BENTHIC MACROINVERTEBRATE COMMUNITIES OF RECONSTRUCTED FRESHWATER TIDAL WETLANDS IN THE ANACOSTIA RIVER, WASHINGTON, D.C.

by

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of
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DEDICATION

This is dedicated to my father, Rev. Harold Wilson Brittingham Jr.

A son never forgets

ACKNOWLEDGEMENTS

First, I would like to thank the Baltimore District of the Corps of Engineers, especially Claire O'Neill and Steve Pugh, not only for their finding a way to provide 3-year financial support for this project but for their perspective in recognizing the values in conducting a thorough macroinvertebrate study concerning reconstructed freshwater tidal wetlands. Additional thanks goes to USGS and especially Dr. Dick Hammerschlag for keeping me with a job as I worked on this project. Our countless hours in the Anacostia wetlands getting elevations, repairing goose fence and identifying plants were unforgettable experiences.

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Lastly, and most importantly, I want to thank my God and Saviour who made all things possible! Philippians 4:13, "*I can do all things through Christ which strengtheneth me*."

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ABSTRACT

BENTHIC MACROINVERTEBRATE COMMUNITIES AS INDICATORS OF RECONSTRUCTED FRESHWATER TIDAL WETLANDS IN THE ANACOSTIA RIVER, WASHINGTON, D.C.

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George Mason University, 2011

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Considerable work has been conducted on the benthic communities of inland aquatic systems and brackish water estuarine wetlands, but there remains a scarcity of effort on freshwater tidal wetlands. This study characterized the benthic macroinvertebrate communities of recently reconstructed urban freshwater tidal wetlands along the Anacostia River in Washington, D.C. The focus of the study was Kingman Marsh, which was reconstructed by the U.S. Army Corps of Engineers in 2000 using Anacostia dredge material. Populations from this "new" marsh were compared to those of the similar, but earlier reconstructed Kenilworth Marsh (1993) just one half mile upstream, the relic reference Dueling Creek Marsh in the upper Anacostia estuary and the outside reference Patuxent freshwater tidal marsh in an adjacent watershed. Benthic macroinvertebrate organisms were collected using a range of techniques including the Ekman bottom grab sampler, D-net and Hester-Dendy sampler. Samples were collected

at least seasonally from tidal channels, tidal mudflats, three vegetation/sediment zones (low, middle and high marsh), and pools over a 3-year period (late 2001-2004). The macroinvertebrate communities present at the marsh sites reflected levels of disturbance, stress, and pollution, all of which are effects of urbanization in the watershed. There were also similarities between older reconstructed wetlands and remnant wetlands indicating an age factor in comparisons of macroinvertebrate communities. Macroinvertebrate density was significantly greater at Kingman Marsh than Kenilworth Marsh due to more numerous chironomids and oligochaetes. This may reflect an increase in unvegetated sediments at Kingman (even at elevations above natural mudflat) due to grazing pressure from over-abundant resident Canada geese. Unvegetated sediments yielded greater macroinvertebrate abundance but lower richness than vegetated marsh sites. Data collected from this study provides information on the extent to which benthic macroinvertebrate communities can serve as indicators of a functional reconstructed freshwater tidal marsh.

INTRODUCTION

The U.S. Army Corps of Engineers (CoE) has been the lead agency in conjunction with the District of Columbia Department of Health (D.C.) and the National Park Service (NPS) in the effort to reconstruct and restore several freshwater tidal wetlands along the Anacostia River in Washington, D.C. on NPS managed lands. This large-scale effort justified a rigorous post-reconstruction monitoring program to evaluate the level of success in recreating the wetlands and their multiple habitats. The areas in question were once vital freshwater tidal wetlands but had been severely degraded or even physically obliterated through mandatory dredging by the CoE during the first half of the 20th century. Recently, the CoE rebuilt some of the lost wetlands using dredge material available from the heavily sedimented Anacostia River channels.

Historically, the Anacostia estuary was a fully functional freshwater tidal marsh comprising several thousand acres that provided considerable food and habitat for wildlife and thus was an invaluable support resource for the local Indians and subsequent colonists. Towards the end of the nineteenth century as sewage pollution, agriculturally derived sediments filling the shipping channel, surrounding development, and disease threats increased in the Anacostia, intense pressure developed to remove what were perceived as problematic wetlands (Hammerschlag et al. 2006). The CoE was given the charge to dredge the Anacostia from its mouth at the Potomac River in Washington, D.C. up to Bladensburg, Maryland. In addition to dredging, a stone seawall was constructed which formed a hard boundary between the dredged river channel and the deposited fill behind the seawall. Essentially no emergent wetlands remained (except for narrow edges of transitional wetlands) in the river or even in some dredged backwater areas such as Kenilworth and Kingman Lakes. The NPS eventually became the custodian of these newly built landscapes, which were to be used mostly for recreation. In the 1980s park planners and resource managers began to envision the opportunity of restoring areas like Kenilworth Lake to marshlands to create a vestige of the once productive wetland habitat. Following a long series of planning and technical evaluations, the CoE reconstructed Kenilworth Marsh in 1993 for the NPS as a freshwater tidal marsh (32 acres/13 hectares) (Bowers 1995, Syphax and Hammerschlag 1995).

Currently, the Anacostia watershed, which drains portions of Montgomery and Prince Georges Counties in Maryland as well as the eastern portion of Washington, D.C, is about one-half urban and, one-third forested and with the remainder primarily in agriculture (Baldwin 2004). The presence of sand and gravel strip mines coupled with the considerable urbanization in the watershed has resulted in excessive stormwater flows containing elevated levels of sediment. The heavier sediments drop out first in the upper portions of the estuary, leaving the finer grained sediments to deposit in the channels of the tidal Anacostia River. These finer grain sediments were used to rebuild the wetlands. Historically, the Anacostia carried high levels of contaminants and many of these remain in the tidal sediments. Sediment contaminant levels are high enough in organic pollutants such as PCBs, chlordane and PAHs to justify strict limits on human fish take from the river (Pinkney et al. 2003). In fact, the Anacostia has been labeled as one of the three most contaminated water bodies in the Chesapeake Bay. One function of rebuilt wetlands is to help mitigate impacts from the runoff. The entire tidal Anacostia from Bladensburg to the Potomac contains only fresh water (the salt wedge from the ocean and bay does not reach Washington, D.C.). The reference Patuxent watershed, some fourteen miles east of the Anacostia watershed, is more rural and contains two dams along the mainstem with smaller impoundments elsewhere that act to limit runoff impacts from portions of the developed landscapes (*Figure 1*).

In 2000, portions of Kingman Lake along the Anacostia estuary about one quarter mile south of Kenilworth Marsh (*Figure 2*) were reconstructed as emergent freshwater tidal wetlands and named Kingman Marsh. The process involved using a hydraulic dredge to pump slurry of Anacostia channel sediments into two separate containment cells at Kingman known as Kingman Area 1 and Kingman Area 2. Following dewatering and consolidation the resultant sediment flats covered about 35 acres and were planted with 700,000 emergent wetland plants comprising 6 native species. Volunteer plants also began to grow from the soil seed bank and from propagules transported in by water and air (Neff and Baldwin 2005). Much of the planted area was surrounded by corrals of light plastic fencing to exclude geese and ducks, which graze new plantings. As a

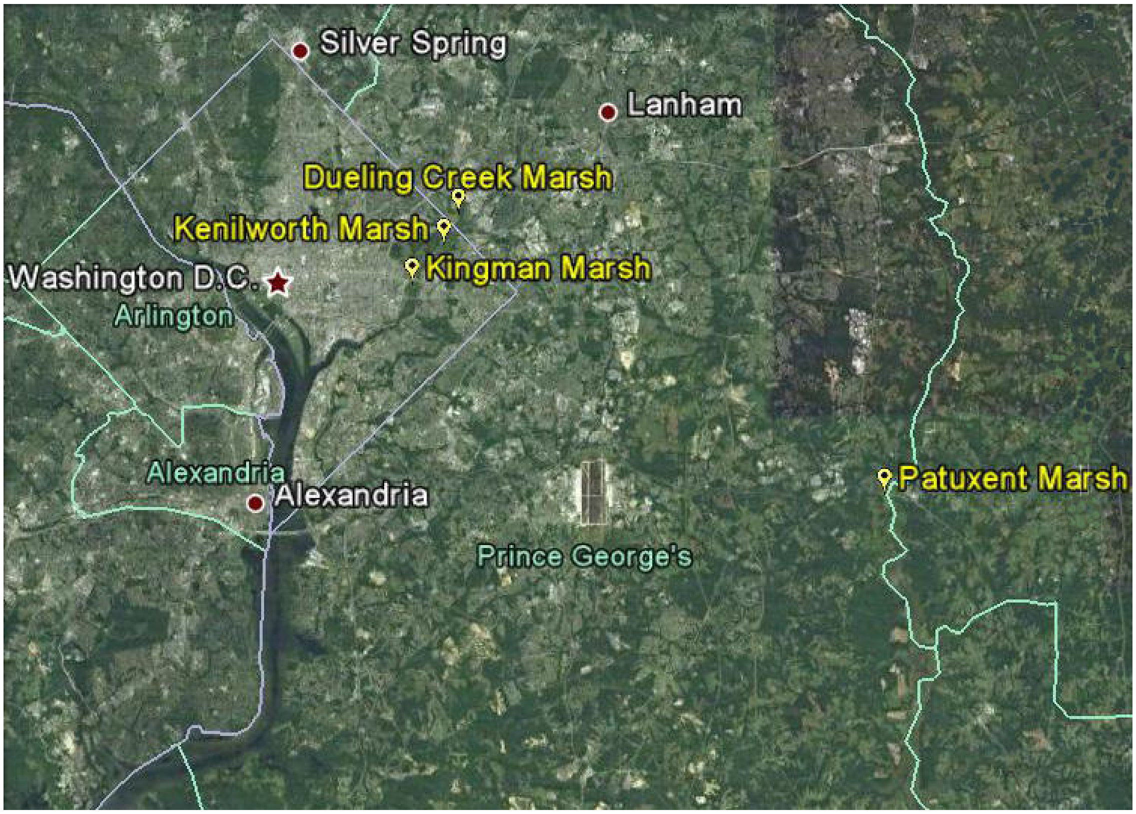

Figure 1: Locations of marsh sites in reference to Washington D.C.

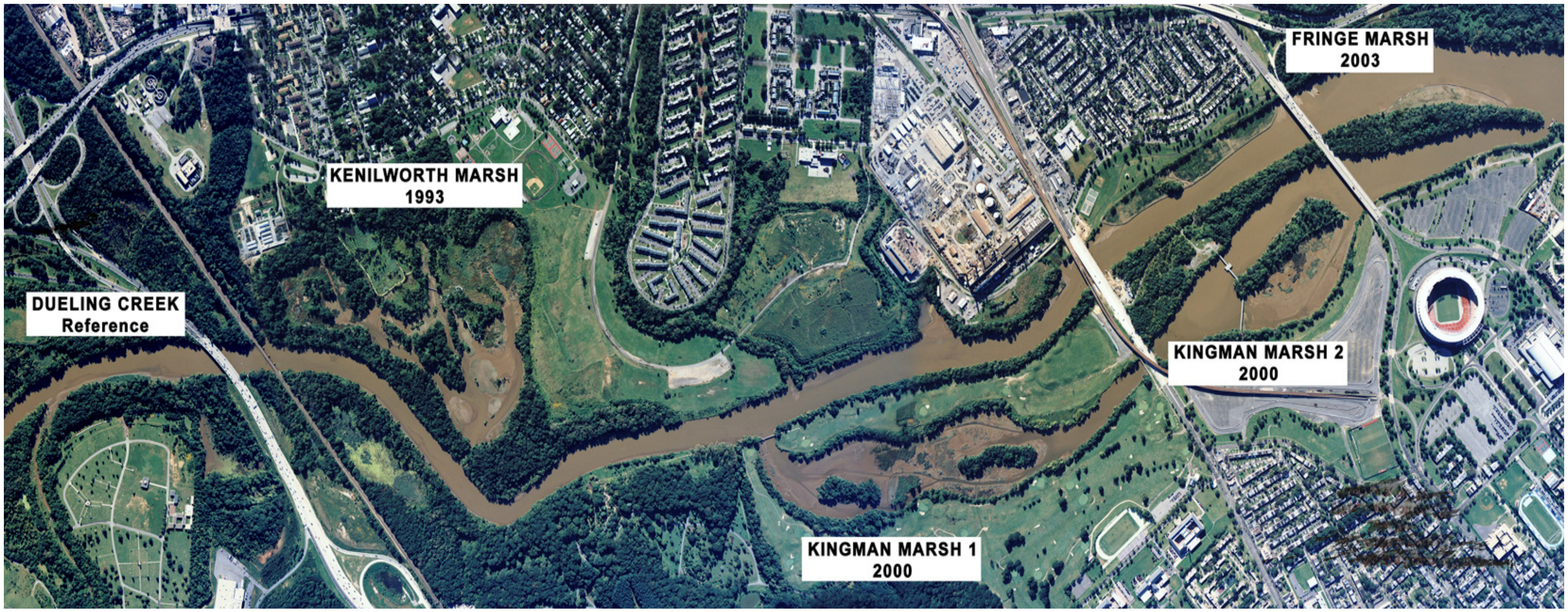

Figure 2. A composite photograph showing the location of several reconstructed wetlands in the Anacostia River, Washington, D.C. Also identified is the internal reference wetland at Dueling Creek. The Anacostia, though tidal, flows from left to right. The dates indicate the year of reconstruction. In this photograph North is to the left.

component of this reconstruction project the CoE in conjunction with D.C. established funding for 5 years of post- reconstruction monitoring (2000-2004) for two elements: (1) food chain accumulation of contaminants (conducted by the U.S. Fish and Wildlife Service) and (2) vegetation establishment (conducted cooperatively by USGS Patuxent Wildlife Research Refuge and the University of Maryland Biological Resources Engineering Department) (Hammerschlag et al., 2006). In addition, the CoE and D.C. decided to fund much of this special three-year study (2002-2004) on benthic macroinvertebrate response based on the expected usefulness of this benthic data and the paucity of practical information in the literature covering such freshwater tidal organisms.

The USGS Patuxent Wildlife Research Center (USGS PWRC) in conjunction with the University of Maryland Department of Biological Resources Engineering has been involved with documenting the pre- and post-reconstruction status of urban freshwater tidal wetlands in the Anacostia River (Hammerschlag et al., 2006). The District of Columbia Department of Environmental Health, Baltimore District of the Corps of Engineers and the National Capital Region of the National Park Service sought the expertise residing at USGS PWRC to conduct a detailed benthic macroinvertebrate study covering the Anacostia and reference wetlands as one of the post-reconstruction indicators of wetland status. Kingman Marsh (reconstructed in 2000) was the study focal point, but data collected from all study wetlands was used to support required monitoring and project baseline studies for the numerous reconstruction projects in the tidal Anacostia being implemented by CoE and D.C.

The high cost investment, high visibility and challenging circumstances for successful freshwater tidal wetland reconstruction in urbanized Washington, D.C. justified multi-year monitoring to measure the level of marsh reconstruction success. Benthic macroinvertebrates were used as short-term indicators given that most taxa of the macroinvertebrate community have relatively short life cycles (<2yrs.) and remain sedentary. It was possible to evaluate the extent to which the urban reconstructed wetlands were developing benthic communities similar to reference wetlands, particularly in terms of habitat and pollution influences. Macroinvertebrate communities of freshwater tidal wetlands have received little attention, which made this study unique due to the use of multiple sampling methods and community types to document the efficiency of using the benthic macroinvertebrate community as an indicator system reflecting wetland status.

There were special challenges in pursuing this work including tidal cycles and fluxes, which resulted in varying inundation periods for the marsh zones. How would macroinvertebrate communities respond to differing periods of flooding? Tidal freshwater wetlands occupy an intermediate landscape position between the brackish and salt marshes of the lower estuary and nontidal freshwater conditions above the fall line. Organisms which are unable to adapt to varying tidal conditions (i.e. exposure) are excluded, but many freshwater invertebrate taxa commonly found in low-gradient rivers and streams and the littoral zone of ponds and lakes are likely to be encountered in tidal freshwater wetlands (Diaz 1989). The combination of freshwater milieu and tidal influence may lead to an interesting and seasonally varying mix of macroinvertebrates.

This study characterized the macroinvertebrate communities in six selected tidal marsh areas representing a range of conditions. Characterization of these benthic communities, based on metrics such as abundance, taxonomic richness and pollution tolerance, as well as taxa composition provided a practical basis for bioassessment. These community parameters were compared to other indicators to further validate the usefulness of benthic organisms as short-term indicators of reconstructed wetland success. Such information will be important to assess progress of the reconstructed Anacostia wetlands and others like them. This study also utilized information from other studies on the subject marshes concerning vegetation, hydrology, sedimentation processes, soil structure and soil properties. While not directly addressed in this study, resident Canada goose herbivory severely impacted the vegetative cover at Kingman Marsh (Hammerschlag et al. 2006). It is not known how this may have influenced the macroinvertebrate community, although some differences between Kingman and the other Anacostia marshes may be related to goose herbivory. Since the tidal Anacostia is a part of the Chesapeake Bay system, this study contributes to the base of information used to better understand the ecology of the Chesapeake Bay.

STUDY DESIGN

The study hypothesis is that tidal freshwater wetlands of varying age and management history will exhibit different macroinvertebrate populations within the Anacostia River. If this hypothesis can be validated, then the overall objective of evaluating the relative success of urban freshwater tidal marsh reconstruction using the benthic community as an indicator can be explored further.

The following specific comparisons will be made to test the overall hypothesis:

- Determine the degree of seasonal and interannual variation in macroinvertebrate communities at the sample sites. Utilize this information to structure statistical approaches to other comparisons.
- Compare macroinvertebrate communities collected by three commonly used sampling techniques.
- Determine whether time of marsh establishment (age) relates to differing macroinvertebrate communities by evaluating as a series: Kingman Marsh as reconstructed in 2000, Kenilworth Marsh as reconstructed seven years prior in

1993, Dueling Creek as a remaining relic, relatively undisturbed marsh area in the Anacostia.

- Compare the macroinvertebrate communities from the three urban Anacostia wetlands (Kingman, Kenilworth and Dueling Creek) to the more rural Patuxent Marsh.

- Evaluate the influence of marsh (sediment) elevations (elevation gradient effect) and tidal regimes on macroinvertebrate community composition in the freshwater tidal system by sampling channel; mud flats (exposed at low tide); low, middle and high marsh zones; and stable yet transient pools.

- Compare the results from this study with those from similar wetland projects as may be reported in the literature.

