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Baseline Port Surveys for Introduced Marine Molluskan, Crustacean and Polychaete Species in the South Atlantic Bight

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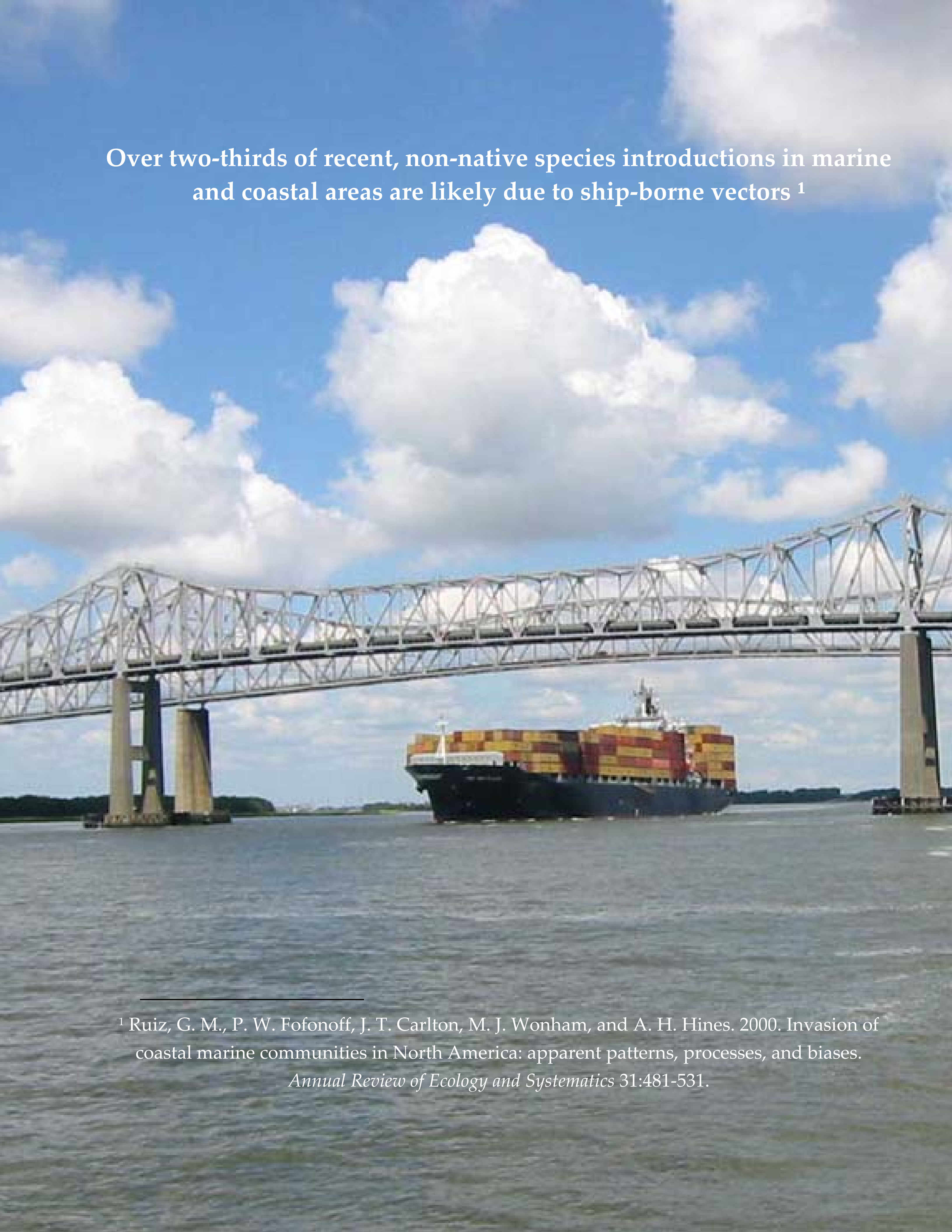

Over two-thirds of recent, non-native species introductions in marine and coastal areas are likely due to ship-borne vectors [1]

[1] Ruiz, G. M., P. W. Fofonoff, J. T. Carlton, M. J. Wonham, and A. H. Hines. 2000. Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. *Annual Review of Ecology and Systematics* 31:481-531.

EXECUTIVE SUMMARY

Objectives

- To conduct an extensive literature review of existing biotic surveys for mollusks, crustaceans and polychaetes in the South Atlantic Bight (SAB) region.
- To describe the ports of Jacksonville, Savannah, Charleston, and Wilmington in terms of their history, geology, hydrography, and shipping movements.
- To conduct a comprehensive search for molluskan, polychaete, and crustacean species in each port.
- To provide baseline information on native biodiversity, and on the presence, distribution, relative abundance, and trophic status of identified nonindigenous molluskan, crustacean and polychaete species.
- To identify priority invasive species either present, or with the potential to occur at each location.
- To determine differences in community structure, sediment size, and water quality parameters across this geographical region.
- To integrate all data with GIS, and to disseminate results to potential end users, including accessible databases to contribute to the national knowledge base of invasive species.

Methodology

We used an array of field sampling devices (traps, sediment cores, fouling plates, piling scrapings, and trawls), mirroring procedures described for an Australian nationwide port survey for nonindigenous species (Hewitt & Martin, 2001[2]). Each port location was divided into three sampling zones; the immediate port area (port, zone 2), one upstream (upper, zone 3), and one downstream at the mouth of each river (lower, zone 1).

Rationale

It has been estimated that at least 7,000 different species are being carried in ballast tanks around the world and that roughly 21 billion gallons of foreign ballast water are annually discharged into U.S. waters (Global Ballast Water Management Programme). While commercial ports represent a main entry point for many species introductions, very few have been surveyed to document the nonindigenous flora and fauna present. One region for which information is particularly lacking is the South Atlantic Bight (Cape Hatteras, North Carolina to West Palm Beach, Florida). This region currently has many of the largest and fastest growing container and automotive ports in the nation. Trade growth is predicted to continue, particularly with Asia. Baseline surveys are critical if we are to reduce the risk of aquatic nuisance species being introduced and transferred to and from this region. Our results will be useful in evaluating regional differences in invasion rates and patterns. Information will be shared with the Smithsonian's National Ballast Water Information Clearinghouse, the Aquatic Nuisance Species Task Force, and the USGS Nonindigenous Aquatic Species Program, coastal natural resource managers, and the respective port authorities.

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[2] Hewitt, C.L. and R.B. Martin. 2001. *Revised protocols for baseline port surveys for introduced marine species: survey design, sampling protocols and specimen handling.* Centre for Research on Introduced Marine Pests. Technical Report No. 22. CSIRO Marine Research, Hobart. 46 pp.

Results

A total of 221 species were collected, comprising 36 mollusks, 122 crustaceans, and 63 polychaetes. Voucher specimens have been placed in the Georgia Museum of Natural History in Athens (GA) and at the Southeastern Regional Taxonomic Center in Charleston (SC). No new invasive species were detected through our surveys, however five previously identified nonindigenous crustaceans were collected, *Balanus trigonus* (barnacle), *Ligia exotica* (isopod), *Apocorophium lacustre* (amphipod), *Balanus amphitrite* (barnacle), and *Petrolisthes armatus* (decapod). The most ubiquitous molluskan species were *Brachidontes exustus*, *Geukensia demissa*, *Sphenia fragilis*, *Lolliguncula brevis*, *Ischadium recurvum*, *Nassarius obsoletus*, *Mytilopsis leucophaeata*, *Amygdalum papyrium*, *Sphenia sp.*, and *Crassostrea virginica*. The most ubiquitous crustacean species were *Callinectes sapidus*, *Litopenaeus setiferus*, *Panopeus herbstii*, *Callinectes similis*, *Farfantepenaeus aztecus*, *Balanus eburneus*, *Melita nitida*, *Balanus juv sp.*, *Palaemonetes vulgaris*, *Eurypanopeus depressus* and *Hyale plumulosa*. The most ubiquitous polychaete species were *Neanthes succinea*, *Leitoscoloplos fragilis*, *Genetyllis castanea*, *Laeonereis culveri*, *Parandalia americana*, *Marenzelleria viridis*, *Polydora ligni (cornuta)*, *Mediomastus californiensis*, *Nereis falsa*, *Aricidea suecica, Lepidonotus sublevis, Sabella sp.* and *Streblospio benedicti*.

In all locations the zone downstream of the ports returned the most species. The results at Wilmington were far less diverse than those other three ports (Shannon-Weiner Diversity Index of 0.56), with species not very evenly distributed (evenness index of 0.14). Charleston, Savannah, and Jacksonville exhibited higher diversity indices at 2.66, 2.58 and 3.27, respectively. In these ports, species were also distributed more evenly with indices ranging from 0.53 to 0.72. Cluster analysis of port zones based on environmental characteristics (sediment parameters and water quality) divided the locations into two main species groupings consisting of marine (Jacksonville lower, Charleston port and lower), and brackish water zones (Jacksonville and Charleston upper, Savannah, and Jacksonville port, Savannah upper and lower), with the brackish water zones further split with the only freshwater zone (Savannah upper) in a subgrouping of its own. Wilmington was excluded from this analysis due to inconsistencies in sediment data. Bray-Curtis similarity indices for each of the gear types indicated the strongest similarity between the samples collected with crab traps over the entire study region.

Overall 13 replicates per sample gear seemed a reasonable number to adequately represent the number of species present in a cost effective manner. If possible, a slight increase to 15 samples for each habitat and gear type is advisable for future port surveys, and we also recommend placing sufficient back-up fouling plates to allow for significant losses.

Through outreach activities a public awareness campaign was initiated to alert recreational and commercial water users to report all unusual sightings in Georgia. Due to this effort the presence of the green mussel, *Perna viridis* was reported in State waters for the first time, representing a range expansion to the Savannah River as its most northerly location in the U.S. Just prior to completing this report a new nonindigenous barnacle species has also been reported in Georgia, possibly *Megabalanus coccopoma* or *M. tintinnabulum*. Neither species has been previously reported in the South Atlantic Bight region. This introduction warrants close attention given the potential fouling impacts that could occur.

A total of 74 publications were consulted to construct a GIS database detailing 36,502 mapping points for 1,738 species of mollusk, crustacean and polychaete fauna throughout the South Atlantic Bight

(SAB) region. The database can be found on the enclosed CD as an ArcView project; or the project is available for download on the University of Georgia Marine Extension Service Shellfish Research Laboratory webpage (www.marex.uga.edu).

Through a second literature review, 14 species of nonindigenous freshwater crustacean species and 8 molluskan species were found to have been reported as occurring in the SAB region. More were found for the marine environment, with 31 nonindigenous species representing 19 crustaceans, ten mollusks, and two polychaetes. Therefore our five collected species represent 9.43% of the total nonindigenous species (53) known to be present in the region. Notes on the distribution, life history, and impacts associated with the introduction of all known nonindigenous species are provided. Based on the review, the ranking of introduction vectors from the most common to the least common for all nonindigenous aquatic molluskan, crustacean, and polychaete species in the SAB are: ship fouling; bait release; ballast water and aquaria releases; aquaculture; range extensions; and fish stockings.

Sediment was similar throughout the region and predominantly poorly sorted fine to medium sand. Total organic carbon and nitrogen ranged from 0.17 % and 0.02 % in Jacksonville to 2.80 % and 0.09 % in Charleston, respectively. Based on water quality records for a one-year period, water temperatures are similar throughout the region with an annual range as follows (data recorded at stations at the mouth of each river system and above the immediate port areas): Wilmington, 7.1 °C to 30.0 °C; Charleston, 8.59 °C to 29.23 °C; Savannah, 10.5 °C to 28.3 °C; and Jacksonville, 9.6 °C to 29.8 °C. In general salinity ranges over the one-year period below each port showed large annual variations: Wilmington, 6.3 ppt to 32.7 ppt; Jacksonville, 8.25 ppt to 35.45 ppt; Savannah, 7.65 ppt to 27.23 ppt; and Charleston, 23.39 ppt to 32.76 ppt. Salinities above each port were less variable: Jacksonville, 0.3 ppt to 15.5 ppt; Wilmington, 0 ppt to 15 ppt; Charleston, 7.66 ppt to 15.29 ppt; and Savannah, 0.04 ppt to 5.52 ppt.

Risk Assessment

Ports represent habitats with natural and anthropogenic disturbance and relatively low diversity, making them particularly vulnerable to invasions. The majority of introduced marine species in the SAB have been introduced on ships' hulls (40 %) and this vector continues to pose a high risk for nonindigenous introductions. Despite recent advances in ballast water management regulations, untreated foreign ballast water continues to be released in U.S. waters and remains an important source for potential new species.

Similarities in environmental conditions between native and introduced areas is important in determining individual species invasion success. Several of the top ranked ports in the world lie in the same latitude range as the South Atlantic Bight, many of which have trade routes established to the region. Wilmington and Charleston have heavy trade with Europe, Savannah with Asia, and Jacksonville with the Caribbean. Other top trading partners include South America, Africa, and Oceania. Environmental conditions in ports of these trading regions should be investigated and related to those determined across our study area. Annual water temperatures in the SAB ports range from 8 to 30 °C and have predominantly poorly sorted fine to medium sand substrates with low to intermediate levels of organic matter. The varying distances each port facility is from the open sea (5.5 to 26 miles) presents a tremendous range in salinity regimes (zero ppt to 35.45 ppt).

The ports of Charleston and Savannah are among the busiest along the Southeast and Gulf coasts.

Annually, both ports are among the top ten in the nation with respect to containerized cargo, and among the top 20 in terms of cargo volume. This is particularly important since container vessels typically have fast and direct transit routes, resulting in a greater probability of nonindigenous species surviving the journey. For this reason these ports might be considered to have a higher risk of invasion. While the ports of Jacksonville and Wilmington do not handle as much traffic, they have unique global trading partners and are visited by more bulk and breakbulk vessels. A particularly low diversity of molluskan, crustacean and polychaete faunal elements was observed for Wilmington which is worth noting since species-poor communities often increase invasive success through the incomplete use of available ecological space.

All ports, with the exception of Wilmington, had reports of foreign untreated ballast water discharges during 2004. Jacksonville had the highest incidence (19.53 %) of untreated discharges (92,703 mt), most of which originated in Puerto Rico and the Bahamas. Ranked in descending order of volume, the following lists all the ballast water origins for untreated discharges at Charleston, Savannah, Jacksonville, or Wilmington during 2004: Puerto Rico, Bahamas, United States, Venezuela, Germany, Netherlands, Colombia, Panama, United Arab Emirates, Australia, France, South Korea, United Kingdom, China, Japan, Oman, Brazil, Italy, and Mexico. It appears that the only major regions from which ballast water was not received were Africa and Southeast Asia. Coastwise introductions through domestic ballast water discharge should not be overlooked. The South Atlantic Bight is relatively close to the ports of the Gulf of Mexico which has two of the top ten ranked ports in the world (South Louisiana, and Houston) and seven of the top ten United States ports in terms of cargo volume (data from 2004). Major ports north of the study area include Hampton Roads, Baltimore and New York/New Jersey. These ports may all serve as a source for future introductions of nonindigenous species.

In anticipation of continued growth, particularly through increasing trade with Asia, all four southeastern ports are currently undergoing expansion and deepening projects to increase their capacity. Clearly the South Atlantic Bight is becoming an important player in the international shipping trade, and should be considered an area of high risk for future introductions. Our study concludes by providing information on some invasive molluskan, crustacean and polychaete fauna that have the potential to be introduced to the SAB through shipping activities.

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1. INTRODUCTION

1.1. Background

Invasions of nonindigenous species are recognized as being second only to anthropogenic habitat destruction as a cause of global extinctions (Pimm, 1987; Gophen *et al*., 1995; Vitousek *et al*., 1997). The transport of hitchhiking organisms on ship hulls, and planktonic organisms in ballast waters are major sources of new invasions worldwide. The impacts of populations becoming established are devastating and irreversible (Cohen & Carlton, 1995; Mills *et al*., 1993; Ruiz *et al*., 1999; and Coles *et al*., 1999).

While commercial ports might represent an important entry point for new introductions, they have received only limited analysis nationwide. In Hawaii, Englund (2002) reported that 48% of all benthic invertebrate and fish species sampled from Pearl Harbor were nonindigenous. Hines & Ruiz (2000) reported 15 nonindigenous species in Port Valdez, Prince William Sound, Alaska. Cohen & Carlton (1995) reported 212 nonindigenous species from the San Francisco Estuary and declared it the most invaded in the nation. In recent years the Smithsonian Environmental Research Center has commenced a fouling community survey at many ports around the nation, in addition to compiling a synthesis of invasive species for the Chesapeake Bay, and an inventory for the Indian River Estuary in Florida. Rapid Assessment Surveys (RAS) designed to survey fouling community species have also been conducted in estuaries along the west coast of the United States since 1998 (Cohen *et al*., 1998; 2000; 2002) and more recently in New England (MIT Sea Grant http://massbay.mit.edu/exoticspecies/exoticmaps/index.html).

Experts concede that the patterns of invasion in U.S. estuaries remain confounded and identify a vital need to initiate "standardized ecological surveys of non-native species across major regions" (Ruiz *et al*., 2000). The Aquatic Nuisance Prevention & Control Act of 1990 established the Aquatic Nuisance Species Task Force and called for the formation of regional panels (Western, Great Lakes, Gulf and South Atlantic, Mid-Atlantic, Mississippi River Basin, and the Northeast) to deal with nonindigenous species issues, and identify regional research and management priorities. A Ballast Water & Shipping Committee has also been formed. Although the focus of each panel is regional, the key issues apply nationally, and each one shares the same priorities. One research priority consistently ranked highly is an assessment of the invasion risk, involving a characterization of the species present to provide baseline information against which invasion rates may be measured. Information on where, and how new invasions are occurring is critical to those developing invasive species management plans.

One area for which information on aquatic nonindigenous species is particularly lacking is the South Atlantic Bight (Figure 1). The SAB is a gently curving Bight of about 1,000 km, stretching from Cape Hatteras, North Carolina (35°N) to West Palm Beach, Florida (27°N).

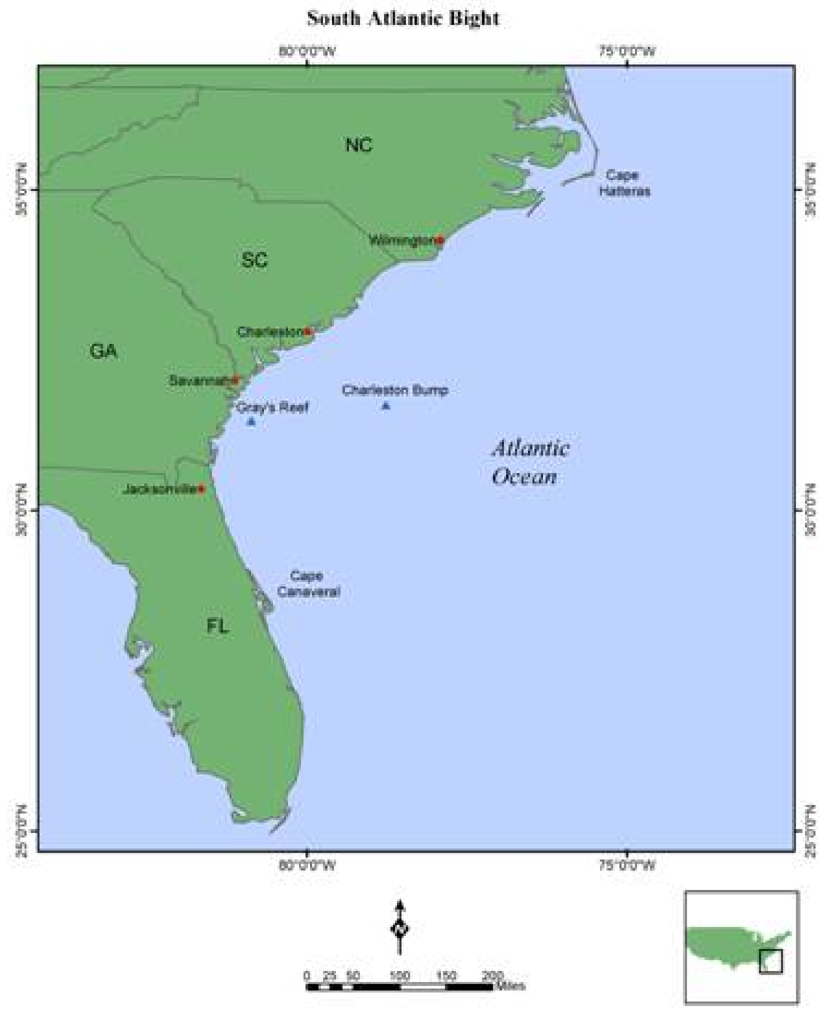


Figure 1 Map of the South Atlantic Bight (source: Southeastern Regional Taxonomic Center, http://www.dnr.sc.gov/marine/sertc/).

The shelf has an approximate width of five km off Palm Beach, 120 km off Georgia and South Carolina, and 30 km off Cape Hatteras. Prevailing currents move northwards away from Florida. The following oceanographic information about the SAB has been taken from the website of the Marine Ecosystem Dynamics Modeling Laboratory (MEDML) at the University of Massachusetts-Dartmouth (http://fvcom.smast.umassd.edu/research_projects/SAltBight/index.html). An inner, middle, and outer shelf divides the Bight, each one being defined by unique physical conditions. The inner shelf (to 20 m) is characterized mainly by a low-salinity front, which results from the interaction between freshwater discharge (ten rivers), wind and tidal mixing. A front between the Gulf Stream and coastal waters dominates the outer shelf. Combined processes on the inner and outer shelves control the mid-shelf (20 to 40 m). A 20-year mean of the total discharge over the Bight shows a seasonal low of 1,000 m^3/s in autumn and a maximum of 4000 m^3/s in spring. Tidal motion dominates the inner shelf with currents of between 30 and 40 cm/s near the coastal area. Tidal energy is largest in the widest part of the shelf between Savannah and South Carolina and smallest at northern and southern ends.

The marine environment of this region has been highly impacted by human activities and particularly shipping related activities since the early days of European settlement. The major ports within the Bight include the Port of Wilmington, NC; Port of Charleston, SC; Port of Savannah, GA; and the Port of Jacksonville, FL. All these ports are currently undergoing phenomenal growth with trade areas worldwide and in particular, Asia. According to the American Association of Port authorities, Charleston was the seventh and Savannah the ninth largest container port in the nation (ranked by TEU's or Twenty Foot Equivalent Unit) in 2005. Jacksonville was ranked 18th but is one of largest ports for automotive imports and exports. In terms of ranked total cargo volume (foreign trade) in 2004, the rankings were Savannah 16th, Charleston 20th, Jacksonville 34th, and Wilmington 45th (US Army Corps of Engineers, Waterborne Commerce Statistics Center). Although the transit time to and from Asia is slower, shippers see these east coast ports as reliable alternatives given the congestion and delays experienced on the west coast. Continued growth in trade with Asia is anticipated for the entire east coast, and in particular in the southeast region which offers the shortest routes. All ports currently have expansion plans including harbor deepening to accommodate even larger vessels (Breskin, 2005).

A prerequisite for any attempt to control the introduction and spread by shipping of nonindigenous marine species into our waters is knowledge of the current distribution and abundance of introduced species in our major ports. Without adequate knowledge of the extent of the invasive species problem in any geographical area, management plans to prevent, control, and minimize their economic, and environmental impacts are inadequate. Our study represents the first attempt to provide a comprehensive regional survey of aquatic nonindigenous species in the major ports of the South Atlantic Bight, an increasingly vulnerable region for nonindigenous invasions.

In addition to providing critical local baseline information, a complete survey will also contribute to national baseline data that is required to evaluate regional differences in invasion rates. This study serves as a comparative model for other regional studies. Port baseline surveys, in conjunction with physical and chemical characterizations using standardized, repeated, quantitative measures across multiple sites nationwide, could help to determine the correlates of invasion success.

1.2. Project Goal and Objectives

The San Francisco Bay/ Delta Estuary has reportedly more than 230 non-native species, 69% of which are mollusks, crustaceans and polychaetes (Cohen & Carlton, 1998). These taxa also comprise >95% of the ecologically important macrofaunal taxa in the mesohaline to euhaline reaches of these estuaries (the only other common group being oligochaetes and then insects in oligohaline to freshwater areas). Therefore we limited the taxonomic scope of our study on these components of the biota. The project goal was to determine whether nonindigenous mollusk, crustacean, and polychaete species have become established within the four major ports of the South Atlantic Bight (Wilmington NC, Charleston SC, Savannah GA, and Jacksonville FL).

The specific objectives were:

1) To conduct an extensive literature review of existing biotic surveys for mollusks, crustaceans and polychaetes in the South Atlantic Bight region.
2) To describe the ports Jacksonville, Savannah, Charleston, and Wilmington in terms of their history, geology, hydrography, and shipping movements.
3) To conduct a comprehensive search for molluskan, polychaete, and crustacean species in each

port.

4) To provide baseline information on native biodiversity, and on the presence, distribution, relative abundance and trophic status of identified nonindigenous molluskan, crustacean and polychaete species.
5) To identify priority invasive species either present or with the potential to occur at each location.
6) To determine differences in community structure, sediment size, and water quality parameters across this geographical region.
7) To integrate all data with GIS, and to disseminate results to potential end users, including accessible databases to contribute to the national knowledge base of invasive species.

2. PORT DESCRIPTIONS

2.1. Port of Wilmington

2.1.1. History

Early attempts in the 1600s to settle the Lower Cape Fear region met with limited success. In 1726, the first port area to be established on the Cape Fear River was named Brunswick Town, located approximately 12 miles upriver from the mouth. The site was convenient for ocean shipping but was too exposed to provide safe harbor for small crafts. Wilmington was established in the 1730s just below the confluence of the two main branches of the Cape Fear River approximately 30 miles upriver from the mouth. The area boasted a deep and safe harbor area and began to compete with Brunswick Town, especially for local traffic. An area of sandbars known as the "Flats" midway between Brunswick Town and Wilmington made it difficult for larger, heavily laden vessels to reach Wilmington and many would unload a portion of their cargo at Brunswick Town before heading upriver to Wilmington. Thus Brunswick Town was able to compete effectively with Wilmington as the primary port on the Cape Fear River until the Revolutionary War when, due to its exposure to British incursions, the residents of Brunswick Town abandoned the city. This established Wilmington as the principal port.

The first public wharves were built in Wilmington at the foot of Dock and Market streets in 1749 and 1752 respectively. Exports prior to the Revolutionary War centered on naval stores such as tar, pitch, rosin, turpentine and timber products derived from the extensive longleaf pine forests located in the region. After the war, exports in naval stores, which had primarily gone to supply the British fleet, declined slightly while exports in timber products and tobacco rose.

In the 1830s, dredging and a series of pile and plank jetties were employed to concentrate currents in order to deepen and broaden the channel between Wilmington and Campbell Island. The channel was deepened from ten to 13 feet and was also broadened and straightened. This resulted in ships being able to reach Wilmington directly without having to lighten their loads at Smithville (modern day Southport) in order to cross the Flats. During this period, cotton replaced tobacco as a major export.

The port of Wilmington proved to be of tremendous value to the Confederacy during the American Civil War and obstacles to navigation that had caused problems for shipping in the prewar period turned out to be a boon for blockade runners. Shipping via blockade runners continued with only minor interruptions until Fort Fisher was captured by Union forces in January 1865. These obstacles however, proved to be problematic once again after the war was over. The Corp of Engineers began dredging operations in 1874 and work to improve the channel continued in various stages until it was briefly suspended in 1917 due to the United States entry into World War I. At this time the river channel had been deepened to 26 feet and it was 300 feet in width. During the latter part of this period, the Corps also undertook the construction of a turning basin in Wilmington's harbor that, when completed, was 24 feet in depth, 300 feet in width and 5,300 feet in length. The requirement for naval stores and timber products declined as the 19th century came to a close and cotton became the major export from Wilmington wharves. After World War I, the Corps resumed its efforts to deepen the channel and by 1932 the channel was uniform 30 feet in depth.

The North Carolina State Ports Authority was created in 1945 to improve shipping capabilities. State Docks were opened in Wilmington 1952 and Wilmington's commerce increasingly flowed through the public facility. Shipping in Wilmington shifted to bulk commodities and by 1960 export tonnage consisted primarily of petroleum products, pulpwood and iron and steel scrap. The institution of the State Docks resulted in greatly improved terminal facilities in the port. By 1960, the facility offered a 2,510 foot wharf that could accommodate five 500 foot vessels simultaneously, transit sheds, storage warehouses, a modern fumigation plant, a freight car holding yard, a truck dock, weighing stations, and two heavy-duty cranes. Military traffic also began to add to the commerce through the port.

From 1970 to 1986 the number of ships coming to the port only rose by about a third but the amount of total tonnage moving through the state port facility more than doubled. This reflected a trend in shipping of using larger ships and a move towards containerization of cargo. This increased a continuing demand for deeper and wider harbor facilities in order for ports to remain competitive. Wilmington was also connected to the nation's interstate system with the completion of Interstate 40 in 1990 (Watson, 1992). The most recent channel deepening project in the Cape Fear River was declared complete in January 2004 and increased the channel depth to at least 42 feet from the ocean to the Wilmington state port facility. With larger ships able to reach the port fully loaded, the number of vessels calling on the port and the tonnage processed is expected to rise over the next ten years. A program is currently underway to double the capacity of the container terminal at the port in order to handle the expected increases. Long term plans are in the works to build a new container terminal in Brunswick County which is only nine miles from the mouth of the river. This would allow the port facility to service even deeper draft vessels without having to dredge the entire channel to Wilmington to a depth of 48 feet in order to accommodate the increasing size of container carrying vessels. This is also supposed to mitigate the ecological impact of deepening the channel on the Lower Cape Fear (North Carolina State Ports Authority).

2.1.2. Shipping Movements

The Port of Wilmington is owned and operated by the North Carolina State Ports Authority and is located in Foreign Trade Zone 66. The port handles containerized, bulk and break-bulk containers and has direct access to Interstates 95 and 40, as well as CSX Railways. The facilities of the Port of Wilmington lie 26 miles from the open sea on the east bank of the Cape Fear River. The main shipping channel is 500 feet wide and has recently been deepened to 42 feet, allowing vessel capacity to increase by 15%. There are a total of nine berthing spaces at the terminal. Wharf frontage is 6,768 feet and deck height is 12 feet above mean low water. The anchorage basin at Wilmington is 2,000 feet long and 900 feet wide at the upper limit and 1,200 feet wide at the lower limit. There are 42 piers, wharves and docks in Wilmington, 24 on the Cape Fear River and 18 on the Northeast Cape Fear River (US Army Corps of Engineers, 1997a). The port has a 70,000 ton storage capacity in an open storage dry bulk facility and a 2.5 million cubic foot storage space in a covered dry bulk facility (Figure 2).

The tonnage trend shows that the Port of Wilmington has handled a consistent amount of tonnage over the past ten years, with the exception of a 29% increase in tonnage in 2005. This was the highest break-bulk, container and bulk tonnage, as well as total tonnage in the ten year period. Total tonnage in 2005 was 3,004,064 tons: 1,271,417 tons break-bulk cargo, 781,046 tons containerized cargo and 951,601 tons bulk cargo (Figure 3). The majority of traffic in the port is shipping vessels (362 in 2005). A fewer number of barges come through the port, with only 14 in 2005, decreasing from 161 in 1996 (Figure 4).

Top imported commodities for 2005 were forest products, chemicals, cement, metal products and general merchandise. Top exported commodities for 2005 were wood pulp, forest products, food products, chemicals and general merchandise. Top imported and exported commodities for 1997-2005 and their relative percentages are presented in Figures five and 6, respectively.

Germany was the top importing country in 2005, while Italy was the top exporting destination. Korea, China and Colombia are also important trading partners (Figure 7). A ranked list of top importing, exporting and total trading partners for the Port of Wilmington are listed in Table 1. Further tonnage and trade statistics for the Port of Wilmington may be obtained @ www.ncports.com.

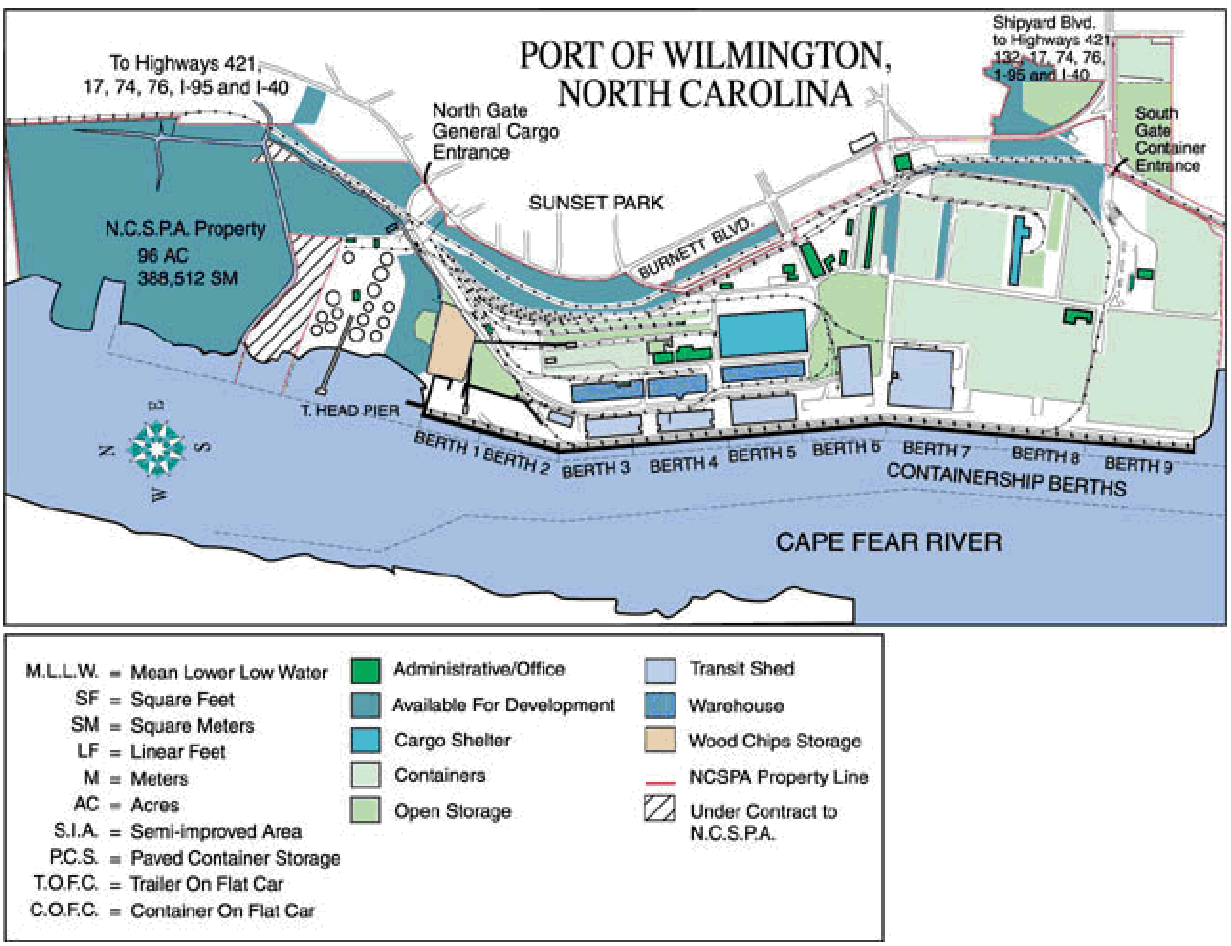


Figure 2 Port of Wilmington illustrating berthing spaces, storage locations and transportation links. (source: North Carolina State Ports Authority)

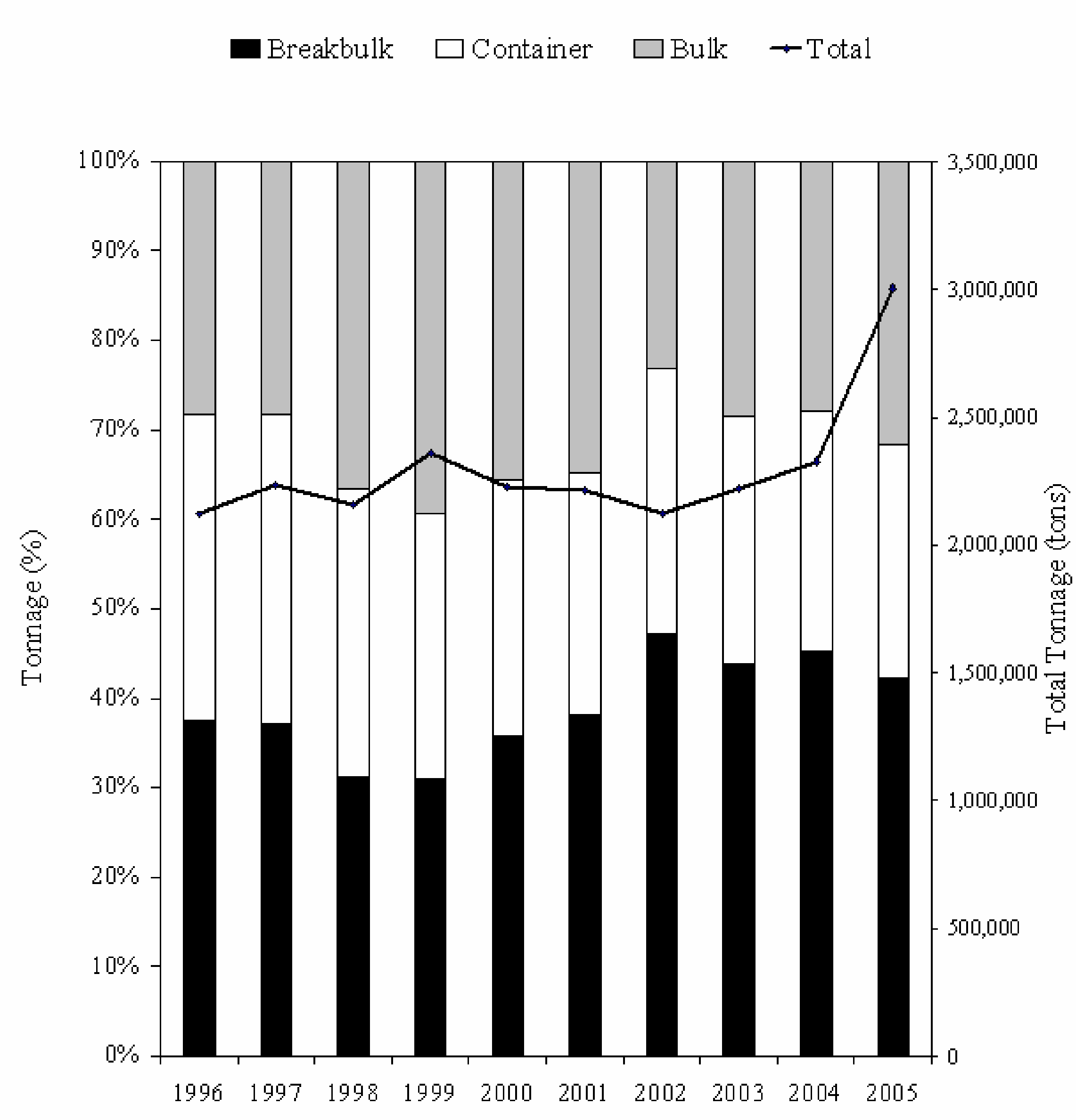


Figure 3 Port of Wilmington ten year tonnages, illustrating percent composition of break-bulk, containerized and bulk cargoes.

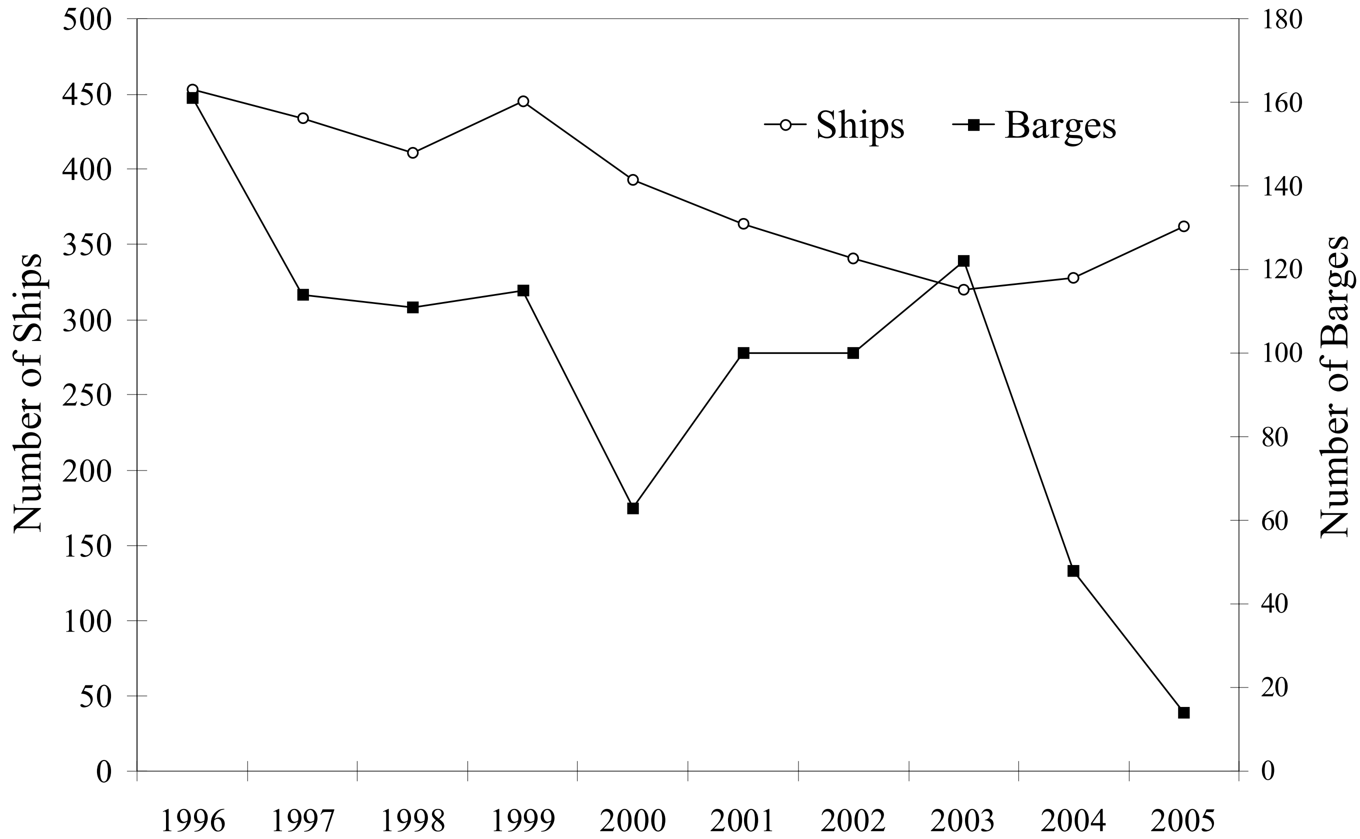


Figure 4 Port of Wilmington ten year vessel trend, illustrating number of ships versus barges, 1996-2005.

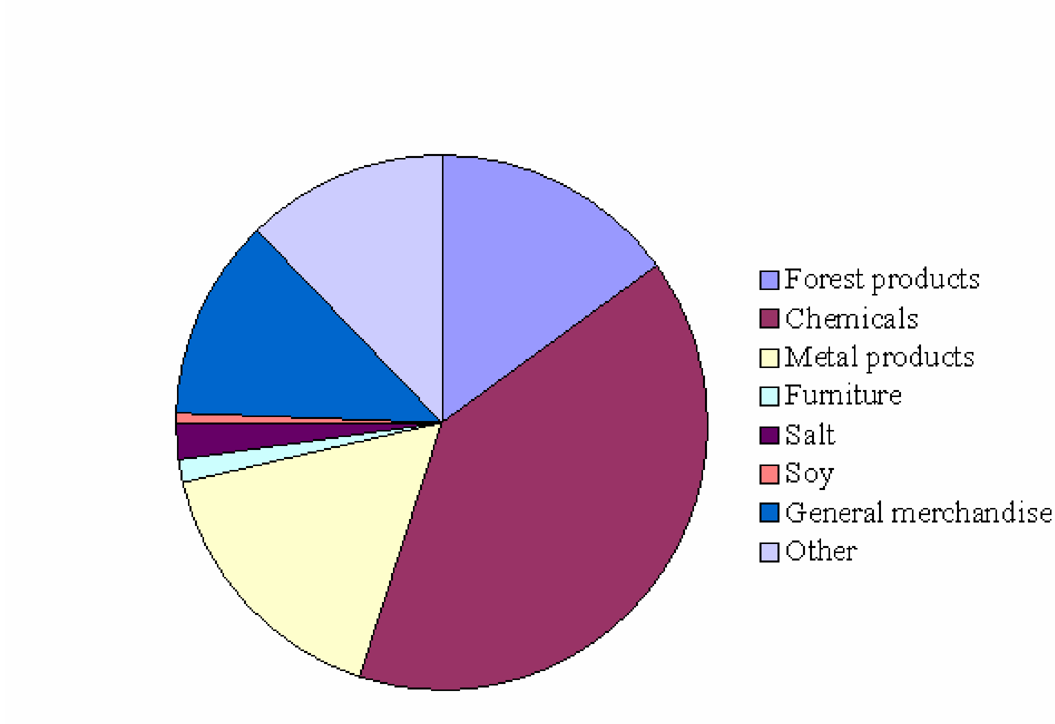


Figure 5 Port of Wilmington top imported commodities 1997-2005. The category other includes grains, potash, sodium nitrate, tobacco and cement.

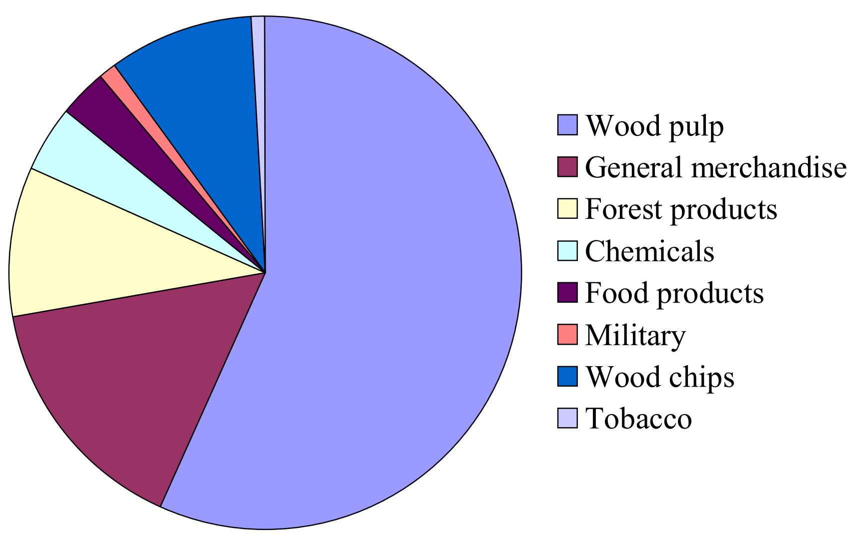


Figure 6 Port of Wilmington top exported commodities 1997-2005.

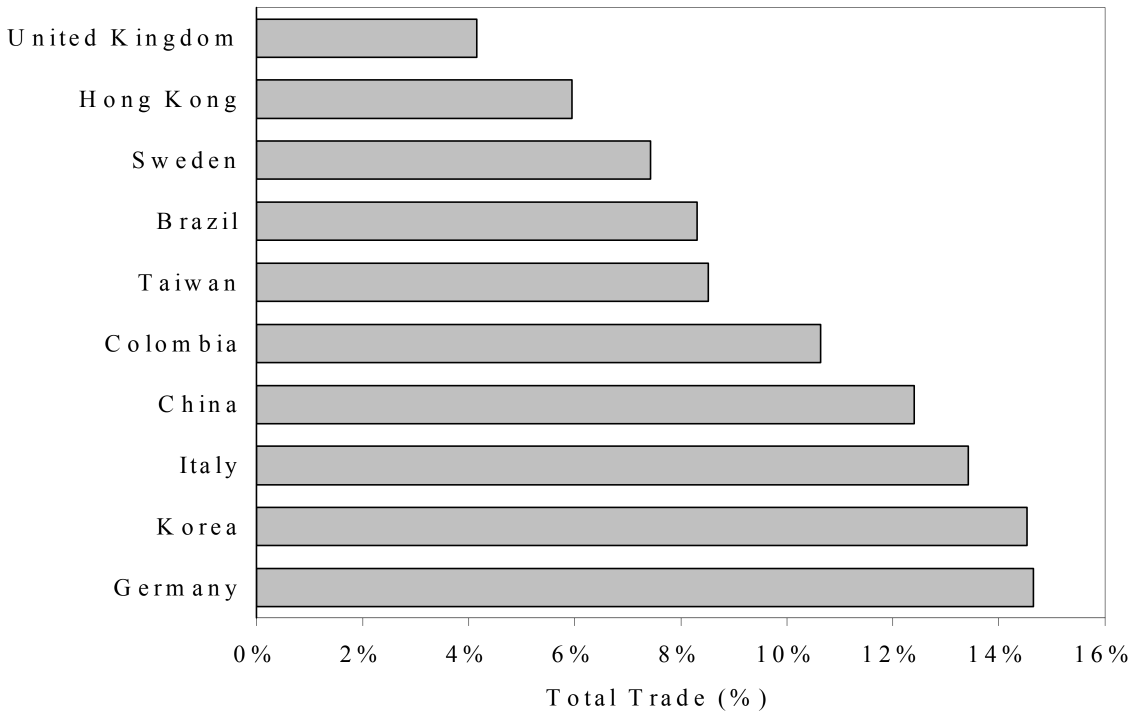


Figure 7 Port of Wilmington top trading partners (total trade) in fiscal year 2005.

