The Effects of Urbanization on Populations of Grass Shrimp *Palaemonetes spp* in Small, High Salinity Estuaries

NOAA Technical Memorandum NOS NCCOS 54

Citation for this Report

J.W. Daugomah, T.C. Siewicki, D.E. Porter, G.I. Scott. 2007. The Effects of Urbanization on Populations of Grass Shrimp *Palaemonetes spp* in Small, High Salinity Estuaries.

NOAA Technical Memorandum NOS NCCOS 54. 28 pp.

The Effects of Urbanization on Populations of Grass Shrimp *Palaemonetes spp* in Small, High Salinity Estuaries

J.W. Daugomah[1], T.C. Siewicki[1], D.E. Porter[2], G.I. Scott[1]

[1] NOAA/National Ocean Service/Center for Coastal Environmental Health and Biomolecular Research, 219 Fort Johnson Road, Charleston, SC 29412

[2] University of South Carolina, Department of Environmental Health Sciences, Norman J. Arnold School of Public Health, Rm. 311 Sumter & Greene Streets, Columbia, SC 29208

NOAA, National Ocean Service
National Centers for Coastal Ocean Science
Center for Coastal Environmental Health and Biomolecular Research
219 Fort Johnson Road
Charleston, South Carolina 29412-9110

NOAA Technical Memorandum NOS NCCOS 54

March 2007

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Carlos M. Gutierrez Secretary	Conrad C. Lautenbacher, Jr. Administrator	John (Jack) H. Dunnigan Assistant Administrator

.

Table of Contents

Table of Figures

.

List of Tables

ABSTRACT

High salinity estuaries in the southeastern U.S. have experienced increased inputs of contaminants from nonpoint source (NPS) urban runoff and decreases in habitat due to filling of wetlands and dock/bulkhead construction. Urbanization may pose significant risks to estuarine fauna, particularly crustaceans. The grass shrimp of the genus *Palaemonetes*, is one of the dominant species found in estuarine tidal creeks, accounting for greater than 50% of all macropelagic fauna on an annual basis. Spatial analytical and geographic information system techniques were used to determine which factors influenced the *Palaemonetes* population structures in a South Carolina bar-built estuary surrounded by urban development. Impacts from land use practices were investigated using concentric circular buffers around study sites. Factors investigated included sediment-associated polycyclic aromatic hydrocarbons concentration, land use classification, percent impervious surfaces, and other selected urban factors. Geographic information system and statistical modeling showed quantitative relationships between land use class and impacts on *Palaemonetes* density. The study suggests that habitat loss is a major factor influencing grass shrimp densities. Multiple regression modeling suggests a significant relationship between habitat alterations and *Palaemonetes* densities.

Key Words: Estuary, Urbanization, Spatial Analysis, Habitat

Introduction

Environmental concerns related to fisheries management in the southeastern United States have increased along with the rapid development of urban and suburban areas as anthropogenic impacts associated with coastal development have changed estuarine ecosystems (Vernberg et al. 1993). High salinity estuaries have experienced increased inputs of chemical contaminants from nonpoint source (NPS) urban runoff (Fulton et al. 1997), and decreases in critical wetlands habitat due to land-use practices including filling of wetlands and dock/bulkhead construction (Trent et.al 1976; Porter et al. 1997). Several studies have identified negative impacts from urbanization resulting from nonpoint source runoff and intensive human use. Findings from these studies have shown impacts from nutrients (Lapointe and Clark 1992), coliform bacteria (Vernberg et al. 1996), metals from dredge effluent (Wirth et al. 1996) and petroleum products (Bidleman et al. 1990; Finley et al. 1999)

Grass Shrimp*, Palaemonetes* species are among the most widely distributed, abundant, and conspicuous of the shallow water macroinvertebrates in the estuaries of the Atlantic and Gulf Coasts (Wood 1967; Welsh 1975). *P spp.* serve as a major secondary producer in estuarine ecosystems and account for greater than 56 % of all macropelagic fauna on an annual basis (Scott et al. 1992). *P. spp.* abundance, sensitivity to contaminants, and overall importance in southeastern estuaries of the U. S. provides a useful ecotoxicological model to examine the effects of increasing NPS runoff pollution (Anderson 1985). Decreases in habitat from shoreline alterations, (e.g. dredging, bulkheading, and filling of coastal marshes) may cause a permanent loss of intertidal vegetation. The nation's coastal counties are losing 1,997 acres per day to urban and

.

other land uses. This is approximately 2 percent faster than noncoastal counties (Crosset et al. 2004). Previous studies have shown decreases in abundance of *P. spp* and other crustacean species due to shoreline alteration (Trent et al 1976; Porter et al. 1997). Decreases in fish assemblages (Hall et al. 1994) and benthic communities (Weisberg et al. 1997) resulting from habitat changes have also been documented.

The goal of this research was to investigate possible relationships between spatial patterns of land use and other attributes in bar built estuaries and *P. spp.* population distribution within the study region using geographic information systems (GIS). This study is concerned with the spatial upland influences that may be associated with *P. spp.* populations in a highly urbanized estuary located at Murrells Inlet (MI), SC. Data from *P. spp.* population estimates and technologies such as GIS, remote sensing, global positioning system (GPS), and environmental statistics have been combined to derive the final model.

