nematodes, harpacticoid copepods, harpacticoid nauplii, ostracods, mites, turbellarians and forams.

The biological-environmental linkage procedure of the software program PRIMER-E (BIO-ENV) allows comparison of similarity matrices calculated for the meiofauna community and environmental data. The procedure was used to select the “best fitting” abiotic variable subsets which maximized rank correlation between a similarity matrix of square root transformed meiofauna abundances by core and all possible (dis)similarity matrices of the historic water quality parameters presented in Tables 6-11. The same procedure was run a second time, this time to correlate the observed meiofauna community structure with measured site characterization metrics and to compare the relative strength of historic factors versus measured sediment and water quality parameters in structuring the meiofauna communities at these sites. Site characterization metrics included sediment characteristics and watershed landuse variables.

Subsets of historical water quality variables that best grouped the regions in a manner consistent with the meiofaunal patterns of abundance incorporate salinity (max, mean, range), water column chlorophyll-a (max), NO_x (min), NH^+_4 (min) and DO (max) (ρ_w= 0.13; Metcalfe 2005). Measured variables that best grouped the sites in a manner consistent with meiofauna community structure are sediment TOC (%) and TN (%), molar C:N, sediment toxicity, and percent farmland (ρ_w = 0.54 - 0.56; Metcalfe 2005). These results indicate the importance of local sediment-associated factors, rather than regional water quality in shaping meiofauna community structure.

Among the linear relationships developed between the most abundant meiofauna taxa and various measures of habitat quality, the negative response of foram abundance to sediment nitrogen content was the only one significant at $\alpha = 0.05$ (Table 31). The lack of any significant relationships between the meiofauna and the B-IBI or the regional water quality indicates that the dominant meiobenthos do not respond to environmental impairment gradients consistent with

Table 31. Summary output of the linear regression analysis between meiofaunal abundance and measures of habitat quality expressed as Chesapeake Bay Index of Biotic integrity (B-IBI), sediment total nitrogen in the top 5 cm of sediment, and median historical dissolved inorganic nitrogen in the water column of the region (Regional DIN) in the near-field (NF) and far-field (FF) strata of the high mesohaline sites. Significance of the regression model, r^2, the x-intercept estimate, independent variable estimate are also presented.

Dependent	Independent	Strata	*p*	r^2	Intercept	Independent estimate
Nematode Abundance (# core^{-1})	B-IBI	NF	0.2251	0.436	2189.69244	-589.66828
Copepod Abundance (# core^{-1})	B-IBI	NF	0.9991	0	17.06953	0.02933
Foram Abundance (# core^{-1})	B-IBI	NF	0.0659	0.7283	-31.32335	13.40932
Nematode:Copepod Ratio	B-IBI	NF	0.2711	0.3764	842.88348	-248.98148
Nematode Abundance (# core^{-1})	B-IBI	FF	0.6425	0.081	85.79245	17.41089
Copepod Abundance (# core^{-1})	B-IBI	FF	0.2889	0.3552	15.09043	-4.11745
Foram Abundance (# core^{-1})	B-IBI	FF	0.6835	0.0631	0.85513	2.25661
Nematode:Copepod Ratio	B-IBI	FF	0.315	0.3257	-3.53039	30.86028
Nematode Abundance (# core^{-1})	Sediment Nitrogen	NF	0.7335	0.0445	305.91002	656.49327
Copepod Abundance (# core^{-1})	Sediment Nitrogen	NF	0.8654	0.0112	20.89924	-15.90171
Foram Abundance (# core^{-1})	Sediment Nitrogen	NF	0.0164	0.8882	20.15256	-51.61905
Nematode:Copepod Ratio	Sediment Nitrogen	NF	0.6995	0.0568	33.35887	337.15872
Nematode Abundance (# core^{-1})	Sediment Nitrogen	FF	0.1219	0.604	-59.53842	10493
Copepod Abundance (# core^{-1})	Sediment Nitrogen	FF	0.78	0.0302	8.85183	-264.85464
Foram Abundance (# core^{-1})	Sediment Nitrogen	FF	0.787	0.0283	13.03798	-333.24246
Nematode:Copepod Ratio	Sediment Nitrogen	FF	0.5839	0.1109	6.75515	3976.07834
Nematode Abundance (# core^{-1})	Regional DIN	NF	0.7238	0.0478	530.89029	-17.42232
Copepod Abundance (# core^{-1})	Regional DIN	NF	0.3259	0.3139	25.86065	-2.15359
Foram Abundance (# core^{-1})	Regional DIN	NF	0.1436	0.5638	12.25493	-1.05264
Nematode:Copepod Ratio	Regional DIN	NF	0.791	0.0272	88.59947	5.97108
Nematode Abundance (# core^{-1})	Regional DIN	FF	0.0825	0.6875	103.355	7.25704
Copepod Abundance (# core^{-1})	Regional DIN	FF	0.7018	0.0559	3.05519	0.23374
Foram Abundance (# core^{-1})	Regional DIN	FF	0.1307	0.5873	10.91442	-0.98489
Nematode:Copepod Ratio	Regional DIN	FF	0.4599	0.1925	65.8691	3.39504

our a priori hypotheses. It should be noted, that the taxonomic detail used in the analysis of the meiofauna (at the phyla to subclass levels) was coarser than that used for the macrofauna (at the species level) and that the response to environmental stressors may be specific to taxonomic levels finer than phylum. The multivariate analysis of the entire meiofaunal community to habitat characteristics was able to discern the influence of habitat quality (sediment organic content in particular) on community structure that the univariate linear regressions by and large could not. These results suggest that the consideration of the entire meiofaunal community described at higher taxonomic levels is enough to discern the broad influence of the habitat on the meiofauna, but that increased taxonomic details will possibly yield better linkages to the habitat quality, as is seen in the study of macrofauna.

5.6 Ecosystem Processes

5.6.1 Sediment Metabolism – Variability Within Salinity Regimes

A primary objective of this study was to determine how metrics of ecosystem function vary along gradients of impairment both within and across salinity regimes. The metrics that we had predicted would be most responsive to disturbance both within and across salinity regimes were sediment metabolism and microbial nitrogen cycling process rates. In this section we assess variability of metabolic and nitrogen cycling rates within salinity regimes. To assess metabolic rates DO fluxes were measured in cores taken from near-field and far-field stations at all study sites. Upward pointing bars in the DO flux figures represent release of DO resulting from net primary production; downward pointing bars represent uptake of DO due to respiration and other consumptive processes such as sulfide oxidation and nitrification. DO fluxes are shown both for sediment cores and for water column "blanks." Sediment fluxes have been corrected for DO uptake or release in the water column. One-way ANOVA of sediment metabolism rates within a single stratum and salinity regime were performed to assess variation between sites (Table 32), followed by Tukey's Test to show differences between means by site. Bars with different letters on Figures 93, 95, and 97 are significantly different at $p < 0.05$. Additional statistical analyses of these data were performed by three-way ANOVA to assess the effects of stratum, status, and salinity, as described in section 5.6.3, and by Principal Components Analysis, described in section 5.6.7.

<u>High Mesohaline Sites</u>

At all of the high mesohaline far and near-field sites, net DO production in the light exceeded uptake in the dark (Figure 92). Thus, both sediment and water column at these sites were net autotrophic, as a result of benthic microalgal and phytoplankton photosynthesis.

Respiration rates were not significantly different between sites for sediments from both far- and near-field stations, except for the near-field Elizabeth River, which demonstrated higher rates of respiration, perhaps because of its higher organic content (Figure 93-A, Figure 43). All the sites demonstrated negative NEM rates, indicating net autotrophy and uptake of inorganic carbon (Figure 93-B). Thorntons Creek sediments were distinctly more net autotrophic at the far-field station and less net autotrophic at the near-field station when compared to all other sites. GPP was also higher in Thorntons Creek far-field stations and lower in Thorntons Creek near-field stations than rates observed for the other high mesohaline sites (Figure 93-C).

<u>Low Mesohaline Sites</u>

In the light, there was net DO production in sediments sampled in far-field stations at Monie Bay, Fort Eustis, and PAX, demonstrating the importance of benthic photosynthesis, but net oxygen consumption in Pagan River sediments, as one might expect given the low sediment chlorophyll a and high phaeophytin in the Pagan River sediments (Figure 94, Figure 52, 53). There was net DO consumption in the light in sediments from near-field stations in Monie Bay,

Table 32. One-way ANOVA of sediment metabolism rates for each salinity regime and stratum. *Sediment gross primary production (GPP) data were transformed with ln(-GPP+2).

High Mesohaline Sites										
	Far-field					**Near-field**				
	source of variation	**df**	**ms**	**F**	**p**	**source of variation**	**df**	**ms**	**F**	**p**
Sediment Respiration	site	2	88.31	1.49	0.25	site	2	398.32	8.60	0.002
	error	23				error	22			
	total	25				total	24			
Sediment NEM	site	2	12676.81	40.35	<0.001	site	2	6747.36	15.57	<0.001
	error	23				error	22			
	total	25				total	24			
Sediment GPP*	site	2	1.36	14.26	<0.001	site	2	1.55	14.83	<0.001
	error	23				error	22			
	total	25				total	24			
Low Mesohaline Sites										
	Far-field					**Near-field**				
	source of variation	**df**	**ms**	**F**	**p**	**source of variation**	**df**	**ms**	**F**	**p**
Sediment Respiration	site	3	3005.60	161.00	<0.001	site	3	2190.21	114.73	<0.001
	error	32				error	32			
	total	35				total	35			
Sediment NEM	site	3	3734.65	45.43	<0.001	site	3	20198.27	500.66	<0.001
	error	32				error	32			
	total	35				total	35			
Sediment GPP*	site	3	15.70	91.32	<0.001	site	3	15.54	253.89	<0.001
	error	32				error	32			
	total	35				total	35			
Tidal Freshwater Sites										
	Far-field					**Near-field**				
	source of variation	**df**	**ms**	**F**	**p**	**source of variation**	**df**	**ms**	**F**	**p**
Sediment Respiration	site	3	563.68	10.25	<0.001	site	3	1298.62	28.48	<0.001
	error	27				error	25			
	total	30				total	28			
Sediment NEM	site	3	897.52	12.92	<0.001	site	3	1032.50	18.18	<0.001
	error	26				error	24			
	total	29				total	27			
Sediment GPP*	site	3	0.70	2.33	0.10	site	3	0.20	2.11	0.13
	error	26				error	24			
	total	29				total	27			

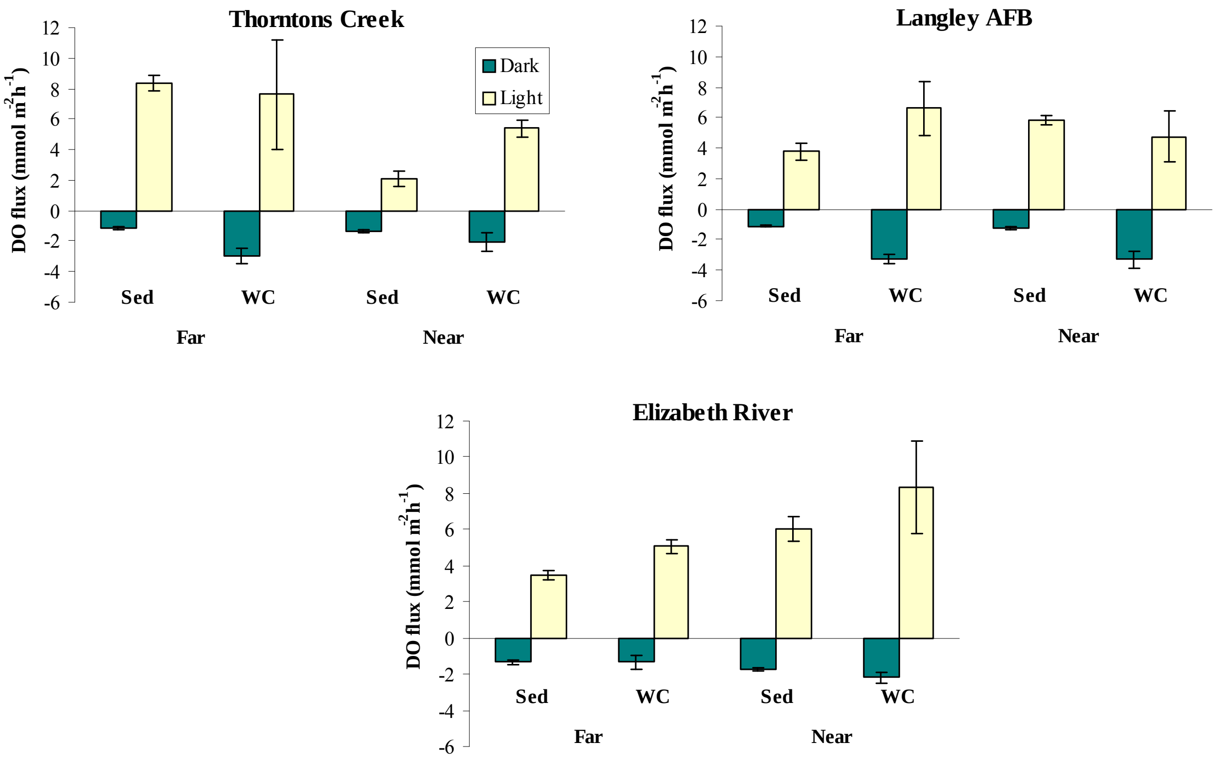


Figure 92. Mean DO fluxes for sediment and water column (WC) at high mesohaline far- and near-field strata in Thorntons Creek, Langley AFB, and Elizabeth River. Error bars represent standard errors.

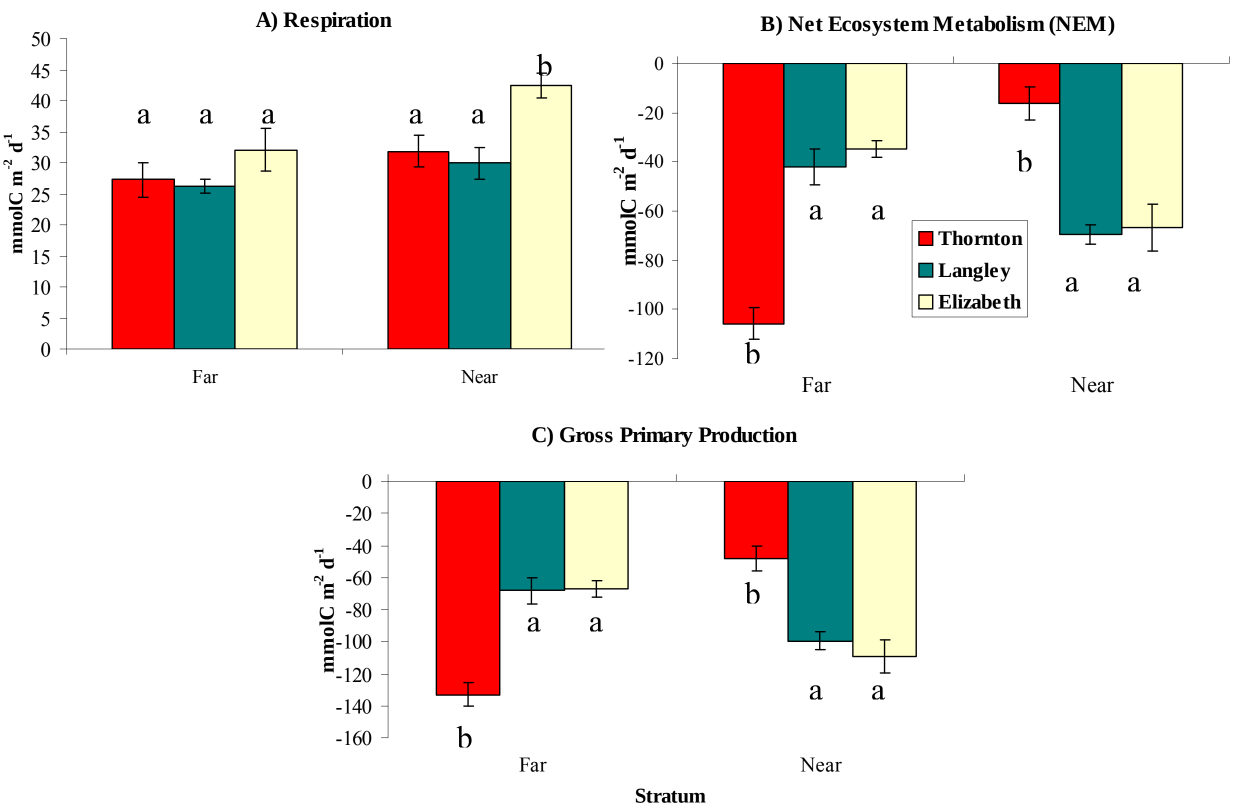


Figure 93. A) Mean sediment respiration, B) mean sediment net ecosystem metabolism, and C) mean sediment gross primary production at high mesohaline far- and near-field strata in Thorntons Creek, Langley AFB, and Elizabeth River. Error bars represent standard errors. Different letters within a stratum denote significantly different mean values (Tukey's test, $p<0.05$)

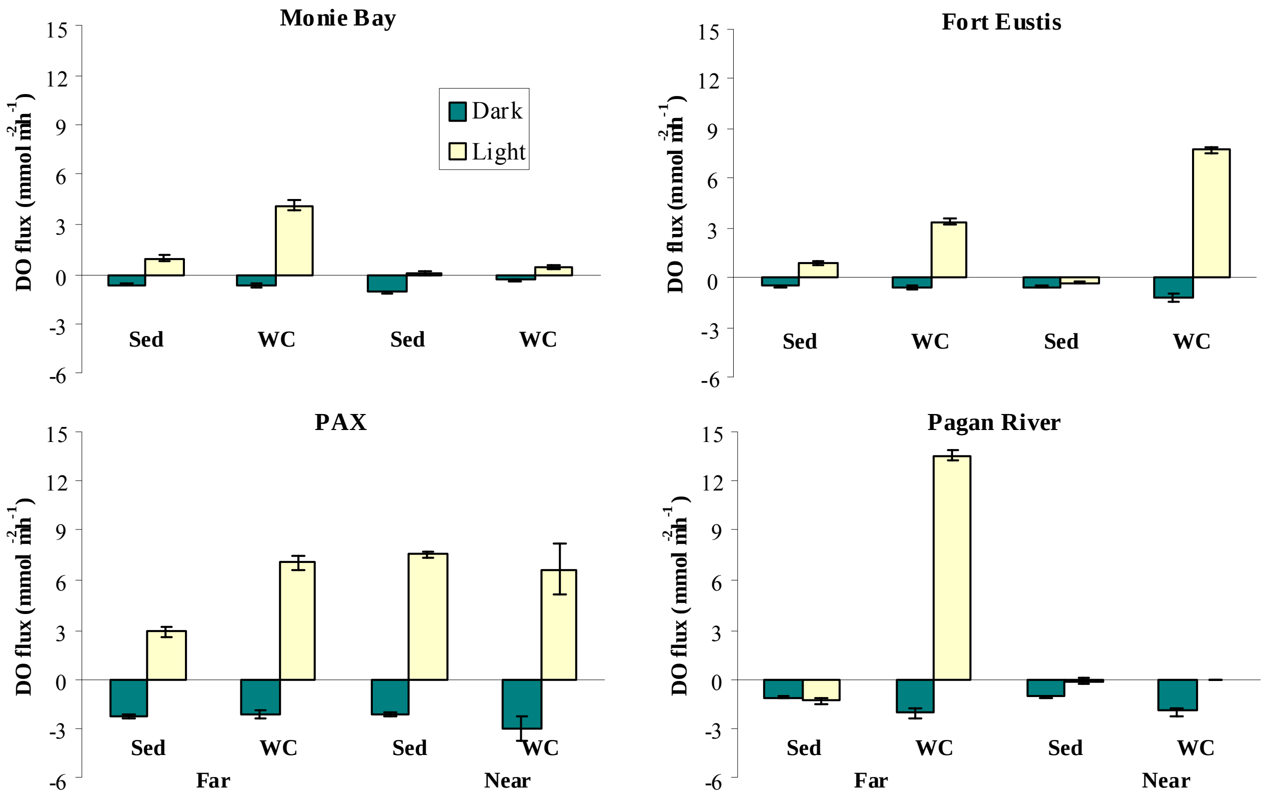


Figure 94. Mean DO fluxes for sediment and water column (WC) at low mesohaline far- and near-field strata in Monie Bay, PAX, Fort Eustis, and the Pagan River. Error bars represent standard errors.

Fort Eustis, and the Pagan River, but strong net DO production in PAX sediments. At all the sites except the Pagan River, water column DO production in the light exceeded production in the dark, indicating net autotrophy in the water column.

Both sediment respiration and GPP were markedly higher in PAX sediments sampled from both near and far-field strata compared to the other low mesohaline sites (Figure 95). Since GPP exceeded respiration, NEM at PAX near- and far-field stations was net autotrophic. In contrast, at the Pagan River site, impaired by high water column nutrients and light attenuation (Table 32) NEM rates in both far and near sediments from the Pagan River were net heterotrophic with respiration exceeding GPP. At both Monie Bay and Fort Eustis, NEM was heterotrophic in near-field and autotrophic in far-field sediments, perhaps a consequence of the high sediment organic content and high light attenuation at the near-field sites (Table 32). The high benthic microalgal production at PAX likely reflects the fact that sampling stations tended to be in more protected embayments and subject to less disturbance due to wave action and resuspension than at other low mesohaline sites. Such conditions, along with the low water column K_d, are likely to contribute to the high benthic microalgal abundance and activity observed at PAX stations (Table 18 and Figure 52).

Tidal Freshwater Sites

Benthic production of oxygen was negligible at most tidal freshwater sites and generally was exceeded by uptake in the dark (Figure 96). As a result, GPP was low and not significantly different between far-field or near-field sites. Respiration was the important driver regulating NEM. At the far-field sites respiration was significantly higher at Anacostia, and at the near-field sites respiration increased along the gradient of site impairment, resulting in greater net heterotrophy (Figure 97, Table 32). Light oxygen production, far exceeding dark uptake, in the water column at both the Anacostia and Quantico far-field sites was expected based on the high observed water column chlorophyll a (Table 18), suggesting that these sites are experiencing eutrophication.

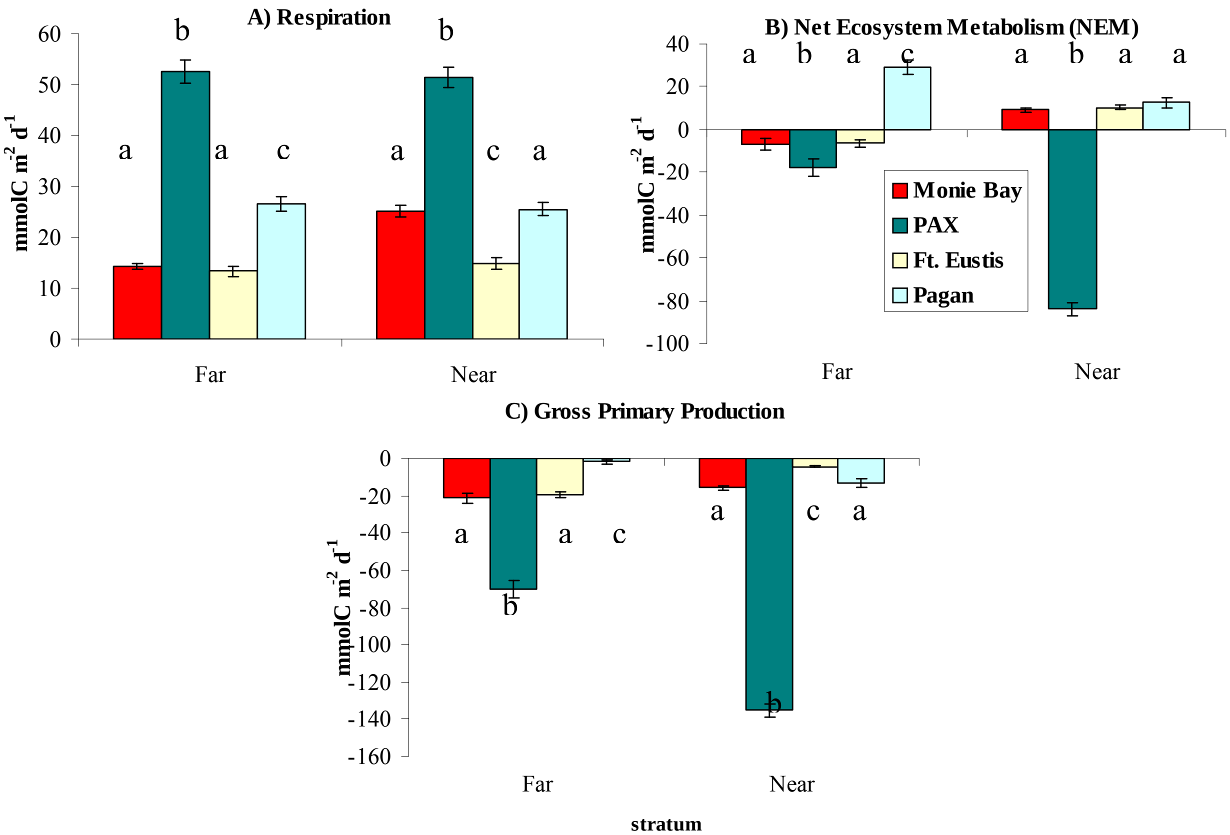


Figure 95. A) Mean sediment respiration, B) mean sediment net ecosystem metabolism, and C) mean sediment gross primary production at low mesohaline far- and near-field strata in Monie Bay, PAX, Fort Eustis, and the Pagan River. Error bars represent standard errors. Different letters within a stratum denote significantly different mean values (Tukey's test, $p<0.05$)

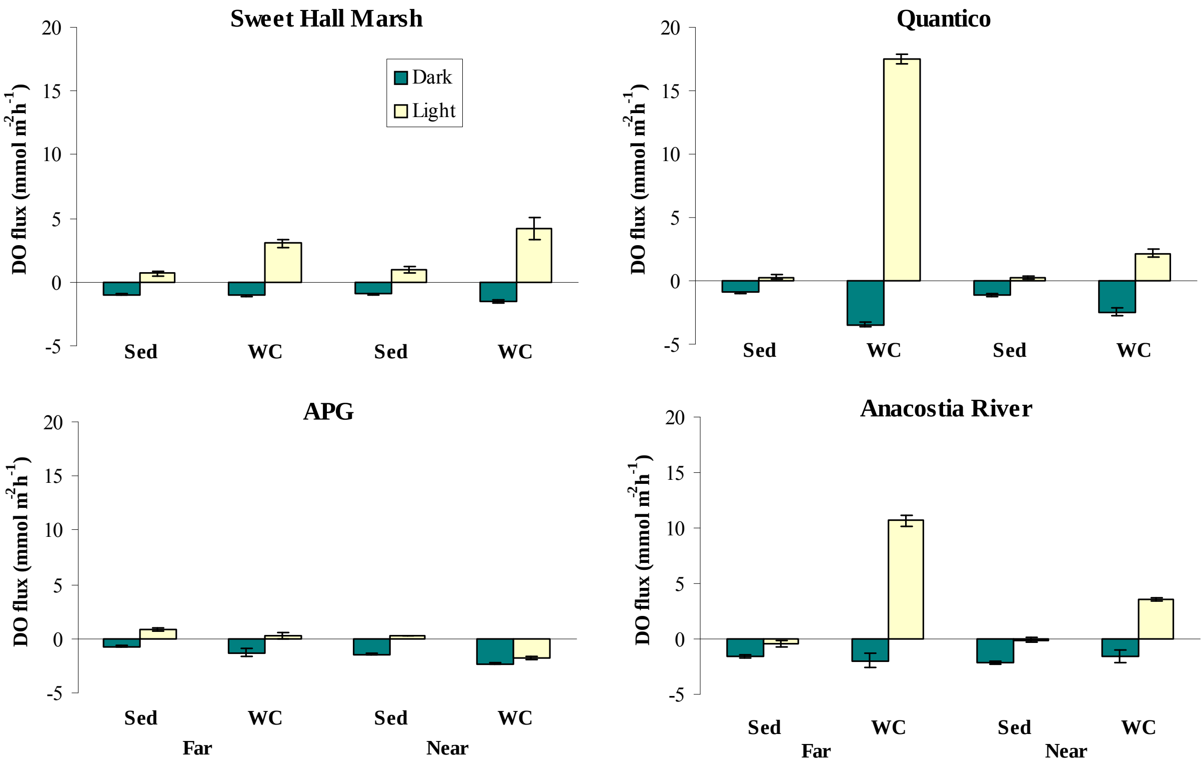


Figure 96. Mean DO fluxes for sediment and water column (WC) at tidal freshwater far- and near-field strata in Sweet Hall Marsh, Quantico, APG, and the Anacostia River. Error bars represent standard errors.

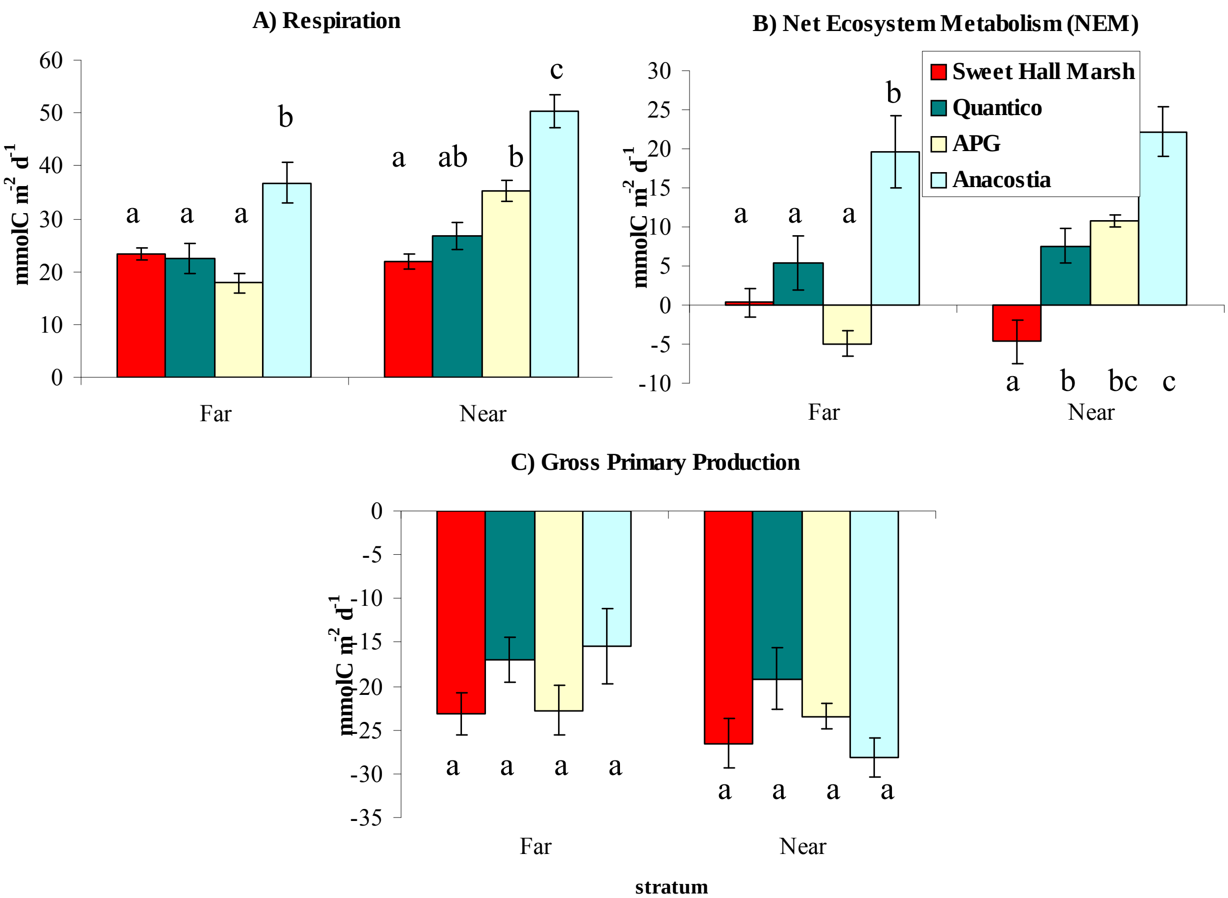


Figure 97. A) Mean sediment respiration, B) mean sediment net ecosystem metabolism, and C) mean sediment gross primary production at tidal freshwater far- and near-field strata in Sweet Hall Marsh, Quantico, APG, and the Anacostia River. Error bars represent standard errors. Different letters within a stratum denote significantly different mean values (Tukey's test, $p<0.05$)

5.6.2 Sediment-Water Nutrient Fluxes – Variability Within Salinity Regimes

The status (condition) of a site, as determined by numerous factors such as organic content, exposure to high nutrient waters, light attenuation, bacterial N-cycling rates, anoxia/hypoxia, and grain size, is likely to play an important role in regulating sediment – water column exchanges of nutrients. At net autotrophic sites with high GPP, benthic microalgal-mediated uptake of nutrients was predicted to result in reduced fluxes from sediments to the water column. This is likely to be especially true of nitrogen, which is often the nutrient that limits both water column and benthic primary production at sites in the lower Chesapeake Bay region, whereas phosphate may limit production in the upper Bay.

In order to better understand the relationship between site condition and nutrient fluxes, we measured sediment – water exchanges of ammonium, nitrate + nitrite (NO_x), and DIP in sediment cores taken from all sites and strata. Upward pointing bars in the figures represent net release of the nutrient from the sediment; downward pointing bars represent net uptake of the nutrient into the sediment. Sediment nutrient fluxes have been corrected for nutrient uptake or release by particulates and phytoplankton in the water column. One-way ANOVA of sediment-water nutrient fluxes within a single stratum and salinity regime were performed to assess site variations (Table 33), followed by Tukey's Test to show differences between means by site. Bars with different letters on Figures 98-100 are significantly different at $p < 0.05$. Additional statistical analyses of daily NH_4^+ flux data were performed by three-way ANOVA to assess the effects of stratum, status, and salinity, as described in section 5.6.3, and by Principal Components Analysis, described in section 5.6.7.

<u>High Mesohaline Sites</u>

During the 2003 study of high mesohaline sites, ammonium fluxes into or out of sediments were negligible and not significantly different at far-field sites, whereas near-field sites at LAFB and Elizabeth River exhibited net uptake of ammonium into sediments (Figure 98-A). Benthic microalgal-mediated uptake likely served as a sink for remineralized nitrogen in these net autotrophic sediments (Figure 98-A). However, at the Thorntons Creek near-field site, where GPP was low relative to the other high mesohaline near-field sites (Figure 93-C), we observed a net flux of NH_4^+ out of the sediment; low ammonium concentrations in the water column may also have been a factor (Table 18). NO_x fluxes were negligible except for the Elizabeth River near-field stations (Figure 98-B), where strong NO_x uptake was likely due to the high concentrations of NO_x in the water column (Table 18). Net DIP release to the water column was observed at all the high mesohaline far- and near-field sites, except for Thorntons far-field site (Figure 98-C).

<u>Low Mesohaline Sites</u>

At the low mesohaline far-field stations, there were strong fluxes of ammonium out of sediments at both PAX and the Pagan River and negligible or weak fluxes into sediments at Monie Bay and Fort Eustis (Figure 99-A). Of the far-field stations studied, net heterotrophic ecosystem metabolism was observed only in the Pagan (Figure 95); thus, one would expect a release of ammonium from the Pagan far-field sediment and uptake at all other stations. The observed release of NH_4^+ out of the sediment at PAX may be explained by the high gross N mineralization observed at this site (data not shown). All near-field station sediments, except for PAX, were net heterotrophic and demonstrated release of ammonium as expected (Figures 95 and 99-A). NO_x fluxes were negligible at all far-field stations except for the net heterotrophic Pagan, which demonstrated net release from sediments (Figure 99-B). For the net autotrophic far-field sites, benthic microalgae likely served to take up NO_x and ammonium, thereby reducing N fluxes out of the sediments. NO_x was released from the net heterotrophic near-field station sediments, except those in the Pagan, which took up NO_x. The uptake of NO_x and concomitant release of ammonium at Pagan suggest the possibility of dissimilatory nitrate reduction to ammonium (DNRA), an anoxic process, which tends to occur when concentrations of labile DOC and nitrate are available. Denitrification was observed at all sites except for PAX far-field and Fort Eustis near-field (Figure 99-D). Fluxes of DIP were either negligible or out of sediments for all sites (Figure 99-C). Highest fluxes were observed from Pagan sediment, likely due to remineralization of organic matter.

Tidal Freshwater Sites

Net daily ammonium fluxes from the tidal freshwater far-field stations were negligible (Figure 100-A). At near-field stations, fluxes were directed out of the sediments and generally increased along a gradient of impairment in response to higher respiration rates (Figures 97-A and 100-A), whereas at the high and low mesohaline sites benthic autotrophy buffered the effects of impairment, reducing or even reversing fluxes of ammonium from sediments to the water column. Uptake of NO_x by the near- and far-field sediments occurred at Anacostia and APG and release was observed only at the least disturbed sites, Sweet Hall and Quantico (Figure 100-B). Denitrification was observed at all far-field sites except for Quantico and at near-field sites only at Sweet Hall (Figure 100-D). Anacostia near-field sediment demonstrated high NOx uptake and concomitant NH_4^+ release suggesting the occurrence of DNRA, a process that competes with denitrification for substrate. Most of the far- and near-field sites had negligible or uptake of DIP, except Sweet Hall far-field sediments (Figure 100-C). Phosphate tends to be bound tightly to particulates, especially in tidal freshwater, iron-rich, oxic sites. It may be released in anoxic sediments.

Table 33. One-way ANOVA of sediment-water nutrient fluxes for each salinity regime and stratum.

High Mesohaline Sites	source of variation	Far-field df	ms	F	p	source of variation	Near-field df	ms	F	p
Daily NH_4^+ flux	site	2	0.043	0.026	0.97	site	2	53.40	49.96	<0.001
	error	22				error	22			
	total	24				total	24			
Daily NOx flux	site	2	0.40	2.22	0.13	site	2	4.16	41.12	<0.001
	error	22				error	22			
	total	24				total	24			
Daily PO_4^{3-} flux	site	2	0.032	2.69	0.09	site	2	0.00017	0.037	0.96
	error	19				error	22			
	total	21				total	24			
Dark N_2 flux	site	2	108106.9	12.12	<0.001	site	2	10495.06	0.87	0.43
	error	22				error	23			
	total	24				total	25			

Low Mesohaline Sites	source of variation	Far-field df	ms	F	p	source of variation	Near-field df	ms	F	p
Daily NH_4^+ flux	site	3	29.61	27.47	<0.001	site	3	10.90	9.72	<0.001
	error	32				error	32			
	total	35				total	35			
Daily NOx flux	site	3	0.186	33.37	<0.001	site	3	1.34	230.74	<0.001
	error	31				error	32			
	total	34				total	35			
Daily PO_4^{3-} flux	site	3	0.055	79.59	<0.001	site	3	0.091	9.63	<0.001
	error	32				error	31			
	total	35				total	34			
Dark N_2 flux	site	3	88457.9	3.07	0.04	site	3	65689.9	5.40	0.004
	error	27				error	32			
	total	30				total	35			

Tidal Fresh Sites	source of variation	Far-field df	ms	F	p	source of variation	Near-field df	ms	F	p
Daily NH_4^+ flux	site	3	2.02	1.27	0.31	site	3	34.87	16.53	<0.001
	error	26				error	25			
	total	29				total	28			
Daily NOx flux	site	3	1.12	2.17	0.12	site	3	18.32	70.49	<0.001
	error	26				error	25			
	total	29				total	28			
Daily PO_4^{3-} flux	site	3	0.003	7.36	0.001	site	3	0.029	8.33	<0.001
	error	26				error	25			
	total	29				total	28			
Dark N_2 flux	site	3	52125.9	9.52	<0.001	site	3	58702.4	8.11	<0.001
	error	27				error	24			
	total	30				total	27			

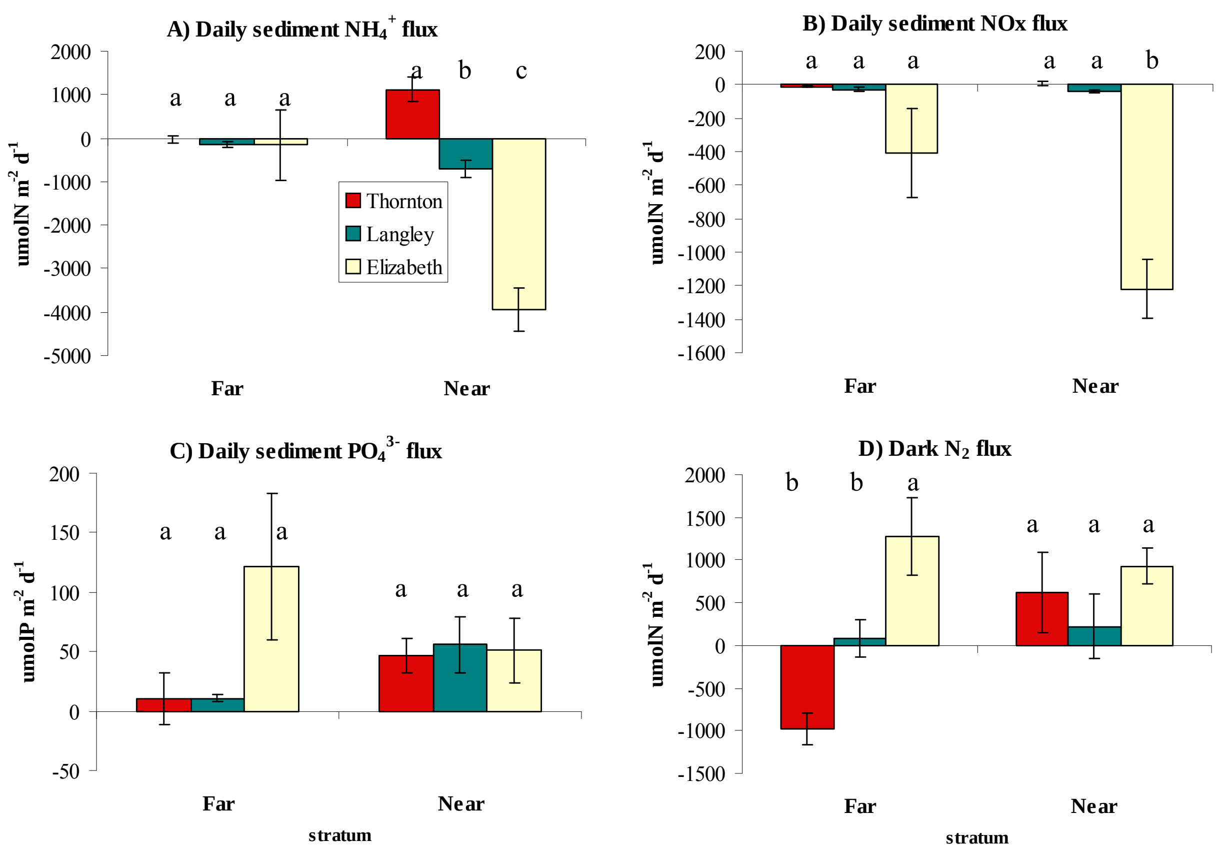


Figure 98. Mean daily sediment A) NH_4^+ flux, B) NO_X flux, and C) PO_4^{3-} and D) dark N_2 flux at high mesohaline far- and near-field strata in Thorntons Creek, Langley AFB, and Elizabeth River. Error bars represent standard errors. Different letters within a stratum denote significantly different mean values (Tukey's test, $p<0.05$)

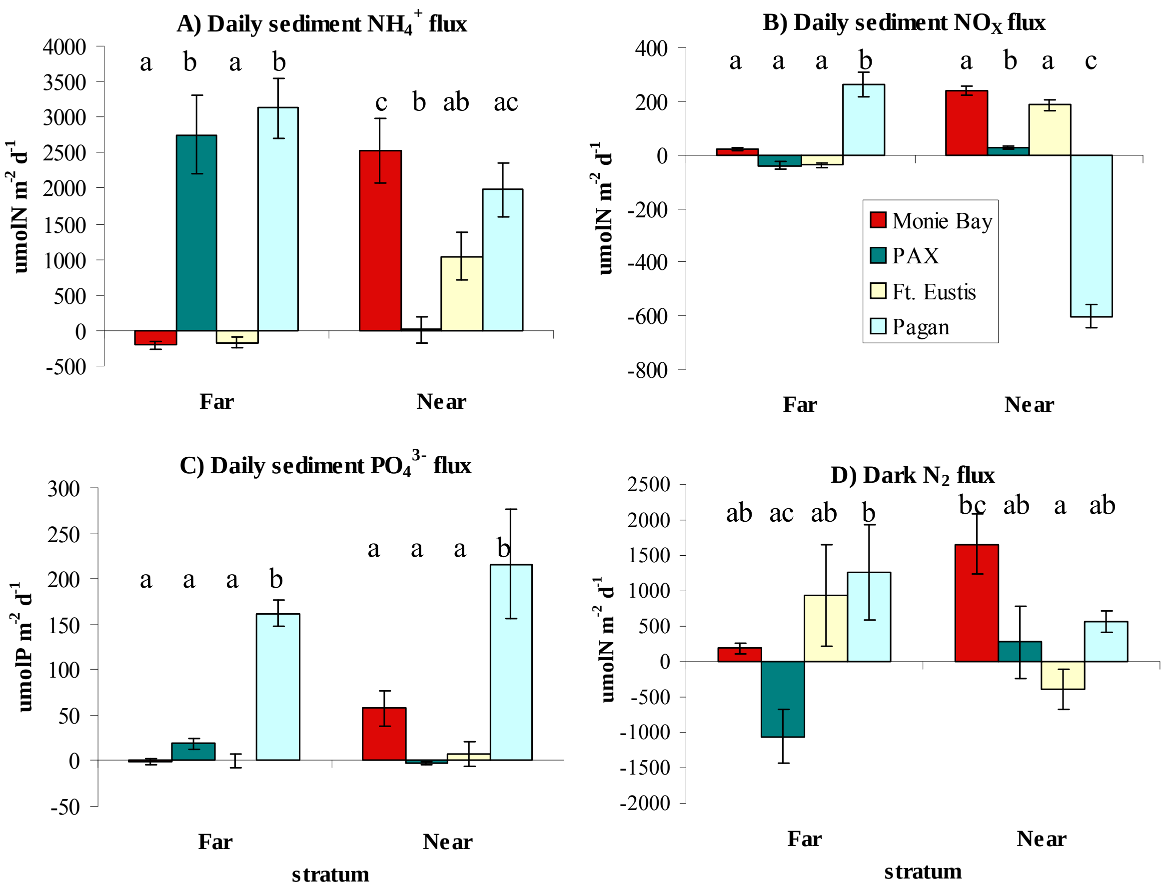


Figure 99. Mean daily sediment A) NH_4^+ flux, B) NO_X flux, and C) PO_4^{3-} and D) dark N_2 flux at low mesohaline far- and near-field strata in Monie Bay, PAX, Fort Eustis, and the Pagan River. Error bars represent standard errors. Different letters within a stratum denote significantly different mean values (Tukey's test, $p<0.05$)

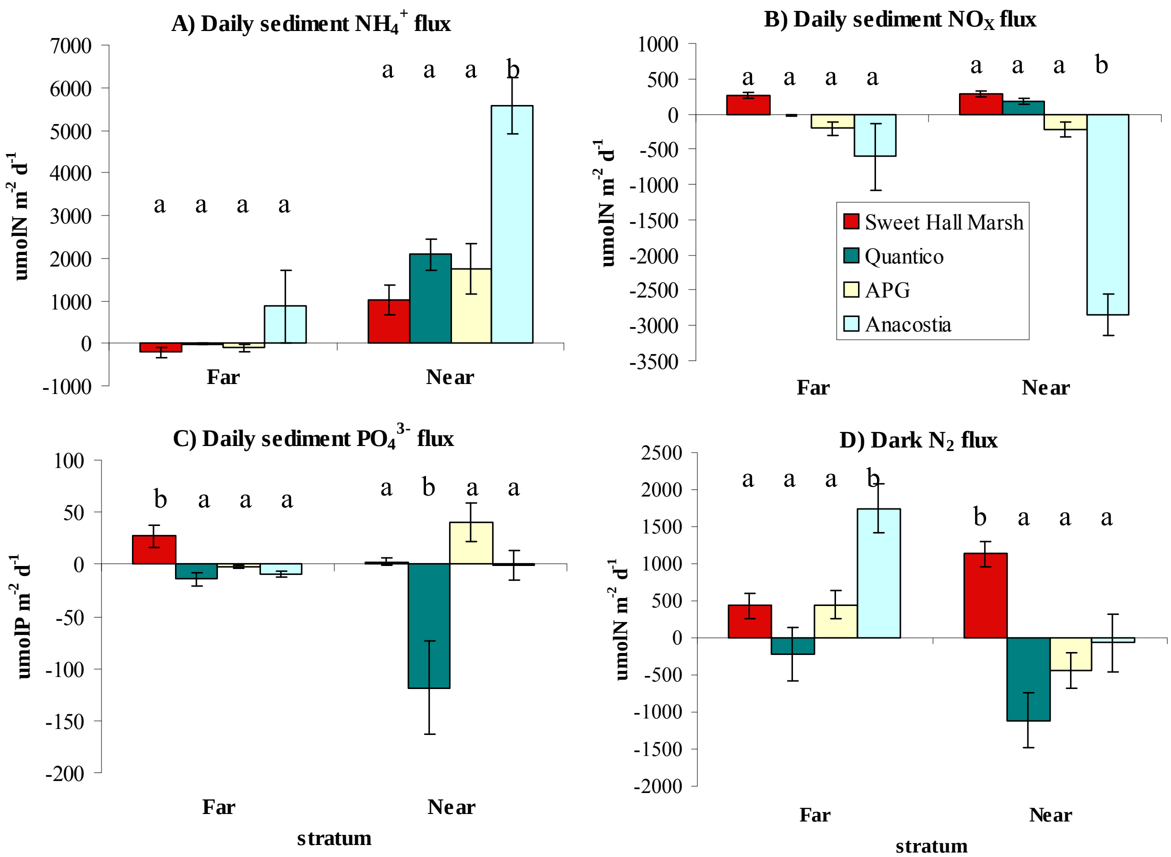


Figure 100. Mean daily sediment A) NH_4^+ flux, B) NO_X flux, and C) PO_4^{3-} and D) dark N_2 flux at tidal freshwater far- and near-field strata in Sweet Hall Marsh, Quantico, APG, and the Anacostia River. Error bars represent standard errors. Different letters within a stratum denote significantly different mean values (Tukey's test, $p<0.05$)

5.6.3 The Role of Site Condition, Stratum, and Salinity in Regulation of Ecosystem Function

We used three-way ANOVA to examine the main effects of stratum (near-field mud, far-field sand), status (reference, unclassified, degraded), and salinity regime (high mesohaline, low mesohaline, tidal freshwater) on ecosystem process rates of benthic GPP, R, NEM, P/R, mineralization, and daily ammonium flux. We ran Least Squares Means post-hoc analyses to examine differences of significant main effects and two-way interaction effects. Differences were significant at $p<0.05$.