Rank	Import	Export	Total Trade
1	Germany	Italy	Germany
2	Colombia	Korea	Korea
3	China	China	Italy
4	Brazil	Taiwan	China
5	Korea	Hong Kong	Colombia
6	Sweden	United Kingdom	Taiwan
7	Taiwan	Netherlands	Brazil
8	Canada	Belgium	Sweden
9	Chile	Spain	Hong Kong
10	Trinidad/Tobago	Germany	United Kingdom

Table 1 Port of Wilmington top ten trading partners ranked highest to lowest in fiscal year 2005.

2.1.3. Hydrography

The Cape Fear River can be described as a soft water, moderately acidic Coastal Plain river (Patrick, 1996). It flows in a generally southeasterly direction for approximately 200 miles. The area of the Cape Fear River Basin is approximately 9,300 square miles and is comprised of 6,300 miles of streams and rivers.

The Cape Fear River begins with the confluence of the Haw River and the Deep River. The Haw River originates near Oak Ridge and drains 1,526 square miles and the Deep River originates in Forsyth County and drains 1,442 square miles. These two rivers converge near the fall line, near the border of Chatham and Lee counties, to form the mainstream of the Cape Fear River. The fall line also marks the separation of the Piedmont sub basin, which comprises one-third of the Cape Fear River Basin (Haw and Deep Rivers), and the Coastal Plain sub basin, the remaining two-thirds of the Cape Fear River Basin. The Piedmont region is characterized by rolling terrain and forested floodplains. Everett Jordan Lake, a reservoir near the confluence of the Haw and Deep Rivers provides primary freshwater flow for the Cape Fear River. The high turbidity of the Cape Fear River can also be attributed to the Piedmont sub basin.

The Coastal Plain region is characterized by flat terrain, slow moving streams, swampland and estuarine areas. In the Coastal Plain sub basin, the Upper Little River joins the mainstream below the town of Lillington. The Lower Little River converges with the mainstream near Fayetteville, as does Rockfish Creek. Further downstream, the Black and South Rivers join. At Wilmington the Northeast Cape Fear River joins the mainstream to travel the remaining 24 miles to the mouth of the Cape Fear River. The Atlantic Intracoastal Waterway enters the Cape Fear River at Snows Cut and leaves the river three miles above the river mouth at Southport. The mouth of the Cape Fear River is located five miles west of Cape Fear, between Smith Island on the east and Oak Island on the west (Figure 8). The deepwater channel entrance is dredged across the bar and upstream to Wilmington.

Tidal influence is felt to 65 miles upstream from the mouth of the river (Mallin). Tidal ranges of the Cape Fear River are as follows: entrance, 4.5 feet; Southport, 4.1 feet; Wilmington, 4.2 feet. Water temperatures in the Cape Fear River range from 4°C to 32°C. The Cape Fear River Basin is subject to tropical cyclones and northeasters. The rain and storm surge result in riverine and coastal flooding (Dewberry & Davis, 2001).

The 2000 Census estimates 1,852,300 people living in the Cape Fear River Basin, averaging to 195 people per square mile (Cape Fear River Assembly, 2002). Urbanized and industrialized areas of the Cape Fear River Basin include Greenboro, High Point, Burlington, Chapel Hill and Durham in the upper basin, and Fayetteville and Wilmington in the Middle and Lower Basins. Fort Bragg Military Reservation is located within the Middle Basin. These areas have increased discharges and nonpoint source runoff (NCDENR, 2004). The final 45 km of the Cape Fear River, known as the Cape Fear River Tidal Basin is the final receiving area of these effluents (Mallin *et al*., 1999).

2.1.4. Geology

The two general geologic regions of the Cape Fear River Basin are the Coastal Plain Province and the Piedmont Province. The topography of the Coastal Plain Province is characterized by flat plains and that of the Piedmont Province is irregular plains. Each region is underlain by multiple geologic rock units. The Piedmont is underlain by belts of metamorphic and metavolcanic rocks of the Carolina Slate Belt. The underlying rocks include granite, granite gneiss, and slate. Another unit within the Piedmont is the Triassic basin which is underlain by basalt and fine-grained sedimentary rocks including mudstone, siltstones and shale. (US Geological Survey, 2001).

The transition from the Piedmont to the Coastal Plain occurs in Moore, Lee and Harnett counties. This transition is signified by a gradual change from well drained and gently rolling surfaces to flat surfaces. The Coastal Plain Basin is mostly underlain by unconsolidated sediments composed of alternating layers of sand, silt and clay. Changes in geology and soil types widely affect the flow characteristics of the Cape Fear River Basin. (US Geological Survey report 01-4094). Some soils in the upstream parts of the Cape Fear River Basin have low infiltration rates. These soils have low potential to sustain base flows for some streams in that area. Well drained and moderately drained soils are present in the central part of the basin with one of the largest concentrations of well-drained soils found in the Sand Hills. Variability of soil hydrologic groups in the Cape Fear River Basin is reflected in the potential to sustain low flow.

Figure 8 Map of the Cape Fear River, illustrating major tributaries.

Riverine sediments are typically imbedded dark clays and light sand, commonly containing a thin gravel layer at the base. Woody materials are common throughout: (North Carolina Division of Water Quality, 1995). The major clay materials are illite-smectite and kaolinite. The sands are variable largely because of the mixing of reworked Coastal Plain sediments and much less weathered minerals from the crystalline rocks of the piedmont with quartz and feldspar (the major sand minerals) with feldspar decreasing rapidly down valley (Owens, 1989).

Flow characteristics in the Cape Fear River Basin vary widely in response to changes in geology and soil types. The lowest potentials for base flow (contribution to stream flow from groundwater or spring discharge) is in parts of Durham, Wake, and Chatham counties. These soils are derived from basalt and fine-grained sedimentary rocks that allow very little infiltration of water into the shallow aquifers for storage and later release to streams. The area of the basin with the highest base flows is the Sand Hills region in parts of Moore, Harnett, Hoke, and Cumberland counties. Well-drained sandy soils in combination with higher topographic relief contribute to the occurrence of high potentials for sustained base flow.

2.2. Port of Charleston

2.2.1. History

For a detailed treatise on the history of Charleston see Coker, 1987; Edgar, 1998; Fraser, 1989; Leland, 1980; Rosen, 1997; Sully, 1998; and Tibbetts, 2002. In 1663, King Charles II of England granted a charter to the Absolute and True Lords Proprietors for control of the new territory of Carolina. Seven years later these men invested in Carolina's first permanent settlement, Albermarle Point, soon renamed Charles Town in honor of the King. The area quickly established its maritime prominence in the colonial South, becoming the largest and wealthiest city south of Philadelphia. By the 1730s South Carolina's rice plantation economy thrived on maritime global trade. Eight privately owned wharves were built from Bay Street into the Cooper River to serve the 500 deep-sea vessels a year that sailed in to trade. Charles Town was a primary North American destination for English ships. Due to the merchant's ships dependence on the trade winds, Charles Town was one of the first ports encountered after arriving at the Caribbean and turning north to following the Gulf

Stream along the eastern shoreline of North America. South Carolina declared its independence from England in 1774, leading to a siege on the coastal city. The British regained control in 1780 and subsequently retreated in 1782, when the city's name was officially changed to Charleston. In the post-Revolutionary years Charleston became even more prosperous, particulary due to the invention of the cotton gin in 1793 and the thriving slave trade. Approximately 22% of all slaves brought into North America from Africa during the 18th century arrived in Charleston.

Beginning in the early nineteenth century, however, South Carolina's shipbuilding industry was having difficulty competing with New England's. Laborers who could not work as cheaply as slaves migrated to shipbuilding cities in Rhode Island, Connecticut, and Massachusetts. Additionally, the Port of Charleston began losing maritime trade to other cities. Savannah, Mobile and New Orleans ports were becoming more favorable for cotton trading, while competition for rice trade was increasing from European colonies in Asia.

In 1825, the Erie Canal was completed, allowing barges to travel from the Great Lakes to the Erie Canal to the Hudson River and south to New York. This was the first waterway linkage between an Atlantic port and the agricultural lands beyond the Appalachian Mountains. Philadelphia and Baltimore followed suit. Progress in navigation and improved vessels soon opened new transatlantic routes, connecting the rapidly developing northeast directly to Europe. Charleston never constructed a railroad connection beyond the mountains and its harbor was also too shallow for these new steamships.

In 1860, the South Carolina legislature was the first state to vote for secession from the Union, and the first shots of the American Civil War were fired in Charleston Harbor in 1861. After being defeated, the economy in the South was ruined and for years the region had little to export. The war had shattered the prosperity of the antebellum city. Freed slaves were faced with poverty and discrimination. Charleston's wharves were destroyed by neglect, fires, a major hurricane in 1885, and a catastrophic earthquake in 1886. In the late 19th century, northern financiers held the monopoly over rail transport in the state and manipulated freight rates for the benefit of New York trading interests.

The Federal government authorized the first harbor deepening project through the Rivers and

Harbors Act of 1878 and included a channel draft of 21 feet across the bar and two stone jetties. Until the First World War, port trade was insignificant and primarily phosphate and lumber to supply the northeast. In the 1920s, a campaign was initiated to improve the infrastructure, however the Depression in the 1930s took a huge toll. The Charleston Naval Shipyard, founded in 1901, became by far the major industry in the area during World War II.

In an effort to rebuild, the General Assembly created the S.C. State Ports Authority (SPA) in 1942, and enabling legislation mandated development, construction, operation and advancement of ports in Charleston, Georgetown, and Port Royal. After the war, the Ports Authority received surplus property of the Army Port of Embarkation north of Charleston, and the docks in downtown Charleston. The Ports Authority enlarged berthing and storage facilities and obtained new business. Manufacturing firms were soon attracted south to the anti-union, low wage region. In 1966, the port handled its first standardized container, which had become the new and most efficient way to transport goods globally. Authorization to further deepen the harbor to 40 feet (MLW) occurred in 1986 and to 45 feet (MLW) in 1996. The entrance channel is 47 feet (MLW) and is dredged to 1,000 feet in width. The main channel width varies from 400 to 600 feet. Given the width of the harbor, depths and the proximity to the ocean, Charleston has a competitive edge over neighboring Savannah, Jacksonville and Wilmington.

Today the port has five intermodal terminals (Figure 9) and has become the busiest container port after New York on the East and Gulf coasts. In 2005, it was ranked the seventh busiest in the nation (American Association of Port Authorities). A sixth terminal is being built on a portion of the former Charleston Naval Base to meet future needs. A $635 million bridge, the largest cable-stayed bridge span in country, has also been constructed to provide a 186-foot vertical clearance over MHW, and a 1,546-foot horizontal clearance. There are also over 50 private terminal facilities in Charleston Harbor (shipyards, oil terminals, chemical terminals, steel terminals, tug operations, fisheries, scrap, wood products), most occurring along the west shore of the Cooper River. International trade through the Ports Authority facilities provides 281,660 jobs paying $9.4 billion in wages. In all, trade pumps $23 billion into the state economy and generates $2.5 billion in state and local taxes. Despite the closure of the Naval Shipyard and Naval Base in 1996, the Department of Defense has remained a large part of the region’s economy, with the Charleston Air Force Base, U.S.

Coast Guard, and other Department of Defense installations here. More information about the Port of Charleston can be found on the South Carolina State Ports Authority website @ www.port-of-charleston.com.

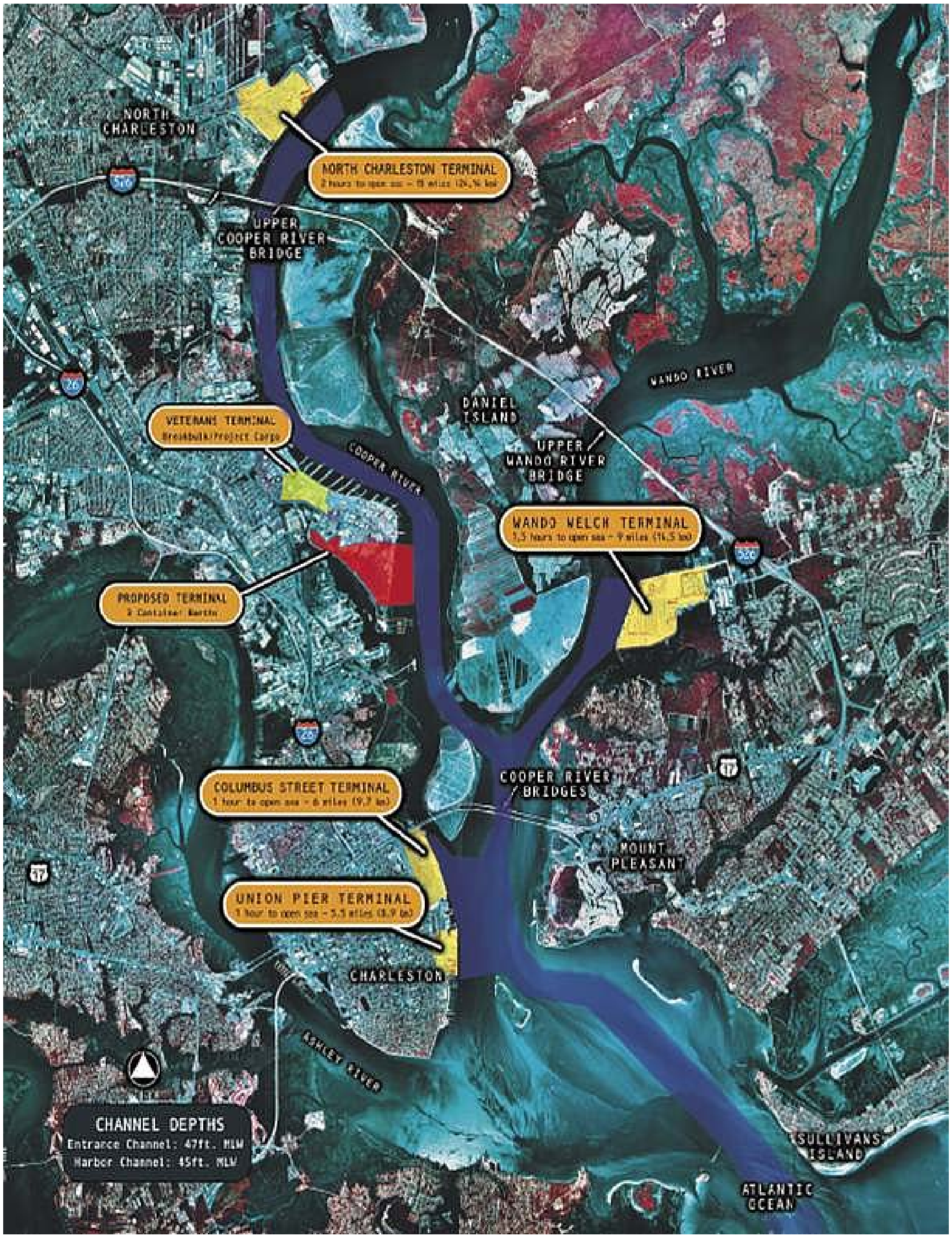


Figure 9 Port of Charleston illustrating five current terminals and proposed sixth (source: South Carolina State Ports Authority).

2.2.2. Shipping Movements

The five terminals which handle container, break-bulk, bulk and RO/RO (Roll On/Roll Off) cargo are:

(1) Columbus Street: break-bulk and container terminal; on Cooper River; 14.4 nautical miles from channel entrance; six berths (two container, four break-bulk); 3,875 feet berth space; 35-40 feet (MLW) depth at berths; four container cranes; total area of 160 acres with 70 acres open storage; 525,054 square feet transit sheds.

(2) North Charleston: container facility and grain elevator; on Cooper River, adjacent to Naval Weapons Station; 22 nm (nautical miles) from channel entrance; three berths; 35-40 feet (MLW) at berths; 2,500 feet berth space; six cranes; 201 acres with 123 acres for processing and storage.

(3) Union Pier: break-bulk and RO-RO cargo terminals; on Cooper River; 14.2 nm from channel entrance; four berths; 2,470 feet of berth; berth depth 38 feet (MLW); 70 acres; 728,828 square feet of transit shed; terminal includes a cruise passenger facility adjacent to berth one.

(4) Wando Welch: container and break-bulk; east side Wando River; ports largest terminal; 16.6 nm from channel entrance; 3,800 feet berth space, berth depth 40 feet (MLW); 673 acres; 194 acres for handling and storage; ten cranes.

(5) Veterans Terminal: bulk, break bulk, RO-RO.

There are a total of 21 container cranes at Charleston Port and all terminals are within two miles of Interstate 26. There are 150 motor carriers offering services into and out of the port, and rail services from both Norfolk Southern and CSX.

In 2004, the South Carolina State Ports Authority served 1.86 million TEUs through the Port of Charleston, up 10% from 2003. Of this container volume, 955,558 TEUs were exports and 908,358 TEUs were imports. A total of 1,919 ship calls were recorded for 2004, but this does not include barges or calls to private terminals (Figure 10). The break-bulk cargo totaled 607,000 tons and top commodities across included agricultural products, consumer goods, machinery, metals, vehicles, chemicals, and clay products. The port remains the busiest container port along the southeast and Gulf coasts and ranks fourth nationally. It ranks as the nations sixth largest in dollar value of international shipments, with approximately $39 billion annually. A further breakdown of the types of vessel by the number of calls (2,344 total) during 2003 is presented in Figure 11. All data presented was obtained from the South Carolina State Ports Authority website (www.port-of-charleston.com) and from personal communication with the Public Relations Manager.

More than 40 ocean carriers have ships carrying trade between Charleston and 140 nations around the world. The top trading partners are north Europe, Asia, Latin America, Mediterranean, Middle East, Indian subcontinent, Africa, and Eastern Europe (Figure 12, Table 2). The trade lanes served are Africa, Asia-Indian Ocean, Asia-Pacific, Australia-New Zealand, Caribbean, Europe-Atlantic, Mediterranean, South America-Atlantic, and South America-Pacific. New additional shipping services have recently been added to Central America, the Middle East, and South America.

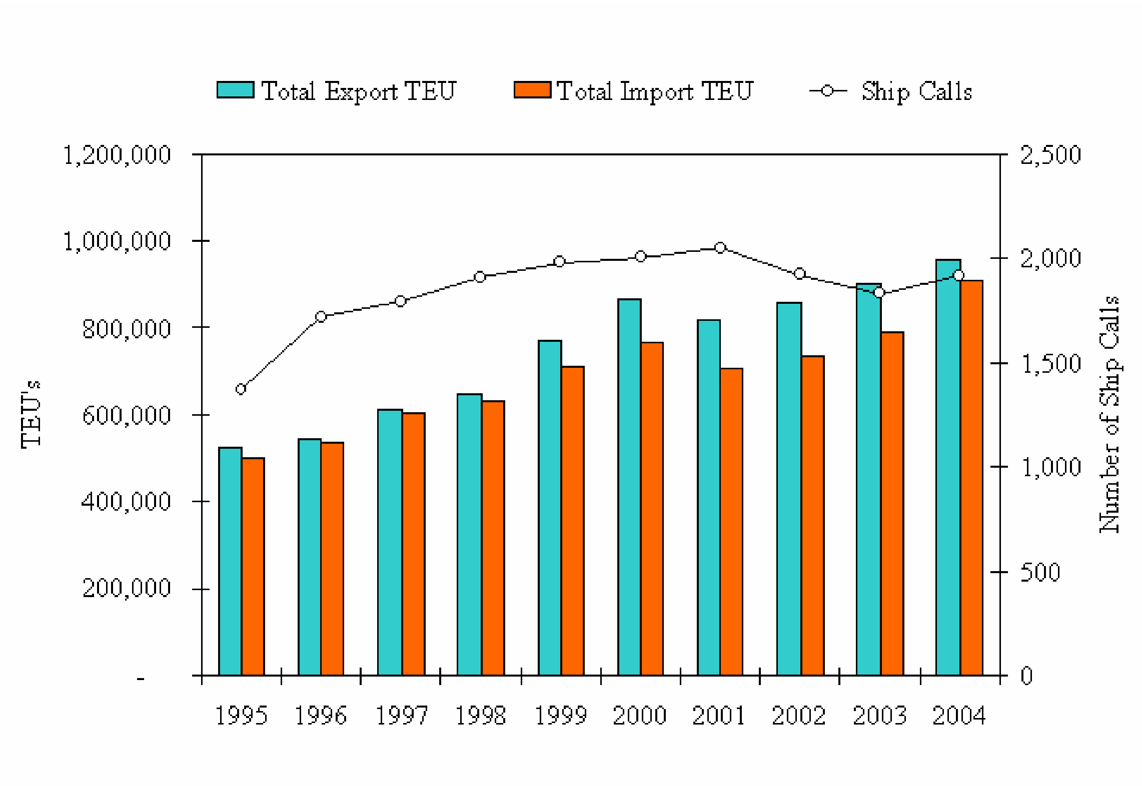


Figure 10 Charleston Ports Authority container volume history and the number of ship calls (not include private terminals and barges).

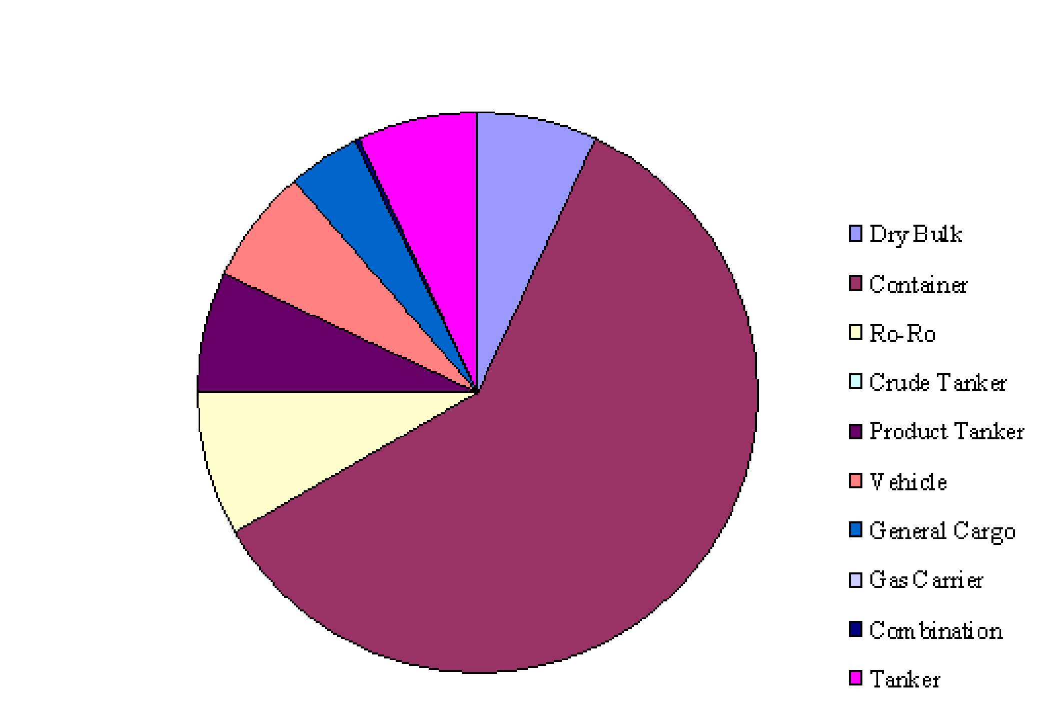


Figure 11 Vessel types and numbers of calls at Charleston Port during 2003 (America's Freight Transportation Gateways, February 2005, USDOT Bureau of Transportation Statistics).

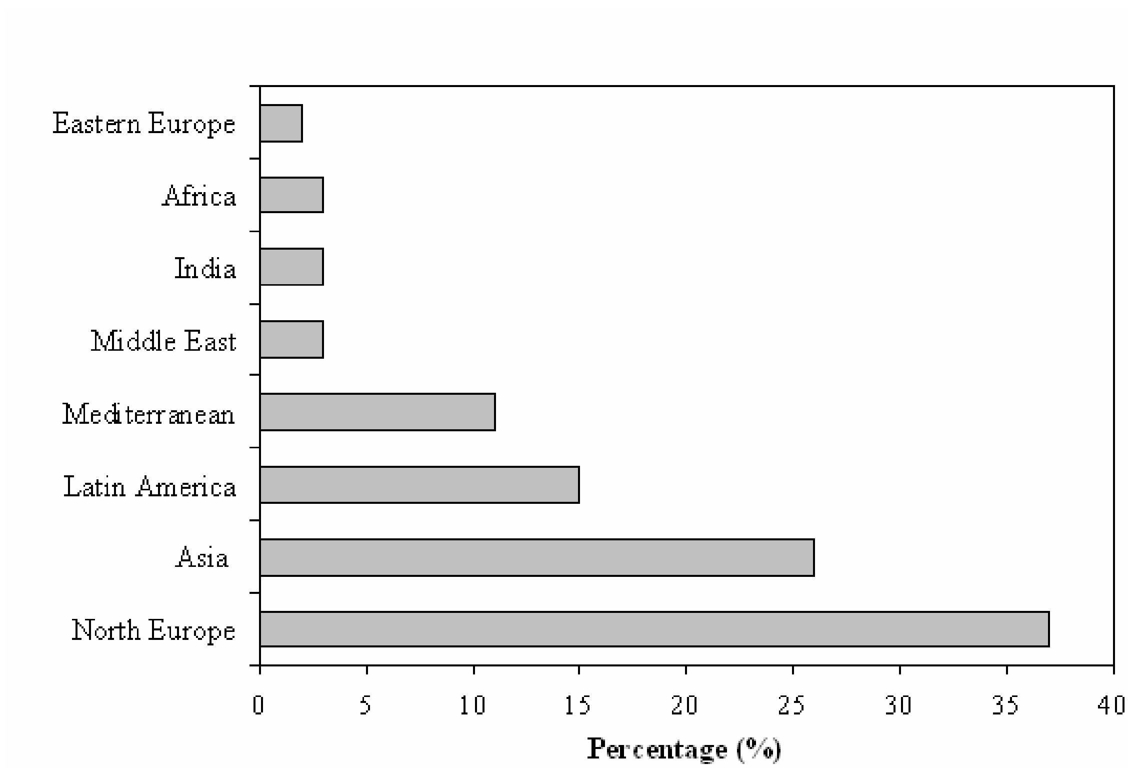


Figure 12 Charleston top trading partners in fiscal year 2005 (not include private terminals and barges).

Rank	Port	Country	Rank	Port	Country
1	ROTTERDAM	Netherlands	11	GIOIA TAURO	Italy
2	BREMERHAVEN	Germany	12	TOKYO	Japan
3	ANTWERP	Belgium	13	JAWAHARLAL NE	India
4	HONG KONG	Hong Kong	14	SHANGHAI	China
5	KAOHSIUNG	Taiwan	15	SANTOS	Brazil
6	HAMBURG	Germany	16	FREEPORT	Bahamas
7	ALGECIRAS	Spain	17	PUNTA MANZANI	Panama
8	FELIXSTOWE	United Kingdom	18	BUSAN	South Korea
9	LE HAVRE	France	19	YANTIAN	China
10	GENOA	Italy	20	SOUTHAMPTON	United Kingdom

Table 2 The current top 20 foreign port pairs in loaded containers - first/last overseas loading/discharge ports and do not reflect last ports of call prior to arrival (data courtesy Mr. Byron Miller, Public Relations Manager, South Carolina State Ports Authority 07/12/2005).

2.2.3. Hydrography

Hydrographic circulation patterns, sedimentation patterns, and the distribution of basic water quality parameters such as temperature, salinity, dissolved oxygen, pH and nutrients are all strongly affected by climatic conditions, tides, and freshwater flow. An extensive characterization of the hydrography of Charleston Harbor is provided by Van Dolah *et al*. (1990) and the U.S. Army Corps of Engineers (2005). The climate in Charleston is subtropical, with mild winters 10.1^{o}C/50.2^{o}F in

December, 27.2°C/81°F in July. An average of 1.4 hurricanes and tropical storms affect this region every year between June and November. Winds are seasonal, with northerly components dominating in fall and winter, and southerly components dominate in spring and summer (Landers, 1970). There is plenty of precipitation, averaging 48" per year with an annual distribution of rainfall maximum of seven inches in July and two inches in November. The summer months produce numerous thunderstorms (average of 57 annually). The net recharges to the surficial aquifer in the Charleston peninsula were four inches/year in 1989 and two inches/year in 1994. Generally the regional flow in the system is parallel to the Atlantic coast, from the southwest to the northeast. Surface waters include fresh waters and estuarine salt waters of the Catawba-Santee Watershed. This watershed (5,342 square miles: NOAA, 1985) is divided into five basins: the Catawba Wateree River Basin (2,381 square miles), Santee River Basin (1,208 square miles), Cooper River (830 square miles), Ashley River Basin (587 square miles) and Coastal Basin (334 square miles). These basins are further divided into 47 sub-basins or hydrologic units. The Cooper River, Ashley and Coastal Basins originate in the lower coastal plain and flow through the coastal zone region.

The Cooper River Basin has eight units, 830 square miles of watershed, 1,170 stream miles, and 45 square miles of estuarine area. The Catawba River crosses the South and North Carolina border near Charlotte NC, flowing through Lake Wylie and into Fishing Creek Reservoir, Cedar Creek Reservoir and Great Falls Reservoir. From Cedar Creek, it joins Big Wateree Creek and forms the Wateree River. The Wateree River merges with the Congaree River to form the Santee River. The Santee flows into Lake Merion, and is diverted east through Wilson Dam or south into Lake Moultrie. Lake Moultree discharges through the Pinopolis Dam and merges with the Wadboo Swamp to form the West Branch Cooper River. This is an 18 mile natural channel bordered by tidal marshes, and flows to the confluence with the East Branch Cooper River. The Cooper River is formed at the confluence of the branches and receives flows from Tidal Creek, Grove Creek, Back River, Flag Creek, Slack Reach, Yellow House Creek, Goose Creek, Filbin Creek, Noisette Creek, Clouter Creek, Shipyard Creek, Newmarket Creek, and the Wando River before draining into the Charleston Harbor and the Atlantic Ocean. The Wando River is a tidal slough that joins the Cooper River on the north side of the Charleston Peninsula and becomes a narrow tidal creek near Ward Bridge 22 miles upstream. Depths range from 1.5 m to 12.8 m, and it is influenced by tidal action throughout its length.

The Ashley River Basin has five units, and 587 square miles, with depths ranging from 1.8 to 11 m. The Stono River enters the Lower Ashley River through Wappoo Creek. The headwaters of Ashley River are comprised of Cypress Swamp, Dorchester Creek, Eagle Creek, and their tributaries. Ashley River flows through Bobs Lake and Schultz Lake, and drains into the Lower Ashley River. From here it flows downstream and receives drainage from Coosaw Creek, Olive Branch, Sawpit Creek, Popperdam Creek, Macbeth Creek, Keivling Creek, Church Creek, Bulls Creek, Duck Island Canal, Brickyard Creek, Orangegrove Creek, and drains into the Charleston Harbor and the Atlantic Ocean. The Ashley River is a tidal slough that extends approximately 28 miles from the peninsula of Charleston to Cypress Swamp.

The Coastal Basin has two units, 334 square miles, and 183 square miles of estuarine areas. The Basin comprises the Intracoastal Waterway which joins Charleston Harbor, from the west near the mouth of Ashley River, and from the east near Sullivan's Island. Awendaw Creek and the Stono River are the principal streams feeding this section of the Intracoastal. Charleston Harbor covers an area of 12 square miles, with the City of Charleston to the west, James Island and Morris Island to the south, Mt. Pleasant and Sullivan's Island to the north, and the Atlantic Ocean to the east. It receives flow from the Intracoastal Waterway, Shem Creek, Dill Creek, James Island Creek, Mill Creek, Kushiwah Creek , and the Ashley, Cooper, and Wando Rivers. The average depth of the harbor basin at mean low water is 3.7 m, and navigation channels are deepened to 12.2 m.

A major diversion project was completed by the South Carolina Public Service Authority in 1942 that diverted flow from the Santee to the West Branch Cooper River (Kjerfve, 1976). This transformed Charleston Harbor from a well mixed estuary to a partially mixed estuary, and a sediment trap. To alleviate shoaling problems the U.S. Army Corps of Engineers initiated the "Cooper River Rediversion Project" which was completed in 1985. This rediverted 70% of water flow from the Cooper River back into the Santee River through a canal. As a result the estuarine boundaries were extended through increased saltwater intrusion, the salinity regimes within the estuary was redistributed, the harbor went from being a stratified to a vertically mixed estuary, current patterns changed, water levels in the Upper Cooper river were reduced, and changes in the dilution and flushing rates of pollutants in the system occurred (Benson, 1976, 1977; Kjerfve & Magill, 1990).

Charleston Harbor, the Cooper River, Wando River, Ashley River and their tributaries experience semi diurnal tides, extreme tidal ranges and saltwater prism. The tidal range produces current velocities at all tidal entrances and creeks that often exceed 1.5 m/s. At the harbor entrance mean and spring tidal ranges are 5.13 and 5.95 feet, respectively. Near the city of Charleston, mean and spring tides are 5.27 and 6.11 feet. The Cooper River is affected tidally throughout it's entire reach up to the Tailrace Canal, and has mean and spring ranges of 5.4 and 6.26 feet at the south entrance of Clouter Creek, near Daniel Island, and mean and spring tides of 1.70 and 1.97 at Pimlico on the West Branch. Saltwater extends from the harbor to several miles below the confluence of the West and East Branches. Tidal ranges in the Wando River amplify upstream. Mean and spring at Hobcaw Point near the confluence with the Cooper River are 5.44 and 6.31 feet, respectively, which increase to 6.54 and 7.59 feet at Big Paradise Island. Saltwater extends throughout the entire river. The Ashley River is tidally affected throughout its entire length up to Bacon Beach. Mean and spring tides are 5.36 and 6.22 feet at James Island Creek on the Lower Ashley River near the harbor, and decrease to 1.94 and 2.25 feet at Bacon Bridge. Saltwater extends throughout its length.

There are no real salinity seasonal trends apparent in the system but there are distinct geographic trends. The harbor basin exhibits a polyhaline salinity regime; Cooper River is polyhaline in the lower reaches to limnetic in its upper; Ashley River is polyhaline to oligohaline; and the Wando River is almost entirely polyhaline. Salinity regimes in the Ashley and Wando Rivers are less stratified than in the Cooper River and the harbor. Dissolved oxygen percent saturation does have distinct seasonal trends throughout the estuary with highest levels in winter, lower levels in the spring and fall, and lowest in late summer (2.56 to 12.81 mg/l, averaging 7.09 mg/l). Typically levels decrease upriver. Turbidity levels do not exhibit seasonal trends but are highest in the upper Ashley River, lower in the harbor basin, and lowest in the Cooper and Wando Rivers. Nutrient levels are generally higher during the summer than winter and highest in the Ashley River. Post diversion daily mean freshwater flows exhibit negligible seasonal trends. Water temperatures range from 6.2^{o}C to 29.9^{o}C, averaging 19.8^{o}C (1985-1988), and bottom water is slightly lower than surface.

2.2.4. Geology

The Coastal Plain physiographic province of South Carolina consists of a wedge shaped sequence of deltaic and marine sediment deposits that gradually thicken to the Atlantic Coast. The outer shore is composed of geologically young developed barrier islands which are relatively flat (< ten feet above MSL). Sheltered by the barrier islands is an extensive intertidal salt marsh/tidal creek system. The shoreline has a dendritic drainage pattern which is typical of drowned coastal plain areas. Sediments in the Charleston area are approximately 2,500 feet thick, and are represented by the Cooper Marl (Oligocence), and recent surficial beach ridge sediments (Pleistocene). The Cooper Marl is calcareous clay deposited on a surface of Santee limestone which is similar to and a continuation of the rocks underlying the adjoining Piedmont Province. The Charleston estuary lies on the extreme southwest border of the Great Carolina Arch. In 1886 Charleston experienced the most damaging earthquake in the eastern United States, measuring 7.6 on the Richter scale. Since then the largest earthquake recorded was a 4.1 in 1992.

Surficial sediments originate from marine sources and freshwater runoff and exhibit spatial variability in their distribution. Sediment deposition is controlled by riverine flow rates, the location of the saltwater wedge, and tidal currents. The three main tributaries reflect a trend towards sandier sediments upriver, corresponding to a decrease in the percentage of silt and clay with increasing distance from the mouth (Van Dolah et al., 1990). The Lower Wando River has mostly fine to medium sand (70-75% sand, 20% clay, 5% silt, and small amounts of shell hash), and organic matter is low. The center of the river can have even higher proportions of sand and the nearshore higher amounts of silt and clay. The Lower Cooper River has more silt and clays in the center of the channel (clay 30-80%, silt 10-60%, sand 1-20%). Organic matter in general is closely associated with the occurrence of silt and clay size material.

2.3. Port of Savannah

2.3.1. History

In November 1732 General James Oglethorpe and 114 colonists set sail from Britain aboard the *Anne*. The colonists left seeking to dissolve their debts to King George II by establishing a new colony and producing goods for exportation. The *Anne* landed at Yamacraw Bluff (present day West Bay Street) on February 12th 1733. Oglethorpe declared the colony Georgia in honor of the King. They were met by Yamacraw Indians, led by Chief Tomochici who was friendly toward the colonists and helped negotiate meetings between the English and the Indians.

Oglethorpe named the river and city Savannah derived from a Muskogean Indian word. In May of 1733 the second ship of colonists landed in Savannah aboard the *James*. It reported a depth of 15 feet in which to anchor at low tide (Rhodes, 1949). Although slavery was illegal in Georgia, the colonists openly purchased slaves from the neighboring colony in South Carolina and in 1750 the colonists accepted the English charter making slavery legal.

Being ideally situated on the water with navigable channels, Savannah became heavily involved in the West African slave trade. The availability of slave labor led to the production and exportation of rice, cotton, tobacco and the creation of naval stores. These businesses flourished and the demand for slaves increased. In addition to the importation of slaves many non-British immigrants came to Savannah, including Jewish immigrants from Spain and Portugal fleeing the Inquisition in the early to mid 1700s.

Prior to the Revolutionary War of 1776 (America's War of Independence from Great Britain) the channel conditions changed rapidly due to heavy deposits of silt and sand and the discharge of ballast water from sailing vessels. The channel depth ranged from ten to 21 ft. During the Revolutionary War ships were sunk in the channel to make navigation impossible. The first plans for harbor improvement were drawn in 1796 at which time the State Legislature approved the Commissioners of Pilotage to make cut-offs in order to divert water from unused channels into the shipping channel (Rhodes, 1949). Ship movements decreased after the slavery ban in 1798 and in 1818 a yellow fever epidemic struck the city causing shipping business to stop almost completely.

A major accomplishment for shipping in the city occurred the year following the yellow fever epidemic. On May 22nd, 1819 the *SS Savannah* departed from the city to become the first steam ship to cross the Atlantic Ocean, returning on November 30th, 1819. Many people reported the passing of a ship on fire as she steamed her way along the Atlantic Seaboard. From the 1880s until the 1920s Savannah was the world's leading exporter of naval stores products, including pine timber, rosin, cotton and distilled turpentine. By 1905 Savannah's exports, chiefly cotton and naval stores, were greater than the combined exports of all other south Atlantic seaports.

The first Federal improvements to the port were made in 1826 when $50,000 was appropriated to close the Cross Tides Channel, to remove obstacles and dredge. The U.S. Army Engineers recommended dredging to a depth of 22feetin 1873 (Rhodes, 1949). Over 100 years later the U.S. Army Corps of Engineers is still recommending dredging of the channel.

Several attempts at modification of the channel to improve ship navigation have been made. These modifications include building dams, dredging, making cut-offs, constructing training walls and jetties, and the removal of obstacles. A dredged channel 40feetdeep at mean low water and 600 feet wide is maintained for about seven miles from the sea buoy (Tybee Lighted Whistle Buoy T. 31°58.3’N, 80°44.0’W) to the jetties. From this point channel depths are maintained at 38 feet MLW as the width decreases to 500 ft, then later to 400 feet (http://www.globalsecurity.org). There are several turning basins and pilotage is available 24 hours a day.

During World War II (1937-1945) Savannah’s port was one of the nation’s most active shipyards constructing Liberty Ships (emergency maritime cargo vessels) for the war. Though the port had been prominent since the mid 1700s, it was not until 1945 during the post WWII economic boom that the Georgia Ports Authority (GPA) was officially established by Georgia’s legislature recognizing both Savannah and Brunswick as official state ports. The Port of Savannah is located at latitude 32°02’N and longitude 80°54’W.

After the national security scare of September 11th, 2001 the Department of Homeland Security awarded the GPA $1.53 million in new security funding.

2.3.2. Shipping Movements

Savannah Port is comprised of two facilities, the Ocean City Terminal and the Garden City Terminal (Figure 14). Both are located close to Interstates 16 and 15, and are served by over one hundred trucking companies, and two railroads (http://www.gaports.com/index2.html). Sometimes referred to as "America's Retail Port" it is a prominent receiving point for companies such as Best Buy, California Cartage/Kmart, The Home Depot, Lowe's, Michael's, Pier I Imports, and Wal-Mart. Expansion projects are planned for both the Garden City Terminal and the Ocean City Terminal.

The Ocean City Terminal is a 208 acre facility located in downtown Savannah (32°05'24" N and 81°06'06"W). This facility is a secured, dedicated break-bulk facility specializing in the rapid and efficient handling of a vast array of forest and solid wood products, steel, RO/RO, project shipments and heavy-lift cargoes (http://www.gaports.com/Facilities/otoverview.html). It is located 15 nautical miles from Sea Buoy and 5.5 nautical miles from the Intracoastal Waterway (http://www.gaports.com). It has 6,688 linear feet (2,039 linear meters) of deepwater berthing, approximately 1.5 million square feet (138,164 square meters) of covered storage and 96 acres of open, versatile storage (http://www.gaports.com/index2.html).

The Garden City Terminal is a secured, dedicated container facility, the largest of its kind on the U.S. East and Gulf coasts (http://www.gaports.com). The 1,200 acre single terminal facility features 7,726 linear feet (2,874 linear meters) of continuous berthing and more than 1.3 million square feet (127,120 square meters) of covered storage (http://www.gaports.com). It is located at latitude 32°06'30" N and longitude 81°09'23" W.

Container traffic through the Port of Savannah comprises approximately 64% of the GPA's total tonnage and is greater than break-bulk and bulk traffic combined (Figure 13). The dramatic growth in this sector is significant. In 2002 (fiscal), container volume jumped 11% and, combined with the previous years performance totals, denotes a two-year increase of 30% (http://www.gaports.com). Ships come from all over the world to the Savannah Port but the majority of the trade is with the Far East, chiefly Asia. Other top trading partners include Africa, Oceania, and the Mediterranean (Figures 15 and 16) (pers. Comm. Hope Moorer, Program Manager, Navigation Improvement Projects, Georgia Ports Authority, Savannah, Georgia, September 2nd, 2005).

1n 2005, the Savannah Port was ranked the ninth largest container port in the U.S. when it moved almost two million Twenty-foot Equivalent Units (TEU's). This was a 14.4% increase from

2004. Figure 17 presents the TEU trend for a ten year period, it does not however include TEU's from private terminals. In 2004 the port was ranked the 16th largest port in the nation in terms of total foreign trade cargo volume, and fourth on the east coast after New York/New Jersey, Hampton Roads, and Baltimore. In 1992 the port was deepened to 42 feet MLW to accommodate larger container ships therefore increasing trade revenue. Georgia Ports Authority wants to deepen the channels to 48 feet to accommodate even larger "mega container ships". Economic growth is the driving force behind the harbor expansion project. The rate of containerized cargo growth at the Savannah Port is higher than the United States as a whole because Savannah has a greater share of trade with developing regions of the world (GPA, 1998). Under the Water Resources Development Act of 1999 congress authorized a $200 million harbor expansion project involving the deepening of the channel to 48 feet contingent upon the completion of a Tier II Environmental Impact Study (EIS), approval by the Environmental Protection Agency (EPA), Commerce, Interior and Army departments, and a final mitigation plan to adequately address the potential environmental impacts.

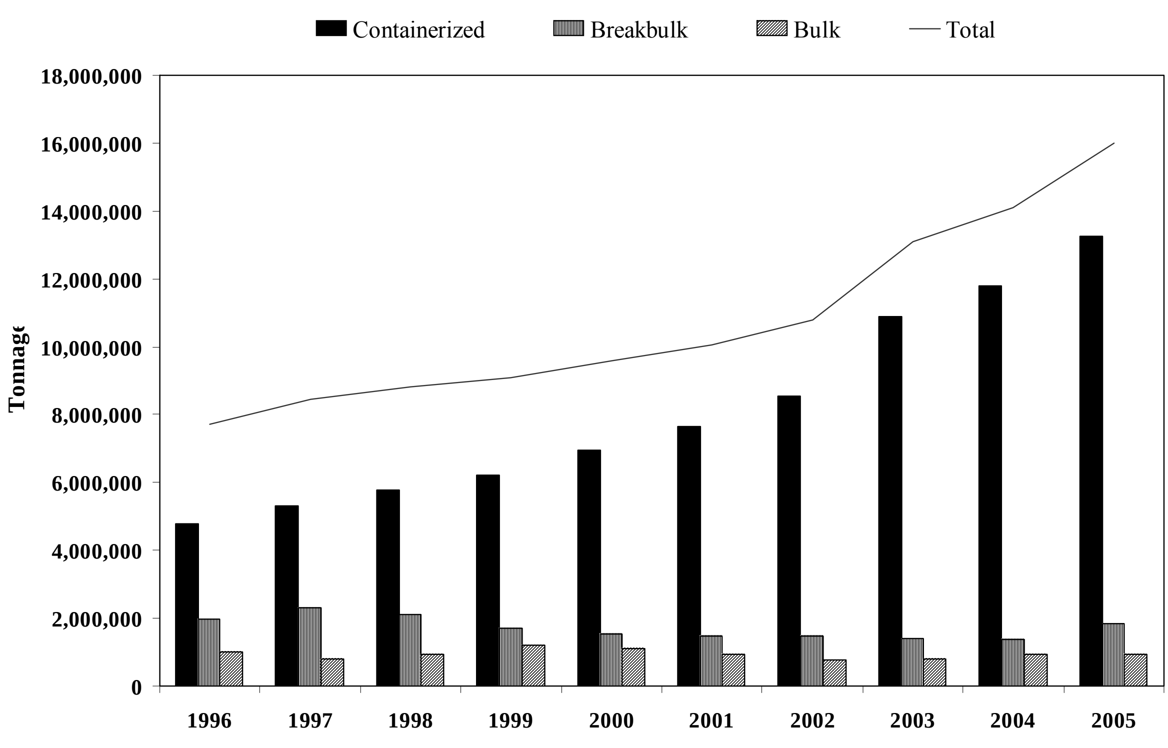


Figure 13 Port of Savannah cargo type by year (Georgia Ports Authority, data does not include private terminals).

Figure 14 Savannah Harbor (Georgia Ports Authority).