Materials and Methods

Study Site

Murrells Inlet (MI) estuary is a bar-built inlet comprising approximately 1200 ha of wetland, open water, residential and light commercial development located on the South Carolina coast 160 km north of Charleston, SC (Fig. 1). The dominant marsh vegetation is *Spartina alterniflora*. Six marinas, numerous restaurants and other tourist-related service industries and private homes dominate areas adjacent to estuarine areas. The permanent residential population density is about 280/km^2 as compared to the average population of 50 residents per km^2 in South Carolina (South Carolina Budget and Control Board 2000). MI estuary is located on the southern end of South Carolina's "Grand Strand" which receives 12 million visitors annually (Myrtle Beach, SC Chamber of Commerce 2000) during the summer tourist season that leads to increased pressures on coastal resources. MI estuary has been subjected to anthropogenic alterations resulting from extensive upland and shoreline development associated with urbanization and dredging of waterways (Jefferson et al. 1991). The distribution and magnitude of these anthropogenic influences make the MI estuary an ideal study site to assess the impacts of urbanization.

The MI estuary was classified into three regions including: upland (urbanized) middle-estuary (undeveloped) and mouth (urbanized). These estuary classifications provide the ability to identify land use factors that might impact sample sites in each region.

Palaemonetes spp Population Sampling Methods

The push net method is a rapid assessment method for estimating *P. spp.* densities and provides comparable results to more intensive sampling methodologies Fulton et al. 1993). Thirty tidal creek sites were sampled approximately two hours before low tide by a push net with a mouth opening of 1000 cm^2 (3mm mesh x 40cm x 25cm) along the bank or fringe of the *Spartina alterniflora* marsh at a depth of 25 to 50 cm. Each sample included a 75m transect to collect adult (>15mm) grass shrimp *(Palaemonetes spp.* including *Palaemonetes pugio, P. vulgaris* and *P. intermedius*). The majority (> 90%) of grass shrimp were identified as *P. pugio*. Sites were located by GPS and synoptic samples of each creek bank were combined for the population sample at each site. Samples were placed in plastic containers and immediately transported back to the laboratory in a cooler where density ($\#/m^3$) and biomass (g/m^3) were measured. Samples were then preserved in 100% ethanol. Temperature (°C), and Dissolved oxygen (DO, mg/L) were measured using a YSI model 85 multiparameter meter (YSI Inc., Yellow

.

Springs, Ohio) at each sample location. Salinity was measured with a refractometer (model A366ATC Spartan Inc, Japan) at each sample location. Each instrument was calibrated daily before use.

The sediment polycyclic aromatic hydrocarbon (PAH) contaminant data used in this study was previously published by Sanders (1995). Sediments were collected at each of the 30 sites for PAH analysis. A semivariance analysis model of sediment PAH concentrations (spherical, isotropic, $R^2 = 0.75$) was kriged (point isotropic, 20 x 20 m grid CV $R^2 = 0.43$) within MI estuary using Geostatitistics for Environmental Sciences 3.2 and concentrations were estimated at *P. spp* collection sites. The kriged sediment concentration was used for analysis.

Spatial Methods

Polygon land use coverage maps of the MI estuary were created using standard stereoscopic photo interpretation techniques. Photo interpretation and classification of 1994 National Aerial Photography Program (NAPP) Color Infrared (CIR) photographs covering the study sites were performed to level III of the Florida Land Use and Cover Classification System (FLUCCS) (Florida Department of Transportation 1985). Level IV was classified where features were discernable including (1) nonurban upland, (2) urban upland, (3) wetland, and (4) water (Fig. 1). The FLUCCS system is hierarchical and is a modified Anderson Classification System. In previous research the FLUCCS system has been used to classify land use and land cover in coastal South Carolina (Holland et al. 1993; Porter et al. 1997]. Quality control consisted of visual assessment of the photo interpretation effort and on site assessment. Next, the photo interpretation information was transferred and registered to stable-based mylar 1:24000-scale United States

Geographical Survey (USGS) topographic maps of MI estuary for use in the digitization process. Land use and land cover classes were digitized, attributed, and registered to Zone 17 of the Universal Transmercator (UTM) system. Plots of the land use and land cover GIS layers were produced at 1:24,000-scale and placed under the original mylars for additional quality assurance (Porter et al. 1997).

Airborne Terrestrial Applications Sensor (ATLAS) imagery was used to classify areas of MI estuary into three land cover classes: impervious surface, open land, and vegetation. The spectral range of ATLAS is 0.45 – 12.2 µm and is displayed in 14 channels with a 3 meter ground spatial resolution. The ATLAS data were rectified, transformed using ENVI's Principal Components analysis, classified using parallelepiped classifier from ERDAS, Inc. Image Analysis extension for ArcView, and converted to vector format for use with the GIS.

The shoreline covered with bulkhead (BH) within MI estuary was measured by recording the beginning and ending points along the shoreline using a GPS receiver (Trimble GeoExporer 2, Sunnvale,CA). The BH points were post processed using Trimble Pathfinder software to submeter accuracy. Points for each bulkhead were connected with a line and "best fit" to the existing shoreline (Fig. 2). Random manual BH measurements were made with a tape measure to the nearest meter. These measurements were compared to the GPS distance estimates resulting in 98% accuracy.

Dock locations were identified from a 1994 NAPP photo and a point location for each dock was made using Arcview 3.2 software (Fig. 2). The points representing the docks were located by placing an icon where the dock met the water edge of the creek.

.

The *P. spp* densities were assigned to a single point in the center of the creek for each 75 meter transect for each sample location when doing the spatial calculations. Concentric circular buffers were created around each sample point origin with a radius of 25, 50, 100, 200, and 400m (Fig. 2). The percent land use for each of the four FLUCCS landuse classifications, area (m^2) of impervious surface from the ATLAS imagery, the number of docks and the length of bulkheading (m) at each distance was calculated by clipping each concentric buffer in ArcView Spatial Analyst 3.2.