STUDY SITES

This three-year study was conducted from 2002-2005, 3-5 year post-reconstruction at Kingman Marsh (2000) and 10-12 years post-reconstruction at Kenilworth Marsh (1993). It was designed to target and compare like habitat units (channel, mudflat, low marsh, middle marsh, high marsh and pools) in each of the four tidal freshwater wetlands differing in age or mode of establishment. Two natural tidal freshwater wetlands with similar tidal ranges were selected as reference sites to provide a basis for evaluating macroinvertebrate populations in the reconstructed wetlands. One of these sites, Patuxent Marsh, which included Mill Creek channel (*Figure 3*) is a relatively rural tidal freshwater wetland (Anderson et al.1968) located along the Patuxent River in an adjacent watershed. The Patuxent Marsh considered the external reference site, straddles Route 4 in Upper Marlboro, Maryland. Mill Creek is a small tidal channel that is part of the primary Patuxent Marsh study area. The other site, Dueling Creek Marsh (*Figure 2*) is a remnant urban wetland located on a small tributary to the Anacostia River a half mile upstream of Kenilworth Marsh. Dueling Creek Marsh was the best remaining unreconstructed wetland in the urban Anacostia watershed (personal observation) and was used as the Anacostia internal reference site. Dueling Creek Marsh is a narrow elevated bench along

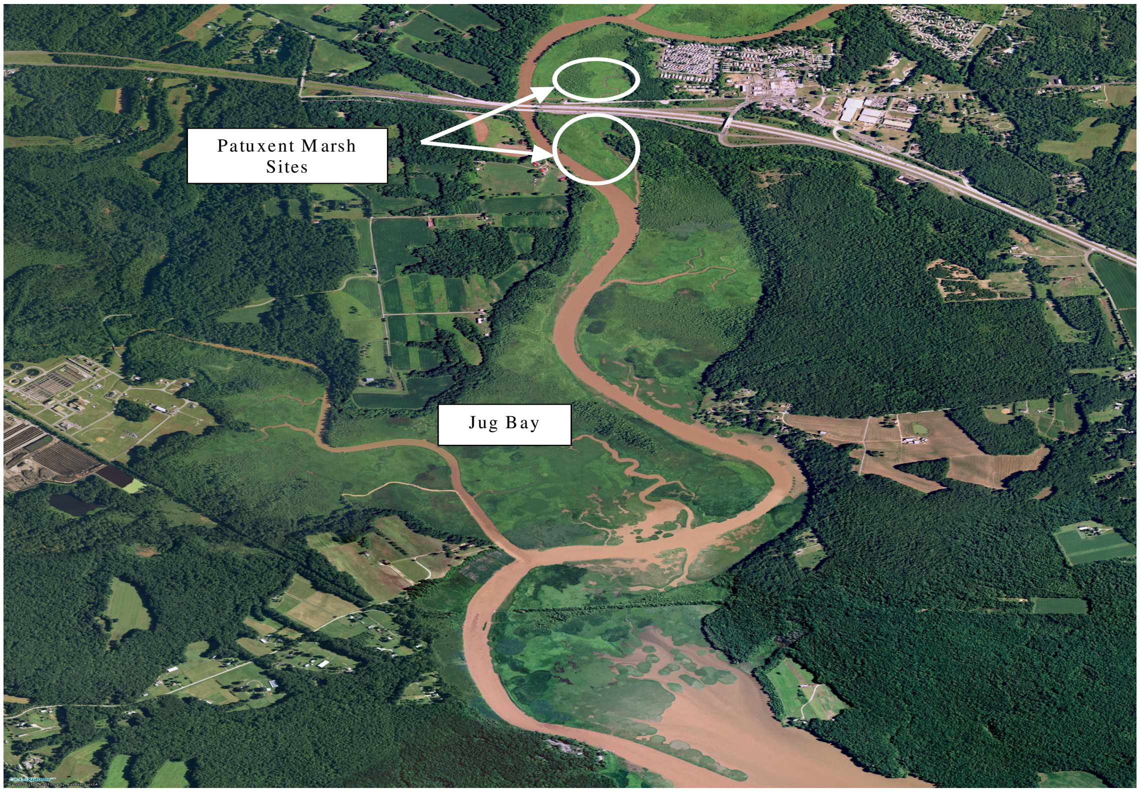

Figure 3. Photograph of Patuxent Marsh at the Route 4 Bridge.

the tidal Dueling Creek Channel that was formerly part of the primary Anacostia channel but was cut off when a straight-line channel was dredged to Bladensburg, Maryland.

Kenilworth Marsh is located just one half mile upstream from Kingman Marsh and a half-mile downstream from Dueling Creek Marsh (*Figure 2*). Historically, a tidal freshwater marsh existed at the location of Kenilworth Marsh, but the site was dredged to create a recreational lake in the 1940s. Kenilworth Marsh was reconstructed in 1993 using sediment dredged from the adjacent Anacostia River. Containment cells were filled with dredge material to multiple sediment elevations separated by tidal guts creating more that 30 acres of tidal freshwater wetlands. The Kingman Marsh was reconstructed in 2000 using Anacostia dredge material similarly to Kenilworth Marsh creating 42 acres of tidal freshwater wetlands. Sediment elevations were designed to be lower than those at Kenilworth Marsh to reduce colonization by invasive plant species. Both Kingman Marsh, the focal wetland of this study, and Kenilworth Marsh are located in low energy backwater portions of the Anacostia estuary.

METHODS

Methods for sampling tidal wetland macroinvertebrates have not been as well documented as the protocols for monitoring streams (Adamus and Brandt 1990). Designing an effective sampling program for freshwater wetlands presents several challenges. First, choosing representative sample sites is not straightforward. Marshes are usually patterned into a mosaic of discrete vegetation associations, and sampling should be stratified with respect to these large-scale patterns (Turner and Trexler 1997) so as to reflect habitat types and sediment elevation in the tidal regime. Marsh vegetation may also be very dense, and the sampler used in these habitats must be able to perform effectively. Finally, marsh water levels vary tidally, seasonally and spatially, and macroinvertebrate samplers must be able to function at various water depths. Sampling was conducted as close to high tide as possible to permit the use of a wide array of samplers along the vegetation community gradient and in all habitat types. Sampling sites were accessed on foot with the use of chest-high waders and a small inflatable raft for holding samples and equipment. The marsh sites experienced a semidiurnal tidal pattern, with two high tides and two low tides each 24-hour period.

This project used three quantitative sampling methods: Ekman grab, D-net and Hester-Dendy plate sampler. The primary sampler was an Ekman bottom grab sampler, which could be used effectively at all six habitat units. The Ekman sampler measures 6”x 6”x 6” (216 cu. in.) and samples a 0.023 m^2 area of sediment. The sampler was attached to a 5’ extension handle for shallow water operation. It had a spring-loaded trap door on the bottom to retain grabbed samples and a screen over the top to ensure that organisms were not lost. The Ekman was used as a quantitative means of sampling, which permitted the estimation of the numbers of organisms per square meter. This approach has been well documented in the literature (Elliott and Drake 1981, Lewis et al. 1982, Merritt and Cummins 1996, Brittingham 1997, Helgen 2001). Ekman grabs (up to two replicates) were taken at each sampling location to determine sampling variance. In the field, each sediment sample was washed through a 600 µm mesh sieve and the contents were placed in a preservative of 70% alcohol stained with rose bengal for later laboratory identification and enumeration.

The two other types of samplers used were the D-shaped dip net (D-net), and the Hester-Dendy plate sampler (H-D). The D-net had a 12-inch diameter opening with an 800 µm mesh. The D-net was used to take an approximate 1-meter long sweep of the sample site water column (sample area of 0.3 m^2) with a horizontal bumping action along the bottom. Since it sampled the water column immediately above the sediment, the D-net sample required water to be present at each site, thus the need to sample near high tide for several of the six habitat types. The D-net method represented a semi quantitative sampling method yielding a general assessment of the taxa of aquatic organisms present in the near-sediment water column and surface sediments, as well their relative abundance (Swanson 1995, Merritt and Cummins 1996, Helgen 2001). It is recognized that some of these organisms may not be permanent residents, but may be brought in on the rising tide. D-net samples were taken at the same time as the Ekman samples to capture other organisms present that the Ekman sampler might have missed especially those on the sediment surface and in the water column. Samples were washed in the field and preserved in 70% alcohol with rose bengal.

The Hester-Dendy is an artificial substrate sampler placed in areas below high tide that are constantly inundated, this sampler attracts mobile macro-benthic organisms seeking protection from predation and sessile organisms seeking hard substrate or the interstices provided by the sampler. It is composed of nine 3-inch square plates separated by spacers held together by stainless steel eyebolts and wing nuts (Merritt and Cummins 1996). The plates were made of smooth tempered hardboard 1/8" thick (3 mm) separated by a nylon spacer 1/8" thick (3 mm) (total sampling area of 0.1 m^2). The H-D is a quantifiable means of sampling that aided determination of the full spectrum of organisms present in the marsh habitat. As shown in Table 1, the H-Ds were deployed only at channel and pool sites, one per site on a bimonthly basis. The sampler usually was tied to a stake, which served as a locator and placed below the surface of the water for a period of four to six weeks. The location was chosen relative to the tidal cycle, which would allow the H-D to be inundated through the low tide phase. At the end of this time the sampler was removed and placed in a watertight container until it was disassembled in the laboratory where it was carefully washed and scraped clean. Organisms from the substrate were washed using a 600 µm mesh sieve and placed in the 70% alcohol solution for further identification. H-D samplers proved difficult to maintain in the tidal regime, especially over winter. Also, it was not always possible to keep them inundated in the channels during very low tides. Vandalism and storms were likely causes for loss of these tethered samplers. As a result, while the H-D's provided a good picture of the presence of a series of organisms not as readily captured by other means, it could not be used as a quantitative sampling device in this study.

The wetlands of the Anacostia River that were sampled are as follows: Kingman Marsh Areas 1 and 2 (*Figure 4&5*), Kenilworth Marsh Mass Fills 1 and 2 (*Figure 6*), and Dueling Creek Marsh (*Figure 7*); and an outside reference marsh located along the Patuxent River (*Figure 7*). Thus there were six sampling locations. Within each marsh location six separate habitats units were sampled: tidal channel (tidal guts or channels that carried water into and out of the wetland); pool (large areas that were depressed enough to hold water almost continuously); mudflat (low elevation zones that were exposed sediments at low tide, but were lower than any of the vegetation zones); and intertidal vegetation zones (low, middle, and high marsh).

The three vegetation zones were sampled independently. Typical low marsh areas at Kingman Marsh were populated with such key species as *Peltandra virginica, Nuphar lutea, Pontedaria cordata* and *Zizania aquatica*. Mid marsh often contained