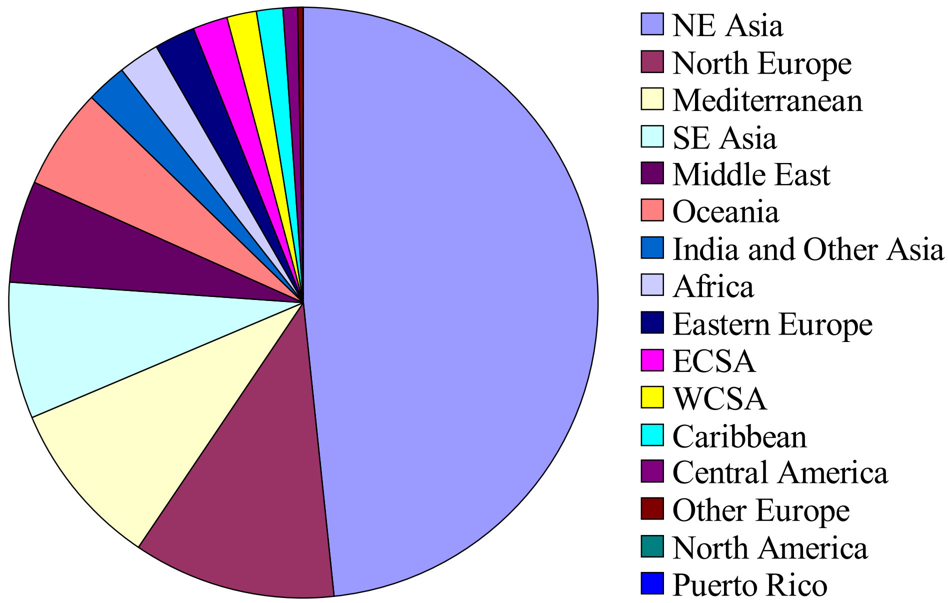


Figure 15 Port of Savannah 2004 Containerized Export Regions (Source: Georgia Port Authority).

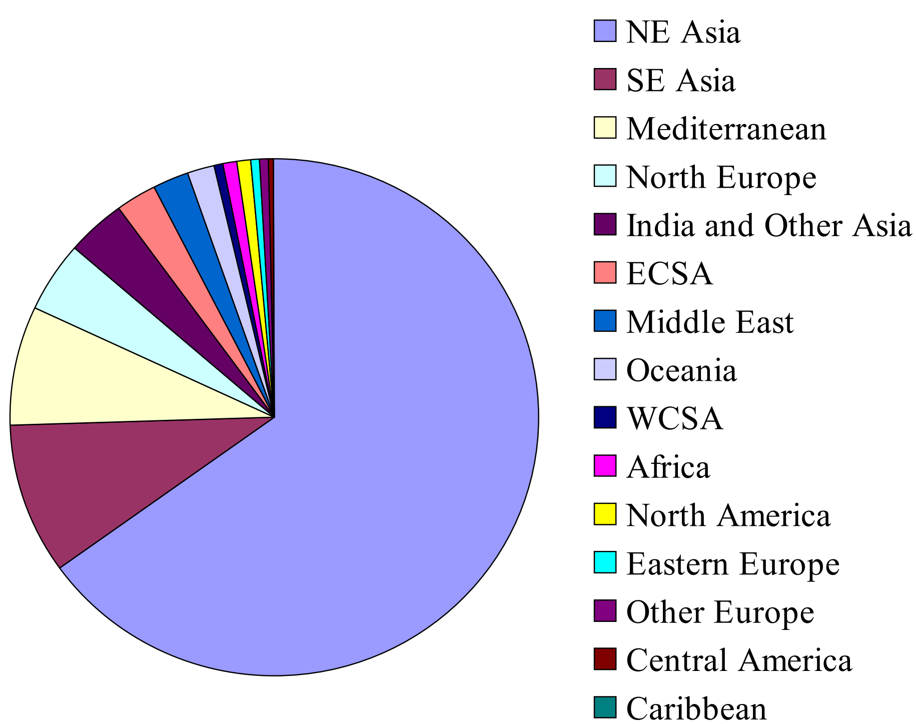


Figure 16 Port of Savannah 2004 Containerized Import Regions (Source: Georgia Port Authority).

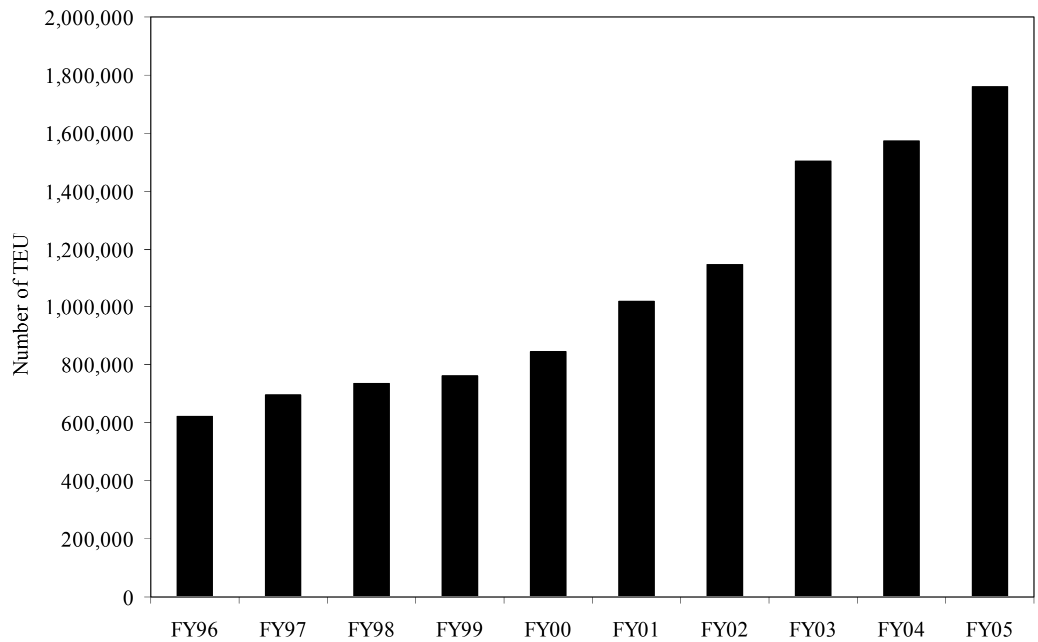


Figure 17 Port of Savannah TEU's 1996-2005 (Georgia Port Authority, data does not include private terminals)

2.3.3. Hydrography

The Savannah River is formed by three river systems; the Tallulah, the Chattooga and the Seneca (Figure 18). The Tallulah and the Chattooga originate in the Blue Ridge Mountains of North Carolina merging near Toccoa, Georgia to form the Tugaloo River. The Tugaloo River joins the Seneca River (originating near Clemson, South Carolina) near Hartwell, Georgia to form the Savannah River (begins 7.1 miles above the Hartwell Dam) which serves as the boundary line between Georgia and South Carolina. The river has a total length of 312 miles. The mouth of the Savannah River (~32°02'20"N, 80°50'27"W) is approximately 80 miles from the westerly edge of the Gulf Stream in the Atlantic Ocean (Rhodes, 1949).

The bathymetry east of the Savannah River mouth is characterized by shallow shoals and banks. The continental shelf reaches a maximum width of 130 km off the Georgia coast and ranges in depth from 0-70 m and includes a mid-shelf region between 14-45 m. The 50 fathom curve begins about 74 miles offshore, the 100 fathom curve is about 80 miles offshore, while the 1,000 fathom curve is 225 miles offshore (Rhodes, 1949). In comparison, Cape Hatteras, NC has depths of over 1,000 fathoms just 30 miles offshore.

The Savannah River Basin consists of an area of 10,577 square miles (GPA, 1998) and is divided into three physiographic areas: Mountain, Piedmont and Coastal Plain (Figure 6). The Piedmont is the largest of the three areas containing 5,223 square miles. The Savannah River varies in elevation from 5,030 feet in the North Carolina mountains to four feet or less in the Coastal Plain (Rhodes, 1949).

River flow is affected by the tides, run-off, and precipitation. The lower portion of the Savannah River is tidally influenced by semi-diurnal tides, meaning there are two high tides and two low tides every 24 hours and 50 minutes (Rhodes, 1949). At the Savannah River entrance the mean high water level is approximately seven feet and mean low water (MLW) is 0.2 feet. Tidal fluctuations average 6.8 feet at the mouth of the estuary and 7.9 feet at the upper limit of the harbor. The tidal influence extends approximately 45 miles upstream to Ebenezer Landing, Georgia. Maximum velocities encountered in the navigation channel are approximately four feet per second on the flood tide and five feet per second on ebb tide. Ebb velocities are usually somewhat higher than flood velocities. Tides vary depending on freshwater input from rivers, wind, rain, and the sun/moon phase and position. Exceptionally high tides sometimes occur reaching over nine feet and extreme low tides can drop to -4.5 feet. Freshwater discharges into the tidal section near Clyo, Georgia (River Mile 65), average 11,600 cubic feet per second, with maximum and minimum annual mean discharges of 20,900 and 9,820 cubic feet per second, respectively, since 1962 (GPA, 1998). Flows during the growing season typically are in the range of 8,000 to 9,000 cubic feet per second (GPA, 1998). The USGS station at Clyo, approximately 61 miles upstream of the mouth of the Savannah River, is the most downstream gage that records river discharges. Below this point, the Savannah River is tidal and the flow measurements are unreliable.

Rainfall is variable from year to year and many times the Savannah River Basin has gone through drought stages. In 1931 minimum annual precipitation was recorded in Savannah with only 22 inches for the year (Rhodes, 1949). Precipitation averages 48.9 inches/year, about half falling during summer thundershowers. Runoff averages about 15 inches/year over the basin (GPA, 1998).

Savannah Georgia has a subtropical climate. The winters are mild and the summers are extremely humid. The seasonal mean temperatures are 10.6°C in winter, 17.8°C in spring, 27°C in summer, and 18.9°C in autumn.

The Georgia coastline latitude, 31°N, corresponds with the mean latitude of the axis of the subtropical ridge (deep high pressure systems, caused by the accumulation of air as a result of the convergence in the upper troposphere), and the orientation of the coastline is parallel to the mean storm track. Tropical storms typically follow a track of angling northwest at 30°N and then shifting to the notheast. By the time most hurricanes reach Savannah they have crossed over land and lost momentum or they tend to move parallel to the coastline while remaining well offshore (www.cnmoc.nay.mil). Georgia periodically receives heavy rainfall from these storms in the late summer to early fall months (Rhodes, 1949). The Savannah Port is protected from storms because it is far inland and has relatively shallow water depths, 30-45 feet.

Salinities in the Savannah River range from zero in the upper portion to 28 ppt at the mouth (Brush *et al.*, 2004). Prior to 1970 the front of the saltwater wedge (water having salinities of 0.5 ppt) began at river mile 22.7 (Pearlstine *et al.*, 1990). In 1970 a tide gate was constructed to divert water from the Back River into the Savannah Harbor for the purpose of scouring the Front River channel and reducing maintenance dredging (Jennings & Weyers, 2002). The salt wedge moved 2.3 miles farther up the Front River with the tide gate in operation (Pearlstine *et al.*, 1990). Salinity gradients can now be detected over 25 miles up river (Bossart & Wallace, 2003). The construction of the tide gate led to the conversion of 74% of tidal freshwater marshes to brackish and subsaline wetlands (Pearlstine *et al.*, 1990).

The Savannah River estuary serves as a nursery ground for many species of fish and invertebrates (Jennings & Weyers, 2002). Higher salinities coupled with accelerated flow led to a decline in the striped bass population due to increased mortality of juvenile larvae and eggs (Jennings & Weyers, 2002). Subsequently, the tide gate was dismantled in 1991. Studies show salinity and flow patterns have returned to pre-tide gate conditions (Reinert & Jennings, 2000). Water temperatures in the estuary range from 8.5°C to 29.9°C (2000-2003), averaging 21°C.

Salt water intrusion into the Upper Floridian Aquifer can also cause trouble for the states' fresh water resources. Many counties in Georgia (24) rely on fresh water from the aquifer for use in industrial, municipal, and agricultural operations. Management strategies for saltwater intrusion in Georgia include the restriction of pumping wells in some areas, encouraging water conservation practices, and performing hydrologic studies and water quality monitoring practices to watch for and understand saltwater intrusion in the aquifer (http://water.usgs.gov). The state is also looking for alternative sources of freshwater such as shallower surficial waters and the use of other aquifers.

Dissolved organic carbons in the Savannah River at river km 206 ranged between 3.42 and 7.96 mg/L and comprised the majority of the total organic carbon transported by the river (Patrick, 1996). Dissolved organic carbon affects contaminant availability and transport and nutrient availability and transport. Dissolved organic compounds that occur naturally in river waters are not known to be toxic; but breakdown products or fragments of humic substances produced by chemical or biological processes may be assimilated by humans and have an effect on health (Spitzy & Leenheer, 1991).

There are many potential sources of pollution along the Savannah River especially in those areas experiencing high industrial and shipping activities. Several studies have been conducted to examine contaminants in dredge material within the Savannah Port. Likely sources of contaminants are past use of DDT, pesticides, combustion of fossil fuels, antifouling agents, petroleum products from effluents or spills, industries, smelters, naturally occurring metals, electroplating and cooling waters from electric power industries, acid mine drainage, metal plating industries, unknown sources, weathering of rock, combustion of coal, and agricultural irrigation drainage systems (Winger *et al.,* 1990).

There is one nuclear facility located along the Savannah River. The Department of Energy's Savannah River Site (SRS) is located in South Carolina approximately 25 miles southeast of Augusta, Georgia (http://www.srs.gov). Its primary mission since inception in the early 1950s until the early 1990s was the production and separation of plutonium and tritium for use in national defense programs (http://www.globalsecurity.org/wmd/facility/savannah_river.htm). Since 1951 the Academy of Natural Sciences has been studying the water quality and biology of the Savannah River to assess potential effects of SRS contaminants and warm-water discharges on the general health of the river and its tributaries (http://www.acnatsci.org/research/pcer/savanah.html). The SRS is on the National Priority List for environmental cleanup. A ground water remediation program began in the early 1980s to remove contaminants from subsurface waters. The program employs advanced technological as well as natural remediation techniques to remove contaminants.

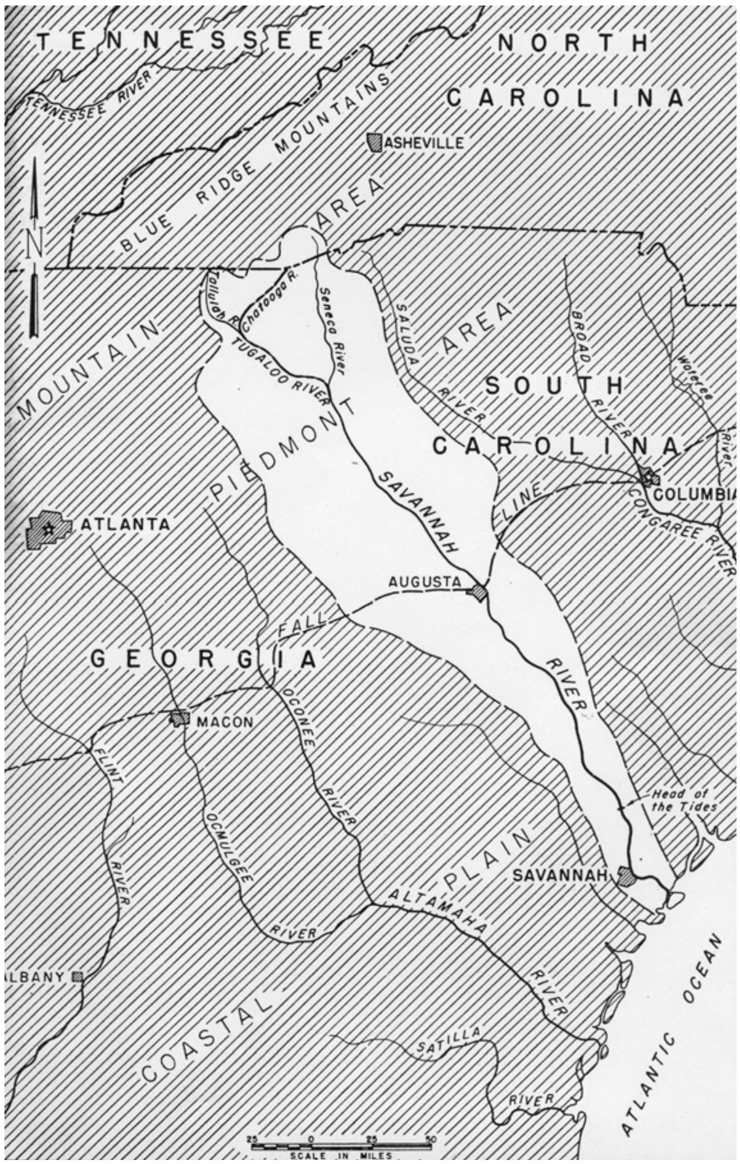


Figure 18 Savannah River Basin (Rhodes, 1949).

2.3.4. Geology

Two types of rivers are found in Georgia's Coastal Plain, through-flowing and coastal plain rivers. Through-flowing rivers begin above the fall line and are characterized by fast moving water carrying silt, sand, and clay. Coastal plain rivers meander and are generally clearer carrying decaying vegetation or small sediment particles. The Savannah River is a through-flowing river carrying a high load of clay which accounts for its characteristic reddish brown color.

Sands, clays, calcium and magnesium carbonates, limestones, sandstones, and marine deposits make up the soils of the Coastal Plain (Rhodes, 1949). The Coastal Plain and the continental shelf are separated by the seashore of the Atlantic Ocean. Together these two geographic regions form the Atlantic Plain. The continental shelf is the remaining submerged portion of the Coastal Plain. 40 million years ago the fall line (beginning of the Piedmont region) was the shoreline, and the entire Coastal Plain was covered by the Atlantic Ocean (Schoettle, 1996). The continental shelf is made of many under water terraces.

River bed sediment soils of the Savannah River Basin consist of various surface soils with finer subsoils lying underneath. Weathered granites, gneisses and schists are predominant in the Mountain region. Surface soil texture in this region is sandy loams with stones outcropping and subsoils containing clay loams and clays. The Piedmont area contains surface soils ranging from sandy loam to silty loam. The subsoils range from sandy clay loam to silty clay. The surface soils in the Upper Coastal Plain contain loamy sand, to sandy loam and subsoils are comprised of sandy clay loam, to sandy clay. External drainage in the Mountain and Piedmont region is moderate to rapid and internal drainage is moderate. The Coastal Plain area is somewhat poorly drained, with grayish soils formed from thin beds of sandy clay loam and sandy loam. Surface runoff and internal drainage occurs in the broad flat areas (Patrick, 1996). Limestones of tertiary and quaternary age underlying the Coastal Plain form one of the most productive aquifer systems in the country (GPA, 1998). The Lower Coastal Plain is flanked by marshes and barrier islands running parallel to the coastline. There are eight major clusters of barrier islands along the Georgia coastline, 88 miles of beach and 375,000 acres of marsh land.

2.4. Port of Jacksonville

2.4.1. History

In 1562, Jean Ribault led the Huguenots on an expedition to establish a settlement for the French Protestants. The expedition claimed the area now known as the St. Johns River in Jacksonville, Florida. Three years later, English traders sailed into the territory and bartered guns and ammunition for food and a vessel from the French. This exchange is the first recorded act of international waterborne commerce in the New World, establishing Jacksonville as America's First Port.

In 1565, the Spanish conquered the French territory. Florida remained in the hands of the Spanish until becoming a United States territory in 1821. In 1822, residents of Cowford, a settlement along the St. Johns River, appealed to the American government to recognize their position as a port of entry to the United States. The government agreed, and the inhabitants of Cowford renamed their city "Jacksonville". By 1845, Florida achieved statehood and the Jacksonville port had become an important cotton and timber trading center.

The main channel of the St. Johns River was deepened to 24 feet in 1906. In 1913, construction bonds were granted to the port in the amount of $1.5 million to build docking facilities. The channel was deepened again in 1916 and 1952, to 30 feet and 34 feet, respectively. In 1957, seven Volkswagon Beetles entered the port, marking the first shipment of imported automobiles. However, minimal financial investment in the port over the years resulted in Jacksonville being left out of the post-war shipping boom, leaving the port in need of repair and construction.

In attempt to rebuild the port business, the Florida Legislature created the Jacksonville Port Authority (JPA) in 1963. The JPA was granted the area of land now known as Blount Island, nine miles from the Atlantic Ocean, where the Blount Island Marine Terminal was established. The JPA was also granted the Talleyrand Municipal Docks in downtown Jacksonville, located 21 miles from the Atlantic Ocean. This site became known as the Talleyrand Marine Terminal, establishing the shipping channel as the 23 mile stretch beginning at the mouth of the St. Johns River and ending past the Talleyrand Marine Terminal. One year later, the JPA was issued a $25 million General

Obligation Bond for port improvements. The following year, the port's annual city allocation was capped at $800,000. The JPA was given no taxing authority, and instead is funded and utilized by private companies, as remains to be the case today.

In 1968, the JPA was given possession and handling of the city's airports. In 1978, the shipping channel was deepened from 34 feet to 38 feet. Twenty years later, the JPA gained property at Dames Point, located 12 miles from the Atlantic Ocean. Here a third terminal was established, Dames Point Marine Terminal. In 2001, the JPA took measures to increase security against domestic crimes and acts of terrorism. Some of these measures included increased security fencing, security patrolling, lighting and security cameras. A full-time Jacksonville Sheriff's Office was also placed on the premises. Also in 2001, the JPA was divided into two new divisions, the Jacksonville Airport Authority (JAA) and the Jacksonville Seaport Authority (JAXPORT). The JAA was designated to oversee the operation and maintenance of the aviation facilities, and JAXPORT the marine facilities.

In 2003, the main shipping channel was deepened from 38 feet to a maintained depth of 40 feet on the 14 mile stretch from the mouth of the St. Johns River to Drummond Point. This same year, Celebrity and Carnival Cruises began services in Jacksonville out of a new cruise terminal located one mile northwest of Dames Point Terminal.

According to the census of April 2000, Jacksonville ranks 13th in in the nation in population size with an estimated population of 735,617 individuals. The JPA has approximately 150 employees. Additionally, it is estimated that 45,000 jobs in northeast Florida are related to port activity. Port activities also generate 2.6 billion dollars annually in economic impact. Future plans for the port include the proposed expansion of the channel from Drummond Point to the Talleyrand Marine Terminal to a maintained depth of 40 feet. Studies are also being conducted by the U.S. Army Corps of Engineers to assess the impacts of deepening the channel to 45 feet.

2.4.2. Shipping Movements

The Jacksonville Port Authority (JAXPORT) occupies over 1,400 acres and houses three cargo terminals and one cruise terminal (Figure 19, Table 3). Three interstates travel through or near

Jacksonville, I-10, I-95 and I-75. In addition, three major railroads intersect in Jacksonville, Norfolk Southern, Florida East Coast Railway (FEC) and Jacksonville-based CSX Transportation. These transportation links allow rapid movement of cargo across the United States.

Blount Island Marine Terminal is JAXPORT's largest at 754 acres, located nine miles from the Atlantic Ocean. The terminal is located in Foreign Trade Zone #64. The terminal handles approximately eighty percent of the container activity that moves through the port. The Blount Island Marine Terminal has 5,280 feet of berthing space on 41 feet of deepwater and 1,350 feet of berthing space on 38 feet of water. The terminal is one of the country's largest automobile import-export centers, in addition to handling recreational boats, paper, woodpulp, steel and consumer goods containers.

Talleyrand Marine Terminal occupies 173 acres and is located on 38 feet of water. Located 21 miles from the Atlantic Ocean, the terminal is also located in Foreign Trade Zone #64. Many cargoes are handled at this terminal, including automobiles, consumer goods, poultry, beef, produce, steel, paper and liquid cargoes. The terminal also handles South American and Caribbean containerized cargoes.

Dames Point Marine Terminal is JAXPORT's newest terminal located 12 miles from the Atlantic Ocean. The terminal measures 585 acres and is on 41 feet of deepwater, with much still to be developed. Currently, the Dames Point Marine Terminal handles some bulk cargo activity, but there is planned development for break-bulk and automobiles.

The JAXPORT temporary cruise terminal measures 63,000 square feet and is located in northeast Jacksonville, one mile northwest of Dames Point Marine Terminal. Beginning in fiscal year 2004, two cruise lines, Celebrity and Carnival, began operation out of the terminal. Fifty cruises departed from the terminal, with a total of 85,382 passengers.

	Blount Island Marine Terminal	**Talleyrand Marine Terminal**	**Dames Point Marine Terminal**
Distance from Atlantic Ocean	9 miles	21 miles	10 miles
Terminal Area	754 acres	173 acres	585 acres
Berthing Spaces	#20 – 750 linear feet #22 – 600 linear feet #30 – 700 linear feet #31 – 900 linear feet #32 – 900 linear feet #33 – 1,000 linear feet #34 – 1,000 linear feet #35 – 750 linear feet	#3 – 700 linear feet #4 – 800 linear feet #5 – 800 linear feet #6 – 800 linear feet #7 – 800 linear feet #8 – 900 linear feet	#10 – 1,200 feet
Berthing Depth (MLW)	38 – 41 feet	39 feet	41 feet
Deck Height (MSL)	9 – 10 feet	7 feet	8 feet
Mechanical Handling Facilities	-Eight container cranes -One 100-ton gantry whirly crane -One 40-ton straddle crane	-Six container cranes -Two rubber tired gantry cranes -One 100-ton multipurpose whirly crane -Three 40-ton container stackers	-Under development
Use	Containers, RO/RO, Break-bulk and General Cargo	Container, RO/RO, Liquid Bulk and General Cargo	Bulk Cargo

Table 3 Jacksonville Port terminal information.

JAXPORT handles automobile, container, and cruise, liquid, dry, break-bulk and idle vessels. JAXPORT has not handled petroleum vessels since fiscal year 1999/2000. In fiscal year 2003/2004, 1,582 vessels came through JAXPORT, including 850 containerized vessels, 426 automobile vessels, 127 break-bulk vessels, 83 liquid container vessels, 50 cruise ships, 31 dry container vessels and 15 idle container vessels. In the past ten fiscal years, it has been the general trend that container and automobile vessels account for the highest percentage of vessel traffic each year, 52-60% and 23-31%, respectively (Figure 20).

Fiscal year 2003/2004 also saw the highest amount of import/export tonnage that traveled through JAXPORT, at 7,688,268 tons. Trends show that containers comprise a majority of the tonnage (51% in FY 2003/2004), followed by bulk (24%), automobile (14%) and break-bulk (11%) (Figures 20, 21). Since fiscal year 1998/1999, import tonnage has exceeded export tonnage. In fiscal year 2003/2004, 4,130,444 tons were imported and 3,557,824 tons were exported through JAXPORT (Figures 22, 23). This was the highest import tonnage JAXPORT has handled. The tonnage was comprised of 42% bulk, 23% containers, 19% automobiles and 16% break-bulk. It is a general trend that the majority of imports are bulk, followed by containers, automobiles and break-bulk (Figure 22). The vast majority of JAXPORT's exports are containers, followed by automobiles, bulk and break-bulk (Figure 23). In fiscal year 2003/2004, these percentages were 84%, 8%, 5% and 3%, respectively.

Puerto Rico is JAXPORT's top trading partner, having comprised 54-77% of the container traffic. JAXPORT's other top trading partners include South America (Brazil, Argentina, Venezuela and Colombia), the Caribbean (Bahamas, Cuba and Virgin Islands) and Mexico. (Figure 24).

Figure 19 Port of Jacksonville illustrating cargo and cruise terminals

(source: Jacksonville Ports Authority).

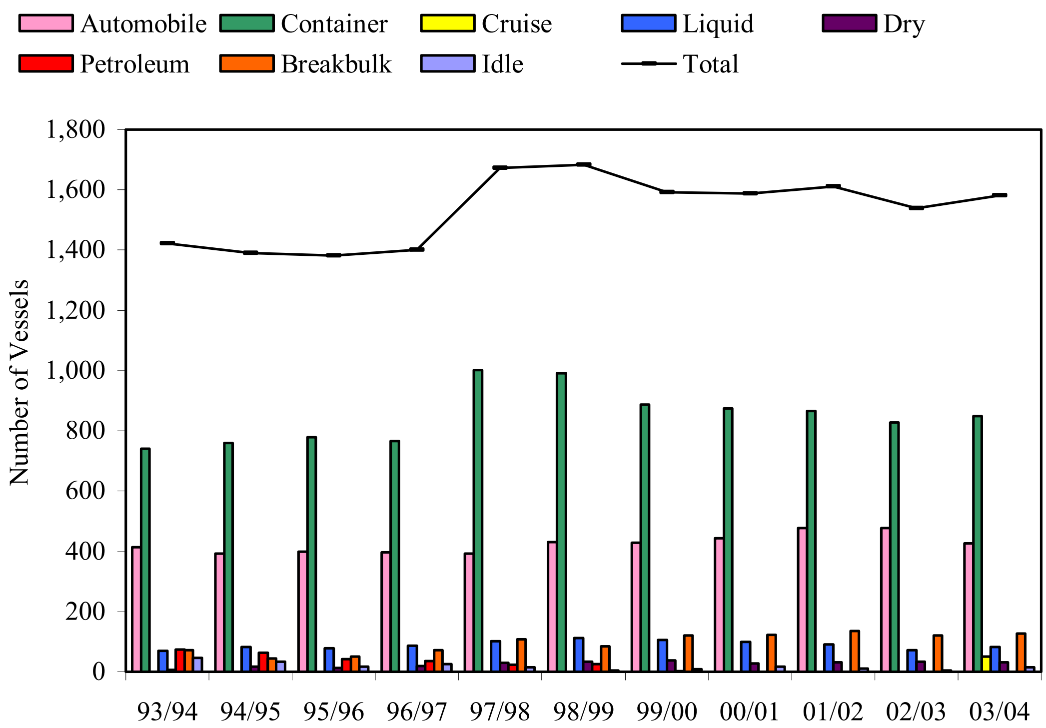


Figure 20 Jacksonville number of vessels and cargo type per fiscal year (Jacksonville Ports Authority).

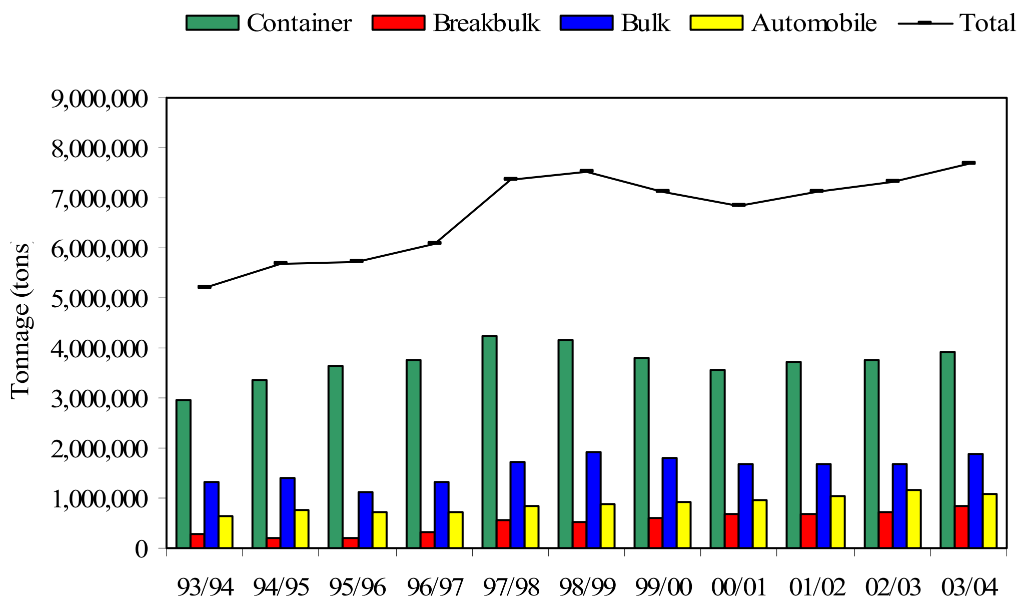


Figure 21 Port of Jacksonville tonnage by cargo type per fiscal year (Jacksonville Ports Authority).

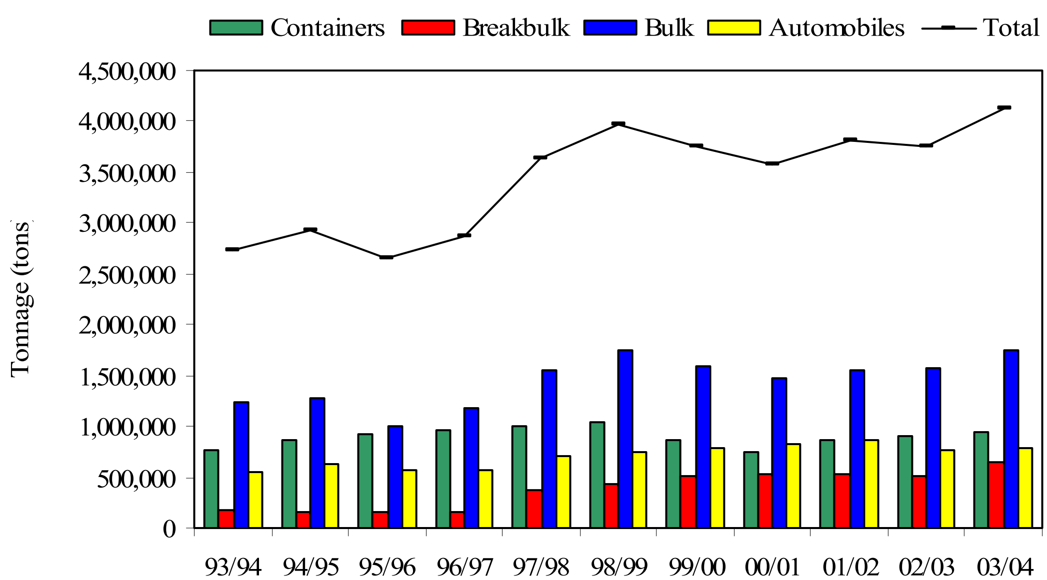


Figure 22 Port of Jacksonville import tonnage per fiscal year (Jacksonville Ports Authority).

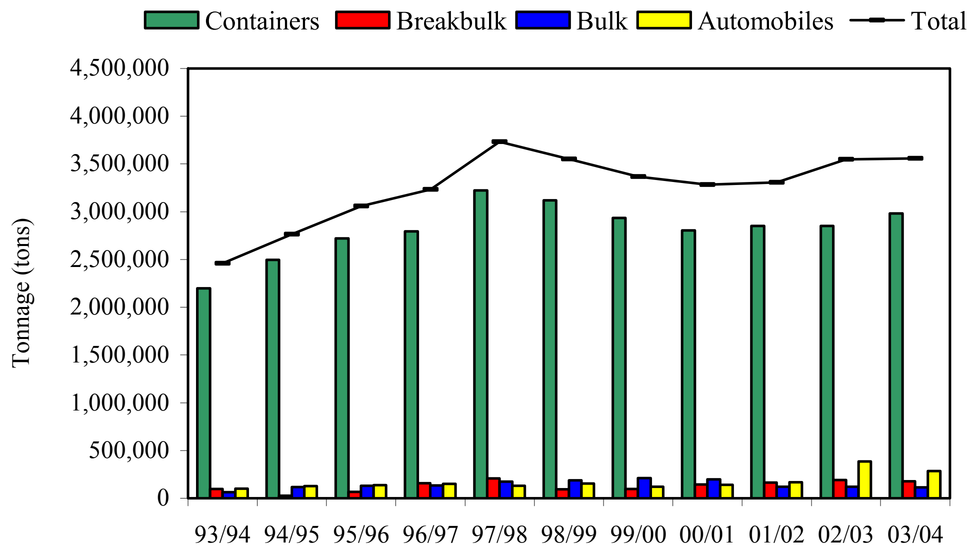


Figure 23 Port of Jacksonville Export Tonnage per Fiscal Year (Jacksonville Ports Authority).

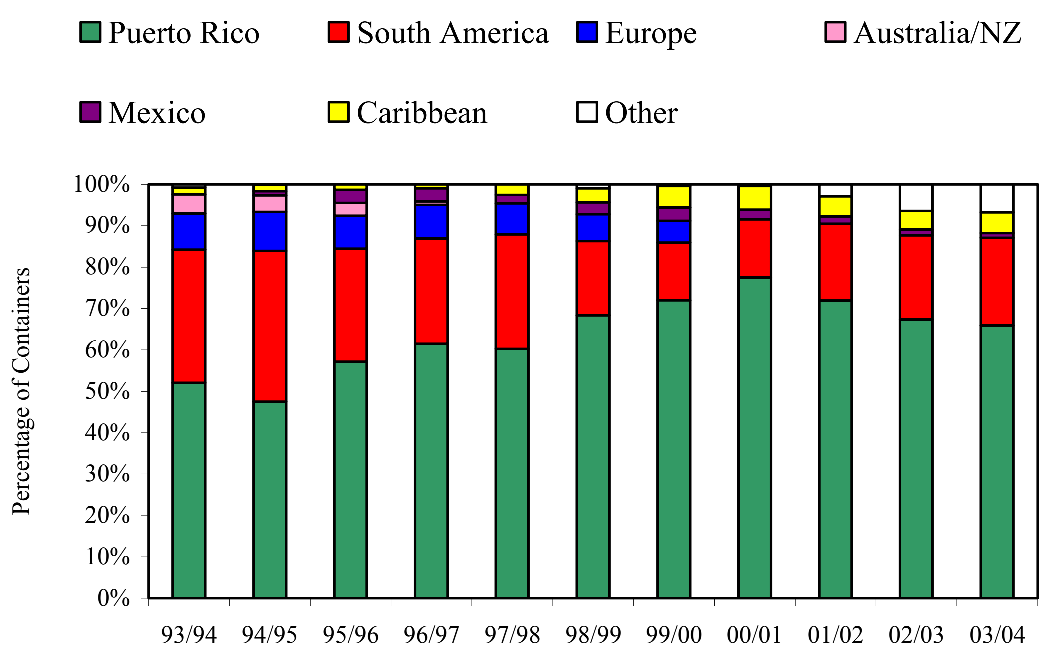


Figure 24 Port of Jacksonville Percentage of Containers from Top Trading Partners per Fiscal Year (Source: Jacksonville Ports Authority).

2.4.3. Hydrography

The St. Johns is a coastal plain river that spans approximately 310 miles (Figure 25). Water surface elevation upstream reaches only 6.1 meters above mean sea level. Along the river path, the total change in elevation is approximately eight meters, causing the St. Johns to have a one percent slope (DeMort, 1991). This drop rate results in slow flow of water, making the St. Johns River one of the "laziest" rivers in the world.

The St. Johns River begins in the freshwater marshes of St. Lucie and Indian River counties. where the basin of the river is formed from two main tributaries, the Econlochhatchee and Wekiva Rivers. The Econlochhatchee River drains the western slope of the watershed from Orlando to Bithlo. The Wekiva River drains groundwater discharge from the Floridian aquifer (Livingston & Fernald, 1991). The Upper St. Johns River Basin is characterized by sloughs, lagoons and indistinct banks. Several large lakes in the upper basin have formed in the path of St. Johns River. Traveling north, these include Lake Hellen Blaze, Sawgrass Lake, Lake Washington, Lake Windsor, Lake Poinsett, Ruth Lake and Puzzle Lake. The middle basin of the St. Johns River flows through Lake Harney, Lake Jesup, Lake Monroe and Lake George. Farther north, the largest tributary of the St. Johns River, the Ocklawaha River, converges, marking the beginning of the lower basin. Tributaries in the Lower St. Johns River Basin include Dunn's Creek and Black Creek. Dunns Creek drains swamps and Karst lakes while Black Creek drains the eastern slope of Trail Ridge. The St. Johns River takes a turn to the east at the city of Jacksonville, where it travels to the Atlantic Ocean (DeMort, 1991). Approximately five miles above the river mouth, the St. Johns River is crossed by the Atlantic Intracoastal Waterway. The mouth of the St. Johns River is located at latitude 30° 24′ N and longitude 81° 23′ W, at the town of Mayport (US Army Corps of Engineers, 1997b). The St. Johns River Basin covers a total of 24,766 square kilometers (Mason, 1998).

The St. Johns River receives most of its freshwater input from swamps, and less from springs and spring-fed streams. Average rainfall per year is 52 inches occurring mainly between June and September as a result of convective activity. Salt water input is from the Atlantic Ocean. A horizontal and vertical salinity wedge in the Mayport area can reach Orange Park 40 miles upstream. with salinities ranging between two and five parts per thousand (DeMort, 1991).

The tide of the St. Johns River can be described as a mixed semidiurnal tide. The average tidal range is as follows: 4.9 feet at the river entrance, 2.6 feet at Dames Point and 1.2 feet at the city of Jacksonville. Tidal currents vary across the St. Johns River. Between the entrance jetties, currents average 1.9 knots on incoming tides and 2.3 knots on outgoing tides. At the town of Mayport, currents average 2.2 knots on incoming tides and 3.1 on outgoing tides. At the city of Jacksonville, currents average 1.0 knots. The incoming tide in increased by northeasterly and easterly winds and the outgoing tide is increased by southwesterly and westerly winds (US Army Corps of Engineers, 1997b). Tide reversal typically occurs from the mouth of the river to Lake George, approximately 100 miles, but can occur to Lake Monroe, approximately 118 miles (DeMort, 1991). Average discharge at the mouth of the St. Johns is 6,105 cubic feet per second. Flow ratios indicate that freshwater volumes are one quarter or less of total tidal volumes (Keller and Schell, 1993).

The shipping channel of the St. Johns River has a deep water entrance located between two jetties which extend in an east-west direction. The channel runs southwestward along the inshore end of the south entrance jetty to the town of Mayport, approximately three miles from the mouth of the St. Johns River. From this point, the channels follow their natural course through the river until reaching the terminating point of the dredging project at St. Elmo Acosta Bridge, 24.9 miles from the mouth of the St. Johns River. There are two channels located in the main harbor area, the Terminal Channel and Arlington Cut, which run almost parallel to one another (US Army Corps of Engineers, 1997b). Jacksonville Port is approximately located at latitude 30° 24′ N and longitude 81° 34′ W (Keller and Schell, 1993).

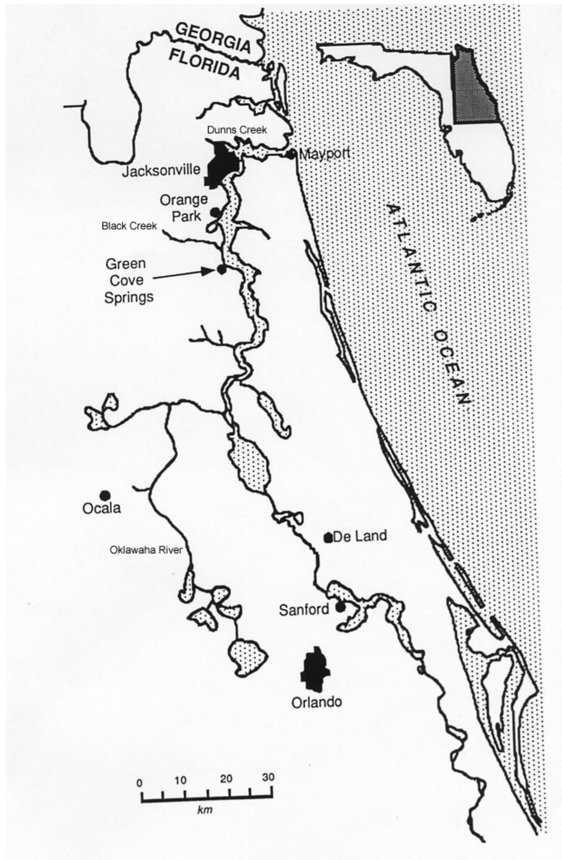


Figure 25 Map of St. Johns River (source: DeMort, 1991).

2.4.4. Geology

The formation of the St. Johns River Valley was the result of erosion, changing sea levels and the effects of winds, waves and currents. The river valley originated in the Pleistocene epoch (1.8-10,000 years B.P.). At this time, sea levels were approximately 40 feet higher than current levels; thus, most of the peninsula of Florida was inundated. A lagoon, located in what is now Duval and St. Johns counties, was separated from the ocean by barrier islands and land bars. This lagoon was defined by tidal and wind action. A period of glaciation followed, dropping sea levels to 60 feet under present levels. Thus the lagoon was exposed to wind, rain and erosion. This began the early development of the St. Johns River. Sea levels rose again in the interglacial period, followed by a regression of the sea, which continued to sculpt the basin. Today, the lower St. Johns River can be described as a shallow tidal estuary that is constantly defined by the weather, tides, currents, ship traffic and dredging (Keller and Schell, 1993).

Most sediments of the river are fine-textured silts and clays that are dark in color, high in percent moisture and poorly sorted. The river bottom is primarily composed of fine-grained sediment. Coarse sediment is present near the mouth of the river where ocean currents move large amounts of sand in and out of the river. Mud deposits resulting from flocculation of silt-clay particles settle at slack tides in low energy fringe areas. Muck sediments are present due to poor soil management. Tide forces, boat traffic and dredging result in fluctuations in sediment distribution (Keller and Schell, 1993).

Median particle size is 0.25 mm to 0.063 mm. Mainstream river particles are 0.135 mm. There is a varied particle size distribution, but the sediment composure is dominated by fine silt and clay or flocculent material. The St. Johns River has low bed load due to the lack of strong downstream currents to move sediment. The major sources of sediment are the erosion of sand and clay from adjacent watersheds and the production of organic sediments. More coarse sediments are present near the river's edge where waves erode sandy bluffs and at the river mouth where marine sediments are carried landward by ocean currents.

Factors affecting sedimentation processes include tidal currents, river inflow, river traffic, dredging and density contrast between freshwater and saltwater. The average gradient of the main river channel is 0.022 m/km. This low gradient causes many areas to be shallow, allowing wind to effect currents and sediment mixing. The topography of the basin causes far-reaching tidal influence in the river. The mixing of saltwater and freshwater causes flocs, leading to sedimentation of organic contaminants and precipitation of dissolved metals (Keller and Schell, 1993).

In 1987, the Surface Water Improvement and Management Act (SWIM) was established by the Florida Legislature. SWIM exists to target non-point source pollution in water systems in danger of degradation. The Lower St. Johns River was included on the list, and remains to be today (http://www.dep.state.fl.us/water/watersheds/swim.htm). Studies conducted in 1996-1997 found the sediments of the Lower St. Johns River near Jacksonville to have elevated concentrations of contaminants, particularly polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and toxic metals (Durell *et al*., 1998). Previous studies have shown the lower St. Johns River to have relatively high total organic carbon contents (Keller and Schell, 1993).

3. REVIEW OF EXISTING REGIONAL INFORMATION

3.1. Biological Literature Review

A literature review of existing biological studies was conducted to document polychaete, mollusk and crustacean species known to occur in the SAB region and their specific locality information. Publications (technical reports, theses, scientific publications) were selected that provided reference to species collected during biotic surveys, ecological experiments and monitoring studies. A Geographical Information System (GIS) database was created from this literature review to graphically display their occurrence (Figure 26). A total of 74 publications were compiled (see Appendix 1), as well as the results of the current baseline port surveys, resulting in 36,502 mapping points. These mapping points represent locality information for 1,738 species of mollusks, crustaceans and polychaetes in the South Atlantic Bight. This database is provided on the enclosed CD as an ArcView project; or the project is available for download on the University of Georgia Marine Extension Service Shellfish Research Laboratory webpage (www.marex.uga.edu). The user must have ArcView in order to use this project (CD or downloaded format). The GIS database has also been placed in the Georgia Museum of Natural History and with the Southeastern Regional Taxonomic Center.

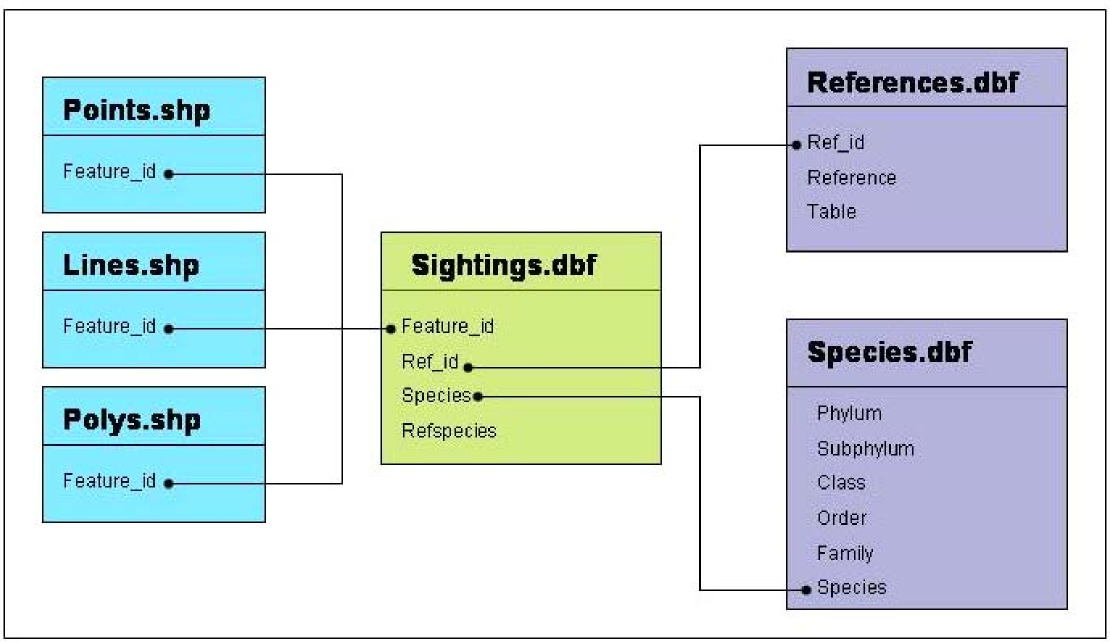


Figure 26 The table relationships within the biological literature review ArcView GIS project.