Canonical correlation analysis Proc Cancorr, (SAS Institute Inc., 1999) was used to identify the best land use buffer distances for predicting *P. spp* density but no trend was evident. Therefore, multiple regression models to predict *P. spp* density were tested at each distance (25M, 50M, 100M, 200M and 400M) for concentric circular buffers. A log transformation ($\log_{10}(x+1)$) of *P. spp* density was used to normalize the distribution of the dependent variable. Each model was tested using forward, backward and stepwise selection methods (Proc Reg, SAS Institute Inc., 1999). Each regression model included the following independent variables: percent upland, percent wetland, percent water, percent urban, percent impervious surface, kriged PAH concentration, number of docks, and shoreline length of bulkheads.

Results

Palaemonetes spp Population Study

Average estuary-wide grass shrimp densities at MI estuary were 31.0/m^3 (Fig. 3). The densities were highest in the middle sections of the estuary where the least area of urban land class is present.

The DO ranged 1.9 to 5.9 mg/l for MI estuary with a mean of 4.1 mg/l (Table 1). The salinity range for MI estuary was 25 to 36 ppt with a mean of 33 ppt (Table 1).

Kriged PAH concentrations ranged 49.21 to 2085.62 ng/g in MI estuary with a mean of 513.23 ng/g (Table 1). The temperature range for MI estuary was 25.3 to 32.0 ^{0}C with a mean of 29.6 ^{0}C (Table 1).

Spatial Analysis

The mean bulkhead lengths for MI estuary ranged from 2.53m in the 25m circular buffer size to 283.14 m in the 400m circular buffer size (Table 2). The mean number of docks in MI ranged from 0.20 in the 25m circular buffer to 17.36 in the 400m circular buffer size (Table 2). Land use classification and the percentages present at each circular buffer distance are shown in (Table2). Impervious surface was estimated to be 24 –27% within MI.

For circular buffers, the most predictive model for *P. spp* density (adjusted r squared=0.52; p= 0.0005) reduced the independent variables to percent water and percent urban at 400M (logden = -0.145 (Water 400) -0.051 (Urban 400)) + 9.298. The model illustrated that there was a significant relationship between the parameters in the model and *P. spp* density. Therefore water and urban land class explain 52% of the variability in *P. spp* density for the model.

Discussion

The *P. spp.* population model attempts to provide an accurate habitat utilization estimate**.** *P. spp.* samples were collected on an ebbing tide when the organisms would be predominantly returning to the main creek channel and the edge of *S. alterniflora* habitat. Eggleston (1998) found that *P. spp* respond to an edge effect, either as a refuge, for foraging, or both. The sizes of *P. spp* differ significantly among habitats, with the largest mean sizes occurring in the edge habitat and the smallest on nonvegetated bottom Khan

.
et al. 1997). Peterson and Turner (1994) used flumes and seines to compare the relative importance of the marsh habitat at the creek edge versus the interior marshes for species specific differences in marsh use. The *P. spp* penetrated to the interior marsh and most returned to the creek at low tide.

Sanger (1999) found that *P. pugio* populations in South Carolina tidal creeks were significantly higher in creeks surrounded by forested upland than in industrial, urban and suburban creeks. Fulton et al. (1997) identified significant decreases for *P. pugio* densities in the MI estuary within proximity to estuarine areas adjacent to upland shoreline modifications when comparing one site in MI to one reference site North Inlet, SC (NI) annually. Finley et al. (1999) completed a two year study in MI at six temporal study sites that were distributed from north to south along the inner, predominantly urban portions of the MI estuary. All six sites showed densities were significantly ($p< 0.05$) reduced, averaging 89.4% density reduction and 89.3% density reduction in consecutive years within MI estuary compared to the NI reference site.

Spatial Analysis

The concentric circular buffer analysis surrounding *P. spp* sample locations provides the ability to model varying land use combinations by increasing the buffer size. The potential influence of each land use classification on *P. spp* densities can be estimated with this method. The results of the land use combinations were tested for forward, backward, and stepwise multiple regression selection processes. The area of water land use present was consistently a significant variable with increasing concentric circular buffer size using the backward selection process (Table 3). The strongest *P. spp* density model for all three selection processes showed area of water land use class and urban land use class as significant variables (Table 3). A negative correlation with *P. spp* densities was shown for both land classes (Table 3). The water land use class shows a decreasing percentage of area within each concentric buffer as buffer size increases (Table 2). This decreasing percentage pattern is accompanied by an increase in the percentage of the urban and wetland land class area that surrounds sample sites with larger concentric circular buffer sizes within MI estuary.

The area of urban land class within the 400m circular buffer generally increases as the area of water land class decreases (Table 2). The area of urban land use classification within the 400 meter concentric circular buffer surrounding the *P. spp* sample sites averages 22% of total land use (Table 2). Population results estimate 66% of the *P. spp* sample locations have urban land use class within the 400 m concentric circular buffer area. Urban development has been concentrated in the mouth region and inner region near upland land class within the MI estuary. *P. spp* population densities in the mouth region averaged 10.91 m^3 of MI estuary and 17.91 m^3 for the inner region. The *P. spp* population densities in the middle region of MI estuary average 64.81 m^3 and are highest in this region, most distant from urban influences. Porter et al. (1997) identified grass shrimp "deserts" in the mouth and inner regions of MI estuary. These regions were found to be absent of *P. spp* and statistically significant decreases where recorded when compared to a reference estuary. MI estuary leads to the open ocean and factors such as dredging and jetty construction could impact *P. spp* at sites in the mouth region of the estuary.