We hypothesized that within each salinity regime, **benthic GPP** would be highest (most autotrophic, lowest values) at sites with unclassified condition and lowest at degraded sites (unclassified>reference>degraded). The patterns we observed for main effects were for the most part consistent with our initial hypotheses (Table 34, Figure 101). Near-field sites had significantly higher mean GPP than far-field sites. Reference and unclassified condition sites had higher mean GPP than sites with degraded status (reference=unclassified>degraded). There were significant differences among sites based on salinity regime (high mesohaline>tidal fresh>low mesohaline).

The interaction of main effects **stratum and status** was significant ($F = 13.5$, $p <0.0001$). For the far-field stratum, reference and unclassified condition sites were significantly greater than degraded sites (reference=unclassified>degraded). For the near-field stratum there were significant differences between unclassified and reference sites (unclassified>reference). For reference sites, the mean GPP was significantly greater at far-field sites, but for degraded sites, mean GPP was significantly greater at near-field sites. Far-field and near-field sites with unclassified status were not significantly different. The low light attenuation coefficient observed at the Elizabeth River and PAX near-field sites relative to other sites in their same stratum and salinity regime likely influenced the high GPP observed at these sites (Table 18).

The interaction of main effects **status and salinity** was significant ($F = 11.47$, $p < 0.0001$). Within the high mesohaline and tidal freshwater salinity regimes, mean GPP was not significantly different by status. However for the low mesohaline sites, status was significant (unclassified>reference>degraded). When sites were classified by status, salinity regime was important with mean GPP highest at the high mesohaline sites for all conditions, but the rank order of GPP was different for the other salinity regimes: reference (high mesohaline>low mesohaline=tidal fresh); unclassified (high mesohaline>low mesohaline>tidal fresh); degraded (high mesohaline>tidal fresh>low mesohaline). These results suggest that sites in the lower estuary experience conditions, such as greater light availability, that promote benthic microalgal production.

The interaction of main effects **stratum and salinity** was not significant.

For **benthic respiration**, all main effects were significant (table 34; Figure 102). Near-field sites had significantly higher mean respiration rates than far-field sites, as expected due to

Table 34. Summary of the three-way ANOVAs of ecosystem process rates with the parameter evaluated, number of samples (n), model p-value, model r2, the F-statistic and degrees of freedom (model, error), the probability for each of the main effects, significant interactions terms, the least square means contrasts for the main effects. Least squares means are arranged left to right for highest to lowest. Similarity of least squares mean values for stratum, status and salinity occur when values co-occur in the same row. The following parameters were transformed: GPP: ln (-GPP+2); P/R: ln(P/R+1); mineralization: sqrt(mineralization). **FF** = far-field, **NF** = near-field, **R** = reference, **U** = unclassified, **D** = degraded, **HM** = high-mesohaline, **LM** = low-mesohaline, **TF** = tidal freshwater.

parameter	n	model p-value	model R^2	F	df	stratum p-value	status p-value	salinity p-value	significant interactions	stratum effect	status effect	salinity regime effect
Benthic GPP	181	<0.0001	0.636	16.8	17, 163	0.048	<0.0001	<0.0001	stratum*status	Near	U R	HM
									salinity*status	Far	D	TF
									stratum*status*salinity			LM
Benthic Respiration	183	<0.0001	0.364	5.56	17, 165	0.006	<0.0001	0.018	salinity*status	Near	D	HM TF
										Far	U	LM
											R	
Benthic NEM	181	<0.0001	0.755	29.5	17, 163	0.639	<0.0001	<0.0001	all	Near Far	D	TF
											R U	LM
												HM
Benthic P/R	181	<0.0001	0.751	29	17, 163	0.038	<0.0001	<0.0001	stratum*status	Far	R U	HM
									salinity*status	Near	D	LM TF
									stratum*status*salinity			
Benthic Mineralization	161	<0.0001	0.33	4.15	17, 140	<0.0001	0.85	0.015	stratum*salinity	Near	R U D	TF
									stratum*status	Far		HM LM
Sediment Daily NH_4^+ flux	181	<0.0001	0.686	21	17, 163	0.002	0.0045	<0.0001	all	Near	D	LM TF
										Far	R U	HM

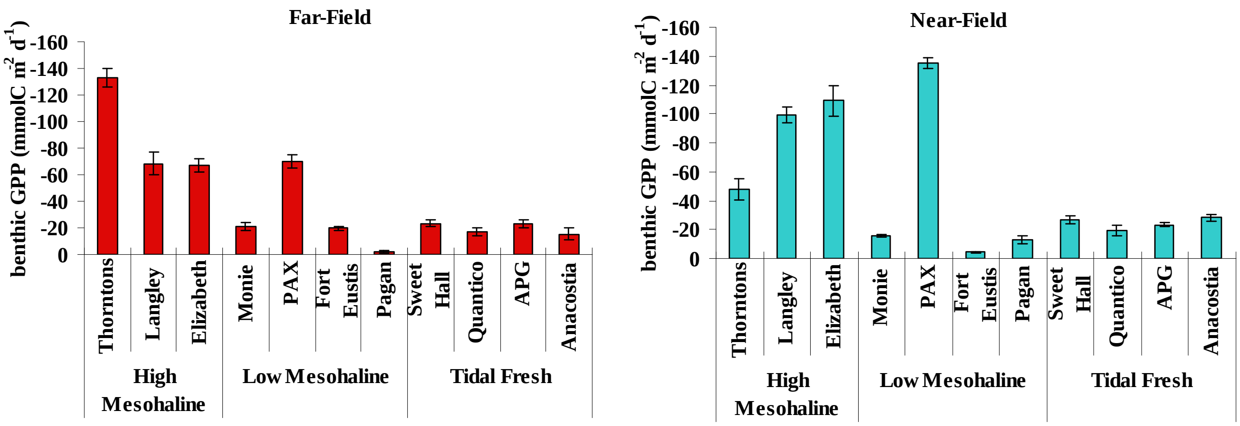


Figure 101. Benthic gross primary production (GPP) ratio for far- and near-field strata by salinity regimes. Note that the y-axis scale is reversed. Sites within a salinity regime are arrayed by increasing disturbance from left to right (Mean ± SE).

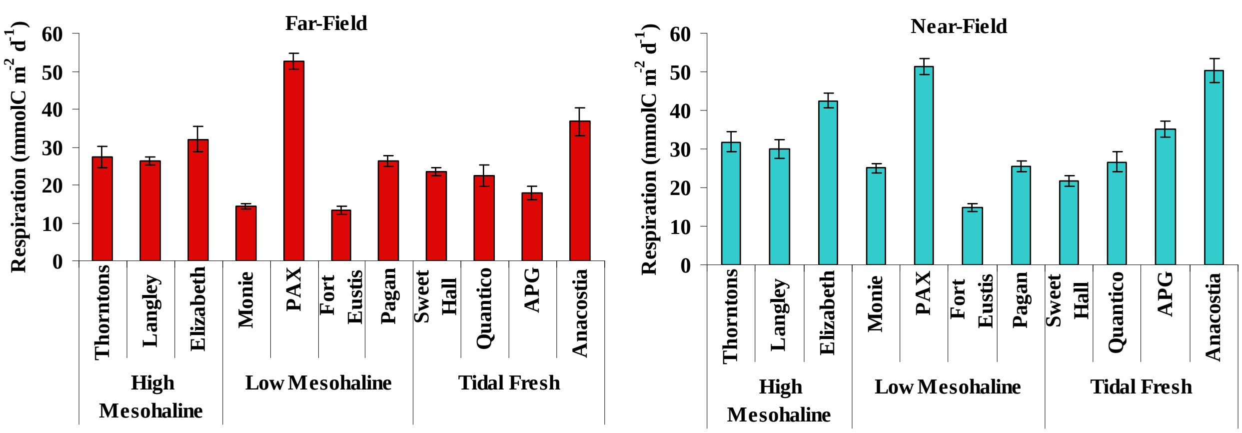


Figure 102. Benthic respiration for far- and near-field strata by salinity regimes. Sites within a salinity regime are arrayed by increasing disturbance from left to right (Mean ± SE).

the greater organic matter content in near-field sediments. Sites of different status had significantly different respiration rates (degraded>unclassified>reference). Respiration was significantly greater at high mesohaline and tidal freshwater sites relative to low mesohaline sites (high mesohaline=tidal freshwater>low mesohaline).

The interactions of main effects (1) **stratum and salinity** and (2) **stratum and status** were not significant.

The interaction of main effects **status and salinity** was significant ($F = 8.94$, $p < 0.0001$). Within the high mesohaline and tidal freshwater salinity regimes, mean respiration was higher at degraded relative to reference and unclassified condition sites (degraded>reference=unclassified). However for the low mesohaline salinity regime, unclassified sites were significantly greater than reference and degraded sites (unclassified>reference=degraded). When sites were classified by status, salinity regime was important, but the rank order of respiration was different for each salinity regime: reference (high mesohaline>low mesohaline); unclassified (low mesohaline>tidal fresh); degraded (low mesohaline>high mesohaline=tidal fresh).

As shown in Figure 2, we had hypothesized that net primary production (NPP) would track with GPP. For this analysis, however, we deemed NEM a more appropriate metric since it includes process rates measured on a 24-hour rather than 12-hour time scale. We hypothesized that within a salinity regime, **benthic NEM** would be highest (most heterotrophic) at degraded sites relative to unclassified condition and reference sites (degraded>reference=unclassified). The patterns we observed for main effects were consistent with our initial hypotheses (Table 34; Figure 103). Status and salinity regime effects were significant. NEM was not significantly different at near-field and far-field sites. Degraded sites had higher mean NEM than sites with reference and unclassified status (degraded>reference=unclassified). There were significant differences among sites based on salinity regime (tidal fresh>low mesohaline>high mesohaline), indicating greater benthic heterotrophy in the upper estuary, as one might expect given the higher light attenuation, and both sediment and water column nutrient enrichment in the tidal freshwater areas of the Chesapeake Bay.

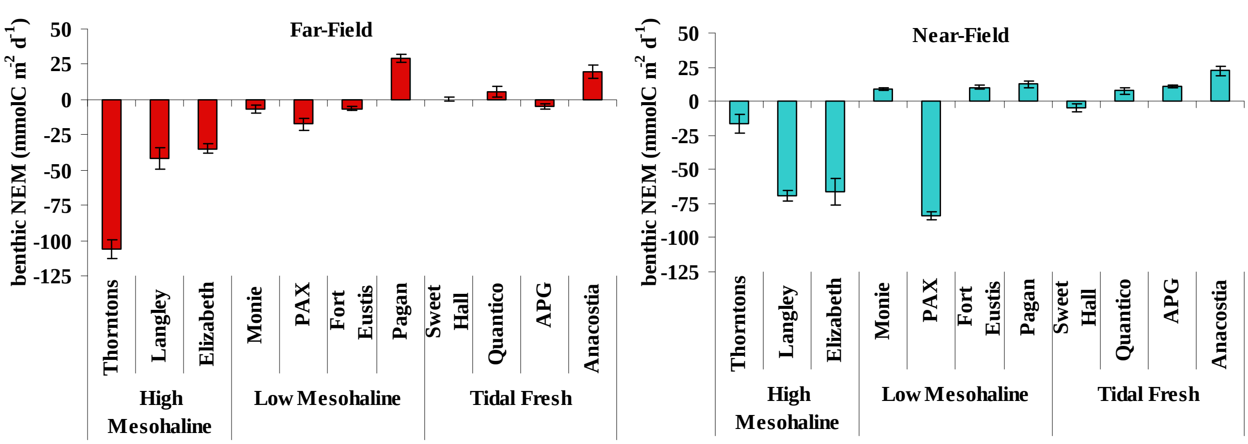


Figure 103. Benthic net ecosystem metabolism (NEM) for far- and near-field strata by salinity regimes. Sites within a salinity regime are arrayed by increasing disturbance from left to right (Mean ± SE).

The interaction of main effects **stratum and status** was significant (F = 25.85, p <0.0001). For the far-field stratum, sites of different status had significantly different NEM (degraded>unclassified>reference). For the near-field stratum, NEM at reference and degraded sites were significantly greater than at unclassified condition sites (reference=degraded >unclassified). For degraded and unclassified condition sites, the mean NEM was significantly greater at far-field sites, but for reference sites, mean NEM was significantly greater at near-field sites.

The interaction of main effects **status and salinity** was significant (F = 7.73, p < 0.0001). Within the high mesohaline salinity regime, mean NEM was not significantly different by status. However for the low mesohaline sites, status was significant (degraded>reference>unclassified). For the tidal freshwater sites, mean NEM was higher at degraded sites relative to reference and unclassified condition sites (degraded>reference=unclassified). Status had significant effects on NEM within each salinity regime: reference and degraded (low mesohaline, tidal fresh>high mesohaline); unclassified (tidal fresh>low mesohaline>high mesohaline).

The interaction of main effects **stratum and salinity** was significant (F = 3.14, p=0.046). When sites were classified by stratum, salinity regime was important, but the rank order of NEM was slightly different for each stratum: far-field (tidal fresh=low mesohaline>high mesohaline); near-field (tidal fresh>low mesohaline>high mesohaline). When sites were classified by salinity regime, NEM was not significantly different at far- and near-field sites.

We hypothesized that within a salinity regime, **benthic P/R ratio** would be highest (most autotrophic, P/R>1) at unclassified condition sites and lowest at degraded sites (P/R <1) (unclassified>reference>degraded). The patterns we observed for main effects were largely consistent with our initial hypotheses (Table 34, Figure 104). All main effects were significant. Far-field sites had significantly higher mean P/R than near-field sites. Reference and

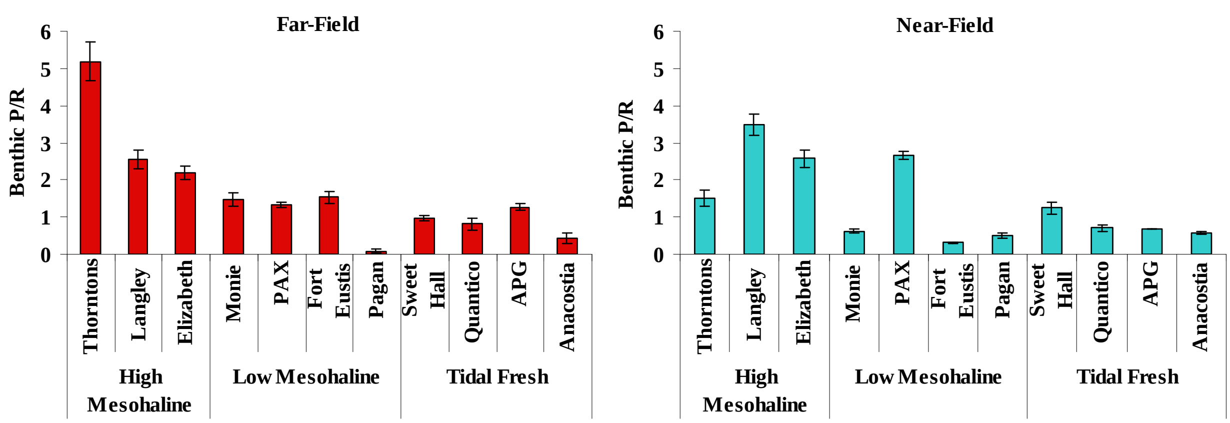


Figure 104. Benthic gross primary production/respiration (P/R) ratio for far- and near-field strata by salinity regimes. Sites within a salinity regime are arrayed by increasing disturbance from left to right (Mean ± SE).

unclassified condition sites had higher mean P/R than sites with degraded status (reference= unclassified>degraded). P/R was significantly greater at high mesohaline sites relative to both low mesohaline and tidal freshwater sites (high mesohaline>low mesohaline=tidal fresh), indicating net autotrophic conditions in the lower estuary.

The interaction of main effects **stratum and status** was significant (F = 19.25, p <0.0001). For the far-field stratum, sites of different status had significantly different P/R values (reference>unclassified>degraded). For the near-field stratum, P/R at sites with unclassified condition was significantly greater than at reference and degraded sites (unclassified>reference=degraded). Status had significant effects on P/R within each stratum for reference (far>near) and degraded (near>far) sites. P/R was not significantly different by stratum for unclassified condition sites.

The interaction of main effects **status and salinity** was significant (F = 5.86, p=0.0002). For all salinity regimes, degraded sites had the lowest mean P/R, but the ranking of reference and unclassified sites varied by salinity regimes: high mesohaline (unclassified>degraded); low mesohaline (unclassified>reference>degraded); tidal freshwater (unclassified=reference>degraded). Status had significant effects on P/R within each salinity regime: reference and degraded (high mesohaline>low mesohaline=tidal fresh); unclassified (high mesohaline>unclassified>tidal fresh).

The interaction of main effects **stratum and salinity** was not significant.

We hypothesized that within a salinity regime, **benthic mineralization** would be highest at degraded sites (degraded>reference=unclassified). The patterns we observed for main effects were not consistent with our initial hypotheses (Table 34, Figure 105). Main effects were significant for stratum and salinity but not for status. Near-field sites had significantly higher mean mineralization rates than did far-field sites. Mineralization was significantly greater at

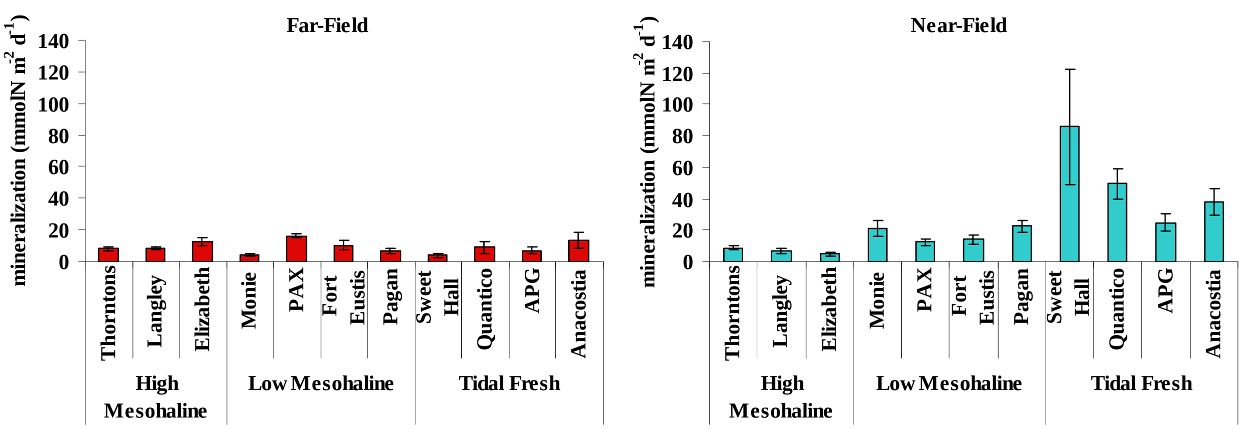


Figure 105. Benthic gross mineralization for far- and near-field strata by salinity regimes. Sites within a salinity regime are arrayed by increasing disturbance from left to right (Mean ± SE).

tidal freshwater sites relative to both low and high mesohaline sites (tidal fresh>low mesohaline=high mesohaline); thus, it appears that mineralization was affected mainly by sediment organic content and nitrogen enrichment, both of which were higher in near-field than in far-field sites and somewhat higher in tidal freshwater than in other salinity regimes.

The interaction of main effects **stratum and status** was significant (F = 3.20, p=0.044). For the far-field stratum, status was not important, but for the near-field stratum, mineralization rates were significantly greater at reference than unclassified condition sites (reference>unclassified). For degraded and reference sites, mineralization was higher in near-field than far-field strata. Mineralization was not significantly different by stratum for unclassified condition sites.

The interaction of main effects **status and salinity** was not significant.

The interaction of main effects **stratum and salinity** was significant (F = 15.59, p<0.0001). When sites were classified by stratum, salinity regime was not important for mineralization at far-field sites, but was important at near-field sites (tidal fresh>low mesohaline>high mesohaline). Within the low mesohaline and tidal freshwater salinity regimes, mean mineralization rates were higher at near-field than far-field sites (near>far). Mineralization was not significantly different by stratum in the high mesohaline salinity regime.

We hypothesized that within a salinity regime, **daily sediment NH_4^+ flux** would be lowest (flux into sediment, negative values) at unclassified condition sites and highest (flux out of the sediment, positive values) at degraded sites (degraded>reference>unclassified). In addition, we expected that NH_4^+ uptake would be highest at those sites where GPP and P/R were highest. The patterns we observed for main effects were generally consistent with our initial hypotheses (Table 34, Figure 106). All main effects were significant. Near-field sites, which are more likely to have P/R < 1, had significantly higher mean NH_4^+ fluxes than far-field sites.

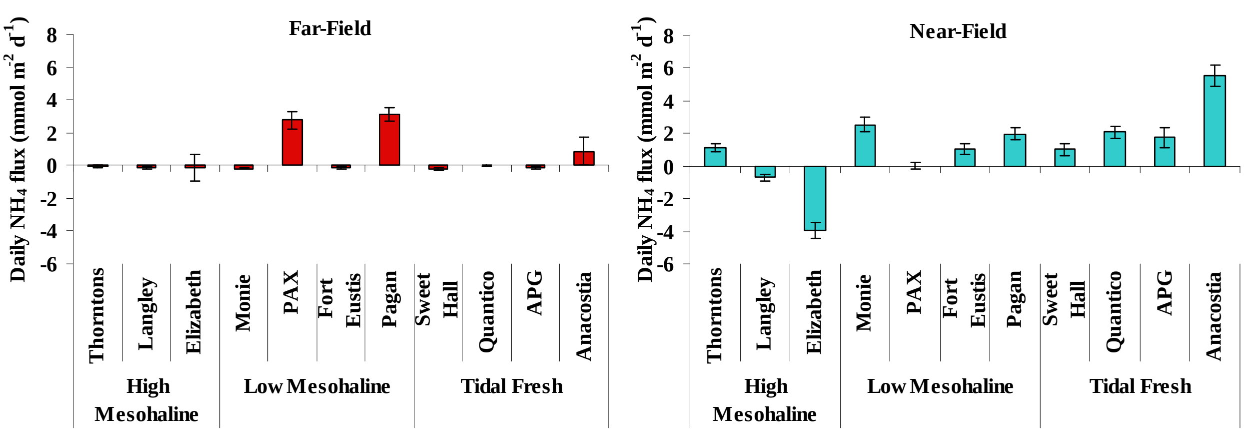


Figure 106. Daily NH_4^+ flux for far- and near-field strata by salinity regimes. Sites within a salinity regime are arrayed by increasing disturbance from left to right (Mean ± SE).

Degraded sites had higher mean NH_4^+ fluxes than reference and unclassified condition sites (degraded> reference=unclassified). NH_4^+ fluxes were significantly greater at both low mesohaline and tidal freshwater sites relative to high mesohaline sites (low mesohaline=tidal fresh>high mesohaline). High mesohaline sites generally have higher P/R values than low mesohaline and tidal freshwater sites.

The interaction of main effects **stratum and status** was significant ($F = 7.10$, $p=0.001$). For the far-field stratum, degraded sites had significantly greater NH_4^+ fluxes than reference and unclassified condition sites (degraded>reference=unclassified), whereas for the near-field stratum, reference sites had greater NH_4^+ fluxes than unclassified condition sites (reference>unclassified). For reference sites, NH_4^+ fluxes were higher in the near-field stratum than far-field stratum (near>far). NH_4^+ fluxes were not significantly different by stratum for degraded and unclassified condition sites.

The interaction of main effects **status and salinity** was significant ($F = 21.93$, $p < 0.0001$). Salinity had significant effects on NH_4^+ flux by status: high mesohaline (reference>unclassified>degraded); low mesohaline and tidal freshwater (degraded>reference=unclassified). For degraded and unclassified condition sites, NH_4^+ fluxes were higher in both tidal freshwater and low mesohaline sites than in high mesohaline sites (tidal fresh=low mesohaline>high mesohaline). For reference sites, there were no significant differences by salinity regime.

The interaction of main effects **stratum and salinity** was significant ($F = 28.84$, $p<0.0001$). When sites were classified by stratum, salinity regime was important, but the rank order of NH_4^+ flux was different for each stratum: far-field (low mesohaline>high mesohaline=tidal fresh); near-field (tidal fresh>low mesohaline>high mesohaline). Salinity had significant effects on NH_4^+ flux by stratum: high mesohaline (far>near); tidal freshwater (near>far). For low mesohaline sites, NH_4^+ flux was not significantly different at far- and near-field sites.

5.6.4 The Role of Benthic Autotrophy in Modulating Responses to Site Impairment

At sites across the Chesapeake Bay estuarine gradient 91% of the variation observed in benthic NEM was explained by benthic GPP (Figure 107). The majority of high and low mesohaline benthic sites studied in 2003 and 2004 were net autotrophic. The strong relationship observed between GPP and NEM, regardless of site condition and salinity, demonstrates that primary production by benthic microalgae was the predominant driver of NEM in these shallow water systems.

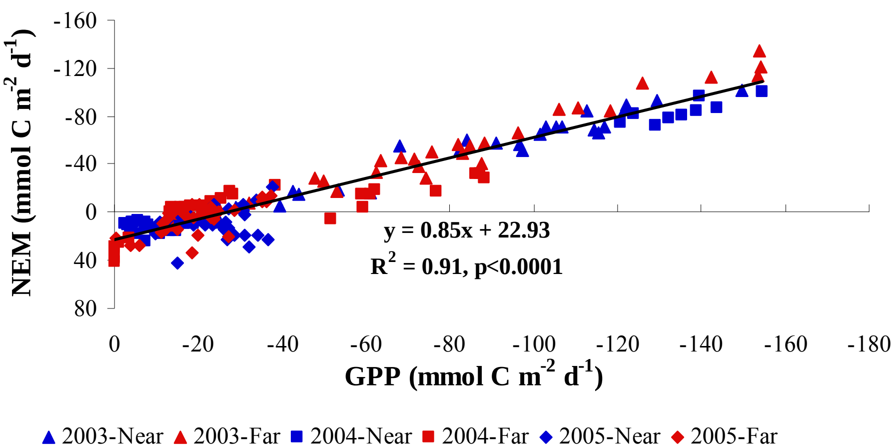


Figure 107. Linear regression of benthic net ecosystem metabolism (NEM) vs. gross primary production (GPP) for all sites (2003=high mesohaline, 2004=low mesohaline, 2005=tidal freshwater sites).

The ratio of benthic production to respiration (P/R), in which values greater than 1 indicate net autotrophy and values less than one indicate net heterotrophy, varied across both the entire estuarine salinity gradient as well as along gradients of impairment within a salinity regime. As shown in Figure 104, there was a trend of decreasing P/R with salinity along the Chesapeake Bay estuarine gradient. P/R also tended to decline with increasing site impairment at far-field high mesohaline sites and at near-field tidal freshwater sites. The trend is not clear in other segments of the salinity gradient. Decreasing P/R, thus greater heterotrophy, has implications with regard to the development of sediment hypoxia/anoxia, accumulation of sediment organic matter, fate of sediment nitrogen, and sediment – water exchanges of nitrogen.

Relationships between GPP, NEM, and respiration observed at tidal freshwater sites in 2005 showed a strong departure from those observed at low and high mesohaline sites. NEM was closely related to respiration at both far and near-field sites (Figure 108). Nearly all of the tidal freshwater sites were net heterotrophic. In most cases net heterotrophic sediments are a source of ammonium to the water column. The daily ammonium flux from sediments to the overlying water column increased as a function of R at net heterotrophic, tidal freshwater sites (Figure 109).

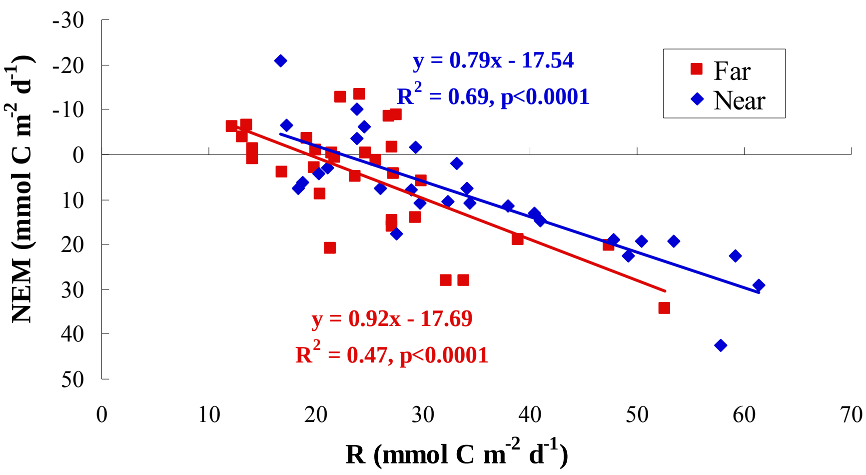


Figure 108. Regression relationship of benthic net ecosystem metabolism (NEM) vs. respiration (R) by far- and near-field stations for tidal freshwater sites.

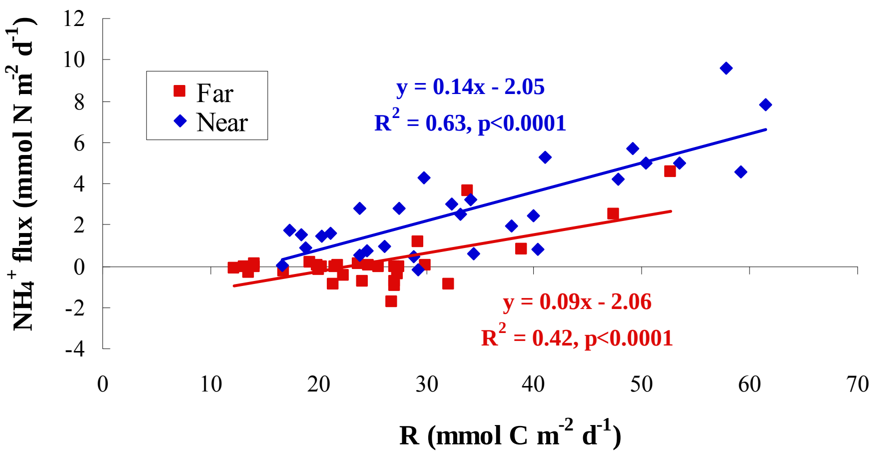


Figure 109. Linear regression of daily NH_4^+ flux vs. benthic respiration (R) for far- and near-field stations of tidal freshwater sites.

These results support other observations that benthic microalgae do not play as important a role in buffering site condition at tidal freshwater sites as compared to low and high mesohaline sites.

The role of benthic microalgal-mediated uptake in modulating sediment – water NH_4^+ fluxes is evident in Figure 110, which demonstrates reduced fluxes or uptake in the light compared to the dark at virtually all sites, regardless of condition.

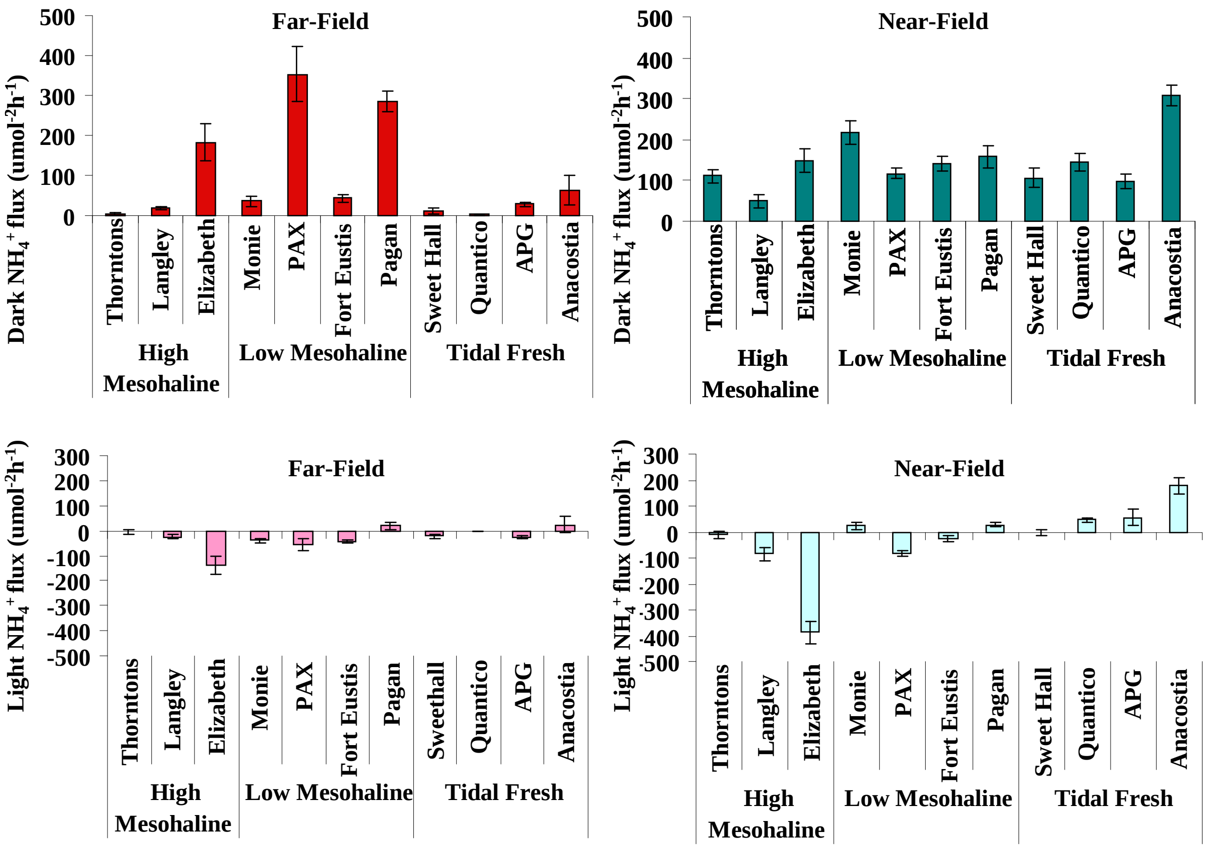


Figure 110. Dark and light NH_4^+ fluxes for far- and near-field strata by salinity regime. Sites within a salinity regime are arrayed by increasing disturbance from left to right (mean ± SE).

The shift from net benthic autotrophy to net heterotrophy and the resulting switch from ammonium uptake to release along the estuarine salinity gradient is well illustrated in Figure 111, which plots sediment ammonium flux vs. the P/R ratio for sites within each salinity regime. Points to the right of the y-axis represent net autotrophic sediments and those to the left net heterotrophic sediments. Points above the x-axis represent ammonium release and those below the axis ammonium uptake. Most sediments at the 2003 high mesohaline sites were net autotrophic and took up ammonium. Stations at the 2004 low mesohaline sites included a mix of net autotrophic and net heterotrophic sediments, some of which took up ammonium whereas others released ammonium. At the 2005 tidal freshwater sites most sediments were net heterotrophic and released ammonium.

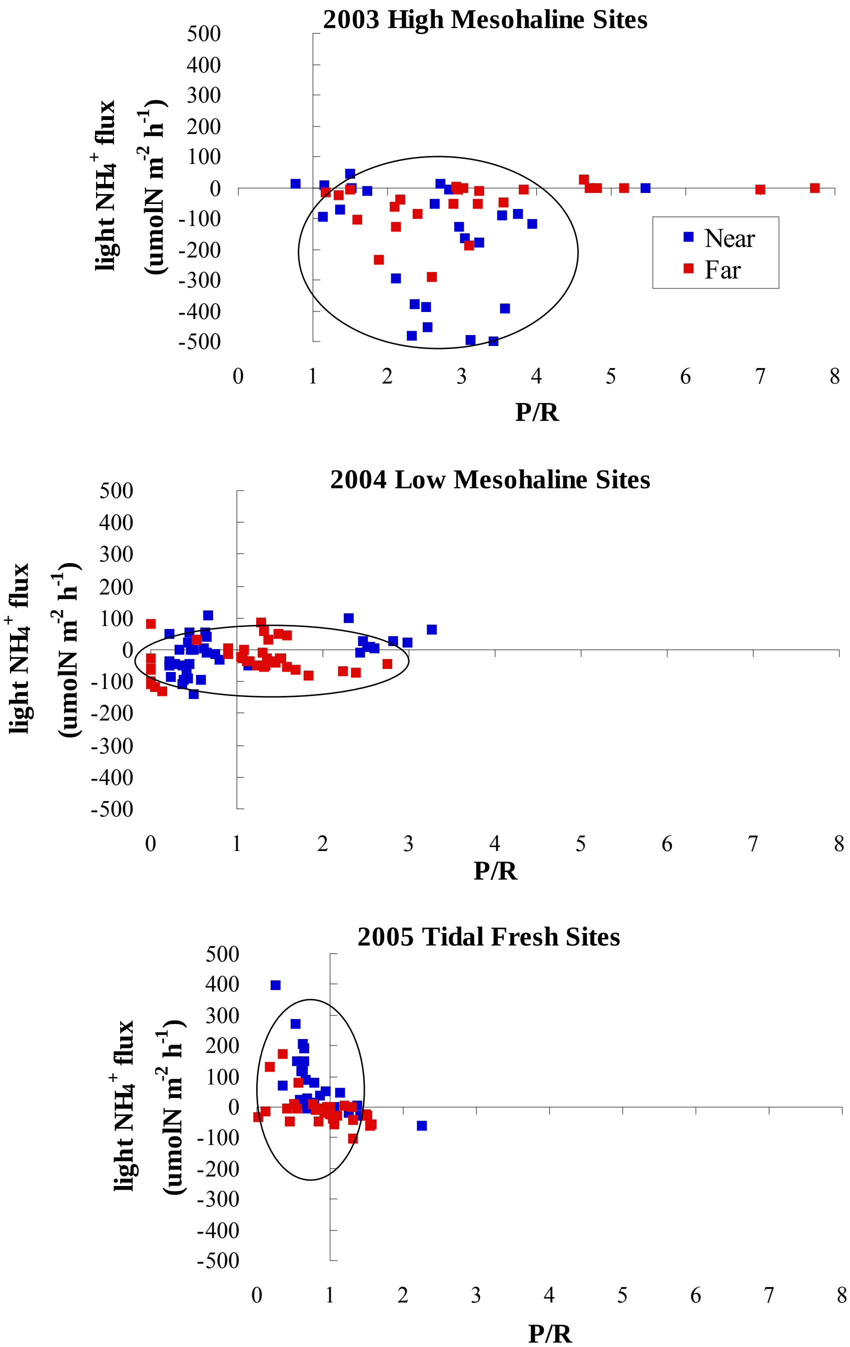


Figure 111. Light NH_4^+ flux vs. benthic production: respiration (P/R) ratio for each salinity regime.

Another example demonstrating the ability of benthic autotrophy to buffer the effects of site impairment is evident in Figure 112, which show variations in benthic GPP and ammonium flux at high mesohaline sites studied in 2003 and at tidal freshwater sites studied in 2005. Along the impairment gradient at the high mesohaline 2003 sites, GPP increased with a corresponding increase in sediment ammonium uptake, whereas at the tidal freshwater 2005 sites, benthic microalgae were not as effective and ammonium fluxes to the water column tended to increase along the impairment gradient. Thus, although numerous factors indicate that the Elizabeth River is highly impaired, its benthos continues to contribute ecosystem service by removing ammonium from the water column due to high rates of benthic gross primary production. Net heterotrophic sediments, such as those found in the Anacostia River, which are not buffered by the activities of benthic microalgae, do not contribute such services to the ecosystem.

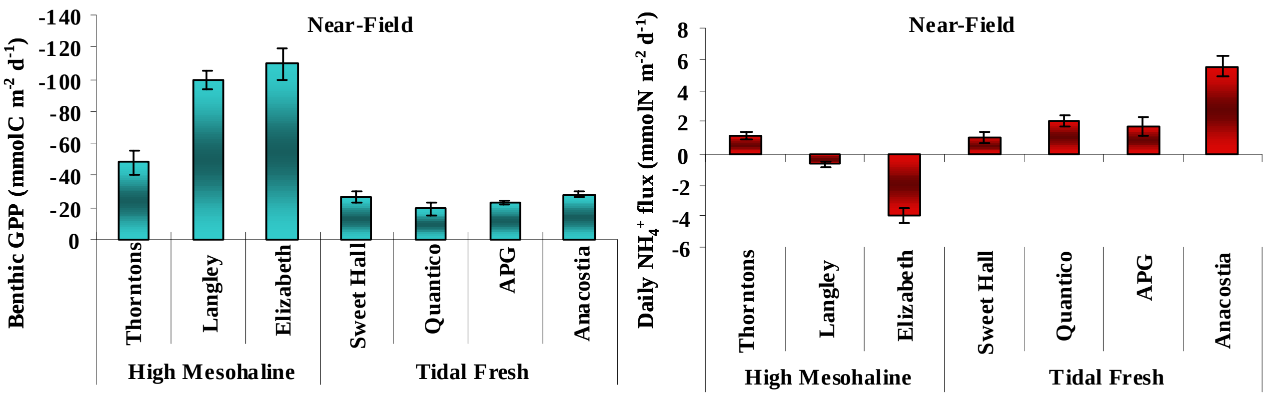


Figure 112. Benthic gross primary production (GPP) and daily NH_4^+ fluxes for near-field sites by high mesohaline and tidal freshwater salinity regimes. Sites within a salinity regime are arrayed by increasing disturbance from left to right (mean ± SE).

5.6.5 Nitrogen Cycling Across Disturbance Gradients

Nitrogen cycling processes are likely to be impacted by site condition and play an important role in determining the fate of nitrogen, either taken up from the water column or produced within the sediments by mineralization of organic matter. A mass balance analysis was performed of measured nitrogen cycling processes, which are sources or sinks of inorganic nitrogen in the benthos. Processes, which contribute inorganic nitrogen, include nitrogen fixation, organic matter mineralization, and DIN flux from the water column; removal processes include denitrification, autotrophic nitrogen demand (by benthic microalgae), and flux to the water column. Figure 113 compares sources and sinks of DIN at near-field sites located both along the estuarine salinity gradient and along gradients of impairment within the same salinity regime. Whereas the sum of DIN sources balanced the sum of sinks in the high mesohaline sites, the magnitude of the sources relative to the sinks became increasingly unbalanced at the low mesohaline and tidal freshwater sites. This was especially true at the tidal freshwater sites, which demonstrated very high rates of gross nitrogen mineralization relative to rates of other nitrogen cycling processes. Although the tidal freshwater sites all demonstrated higher rates of ammonium flux from sediments to the water column when compared to the high and low mesohaline sites, losses of ammonium to the water column were not sufficient to balance the production by mineralization. Nor was denitrification a sink for DIN at the tidal freshwater sites. In fact, in tidal freshwater sediments from the Anacostia River, nitrate was removed from the water column and transformed to ammonium (Figure 114), most likely by dissimilatory nitrate reduction to ammonium (DNRA), a process that we did not measure. DNRA tends to conserve inorganic nitrogen in sediments and is common in anoxic, organic enriched sediment, such as found in intertidal marshes. Heterotrophic microbial processes, thus, contribute to the high sediment ammonium and to the accretion of organic matter that occurs in tidal freshwater sediments (Figures 46, 47). Although a trend of increasing enrichment of sediment nitrogen due to microbial processes was observed with decreasing salinity along the Chesapeake Bay estuarine gradient at the near-field stratum, it was not observed in the far-field sites (Figure 48).