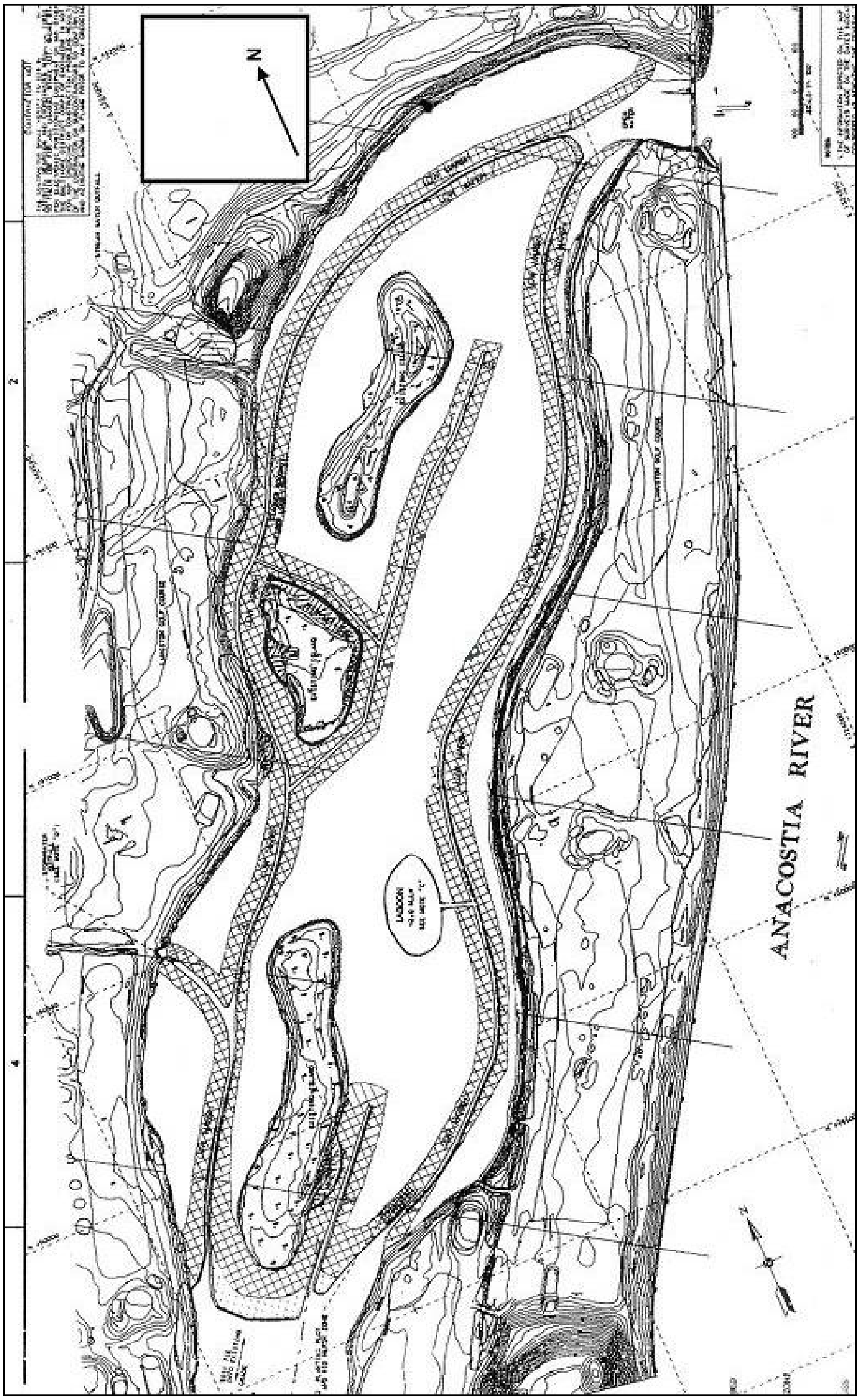

Figure 4: Kingman Area 1

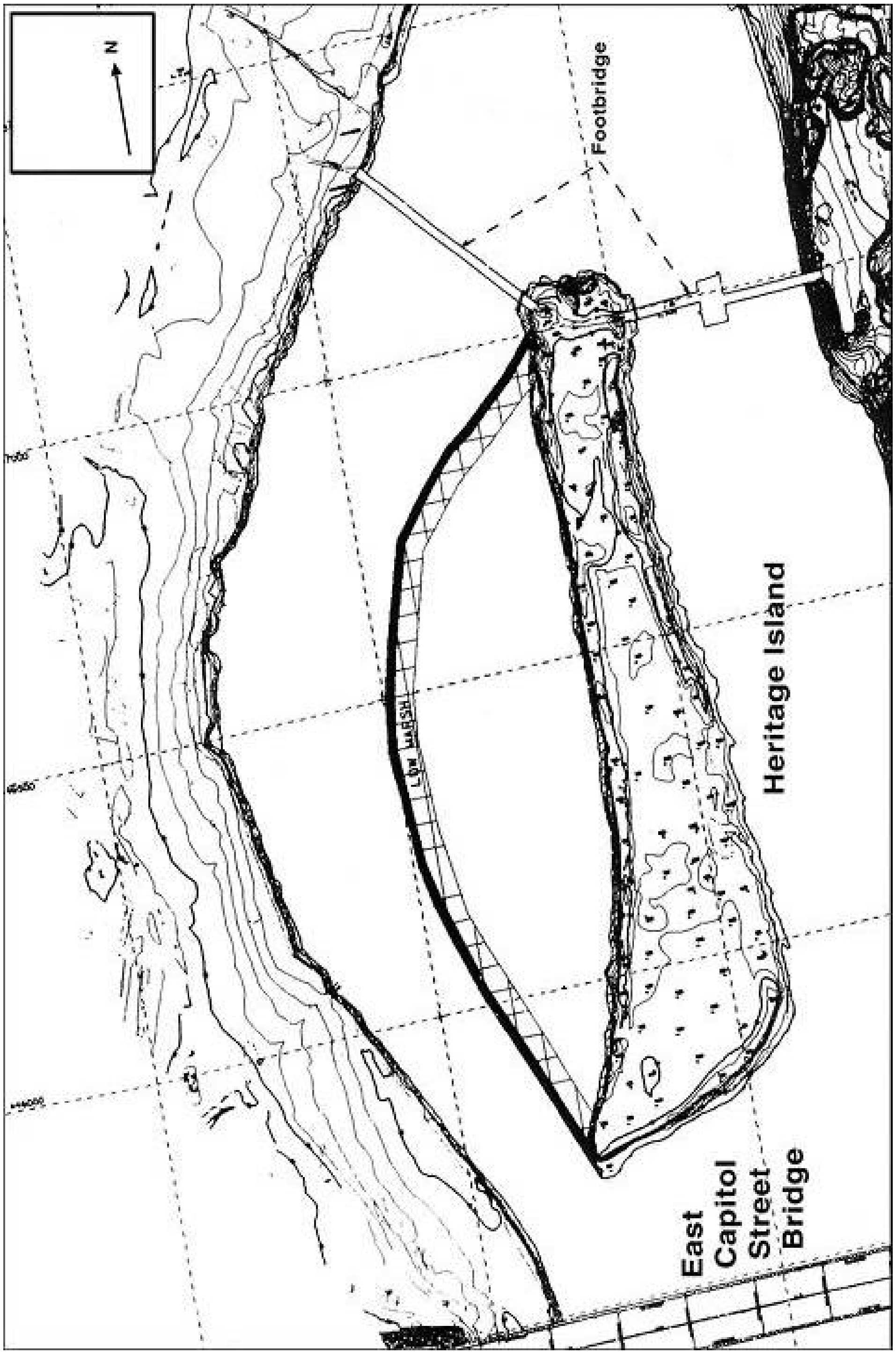

Figure 5: Kingman Marsh Area 2

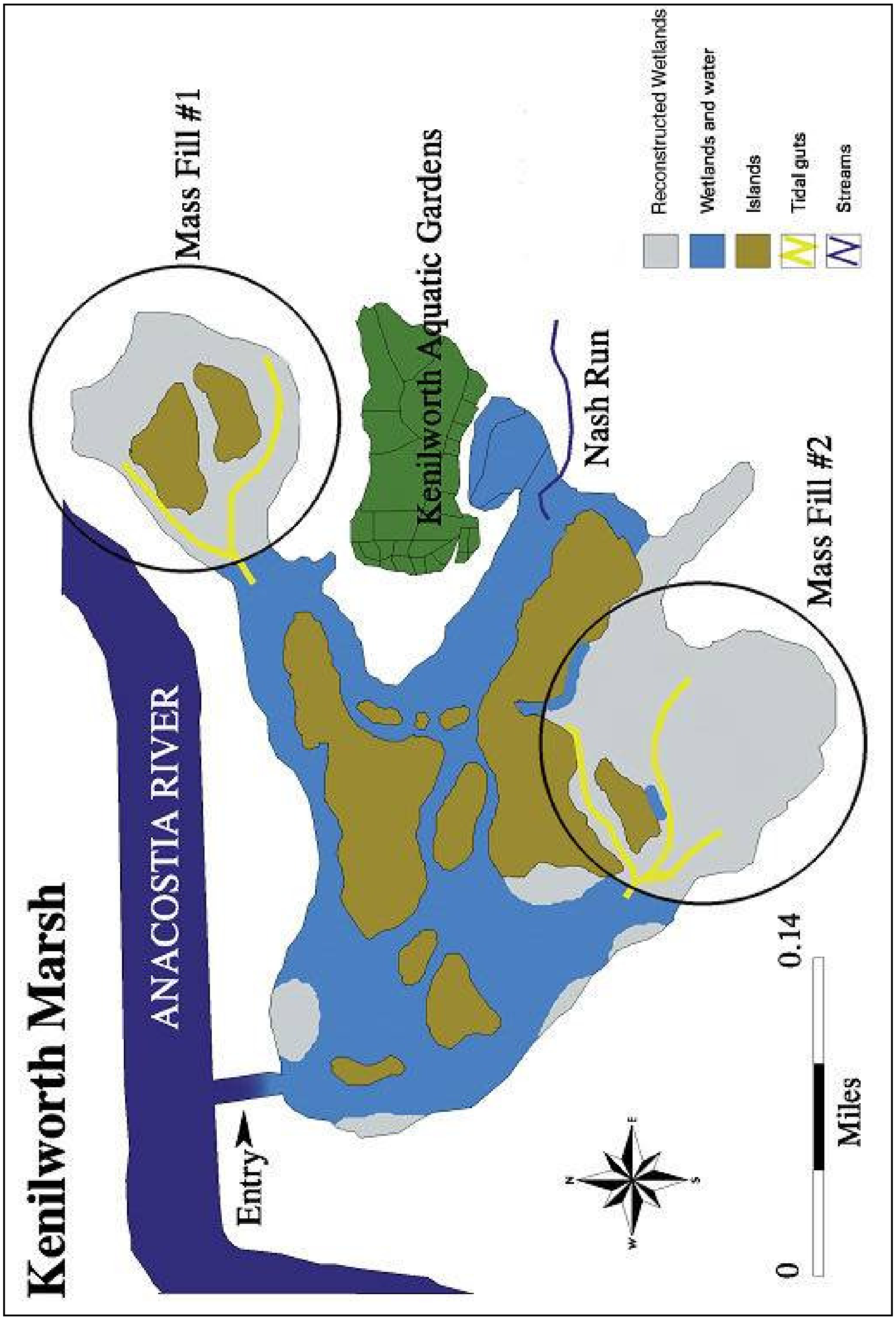

Figure 6: Kenilworth Marsh showing Mass Fill 1 and 2

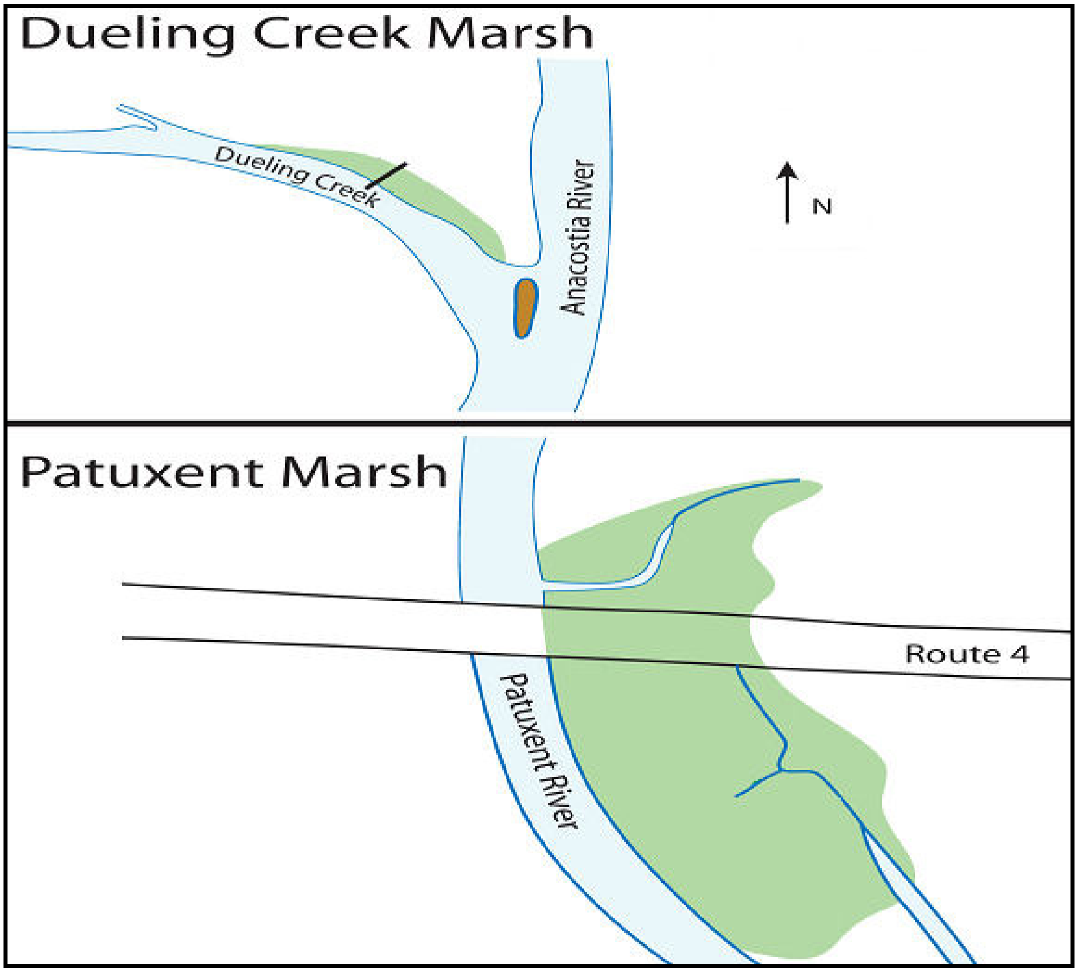

Figure 7: Reference marshes: Dueling Creek a tributary of the Anacostia and Patuxent River Marsh

Schoenoplectus tabernaemontani, Schoenoplectus fluviatilis, P. virginica, Sagittaria latifolia and *Juncus effusus*. High marsh often possessed dominants such as *Typha* spp., *Phragmites australis, and Lythrum salicaria* along with several annuals. A complete listing of species, common names and habitat preference may be found in the Final Report covering the vegetation study (Hammerschlag et al. 2006).

Elevations for the intertidal vegetated zones (high, middle and low marsh) were surveyed using existing benchmarks installed by the CoE according to the National Geodetic Vertical Datum of 1929 (NGVD ’29 = the mean tide levels recorded in the 1929 time period). Measurements of the benchmarks and vegetated zone sites were taken using a laser level and surveyor’s rod. Guidelines for determining the elevations and inundation periods of the vegetated zones were taken from a technical report by Offshore & Coastal Technologies, Inc. (1996) submitted to the CoE for the Kingman Lake wetlands. According to the report, low marsh sites were inundated about 36% of the time and occupy elevations of 1.5’ to 1.7’ NGVD '29; mid marsh sites were inundated about 27% of the time and occupy elevations of 1.7’ to 2.1’ NGVD '29; and high marsh sites were inundated about 19% of the time and occupy elevations of 2.1’ to 2.3’ NGVD '29. Mudflats were unvegetated areas less than 1.5' NGVD '29 and inundated more than 40% of the time with short periods of exposure to the atmosphere. However, at Kingman Marsh there were disturbed ‘mudflats’ areas where vegetation would normally occur but were devoid due to wildlife grazing. These were not sampled as ‘mudflats’ because of the higher elevation nor were they sampled as ‘vegetated’ due to lack of vegetation from grazing. Reconstructed marsh sediments often contained intact or partially decomposed organic matter fragments, but the soils did not contain a developed organic matter layer.

The sampling schedule for the three-year study is shown in Table 1. Sampling was to be conducted at each of the six collection sites seasonally (quarterly) at randomly selected points within each of the above-mentioned site habitat units using the three sampling techniques for three consecutive years. Sampling began in the winter of 2002 and ended in the spring of 2004. By referring to Table 1 we can see the specific schedule for each of the six sites. Note that the three vegetation zones have been pooled in to one "vegetated" habitat unit. On each date one sample was collected at each site from each vegetation zone. As noted above, results from the three vegetation zones were pooled into a "vegetated" habitat unit in all analyses. The H-Ds were sampled every other month at the channel and pool habitats (*12 samples/year*). The Ekman was used to collect two replicates the first month of each season at the channel (8 samples/year), mudflat (8 samples/year), and pool habitat units (8 samples/year). One Ekman sample was collected at the 3 vegetated zones each season (12 samples/year). The samples collected at each date in vegetated zones were assumed to be replicates since it was determined that no difference existed among the three vegetated habitat zones in terms of macroinvertebrate community *(*12 samples/year). Finally the D-net was used at each habitat unit in conjunction with the Ekman samples. Only one of the vegetated zones was sampled on each quarterly trip. The zone utilized was selected randomly using a random number table.

Table 1: Sampling Schedule for Anacostia Wetland Project

KINGMAN-AREA 1	W2	SP2	SU2	F2	W3	SP3	SU3	F3	W4	SP4	TOTAL
Kingman - channel											
Hester-Dendy	1	1	1	1		1	1	1			7
Ekman	2	2	2	2	1	2	2	2	2	2	19
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											36
Kingman - mudflat											
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											27
Kingman - pool											
Hester-Dendy	1	1	1	1	1	1	1	1	1	1	10
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											37
Kingman – vegetated											
Ekman	2	3	3	3	3	3	3	3	3	3	29
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											38
STUDY TOTAL											**138**

Table 1: (cont.)

KINGMAN-AREA 2	W2	SP2	SU2	F2	W3	SP3	SU3	F3	W4	SP4	TOTAL
Kingman - channel											
Hester-Dendy	1	1	1	1		1	1	1	1		8
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											35
Kingman - mudflat											
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											27
Kingman - pool											
Hester-Dendy	1	1	1	1	1	1	1	1		1	9
Ekman		2	2	2	1	2	2	2	2	2	17
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											36
Kingman - vegetated											
Ekman	2	3	3	3	3	3	3	3	3	3	29
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											39
STUDY TOTAL											**137**

Table 1: (cont.)

KENILWORTH-MF 1	**W2**	**SP2**	**SU2**	**F2**	**W3**	**SP3**	**SU3**	**F3**	**W4**	**SP4**	**TOTAL**
Kenilworth - channel											
Hester-Dendy	1	1	1	1		1	1	1	1		8
Ekman	2	2	2	2	1	2	2	2	2	2	19
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											37
Kenilworth - mudflat											
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											28
Kenilworth - pool											
Hester-Dendy	1	1	1	1	1	1	1	1	1		9
Ekman		2	2	2	1	2	2	2	2	2	17
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											36
Kenilworth - vegetated											
Ekman	2	3	3	3	3	3	3	3	3	3	29
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											39
STUDY TOTAL											**140**

Table 1: (cont.)

KENILWORTH-MF 2	W2	SP2	SU2	F2	W3	SP3	SU3	F3	W4	SP4	TOTAL
Kenilworth - channel											
Hester-Dendy	1	1	1	1		1	1	1	1		8
Ekman	2	2	2	2	1	2	2	2	2	2	19
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											36
Kenilworth - mudflat											
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											27
Kenilworth - pool											
Hester-Dendy	1	1	1	1			1	1	1		7
Ekman		2	2	2	1	2	2	2	2	2	17
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											34
Kenilworth - vegetated											
Ekman	2	3	3	3	3	3	3	3	3	3	29
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											38
STUDY TOTAL											**135**

Table 1: (cont.)

Dueling Creek	W2	SP2	SU2	F2	W3	SP3	SU3	F3	W4	SP4	TOTAL
Dueling - channel											
Hester-Dendy	1	1	1	1	1	1	1	1	1	1	10
Ekman	2	2	2	2	1	2	2	2	2	2	19
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											38
Dueling - mudflat											
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net			1	1	1	1	1	1	1	1	8
TOTAL											26
Dueling - pool											
Hester-Dendy	1	1		1		1	1	1	1	1	8
Ekman		2	2	2	1	2	2	2	2	2	17
D-net	1	1	1	1	1	1	1	1	1	1	10
TOTAL											35
Dueling - vegetated											
Ekman	3	3	3	3	3	3	3	3	3	3	30
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											39
STUDY TOTAL											**138**

Table 1: (cont.)

Patuxent	W2	SP2	SU2	F2	W3	SP3	SU3	F3	W4	SP4	TOTAL
Patuxent - channel											
Hester-Dendy	1	1	1	1	1	1		1	1	1	9
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net	2	1	1	1	1	1	1	1	1	1	11
TOTAL											38
Patuxent - mudflat											
Ekman	1	2	2	2	1	2	2	2	2	2	18
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											27
Patuxent - pool											
Hester-Dendy	1	1	1	1	1	1	1	1	1	1	10
Ekman		2	2	2	1	2	2	2	2	2	17
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											36
Patuxent - vegetated											
Ekman	2	3	3	3	3	3	3	3	3	3	29
D-net		1	1	1	1	1	1	1	1	1	9
TOTAL											38
STUDY TOTAL											**139**

This resulted in single quarterly samples from 4 habitat units sampled (*16samples/year*). Thus a total of 64 samples were collected at each of the 6 study sites each year to yield a total of 384 samples/year. While this was a large sampling size to handle, it constituted the smallest number acceptable to meet the study design.

However, this sampling schedule was not followed completely over the course of the study due to various weather conditions, unforeseen circumstances and lack of pool habitat. Ice accumulation in the winter months would shear off H-Ds from the attachment stakes and were not found. Heavy snowfall and freezing temperatures would hinder any sampling in the marshes as well. Pool habitat was the hardest to find in the Anacostia wetlands. Pools present one year were not there the following year. Some were so small that taking two Ekman samples and one D-net sample would be too much disturbance for the pool area to handle. So then only one Ekman and one D-net sample were taken. Other times pools would dry out over the summer months leaving the H-D sampler high and dry. Even though this sample schedule was followed as best as possible, some samples were not taken and therefore only 121 H-D samples, 498 Ekman samples, and 226 D-net samples were taken over the course of the study.

Samples brought back to the lab were washed again through the 600µm mesh screen and placed in trays for sorting and enumeration under a dissecting scope. All samples were picked to completion; no sub-sampling was used (It often took at least one hour to sort a sample, with some samples containing over 500 organisms.). Organisms were identified to the lowest taxonomic group (primarily to family, but to genera or even species where possible), preserved in 70% alcohol and placed in vials for a reference collection. Macroinvertebrate identifications were verified by Rob Hood of USGS, Water Resources Division, Denver, Colorado; and Tim Morris of Cove Point Lab, Solomons Island, Maryland.

The samples were compared using community attributes commonly used by aquatic ecologists: invertebrate abundance, species richness, relative abundance, and taxonomic composition. Shannon's Index of Diversity was calculated for all samples, which combined richness and evenness in a summary statistic. Total number of taxa (usually identified to the genus level) provided a richness component in calculating the value of diversity indices; the number of individuals per taxon provided an evenness component (Washington 1984, King and Richardson 2002). To test hypotheses about taxa abundance, I analyzed statistically only those taxa that represented >1% of the total number of individuals (i.e. common taxa) collected throughout the study. I used two-way ANOVAs to compare the abundances of the common taxa between the marsh sites, habitats, seasons, and collection year. A Tukey's post-hoc test was used to detect where the significant differences occurred. All data were $\log_{10}(x+1)$ transformed prior to analysis to equalize variances (Zar, 1996).

Pollution tolerance was addressed by relating the species found to lists of documented pollution tolerant and intolerant species. Tolerance values were taken from the Maryland Biological Stream Survey (MBSS) 2000-2004 Report (Boward et al. 2005). Comparison also was made between the species found in the polluted Anacostia estuary (particularly as related to toxic components – Pinkney et al. 2003) as compared to the nearby less polluted situation at Patuxent Marsh.

RESULTS

Over the course of the study some 110,000 macroinvertebrate organisms were collected by the three sampling methods representing 70+ taxa (*Table 2*). Table 2 is a complete taxonomic list of all organisms collected throughout the study from all sampling methods. The taxa include 57 genera and 12 orders comprised of 48 identified families. Dipterans (aquatic flies) were the most diverse order representing over 20 species. Within the order Diptera, the family Chironomidae was the most abundant group at each marsh with densities reaching over $20{,}000/m^2$. The segmented aquatic worms (class Oligochaeta) were the second most abundant group in the study with densities reaching $16{,}000/m^2$ (referred to as oligochaetes hereafter).

A family level comparison of the six marshes with pooling data from all samples at each site during the entire study representing a total of 498 Ekman samples taken over the course of the three-year study is shown in *Table 3*. Over 95% of the organisms counted at Kingman and over 85% at Kenilworth were either chironomids or oligochaetes. While about 23 families were represented at the Anacostia wetlands (Kingman, Kenilworth and Dueling), Patuxent had contributions from 30 families. Also striking as revealed in the Shannon Diversity Index, is how evenly spread the counts are among all families at

Patuxent, not just clustered in the aquatic fly larvae and segmented worms *(Table 3)*. The ANOVA table for all the figures can be seen in *Table 4*.

Table 2: Anacostia Taxonomic List

Insecta
- Ephemeroptera
  - Caenidae
    - *Caenis sp.*
  - Baetidae

- Odanata
  - Aeshnidae
    - *Anax sp.*
  - Libellulidae/Corduliidae
    - *Plathemis sp.*
  - Gomphidae
    - *Arigomphus sp.*
    - *Gomphus sp.*
  - Coenagrionidae
    - *Ishnura sp.*
    - *Enallagma sp.*

- Hemiptera
  - Belostomatidae
    - *Belostoma sp.*
  - Corixidae
    - *Sigara sp.*
  - Gerridae
    - *Gerris sp.*
  - Hydrometridae
    - *Hydrometra sp.*
  - Nepidae
    - *Ranatra sp.*
  - Saldidae
  - Veliidae

- Trichoptera
  - Polycentropodidae
    - *Cyrnellus fraternus*
  - Leptoceridae
    - *Leptocerus sp.*
    - *Oecetis sp.*

Coleoptera
- Haliplidae
  - *Peltodytes sp.*
- Elmidae
- Hydrophilidae
  - *Berosus sp.*
  - *Hydrophilus sp.*
- Lampyridae
- Carabidae

Dipteran
- Ephydridae
- Muscidae
- Sciomyzidae
  - *Sepedon sp.*
- Syrphidae
  - *Eristalis sp.*
- Dolichopodidae
- Stratiomydae
  - *Odontomyia sp.*
- Tabanidae
  - *Chrysops sp.*
  - *Merycomyia sp.*
  - *Tabanus sp.*
- Ceratopogonidae
  - *Dasyhelea sp.*
- Chaoboridae
  - *Chaoborus sp.*
- Chironomidae
  - *Chironomus sp.*
  - *Procladius sp.*
  - *Tanytarsus sp.*
- Culicidae
  - *Aedes sp.*
- Psychodidae
  - *Pericoma sp.*
  - *Psychoda sp.*
- Ptychopteridae
  - *Bittacomorphella sp.*

Table 2: cont.

Dipteran cont.
Tipulidae
Erioptera sp.
Limnophila sp.
Pseudolimnophila sp.
Tipula sp.
Pilaria sp.

Crustacea
Amphipoda
Gammaridae
Gammarus sp.
Isopoda
Asellidae
Asellus sp.

Mollusca
Gastropoda
Hydrobiidae
Lymnaeidae
Physidae
Physa sp.
Planorbidae

Bivalvia
Corbiculidae
Corbicula fluminea
Sphaeriidae
Musculium sp.
Pisidium sp.
Sphaerium sp.
Unionidae
Anodonta sp.
Elliptio sp.

Oligochaeta
Lumbriculidae
Lumbriculus sp.
Lumbricidae
Megadrili sp.
Tubificidae
Branchiura sp.

Hirudinea
Erpobdellidae
Erpobdella punctata
Mooreobdella tetragon
Mooreobdella microstoma
Glossiphoniidae
Desserobdella phalera
Gloiobdella elongata
Helobdella fusca
Helobdella stagn

Table 3: Summation of Ekman macroinvertebrate data at the family level for the 2002-2004 study

	Kingman Area 1		Kingman Area 2		Kenilworth MF1		Kenilworth MF2	
Taxa	Count	% Total	Count	% Total	Count	% Total	Count	% Total
Caenidae	0	0.00	0	0.00	0	0.00	0	0.00
Aeshnidae	1	0.01	0	0.00	0	0.00	0	0.00
Libellulidae/Corduliidae	2	0.01	0	0.00	4	0.04	0	0.00
Gomphidae	0	0.00	0	0.00	0	0.00	0	0.00
Coenagrionidae	63	0.38	0	0.00	0	0.00	0	0.00
Belostomatidae	0	0.00	0	0.00	2	0.02	0	0.00
Polycentropodidae	0	0.00	0	0.00	0	0.00	0	0.00
Elmidae	0	0.00	0	0.00	0	0.00	3	0.03
Hydrophilidae	1	0.01	0	0.00	4	0.04	0	0.00
Syrphidae	2	0.01	0	0.00	20	0.18	12	0.11
Dolichopodidae	14	0.08	2	0.02	15	0.14	28	0.25
Stratiomydae	0	0.00	2	0.02	10	0.09	1	0.01
Tabanidae	0	0.00	4	0.03	5	0.05	13	0.11
Ceratopogonidae	718	4.30	516	4.29	1002	9.09	739	6.50
Chironomidae	8133	48.74	5573	46.30	4325	39.25	3566	31.35
Psychodidae	0	0.00	0	0.00	6	0.05	39	0.34
Tipulidae	15	0.09	19	0.16	50	0.45	75	0.66
Amphipoda	15	0.09	9	0.07	13	0.12	34	0.30
Isopoda	0	0.00	0	0.00	141	1.28	21	0.18
Hydrobiidae	0	0.00	1	0.01	0	0.00	0	0.00
Lymnaeidae	0	0.00	1	0.01	0	0.00	0	0.00
Physidae	13	0.08	10	0.08	7	0.06	10	0.09
Planorbidae	2	0.01	2	0.02	1	0.01	0	0.00
Corbiculidae	5	0.03	1	0.01	6	0.05	22	0.19
Sphaeriidae	170	1.02	69	0.57	556	5.05	378	3.32
Unionidae	1	0.01	6	0.05	0	0.00	1	0.01
Oligochaeta	7372	44.18	5732	47.62	4695	42.60	6277	55.18
Lumbriculidae	0	0.00	0	0.00	4	0.04	0	0.00
Megadrili sp.	6	0.04	0	0.00	43	0.39	24	0.21
Branchiura sp.	123	0.74	72	0.60	81	0.74	54	0.47
Erpobdellidae	8	0.05	4	0.03	0	0.00	0	0.00
Glossiphoniidae	22	0.13	14	0.12	30	0.27	78	0.69
TOTAL organisms	16,686		12,037		11,020		11,375	
Shannon's Index	**1.00**		**0.95**		**1.34**		**1.23**	
Ekman samples	84		82		83		83	

Table 3 cont.