The U.S. Army Corps of Engineers began dredging to maintain the migratory inlet mouth of MI estuary in 1966 and stabilization of the mouth with north and south flanking jetties was accomplished from 1977 to 1980 (U.S. Army Corps of Engineers 1975) . Concurrent with the construction of the jetties was an extensive dredging of an entrance channel where the bottom is characterized by shell and coarse sand. A navigation channel up Main Creek to the mainland edge of MI was also dredged. It is possible that these physical alterations in MI estuary are having long range chronic impact to the biota. Calder et al. (1976) predicted that the most serious environmental effects from dredging in the MI estuary would occur in Main Creek near the mouth of MI estuary.

The alteration of historical wetland land class to urban land class within MI estuary could contribute to the decreases in *P. spp* density in the estuary regions most impacted by land use alteration (mouth and inland) regions (Fig. 3). Generally the lowest *P. spp* densities within MI estuary were recorded at the stations near the mouth and inland regions of the estuary where shoreline modifications are present. Earlier land use studies completed in MI estuary found the rate of wetland alteration was significantly different when comparing the MI estuary to a reference estuary between 1983 and 1989 (Porter 1995). The residential and commercial development in MI estuary is highest in the northern two thirds of the estuary. The southern region of the estuary is within the boundaries of Huntington Beach State Park and undeveloped. Wetland land use class was not significant by itself with *P. spp* densities in this study but decreased population estimates consistent with the findings of Finley et al. (1999) and Fulton et al. (1997) suggest an association with land use on *P. spp*. The area of the 400m circular buffer that includes wetland land use is 52%; water land use at the 400m circular buffer is 23% (Table 2). This suggests that there is more quality habitat available in the middle region of MI estuary where the water land class decreases within the circular buffer and wetland land use class increases.

Alterations of the wetland land use class have primarily been at the estuarine shoreline, specifically bulkhead and dock building within MI estuary. Bulkheads have been traditionally built to help control erosion along creek banks but are often built at the expense of *S. alterniflora* habitat. Calculations of BH areas within MI estuary show that approximately 33% of wetland land use in MI estuary has BH along the shoreline. The results of this study suggest BH construction alters and decreases the *S alterniflora* habitat and these alterations may contribute to the decreases in *P. spp* populations.

Aerial photography identified 347 docks within the MI estuary located primarily along the urban land class shoreline. The presence of bulk heading and docks suggests a synergystic relationship with the anthropogenic inputs associated with these urban factors**.** Porter (1995) compared the presence of regulatory permitted activities, including dock and bulkhead construction in MI. He found a high correlation with increased wetlands loss compared to expected losses from physiographic influences when these activities occurred. This complexity underscores the difficulty in determining cause and effect in risk assessment of urban effects. Bulkhead and dock construction in general, are a common result of urban development and should be further studied.

This study was designed to provide a rapid assessment using a one time collection sample design. The water quality readings collected for this study were for one point in time and did not show a significant relationship for the *P. spp* density model. Summers et al. (1997) found monitoring strategies that involve single point sampling of dynamic parameters (e.g. DO) may often misclassify an estuary as having good water quality.

.

Thus, characterizing estuarine DO concentrations can be difficult except through the use of long term continuous monitoring.

A significant relationship between kriged PAH concentrations and *P. spp* densities did not appear in the *P. spp* density model. The acute and chronic effect of PAH interaction on faunal organisms and the extent to which bioaccumulation may occur is not completely understood. Thus, it is likely to be difficult to evaluate subtle, chronic effects of PAH contamination on *P. spp* abundance within MI estuary. Previous studies in MI estuary suggest urban runoff containing PAH contamination was not acutely toxic to adult grass shrimp and that chronic sublethal effects (e.g. reproduction) may be more likely (Vernberg et al. 1993; Fulton et al. 1997). Finley (1999) noted alterations in the development time of gravid grass shrimp in MI estuary which correlated with PAH exposure.

Potential negative impacts to estuarine environments and water quality can be related to increases in impervious surface. Impervious land cover has emerged as an environmental indicator and potential contributor to the environmental impacts of urbanization. Schuler (1994) concluded that stream degradation occurs at relatively low levels of imperviousness (10-20%). Lerberg (1997) found that when impervious surfaces exceed 30 to 35% then it is likely that the water and sediment quality are degraded and the condition of the macrobenthic community will be undesirably altered. In MI estuary the percentage of impervious surface generally increases as the area of the buffer increases (Table 2). This relationship is consistent with increasing buffer size and the percentage of water land use class increasing. The 200 m buffer distance showed a significant relationship for the percentage of impervious surface present along with the area of water land use class. Nichols (2000) estimated total upland impervious surface in MI to be 24-27%, this estimate falls within the range that degradation might occur.

Conclusions

The spatial analysis completed for this research begins to identify potential impacts of urbanization and can provide resource managers the ability to integrate ecotoxicology and chemistry data with geographic data. Concentric circular buffers, used to evaluate land uses surrounding the study sites, yielded a model using open water and urban upland within the 400m circular buffer area. Agreement between measured and predicted *P. spp* densities was best in the less impacted (southern) end of MI estuary. GIS and statistical modeling showed quantitative relationships between urban landscape features and impacts on productivity of an important prey species. The study suggests that habitat loss is a major factor influencing *P. spp* densities. Multiple regression modeling suggests that a significant relationship can be drawn with land use changes and *P. spp* densities. Additional work is needed to more completely characterize the relationship between urbanization and *P. spp* densities.