The GIS database is designed to allow the user to obtain a map illustrating the presence of a selected species in the SAB. Upon opening the project in ArcView, the user will see four windows: the project window, a species table with taxonomic classification; a reference table listing all sources used to create the database; and a view showing a map of the SAB (Figure 27).

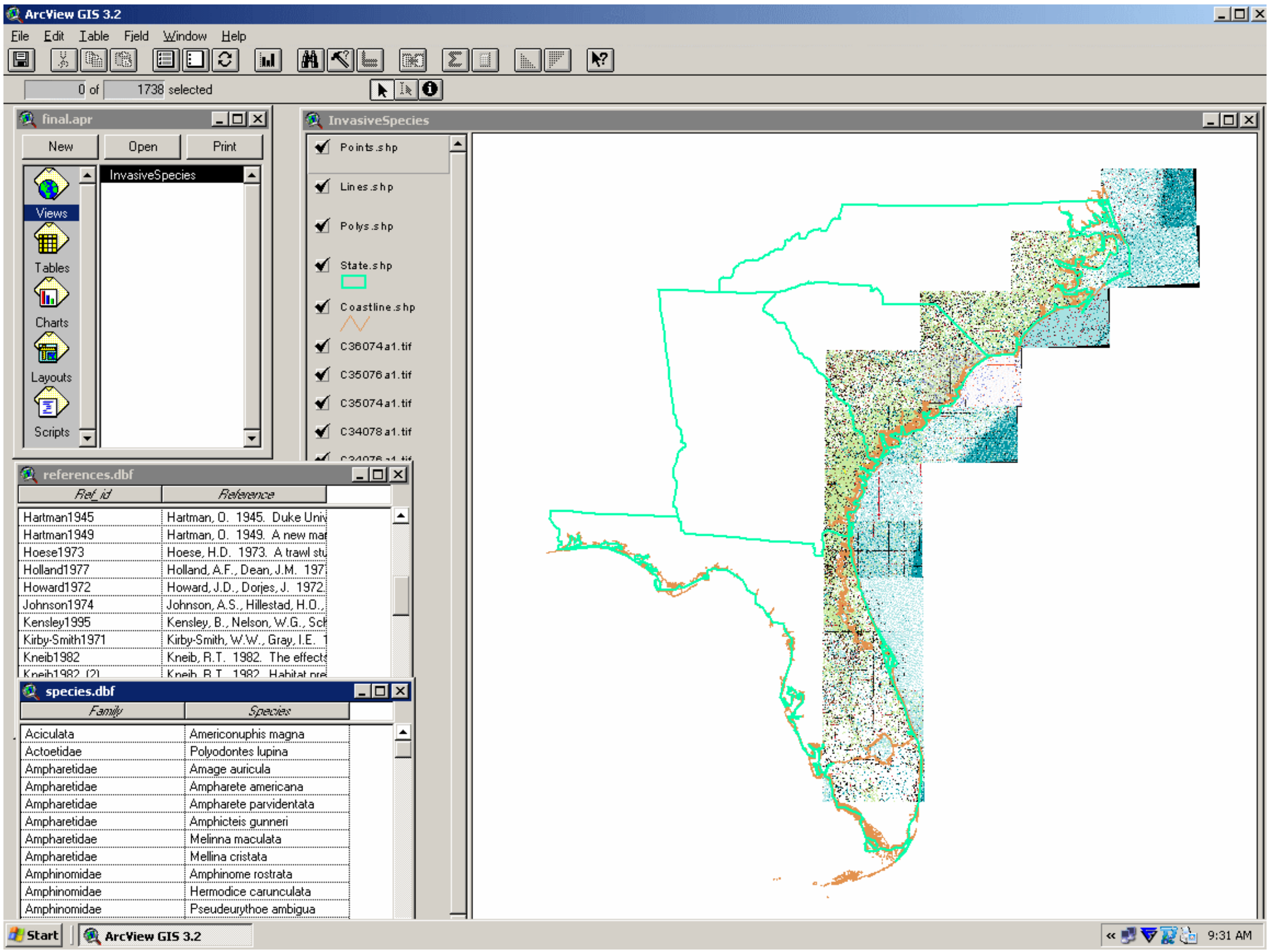


Figure 27 The project window, taxonomic, species table, reference table and South Atlantic Bight map that appears when the GIS database is opened in ArcView.

The user may then select a record from the species table. All references that document the presence of the species selected are highlighted in the table, and the locality information associated with the species is displayed in the view. With each record selected, the view will redraw to illustrate the selected species distribution (Figure 28).

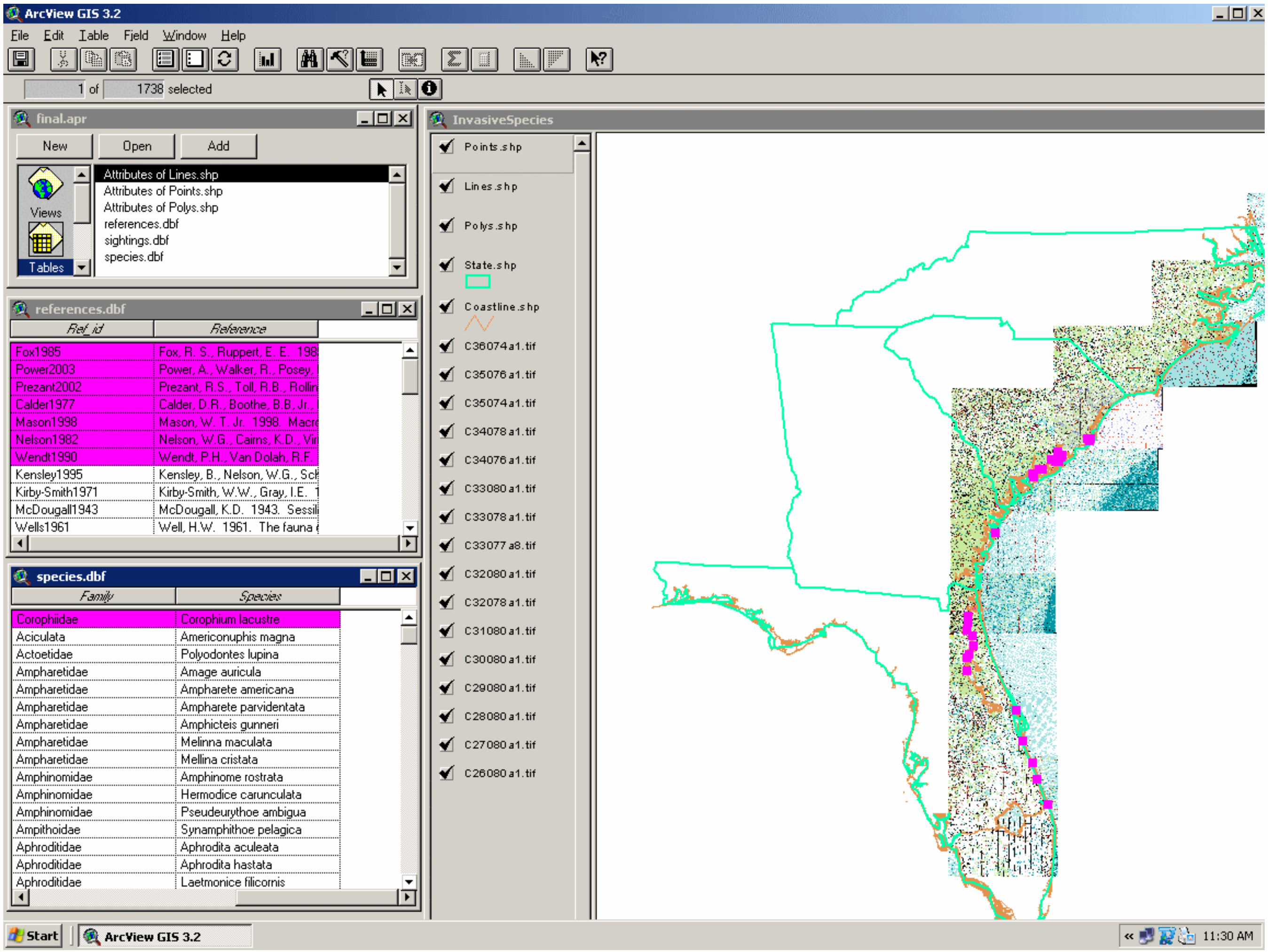


Figure 28 The project window, taxonomic, species table, reference table and map that appears when the GIS database is opened in Arcview and a search for *Corophium lacustre* is initiated.

The user also has the option of selecting a reference from the reference table. This will highlight all species and their localities associated with that particular study (Figure 29).

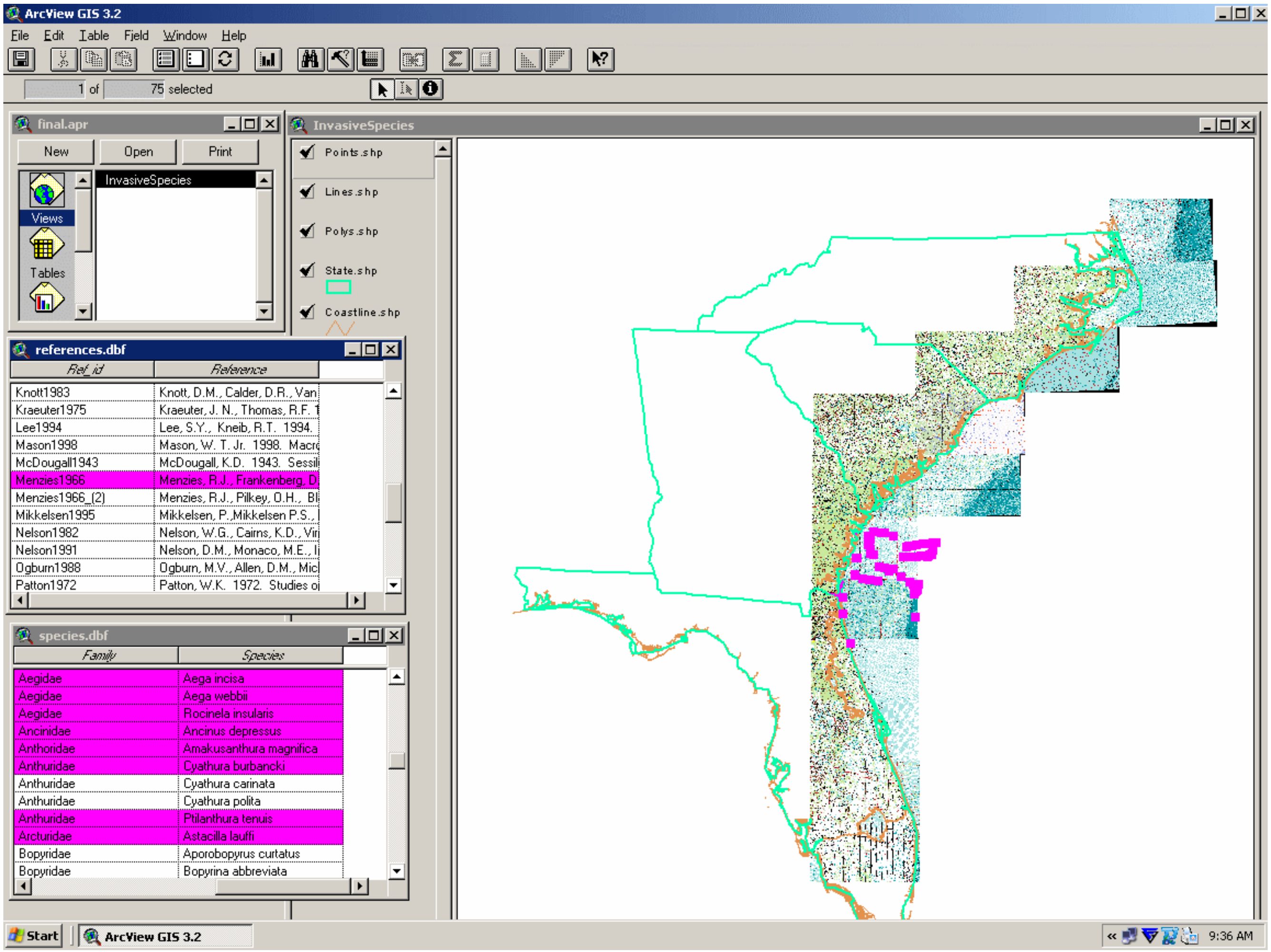


Figure 29 The project window, taxonomic, species table, reference table and South Atlantic Bight map that appears when the GIS database is opened in Arcview and a bibliographic reference is selected.

3.2. Water Quality

Surface temperature and salinity records for the span of a one-year period (year in which our sampling occurred) were compiled for the St. Johns River, Florida, Savannah River, Georgia, Charleston Harbor and Cooper River, South Carolina, and Cape Fear River, North Carolina. For each study site, two locations were selected: one to represent the upper reaches/lower salinity sampling areas of the estuaries; and one to represent the lower reaches/higher salinity sampling areas of the estuaries (Appendix 2). Temperature and salinity were also recorded during our sampling events (Appendix 3).

4. SURVEY METHODS

4.1. Sampling Strategy

For each port, our targeted surveys were designed to determine:

(i) the distribution and relative abundance of targeted phyla of aquatic invertebrates;

(ii) a baseline assessment of introduced species; and

(iii) a baseline assessment of native species.

In order to develop an effective inventory, these baseline surveys incorporated the following suite of requirements to facilitate future comparisons (New, 1996; Yen & Butcher, 1997):

1) an accepted minimum standard for sampling design, methods, and information archiving;
2) identification of material to species level where possible;
3) species identifications verified by taxonomic experts where possible;
4) survey material to be vouchered and placed in the Georgia Museum of Natural History in Athens, GA and in the Southeastern Regional Taxonomic Center in Charleston, SC.

We used stratified designs with replicates. This experimental design is recommended by Hayek & Buzas (1997) for surveys to collect biological material because:

1) consistency between samples is guaranteed;
2) sampling from each stratum eliminates a primary source of variation because the largest component of variability is between groups rather than within them;
3) sampling intensity can be increased.

The detection of species in the early stages of an invasion (i.e. those with limited distribution and limited abundance) is important in the design of an appropriate sampling program. A power analysis to determine the appropriate sampling effort, using the methods of Green & Young (1993) for species with a Poisson distribution, suggested that a sample size of approximately 13 samples is necessary to detect a species with a mean Poisson density of 0.1 individuals per sample unit at a 95% probability (Hewitt & Martin, 2001). Therefore each gear type was used to collect 13 samples in each zone in each port. The sampling methods provided presence/absence information and semi-quantitative indices of abundance. Since the processing and identification of samples is costly and time consuming, sampling techniques that produce small volumes of material were used.

The adequacy of sampling intensity was evaluated by calculating cumulative species curves for each sampling technique at each study location. Typically as more samples are taken, additional species accumulated begin to decrease until an asymptote is approached, where essentially all the species in all the habitats have been collected.

Our sampling locations were standardized with regard to depth, and location within the different estuarine systems. Differences in community structure between study locations were examined using Bray-Curtis dissimilarity measures (Krebs, 1989). The calculated values are based on the following equation:

$B' = 1-B$

$B = \text{sum} \left| X_{ij}-X_{ik} \right| / \text{sum} (X_{ij}+X_{ik})$

where X_{ij} = frequency of species i in sample j

X_{ik} = frequency of species i in sample k

If B' = 0 then samples are dissimilar, if B' = 1 then samples are similar.

Cluster analyses were run by gear type for all zones using SAS Version 8, technique outlined by Krebs (1989). Parameters included in the analyses were surface water temperature and salinity, and sediment type, sorting, skewness, and percent nitrogen and carbon content.

4.2. Sampling Methods

4.2.1 Sampling Zones

Nonindigenous populations are typically patchily distributed across many habitats; however we attempted a broad and comprehensive search by using an array of field sampling devices. Sampling procedures broadly mirrored those described for an Australian nationwide port survey (Hewitt & Martin, 2001). Researchers at the University of Georgia conducted sampling at Jacksonville, Savannah, and Charleston on the *R/V Georgia Bulldog* during August and September 2003. At that same time researchers at the University of North Carolina, Wilmington conducted sampling of Wilmington port. We focused on the immediate port areas (zone two), as well as areas above or upstream of the port (zone 3), and below or downstream of the port in the outer reaches of each estuary (zone 1). This resulted in a total of 12 zones over the entire study area (Figures 30-33). Each gear with the exception of fouling plates and scrapings was used 13 times in each zone.

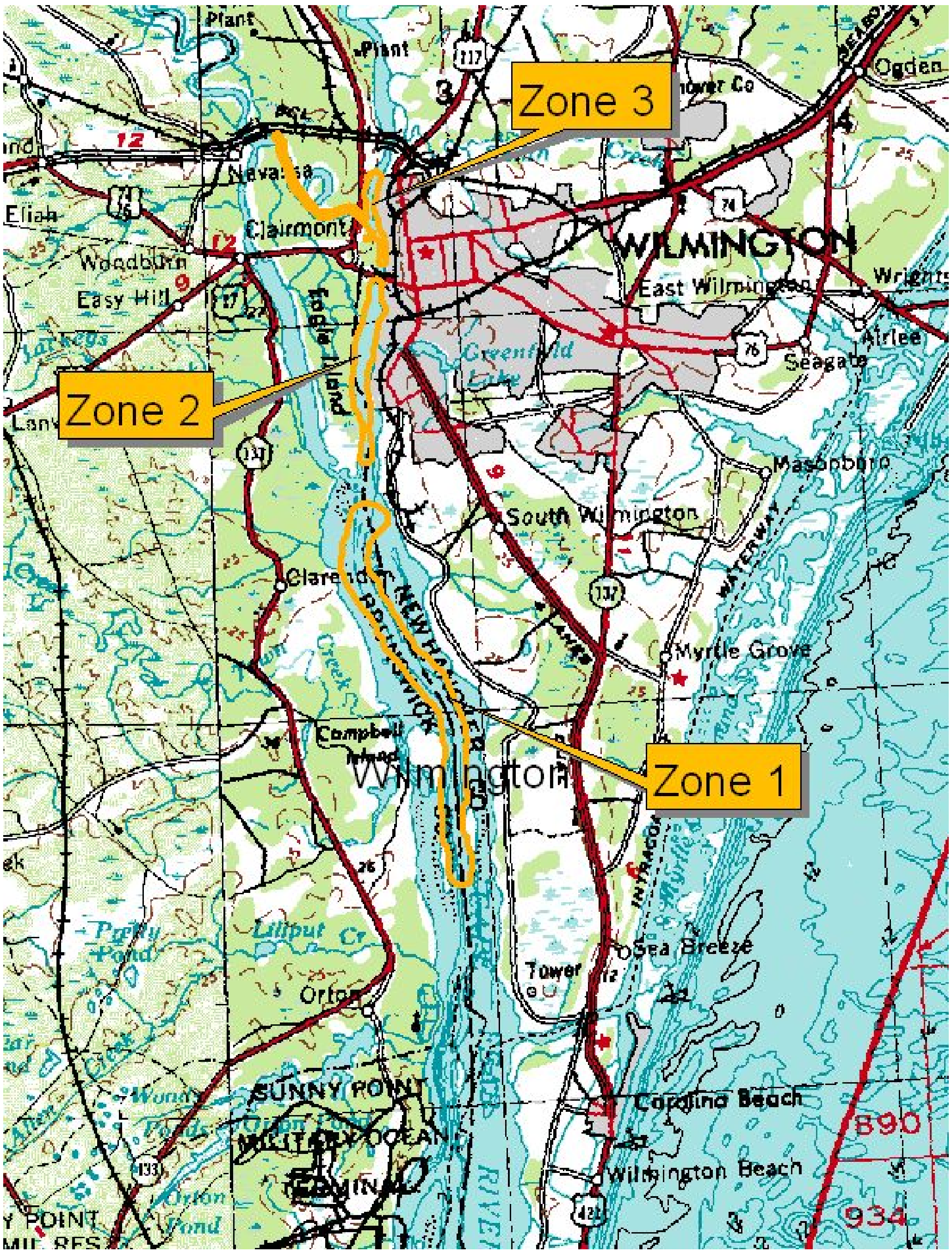


Figure 30 Port of Wilmington illustrating sampling zones.

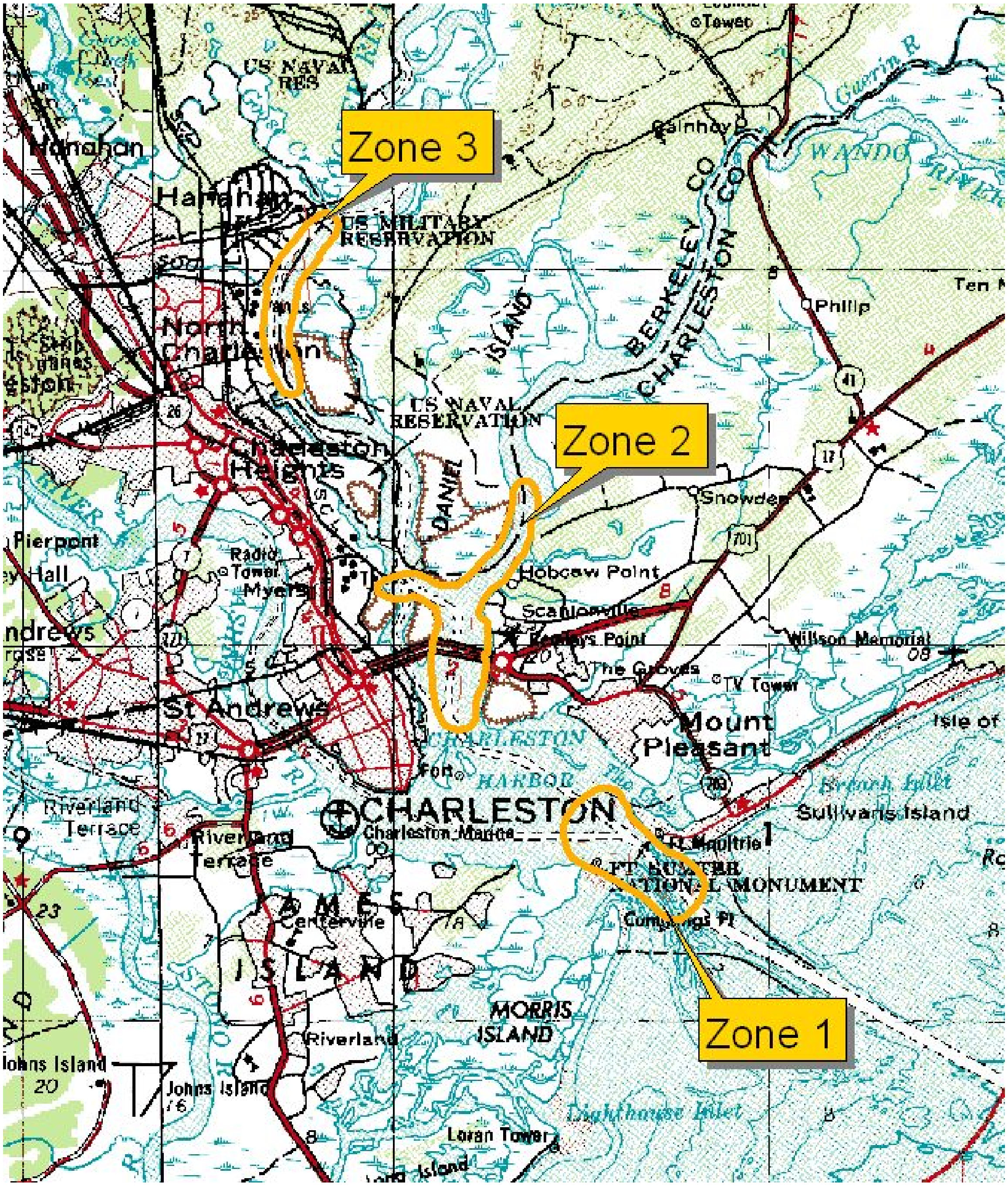


Figure 31 Port of Charleston illustrating sampling zones.

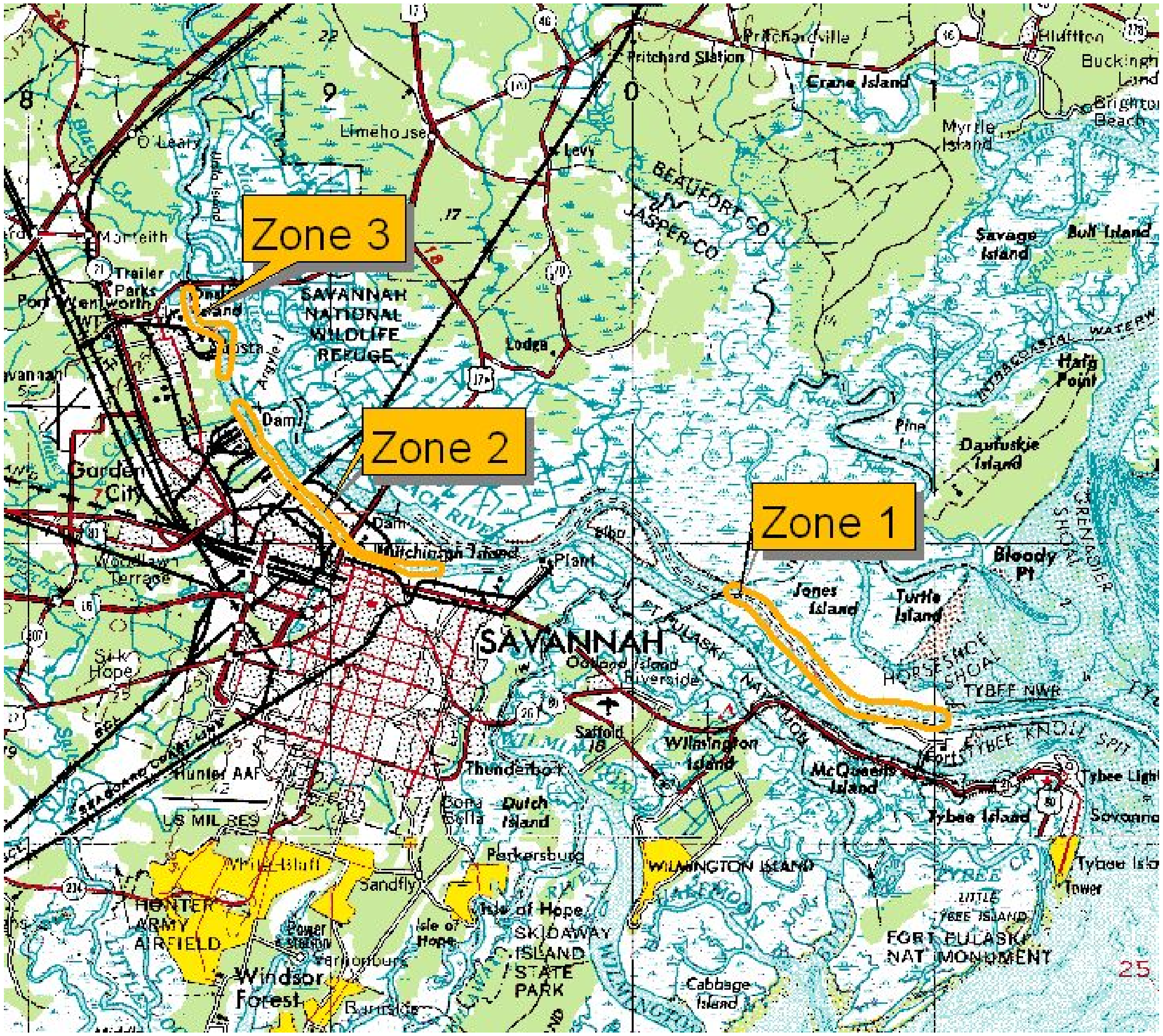


Figure 32 Port of Savannah, illustrating sampling zones

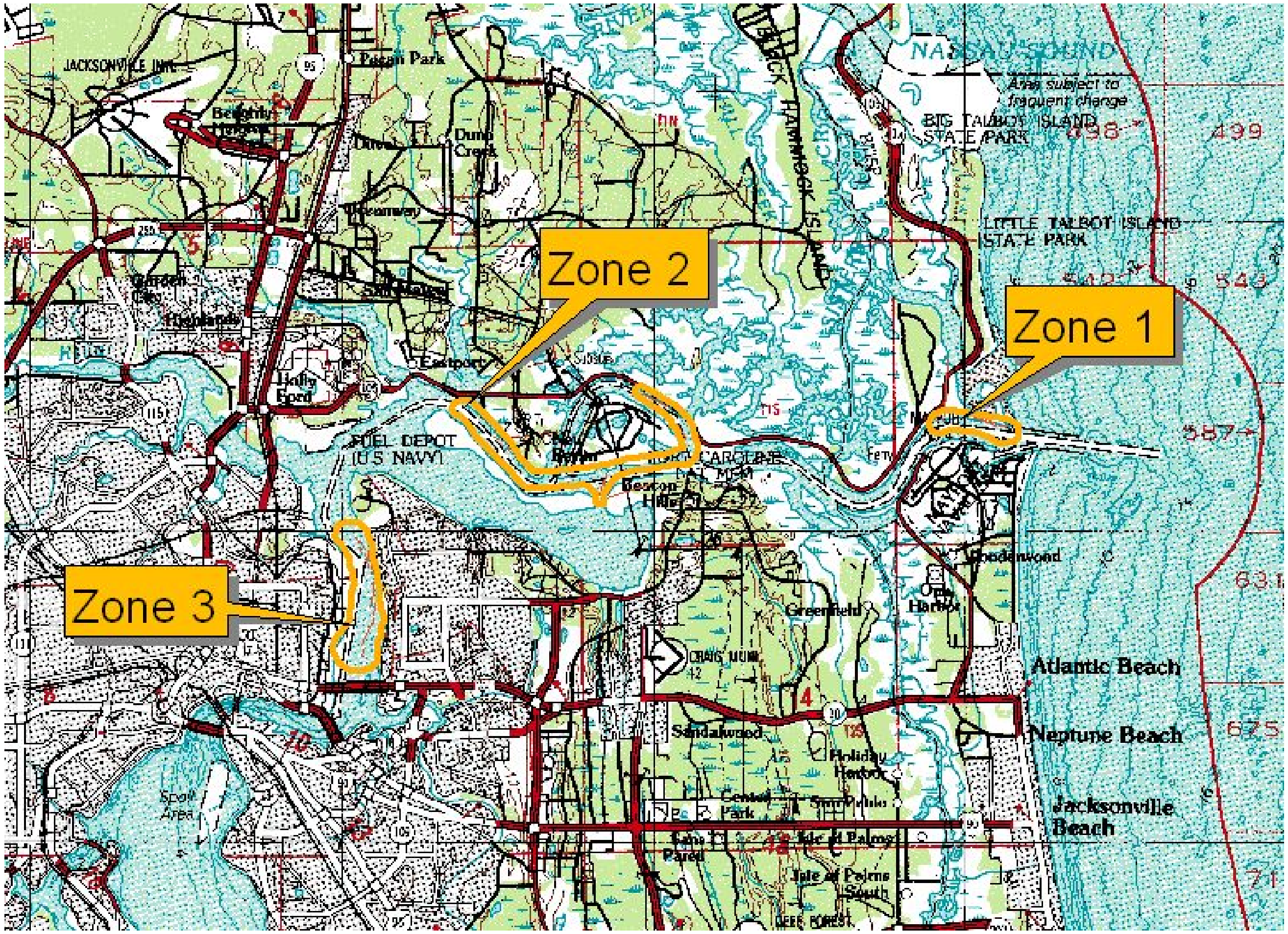


Figure 33 Port of Jacksonville, illustrating sampling areas.

4.2.2. Traps

13 locations from zones one, two and three of each port were sampled with baited traps. Standard commercial crab traps measuring 24x24x24”with a mesh size of 1.5” were deployed to capture mobile large crabs (Figure 34). These traps have four funnel entrances measuring 6.5” in diameter surrounding the base. Crabs entering the traps swim into an upper chamber above where an internal bait box is secured to the lower frame. In addition, galvanized minnow traps measuring 16” long with a mesh size of ¼” were deployed to capture smaller crustaceans (Figure 34). These traps have a tapered inwardly directed entry cone at each end. Locally available fish (menhaden) were used as bait. All traps were deployed in the late afternoon, and recovered early the following morning (approx. 12 hour soak time). All specimens were preserved in 10% seawater buffered formalin.

Figure 34 Crab and minnow trap

Figure 35 Baiting traps

4.2.3. Sediment Cores

Triplicate core samples (10 cm diameter, 15 cm depth) were taken at 13 locations within zones one, two and three of each port to sample the benthic infauna (Figures 36, 37). These samples were drained and rinsed on a one mm-mesh sieve to remove the fine sediment from the sample. All remaining material was preserved in 10% seawater buffered formalin. A one mm-mesh sieve rather than the standard 0.5 mm size was used to concentrate our efforts on the juvenile and early life stages of decapods, amphipods, other crustaceans, non-juvenile bivalves and larger polychaete taxa.

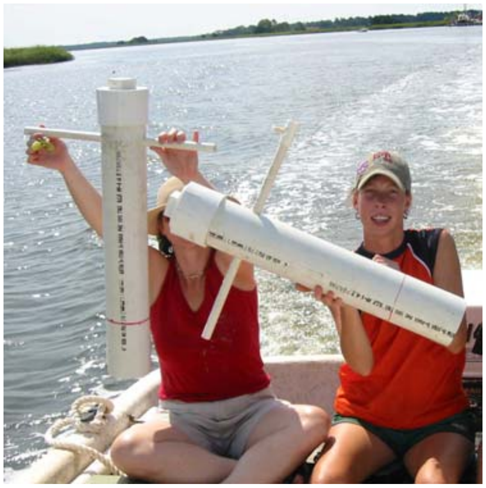


Figure 36 Sediment cores

Figure 37 Taking core samples

4.2.4 Trawls

A trawl with a four-foot mouth and one cm mesh bag was towed for five minutes at 13 sites in zones one, two, and three of each port to sample the epibenthos (Figure 38). Towing speed did not exceed 0.5m/s. All contents were emptied into five gallon buckets and preserved in 10% seawater buffered formalin (Figure 39). For Jacksonville, our try-net was required to be equipped with a Turtle Exclude Device (TED), which was not consistent with sampling in the other ports.

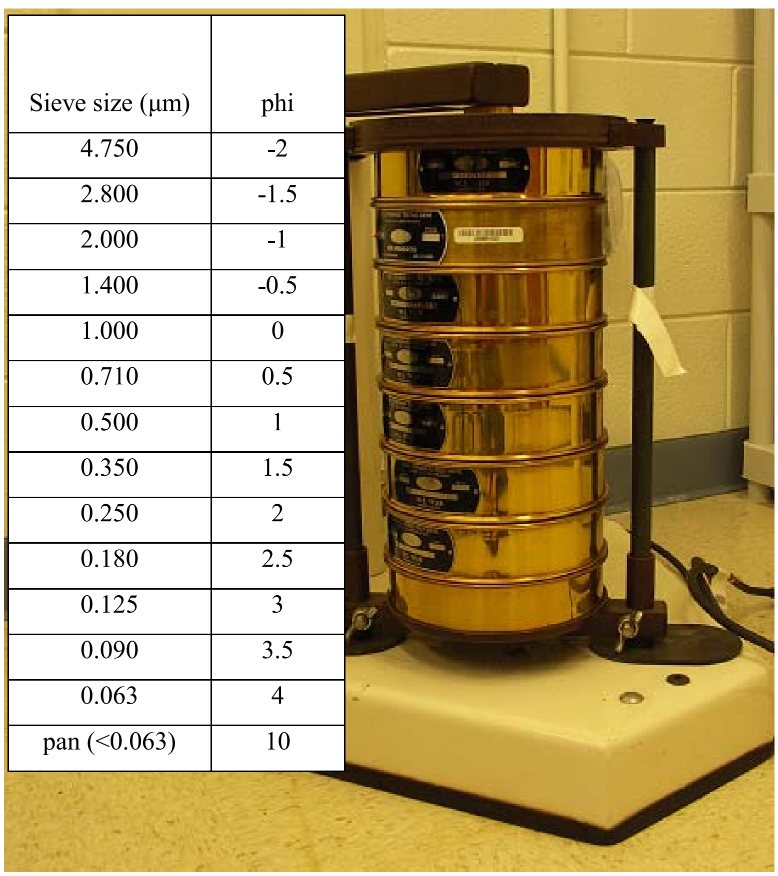
Figure 38 Trawling

Figure 39 Trawl sample

4.2.5. Sediment Particle Sizing and Organic Content

An additional sediment core sample (10 cm diameter, 15 cm depth) was also taken at each of the benthic infaunal core sampling sites. A 100 g sub-sample of each core taken was frozen. Samples were later thawed at the laboratory; a 15-25 g sample from each core was dried in an oven at 95°C for 24 hr. The sample was then sent to the Stable Isotope/Soil Biology Laboratory at the University of Georgia's Institute of Ecology. Total nitrogen and total carbon analysis was conducted through dry Micro-Dumas combustion, which is based on the transformation to gas phase by extremely rapid and complete flash combustion of the sample material (Kirsten, 1983).

A further 20-30 g sample was wet sieved through a stack of U.S. Standard Sieves on a mechanical shaker (Figure 40).



Sieve size (μm)	phi
4.750	-2
2.800	-1.5
2.000	-1
1.400	-0.5
1.000	0
0.710	0.5
0.500	1
0.350	1.5
0.250	2
0.180	2.5
0.125	3
0.090	3.5
0.063	4
pan (<0.063)	10

Figure 40 Sediment sieve shaker and sizes.

Each resulting fraction was dried at 95°C for 24 hr and weighed. The proportion of each component was calculated as a percentage of the total dry sample**.** A cumulative frequency curve was produced for sample, plotting phi value against cumulative percent mass of the sample. Phi values at the percentages of 5, 16, 50, 84, and 95 ($\Phi5$, $\Phi16$, $\Phi50$, $\Phi84$, $\Phi95$, respectively) were used to characterize each sediment sample based on the following three parameters, which utilize up to 90% of the curve (Folk, 1974): graphic mean; inclusive graphic standard deviation; and inclusive graphic skewness. The parameters for 13 samples for each zone were then averaged to gain an overall characterization of the sediment in each zone at each port.

Graphic Mean (Mz) is a measure of the average particle size of the sediment and can be used to provide an overall description of the sample. A negative graphic mean indicates coarser particles while a positive graphic mean indicates finer particles.

$$Mz = \frac{\Phi16 + \Phi50 + \Phi84}{3}$$

Inclusive Graphic Standard Deviation or Sorting (δ_1) is used to determine the departure from a curve of a homogenous sample in describing the cumulative frequency distribution of particle sizes. A curve with no weighted distribution on one side of the mean would theoretically have a δ_1 value of "0"; however, a normal curve would exhibit a δ_1 value of 1. A δ_1 value of less than 1 implies good sorting while a δ_1 value greater than 1 implies poor sorting.

$$\delta_1 = \frac{(\Phi84 - \Phi16)}{4} + \frac{(\Phi95 - \Phi5)}{6}$$

Inclusive Graphic Skewness (SK_1) is a measure of the degree of bilateral symmetry of the curve. A symmetrical curve would have a SK_1 value of "0"; the degree of asymmetry is reflected by the departure of the SK_1 value from "0", with positive values indicating excess fine material, and negative values indicating excess coarse material.

$$SK1 = \frac{(\Phi16 + \Phi84 - 2\,\Phi50)}{2(\Phi84 - \Phi16)} + \frac{(\Phi5 + \Phi95 - 2\,\Phi50)}{2(\Phi95 - \Phi5)}$$

The range values and implications for particle size cumulative frequency curve parameters are listed in Table 4 (Folk, 1974).

Parameters	Range Values	Implications
Graphic Mean (M_z)	<-6 Φ	Cobble
	-6 Φ to -2 Φ	Pebble
	-2 Φ to -1 Φ	Granule
	-1 Φ to +1 Φ	Coarse sand
	+1 Φ to +2 Φ	Medium sand
	+2 Φ to +4 Φ	Fine sand
	+4 Φ to +8 Φ	Silt
	>+8 Φ	Clay
Inclusive Graphic Standard Deviation (Sorting)	<0.35 Φ	Very well sorted
	0.35 Φ to 0.50 Φ	Well sorted
	0.50 Φ to 0.71 Φ	Moderately well sorted
	0.71 Φ to 1.0 Φ	Moderately sorted
	1.0 Φ to 2.0 Φ	Poorly sorted
	2.0 Φ to 4.0 Φ	Very poorly sorted
	>4.0 Φ	Extremely poorly sorted
Inclusive Graphic Skewness	+1.0 to +0.30	Strongly fine skewed
	+0.30 to +0.10	Fine skewed
	+0.10 to -0.10	Symmetrical
	-0.10 to -0.30	Coarse skewed
	-0.30 to -1.00	Strongly coarse skewed

Table 4 Range values and implications for sediment particle size cumulative frequency curve parameters.

4.2.6. Piling Scrapes and Fouling Plates

An area of oyster clumps large enough to fill a one gallon bucket was scraped off 13 pilings only within zone two of each port during low tide to sample fouling organism (Figure 41). All attached fouling organisms were collected into a large one mm mesh bag. All specimens were narcotized with isotonic magnesium chloride for one hour prior to preservation in 10% seawater buffered formalin. Additionally, Hester-Dendy colonizing plates were suspended within zones two in each of the ports (Figure 42). The suspension of the fouling plates from port piers proved problematic with Jacksonville and Charleston port authorities not approving their deployment in the vicinity. In this situation we floated the plates on weighted lines nearby, however many of these could not be found when we returned to retrieve them three-months later. These multiple plate samplers comprise of fourteen 7.5 cm diameter hardboard plates divided by eight special nylon spacers. There is one double spacer, two triple spacers, and two quadruple spacers. The plates have smooth surfaces on each side, and are fastened together with a long eyebolt. After three months, the plate was placed into a bucket and the specimens were relaxed and then preserved in 10% seawater buffered formalin. The plates were then disassembled and the specimens removed.

Figure 41 Taking piling scraping sample

Figure 42 Hanging Hester-Dendy plate sampler

4.2.7. Species Identification

All specimens were identified to species level wherever possible. Problematic specimens were identified by the Southeastern Regional Taxonomic Center in Charleston. Nomenclature follows the Integrated Taxonomic Information System (http://www.itis.usda.gov/). The following references were used in the identification process:

Abbott, Tucker R. 1974. American Seashells. The marine molluska of the Atlantic and Pacific coasts of North America. 2nd edition. Published by Von Nostrand Reinhold Co. pp.1-663.

Abbott, Tucker R. and S. Peter Dance. 1986. Compendium of Seashells. A Color Guide to More than 4,200 of the World's Marine Shells. Madison Publishing Associates. pp. 1-411.

Abbott, R. Tucker and Morris, Percy A. 1995. A Field Guide to Shells of the Atlantic and Gulf Coasts and the West Indies. The Petersons Field Guide Series. Houghton Mifflin Company. 350pp.

Blake, J.A. and N.J. Maciolek. 1987. A redescription of *Polydora cornuta* BOSC (Polychaeta: Spionidae) and designation of a neotype. Biol. Soc. Wash. Bull. No. 7, pp. 11-15.

Bousefield, E.L. 1973. Shallow-water gammardidean amphipoda of New England. Comstock Publishing Associates. 312 pp.

Brigham, A.R. and W.U. Brigham. 1982. Aquatic insects and oligochaetes of North and South Carolina. A. Gnilka (ed). Midwest Aquatic Enterprises, Sponsored by Duke Power Co.

Carpenter, K.E. (ed.) 2002. The living marine resources of the Western Central Atlantic. FAO species identification guides for fishery purposes and American Society of Ichthylologists and Herpetologists special publication No. 5. Vol. 2: Bony fishes part 1 (Acipenseridae to Grammatidae). pp 601-1374.

Carpenter, K.E. (ed.) 2002. The living marine resources of the Western Central Atlantic. FAO species identification guides for fishery purposes and American Society of Ichthylologists and Herpetologists special publication No. 5. Vol. 3: Bony fishes part 2 (Opistognathidae to Molidae), sea turtles and marine mammals. pp 1375-2127.

Cushman, Joseph A. 1948. Foraminifera. Harvard Press. 605pp.

Epler, J.H. 1995. Identification manual for the larval Chironomidae (Diptera) of Florida. Revised edition. Florida Department of Environmental Regulation.

Fauchald, Kristian. 1977. The Polychaete Worms: Definitions and Keys to the Orders, Families and Genera. Science Series 28. Natural History Museum of Los Angeles County in conjunction with the Allan Hancock Foundation, University of Southern California. pp 1-188.

Gilbert, C.R. and J.D. Williams. 2002. National Audubon Society Field Guide to Fishes. Alfred A. Knoph. 607 pp.

Gosner, Kenneth L. 1978. A Field Guide to the Atlantic Seashore from Bay of Fundy to Cape Hatteras. The Petersons Field Guide Series. Houghton Mifflin Company. 329pp.

Hartman, Olga. 1945. The Marine Annelids of North Carolina. Duke University Marine Station Bulletin No. 2. Duke University Press.

Heard, Richard W. 1982. Guide to Common Tidal Marsh Invertebrates of the Northeastern Gulf of Mexico. Mississippi Alabama Sea Grant Consortium. MASGP-79-004. pp. 1-82.

Rhyne, Nancy. 1982. Carolina Seashells. Fast & McMillan Publishers, Inc. pp. 9-95.

Ruppert, Edward E. and Richard S. Fox. 1988. Seashore Animals of the Southeast. University of South Carolina Press. pp. 3-429.

Schoettle, T. 1996. A Guide to a Georgia Barrier Island. St. Simons Island, GA: Watermarks Publishing.

Turgeon, D.D., A.E. Bogan, E.V. Coan, W.K. Emerson, W.G. Lyons, W.L. Pratt, C.F.E. Roper, A. Scheltema, F.G. Thompson, & J.D. Williams. 1988. Mollusks – Common and Scientific Names of Aquatic Invertebrates from the United States and Canada. American Fisheries Society Special Publication 16. pp. 1-277.

Vittor, Barry, Joan M.Uebelecker and Paul G. Johnson. 1984. Taxonomic Guide to the Polychaetes of the Northern Gulf of Mexico. Volume III. Prepared for the U.S. Department of the Interior.

Williams, A.B., L.G. Abele, D.L. Felder, H.H. Hobbs, Jr., R.B. Manning, P.A. McLaughlin, & I. Perez Farfante.. 1989. Decapod Crustaceans – Common and Scientific Names of Aquatic Invertebrates from the United States and Canada. American Fisheries Society Special Publication 17. pp. 1-77.

Williams, Austin B. 1984. Shrimps, Lobsters, and Crabs of the Atlantic Coast of the Eastern United States, Maine to Florida. Smithsonian Institute Press. 550pp.

5. RESULTS

5.1. Sample Labelling

For each zone within each port, an identifier was established for coding of the location. These identifiers consist of a three-letter city code and the zone number. In addition, identifiers were established to code the different gear types. These identifiers consist of the city code, zone number and a two-letter code for gear type. All identifiers are listed in Appendix 4.

5.2. Adequacy of Sampling Intensity

Cumulative species curves for each sampling technique at each study location are provided in Appendix 5. Figure 43 summarizes the number of species obtained in each port zone according to sampling gear and also indicates which samples attained an asymptote, which did not (marked A), and those that were approaching one at 13 samples (marked B). Sampling techniques for which an asymptote was consistently reached included crab traps and minnow traps. The number of species recorded in crab traps ranged from one which was typical of the above port zones to 16 below the port in Jacksonville (zone one). The number of species captured by minnow traps ranged from two at the Wilmington port (zone two) to eight below Jacksonville port (zone 1).

Species curves for core samples reached an asymptote in a majority of the zones, with the exception of the zone above the port in Wilmington (zone three) where six species were collected, and below the ports in Charleston and Wilmington (zone one) where 22 and 26 species were collected respectively.