	Dueling Creek		Patuxent Marsh	
Taxa	Count	% Total	Count	% Total
Caenidae	2	0.02	19	0.38
Aeshnidae	0	0.00	0	0.00
Libellulidae/Corduliidae	0	0.00	29	0.58
Gomphidae	0	0.00	5	0.10
Coenagrionidae	0	0.00	37	0.75
Belostomatidae	0	0.00	2	0.04
Polycentropodidae	0	0.00	1	0.02
Elmidae	1	0.01	0	0.00
Hydrophilidae	0	0.00	9	0.18
Syrphidae	8	0.07	1	0.02
Dolichopodidae	16	0.15	9	0.18
Stratiomydae	5	0.05	2	0.04
Tabanidae	36	0.33	4	0.08
Ceratopogonidae	2087	19.40	408	8.22
Chironomidae	3401	31.62	1661	33.46
Psychodidae	3	0.03	1	0.02
Tipulidae	34	0.32	3	0.06
Amphipoda	13	0.12	267	5.38
Isopoda	8	0.07	410	8.26
Hydrobiidae	0	0.00	16	0.32
Lymnaeidae	1	0.01	44	0.89
Physidae	12	0.11	34	0.68
Planorbidae	1	0.01	133	2.68
Corbiculidae	42	0.39	10	0.20
Sphaeriidae	332	3.09	703	14.16
Unionidae	1	0.01	2	0.04
Oligochaeta	4735	44.02	1101	22.18
Lumbriculidae	0	0.00	2	0.04
Megadrili sp.	12	0.11	4	0.08
Branchiura sp.	1	0.01	5	0.10
Erpobdellidae	0	0.00	9	0.18
Glossiphoniidae	5	0.05	33	0.66
TOTAL organisms	10,756		4,964	
Shannon's Index	**1.28**		**2.00**	
Ekman samples	84		82	

Table 4: ANOVA Table

Figure	Parameter & Treatment	Sum of Squares	df	Mean Square	F-ratio	P-value
Figure 8	D-net Density by wetland	1.039	3	0.346	3.962	0.009
	Error	19.409	222	0.087		
Figure 9	D-net Richness by wetland	284.337	3	94.779	25.424	0.000
	Error	827.597	222	3.728		
Figure 11	Density by season	5.082	3	1.694	15.122	0.000
	Error	55.339	494	0.112		
Figure 14	Density by wetland	13.574	3	4.525	47.714	0.000
	Error	46.846	494	0.095		
Figure 15	Taxa Richness by wetland	269.539	3	89.846	36.754	0.000
	Error	1207.586	494	2.44		
Figure 16	Shannon's Index by wetland	16.403	3	5.468	59.529	0.000
	Error	45.373	494	0.092		
Figure 17	Tolerance Values by wetland	56.05	3	18.68	4.133	0.007
	Error	628.29	139	4.52		
Figure 18	Tolerance Values by watershed	27.034	1	27.034	5.799	0.017
	Error	657.31	141	4.66		
Figure 20	Chironomidae Density by wetland	20.501	3	6.834	15.892	0.000
	Error	212.414	494	0.430		
Figure 21	Oligochaete Density by wetland	40.813	3	13.604	98.873	0.000
	Error	67.971	494	0.138		
Figure 25a	Denisty by habitat units	1.64	8	0.328	2.745	0.019
	Error	58.78	492	0.119		
Figure 25b	Richness by habitat units	91.844	5	18.369	6.524	0.000
	Error	1385.281	492	2.816		

Comparison of Sampling Techniques

Overall

There are similar findings when comparing data from the two main sampler types (Ekman and D-net). Mean Ekman and D-net numbers had the same pattern with Kingman having significantly higher individuals per meter squared than the other wetlands and Patuxent had less abundance ($p<0.05$) (*Figure 8*). Taxa richness for the two samplers also had a similar pattern with Patuxent having significantly higher richness than the Anacostia wetlands while Kenilworth had more taxa than either of the other Anacostia marshes ($p<0.05$)(*Figure 9*). This suggests that both samplers collected assemblages, which could provide some discriminatory power when comparing sites. The Ekman did collect an order of magnitude greater number of organisms than the D-net.

Individual Taxa

The dominant taxa for the three sampling techniques are shown in Table 5. Family chironomidae and class oligochaeta accounted for the majority of organisms collected in the Anacostia wetlands. Regardless of sampling technique these two groups represented between 57% and 94% of the total organisms collected for the entire study. Patuxent marsh had between 24% and 55% of the total organism count represented by chironomids and oligochaetes, which is reflected in the higher Shannon Diversity Index score when compared to the Anacostia wetlands.

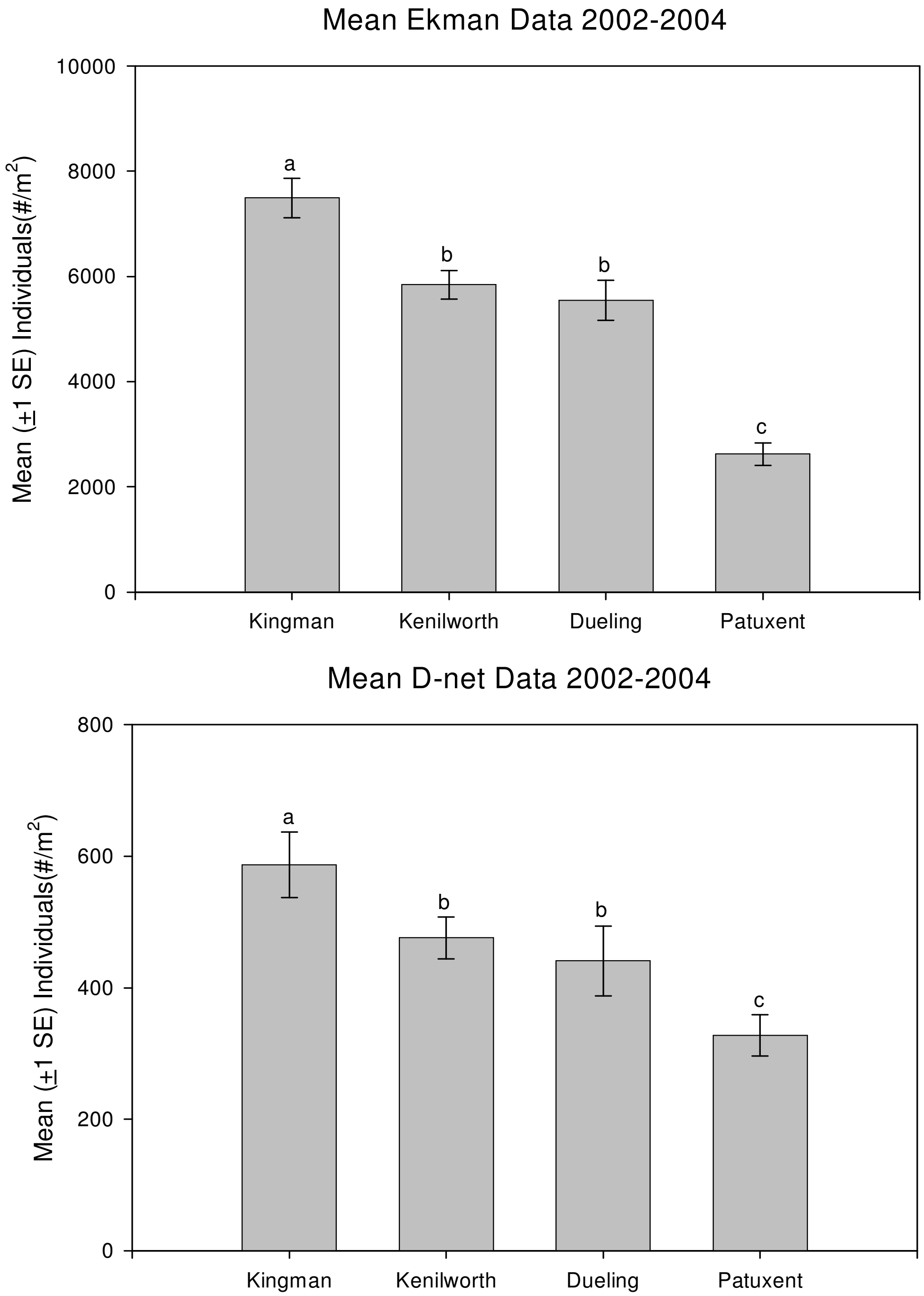

Figure 8: Mean (± 1 SE) Ekman and D-net abundances for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

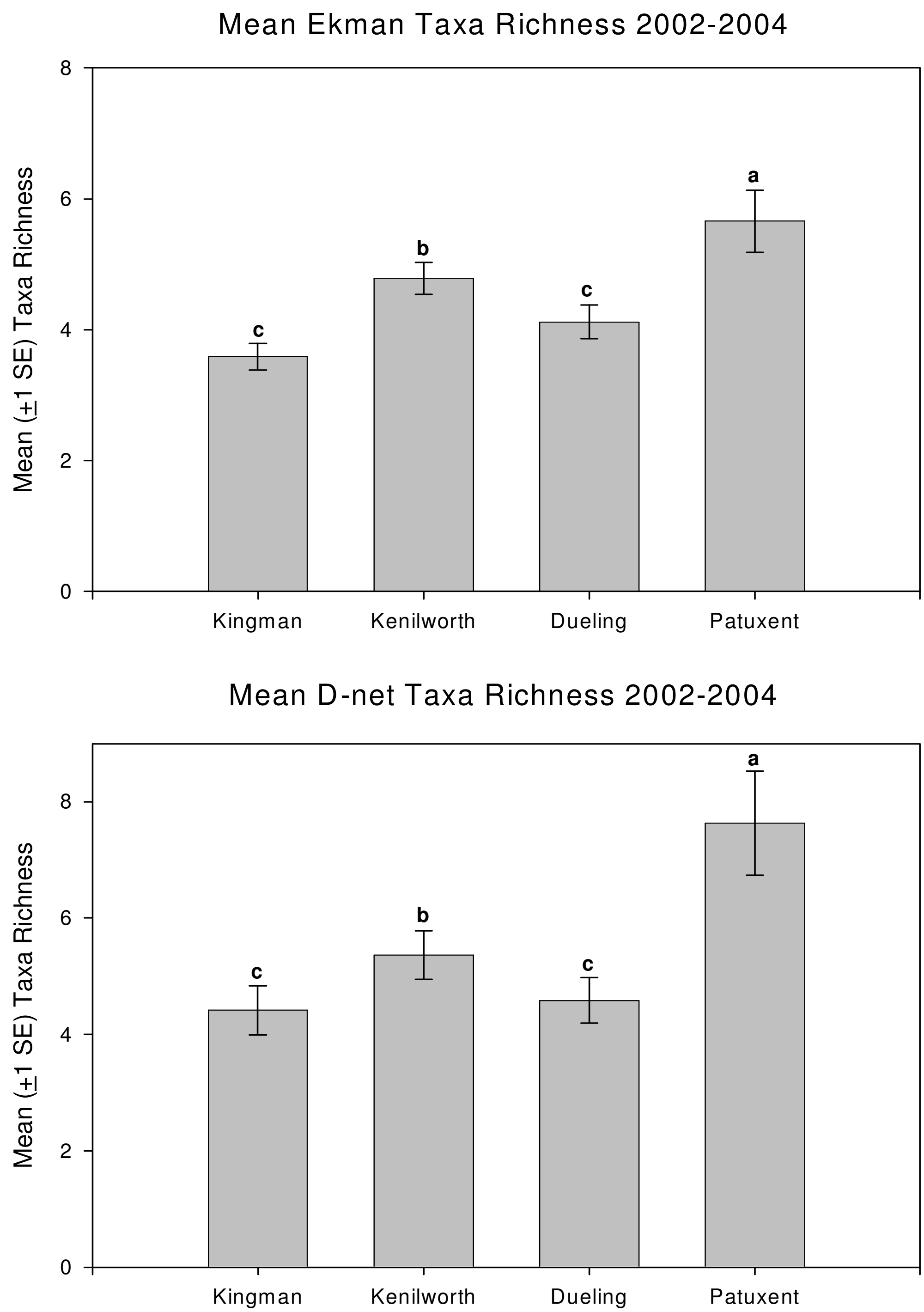

Figure 9: Mean (+ 1 SE) Ekman and D-net taxa richness for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

		Chironomidae	Oligochaete	% of Total Organisms
Kingman				
	Ekman	13,706 (48%)	13,104 (46%)	94%
	D-net	7,020 (54%)	4,532 (35%)	89%
	H-D	1,603 (60%)	693 (26%)	86%
Kenilworth				
	Ekman	7,891 (35%)	10,972 (49%)	84%
	D-net	4,249 (39%)	4,321 (40%)	79%
	H-D	206 (20%)	376 (37%)	57%
Dueling Creek				
	Ekman	3,401 (32%)	4,735 (44%)	76%
	D-net	2,113 (45%)	1,658 (35%)	80%
	H-D	329 (26%)	563 (44%)	70%
Patuxent				
	Ekman	1,661 (33%)	1,101 (22%)	55%
	D-net	1,076 (29%)	456 (12%)	41%
	H-D	291 (18%)	99 (6%)	24%

Table 5: Number of individual organisms collected by each sampler for the 2002-2004 study. Percentages indicate total for each dominant taxa and percent total for entire study.

A comparison of the individual taxa collected by the three samplers over the course of the study can be seen in *Table 6*. The numbers shown are individual counts for each taxonomic group and counts by sampling site. The Ekman sampler collected almost 50% more individuals than the D-net sampler and 17% more than the H-Ds. However, the three samplers collected representatives of the same twelve taxonomic groups. These twelve taxonomic groups were: order Ephemeroptera, order Odanata, order Hemiptera, order Trichoptera, order Coleoptera, order Dipteran, order Amphipoda, order Isopoda, class Gastropoda, class Bivalvia, class Oligochaeta, and class Hirudinea. However, a few individuals only represented some of these groups over the course of the study. The greatest individual numbers were found in the Dipterans, and Oligochaetes.

Table 6: Summation of macroinvertebrate data from the three samplers for the 2002-2004 study

Ekman taxa	**#'s**
Caenidae	21
Aeshnidae	1
Libellulidae/Corduliidae	35
Gomphidae	5
Coenagrionidae	100
Belostomatidae	4
Polycentropodidae	1
Elmidae	4
Hydrophilidae	14
Syrphidae	43
Dolichopodidae	84
Stratiomydae	20
Tabanidae	62
Ceratopogonidae	5470
Chironomidae	26659
Psychodidae	49
Tipulidae	196
Amphipoda	351
Isopoda	580
Hydrobiidae	17
Lymnaeidae	46
Physidae	86
Planorbidae	139
Corbiculidae	86
Sphaeriidae	2208
Unionidae	11
Oligochaeta	29918
Megadrili sp.	89
Branchiura sp.	336
Erpobdellidae	21
Glossiphoniidae	182
Total	66838

marsh	total
KG1	16688
KG2	12036
KW1	11023
KW2	11378
DC	10763
PX	4981

Dnet taxa	**#'s**
Caenidae	109
Aeshnidae	4
Libellulidae/Corduliidae	58
Gomphidae	8
Coenagrionidae	459
Belostomatidae	32
Polycentropodidae	5
Elmidae	3
Hydrophilidae	9
Syrphidae	44
Dolichopodidae	33
Stratiomyidae	5
Tabanidae	7
Ceratopogonidae	1600
Chironomidae	14458
Psychodidae	4
Tipulidae	44
Amphipoda	406
Isopoda	553
Hydrobiidae	47
Lymnaeidae	68
Physidae	260
Planorbidae	236
Corbiculidae	90
Sphaeriidae	2425
Unionidae	6
Oligochaeta	10967
Megadrili sp.	14
Branchiura sp.	53
Erpobdellidae	2
Glossiphoniidae	49
Total	32058

marsh	total
KG1	7588
KG2	5394
KW1	6273
KW2	4528
DC	4678
PX	3706

HD taxa	**#'s**
Caenidae	2
Libellulidae/Corduliidae	5
Coenagrionidae	40
Belostomatidae	5
Polycentropodidae	105
Hydrophilidae	8
Dolichopodidae	11
Stratiomyidae	4
Tabanidae	2
Ceratopogonidae	24
Chironomidae	4201
Psychodidae	2
Tipulidae	4
Amphipoda	2064
Isopoda	651
Hydrobiidae	2
Lymnaeidae	8
Physidae	356
Planorbidae	178
Corbiculidae	3
Sphaeriidae	270
Oligochaeta	2979
Branchiura sp.	1
Erpobdellidae	13
Glossiphoniidae	237
Total	11175

marsh	total
KG1	2154
KG2	2961
KW1	1545
KW2	1617
DC	1247
PX	1651

Documentation of Seasonal and Interannual Patterns

Overall

Year to year and seasonal patterns for Ekman samples showed some interesting results. *Figure 10* represents the mean Ekman numbers for Kingman Area 1 and 2 along with Kenilworth Area 1 and 2. Both showed significant seasonal variation with no year to year variation. However, there were a few significant differences in the Kingman Ekman data. In winter of 2002, Kingman Area 2 was only sampled four times because of weather and ice. This could explain the significant difference ($p < 0.05$) between Kingman Area 1 and Area 2 winter 2002 samples. Fall 2003 samples were also significantly different ($p < 0.05$) for Kingman marshes. Besides winter 2002 and fall 2003 samples, all other sampling dates showed no significant difference year to year or between Kingman Area 1 and Area 2.

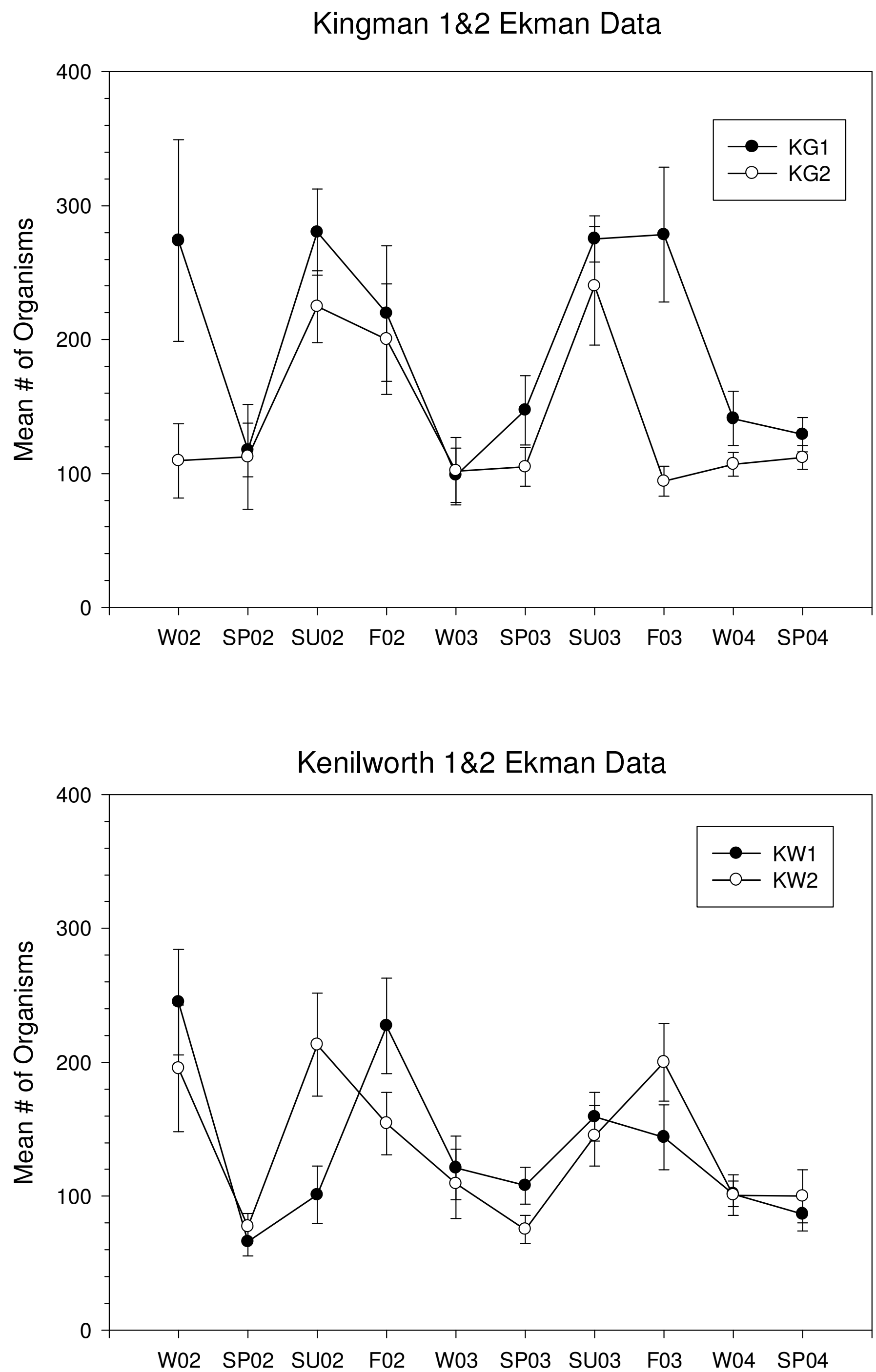

Figure 10: Mean Ekman numbers of organisms for Kingman Marsh 1 & 2 and Kenilworth Marsh 1 & 2 for the 2002-2004 study.