Acknowledgements: Pete Key, John Devane, Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) for assistance in sample collection. NOAA/NOS/NCCOS

.

NOAA DISCLAIMER

This publication does not constitute an endorsement of any commercial product or intend to be an opinion beyond scientific or other results obtained by the National Oceanic and Atmospheric Administration (NOAA). No reference shall be made to NOAA, or this publication furnished by NOAA, to any advertising or sales promotion which would indicate or imply that NOAA recommends or endorses any proprietary product mentioned herein, or which has as its purpose an interest to cause the advertised product to be used or purchased because of this publication.

References

Anderson, G. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrate (Gulf of Mexico) – grass shrimp. U. S. Fish and Wildlife Service Biology Report 82 (11.35) U.S. Army Corps of Engineer, TREL-82-4. 19 pp.

Bidleman, T.F., A.A. Castlberry, W. Foreman, W.T. Foreman, W.T. Zaranski, D.W. Wall. 1990. Petroleum hydrocarbons in the surface water of two estuaries in the southeastern United States. *Estuarine, Coastal and Shelf Science*.30:91-109

Calder DR, Gearden CM, Boothe BB Jr. 1976. Environmental inventory of a small neutral embayment: Murrells Inlet, South Carolina, Tech Rep No. 10. SC Wildlife and Marine Res Center, Charleston, SC, 58 p.

Crossett, K.M., T.J. Culliton, T.C. Wiley, T.R. Goodspeed, Population Trends Along the Coastal United States: 1980-2008. Coastal Trends Report Series: National Oceanic and Atmospheric Administration, NOAA's National Ocean Service, Management and Budget Office, Special Projects. September 2004. 47 pages.

Eggleston, D. B., L.L. Etherington, W. E. Elis. 1998. Organism response to habitat patchiness: species and habitat-dependent recruitment of decapod crustaceans. *Journal Experimental Marine Biology and Ecology* 223:111-132.

Fulton, M.H. G. I. Scott, A. Fortner, T. F. Bidleman, N. Ngabe, 1993. The Effects of Urbanization on Small High Salinity Estuaries of the Southeastern United States. *Achive Environmental Contaminants Toxicology*. 25:476-484.

Fulton, M.H., G. T. Chandler, and G.I. Scott. 1997. Urbanization effects on the fauna of a southeastern U.S.A. estuary bar-built estuary. In F.J. Vernberg, W.B. Vernberg and T. Siewicki Eds., Sustainable Development in Southeastern Coastal Zone; Belle W. Baruch Library in Marine Science, Vol. 20:477-504.

Finley, D.B., G.I. Scott, J.W. Daugomah, S.L. Layman, L.A. Reed, M. Sanders, S.K. Sivertson, E.D. Strozier. 1999. Case Study: Ecotoxicological Assessment of Urban and Agricultural Nonpoint Source Runoff Effects on the Grass Shrimp., Palaemonetes pugio. In Ecotoxicology and Risk Assessment for Wetlands. M.A. Lewis, F.L. Mayer, R.L. Powell, M.K. Nelson, S.J. Klaine, M.G. Henr, and G.W. Dickson eds. Society for Environmental Toxicology and Chemistry, Pensacola FL USA. pp. 243-273.

Florida Department of Transportation, 1985. Florida Land Use, Cover and Forms. Classification System. Florida Department of Transportation, Tallahassee, FL.

Hall, L. W. Jr., S. A. Fischer, W. D. Killen Jr. M. C. Scott, M. C. Ziegenfuss, and R. D. Anderson. 1994. Status Assessment in Acid-Sensitive and Non-Acid-Sensitive Maryland Coastal Plain Streams Using an Integrated biological, chemical, physical, and Land-use approach, *Journal of Aquatic Ecosystem Health* 3:145-167.

.

Holland, A.F., D.E. Porter, R.F. Van Dolah, R.H., Dunlap, F.H. Steele, and S.M. Upchurch. 1993. Environmental Assessment for Alternative Dredged Material Disposal sites in Charleston Harbor. Technical Report 82. Marine Resources Division, South Carolina Wildlife and Marine Resources Department, Charleston, SC, 92p.

Jefferson, W.H., W.K. Michener, D.A. Karinshak, W. Anderson and D.E. Porter. 1991. Developing GIS Data Layers for Estuarine Resource Management. *Proceedings*, *GIS/LIS 91*. Pp 331-342.

Khan, R.N., H.C. Merchant, R.E. Knowlton. 1997. Effects of macrophytic cover on the distribution of grass shrimps, *Palaemonetes pugio* and *P. vulgaris*. *Invertebrate Biology*. 116(3):243-247.

Lapointe, B.E. and D.W. Clark. 1992. Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. *Estuaries*. 15:465-476.

Lerberg, S. B. 1997. Effects of watershed development on macrobenthic communities in the tidal creeks of the Charleston Harbor estuary. Masters Thesis. University of Charleston, SC. 197 pages + appendices.

Nichols, C.C. 2000. Coastal Landcover Classification using NASA's Airborne Terrestrial Applications Sensor (ATLAS) Data. *Proceedings Sixth International Conference on Remote Sensing for Marine and Coastal Environments*, Charleston, SC, 1-3 May 2000.

Peterson, G.W. and R.E. Turner. 1994. The value of Salt Marsh vs Interior as a Habitat for Fish and Decapod Crustaceans in a Louisiana Tidal Marsh. *Estuaries*. Vol. 17, No. 1B, p. 235-262.