Wilmington was the only port in which cumulative species curves for trawl samples reached an asymptote for all, however it should be noted that three was the highest number of species recorded in any of these zones, a substantially lower number than found in any of the other ports. With the exception of the zone below the port in Charleston, the number of new species in additional trawl samples from Jacksonville, Savannah and Charleston had begun to level off as 13 replicates were approached. The zone of exception in Charleston did in fact return 68 species, the highest number of species for any port zone with any gear type.

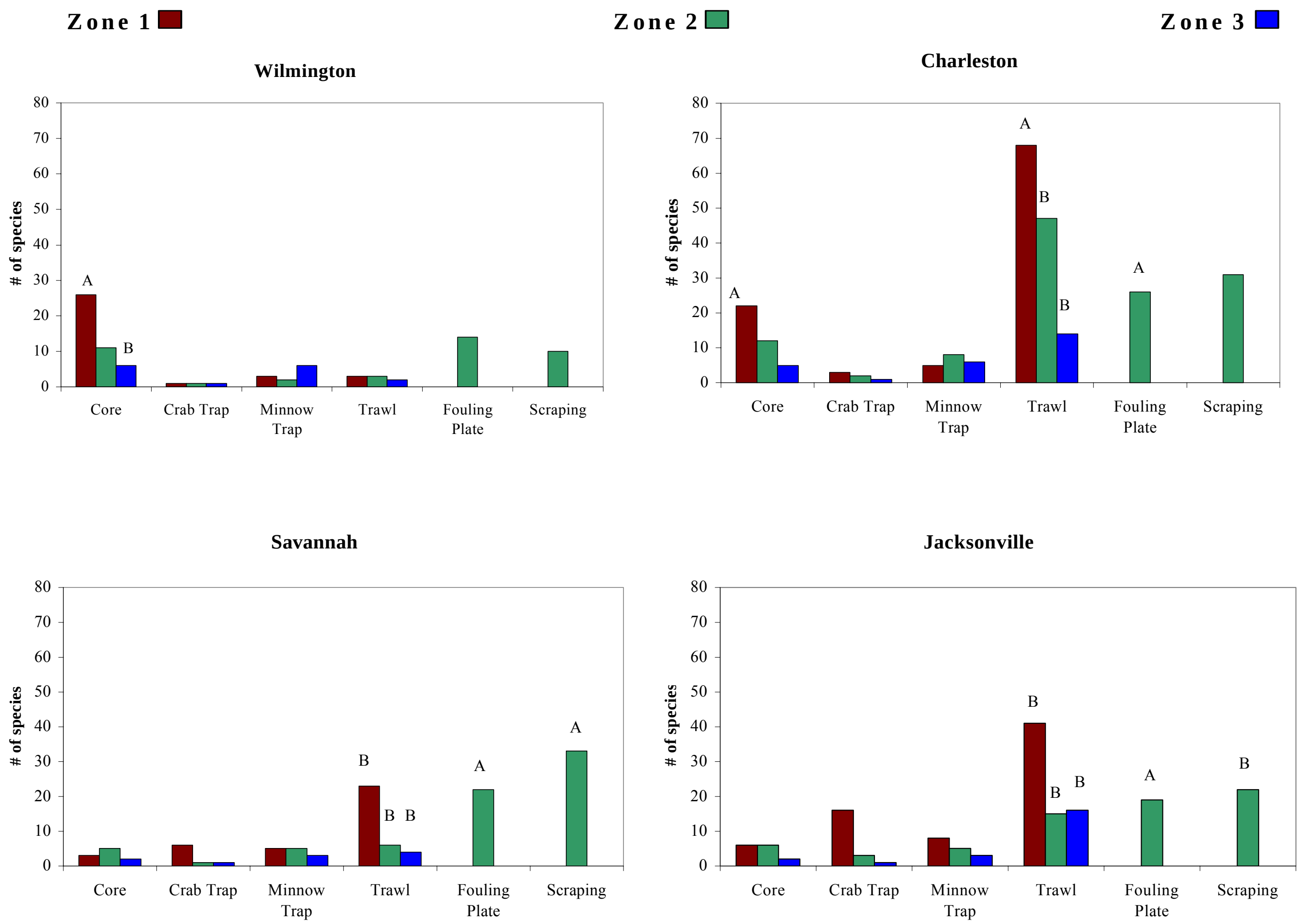


Figure 43 Adequacy of sample size number per gear type zone and port (A = species cumulative curve did not reach asymptote, B = curve approached asymptote but did not reach one).

In Jacksonville and Charleston, several plates were lost over the sampling period (three were retrieved from Jacksonville, five from Charleston) and therefore curves were not expected to reach an asymptote. Fouling plates reached an asymptote in Wilmington only. In Savannah, all 13 plates were retrieved; however, the curve does not begin to reach an asymptote. More species were collected from the plates in Savannah, with 22 versus 14 from Wilmington. The curves for scraping samples reached an asymptote for Charleston and Wilmington and approached one for Jacksonville, however the curves for Savannah did not approach an asymptote. Savannah again returned the greatest number of species with 33 versus 31 in Charleston, 22 in Jacksonville, and ten in Wilmington.

Overall 13 replicates seemed a reasonable number to adequately represent the number of species present. The outcome per gear type was not always consistent however over each port. In most situations where asymptotes were not attained, few additional species were in fact being found as the number of replicates approached 13 and the numbers collected in additional samples may not justify the extra cost in time and labor. We recommend slightly increasing the sample size in future surveys to 15 and placing sufficient back-up fouling plates to allow for significant losses.

5.3. Fauna

A total of 221 species were collected, comprising of 36 mollusks, 122 crustaceans, and 63 polychaetes. A complete listing of species and quantities collected by location and gear type is in Appendix 4. Detailed taxonomic classification for the species collected as provided by www.itis.usda.gov can be found in Appendix 8. Voucher specimens were placed in the Georgia Museum of Natural History and the Southeastern Regional Taxonomic Center in Charleston.

5.3.1 Molluska

Mollusks from this survey were collected from all four ports and in all three zones. Altogether, 27 bivalve, eight gastropod and one cephalopod species totaling 10,793 specimens were collected. Trawl samples returned the greatest number of species (25), followed by scrapings (11), fouling plates (nine), cores (eight), crab traps (four) and minnow traps (one). The Atlantic ribbed mussel, *Geukensia demissa* was the only species collected at all four ports (1,582 specimens in Savannah, 653 in Jacksonville, 583 in Charleston, four in Wilmington). Of the remaining species collected, seven were found in three of the ports, five in any two of the ports , and 22 species were found in a single port (Table 5).

All mollusks collected from crab traps were found on hermit crab shells below the port (zone 1) in Savannah and Jacksonville. Core samples from Charleston exhibited the highest molluskan richness with six of the nine species collected here being found. The species recorded in core samples differed over each port, in fact the Eastern mud snail, *Nassarius obsoletus* was the only one detected in more than one of the ports cores (Wilmington, Charleston and Jacksonville). This species was also the most abundant mollusk in core samples comprising 33 of the total of 49 molluskan core sample specimens. However, the structure of molluskan fouling communities (combining fouling plates and scrapings) for all four ports was quite similar. From an overall species richness of 13 in these samples, nine of the species appear in at least two of the ports. The fouling community samples also accounted for 88% of the number of individual molluskan specimens collected at the four ports (9,498 specimens).

Species collected in an overall abundance of 50 individuals or higher include *Brachidontes exustus* (4,262), *Geukensia demissa* (2,822), *Ischadium recurvum* (2,056), *Sphenia fragilis* (523), *Ostrea equestris* (288), *Amygdalum papyrium* (212), *Mytilopsis leucophaeata* (175), *Lolliguncula brevis* (152), *Crassostrea virginica* (72) and *Sphenia sp.* (72). There were 43 instances of collections of 50 individuals or more of a single species from a single sample. Of these samples 38 were scrapings and five were from trawls. The species, with the number of samples in which this occurred were *Geukensia demissa* (22), *Brachidontes exustus* (20), *Ischadium recurvum* (ten), *Sphenia fragilis* (two), *Amygdalum papyrium* (one), *Ostrea equestris* (one) and *Sphenia sp.* (one)

Ports ranked in order of molluskan species richness based on our sampling are as follows: Charleston (26 species); Jacksonville (19 species); Savannah (ten species); and Wilmington (five species). For each individual port, the number of species from each molluskan class was as follows: Charleston, 18 bivalves, seven gastropods, one cephalopod; Jacksonville, 15 bivalves, three gastropods, one cephalopod; Savannah, nine bivalves, one cephalopod; Wilmington, four bivalves, one gastropod. Charleston and Jacksonville had the most similar molluskan fauna, with 11 of the same species. Savannah and Jacksonville shared eight species, Charleston and Savannah six species, Jacksonville and Wilmington three species, and finally Wilmington and Charleston and Wilmington and Savannah which both shared two species.

A total of 956 samples were taken over the entire study area with various sampling gear. The most ubiquitous molluskan species were *Brachidontes exustus* (occurring in 62 samples), *Geukensia demissa* (58), *Sphenia fragilis* (39), *Lolliguncula brevis* (34), *Ischadium recurvum* (31), *Nassarius obsoletus* (20), *Mytilopsis leucophaeata* (18), *Amygdalum papyrium* (11), *Sphenia sp.* (nine), and *Crassostrea virginica* (seven). The most ubiquitous species collected in each individual port was as follows: Wilmington, *Modiolus* juv sp. (six); Charleston and Jacksonville, *Brachidontes exustus* (23 and 24, respectively); and Savannah, *Geukensia demissa* (25).

Our biological literature GIS database indicates the presence of at least 693 mollusks occurring in the South Atlantic Bight. These species represent 408 gastropods, 263 bivalves, ten cephalopods, seven scaphopods and five polyplacophora. The present survey therefore detected a mere 2% of the gastropods, 7% of the bivalves and 10% of the cephalopods reported by the database to be present in the region (or 5% of all combined). It should be noted, however, that the database includes offshore species and unfortunately our database is not searchable by habitat.

5.3.2. Crustacea

Crustaceans were collected from all four ports in all three zones. Altogether, 51 decapod, 30 amphipod, 18 isopod, 12 barnacle, three mysid, three tanaid, two stomatopod, one copepod, one mysidacean and one ostracod species totaling 122 species and 42, 583 specimens were collected. Trawl samples returned the greatest number of species (72), followed by minnow traps (37), scrapings (27), cores (20), fouling plates (16) and crab traps (ten). As shown in Table 6 a total of eight species were found in all four ports: the aviu shrimp, *Acetes americanus carolinae* (265 specimens in Charleston, 18 Savannah, three Jacksonville, one Wilmington); the blue crab, *Callinectes sapidus* (207 Jacksonville, 107 Wilmington, 105 Savannah, 71 Charleston): the lesser blue crab, *Callinectes similis* (99 Jacksonville, 42 Charleston, 19 Savannah, one Wilmington): white shrimp, *Litopenaeus setiferus* (1,416 Savannah, 600 Charleston, 187 Wilmington, 146 Charleston); the amphipod, *Melita nitida* (456 Wilmington, 182 Charleston, 135 Jacksonville, 28 Savannah); the long-armed hermit crab, *Pagurus longicarpus*, (21 Jacksonville, 12 Charleston, five Savannah, one Wilmington); grass shrimp, *Palaemontes pugio* (72 Savannah, 14 Wilmington, three Charleston, three Jacksonville); grass shrimp *Palaemonetes vulgaris* (85 Charleston, 20 Savannah, 12 Wilmington, eight Jacksonville). Of the remaining species collected, 19 were found in three of the ports (Table 6), 29 in any two of the ports (Table 7), and 66 species were found in a single port (Tables 8, 9).

The structure of the infaunal benthic community was quite dissimilar across the study area; 17 out of the 20 species collected using core samples were found in a single port, while the remaining three were found in only two of the four ports. Almost half of the species collected in trawl samples were common to at least two of the ports and *Litopenaeus setiferus* was found in all three zones of all four ports.

Four Ports	Three Ports	Two Ports	One Port	
Geukensia demissa (Dillwyn, 1817)	*Brachidontes exustus* (Linnaeus, 1758)	*Anadara floridana* (Conrad, 1869)	*Abra aequalis* (Say, 1822)	*Amygdalum papyrium* (Conrad, 1846)
	Ischadium recurvum (Rafinesque, 1820)	*Boonea impressa* (Say, 1822)	*Anadara notabilis* (Roding, 1798)	*Anadara ovalis* (Bruguiere, 1789)
	Lolliguncula brevis (Blainville, 1823)	*Crassostrea virginica* (Gmelin, 1791)	*Anadara transversa* (Say, 1822)	*Angulus texana* (Dall, 1900)
	Mytilopsis leucophaeata (Conrad, 1831)	*Musculus lateralis* (Say, 1822)	*Barnea truncata* (Say, 1822)	*Cerithiopsis* sp. (Forbes & Hanley, 1851)
	Nassarius obsoletus (Say, 1822)	*Ostrea equestris* (Say, 1834)	*Chione elevata* (Say, 1822)	*Corbula contracta* (Say, 1822)
	Sphenia fragilis (H. & A. Adams, 1854)		*Cumingia tellinoides* (Conrad, 1831)	*Littoraria irrorata* (Say, 1822)
	Sphenia sp. (Turton, 1822)		*Mitrella* sp. (Risso, 1826)	*Modiolus* juv sp. (Lamarck, 1799)
			Mytilopsis sp. (Conrad, 1857)	*Mytilus edulis* (Linnaeus, 1758)
			Raeta plicatella (Conrad, 1831)	*Simnialena uniplicata* (G. B. Sowerby II, 1848)
			Spisula raveneli (Say, 1822)	*Tagelus plebeius* (Lightfoot, 1786)
			Triphora sp. (de Blainville, 1828)	*Urosalpinx* sp. (Stimpson, 1865)

Table 5 Molluskan species recorded at four, three, two and one of the four ports sampled in the South Atlantic Bight.

Four Ports	Three Ports	
Acetes americanus carolinae (Hansen, 1933)	*Apocorophium lacustre* (Vanhoffen, 1911)	*Balanus amphitrite amphitrite* (Darwin, 1854)
Callinectes sapidus (M. J. Rathbun, 1896)	*Balanus eburneus* (Gould, 1841)	*Balanus juv sp.* (Da Costa, 1778)
Callinectes similis (A. B. Williams, 1966)	*Balanus sp.* (Da Costa, 1778)	*Cleantioides planicauda* (J. E. Benedict, 1899)
Litopenaeus setiferus (Linnaeus, 1767)	*Cymothoa excisa* (Perty, 1833)	*Eurypanopeus depressus* (S. I. Smith, 1869)
Melita nitida (S. I. Smith, 1873)	*Farfantepenaeus aztecus* (Ives, 1891)	*Hyale plumulosa* (Stimpson, 1857)
Pagurus longicarpus (Say, 1817)	*Ligia exotica* (Roux, 1828)	*Panopeus herbstii* (H. Milne Edwards, 1834)
Palaemonetes pugio (Holthuis, 1949)	*Petrolisthes armatus* (Gibbes, 1850)	*Pleusymtes glaber* (Boeck, 1861)
Palaemonetes vulgaris (Say, 1818)	*Rhithropanopeus harrisii* (Gould, 1841)	*Stenothoe minuta* (Holmes, 1903)
	Synidotea sp. (Harger, 1878)	*Xanthidae juv. sp.* (MacLeay, 1838)
	Zaops ostreum (Say, 1817)	

Table 6 Crustacean species recorded at three and four of the four ports sampled in the South Atlantic Bight.

Two Ports		
Alpheus heterochaelis (Say, 1818)	*Amphilochus spencebatei* (Bate, 1862)	*Ampithoe valida* (S. I. Smith, 1873)
Armases cinereum (Bosc, 1802)	*Balanus improvisus* (Darwin, 1854)	*Balanus venustus* (Darwin, 1854)
Balanus improvisus (Darwin, 1854)	*Balanus venustus* (Darwin, 1854)	*Batea catharinensis* (F. Müller, 1865)
Caprella equilibra (Say, 1818)	*Cassidinidea lunifrons* (Richardson, 1900B)	*Clibanarius vittatus* (Bosc, 1802)
Corophium sp. (Latreille, 1806)	*Cyathura polita* (Stimpson, 1855)	*Decapoda sp.* (Latreille, 1802)
Latreutes parvulus (Stimpson, 1866)	*Libinia dubia* (H. Milne Edwards, 1834)	*Menippe mercenaria* (Say, 1818)
Neomysis Americana (S. I. Smith, 1873)	*Pachygrapsus transverses* (Gibbes, 1850)	*Pagurus pollicaris* (Say, 1817)
Pagurus sp. (Fabricius, 1775)	*Parahaustorius holmesi* (Bousfield, 1965)	*Parapenaeus politus* (S. I. Smith, 1881)
Penaeidae sp. (Rafinesque, 1815)	*Portunus gibbesii* (Stimpson, 1859)	*Rimapenaeus constrictus* (Stimpson, 1871)
Rocinela americana (Schioedte and Meinert, 1879)	*Sinelobus stanfordi* (H. Richardson, 1901)	*Sphaeroma quadridentatum* (Say, 1818)
Squilla empusa (Say, 1818)		

Table 7 Crustacean species recorded at two of the four ports sampled in the South Atlantic Bight.

One Port		
Ampelisca abdita (Mills, 1964)	*Ampelisca verrilli* (Mills, 1967)	*Amphipoda spp.* (Latreille, 1816)
Anilocra acuta (H. Richardson, 1910)	*Balanus amphitrite* (Darwin, 1854)	*Balanus calidus* (Pilsbry, 1916)
Balanus spp. (Da Costa, 1778)	*Balanus trigonus* (Darwin, 1854)	*Bowmaniella juv sp.* (Bacescu, 1968)
Brasilomysis castroi (Bacescu, 1968)	*Caprellidae sp.* (Leach, 1814)	*Caridea sp.* (Dana, 1852)
Cassidinidea ovalis (Say, 1818)	*Chelonibia testudinaria* (Linnaeus, 1758)	*Chiridotea caeca* (Say, 1818)
Conopea galeata (Linnaeus, 1771)	*Corophium volutator* (Pallas, 1766)	*Crangonyx pseudogracilis* (Bousfield, 1958)
Crangonyx richmondensis richmondensis (Ellis, 1940)	*Cronius sp.* (Stimpson, 1860)	*Dulichiella appendiculata* (Say, 1818)
Dynamene sp. (Leach, 1814)	*Dyspanopeus sayi* (S. I. Smith, 1869)	*Edotia sp.* (Guerin-Meneville, 1843)
Elasmopus levis (S. I. Smith, 1873)	*Emerita talpoida* (Say, 1817)	*Ericthonius brasiliensis* (Dana, 1853)
Exhippolysmata oplophoroides (Holthuis, 1948)	*Farfantepenaeus duorarum* (Burkenroad, 1939)	*Gammarus fasciatus* (Say, 1818)
Gammarus tigrinus (Sexton, 1939)	*Hargeria rapax* (Harger, 1879)	*Harpacticoida sp.* (G. O. Sars, 1903)
Jassa marmorata (Holmes, 1903)	*Lembos smithi* (Holmes, 1903)	*Leucothoe spinicarpa* (Abildgaard, 1789)

Table 8 Crustacean species recorded at only one of the four ports sampled in the South Atlantic Bight.

One Port (ctd)		
Leucothoe spinicarpa complex (Abildgaard, 1789)	*Listriella barnardi* (Wigley, 1966)	*Livoneca reniformis* (Menzies and Frankenberg, 1966)
Lysmata wurdemanni (Gibbes, 1850)	*Macrobrachium acanthurus* (Wiegmann, 1836)	*Monocorophium acherusicum* (Costa, 1857)
Monoculodes edwardsi (Holmes, 1905)	*Mysidacea sp.* (Haworth, 1825)	*Nerocila sp.* (Leach, 1818)
Ostracoda sp. (Latreille, 1802)	*Ovalipes sp.* (Rathbun, 1898)	*Pagurus carolinensis* (McLaughlin, 1975)
Palaemonetes sp. (Heller, 1869)	*Pelia mutica* (Gibbes, 1850)	*Periclimenes longicaudata* (Stimpson, 1860)
Portunus sp. (Weber, 1795)	*Probopyrus pandalicola* (Packard, 1879)	*Progebiophilus upogebiae* (Hay, 1917)
Squilla juv. sp. (Fabricius, 1787)	*Synalpheus townsendi* (Coutière, 1909)	*Synidotea nebulosa* (J. E. Benedict, 1897)
Tanaidacea sp. (Dana, 1849)	*Thor sp.* (Kingsley, 1878)	*Uca juv. Sp.* (Leach, 1814)
Uca pugilator (Bosc, 1802)	*Uca sp.* (Leach, 1814)	*Upogebia affinis* (Say, 1818)
Xanthidae spp. (MacLeay, 1838)	*Xanthidae spp.* (MacLeay, 1838)	*Xiphopenaeus kroyeri* (C. Heller, 1862)

Table 9 Crustacean species recorded at only one of the four ports sampled in the South Atlantic Bight continued

Trapping (minnow and crab traps combined) returned a total of 23 species, 16 of which were found in at least two of the ports. *Callinectes sapidus* was collected in traps from all three zones of all four ports, with the exception of the mouth of the Savannah River (zone 1). Half of all fouling species recorded occurred in more than a single port.

Species collected in an overall abundance of 50 individuals or higher include *Balanus* juv sp. (29,653), *Balanus sp.* (1,122), *Litopenaeus setiferus* (2,349), *Gammarus tigrinus* (1,163), *Melita nitida* (801), *Hyale plumulosa* (713), *Listriella barnardi* (703), *Balanus calidus* (603), *Callinectes sapidus* (490), *Farfantepenaeus aztecus* (403), *Balanus eburneus* (374), *Apocorophium lacustre* (353), *Panopeus herbstii* (321), *Synidotea sp.* (318), *Balanus venustus* (315), *Acetes americanus carolinae* (287), *Cassidinidea lunifrons* (245), *Caprella equilibra* (205), *Zaops ostreum* (197), *Callinectes similis* (161), *Palaemonetes vulgaris* (125), *Pleusymtes glaber* (120), *Eurypanopeus depressus* (103), *Leucothoe spinicarpa complex* (103), *Portunus gibbesii* (99), *Ligia exotica* (94), *Palaemonetes pugio* (92), *Ampithoe valida* (85), *Petrolisthes armatus* (78), *Balanus improvisus* (70) and *Leucothoe spinicarpa* (60). There were 84 instances where more than 50 individuals of a single species were found in a sample. Of these samples, 30 were fouling plates, 29 trawls, 21 scrapings and four were in crab traps. The species, with the number of samples in which this occurred were *Balanus* juv. sp. (34), *Litopenaeus setiferus* (11), *Balanus sp.* (six), *Melita nitida* (five), *Listriella barnardi* (five), *Hyale plumulosa* (four), *Gammarus tigrinus* (four), *Balanus calidus* (four), *Balanus venustus* (three), *Apocorophium lacustre* (three), *Caprella equilibra* (two), *Synidotea sp.* (one), *Leucothoe spinicarpa complex* (one), and *Acetes americanus carolinae* (one).

Ports ranked in order of crustacean species richness based on our collections are as follows: Charleston, 79; Jacksonville, 59, Savannah, 46; and Wilmington, 29. For each port, the number of species breaks down as follows: Charleston - 37 decapods, 21 amphipods, ten isopods, eight barnacles, two stomatopods, and one mysid; Jacksonville - 28 decapods, ten amphipods, ten barnacles, five isopods, three mysids, one mysidacean, one stomatopod and one tanaid; Savannah - 24 decapods, ten isopods, nine amphipods, and three barnacles; Wilmington - 11 decapods, seven amphipods, five isopods, three tanaids, one barnacle, one copepod, and one ostracod. Charleston and Jacksonville shared the most similarity in crustacean fauna, with 39 of the same species. Savannah and Jacksonville shared 34 species, Charleston and Savannah 30 species, Wilmington and Savannah and Wilmington and Jacksonville both shared 11 species and Wilmington and Charleston shared ten species.

The most ubiquitous species was *Callinectes sapidus*, which was found in 159 out of 956 samples (16%). Other species collected frequently and ranked in descending order together with the number of samples they occurred in were: *Litopenaeus setiferus* (144), *Panopeus herbstii* (87), *Callinectes similis* (63), *Farfantepenaeus aztecus* (52), *Balanus eburneus* (51), *Melita nitida* (49), *Balanus juv sp.* and *Palaemonetes vulgaris* (each taken in 39 samples), and *Eurypanopeus depressus* and *Hyale plumulosa* (each taken in 35 samples). The most ubiquitous species collected in each individual port was as follows: Charleston, Jacksonville and Wilmington,, *Callinectes sapidus* (37, 34 and 63, respectively) and Savannah, *Litopenaeus setiferus* (49).

Our biological literature GIS database indicates the presence of at least 678 crustaceans occurring the in the South Atlantic Bight. These species represent 263 decapods, 156 amphipods, 80 isopods, 27 barnacles, 13 mysids, six tanaids, seven stomatopods, 106 copepods, one mysidacean and five ostracods. The present survey therefore detected approximately 19% of the decapods, 19% of the amphipods, 23% of the isopods, 44% of the barnacles, 23% of the mysids, 50% of the tanaids, 29% of the stomatopods, less than 1% of the copepods, and 20% of the ostracods reported present in the region by our database (or 18% of all groups combined). It should be noted, however, that the database includes several habitats other than those sampled in this survey.

5.3.3. Polychaeta

Polychaetes from this survey were collected from all three zones in each of the four ports. A total of 2,640 specimens were collected, representing 63 polychaete species. Sediment core samples returned the greatest number of species (33), followed by trawls (21), scrapings (11), fouling plates (seven) and crab traps (three). No polychaetes were collected from minnow traps. Three species were found at all four ports (Table 11): *Laeonereis culveri* (50 specimens in Jacksonville, eight in Wilmington, five in Savannah, one in Charleston); *Leitoscoloplos fragilis* (317 in Savannah, 124 in Charleston, 31 in Jacksonville, 12 in Wilmington); and *Neanthes succinea* (365 in Savannah, 199 in Charleston, 131 in Jacksonville, three in Wilmington). Of the remaining species collected, five were found in any three of the ports, 13 in any two of the ports (Table 11) and 42 species were found in a single port only (Table 12).

Species collected from trawl samples were quite dissimilar over the study region, with only six (out of 21) of the same species being collected in this manner at more than a single port. In Charleston our trawl samples were the most diverse, returning 19 of the 21 species collected altogether through trawling. The polychaete fouling community was represented by 14 species, three of which occurred in at least two of the ports. Approximately 36% of the polychaete species collected in sediment cores were found in more than one port. Polychaetes collected from crab traps included *Lepidonotus sublevis, Neanthes succinea* and *Sabellaria vulgaris*, and were found inside or on hermit crab shells.

Species collected in an overall abundance of 50 individuals or higher include *Genetyllis castanea* (859), *Neanthes succinea* (698), *Leitoscoloplos fragilis* (484), *Marenzelleria viridis* (101), *Laeonereis culveri* (64), *Sabellaria vulgaris beaufortensis* (61), *Parandalia americana* (57) and *Sabellaria vulgaris* (52). The species collected in the highest abundance for each port were: Charleston, *Genetyllis castanea* (417); Savannah and Jacksonville, *Neanthes succinea* (365 and 131, respectively); Wilmington, *Streblospio* benedicti (41). There were seven instances of collections of 50 individuals in a single species from a single sample. The species, with the number of samples in which this occurred were *Genetyllis castanea* (five, in scraping samples) and *Leitoscoloplos fragilis* (two, in sediment core samples).

Ports ranked in order of polychaete species richness based on our sampling are as follows: Charleston (46 species); Wilmington (18 species); Savannah, (16 species); and Jacksonville (15 species). Charleston and Jacksonville had the most similar polychaete fauna, with 11 of the same species collected, followed by: Charleston and Wilmington (ten species); Charleston and Savannah (eight species); Jacksonville and Savannah (eight species); Savannah and Wilmington (five species); Jacksonville and Wilmington (four species).

The most ubiquitous species collected for all four ports were *Neanthes succinea* (collected in 71 out of 956 samples), *Leitoscoloplos fragilis* (55), *Genetyllis castanea* (38), *Laeonereis culveri*

(29), *Parandalia americana* (25), *Marenzelleria viridis* (24), *Polydora ligni cornuta* (15), *Mediomastus californiensis* (nine), *Nereis falsa* (seven), and *Aricidea suecica, Lepidonotus sublevis, Sabella sp.* and *Streblospio benedicti* (all taken in six samples). The most ubiquitous species collected in each port was as follows: Charleston, Savannah and Jacksonville, *Neanthes succinea* (22, 24 and 21 samples, respectively); Wilmington, *Marenzelleria viridis* and *Parandalia americana* (both in six samples).

Our biological literature GIS database indicates the presence of at least 367 polychaetes in the South Atlantic Bight region. The present survey therefore detected approximately 17% of the total polychaete fauna reported in our database to be present in the South Atlantic Bight. It should be noted, however, that the database includes habitats other than those sampled in this survey and unfortunately our database is not searchable by habitat.

5.3.4. Differences in Community Structure Between Ports And Zones

Table 10 lists the biological community parameters for each port. Biological indices per gear type, zone and port are provided in Appendix 6. Mean port species richness ranged from 53 (Wilmington) to 151 (Charleston). Wilmington was far less diverse than the other three ports (Shannon-Weiner Diversity Index of 0.56), with species not very evenly distributed (evenness index of 0.14). Charleston, Savannah and Jacksonville exhibited higher diversity indices at 2.66, 2.58 and 3.27, respectively. Species were also distributed more evenly with indices ranging from 0.53 to 0.72.

Port	**Species Richness**	**Species Evenness**	**Shannon-Wiener Diversity Index**
Wilmington	53	0.14	0.56
Charleston	151	0.53	2.66
Savannah	72	0.60	2.58
Jacksonville	94	0.72	3.27

Table 10 Biological Indices averaged for each port.

Table 13 lists community parameters for the different zones in each port. Because the fouling community was sampled only in the port zone (zone 2) this is considered separately (Table 14). In each port, the region below the port returned the greatest number of species, followed by the port region, and finally the region above port i.e. increasing from the estuary upriver. Diversity indices were also higher below the ports (1.71 to 2.50) with the exception of Charleston, where diversity was lowest in this zone (1.37) and highest in the port zone (2.50). Evenness indices ranged from 0.31 to 0.82, with the highest values recorded in Wilmington and Jacksonville.

In considering the fouling community, species richness per port zone ranged from 19 to 49 species. Diversity indices were relatively high, with values from 2.15 to 2.35, while evenness indices were mid-scale, 0.57 to 0.67. Lower richness, evenness and diversity indices in Wilmington may be attributed to the presence of high numbers of *Balanus* juvenile species (28,290 specimens collected out of 31,682).

Table 15 lists community parameters broken down for each gear type at each port zone. No specific patterns could be established, species richness, species evenness and Shannon-Wiener diversity indices varied both within and between ports.

Lowest diversity was exhibited in crab traps, where only one species, the blue crab, *Callinectes sapidus*, was captured in seven of the 12 zones. In the remaining zones, species richness from crab traps ranged from two to 16, and evenness and diversity varied due to the presence of the lesser blue crab, *Callinectes similis,* the stone crab, *Menippe mercenaria*, or hermit crabs, *Clibanarius vittatus* and *Pagurus pollicaris*, and their associated symbionts. However, diversity remained low with the highest value calculated as 1.24 below the port in Jacksonville (zone 1) while evenness was fairly high, 0.47 to 0.94. Minnow traps also exhibited low diversity, with values ranging from 0.50 to 1.50 (the highest value recorded from below port in Charleston (zone 1) and species richness ranging from two to eight. Species were fairly evenly distributed, however, with evenness indices between 0.51 and 0.95.

Four Ports	Three Ports	Two Ports	
Laeonereis culveri (Webster, 1879)	*Genetyllis castanea* (Malmgren, 1865)	*Aricidea suecica* (Eliason)	*Capitella capitata* (Fabricius, 1780)
Leitoscoloplos fragilis (Day, 1977)	*Marenzelleria viridis* (Verrill, 1873)	*Eteone heteropoda* (Hartman)	*Glycera dibranchiata* (Ehlers, 1868)
Neanthes succinea (Frey and Leuchart, 1847)	*Marphysa sanguinea* (Montagu, 1815)	*Heteromastus filiformis* (Claparede)	*Lepidonotus sublevis* (Verrill, 1873)
	Parandalia americana (Emerson and Fauchald, 1971)	*Mediomastus californiensis* (Hartman, 1944)	*Mediomastus sp.* (Hartman, 1944)
	Polydora ligni cornuta (Bosc, 1802)	*Nereis falsa* (Linnaeus, 1758)	*Sabella sp. A* (Linnaeus, 1767)
		Sabellaria vulgaris (Verrill)	*Sabellaria vulgaris vulgaris* (Verrill)
		Streblospio benedicti (Webster, 1879)	

Table 11 Polychaete species recorded at two, three and four of the four ports sampled in the South Atlantic Bight.

One Port			
Anaitides mucosa (Czerniavsky, 1882)	*Autolytus cornutus* (Grube, 1850)	*Boccardia sp. A* (Carazzi, 1895)	*Boccardiella sp. A* (Blake and Kudenov, 1978)
Capitellidae sp. (Grube, 1862)	*Caulleriella killariensis* (Southern)	*Cirratulidae sp.* (Ryckholdt, 1851)	*Cirrophorus sp.* (Ehlers, 1908)
Demonax microphthalmus (Kinberg, 1867)	*Dentatisyllis carolinae* (Perkins, 1981)	*Diopatra cuprea* (Bosc, 1802)	*Dispio uncinata* (Hartman, 1951)
Drilonereis longa (Webster)	*Eupolymnia sp. A* (Verrill, 1900)	*Glycera americana* (Leidy)	*Glycera sp.* (Savigny, 1818)
Hesionura sp. A (Hartmann-Schroeder, 1958)	*Hydroides dianthus* (Verrill)	*Loimia medusa* (Savingy, 1818)	*Marphysa sp.* (Quatrefages, 1865)
Marphysa sp.B (Quatrefages, 1865)	*Nereiphylla fragilis* (Blainville, 1828)	*Odontosyllis enopla* (Claparede, 1863)	*Orbinia ornata* (Quatrefages, 1865)
Parandalia sp. (Emerson and Fauchald, 1971)	*Parandalia sp. A* (Emerson and Fauchald, 1971)	*Paraonis fulgens* (Levinsen)	*Paraprionospio pinnata* (Ehlers)
Pista palmata (Verrill)	*Podarke obscura* (Ehlers, 1864)	*Polycirrus sp. B* (Grube, 1850)	*Polynoidae sp.* (Malmgren, 1867)
Potamilla cf reniformis (Leuckart)	*Prionospio cristata* (Foster)	*Sabellaria vulgaris beaufortensis* (Verrill)	*Scoletoma tenuis* (Verrill, 1873)
Spionidae sp. (Grube, 1850)	*Spiophanes bombyx* (Claparede, 1870)	*Streblosoma hartmanae* (Sars, 1872)	*Streptosyllis pettiboneae* (Webster and Benedict, 1884)
Syllis sp. (Savigny, 1818)	*Tharyx dorsobranchialis* (Kirkegaard, 1959)		

Table 12 Polychaete species recorded at only one of the four ports sampled in the South Atlantic Bight.

ID	Species Richness	Species Evenness	Shannon-Wiener Diversity Index
WIL01	30	0.71	2.41
WIL02	15	0.82	2.23
WIL03	15	0.79	2.15
CHA01	90	0.30	1.37
CHA02	61	0.62	2.56
CHA03	20	0.66	1.96
SAV01	30	0.50	1.71
SAV02	15	0.53	1.43
SAV03	9	0.49	1.07
JAX01	57	0.61	2.48
JAX02	24	0.61	1.93
JAX03	19	0.63	1.84

Table 13 Biological indices averaged for each port zone.

ID	Species Richness	Species Evenness	Shannon-Wiener Diversity Index
WIL02	19	0.25	0.75
CHA02	49	0.57	2.20
SAV02	42	0.57	2.15
JAX02	34	0.67	2.35

Table 14 Biological indices for fouling community samples collected.

For the majority of the sediment core samples, between two and 12 species were collected. The exceptions were below the ports of Wilmington and Charleston, where 22 and 26 species were collected, respectively. These exceptions also provided the highest diversity indices recorded for any gear type, 2.51 and 2.68, respectively. The remaining samples with lower species richness also exhibited lower diversity indices, from 0.10 to 1.96. Overall values of evenness varied between 0.11 and 0.87; however, it should be noted that some of the higher evenness values could be attributed to samples with lower diversity and/or richness.

All parameters for trawls varied significantly between the different zones of each port. Species richness ranged anywhere between two and 68 species, diversity between 0.08 and 2.21, and evenness between 0.06 and 0.66.

Species richness of fouling plate samples ranged between 14 and 26 species, diversity indices between 1.37 and 2.12, and evenness indices between 0.52 and 0.70. Despite the loss of fouling plates in Charleston and Jacksonville, (five and three plates returned, respectively), parameter values within these ports were higher than Wilmington and Savannah, with diversity indices of 2.12 and 2.07 and evenness indices of 0.65 and 0.70, respectively. Charleston also returned the greatest species richness for fouling plates (26).

Wilmington scrapings differed significantly from the other three ports with regard to community parameters. Species richness was significantly lower (ten in Wilmington, compared to 22-33 for the remaining ports), as was diversity (0.03) and evenness (0.06). Diversity indices were significantly higher for Charleston, Savannah and Jacksonville, ranging between 1.82 and 1.99, while evenness indices were somewhat higher, between 0.53 and 0.65.

Cluster analysis of sites based on environmental characteristics divided the sites into two main groupings consisting of marine and brackish water sites (Figure 44). Within the brackish water grouping, sites were further split into mesohaline and tidal fresh. Other possible clusters were examined for qualitative groupings based on sediment analysis, and quartile ranges for water temperature, total carbon and total nitrogen (Table 22). Wilmington port was not included due to inconsistencies in sediment data.

Bray-Curtis similarity indices for core samples, crab traps, minnow traps, trawl samples, fouling plates and scrapings are listed in Tables 16-21, respectively. There were 19 samples in which the calculated index is higher than 0.75 (highlighted in blue), indicating strong similarity between the corresponding samples.

ID	Species Richness	Species Evenness	Shannon-Wiener Diversity Index
WIL01CO	26	0.77	2.51
WIL01CR	1	0.00	0.00
WIL01MI	3	0.72	0.79
WIL01TR	3	0.22	0.25
WIL02CO	11	0.82	1.96
WIL02CR	1	0.00	0.00
WIL02HD	14	0.52	1.37
WIL02MI	2	0.72	0.50
WIL02SC	10	0.03	0.06
WIL02TR	3	0.66	0.72
WIL03CO	6	0.65	1.16
WIL03CR	1	0.00	0.00
WIL03MI	6	0.82	1.5
WIL03TR	2	0.49	0.34
CHA01CO	22	0.87	2.68
CHA01CR	3	0.47	0.52
CHA01MI	5	0.93	1.50
CHA01TR	68	0.29	1.23
CHA02CO	12	0.29	0.72
CHA02CR	2	0.59	0.41
CHA02MI	8	0.57	1.19
CHA02TR	47	0.57	2.21
CHA02HD	26	0.65	2.12
CHA02SC	31	0.53	1.82
CHA03CO	5	0.65	1.05
CHA03CR	1	0.00	0.00
CHA03MI	6	0.58	1.04
CHA03TR	14	0.52	1.38
SAV01CO	3	0.11	0.12
SAV01CR	6	0.64	1.15
SAV01MI	5	0.80	1.28
SAV01TR	23	0.39	1.22
SAV02CO	5	0.34	0.54
SAV02CR	1	0.00	0.00
SAV02MI	5	0.76	1.22
SAV02TR	6	0.11	0.20
SAV02HD	22	0.52	1.62
SAV02SC	33	0.57	1.98
SAV03CO	2	0.20	0.14
SAV03CR	1	0.00	0.00
SAV03MI	3	0.91	1.00
SAV03TR	4	0.06	0.08
JAX01CO	6	0.78	1.40
JAX01CR	16	0.45	1.24
JAX01MI	8	0.70	1.46
JAX01TR	41	0.54	2.01
JAX02CO	6	0.76	1.36
JAX02CR	3	0.94	1.03
JAX02MI	5	0.79	1.26
JAX02TR	15	0.54	1.46
JAX02HD	19	0.70	2.07
JAX02SC	22	0.65	2.00
JAX03CO	2	0.15	0.10
JAX03CR	1	0.00	0.00
JAX03MI	3	0.51	0.56
JAX03TR	16	0.61	1.68

Table 15 Biological indices averaged for each port zone by gear type (CO = sediment core, CR = crab trap, MI = minnow trap, TR = trawl, HD = Hester Dendy, SC = scraping)

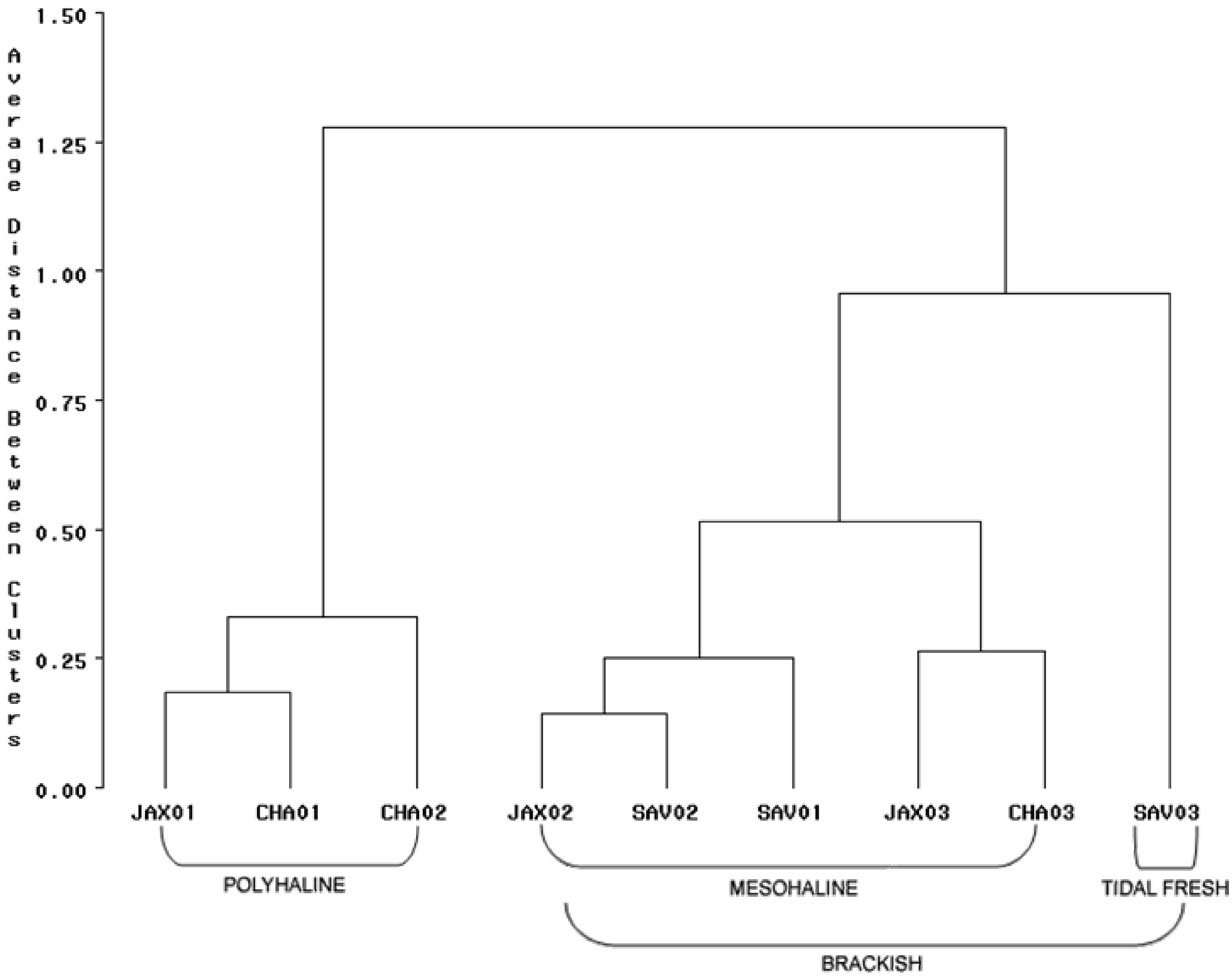


Figure 44 Dendrogram derived from cluster analysis of environmental characteristics for nine sampling zones associated with three ports in the south Atlantic Region (JAX = Jacksonville, CHA = Charleston, SAV = Savannah, 01 = lower zone, 02 = port zone, 03 = upper zone). Labels at the bottom indicate the salinity groupings for the samplings sites.

	CHA02CO	CHA03CO	JAX01CO	JAX02CO	JAX03CO	SAV01CO	SAV02CO	SAV03CO	WIL01CO	WIL02CO	WIL03CO
CHA01CO	0.0402	0.2381	0.0000	0.1205	0.0198	0.0000	0.0374	0.0230	0.0670	0.0000	0.0000
CHA02CO		0.0092	0.1657	0.1839	0.0000	0.5277	0.0101	0.0000	0.1185	0.0279	0.0000
CHA03CO			0.0000	0.0396	0.0000	0.0000	0.0160	0.0000	0.0914	0.0563	0.0000
JAX01CO				0.5846	0.0241	0.1219	0.0225	0.0290	0.1615	0.0189	0.0286
JAX02CO					0.1053	0.1130	0.0976	0.0323	0.2078	0.0000	0.0000
JAX03CO						0.0000	0.1000	0.0500	0.0814	0.0171	0.0247
SAV01CO							0.0000	0.0000	0.0533	0.0000	0.0000
SAV02CO								0.7674	0.0787	0.3089	0.0230
SAV03CO									0.0380	0.3495	0.0299
WIL01CO										0.1846	0.1384
WIL02CO											0.4038

Table 16 Bray-Curtis similarity indices for the 12 zones where core samples were taken. (0 – dissimilar; 1 – similar)

	CHA02CR	CHA03CR	JAX01CR	JAX02CR	JAX03CR	SAV01CR	SAV02CR	SAV03CR	WIL01CR	WIL02CR	WIL03CR
CHA01CR	0.1765	0.7302	0.0565	0.2703	0.8980	0.0000	0.6133	0.5750	0.6866	0.8519	0.8980
CHA02CR		0.0465	0.0162	0.1176	0.0690	0.0000	0.0364	0.0333	0.0426	0.0588	0.0690
CHA03CR			0.0805	0.2174	0.7586	0.0000	0.8571	0.8090	0.9474	0.8571	0.7586
JAX01CR				0.0230	0.0500	0.1264	0.0839	0.0834	0.0846	0.0610	0.0500
JAX02CR					0.3125	0.0342	0.1724	0.1587	0.2000	0.2703	0.3125
JAX03CR						0.0000	0.6286	0.5867	0.7097	0.8980	1.0000
SAV01CR							0.0000	0.0000	0.0000	0.0000	0.0000
SAV02CR								0.9505	0.9091	0.7200	0.6286
SAV03CR									0.8602	0.6750	0.5867
WIL01CR										0.8060	0.7097
WIL02CR											0.8980

Table 17 Bray Curtis similarity indices for the 12 zones where crab traps were used for sampling. (0 – dissimilar; 1 – similar)

	CHA02MI	CHA03MI	JAX01MI	JAX02MI	JAX03MI	SAV01MI	SAV02MI	SAV03MI	WIL01MI	WIL02MI	WIL03MI
CHA01MI	0.1229	0.2362	0.1429	0.5185	0.4314	0.2759	0.0824	0.0727	0.5882	0.1290	0.1481
CHA02MI		0.2803	0.1362	0.2932	0.0532	0.4821	0.4235	0.2500	0.0819	0.0952	0.0314
CHA03MI			0.1421	0.4029	0.1029	0.4884	0.2039	0.3143	0.2017	0.1552	0.0576
JAX01MI				0.2182	0.0748	0.1119	0.0531	0.0721	0.0444	0.0460	0.0182
JAX02MI					0.2857	0.5455	0.2527	0.5373	0.3478	0.0930	0.1212
JAX03MI						0.1042	0.0559	0.0000	0.2791	0.1000	0.1270
SAV01MI							0.4279	0.4800	0.2532	0.2105	0.0606
SAV02MI								0.3716	0.0617	0.1258	0.1758
SAV03MI									0.0426	0.2727	0.2985
WIL01MI										0.2609	0.1739
WIL02MI											0.0465

Table 18 Bray Curtis similarity indices for the 12 zones where minnow traps were used for sampling. (0 – dissimilar; 1 – similar).