Kenilworth marshes (MF 1 and MF 2) had similar patterns to the Kingman marshes. Year to year and seasonally there were no significant differences. Both Kenilworth marshes followed the same pattern seasonally and year to year as did the Kingman marshes, which allowed the combination of the two marsh areas into one data set representing each respected marsh. Therefore Ekman data from Kingman Area 1 and Area 2 were combined to represent Kingman Marsh, and Kenilworth MF 1 and MF 2 were combined to represent Kenilworth Marsh. There was also no significant differences within years, for example there were significantly greater abundances (mean $\#/m^2$) observed in summer and fall than winter or spring ($p<0.05$)(*Figure 11*).

Individual Taxa

This pattern of significantly higher abundances in summer and fall than winter or spring was observed in individual taxa as well. *Figure 12* shows this pattern in the Chironomidae Ekman data when combined from all marsh locations for the entire study. Summer and fall were significantly higher ($p<0.05$) than winter and spring, with summer having the highest abundance values. The Oligochaetes did not show this similar seasonal pattern and were basically abundant through all seasons with a slight nonsignificant decrease in spring.

A detailed look into this Chironomidae seasonal pattern can be seen in *Figure 13*. All marsh sites had higher abundances in summer and fall except for Patuxent Marsh in

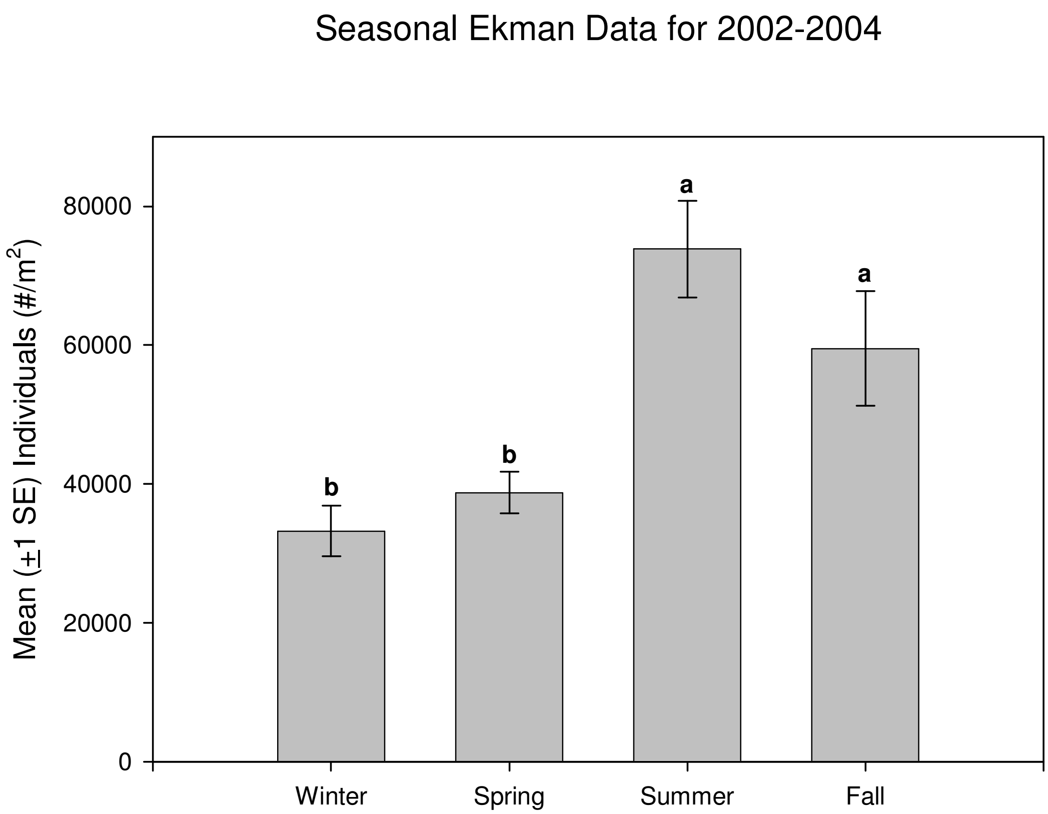

Figure 11: Mean (± 1 SE) seasonal macroinvertebrate density for the combined marshes during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to determine where significant differences occurred.

Seasonal Ekman Data

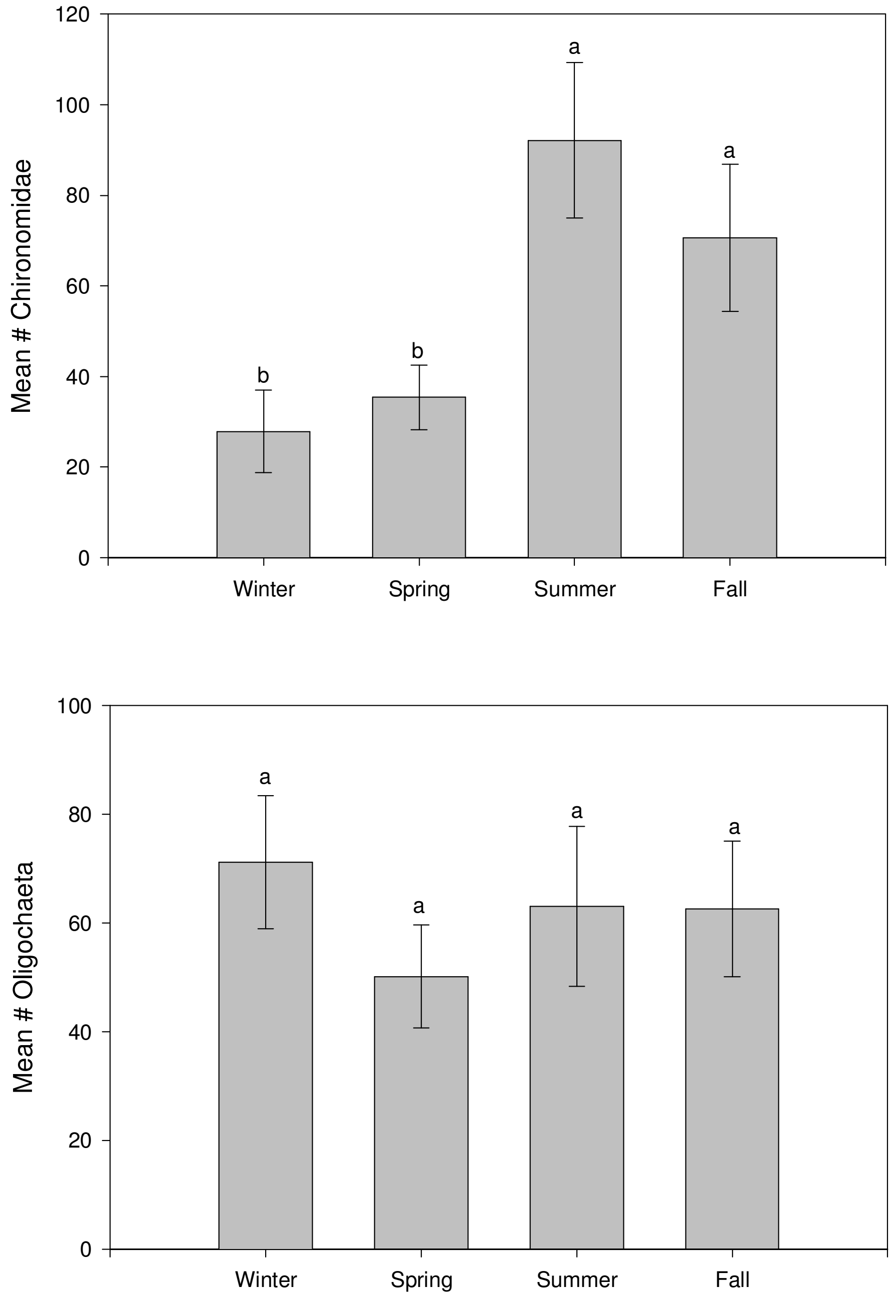

Figure 12: Mean (± 1 SE) chironomidae and oligochaeta seasonal macroinvertebrate density for the combined marshes during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to determine where significant differences occurred.

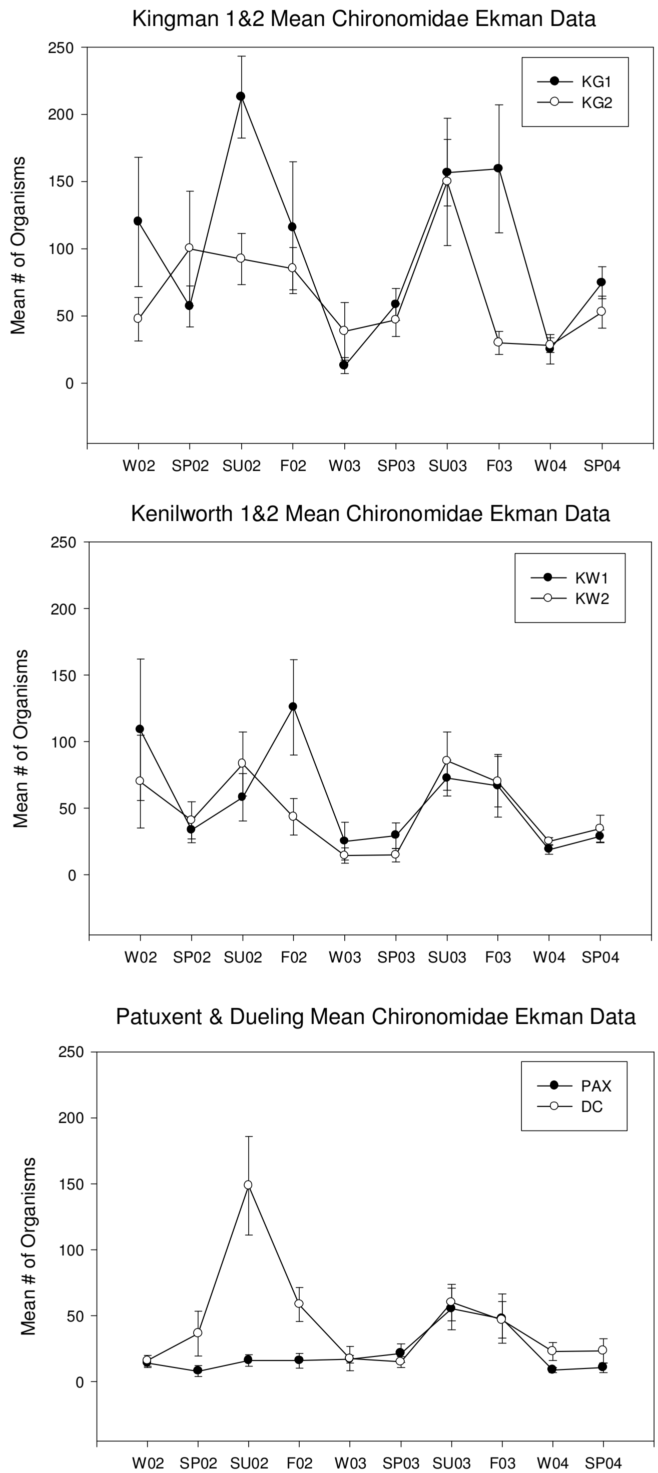

Figure 13: Mean chironomidae Ekman data for the six marsh sites.

2002. Interestingly in 2003 and 2004 abundances followed a similar pattern at all locations even both reference sites. Overall Chironomidae abundances were higher in 2002 for all sites except Patuxent and Kingman Area 1.

Between Site Comparisons

Overall

Since the Ekman sampling method was used at all sampling locations and was the most quantitative, much of the analysis is based on those data. Table 7 gives an over view of the six marsh sites in respect to density, taxa richness, Shannon Index, season and the two overall taxa for the entire study. There was little significant difference when comparing the Ekman data for the two Kingman Marsh sites and the two Kenilworth Marsh sites for the entire study (*Figure 10*). Because of this fact, the data from Kingman Area 1 and 2 as well as Kenilworth MF 1 and 2 were combined and labeled simply as Kingman and Kenilworth. Since there was little significant difference in the data from year-to-year, counts and percent total numbers were combined for the entire study (2002-2004) for each marsh. This was a very important factor in the analyses for this study. The lack of significant trends or year-to-year differences allowed the data for most of the comparison analyses to be combined which reduced variation and permitted stronger statistical results.

Based on mean abundance (#/m^2) over the course of the study, Kingman had a significantly higher abundance of macroinvertebrate organisms (7,500/m^2) than the other three marsh sites ($p<0.05$) (*Figure 14*). Kenilworth and Dueling were similar in

Table 7. Overview of the six marsh sites showing Ekman sampler data.

Kingman area 1

Season	Density (#/m2)	Taxa Richness	Shannon Index	Chironomidae	Oligochaeta
W02	11,359	5	0.8	5,111 (45%)	5,452 (48%)
SP02	6,197	3.1	0.6	2,478 (40%)	3,594 (58%)
SU02	12,114	3.6	0.6	9,206 (76%)	2,543 (21%)
F02	9,507	4.1	0.8	5,038 (53%)	3,802 (40%)
W03	4,265	4.3	0.5	383 (9%)	3,582 (84%)
SP03	6,380	3.5	0.7	2,233 (35%)	3,891 (61%)
SU03	11,917	4.1	0.7	6,077 (51%)	4,647 (39%)
F03	12,057	5.1	0.7	6,872 (57%)	3,617 (30%)
W04	6,105	3.3	0.5	1,098 (18%)	4,295 (72%)
SP04	5,586	2.6	0.6	2,513 (45%)	2,904 (52%)
AVG	**8,549**	**3.9**	**0.7**	**43%**	**51%**

Kenilworth area 1

Season	Density (#/m2)	Taxa Richness	Shannon Index	Chironomidae	Oligochaeta
W02	10,600	4	0.7	4,664 (44%)	4,664 (44%)
SP02	3,498	4.2	0.9	1,294 (37%)	1,749 (50%)
SU02	4,359	5.4	1.2	2,223 (51%)	1,089 (25%)
F02	9,839	4.8	1.1	5,411 (55%)	2,361 (24%)
W03	5,247	4.8	0.9	734 (14%)	3,358 (64%)
SP03	4,667	5.2	0.9	1,260 (27%)	1,680 (36%)
SU03	6,894	5	1	2,826 (41%)	3,102 (45%)
F03	6,230	5	1	2,865 (46%)	2,367 (38%)
W04	4,397	4	0.7	483 (11%)	3,297 (75%)
SP04	3,748	4.3	1	1,236 (33%)	2,061 (55%)
AVG	**5,948**	**4.7**	**0.9**	**36%**	**46%**

Kingman area 2

Season	Density (#/m2)	Taxa Richness	Shannon Index	Chironomidae	Oligochaeta
W02	4,741	3.3	0.7	2,038 (43%)	2,607 (55%)
SP02	5,951	2.4	0.6	3,392 (57%)	1,428 (24%)
SU02	9,723	3.3	0.6	3,986 (41%)	5,444 (56%)
F02	8,684	3.5	0.8	3,647 (42%)	3,472 (40%)
W03	4,409	3.3	0.7	1,675 (38%)	2,469 (56%)
SP03	4,547	3.4	0.7	2,000 (44%)	2,318 (51%)
SU03	10,416	4	0.7	6,457 (62%)	3,437 (33%)
F03	4,075	3.4	0.7	1,304 (32%)	2,608 (64%)
W04	4,628	3.2	0.5	925 (20%)	3,563 (77%)
SP04	4,804	3.2	0.7	2,017 (42%)	2,498 (52%)
AVG	**6,198**	**3.3**	**0.7**	**42%**	**51%**

Kenilworth area 2

Season	Density (#/m2)	Taxa Richness	Shannon Index	Chironomidae	Oligochaeta
W02	8,452	5.4	0.8	2,451 (29%)	5,324 (63%)
SP02	4,089	4.5	1	1,594 (39%)	1,717 (42%)
SU02	9,228	5.6	1.1	3,229 (35%)	4,614 (50%)
F02	6,673	5	0.9	1,668 (25%)	3,803 (57%)
W03	4,727	5	0.9	425 (9%)	3,450 (73%)
SP03	3,252	5.1	0.9	650 (20%)	2,113 (65%)
SU03	6,283	5.1	0.9	3,267 (52%)	2,136 (34%)
F03	8,660	5.6	1	3,031 (35%)	4,589 (53%)
W04	4,364	3.4	0.6	741 (17%)	3,316 (76%)
SP04	4,330	3.7	0.8	1,342 (31%)	2,598 (60%)
AVG	**6,006**	**4.8**	**0.9**	**29%**	**57%**

Patuxent marsh

Season	Density (#/m2)	Taxa Richness	Shannon Index	Chironomidae	Oligochaeta
W02	2,576	7.3	1.6	618 (24%)	901 (35%)
SP02	2,473	6.2	1.5	346 (14%)	717 (29%)
SU02	1,554	4.6	1.2	621 (40%)	357 (23%)
F02	3,738	6.4	1.4	560 (15%)	672 (18%)
W03	2,735	6.6	1.3	382 (14%)	683 (25%)
SP03	2,444	5.2	1.2	928 (38%)	293 (12%)
SU03	4,994	6.2	1.1	2,397 (48%)	948 (19%)
F03	3,276	6.5	1.2	1,834 (56%)	327 (10%)
W04	1,232	4.6	1.1	308 (25%)	628 (51%)
SP04	1,203	3.8	1.1	469 (39%)	481 (40%)
AVG	**2,623**	**5.7**	**1.3**	**31%**	**26%**

Dueling Creek marsh

Season	Density (#/m2)	Taxa Richness	Shannon Index	Chironomidae	Oligochaeta
W02	4,027	4.5	0.9	563 (14%)	2,859 (71%)
SP02	6,048	4.6	0.9	1,391 (23%)	2,600 (43%)
SU02	8,405	4.8	1	4,958 (59%)	2,353 (28%)
F02	9,093	4	1	2,546 (28%)	2,546 (28%)
W03	4,864	4.6	1	632 (13%)	2,480 (51%)
SP03	4,037	3.6	0.8	645 (16%)	1,493 (37%)
SU03	4,927	3.7	0.8	2,611 (53%)	1,970 (40%)
F03	5,056	3.6	0.9	1,820 (36%)	2,426 (48%)
W04	4,032	3.8	0.6	766 (19%)	2,943 (73%)
SP04	4,224	3.7	0.7	802 (19%)	2,956 (70%)
AVG	**5,471**	**4.1**	**0.9**	**28%**	**49%**