Porter, D.E. 1995. Use of geographic information processing technology to model cumulative impacts of regulatory permitting programs on coastal wetlands: a South Carolina Perspective. Ph.D. dissertation. Department of Geography, University of South Carolina, Columbia, SC.

Porter, D., D. Edwards, G.I. Scott, B. Jones, W.S. Street and C. Moise. 1997. Assessing the impacts of anthropogenic and physiographic influences on grass shrimp in localized salt-marsh estuaries: a multi-disciplinary approach. *Aquatic Botany* 58:289-306.

Sanders, M. 1995. Distribution of polycyclic aromatic hydrocarbons in oyster (*Crassostrea virginica*) and surface sediments from two estuaries in South Carolina. *Archives of Environmental Contamination and Toxicology*. 28:397-405.

Sanger, D.M., A.F. Holland, G.I. Scott. 1999. Tidal Creek and Salt Marsh Sediments in South Carolina Coastal Estuaries: I. Distribution of Trace Metals. *Archives of Environmental Contamination and Toxicology* 37,445-457.

SAS Institute Inc. 1999.SAS/STAT Guide for Personal Computers, Version 6 Edition. SAS Institute, Inc., Cary, NC.

Schuler, T.R. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*. Vol. 1. Number 3:100-111.

Scott, G.I., M.H. Fulton, M.C. Crosby, P.B. Key, J.W. Daugomah, J.T. Waldren, E.D. Strozier, C.J. Louden, G.T. Chandler, T.F. Bidleman, K.L. Jackson, T.W. Hampton, T. Huffman, A. Shultz, and M. Bradford. 1992. Agriculture nonpoint runoff effects on estuarine organisms: correlating laboratory and field bioassays and ecotoxicological biomonitoring. Final Report. US EPA, Gulf Breeze, Fl. 281pp.

South Carolina Budget and Control Board Census 2000, Columbia, SC. 2000. www.ors2.state.sc.us/census2000/census_index.asp#State.

South Carolina Statistical Abstract for the Myrtle Beach Area of South Carolina. 2000. Marketing Research Department, Myrtle Beach, SC Chamber of Commerce.

Summers, J.K. , S. B. Weisberg, A. F. Holland, J. Kou, V. D. Engle, D. L. Breitberg, and R. F. Diaz. 1997. Characterizing dissolved oxygen conditions in estuarine environments. *Environmental Monitoring and Assessment* 45:319-328.

Trent, L. R.J. Pullen, and R. Proctor. 1976. Abundance of macrocrustaceans in a natural marsh and a marsh altered by dredging, bulkheading, and filling. U.S. National Marine Fishery Service. *Fishery Bulletin* 74:195-200.

United States Army Engineer District. 1975. Draft Environmental Impact Assessment, Murrells Inlet Navigation Project, Georgetown County, South Carolina, Charleston, S.C.

Vernberg, F.J., W. B. Vernberg, E. Blood, A. Fortner, M. Fulton, H. McKellar, W. Mitchner, G.I. Scott, and K. El-Fiji. 1993. Impacts of Urbanization on High Salinity Estuaries of the Southeastern U.S. *Netherlands Journal of Deep Sea Research* 30:239-48.

Vernberg, W.B., G.I. Scott, S. H. Strozier, J. Bemiss, and J.W. Daugomah. 1996. The Effects of Urbanization on Human and Ecosystem Health. In Sustainable Development In the Southeastern Coastal Zone. F.J. Vernberg, W.B. Vernberg and T.S. Siewicki eds. p221-239

Weisberg, S.B. LC. Schaffer, R.J. Diaz, D.M. Dauer, J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries*. Vol. No. 1 p. 149-158.

Welsh, B.L. 1975. The role of grass shrimp, *Palaemonetes pugio*, in a tidal marsh ecosystem. *Ecology* 56:513-530.

.

Wirth, E.F., G. I. Scott, M. H. Fulton, R. J. Van Dolah, P.P. Maire, N. Halley, J. W. Daugomah, and P. B. Key. 1996. *In situ* bioassay approach for the determination of toxicity of dredge spoils using *Crassostrea virginica. Archives of Environmental Contaminants and Toxicology*. 30:340-348.

Wood, C.E. 1967. Physioecology of the grass shrimp, *P. pugio*, in Galveston Bay estuarine system. *Contributions in Marine Science*. 12:54-79.

Figure 1. **Murrells Inlet, SC study site. Thirty *Palaemonetes* species sample locations are shown along with land use classifications.**

.