	CHA02TR	CHA03TR	JAX01TR	JAX02TR	JAX03TR	SAV01TR	SAV02TR	SAV03TR	WIL01TR	WIL02TR	WIL03TR
CHA01TR	0.1150	0.1110	0.3060	0.0441	0.0457	0.1096	0.0671	0.0660	0.0322	0.0358	0.0155
CHA02TR		0.2611	0.0993	0.1928	0.1505	0.3062	0.5121	0.5426	0.1941	0.2118	0.0976
CHA03TR			0.1019	0.1536	0.1417	0.1440	0.3079	0.2994	0.1749	0.1908	0.0901
JAX01TR				0.1457	0.0287	0.0523	0.0088	0.0076	0.0096	0.0083	0.0086
JAX02TR					0.1917	0.0829	0.1950	0.1872	0.2779	0.2725	0.1832
JAX03TR						0.0823	0.1683	0.1621	0.1710	0.1911	0.0917
SAV01TR							0.2276	0.2421	0.0765	0.0846	0.0373
SAV02TR								0.9362	0.4600	0.4873	0.2491
SAV03TR									0.4331	0.4667	0.2366
WIL01TR										0.8875	0.6606
WIL02TR											0.5920

Table 19 Bray Curtis similarity indices for the 12 zones where trawl gear was used for sampling. (0 – dissimilar; 1 – similar)

	JAX02HD	SAV02HD	WIL02HD
CHA02HD	0.2257	0.1254	0.0252
JAX02HD		0.3646	0.0048
SAV02HD			0.0104

Table 20 Bray Curtis similarity indices for Hester- Dendy collectors (0 – dissimilar; 1 – similar).

	JAX02SC	SAV02SC	WIL02SC
CHA02SC	0.5458	0.5443	0.0000
JAX02SC		0.4421	0.0002
SAV02SC			0.0063

Table 21 Bray Curtis similarity indices for the four zones where piling scrapings were taken. (0 – dissimilar; 1 – similar)

	JAX01	CHA01	CHA02	JAX02	SAV02	SAV01	JAX03	CHA03	SAV03
Salinity	Polyhaline	Polyhaline	Polyhaline	Mesohaline	Mesohaline	Mesohaline	Mesohaline	Mesohaline	Tidal Fresh
Water Temp	<25%	<25%	>75%	50 – 75%	<25%	>75%	50 – 75%	>75%	25 – 50%
Sediment Type	Fine Sand	Fine Sand	Medium Sand	Fine Sand	Medium Sand	Medium Sand	Medium Sand	Fine Sand	Fine Sand
Sorting	Moderate	Poor	Poor	Well	Poor	Moderate	Poor	Very Poor	Poor
Skewness	Coarse	Symmetric	Coarse	Coarse	Coarse	Symmetric	Coarse	Fine	Fine
Total N (%)	<25%	50 – 75%	>75%	<25%	50 – 75%	25 – 50%	25 – 50%	>75%	>75%
Total C (%)	25 – 50%	50 – 75%	>75%	<25%	<25%	<25%	>75%	>75%	25 – 50%

Table 22 Water quality and sediment parameters averaged for each port zone. Water temperature and sediment organic content (carbon and nitrogen) are expressed as percentage quartiles of their respective total values for all the port zones combined.

5.3.5. Nonindigenous Faunal Comparisons with Other Ports

The present survey collected 221 species, five of which are considered nonindigenous crustaceans (approximately 2.26% of the species collected). Overall, far less nonindigenous species were collected in the present survey than in other similar surveys from other port locations.

West coast rapid assessment surveys species identified the following numbers of nonindigenous species in fouling communities: 25 crustaceans, 5 mollusks, and ten polychaetes in southern California (Cohen *et al.*, 2002); 12 crustaceans, seven mollusks, and two polychaetes in the Puget Sound, Washington (Cohen *et al.*, 1998); five crustaceans, two mollusks, and two polychaetes in Elliott Bay, Washington (Cohen *et al.*, 2001); five crustaceans, five mollusks, and one polychaete in Totten and Eld Inlets, Washington (*loc. cit.*); ten crustaceans, nine mollusks, and five polychaetes in Willapa Bay, Washington (*loc. cit.*). Rapid Assessment Surveys were also conducted throughout the New England Coast in 2000 and 2003, finding seven nonindigenous crustaceans, three mollusks, and one polychaete species (MIT Sea Grant http://massbay.mit.edu/exoticspecies/exoticmaps/index.html).

Ruiz *et al.* (2000) summarizes additional previous surveys and notes the following number of nonindigenous invertebrates as being established in the following estuaries: 52 crustaceans, 30 mollusks, and ten polychaetes in San Francisco Bay, California; 19 crustaceans, eight mollusks, and four polychaetes in Coos Bay, Oregon; 17 crustaceans, 16 mollusks, and two polychaetes in the Puget Sound, Washington; one mollusk, and one polychaete in Prince William Sound, Alaska; six crustaceans, 12 mollusks, and one polychaete in the Chesapeake Bay, Virginia; 13 crustaceans, six mollusks, and eight polychaetes Port Philip Bay, Australia. Englund *et al.* (2000) collected the following nonindigenous species in Pearl Harbor, Hawaii ─ six crustaceans, nine mollusks and one polychaete.

An extensive literature review for nonindigenous species in the United States conducted by Ruiz *et al.* (2000) reports: 27 crustaceans, 31 mollusks, and five polychaetes from the east coast; 11 crustaceans, six mollusks, and four polychaetes from the Gulf coast; and 78 crustaceans, 51 mollusks, and 19 polychaetes from the west coast. Based on a literature review in the current study

(Section 6.2, we report the total nonindigenous listings for freshwater and marine crustaceans, mollusks, and polychaetes in the South Atlantic Bight region as 33, 18, and two species, respectively.

5.4. Sediment

5.4.1. Particle Size

Calculated average values and implications for the particle size cumulative frequency curve parameters for each of the 13 sediment replicate cores for each zone and each port are presented in Tables 23-25. Sediment samples collected at Wilmington were excluded from this analysis due to an inconsistency in procedure and results. The calculated average values and implications for the particle size cumulative frequency curve parameters from zones one, two, and three in Charleston, Savannah and Jacksonville are listed in Table 26.

In Charleston (Table 26), the graphic mean values ranged from coarse sand in all three zones (-0.29Φ, -0.19Φ, and 0.77Φ) to fine sand in both zones one and two (3.55Φ and 2.95Φ, respectively) and silt in zone three (4.57Φ). Sorting values ranged from well (0.49Φ zone 1), moderately well (0.57Φ zone 3) and moderately (0.94Φ zone 2) to very poorly at all three zones (2.08Φ to 3.61Φ). Skewness went from symmetrical (-0.07 zone 1), coarse (-0.21 zone 3), and strongly coarse (-0.71) to strongly fine in zones one and two (0.67 and 0.32), and fine in zone three (0.50).

In Savannah (Table 26), the graphic mean values ranged from coarse sand in zones one and two (-0.47Φ and 0.39Φ, respectively) and medium sand in zone three (1.16Φ) to medium sand in zone one (1.76Φ) and silt in zones two and three (5.97Φ and 5.98Φ, respectively). Sorting values ranged from moderately well in all three zones (0.67Φ zone 1, 0.62Φ zone 2, and 0.69Φ zone 3) to poorly sorted in zone one (1.34Φ) and very poorly sorted in zones two and three (2.54Φ and 2.71Φ, respectively). Skewness values ranged from coarse in zones one and three (-0.21 and -0.19) and strongly coarse in zone two (-1.11) to fine in zone two (0.16) and strongly fine in zones one and three (0.38 and 0.49).

In Jacksonville (Table 26), the graphic mean values ranged from coarse sand in zone three (-0.13Φ), medium sand in zone one (2.42Φ) to medium sand in zone three (1.75Φ) and fine sand in zone one (2.87Φ). All values for zone two characterized the sediment as fine sand (2.42Φ to 3.19Φ). Sorting values ranged from well sorted in zones one and two (0.49Φ and 0.34Φ) and moderately well sorted in zone three (0.68Φ) to moderately well sorted in zone two (0.63Φ) and poorly sorted in zones one and three (1.49Φ and 1.64Φ). Skewness values ranged from strongly coarse in all zones (-2.04, -0.70, and -0.58) to symmetrical in zone three (0.07) and fine skewed in zones one and two (0.26 and 0.28).

5.4.2. Organic Content

Total percent organic carbon, organic nitrogen and the organic carbon to nitrogen ratios for sediment samples from zones one, two, and three in Charleston, Savannah and Jacksonville are listed in Tables 23-25. In Charleston, zone three had the sample with the highest organic nitrogen (0.03%) and carbon (11.04%) content, while zone two had the lowest (<0.01 and 0.04%, respectively). In Savannah, zone three also had the highest organic nitrogen (0.188%) and carbon (2.89%) content (both occurring in the same sample). Zone one had the lowest organic nitrogen (0.008%) and carbon (0.018%) content. In Jacksonville, highest organic nitrogen and carbon content was again detected in zone three (0.039% and 7.836%, respectively). Lowest organic nitrogen content was in a sample from zone one (0.008%) while zone two had lowest carbon content (0.037). The percent content for all 13 samples for each port zone were averaged, resulting in a single representative value for each zone and this is presented in Table 27.

5.4.3. Differences in Sediment Parameters between Ports

Graphic mean values averaged for each port zone all lie between 1.00Φ (SAV01) and 2.68Φ (JAX02), indicating that sediment were similar throughout the region and were composed of mainly fine to medium sands. Mean zone sorting values ranged from 0.84Φ (JAX01) to 2.23Φ (CHA03). Charleston sediment was generally either poorly or very poorly sorted, Savannah moderately to very poorly sorted, and Jacksonville well to poorly sorted. Charleston and Savannah exhibited similar skewness in their below port (symmetrical), at port (coarse) and above port (fine) zones. All zones in Jacksonville zones had coarse skewed sediment. Total organic carbon ranged from 0.17%

(JAX01) to 2.80% (CHA02). Overall, carbon levels were highest in Charleston (average 2.38%) and lowest in Savannah (average 0.62%). Total nitrogen ranges were close, ranging from 0.02% (JAX03) to 0.09% (CHA03). Total organic carbon to total nitrogen ratios more closely related in Charleston and Jacksonville (averages 64.41 and 63.86, respectively) than in Savannah (13.78).

5.5. Water Quality

Temperature (°Celsius) and salinity (ppt) were recorded during our surveys sampling events. In addition we also compiled available records for a one year period for each location to provide an example of the range of these values annually.

5.5.1. Temperature and Salinity

Average monthly surface temperature and salinity records for a one-year period (year in which our sampling occurred) were compiled for the St. Johns River, Florida, Savannah River, Georgia, Charleston Harbor and Cooper River, South Carolina, and Cape Fear River, North Carolina. For each port, two locations were selected: one to represent the upper reaches/lower salinity sampling areas of the estuaries; and one to represent the lower reaches/higher salinity sampling areas of the estuaries, providing a range of temperature and salinity records for the entire sampling area. Data is presented in Appendix 2 and illustrated graphically below in Figures 45 and 46. Data was provided by:

a) Florida STORET, November 15, 2005 (http://storet.dep.state.fl.us/);
b) Unpublished data, St. Johns River Water Management District, received December 7, 2005;
c) U.S. Environmental Protection Agency STORET Database, November 2005 (http://www.epa.gov/storet/dbtop.html);
d) USGS NWISWeb Data, November 14, 2005 (http://waterdata.usgs.gov/nwis/);
e) Mallin, M.A. et al. Environmental Assessment of the Lower Cape Fear River System, 2002-2003. CMC Report Number 03-03 (http://www.uncwil.edu/cmsr/aquaticecology/lcfrp/WQ%20Reports/02-03/Report.htm).

Temperature and salinity recorded at the time of our sampling can be found in Appendix 3 and averaged for each port zone are in Tables 28 and 29.

ID	Graphic Mean (Φ)	Graphic Mean Implications	Inclusive Graphic Standard Deviation (Φ)	Sorting	Inclusive Graphic Skewness	Skewness	Total N (%)	Total C (%)	C/N Ratio
CHA01SED01	2.34	Fine sand	1.18	Poorly sorted	-0.60	Strongly coarse skewed	0.012	1.290	106.85
CHA01SED02	2.60	Fine sand	0.93	Moderately sorted	-0.42	Strongly coarse skewed	0.018	2.610	146.94
CHA01SED03	3.55	Fine sand	1.44	Poorly sorted	0.67	Strongly fine skewed	0.041	1.020	24.89
CHA01SED04	2.92	Fine sand	0.88	Moderately sorted	0.19	Coarse skewed	0.054	1.265	23.56
CHA01SED05	2.96	Fine sand	0.49	Well sorted	-0.07	Symmetrical	0.039	0.978	24.85
CHA01SED06	3.21	Fine sand	1.27	Poorly sorted	0.58	Strongly fine skewed	0.063	1.030	16.22
CHA01SED07	1.57	Medium sand	2.08	Very poorly sorted	-0.72	Strongly coarse skewed	0.031	2.233	72.49
CHA01SED08	1.89	Medium sand	1.67	Poorly sorted	-0.65	Strongly coarse skewed	0.042	4.010	94.94
CHA01SED09	3.16	Fine sand	0.53	Moderately well sorted	0.15	Fine skewed	0.024	0.466	19.77
CHA01SED10	2.99	Fine sand	0.99	Moderately sorted	-0.37	Strongly coarse skewed	0.019	0.966	50.22
CHA01SED11	-0.29	Coarse sand	1.84	Poorly sorted	0.54	Strongly fine skewed	0.013	2.205	169.35
CHA01SED12	2.25	Fine sand	1.20	Poorly sorted	-0.49	Strongly coarse skewed	0.020	1.104	55.68
CHA01SED13	2.15	Fine sand	2.00	Very poorly sorted	-0.10	Symmetrical	0.056	1.857	32.95
CHA02SED01	-0.19	Coarse sand	1.66	Poorly sorted	0.23	Fine skewed	0.021	2.514	122.60
CHA02SED02	0.04	Coarse sand	1.69	Poorly sorted	0.01	Symmetrical	0.024	5.656	231.73
CHA02SED03	0.85	Coarse sand	1.40	Poorly sorted	0.04	Symmetrical	0.015	2.691	179.13
CHA02SED04	1.22	Medium sand	1.40	Poorly sorted	-0.12	Coarse skewed	0.021	4.598	222.87
CHA02SED05	0.00	Coarse sand	1.76	Poorly sorted	0.19	Fine skewed	0.100	6.222	62.32
CHA02SED06	0.75	Coarse sand	1.80	Poorly sorted	-0.52	Strongly coarse skewed	0.024	3.453	146.59
CHA02SED07	1.23	Medium sand	1.73	Poorly sorted	-0.71	Strongly coarse skewed	0.020	1.861	92.94
CHA02SED08	1.57	Medium sand	1.28	Poorly sorted	-0.17	Strongly coarse skewed	0.006	0.042	6.44
CHA02SED09	1.89	Medium sand	0.94	Moderately sorted	-0.41	Strongly coarse skewed	0.010	0.227	23.62
CHA02SED10	2.00	Fine sand	0.96	Moderately sorted	-0.27	Coarse skewed	0.012	0.164	13.27
CHA02SED11	1.30	Medium sand	1.99	Poorly sorted	-0.71	Strongly coarse skewed	0.093	1.879	20.17
CHA02SED12	2.37	Fine sand	1.01	Poorly sorted	-0.44	Strongly coarse skewed	0.017	1.601	95.27
CHA02SED13	2.95	Fine sand	3.19	Very poorly sorted	0.32	Strongly fine skewed	0.311	5.454	17.53
CHA03SED01	2.48	Fine sand	0.57	Moderately well sorted	-0.04	Symmetrical	0.028	0.590	21.09
CHA03SED02	4.57	Silt	2.50	Very poorly sorted	0.50	Fine skewed	0.125	2.950	23.67
CHA03SED03	1.94	Medium sand	1.79	Poorly sorted	-0.21	Coarse skewed	0.086	3.010	35.06
CHA03SED04	2.83	Fine sand	2.59	Very poorly sorted	0.22	Fine skewed	0.180	3.085	17.13
CHA03SED05	2.28	Fine sand	1.87	Poorly sorted	-0.02	Symmetrical	0.084	3.12	37.05
CHA03SED06	4.15	Silt	3.26	Very poorly sorted	0.17	Fine skewed	0.186	3.23	17.38
CHA03SED07	0.77	Coarse sand	2.51	Very poorly sorted	0.27	Fine skewed	0.028	1.50	53.06
CHA03SED08	2.44	Fine sand	2.41	Very poorly sorted	0.16	Fine skewed	0.057	2.34	41.37
CHA03SED09	1.73	Medium sand	3.61	Very poorly sorted	0.35	Strongly fine skewed	0.267	3.80	14.23
CHA03SED10	3.83	Fine sand	2.66	Very poorly sorted	0.25	Fine skewed	0.077	11.04	143.02
CHA03SED11	1.47	Medium sand	1.16	Poorly sorted	-0.09	Symmetrical	0.024	0.15	6.44
CHA03SED12	1.40	Medium sand	1.44	Poorly sorted	-0.10	Symmetrical	0.026	0.46	18.05
CHA03SED13	3.32	Fine sand	2.67	Very poorly sorted	0.47	Strongly fine skewed	0.031	0.35	11.23

Table 23 Sediment parameters for each port zone replicate in Charleston (CHA), 01 = lower zone, 02 = port zone, 03 = upper zone, SED = sediment.

ID	Graphic Mean (Φ)	Graphic Mean Implications	Inclusive Graphic Standard Deviation (Φ)	Sorting	Inclusive Graphic Skewness	Skewness	Total N (%)	Total C (%)	C/N Ratio
SAV01SED01	0.68	Coarse sand	1.07	Poorly sorted	-0.21	Coarse skewed	0.008	0.815	108.27
SAV01SED02	1.68	Medium sand	0.69	Moderately well sorted	-0.06	Symmetrical	0.012	0.050	4.28
SAV01SED03	1.76	Medium sand	0.67	Moderately well sorted	-0.08	Symmetrical	0.017	0.020	1.13
SAV01SED04	1.13	Medium sand	0.91	Moderately sorted	0.03	Symmetrical	0.018	0.166	9.46
SAV01SED05	1.08	Coarse sand	1.03	Poorly sorted	-0.07	Symmetrical	0.020	0.037	1.85
SAV01SED06	1.09	Coarse sand	1.10	Poorly sorted	0.08	Symmetrical	0.025	0.257	10.45
SAV01SED07	0.50	Coarse sand	1.11	Poorly sorted	-0.01	Symmetrical	0.018	0.019	1.09
SAV01SED08	0.17	Coarse sand	1.07	Poorly sorted	-0.10	Coarse skewed	0.012	0.089	7.52
SAV01SED09	0.95	Coarse sand	0.97	Moderately sorted	-0.17	Coarse skewed	0.018	0.018	1.00
SAV01SED10	-0.47	Coarse sand	1.22	Poorly sorted	0.19	Fine skewed	0.011	0.130	11.73
SAV01SED11	1.42	Medium sand	0.67	Moderately well sorted	-0.10	Symmetrical	0.041	0.593	14.30
SAV01SED12	1.54	Medium sand	1.34	Poorly sorted	0.38	Strongly fine skewed	0.049	0.931	18.98
SAV01SED13	1.54	Medium sand	0.79	Moderately sorted	0.21	Fine skewed	0.033	0.738	22.66
SAV02SED01	1.91	Medium sand	2.36	Very poorly sorted	-0.24	Coarse skewed	0.040	0.953	24.04
SAV02SED02	0.98	Coarse Sand	0.78	Moderately sorted	-0.22	Coarse skewed	0.030	0.269	8.85
SAV02SED03	1.03	Medium sand	1.54	Poorly sorted	-0.15	Coarse skewed	0.028	0.441	15.72
SAV02SED04	0.89	Coarse Sand	0.95	Moderately sorted	0.04	Symmetrical	0.017	0.055	3.15
SAV02SED05	1.12	Medium sand	0.93	Moderately sorted	-1.11	Strongly coarse skewed	0.009	0.082	8.82
SAV02SED06	0.73	Coarse Sand	0.65	Moderately well sorted	0.03	Symmetrical	0.009	0.081	8.52
SAV02SED07	0.39	Coarse Sand	1.77	Poorly sorted	-0.36	Strongly coarse skewed	0.028	0.346	12.34
SAV02SED08	5.52	Silt	2.52	Very poorly sorted	0.16	Fine skewed	0.097	1.629	16.88
SAV02SED09	5.97	Silt	2.54	Very poorly sorted	-0.01	Symmetrical	0.064	0.787	12.20
SAV02SED10	0.91	Coarse Sand	0.98	Moderately sorted	-0.32	Strongly coarse skewed	0.017	0.055	3.30
SAV02SED11	0.83	Coarse Sand	1.13	Poorly sorted	-0.08	Symmetrical	0.011	0.154	13.85
SAV02SED12	1.17	Medium sand	0.62	Moderately well sorted	-0.16	Coarse skewed	0.019	0.047	2.51
SAV02SED13	1.16	Medium sand	1.15	Poorly sorted	-0.56	Strongly coarse skewed	0.014	0.175	12.52
SAV03SED01	1.16	Medium sand	1.00	Moderately sorted	0.32	Strongly fine skewed	0.017	0.166	9.81
SAV03SED02	4.64	Silt	2.68	Very poorly sorted	0.42	Strongly fine skewed	0.009	0.091	9.72
SAV03SED03	2.93	Fine sand	1.47	Poorly sorted	0.30	Strongly fine skewed	0.164	2.853	17.42
SAV03SED04	2.77	Fine sand	0.97	Moderately sorted	0.02	Symmetrical	0.087	1.526	17.54
SAV03SED05	4.79	Silt	2.71	Very poorly sorted	0.36	Strongly fine skewed	0.169	2.705	16.01
SAV03SED06	4.27	Silt	2.42	Very poorly sorted	0.49	Strongly fine skewed	0.106	2.018	18.95
SAV03SED07	1.63	Medium sand	2.03	Very poorly sorted	0.38	Strongly fine skewed	0.036	0.762	21.39
SAV03SED08	1.16	Medium sand	0.72	Moderately sorted	-0.04	Symmetrical	0.013	0.101	8.09
SAV03SED09	1.72	Medium sand	1.40	Poorly sorted	-0.01	Symmetrical	0.106	1.640	15.41
SAV03SED10	2.03	Fine sand	1.12	Poorly sorted	-0.19	Coarse skewed	0.011	0.139	12.20
SAV03SED11	2.14	Fine sand	1.09	Poorly sorted	-0.06	Symmetrical	0.014	0.155	10.71
SAV03SED12	5.98	Silt	2.54	Very poorly sorted	-0.05	Symmetrical	0.188	2.896	15.37
SAV03SED13	1.72	Medium sand	0.69	Moderately well sorted	0.15	Fine skewed	0.010	0.094	9.35

Table 24 Sediment parameters for each port zone replicate in Savannah (SAV), 01 = lower zone, 02 = port zone, 03 = upper zone, SED = sediment.

ID	Graphic Mean (Φ)	Graphic Mean Implications	Inclusive Graphic Standard Deviation (Φ)	Sorting	Inclusive Graphic Skewness	Skewness	Total N (%)	Total C (%)	C/N Ratio
JAX01SED01	2.24	Fine sand	0.75	Moderately sorted	-0.47	Strongly coarse skewed	0.018	1.760	97.79
JAX01SED02	2.06	Fine sand	0.70	Moderately well sorted	0.26	Fine skewed	0.015	0.188	12.59
JAX01SED03	1.56	Medium sand	0.67	Moderately well sorted	-0.12	Coarse skewed	0.015	0.596	38.52
JAX01SED04	1.65	Medium sand	0.76	Moderately sorted	-0.16	Coarse skewed	0.016	0.368	23.60
JAX01SED05	2.12	Fine sand	0.78	Moderately sorted	-0.32	Strongly coarse skewed	0.008	1.690	202.40
JAX01SED06	2.13	Fine sand	0.66	Moderately well sorted	-0.17	Coarse skewed	0.016	0.092	5.81
JAX01SED07	1.80	Medium sand	1.02	Poorly sorted	-0.31	Strongly coarse skewed	0.015	0.453	30.69
JAX01SED08	2.57	Fine sand	1.04	Poorly sorted	0.01	Symmetrical	0.017	0.235	14.01
JAX01SED09	2.73	Fine sand	0.49	Well sorted	0.21	Fine skewed	0.018	0.114	6.42
JAX01SED10	2.87	Fine sand	0.59	Moderately well sorted	-0.24	Coarse skewed	0.018	0.959	52.70
JAX01SED11	2.25	Fine sand	1.49	Poorly sorted	-0.70	Strongly coarse skewed	0.017	0.554	33.50
JAX01SED12	2.54	Fine sand	0.78	Moderately sorted	-0.43	Strongly coarse skewed	0.013	0.457	35.64
JAX01SED13	2.26	Fine sand	1.20	Poorly sorted	-0.61	Strongly coarse skewed	0.020	1.484	73.14
JAX02SED01	2.53	Fine sand	0.45	Well sorted	-0.33	Strongly coarse skewed	0.010	0.097	9.32
JAX02SED02	2.49	Fine sand	0.63	Moderately well sorted	-0.46	Strongly coarse skewed	0.009	0.357	39.32
JAX02SED03	2.57	Fine sand	0.44	Well sorted	-0.28	Coarse skewed	0.009	0.037	4.22
JAX02SED04	2.44	Fine sand	0.61	Moderately well sorted	-0.43	Strongly coarse skewed	0.009	0.044	4.92
JAX02SED05	2.70	Fine sand	0.45	Well sorted	-0.02	Symmetrical	0.032	0.473	14.56
JAX02SED06	2.52	Fine sand	0.34	Very well sorted	-0.05	Symmetrical	0.022	0.260	11.95
JAX02SED07	2.85	Fine sand	0.43	Well sorted	-0.05	Symmetrical	0.012	0.181	14.80
JAX02SED08	2.81	Fine sand	0.39	Well sorted	0.02	Symmetrical	0.012	0.081	6.49
JAX02SED09	2.43	Fine sand	0.59	Moderately well sorted	0.28	Fine skewed	0.014	0.169	11.80
JAX02SED10	2.89	Fine sand	0.44	Well sorted	-0.05	Symmetrical	0.017	0.237	14.20
JAX02SED11	3.19	Fine sand	0.41	Well sorted	-2.04	Strongly coarse skewed	0.010	0.078	7.63
JAX02SED12	2.94	Fine sand	0.40	Well sorted	0.00	Symmetrical	0.011	0.131	12.25
JAX02SED13	2.42	Fine sand	0.38	Well sorted	0.01	Symmetrical	0.012	0.073	6.11
JAX03SED01	1.21	Medium sand	1.61	Poorly sorted	-0.47	Strongly coarse skewed	0.020	0.500	25.25
JAX03SED02	1.70	Medium sand	0.73	Moderately sorted	-0.13	Coarse skewed	0.010	0.053	5.06
JAX03SED03	1.75	Medium sand	0.68	Moderately well sorted	-0.14	Coarse skewed	0.019	1.212	64.20
JAX03SED04	1.36	Medium sand	1.16	Poorly sorted	0.03	Symmetrical	0.013	0.210	15.97
JAX03SED05	1.67	Medium sand	1.26	Poorly sorted	-0.58	Strongly coarse skewed	0.022	2.256	101.82
JAX03SED06	1.58	Medium sand	1.21	Poorly sorted	-0.45	Strongly coarse skewed	0.016	2.666	167.74
JAX03SED07	0.83	Coarse sand	1.40	Poorly sorted	-0.13	Coarse skewed	0.039	4.243	108.56
JAX03SED08	1.24	Medium sand	1.37	Poorly sorted	-0.51	Strongly coarse skewed	0.012	2.057	176.87
JAX03SED09	1.52	Medium sand	1.47	Poorly sorted	-0.48	Strongly coarse skewed	0.014	3.685	271.00
JAX03SED10	-0.13	Coarse sand	1.53	Poorly sorted	0.07	Symmetrical	0.019	7.836	404.50
JAX03SED11	0.30	Coarse sand	1.64	Poorly sorted	0.02	Symmetrical	0.018	6.049	335.04
JAX03SED12	1.47	Medium sand	1.18	Poorly sorted	-0.48	Strongly coarse skewed	0.023	0.056	2.42
JAX03SED13	1.69	Medium sand	1.22	Poorly sorted	-0.51	Strongly coarse skewed	0.020	0.544	27.68

Table 25 Sediment parameters for each port zone replicate in Jacksonville (JAX), 01 = lower zone, 02 = port zone, 03 = upper zone, SED = sediment.

ID	Graphic Mean (Φ)	Graphic Mean Implications	Inclusive Graphic Standard Deviation (Φ)	Sorting	Inclusive Graphic Skewness	Skewness
CHA01	2.41	Fine sand	1.27	Poorly sorted	-0.10	Symmetrical
CHA02	1.23	Medium sand	1.60	Poorly sorted	-0.20	Coarse skewed
CHA03	2.55	Fine sand	2.23	Very poorly sorted	0.15	Fine skewed
SAV01	1.00	Medium sand	0.97	Moderately sorted	0.01	Symmetrical
SAV02	1.74	Medium sand	1.38	Poorly sorted	-0.23	Coarse skewed
SAV03	2.84	Fine sand	1.60	Poorly sorted	0.16	Fine skewed
JAX01	2.22	Fine sand	0.84	Moderately sorted	-0.24	Coarse skewed
JAX02	2.68	Fine sand	0.46	Well sorted	-0.26	Coarse skewed
JAX03	1.24	Medium sand	1.26	Poorly sorted	-0.29	Coarse skewed

Table 26 Sediment parameters averaged for each port zone (CHA = Charleston, SAV = Savannah, JAX = Jacksonville, 01 = lower zone, 02 = port zone, 03 = upper zone).

ID	Total N(%)	Total C(%)	C/N Ratio
CHA01	0.03	1.62	64.52
CHA02	0.05	2.80	94.96
CHA03	0.09	2.74	33.75
SAV01	0.02	0.30	16.36
SAV02	0.03	0.39	10.98
SAV03	0.07	1.17	14.00
JAX01	0.02	0.69	48.22
JAX02	0.01	0.17	12.12
JAX03	0.02	2.41	131.24

Table 27 Sediment organic carbon (C) and organic Nitrogen (N) averaged for each port zone (CHA = Charleston, SAV = Savannah, JAX = Jacksonville, 01 = lower zone, 02 = port zone, 03 = upper zone).

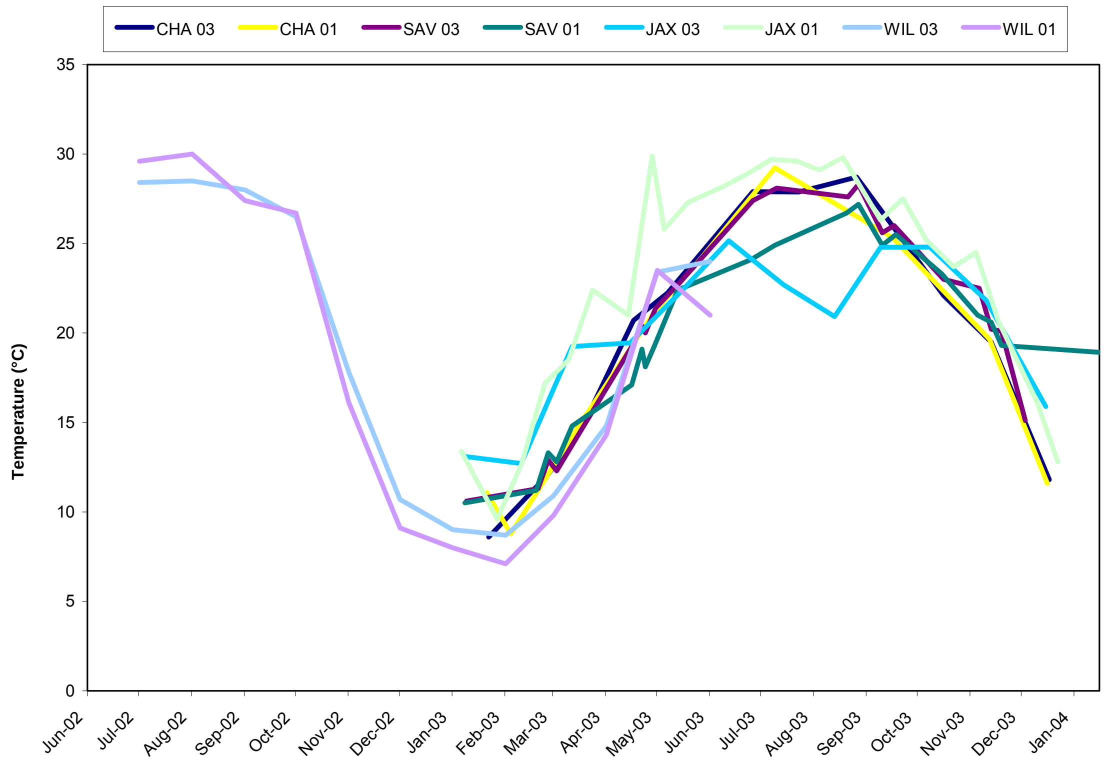


Figure 45 Published surface water temperature (°C) for Charleston (CHA), Savannah (SAV) Jacksonville (JAX), and Wilmington (WIL) for a one year period around the time of our sampling (03 = upper zone, 01 = lower zone).

Location ID	Port	Zone	Water Temperature (°C)
CHA01	Charleston	1	27.28
CHA02	Charleston	2	28.84
CHA03	Charleston	3	29.58
SAV01	Savannah	1	28.47
SAV02	Savannah	2	27.20
SAV03	Savannah	3	27.64
JAX01	Jacksonville	1	27.52
JAX02	Jacksonville	2	27.75
JAX03	Jacksonville	3	27.72
WIL01	Wilmington	1	20.00
WIL02	Wilmington	2	19.00
WIL03	Wilmington	3	17.50

Table 28 Average surface water temperature (°Celsius) taken the time of our sampling (August-September 2003) for each port zone.

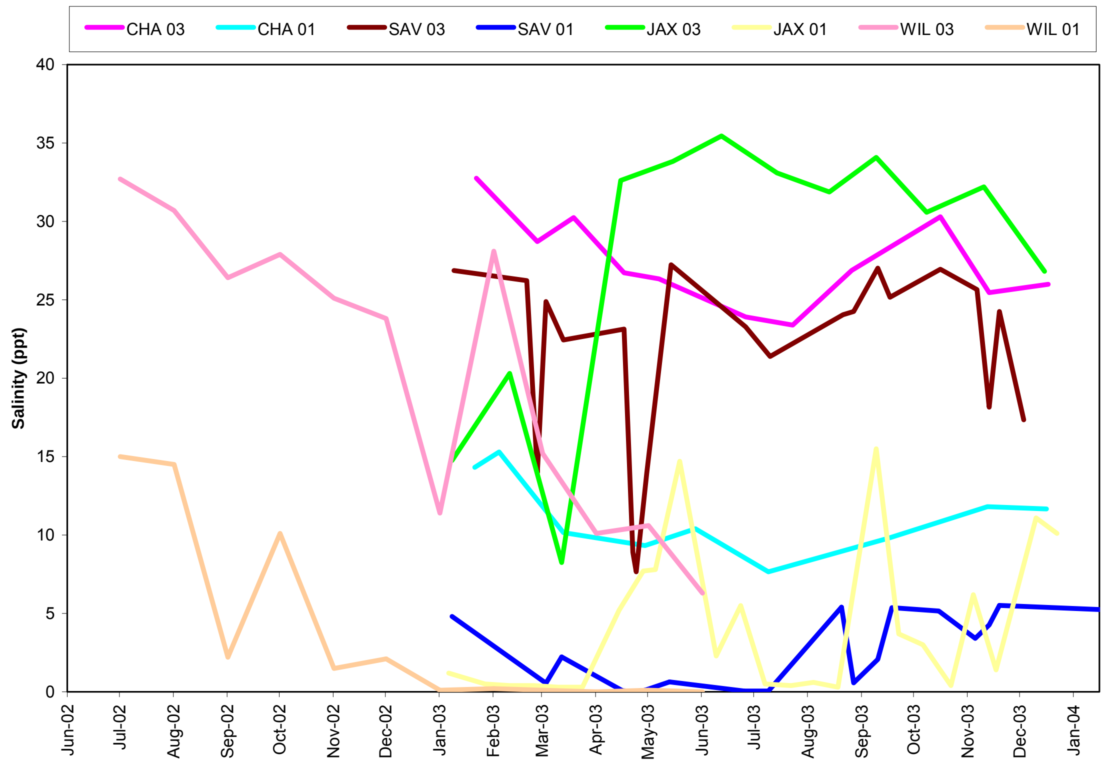


Figure 46 Published surface water salinity (ppt) for Charleston (CHA), Savannah (SAV) Jacksonville (JAX), and Wilmington (WIL) for a one year period around the time of our sampling (03 = upper zone, 01 = lower zone).

Location ID	**Port**	**Zone**	**Salinity (ppt)**
CHA01	Charleston	1	26
CHA02	Charleston	2	22
CHA03	Charleston	3	9
SAV01	Savannah	1	15
SAV02	Savannah	2	12
SAV03	Savannah	3	0
JAX01	Jacksonville	1	24
JAX02	Jacksonville	2	13
JAX03	Jacksonville	3	7
WIL01	Wilmington	1	9
WIL02	Wilmington	2	11
WIL03	Wilmington	3	1

Table 29 Average surface water salinity (ppt) taken the time of our sampling: August-September 2003 for Charleston, Savannah, and Jacksonville, and October 2003 for Wilmington.

5.5.2. Differences in Water Quality between Ports

Based on water quality records for a one-year period, water temperatures are similar throughout the region with an annual range as follows for each of the ports: Wilmington, 7.1°C to 30.0°C; Charleston, 8.59°C to 29.23°C; Savannah, 10.5°C to 28.3°C; and Jacksonville, 9.6°C to 29.8°C. Annual water temperature averages for each port were Wilmington, 18.9°C; Charleston, 19.04°C; Savannah, 19.98°C; and Jacksonville, 21.58°C.

Water temperature in Charleston, Savannah, and Jacksonville at the time of sampling ranged from 27.2°C (SAV02) to 29.58°C (CHA03). Most sampling occurred in late October in Wilmington, resulting in lower water temperature records (average, 18.83°C) than in the other three ports where sampling occurred from late August to late September.

Salinity ranges over the one-year period below each port (zone 1) showed a large annual variation with the exception of Charleston: Wilmington, 6.3ppt to 32.7ppt; Jacksonville, 8.25ppt to 35.45ppt; Savannah, 7.65ppt to 27.23ppt; and Charleston, 23.39ppt to 32.76ppt. Salinity above each port (zone 3) was less variable and ranked in terms of decreasing annual ranges were as follows: Jacksonville, 0.3ppt to 15.5ppt; Wilmington, 0ppt to 15ppt; Charleston, 7.66 to 15.29; and Savannah, 0.04ppt to 5.52ppt.

Charleston's salinities for zones one, two, and three (26ppt, 22ppt and 9ppt, respectively) during sampling were higher than the respective zones of the other three ports due to the port's closer proximity to the Atlantic Ocean. The port zone (2) of Wilmington, Savannah, and Jacksonville all had similar salinities ranging from 11-13ppt. Jacksonville showed a similar pattern to Charleston averaging 24ppt in zone one and 7ppt in zone 3. Wilmington and Savannah had similar salinities in zone three (1ppt and 0ppt, respectively).

5.6. Survey Limitations

It is noted that the current survey had several limitations. These are discussed below for consideration in future survey and monitoring efforts. The Hester-Dendy fouling plate component proved to be quite problematic. It was sometimes difficult to find suitable locations for suspension of the plates in and near port docks. Additionally, access to these docks relied on coordination with port and Coast Guard personnel, which could be challenging given recent security concerns. All sampling required extensive permitting or coordination with each states Marine Patrol, Coast Guard, port authorities, Department of Natural Resources, and Corps of Engineers. This was sometimes difficult, particularly out of state. It is recommended that any port surveys be conducted with collaborators from the respective state. We failed to get access to docks in Jacksonville port. In this situation plates were attached to a buoy and anchored outside the shipping channel. Only three of these 13 plates were retrieved. Plates may have been lost due to currents or may have been interfered with. Given the distance away from Savannah, it was not possible to monitor their status regularly. Losses were incurred even in Charleston where plates were suspended from port docks.

Collections of scrapings was also difficult. Several ports had very strong currents, making it difficult to safely approach and remain at pilings by boat. Dense growth on the pilings required the use of hammers and scrapers to collect the samples, often resulting in damaged specimens. It was also difficult to scrape a consistently sized area; in those cases, we opted to fill a three and a half gallon bucket halfway.

Trawling was particularly time consuming in the immediate port zone in most ports. Large quantities of bottom debris in these areas resulted in numerous net snags. This slowed down the sampling process and caused extensive net damage. Different regulations in Florida meant our nets there had to be pulled equipped with a Turtle Excluder Device which was not consistent with the other locations.

A literature review detailed in section 6.2 lists 53 nonindigenous species for freshwater and marine crustaceans, mollusks, and polychaetes in the South Atlantic Bight (33 crustaceans, 18 mollusks, and two polychaetes). While some of these species may not be specific to the habitats sampled in this study, it seems likely more nonindigenous species than the five we collected were present in the study area and were not detected. Section 6.2 details instances where sampling intensity may not have been adequate to guarantee collection of all species present. It should be noted that our survey was not designed to identify all nonindigenous species present, rather it was to identify species with a mean Poisson density of 0.1 individuals per sample unit at a 95% probability.

We recommend a slight increase in sampling intensity, and the inclusion of all habitats present. An additional aspect of this study that may have prevented the collection of more species (both native and nonindigenous) is the one time sampling design. Certain species are more prevalent and available for collection at specific times of the year. Ideally, a seasonal collection study would complement this one time sampling event to guarantee a thorough inventory. On the other hand, 45,228 specimens were collected and sample processing was a labor and time intensive process. In order for a seasonal collection to be feasible far more resources would be needed or the survey would need to be redesigned as a more "Rapid Assessment" type survey using many taxonomic experts in the field.

Finally, the present study was limited to the identification of crustaceans, mollusks and polychaetes. This does not include several taxonomic groups that were collected, specifically fish, echinoderms, cnidarians, oligochaetes and other arthropod subphyla. Given the sampling effort involved in collection it seems wasteful that we did not have the resources to include them in the analysis. These specimens were however retained and we hope to identify each one later.

6. RISK ASSESSMENT

6.1. Nonindigenous Species Recorded in Survey

No new invasive species in the South Atlantic Bight were detected through our surveys, however five previously identified nonindigenous crustaceans were collected, *Balanus trigonus* (Darwin, 1854), *Ligia exotica* (Roux, 1828), *Apocorophium lacustre* (Vanhoeffen, 1911)**,** *Balanus amphitrite* (Darwin, 1854), and *Petrolisthes armatus* (Gibbes, 1850).

6.1.1. Balanus trigonus (Darwin, 1854)

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Crustacea
Class: Maxillopoda
Subclass: Thecostraca
Infraclass: Cirripedia
Superorder: Thoracica
Order: Sessilia
Suborder: Balanomorpha
Superfamily: Balanoidea
Family: Balanidae
Genus: *Balanus*
Species: *trigonus*

Figure 47 *Balanus trigonus*

Balanus trigonus (Figure 47) is a subtidal, euhaline fouling barnacle native to the Pacific Ocean, now cosmopolitan in distribution among tropical and subtropical seas. *Balanus trigonus* was first detected in the Gulf of Mexico in 1885, with Werner (1967) documenting several additional occurrences in the Caribbean, Gulf of Mexico, and North Atlantic in the 1900s. *Balanus trigonus* was detected in the present study from the port zone (Zone 2) of Charleston, South Carolina in a trawl sample. Our biological literature GIS database indicates the presence of the species throughout the South Atlantic Bight region (Cain, 1972; Fox and Ruppert, 1985; Wells *et al*., 1964;

and Wenner *et al*., 1983). *Balanus trigonus* is believed to have been introduced to this region via hull fouling transport. New England and European whaling vessels are thought to have spread the species further north to the Central and North Atlantic. The northern limit of *Balanus trigonus* along the North American coast is near Cape Lookout, North Carolina (Zullo, 1992). Gittings (1985) suggests that the range of *Balanus trigonus* may be limited by water temperature. Cirral activity of *Balanus trigonus* was shown to cease at 31°C, indicating intolerance to extremely warm water temperatures.

Ayling (1976) has shown that *Balanus trigonus* adopts an orientation strategy that allows efficient food collection in a variety of water movement regimes and wide range of conditions, perhaps contributing to its success in non-native environments. Additionally, 3-weeks old individuals have been found to contain larvae, and each barnacle is capable of more than one brood per year. There is also evidence that *Balanus trigonus* may be capable of self-fertilization (Werner, 1967).

6.1.2. Ligia exotica (Roux, 1828)

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Crustacea
Class: Malacostraca
Subclass: Eumalacostraca
Superorder: Peracarida
Order: Isopoda
Suborder: Oniscidea
Infraorder: Ligiamorpha
Family: Ligiidae
Genus: *Ligia*
Species: *exotica*

Figure 48 *Ligia exotica*

Ligia exotica (Figure 48) a "wharf roach" is native to the northeast Atlantic and the Mediterranean basin. The species has been transported to warm and temperate seas worldwide via ship fouling (Eldredge and Smith, 2001a). Wharf roaches are related to terrestrial isopods and will drown if submerged. They can be found scavenging in the littoral and supralittoral zones on rocks and pilings. Dry ballast or cargo is a likely vector for their introduction (Baker *et al*., 2004). A semelparous species, *Ligia exotica* has separate sexes and internal fertilization. Females bear a brood pouch. In Taiwan the species has exhibited rapid growth rate leading up to reproduction, followed by mortality in females (Tsai and Dai, 2001). Male longevity averaged 25 months while females averaged 22 months. Differences in life history traits, including generation time, age/size at reproduction, and quantity and size of eggs were also found between a littoral population and a population that had invaded an inland creek (*loc. cit.*). This together with an aggregative behavior (Farr, 1978) indicates an adaptive strategy lending *Ligia exotica* to invasion. Populations of *Ligia exotica* were detected in the present survey from Jacksonville, Savannah and Charleston. All were present in scraping samples taken within the port zones (Zone 2). Our biological literature GIS database indicates the presence of the species throughout the South Atlantic Bight region (Fox and Ruppert, 1985; Kensley *et al*., 1995; Kirby-Smith and Gray, 1971; McDougall, 1943; Prezant *et al*., 2002; Wells, 1961).

6.1.3. Apocorophium lacustre (Vanhoffen, 1911)

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Crustacea
Class: Malacostraca
Subclass: Eumalacostraca
Superorder: Peracarida
Order: Amphipoda
Suborder: Gammaridea
Family: Corophiidae
Genus: *Apocorophium*
Species: *lacustre*

Figure 49 *Apocorophium lacustre*

Apocorophium lacustre (Figure 49) is pollution tolerant, surface-deposit feeding amphipod (Ysebaert *et al.*, 2000; Evans *et al.*, 2004). The species is typically found in estuarine-brackish mud and/or salt marsh, and rarely in full marine salinities. It occurs predominantly in the lower intertidal, on banks and pilings. *A. lacustre* undergoes an annual life cycle with females bearing eggs between May and September (Bousfield, 1973). Native to the Eastern Atlantic, the species is believed to have been brought to the East coast of the United States via ballast water (Benson *et al.*, 2001). Populations of *Apocorophium lacustre* were detected in the present survey in Jacksonville, Savannah and Wilmington. They were collected from fouling plates in the immediate port area (i.e. zone 2) of the three ports and also in Savannah and Wilmington scraping samples (zone 2), and a Wilmington sediment core sample from the estuary of the Cape Fear River (zone 1). Our biological literature GIS database indicates the presence of the species throughout the South Atlantic Bight (Calder *et al.*, 1977; Fox and Ruppert, 1985; Mason, 1998; Nelson *et al.*, 1982; Prezant *et al.*, 2002; Wendt and Van Dolah, 1990). *Apocorophium lacustre* is known to smother mussels and provide competition for food sources (NEANS, 2003).

6.1.4. Petrolisthes armatus (Gibbes, 1850)

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Crustacea
Class: Malacostraca
Subclass: Eumalacostraca
Superorder: Eucarida
Order: Decapoda
Suborder: Pleocyemata
Infraorder: Anomura
Superfamily: Galatheoidea
Family: Porcellanidae
Genus: *Petrolisthes*
Species: *armatus*

Figure 50 *Petrolisthes armatus*

Petrolisthes armatus (Figure 50) is commonly known as the green porcelain crab. It is a filter feeding species that can be found on oyster reefs, pilings, shell bottoms and jetties in estuarine to marine waters (Felder, 1973). *P. armatus* is native to South America and the Caribbean (Ray, 2005).