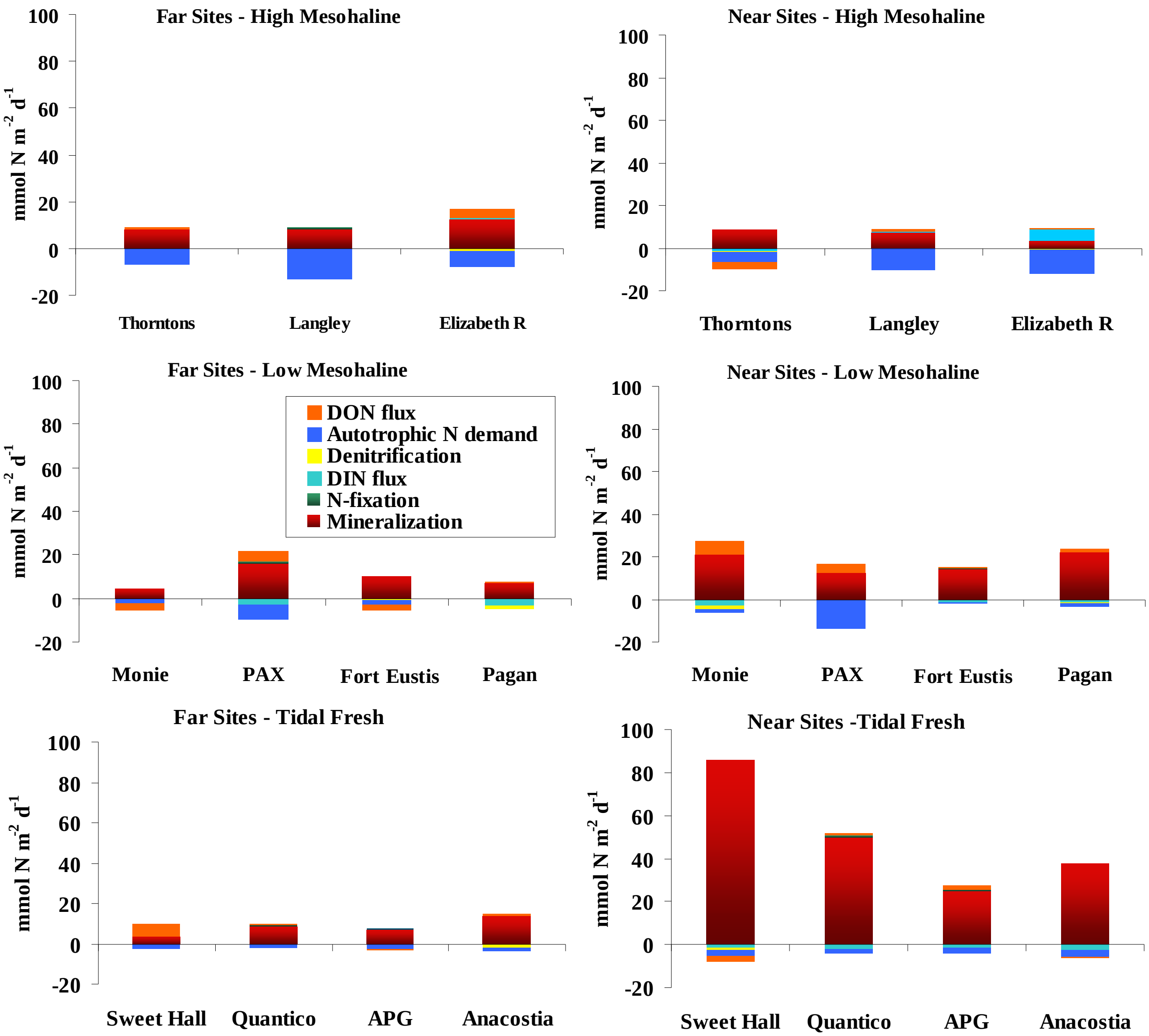


Figure 113. Nitrogen cycling rates at all sites. Positive values are sources of N, and negative values are sinks for N. DON=dissolved organic nitrogen; DIN=dissolved inorganic nitrogen.

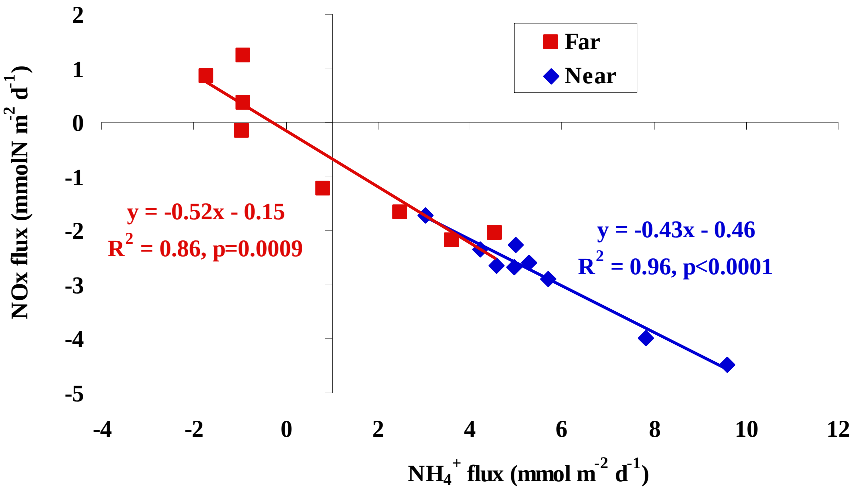


Figure 114. Regression relationship of daily NOx flux vs. daily NH_4^+ fluxes for far- and near-field stations at Anacostia River.

5.6.6 *Large Scale Variation of Ecosystem Function across the Chesapeake Bay Estuarine Gradient*

Two primary stressors likely to regulate microbial processes across the Chesapeake Bay estuarine gradient are nitrogen enrichment and light availability. We expected that along gradients of decreasing salinity, increasing nitrogen loads and decreasing light availability responses would include: (1) a shift from benthic to pelagic primary production; (2) a shift in system metabolism from net autotrophy to net heterotrophy; (3) a decrease in the ratio of benthic production to respiration (P/R); and (4) increased net efflux of nitrogen from sediments to the water column.

Unfortunately we lacked N-loading data and had only summertime light attenuation data for our sampling sites across Chesapeake Bay. We, therefore, assessed use of winter median DIN values from the 1993 – 2002 Chesapeake Bay Program dataset (http://www.chesapeakebay.net/data_waterquality.aspx) as a possible proxy for N-loads to our study sites. In addition, we used annual mean data for total suspended solids (TSS) from the same dataset as a proxy for light availability at our sites. We made the assumption that sediment properties and their affects on microbial processes are determined by long-term drivers such as N-loading and TSS. Where N-loading data were available for stations close to our sampling sites from the U.S. Geological Survey dataset (http://va.water.usgs.gov/chesbay/RIMP/index.html), we regressed the measured N-loads against winter DIN concentrations to determine whether winter median DIN concentrations could serve as a reliable proxy for N-loads for our sites. Figure 115 demonstrates strong relationships between median winter DIN and total nitrogen loads at sites close to our Aberdeen Proving Ground, Anacostia River, Fort Eustis, and Elizabeth River sites.

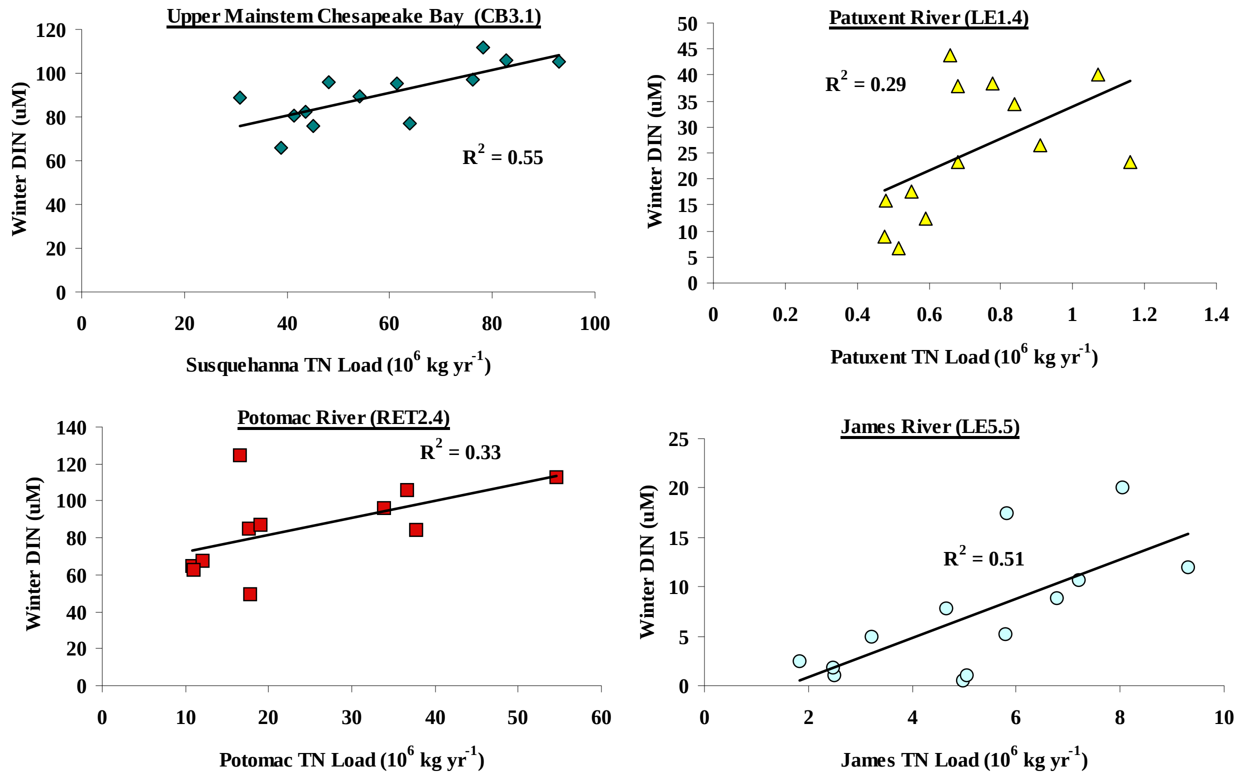


Figure 115. Regression relationship of winter dissolved inorganic nitrogen (DIN) concentration from Chesapeake Bay Program dataset versus total nitrogen (TN) loading.

From high mesohaline to tidal fresh waters across the Chesapeake Bay, historic median winter DIN water column concentrations (a proxy for N-loads), the ratio of water column DIN/DIP, water column chlorophyll a, and total suspended solids (a proxy for light attenuation) increased as historic mean salinity decreased (Figure 116). Along the same trajectory from high mesohaline to tidal freshwater in shallow near-field and far-field habitats, sediment ammonium generally increased and sediment chlorophyll decreased, suggesting responses to increased water column nutrients and decreased light availability along the estuarine gradient (Figure 117).

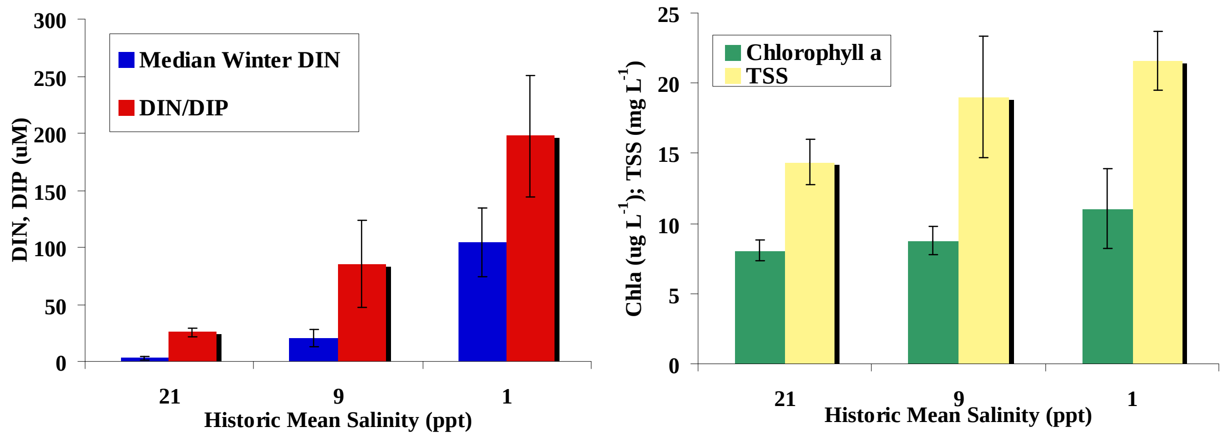


Figure 116. Historic regional water quality median winter dissolved inorganic nitrogen (DIN) and winter median DIN:DIP ratio vs. historic mean salinity (left); historic regional water quality mean chlorophyll a and total suspended solids (TSS) vs. historic mean salinity (right) (mean ± SE).

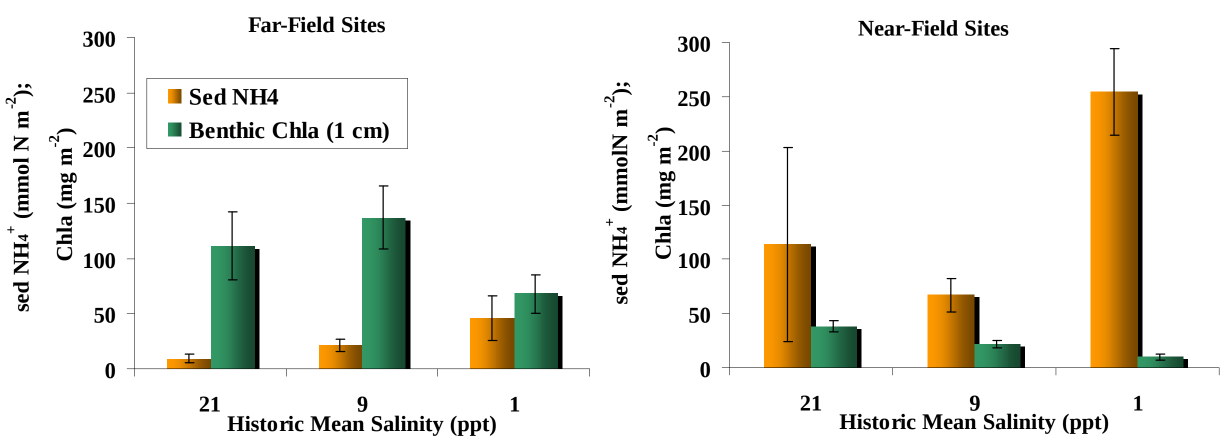


Figure 117. Sediment NH_4^+ in 25 cm section and benthic chlorophyll a in 1 cm section vs. historic mean salinity by far- and near-field strata (mean ± SE).

Along the gradient of historic nitrogen loading to Chesapeake Bay (historic winter median DIN), sediment chlorophyll a decreased (Figure 118), as did those ecosystem processes dependent on sediment chlorophyll a, namely benthic GPP and benthic P/R (Figure 119).

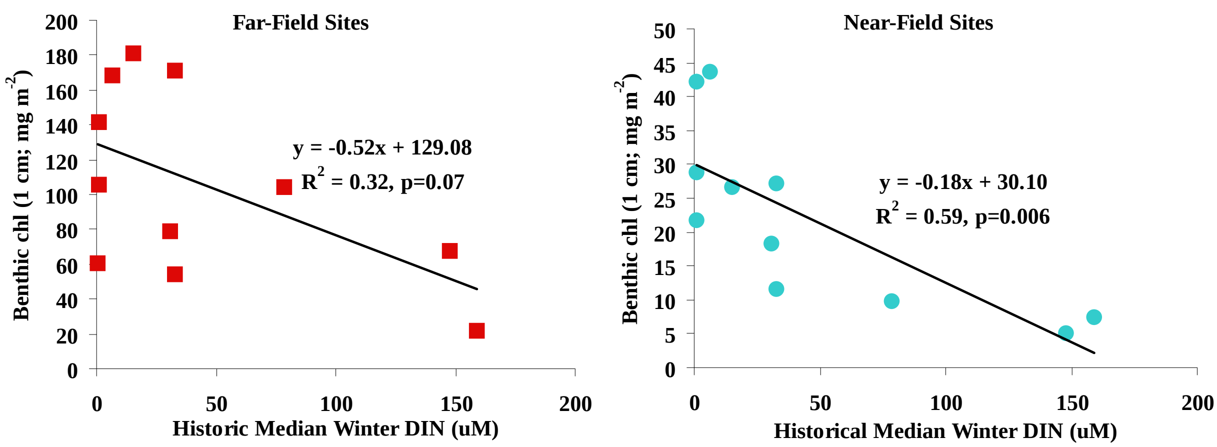


Figure 118. Regression relationships of benthic chlorophyll a in 1 cm section vs. historic median winter dissolved inorganic nitrogen (DIN) for far- and near-field strata.

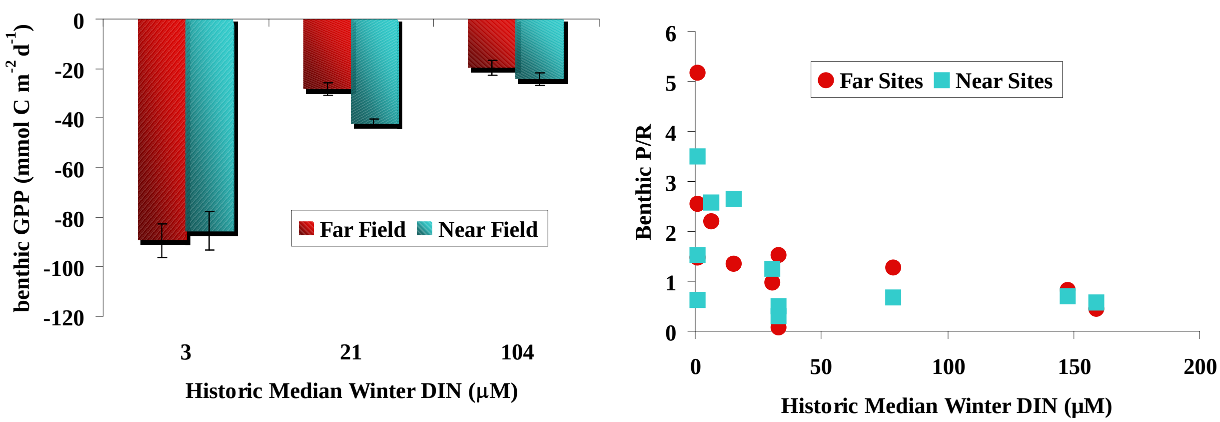


Figure 119. Benthic chlorophyll a in 1 cm section vs. mean historic median winter dissolved inorganic nitrogen (DIN) (grouped by salinity regime) for far- and near-field strata (mean ± SE) (left); benthic production: respiration (P/R) ratio vs. historic median winter DIN for far- and near-field strata (right).

Benthic GPP showed a strong relationship not only to historic nitrogen loading but also to increased concentrations of TSS historically observed across Chesapeake Bay from high to low salinity (Figure 120). Thus, nitrogen loading and decreased light availability due to increased TSS act in concert to reduce benthic autotrophy and increase heterotrophy along the estuarine gradient.

As benthic GPP and P/R decrease, a positive feedback may result, which further decreases water quality as organic matter is remineralized in sediments thus increasing fluxes of nitrogen to the water column. The entire system (benthos and water column) may then shift from net autotrophy (negative NEM) to net heterotrophy (positive NEM). This was observed in the upper Bay at near-field sites (points above the X-axis) (Figure 121).

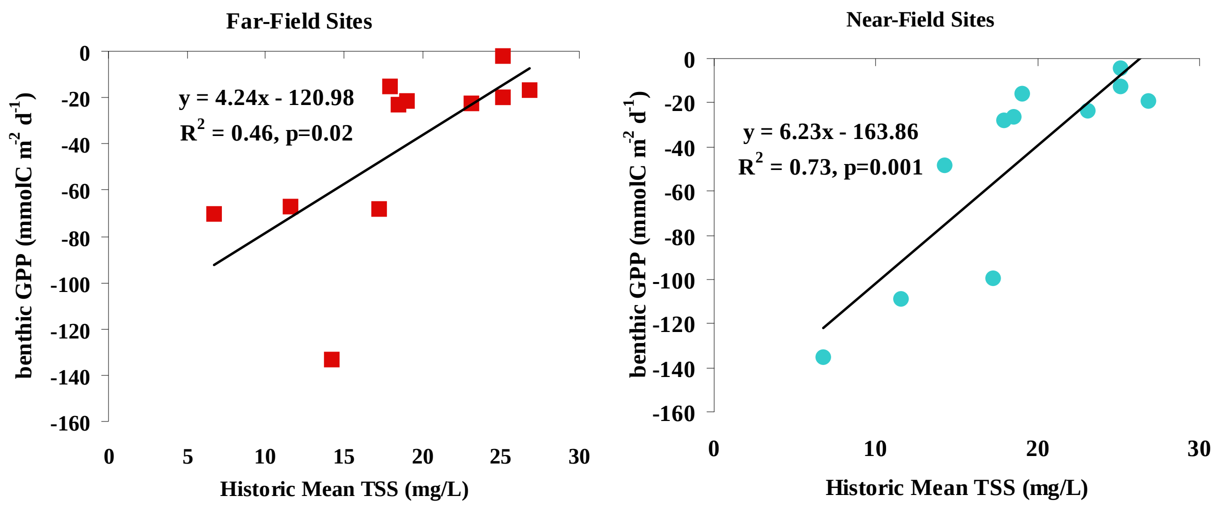


Figure 120. Regression relationships of mean benthic gross primary production (GPP) vs. historic regional mean total suspended solids (TSS) in water column for far- and near-field strata.

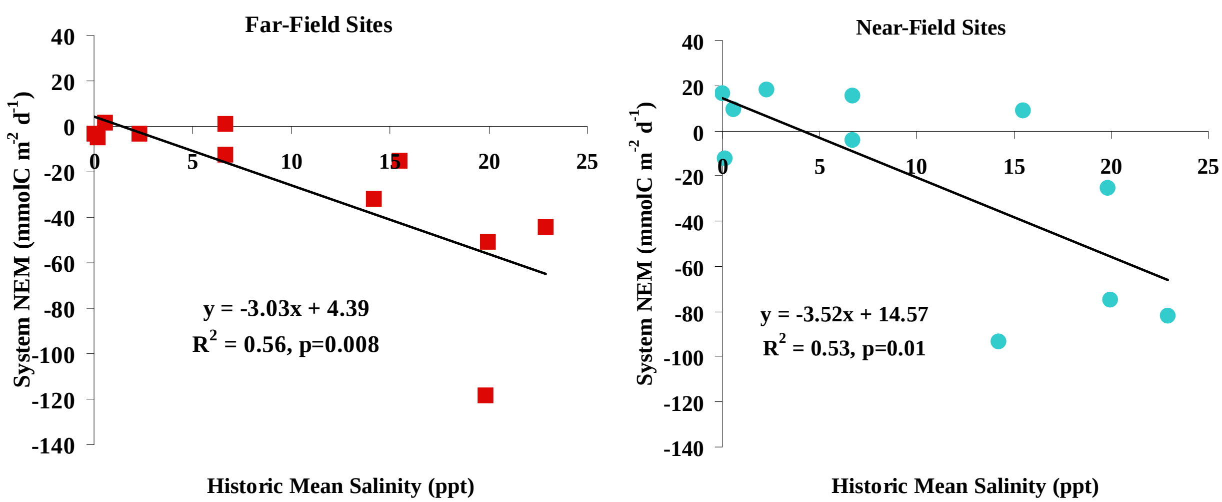


Figure 121. Regression relationships of mean system net ecosystem metabolism (NEM) vs. historic regional mean salinity for far- and near-field strata.

It has been hypothesized by us and by others (Duarte 1995, Joye and Anderson 2008, McGlathery et al. 2007, Valiela et al. 1997) that with increasing nutrient loading and decreasing light availability there will be a shift from benthic to pelagic production. Although predicted, this hypothesis has not been previously supported for shallow estuarine systems. Data shown in Figure 122 demonstrate that for shallow systems along the Chesapeake Bay estuarine gradient, there was a shift from benthic to pelagic production. Symptoms of this shift could include: phytoplankton blooms, harmful algal blooms, sediment and water column hypoxia/anoxia, organic enrichment of sediments, decreased removal of nitrogen by microbial processes such as denitrification, and increased conservation of nitrogen in sediments due to dissimilatory nitrate reduction to ammonium. The responses that develop to stressors such as N-loads and TSS depend upon complex interactions between biological, chemical, and physical variables. For example, where residence time is short, phytoplankton blooms may not develop. At sites exposed to strong physical forcings such as waves and resuspension, for example at some of our far-field sites, we predicted lower accumulation of nitrogen and organic matter, lower remineralization and respiration rates, and lower sediment – water ammonium fluxes when compared to near-field sites in the same salinity regime.

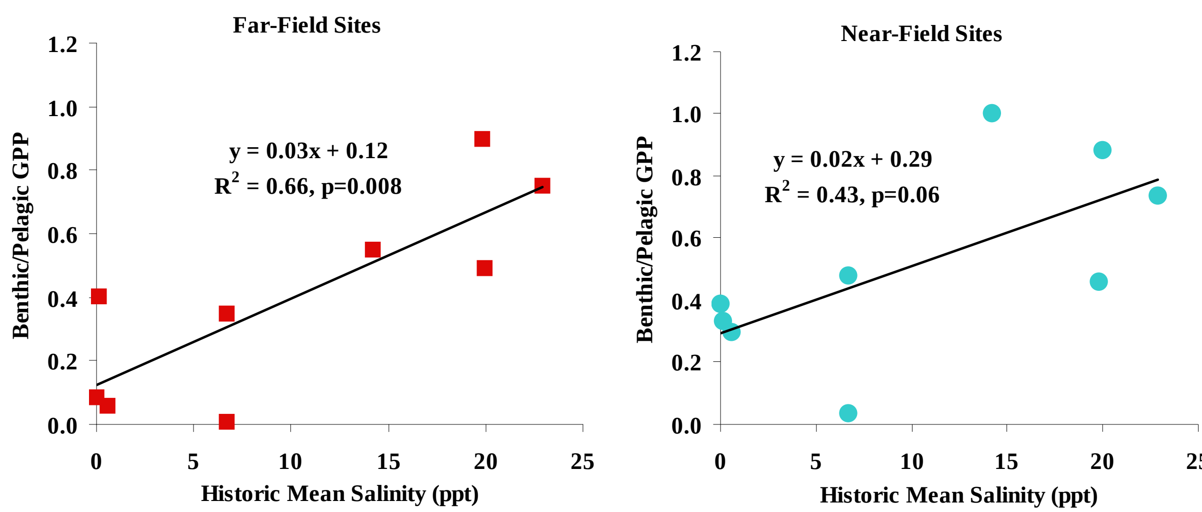


Figure 122. Regression relationships of mean benthic GPP: pelagic GPP ratios vs. historic regional mean salinity for far- and near-field strata. Data from Monie Bay and Aberdeen Proving Ground were excluded because heavy precipitation on the day prior to sampling affected pelagic GPP.

5.6.7 *Drivers Responsible for Differences in Ecosystem Function among Sites*

Principal Components Analysis (PCA) was performed in order to explore relationships between metrics of ecosystem function, nitrogen cycling processes, and sediment characteristics and to identify which of these metrics were most important in determining differences between study sites. Based upon the 3-way ANOVA described above, which showed a stratum effect for almost all functions, we performed the PCA within strata. Figure 123 shows results for near-field sites. The first two principal components explained 52% of the variance in the ordination of functional metrics. Relationships between functional metrics and principal components 1 and 2 are given in Table 35. Coefficients of the eigenvectors (x10) are used to show the relative relationships and weightings of each variable in ordination space on Figure 123. Stations arrayed across PC1 are separated primarily on the basis of net autotrophy vs. heterotrophy. Those metrics, which either contribute to autotrophy or express autotrophy have positive values on PC1 and include sediment P/R, GPP, and chlorophyll a. Arrayed on the positive side of PC1 are the high mesohaline sites, Thorntons Creek, Langley, and the Elizabeth River, as well as the low mesohaline site, PAX, which as described previously demonstrated unexpectedly high GPP, perhaps because of the location of sampling stations in a highly protected embayment (Figure 19). Metrics with negative scores on PC1 include sediment heterotrophy, mineralization, NH_4^+ and organic content, all of which tend to cluster together. Sites expressing these characteristics include the low mesohaline sites, Fort Eustis, Pagan, Monie Bay, and the tidal freshwater sites, Quantico and Aberdeen. PC2 separates sites based upon processes such as sediment – water NH_4^+ flux and respiration (positive values); NO_x flux, sediment %N and organic content (negative values). Anacostia, whose sediments were net heterotrophic with high respiration rates and high ammonium fluxes related to nitrate uptake, showed high scores on the PC2 axis. The PCA analysis of near-field sites based upon the functional metrics measured did not clearly separate sites based upon site status or degree of impairment. Instead it demonstrated that sites such as Thorntons, a reference site, and the Elizabeth River, an end member impaired site, can express some similar characteristics. Where light is sufficient, sediment autotrophy in sites such as the Elizabeth River may buffer the effects of impairment.

Figure 124 shows results of the PCA for far-field sites. The first two principal components explain 50% of the variance in the ordination of the functional metrics measured (Table 36). Far-field sites are somewhat arrayed along PC1 based upon site status with the reference sites showing positive scores and the impaired sites negative scores. Metrics that explain separation along PC1 include those related to autotrophy (positive scores) and those related to sediment enrichment and NH_4^+ flux (negative scores). Thus sites such as Thorntons with high GPP, P/R and sediment chlorophyll a are located at the positive end of PC1, whereas Anacostia and Pagan with high sediment organic content and nitrogen enrichment fall at the negative end of PC1. Along the PC2 axis Anacostia and the Elizabeth River have negative scores, likely related to the high sediment respiration and mineralization rates at these sites. Sweet Hall and Monie, both reference sites surrounded by emergent wetlands, and with P/R near 1, separate from PAX on PC2 because of the high sediment respiration and mineralization rates at PAX.

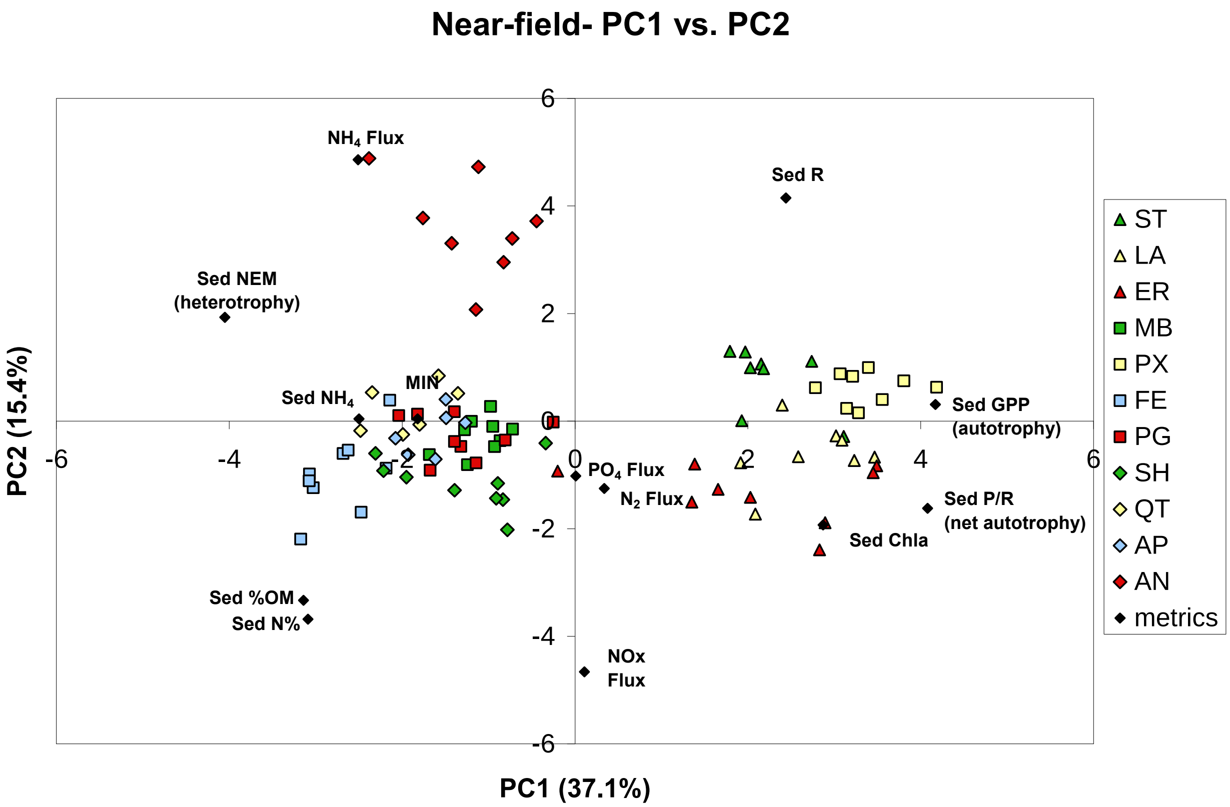


Figure 123. PCA ordinations of ecosystem processes and sediment characteristics for all near-field stations. The coefficients for the metrics are multiplied by 10 in order to plot them on the same graph as the PC scores.

Table 35. Coefficients of the eigenvectors for principal components 1-3 for near-field stations, based on sediment (benthic) ecosystem processes and characteristics. The following variables (metrics) were transformed: GPP: ln(-GPP+2); P/R: ln(P/R+1); mineralization: sqrt(min); sed NH_4^+: ln(sed NH_4^+); %N by mass: ln(%N by mass).

Near-field		**Coefficients**	
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	*37.1*	*15.4*	*13.7*
Sediment Gross Primary Production (GPP)	0.417	0.031	0.232
Sediment P/R ratio	0.408	-0.162	0.142
Sediment Chlorophyll a in 3 cm	0.287	-0.193	0.011
Sediment Respiration (R)	0.244	0.415	0.356
N_2 flux	0.034	-0.125	-0.005
Daily NOx flux	0.011	-0.466	-0.435
Daily PO_4^{3-} flux	0.001	-0.102	-0.093
Mineralization (MIN)	-0.182	0.004	-0.059
Sediment NH_4^+ content	-0.250	0.004	0.566
Daily NH_4^+ flux	-0.251	0.486	-0.163
Sediment %N by mass	-0.309	-0.368	0.322
Sediment % organic matter (OM) content	-0.314	-0.333	0.353
Sediment Net Ecosystem Metabolism (NEM)	-0.405	0.193	-0.150

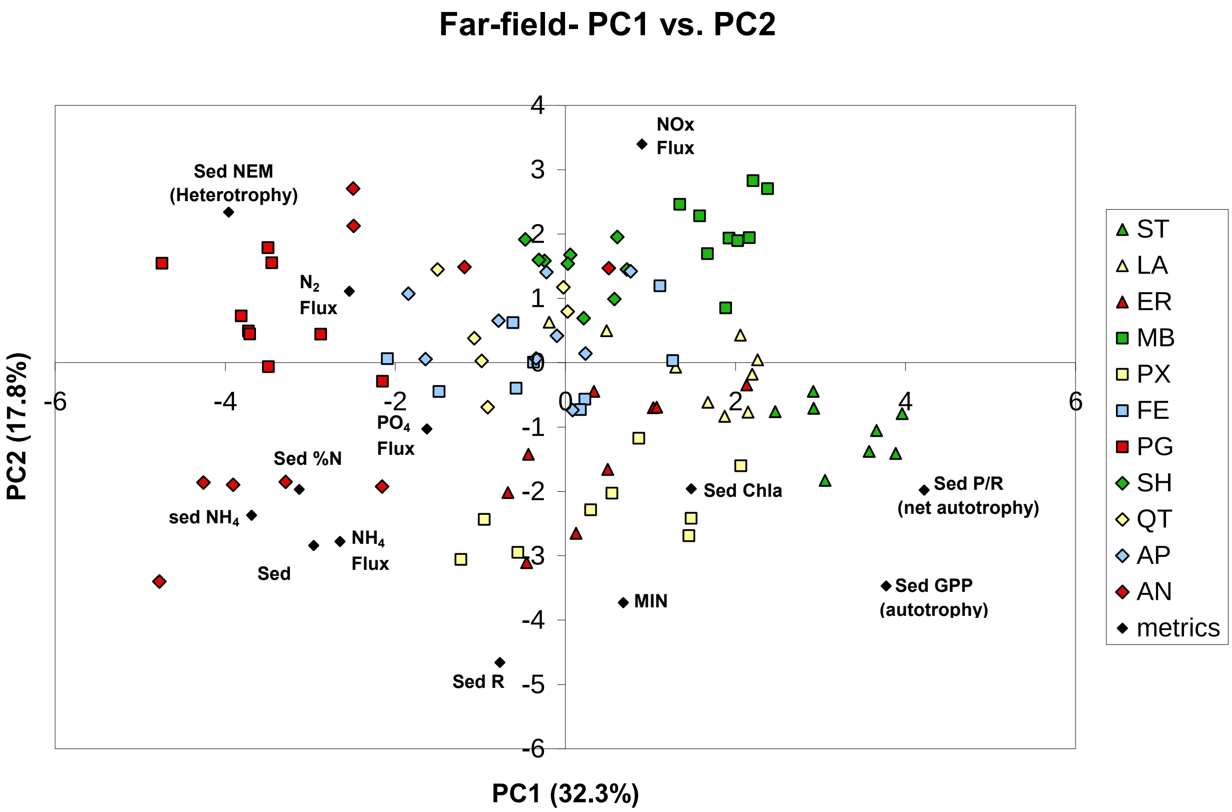


Figure 124. PCA ordinations of ecosystem processes and sediment characteristics for all far-field stations. The coefficients for the metrics are multiplied by 10 in order to plot them on the same graph as the PC scores.

Table 36. Coefficients of the eigenvectors for principal components 1-3 for far-field stations, based on sediment (benthic) ecosystem processes and characteristics. The following variables (metrics) were transformed: GPP: ln(-GPP+2); P/R: ln(P/R+1); sed %OM: ln(sed %OM); MIN: sqrt(min); sed NH_4^+: ln(sed NH_4^+); %N by mass: ln(%N by mass).

Far-field		**Coefficients**	
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	*32.3*	*17.8*	*12.2*
Sediment P/R ratio	0.422	-0.198	-0.220
Sediment Gross Primary Production (GPP)	0.377	-0.347	-0.118
Sediment Chlorophyll a in 3 cm	0.148	-0.196	0.081
Daily NOx flux	0.090	0.340	0.020
Mineralization (MIN)	0.068	-0.373	0.181
Sediment Respiration (R)	-0.077	-0.466	0.285
Daily PO_4^{3-} flux	-0.163	-0.103	0.398
N_2 flux	-0.254	0.111	-0.124
Daily NH_4^+ flux	-0.265	-0.278	0.431
Sediment % organic matter (OM) content	-0.296	-0.284	-0.434
Sediment %N by mass	-0.313	-0.197	-0.443
Sediment NH_4^+ content	-0.369	-0.237	-0.213
Sediment Net Ecosystem Metabolism (NEM)	-0.396	0.234	0.163

In order to evaluate the influence of bay-wide stressors on site ecosystem processes, we performed PCA of historic median winter DIN concentration (a proxy for N-loads), historic annual mean TSS (a proxy for light attenuation), key sediment characteristics, and functional metrics measured in this study. Figure 125 shows results of PCA for near-field sites and is based upon averages of metrics for each site. The first two principal components explain 65% of the variance in the ordination of metrics measured across the estuarine gradient of Chesapeake Bay (Table 37). The influence of the upper Bay stressors, TSS (light attenuation), and Winter DIN (N-load) on tidal freshwater sites (SH, QT, AP, and AN) can be seen with negative scores on the PC1 axis, whereas the high mesohaline sites in the lower Bay all have positive scores due to high sediment GPP, P/R, and high benthic/pelagic GPP. Along the PC2 axis, sites sort based upon the high fluxes of N_2, likely due to denitrification, at the low mesohaline sites, especially Monie Bay (positive scores), whereas negative scores are associated with high Winter DIN, sediment NH_4^+ and sediment respiration observed at the highly impaired Anacostia site.

Figure 126 shows results of PCA analysis for far-field sites across the Chesapeake Bay estuarine gradient. Principle components one and two explain 66% of the variance in ordination of metrics at the far-field sites (Table 38). As was observed for the near-field sites, stations sort along the PC1 axis based upon metrics related to sediment autotrophy (GPP, P/R – positive scores) and metrics related to nutrient enrichment and light attenuation (Winter DIN, TSS, sediment %N, and sediment NH_4^+ - negative scores). Thus on PC1 the high mesohaline reference site, Thorntons, has a highly positive score, whereas the tidal freshwater degraded site, Anacostia, and low mesohaline degraded site, Pagan, demonstrate the most negative scores. On the PC2 axis, sites sort by light availability (TSS – positive scores) and high NH_4^+ fluxes, which are associated with high sediment respiration and nitrogen mineralization rates (negative scores). The two sites surrounded by emergent marshes, Monie and Sweet Hall demonstrate the most positive scores on PC2 with low mineralization rates and NH_4^+ fluxes. Anacostia with high NH_4^+ fluxes and sediment NH_4^+ enrichment and PAX with high NH_4^+ fluxes, respiration and mineralization rates have the most negative scores.

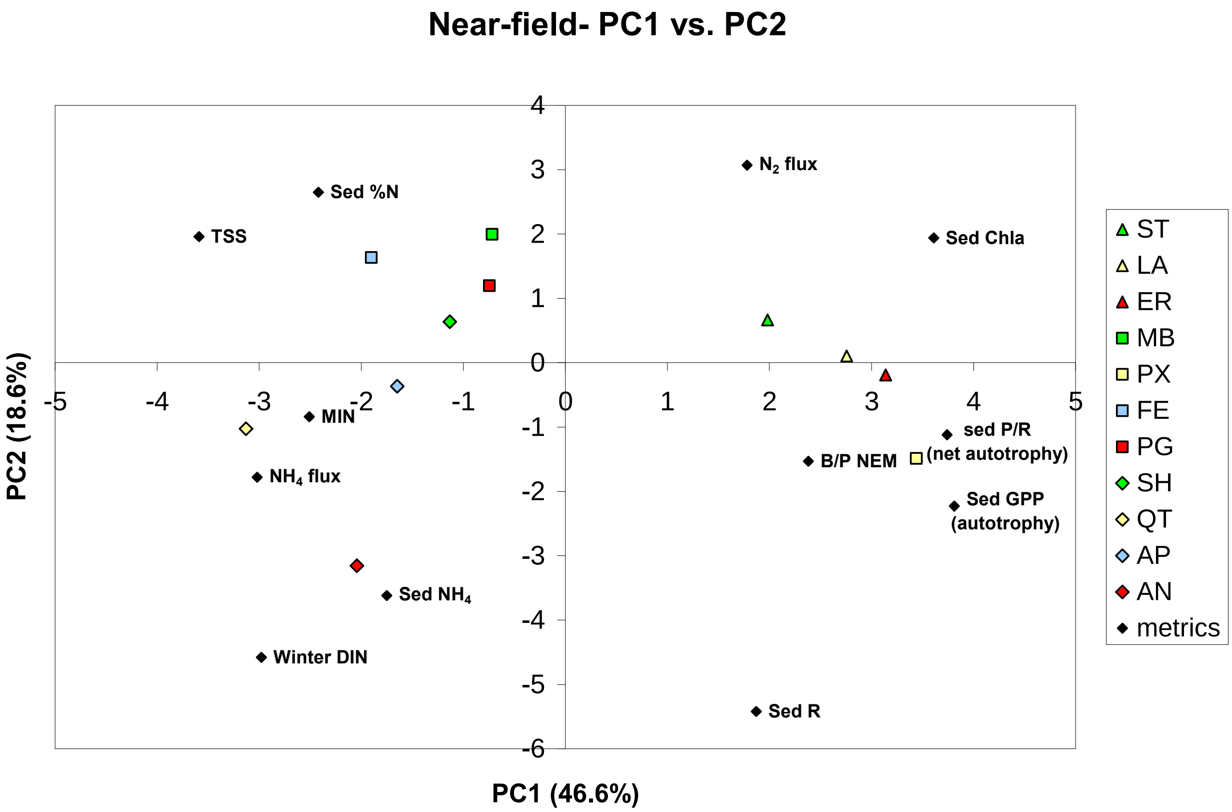


Figure 125. PCA ordinations of mean ecosystem processes, sediment characteristics, and historic water quality for all near-field sites. The coefficients for the metrics are multiplied by 10 in order to plot them on the same graph as the PC scores.

Table 37. Coefficients of the eigenvectors for principal components 1-3 for near-field sites, based on mean sediment (benthic) ecosystem processes, sediment characteristics, and historic water quality. #The mean GPP values were inversed, thus greater GPP is more autotrophic.

Near-field	**Coefficients**		
Variable	**PC1**	**PC2**	**PC3**
Total percent of variation	*46.6*	*18.6*	*12.2*
Sediment Gross Primary Production (GPP)#	0.381	-0.223	0.112
Sediment P/R	0.374	-0.112	0.176
Sediment chlorophyll a in top 1 cm	0.361	0.194	-0.105
Benthic/Pelagic Net Ecosystem Metabolism (NEM)	0.238	-0.153	0.502
Sediment Respiration (R)	0.187	-0.542	-0.182
N_2 flux	0.178	0.307	-0.533
Sediment NH_4^+ content	-0.175	-0.362	0.002
Sediment %N by mass	-0.242	0.265	0.393
Mineralization (MIN)	-0.251	-0.084	-0.108
Historic Regional Median Winter Dissolved Inorganic Nitrogen (DIN) concentration	-0.298	-0.458	0.050
Daily NH_4^+ flux	-0.302	-0.178	-0.378
Historic Regional Mean Total Suspended Solids (TSS)	-0.359	0.196	0.255

Far-field- PC1 vs. PC2

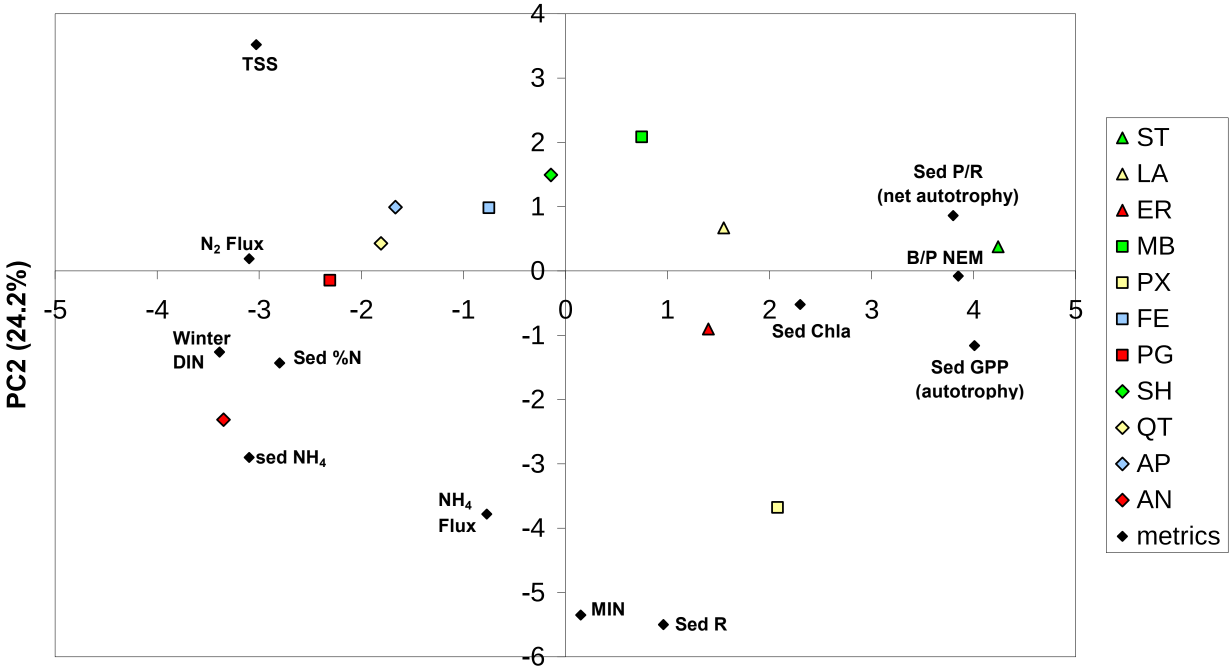


Figure 126. PCA ordinations of mean ecosystem processes, sediment characteristics, and historic water quality for all far-field sites. The coefficients for the metrics are multiplied by 10 in order to plot them on the same graph as the PC scores.