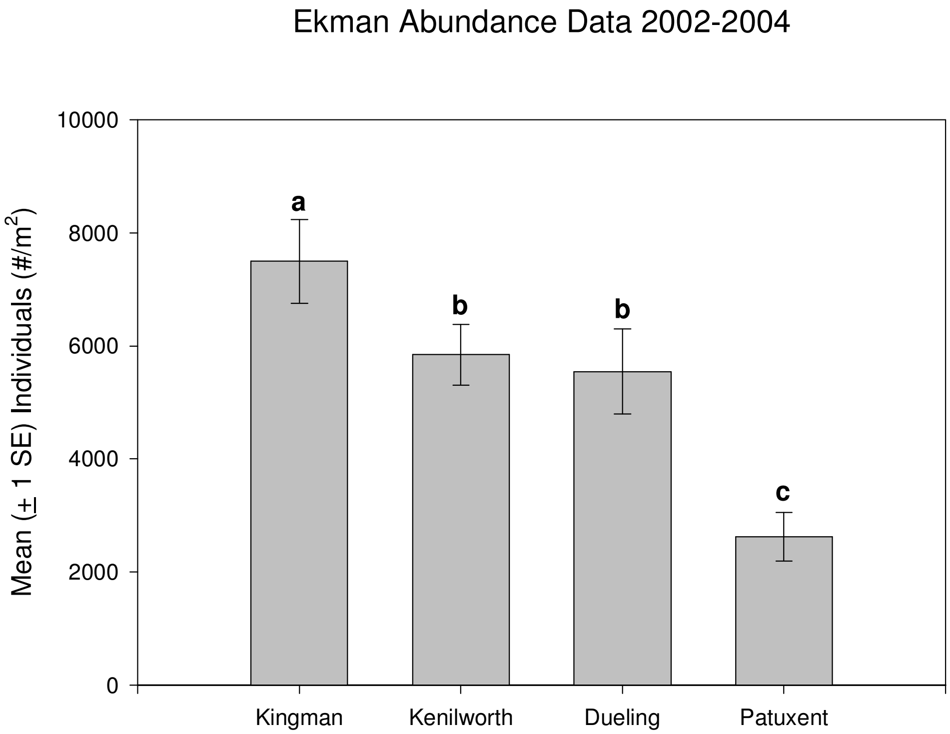

Figure 14: Mean (±1 SE) macroinvertebrate density for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

abundance, but significantly higher than Patuxent ($p<0.05$). All three urban Anacostia sites had significantly greater abundance than the more rural Patuxent Marsh ($p<0.05$). Thus the references sites, urban Anacostia Dueling Creek and rural Patuxent, were also significantly different from each other. However, the sites with the higher abundances also had the lowest taxa richness (*Figure 15*). The more rural Patuxent had significantly higher taxa richness than all sites, and Kenilworth was greater than Kingman and Dueling Creek, which were similar with the lowest taxa richness ($p<0.05$). Using Shannon's Index of Diversity, we determined that Patuxent Marsh had a greater diversity and evenness than the other sites (*Figure 16*). Kingman had the lowest score, with Kenilworth and Dueling showing similar scores. This data derived from the Ekman sampler was similar to that displayed from all the sampling methods combined as can be derived from *Table 3.*

Mean pollution tolerance values over all Ekman samples from each site are shown in *Figure 17*. Tolerance values were taken from updated MBSS Technical Report of 2005 (Boward et al. 2005). Tolerance values were calculated for lowest taxon represented in each marsh (i.e., family or genera). Importantly, Kingman Marsh was significantly different from the other wetlands ($p<0.05$), and there were no significant differences between Kenilworth, Dueling Creek and Patuxent Marshes. Patuxent Marsh did have the lowest pollution tolerance score, but was not low enough to be significant. However, when compared on a watershed level, the macroinvertebrate tolerance levels of the Anacostia wetlands were significantly different from Patuxent ($p<0.01$) (*Figure 18*). This difference is due to the abundance of chironomids and oligochaetes at Kingman.

Figure 15: Mean (±1 SE) taxa richness for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

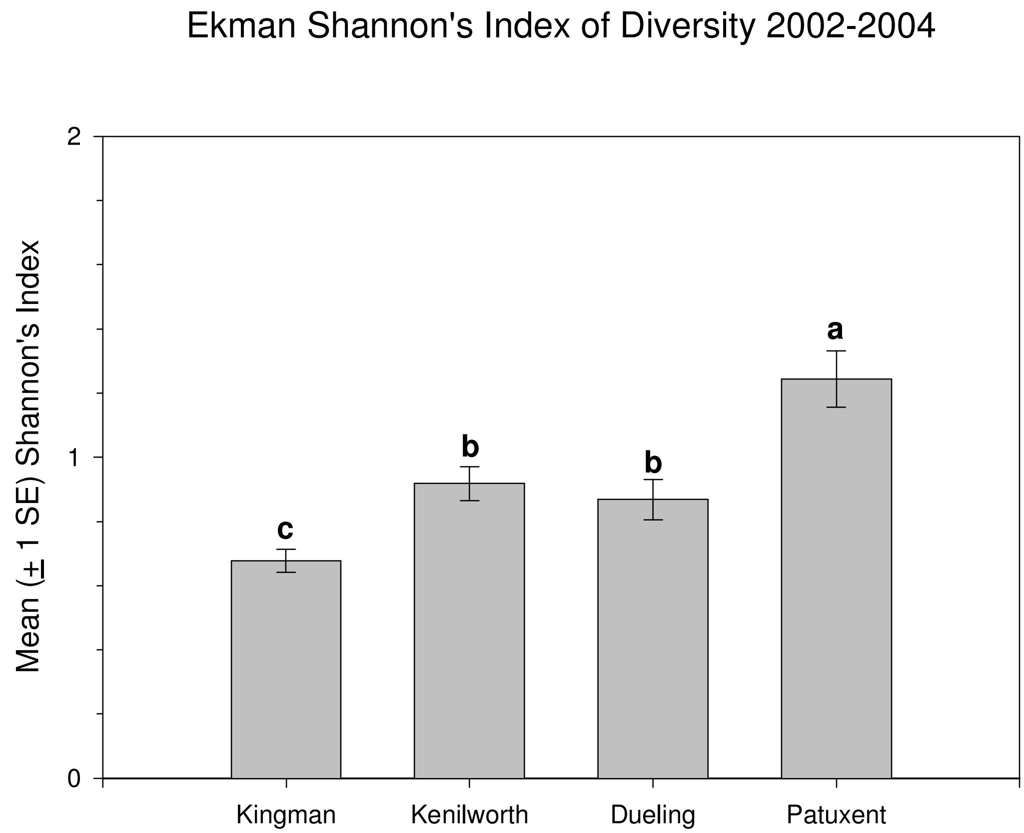

Figure 16: Mean (±1 SE) Shannon's Index for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred

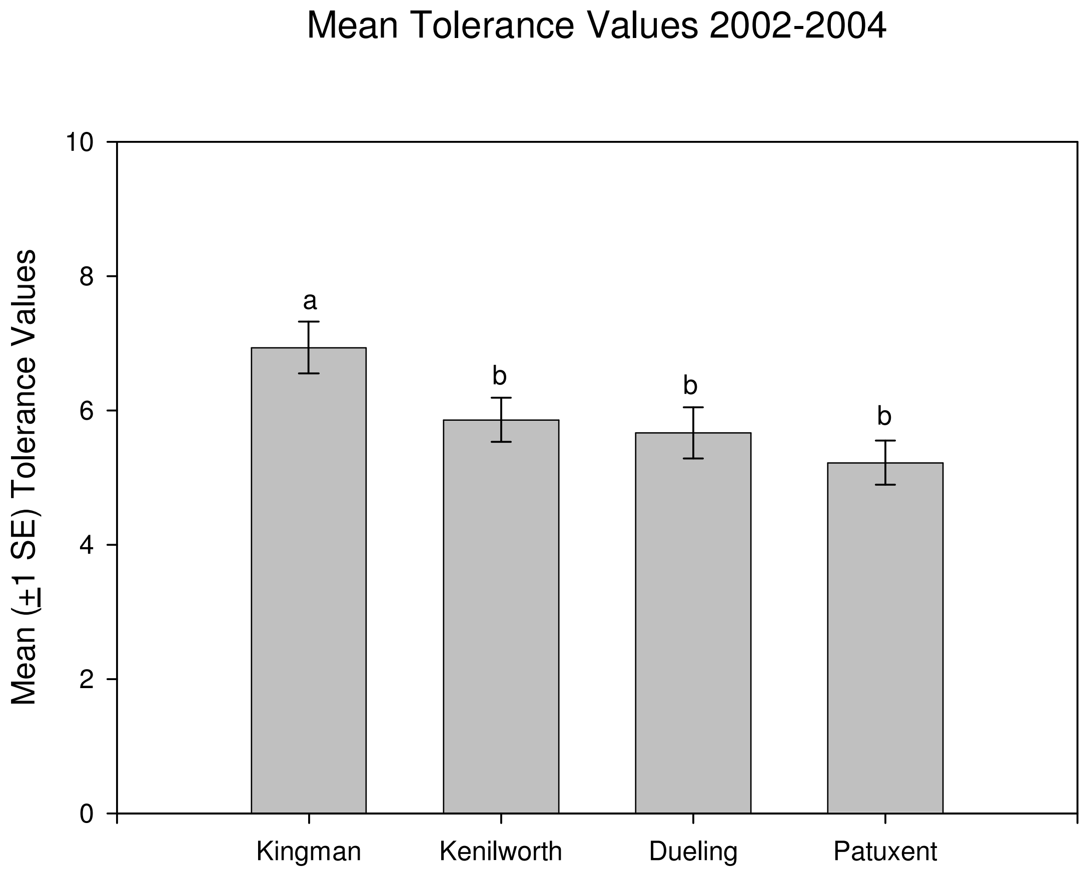

Figure 17: Mean (± 1 SE) tolerance values for each marsh for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

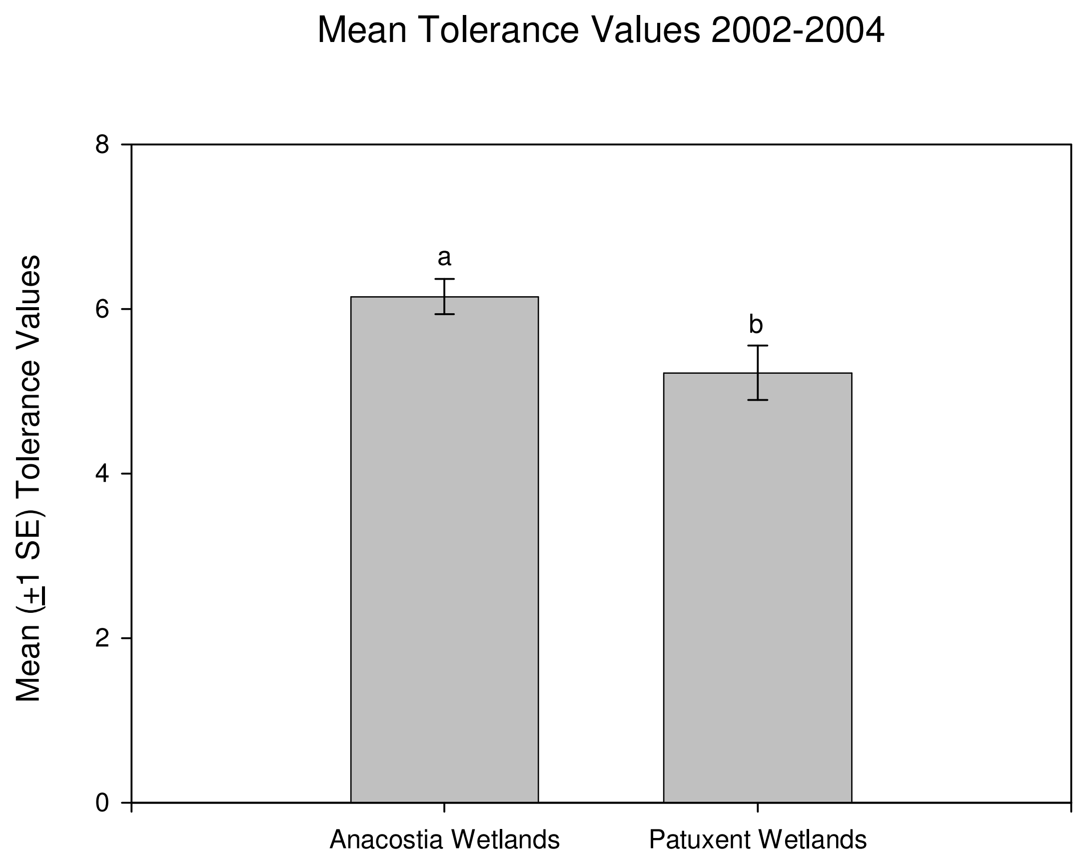

Figure 18: Mean (± 1 SE) tolerance values for comparison of the Anacostia Wetlands to the Patuxent Wetlands for the 2002-2004 study. Means sharing the same letter are not significantly different.

Individual Taxa

The top four taxa with respect to abundance represented in the data was calculated in *Figure 19*. The family Chironomidae and class Oligochaeta made up the top two taxa at all four marshes. Another family from the dipterans, Ceratopogonidae and the family Sphaeriidae (fingernail clams) made up the other two. At Kingman, Kenilworth, and Dueling these four taxa made up the majority (99%, 96%, and 98%, respectively) of the total. At Patuxent these four taxa groups only made up 77% of the total. At Kingman and Kenilworth the preponderance of benthic organisms encountered were either Chironomidae or Oligochaeta.

When looking at only the Chironomidae data from the study, some of the same patterns emerged (*Figure 20*). Kingman had significantly greater chironomid density than the other three sites; Patuxent was significantly lower than the other marshes, while Kenilworth and Dueling were similar to each other yet differed from the other two wetlands ($p<0.05$). The Oligochaeta data followed the same pattern as the family Chironomidae, with Kingman significantly greater and Patuxent less dense than the other marshes (*Figure 21*).

The family Ceratopogonidae in the Dipteran order showed some between site patterns. Abundances peaked in the fall of 2002 for all marsh sites however the same peak was not seen in 2003 (*Figure 22)*. Dueling Creek had the highest abundance of any marsh site with over 2,000 individuals collected representing over 19% of the total

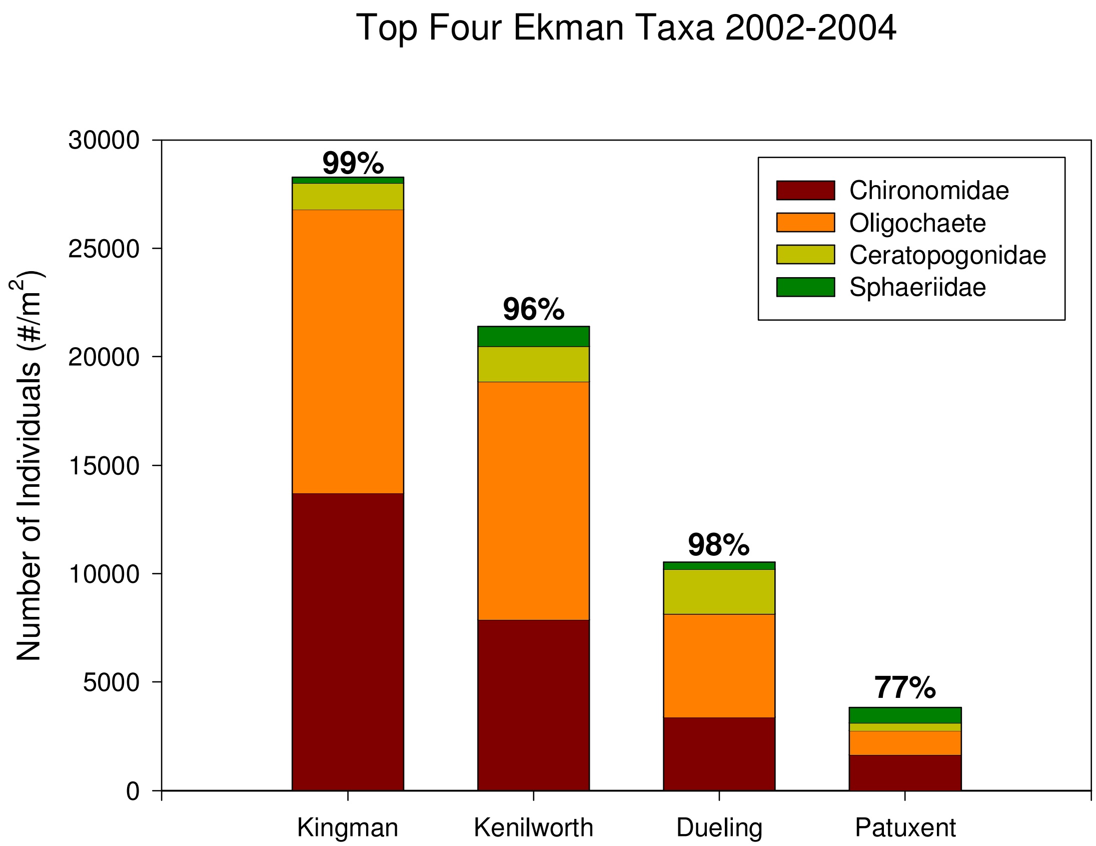

Figure 19: Density of the top four taxa of each marsh during the 2002-2004 study

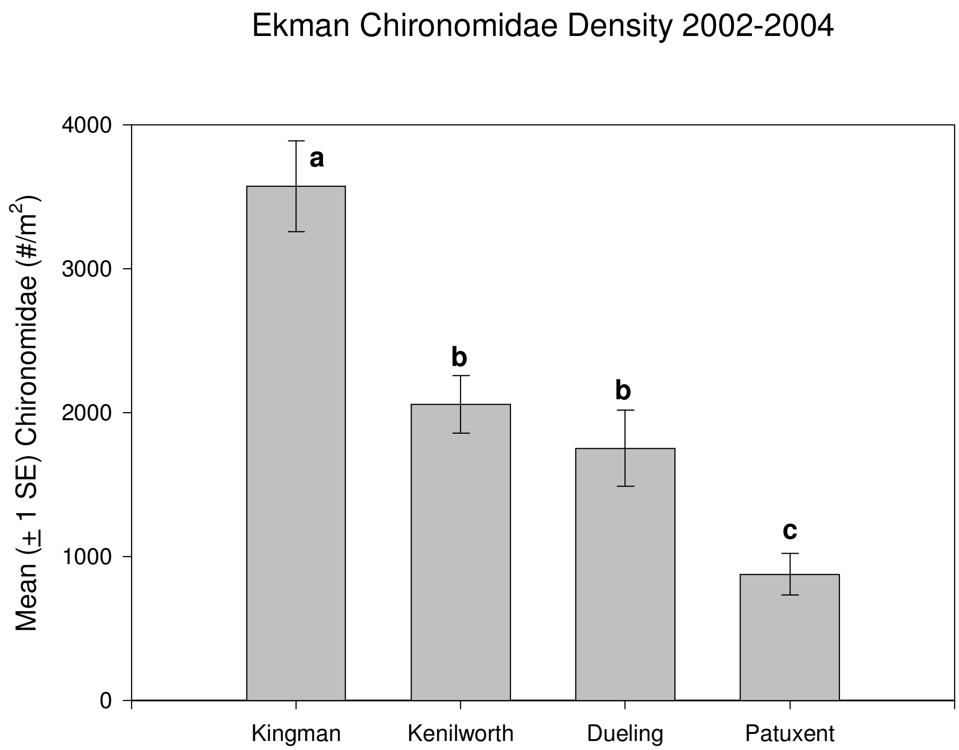

Figure 20: Mean (± 1 SE) chironomidae density for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