This species was established in the Indian River system in Florida as early as 1977. In 1994, populations were reported from St. Catherine's Island, Georgia and had reached South Carolina by 1995 (Knott *et al*., 1999). The spread of *P. armatus* may be the result of a natural range extension or an inadvertent introduction through ballast water or the importation of mollusk cultures (Ray, 2005). Specimens were collected in the present survey in Jacksonville, Savannah and Charleston. All were found in scraping samples from each port area (zone 2), and from fouling plates and trawls in Charleston (zone 2), and also from Jacksonville trawl samples below the port (zone 1). Our biological literature GIS database indicates the presence of the species in Georgia (SEAMAP, 2003; Prezant *et al*., 2002).

Numerous studies have been conducted to determine the potential impacts of *Petrolisthes armatus*. Bishop and Hurley (2003) found that the abundance of *P. armatus* was higher than any other crab on seven oyster reef substrate samplers on Sapelo Island, Georgia. Hartman *et al.* (2001) and Hollebone and Hay (2003) found that cohabitation of *P. armatus* with xanthid crabs provides an alternative prey option for predators. When consumption of xanthid crabs decreases, xanthid crab feeding on oyster spat increases. The species may therefore have an indirect negative impact on oyster recruitment throughout the region.

6.1.5. Balanus amphitrite (Darwin, 1854)

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Crustacea
Class: Maxillopoda
Subclass: Thecostraca
Infraclass: Cirripedia
Superorder: Thoracica
Order: Sessilia
Suborder: Balanomorpha
Superfamily: Balanoidea
Family: Balanidae
Genus: *Balanus*
Species: *amphitrite*

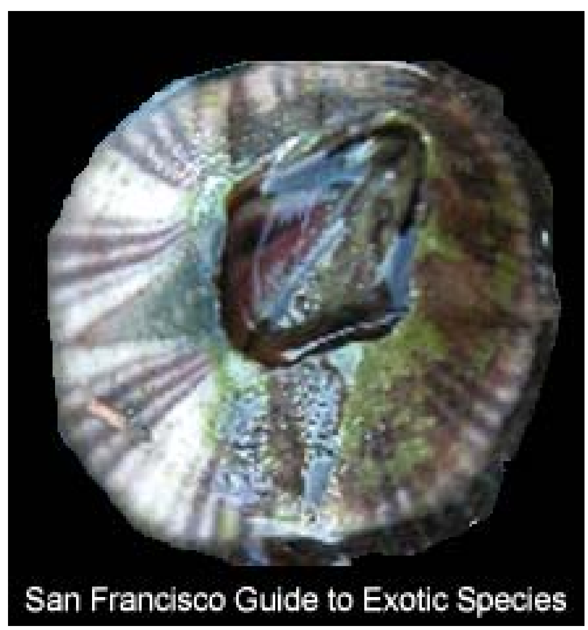


Figure 51 *Balanus amphitrite*

Balanus amphitrite (Figure 51) is a common member of the intertidal fouling community, often associated with polluted environments (Calcagno *et al.*, 1998). Native to the Southwest Pacific and Indian Ocean, *B. amphitrite* has been distributed worldwide in warm and temperate seas via ship fouling (Eldredge and Smith, 2001b). Specimens were collected in the present survey from Jacksonville, Savannah and Charleston. All occurred in scraping samples within the port zones (zone 2) and we also collected specimens attached to gastropod shells in crab traps from below Jacksonville port in the Mayport area (zone 1). Our biological literature GIS database indicates the presence of the species in Georgia, South Carolina and North Carolina (Calder *et al.*, 1977; Fox and Ruppert, 1985; Pearse, 1936; Pearse, 1947; Prezant *et al.*, 2002; Richardson, 1991; Sutcliffe, 1947; Sutherland and Karlson, 1972; Wells *et al.*, 1964; Wirtenson, 1964).

Populations of *Balanus amphitrite* have been shown to spawn throughout the year with the potential to release 1,000 to 10,000 eggs per brood, and up to 24 broods a year (Gulf States Marine Fisheries Commission, 2003). They often grow in dense aggregations that can serve as refuge for other alien species. Heavy fouling on hulls has also been shown to decrease ship speed by up to 40 % (Cohen, 2005).

6.2. Other Nonindigenous Mollusk, Crustacean, and Polychaete Species in the Region

6.2.1. Information Sources

Tables 30 and 31 present nonindigenous freshwater and marine crustacean, molluskan, and polychaete species which have been reported in the South Atlantic Bight region. These lists have been created by compiling information from the following sources and all information was current as of January 2006:

a) Nonindigenous Aquatic Species (NAS) information database for the United States Geological Survey: Located at the Center for Aquatic Resource Studies, Gainesville, Florida, this site has been established as a central repository for accurate and spatially referenced biogeographic accounts of nonindigenous aquatic species (http://nas.er.usgs.gov).

b) Benson, A. J., Fuller, P. L., and Jacono, C. C. 2001. Summary Report of Nonindigenous

Aquatic Species in U.S. Fish and Wildlife Service Region 4. U.S. Geological Survey Florida Caribbean Science Center. 60 pp (http://cars.er.usgs.gov/Region_4_Report/).

c) Non-Native Aquatic Species in the Gulf of Mexico and South Atlantic Regions, Gulf States Marine Fisheries Commission website (http://nis.gsmfc.org).

d) Ray, G. L. 2005. Invasive estuarine and marine animals of the South Atlantic and Puerto Rico. Aquatic Nuisance Species Research Program (ANSRP) Technical Notes Collection (ERDC TN-ANSRP-05-5), U.S. Army Engineer Research and Development Center, Vicksburg, MS. (http://el.erdc.usace.army.mil/elpubs/pdf/ansrp05-5.pdf).

Total nonindigenous listings for freshwater crustaceans, mollusks, and polychaetes were 22 species, comprising 14 crustaceans and eight mollusks. The crustacean component included 11 decapods, the majority of which were crayfish (10 and one shrimp), two copepods and one water flea. The mollusks were dominated by gastropod snails numbering seven, with one bivalve species. More nonindigenous species were listed for the marine environment, with a total of 31 comprising 19 crustaceans, ten mollusks, and two polychaetes. The crustaceans included ten decapods (six crabs, two shrimp, and two prawns), three barnacles, four isopods, and two amphipods. The mollusks comprised six bivalves and four gastropods (2 snails and two nudibranchs). All species listings include the five identified in the present survey and discussed above (section 6.1). Our five identified nonindigenous species represent 9.43% of the total nonindigenous species (53) known to be present in the region. The largest number of species for both fresh and marine environments combined was found among the crustaceans (33 species, or 62%) followed by the mollusks (18, or 34%) and then polychaetes (two, or 4%). Some of the species listed have not become established in the region and others only appear in either the extreme north or south of the Bight region.

Notes on the distribution, life history, and impacts associated with the introduction of all known nonindigenous species in Tables 30 (freshwater) and 31 (marine) are provided in the following section. The above and following referenced sources were found useful:

e) Literature Review and Field Survey of Tampa Bay for Nonindigenous Marine and Estuarine Species, February 2004. Tampa Bay Estuary Program Technical Publication # 02-04. Patrick Baker, Shirley M. Baker, and Jon Fajans, Department of Fisheries and Aquatic Sciences, University of

Florida (http://dl.nwrc.gov/net_prod_download/public/gom_net_pub_products/DOC/Tech-02-04-Invasives.pdf).

f) Blue Crabs of the South Atlantic Bight. Southeastern Regional Taxonomic Center Species of the Month Fact Sheet (http://www.dnr.sc.gov/marine/sertc/Blue%20Crab%20SOM.pdf).

g) Integrated Taxonomic Information System (http://www.itis.usda.gov/).

h) Shrimps and prawns of the world. An Annotated Catalogue of Species of Interest to Fisheries. Food and Agricultural Organization of the United Nations, Rome. L.B. Holthuis, 1980. FAO Fisheries Synopsis No.125, Volume 1. (http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/009/ac477e/ac477e00.htm).

i) Hull fouling as a vector for the translocation of marine organisms. Phase one study ─ hull fouling research. Department of Agriculture, Fisheries and Forestry ─ Australia. Strategic Ballast Water R&D Program. Report No. 1 ─ Volume 1. February 2002.

j) Parasites, infections and diseases of fishes in Africa - An update *CIFA Technical Paper*. No.31. Food and Agricultural Organization of the United Nations, Rome, 1996. Paperna, I. 220 pp. (http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/008/v9551e/V9551E19.htm).

k) Global crayfish resources at the Carnegie Museum of Natural History (http://iz.carnegiemnh.org/).

l) Galveston Bay Invasive Species Risk Assessment- Final Report. March 2004. Prepared by Lisa Gossett and Jim Lester for the Galveston Bay Estuary Program, Texas Commission on Environmental Quality (http://galvbaydata.org/projects/invasive/Invasive.html).

m) Fofonoff, P.W., G.M. Ruiz, B. Steves, A.H. Hines, & J.T. Carlton. 2003. National Exotic Marine and Estuarine Species Information System. (http://invasions.si.edu/nemesis/).

6.2.2. Freshwater Decapods

Crayfish are largest contributor in this category with ten nonindigenous species reported in the region. Most of these are native transplants and have been introduced to various parts of the region through aquaculture for food, the live bait trade, and the pet/aquarium trade food trade (Huner, 1997; Lodge *et al*., 2000). ***Cambarus longirostris*** (Faxon, 1885) is native to the Tennessee River Basin. ***Orconectes (Procericambarus) placidus*** (Hagen, 1870), the bigclaw crayfish has a wide native range, from the Cumberland, Tennessee, and lower Ohio river drainages. ***Oronectes virilis*** (Hagen, 1870) the northern crayfish has a native range encompassing all of the Prairie Region. ***Cambarellus shufeldtii*** (Faxon, 1885), the dwarf crayfish is from the floodplains of the Upper Mississippi River. ***Procambarus acutus*** (Girard, 1852), the white river crayfish occurs across the coastal plain and piedmont from Maine to Georgia, from the Florida panhandle to Texas, and from Minnesota to Ohio. ***Orconectes palmeri creolanus*** (Creaser, 1933) is native to Mississippi and Louisiana in the Lake Pontchartrain drainage area and the Pearl and Pascagoula rivers. ***Faxonella clypeata*** (Hay, 1899) the ditch fencing crayfish is reported from Oklahoma east to Gadsden County, Florida, and Richland County, South Carolina. ***Procambarus (Ortmannicus) seminolae*** (Hobbs, 1942) occurs in Georgia.

The remaining two species, the red swamp crayfish, ***Procambarus clarkii*** (Girard, 1852) and the rusty crayfish, ***Orconectes rusticus*** (Girard, 1852) are more notable. Adult red swamp crayfish are dark red with a wedge-shaped black stripe present on the abdomen. Chelae have bright red tubercles. In contrast, juveniles are a drab grey, and sometimes overlain by dark wavy lines. Originally it was distributed from northern Mexico to Florida, and north to southern Illinois and Ohio. It now occurs throughout the U.S. (Arizona, California, Georgia, Hawaii, Idaho, Indiana, Maryland, Nevada, New Mexico, North Carolina, Ohio, Oregon, South Carolina, Utah, and Oklahoma) where it is the dominant commercial crayfish species and is also available as bait. The species has also been introduced to South and Central America (Belize, Brazil, Costa Rica, and Dominican Republic), Europe (Portugal, Spain, France, and Cyprus), Asia (Japan, China, and Taiwan) and Africa (Kenya, and Uganda). The rusty crayfish has robust claws and dark, rusty spots on each side of their carapace. The native range includes Indiana, Ohio, Kentucky, and Michigan; however, it has invaded many surrounding areas and is found as far west as North and South Dakota, north as Canada and Maine, and south as Tennessee.

The red swamp crayfish avoids strong water flow instead favoring streams, swamps, ditches, sloughs, and ponds especially with lots of organic matter to provide for its benthic omnivorous feeding habits (Hobbs, 1989). They exhibit a wide salinity tolerance occurring in both fresh and brackish waters. The rusty crayfish can be found in both sluggish and fast flowing freshwater streams, particularly where large rocks, logs and other debris are available to provide shelter. Both species are aggressive and exhibit territorial behavior.

Impacts associated with these crayfish species include the rapid displacement of native crayfish species through competition, predation and reproductive interference (Lodge *et al*., 2000; Perry *et al*., 2002; Bowen, 2003). Non- native crayfishes can also carry pathogens harmful to native species. The crayfish plague (the fungi, *Aphanomyces astaci* Schikor), endemic to North America species and lethal to European species, has reduced populations of native European crayfish species by as much as 90% in some regions (Lodge *et al*., 2000). Many species have also been shown to reduce aquatic plant abundance and species diversity decreasing essential habitat for invertebrates, fish, birds, and erosion control. They can also pinch swimmers that are unfortunate enough to step on them. Female red swamp crayfishes are burrowers, this activity can cause damage to water control structures which has lead to agricultural impacts, particularly for rice irrigation systems.

The bristled river shrimp, ***Macrobrachium olfersii*** (Wiegmann, 1836) is another nonindigenous freshwater decapod crustacean in the region. The bristled river shrimp is native to Central and South America from Mexico to Brazil. It was first reported in Florida in St. Augustine in the 1930s, possibly introduced with aquatic fish and vegetation from South America (Holthius and Provenzano, 1970). It is now present in the northeast, southeast and in the panhandle, although in low abundances. It has also been reported from Texas, Louisiana, Mississippi, and Florida (White, 1977; Anderson and Fillingame, 1980; Reimer and Trudeau, 1975; Horne and Beisser, 1977).

The biology and life history of the bristled river shrimp is provided by Dugger and Dobkin (1975). This is a large shrimp, males reaching nine cm in length (telson to rostrum) and females six to seven cm (Holthuis, 1952). The spiny chelipeds are unequal in size and the larger one has an inflated palm. Males have blue-green or black-brown chelipeds, and females have green chelipeds mottles with blue. The body of this freshwater shrimp has a brown carapace, which is occasionally speckled, with a laterally streaked appearance. Females are can produce 170-8,960 eggs per brood. The life cycle is typical of the genus, in which adults live and reproduce in freshwater, but zoea larvae are carried to estuaries, where they can tolerate salinities up to 28 ppt. Metamorphosis and growth occur here and the planktobenthic juveniles then migrate upstream where the adult completes its life cycle (McNamara *et al*., 1986). This dispersal pattern of the larvae can help spread the species through river systems. The species represents some commercial interest as culture for food (Thang, 1995).

6.2.3. Freshwater Copepods

Two freshwater nonindigenous copepods are reported in the region, both of which are parasitic on commercial aquaculture species. The anchorworm ***Lernaea cypriniacea*** (Linnaues, 1758) has an elongate, tubular body 1 - 1.5 cm in length with "anchors" or outgrowths on the cephalothorax by which the female attaches itself to hosts (Robinson & Avenant-Oldewage, 1996). While there are differences in the growth of the anchors depending on the consistency of the host tissue to which the parasite is attached (Fryer, 1968), the anchor shape is considered the most useful taxonomic feature. Now cosmopolitan in its distribution (Putz & Bowen, 1964; Fryer, 1968) it is thought have to originated from Eurasia. Its spread is in part attributed to international trade of tropical fishes (Robinson & Avenant-Oldewage, 1996). It is found throughout the Southeastern United States region.

The female of the species is parasitic on many fish families including the Amiidae, Catostomidae, Salmonidae, Sciaenidae, and Umbridae and tadpoles of *Rama* spp. (Hoffman, 1976). Adult females attach to the exposed body surfaces of host fishes, where they cause acute hemorrhage and ulcers at the site of penetration. Fatality occurs as a result of blood loss and secondary infections (Putz & Bowen, 1964). The parasite can be found on various parts of the host's body surface, and appear as small worm-like protrusions. The species can cause serious economic problems for fish aquaculture. Infestations are treated with one ppm dipterex. The copepod can develop from mature eggs to the first copepodid or parasitic larval stage in as little as four to eight days (Al-Hamed & Hermiz, 1973).

Another parasitic copepod is ***Argulus japonicus*** (Thiele, 1900). A member of the family Argulidae these "fish lice" are economically important pathogens of finfish in temperate (Hoffman, 1977) and tropical regions (Kabata, 1985). A native to Asia it has been introduced into the U.S. through importations of host fish (Cressey, 1978). It has been reported from both Florida and

Georgia in the Southeast region. The species is also reported from Africa (Fryer, 1960), Israel (Paperna, 1964), and New Zealand (Pilgrim, 1967).

Mouthparts and antennae are modified for their parasitic lifestyle and form a proboscis with hooks, spines, and suckers which they use to attach behind the fish operculum or a fin. They are capable of leaving their host for up to three weeks while they try to find a different host, or to lay eggs. The number of eggs per clutch can vary dramatically and development is temperature dependent lasting between a week and several months (Fryer, 1982; Mikheev *et al.*, 2001). Upon hatching the juveniles are immediately parasitic and must find a host within the first two to three days (Lester & Roubal, 1995). In fish aquaculture infestations can have a large economic impact, causing fish to cease feeding and deteriorate in condition (Lester & Roubal, 1995). The wounds created by *Argulus* species also present a site for viral and bacterial infection (Shimura *et al*., 1983; Stammer, 1959).

6.2.4. Freshwater Waterfleas

Daphnia lumholtzi (Sars, 1885) a cladoceran or "waterflea" is a zooplankton species native to Africa, Asia, and Australia that has recently invaded North America (Havel & Hebert, 1993). It was first reported in an East Texas reservoir in 1991. The reservoir had been stocked in the 1980s with at least two species of African fish, tilapia and Nile perch. *Daphnia lumholtzi* was later found in samples collected from Missouri reservoirs as far back as 1990. It is generally believed that the species was introduced with Nile perch but it may also have been introduced through the aquarium trade (Stoeckel *et al*., 1996). It is now known to be present in Alabama, Arkansas, Florida, Illinois, Kansas, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, Ohio, South Carolina, Tennessee, Texas, and Utah.

The species can reach approximately 3.5 mm. Zooplankton are an important food source for fish species. *Daphnia lumholtzi* has much larger and more numerous spines than native U.S. species. The large spines associated with this introduced species make it difficult for larval and juvenile fish to consume. This ability to avoid predation could result in population explosions, the replacement of native *Daphnia* species, and reduced food availability for economically and ecologically important fish species (Havel *et al*., 1995).

6.2.5. Freshwater Gastropods

Three members of the family Ampullariidae, two Thiaridae, and one Viviparidae make up the nonindigenous freshwater gastropod species in the region. Most of these are believed to have been introduced through the aquarium trade. The Ampullariidae are also known as apple snails and have many adaptations that have contributed to their success as invading species. A branchial respiration system allows them to breathe under water while a lung facilitates respiration in air. This adaptation is related to their native distribution, tropical regions characterized by periods of drought alternating with periods of high rainfall. Many also deposit eggs above the waterline in calcareous clutches to protect against predation by fish and other aquatic inhabitants. Unlike many snail species, applesnails are not hermaphroditic, but gonochoristic: a male and a female are needed for reproduction.

The giant ramhorn snail, ***Marisa cornuarietis*** (Linnaeus, 1758) is an applesnail native to Brazil, northern South America and Central America (Baker, 1930; Dundee, 1974). It was first reported in Cuba in the 1940s (Penalver, 1950) and Puerto Rico in 1952 (Oliver-Gonzalez *et al*., 1956). Reports in Florida appeared in the 1970s and has also since been found in Texas (Dundee, 1974; Emerson and Jacobson, 1976; Thompson, 1984; Howells, 1992).

Young *Marisa* have reddish-brown shells that, as adults, become mostly dark brown or occasionally banded with three planetary, thin, chocolate-brown stripes. The body whorl is circumscribed with transverse striations that are especially pronounced near the aperture. Shell diameter typically reaches 50 mm (Thompson, 1984). It is found in many water bodies, lakes, rivers, ponds, irrigation systems and swamps and typically at depths less than one meter near vegetation (Ferguson and Palmer, 1958). It is very pollution tolerant, can survive months in dissolved oxygen levels less than 0.5 ppm, in salinities up to 8.5 ppt and temperatures down to 13°C (Ferguson and Palmer, 1958; Hunt, 1958, 1961; Akerlund, 1974). This together with its popularity as an aquarium snail, stream flooding and natural migration have helped the species spread. Eggs are laid in gelatinous clusters in the water typically among thick stands of aquatic vegetation (Hunt, 1958).

It has a voracious omnivorous feeding habit which can have detrimental effects on aquatic vegetation and native snails through competition and direct predation of eggs and young (Hunt, 1958). In regions of the world where schistosomiasis, bilharziosis, and other water borne parasitic worm diseases affect human health, the species has been deliberately introduced to help control populations of snails that act as intermediate hosts to the parasites (Radke *et al.*, 1961; Jobin, 1970). It is also useful in removing stands of invasive aquatic plants (e.g. water hyacinth) which in turn assists mosquito control (Ferguson and Palmer, 1958).

The channeled applesnail, ***Pomacea canaliculata*** (Lamarck, 1819) and the spiketop applesnail ***Pomacea bridgesi*** (Reeve, 1856) are two other South American gastropod species found in the southeastern U.S. The channeled applesnail is native to Argentina, Bolivia, Brazil, Paraguay and Uruguay (Albrecht *et al.*, 1996). It has also been introduced into parts of Asia (Albrecht *et al.*, 1996) and there are established populations in Florida and Texas (Neck and Schultz, 1992; Collins, 1996; Thompson, 1997). The spiketop applesnail is native to the entire Amazon River system (Bolivia, Brazil, Paraguay and Peru) and was introduced to Hawaii in the 1960s, to south-east Asia (Indonesia, Thailand, Cambodia, Hong Kong, China, Japan, and the Philippines) in the 1980s and to Florida in the early 1980s (Thompson, 1984).

The shells of these species have between five and six whorls separated by deep sutures. The spiketop has a square shoulder on each whorl. Both species can reach 50 – 60 mm (Burch, 1982; Thompson, 1984), the spire being high and sharp in the spiketop. Variations in color exist with both ranging from yellow to green to brown and with or without dark spiral bands. The reproductive rate of these snails varies with the temperature and partly by the availability of food. Eggs are spawned several centimeters above the water and are reddish due to a high carotenoid content. The eggs are loosely attached to each other and their size varies from 2.20 to 3.5 mm (0.5 to 0.9 inch) diameter. An average clutch contains 200 to 600 eggs.

The channeled applesnail is mainly herbivorous, typically feeding on macrophytes, and occasionally feeding on the eggs and juveniles of other snails (Estebenet, 1995). In parts of Asia and South America, the channeled applesnail is a major pest in rice plantations (Litsinger and Estano, 1993; Halwart, 1994; Albrecht et al., 1996). The spiketop snail has smaller teeth and prefers dead and rotting vegetation. Both species may serve as a vector for diseases and parasites. Again in Asia, the channeled applesnail is an intermediate host for *Angiostrongylus cantonensis*, a rodent parasite that can be transmitted to humans (Albrecht et al., 1996).

The Chinese mystery snail, ***Cipangopaludina chinensis*** (Reeve, 1863) a member of the Viviparidae family, is native to Burma, Thailand, South Vietnam, China, Korea, Asiatic Russia, Japan, the Philippines, and Java (Pace, 1973). In 1892, Chinese mystery snails were imported into live markets in San Francisco (Wood, 1892). In 1911, they were found in San Francisco Bay; in 1915 they were found in Boston, Massachusetts, in 1950 in Florida, and in 1965 in the Great Lakes (Hannibal, 1911; Johnson, 1923; Clench, 1940; Abbott, 1950; Jacobson and Emerson, 1961; Clench and Fuller, 1965; Dundee, 1974; Barnhart, 1978; Clarke, 1978).

The shell is a uniform color throughout without banding and is usually a light to dark olive-green. Large specimens reach 65 mm in length; their shells have six or seven whorls (Clench and Fuller, 1965). The whorls are strongly convex and each suture is very indented. They occur partially buried in mud substrate in lakes, ponds, rice paddies, irrigation ditches, roadside ditches, and slow-moving streams (Pace, 1973; Clench and Fuller, 1965). The species has polymorphic spermatozoa and females give birth to live, crawling young (Pace, 1973). They eat zooplankton and phytoplankton (Plinski *et al*., 1978). Mystery snails have a feature called a "trap door" which allows them to close up the opening in their shell when water conditions are unfavorable.

Chinese mystery snails can serve as vectors for the transmission of human parasites and diseases ─ *Echinocasmus elongatus, E. redioduplicatus, E. rugosus, Eupariphium ilocanum, E. recurvatum, Echinostoma macrorchis*, and *E. cinetorchis* (Pace, 1973). In high densities they can clog the screens of water intake pipes, and can compete with native snail populations.

Two nonindigenous Thiaridae species occur in the southeastern U.S., the red-rimmed melania, ***Melanoides tuberculata*** (Muller, 1774) and the fawn melania, ***Melanoides turriculus*** (Lea, 1850). *M. tuberculata* is native to subtropical and tropical areas of northern and eastern Africa and southern Asia from Morocco and Madagascar to Saudi Arabia, Iran, Pakistan, India, southern China, and Indonesia east to Java and Celebes, Northern Australia and the New Hebrides (Clench, 1969; Pace, 1973; Neck, 1985). *M. turriculus* is native to the Philippines; however its status as a distinct species is questionable and may in fact be an ecological variant of *M. tuberculata* (Thompson, 1999). The taxonomy of thiarids is problematic; outside of the Middle East *M. tuberculata* is asexual, so new morphologies may easily be established (Livshits *et al*., 1984). Invasive populations represent several independent lineages with multiple morphotypes. Both species were introduced into Florida, Louisiana, and Texas, and Central America probably through aquarium releases (Abbott, 1952, 1973; Russo, 1974; Murray, 1971, 1975; Dundee, 1974; Neck, 1985; Burch, 1982; Howells, 1992).

In Florida, the two snails are ecologically segregated. *Melanoides tuberculata* is usually in quiet, euthrophic, turbid habitats, whereas *M. turriculus* is in cleaner, oligotrophic springs and runs (Thompson, 1984). *M. tuberculata* can flourish in waters with salinity ranging from zero to 30 ppt (Roessler *et al*., 1977). The thermal tolerance range is about 18-25^{o}C, but *M. tuberculata* can survive cooler temperatures by burrowing, and appears to be tolerant of low oxygen levels (Roessler *et al*., 1977). Both snails are similar in appearance, shells are elongate and conical, the high spired (< twice aperture) has about five ribbed whorls in mature specimens, and the operculum has an offset spiral growth pattern. The last whorl is usually broken (Lee, 1973). Shells are tan to brown, often mottled with red or rust-colored spots. *M. turriculus* typically has more of an olive colored shell. Red-rimmed melania may reproduce both sexually and by parthenogenesis. The species is viviparous with up to 70 offspring (number is dependent on size of adult) being held in a brood pouch in the mantle cavity until they are released at 1-2 mm (Livshits and Fishelson, 1983). Melania snails consume detritus and benthic microalgae and are mostly nocturnal (Lee, 1973).

Melania snails are intermediate hosts for important human or wildlife trematode parasites ─ *Clonorchis sinensis*, the Chinese liver fluke; *Paragonimus westermani*, the Oriental lung fluke; *Diorchitrema formosanum* an intestinal trematode; *Opisthorchis sinensis*, the human liver fluke; *Philophthalmus sp.*, the avian eye fluke (Jacobson, 1975; Murray, 1971; Kotrla, 1975; Dundee and Paine, 1977). *Melanoides tuberculata* has been reported at population densities of up to 10,000 m^2 in the St. Johns River in Florida (Thompson, 1984). At high densities like this, these snails can replace native detritivores, and can become an agricultural pest (Lee, 1973; Roessler *et al*., 1977).

6.2.6. Freshwater Bivalves

The Asian clam, ***Corbicula fluminea*** (Müller, 1774) has a wide natural range from tropical southern Asia, southeastern Russia, the eastern Mediterranean, Africa and central and eastern Australia (Lachner *et al*., 1970; Britton and Morton, 1979). Initial North American introductions in Washington in 1938 were intentional (food item), and further introductions (bilge water, fishing bait, aquarium trade) plus the species' own dispersal ability have spread it throughout the United States (Dundee and Harman, 1963; Dundee, 1974; Sinclair, 1971; McMahon, 1983; Isom, 1986; Counts, 1986, 1991).

The shell of *C. fluminea* is symmetrically triangular to circular in outline, deeply inflated, and robust. There is a heavy, smooth periostracum (shell coating), yellow to black, and the interior of the shell may be tinged with purple. *C. fluminea* may be confused with related oligohaline marsh clams, *Polymesoda* spp., but the shell outlines of the latter are not as symmetrical. A small bivalve (maximum of 65 mm in shell length, > 25 mm uncommon) they occur in high densities (1,000 to 25,000/feet^2) and have a relatively high growth rate (Sinclair, 1971; Gottfried and Osborne, 1982; Hall, 1984; Stites *et al*., 1995). Life span varies according to habitat, with a maximum life span of approximately seven years (Hall, 1984). Reproductive activities are typically highest in the fall (Kraemer and Galloway, 1986). For the first two years, Asian clams are protandric consecutive hermaphrodites. Larvae are brooded within the branchial cavity until metamorphosis and released as crawl-away juveniles (Morton, 1987). Self-fertilization may occur (Kraemer and Galloway, 1986; Siripattrawan *et al*., 2000). Larvae spawned in late spring and early summer may reach sexual maturity by the fall (Hall, 1984; King *et al*., 1986). *Corbicula* can tolerate a wide range of water temperatures and does not tolerate salinities of greater than 13 ppt for long periods (Haertel and Osterberg 1967; Sickel 1986). Well oxygenated clear waters, and fine clean sand, clay, and coarse sand are preferred substrates (Belanger *et al*., 1985; Stites *et al*., 1995).

Its high densities and filter-feeding capabilities can lead to substratum space and food competition with native unionids (freshwater mussels) and shaeriid (freshwater clams) endemics (Boozer and Mirkes, 1979; Cooper and Johnson, 1980; Clarke, 1988). *Corbicula* has an advantage over many native species because it tolerates anthropogenic activities and quickly adapts to disturbed environments (McMahon, 1983). Accumulations of dead shells can impede water flow in irrigation systems, and municipal water-treatment facilities and power-generation plants (Ingram 1959; Ray 1962; Sinclair 1974; Smith *et al.* 1979; Eng, 1979; McMahon, 1983). Some benefits associated with its introduction include its use as an index organism in pollution studies, as a local food for fishes and wildlife, as fish bait and as possible food for birds, and improved water clarity through filtration (Villadolid and Del Rosario, 1930; Metcalf, 1966; Keup *et al*., 1963; Beaver *et al*., 1991).

6.2.7. Marine Decapods

Three species of nonindigenous *Callinectes* (Family Portunidae) crabs have been reported in the South Atlantic Bight region ─ the red blue crab ***Callinectes bocourti*** (A. Milne-Edwards, 1879), the rugose swimming crab ***Callinectes exasperatus*** (Gerstaecker, 1856), and the masked swimming crab ***Callinectes larvatus*** (Ordway, 1863). The red blue crab typically occurs between Jamaica and Belize south to Brazil, the others from the southern tip of Florida to Brazil, the western Gulf of Mexico, and Bermuda. All three species can occasionally drift north into our waters on warm ocean currents associated with the Gulf Stream, by drift associated with storm events or by ballast water transport (Williams and Williams, 1981). The first reported occurrence for these crabs was for the red blue in Biscayne Bay, Florida in 1950 (Provenzano, 1961). In subsequent years the species was reported from Biloxi Bay estuary, in Mississippi Mobile Bay, Alabama, the Atlantic coast of Florida, South Carolina, and North Carolina (Perry, 1971; Gore and Grizzle, 1974; Williams and Williams, 1981). In 2002, the red blue crab was collected by fishermen from Jacksonville, Florida and South Carolina (http://www.dnr.sc.gov/marine/sertc/Blue%20Crab%20SOM.pdf). In 2005 it appeared off the Gulf coast of Florida in Collier County (http://nas.er.usgs.gov/). The rugose swimming crab was collected from Cape Fear, North Carolina in 1977, South Carolina in 2002, and Georgia in 2003. The masked swimming crab was also found in South Carolina in 2002.

Callinectes species are widely distributed in the neotropics and subtropics where they are a key resource in local fisheries and are important in trophic relations of fish and organisms of sandy and sandy-mud bottoms, and in seagrass meadows (Conde, 2002). All species have a pair of flat, oar shaped rear legs (pereopods) for swimming. Members of the genus have a flat broad carapace with a series of distinct lateral teeth along each frontal margin between the eyes and the large terminal spines at the widest part of the carapace. There are also four to six frontal teeth between the eyes; the number, shape, and relative length of these teeth are used in distinguishing the different species.

The carapace of the red blue crab has four triangular frontal teeth (does not include the inner orbital teeth) with tips reaching a nearly common level, however the species exhibits morphological plasticity (Williams, 1974). Chelae and the carapace are smooth, with the fingers of the chelae heavily toothed. The carapace color is typically olive green, but may be shades of brown, gray or green, sometimes with variable purplish-red markings. The chelae are red to dark red-brown, and the joints often have a purple-red cast. Legs are typically red above, with shades of maroon, yellow and olive green below in the underbelly region. They inhabit shallow, brackish waters and generally prefer mud and mud-sand substrates. After mating females move into more saline waters. The red blue crab is more pollution tolerant than other species in the genus. Males can reach 76 mm in carapace width and females are slightly smaller.

The potential effect of these species on native *C. similis* and *C. sapidus* populations is unknown, however not thought to be significant since few specimens were collected in each instance and they are not thought to be established. If populations were to reproduce and become established, competition for food and refuge would occur which could have an impact on commercial fisheries since the red blue crab is smaller and less desirable for processing.

Another portunid crab that has been reported throughout the southeast region is the Indo-Pacific swimming crab ***Charybdis hellerii*** (A. Milne-Edwards, 1867). This crab is native to the Indo-Pacific: Japan, Philippines, New Caledonia, Australia, Hawaii, and throughout the Indian Ocean, including the Red Sea (Stephenson, 1972; Kathirvel and Gopalakrishnan, 1974; Vannini, 1976; Javed and Mustaquim, 1994). It is now present in the eastern Mediterranean (Israel, Egypt, and Lebanon), probably having migrated through the Suez Canal (Steinitz, 1929; Campos & Turkay, 1989; Galil, 1992). Several locations in the western Atlantic have also reported its occurrence: Cuba (Gomez & Martinez-Iglesias, 1990); Venezuela (Hernandez & Bolanos, 1995); Colombia (Campos and Turkay, 1989); Brazil (Tavares & De Mendonca, 1996); the Caribbean and Florida (Lemaitre, 1995).

Charybdis hellerii is found in soft-bottom areas, under rocks and in corals from the intertidal zone to 30 - 51 m (Stephenson *et al*., 1957). A prominent spine on the carpus of the swimming leg, and bristles stopping before the tip of the first male pleopod are considered diagnostic traits for *C. hellerii* (Stephenson, 1972). The maximum size reported from Malaysia was a male measuring 80 mm in carapace width (Wee & Ng, 1995). The carapace is dark green with pale green or whitish areas on frontal, hepatic and epibranchial regions. The fingers of chelipeds are dark purple (Lemaitre, 1995). Females are sexually mature at approximately 50 mm carapace width (Stephenson *et al.,* 1957) and eggs are bright yellow in color, with spherical diameters ranging from 0.224 to 0.322 mm (Kathirvel & Gopalakrishnan, 1974). Fecundity has been reported to range from 22,517 to 292,050 eggs per female (Siddiqui & Ahmed, 1992).

The impacts of *Charybdis helleri* introductions are currently unknown. In high numbers it could compete with native commercial species e.g. *Callinectes sapidus* for food and habitat. It is itself a commercially important species in Southeast Asia (Moosa, 1981), but no market currently exists for it in the United States.

The Japanese or Asian shore crab, ***Hemigrapsus sanguineus*** (de Haan, 1853) is a member of the family Grapsidae. This family includes several marsh crabs and indeed species from this family are always found in shallow water or on land near water. A native of the western Pacific Ocean from Russia and Korea south to Hong Kong and the Japanese archipelago (McDermott, 1998), it has been introduced into the Atlantic Ocean off both Europe and North America (Breton *et al*., 2002; Schubart, 2003; Gerard *et al.* 1999) and also in the Mediterranean (Ben Souissi *et al*., 2004). In the United States it was first identified in 1988 in New Jersey (McDermott 1991). Ballast water is suspected as the pathway. This species is now well established and abundant from North Carolina to New Hampshire and possibly Maine (Williams & McDermott, 1990; Lohrer & Whitlatch, 1997).

These crabs have a distinctive square carapace, with eyes close to the corners and three spines on each side. The carapace color ranges from greenish-brown to purple to orange-brown to red. It has light and dark bands along its legs and red spots on the upper parts of the chelipeds. Male crabs have a distinctive fleshy, bulb-like structure at the base of the moveable finger on the claws. This species is small reaching up to 42 mm in carapace width and have been reported at densities as high as 120/m^2 (Lohrer & Whitlatch 1997; O'Connor, 2001). Found on all types of shallow hard-bottom intertidal and sometimes subtidal habitat including artificial structures, oyster reefs, rocks, they can tolerate a wide range of salinities and temperatures but adults prefer salinities of 20 ppt or higher (Fukui 1988; Bourdeau & O'Connor 1999; Percival & Wilson, 2001; Ledesma and Connor, 2001; Brousseau *et al.,* 2003).

The Japanese shore crab has broad food preferences including macroalgae, gastropods, mussels, barnacles, larval and juvenile fish, and amphipods (Lohrer & Whitlatch, 1997; Bourdeau & O'Connor, 1999; Gerard *et al.,* 1999). In the western Atlantic the crab reproduces from late April through September, with a fecundity of up to 50,000 eggs in each brood, and females are capable of having three or four broods per season (Fukui, 1988; McDermott, 1998; Gerard *et al.,* 1999). Zoeal larvae are tolerant of a wide range of temperature/salinity combinations and settle and metamorphose after about 25 days (Epifanio *et al*. 2003). Crabs reach sexual maturity in about two years and can live for approximately eight years (Fukui, 1988).

These opportunistic omnivores may pose threats to populations of native crab, fish and shellfish and to oyster and blue crab aquaculture operations by direct predation or competition for food and space. In many introduced areas it has quickly become the most abundant species in the rocky intertidal zone (Lohrer and Whitlatch, 1997; Jensen *et al*., 2002).

Nonindigenous shrimp species have been used in aquaculture in the southeastern United States, including operations in Florida, Georgia and South Carolina (Wenner and Knott, 1992). The African prawn ***Palaemon macrobranchion*** **(**Herklots, 1851) is a member of the Superfamily Palaemonidea and Family Palaemonidae and is native to the Eastern Atlantic off the coast of Africa between Senegal and Angola. It can be found in both fresh and brackish water where it reaches a maximum size of 78 mm (Holthius, 1980). Although a small sized species it has some commercial significance in Liberia (Miller, 1971) and Guinea (Gruvel, 1913). It was intentionally released in Florida in 1995, however has not become established (Benson *et al*., 2001).

Three members of the Superfamily Penaeoidea and family Penaeidae make up the rest of the nonindigenous marine decapoda reported in the region. ***Liptopenaeus vannamei*** (Boone, 1931), the

Pacific white shrimp and ***Penaeus stylirostris*** (Stimpson, 1874), the blue shrimp are native to the Eastern Pacific from Mexico to Peru (Perez Farfante & Kensley, 1997). Juveniles occupy shallow estuarine waters, while adults are usually found in deeper waters (to 72 m *L. vannamei*; to 27 m *P. stylirostris*). Both species reach a maximum total length of 230 mm and have commercial significance in Mexico, Guatemala, El Salvador, Honduras, Costa Rica and Panama. ***Penaeus monodon*** (Fabricius, 1798), the jumbo or giant tiger shrimp is native to the Indo-West Pacific: east and southeast Africa and Pakistan to Japan, the Malay Archipelago and northern Australia (Dore & Frimodt, 1987; Perez Farfante & Kensley, 1997). In 1988, an undetermined number of animals that were imported as post-larvae from the Hawaii Department of Aquaculture were released by accident from the Waddell Mariculture Center, Bluffton, South Carolina. Several adults were later captured by commercial shrimpers as far south as Cape Canaveral, Florida however the species did not become established (McCann *et al*., 1996).

Penaeus monodon is generally dark colored with the carapace and abdomen transversely banded with black and white (Grey *et al.*, 1983). Juveniles occupy shallow estuarine waters sporadically entering rivers, while adults are usually found in waters up to 110 m deep (Grey *et al*., 1983). This species is the largest commercially available shrimp, reaching 336 mm in total length (Dore & Frimodt, 1987). It has some commercial significance in Natal, Somalia, Madagascar, India, Malaya, Thailand, Singapore, Indonesia, the Philippines, Taiwan, Australia, New Guinea (Chopra,1939; Yoshida, 1941; Domantay, 1956; Harrison *et al*., 1965; Jones, 1967; Rapson & McIntosh, 1971; Kurian & Sebastian, 1976. *P. monodon* diet preferences includes crustaceans and mollusks (85% ingested food), and the remaining 15% consisting of vegetable matter, polychaetes, fish, debris and sand, indicating that the giant tiger prawn is more of a predator rather than a scavenger or detritus feeder (Solis, 1988). Females attain a relatively larger size than males (Primavera, 1988). Males mature at 37 mm carapace length and females at 47 mm (Motoh, 1981). Females can release between 248,000 and 811,000 yellowish green eggs with an average diameter of 29 mm (Motoh, 1981).

It has been reported that exotic shrimp viruses may pose a risk to Gulf of Mexico and Southeastern U.S. Atlantic fisheries, including economically important penaeid shrimp as well as other crustaceans (J.S.A., 1997). Most of the above species can carry disease pathogens, and various forms of bacterial, fungal, and viral infections ─ *Baculovirus penaei* (BP), *Monodon baculovirus* (MBV), yellow-head virus (YHV). Infectious hypodermal and hematopoietic necrosis virus (IHHNV), hepatopancreatic parvo-like virus (HPV), baculoviral midgut gland necrosis virus (BMNV), *P. monodon* - type baculovirus (MBV), lymphoidal parvo-like virus (LPV), Taura Syndrome virus (TSV) and Reo-like virus (RLV) (Lightner *et al*., 1983, 1985; Lightner, 1993, 1996). These viruses can be transmitted to native wild penaeid shrimp populations (Overstreet *et a*l., 1997; JSA, 1997).

6.2.8. Marine Amphipods

The Cheluridae are a small family of highly modified wood-scraping amphipods that burrow into submerged and waterlogged timber which has already been attacked by the wood-boring isopod *Limnoria* (Barnard, 1955). They are shallow water species ranging from about low-water to a few meters. Becker (1971) discussed their biology, physiology and ecology. A key to genera is found in Barnard & Karaman (1991). ***Chelura terebrans*** (Philippi, 1839) is a species of unknown origin. It is now widespread in the North Atlantic off both the American (Florida, California, Washington) and European coasts, in the North Sea, the Mediterranean, the Black Sea, and also off South Africa, Australia, and New Zealand, presumably spread through ship fouling (McNeill, 1932; Cohen *et al*., 2002; Ray, 2005; Robinson *et al*., 2005; http://nas.er.usgs.gov). It can reach a maximum size of six mm and is pale brown in color. The ecological and economic impacts of introductions of this species are unknown.

6.2.9. Marine Isopods

The Asian isopod ***Synidotea laevidorsalis*** (Miers, 1881) is synonymous with ***Synidotea laticauda*** (Benedict, 1897). A native to the Western Pacific Ocean it has been introduced to estuaries in the United States (California, New Jersey, South Carolina), Europe, South America, and Australia through ship hull fouling or with cargoes of the Japanese oyster *Crassostrea gigas* (Carlton, 1979a; Hopkins, 1986; Markmann, 1986; Chapman and Carlton, 1991, 1994; Mees & Fockedey, 1993; Ray, 2005; Bushek & Boyd, 2006; http://nas.er.usgs.gov). The body has a mottled brown camouflage pattern and can grow to three cm in length. It shows a preference for shallow and calm subtidal waters in brackish to full seawater. Often found attached to algae, hydroids, and artificial structures, it is an omnivorous scavenger with a preference for hydroids.

While the impacts of the species in introduced environments are largely unknown it has been noted that they can quickly become the most abundant invertebrate and thus could outcompete native scavenging species. In some locations it is thought to be an important food of diving ducks and fish (Painter, 1966). Finally since it is a fouling species there are economic costs associated with cleaning structures including pilings, and buoys.

Two wood-boring isopods (warty pillbugs) are also present in the South Atlantic ***Sphaeroma terebrans*** and ***S. walkeri*** (Stebbing, 1905). *S. terebrans* is suspected to be native to the Indo-Pacific but has been introduced to the Atlantic basin (Brazil to Virginia, Liberia to the Congo) probably on the hulls of wooden ships (Kensley and Schotte, 1989; Carlton and Ruckelshaus, 1997; Brooks and Bell, 2002, 2005). *Sphaeroma walkeri* is thought to be native to India but now has a cosmopolitan distribution (Carlton and Iverson, 1981; Nelson and Demetriades, 1992). In their native range they are mainly found in the mid-to-lower intertidal range in mangrove roots. Unlike *S. terebrans* it is thought that *S. walkeri* does not actively burrow into these roots but instead occupies burrows excavated by other species (Carlton and Iverson, 1981). *S. terebrans* occurs in salinities above 17 ppt and has a wide temperature tolerance (Kensley and Schotte, 1989; Thiel, 1999; Ng and Sivasothi, 2001). *S. walkeri* also has a broad salinity and thermal tolerance, but thrives only above 25 ppt and 15^{o}C (Scaico, 1982). Both species attain a maximum size of about ten mm, and have a yellowish-to-dark brown body that has warty protrusions covering the posterior half. *S. terebrans* may reproduce more than one time each year brooding on average between five and 20 juveniles each time (Thiel, 1999). It feeds on bacteria and fungi and filter-feeds (Kensley & Schotte, 1989).

In Florida there has been controversy over the role that *Sphaeroma terebrans* may play in the destruction or stimulation of mangrove (*Rhizophora mangle*) habitat through burrowing activities into the prop roots (Rehm & Humm, 1973; Simberloff *et al*., 1978; Brooks & Bell, 2002). It seems likely that when *S. terebrans* is abundant mangrove populations are negatively impacted which in turn can lead to increased shoreline erosion. In Florida, *S. walkeri* does not appear to impact mangroves but has become one of the most abundant species on oyster and sabellid worm reefs which could alter food web dynamics and native populations (Nelson & Demetriades, 1992).

6.2.10. Marine Barnacles

In addition to *Balanus trigonus* and *B. amphitre* a third nonindigenous species, the striped barnacle ***B. reticulatus*** (Utinomi, 1967) is also present in the South Atlantic Bight region and is thought to have been introduced to the Atlantic basin centuries ago through hull fouling (Carlton and Ruckelshaus, 1997).

Balanus reticulatus occurs in the mid-to-upper intertidal zone, and is common on artificial floating structures. It shows a preference for strong currents, and high salinity, and is tolerant of freezing air temperatures for brief periods. The test has radial purple stripes, and concentric ridges perpendicular to the stripes. Like the other species, *B. reticulatus* is a simultaneous hermaphrodite and fertilization is internal and may occur throughout the year. Larval development is documented by Lee *et al*. (1999). Growth is rapid, and sexual maturity is attained in weeks. The species have been introduced for such a long period that their impact on native species is unknown. It has economic impacts, being a marine biofouler.

6.2.11. Marine Gastropods

Truncatella subcylindrica (Linnaeus, 1767), the looping snail, is native to the Atlantic coast of Europe (an far north as Ireland) and north Africa (Morocco and the Canaries and Azores), and to the Mediterranean, Aegean, Marmara, Black, and Azov Seas (Barnes, 1994; Fretter & Graham, 1978; Hayward & Ryland, 1990; Butakov *et al*., 1997; Kileen & Light, 1998; Nunn et al., 2005; White, 2006). It was first reported in U.S. waters in the late 1800s off Newport, Rhode Island (Verrill, 1880; Burch, 1962). It has also been reported from Florida (Ray, 2005).

It is most common in sheltered estuarine waters in the lower littoral and the fringes of the upper littoral zones under rocks and macrophytes. It prefers sheltered waters with salinities between 18 and 40 ppt. A small species, the yellowish shell reaches a maximum length of five mm and has three to five convex whorls. As the snail grows it will typically lose apical whorls, giving a truncated and cylindrical appearance. It is a dioecious species; eggs are fertilized internally and laid in egg capsules that are attached to detritus. Impacts associated with its introduction are unknown.