Table 38. Coefficients of the eigenvectors for principal components 1-3 for far-field sites, based on mean sediment (benthic) ecosystem processes, sediment characteristics, and historic water quality. #The mean GPP values were inversed, thus greater GPP is more autotrophic.

Far-field	**Coefficients**		
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	*42.0*	*24.2*	*11.5*
Sediment Gross Primary Production (GPP)#	0.401	-0.116	0.276
Benthic/Pelagic Net Ecosystem Metabolism (NEM)	0.385	-0.008	0.304
Sediment P/R	0.380	0.086	0.343
Sediment chlorophyll a in top 1 cm	0.230	-0.052	-0.473
Sediment Respiration (R)	0.096	-0.550	-0.019
Mineralization (MIN)	0.015	-0.535	0.061
Daily NH_4^+ flux	-0.077	-0.378	-0.368
Sediment %N by mass	-0.280	-0.143	-0.008
Historic Regional Mean Total Suspended Solids (TSS)	-0.303	0.352	0.087
Sediment NH_4^+ content	-0.310	-0.290	0.386
N_2 flux	-0.310	0.019	-0.049
Historic Regional Median Winter Dissolved Inorganic Nitrogen (DIN) concentration	-0.339	-0.126	0.437

5.7 Relationships between Benthic Community Structure and Ecosystem Function – A Synthetic Perspective

The estuarine nearshore region supports highly productive benthic communities ranging from benthic microalgae and bacteria to macroinvertebrates. As a result, ecosystem function in shallow water is strongly influenced by benthic processes. We conducted a holistic assessment of the relationships between structure and function in representative shallow water estuarine habitats. This approach provides much useful information and insights that will improve the measurement and understanding of human impacts on benthic communities, important processes and the provision of ecological services in estuarine habitats.

We used Principal Components Analysis (PCA) to document the relationships among metrics of community structure and ecosystem processes and to determine which of these were most important for distinguishing sites on the basis of status. We did not use the full suite of metrics employed in previous analyses because some were shown to be highly correlated and others were not available for all sites.

Far-field sites

The importance of environmental condition, as reflected in the a priori classification status of our sites (reference, unclassified, degraded) is evident in the ordinations for the far-field sites. In addition, the possible effects of salinity and light gradients are apparent, especially for tidal freshwater sites (Figure 127). The first three principal components accounted for 62.5% of the variance in the far-field data (Table 39). Stations from sites classified a priori as reference were skewed towards positive scores on both PC1 and PC2. Stations from the Elizabeth River (degraded) site were associated with a cluster of stations from reference and unclassified sites, including Thorntons Creek (reference) site. Stations from the Anacostia (degraded) site had highly negative scores on PC1, while stations from the Pagan (degraded) stations highly negative scores on PC2. Most of the stations from unclassified sites were commingled with stations from reference sites.

Positive scores on PC1, which accounted for 28.7% of the variation, were associated with increasingly autotrophic sediments. These stations were characterized by higher GPP, higher sediment chlorophyll a, higher P/R, higher species diversity and evenness, and higher B-IBI than stations with negative scores on PC1. Negative scores on PC1 were associated with heterotrophic conditions at two freshwater sites, the Anacostia (degraded) and Aberdeen Proving Ground (unclassified). Stations at these sites had higher NEM, higher % abundance and biomass of pollution indicative species, higher total abundance of deep deposit feeding macrofauna, and lower chlorophyll a relative to stations with positive scores on PC1. In addition to light limitation of GPP at these sites, bioturbation by deep deposit feeders would serve to move chlorophyll a away from the sediment water interface, which would result in a lowering of GPP and higher NEM. Based on the relative weightings of the B-IBI for PCs 1-3, our results demonstrate that the optimal habitat quality for benthic macroinvertebrates collected at near-field sites was where P/R was balanced to autotrophic. This finding is consistent with our initial hypotheses.

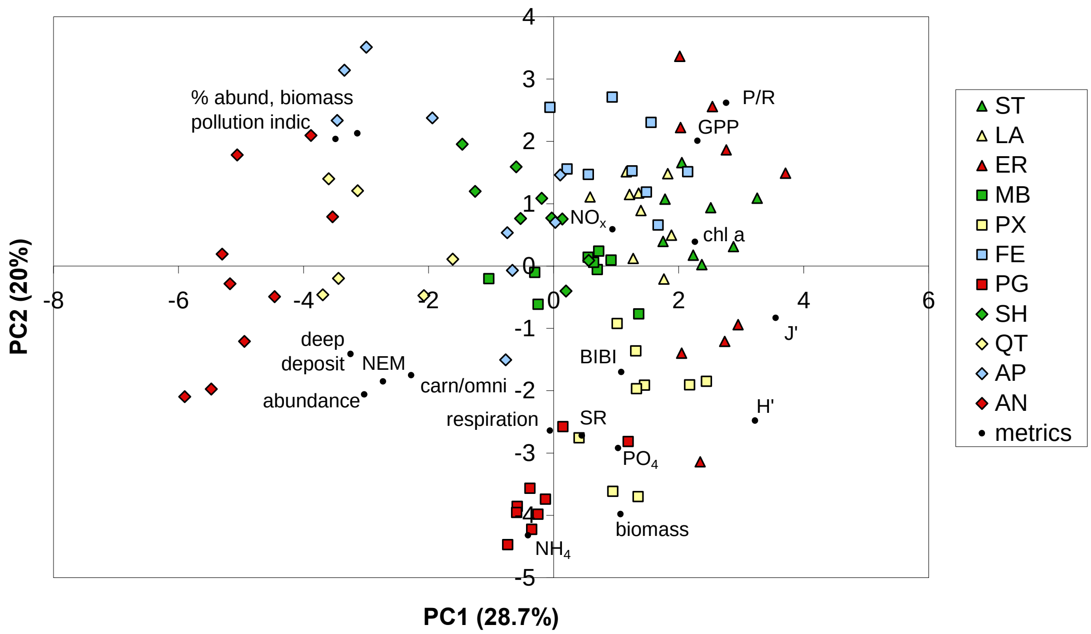
Negative scores on PC2, which accounted for 20% of the variation in the data, were associated with ammonium and phosphate flux out of the sediment, high macrofauna biomass and abundance, high species richness and diversity and high sediment respiration, whereas positive scores were associated with high % abundance and biomass of pollution indicative species, higher P/R and GPP. This slight shift in structure and function is associated with high nutrient availability for benthic primary producers in the presence of high light.

Stations with positive scores on PC3, which accounted for 13.8% of the variation, had high NEM, high B-IBI and high flux of phosphate from the sediment, while stations with negative scores on PC3 had high GPP, high respiration and high P/R, as well as high species richness, high total abundance, and high abundance of deep deposit feeders.

Table 39. Coefficients of the eigenvectors for principal components 1-3, based on far-field macrofauna and ecosystem process metrics.

Far-field	**coefficients**		
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	*28.7*	*20.0*	*13.8*
Species Evenness - J'	0.355	-0.083	0.142
Species Diversity - H' (log_2)	0.322	-0.248	-0.054
Sediment P/R ln(p/r+1)	0.276	0.262	-0.330
Sediment GPP ln(-gpp+2) (mmol C m^{-2} d^{-1})	0.230	0.201	-0.443
Total Sediment Chl a 0-3 cm (mg m^{-2})	0.226	0.039	-0.043
Benthic Index of Biotic Integrity	0.108	-0.170	0.238
Biomass (log_{10}(x+1))	0.107	-0.398	-0.130
Sediment daily PO_4 flux (mmol P m^{-2} d^{-1})	0.103	-0.292	0.196
Sediment daily NO_X flux (mmol N m^{-2} d^{-1})	0.094	0.059	0.223
Species Richness (no. of species)	0.045	-0.272	-0.303
Sediment Respiration (mmol C m^{-2} d^{-1})	-0.006	-0.264	-0.359
Sediment daily NH_4 flux (mmol N m^{-2} d^{-1})	-0.041	-0.432	-0.027
Abundance Carnivores/Omnivores (ln(carn+1))	-0.228	-0.175	-0.104
Sediment NEM (mmol C m^{-2} d^{-1})	-0.273	-0.185	0.361
Abundance (log_{10}(x+1))	-0.303	-0.206	-0.292
Abundance – Pollution Indicative Species (%)	-0.314	0.213	-0.061
Abundance Deep Deposit Feeders (ln(DD+1))	-0.325	-0.141	-0.231
Biomass - Pollution Indicative Species (%)	-0.349	0.204	-0.056

Far-field- PC1 vs. PC2



Far-field- PC1 vs. PC3

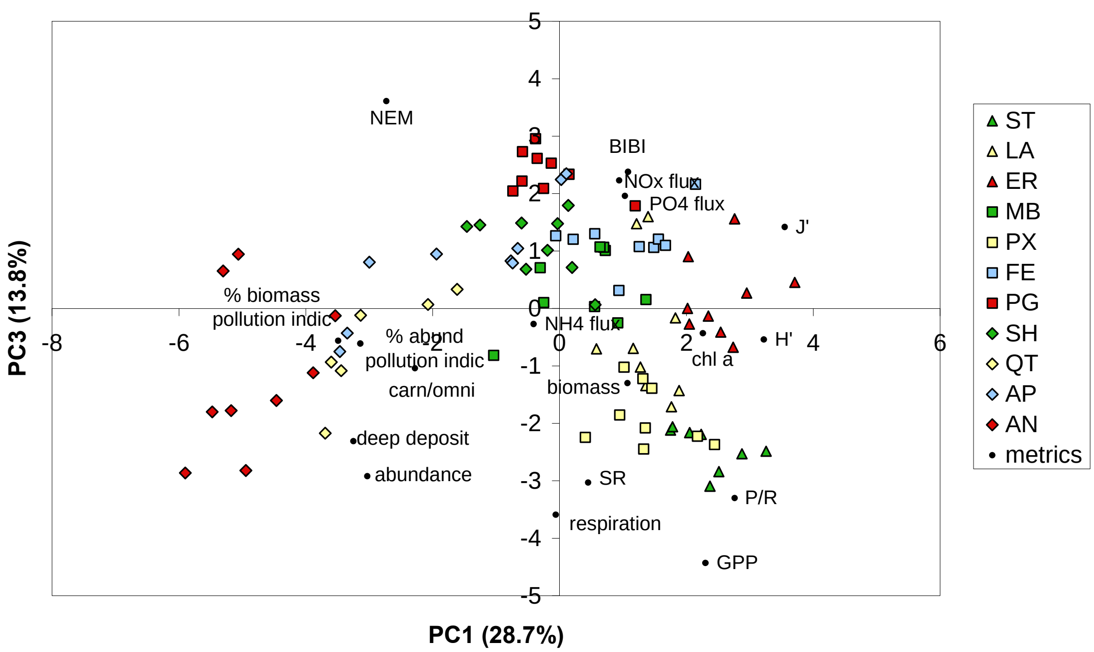


Figure 127. PCA ordinations of macrofauna metrics, including the B-IBI, and ecosystem process indicators for far-field stations. Relationships between each variable (metric) and principal components 1-3 are given in Table 39. The coefficients for the metrics are multiplied by 10 in order to plot them on the same graph as the PC scores. For additional information refer to text.

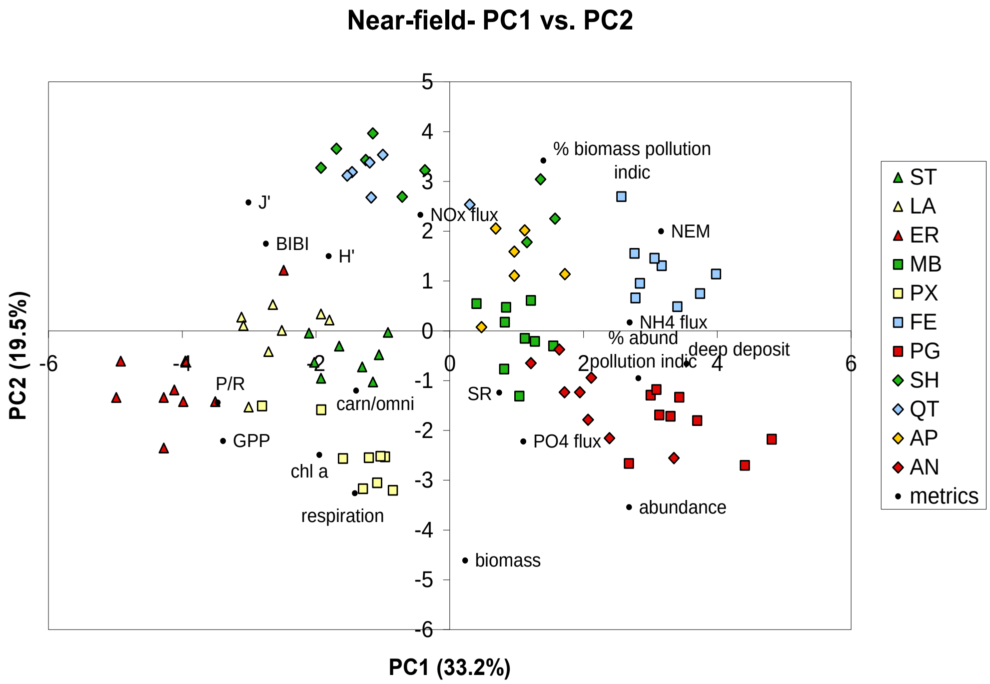
The relatively central position of all three reference sites along PC1 again indicates that conditions at these sites were intermediate for many of the parameters measured. However, the overall patterns are more complex for the far-field sites relative to the near-field sites and the degraded sites represent distinctive end points. This may be because a more diverse suite of stressors, including physical disturbance, which we were unable to characterize, influence structure and function in these habitats.

Near-field sites

The importance of environmental impairment, as reflected in the a priori classification status of our sites (reference, unclassified, degraded), as well as shifts in salinity and light regimes, on benthic community structure and function is evident in the ordinations comparing PC1 - PC3 for the near-field sites (Figure 128). Together the first three principal components accounted for 68.1% of the variance in the data (Table 40). In both ordinations presented, sites selected to represent reference conditions are centrally located along PC1, while sites selected to represent degraded environmental conditions have highly positive (Pagan and Anacostia) or highly negative (Elizabeth River) scores on PC1.

Table 40. Coefficients of the eigenvectors for principal components 1-3, based on near-field macrofauna and ecosystem process metrics.

Near-field		**coefficients**	
Variable	**PC1**	**PC2**	**PC3**
Percent of total variation	*33.2*	*19.5*	*15.3*
Abundance Deep Deposit Feeders (ln(DD+1))	0.354	-0.066	0.199
Sediment NEM (mmol C m^{-2} d^{-1})	0.316	0.2	0.197
Abundance – Pollution Indicative Species (%)	0.282	-0.095	-0.258
Sediment daily NH_4 flux (mmol N m^{-2} d^{-1})	0.269	0.017	0.31
Abundance (log_{10}(x+1))	0.268	-0.354	0.113
Biomass - Pollution Indicative Species (%)	0.14	0.342	-0.091
Sediment daily PO_4 flux (mmol P m^{-2} d^{-1})	0.11	-0.222	-0.164
Species Richness (no. of species)	0.074	-0.124	0.396
Biomass (log_{10}(x+1))	0.023	-0.461	0.228
Sediment daily NO_X flux (mmol N m^{-2} d^{-1})	-0.044	0.233	-0.111
Abundance Carnivores/Omnivores (ln(carn+1))	-0.14	-0.12	0.369
Sediment Respiration (mmol C m^{-2} d^{-1})	-0.142	-0.326	0.083
Species Diversity - H' (log_2)	-0.181	0.15	0.431
Total Sediment Chl a 0-3 cm (mg m^{-2})	-0.195	-0.249	-0.136
Benthic Index of Biotic Integrity	-0.275	0.175	0.293
Species Evenness - J'	-0.301	0.258	0.185
Sediment GPP ln(-gpp+2) (mmol C m^{-2} d^{-1})	-0.339	-0.221	-0.062
Sediment P/R ln(p/r+1)	-0.347	-0.144	-0.138



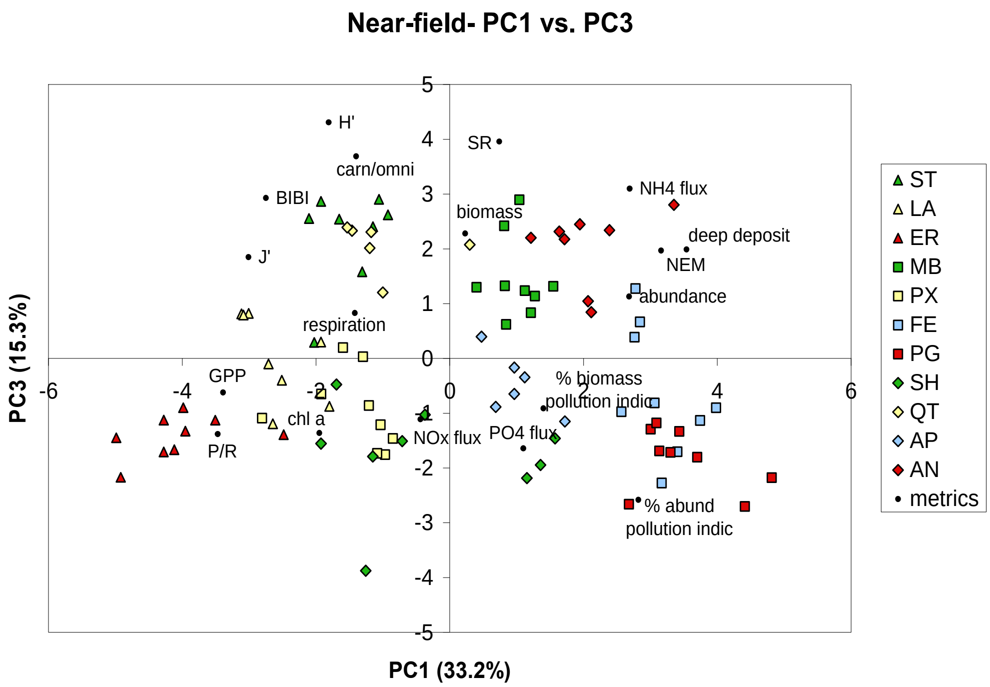


Figure 128. PCA ordinations of macrofauna metrics, including the B-IBI, and ecosystem process indicators for near-field stations. Relationships between each variable (metric) and principal components 1-3 are given in Table 40. The coefficients for the metrics are multiplied by 10 in order to plot them on the same graph as the PC scores. For additional information refer to text.

Highly positive scores on PC1, which accounted for 33.2% of the variation, are consistent with habitat degradation due to eutrophication. Stations with the positive scores on PC1 had higher NEM (heterotrophy), higher % abundance of pollution indicative species and total abundance of deep deposit feeding macrofauna, and net flux of ammonium from the sediments relative to stations with negative scores on PC1. Based on the high abundance of deep deposit feeders, and high biomass and abundance of pollution indicative species, we can infer that these stations had high rates of bioturbation both near the sediment-water interface and at depth, which is consistent with high flux of ammonium from the sediments. High rates of bioturbation are also expected to lower sediment chlorophyll a due to grazing and physical mixing, which would tend to lower GPP and increase NEM. Sites with positive scores on PC1 were all from the low mesohaline to tidal freshwater, which demonstrates that some of the parameters vary with the estuarine gradient. Highly negative scores on PC1 were associated with net autotrophic sediments, which were mostly limited to the lower estuary, where light availability was greatest, however, stations with negative scores on PC1 came from all three salinity regimes. These stations were characterized by higher GPP, higher sediment chlorophyll a, and higher P/R than stations with positive scores on PC1.

The relatively central position of all three reference sites along PC1 indicates that conditions at these sites were intermediate for many of the parameters measured. For the extreme ER case, the combination of high nutrients and high light, but few infauna due to sediment toxicity, favored the proliferation of benthic microalgae. Based on the relative weightings of the B-IBI for PCs 1-3, our results demonstrate that the optimal habitat quality for benthic macroinvertebrates collected at near-field sites was where P/R was balanced to autotrophic, although very high GPP will signal that the macrofauna is being controlled by something other than food availability. This finding is consistent with our initial hypotheses.

Positive scores on PC2, which accounted for 19.5% of the variation, were associated with high % biomass of pollution indicative species, but low overall macrofaunal biomass, high species evenness, and little net flux of nitrate and nitrite out of the sediment, whereas negative scores were associated with high macrofaunal abundance and biomass, high sediment respiration, and a net flux into the sediment of nitrate and nitrite. High biomass at our sites was primarily attributable to bivalves, and secondarily to large polychaetes. Both may enhance the coupling of nitrification/denitrification through the aeration of their tubes and burrows, or the production of fecal pellets (Mayer et al. 1995), which may enhance the net uptake of nitrate and nitrite. Effective coupling of these processes can result in the release of nitrogen gas for the estuary, which could help to reduce eutrophication. Alternatively, dissimilatory nitrate reduction to ammonium (DNRA) may be occurring. This process competes with denitrification for substrate and tends to occur when labile DOC and nitrate are readily available. This process does not result in loss of nitrogen and will not reduce the potential for eutrophication. Their high biomass, as well as microbial breakdown of any fecal pellets produced, may also have contributed to higher respiration rates measured at these sites.

Positive scores on PC3, which accounted for 15.3% of the variation, were associated with high species diversity and species richness, and high abundance of the carnivore/omnivore trophic group of macrofauna. This group includes the macrofaunal grazers of microalgae, as well as predators that feed on meiofaunal grazers of benthic microalgae. Negative scores on PC3 were associated with high % abundance of pollution indicative species and net flux out of PO_4.

As noted earlier, sediment autotrophy was especially pronounced at our Elizabeth River near-field site. The high light, high nutrient conditions of the near-field stations favored the proliferation of benthic microalgae, as reflected in high sediment chlorophyll a. The ordination of collections from ER near-field emphasizes their unique character but also the fact that they had higher than expected B-IBIs. How can this be when sediment toxicity should limit infauna at this site? One clue is that the traditional benthic food web was largely absent at this site. Three out of the five benthic invertebrate species we collected from the ER near-field site are carnivores or omnivores and a fourth feeds on detrital materials at the sediment water interface. This major shift in the food web structure away from the typical deposit and suspension-feeder dominance of estuarine soft-sediments appears to be tied to the high benthic primary production (Gillett in progress). The interaction of high nutrient and light availability, which supports benthic microalgal growth and an associated suite of macrofaunal grazers, coupled with sediment toxicity, which limits the traditional food web, was not observed at any of our other study sites. Grazers, omnivores, and carnivores proliferated at the ER near-field stations, but our results indicate that grazing by macrofauna and meiofauna was insufficient to limit benthic microalgae biomass.

The complex effects of stressors at the ER near-field site suggests that restoration activities in urban estuaries could have unexpected results. As mentioned earlier (see Sections 5.6.4 & 5.6.7) our results suggest that benthic microalgae buffer the local benthic community from the full effects of local sediment impairment. This finding has important implications for restoration activities. First, reductions in nutrient loadings or increases of TSS loading that result in lower GPP and benthic chlorophyll a could lead to a collapse of shallow water food webs in areas with toxic sediments. Conversely, cleaning up toxic sediments without controls on regional water quality will likely make effects of sediment impairments due to eutrophication more prominent. This could produce a situation more like what we observed at the Pagan River near-field site, where an apparent stimulation of abundance and biomass contributed to very low B-IBI scores.

That high macrofaunal biomass is more strongly associated with PC2 than PC1 suggests that benthic invertebrate biomass at most of the sites we studied is not, however, directly linked to local benthic primary production. Bivalves and other large infauna present at the sites we studied range from head down deposit feeders to surface deposit feeders to suspension feeders. Most are able to utilize a variety of food sources including benthic microalgae, phytoplankton, and detritus. Ongoing studies (Gillett in progress) will soon provide additional details on the food web structure at these sites based on stable isotope and diet studies of resident consumers.

6. CONCLUSIONS

The sites we studied had demonstrable gradients in water and sediment quality from relatively pristine conditions found at National Estuarine Research Reserve sites to highly impacted urban estuaries at Norfolk, VA and Washington, DC. DoD installations generally had intermediate environmental conditions, in terms of the regional water and local sediment quality parameters measured, which did not include sediment contaminants. We did include measures of sediment toxicity in 2003. Only the Elizabeth River near-field site had significant sediment toxicity.

Results and Recommendations

Stressor Gradients

Relative to identifying stressor gradients, our major results and recommendations are:

- Regional water quality and local environmental setting interact to influence local sediment quality. Labile organic matter accumulated in muddy, depositional habitats, but not in sandy habitats, which were exposed to greater physical energy from waves and currents.
- While some effects of regional eutrophication (e.g. sediment organic enrichment) will be greater in protected muddy nearshore habitats relative to exposed, sandy nearshore habitats, other effects (e.g. shift to autotrophic system) may be greater in sandy habitats if light is more readily available. This differential response of benthic habitats to regional water quality impairments should be taken into account when designing monitoring and restoration programs.

Results of benthic macrofauna studies generally supported the overarching hypotheses for this study:

- The Benthic Index of Biotic Integrity (B-IBI) was useful for detecting gradients of water and sediment quality impairment, within and across major habitat types and salinity regimes.
- The B-IBI and component metric results demonstrate that impairment gradients are stronger in near-field than far-field habitats, consistent with water and sediment quality metrics such as organic enrichment and sediment toxicity (2003 only). Sediment associated stressors acted to degrade benthic communities locally.
- The B-IBI is useful for detecting effects of multiple stressors acting together on benthos. However, results presented for the Elizabeth River near-field study site demonstrate that the B-IBI is influenced by stressor interactions (e.g. sediment contaminants and eutrophication).
- For areas where both contaminants and eutrophication are likely to determine environmental conditions, we recommend that a Multiple Lines of Evidence (MLOE) approach be used to assess environmental quality. See for example: http://www.swrcb.ca.gov/bptcp/sediment.html

Meiofauna as Indicators of Environmental Quality

Results of the benthic meiofauna studies did not follow the originally proposed hypotheses.

- Meiofauna identified to major taxa were of limited use in understanding the environmental conditions of the shallow water high mesohaline to tidal freshwater habitats we studied. The estuary may represent an ecotone that separates meiofauna populations of marine and freshwater systems, leaving a depauperate community at intermediate salinities.
- Increased taxonomic detail in the study of meiofauna, which was beyond the scope of this project, would likely strengthen the relationship between meiofauna community structure and habitat quality by illustrating species-specific sensitivities that are undetectable at higher taxonomic levels, much like macrofaunal communities.

Secondary production of macrofauna was useful for linking environmental quality and benthic community structure to the provision of ecosystem services.

- Secondary production of macrofauna decreased with decreasing habitat quality in habitats where organic matter or contaminants accumulated in the sediment (i.e., near-field sites). Secondary production was decoupled from local habitat quality in those environments where organic matter and contaminants did not accumulate (i.e., far-field sites).
- Our results failed to show a strong linkage between secondary production of tidal freshwater macrofauna and habitat quality, regardless of major habitat type. Stressors that were not captured in our data may be more important to controlling production in tidal freshwater (e.g., presence of invasive SAV, episodic salinity intrusion, or sedimentation).
- Estimates of secondary production can be made relatively easily once benthic community data have been assembled, are valuable for assessing food web support of higher trophic levels and can be used to demonstrate the value of nearshore regions as essential fish habitat.

Responses of ecosystem process rates to estuarine gradients and impairments

Results of ecosystem process studies generally supported the hypotheses for this study.

- Across the entire estuarine gradient of the Chesapeake Bay, nitrogen loading and light availability played an essential role in determining benthic ecosystem function.
- The primary responses that differentiated sites along the estuarine gradient were associated with sediment autotrophy (GPP, P/R, sediment chlorophyll a).
- All ecosystem process rates measured, except for mineralization, responded to site impairment (status, condition).
- However, the local response of a process rate to a stressor such as nutrient enrichment varied depending upon regional light availability, sediment type (stratum), and salinity.
- Benthic microalgal – mediated nutrient uptake may buffer the effect of nutrient enrichment provided that sufficient light is available.
- Across the estuarine gradient from high mesohaline to tidal fresh waters in the Chesapeake Bay, there was a shift:
    - From net benthic autotrophy to net heterotrophy, and
    - From primary production in the benthos to the pelagic zone.

Relationships between benthic integrity and ecosystem function

The estuarine nearshore region supports highly productive benthic communities. As a result, function in these areas is strongly influenced by benthic processes. An assessment of relationships between structure and function of shallow water habitats has been used to quantify the impacts of human activities on biodiversity, benthic condition, important functional processes, and the provision of ecological services. This holistic approach shows that:

- Consistent with our initial hypotheses, benthic community condition was greatest in habitats with balanced or autotrophic conditions as reflected in GPP, NEM, respiration, and P/R, as long as the sediments were not toxic.
- Major habitat types, position along the estuarine gradient, and factors related to regional water quality were the most useful predictors of environmental quality, biodiversity, and ecosystem function at the sites we studied. Local stressors may, however, interact with and modulate the effects of regional water quality impairments.
- Benthic microalgae, which due to light availability are most abundant in shallow, nearshore waters, may serve to buffer the benthic community from the full effects of local sediment impairment associated with toxic sediments. This finding has implications for restoration activities:
    - First, reductions in nutrient loadings or increases of turbidity that result in lower benthic primary production could lead to a collapse of shallow water food webs in areas with toxic sediments, much as is seen in deeper waters where light is not available.
    - Conversely, cleaning up toxic sediments without controls on regional water quality will likely make effects of sediment impairments due to eutrophication more prominent.

Ecosystem responses to DOD activities

Although DoD activities along the shorelines of the Chesapeake Bay create some unique stressors for nearshore habitats, the DoD sites we studied generally had intermediate environmental conditions relative to the range observed within representative Chesapeake Bay shallow water habitats. The major patterns we observed in community structure, benthic condition, and ecosystem processes were concordant with a priori classifications of sites based on position along the estuarine gradient, historic regional water quality and land use, and major habitat type.

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8. APPENDICES

Appendix A: Macrofaunal abundance data

Appendix B: Meiofaunal abundance data

Appendix C: Ecosystem processes data

Appendix D: Sediment characteristics data

Appendix E: Macrofaunal biomass data

Appendix F: List of Technical Publications

Appendix A. Macrofaunal abundance data, 2003. Taxa listed by sites and strata sampled in 2003. Mean number of individuals by taxon per core (area sampled = 130 cm^2; core depth = 25 cm). SE = standard error of mean; N = number of stations per site/stratum.

Chisman Creek Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Tubificoides brownae*	3.33	0.78	9
Annelida: Polychaeta	*Eteone heteropoda*	1.11	0.26	9
Annelida: Polychaeta	*Glycera americana*	0.11	0.11	9
Annelida: Polychaeta	*Glycera dibranchiata*	0.11	0.11	9
Annelida: Polychaeta	*Heteromastus filiformis*	1.33	0.50	9
Annelida: Polychaeta	*Laeonereis culveri*	0.11	0.11	9
Annelida: Polychaeta	*Leitoscoloplos fragilis*	1.11	0.35	9
Annelida: Polychaeta	Lumbrineridae	0.11	0.11	9
Annelida: Polychaeta	*Neanthes succinea*	1.44	0.18	9
Annelida: Polychaeta	*Paraprionospio pinnata*	0.56	0.18	9
Annelida: Polychaeta	Spionidae	0.11	0.11	9
Annelida: Polychaeta	*Streblospio benedicti*	41.11	8.76	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	18.67	2.42	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.11	0.11	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.11	0.11	9
Arthropoda: Insecta	Chironomidae	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	2.00	0.47	9
Mollusca: Bivalvia	*Macoma balthica*	3.11	0.81	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.11	0.11	9
Mollusca: Bivalvia	*Tagelus plebius*	0.11	0.11	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 2	1.78	0.36	9

Chisman Creek Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Tubificoides brownae*	0.78	0.46	9
Annelida: Polychaeta	*Brania wellfleetensis*	0.11	0.11	9
Annelida: Polychaeta	*Clymenella torquata*	5.33	1.70	9
Annelida: Polychaeta	*Drilonereis longa*	0.56	0.18	9
Annelida: Polychaeta	*Eteone heteropoda*	2.33	0.87	9
Annelida: Polychaeta	*Glycera americana*	5.56	1.11	9
Annelida: Polychaeta	*Glycera dibranchiata*	0.33	0.17	9
Annelida: Polychaeta	*Glycinde solitaria*	0.11	0.11	9
Annelida: Polychaeta	*Heteromastus filiformis*	21.44	4.79	9
Annelida: Polychaeta	*Leitoscoloplos fragilis*	2.89	0.86	9
Annelida: Polychaeta	*Marenzellaria viridis*	0.11	0.11	9
Annelida: Polychaeta	*Mediomastus ambiseta*	0.11	0.11	9
Annelida: Polychaeta	*Melinna maculata*	0.11	0.11	9
Annelida: Polychaeta	*Neanthes succinea*	0.22	0.15	9
Annelida: Polychaeta	*Paraprionospio pinnata*	0.11	0.11	9
Annelida: Polychaeta	*Pokarkeopsis levifuscina*	1.44	0.24	9
Annelida: Polychaeta	*Polydora cornuta*	0.11	0.11	9
Annelida: Polychaeta	*Scolelepis texana*	1.44	0.58	9
Annelida: Polychaeta	Spionidae	0.11	0.11	9
Annelida: Polychaeta	*Spiophanes bombyx*	1.44	0.53	9
Annelida: Polychaeta	*Streblospio benedicti*	68.44	7.39	9
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.11	0.11	9
Arthropoda: Amphipoda	*Corophium insidiosum*	0.22	0.15	9
Arthropoda: Amphipoda	*Listriella barnardi*	1.00	0.53	9
Arthropoda: Amphipoda	*Listriella clymenellae*	1.67	0.44	9
Arthropoda: Cumacea	*Campylapsis rubicunda*	0.33	0.17	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.22	0.15	9
Arthropoda: Cumacea	*Oxyurostylis smithi*	0.22	0.22	9
Arthropoda: Isopoda	*Edotea triloba*	0.33	0.17	9
Arthropoda: Mysidacea	*Neomysis americana*	4.67	2.44	9
Mollusca: Bivalvia	*Aligena elevata*	1.00	0.55	9
Mollusca: Bivalvia	*Macoma balthica*	3.67	0.97	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.22	0.22	9
Mollusca: Bivalvia	*Tagelus plebius*	0.11	0.11	9
Mollusca: Gastropoda	*Acetocina canaliculata*	0.11	0.11	9
Mollusca: Gastropoda	*Cylichna alba*	0.11	0.11	9
Nemertea	Nemertean	0.22	0.15	9
Nemertea	Nemertean sp. 2	0.22	0.15	9

Chisman Creek Far-Field, continued

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Phoronida	Phoronidae	3.78	2.37	9
Phoronida	Phoronis sp.	0.11	0.11	9
Turbellaria	Turbellaria sp. 1	0.22	0.22	9
Turbellaria	Turbellaria sp. 2	0.22	0.22	9

Elizabeth River Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Tubificoides wasselli*	0.11	0.11	9
Annelida: Polychaeta	*Hobsonia florida*	24.56	3.84	9
Annelida: Polychaeta	*Laeonereis culveri*	29.33	6.27	9
Annelida: Polychaeta	*Neanthes succinea*	1.22	0.32	9
Arthropoda: Isopoda	*Cyathura polita*	9.22	1.66	9

Elizabeth River Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	2.33	0.94	9
Annelida: Polychaeta	*Ampharete parvidentata*	0.11	0.11	9
Annelida: Polychaeta	Ampharetidae	0.67	0.33	9
Annelida: Polychaeta	*Capitella capitata*	0.11	0.11	9
Annelida: Polychaeta	*Capitomastus aciculatus*	0.78	0.43	9
Annelida: Polychaeta	*Eteone heteropoda*	1.67	0.87	9
Annelida: Polychaeta	*Glycera* sp.	0.11	0.11	9
Annelida: Polychaeta	*Heteromastus filiformis*	4.00	1.37	9
Annelida: Polychaeta	*Hobsonia florida*	1.00	0.41	9
Annelida: Polychaeta	*Laeonereis culveri*	4.00	1.50	9
Annelida: Polychaeta	*Leitoscoloplos fragilis*	1.44	0.58	9
Annelida: Polychaeta	*Marenzellaria viridis*	0.78	0.46	9
Annelida: Polychaeta	*Mediomastus ambiseta*	7.33	2.33	9
Annelida: Polychaeta	*Neanthes succinea*	0.11	0.11	9
Annelida: Polychaeta	Spionidae	0.56	0.38	9
Annelida: Polychaeta	*Streblospio benedicti*	1.11	0.81	9
Arthropoda: Amphipoda	*Corophium insidiosum*	0.11	0.11	9
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.22	0.15	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	3.00	0.55	9
Arthropoda: Isopoda	*Edotea triloba*	1.44	0.47	9
Arthropoda: Isopoda	Isopoda sp. 1	0.33	0.33	9
Arthropoda: Ostracoda	Ostracod sp. 1	0.11	0.11	9
Mollusca: Bivalvia	Bivalvia	0.11	0.11	9
Mollusca: Bivalvia	*Macoma balthica*	3.56	1.36	9
Mollusca: Bivalvia	*Macoma* spp.	0.11	0.11	9
Mollusca: Bivalvia	*Tagelus plebius*	0.44	0.24	9
Mollusca: Gastropoda	Gastropoda	0.11	0.11	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 1	0.11	0.11	9

Langley Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Paranais litoralis*	0.75	0.75	8
Annelida: Oligochaeta	Tubificidae	1.00	1.00	8
Annelida: Oligochaeta	*Tubificoides brownae*	10.63	3.92	8
Annelida: Oligochaeta	*Tubificoides heterochaetus*	0.25	0.16	8
Annelida: Oligochaeta	*Tubificoides motei*	0.13	0.13	8
Annelida: Oligochaeta	*Tubificoides sp.*	0.25	0.25	8
Annelida: Polychaeta	*Eteone heteropoda*	1.75	0.73	8
Annelida: Polychaeta	*Glycinde solitaria*	2.13	0.88	8
Annelida: Polychaeta	*Heteromastus filiformis*	2.25	0.77	8
Annelida: Polychaeta	*Hobsonia florida*	0.25	0.25	8
Annelida: Polychaeta	*Leitoscoloplos fragilis*	8.00	0.89	8
Annelida: Polychaeta	*Mediomastus ambiseta*	15.25	3.16	8
Annelida: Polychaeta	*Neanthes succinea*	2.13	0.79	8
Annelida: Polychaeta	*Paraprionospio pinnata*	1.25	0.41	8
Annelida: Polychaeta	*Pokarkeopsis levifuscina*	0.50	0.27	8
Annelida: Polychaeta	*Streblospio benedicti*	14.00	2.78	8
Annelida: Polychaeta	*Tharyx acutus*	0.25	0.16	8
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.13	0.13	8
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	1.38	0.63	8
Arthropoda: Cumacea	*Leucon americanus*	0.88	0.88	8
Arthropoda: Isopoda	*Cyathura polita*	0.75	0.49	8
Arthropoda: Isopoda	*Edotea triloba*	0.75	0.41	8
Arthropoda: Ostracoda	Ostracod sp. 1	0.38	0.26	8
Arthropoda: Ostracoda	Ostracod sp. 3	1.13	1.13	8
Cnidaria: Anthozoa	*Actinaria sp. 1*	0.25	0.25	8
Mollusca: Bivalvia	*Gemma gemma*	0.13	0.13	8
Mollusca: Bivalvia	*Macoma balthica*	0.63	0.26	8
Mollusca: Bivalvia	*Macoma mitchelli*	0.13	0.13	8
Mollusca: Bivalvia	*Macoma spp.*	0.38	0.26	8
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.13	0.13	8
Mollusca: Gastropoda	*Acteon punctostriatus*	0.13	0.13	8
Nemertea	Nemertean sp. 1	1.75	0.59	8
Nemertea	Nemertean sp. 2	1.00	0.42	8
Nemertea	Nemertean sp. 4	0.13	0.13	8
Nemertea	Nemertean sp. 5	0.13	0.13	8
Phoronida	*Phoronis sp.*	1.13	0.58	8
Turbellaria	Turbellaria sp. 1	0.50	0.38	8
Turbellaria	Turbellaria sp. 2	0.13	0.13	8
Turbellaria	Turbellaria sp. 3	0.13	0.13	8

Langley Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	1.33	0.53	9
Annelida: Polychaeta	*Capitella capitata*	0.11	0.11	9
Annelida: Polychaeta	*Chaetopterus variopedatus*	0.11	0.11	9
Annelida: Polychaeta	*Clymenella torquata*	1.11	0.59	9
Annelida: Polychaeta	*Drilonereis longa*	0.67	0.24	9
Annelida: Polychaeta	*Eteone heteropoda*	0.33	0.24	9
Annelida: Polychaeta	*Glycinde solitaria*	10.67	1.55	9
Annelida: Polychaeta	*Heteromastus filiformis*	2.22	0.57	9
Annelida: Polychaeta	*Leitoscoloplos fragilis*	1.67	0.53	9
Annelida: Polychaeta	*Loimia medusa*	0.11	0.11	9
Annelida: Polychaeta	*Marenzellaria viridis*	0.33	0.17	9
Annelida: Polychaeta	*Mediomastus ambiseta*	18.00	5.42	9
Annelida: Polychaeta	*Neanthes succinea*	0.11	0.11	9
Annelida: Polychaeta	*Pokarkeopsis levifuscina*	0.56	0.44	9
Annelida: Polychaeta	*Polydora cornuta*	0.11	0.11	9
Annelida: Polychaeta	*Scolelepis texana*	1.78	0.55	9
Annelida: Polychaeta	*Spiochaetopterus oculatus*	0.89	0.45	9
Annelida: Polychaeta	*Spiophanes bombyx*	0.11	0.11	9
Annelida: Polychaeta	*Streblospio benedicti*	10.89	3.07	9
Annelida: Polychaeta	*Tharyx acutus*	0.78	0.36	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.11	0.11	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella clymenellae*	0.67	0.37	9
Arthropoda: Ostracoda	Ostracod sp. 1	0.11	0.11	9
Mollusca: Bivalvia	*Aligena elevata*	2.33	1.17	9
Mollusca: Bivalvia	*Tagelus plebius*	0.11	0.11	9
Mollusca: Gastropoda	*Acetocina canaliculata*	0.22	0.15	9
Mollusca: Gastropoda	*Skeneopsis planorbis*	0.11	0.11	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 1	0.22	0.15	9
Nemertea	Nemertean sp. 2	0.67	0.33	9
Phoronida	*Phoronis* sp.	5.89	1.36	9
Turbellaria	Turbellaria sp. 2	0.56	0.29	9
Turbellaria	Turbellaria sp. 3	0.33	0.33	9

Sarah Creek Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Limnodriloides anxius*	0.33	0.17	9
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	21.44	6.89	9
Annelida: Oligochaeta	*Tubificoides motei*	1.11	0.51	9
Annelida: Polychaeta	*Capitella capitata*	2.67	1.04	9
Annelida: Polychaeta	*Capitomastus aciculatus*	9.33	3.11	9
Annelida: Polychaeta	*Eteone heteropoda*	4.89	1.95	9
Annelida: Polychaeta	*Heteromastus filiformis*	0.78	0.28	9
Annelida: Polychaeta	*Laeonereis culveri*	0.44	0.24	9
Annelida: Polychaeta	*Leitoscoloplos fragilis*	0.11	0.11	9
Annelida: Polychaeta	*Neanthes succinea*	0.22	0.15	9
Annelida: Polychaeta	*Pokarkeopsis levifuscina*	0.11	0.11	9
Annelida: Polychaeta	*Polydora cornuta*	0.11	0.11	9
Annelida: Polychaeta	*Streblospio benedicti*	28.67	7.62	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.11	0.11	9
Arthropoda: Insecta	Chironomidae	1.22	0.66	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 1	0.11	0.11	9
Nemertea	Nemertean sp. 2	0.11	0.11	9

Sarah Creek Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.89	0.45	9
Annelida: Oligochaeta	*Tubificoides motei*	0.11	0.11	9
Annelida: Polychaeta	*Amastigos caperatus*	0.22	0.22	9
Annelida: Polychaeta	*Ancistrosylis hartmanae*	0.11	0.11	9
Annelida: Polychaeta	*Apoprionspio dayi*	0.11	0.11	9
Annelida: Polychaeta	*Capitella capitata*	1.67	0.62	9
Annelida: Polychaeta	*Capitella jonesi*	1.00	0.47	9
Annelida: Polychaeta	*Capitomastus aciculatus*	3.00	0.91	9
Annelida: Polychaeta	*Clymenella torquata*	1.22	0.62	9
Annelida: Polychaeta	*Cossura longocirrata*	0.11	0.11	9
Annelida: Polychaeta	*Diopatra cuprea*	0.11	0.11	9
Annelida: Polychaeta	*Drilonereis longa*	0.22	0.15	9
Annelida: Polychaeta	*Eteone heteropoda*	2.22	0.55	9
Annelida: Polychaeta	*Glycera dibranchiata*	0.56	0.24	9
Annelida: Polychaeta	*Glycinde solitaria*	0.11	0.11	9
Annelida: Polychaeta	*Gyptis vittata*	0.11	0.11	9
Annelida: Polychaeta	*Heteromastus filiformis*	12.11	2.31	9
Annelida: Polychaeta	*Laeonereis culveri*	0.67	0.33	9
Annelida: Polychaeta	*Leitoscoloplos fragilis*	0.22	0.15	9
Annelida: Polychaeta	*Marenzellaria viridis*	0.33	0.24	9
Annelida: Polychaeta	*Mediomastus ambiseta*	1.00	0.44	9
Annelida: Polychaeta	*Neanthes succinea*	3.22	2.13	9
Annelida: Polychaeta	*Pokarkeopsis levifuscina*	0.33	0.24	9
Annelida: Polychaeta	*Polydora cornuta*	1.56	0.85	9
Annelida: Polychaeta	*Scolelepis texana*	2.11	0.96	9
Annelida: Polychaeta	*Scoloplos rubra*	0.11	0.11	9
Annelida: Polychaeta	*Spiophanes bombyx*	1.33	0.69	9
Annelida: Polychaeta	*Streblospio benedicti*	46.67	11.20	9
Annelida: Polychaeta	*Tharyx acutus*	0.78	0.36	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.22	0.22	9
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.33	0.17	9
Arthropoda: Amphipoda	*Cymadusa compta*	0.33	0.33	9
Arthropoda: Amphipoda	*Gammarus mucronatus*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.22	0.15	9
Arthropoda: Amphipoda	*Listriella clymenellae*	1.56	0.56	9
Arthropoda: Cumacea	*Campylapsis rubicunda*	0.89	0.54	9
Arthropoda: Cumacea	*Oxyurostylis smithi*	0.11	0.11	9
Arthropoda: Isopoda	*Edotea triloba*	1.56	1.08	9
Arthropoda: Isopoda	*Erichsonella attenuata*	0.22	0.15	9
Arthropoda: Mysidacea	*Neomysis americana*	2.22	0.81	9