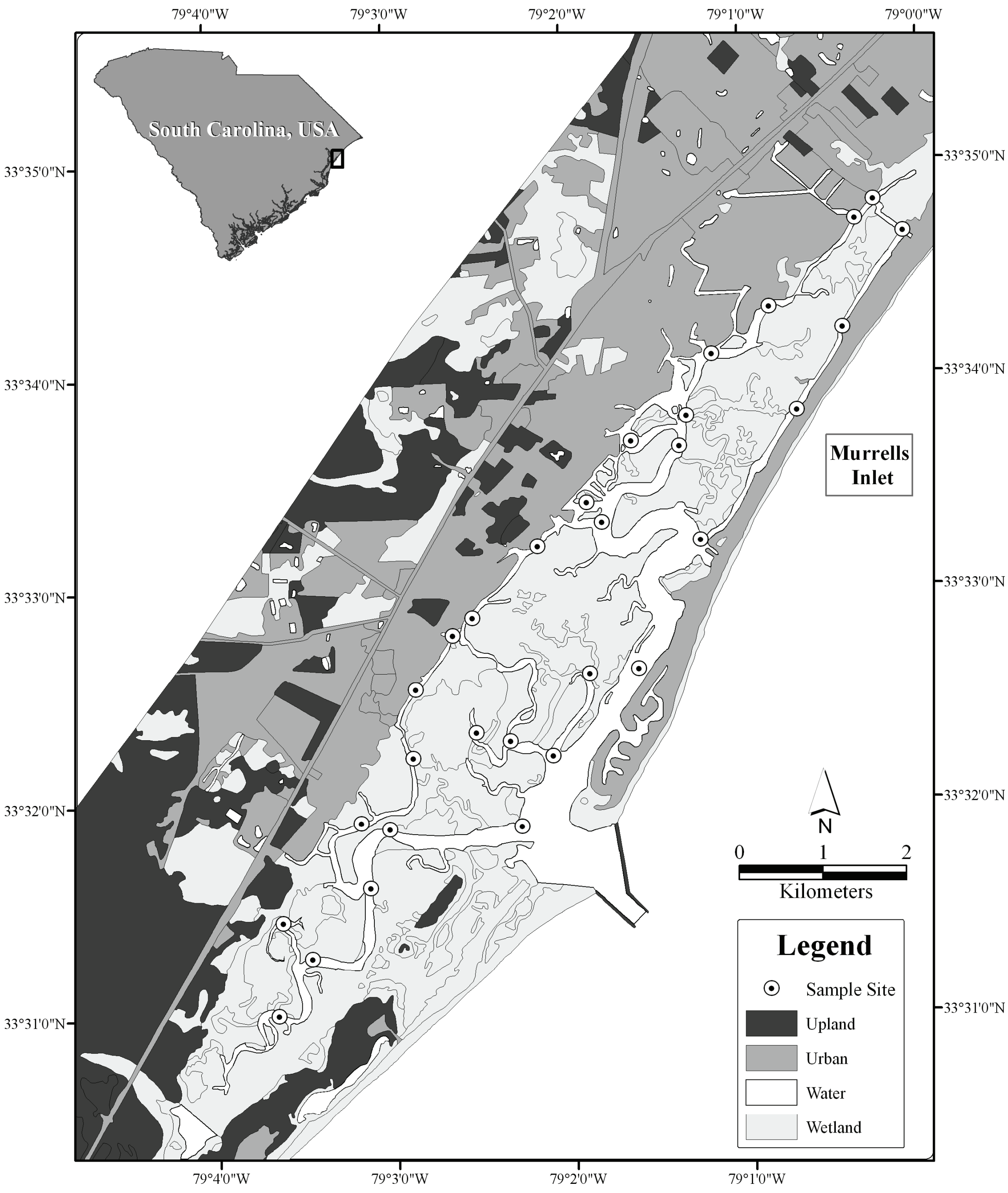
79°4'0"W
79°3'0"W
79°2'0"W
79°1'0"W
79°0'0"W
33°35'0"N
33°34'0"N
33°33'0"N
33°32'0"N
33°31'0"N
South Carolina, USA
Murrells Inlet
N
0 1 2
Kilometers
Legend
Sample Site
Upland
Urban
Water
Wetland

Figure 2. **Concentric circular buffer example of *Palaemonetes* species sample sites with bulkhead, docks, and Florida Land Use and Cover Classification System general class system. Spatial analysis to determine the optimum relationship between urban factors, land use and *Palaemonetes spp.* density was completed for each of 30 sample sites within Murrells Inlet, SC.**

.

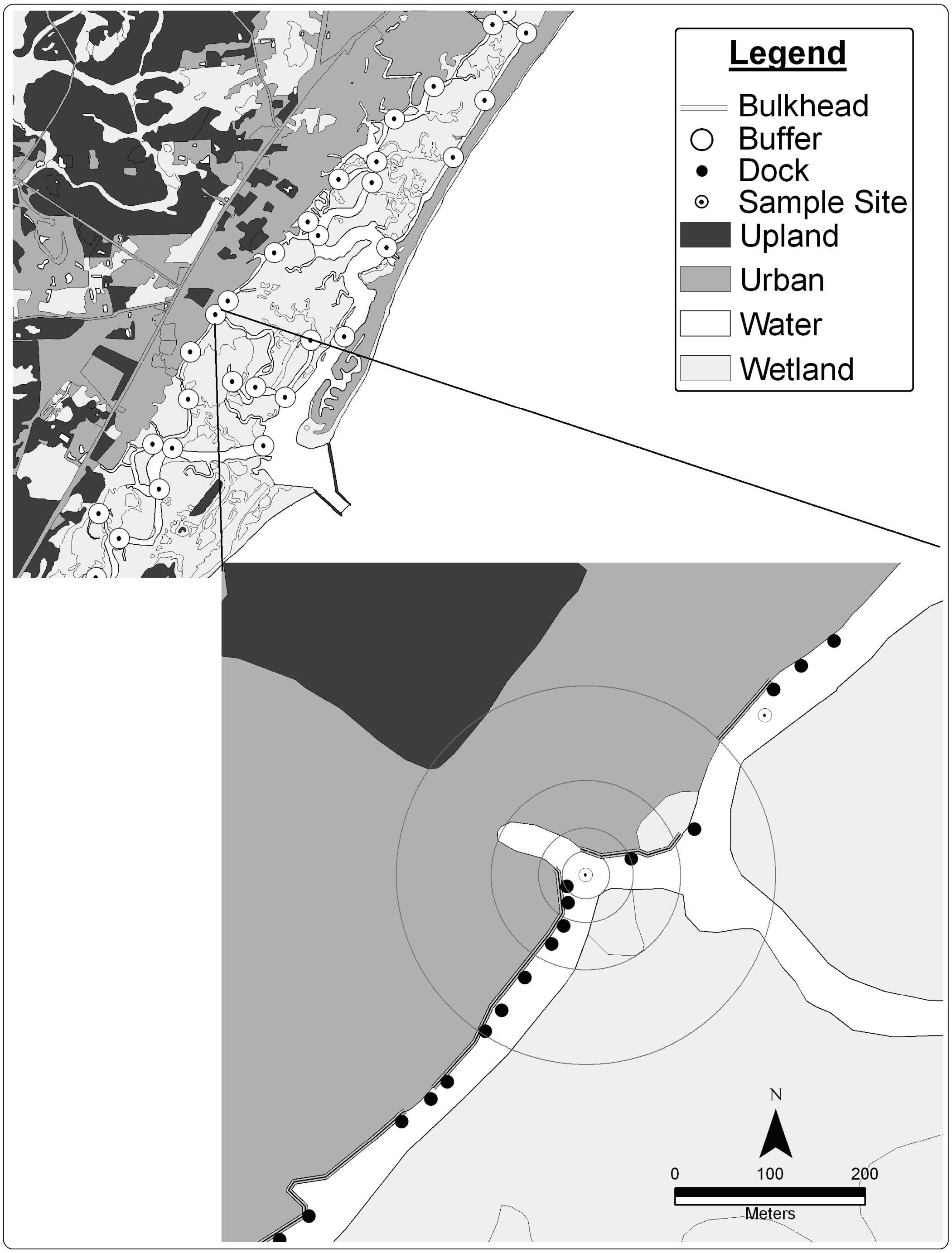
Legend
Bulkhead
Buffer
Dock
Sample Site
Upland
Urban
Water
Wetland
N
0
100
200
Meters