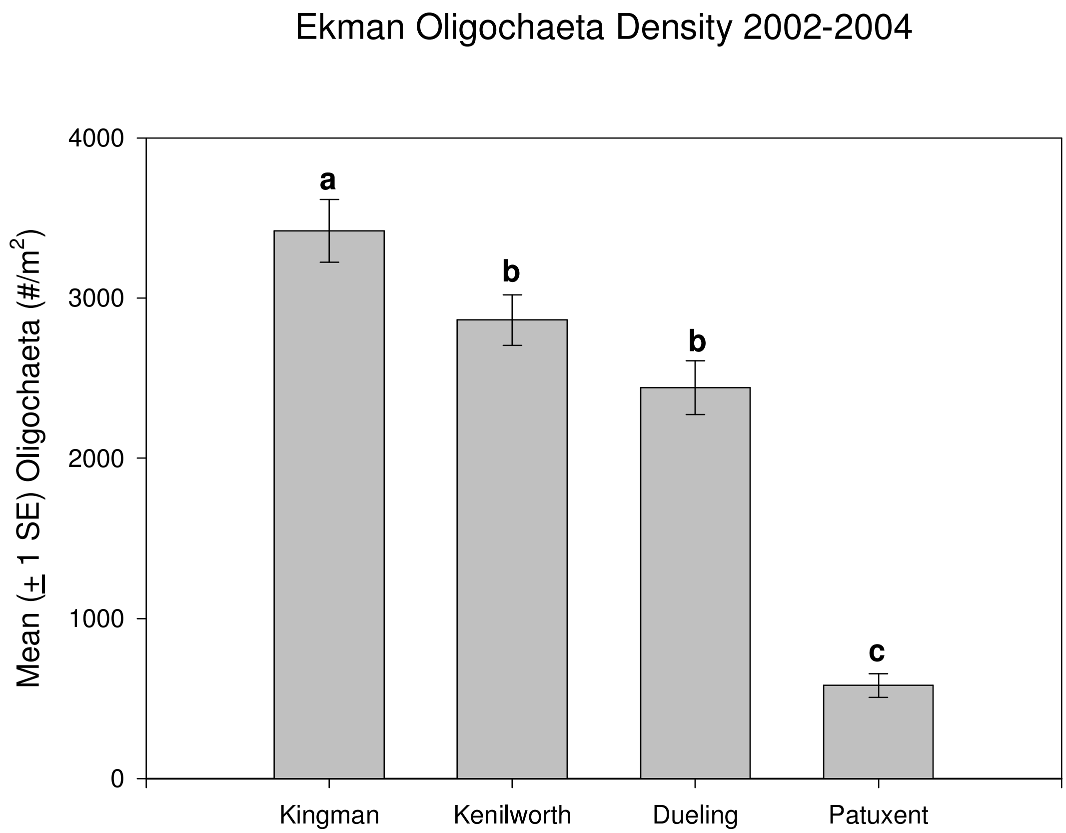

Figure 21: Mean (± 1 SE) oligochaete density for each marsh during the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

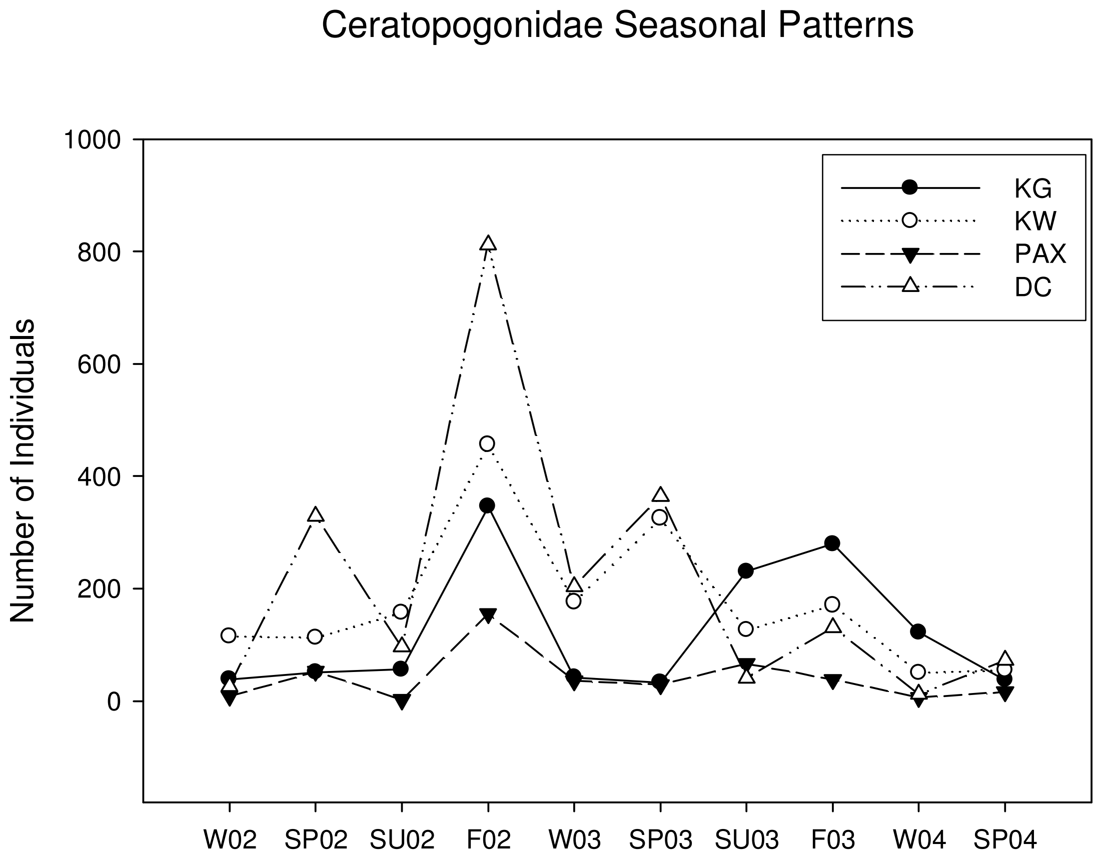

Figure 22: Ceratopogonidae Ekman counts for the four marsh sites showing seasonal and year to year patterns.

number of organisms (*Table 3*). Dueling Creek had peak abundances of Ceratopogonidae in spring and fall of 2002 and 2003. The Anacostia wetlands had much higher abundances than the external reference site at Patuxent, which only showed a slight increase in Ceratopogonidae abundance in the fall of 2002.

Within Site Comparisons

Overall

A comparison of the three vegetated zones (high, middle, and low marsh) was performed to determine if the data could be pooled as one vegetated zone. Kingman Marsh data showed similar patterns to the seasonal data with high abundances in summer and fall for all three zones (*Figure 23*). Overall the three vegetated zones were very similar with no significant difference between groups (p=0.5). Kenilworth Marsh data did not have as high abundances as Kingman Marsh but showed a similar pattern with no significant difference between groups (p=0.08). Both reference sites had far less macroinvertebrate abundance for all three vegetated zones when compared to Kingman and Kenilworth Marshes.

A comparison of vegetated to un-vegetated sites was performed in order to get an idea of the effect that vegetation and/or elevation might have on macroinvertebrate populations. Vegetated sites consisted of high, middle and low marsh, whereas un-vegetated sites were pool, mudflat and channel. Macroinvertebrate abundance was similar for Kingman between vegetated and un-vegetated sites. However, Kenilworth

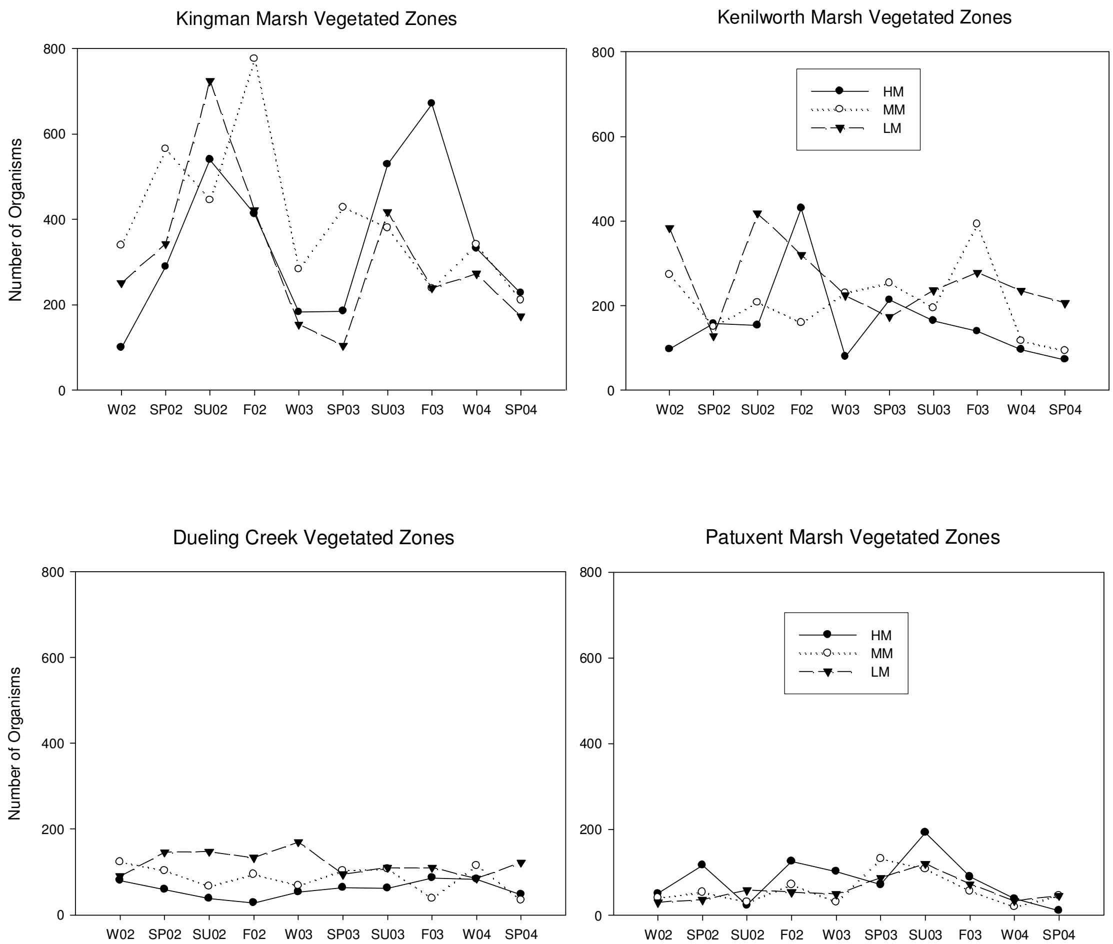

Figure 23: Macroinvertebrate counts for the Ekman sampler compared between the three marsh zones (high, middle and low marsh) for each of the four marsh sites.

and Dueling had similar comparisons to each other with un-vegetated sites supporting greater abundance than vegetated (*Figure 24a*). When looking at taxa richness (*Figure 24b*) vegetated sites had a higher richness than un-vegetated sites for all the Anacostia wetland locations, but not Patuxent Marsh.

A comparison of the habitat units established by marsh elevation (high, middle, and low marsh) to those below 1.5' NGVD '29 (pool, mudflat, and channel) for all marshes can be seen in *Figure 25*. Macroinvertebrate abundance was significantly higher for mudflat and channel than for the other habitats with high, middle and low marsh similar to pool habitats (*Figure 25a*). The six habitat units were represented by the follow number of Ekman samples: high marsh n=56, middle marsh n=60, low marsh n=59, pool n=103, mudflat n=108, and tidal gut n=112. Taxa richness was significantly higher for the vegetated zones (high, middle and low marsh) than for those sites below 1.5' NGVD '29 (*Figure 25b*).

Individual Taxa

Since the dominant taxa for the majority of samples belonged to chironomids and oligochaetes (55% to 94% of the total organisms collected) it was difficult to show any pattern of other organisms because they were usually less than 1% of the total. However, Patuxent Marsh had the greatest diversity of macroinvertebrates and some interesting patterns emerged from the individual taxa. The two crustacean representatives,

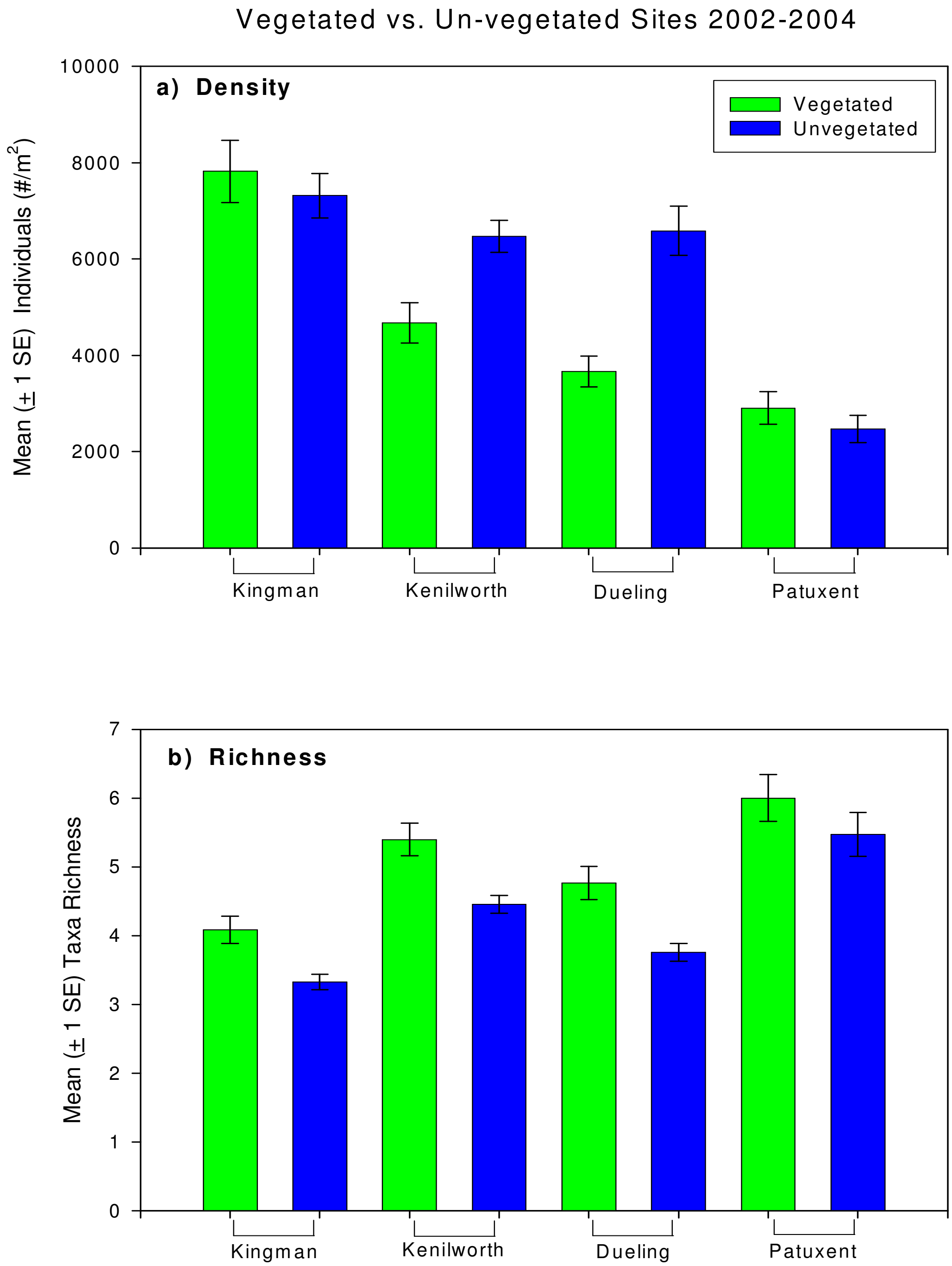

Figure 24: Mean (+ 1 SE) density and taxa richness for each marsh comparing vegetated to un-vegetated sites for the 2002-2004 study.

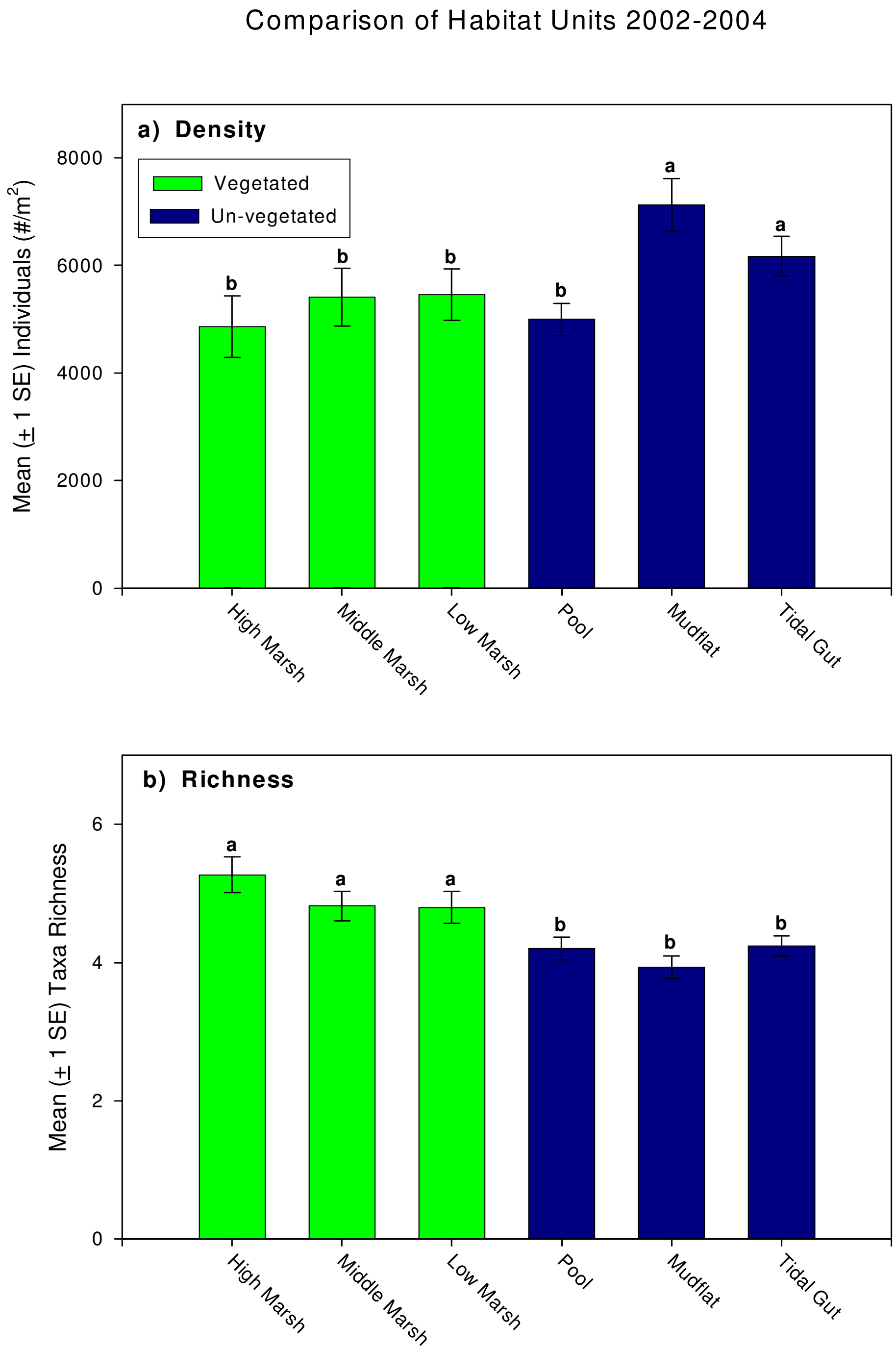

Figure 25: Mean (+ 1 SE) density and taxa richness for habitat units combined from all marsh locations for the 2002-2004 study. Means sharing the same letter are not significantly different. A Tukey's post-hoc test was used to detect where significant differences occurred.

amphipods (*Gammarus sp.*) and isopods (*Asellus sp.*) showed high abundance peaks and then a sharp decline (*Figure 26*) for both 2002 and 2003 samples. The two mollusk representatives, the gastropods (snails) and the sphaerids (fingernail clams) had a different pattern. The fingernail clams were on the increase throughout the samples in 2002 and peaked in the fall. After the fall of 2002 they were on the decline and by the fall of 2003 their numbers had disappeared. The gastropods were somewhat consistent in the samples with a spike in abundance in the summer of 2003.

The three groups with the highest abundances at Patuxent Marsh were the chironomids, oligochaetes and the ceratopogonids. These groups showed a similar pattern in 2002, but after the winter of 2003 the chironomid abundance sharply peaked while the ceratopogonids declined (*Figure 26*). The oligochaetes had a mean abundance of 110 individuals and nearly doubled that in the summer of 2003.