Sarah Creek Far-Field, continued

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Mollusca: Bivalvia	*Aligena elevata*	0.22	0.15	9
Mollusca: Bivalvia	*Gemma gemma*	0.89	0.42	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.11	0.11	9
Mollusca: Bivalvia	*Tagelus plebius*	0.33	0.24	9
Nemertea	Nemertean sp. 2	0.22	0.15	9
Nemertea	Nemertean sp. 7	0.33	0.17	9
Phoronida	*Phoronis* sp.	11.00	4.34	9

Severn Thornton Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Tubificoides brownae*	3.88	1.41	8
Annelida: Oligochaeta	*Tubificoides motei*	0.13	0.13	8
Annelida: Oligochaeta	*Tubificoides wasselli*	3.25	1.37	8
Annelida: Polychaeta	*Bhawania heteroseta*	0.13	0.13	8
Annelida: Polychaeta	*Chaetopterus variopedatus*	0.25	0.25	8
Annelida: Polychaeta	*Clymenella torquata*	17.88	3.70	8
Annelida: Polychaeta	*Eteone heteropoda*	0.13	0.13	8
Annelida: Polychaeta	*Glycera americana*	0.13	0.13	8
Annelida: Polychaeta	*Glycera dibranchiata*	0.13	0.13	8
Annelida: Polychaeta	*Glycinde solitaria*	0.50	0.19	8
Annelida: Polychaeta	*Gyptis crypta*	0.25	0.25	8
Annelida: Polychaeta	*Hauchiella* sp.	0.13	0.13	8
Annelida: Polychaeta	*Heteromastus filiformis*	5.75	1.00	8
Annelida: Polychaeta	*Leitoscoloplos fragilis*	5.25	0.82	8
Annelida: Polychaeta	*Loimia medusa*	0.13	0.13	8
Annelida: Polychaeta	*Mediomastus ambiseta*	41.63	6.19	8
Annelida: Polychaeta	*Neanthes succinea*	1.25	0.49	8
Annelida: Polychaeta	*Notomastus* sp. A Ewing	2.13	0.85	8
Annelida: Polychaeta	*Parahesione luteola*	0.13	0.13	8
Annelida: Polychaeta	*Paraprionospio pinnata*	1.50	0.53	8
Annelida: Polychaeta	*Pokarkeopsis levifuscina*	4.50	1.39	8
Annelida: Polychaeta	*Polydora cornuta*	0.75	0.41	8
Annelida: Polychaeta	*Prionospio perkinsi*	0.13	0.13	8
Annelida: Polychaeta	*Spiochaetopterus oculatus*	0.38	0.26	8
Annelida: Polychaeta	*Streblospio benedicti*	7.50	1.92	8
Annelida: Polychaeta	Terebellidae	0.25	0.16	8
Annelida: Polychaeta	*Tharyx acutus*	0.38	0.18	8
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	2.13	0.61	8
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.13	0.13	8
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.13	0.13	8
Arthropoda: Amphipoda	*Listriella barnardi*	1.13	0.48	8
Arthropoda: Amphipoda	*Listriella clymenellae*	9.25	1.94	8
Arthropoda: Cumacea	*Leucon americanus*	0.13	0.13	8
Arthropoda: Isopoda	*Cyathura polita*	0.50	0.27	8
Arthropoda: Isopoda	*Edotea triloba*	0.13	0.13	8
Arthropoda: Ostracoda	Ostracod sp. 2	4.38	1.70	8
Arthropoda: Ostracoda	Ostracod sp. 4	0.13	0.13	8
Cnidaria: Anthozoa	Cnidaria	0.38	0.38	8
Mollusca: Bivalvia	*Aligena elevata*	24.63	5.63	8
Mollusca: Bivalvia	*Macoma balthica*	0.13	0.13	8
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	1.88	0.58	8

Severn Thornton Near-Field, continued

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Mollusca: Bivalvia	*Tagelus plebius*	0.13	0.13	8
Mollusca: Gastropoda	*Acetocina canaliculata*	0.38	0.26	8
Mollusca: Gastropoda	*Acteon punctostriatus*	0.13	0.13	8
Mollusca: Gastropoda	Gastropod sp. 4	0.50	0.38	8
Mollusca: Gastropoda	Gastropoda	0.13	0.13	8
Mollusca: Gastropoda	*Skeneopsis planorbis*	0.25	0.25	8
Nemertea	Nemertean	0.38	0.26	8
Nemertea	Nemertean sp. 2	0.25	0.25	8
Nemertea	Nemertean sp. 4	0.13	0.13	8
Nemertea	Nemertean sp. 6	0.13	0.13	8
Nemertea	Nemertean sp. 7	0.13	0.13	8
Phoronida	*Phoronis* sp.	10.88	3.55	8
Turbellaria	Turbellaria sp. 3	0.13	0.13	8

Severn Thornton Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Tubificoides brownae*	0.38	0.26	8
Annelida: Polychaeta	*Clymenella torquata*	9.25	2.06	8
Annelida: Polychaeta	*Drilonereis longa*	0.13	0.13	8
Annelida: Polychaeta	*Eteone heteropoda*	0.75	0.25	8
Annelida: Polychaeta	*Glycera dibranchiata*	0.38	0.18	8
Annelida: Polychaeta	*Glycinde solitaria*	0.63	0.42	8
Annelida: Polychaeta	*Heteromastus filiformis*	10.50	3.35	8
Annelida: Polychaeta	*Leitoscoloplos fragilis*	3.50	0.68	8
Annelida: Polychaeta	*Mediomastus ambiseta*	41.38	4.03	8
Annelida: Polychaeta	*Melinna maculata*	0.38	0.26	8
Annelida: Polychaeta	*Neanthes succinea*	0.63	0.32	8
Annelida: Polychaeta	*Notomastus* sp. A Ewing	0.13	0.13	8
Annelida: Polychaeta	*Paraprionospio pinnata*	0.13	0.13	8
Annelida: Polychaeta	*Pectinaria gouldi*	0.13	0.13	8
Annelida: Polychaeta	*Pokarkeopsis levifuscina*	0.63	0.32	8
Annelida: Polychaeta	*Scolelepis texana*	2.88	0.90	8
Annelida: Polychaeta	*Spiochaetopterus oculatus*	0.25	0.16	8
Annelida: Polychaeta	*Spiophanes bombyx*	2.25	0.53	8
Annelida: Polychaeta	*Streblospio benedicti*	5.63	0.53	8
Annelida: Polychaeta	*Tharyx acutus*	1.00	0.38	8
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	1.00	0.42	8
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.88	0.35	8
Arthropoda: Amphipoda	*Caprella penantis*	0.13	0.13	8
Arthropoda: Amphipoda	*Corophium ascheruscium*	0.25	0.16	8
Arthropoda: Amphipoda	*Corophium lacustre*	0.13	0.13	8
Arthropoda: Amphipoda	*Elamopus levis*	0.63	0.63	8
Arthropoda: Amphipoda	*Listriella barnardi*	0.25	0.16	8
Arthropoda: Amphipoda	*Listriella clymenellae*	0.50	0.33	8
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.13	0.13	8
Arthropoda: Mysidacea	*Americamysis bigelowi*	0.25	0.16	8
Arthropoda: Ostracoda	Ostracod sp. 1	0.25	0.25	8
Arthropoda: Ostracoda	Ostracod sp. 2	8.25	1.74	8
Cnidaria: Anthozoa	*Edwardsia elegans*	0.13	0.13	8
Mollusca: Bivalvia	*Aligena elevata*	7.00	1.65	8
Mollusca: Bivalvia	*Ensis directus*	0.13	0.13	8
Mollusca: Gastropoda	*Acetocina canaliculata*	0.25	0.25	8
Mollusca: Gastropoda	Gastropod sp. 3	0.13	0.13	8
Mollusca: Gastropoda	Gastropoda	0.38	0.26	8
Mollusca: Gastropoda	*Skeneopsis planorbis*	0.13	0.13	8
Nemertea	Nemertean sp. 1	0.13	0.13	8
Nemertea	Nemertean sp. 2	0.13	0.13	8

Severn Thornton Far-Field, continued

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Nemertea	Nemertean sp. 3	0.13	0.13	8
Nemertea	Nemertean sp. 7	0.13	0.13	8
Phoronida	*Phoronis* sp.	32.25	6.85	8
Turbellaria	Turbellaria sp. 3	0.13	0.13	8

Appendix A. Macrofaunal abundance data, 2004. Taxa listed by sites and strata sampled in 2004. Mean number of individuals by taxon per core (area sampled = 130 cm^2; core depth = 25 cm). SE = standard error of mean; N = number of stations per site/stratum.

Fort Eustis Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida	Annelida	0.08	0.08	12
Annelida: Hirudinae	Hirudinae	0.08	0.08	12
Annelida: Oligochaeta	*Linmodriloides anxius*	0.25	0.18	12
Annelida: Oligochaeta	*Paranais litoralis*	0.25	0.18	12
Annelida: Oligochaeta	*Tubificoides brownae*	0.17	0.11	12
Annelida: Oligochaeta	*Tubificoides heterochaetus*	253.83	54.50	12
Annelida: Polychaeta	*Fabricia sabella*	0.08	0.08	12
Annelida: Polychaeta	*Hobsonia florida*	6.75	2.30	12
Annelida: Polychaeta	*Laeonereis culveri*	2.17	1.26	12
Annelida: Polychaeta	*Marenzellaria viridis*	0.92	0.40	12
Annelida: Polychaeta	*Mediomastus ambiseta*	7.75	2.36	12
Annelida: Polychaeta	*Neanthes succinea*	0.17	0.11	12
Annelida: Polychaeta	*Polydora cornuta*	23.83	11.86	12
Annelida: Polychaeta	*Streblospio benedicti*	95.50	13.74	12
Arthropoda: Amphipoda	Amphipod	0.08	0.08	12
Arthropoda: Amphipoda	*Corophium lacustre*	0.58	0.58	12
Arthropoda: Amphipoda	*Corophium simile*	9.25	5.83	12
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	3.42	0.81	12
Arthropoda: Amphipoda	*Protohaustorius deichmannae*	0.17	0.17	12
Arthropoda: Decapoda	*Pagurus longicarpus*	0.42	0.26	12
Arthropoda: Decapoda	*Rithropanopeus harrisii*	0.33	0.19	12
Arthropoda: Insecta	Chironomidae	0.17	0.11	12
Arthropoda: Insecta	Chironominae	0.17	0.17	12
Arthropoda: Insecta	*Chironomus sp.*	0.08	0.08	12
Arthropoda: Insecta	Insecta	0.08	0.08	12
Arthropoda: Insecta	*Parachironomus directus*	0.08	0.08	12
Arthropoda: Insecta	*Peltoperla*	0.17	0.11	12
Arthropoda: Insecta	*Probezzia* sp.	0.08	0.08	12
Arthropoda: Insecta	*Pseudochironomus* sp.	0.50	0.36	12
Arthropoda: Insecta	Tanypodinae	0.25	0.13	12
Arthropoda: Insecta	*Tanypus neopunctipennis*	0.08	0.08	12

Fort Eustis Near-Field, continued

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Arthropoda: Isopoda	*Cyathura polita*	0.42	0.19	12
Arthropoda: Isopoda	*Edotea triloba*	3.00	1.44	12
Arthropoda: Ostracoda	Ostracoda sp. 1	0.75	0.33	12
Arthropoda: Ostracoda	Ostracoda sp. 3	1.50	0.60	12
Arthropoda: Ostracoda	Ostracoda sp. 5	0.67	0.36	12
Arthropoda: Ostracoda	Ostracoda sp.6	0.25	0.18	12
Mollusca: Gastropoda	*Assiminea succinae*	0.92	0.75	12
Mollusca: Gastropoda	Gastropod sp. 5	0.33	0.22	12
Mollusca: Gastropoda	Gastropod sp. 6	0.25	0.18	12
Mollusca: Gastropoda	Gastropoda	0.92	0.38	12
Mollusca: Bivalvia	*Congaria leucophaeta*	0.33	0.26	12
Mollusca: Bivalvia	*Gemma gemma*	0.08	0.08	12
Mollusca: Bivalvia	*Macoma balthica*	0.17	0.11	12
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	1.67	0.69	12
Mollusca: Bivalvia	*Mulinea lateralis*	2.00	0.74	12
Nemertea	Nemertea sp. 1	0.08	0.08	12
Nemertea	Nemertea sp. 2	0.67	0.28	12
Turbellaria	Turbellaria	0.08	0.08	12
Turbellaria	Turbellarian sp. 3	0.08	0.08	12
Turbellaria	Turbellarian sp. 5	0.33	0.22	12
Turbellaria	Turbellarian sp. 7	0.08	0.08	12

Fort Eustis Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Tubificoides heterochaetus*	1.92	0.77	12
Annelida: Polychaeta	*Heteromastus filiformis*	2.42	0.45	12
Annelida: Polychaeta	*Laeonereis culveri*	8.42	1.25	12
Annelida: Polychaeta	*Marenzellaria viridis*	7.00	1.26	12
Annelida: Polychaeta	*Mediomastus ambiseta*	0.08	0.08	12
Annelida: Polychaeta	*Polydora cornuta*	0.08	0.08	12
Annelida: Polychaeta	*Streblospio benedicti*	8.92	1.28	12
Arthropoda: Amphipoda	*Corophium simile*	0.17	0.17	12
Arthropoda: Amphipoda	Gammaridea	0.17	0.17	12
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	10.83	1.01	12
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.08	0.08	12
Arthropoda: Amphipoda	*Protohaustorius deichmannae*	16.67	1.79	12
Arthropoda: Insecta	*Cryptochironomus* sp.	0.33	0.19	12
Arthropoda: Isopoda	*Cyathura polita*	1.33	0.26	12
Cnidaria: Anthozoa	Actinaria juv.	0.08	0.08	12
Cnidaria: Scyphazoa	Scyphazoa	0.25	0.25	12
Mollusca: Gastropoda	Gastropod sp. 6	0.17	0.17	12
Mollusca: Gastropoda	Gastropoda	0.25	0.18	12
Mollusca: Bivalvia	*Congaria leucophaeta*	0.08	0.08	12
Mollusca: Bivalvia	*Gemma gemma*	0.08	0.08	12
Mollusca: Bivalvia	*Macoma balthica*	0.08	0.08	12
Mollusca: Bivalvia	*Mulinea lateralis*	0.92	0.57	12
Mollusca: Bivalvia	*Rangia cuneata*	1.25	0.39	12
Nemertea	Nemertea sp. 2	0.33	0.33	12
Phoronida	Phoronidaae	0.58	0.58	12
Turbellaria	Turbellarian sp. 5	0.08	0.08	12

Monie Bay Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Linmodriloides anxius*	4.67	2.27	9
Annelida: Oligochaeta	*Paranais litoralis*	0.33	0.17	9
Annelida: Oligochaeta	*Tubificoides brownae*	55.78	18.25	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	269.11	37.89	9
Annelida: Polychaeta	*Eteone heteropoda*	5.78	0.98	9
Annelida: Polychaeta	*Glycinde solitaria*	0.11	0.11	9
Annelida: Polychaeta	*Hesionidae*	0.44	0.44	9
Annelida: Polychaeta	*Heteromastus filiformis*	2.78	0.74	9
Annelida: Polychaeta	*Hobsonia florida*	3.56	1.33	9
Annelida: Polychaeta	*Laeonereis culveri*	0.78	0.36	9
Annelida: Polychaeta	*Marenzellaria viridis*	0.33	0.17	9
Annelida: Polychaeta	*Neanthes succinea*	1.44	0.44	9
Annelida: Polychaeta	*Streblospio benedicti*	15.56	2.07	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.11	0.11	9
Arthropoda: Amphipoda	Amphipoda	0.33	0.33	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	38.00	4.91	9
Arthropoda: Amphipoda	*Rudilemboides naglei*	0.78	0.78	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.33	0.17	9
Arthropoda: Cumacea	*Leucon americanus*	0.89	0.39	9
Arthropoda: Decapoda	*Rithropanopeus harrisii*	0.11	0.11	9
Arthropoda: Insecta	Chironomidae	0.11	0.11	9
Arthropoda: Insecta	Chironominae	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	6.33	2.03	9
Arthropoda: Isopoda	*Edotea triloba*	2.00	0.85	9
Arthropoda: Isopoda	Isopoda sp. 1	0.33	0.33	9
Arthropoda: Ostracoda	Ostracoda sp. 1	6.44	3.66	9
Arthropoda: Ostracoda	Ostracoda sp. 5	0.22	0.22	9
Arthropoda: Ostracoda	Ostracoda sp.6	1.11	0.99	9
Cnidaria: Anthozoa	*Edwardsia elegans*	5.22	1.69	9
Mollusca: Gastropoda	*Assiminea succinae*	0.22	0.15	9
Mollusca: Bivalvia	*Gemma gemma*	0.11	0.11	9
Mollusca: Bivalvia	*Macoma balthica*	0.33	0.24	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	1.89	0.90	9
Mollusca: Bivalvia	*Mulinia lateralis*	0.89	0.89	9
Mollusca: Bivalvia	*Mya arenaria*	3.44	1.53	9
Nemertea	Nemertea sp. 1	1.00	0.58	9
Nemertea	Nemertea sp. 2	0.78	0.22	9
Porifera	Porifera	0.11	0.11	9

Monie Bay Near-Field, continued

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Turbellaria	Turbellaria sp. 4	1.00	0.37	9
Turbellaria	Turbellaria sp. 6	0.56	0.29	9
Turbellaria	Turbellarian sp. 3	0.11	0.11	9
Turbellaria	Turbellarian sp. 5	7.44	2.36	9

Monie Bay Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Hirudinae	Hirudinae	0.75	0.41	8
Annelida: Oligochaeta	*Linmodriloides anxius*	0.13	0.13	8
Annelida: Oligochaeta	*Tubificoides brownae*	26.63	4.28	8
Annelida: Polychaeta	*Eteone heteropoda*	0.50	0.27	8
Annelida: Polychaeta	*Glycera dibranchiata*	0.13	0.13	8
Annelida: Polychaeta	*Glycinde solitaria*	1.13	0.40	8
Annelida: Polychaeta	*Heteromastus filiformis*	6.75	1.39	8
Annelida: Polychaeta	*Laeonereis culveri*	3.38	0.75	8
Annelida: Polychaeta	*Leitoscoloplos fragilis*	0.13	0.13	8
Annelida: Polychaeta	*Marenzellaria viridis*	10.00	1.38	8
Annelida: Polychaeta	*Neanthes succinea*	19.75	2.79	8
Annelida: Polychaeta	*Paraonis fulgens*	0.13	0.13	8
Annelida: Polychaeta	*Streblospio benedicti*	1.63	0.46	8
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.25	0.16	8
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.63	0.42	8
Arthropoda: Cumacea	*Leucon americanus*	0.13	0.13	8
Arthropoda: Isopoda	*Cyathura polita*	0.25	0.16	8
Arthropoda: Ostracoda	Ostracod sp. 1	21.38	9.78	8
Arthropoda: Ostracoda	Ostracod sp.6	0.38	0.38	8
Arthropoda: Ostracoda	Ostracod sp.7	0.13	0.13	8
Mollusca: Bivalvia	Bivalve sp. 1	1.13	0.58	8
Mollusca: Bivalvia	Bivalvia	0.63	0.63	8
Mollusca: Bivalvia	*Gemma gemma*	97.50	42.58	8
Mollusca: Bivalvia	*Macoma balthica*	1.13	0.52	8
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	2.88	1.51	8
Mollusca: Bivalvia	*Mulinia lateralis*	5.13	2.49	8
Mollusca: Gastropod	*Assiminea succinae*	0.50	0.38	8
Mollusca: Gastropod	Gastropod sp. 8	1.38	0.84	8
Mollusca: Gastropod	Gastropoda	0.25	0.16	8
Nemertea	Nemertean sp. 1	25.63	9.71	8
Nemertea	Nemertean sp. 7	11.25	8.28	8
Turbellaria	Turbellarian sp. 5	0.38	0.26	8

Pagan River Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Ilyodrilus templetoni*	0.22	0.15	9
Annelida: Oligochaeta	*Monopylephorus rubroniveus*	0.89	0.56	9
Annelida: Oligochaeta	*Nais variabilis*	1.11	0.39	9
Annelida: Oligochaeta	*Pristina idrensis*	1.33	0.58	9
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	74.67	26.31	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	671.22	145.12	9
Annelida: Oligochaeta	*Tubificoides motei*	0.44	0.44	9
Annelida: Polychaeta	*Heteromastus filiformis*	0.33	0.24	9
Annelida: Polychaeta	*Laeonereis culveri*	1.00	0.44	9
Annelida: Polychaeta	*Mediomastus ambiseta*	13.22	3.55	9
Annelida: Polychaeta	*Neanthes succinea*	0.44	0.24	9
Annelida: Polychaeta	*Streblospio benedicti*	35.00	8.75	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.11	0.11	9
Arthropoda: Amphipoda	Amphipoda	0.11	0.11	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	1.11	0.42	9
Arthropoda: Amphipoda	*Paraphoxus spinosis*	0.33	0.33	9
Arthropoda: Amphipoda	*Protohaustorius deichmannae*	0.11	0.11	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.11	0.11	9
Arthropoda: Decapoda	*Pagurus longicarpus*	0.11	0.11	9
Arthropoda: Insecta	*Chironomus* sp.	0.11	0.11	9
Arthropoda: Insecta	Insecta	0.11	0.11	9
Arthropoda: Insecta	*Pseudochironomus* sp.	0.11	0.11	9
Arthropoda: Insecta	Tanypodinae	0.22	0.22	9
Arthropoda: Insecta	*Tanypus carinatus*	0.22	0.22	9
Arthropoda: Insecta	*Tanypus neopunctipennis*	0.22	0.22	9
Arthropoda: Insecta	*Tanypus stellatis*	0.11	0.11	9
Arthropoda: Isopoda	*Edotea triloba*	0.11	0.11	9
Mollusca	Mollusca	0.11	0.11	9
Mollusca: Bivalvia	Bivalvia	0.11	0.11	9
Mollusca: Bivalvia	*Congaria leucophaeta*	0.33	0.24	9
Mollusca: Bivalvia	*Gemma gemma*	0.22	0.15	9
Mollusca: Bivalvia	*Macoma balthica*	0.78	0.32	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	5.89	1.05	9
Mollusca: Bivalvia	*Mulinia lateralis*	0.33	0.24	9
Mollusca: Bivalvia	*Rangia cuneata*	0.11	0.11	9
Nemertea	Nemertean sp. 2	0.33	0.17	9
Turbellaria	Turbellarian sp. 5	0.11	0.11	9

Pagan River Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Hirudinae	Hirudinae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	4.67	1.57	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	16.22	2.52	9
Annelida: Polychaeta	*Glycinde solitaria*	1.67	0.41	9
Annelida: Polychaeta	*Heteromastus filiformis*	3.22	0.57	9
Annelida: Polychaeta	*Laeonereis culveri*	11.11	3.13	9
Annelida: Polychaeta	*Marenzellaria viridis*	3.67	1.03	9
Annelida: Polychaeta	*Mediomastus ambiseta*	47.67	5.21	9
Annelida: Polychaeta	*Neanthes succinea*	2.00	0.44	9
Annelida: Polychaeta	Spionidae	0.11	0.11	9
Annelida: Polychaeta	*Streblospio benedicti*	8.44	1.21	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	18.44	5.25	9
Mollusca: Gastropoda	*Acteocina canaliculata*	0.11	0.11	9
Mollusca: Gastropoda	*Acteon punctostriatus*	0.44	0.24	9
Mollusca: Gastropoda	*Assiminea succinae*	0.11	0.11	9
Mollusca: Gastropoda	Gastropod sp. 6	0.11	0.11	9
Mollusca: Gastropoda	Gastropod sp 8	1.44	0.41	9
Mollusca: Gastropoda	Gastropod sp. 9	0.44	0.34	9
Mollusca: Bivalvia	*Gemma gemma*	0.89	0.39	9
Mollusca: Bivalvia	*Macoma balthica*	12.11	1.46	9
Mollusca: Bivalvia	*Macoma mitchelli*	0.22	0.15	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.22	0.15	9
Mollusca: Bivalvia	*Mulinia lateralis*	0.11	0.11	9
Mollusca: Bivalvia	*Rangia cuneata*	0.22	0.15	9
Nemertea	Nemertea sp. 1	0.33	0.33	9
Nemertea	Nemertea sp. 2	0.78	0.36	9
Turbellaria	Turbellarian sp. 5	0.22	0.22	9

Patuxent River Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Linmodriloides anxius*	2.78	1.47	9
Annelida: Oligochaeta	*Paranais litoralis*	1.22	0.60	9
Annelida: Oligochaeta	*Tubificoides brownae*	5.89	1.30	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	8.00	2.68	9
Annelida: Polychaeta	*Eteone heteropoda*	1.78	0.36	9
Annelida: Polychaeta	*Heteromastus filiformis*	1.67	0.47	9
Annelida: Polychaeta	*Hobsonia florida*	0.11	0.11	9
Annelida: Polychaeta	*Laeonereis culveri*	2.33	1.12	9
Annelida: Polychaeta	*Marenzellaria viridis*	13.22	1.66	9
Annelida: Polychaeta	*Mediomastus ambiseta*	0.11	0.11	9
Annelida: Polychaeta	*Neanthes succinea*	2.00	0.58	9
Annelida: Polychaeta	*Streblospio benedicti*	308.33	56.26	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	53.56	6.60	9
Arthropoda: Cumacea	*Cyclaspis varians*	1.56	0.56	9
Arthropoda: Insecta	*Chironomus* sp.	0.56	0.18	9
Arthropoda: Insecta	*Palpomyia*	0.11	0.11	9
Arthropoda: Insecta	Tanypodinae	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	3.44	0.67	9
Arthropoda: Isopoda	*Edotea triloba*	0.44	0.34	9
Arthropoda: Mysidacea	Mysidacea	0.11	0.11	9
Arthropoda: Mysidacea	*Mysidaceaopsis bigelowi*	0.33	0.33	9
Arthropoda: Ostracoda	Ostracoda sp.6	3.22	2.13	9
Arthropoda: Tanaidacea	*Leptochelia rapax*	0.11	0.11	9
Mollusca: Gastropoda	Gastropoda	0.11	0.11	9
Mollusca: Bivalvia	*Macoma balthica*	1.22	0.66	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	5.56	2.40	9
Turbellaria	Turbellarian sp. 5	0.11	0.11	9

Patuxent River Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Linmodriloides anxius*	5.00	1.14	9
Annelida: Oligochaeta	*Tubificoides brownae*	11.89	4.43	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	1.22	0.98	9
Annelida: Polychaeta	*Eteone heteropoda*	7.00	0.97	9
Annelida: Polychaeta	*Heteromastus filiformis*	11.67	2.79	9
Annelida: Polychaeta	*Hobsonia florida*	0.11	0.11	9
Annelida: Polychaeta	*Laeonereis culveri*	11.11	2.12	9
Annelida: Polychaeta	*Marenzellaria viridis*	31.00	3.21	9
Annelida: Polychaeta	*Neanthes succinea*	24.44	4.35	9
Annelida: Polychaeta	*Polydora cornuta*	1.78	1.78	9
Annelida: Polychaeta	*Streblospio benedicti*	34.67	5.64	9
Arthropoda: Amphipoda	*Corophium lacustre*	0.56	0.56	9
Arthropoda: Amphipoda	*Corophium simile*	0.11	0.11	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	5.67	2.05	9
Arthropoda: Cumacea	*Cyclaspis varians*	4.67	1.69	9
Arthropoda: Decapoda	*Rithropanopeus harrisii*	0.89	0.65	9
Arthropoda: Insecta	Chironominae	0.44	0.34	9
Arthropoda: Insecta	*Polypedilum scalaenum*	0.22	0.22	9
Arthropoda: Insecta	*Pseudochironomus* sp.	0.56	0.24	9
Arthropoda: Insecta	Tanypodinae	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	6.44	0.84	9
Arthropoda: Isopoda	*Edotea triloba*	1.33	0.71	9
Arthropoda: Mysidacea	*Mysidaceaopsis bigelowi*	0.33	0.17	9
Arthropoda: Ostracoda	Ostracoda sp.7	0.44	0.44	9
Arthropoda: Tanaidacea	*Leptochelia rapax*	23.89	11.18	9
Cnidaria: Anthozoa	*Edwardsia elegans*	0.22	0.15	9
Mollusca: Bivalvia	*Gemma gemma*	3.11	2.28	9
Mollusca: Bivalvia	*Macoma balthica*	2.78	0.66	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	4.44	2.03	9
Mollusca: Bivalvia	*Mulinea lateralis*	0.11	0.11	9
Mollusca: Bivalvia	*Mya arenaria*	0.33	0.17	9
Mollusca: Bivalvia	*Rangia cuneata*	0.11	0.11	9
Nemertea	Nemertea sp. 1	0.11	0.11	9
Nemertea	Nemertea sp. 8	0.22	0.22	9
Turbellaria	Turbellaria sp. 4	0.11	0.11	9

Appendix A. Macrofaunal abundance data, 2005. Taxa listed by sites and strata sampled in 2005. Mean number of individuals by taxon per core (area sampled = 130 cm^2; core depth = 25 cm). SE = standard error of mean; N = number of stations per site/stratum.

Anacostia Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Hirudinae	Hirudinae	6.38	3.32	8
Annelida: Oligochaeta	*Aulodrilus pigueti*	22.00	7.02	8
Annelida: Oligochaeta	*Branchiura sowerbyi*	14.88	2.73	8
Annelida: Oligochaeta	*Dero digitata*	41.63	10.40	8
Annelida: Oligochaeta	*Ilyodrilus templetoni*	108.50	22.33	8
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	318.50	49.31	8
Annelida: Oligochaeta	*Pristinella jenkinae*	0.13	0.13	8
Annelida: Oligochaeta	*Spirosperma ferox*	3.50	2.18	8
Arthropoda: Cladocera	Cladocera	33.63	6.19	8
Arthropoda: Insecta	Chironomidae	0.13	0.13	8
Arthropoda: Insecta	*Chironomus sp.*	6.00	1.63	8
Arthropoda: Insecta	*Coelotanypus* sp.	4.75	1.67	8
Arthropoda: Insecta	*Procladius* sp.	25.88	6.90	8
Arthropoda: Insecta	Tanypodinae	0.38	0.38	8
Arthropoda: Insecta	*Tanypus neopunctipennis*	0.25	0.25	8
Arthropoda: Insecta	*Tanypus* sp.	1.13	0.74	8
Mollusca: Bivalvia	*Corbicula manilensis*	1.38	0.60	8
Mollusca: Bivalvia	*Musculium transversum*	0.13	0.13	8
Mollusca: Bivalvia	*Pisidium* sp. 1	2.13	0.99	8
Mollusca: Bivalvia	*Sphaerium rhomboideum*	1.13	0.48	8
Turbellaria	Turbellaria	0.25	0.25	8

Anacostia Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Hirudinae	Hirudinae	0.89	0.31	9
Annelida: Oligochaeta	*Aulodrilus pigueti*	162.78	54.75	9
Annelida: Oligochaeta	*Branchiura sowerbyi*	0.89	0.54	9
Annelida: Oligochaeta	*Dero digitata*	41.89	9.36	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	111.00	43.10	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	531.44	116.02	9
Annelida: Oligochaeta	*Pristina breviseta*	0.22	0.15	9
Annelida: Oligochaeta	*Spirosperma ferox*	3.78	1.28	9
Arthropoda: Amphipoda	*Gammarus lacustris*	0.44	0.44	9
Arthropoda: Cladocera	Cladocera	18.56	5.89	9
Arthropoda: Insecta	*Caenis* sp.	0.33	0.24	9
Arthropoda: Insecta	Chironomidae	0.11	0.11	9
Arthropoda: Insecta	*Chironomus* sp.	32.56	6.82	9
Arthropoda: Insecta	*Coelotanypus* sp.	1.44	0.97	9
Arthropoda: Insecta	*Dicrotendipes modestus*	0.44	0.44	9
Arthropoda: Insecta	*Polypedilum halterale* group	1.44	0.58	9
Arthropoda: Insecta	*Polypedilum* sp.	0.22	0.22	9
Arthropoda: Insecta	*Procladius* sp.	14.44	2.81	9
Arthropoda: Insecta	*Tanypus* sp.	1.22	0.49	9
Arthropoda: Insecta	*Tanytarsus* sp.	0.11	0.11	9
Mollusca: Bivalvia	*Corbicula manilensis*	8.00	3.43	9
Mollusca: Bivalvia	*Musculium transversum*	0.33	0.17	9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.33	0.24	9
Turbellaria	Turbellaria	0.78	0.43	9
Turbellaria	Turbellarian sp. 5	0.22	0.22	9

Aberdeen Proving Ground Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Hirudinae	Hirudinae	0.22	0.22	9
Annelida: Oligochaeta	*Aulodrilus pigueti*	6.33	2.00	9
Annelida: Oligochaeta	*Dero (Aulophorus) flabelliger*	8.11	2.93	9
Annelida: Oligochaeta	*Dero digitata*	1.11	0.39	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	50.56	6.35	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	64.00	11.54	9
Annelida: Oligochaeta	*Nais behningi*	0.11	0.11	9
Annelida: Oligochaeta	*Pristina leidyi*	0.11	0.11	9
Annelida: Oligochaeta	*Slavina appendiculata*	5.89	2.31	9
Annelida: Oligochaeta	*Spirosperma ferox*	0.33	0.33	9
Annelida: Oligochaeta	*Stylaria lacustris*	0.56	0.34	9
Arthropoda: Amphipoda	*Gammarus lacustris*	3.44	1.26	9
Arthropoda: Cladocera	Cladocera	0.22	0.15	9
Arthropoda: Insecta	Arthropoda: Insecta	0.22	0.15	9
Arthropoda: Insecta	*Caenis* sp.	0.11	0.11	9
Arthropoda: Insecta	Chironomidae	0.11	0.11	9
Arthropoda: Insecta	*Chironomus* sp.	0.44	0.44	9
Arthropoda: Insecta	*Cladopelma* sp.	0.11	0.11	9
Arthropoda: Insecta	*Cladotanytarsus* sp.	0.11	0.11	9
Arthropoda: Insecta	*Cladotanytarsus* sp. A	0.44	0.34	9
Arthropoda: Insecta	*Cladotanytarsus* sp. B	0.22	0.22	9
Arthropoda: Insecta	*Clinotanypus* sp.	2.33	1.00	9
Arthropoda: Insecta	*Dicrotendipes modestus*	0.56	0.44	9
Arthropoda: Insecta	Ephemeroptera	0.11	0.11	9
Arthropoda: Insecta	Palpomyia	0.22	0.15	9
Arthropoda: Insecta	*Polypedilum halterale* group	0.11	0.11	9
Arthropoda: Insecta	*Procladius (Holotanypus)* sp.	0.11	0.11	9
Arthropoda: Insecta	Tanypodinae	0.22	0.15	9
Arthropoda: Insecta	*Tanypus punctipennis*	0.22	0.15	9
Arthropoda: Insecta	*Tanypus* sp.	0.22	0.22	9
Arthropoda: Insecta	*Tanytarsus* sp.	0.67	0.24	9
Arthropoda: Insecta	Trichoptera	0.33	0.33	9
Arthropoda: Insecta	Zavreliella sp.	2.56	1.29	9
Mollusca: Bivalvia	*Corbicula manilensis*	2.22	0.95	9
Mollusca: Bivalvia	Sphaerium sp.	0.11	0.11	9

Aberdeen Proving Ground Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.22	0.15	9
Annelida: Oligochaeta	*Dero digitata*	0.22	0.22	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	5.00	2.41	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	42.78	11.87	9
Annelida: Oligochaeta	*Nais communis*	0.22	0.15	9
Annelida: Oligochaeta	*Paranais litoralis*	0.89	0.56	9
Arthropoda: Amphipoda	*Gammarus lacustris*	5.33	4.05	9
Arthropoda: Cumacea	*Cyclaspis varians*	3.78	2.93	9
Arthropoda: Insecta	*Cladotanytarsus* sp.	8.56	5.93	9
Arthropoda: Insecta	*Cladotanytarsus* sp. A	2.00	1.09	9
Arthropoda: Insecta	*Cladotanytarsus* sp. B	10.67	4.57	9
Arthropoda: Insecta	*Cladotanytarsus* sp. F	0.67	0.33	9
Arthropoda: Insecta	*Clinotanypus* sp.	0.11	0.11	9
Arthropoda: Insecta	*Cryptochironomus* sp.	2.67	0.88	9
Arthropoda: Insecta	*Dicrotendipes modestus*	1.56	1.43	9
Arthropoda: Insecta	*Polypedilum bergi*	0.11	0.11	9
Arthropoda: Insecta	*Polypedilum halterale* group	22.44	5.21	9
Arthropoda: Insecta	*Polypedilum tritum*	0.22	0.15	9
Arthropoda: Insecta	*Stempellina* sp.	0.11	0.11	9
Arthropoda: Insecta	*Tanytarsus* sp.	0.56	0.44	9
Arthropoda: Insecta	Trichoptera	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	0.22	0.22	9
Mollusca: Bivalvia	*Corbicula manilensis*	2.89	1.12	9
Mollusca: Bivalvia	*Rangia cuneata*	0.11	0.11	9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.11	0.11	9
Mollusca: Bivalvia	*Sphaerium* sp.	0.11	0.11	9

Quantico Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Aulodrilus pigueti*	15.44	4.38	9
Annelida: Oligochaeta	*Branchiura sowerbyi*	2.22	0.60	9
Annelida: Oligochaeta	*Dero digitata*	4.44	1.13	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	4.89	0.98	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	10.56	2.44	9
Annelida: Oligochaeta	*Pristinella longisoma*	0.11	0.11	9
Annelida: Oligochaeta	*Stylaria lacustris*	0.22	0.15	9
Annelida: Polychaeta	*Laeonereis culveri*	0.11	0.11	9
Arthropoda: Amphipoda	*Gammarus lacustris*	0.67	0.37	9
Arthropoda: Arachnid	Hydracarina	1.11	0.81	9
Arthropoda: Cladocera	Cladocera	7.89	2.01	9
Arthropoda: Insecta	Chironomidae	0.56	0.34	9
Arthropoda: Insecta	*Chironomus* sp.	2.11	1.14	9
Arthropoda: Insecta	*Cladopelma* sp.	0.33	0.17	9
Arthropoda: Insecta	*Clinotanypus* sp.	0.11	0.11	9
Arthropoda: Insecta	*Coelotanypus* sp.	0.67	0.44	9
Arthropoda: Insecta	*Cryptochironomus* sp.	1.67	0.55	9
Arthropoda: Insecta	*Cryptotendipes*	1.67	0.76	9
Arthropoda: Insecta	*Dicrotendipes modestus*	1.56	1.08	9
Arthropoda: Insecta	*Hyporhygma quadrapunctatum*	0.11	0.11	9
Arthropoda: Insecta	*Polypedilum halterale* group	0.56	0.24	9
Arthropoda: Insecta	*Polypedilum* sp.	0.22	0.22	9
Arthropoda: Insecta	*Probezzia* sp.	0.11	0.11	9
Arthropoda: Insecta	*Procladius* sp.	6.44	0.73	9
Arthropoda: Insecta	Tanypodinae	0.11	0.11	9
Arthropoda: Insecta	*Tanypus punctipennis*	0.56	0.56	9
Arthropoda: Insecta	*Tanytarsus* sp.	6.56	1.56	9
Arthropoda: Insecta	*Zavreliella* sp.	0.11	0.11	9
Mollusca: Bivalvia	*Corbicula manilensis*	0.33	0.24	9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.22	0.22	9
Mollusca: Gastropoda	*Amnicola limnosa*	13.89	8.41	9

Quantico Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Aulodrilus pigueti*	3.22	2.19	9
Annelida: Oligochaeta	*Branchiura sowerbyi*	0.56	0.29	9
Annelida: Oligochaeta	*Dero (Aulophorus) flabelliger*	1.44	0.88	9
Annelida: Oligochaeta	*Dero digitata*	11.89	4.09	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	14.56	3.20	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	131.00	30.21	9
Annelida: Oligochaeta	*Nais communis*	5.22	3.18	9
Annelida: Oligochaeta	*Paranais litoralis*	0.56	0.56	9
Annelida: Oligochaeta	*Pristina breviseta*	0.33	0.24	9
Annelida: Oligochaeta	*Pristina leidyi*	0.11	0.11	9
Annelida: Oligochaeta	*Slavina appendiculata*	0.78	0.43	9
Annelida: Oligochaeta	*Stephensoniana trivandrana*	1.00	0.50	9
Annelida: Polychaeta	*Heteromastus filiformis*	0.11	0.11	9
Arthropoda: Amphipoda	*Gammarus lacustris*	9.44	3.95	9
Arthropoda: Arachnid	Hydracarina	0.33	0.17	9
Arthropoda: Cladocera	Cladocera	10.44	2.68	9
Arthropoda: Insecta	*Ablabesmyia (Karelia)* sp.	0.11	0.11	9
Arthropoda: Insecta	*Apedilum* sp.	0.11	0.11	9
Arthropoda: Insecta	Arthropoda: Insecta	0.11	0.11	9
Arthropoda: Insecta	*Caenis* sp.	8.33	1.05	9
Arthropoda: Insecta	Chironomidae	0.44	0.24	9
Arthropoda: Insecta	*Cladopelma* sp.	0.33	0.17	9
Arthropoda: Insecta	*Cladotanytarsus* sp.	0.33	0.24	9
Arthropoda: Insecta	*Cladotanytarsus* sp. A	1.11	0.51	9
Arthropoda: Insecta	*Cladotanytarsus* sp. B	18.33	11.88	9
Arthropoda: Insecta	*Cladotanytarsus* sp. F	0.33	0.24	9
Arthropoda: Insecta	*Clinotanypus* sp.	1.78	1.01	9
Arthropoda: Insecta	*Coelotanypus* sp.	1.67	1.03	9
Arthropoda: Insecta	*Cryptochironomus* sp.	10.22	2.45	9
Arthropoda: Insecta	*Cryptotendipes*	1.56	0.38	9
Arthropoda: Insecta	*Dicrotendipes modestus*	2.22	0.60	9
Arthropoda: Insecta	*Endochironomus* sp.	0.11	0.11	9
Arthropoda: Insecta	*Labrundinia* sp.	0.11	0.11	9
Arthropoda: Insecta	*Palpomyia*	0.44	0.29	9
Arthropoda: Insecta	*Paratendipes albimanus*	0.11	0.11	9
Arthropoda: Insecta	*Polypedilum halterale* group	19.78	5.29	9
Arthropoda: Insecta	*Probezzia* sp.	0.89	0.31	9
Arthropoda: Insecta	*Procladius (Holotanypus)* sp.	0.11	0.11	9

Quantico Far-Field, continued

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Arthropoda: Insecta	*Procladius* sp.	4.67	1.74	9
Arthropoda: Insecta	*Pseudochironomus* sp.	2.56	1.71	9
Arthropoda: Insecta	*Stictochironomus* sp.	4.67	1.28	9
Arthropoda: Insecta	Tanypodinae	0.44	0.24	9
Arthropoda: Insecta	*Tanypus* sp.	0.78	0.55	9
Arthropoda: Insecta	*Tanytarsus* sp.	5.56	2.52	9
Arthropoda: Insecta	Trichoptera	1.11	0.26	9
Arthropoda: Insecta	*Zavreliella* sp.	0.11	0.11	9
Arthropoda: Ostracoda	Ostracoda sp. 1	1.78	1.20	9
Mollusca: Bivalvia	*Corbicula manilensis*	4.44	1.06	9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.11	0.11	9
Mollusca: Gastropoda	*Amnicola limnosa*	14.33	4.90	9

Sweet Hall Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.44	0.24	9
Annelida: Oligochaeta	*Dero digitata*	0.11	0.11	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	4.33	1.74	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	19.33	7.52	9
Annelida: Oligochaeta	*Pristina breviseta*	0.22	0.15	9
Annelida: Oligochaeta	*Pristinella jenkinae*	0.11	0.11	9
Annelida: Oligochaeta	*Spirosperma ferox*	1.22	0.32	9
Annelida: Oligochaeta	*Stephensoniana trivandrana*	5.11	2.69	9
Annelida: Polychaeta	*Polydora cornuta*	0.33	0.33	9
Arthropoda: Amphipoda	*Hyalella azteca*	0.11	0.11	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.33	0.17	9
Arthropoda: Decapoda	*Paleomonetes pugio*	0.33	0.33	9
Arthropoda: Insecta	*Coelotanypus* sp.	0.33	0.24	9
Arthropoda: Insecta	Coleoptera	0.11	0.11	9
Arthropoda: Insecta	*Cryptochironomus* sp.	0.44	0.24	9
Arthropoda: Insecta	*Epoicocladius* sp. 3	0.22	0.22	9
Arthropoda: Insecta	*Polypedilum flavum*	0.11	0.11	9
Arthropoda: Insecta	*Polypedilum halterale* group	0.22	0.15	9
Arthropoda: Insecta	*Procladius* sp.	0.44	0.24	9
Arthropoda: Insecta	*Tanypus* sp.	0.22	0.15	9

Sweet Hall Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Aulodrilus pigueti*	1.67	1.08	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	23.44	4.42	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	27.44	2.89	9
Annelida: Oligochaeta	*Nais communis*	0.33	0.33	9
Annelida: Oligochaeta	*Pristina breviseta*	0.56	0.56	9
Annelida: Oligochaeta	*Pristinella jenkinae*	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	1.22	0.66	9
Annelida: Polychaeta	*Laeonereis culveri*	0.11	0.11	9
Annelida: Polychaeta	*Marenzellaria viridis*	1.78	0.36	9
Annelida: Polychaeta	*Polydora cornuta*	0.11	0.11	9
Arthropoda: Arachnid	Arachnid	0.11	0.11	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	4.78	0.98	9
Arthropoda: Cumacea	*Leucon americanus*	0.22	0.15	9
Arthropoda: Insecta	Arthropoda: Insecta	0.22	0.22	9
Arthropoda: Insecta	Chironominae	0.11	0.11	9
Arthropoda: Insecta	*Cladotanytarsus* sp. A	0.22	0.15	9
Arthropoda: Insecta	*Coelotanypus* sp.	0.22	0.15	9
Arthropoda: Insecta	*Cryptochironomus* sp.	0.56	0.24	9
Arthropoda: Insecta	*Polypedilum halterale* group	2.11	0.84	9
Arthropoda: Insecta	*Polypedilum* sp.	0.78	0.78	9
Arthropoda: Insecta	*Procladius* sp.	0.22	0.15	9
Arthropoda: Insecta	*Stictochironomus* sp.	0.22	0.15	9
Arthropoda: Insecta	Tanypodinae	0.33	0.24	9
Arthropoda: Insecta	*Tanytarsus* sp.	0.56	0.34	9
Arthropoda: Insecta	Zygoptera	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	2.33	0.29	9
Arthropoda: Tanaidacea	*Leptochelia rapax*	3.00	2.88	9
Mollusca: Bivalvia	*Corbicula manilensis*	0.33	0.24	9
Mollusca: Bivalvia	*Rangia cuneata*	1.00	0.37	9

Appendix B. Meiofaunal abundance data, 2003. Taxa listed by sites and strata sampled in 2003. Mean number of individuals by major taxon per core (1.13 cm2); SE = standard error of mean; N = number of stations per site/stratum.