Figure 3. **Murrells Inlet, SC *Palaemonetes* species density estimates grouped into estuary position.**

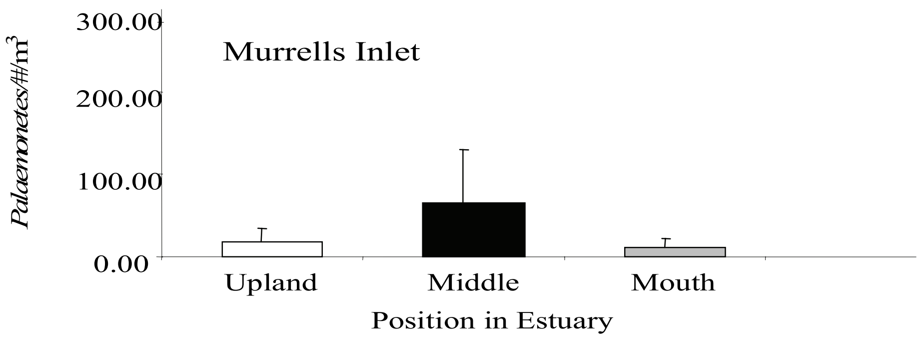
Murrells Inlet
Palaemonetes/#/m3
300.00
200.00
100.00
0.00
Upland
Middle
Mouth
Position in Estuary

Table 1. Mean Murrells Inlet Estuary, SC water and sediment quality parameters for 30 *Palaemonetes* species sample sites.

Parameter	Mean	SE	Range
Salinity (ppt)	33.0	0.5	25 to 36
Dissolved Oxygen (mg/L)	4.1	0.3	1.9 to 5.9
Temperature (^{0}C)	29.6	0.42	25.3 to 32
Total Kriged PAH's (ng/g)	513.2	88.9	49.2 to 2085.6

.

Table 2. Mean spatial parameter values measured in Murrells Inlet, SC within each concentric buffer distance at *Palaemonetes* species sample locations.

	Buffer Distance (m)				
Parameter	25	50	100	200	400
Urban %	4.20	10.26	17.39	22.20	21.95
Water %	86.90	68.39	46.38	30.68	23.44
Wetland %	8.89	21.39	36.23	44.63	52.42
Upland %	0.00	0.00	0.00	2.48	2.18
Impervious %	0.81	1.98	3.36	4.83	4.78
Docks (n)	0.20	0.63	2.03	3.33	17.36
Bulkhead (m)	2.53	22.23	59.20	124.52	283.14

Table 3. Independent Variable that were significant for multiple regression analysis of 30 *Palaemonetes* species sites within Murrells Inlet, SC. Adjusted R square is shown for each significant variable. Independent variables are Docks, Bulkheads, Impervious Surface, Kriged PAH value and Land Use (Upland, Wetland, Water, Urban), at each concentric circle buffer size.

	Concentric Circular Buffer Size (m)				
Selection Process	25	50	100	200	400
Stepwise	None	None	Water R^2=0.23	None	Water, Urban R^2=0.52
Forward	None	None	Water R^2=0.23	None	Water, Urban R^2=0.52
Backward	None	None	Bulkhead, Water R^2=0.28	Impervious Surface, Water R^2=0.26	Water, Urban R^2=0.52

United States Department of Commerce

Carlos M. Gutierrez
Secretary

National Oceanic and Atmospheric Administration

Vice Admiral Conrad C. Lautenbacher, Jr. USN (Ret.)
Under Secretary of Commerce for Oceans and Atmospheres

National Ocean Service

John (Jack) H. Dunnigan
Assistant Administrator for Ocean Service and Coastal Zone Management