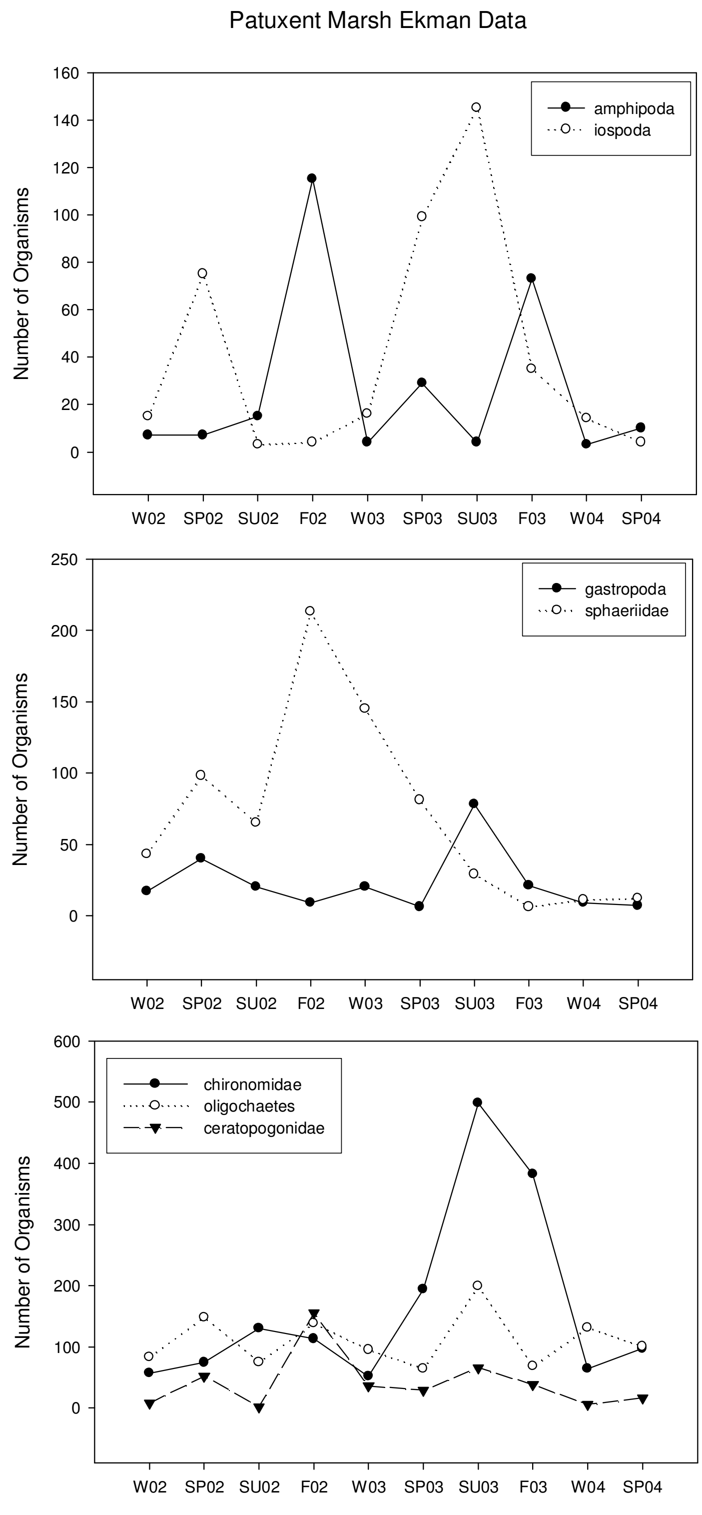

Figure 26: Comparison of six taxa groups from the Patuxent Marsh using Ekman data

DISCUSSION

Some significant differences were found among the study sites that could relate to disturbance and restoration regimes. Taxa in the Anacostia reconstructed wetlands (Kingman, Kenilworth and the internal reference site Dueling Creek) had macroinvertebrate abundances significantly greater than the more rural wetland at Patuxent, while taxonomic diversity was significantly greater at Patuxent. This result is largely due to the large populations of chironomids and oligochaetes occupying the unvegetated mudflats of the most recently reconstructed wetlands of the Anacostia where more pollution intolerant taxa will not thrive.

On the other hand seasonal patterns on a year to year basis were similar for each marsh, regardless of differences in age, urban vs. rural, reconstructed or remnant wetland, and within any year abundance was greater in the warmer seasons, which promoted growth and reproduction (Yozzo and Smith 1995). There were no seasonal patterns based on tidal elevation, though wetter periods would raise water levels and yield longer periods of inundation (Neckles 1990, Hammerschlag et al. 2006).

There are additional factors involved at Kingman that are significantly impacting the macroinvertebrate community. Overabundant resident Canada geese have grazed the marsh causing major loss of vegetation and community richness at Kingman Marsh (personal observations and Hammerschlag et al. 2006). This has created open areas in the marsh, which in turn has led to sediment scouring. Such erosional substrate is ideal for chironomids and oligochaetes as seen in the Kingman Ekman data (*Figures 20 & 21*). Erosional substrates also support a greater abundance of benthic invertebrates (McIvor and Odum 1988), which could explain the significantly higher abundance at Kingman (*Figure 14*). However, erosional substrates are not ideal conditions for most macroinvertebrates, and therefore suppress the overall taxa richness of the marsh (*Figures 15 & 16*). The macroinvertebrate community present at Kingman Marsh is a good indication of a disturbed, somewhat polluted area being composed of the extremely large concentrations of pollution tolerant chironomid and oligochaete families but with low taxa richness and low Shannon's Index score.

The age of the marsh (i.e., since the year of reconstruction, Kenilworth 1993 and Kingman 2000) may have had some influence on the macroinvertebrate communities; however, goose herbivory at Kingman likely confounds interpretation of our results. It is well documented that macroinvertebrates can quickly colonize newly created marsh habitats (Streever et al. 1996, Diaz and Boesch 1977, Diaz et al. 1978, Diaz 1989, Stanczak and Keiper 2004). The higher abundance and lower taxa richness at Kingman may be a result of an erosional substrate due to lack of vegetation. Without the disturbance of the Canada geese, Kingman and Kenilworth might have been more similar. The age factor may have some influence on the taxa richness of the marsh, which is evident at Kenilworth. Kenilworth Marsh, which has had a greater opportunity to develop, compares favorably with the Anacostia reference marsh at Dueling Creek in terms of macroinvertebrate populations, but differs from the more disturbed and younger Kingman Marsh. A well-established marsh with diverse vegetation provides multiple niches for benthic and epiphytic aquatic invertebrates (Diaz and Boesch 1977), which would manifest itself in the increased richness and diversity.

Kenilworth Marsh, which was reconstructed in 1993 and thus had a longer period than Kingman Marsh (reconstructed in 2000) to restore, was also less disturbed by geese than Kingman Marsh. Kenilworth in most of the macroinvertebrate comparisons was similar to the Anacostia reference site at Dueling Creek, but both Kenilworth and Dueling were different from Kingman. One case where Kenilworth was significantly and perhaps unexpectedly different from Dueling was where it had a significantly greater taxa richness ($p<0.05$) (*Figure 15*). Thus the macroinvertebrate populations seemed to be a good indicator of wetland status with the disturbed urban Kingman Marsh differing from the more intact or older restored Anacostia marshes and the more rural Patuxent Marsh. That Kenilworth Marsh has many similarities to the reference Anacostia marsh at Dueling with respect to the macroinvertebrate community suggests the reconstructed Kenilworth wetland is now (10-12 years post reconstruction) becoming more like a well-established Anacostia wetland.

Macroinvertebrate diversity and abundance are often higher in vegetated than in bare bottomed habitats (Olson et al. 1995, Yozzo and Smith 1995, Batzer and Wissinger 1996). The manipulation of vegetation structure is a common practice in managed wetlands and studies have provided experimental evidence that vegetation structure is an important causal factor that affects invertebrate composition, diversity, and abundance (Kirkman and Sharitz 1994, Foster and Procter 1995). A variety of mechanisms have been offered to explain the positive relationship between vegetation and macroinvertebrate diversity and abundance, including that vegetation provides (1) greater surface area and thus more habitat; (2) greater surface area, hence more epiphytic nutrition for grazers; (3) refuge from predators; and (4) more types of spatial niches (Heck and Crowder 1991, Jordan et al. 1996). The significantly higher taxa richness of Kenilworth Marsh in comparison to Kingman and Dueling can be attributed to greater presence of vegetation at Kenilworth (*Figure 15*) (Hammerschlag et al. 2006).

Dueling Creek (internal reference site) and Kenilworth were similar in all comparisons (differences with Kingman are explained above). However, the external reference site at Patuxent was significantly different in most aspects of the benthic community. One key difference is the presence of submerged aquatic vegetation (SAV) at Patuxent Marsh. Water quality, especially clarity (turbidity) is influential on the success of SAV. Since turbidity is generally high in the Anacostia, SAV would have a difficult time establishing itself in the marshes there. SAV creates opportunities for macroinvertebrate organisms especially filter feeders and more habitat for macroinvertebrates to utilize as shelter from predators. Although water quality parameters were not monitored during the study, the overall quality may reflect the pollution tolerance values (*Figure 17*) given to the macroinvertebrates that make up the communities found in the Anacostia marshes.

The macroinvertebrate community found at Patuxent had fewer pollution tolerant and more pollutant intolerant taxa than the Anacostia marshes at Kingman, Kenilworth and Dueling Creek. The presence of extremely large populations of oligochaetes and chironomids at the Anacostia sites, both of which are pollution tolerant taxa, speaks extremely strongly to the polluted nature of the Anacostia, especially the mudflats. Another factor that is influencing the macroinvertebrate community at Patuxent Marsh is the presence of a beaver dam across the channel on the south side of the marsh. The dam was established in the winter of 2003 and continues to retain water, inundating high, middle and low marsh habitat. This alteration from a tidal marsh to essentially an impoundment has altered inundation periods and consequently the marsh vegetation. The macroinvertebrate community is changing also, with an increase in the families of Chironomidae, Physidae and Planorbidae and the loss of organisms such as the family Tipulidae that would not normally inhabit pond-like environments.

Great attention was given to elevations of the marsh habitats that were sampled. To say that elevation could have an effect on macroinvertebrate populations would not be true by itself without the consideration of the associated vegetation. As an example, in

Kingman Marsh there are “high marsh” mudflats; they may be at an elevation suitable to support high marsh, but the vegetation is gone as a result of goose herbivory. The macroinvertebrates found at these locations resemble those that are found in the mudflats at lower elevations. It had been hypothesized that the macroinvertebrate population might be elevation responsive in a manner similar to the vegetation. However, elevation does not seem to be as much of a driving force as the associated vegetation. Overall, vegetated sites had higher macroinvertebrate diversity than un-vegetated sites regardless of elevation *(Figures 24 & 25*). Pool locations were rare and often transient but when present and containing vegetation, they provided habitat for a diverse array of benthic organisms, perhaps because they were relatively stable (personal observations by Kevin Brittingham). Stability is mentioned because in tidal systems the waters come and go twice a day. The great importance of the chance pools and puddles then is that they provide refugia particularly during out going and low tide portions of the tide cycle for many of the macroinvertebrate organisms, especially those that cannot survive for long in exposed mud. However, it is important for the pools to provide some kind of cover, otherwise fish trapped there will likely deplete the macroinvertebrates. One pool at Kingman Marsh existed long enough one year to become infilled with *Ludwigia* spp. (surface spreading plant) and *Ceratophyllum demersum* (submersed aquatic plant). It had the greatest taxa richness of any location sampled. The following years, this site did not infill with vegetation and correspondingly supported few macroinvertebrate taxa.

Macroinvertebrate diversity within wetlands also appears to be strongly affected by the number of different types of sub-habitats or vegetation zones. Different types and zones of vegetation contain different macroinvertebrate species, and wetlands with the greatest diversity of plant species or types of vegetation have the most diverse macroinvertebrate fauna (Kirkman and Sharitz 1994). Studies in which multiple sampling strategies include all vegetation zones and year-round sampling have found an incredible diversity of macroinvertebrate species (Williams et al. 1996). However, most studies do not include multiple sampling strategies, all spatial habitats, and/or all seasons, and several authors note that for one or more of these reasons their species lists are incomplete (McElligott and Lewis 1994, Brinkman and Duffy 1996, Turner and Trexler 1997, Soumille and Thiery 1997).

One task component of this study was to use a multiple sampler approach. This was done to both characterize as fully as possible the macroinvertebrate community that was present in the marshes and elucidate the role of the several techniques in the tidal wetlands. The data from the Ekman dredge and D-net were similar reflecting comparable abundance patterns and taxa richness levels (*Figures 8 & 9)*. Only a few organisms were unique to the D-net samples, which represented those found in open water habitats such as water beetles and aquatic true bugs. Data from the Hester-Dendys (HD) represented organisms that had an affinity for structure such as vegetation (*Table 6*). Thus, high numbers of amphipods, isopods, snails, and one species of caddisfly in the family Polycentropodidae (*Cyrnellus fraternus.)* were found in the HD samples. This multiple sampler approach gave a broader description of the macroinvertebrate community found in these marshes. However from a management viewpoint, one technique such as the Ekman or D-net is probably adequate for a reasonable portrayal with less effort. The D-net provided a good description of the macroinvertebrate community in terms of abundance and richness, with less effort than the other samplers. However, sampling was limited to high tide situations to cover all the sites within the same time frame. In addition the D-net is less easily quantified than the sediment samplers used and it samples primarily the water column and surface sediments.

The macroinvertebrate communities found in this study correspond to those found in other studies of similar habitats (Ettinger 1982, Odum et al. 1988, Findlay et al. 1989), but with the Kingman Marsh definitely yielding a predominance of pollution tolerant chironomids and oligochaetes. Batzer et al. 1999 stated, "Wetland invertebrate communities are dominated by a distinctive group of taxa, many of which do not occur in terrestrial or aquatic (>2 meter depth) ecosystems". The fauna of freshwater tidal wetlands can be dominated by invertebrates adapted to the shallow and often fluctuating water levels**.** The taxonomic lists included in Batzer et al. 1999 are similar to those found in this study. Another study conducted on the tidal freshwater marshes of the James River had similar findings (Diaz 1977). The marsh macroinvertebrates were dominated by oligochaetes and chironomids. The oligochaetes were the most abundant group and the chironomids were the most diverse group. All these studies show that the macroinvertebrate fauna found in the tidal freshwater marshes are considerably lower in diversity than that found in nontidal freshwater further upstream. The overall habitat described in these studies was a silty muddy bottom with a lack of structure and diverse habitat. Diaz 1977 associated tidal freshwater macroinvertebrate communities to those found in lakes and ponds, or river mouths. He concluded that there was no benthic macroinvertebrate that was specialized for the freshwater tidal wetland habitat. Species found in the wetlands had no specific preference for tidal freshwater and were capable of inhabiting a wide range of environmental conditions. However, the macroinvertebrates of freshwater tidal wetlands and their diverse taxonomic affiliations are extremely important for accurately assessing the biological diversity in wetlands and for understanding the various roles that macroinvertebrates play in wetland ecosystem function (Richter et al. 1997).

SUMMARY and CONCLUSIONS

(1) Habitat heterogeneity can play a role in determining the overall diversity of invertebrates along with patterns of distribution and abundance in a wetland. Unvegetated sites like mudflats and channels generally supported greater numbers of invertebrates (primarily chironomids and oligochaetes) while vegetated sites (increased structural diversity) promoted invertebrate species richness (*Figures 24 & 25*). While pools tend to be transient in the tidal marsh (they likely are a function of scour events but soon fill as a result of leveling tidal action), those that persist for at least several months and develop submersed and/or floating vegetative communities support a vigorous invertebrate population. Thus, even though generally short lived, pools in the tidal marsh landscape provide more stable environments similar to nontidal aquatic systems than areas that are flooded and drained twice daily by tides.

(2) Macroinvertebrate taxa had similar abundance at the reconstructed Kenilworth Marsh, which had been in existence for roughly 10 years since reconstruction, when compared with the internal Anacostia reference site at Dueling Creek and was closer to the more rural Patuxent Marsh with respect to richness (*Figure 15*). In

addition to being restored earlier, Kenilworth, unlike Kingman Marsh, had remained vegetated and was seemingly unaffected overall by wildlife grazing. Thus the macroinvertebrates were a good indicator of successful marsh reconstruction.

(3) The loss of vegetation and erosional substrate at the recently reconstructed (2000) Kingman Marsh due to wildlife grazing (primarily resident Canada geese) affected the macroinvertebrate community development. Kingman had a significantly greater density of macroinvertebrates (chironomids and oligochaetes) than Kenilworth but supported a lower number of species per unit area.

(4) This study was designed, using the macroinvertebrates as an indicator, to measure whether Kingman Marsh (reconstructed in 2000) was developing successfully as compared to Kenilworth Marsh (reconstructed 7 years prior in 1993) and the internal Anacostia control site at Dueling Creek. As described in #3 above the benthic community had reduced taxa richness and diversity and increased abundance of disturbance tolerant taxa indicating that it had not progressed as far in the restoration process as the more intact Anacostia marshes (Kenilworth and Dueling). Unfortunately, the restoration process was being hindered by the unanticipated impact from the goose herbivory at Kingman due to the loss of vegetation cover and richness. Thus, it was impossible to discriminate the effects of ongoing goose habitat disturbance and the potential time lag in recovery in general.

(5) The macroinvertebrate community at Kingman Marsh comprised of large populations of pollution tolerant chironomids and oligochaetes *(Figures 20 and 21)* reflected a degraded system. Kingman Marsh also had a significantly lower Shannon Index than the other marshes (*Figure 16*) reflecting reduced diversity. The Anacostia, an urbanized watershed, is recognized as one of the most polluted systems in the United States (Pinkney et al. 2003), having consistently high levels of nutrients, bacteria and toxics as well as low dissolved oxygen. Part of the problem stems from a slow flushing time (about 30 days for the 8 mile tidal reach) and propensity for combined sewer overflows.

(6) The macroinvertebrate community at the more rural Patuxent Marsh consistently differed significantly from each of the urban Anacostia wetlands in abundance and richness *(Figures 14 & 15)*. The Patuxent macroinvertebrate community had fewer pollution tolerant taxa than the Kingman Marsh in the Anacostia (*Figure 17)*. The densities were significantly lower (far fewer chironomids and oligochaetes) (*Figures 20 & 21)* but consisted of a significantly greater taxa richness at Patuxent Marsh than any of the urban Anacostia marshes (*Figures 15 & 16*). While the same four taxa (Chironomidae, Oligochaeta, Ceratopogonidae and Sphaeriidae) yielded over 95% of all the macroinvertebrate organisms in each of the Anacostia marshes, the same genera contributed only 77% at Patuxent; and the population density levels were less than one-third of those in the Anacostia wetlands (*Figure 19*). Better water quality and the presence of considerable submersed aquatic vegetation

(SAV) at Patuxent Marsh were likely key factors promoting the diverse macroinvertebrate community there. These macroinvertebrate communities were an accurate indicator of the relative pollution conditions at the studied wetlands and could be used to distinguish urban wetlands from more rural wetlands.

(7) The study was designed to measure whether elevation affected the make-up of the macroinvertebrate communities of the tidal marsh. Elevation does influence the vegetation community structure, so it might also for the macroinvertebrates. Since elevation affects the vegetation of the marsh, which in turn affects the associated macroinvertebrates, elevation and vegetation effects will probably be confounded. That is, when one looks at the vegetated community as one group, which is generally more elevated than unvegetated, a difference in the macroinvertebrate community exists, especially with respect to increased taxa richness (*Figure 24*). However, when ascending the low, mid, to high marsh gradient no significant differences were found (*Figure 25*). The point is, based on this study design, we couldn't verify whether macroinvertebrate populations sorted due to elevation or vegetation - most likely both are involved – but there was a strong influence of vegetated versus unvegetated. The vegetated sites possession of greater taxa richness was perhaps due to more complex habitat structure.

(8) This study resulted in a more complete macroinvertebrate community profile due to the multiple samplers, year-round seasonal collections, and sampling multiple

vegetated zones *(Tables 1, 2 and 3)*. Where funding and time are controlling factors a good snapshot of the macroinvertebrate population in a freshwater tidal system could be obtained from sampling vegetated and unvegetated zones using a general technique such as the Ekman or D-net sampler alone *(Figures 8 & 9, Table 6*).

(9) The macroinvertebrate communities found in this study were similar to those found in the few other studies involving benthic macroinvertebrates in freshwater tidal systems (Ettinger 1982, Finlay et al. 1989, Batzer et al. 1999), but the community groups tended to differ at the various wetlands studied.

(10) There were significantly more macroinvertebrates present in the wetlands studied during the summer and fall than the other seasons (*Figure 11*).

(11) The composition of the benthic macroinvertebrate community proved to be a useful indicator of the status of reconstructed and reference wetlands in this study and should similarly in other like environments.

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