Chisman Creek Near-Field

Taxon	***Mean***	***SE***	***N***
Annelida: Polychaeta	7.11	1.23	9
Arthropoda: Copepoda	26.44	5.41	9
Arthropoda: Copepoda (Naupli	0.78	0.40	9
Arthropoda: Mite	0.22	0.15	9
Arthropoda: Ostracoda	0.56	0.34	9
Foramanifera	9.33	3.16	9
Nematoda	418.78	109.17	9
Turbellaria	0.44	0.34	9

Chisman Creek Far-Field

Taxon	***Mean***	***SE***	***N***
Annelida: Polychaeta	5.33	1.52	9
Arthropoda: Copepoda	2.33	1.29	9
Arthropoda: Copepoda (Naupli	0.56	0.34	9
Arthropoda: Mite	0.22	0.15	9
Arthropoda: Ostracoda	2.67	0.88	9
Foramanifera	9.00	2.13	9
Mollusca: Bivalvia	1.56	0.44	9
Nematoda	125.78	20.69	9
Turbellaria	0.33	0.24	9

Elizabeth River Near-Field

Taxa	***Mean***	***SE***	***N***
Annelida: Oligochaeta	0.11	0.11	9
Annelida: Polychaeta	4.56	0.88	9
Arthropoda: Copepoda	5.33	1.35	9
Arthropoda: Copepoda (Naupli	11.00	3.31	9
Arthropoda: Mite	0.33	0.24	9
Arthropoda: Ostracoda	0.44	0.34	9
Foramanifera	3.00	1.32	9
Nematoda	61.22	18.82	9
Turbellaria	0.56	0.34	9

Elizabeth River Far-Field

Taxa	***Mean***	***SE***	***N***
Annelida: Oligochaeta	0.22	0.15	9
Annelida: Polychaeta	5.33	2.55	9
Arthropoda: Copepoda	2.00	0.71	9
Arthropoda: Copepoda (Naupli	0.78	0.32	9
Arthropoda: Mite	0.33	0.17	9
Arthropoda: Ostracoda	0.44	0.18	9
Foramanifera	1.56	0.56	9
Nematoda	203.11	62.56	9

Langley Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Oligochaeta	0.22	0.15	9
Annelida: Polychaeta	1.56	0.56	9
Arthropoda: Copepoda	43.78	9.08	9
Arthropoda: Copepoda (Naupli	36.00	11.39	9
Arthropoda: Mite	0.11	0.11	9
Arthropoda: Ostracoda	5.00	2.29	9
Foramanifera	10.44	2.24	9
Mollusca: Bivalvia	0.56	0.34	9
Nematoda	612.56	193.27	9
Turbellaria	0.22	0.15	9

Langley Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Oligochaeta	1.11	0.89	9
Annelida: Polychaeta	5.00	1.37	9
Arthropoda: Copepoda	2.56	0.87	9
Arthropoda: Copepoda (Naupli	0.89	0.89	9
Arthropoda: Ostracoda	0.44	0.34	9
Foramanifera	15.67	3.79	9
Mollusca: Bivalvia	2.22	0.72	9
Nematoda	110.67	26.08	9

Sarah Creek Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	2.89	0.87	9
Arthropoda: Copepoda	6.22	1.93	9
Arthropoda: Copepoda (Naupli	0.11	0.11	9
Arthropoda: Mite	1.11	0.48	9
Arthropoda: Ostracoda	5.00	2.30	9
Foramanifera	0.56	0.34	9
Nematoda	993.11	155.64	9
Turbellaria	1.89	1.06	9

Sarah Creek Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	6.22	1.44	9
Arthropoda: Copepoda	12.00	3.18	9
Arthropoda: Copepoda (Naupli	6.11	4.20	9
Arthropoda: Mite	0.33	0.24	9
Arthropoda: Ostracoda	2.22	0.66	9
Foramanifera	1.67	0.69	9
Mollusca: Bivalvia	0.56	0.24	9
Nematoda	109.56	29.02	9

Severn Thornton Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Oligochaeta	0.25	0.16	8
Annelida: Polychaeta	1.00	0.38	8
Arthropoda: Copepoda	4.50	1.38	8
Arthropoda: Copepoda (Naupli	0.25	0.25	8
Arthropoda: Mite	0.13	0.13	8
Arthropoda: Ostracoda	3.50	1.10	8
Foramanifera	18.75	6.98	8
Mollusca: Bivalvia	0.13	0.13	8
Nematoda	243.75	44.89	8
Turbellaria	0.75	0.41	8

Severn Thornton Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Oligochaeta	0.25	0.25	8
Annelida: Polychaeta	1.62	0.50	8
Arthropoda: Copepoda	1.25	0.65	8
Arthropoda: Copepoda (Naupli	0.75	0.31	8
Arthropoda: Mite	0.13	0.13	8
Arthropoda: Ostracoda	0.63	0.26	8
Foramanifera	7.63	2.83	8
Nematoda	128.63	36.11	8

Appendix B. Meiofaunal abundance data, 2004. Taxa listed by sites and strata sampled in 2004. Mean number of individuals by major taxon per core (1.13 cm2); SE = standard error of mean; N = number of stations per site/stratum.

Fort Eustis Near-Field

Taxon	*Mean*	*SE*	*N*
Annelida: Polychaeta	3.44	1.07	9
Arthropoda: Copepoda	7.78	1.28	9
Arthropoda: Copepoda (Naupli	0.89	0.59	9
Arthropoda: Mite	0.33	0.17	9
Arthropoda: Ostracoda	11.78	6.14	9
Mollusca: Bivalvia	0.22	0.15	9
Mollusca: Gastropoda	11.22	2.66	9
Nematoda	29.56	7.46	9
Turbellaria	1.22	0.62	9

Fort Eustis Far-Field

Taxon	*Mean*	*SE*	*N*
Annelida: Polychaeta	11.44	6.72	9
Aplacophora	37.11	12.83	9
Arthropoda: Copepoda	19.33	4.26	9
Arthropoda: Copepoda (Naupli	1.22	0.64	9
Arthropoda: Mite	0.11	0.11	9
Arthropoda: Ostracoda	15.78	3.28	9
Mollusca: Bivalvia	0.44	0.24	9
Mollusca: Gastropoda	1.44	0.41	9
Nematoda	37.33	7.39	9
Turbellaria	0.11	0.11	9

Monie Bay Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	2.44	0.60	9
Arthropoda: Copepoda	9.67	1.75	9
Arthropoda: Copepoda (Naupli	0.44	0.29	9
Arthropoda: Ostracoda	7.00	1.72	9
Foramanifera	0.11	0.11	9
Mollusca: Bivalvia	0.22	0.22	9
Mollusca: Gastropoda	1.33	0.47	9
Nematoda	385.22	70.27	9
Turbellaria	0.33	0.24	9

Monie Bay Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	18.22	9.56	9
Arthropoda: Copepoda	12.11	2.34	9
Arthropoda: Copepoda (Naupli	2.22	1.23	9
Arthropoda: Mite	1.78	0.43	9
Arthropoda: Ostracoda	10.44	1.95	9
Foramanifera	1.56	0.77	9
Mollusca: Bivalvia	1.33	0.69	9
Mollusca: Gastropoda	0.33	0.24	9
Nematoda	92.78	16.58	9
Turbellaria	0.11	0.11	9

Pagan Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	2.13	0.52	8
Arthropoda: Copepoda	1.38	1.10	8
Arthropoda: Copepoda (Naupli	0.63	0.50	8
Arthropoda: Mite	0.13	0.13	8
Arthropoda: Ostracoda	1.63	0.60	8
Mollusca: Gastropoda	0.38	0.18	8
Nematoda	54.88	7.03	8
Turbellaria	0.38	0.18	8

Pagan Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	6.89	2.98	9
Aplacophora	0.11	0.11	9
Arthropoda: Copepoda	0.56	0.34	9
Arthropoda: Copepoda (Naupli	1.44	0.88	9
Arthropoda: Mite	0.11	0.11	9
Arthropoda: Ostracoda	10.78	2.09	9
Foramanifera	0.56	0.29	9
Mollusca: Bivalvia	0.11	0.11	9
Nematoda	125.22	16.08	9
Turbellaria	0.33	0.24	9

Patuxent Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	4.33	0.85	9
Arthropoda: Copepoda	1.44	0.41	9
Arthropoda: Copepoda (Naupli	0.33	0.33	9
Arthropoda: Ostracoda	11.89	4.64	9
Foramanifera	0.67	0.29	9
Mollusca: Bivalvia	1.33	0.50	9
Nematoda	471.00	53.46	9
Turbellaria	0.11	0.11	9

Patuxent Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	2.67	0.80	9
Arthropoda: Copepoda	7.89	3.28	9
Arthropoda: Copepoda (Naupli	12.56	12.31	9
Arthropoda: Ostracoda	40.78	10.64	9
Foramanifera	4.00	1.91	9
Mollusca: Bivalvia	2.00	0.80	9
Nematoda	291.00	34.41	9

Appendix B. Meiofaunal abundance data, 2005. Taxa listed by sites and strata sampled in 2005. Mean number of individuals by major taxon per core (1.13 cm2); SE = standard error of mean; N = number of stations per site/stratum.

Anacostia Near-Field

Taxon	*Mean*	*SE*	*N*
Annelida: Polychaeta	7.00	0.96	9
Aplacophora	1.11	0.99	9
Arthropoda: Chironomidae	0.44	0.24	9
Arthropoda: Cladocera	0.56	0.56	9
Arthropoda: Copepoda (Naupli	0.11	0.11	9
Arthropoda: Mite	0.11	0.11	9
Arthropoda: Ostracoda	1.67	0.60	9
Nematoda	16.56	3.87	9

Anacostia Far-Field

Taxon	*Mean*	*SE*	*N*
Annelida: Polychaeta	9.44	3.33	9
Arthropoda: Chironomidae	0.56	0.34	9
Arthropoda: Cladocera	1.33	1.33	9
Arthropoda: Copepoda	0.33	0.24	9
Arthropoda: Mite	0.33	0.24	9
Arthropoda: Ostracoda	4.33	2.01	9
Mollusca: Bivalvia	0.11	0.11	9
Nematoda	25.78	6.80	9

Aberdeen Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	0.33	0.24	9
Arthropoda: Chironomidae	0.00	0.00	9
Arthropoda: Copepoda	0.44	0.29	9
Arthropoda: Mite	0.22	0.22	9
Arthropoda: Ostracoda	2.44	1.02	9
Foramanifera	0.22	0.22	9
Nematoda	1.67	0.17	9

Aberdeen Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	1.11	0.31	9
Aplacophora	0.11	0.11	9
Arthropoda: Chironomidae	1.44	0.38	9
Arthropoda: Copepoda	4.56	1.68	9
Arthropoda: Mite	0.11	0.11	9
Arthropoda: Ostracoda	0.67	0.29	9
Mollusca: Bivalvia	2.22	0.78	9
Nematoda	8.11	2.27	9

Quantico Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	1.75	0.41	8
Arthropoda: Chironomidae	0.38	0.26	8
Arthropoda: Copepoda	0.88	0.44	8
Arthropoda: Copepoda (Naupli	0.13	0.13	8
Arthropoda: Ostracoda	1.38	0.42	8
Nematoda	32.63	9.38	8

Quantico Far-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	5.75	2.41	8
Arthropoda: Chironomidae	0.25	0.16	8
Arthropoda: Copepoda	6.50	1.51	8
Arthropoda: Copepoda (Naupli	0.88	0.52	8
Arthropoda: Ephemeroptera	0.13	0.13	8
Arthropoda: Ostracoda	1.13	0.48	8
Nematoda	5.75	1.01	8
Rotifera	0.38	0.38	8

Sweet Hall Near-Field

Taxa	*Mean*	*SE*	*N*
Annelida: Polychaeta	1.00	0.37	9
Arthropoda: Copepoda	5.44	0.99	9
Arthropoda: Mite	0.22	0.22	9
Arthropoda: Ostracoda	2.56	0.77	9
Mollusca: Gastropoda	0.44	0.34	9
Nematoda	11.22	3.26	9

Sweet Hall Far-Field

Taxa	*Mean*	*SE*	*N*
Arthropoda: Chironomidae	2.00	0.82	9
Arthropoda: Mite	0.11	0.11	9
Arthropoda: Ostracoda	0.56	0.24	9
Mollusca: Bivalvia	1.22	0.46	9
Nematoda	0.67	0.37	9

Appendix C. Ecosystem processes data: notes and abbreviations.

site-strata	Site	Stratum	Comment
AN-F	Anacostia River	Far-field	
AN-N	Anacostia River	Near-field	
AP-F	Aberdeen Proving Ground	Far-field	
AP-N	Aberdeen Proving Ground	Near-field	3 cores with submerged aquatic vegetation were not included in the mean and standard error calculations
ER-F	Elizabeth River	Far-field	
ER-N	Elizabeth River	Near-field	
FE-F	Fort Eustis	Far-field	
FE-N	Fort Eustis	Near-field	
LA-F	Langley Air Force Base	Far-field	
LA-N	Langley Air Force Base	Near-field	
MB-F	Monie Bay	Far-field	
MB-N	Monie Bay	Near-field	
PG-F	Pagan River	Far-field	
PG-N	Pagan River	Near-field	
PX-F	Patuxent Naval Air Station	Far-field	
PX-N	Patuxent Naval Air Station	Near-field	
QT-F	Quantico	Far-field	3 cores with submerged aquatic vegetation were not included in the mean and standard error calculations
QT-N	Quantico	Near-field	3 cores with submerged aquatic vegetation were not included in the mean and standard error calculations
SH-F	Sweet Hall Marsh	Far-field	
SH-N	Sweet Hall Marsh	Near-field	
ST-F	Thorntons Creek/Severn River	Far-field	
ST-N	Thorntons Creek/Severn River	Near-field	

Variables in ecosystem process rates sheet

Sediment Respiration
Sediment Gross Primary Production (GPP)
Sediment gross primary production/respiration ratio (P/R)
Sediment Net Ecosystem Metabolism (NEM)
Sediment daily NH4 flux
Sediment daily NOx flux
Sediment daily PO4 flux
Sediment daily DON flux
Sediment daily DOC flux
Sediment gross mineralization rates
Sediment N2 flux rates
Sediment dark DO flux
Sediment light DO flux
Sediment dark NOX flux
Sediment light NOX flux
Sediment dark NH4 flux
Sediment light NH4 flux
Sediment dark PO4 flux
Sediment light PO4 flux

Appendix C. Ecosystem processes data. SE = standard error of mean; N = number of stations per site/stratum.

Variable	units	site-strata	Mean	SE	N
Sediment Respiration	**mmolC/m2/d**	AN-F	36.75	3.77	9
		AN-N	50.29	3.08	9
		AP-F	17.87	1.89	8
		AP-N	35.22	2.06	6
		ER-F	32.11	3.36	9
		ER-N	42.46	1.94	9
		FE-F	13.36	0.99	9
		FE-N	14.78	1.15	9
		LA-F	26.31	1.09	9
		LA-N	29.98	2.56	9
		MB-F	14.31	0.61	9
		MB-N	25.10	1.18	9
		PG-F	26.44	1.42	9
		PG-N	25.52	1.28	9
		PX-F	52.59	2.22	9
		PX-N	51.38	2.03	9
		QT-F	22.41	2.90	6
		QT-N	26.71	2.57	6
		SH-F	23.43	1.14	9
		SH-N	21.82	1.52	9
		ST-F	27.24	2.78	9
		ST-N	31.86	2.57	9
Sediment Gross Primary Production (GPP)	**mmolC/m2/d**	AN-F	-15.40	4.25	9
		AN-N	-28.08	2.20	9
		AP-F	-22.77	2.87	8
		AP-N	-23.44	1.59	6
		ER-F	-67.06	4.79	9
		ER-N	-109.00	10.20	9
		FE-F	-19.78	1.55	9
		FE-N	-4.41	0.46	9
		LA-F	-68.27	8.27	9
		LA-N	-99.43	5.41	9
		MB-F	-21.27	2.82	9
		MB-N	-15.80	1.17	9
		PG-F	-1.94	1.42	9
		PG-N	-12.91	2.37	9
		PX-F	-70.14	4.78	9
		PX-N	-135.32	3.48	9
		QT-F	-17.02	2.62	6
		QT-N	-19.14	3.46	6
		SH-F	-23.13	2.38	9
		SH-N	-26.53	3.06	9
		ST-F	-133.06	7.20	9
		ST-N	-48.19	7.43	9

Variable	units	site-strata	Mean	SE	N
Sediment gross primary production/respiration ratio (P/R)		AN-F	0.44	0.14	9
		AN-N	0.57	0.04	9
		AP-F	1.27	0.09	8
		AP-N	0.68	0.02	6
		ER-F	2.19	0.17	9
		ER-N	2.57	0.25	9
		FE-F	1.53	0.16	9
		FE-N	0.31	0.03	9
		LA-F	2.55	0.26	9
		LA-N	3.49	0.28	9
		MB-F	1.49	0.18	9
		MB-N	0.63	0.04	9
		PG-F	0.08	0.06	9
		PG-N	0.51	0.08	9
		PX-F	1.34	0.08	9
		PX-N	2.66	0.10	9
		QT-F	0.82	0.16	6
		QT-N	0.70	0.09	6
		SH-F	0.98	0.08	9
		SH-N	1.24	0.17	9
		ST-F	5.18	0.52	9
		ST-N	1.52	0.22	9
Sediment Net Ecosystem Metabolism (NEM)	**mmolC/m2/d**	AN-F	19.61	4.56	9
		AN-N	22.21	3.08	9
		AP-F	-4.91	1.63	8
		AP-N	10.83	0.86	6
		ER-F	-34.95	3.45	9
		ER-N	-66.55	9.51	9
		FE-F	-6.42	1.54	9
		FE-N	10.37	1.16	9
		LA-F	-41.96	7.46	9
		LA-N	-69.45	3.85	9
		MB-F	-6.96	2.70	9
		MB-N	9.30	1.02	9
		PG-F	29.12	3.11	9
		PG-N	12.61	2.43	9
		PX-F	-17.55	4.15	9
		PX-N	-83.95	3.10	9
		QT-F	5.39	3.51	6
		QT-N	7.57	2.28	6
		SH-F	0.30	1.85	9
		SH-N	-4.70	3.01	9
		ST-F	-105.82	6.49	9
		ST-N	-16.33	6.83	9

Variable	units	site-strata	Mean	SE	N
Sediment daily NH4 flux	**mmolN/m2/d**	AN-F	0.87	0.85	9
		AN-N	5.57	0.66	9
		AP-F	-0.11	0.08	8
		AP-N	1.75	0.60	6
		ER-F	-0.16	0.80	9
		ER-N	-3.94	0.49	9
		FE-F	-0.17	0.07	9
		FE-N	1.04	0.34	9
		LA-F	-0.15	0.07	9
		LA-N	-0.70	0.20	9
		MB-F	-0.20	0.05	9
		MB-N	2.52	0.45	9
		PG-F	3.13	0.42	9
		PG-N	1.98	0.38	9
		PX-F	2.76	0.54	9
		PX-N	0.02	0.18	9
		QT-F	-0.01	0.01	6
		QT-N	2.09	0.36	6
		SH-F	-0.21	0.11	9
		SH-N	1.00	0.35	9
		ST-F	-0.03	0.08	9
		ST-N	1.12	0.28	9
Sediment daily NOx flux	**mmolN/m2/d**	AN-F	-0.604	0.476	9
		AN-N	-2.847	0.288	9
		AP-F	-0.205	0.098	8
		AP-N	-0.219	0.105	6
		ER-F	-0.407	0.265	9
		ER-N	-1.220	0.175	9
		FE-F	-0.039	0.011	9
		FE-N	0.185	0.020	9
		LA-F	-0.034	0.016	9
		LA-N	-0.038	0.010	9
		MB-F	0.022	0.007	9
		MB-N	0.238	0.019	9
		PG-F	0.265	0.046	9
		PG-N	-0.602	0.043	9
		PX-F	-0.041	0.014	9
		PX-N	0.026	0.007	9
		QT-F	-0.017	0.006	6
		QT-N	0.179	0.038	6
		SH-F	0.271	0.046	9
		SH-N	0.289	0.049	9
		ST-F	-0.013	0.004	9
		ST-N	0.007	0.013	9

Variable	units	site-strata	Mean	SE	N
Sediment daily PO4 flux	**mmolP/m2/d**	AN-F	-0.010	0.003	9
		AN-N	-0.001	0.014	9
		AP-F	-0.003	0.002	8
		AP-N	0.041	0.019	6
		ER-F	0.122	0.062	9
		ER-N	0.051	0.027	9
		FE-F	0.000	0.007	9
		FE-N	0.008	0.014	9
		LA-F	0.011	0.003	9
		LA-N	0.056	0.023	9
		MB-F	-0.001	0.004	9
		MB-N	0.058	0.019	9
		PG-F	0.162	0.014	9
		PG-N	0.216	0.060	9
		PX-F	0.019	0.006	9
		PX-N	-0.002	0.001	9
		QT-F	-0.014	0.006	6
		QT-N	-0.118	0.045	6
		SH-F	0.027	0.011	9
		SH-N	0.002	0.004	9
		ST-F	0.010	0.022	9
		ST-N	0.047	0.015	9
Sediment daily DON flux	**mmolN/m2/d**	AN-F	-1.27	0.74	9
		AN-N	0.63	0.86	9
		AP-F	0.12	1.69	8
		AP-N	-2.22	1.36	6
		ER-F	-3.47	1.28	9
		ER-N	-0.80	2.34	9
		FE-F	2.68	1.20	9
		FE-N	-0.27	0.86	9
		LA-F	0.13	0.20	9
		LA-N	-1.22	0.42	9
		MB-F	2.88	2.55	9
		MB-N	-6.26	3.02	9
		PG-F	-0.73	0.73	9
		PG-N	-1.46	1.48	9
		PX-F	-4.50	1.70	9
		PX-N	-2.62	2.21	9
		QT-F	-0.64	0.27	6
		QT-N	-1.17	0.56	6
		SH-F	-5.86	1.51	9
		SH-N	2.58	1.16	9
		ST-F	-0.89	0.28	9
		ST-N	3.27	0.77	9

Variable	units	site-strata	Mean	SE	N
Sediment daily DOC flux	**mmolC/m2/d**	AN-F	6.05	9.52	9
		AN-N	3.70	27.80	9
		AP-F	10.61	21.40	8
		AP-N	-3.31	7.91	6
		ER-F	-10.70	27.50	9
		ER-N	52.70	41.70	9
		FE-F	2.23	6.54	9
		FE-N	*	*	9
		LA-F	2.14	8.11	9
		LA-N	-6.61	9.63	9
		MB-F	-11.24	5.00	9
		MB-N	-40.70	27.70	9
		PG-F	-18.60	4.46	9
		PG-N	14.00	21.50	9
		PX-F	4.78	8.65	9
		PX-N	4.71	6.36	9
		QT-F	8.80	11.00	6
		QT-N	7.63	1.57	6
		SH-F	34.00	25.70	9
		SH-N	-16.80	17.80	9
		ST-F	40.00	63.20	9
		ST-N	-146.90	72.10	9
Sediment gross mineralization rates	**mmolN/m2/d**	AN-F	7.20	3.70	9
		AN-N	31.77	9.30	9
		AP-F	6.59	3.20	9
		AP-N	16.75	7.53	6
		ER-F	11.24	2.96	9
		ER-N	5.23	1.54	9
		FE-F	11.74	5.03	9
		FE-N	14.60	4.83	9
		LA-F	8.75	1.07	9
		LA-N	6.32	2.16	9
		MB-F	4.64	0.74	9
		MB-N	18.99	4.26	9
		PG-F	6.24	2.06	9
		PG-N	21.80	2.47	9
		PX-F	15.66	1.25	9
		PX-N	12.04	2.77	9
		QT-F	12.15	6.43	6
		QT-N	56.80	17.80	6
		SH-F	3.78	2.15	9
		SH-N	101.90	63.80	9
		ST-F	7.95	1.03	9
		ST-N	9.16	2.70	9

Variable	units	site-strata	Mean	SE	N
Sediment N2 flux rates	**mmolN/m2/h**	AN-F	174.6	33.0	9
		AN-N	-6.4	39.4	9
		AP-F	44.8	19.6	9
		AP-N	-43.5	24.3	6
		ER-F	127.8	45.0	9
		ER-N	92.6	20.8	9
		FE-F	93.8	71.9	9
		FE-N	-39.1	28.3	9
		LA-F	8.8	23.1	9
		LA-N	22.3	39.5	9
		MB-F	18.9	7.2	9
		MB-N	165.9	42.5	9
		PG-F	126.3	66.9	9
		PG-N	57.5	15.3	9
		PX-F	-105.8	38.5	9
		PX-N	27.6	50.7	9
		QT-F	-22.6	35.7	6
		QT-N	-111.1	37.3	6
		SH-F	43.1	16.6	9
		SH-N	113.3	17.2	9
		ST-F	-97.6	19.2	9
		ST-N	62.7	47.2	9
Sediment dark DO flux	**mmol/m2/h**	AN-F	-1.53	0.16	9
		AN-N	-2.10	0.13	9
		AP-F	-0.74	0.08	8
		AP-N	-1.47	0.09	6
		ER-F	-1.34	0.14	9
		ER-N	-1.77	0.08	9
		FE-F	-0.65	0.04	9
		FE-N	-0.80	0.05	9
		LA-F	-1.10	0.05	9
		LA-N	-1.25	0.11	9
		MB-F	-0.70	0.03	9
		MB-N	-1.11	0.05	9
		PG-F	-1.44	0.06	9
		PG-N	-1.38	0.06	9
		PX-F	-2.58	0.09	9
		PX-N	-2.58	0.08	9
		QT-F	-0.93	0.12	6
		QT-N	-1.11	0.11	6
		SH-F	-0.98	0.05	9
		SH-N	-0.91	0.06	9
		ST-F	-1.14	0.12	9
		ST-N	-1.33	0.11	9

Variable	units	site-strata	Mean	SE	N
Sediment light DO flux	**mmol/m2/h**	AN-F	-0.36	0.29	9
		AN-N	-0.09	0.16	9
		AP-F	0.88	0.15	8
		AP-N	0.25	0.04	6
		ER-F	3.45	0.27	9
		ER-N	6.02	0.70	9
		FE-F	1.35	0.09	9
		FE-N	0.86	0.04	9
		LA-F	3.78	0.56	9
		LA-N	5.85	0.31	9
		MB-F	1.56	0.19	9
		MB-N	0.16	0.07	9
		PG-F	0.94	0.17	9
		PG-N	-0.14	0.17	9
		PX-F	4.11	0.32	9
		PX-N	8.50	0.22	9
		QT-F	0.28	0.20	6
		QT-N	0.25	0.18	6
		SH-F	0.68	0.14	9
		SH-N	0.99	0.21	9
		ST-F	8.37	0.48	9
		ST-N	2.11	0.50	9
Sediment dark NOX flux	**umolN/m2/h**	AN-F	-33.80	22.60	9
		AN-N	-132.60	11.40	9
		AP-F	-5.94	4.74	8
		AP-N	-16.33	2.07	6
		ER-F	-54.80	12.90	9
		ER-N	-127.60	11.40	9
		FE-F	-1.93	0.64	9
		FE-N	7.91	0.79	9
		LA-F	-0.57	0.37	9
		LA-N	-2.37	0.92	9
		MB-F	1.46	0.60	9
		MB-N	4.54	1.22	9
		PG-F	9.32	1.60	9
		PG-N	-39.95	2.26	9
		PX-F	-6.57	0.49	9
		PX-N	1.35	0.41	9
		QT-F	0.76	0.59	6
		QT-N	3.74	1.93	6
		SH-F	23.56	1.94	9
		SH-N	9.29	0.89	9
		ST-F	-1.74	0.44	9
		ST-N	-1.57	0.89	9

Variable	units	site-strata	Mean	SE	N
Sediment light NOX flux	**umolN/m2/h**	AN-F	-26.60	18.40	9
		AN-N	-108.70	13.10	9
		AP-F	-10.38	5.42	8
		AP-N	-4.00	7.69	6
		ER-F	9.50	13.70	9
		ER-N	4.00	10.70	9
		FE-F	1.77	0.86	9
		FE-N	12.24	2.48	9
		LA-F	-1.99	1.17	9
		LA-N	-0.99	0.47	9
		MB-F	0.54	0.32	9
		MB-N	-1.35	0.47	9
		PG-F	0.92	0.41	9
		PG-N	-14.47	2.14	9
		PX-F	13.75	0.94	9
		PX-N	7.55	1.58	9
		QT-F	-1.76	0.75	6
		QT-N	10.15	1.55	6
		SH-F	2.50	2.78	9
		SH-N	13.99	3.02	9
		ST-F	0.34	0.03	9
		ST-N	1.01	0.73	9
Sediment dark NH4 flux	**umolN/m2/h**	AN-F	62.20	36.30	9
		AN-N	308.70	24.70	9
		AP-F	28.19	6.13	8
		AP-N	96.80	18.90	6
		ER-F	182.90	46.90	9
		ER-N	148.50	27.60	9
		FE-F	42.81	8.09	9
		FE-N	139.80	18.10	9
		LA-F	18.39	3.76	9
		LA-N	49.00	16.50	9
		MB-F	35.60	11.70	9
		MB-N	216.70	29.80	9
		PG-F	285.30	26.20	9
		PG-N	158.30	27.50	9
		PX-F	352.30	68.50	9
		PX-N	116.90	12.60	9
		QT-F	2.34	1.78	6
		QT-N	144.40	21.10	6
		SH-F	10.27	6.50	9
		SH-N	106.80	25.00	9
		ST-F	3.73	2.05	9
		ST-N	111.60	16.80	9

Variable	units	site-strata	Mean	SE	N
Sediment light NH4 flux	**umolN/m2/h**	AN-F	24.00	33.10	9
		AN-N	177.50	32.70	9
		AP-F	-28.11	6.15	8
		AP-N	56.10	32.80	6
		ER-F	-138.90	33.40	9
		ER-N	-387.50	42.60	9
		FE-F	-54.80	23.90	9
		FE-N	20.00	15.40	9
		LA-F	-23.65	7.15	9
		LA-N	-85.30	23.90	9
		MB-F	-40.07	8.93	9
		MB-N	-42.52	4.44	9
		PG-F	-82.30	13.30	9
		PG-N	28.30	10.90	9
		PX-F	25.40	14.10	9
		PX-N	-25.30	11.80	9
		QT-F	-2.59	1.30	6
		QT-N	45.80	10.80	6
		SH-F	-22.63	8.50	9
		SH-N	-4.60	11.30	9
		ST-F	-4.78	7.04	9
		ST-N	-10.20	15.00	9
Sediment dark PO4 flux	**umolP/m2/h**	AN-F	0.03	0.22	9
		AN-N	0.04	1.61	9
		AP-F	-0.48	0.14	8
		AP-N	3.45	0.85	6
		ER-F	8.49	4.11	9
		ER-N	9.51	2.37	9
		FE-F	1.33	0.43	9
		FE-N	1.03	1.05	9
		LA-F	0.05	0.21	9
		LA-N	5.82	1.84	9
		MB-F	0.14	0.30	9
		MB-N	3.28	0.96	9
		PG-F	11.58	0.84	9
		PG-N	19.32	3.25	9
		PX-F	1.49	0.25	9
		PX-N	-0.26	0.09	9
		QT-F	-1.42	0.58	6
		QT-N	-4.99	2.26	6
		SH-F	1.69	0.35	9
		SH-N	0.16	0.18	9
		ST-F	-0.52	0.65	9
		ST-N	4.00	0.51	9

Variable	units	site-strata	Mean	SE	N
Sediment light PO4 flux	**umolP/m2/h**	AN-F	-0.78	0.13	9
		AN-N	-0.13	1.01	9
		AP-F	0.16	0.09	8
		AP-N	0.43	0.81	6
		ER-F	3.30	1.58	9
		ER-N	-3.14	0.72	9
		FE-F	0.31	0.37	9
		FE-N	3.28	0.81	9
		LA-F	0.74	0.23	9
		LA-N	-0.16	0.88	9
		MB-F	-0.16	0.18	9
		MB-N	-0.95	0.43	9
		PG-F	0.02	0.12	9
		PG-N	1.61	3.11	9
		PX-F	1.55	0.76	9
		PX-N	-0.16	0.55	9
		QT-F	0.01	0.11	6
		QT-N	-4.89	2.42	6
		SH-F	0.73	0.55	9
		SH-N	0.04	0.15	9
		ST-F	0.74	0.95	9
		ST-N	0.13	1.03	9

Appendix D. Sediment characteristics data: notes and abbreviations.

site-strata	Site	Stratum	Comment
AN-F	Anacostia River	Far-field	
AN-N	Anacostia River	Near-field	
AP-F	Aberdeen Proving Ground	Far-field	
AP-N	Aberdeen Proving Ground	Near-field	3 cores with submerged aquatic vegetation were not included in the mean and standard error calculations
ER-F	Elizabeth River	Far-field	
ER-N	Elizabeth River	Near-field	
FE-F	Fort Eustis	Far-field	
FE-N	Fort Eustis	Near-field	
LA-F	Langley Air Force Base	Far-field	
LA-N	Langley Air Force Base	Near-field	
MB-F	Monie Bay	Far-field	
MB-N	Monie Bay	Near-field	
PG-F	Pagan River	Far-field	
PG-N	Pagan River	Near-field	
PX-F	Patuxent Naval Air Station	Far-field	
PX-N	Patuxent Naval Air Station	Near-field	
QT-F	Quantico	Far-field	3 cores with submerged aquatic vegetation were not included in the mean and standard error calculations
QT-N	Quantico	Near-field	3 cores with submerged aquatic vegetation were not included in the mean and standard error calculations
SH-F	Sweet Hall Marsh	Far-field	
SH-N	Sweet Hall Marsh	Near-field	
ST-F	Thorntons Creek/Severn River	Far-field	
ST-N	Thorntons Creek/Severn River	Near-field	

Variables in sediment characteristics

grain size
total sediment chlorophyll a in 3 cm
total sediment phaeophytin in 3 cm
sed chlorophyll a: 0-1 cm
sediment phaeophytin: 0-1 cm
sediment chlorophyll a: 1-2 cm
sediment phaeophytin: 1-2 cm
sediment chlorophyll a: 2-3 cm
sediment phaeophytin: 2-3 cm
sediment bulk density, averaged over 25 cm
sediment % organic matter (OM) content, averaged over 25 cm
sediment bulk density: 0-2 cm
sediment % OM: 0-2 cm
sediment bulk density: 2-5 cm
sediment % OM: 2-5 cm
sediment bulk density: 5-15 cm
sediment % OM: 5-15 cm
sediment bulk density: 15-25 cm
sediment % OM: 15-25 cm
sediment NH_4 (averaged over 25 cm)
sediment NH_4: 0-2 cm
sediment NH_4: 2-5 cm
sediment NH_4: 5-15 cm
sediment NH_4: 15-25 cm
sediment %N by mass: 0-2cm
sediment %C by mass: 0-2cm
sediment %N by mass: 2-5 cm
sediment %C by mass: 2-5 cm
sediment %N by mass: 5-15 cm
sediment %C by mass: 5-15 cm
sediment %N by mass: 15-25 cm
sediment %C by mass: 15-25 cm
sediment %N by mass (averaged over 25 cm)
sediment %C by mass (averaged over 25 cm)

Appendix D. Sediment characteristics data: grain size. Sand, silt and clay (% dry weight) for all sites and strata sampled. SE = standard error of mean; N = number of stations per site/stratum. Core had a surface area of 5.73 cm^2 and sampled the depth interval 0-5 cm.

Site	Stratum	Percent Sand:			Percent Silt			Percent Clay		
		Mean	***SE***	***N***	***Mean***	***SE***	***N***	***Mean***	***SE***	***N***
2003 Sites										
Chisman Creek	Near	9.44	1.47	9	56.42	1.95	9	34.15	2.30	9
Chisman Creek	Far	96.81	0.59	9	0.67	0.40	9	2.52	0.39	9
Elizabeth River	Near	38.11	3.07	9	38.90	1.36	9	22.99	1.93	9
Elizabeth River	Far	88.16	2.11	9	7.42	1.33	9	4.41	0.88	9
Langley AFB	Near	8.95	1.15	9	60.63	4.30	9	30.43	3.54	9
Langley AFB	Far	92.94	0.86	9	5.54	0.94	9	1.52	0.51	9
Sarah Creek	Near	25.75	6.11	9	47.85	3.87	9	26.40	2.89	9
Sarah Creek	Far	98.02	0.38	9	0.60	0.24	9	1.37	0.25	9
Severn Thornton	Near	73.15	3.46	8	8.44	1.63	8	18.41	1.94	8
Severn Thornton	Far	94.70	0.51	8	0.85	0.30	8	4.44	0.54	8
2004 Sites										
Fort Eustis	Near	14.96	1.76	12	39.67	1.45	12	45.37	2.03	12
Fort Eustis	Far	94.28	2.40	12	2.67	1.34	12	3.05	1.07	12
Monie Bay	Near	13.31	1.16	9	56.25	0.60	9	30.44	0.85	9
Monie Bay	Far	96.83	0.18	9	0.75	0.32	9	2.42	0.34	9
Pagan River	Near	5.13	1.12	9	28.60	3.66	9	55.16	6.93	9
Pagan River	Far	88.22	0.83	9	4.20	0.68	9	7.58	0.45	9
Patuxent River	Near	27.22	5.31	9	56.11	4.47	9	16.67	1.15	9
Patuxent River	Far	94.17	0.46	9	3.25	0.33	9	2.58	0.25	9

Site	Stratum	Percent Sand:			Percent Silt			Percent Clay		
		Mean	***SE***	***N***	***Mean***	***SE***	***N***	***Mean***	***SE***	***N***
2005 Sites										
Aberdeen PG	Near	22.90	2.48	9	47.76	1.66	9	29.34	2.79	9
Aberdeen PG	Far	89.44	2.33	9	9.95	2.20	9	0.61	0.24	9
Anacostia	Near	15.75	3.27	9	54.71	1.03	9	29.53	2.85	9
Anacostia	Far	90.26	2.24	9	6.55	1.55	9	3.19	0.74	9
Quantico	Near	3.14	0.78	9	58.72	0.95	9	38.14	0.46	9
Quantico	Far	94.05	0.64	9	1.44	0.17	9	4.51	0.54	9
Sweet Hall	Near	4.57	0.87	9	41.84	2.14	9	53.59	2.70	9
Sweet Hall	Far	95.64	0.72	9	2.18	0.32	9	2.18	0.46	9

Appendix D. Sediment characteristics data: other sediment characteristics. SE = standard error of mean; N = number of stations per site/stratum.

Variable	units	site-strata	Mean	SE	N
total sediment chlorophyll a in 3 cm	**mg/m2**	AN-F	45.60	9.32	9
		AN-N	28.27	7.66	9
		AP-F	201.00	30.50	9
		AP-N	40.76	5.14	6
		ER-F	402.30	35.90	9
		ER-N	101.82	7.25	9
		FE-F	479.60	38.00	9
		FE-N	27.49	6.64	9
		LA-F	142.00	21.30	9
		LA-N	74.20	12.90	9
		MB-F	342.60	41.20	9
		MB-N	55.91	1.80	9
		PG-F	164.75	5.52	9
		PG-N	81.36	3.56	9
		PX-F	441.00	39.70	9
		PX-N	66.68	3.47	9
		QT-F	128.50	24.30	6
		QT-N	20.15	1.95	6
		SH-F	116.13	6.89	9
		SH-N	53.72	9.03	9
		ST-F	186.50	17.40	9
		ST-N	94.99	3.59	9
total sediment phaeophytin in 3 cm	**mg/m2**	AN-F	36.64	5.44	9
		AN-N	41.60	12.40	9
		AP-F	35.68	2.32	9
		AP-N	40.48	4.12	6
		ER-F	48.00	10.10	9
		ER-N	232.70	15.80	9
		FE-F	1.88	0.95	9
		FE-N	11.45	3.53	9
		LA-F	47.93	6.81	9
		LA-N	24.27	5.47	9
		MB-F	1.14	0.37	9
		MB-N	15.79	1.75	9
		PG-F	15.32	2.47	9
		PG-N	28.32	2.64	9
		PX-F	8.31	2.31	9
		PX-N	14.99	1.60	9
		QT-F	8.25	2.42	6
		QT-N	23.46	3.94	6
		SH-F	28.50	4.82	9
		SH-N	86.30	18.20	9
		ST-F	18.93	4.49	9
		ST-N	68.58	4.22	9

Variable	units	site-strata	Mean	SE	N
sediment chlorophyll a: 0-1 cm	**mg/m2**	AN-F	21.71	5.63	9
		AN-N	7.34	2.41	9
		AP-F	104.30	12.90	9
		AP-N	9.84	1.20	6
		ER-F	168.00	14.30	9
		ER-N	43.73	3.25	9
		FE-F	171.30	12.20	9
		FE-N	11.56	2.93	9
		LA-F	60.30	12.20	9
		LA-N	28.73	5.60	9
		MB-F	141.30	13.20	9
		MB-N	21.71	1.29	9
		PG-F	54.19	4.48	9
		PG-N	27.17	1.30	9
		PX-F	181.10	16.70	9
		PX-N	26.70	2.07	9
		QT-F	67.80	15.00	6
		QT-N	5.00	0.79	6
		SH-F	78.88	4.64	9
		SH-N	18.27	3.05	9
		ST-F	105.60	15.10	9
		ST-N	42.17	0.92	9
sediment phaeophytin: 0-1 cm	**mg/m2**	AN-F	15.02	1.72	9
		AN-N	16.60	4.25	9
		AP-F	13.09	2.30	9
		AP-N	13.12	0.91	6
		ER-F	15.55	4.33	9
		ER-N	82.42	5.02	9
		FE-F	5.23	2.55	9
		FE-N	15.23	4.03	9
		LA-F	17.88	3.30	9
		LA-N	7.93	1.89	9
		MB-F	0.00	0.00	9
		MB-N	18.63	1.45	9
		PG-F	9.17	1.93	9
		PG-N	33.72	2.20	9
		PX-F	9.53	2.42	9
		PX-N	17.68	1.27	9
		QT-F	3.84	1.20	6
		QT-N	5.82	1.36	6
		SH-F	11.75	1.27	9
		SH-N	31.80	5.96	9
		ST-F	5.28	2.71	9
		ST-N	24.41	1.87	9

Variable	units	site-strata	Mean	SE	N
sediment chlorophyll a: 1-2 cm	**mg/m2**	AN-F	12.49	1.95	9
		AN-N	11.56	3.35	9
		AP-F	57.80	11.00	9
		AP-N	12.65	1.26	6
		ER-F	124.90	12.20	9
		ER-N	31.23	3.26	9
		FE-F	173.50	14.20	9
		FE-N	8.12	2.34	9
		LA-F	43.10	5.86	9
		LA-N	27.33	5.68	9
		MB-F	130.70	17.30	9
		MB-N	16.24	0.71	9
		PG-F	57.94	1.90	9
		PG-N	26.39	1.26	9
		PX-F	145.10	13.90	9
		PX-N	23.89	1.74	9
		QT-F	45.10	16.30	6
		QT-N	7.65	0.85	6
		SH-F	28.27	3.87	9
		SH-N	17.65	3.24	9
		ST-F	45.33	2.88	9
		ST-N	27.41	2.30	9
sediment phaeophytin: 1-2 cm	**mg/m2**	AN-F	12.21	2.34	9
		AN-N	14.87	3.74	9
		AP-F	9.56	1.53	9
		AP-N	17.19	0.86	6
		ER-F	15.93	3.78	9
		ER-N	76.55	7.13	9
		FE-F	0.11	0.11	9
		FE-N	13.12	3.79	9
		LA-F	16.80	1.99	9
		LA-N	7.78	1.86	9
		MB-F	0.67	0.67	9
		MB-N	16.01	0.80	9
		PG-F	14.32	2.60	9
		PG-N	31.00	2.00	9
		PX-F	7.21	2.74	9
		PX-N	17.65	1.14	9
		QT-F	2.42	1.10	6
		QT-N	10.17	0.86	6
		SH-F	8.35	1.78	9
		SH-N	32.97	5.45	9
		ST-F	8.07	2.08	9
		ST-N	20.56	1.88	9

Variable	units	site-strata	Mean	SE	N
sediment chlorophyll a: 2-3 cm	**mg/m2**	AN-F	11.40	2.45	9
		AN-N	9.37	2.52	9
		AP-F	38.90	10.20	9
		AP-N	18.27	4.76	6
		ER-F	109.30	12.70	9
		ER-N	27.33	2.76	9
		FE-F	134.80	12.60	9
		FE-N	7.81	1.71	9
		LA-F	37.64	5.04	9
		LA-N	21.08	3.21	9
		MB-F	70.60	13.80	9
		MB-N	17.96	0.51	9
		PG-F	52.63	3.39	9
		PG-N	27.80	1.34	9
		PX-F	114.90	13.30	9
		PX-N	16.08	1.10	9
		QT-F	15.62	3.55	6
		QT-N	7.50	0.80	6
		SH-F	15.62	3.56	9
		SH-N	17.80	2.94	9
		ST-F	35.49	4.63	9
		ST-N	25.42	1.82	9
sediment phaeophytin: 2-3 cm	**mg/m2**	AN-F	9.40	2.24	9
		AN-N	15.12	4.60	9
		AP-F	13.04	1.67	9
		AP-N	17.97	1.55	6
		ER-F	16.49	3.64	9
		ER-N	66.14	8.84	9
		FE-F	0.30	0.30	9
		FE-N	12.20	3.23	9
		LA-F	13.31	1.85	9
		LA-N	7.78	2.21	9
		MB-F	2.75	0.85	9
		MB-N	18.01	0.61	9
		PG-F	22.47	3.36	9
		PG-N	32.98	1.50	9
		PX-F	8.18	2.19	9
		PX-N	13.98	0.76	9
		QT-F	1.98	0.65	6
		QT-N	9.12	1.05	6
		SH-F	9.09	1.86	9
		SH-N	32.70	5.35	9
		ST-F	5.58	1.75	9
		ST-N	23.61	1.79	9

Variable	units	site-strata	Mean	SE	N
sediment bulk density, averaged over 25 cm	**gDW/mL**	AN-F	1.34	0.08	9
		AN-N	0.69	0.02	9
		AP-F	1.52	0.08	9
		AP-N	0.38	0.02	6
		ER-F	1.51	0.09	9
		ER-N	0.45	0.03	9
		FE-F	1.20	0.07	9
		FE-N	0.37	0.05	9
		LA-F	1.57	0.04	9
		LA-N	0.66	0.05	9
		MB-F	1.68	0.03	9
		MB-N	0.45	0.01	9
		PG-F	1.48	0.03	9
		PG-N	0.35	0.01	9
		PX-F	1.79	0.08	9
		PX-N	0.94	0.08	9
		QT-F	1.54	0.04	6
		QT-N	0.39	0.02	6
		SH-F	1.69	0.04	9
		SH-N	0.34	0.03	9
		ST-F	1.36	0.07	9
		ST-N	1.05	0.04	9
sediment % organic matter (OM) content, averaged over 25 cm	**%**	AN-F	2.58	0.50	9
		AN-N	8.91	0.27	9
		AP-F	1.44	0.32	9
		AP-N	17.39	0.55	6
		ER-F	2.19	0.52	9
		ER-N	14.21	1.19	9
		FE-F	2.23	0.46	9
		FE-N	16.67	1.74	9
		LA-F	0.79	0.08	9
		LA-N	6.08	0.59	9
		MB-F	0.19	0.01	9
		MB-N	10.68	0.20	9
		PG-F	1.68	0.05	9
		PG-N	12.36	0.41	9
		PX-F	1.14	0.42	9
		PX-N	4.66	0.46	9
		QT-F	1.25	0.22	6
		QT-N	11.62	0.18	6
		SH-F	0.75	0.07	9
		SH-N	14.64	0.76	9
		ST-F	0.81	0.05	9
		ST-N	2.75	0.36	9

Variable	units	site-strata	Mean	SE	N
sediment bulk density: 0-2 cm	**gDW/mL**	AN-F	1.16	0.16	9
		AN-N	0.53	0.03	9
		AP-F	1.42	0.06	9
		AP-N	0.28	0.03	6
		ER-F	1.56	0.04	9
		ER-N	0.53	0.05	9
		FE-F	1.17	0.04	9
		FE-N	0.41	0.09	9
		LA-F	1.53	0.08	9
		LA-N	0.55	0.03	9
		MB-F	1.48	0.05	9
		MB-N	0.29	0.01	9
		PG-F	1.33	0.05	9
		PG-N	0.28	0.02	9
		PX-F	1.37	0.08	9
		PX-N	0.54	0.05	9
		QT-F	1.19	0.06	6
		QT-N	0.20	0.01	6
		SH-F	1.13	0.10	9
		SH-N	0.25	0.04	9
		ST-F	1.45	0.10	9
		ST-N	1.15	0.12	9
sediment % OM: 0-2 cm	**%**	AN-F	4.79	1.34	9
		AN-N	12.67	0.95	9
		AP-F	1.11	0.21	9
		AP-N	22.97	0.97	6
		ER-F	1.30	0.17	9
		ER-N	16.05	1.18	9
		FE-F	0.88	0.14	9
		FE-N	16.05	1.83	9
		LA-F	0.86	0.12	9
		LA-N	9.49	0.77	9
		MB-F	0.33	0.03	9
		MB-N	13.92	0.30	9
		PG-F	1.21	0.09	9
		PG-N	17.15	0.60	9
		PX-F	1.17	0.17	9
		PX-N	7.07	0.55	9
		QT-F	1.23	0.21	6
		QT-N	20.44	0.73	6
		SH-F	1.91	0.28	9
		SH-N	18.89	1.40	9
		ST-F	0.70	0.07	9
		ST-N	2.87	0.51	9

Variable	units	site-strata	Mean	SE	N
sediment bulk density: 2-5 cm	**gDW/mL**	AN-F	1.26	0.12	9
		AN-N	0.59	0.03	9
		AP-F	1.44	0.07	9
		AP-N	0.30	0.00	6
		ER-F	1.63	0.04	9
		ER-N	0.61	0.05	9
		FE-F	1.57	0.05	9
		FE-N	0.38	0.03	9
		LA-F	1.65	0.05	9
		LA-N	0.64	0.05	9
		MB-F	1.55	0.07	9
		MB-N	0.36	0.01	9
		PG-F	1.45	0.04	9
		PG-N	0.24	0.02	9
		PX-F	1.43	0.07	9
		PX-N	0.73	0.06	9
		QT-F	1.44	0.06	6
		QT-N	0.28	0.01	6
		SH-F	1.55	0.06	9
		SH-N	0.31	0.05	9
		ST-F	1.34	0.06	9
		ST-N	0.91	0.08	9
sediment % OM: 2-5 cm	**%**	AN-F	3.10	0.73	9
		AN-N	10.08	0.34	9
		AP-F	1.21	0.20	9
		AP-N	20.84	0.93	6
		ER-F	1.43	0.25	9
		ER-N	13.68	0.63	9
		FE-F	0.48	0.02	9
		FE-N	16.58	1.53	9
		LA-F	0.57	0.05	9
		LA-N	8.20	0.59	9
		MB-F	0.28	0.02	9
		MB-N	13.82	0.58	9
		PG-F	1.52	0.08	9
		PG-N	16.95	0.93	9
		PX-F	1.03	0.14	9
		PX-N	5.45	0.42	9
		QT-F	0.98	0.17	6
		QT-N	14.53	0.66	6
		SH-F	0.64	0.07	9
		SH-N	17.08	1.33	9
		ST-F	0.50	0.02	9
		ST-N	2.74	0.54	9

Variable	units	site-strata	Mean	SE	N
sediment bulk density: 5-15 cm	**gDW/mL**	AN-F	1.26	0.07	9
		AN-N	0.68	0.03	9
		AP-F	1.61	0.25	9
		AP-N	0.36	0.02	6
		ER-F	1.52	0.10	9
		ER-N	0.43	0.03	9
		FE-F	1.31	0.07	9
		FE-N	0.35	0.04	9
		LA-F	1.47	0.05	9
		LA-N	0.63	0.05	9
		MB-F	1.68	0.04	9
		MB-N	0.44	0.01	9
		PG-F	1.48	0.05	9
		PG-N	0.34	0.01	9
		PX-F	1.75	0.14	9
		PX-N	0.94	0.09	9
		QT-F	1.50	0.08	6
		QT-N	0.32	0.02	6
		SH-F	1.69	0.07	9
		SH-N	0.34	0.03	9
		ST-F	1.28	0.10	9
		ST-N	1.02	0.04	9
sediment % OM: 5-15 cm	**%**	AN-F	2.54	0.53	9
		AN-N	8.51	0.30	9
		AP-F	1.39	0.33	9
		AP-N	16.95	1.14	6
		ER-F	1.47	0.23	9
		ER-N	14.81	1.57	9
		FE-F	1.89	0.42	9
		FE-N	17.08	1.86	9
		LA-F	0.64	0.07	9
		LA-N	6.19	0.71	9
		MB-F	0.17	0.02	9
		MB-N	10.53	0.42	9
		PG-F	1.82	0.10	9
		PG-N	11.46	0.36	9
		PX-F	0.70	0.09	9
		PX-N	4.78	0.47	9
		QT-F	0.92	0.13	6
		QT-N	10.81	0.28	6
		SH-F	0.73	0.12	9
		SH-N	13.84	0.65	9
		ST-F	0.67	0.13	9
		ST-N	2.93	0.27	9

Variable	units	site-strata	Mean	SE	N
sediment bulk density: 15-25 cm	**gDW/mL**	AN-F	1.48	0.09	9
		AN-N	0.77	0.03	9
		AP-F	1.49	0.12	9
		AP-N	0.45	0.03	6
		ER-F	1.45	0.15	9
		ER-N	0.40	0.03	9
		FE-F	1.00	0.13	9
		FE-N	0.39	0.05	9
		LA-F	1.66	0.10	9
		LA-N	0.71	0.06	9
		MB-F	1.75	0.06	9
		MB-N	0.52	0.02	9
		PG-F	1.51	0.04	9
		PG-N	0.42	0.02	9
		PX-F	2.03	0.12	9
		PX-N	1.08	0.12	9
		QT-F	1.69	0.07	6
		QT-N	0.52	0.03	6
		SH-F	1.85	0.06	9
		SH-N	0.38	0.04	9
		ST-F	1.43	0.06	9
		ST-N	1.11	0.07	9
sediment % OM: 15-25 cm		AN-F	2.03	0.31	9
		AN-N	8.21	0.34	9
		AP-F	1.62	0.50	9
		AP-N	15.68	0.62	6
		ER-F	3.32	1.14	9
		ER-N	13.72	1.14	9
		FE-F	3.30	0.75	9
		FE-N	17.89	2.40	9
		LA-F	0.98	0.13	9
		LA-N	4.64	0.51	9
		MB-F	0.16	0.02	9
		MB-N	9.24	0.20	9
		PG-F	1.68	0.08	9
		PG-N	10.92	0.59	9
		PX-F	1.59	1.00	9
		PX-N	3.82	0.51	9
		QT-F	1.68	0.47	6
		QT-N	9.80	0.26	6
		SH-F	0.56	0.08	9
		SH-N	13.84	0.64	9
		ST-F	1.06	0.06	9
		ST-N	2.54	0.28	9

Variable	units	site-strata	Mean	SE	N
sediment NH4 (averaged over 25 cm)	**mmolN/ m2**	AN-F	95.50	25.20	9
		AN-N	361.60	11.10	9
		AP-F	18.29	5.93	9
		AP-N	170.90	12.00	6
		ER-F	16.65	2.25	9
		ER-N	292.00	105.00	9
		FE-F	27.18	4.11	9
		FE-N	90.90	11.60	9
		LA-F	6.36	0.77	9
		LA-N	39.05	5.26	9
		MB-F	3.59	1.11	9
		MB-N	63.71	3.83	9
		PG-F	29.06	1.10	9
		PG-N	87.60	11.10	9
		PX-F	25.75	7.87	9
		PX-N	25.51	1.79	9
		QT-F	62.30	12.10	6
		QT-N	226.80	31.60	6
		SH-F	7.90	0.92	9
		SH-N	258.00	61.20	9
		ST-F	5.33	0.61	9
		ST-N	10.31	2.79	9
sediment NH4: 0-2 cm	**mmolN/ m2**	AN-F	9.03	3.75	9
		AN-N	15.90	1.09	9
		AP-F	2.59	0.60	9
		AP-N	11.13	1.56	6
		ER-F	2.35	0.22	9
		ER-N	7.26	1.65	9
		FE-F	0.60	0.06	9
		FE-N	5.06	0.67	9
		LA-F	1.38	0.18	9
		LA-N	3.26	0.55	9
		MB-F	0.62	0.08	9
		MB-N	2.25	0.16	9
		PG-F	0.66	0.05	9
		PG-N	5.13	0.35	9
		PX-F	1.60	0.11	9
		PX-N	0.65	0.06	9
		QT-F	15.27	2.67	6
		QT-N	8.21	1.40	6
		SH-F	0.85	0.14	9
		SH-N	11.58	3.07	9
		ST-F	1.05	0.12	9
		ST-N	1.59	0.14	9

Variable	units	site-strata	Mean	SE	N
sediment NH4: 2-5 cm	**mmolN/ m2**	AN-F	15.51	3.33	9
		AN-N	63.38	4.24	9
		AP-F	7.88	2.18	9
		AP-N	35.16	7.25	6
		ER-F	5.07	0.60	9
		ER-N	23.68	5.13	9
		FE-F	1.63	0.23	9
		FE-N	21.83	3.63	9
		LA-F	1.92	0.21	9
		LA-N	9.08	0.98	9
		MB-F	0.69	0.06	9
		MB-N	8.73	0.35	9
		PG-F	2.16	0.14	9
		PG-N	9.21	0.85	9
		PX-F	3.37	0.41	9
		PX-N	3.72	0.39	9
		QT-F	36.60	6.47	6
		QT-N	41.22	3.10	6
		SH-F	2.70	0.40	9
		SH-N	49.96	17.20	9
		ST-F	1.14	0.09	9
		ST-N	3.09	0.62	9
sediment NH4: 5-15 cm	**mmolN/ m2**	AN-F	120.24	32.27	9
		AN-N	381.31	20.26	9
		AP-F	27.63	9.42	9
		AP-N	177.77	16.71	6
		ER-F	22.36	2.61	9
		ER-N	233.45	64.52	9
		FE-F	27.66	8.62	9
		FE-N	94.33	11.88	9
		LA-F	7.69	1.23	9
		LA-N	40.18	6.02	9
		MB-F	3.00	0.73	9
		MB-N	50.81	3.85	9
		PG-F	21.48	1.68	9
		PG-N	72.87	14.60	9
		PX-F	17.67	2.83	9
		PX-N	25.56	1.28	9
		QT-F	91.49	23.34	6
		QT-N	207.50	16.62	6
		SH-F	10.49	1.42	9
		SH-N	286.67	80.22	9
		ST-F	3.63	0.50	9
		ST-N	10.13	1.53	9

Variable	units	site-strata	Mean	SE	N
sediment NH4: 15-25 cm	**mmolN/ m2**	AN-F	112.16	31.97	9
		AN-N	492.72	34.92	9
		AP-F	15.21	7.08	9
		AP-N	227.14	17.13	6
		ER-F	17.14	2.80	9
		ER-N	546.89	144.21	9
		FE-F	39.68	6.43	9
		FE-N	125.26	17.72	9
		LA-F	7.26	1.15	9
		LA-N	51.68	8.43	9
		MB-F	5.64	2.21	9
		MB-N	105.40	9.68	9
		PG-F	50.38	2.51	9
		PG-N	142.39	23.66	9
		PX-F	43.52	17.81	9
		PX-N	36.96	4.12	9
		QT-F	49.84	4.72	6
		QT-N	336.98	61.21	6
		SH-F	8.29	0.98	9
		SH-N	359.35	77.25	9
		ST-F	8.94	1.01	9
		ST-N	13.42	3.79	9
sediment %N by mass: 0-2cm	**%**	AN-F	0.09	0.02	9
		AN-N	0.22	0.02	9
		AP-F	0.04	0.01	9
		AP-N	0.59	0.03	6
		ER-F	0.03	0.00	9
		ER-N	0.31	0.01	9
		FE-F	0.02	0.00	9
		FE-N	0.36	0.05	9
		LA-F	0.02	0.00	9
		LA-N	0.24	0.03	9
		MB-F	0.01	0.00	9
		MB-N	0.36	0.02	9
		PG-F	0.03	0.00	9
		PG-N	0.44	0.01	9
		PX-F	0.03	0.00	9
		PX-N	0.16	0.02	9
		QT-F	0.05	0.01	6
		QT-N	0.40	0.01	6
		SH-F	0.03	0.00	9
		SH-N	0.39	0.04	9
		ST-F	0.02	0.00	9
		ST-N	0.06	0.01	9

Variable	units	site-strata	Mean	SE	N
sediment %C by mass: 0-2cm	**%**	AN-F	1.78	0.47	9
		AN-N	3.98	0.69	9
		AP-F	0.55	0.10	9
		AP-N	8.78	0.40	6
		ER-F	0.59	0.14	9
		ER-N	10.12	0.65	9
		FE-F	0.18	0.02	9
		FE-N	7.88	1.14	9
		LA-F	0.21	0.02	9
		LA-N	2.97	0.41	9
		MB-F	0.09	0.01	9
		MB-N	4.65	0.25	9
		PG-F	0.24	0.02	9
		PG-N	5.06	0.11	9
		PX-F	0.32	0.04	9
		PX-N	1.77	0.20	9
		QT-F	0.44	0.15	6
		QT-N	3.86	0.11	6
		SH-F	0.27	0.03	9
		SH-N	4.37	0.34	9
		ST-F	0.18	0.05	9
		ST-N	0.69	0.12	9
sediment %N by mass: 2-5 cm	**%**	AN-F	0.06	0.02	9
		AN-N	0.18	0.01	9
		AP-F	0.04	0.01	9
		AP-N	0.55	0.03	6
		ER-F	0.02	0.00	9
		ER-N	0.35	0.02	9
		FE-F	0.01	0.00	9
		FE-N	0.42	0.05	9
		LA-F	0.02	0.00	9
		LA-N	0.24	0.03	9
		MB-F	0.01	0.00	9
		MB-N	0.36	0.02	9
		PG-F	0.04	0.00	9
		PG-N	0.42	0.02	9
		PX-F	0.03	0.00	9
		PX-N	0.15	0.02	9
		QT-F	0.02	0.00	6
		QT-N	0.39	0.01	6
		SH-F	0.02	0.00	9
		SH-N	0.41	0.02	9
		ST-F	0.01	0.00	9
		ST-N	0.06	0.01	9

Variable	units	site-strata	Mean	SE	N
sediment %C by mass: 2-5 cm	**%**	AN-F	1.32	0.39	9
		AN-N	3.33	0.13	9
		AP-F	0.66	0.17	9
		AP-N	7.90	0.43	6
		ER-F	0.34	0.07	9
		ER-N	12.14	1.35	9
		FE-F	0.10	0.01	9
		FE-N	8.14	0.96	9
		LA-F	0.14	0.01	9
		LA-N	3.02	0.39	9
		MB-F	0.08	0.01	9
		MB-N	4.91	0.15	9
		PG-F	0.37	0.04	9
		PG-N	4.83	0.12	9
		PX-F	0.30	0.04	9
		PX-N	1.72	0.17	9
		QT-F	0.16	0.04	6
		QT-N	3.84	0.11	6
		SH-F	0.23	0.03	9
		SH-N	4.73	0.18	9
		ST-F	0.12	0.01	9
		ST-N	0.70	0.12	9
sediment %N by mass: 5-15 cm	**%**	AN-F	0.04	0.01	9
		AN-N	0.17	0.02	9
		AP-F	0.06	0.02	9
		AP-N	0.47	0.05	6
		ER-F	0.02	0.00	9
		ER-N	0.40	0.05	9
		FE-F	0.04	0.01	9
		FE-N	0.59	0.13	9
		LA-F	0.02	0.00	9
		LA-N	0.20	0.03	9
		MB-F	0.01	0.00	9
		MB-N	0.33	0.02	9
		PG-F	0.04	0.00	9
		PG-N	0.35	0.01	9
		PX-F	0.02	0.00	9
		PX-N	0.14	0.02	9
		QT-F	0.02	0.00	6
		QT-N	0.39	0.01	6
		SH-F	0.02	0.00	9
		SH-N	0.42	0.03	9
		ST-F	0.01	0.00	9
		ST-N	0.07	0.01	9

Variable	units	site-strata	Mean	SE	N
sediment %C by mass: 5-15 cm	**%**	AN-F	0.93	0.19	9
		AN-N	3.25	0.16	9
		AP-F	1.01	0.30	9
		AP-N	6.86	0.61	6
		ER-F	0.49	0.10	9
		ER-N	11.58	1.76	9
		FE-F	0.38	0.14	9
		FE-N	9.72	1.81	9
		LA-F	0.18	0.03	9
		LA-N	2.54	0.43	9
		MB-F	0.05	0.01	9
		MB-N	4.75	0.20	9
		PG-F	0.44	0.02	9
		PG-N	4.15	0.15	9
		PX-F	0.24	0.03	9
		PX-N	1.78	0.21	9
		QT-F	0.12	0.03	6
		QT-N	3.82	0.10	6
		SH-F	0.16	0.03	9
		SH-N	4.69	0.17	9
		ST-F	0.12	0.01	9
		ST-N	0.85	0.11	9
sediment %N by mass: 15-25 cm	**%**	AN-F	0.03	0.01	9
		AN-N	0.13	0.02	9
		AP-F	0.04	0.01	9
		AP-N	0.45	0.02	6
		ER-F	0.04	0.02	9
		ER-N	0.36	0.04	9
		FE-F	0.05	0.01	9
		FE-N	0.53	0.12	9
		LA-F	0.02	0.00	9
		LA-N	0.16	0.02	9
		MB-F	0.01	0.00	9
		MB-N	0.25	0.02	9
		PG-F	0.03	0.00	9
		PG-N	0.31	0.02	9
		PX-F	0.01	0.00	9
		PX-N	0.08	0.02	9
		QT-F	0.01	0.00	6
		QT-N	0.35	0.01	6
		SH-F	0.01	0.00	9
		SH-N	0.42	0.02	9
		ST-F	0.02	0.00	9
		ST-N	0.06	0.01	9

Variable	units	site-strata	Mean	SE	N
sediment %C by mass: 15-25 cm	**%**	AN-F	0.76	0.13	9
		AN-N	3.05	0.30	9
		AP-F	0.59	0.24	9
		AP-N	6.51	0.44	6
		ER-F	1.79	1.06	9
		ER-N	8.85	1.03	9
		FE-F	0.59	0.16	9
		FE-N	9.83	2.35	9
		LA-F	0.22	0.03	9
		LA-N	2.08	0.33	9
		MB-F	0.05	0.01	9
		MB-N	3.82	0.25	9
		PG-F	0.32	0.03	9
		PG-N	3.70	0.21	9
		PX-F	0.14	0.02	9
		PX-N	1.37	0.33	9
		QT-F	0.14	0.06	6
		QT-N	3.63	0.12	6
		SH-F	0.08	0.01	9
		SH-N	4.87	0.20	9
		ST-F	0.21	0.02	9
		ST-N	0.83	0.17	9
sediment %N by mass (averaged over 25 cm)	**%**	AN-F	0.04	0.01	9
		AN-N	0.16	0.01	9
		AP-F	0.05	0.01	9
		AP-N	0.48	0.03	6
		ER-F	0.03	0.01	9
		ER-N	0.37	0.04	9
		FE-F	0.04	0.01	9
		FE-N	0.53	0.10	9
		LA-F	0.02	0.00	9
		LA-N	0.17	0.02	9
		MB-F	0.01	0.00	9
		MB-N	0.31	0.01	9
		PG-F	0.04	0.00	9
		PG-N	0.35	0.01	9
		PX-F	0.02	0.00	9
		PX-N	0.12	0.02	9
		QT-F	0.02	0.00	6
		QT-N	0.37	0.01	6
		SH-F	0.02	0.00	9
		SH-N	0.42	0.02	9
		ST-F	0.02	0.00	9
		ST-N	0.07	0.01	9

Variable	units	site-strata	Mean	SE	N
sediment %C by mass (averaged over 25 cm)	**%**	AN-F	0.98	0.16	9
		AN-N	3.24	0.20	9
		AP-F	0.77	0.19	9
		AP-N	7.00	0.40	6
		ER-F	1.00	0.47	9
		ER-N	10.38	1.30	9
		FE-F	0.43	0.12	9
		FE-N	9.43	1.68	9
		LA-F	0.19	0.02	9
		LA-N	2.22	0.36	9
		MB-F	0.06	0.00	9
		MB-N	4.39	0.16	9
		PG-F	0.37	0.02	9
		PG-N	4.09	0.16	9
		PX-F	0.21	0.03	9
		PX-N	1.61	0.24	9
		QT-F	0.16	0.03	6
		QT-N	3.75	0.10	6
		SH-F	0.14	0.01	9
		SH-N	4.74	0.17	9
		ST-F	0.16	0.01	9
		ST-N	0.81	0.12	9

Appendix E. Macrofaunal biomass, 2003. Taxa listed by sites and strata sampled in 2003. Mean biomass of taxa in mg AFDM per core (area sampled = 130 cm^2; core depth = 25 cm). SE = standard error of mean; N = number of stations per site/stratum. Trace = biomass <0.01mg, as determined from pooled samples.

Chisman Creek Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Tubificoides brownae*	0.89	0.11	9
Annelida: Polycheata	*Eteone heteropoda*	0.89	0.11	9
Annelida: Polycheata	*Glycera americana*	0.11	0.11	9
Annelida: Polycheata	*Glycera dibranchiata*	0.11	0.11	9
Annelida: Polycheata	*Heteromastus filiformis*	2.16	0.82	9
Annelida: Polycheata	*Laeonereis culveri*	0.27	0.27	9
Annelida: Polycheata	*Leitoscoloplos fragilis*	2.15	0.71	9
Annelida: Polycheata	Lumbrineridae	0.11	0.11	9
Annelida: Polycheata	*Neanthes succinea*	7.10	2.97	9
Annelida: Polycheata	*Paraprionospio pinnata*	0.56	0.18	9
Annelida: Polycheata	Spionidae	0.11	0.11	9
Annelida: Polycheata	*Streblospio benedicti*	1.32	0.23	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	4.09	0.71	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.11	0.11	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.11	0.11	9
Arthropoda: Insecta	Chironomidae	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	4.52	0.97	9
Mollusca: Bivalvia	*Macoma balthica*	198.39	61.85	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.11	0.11	9
Mollusca: Bivalvia	*Tagelus plebius*	8.03	8.03	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 2	2.26	0.58	9

Chisman Creek Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Tubificoides brownae*	0.33	0.17	9
Annelida: Polycheata	*Brania wellfleetensis*	0.11	0.11	9
Annelida: Polycheata	*Clymenella torquata*	32.52	8.69	9
Annelida: Polycheata	*Drilonereis longa*	6.06	2.84	9
Annelida: Polycheata	*Eteone heteropoda*	1.00	0.17	9
Annelida: Polycheata	*Glycera americana*	3.11	1.30	9
Annelida: Polycheata	*Glycera dibranchiata*	4.65	4.06	9
Annelida: Polycheata	*Glycinde solitaria*	0.11	0.11	9
Annelida: Polycheata	*Heteromastus filiformis*	7.37	2.56	9
Annelida: Polycheata	*Leitoscoloplos fragilis*	5.93	2.60	9
Annelida: Polycheata	*Marenzellaria viridis*	0.11	0.11	9
Annelida: Polycheata	*Mediomastus ambiseta*	0.11	0.11	9
Annelida: Polycheata	*Melinna maculata*	0.94	0.94	9
Annelida: Polycheata	*Neanthes succinea*	0.22	0.15	9
Annelida: Polycheata	*Paraprionospio pinnata*	0.11	0.11	9
Annelida: Polycheata	*Pokarkeopsis levifuscina*	1.00	0.00	9
Annelida: Polycheata	*Polydora cornuta*	0.11	0.11	9
Annelida: Polycheata	*Scolelepis texana*	0.89	0.31	9
Annelida: Polycheata	Spionidae	0.11	0.11	9
Annelida: Polycheata	*Spiophanes bombyx*	0.88	0.24	9
Annelida: Polycheata	*Streblospio benedicti*	3.51	0.39	9
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.11	0.11	9
Arthropoda: Amphipoda	*Corophium insidiosum*	0.22	0.15	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.44	0.24	9
Arthropoda: Amphipoda	*Listriella clymenellae*	1.11	0.20	9
Arthropoda: Cumacea	*Campylapsis rubicunda*	0.33	0.17	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.22	0.15	9
Arthropoda: Cumacea	*Oxyurostylis smithi*	0.11	0.11	9
Arthropoda: Isopoda	*Edotea triloba*	0.33	0.17	9
Arthropoda: Mysidacea	*Neomysis americana*	1.12	0.45	9
Mollusca: Bivalvia	*Aligena elevata*	1.52	0.89	9
Mollusca: Bivalvia	*Macoma balthica*	1.22	0.15	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.11	0.11	9
Mollusca: Bivalvia	*Tagelus plebius*	0.11	0.11	9
Mollusca: Gastropoda	*Acetocina canaliculata*	0.11	0.11	9
Mollusca: Gastropoda	*Cylichna alba*	0.11	0.11	9
Nemertea	Nemertean	5.51	5.39	9
Nemertea	Nemertean sp. 2	0.27	0.18	9
Phoronida	Phoronidae	11.87	6.13	9
Phoronida	Phoronis sp.	0.11	0.11	9
Turbellaria	Flatworm sp. 1	0.11	0.11	9
Turbellaria	Flatworm sp. 2	0.11	0.11	9

Elizabeth River Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Tubificoides wasselli*	0.11	0.11	9
Annelida: Polycheata	*Hobsonia florida*	2.70	0.52	9
Annelida: Polycheata	*Laeonereis culveri*	9.23	1.93	9
Annelida: Polycheata	*Neanthes succinea*	8.42	3.11	9
Arthropoda: Isopoda	*Cyathura polita*	6.53	1.86	9

Elizabeth River Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.67	0.24	9
Annelida: Polycheata	*Ampharete parvidentata*	0.11	0.11	9
Annelida: Polycheata	*Ampharetidae*	0.33	0.17	9
Annelida: Polycheata	*Capitella capitata*	0.11	0.11	9
Annelida: Polycheata	*Capitomastus aciculatus*	0.44	0.18	9
Annelida: Polycheata	*Eteone heteropoda*	0.67	0.24	9
Annelida: Polycheata	*Glycera sp.*	0.11	0.11	9
Annelida: Polycheata	*Heteromastus filiformis*	2.69	1.27	9
Annelida: Polycheata	*Hobsonia florida*	0.56	0.18	9
Annelida: Polycheata	*Laeonereis culveri*	1.59	0.62	9
Annelida: Polycheata	*Leitoscoloplos fragilis*	0.87	0.39	9
Annelida: Polycheata	*Marenzellaria viridis*	0.72	0.41	9
Annelida: Polycheata	*Mediomastus ambiseta*	0.89	0.26	9
Annelida: Polycheata	*Neanthes succinea*	0.11	0.11	9
Annelida: Polycheata	Spionidae	0.22	0.15	9
Annelida: Polycheata	*Streblospio benedicti*	0.33	0.24	9
Arthropoda: Amphipoda	*Corophium insidiosum*	0.11	0.11	9
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.22	0.15	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.11	0.11	9
Arthropoda: Isopoda	*Cyathura polita*	2.55	0.73	9
Arthropoda: Isopoda	*Edotea triloba*	0.67	0.17	9
Arthropoda: Isopoda	Isopoda sp. 1	0.11	0.11	9
Arthropoda: Ostracoda	Ostracod sp. 1	0.12	0.12	9
Mollusca: Bivalvia	Bivalvia	0.11	0.11	9
Mollusca: Bivalvia	Macoma balthica	13.36	6.13	9
Mollusca: Bivalvia	*Macoma sp.*	0.11	0.11	9
Mollusca: Bivalvia	*Tagelus plebius*	94.11	68.57	9
Mollusca: Gastropoda	Gastropoda	0.11	0.11	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 1	0.11	0.11	9

Langley Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Paranais litoralis*	0.13	0.13	8
Annelida: Oligochaeta	Tubificidae	0.13	0.13	8
Annelida: Oligochaeta	*Tubificoides brownae*	1.25	0.31	8
Annelida: Oligochaeta	*Tubificoides heterochaetus*	0.25	0.16	8
Annelida: Oligochaeta	*Tubificoides motei*	0.13	0.13	8
Annelida: Oligochaeta	*Tubificoides sp.*	0.13	0.13	8
Annelida: Polycheata	*Eteone heteropoda*	0.75	0.25	8
Annelida: Polycheata	*Glycinde solitaria*	0.79	0.18	8
Annelida: Polycheata	*Heteromastus filiformis*	2.35	1.05	8
Annelida: Polycheata	*Hobsonia florida*	0.13	0.13	8
Annelida: Polycheata	*Leitoscoloplos fragilis*	8.99	2.58	8
Annelida: Polycheata	*Mediomastus ambiseta*	0.88	0.13	8
Annelida: Polycheata	*Neanthes succinea*	1.26	0.34	8
Annelida: Polycheata	*Paraprionospio pinnata*	3.30	1.18	8
Annelida: Polycheata	*Pokarkeopsis levifuscina*	0.38	0.18	8
Annelida: Polycheata	*Streblospio benedicti*	1.00	0.00	8
Annelida: Polycheata	*Tharyx acutus*	0.25	0.16	8
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.13	0.13	8
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.69	0.21	8
Arthropoda: Cumacea	*Leucon americanus*	0.13	0.13	8
Arthropoda: Isopoda	*Cyathura polita*	1.15	0.57	8
Arthropoda: Isopoda	*Edotea triloba*	0.38	0.18	8
Arthropoda: Ostracoda	Ostracod sp. 1	0.38	0.26	8
Arthropoda: Ostracoda	Ostracod sp. 3	0.13	0.13	8
Cnidaria: Anthozoa	*Actinaria sp. 1*	0.13	0.13	8
Mollusca: Bivalvia	*Gemma gemma*	0.13	0.13	8
Mollusca: Bivalvia	*Macoma balthica*	11.31	6.74	8
Mollusca: Bivalvia	*Macoma mitchelli*	0.13	0.13	8
Mollusca: Bivalvia	*Macoma sp.*	2.29	2.15	8
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.13	0.13	8
Mollusca: Gastropoda	*Acteon punctostriatus*	0.13	0.13	8
Nemertea	Nemertean sp. 1	1.06	0.43	8
Nemertea	Nemertean sp. 2	1.00	0.48	8
Nemertea	Nemertean sp. 4	0.13	0.13	8
Nemertea	Nemertean sp. 5	0.13	0.13	8
Phoronida	*Phoronis sp.*	0.63	0.32	8
Turbellaria	Flatworm sp. 1	0.25	0.16	8
Turbellaria	Flatworm sp. 2	0.13	0.13	8
Turbellaria	Flatworm sp. 3	0.13	0.13	8

Langley Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.67	0.24	9
Annelida: Polycheata	*Capitella capitata*	0.11	0.11	9
Annelida: Polycheata	*Chaetopterus variopedatus*	0.11	0.11	9
Annelida: Polycheata	*Clymenella torquata*	5.71	3.27	9
Annelida: Polycheata	*Drilonereis longa*	2.81	1.87	9
Annelida: Polycheata	*Eteone heteropoda*	0.22	0.15	9
Annelida: Polycheata	*Glycinde solitaria*	1.54	0.18	9
Annelida: Polycheata	*Heteromastus filiformis*	1.08	0.24	9
Annelida: Polycheata	*Leitoscoloplos fragilis*	2.30	0.98	9
Annelida: Polycheata	*Loimia medusa*	0.11	0.11	9
Annelida: Polycheata	*Marenzellaria viridis*	0.33	0.17	9
Annelida: Polycheata	*Mediomastus ambiseta*	1.16	0.11	9
Annelida: Polycheata	*Neanthes succinea*	0.11	0.11	9
Annelida: Polycheata	*Pokarkeopsis levifuscina*	0.22	0.15	9
Annelida: Polycheata	*Polydora cornuta*	0.11	0.11	9
Annelida: Polycheata	*Scolelepis texana*	0.67	0.17	9
Annelida: Polycheata	*Spiochaetopterus oculatus*	0.75	0.34	9
Annelida: Polycheata	*Spiophanes bombyx*	0.11	0.11	9
Annelida: Polycheata	*Streblospio benedicti*	1.11	0.11	9
Annelida: Polycheata	*Tharyx acutus*	0.44	0.18	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.11	0.11	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella clymenellae*	0.33	0.17	9
Arthropoda: Ostracoda	Ostracod sp. 1	0.11	0.11	9
Mollusca: Bivalvia	*Aligena elevata*	1.04	0.39	9
Mollusca: Bivalvia	*Tagelus plebius*	3.71	3.71	9
Mollusca: Gastropoda	*Acetocina canaliculata*	0.22	0.15	9
Mollusca: Gastropoda	*Skeneopsis planorbis*	0.11	0.11	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 1	0.22	0.15	9
Nemertea	Nemertean sp. 2	0.68	0.44	9
Phoronida	*Phoronis sp.*	17.51	11.42	9
Turbellaria	Flatworm sp. 2	0.33	0.17	9
Turbellaria	Flatworm sp. 3	0.11	0.11	9

Sarah Creek Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Limnodriloides anxius*	0.33	0.17	9
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	1.67	0.28	9
Annelida: Oligochaeta	*Tubificoides motei*	0.44	0.18	9
Annelida: Polycheata	*Capitella capitata*	1.10	0.42	9
Annelida: Polycheata	*Capitomastus aciculatus*	5.19	1.79	9
Annelida: Polycheata	*Eteone heteropoda*	0.89	0.31	9
Annelida: Polycheata	*Heteromastus filiformis*	0.89	0.31	9
Annelida: Polycheata	*Laeonereis culveri*	0.83	0.49	9
Annelida: Polycheata	*Leitoscoloplos fragilis*	1.13	1.13	9
Annelida: Polycheata	*Neanthes succinea*	1.01	0.79	9
Annelida: Polycheata	*Pokarkeopsis levifuscina*	0.11	0.11	9
Annelida: Polycheata	*Polydora cornuta*	0.11	0.11	9
Annelida: Polycheata	*Streblospio benedicti*	1.11	0.11	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.11	0.11	9
Arthropoda: Insecta	Chironomidae	0.44	0.24	9
Nemertea	Nemertean	0.11	0.11	9
Nemertea	Nemertean sp. 1	0.11	0.11	9
Nemertea	Nemertean sp. 2	0.11	0.11	9

Sarah Creek Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	Tubificidae	0.11	0.11	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.33	0.17	9
Annelida: Oligochaeta	*Tubificoides motei*	0.11	0.11	9
Annelida: Polycheata	*Amastigos caperatus*	0.22	0.22	9
Annelida: Polycheata	*Ancistrosylis hartmanae*	0.11	0.11	9
Annelida: Polycheata	*Apoprionspio dayi*	0.11	0.11	9
Annelida: Polycheata	*Capitella capitata*	1.00	0.24	9
Annelida: Polycheata	*Capitella jonesi*	0.44	0.18	9
Annelida: Polycheata	*Capitomastus aciculatus*	1.47	0.47	9
Annelida: Polycheata	*Clymenella torquata*	7.77	3.08	9
Annelida: Polycheata	*Cossura longocirrata*	0.11	0.11	9
Annelida: Polycheata	*Diopatra cuprea*	1.67	1.67	9
Annelida: Polycheata	*Drilonereis longa*	1.50	1.17	9
Annelida: Polycheata	*Eteone heteropoda*	1.32	0.23	9
Annelida: Polycheata	*Glycera dibranchiata*	3.48	1.76	9
Annelida: Polycheata	*Glycinde solitaria*	0.11	0.11	9
Annelida: Polycheata	*Gyptis vittata*	0.11	0.11	9
Annelida: Polycheata	*Heteromastus filiformis*	7.64	1.97	9
Annelida: Polycheata	*Laeonereis culveri*	0.53	0.22	9
Annelida: Polycheata	*Leitoscoloplos fragilis*	0.30	0.20	9
Annelida: Polycheata	*Marenzellaria viridis*	0.27	0.18	9
Annelida: Polycheata	*Mediomastus ambiseta*	0.44	0.18	9
Annelida: Polycheata	*Neanthes succinea*	1.09	0.44	9
Annelida: Polycheata	*Pokarkeopsis levifuscina*	0.22	0.15	9
Annelida: Polycheata	*Polydora cornuta*	4.86	4.37	9
Annelida: Polycheata	*Scolelepis texana*	0.80	0.28	9
Annelida: Polycheata	*Scoloplos rubra*	0.49	0.49	9
Annelida: Polycheata	*Spiophanes bombyx*	0.79	0.42	9
Annelida: Polycheata	*Streblospio benedicti*	2.44	0.30	9
Annelida: Polycheata	*Tharyx acutus*	0.56	0.24	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.11	0.11	9
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.33	0.17	9
Arthropoda: Amphipoda	*Cymadusa compta*	0.11	0.11	9
Arthropoda: Amphipoda	*Gammarus mucronatus*	0.11	0.11	9
Arthropoda: Amphipoda	*Listriella barnardi*	0.22	0.15	9
Arthropoda: Amphipoda	*Listriella clymenellae*	0.89	0.26	9
Arthropoda: Cumacea	*Campylapsis rubicunda*	0.44	0.18	9
Arthropoda: Cumacea	*Oxyurostylis smithi*	0.11	0.11	9
Arthropoda: Isopoda	*Edotea triloba*	0.46	0.18	9
Arthropoda: Isopoda	*Erichsonella attenuata*	0.22	0.15	9
Arthropoda: Mysidacea	*Neomysis americana*	0.67	0.17	9
Mollusca: Bivalvia	*Aligena elevata*	0.22	0.15	9
Mollusca: Bivalvia	*Gemma gemma*	0.56	0.24	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.11	0.11	9
Mollusca: Bivalvia	*Tagelus plebius*	125.51	124.82	9
Nemertea	Nemertean sp. 2	0.22	0.15	9
Nemertea	Nemertean sp. 7	0.35	0.18	9
Phoronida	Phoronidae	58.42	23.29	9

Severn Thornton Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Tubificoides brownae*	1.00	0.27	8
Annelida: Oligochaeta	*Tubificoides motei*	0.13	0.13	8
Annelida: Oligochaeta	*Tubificoides wasselli*	0.88	0.23	8
Annelida: Polycheata	*Bhawania heteroseta*	0.13	0.13	8
Annelida: Polycheata	*Chaetopterus variopedatus*	0.26	0.26	8
Annelida: Polycheata	*Clymenella torquata*	65.83	12.80	8
Annelida: Polycheata	*Eteone heteropoda*	0.13	0.13	8
Annelida: Polycheata	*Glycera americana*	1.43	1.43	8
Annelida: Polycheata	*Glycera dibranchiata*	0.55	0.55	8
Annelida: Polycheata	*Glycinde solitaria*	0.50	0.19	8
Annelida: Polycheata	*Gyptis crypta*	0.13	0.13	8
Annelida: Polycheata	*Hauchiella sp.*	0.13	0.13	8
Annelida: Polycheata	*Heteromastus filiformis*	3.58	0.81	8
Annelida: Polycheata	*Leitoscoloplos fragilis*	5.41	0.95	8
Annelida: Polycheata	*Loimia medusa*	0.13	0.13	8
Annelida: Polycheata	*Mediomastus ambiseta*	2.06	0.41	8
Annelida: Polycheata	*Neanthes succinea*	1.12	0.57	8
Annelida: Polycheata	*Notomastus sp. A* Ewing	3.55	1.03	8
Annelida: Polycheata	*Parahesione luteola*	0.13	0.13	8
Annelida: Polycheata	*Paraprionospio pinnata*	4.61	2.04	8
Annelida: Polycheata	*Pokarkeopsis levifuscina*	1.42	0.21	8
Annelida: Polycheata	*Polydora cornuta*	0.38	0.18	8
Annelida: Polycheata	*Prionospio perkinsi*	0.13	0.13	8
Annelida: Polycheata	*Spiochaetopterus oculatus*	0.35	0.24	8
Annelida: Polycheata	*Streblospio benedicti*	1.01	0.01	8
Annelida: Polycheata	*Terebellidae*	3.41	3.24	8
Annelida: Polycheata	*Tharyx acutus*	0.38	0.18	8
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.88	0.13	8
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.13	0.13	8
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.13	0.13	8
Arthropoda: Amphipoda	*Listriella barnardi*	0.63	0.18	8
Arthropoda: Amphipoda	*Listriella clymenellae*	1.63	0.26	8
Arthropoda: Cumacea	*Leucon americanus*	0.13	0.13	8
Arthropoda: Isopoda	*Cyathura polita*	0.38	0.18	8
Arthropoda: Isopoda	*Edotea triloba*	0.13	0.13	8
Arthropoda: Ostracoda	Ostracod sp. 2	0.88	0.23	8
Arthropoda: Ostracoda	Ostracod sp. 4	0.13	0.13	8
Cnidaria: Anthozoa	Cnidaria	0.13	0.13	8
Mollusca: Bivalvia	*Aligena elevata*	11.18	2.45	8
Mollusca: Bivalvia	*Macoma balthica*	0.70	0.70	8
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	11.60	4.05	8
Mollusca: Bivalvia	*Tagelus plebius*	1.49	1.49	8
Mollusca: Gastropoda	*Acetocina canaliculata*	0.25	0.16	8
Mollusca: Gastropoda	*Acteon punctostriatus*	0.13	0.13	8
Mollusca: Gastropoda	Gastropod sp. 4	0.25	0.16	8
Mollusca: Gastropoda	Gastropoda	0.13	0.13	8
Mollusca: Gastropoda	*Skeneopsis planorbis*	0.13	0.13	8
Nemertea	Nemertean	0.36	0.25	8
Nemertea	Nemertean sp. 2	0.49	0.49	8
Nemertea	Nemertean sp. 4	0.13	0.13	8

Severn Thornton Near-Field, continued

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Nemertea	Nemertean sp. 6	0.13	0.13	8
Nemertea	Nemertean sp. 7	0.13	0.13	8
Phoronida	*Phoronis sp.*	4.37	1.43	8
Turbellaria	Flatworm sp. 3	0.13	0.13	8

Severn Thornton Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Tubificoides brownae*	0.25	0.16	8
Annelida: Polycheata	*Clymenella torquata*	21.83	4.24	8
Annelida: Polycheata	*Drilonereis longa*	1.13	1.13	8
Annelida: Polycheata	*Eteone heteropoda*	0.63	0.18	8
Annelida: Polycheata	*Glycera dibranchiata*	7.65	3.98	8
Annelida: Polycheata	*Glycinde solitaria*	0.26	0.17	8
Annelida: Polycheata	*Heteromastus filiformis*	3.50	1.33	8
Annelida: Polycheata	*Leitoscoloplos fragilis*	3.57	1.33	8
Annelida: Polycheata	*Mediomastus ambiseta*	1.51	0.18	8
Annelida: Polycheata	*Melinna maculata*	0.73	0.51	8
Annelida: Polycheata	*Neanthes succinea*	0.38	0.18	8
Annelida: Polycheata	*Notomastus sp. A* Ewing	0.15	0.15	8
Annelida: Polycheata	*Paraprionospio pinnata*	0.19	0.19	8
Annelida: Polycheata	*Pectinaria gouldi*	0.13	0.13	8
Annelida: Polycheata	*Pokarkeopsis levifuscina*	0.38	0.18	8
Annelida: Polycheata	*Scolelepis texana*	1.24	0.25	8
Annelida: Polycheata	*Spiochaetopterus oculatus*	0.39	0.28	8
Annelida: Polycheata	*Spiophanes bombyx*	2.57	0.64	8
Annelida: Polycheata	*Streblospio benedicti*	1.05	0.05	8
Annelida: Polycheata	*Tharyx acutus*	0.88	0.30	8
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	0.50	0.19	8
Arthropoda: Amphipoda	*Ampelisca verrilli*	0.63	0.18	8
Arthropoda: Amphipoda	*Caprella penantis*	0.13	0.13	8
Arthropoda: Amphipoda	*Corophium ascheruscium*	0.25	0.16	8
Arthropoda: Amphipoda	*Corophium lacustre*	0.13	0.13	8
Arthropoda: Amphipoda	*Elamopus levis*	0.13	0.13	8
Arthropoda: Amphipoda	*Listriella barnardi*	0.25	0.16	8
Arthropoda: Amphipoda	*Listriella clymenellae*	4.24	4.10	8
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.13	0.13	8
Arthropoda: Mysidacea	*Mysidopsis bigelowi*	0.25	0.16	8
Arthropoda: Ostracoda	Ostracod sp. 1	0.13	0.13	8
Arthropoda: Ostracoda	Ostracod sp. 2	1.00	0.00	8
Cnidaria: Anthozoa	*Edwardsia elegans*	0.13	0.13	8
Mollusca: Bivalvia	*Aligena elevata*	3.68	0.74	8
Mollusca: Bivalvia	*Ensis directus*	5.84	5.84	8
Mollusca: Gastropoda	*Acetocina canaliculata*	0.13	0.13	8
Mollusca: Gastropoda	Gastropod sp. 3	0.13	0.13	8
Mollusca: Gastropoda	Gastropoda	0.25	0.16	8
Mollusca: Gastropoda	*Skeneopsis planorbis*	0.13	0.13	8
Nemertea	Nemertean sp. 1	2.60	2.60	8
Nemertea	Nemertean sp. 2	0.26	0.26	8
Nemertea	Nemertean sp. 3	0.13	0.13	8
Nemertea	Nemertean sp. 7	0.13	0.13	8
Phoronida	*Phoronis sp.*	49.04	10.74	8
Turbellaria	Flatworm sp. 3	0.13	0.13	8

Appendix E. Macrofaunal biomass, 2004. Taxa listed by sites and strata sampled in 2004. Mean biomass of taxa in mg AFDM per core (area sampled = 130 cm^2; core depth = 25 cm). SE = standard error of mean; N = number of stations per site/stratum. Trace = biomass <0.01mg, as determined from pooled samples.

Fort Eustis Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida	Annelid	0.08	0.08	12
Annelida: Hirudinae	Hirudinae	0.09	0.09	12
Annelida: Oligochaeta	*Limnodriloides anxius*	0.01	0.01	12
Annelida: Oligochaeta	*Paranais litoralis*	0.01	0.00	12
Annelida: Oligochaeta	*Tubificoides brownae*	trace		12
Annelida: Oligochaeta	*Tubificoides heterochaetus*	3.44	0.83	12
Annelida: Polycheata	*Fabricra sabella*	0.08	0.08	12
Annelida: Polycheata	*Hobsonia florida*	0.43	0.18	12
Annelida: Polycheata	*Laeonereis culveri*	0.12	0.08	12
Annelida: Polycheata	*Marenzellaria viridis*	2.00	1.06	12
Annelida: Polycheata	*Mediomastus ambiseta*	0.56	0.22	12
Annelida: Polycheata	*Neanthes succinea*	0.36	0.26	12
Annelida: Polycheata	*Polydora cornuta*	0.99	0.42	12
Annelida: Polycheata	*Streblospio benedicti*	3.12	0.51	12
Arthropoda: Amphipoda	Amphipod	trace		12
Arthropoda: Amphipoda	*Corophium lacustre*	0.10	0.10	12
Arthropoda: Amphipoda	*Corophium simile*	0.74	0.46	12
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.34	0.12	12
Arthropoda: Amphipoda	*Protohaustorius deichmannae*	0.01	0.01	12
Arthropoda: Decapoda	*Rithropanopeus harrisii*	0.35	0.33	12
Arthropoda: Decapoda	*Pagurus longicarpus*	0.42	0.27	12
Arthropoda: Insecta	Chironomidae	0.17	0.11	12
Arthropoda: Insecta	Chironominae	0.10	0.10	12
Arthropoda: Insecta	*Chironomus sp.*	trace		12
Arthropoda: Insecta	Insecta	trace		12
Arthropoda: Insecta	*Parachironomus directus*	0.08	0.08	12
Arthropoda: Insecta	*Peltoperla*	0.17	0.11	12
Arthropoda: Insecta	*Probezzia sp.*	0.08	0.08	12
Arthropoda: Insecta	*Pseudochironomus sp.*	trace		12
Arthropoda: Insecta	Tanypodinae	0.17	0.09	12
Arthropoda: Insecta	*Tanypus neopunctipennis*	trace		12
Arthropoda: Isopoda	*Cyathura polita*	0.17	0.10	12
Arthropoda: Isopoda	*Edotea triloba*	0.39	0.21	12
Arthropoda: Ostracoda	Ostracod sp. 1	0.01	0.00	12
Arthropoda: Ostracoda	Ostracod sp. 3	0.02	0.01	12
Arthropoda: Ostracoda	Ostracod sp. 5	0.09	0.08	12
Arthropoda: Ostracoda	Ostracod sp.6	0.08	0.08	12
Mollusca: Bivalvia	*Congaria leucophaeta*	0.02	0.01	12
Mollusca: Bivalvia	*Gemma gemma*	0.01	0.01	12
Mollusca: Bivalvia	*Macoma balthica*	0.21	0.21	12
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	1.72	0.94	12
Mollusca: Bivalvia	*Mulinea lateralis*	0.45	0.15	12
Mollusca: Gastropoda	*Assiminea succinae*	0.04	0.03	12
Mollusca: Gastropoda	Gastropod sp. 5	0.17	0.11	12

Fort Eustis Near-Field, continued

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Mollusca: Gastropoda	Gastropod sp. 6	0.05	0.04	12
Mollusca: Gastropoda	Gastropoda	0.10	0.04	12
Nemertea	Nemertean	0.08	0.08	12
Nemertea	Nemertean sp. 1	trace		12
Nemertea	Nemertean sp. 2	0.25	0.10	12
Turbellaria	Flatworm	trace		12
Turbellaria	Turbellarian sp. 3	0.08	0.08	12
Turbellaria	Turbellarian sp. 5	trace		12
Turbellaria	Turbellarian sp. 7	trace		12

Fort Eustis Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Tubificoides heterochaetus*	0.03	0.02	12
Annelida: Polycheata	*Heteromastus filiformis*	3.23	0.69	12
Annelida: Polycheata	*Laeonereis culveri*	1.85	0.38	12
Annelida: Polycheata	*Marenzellaria viridis*	16.31	3.22	12
Annelida: Polycheata	*Mediomastus ambiseta*	trace		12
Annelida: Polycheata	*Polydora cornuta*	0.01	0.01	12
Annelida: Polycheata	*Streblospio benedicti*	0.28	0.07	12
Arthropoda: Amphipoda	*Corophium simile*	0.04	0.04	12
Arthropoda: Amphipoda	Gammaridea	trace		12
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	1.59	0.22	12
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.03	0.03	12
Arthropoda: Amphipoda	*Protohaustorius deichmannae*	4.37	0.92	12
Arthropoda: Insecta	*Cryptochironomus sp.*	0.09	0.08	12
Arthropoda: Isopoda	*Cyathura polita*	0.68	0.31	12
Cnidaria: Anthozoa	*Actinaria* juv.	trace		12
Cnidaria: Scyphozoa	Scyphozoa	0.13	0.13	12
Mollusca: Bivalvia	*Congaria leucophaeta*	trace		12
Mollusca: Bivalvia	*Gemma gemma*	0.01	0.01	12
Mollusca: Bivalvia	*Macoma balthica*	0.04	0.04	12
Mollusca: Bivalvia	*Mulinea lateralis*	1.54	1.16	12
Mollusca: Bivalvia	*Rangia cuneata*	0.64	0.30	12
Mollusca: Gastropoda	Gastropod sp.6	0.03	0.03	12
Mollusca: Gastropoda	Gastropoda	0.03	0.02	12
Nemertea	Nemertean sp. 2	0.62	0.62	12
Phoronida	Phoronidae	trace		12
Turbellaria	Turbellarian sp. 5	trace		12

Monie Bay Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Limnodriloides anxius*	0.17	0.10	9
Annelida: Oligochaeta	*Paranais litoralis*	0.01	0.01	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.51	0.19	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	1.93	0.25	9
Annelida: Polycheata	*Eteone heteropoda*	0.37	0.07	9
Annelida: Polycheata	*Glycinde solitaria*	0.01	0.01	9
Annelida: Polycheata	*Hesionidae*	trace		9
Annelida: Polycheata	*Heteromastus filiformis*	0.82	0.25	9
Annelida: Polycheata	*Hobsonia florida*	0.20	0.08	9
Annelida: Polycheata	*Laeonereis culveri*	0.33	0.28	9
Annelida: Polycheata	*Marenzellaria viridis*	1.46	1.19	9
Annelida: Polycheata	*Neanthes succinea*	1.79	1.45	9
Annelida: Polycheata	*Streblospio benedicti*	0.49	0.15	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	trace		9
Arthropoda: Amphipoda	Amphipoda	0.01	0.01	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	4.67	0.66	9
Arthropoda: Amphipoda	*Rudilemboides naglei*	0.02	0.02	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.03	0.01	9
Arthropoda: Cumacea	*Leucon americanus*	0.09	0.04	9
Arthropoda: Decapoda	*Rithropanopeus harrisii*	0.49	0.49	9
Arthropoda: Insecta	Chironomidae	trace		9
Arthropoda: Insecta	Chironominae	0.02	0.02	9
Arthropoda: Isopoda	*Cyathura polita*	8.91	1.71	9
Arthropoda: Isopoda	*Edotea triloba*	0.17	0.06	9
Arthropoda: Isopoda	Isopoda sp. 1	0.28	0.28	9
Arthropoda: Ostracoda	Ostracod sp. 1	0.09	0.05	9
Arthropoda: Ostracoda	Ostracod sp. 5	trace		9
Arthropoda: Ostracoda	Ostracod sp.6	0.02	0.02	9
Cnidaria: Anthozoa	*Edwardsia elegans*	0.13	0.05	9
Mollusca: Bivalvia	*Gemma gemma*	0.01	0.01	9
Mollusca: Bivalvia	*Macoma balthica*	30.84	28.79	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.37	0.21	9
Mollusca: Bivalvia	*Mulinea lateralis*	0.40	0.40	9
Mollusca: Bivalvia	*Mya arenaria*	0.08	0.04	9
Mollusca: Gastropoda	*Assiminea succinae*	0.02	0.01	9
Nemertea	Nemertean sp. 1	0.54	0.40	9
Nemertea	Nemertean sp. 2	1.07	0.54	9
Porifera	Porifera	0.06	0.02	9
Turbellaria	Turbellaria sp. 4	0.04	0.01	9
Turbellaria	Turbellaria sp. 6	trace		9
Turbellaria	Turbellarian sp. 3	trace		9
Turbellaria	Turbellarian sp. 5	0.02	0.01	9

Monie Bay Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Hirudinae	Hirudinae	0.49	0.29	8
Annelida: Oligochaeta	*Limnodriloides anxius*	0.01	0.01	8
Annelida: Oligochaeta	*Tubificoides brownae*	0.25	0.04	8
Annelida: Polycheata	*Eteone heteropoda*	0.04	0.02	8
Annelida: Polycheata	*Glycera dibranchiata*	4.26	4.26	8
Annelida: Polycheata	*Glycinde solitaria*	0.23	0.11	8
Annelida: Polycheata	*Heteromastus filiformis*	9.46	2.38	8
Annelida: Polycheata	*Laeonereis culveri*	4.23	1.50	8
Annelida: Polycheata	*Leitoscoloplos fragilis*	0.41	0.41	8
Annelida: Polycheata	*Marenzellaria viridis*	20.28	4.42	8
Annelida: Polycheata	*Neanthes succinea*	4.02	0.50	8
Annelida: Polycheata	*Paraonis fulgens*	trace		8
Annelida: Polycheata	*Streblospio benedicti*	0.04	0.01	8
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.01	0.01	8
Arthropoda: Amphipoda	*Monoculodes edwardsi*	0.08	0.08	8
Arthropoda: Cumacea	*Leucon americanus*	0.01	0.01	8
Arthropoda: Isopoda	*Cyathura polita*	0.27	0.24	8
Arthropoda: Ostracoda	Ostracod sp. 1	0.17	0.06	8
Arthropoda: Ostracoda	Ostracod sp.6	0.01	0.01	8
Arthropoda: Ostracoda	Ostracod sp.7	trace		8
Mollusca: Bivalvia	Bivalve sp. 1	0.07	0.05	8
Mollusca: Bivalvia	Bivalvia	0.06	0.06	8
Mollusca: Bivalvia	*Gemma gemma*	4.92	1.65	8
Mollusca: Bivalvia	*Macoma balthica*	3.96	2.87	8
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.63	0.38	8
Mollusca: Bivalvia	*Mulinea lateralis*	1.62	0.68	8
Mollusca: Gastropoda	*Assiminea succinae*	0.03	0.02	8
Mollusca: Gastropoda	Gastropod sp. 8	0.15	0.10	8
Mollusca: Gastropoda	Gastropoda	0.04	0.03	8
Nemertea	Nemertean sp. 1	0.27	0.10	8
Nemertea	Nemertean sp. 7	0.16	0.13	8
Porifera	Porifera	0.01	0.01	8
Turbellaria	Turbellarian sp. 5	trace		8

Pagan River Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Ilyodrilus templetoni*	trace		9
Annelida: Oligochaeta	*Limnodriloides anxius*	0.04	0.02	9
Annelida: Oligochaeta	*Nais variabilis*	0.14	0.05	9
Annelida: Oligochaeta	*Pristina idrensis*	0.09	0.04	9
Annelida: Oligochaeta	Tubificidae	trace		9
Annelida: Oligochaeta	*Tubificoides brownae*	0.76	0.21	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	4.91	1.01	9
Annelida: Oligochaeta	*Tubificoides motei*	0.11	0.11	9
Annelida: Polycheata	*Heteromastus filiformis*	0.58	0.42	9
Annelida: Polycheata	*Laeonereis culveri*	0.10	0.05	9
Annelida: Polycheata	*Mediomastus ambiseta*	0.57	0.16	9
Annelida: Polycheata	*Neanthes succinea*	0.29	0.27	9
Annelida: Polycheata	*Streblospio benedicti*	0.82	0.14	9
Arthropoda: Amphipoda	*Ampelisca abdita-vadorum*	trace		9
Arthropoda: Amphipoda	Amphipoda	trace		9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.33	0.15	9
Arthropoda: Amphipoda	*Paraphoxus spinosis*	trace		9
Arthropoda: Amphipoda	*Protohaustorius deichmannae*	0.11	0.11	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.01	0.01	9
Arthropoda: Decapoda	*Pagurus longicarpus*	0.01	0.01	9
Arthropoda: Insecta	Chironomus sp.	trace		9
Arthropoda: Insecta	Insecta	trace		9
Arthropoda: Insecta	*Pseudochironomus sp.*	trace		9
Arthropoda: Insecta	Tanypodinae	0.01	0.01	9
Arthropoda: Insecta	*Tanypus carinatus*	trace		9
Arthropoda: Insecta	*Tanypus neopunctipennis*	trace		9
Arthropoda: Insecta	*Tanypus stellatis*	trace		9
Arthropoda: Isopoda	*Edotea triloba*	0.11	0.11	9
Mollusca	Mollusca	0.04	0.04	9
Mollusca: Bivalvia	Bivalvia	0.78	0.78	9
Mollusca: Bivalvia	*Congaria leucophaeta*	trace		9
Mollusca: Bivalvia	*Gemma gemma*	0.02	0.01	9
Mollusca: Bivalvia	*Macoma balthica*	28.31	17.14	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	39.78	8.96	9
Mollusca: Bivalvia	*Mulinea lateralis*	0.11	0.10	9
Mollusca: Bivalvia	*Rangia cuneata*	0.11	0.11	9
Nemertea	Nemertean sp. 2	0.29	0.20	9
Turbellaria	Turbellarian sp. 5	trace		9

Pagan River Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Hirudinae	Hirudinae	0.12	0.12	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.15	0.11	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	0.16	0.03	9
Annelida: Polycheata	*Glycinde solitaria*	0.80	0.30	9
Annelida: Polycheata	*Heteromastus filiformis*	6.93	1.91	9
Annelida: Polycheata	*Laeonereis culveri*	5.32	1.68	9
Annelida: Polycheata	*Marenzellaria viridis*	5.52	1.76	9
Annelida: Polycheata	*Mediomastus ambiseta*	1.24	0.29	9
Annelida: Polycheata	*Neanthes succinea*	1.24	0.44	9
Annelida: Polycheata	Spionidae	0.01	0.01	9
Annelida: Polycheata	*Streblospio benedicti*	0.51	0.16	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	1.61	0.48	9
Mollusca: Bivalvia	*Gemma gemma*	0.16	0.11	9
Mollusca: Bivalvia	*Macoma balthica*	379.72	34.61	9
Mollusca: Bivalvia	*Macoma mitchelli*	0.60	0.55	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.08	0.07	9
Mollusca: Bivalvia	*Mulinea lateralis*	0.06	0.06	9
Mollusca: Bivalvia	*Rangia cuneata*	trace		9
Mollusca: Gastropoda	*Acteocina canaliculata*	trace		9
Mollusca: Gastropoda	*Acteon punctostriatus*	0.03	0.02	9
Mollusca: Gastropoda	*Assiminea succinae*	0.01	0.01	9
Mollusca: Gastropoda	Gastropod sp. 6	0.11	0.11	9
Mollusca: Gastropoda	Gastropod sp. 8	0.16	0.04	9
Mollusca: Gastropoda	Gastropod sp. 9	trace		9
Nemertea	Nemertean sp. 1	trace		9
Nemertea	Nemertean sp. 2	1.89	0.97	9
Turbellaria	Turbellarian sp. 5	trace		9

Patuxent River Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Limnodriloides anxius*	0.12	0.07	9
Annelida: Oligochaeta	*Paranais litoralis*	0.03	0.02	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.07	0.02	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	0.09	0.03	9
Annelida: Polycheata	*Eteone heteropoda*	0.37	0.13	9
Annelida: Polycheata	*Heteromastus filiformis*	3.10	1.16	9
Annelida: Polycheata	*Hobsonia florida*	trace		9
Annelida: Polycheata	*Laeonereis culveri*	3.06	2.21	9
Annelida: Polycheata	*Marenzellaria viridis*	59.88	8.85	9
Annelida: Polycheata	*Mediomastus ambiseta*	trace		9
Annelida: Polycheata	*Neanthes succinea*	15.17	7.55	9
Annelida: Polycheata	*Streblospio benedicti*	6.97	0.99	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	8.06	1.22	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.11	0.04	9
Arthropoda: Insecta	*Chironomus sp.*	0.08	0.04	9
Arthropoda: Insecta	*Palpomyia*	trace		9
Arthropoda: Insecta	Tanypodinae	0.01	0.01	9
Arthropoda: Isopoda	*Cyathura polita*	5.79	1.67	9
Arthropoda: Isopoda	*Edotea triloba*	0.05	0.04	9
Arthropoda: Mysidacea	Mysid	trace		9
Arthropoda: Mysidacea	*Mysidopsis bigelowi*	0.17	0.17	9
Arthropoda: Ostracoda	Ostracod sp.6	0.06	0.04	9
Arthropoda: Tanaidacea	*Leptochalia rapax*	0.01	0.01	9
Mollusca: Bivalvia	*Macoma balthica*	13.35	6.34	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	3.20	1.40	9
Mollusca: Gastropoda	Gastropoda	0.02	0.02	9
Turbellaria	Turbellarian sp. 5	trace		9

Patuxent River Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Limnodriloides anxius*	0.22	0.05	9
Annelida: Oligochaeta	*Tubificoides brownae*	0.16	0.07	9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	0.02	0.01	9
Annelida: Polycheata	*Eteone heteropoda*	0.93	0.30	9
Annelida: Polycheata	*Heteromastus filiformis*	10.97	3.61	9
Annelida: Polycheata	*Hobsonia florida*	0.02	0.02	9
Annelida: Polycheata	*Laeonereis culveri*	8.96	2.51	9
Annelida: Polycheata	*Marenzellaria viridis*	34.23	4.24	9
Annelida: Polycheata	*Neanthes succinea*	34.21	5.44	9
Annelida: Polycheata	*Polydora cornuta*	0.11	0.11	9
Annelida: Polycheata	*Streblospio benedicti*	0.85	0.09	9
Arthropoda: Amphipoda	*Corophium lacustre*	trace		9
Arthropoda: Amphipoda	*Corophium simile*	0.02	0.02	9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.53	0.28	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.16	0.04	9
Arthropoda: Decapoda	*Rithropanopeus harrisii*	2.25	1.68	9
Arthropoda: Insecta	Chironominae	0.07	0.07	9
Arthropoda: Insecta	*Polypedilum scalaenum*	trace		9
Arthropoda: Insecta	*Pseudochironomus sp.*	trace		9
Arthropoda: Insecta	Tanypodinae	0.05	0.05	9
Arthropoda: Isopoda	*Cyathura polita*	6.88	1.67	9
Arthropoda: Isopoda	*Edotea triloba*	0.15	0.08	9
Arthropoda: Mysidacea	*Mysidopsis bigelowi*	0.23	0.12	9
Arthropoda: Ostracoda	Ostracod sp.7	trace		9
Arthropoda: Tanaidacea	*Leptochalia rapax*	0.74	0.27	9
Cnidaria: Anthozoa	*Edwardsia elegans*	0.37	0.25	9
Mollusca: Bivalvia	*Gemma gemma*	0.36	0.28	9
Mollusca: Bivalvia	*Macoma balthica*	31.00	12.78	9
Mollusca: Bivalvia	*Macoma tenta-mitchelli*	0.75	0.51	9
Mollusca: Bivalvia	*Mulinea lateralis*	trace		9
Mollusca: Bivalvia	*Mya arenaria*	81.08	53.63	9
Mollusca: Bivalvia	*Rangia cuneata*	trace		9
Nemertea	Nemertean sp. 1	trace		9
Nemertea	Nemertean sp. 8	4.88	4.88	9
Turbellaria	Turbellaria sp. 4	trace		9

Appendix E. Macrofaunal biomass, 2005. Taxa listed by sites and strata sampled in 2005. Mean biomass of taxa in mg AFDM per core (area sampled = 130 cm^2; core depth = 25 cm). SE = standard error of mean; N = number of stations per site/stratum. Trace = biomass <0.01mg, as determined from pooled samples.

Anacostia Near-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Hirudinae	Hirudinae	0.08	0.08	8
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.37	0.16	8
Annelida: Oligochaeta	*Branchiura sowerbyi*	32.22	12.04	8
Annelida: Oligochaeta	*Dero digitata*	0.78	0.22	8
Annelida: Oligochaeta	*Ilyodrilus templetoni*	2.36	0.48	8
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	45.67	5.58	8
Annelida: Oligochaeta	*Pristinella jenkinae*	trace		8
Annelida: Oligochaeta	*Spirosperma ferox*	0.08	0.05	8
Arthropoda: Cladocera	Cladocera	trace		8
Arthropoda: Insecta	Chironomidae	trace		8
Arthropoda: Insecta	*Chironomus sp.*	0.67	0.15	8
Arthropoda: Insecta	*Coelotanypus sp.*	0.71	0.25	8
Arthropoda: Insecta	*Procladius sp.*	1.51	0.36	8
Arthropoda: Insecta	Tanypodinae	0.03	0.03	8
Arthropoda: Insecta	*Tanypus neopunctipennis*	trace		8
Arthropoda: Insecta	*Tanypus sp.*	0.07	0.05	8
Mollusca: Bivalvia	*Corbicula manilensis*	16.93	10.94	8
Mollusca: Bivalvia	*Musculium transversum*	0.11	0.11	8
Mollusca: Bivalvia	Pisidium sp. 1	0.76	0.35	8
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.10	0.04	8
Turbellaria	Flatworm	0.01	0.01	8

Anacostia Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Hirudinae	Hirudinae	0.13	0.13	9
Annelida: Oligochaeta	*Aulodrilus pigueti*	2.34	0.77	9
Annelida: Oligochaeta	*Branchiura sowerbyi*	0.38	0.21	9
Annelida: Oligochaeta	*Dero digitata*	0.69	0.16	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	2.01	0.62	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	30.32	5.83	9
Annelida: Oligochaeta	*Pristina breviseta*	trace		9
Annelida: Oligochaeta	*Spirosperma ferox*	0.08	0.03	9
Arthropoda: Amphipoda	*Gammarus lacustris*	0.03	0.03	9
Arthropoda: Cladocera	Cladocera	trace		9
Arthropoda: Insecta	*Caenis sp.*	0.03	0.02	9
Arthropoda: Insecta	Chironomidae	trace		9
Arthropoda: Insecta	*Chironomus sp.*	2.01	0.49	9
Arthropoda: Insecta	*Coelotanypus sp.*	0.22	0.15	9
Arthropoda: Insecta	*Dicrotendipes modestus*	0.02	0.02	9
Arthropoda: Insecta	*Polypedilum halterale* group	0.02	0.01	9
Arthropoda: Insecta	*Polypedilum sp.*	0.01	0.01	9
Arthropoda: Insecta	*Procladius sp.*	0.79	0.15	9
Arthropoda: Insecta	*Tanypus sp.*	0.11	0.05	9
Arthropoda: Insecta	*Tanytarsus sp.*	trace		9
Mollusca: Bivalvia	*Corbicula manilensis*	12.64	9.77	9
Mollusca: Bivalvia	*Musculium transversum*	0.26	0.19	9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.03	0.02	9
Turbellaria	Flatworm	0.02	0.01	9
Turbellaria	Turbellarian sp. 5	trace		9

Aberdeen Proving Ground Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Hirudinae	Hirudinae	trace		9
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.08	0.03	9
Annelida: Oligochaeta	*Dero* (Aulophorus) *flabelliger*	0.03	0.01	9
Annelida: Oligochaeta	*Dero digitata*	0.02	0.01	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	1.24	0.13	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	9.27	1.05	9
Annelida: Oligochaeta	*Nais behningi*	trace		9
Annelida: Oligochaeta	*Pristina leidyi*	trace		9
Annelida: Oligochaeta	*Slavina appendiculata*	0.05	0.02	9
Annelida: Oligochaeta	*Spirosperma ferox*	0.01	0.01	9
Annelida: Oligochaeta	*Stylaria lacustris*	0.01	0.01	9
Arthropoda: Amphipoda	*Gammarus lacustris*	0.60	0.29	9
Arthropoda: Cladocera	Cladocera	trace		9
Arthropoda: Insecta	*Caenis sp.*	0.01	0.01	9
Arthropoda: Insecta	Chironomidae	trace		9
Arthropoda: Insecta	*Chironomus sp.*	0.05	0.05	9
Arthropoda: Insecta	*Cladopelma sp.*	trace		9
Arthropoda: Insecta	*Cladotanytarsus sp.*	trace		9
Arthropoda: Insecta	*Cladotanytarsus sp. A*	0.01	0.00	9
Arthropoda: Insecta	*Cladotanytarsus sp. B*	trace		9
Arthropoda: Insecta	*Clinotanypus sp.*	0.31	0.13	9
Arthropoda: Insecta	*Dicrotendipes modestus*	0.02	0.02	9
Arthropoda: Insecta	Ephemeroptera	0.04	0.04	9
Arthropoda: Insecta	Insecta	0.01	0.01	9
Arthropoda: Insecta	*Palpomyia*	trace		9
Arthropoda: Insecta	*Polypedilum halterale* group	trace		9
Arthropoda: Insecta	*Procladius* (Holotanypus) *sp* .	trace		9
Arthropoda: Insecta	Tanypodinae	0.02	0.01	9
Arthropoda: Insecta	*Tanypus punctipennis*	0.01	0.01	9
Arthropoda: Insecta	*Tanypus sp.*	0.01	0.01	9
Arthropoda: Insecta	*Tanytarsus sp.*	0.01	0.00	9
Arthropoda: Insecta	Trichoptera	0.02	0.02	9
Arthropoda: Insecta	*Zavreliella sp.*	0.03	0.02	9
Mollusca: Bivalvia	*Corbicula manilensis*	8.98	4.37	9
Mollusca: Bivalvia	*Sphaerium sp.*	trace		9

Aberdeen Proving Ground Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Aulodrilus pigueti*	trace		9
Annelida: Oligochaeta	*Dero digitata*	trace		9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	0.15	0.07	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	2.34	0.58	9
Annelida: Oligochaeta	*Nais communis*	trace		9
Annelida: Oligochaeta	*Paranais litoralis*	0.01	0.01	9
Arthropoda: Amphipoda	*Gammarus lacustris*	0.26	0.21	9
Arthropoda: Cumacea	*Cyclaspis varians*	0.05	0.04	9
Arthropoda: Insecta	*Cladotanytarsus sp.*	0.09	0.06	9
Arthropoda: Insecta	*Cladotanytarsus sp. A*	0.03	0.01	9
Arthropoda: Insecta	*Cladotanytarsus sp. B*	0.13	0.06	9
Arthropoda: Insecta	*Cladotanytarsus sp. F*	0.01	0.00	9
Arthropoda: Insecta	*Clinotanypus sp.*	0.01	0.01	9
Arthropoda: Insecta	*Cryptochironomus sp.*	0.26	0.09	9
Arthropoda: Insecta	*Dicrotendipes modestus*	0.04	0.03	9
Arthropoda: Insecta	*Polypedilum bergi*	trace		9
Arthropoda: Insecta	*Polypedilum halterale group*	0.39	0.09	9
Arthropoda: Insecta	*Polypedilum tritum*	trace		9
Arthropoda: Insecta	*Stempellina sp.*	trace		9
Arthropoda: Insecta	*Tanytarsus sp.*	0.01	0.01	9
Arthropoda: Insecta	*Trichoptera*	0.01	0.01	9
Arthropoda: Isopoda	*Cyathura polita*	0.01	0.01	9
Mollusca: Bivalvia	*Corbicula manilensis*	3.02	2.70	9
Mollusca: Bivalvia	*Rangia cuneata*	30.35	30.35	9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.02	0.02	9
Mollusca: Bivalvia	*Sphaerium sp.*	trace		9

Quantico Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.19	0.06	9
Annelida: Oligochaeta	*Branchiura sowerbyi*	2.18	1.15	9
Annelida: Oligochaeta	*Dero digitata*	0.07	0.02	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	0.15	0.03	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	3.42	0.66	9
Annelida: Oligochaeta	*Pristinella longisoma*	trace		9
Annelida: Oligochaeta	*Stylaria lacustris*	0.01	0.00	9
Annelida: Polycheata	*Laeonereis culveri*	0.12	0.12	9
Arthropoda	Hydracarina	trace		9
Arthropoda: Amphipoda	*Gammarus lacustris*	0.04	0.02	9
Arthropoda: Cladocera	Cladocera	trace		9
Arthropoda: Insecta	Chironomidae	0.01	0.01	9
Arthropoda: Insecta	*Chironomus sp.*	0.40	0.23	9
Arthropoda: Insecta	*Cladopelma sp.*	trace		9
Arthropoda: Insecta	*Clinotanypus sp.*	0.01	0.01	9
Arthropoda: Insecta	*Coelotanypus sp.*	0.10	0.07	9
Arthropoda: Insecta	*Cryptochironomus sp.*	0.21	0.07	9
Arthropoda: Insecta	*Cryptotendipes*	0.05	0.02	9
Arthropoda: Insecta	*Dicrotendipes modestus*	0.07	0.05	9
Arthropoda: Insecta	*Hyporhygma quadrapunctatum*	trace		9
Arthropoda: Insecta	*Polypedilum halterale* group	0.01	0.00	9
Arthropoda: Insecta	*Polypedilum sp.*	0.01	0.01	9
Arthropoda: Insecta	*Probezzia sp.*	trace		9
Arthropoda: Insecta	*Procladius sp.*	0.34	0.04	9
Arthropoda: Insecta	*Tanypodinae*	0.01	0.01	9
Arthropoda: Insecta	*Tanypus punctipennis*	0.03	0.03	9
Arthropoda: Insecta	*Tanytarsus sp.*	0.12	0.03	9
Arthropoda: Insecta	*Zavreliella sp.*	trace		9
Mollusca: Bivalvia	*Corbicula manilensis*	trace		9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.02	0.02	9
Mollusca: Gastropoda	*Amnicola limnosa*	3.60	1.87	9

Quantico Far-Field

Taxon	***Scientific Name***	***Mean***	***SE***	***N***
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.04	0.03	9
Annelida: Oligochaeta	*Branchiura sowerbyi*	0.67	0.42	9
Annelida: Oligochaeta	*Dero* (Aulophorus) *flabelliger*	0.01	0.00	9
Annelida: Oligochaeta	*Dero digitata*	0.19	0.06	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	0.42	0.09	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	8.21	1.97	9
Annelida: Oligochaeta	*Nais communis*	0.04	0.03	9
Annelida: Oligochaeta	*Paranais litoralis*	0.01	0.01	9
Annelida: Oligochaeta	*Pristina breviseta*	trace		9
Annelida: Oligochaeta	*Pristina leidyi*	trace		9
Annelida: Oligochaeta	*Slavina appendiculata*	0.01	0.00	9
Annelida: Oligochaeta	*Stephensoniana trivandrana*	trace		9
Annelida: Polycheata	*Heteromastus filiformis*	0.03	0.03	9
Arthropoda	Hydracarina	trace		9
Arthropoda: Amphipoda	*Gammarus lacustris*	1.18	0.73	9
Arthropoda: Cladocera	Cladocera	trace		9
Arthropoda: Insecta	*Ablabesmyia* (Karelia) *sp* .	trace		9
Arthropoda: Insecta	*Apedilum sp.*	trace		9
Arthropoda: Insecta	*Caenis sp.*	1.04	0.15	9
Arthropoda: Insecta	Chironomidae	0.01	0.00	9
Arthropoda: Insecta	*Cladopelma sp.*	trace		9
Arthropoda: Insecta	*Cladotanytarsus sp.*	trace		9
Arthropoda: Insecta	*Cladotanytarsus sp. A*	0.01	0.01	9
Arthropoda: Insecta	*Cladotanytarsus sp. B*	0.15	0.10	9
Arthropoda: Insecta	*Cladotanytarsus sp. F*	trace		9
Arthropoda: Insecta	*Clinotanypus sp.*	0.24	0.13	9
Arthropoda: Insecta	*Coelotanypus sp.*	0.23	0.15	9
Arthropoda: Insecta	*Cryptochironomus sp.*	0.94	0.21	9
Arthropoda: Insecta	*Cryptotendipes*	0.04	0.01	9
Arthropoda: Insecta	*Dicrotendipes modestus*	0.09	0.02	9
Arthropoda: Insecta	*Endochironomus sp.*	trace		9
Arthropoda: Insecta	Insecta	trace		9
Arthropoda: Insecta	*Labrundinia sp.*	trace		9
Arthropoda: Insecta	*Palpomyia*	trace		9
Arthropoda: Insecta	*Paratendipes albimanus*	trace		9
Arthropoda: Insecta	*Polypedilum halterale* group	1.12	0.88	9
Arthropoda: Insecta	*Probezzia sp.*	0.02	0.01	9
Arthropoda: Insecta	*Procladius* (Holotanypus) *sp* .	trace		9
Arthropoda: Insecta	*Procladius sp.*	0.27	0.09	9
Arthropoda: Insecta	*Pseudochironomus sp.*	0.05	0.03	9
Arthropoda: Insecta	*Stictochironomus sp.*	0.26	0.09	9
Arthropoda: Insecta	*Tanypodinae*	0.03	0.02	9
Arthropoda: Insecta	*Tanypus sp.*	0.05	0.03	9
Arthropoda: Insecta	*Tanytarsus sp.*	0.11	0.06	9
Arthropoda: Insecta	*Trichoptera*	0.11	0.06	9

Quantico Far-Field, continued

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Arthropoda: Insecta	*Zavreliella sp.*	trace		9
Arthropoda: Ostracoda	Ostracod sp. 1	trace		9
Mollusca: Bivalvia	*Corbicula manilensis*	0.75	0.69	9
Mollusca: Bivalvia	*Sphaerium rhomboideum*	0.01	0.01	9
Mollusca: Gastropoda	*Amnicola limnosa*	2.59	1.10	9

Sweet Hall Near-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.01	0.00	9
Annelida: Oligochaeta	*Dero digitata*	trace		9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	0.13	0.05	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	1.45	0.56	9
Annelida: Oligochaeta	*Pristina breviseta*	trace		9
Annelida: Oligochaeta	*Pristinella jenkinae*	trace		9
Annelida: Oligochaeta	*Spirosperma ferox*	0.03	0.01	9
Annelida: Oligochaeta	*Stephensoniana trivandrana*	0.01	0.00	9
Annelida: Polycheata	*Polydora cornuta*	0.01	0.01	9
Arthropoda: Amphipoda	*Hyalella azteca*	trace		9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.05	0.03	9
Arthropoda: Insecta	*Coelotanypus sp.*	0.05	0.04	9
Arthropoda: Insecta	Coleoptera	trace		9
Arthropoda: Insecta	*Cryptochironomus sp.*	0.04	0.02	9
Arthropoda: Insecta	*Epoicocladius sp. 3*	trace		9
Arthropoda: Insecta	*Polypedilum flavum*	trace		9
Arthropoda: Insecta	*Polypedilum halterale* group	trace		9
Arthropoda: Insecta	*Procladius sp.*	0.02	0.01	9
Arthropoda: Insecta	*Tanypus sp.*	0.01	0.01	9

Sweet Hall Far-Field

Taxon	*Scientific Name*	*Mean*	*SE*	*N*
Annelida: Oligochaeta	*Aulodrilus pigueti*	0.02	0.01	9
Annelida: Oligochaeta	*Ilyodrilus templetoni*	0.62	0.12	9
Annelida: Oligochaeta	*Limnodrilus hoffmeisteri*	1.62	0.21	9
Annelida: Oligochaeta	*Nais communis*	trace		9
Annelida: Oligochaeta	*Pristina breviseta*	trace		9
Annelida: Oligochaeta	*Pristinella jenkinae*	trace		9
Annelida: Oligochaeta	*Tubificoides heterochaetus*	0.03	0.01	9
Annelida: Polycheata	*Laeonereis culveri*	0.04	0.04	9
Annelida: Polycheata	*Marenzellaria viridis*	9.03	2.30	9
Annelida: Polycheata	*Polydora cornuta*	trace		9
Arthropoda: Amphipoda	*Leptocheirus plumulosus*	0.68	0.18	9
Arthropoda: Arachnid	Arachnid	trace		9
Arthropoda: Cumacea	*Leucon americanus*	trace		9
Arthropoda: Insecta	Chironominae	trace		9
Arthropoda: Insecta	*Cladotanytarsus sp. A*	trace		9
Arthropoda: Insecta	*Coelotanypus sp.*	0.06	0.04	9
Arthropoda: Insecta	*Cryptochironomus sp.*	0.05	0.02	9
Arthropoda: Insecta	Insecta	0.01	0.01	9
Arthropoda: Insecta	*Polypedilum halterale* group	0.03	0.01	9
Arthropoda: Insecta	*Polypedilum sp.*	0.02	0.02	9
Arthropoda: Insecta	*Procladius sp.*	0.01	0.01	9
Arthropoda: Insecta	*Stictochironomus sp.*	0.05	0.05	9
Arthropoda: Insecta	Tanypodinae	0.02	0.02	9
Arthropoda: Insecta	*Tanytarsus sp.*	0.01	0.01	9
Arthropoda: Insecta	*Zygoptera*	trace		9
Arthropoda: Isopoda	*Cyathura polita*	0.58	0.20	9
Arthropoda: Tanaidacea	*Leptochalia rapax*	0.01	0.01	9
Mollusca: Bivalvia	*Corbicula manilensis*	trace		9
Mollusca: Bivalvia	*Rangia cuneata*	163.83	163.42	9

Appendix F. List of technical publications.

Papers published in peer-reviewed journals:

Borja, A., D. Dauer, R. Díaz, R.J. Llansó, I. Muxika, J.G. Rodríguez, and L. C. Schaffner. 2008. Assessing estuarine benthic quality conditions in Chesapeake Bay: a comparison of three indices. Ecological Indicators 8: 395-403.

Published technical abstracts:

2003

Schaffner, L.C. and I.C. Anderson. Using Biotic Indicators to Measure the Integrity of Coastal Ecosystems. SERDP & ESTCP Partners in Environmental Technology Technical Symposium & Workshop, Washington, DC, December 2-4, 2003.

2004

Schaffner, L.C. Jumping into the structure and function debate: can we make the links for estuarine macrobenthos? Belle Baruch Laboratory of the University of South Carolina, Charleston, SC, October 2004.

Schaffner, L.C. Biodiversity and abundance of estuarine macrobenthos: relationships with salinity and anthropogenic disturbances. European Marine Biology Symposium, Genoa Italy, July 2004.

Schaffner, L.C., I.C. Anderson, and J.W. Stanhope. An Integrated Approach to Understand Relationships Between Shallow Water Benthic Community Structure and Ecosystem Function in the Chesapeake Bay. Atlantic Estuarine Research Society Fall 2004 Meeting, Lyndhurst, NJ, October 14-16, 2004.

Schaffner, L.C., I.C. Anderson, and J.W. Stanhope. An Integrated Approach to Understand Relationships Between Shallow Water Benthic Community Structure and Ecosystem Function in the Chesapeake Bay. SERDP & ESTCP Partners in Environmental Technology Technical Symposium & Workshop, Washington, DC, November 30-December 2, 2004.

2005

Anderson, I. C. Benthic pelagic coupling in shallow littoral zone ecosystems. Mokpo National Maritime University. Mokpo Korea, July 2005.

Anderson, I. C.; Schaffner, L. C., Stanhope, J. W. An integrated approach to understand relationships between shallow water benthic community structure and ecosystem function in the Chesapeake Bay, SERDP Technical Symposium, Washington DC, December 05.

Anderson, I.C., L.C. Schaffner, and J.W. Stanhope. Relationships between benthic ecosystem structure and function at high vs. low energy shallow sites. 18th Biennial Conference of the Estuarine Research Federation (ERF), Norfolk, VA, October 16-20, 2005.

Dauer, D. M., R. J. Llansó, M. F. Lane, R. J. Diaz, and L.C. Schaffner. Twenty Years (1985-2004) of Benthic Monitoring of Chesapeake Bay, USA. Accomplishments, Advances and Future Directions. 18th Biennial Conference of the Estuarine Research Federation (ERF), Norfolk, VA, October 16-20, 2005.

Dauer, D. M., R. J. Llansó, M. F. Lane, R. J. Diaz, and L.C. Schaffner. Twenty Years (1985-2004) of Benthic Monitoring of Chesapeake Bay, USA. Accomplishments, Advances and Future Directions. Benthic Ecology Meeting, Williamsburg, VA, April 2005.

Gillett, D. J., L. C. Schaffner, and I. C. Anderson. Macrobenthic Production and Trophic Transfer Efficiency in Disturbed and Non-Disturbed Shallow Estuarine Habitat. 18th Biennial Conference of the Estuarine Research Federation (ERF), Norfolk, VA, October 16-20, 2005.

Metcalfe, W.J., and L.C. Schaffner. Factors Controlling the Abundance and Distribution of Meiofuana in High Mesohaline Chesapeake Bay. 18th Biennial Conference of the Estuarine Research Federation (ERF), Norfolk, VA, October 16-20, 2005.

Parker, F.M. and I.C. Anderson. The role of benthic microalgae in carbon and nitrogen cycling in shallow water estuarine sediments. 18th Biennial Conference of the Estuarine Research Federation (ERF), Norfolk, VA, October 16-20, 2005.

Schaffner, L.C. Biodiversity of estuarine macrobenthos: moving past Remane’s diagram. ASLO, Salt Lake City, Utah, February 2005.

Schaffner, L.C., I. C. Anderson, J. W. Stanhope, F. Parker, D. Gillett and W. Metcalfe. Relationships between the Benthic Index of Biotic Integrity (B-IBI), ecosystem function and food web structure in shallow water habitats of Chesapeake Bay. 18th Biennial Conference of the Estuarine Research Federation (ERF), Norfolk, VA, October 16-20, 2005.

2006

Anderson, I. C. Relationships between shallow water benthic community structure and ecosystem function along gradients of salinity and disturbance in Chesapeake Bay, Dauphin Island Sea Laboratory, University of South Alabama, May 2006.

Anderson, I. C., Schaffner, L. C., Stanhope, J. W. Relationships between B-IBI scores and ecosystem function along gradients of disturbance and salinity in Chesapeake Bay, USA, ASLO, Victoria BC, June 2006.

Gillett, D. J., L. C. Schaffner, and I. C. Anderson. Macrobenthic Production and Trophic Transfer Efficiency in Disturbed and Non-Disturbed Shallow Estuarine Habitat. Atlantic Estuarine Research Society, Philadelphia, PA, March 2006.

Schaffner, L. C., Anderson, I. C., Metcalfe, W., Gillett, D., Stanhope, J. W., Smith, T. Identifying the effects of multiple stressors using the Benthic Index of Biotic Integrity and meiofauna communities in shallow water habitats of Chesapeake Bay. ASLO, Victoria BC, June 2006.

Schaffner, L. C., Anderson, I. C., Stanhope, J. W., Gillett, D. J., Metcalfe, W. Using a benthic index of biotic integrity (B-IBI) and meiofauna community structure to understand effects of multiple stressors in shallow estuarine habitats, SERDP Technical Symposium, Washington, DC, December 2006.

Schaffner, L.C., I. C. Anderson, J. W. Stanhope, F. Parker, D. Gillett and W. Metcalfe. Relationships between the Benthic Index of Biotic Integrity (B-IBI) and food web structure in shallow water habitats of Chesapeake Bay. Ocean Sciences Meeting, Honolulu, Hawaii, February 2006.

2007

Anderson, I. C., Benthic autotrophy across the Chesapeake Bay estuarine gradient: how effective are benthic microalgae in removing and retaining N? University of South Carolina, November 2007.

Anderson, I. C., Stanhope, J. W., and Schaffner, L. C. Benthic metabolism and nutrient cycling in shallow habitats across the Chesapeake Bay estuarine gradient. ERF, Providence RI, November 2007.

Gillett, D.; Schaffner, L.; Anderson, I., Benthic Habitat Quality and its Effects on Food Web Structure and Trophic Efficiency. ERF, Providence, RI, November 2007.

Parker, F. M. and Anderson, I. C. Tracking the uptake and fate of benthic microalgal C and N: A dual isotopic approach. ERF, Providence, RI, November 2007.

Schaffner, L.; Gillett, D.; Stanhope, J.; Anderson, I., Benthic Community Responses to Multiple Stressors in Shallow Water Habitats of Chesapeake Bay. ERF, Providence, RI, November 2007.

2008

Gillett, D.J., L.C. Schaffner, and I.C. Anderson. Benthic habitat quality and its effects on food web structure and trophic efficiency. Benthic Ecology Meeting, Providence, RI, April 2008.

Published book chapters:

Joye, S. B. and I. Anderson, 2008. Nitrogen cycling in Estuarine and Nearshore Sediments. In: Capone, D., Bronk, D., Carpenter, E. and Mulhollond, M. (Eds), Nitrogen in the Marine Environment, Springer Verlag, Chapter 19, pp 868-915.

Other publications:

Metcalfe, W. J. 2005. Meiofauna abundance and distribution in Chesapeake Bay: Relationships with environmental stressors, sediment toxicity and macrofauna. M.S. thesis, School of Marine Science, College of William and Mary.

Website:

http://web.vims.edu/bio/shallowwater/index.html