Another small introduced snail from the eastern Atlantic is the mouse-ear marshsnail or European Melampus, ***Myosotella myosotis*** (Draparnaud, 1801), a pulmonate air breathing species. Native to the eastern Atlantic coastlines from the British Isles and western Baltic to the Mediterranean, and Black Sea and has been introduced to the western Atlantic from Nova Scotia to the West Indies, the eastern Pacific from Washington to California, and to the coasts of South Africa, Australia, New Zealand, and possibly Uruguay (Morrison, 1963; Abbott, 1974; Carlton, 1979b, 1992; Rosenberg,1995; Martins, 1996; National Exotic Marine and Estuarine Species Information System, 2006 http://invasions.si.edu/nemesis/). In the U.S. the first reports date back to the 19th century: Rhode Island, 1832; Massachusetts, 1841; New York, 1865; California, 1871; New Jersey, 1874; Chesapeake Bay, 1900; Washington , 1927; Maryland, 1954; Oregon, 1965; British Columbia, 1967; Virginia, 1972; Baja California, 1978; North Carolina, South Carolina and Georgia, 1996 (Carlton, 1979b, 1992; Martins, 1996; Perkins, 1869; Hubbard and Smith, 1865; Pilsbry, 1900; Wass, 1972; Allen, 1954). It is believed that since the species lacks a planktonic larva it was most likely introduced to the east coast in solid ballast or through hull fouling and spread nationally in shipments of Atlantic oysters.

Myosotella myosotis reaches a maximum shell length of eight mm and has a smooth, thin shell that is yellow-brown or red-brown. There is no operculum. It can typically be found in salt marsh environments on plant stems and debris and has been collected from environments with salinities ranging from ten to 31 ppt and water temperatures between 16 and 24° C. The typical number of young per reproductive event is between 25 and 30 but can range from 15 to 80 (Meyer, 1955). While it shares a similar dietary niche as other native saltmarsh snails (e.g. *Melampus bidentatus* on the east coast and *Assiminea californica* on the west coast), it does not appear to outcompete, but has instead been reported to exist in localized populations and coexist well (Allen, 1954; Wass, 1972; Berman and Carlton, 1991). There are also no known economic impacts associated with the species.

Two nonindigenous opisthobranch gastropods have been introduced to the region (Florida), one being ***Ercolania fuscovittata***, a native transplant from the eastern Pacific between Alaska and the Gulf of California (Lance, 1962; Case, 1972; Millen, 1989; Behrans, 1991; Trowbridge, 2002; Behrens & Hermosillo, 2005; http://www.seaslugforum.net/). It has been reported as being introduced in Florida and Texas. The anterior surface of this sacoglossan species is covered with cerata and the body is whitish with reddish brown spots. This species feeds on filamentous red algae. Specimens can reach 15 mm in length. Very little information could readily be found about this species. Thus it is not known if the species is established in the southeast and it is assumed that impacts associated with its introduction are neglible. The other species is the harlequin or butterfinger nudibranch, ***Polycera chilluna*** (Marcus, 1961) native to West Africa (Garcia & Bobo, 1984; Ortea & Rolan, 1989; Valles *et al*., 2000). Specimens, eggs and juveniles were collected recently 25 miles south of Cape Lookout, North Carolina (White, 2004). This is a hermaphroditic, carnivorous species that feeds on hydroids, bryozoans, tunicates and barnacles. Again little is known about the introduction and impact of this species.

6.2.12. Marine Bivalves

The green mussel, ***Perna viridis*** (Linnaeus, 1758) is a commonly found mussel of the family Mytilidae in its native tropical waters of the Indo-Pacific region of Asia (Siddall, 1980). The species is dioecious, sexually matures at two to three months, lives for about three years, and has been recorded in densities of up to 35,200/m^2 (http://www.fcsc.usgs.gov). They occur in coastal waters (<10 m), in salinities between 16 and 33 ppt, temperatures between ten and 35°C (27 to 33 ppt, 26 to 32°C optimal), and exhibit a wide tolerance for sediment and pollution (Benson *et al*., 2001). These biological attributes facilitate opportunistic colonization of new areas. Since being accidentally introduced to Tampa Bay (USA) in the Gulf of Mexico in 1999 through ballast water or hull fouling, the green mussel has proliferated and dispersed southwards along peninsular Florida.

During 2002 another introduction occurred on the northeast coast of Florida. Through outreach activities associated with the present survey, a public campaign was initiated to alert recreational and commercial water users to report all sightings in Georgia and South Carolina (Figure 52). Observations of living and dead mussels trickled in during 2003 from all over coastal Georgia confirming the presence of the mussel here for the first time, and representing the expansion of the range of this invasive species to its most northerly location in the United States (Power *et al*., 2004). Mussels were found coastwide subtidally on old abandoned crab traps, crab trap floats, rope, boat fenders, and also in the lower intertidal zone on beach jetties (Figure 53). With the exception of the jetties, all other reports were single specimens. The largest living specimen recorded (N = 17) was 70 mm in length, 35 mm in height, and 23 mm in width (mean ± S.E. = 34.44 mm ± 2.98). Mussels were collected from the surface to approximately 4.5 m in depth. During winter 2004 all intertidal individuals on the jetties died. A large average tidal range of 1.8 m in Georgia and long periods exposed to low air temperatures during winter will limit their success in the intertidal zone. Only one live mussel was reported from coastal waters in 2004, and was pulled from an abandoned crab trap in Sapelo Sound, however many shells were washed ashore coastwide and living mussels were reported from offshore artificial reefs.

Green mussels are important fouling organisms in Caribbean mangrove communities, an economic burden in Tampa Bay due to the clogging of water intake pipes, fouling of navigation buoys and ship hulls, interference with shellfish culture, and have also been identified as a source of toxic shellfish poisoning (Agard *et al*., 1992; Benson *et al*., 2001; Buddo *et al*., 2003). Our surveys failed to detect the presence of the species in any of the four port areas presumably due to a low density in the north Florida and Georgia populations. At this time it appears unlikely that this nonindigenous species will become invasive in the coastal waters of the South Atlantic Bight; however there is some concern about populations possibly surviving at offshore reef locations.

The decline of natural populations and commercial production of the eastern oyster, *Crassostrea virginica* (Gmelin, 1791) in the Chesapeake and Delaware Bays and Pamlico Sound, has led to the investigation of the non-native Asian oyster, ***Crassostrea ariakensis*** (Fujita, 1913) or Suminoe oyster as a commercial species in these areas. It is believed that this species may be less susceptible to diseases (*Perkinsus marinus* and *Haplosporidium nelsoni*) that have decimated the native species. Suminoe oysters are reported to be naturally distributed from southern Japan along the south China coast through southeast Asia to the western coast of the Indian subcontinent (Takatsuki, 1949; Numachi, 1971; Ahmed, 1971; Carriker & Gaffney, 1996; Calvo *et al*., 2001). Larval settlement occurs in estuarine areas with low salinity but juvenile and adult oysters grow within a wide range of salinity (Amemiya, 1928; Ahmed *et al*., 1987; Cai *et al*. 1992; Guo *et al*., 1999).

First introduced to the west coast of the U.S. with shipments of *Crassostrea gigas* (Thunberg, 1793) and *C. sikamea* (Amemiya, 1928) in the 1970s, its aquaculture potential has been established

(Breese & Malouf, 1977; Langdon & Robinson, 1996). It is also a commercially important species in southern China where seed are collected and farmed (Guo *et al*., 1999). Some culture of sterile, triploid *C. ariakensi*s has occurred in Virginia and North Carolina. However, this poses a risk for unintentional establishment of populations of this non-native oyster in the region and beyond through illegal introductions, storms, and a variability in the degree of triploidy. There is also concern that new disease could be introduced to native oysters, in addition to potential interspecific competition with natives in states where populations remain healthy (National Adacemy Press, 2004).

Lyrodus medilobatus (Edmondson, 1942) an Indo-Pacific wood-boring mollusk from the family Teredinidae has been reported from the south-west Pacific and south-eastern Indian oceans, including the Hawaiian Islands, the New Hebrides Islands and New Caledonia, New Zealand, and Australia (Edmondson, 1942; Smith, 1963; Turner & Marshall, 1973). Shipworms are filter-feeding mollusks and dispersed by planktonic larvae. The larvae settle and construct extensive burrow systems on any wooden structures (e.g., boat hulls, marinas, docks, and pilings). Adults of many species are generally tolerant of a wide range of salinities, temperatures, flow conditions, and oxygen concentrations (Turner, 1966). In 1995 it was detected in the Indian River region near Cape Canaveral, Florida (USGS, 2005). Cohen and Carlton (1995) and Hoagland (1983) report extensive damage caused by shipworms on both the west and east coasts of the U.S., respectively. Economic costs for effective control through chemical treatment can be high (Highley, 1999).

Mytella charruana (d'Orbigny, 1846) the charru mussel, is a tropical species with a native range from Bahia de Petatlán, Mexico to San Antonio Cape, Argentina (Soot-Ryen, 1955; Keen, 1971). A euryhaline bivalve, it prefers shallow lagoons and mud-flats in bays, where it can reach large densities (Sibaja, 1985, 1986; Leonel and Silva, 1988). It has commercial significance in Brazil and can reach approximately 25 mm in shell length. It first appeared in Florida in seawater intake pipes of a Jacksonville, Florida power plant in 1986. The population died out during the winter and the species was not seen again until 2004 about 170 km south of Jacksonville (Boudreaux & Walters, 2006). It is thought that the species arrived through ballast water. If populations become established they could outcompete native shellfish species and they also represent a significant biofouling problem.

Pinctada margaritafera (Linnaeus, 1758) the black lipped oyster is distributed throughout tropical Indo-Pacific waters from the Persian Gulf to the Gulf of California and from Japan to the southern islands of the Pacific (Hasan, 1974). This is a large species reaching a diameter of 250 mm and it has a grayish green shell with brown to black margins (Cernohorsky, 1972). It is an epifaunal suspension feeder and can usually be found attached by byssus to hard substrata in the intertidal and subtidal to 18 m (Cernohorsky, 1972; Yukihira *et al*., 1988). It is a significant commercial species, particularly in the French Polynesian pearl industry and optimal temperature and salinity conditions for growth are reported between 26 and 29°C and 28 to 32 ppt (Ellis & Haws, 1999; Doroudi *et al*., 1999). A few specimens have been reported at several locations in Florida, the most northerly location being West Palm Beach (Jacksonville Shell Club, http://www.jaxshells.org). The introductions are thought to have been through ballast water and impacts are unknown.

The final nonindigenous marine bivalve species is ***Rangia cuneata*** (G. B. Sowerby I 1831), the Atlantic rangia which is a native transplant from the Gulf of Mexico (Abbott, 1974). An estuarine species it can be found in subtidal waters with salinities between five and 15 ppt salinity on mud and sand substrates (Traver, 1972; Swingle & Bland, 1974). It can reach a maximum size of 90 mm and has a black to brown shell. In Mexico the species has commercial importance (Wakida *et al*., 2004). It now occurs along the east coast of Florida north to the Chesapeake Bay and has also been reported in the Hudson River in New York. Introductions are thought to have been through intracoastal ballast water or oyster shipments. The impact of its introduction are unknown.

Have You Seen Me?

The green mussel *Perna viridis* is an invasive species from the Indo Pacific region. It was introduced to Georgia during 2003. If found please record as much of the following information as possible and send to:

Dr. Alan Power
University of Georgia Marine Extension Service
20 Ocean Science Circle, Savannah, GA 31411
Telephone: (912) 598 2348; Fax: (912) 598 2399; Email: alanpowr@uga.edu

Date: ______________________________

Location (GPS if available): ______________________________

Number of Living/Dead Mussels: ______________________________

Attached to: ______________________________

Approximate Depth: ______________________________

Water Temperature & Salinity: ______________________________

Shell Length(s): ______________________________

Collectors Name & Contact: ______________________________

1785
The University of Georgia
Marine Extension Service

Public Service & Outreach

Photo Credit: Dr. Richard Gleeson
Guana Tolomato Matanzas National Estuarine Research Reserve

Sea Grant Georgia

Sapelo Island
National Estuarine Research Reserve

Figure 52 A public awareness and request to report sightings of the green mussel.

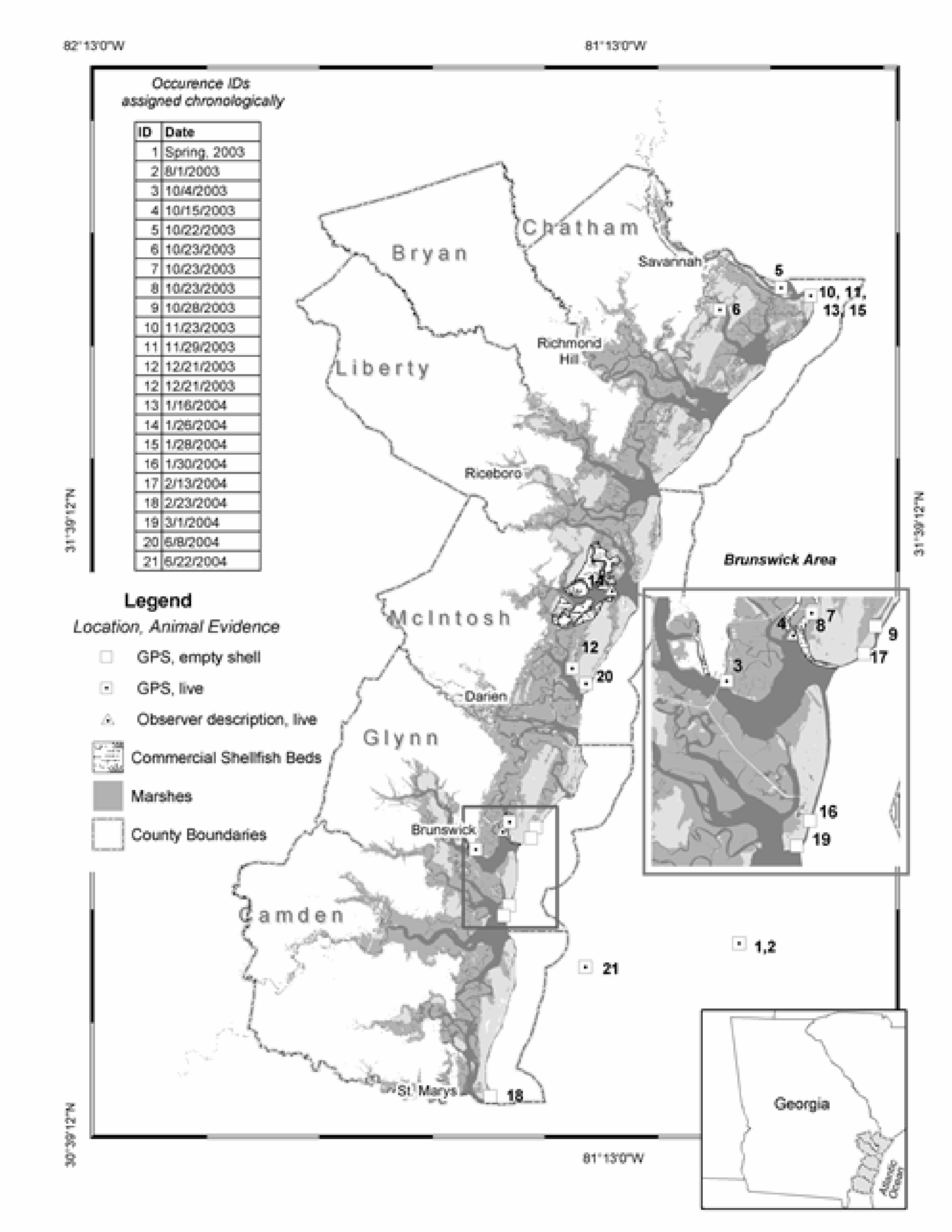


Figure 53 Map illustrating where green mussels were found off Georgia during 2003 and 2004.

6.2.13. Marine Polychaetes

Two nonindigenous calcareous tubeworms of the genus Hydroides have been collected in Florida. ***Hydroides diramphus*** (Mörch, 1863) is thought to be native to the Caribbean but has been introduced to Australia, New Zealand, the Philippines, Italy, Japan, and the U.S. (Imajima, 1978, 1979; Australian Museum Business Services, 2002; Fofonoff *et al*., 2003). In most locations the records are from harbors possibly indicating hull fouling as the primary vector. It is an estuarine species common in the intertidal and sublittoral zones where it fouls natural and artificial hard surfaces. In Florida it was reported from Jacksonville in 2001 and in the Indian River in 2005 (Fofonoff *et al*., 2003 http://invasions.si.edu/nemesis/).

Hydroides elegans (Haswell, 1883) is a widespread species originally native to the Indo-Pacific, but now present in Europe and throughout the Gulf of Mexico and East Florida (Zibrowius, 1971; Perkins & Savage, 1975; Walters, 2001). It is also believed to have been introduced through hull fouling (Zibrowius, 1971; Unabia & Hadfield, 1999). Occurring in great densities on natural and artificial hard surfaces it exhibits a wide temperature tolerance and a preference for salinities between 15 and 20 ppt (Unabia & Hadfield, 1999; Qiu & Qian, 1998). Fertilization is external, and larvae are planktonic for less than one week at 24 to 25^{o}C (Carpizo-Ituarte & Hadfield, 1998; McEdward & Qian, 2001). It produces an irregularly sinuous white or gray calcium carbonate tube which is cemented to the structure it has settled onto and typically is less than three mm in diameter. The polychaete remains within this tube, and when not sealed with an ornate operculum, it feeds on plankton via a feathery crown of pale cirri. In tropical harbors around the world, *H. elegans* is considered one of the most costly fouling organisms and also has economic impacts on the aquaculture industry in China (Zheng & Huang, 1990).

Species	Common name	Classification	Native region	Pathway	FL	GA	SC	NC
Cambarellus shufeldtii	Cajun dwarf crayfish	Crustacean	Southern Mississippi River Basin	Bait release		●		
Cambarus longirostris	Crayfish	Crustacean	Tennessee River Basin	Bait release			●	
Faxonella clypeata	Ditch fencing crayfish	Crustacean	Southern US	Bait release		●		
Orconectes palmeri creolanus	Crayfish	Crustacean	US	Bait release		●		
Orconectes placidus	Big claw crayfish	Crustacean	Tennessee River Basin	Bait release		●		
Orconectes rusticus	Rusty crayfish	Crustacean	Ohio, Tennessee and Cumberland	Bait release				●
Orconectes virilis	Northern crayfish	Crustacean	Northern US	Bait release				●
Procambarus acutus	White river crayfish	Crustacean	Southeast United States	Bait release		●		
Procambarus clarkii	Red swamp crayfish	Crustacean	Southcentral US	Bait release	●	●	●	●
Procambarus seminolae	Crayfish	Crustacean	Southeast US	Bait release		●		
Macrobrachium olfersi	Bristled river shrimp	Crustacean	Central and South America	Aquaculture	●			
Lernaea cyprinacea	Anchorworm	Crustacean	Eurasia	Aquaria release	●	●	●	●
Argulus japonicus	Parasitic copepod	Crustacean	Asia	Fish stockings/Aquaria release	●	●		
Daphnia lumholtzi	Water flea	Crustacean	Africa, Asia and Australia	Fish stockings	●		●	●
Marisa cornuarietis	Giant ramhorn snail	Mollusk	Central and South America	Aquaria release	●			
Pomacea canaliculata	Channeled applesnail	Mollusk	Central and South America	Aquaria release	●			●
Pomacea bridgesi	Spiketop applesnail	Mollusk	South America	Aquaria release	●			
Cipangopaludina chinensis	Chinese mystery snail	Mollusk	Asia	Aquaria release	●		●	●
Melanoides tuberculata	Red-rimmed melania	Mollusk	Africa, Asia	Aquaria release	●			●
Melanoides turriculus	Fawn melania	Mollusk	South Pacific Islands	Aquaria release	●			
Corbicula fluminea	Asian clam	Mollusk	Asia	Aquaria release, Bait release	●	●	●	●

● Compiled from USGS, USFWS, Gulf & South Atlantic Nuisance Species Panel, and the Aquatic Nuisance Species Program

Table 30 Freshwater nonindigenous crustacean and mollusk species reported from the South Atlantic Bight Region.

Species	Common name	Classification	Native region	Pathway	FL	GA	SC	NC
Callinectes bocourti	Bocourt swimming crab	Crustacean	South America	Range extension	●		●	●
Callinectes exasperatus	Rugose swimming crab	Crustacean	S. Florida, W. Gulf of Mexico to Brazil	Range extension		●	●	
Callinectes larvatus	Masked swimming crab	Crustacean	Southern Florida, to Brazil	Range extension			●	●
Charybdis helleri	Indo-Pacific crab	Crustacean	Indo-Pacific	Ballast water	●		●	●
Hemigrapsus sanguineus	Japanese shore crab	Crustacean	Western Pacific	Ballast water				●
Petrolisthes armatus	Green porcelain crab	Crustacean	Atlantic	Aquaculture, Ballast water	●	●	●	
Palaemon africanus	African prawn	Crustacean	Eastern Atlantic	Aquaculture	●			
Litopenaeus vannamei	Pacific white shrimp	Crustacean	Eastern Pacific	Aquaculture			●	
Penaeus stylirostris	Blue shrimp	Crustacean	Southern Atlantic	Aquaculture			●	
Penaeus monodon	Jumbo tiger prawn	Crustacean	Western Pacific	Aquaculture	●	●	●	
Chelura terebrans	Amphipod	Crustacean	Atlantic	Ship fouling	●			
Apocorophium lacustre	Amphipod	Crustacean	Eastern Atlantic	Ballast water	●	■	◘	▲
Ligia exotica	Wharf roach	Crustacean	Eastern Atlantic	Ship fouling	●	■	●	●
Synidotea laevidorsalis	Isopod	Crustacean	Western Pacific	Ship fouling			●	
Sphaeroma terebrans	Isopod	Crustacean	Indian Ocean	Ship fouling	●			
Sphaeroma walkeri	Isopod	Crustacean	Indian Ocean	Ship fouling	●			
Balanus amphitrite	Striped barnacle	Crustacean	Indo-Pacific	Ship fouling	●	●	●	●
Balanus trigonus	Barnacle	Crustacean	Western Pacific	Ship fouling	●	●	●	●
Balanus reticulatus	Barnacle	Crustacean	Western Pacific	Ship fouling	●			
Truncatella subcylindrica	Looping Snail	Mollusk	Northeast Atlantic	Unknown	●			
Myosotella myosotis	Mouse-ear Marsh snail	Mollusk	Eastern Atlantic	Ballast water	●			
Ercolania fuscovittata	Nudibranch	Mollusk	Eastern Pacific	Ship fouling	●			
Polycera chilluna	Harlequin	Mollusk	West Africa	Unknown				●
Perna viridis	Green mussel	Mollusk	Indo-Pacific	Ballast water	●	●		
Crassostrea ariakensis	Suminoe oyster	Mollusk	Asia	Aquaculture				●
Lyrodus medilobatus	Indo-Pacific shipworm	Mollusk	Southwest Pacific	Ship fouling	●			
Mytella charruana	Charru mussel	Mollusk	Southwest Atlantic	Ballast water, Ship fouling	●			
Pinctada margaritafera	Black lipped pearl oyster	Mollusk	Southwest Pacific	Ballast water	●			
Rangia cuneata	Atlantic rangia	Mollusk	Gulf of Mexico	Ballast water	●			●
Hydroides elegans	Tubeworm	Polychaete	Indo-Pacific	Ship fouling	●			
Hydroides diramphus	Tubeworm	Polychaete	Caribbean	Ship fouling	●			

● Compiled from USGS, USFWS, Gulf & South Atlantic Nuisance Species Panel, the Aquatic Nuisance Species Program, and NEMESIS

■ Identified in area from both our survey and GIS literature review database

◘ Identified in area from GIS literature review database

▲ Identified in area from our survey

Table 31 Marine nonindigenous crustacean, mollusk and polychaete species reported from the South Atlantic Bight region.

6.3. Pathways for Introductions

The most likely vector associated with the introduction of all nonindigenous mollusk, crustacean, and polychaete species was determined through a literature review (Tables 30 and 31). In cases where several vectors are implicated each one is included for that particular species in the pie chart illustrations below. Most of the nonindigenous freshwater species were introduced to the SAB region either through bait or aquarium releases (87%) with fish stockings and aquaculture making up the remainder (Figure 54).

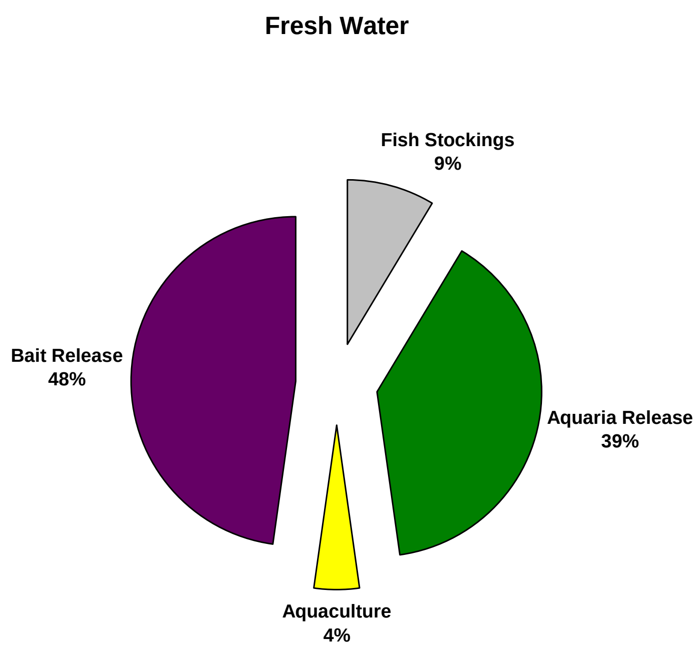


Figure 54 Pathways determined for fresh water nonindigenous mollusks, crustaceans and polychaetes in the South Atlantic Bight (SAB) region.

Most of the marine nonindigenous species are associated with hard structures and contribute to fouling communities. Fouling is the growth of epibiont and infaunal organisms on the surface of submerged natural and artificial structures. Most coastal waters in the South Atlantic Bight are characterized by soft muddy sediments; therefore artificial structures are particularly important for fouling communities, often being the only subtidal hard surface available. It is thought that the majority (40%) of introduced marine species were introduced on ships' hulls (Figure 55).

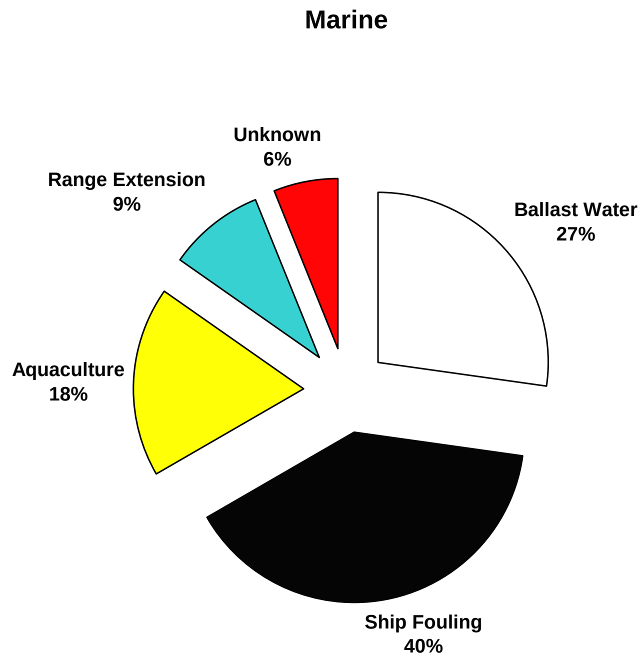


Figure 55 Pathways determined for marine nonindigenous mollusks, crustaceans and polychaetes in the SAB.

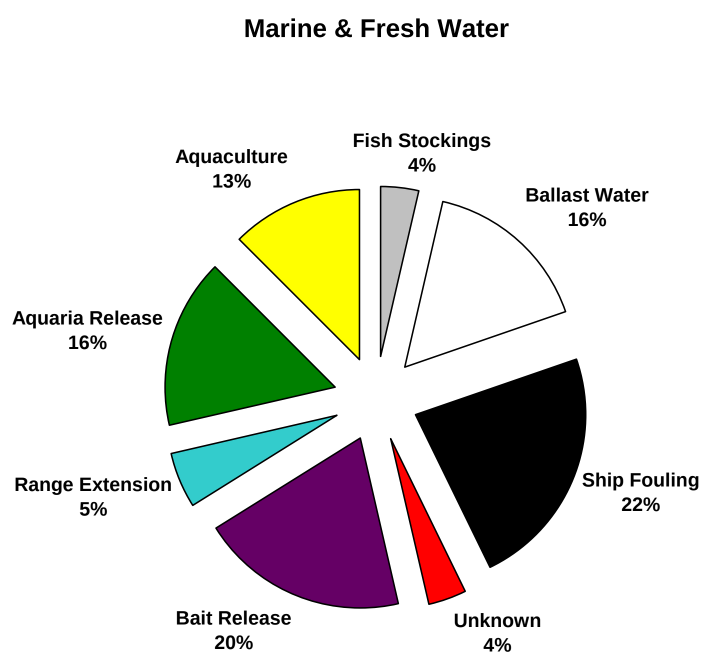


Figure 56 Pathways determined for all aquatic nonindigenous mollusks, crustaceans and polychaetes in the SAB.

Second to hull fouling in the marine environment is the transportation of organisms in ballast waters which accounts for 27% of all introductions in the SAB. The deliberate introduction of marine species for aquaculture purposes has also been a significant pathway in the region (18%).

Overall the ranking of introduction vectors from the most common to the least for all nonindigenous aquatic mollusk, crustacean, and polychaete species in the SAB are: ship fouling; bait release; ballast water and aquaria releases; aquaculture; range extensions; and fish stockings (Figure 56). Organisms associated with hull fouling were mainly from Pacific areas and included: four isopods; three barnacles; two tubeworms; two bivalves; one amphipod; and one nudibranch. Native transplants of crayfish species made up ten of the 11 species introduced through bait release; the remaining species was a bivalve from Asia. Ballast water introductions were associated with four bivalves, three decapods, one amphipod and one gastropod, most of which are native to the Atlantic followed by Pacific and Indo-Pacific waters. Nonindigenous species thought to have been introduced through the aquarium trade were six gastropods, one copepod, one anchorworm and one bivalve, most of which originated in either Asia or Central/South America. Atlantic and Pacific decapod shrimp and prawns (five) comprise the majority of aquaculture related introductions in addition to one parasitic copepod and one bivalve species both form Asia. Central and South American decapod crabs (three) are represented by range extensions while an Asian parasitic copepod and waterflea are attributed to contaminated fish stockings. The pathway of introduction for a gastropod from Europe and a nudibranch from Africa are unknown, although a ship vector is most likely (wet and dry ballast or cargo). The marine environment of this region has been highly impacted by shipping related activities since the early days of European settlement.

6.4. Risk of New Introductions to the South Atlantic Bight through Ports

6.4.1. Hull Fouling

Once considered a major vector for species introductions, its importance today is controversial. Carlton (1985) argued that higher vessel speeds, the development of antifouling technology paints, increased vessel maintenance and shorter port residency times have greatly reduced the ability for hitchhikers to colonize hulls. An exception to this is, of course, cceanic barges which move slowly, have large surface areas and typically have long residence times (Godwin, 2001). Faster transit time has alternatively been proposed as a mechanism for increased introductions, since species spend less time in conditions that might lie outside their normal tolerance ranges, particularly on trans-equatorial routes (Carlton & Hodder, 1995; James & Hayden, 2000). Others question the effectiveness of antifouling coatings and the development of biocide resistance (Hall, 1981), and cite the potential of protected niches (e.g. sea-chests) to carry fouling organisms and epibenthic species (Coutts *et al*., 2003). It is thought that the majority of introduced marine species in the South Atlantic Bight were introduced on ships' hulls (40% ─ Section 6.3). Since the movement of mobile, ripe, adult individuals can have a much more significant impact than species that may be discharged as larvae into a port in ballast water, it seems likely that vessel fouling should be considered to continue to pose a high risk for nonindigenous introductions in this region.

6.4.2. Ballast Water

Ballast water has been considered the most important ship related vector of marine invasions since the latter part of the 20th century (Carlton, 1985; Barrett-O'Leary, 1999). Shipping transfers approximately three to five billion tonnes of ballast water internationally each year with at least 7,000 different species being carried in ballast tanks at any one time globally (Global Ballast Water Management Program, http://globallast.imo.org/). At the federal level, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANCPA, 1990) mandated ballast water management for vessels entering the Great Lakes. This law was reauthorized as the National Invasive Species Act of 1996 (NISA, 1996), which required the development of voluntary ballast management guidelines for all other ships entering U.S. waters. NISA 96 also required the U.S. Coast Guard (USCG) to evaluate the effectiveness of the voluntary ballast management program three years after implementation. In 2004, voluntary guidelines were determined to be ineffective, and thus USCG initiated mandatory ballast management regulations (see Appendix seven or visit http://www.uscg.mil/hq/g-m/mso/ans.htm) for all ships entering U.S. waters from outside the Exclusive Economic Zone (out to 200 nautical miles from shore). Each vessel is now required to submit a ballast water management report to the U.S. Coast Guard and must either:

a. conduct mid-ocean ballast water exchange prior to entering U.S. waters (i.e. outside EEZ);

b. retain the ballast water on board while in U.S. water; or
c. use a Coast Guard approved on board ballast water treatment system.

The Coast Guard has reported increased compliance of ballast water management regulations since its introduction (http://groups.ucanr.org/Ballast_Outreach/documents/newsletter1102.htm 2006). The most common areas of noncompliance is a lack of onboard records and vessel-specific plans. Failure to comply can result in a fine of up to $27,500 per day and willful violations are considered a Class C felony. Several west coast states (CA, OR and WA) and the Great Lakes region have additional coastal exchange requirements for vessels operating within U.S. waters. The International Convention for the Control and Management of Ships Ballast Water and Sediments was adopted by consensus at the International Maritime Organization (IMO) in London in 2004. The convention will enter into force 12 months after ratification by 30 nations, representing 35% of the world shipping tonnage. The goal of the convention is to, "ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments." The convention involves parties: ensuring that ports and terminals have adequate reception facilities for the reception of sediments; promoting and facilitating scientific and technical research on ballast water management; monitoring the effects of ballast water management in waters under their jurisdiction; surveying and certifying ships; avoiding ships being unduly detained or delayed; providing technical assistance to train personnel; ensuring the availability of relevant technology, equipment and facilities.

Recent developments in national and international ballast water management present a tremendous reduction in the potential for ballast water introductions however; the problem has not been completely eliminated. Vessels can exchange ballast water in U.S. waters and claim a safety exemption if the conditions are unsafe for mid-ocean exchange. There are also issues with the effectiveness of mid-ocean exchange and current ship ballast water system designs (Barrett-O-Leary, 2001). Often vessels without ballast water will, in fact, have residual water in their tanks below pump suction capabilities which can contain organisms. Another issue is the fact that not all vessels entering U.S. waters do so from 200 nm offshore and the U.S. cannot require ballast water exchange in other countries EEZ. Treatment technologies offer the best solution to the problem; however ballast water treatment technologies are still in trial by the Coast Guard.

The National Ballast Information Clearing House (NBIC) is a joint program of the Smithsonian Environmental Research Center (SERC) and the United States Coast Guard that tracks the arrival patterns of ships and quantifies their ballast water activities in U.S. coastal systems. Their online database (http://invasions.si.edu/nbic/index.html) was consulted to examine ballast water management in each of the four ports between Jan 01, 2004 and Jan 01, 2005. Fig 57 presents the number of vessels that discharged untreated ballast water as a percentage of ballast water reports submitted for each port. Figure 58 presents the origins of the ballast water that was discharged.

Clearly Jacksonville had the highest incidence at 19.53% or 143 discharges (92,703 mt), mainly from vessels from Puerto Rico (46, 239 mt) and the Bahamas (32, 644 mt) with additional smaller quantities from Colombia, the United Kingdom, Japan, Panama, and Mexico. Savannah had the second largest volume of untreated ballast water at 44,618 mt by 4.02% or 19 vessels, followed by Charleston at 30,432 mt which actually had a higher incidence at 4.99% or 28 vessels. Wilmington had the least incidence (3.70%, or two vessels) and volume (2,262 mt). Foreign ballast water discharged reported in Charleston ranked in decreasing volume originated in Germany (12,594 mt), the Netherlands, the Bahamas, United Arab Emirates, France, China, Panama, Oman, and Brazil (350 mt). Repeating for Savannah: Venezuela (21,546 mt), Australia, South Korea, Panama, Italy, and Brazil (140 mt). All discharges reported in Wilmington were from vessels originating in the United States. Clearly, ballast water remains an important source for potential new invasive species in the region.

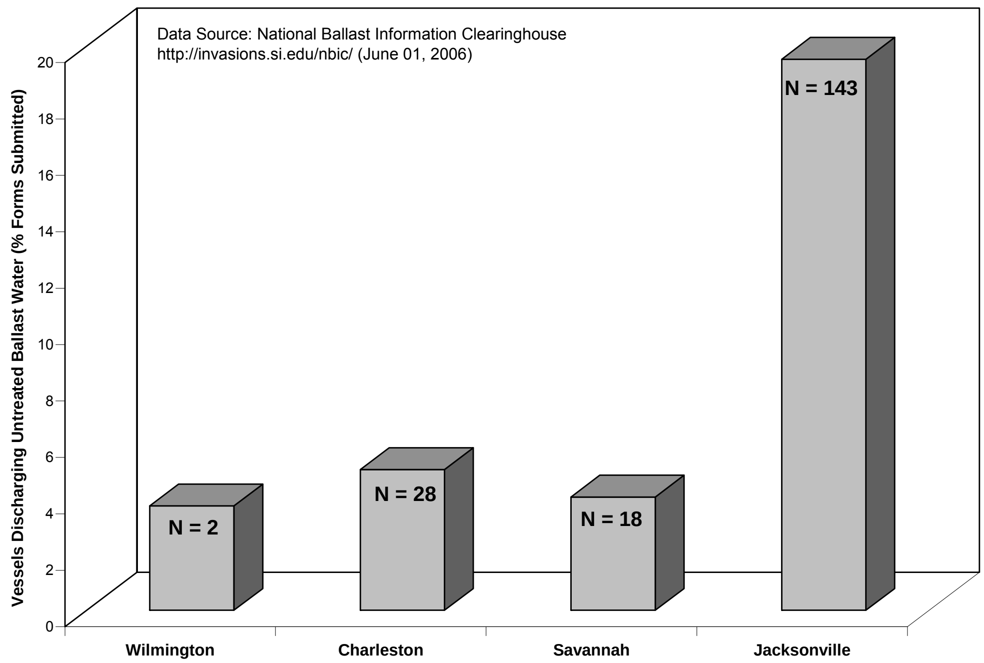


Figure 57 The number of vessels that discharged untreated ballast water as a percentage of all ballast water reports submitted for each port. The number of vessels (N) involved is also provided.

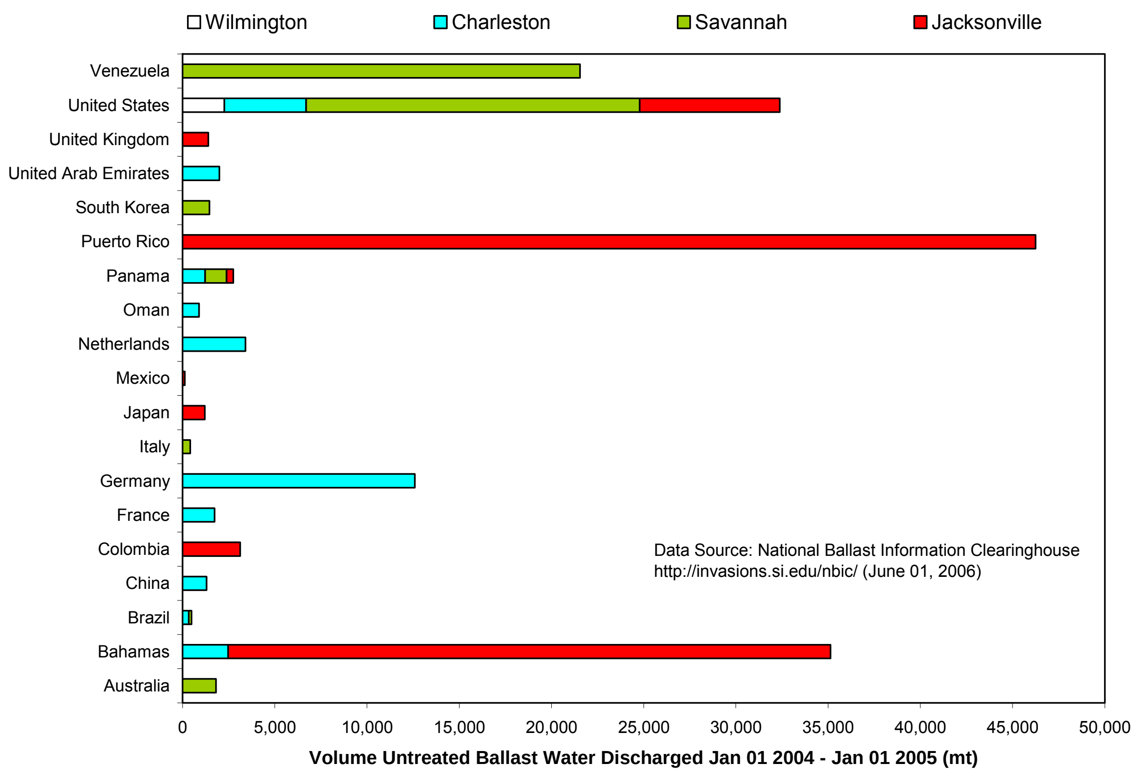


Figure 58 The origins and volume of ballast water reported as untreated discharges at each port.

6.4.3. Southeastern Port Specific Points of Vulnerabilty

Not all aquatic communities are equally vulnerable to invasions, but estuaries and sheltered coastal areas are particularly susceptible. Habitat disturbance often makes systems more prone to invasion (Hobbs, 1989). Isolated environments with a low diversity of native species also tend to be more susceptible (Brown, 1989). Estuaries are naturally disturbed, have relatively low diversity and are historically centers of anthropogenic disturbance associated with navigation, industrial development, and urbanization (Baker *et al*., 2004). Frequent channel dredging in port areas can promote new invasions, given the competitive edge of these species at earlier succession stages in the re-colonization of habitats. Port locations also offer diversity in terms of habitat, providing more opportunities for invaders to find a suitable niche.

In her treatise on Gulf of Mexico ports and their vulnerability to nonindigenous species invasion, Barrett O'Leary (1999) identifies several factors that should be considered including: trade partners; natural environment and port water quality compared to water quality of trade partners; total tonnage; types and proportions of transport vessels and cargoes; and the origin of ballast water discharges. Much of this information in relation to ports in the South Atlantic Bight has been discussed throughout this report. The following summarizes the data we have collected in relation to these factors.

Successful invasion is enhanced by similarity in the physical environment between the source and target areas (Brown, 1989). Environmental conditions were similar across the study area with large annual variations in water temperature (7.78 to 30°C), predominantly poorly sorted fine to medium sand substrates with low to intermediate levels of terrigenous organic matter (carbon, 0.17 to 2.80%; nitrogen, 0.02 to 0.09%). Mean monthly salinities were variable over the different sampling zones established in the study area ranging from zero ppt at Wilmington's upper to 35.45 ppt at Jacksonville's lower. Most hitchhiking organisms are probably introduced while vessels spend periods tied up between their arrival and departure from ports, therefore salinity in the immediate port area is particularly important. In addition, there is also added potential for untreated ballast water discharges to occur during loading. Port facilities in the South Atlantic Bight are located at various distances from the open sea; 5.5 to 10 miles in Charleston; 9 and 21 miles in Jacksonville;

17.3 to 23.1 miles in Savannah, and 26 miles Wilmington. The closest water quality parameters (annual temperature and salinity ranges) available for the immediate port areas were as follows: Charleston, 8.59 to 28.71 °C and 23.39 to 32.76 ppt; Jacksonville, 9.6 to 29.9°C and 0.3 to 15.5 ppt; Savannah 10.5 to 27.2°C and 0.04 to 5.52 ppt; and Wilmington 7.1 to 30.0°C and 0 to 15 ppt.

Many of the top ranked ports in the world (total cargo volume and container traffic) lie in the same latitude range as the South Atlantic Bight, many of which have trade routes established to the region (www.aapa-ports.org/). Some of these ports include Ningbo, Qingdao, Shanghai, Shenzhen (China), Chiba, Kitakyushu, Kobe, Nagoya, Osaka, Tokyo Yokohama (Japan), Busan, Kwangyang (South Korea), Newcastle, Gladstone (Australia), Algeciras (Spain), Richards Bay (South Africa), Itaqui (Brazil), New Orleans, Houston, Long Beach, and Los Angeles (United States). It would be interesting to relate ports that share environmental conditions similar to those described above for ports in the South Atlantic Bight; however this information is not readily available. This would be particularly useful should a new invasion be detected in one location and reported through a global port early warning system.

The ports of Charleston and Savannah are among the busiest along the Southeast and Gulf coasts. Important players in the international container traffic sector of the shipping industry, they are currently undergoing expansion and deepening projects to increase their capacity. Annually, both ports are among the top ten in the nation with respect to containerized cargo, and among the top 20 in terms of cargo volume. This is particularly important since container vessels typically have fast and direct transit routes, resulting in a greater probability of nonindigenous species surviving the journey. For this reason these ports might be considered to have a higher risk of invasion. In recent years each port has handled close to two million TEU's, with approximately half imports and half exports. The top trading regions for Charleston were North Europe and Asia, followed by Latin America and the Mediterranean. In 2004, 4.99% of vessels were reported as releasing a total of 30,432 mt of untreated ballast water in Charleston. Most of the ballast water originated in North Europe the ports top trading area. Savannah's top trading region is Asia, followed by Europe, the Mediterranean, Middle East and Oceania. In 2004, a total of 44,618 mt of untreated ballast water was reported for Savannah (4.02% of vessels), most of which originated in Latin America. Four of the five nonindigenous species detected in the present survey were found in both ports and approximately one third of the total nonindigenous species reported as occurring in the South Atlantic Bight have been collected in both South Carolina and Georgia. In the following section we have detailed species that have become invasive in certain parts of the world through shipping activities and have the potential to be introduced to the southeastern United States. Approximately half of these species are native to regions engaging in frequent trade with the ports of Charleston and Savannah

While the ports of Jacksonville and Wilmington do not handle as much traffic, they are also undergoing expansion, trade with additional global ports, and are visited by more bulk and breakbulk vessels. In 2005, Jacksonville was ranked 34th in the nation in terms of total cargo volume, and Wilmington experienced a tonnage increase of 29% over the previous year. Wilmington's top traders are Europe, South America, Asia, Canada and the Caribbean, while the top trading partner for Jacksonville is by far Puerto Rico, followed by South America, the Caribbean and Mexico. Bulk vessels account for the largest percentage of vessels visiting Jacksonville while breakbulk vessels are the most common at Wilmington. Jacksonville had the highest incidence of untreated ballast water discharges reported out of all four of our studied ports, and Wilmington the least (3.70%, 2,262mt, all domestic). Approximately one in every five vessel ballast reports in Jacksonville had untreated discharges. These amounted to a total of 92,703 mt, more than all other ports combined. Most of this water originated in Puerto Rico and the Bahamas. Since Jacksonville has fewer trading partners than other ports, it is not surprising that less than ten percent of the species listed as potential invaders to the South Atlantic Bight are native to areas with established trading routes. Similarly to Charleston, and Savannah, almost half of the list of potential invaders are native to regions engaging in frequent trade with the port of Wilmington. Four of the five nonindigenous species detected in this survey were collected in Jacksonville, and approximately two-thirds of those reported in the South Atlantic Bight have been reported in Florida. Only one of the five were found in Wilmington, and approximately one-third of the total list of nonindigenous species in the South Atlantic Bight have been reported in North Carolina. Molluskan, crustacean, and polychaete diversity indices were lowest (0.56) in Wilmington and highest (3.27). The low diversity of these faunal elements in Wilmington is worth noting since species-poor communities often increase invasive success through the incomplete use of available ecological space.

6.4.4. Potential New Invasive Species in the South Atlantic Bight

6.4.4.1. Invasive Species Characteristics

The success of invasive nonindigenous species is highly variable, and predictability of invasions is limited in spite of well-established general patterns of invasions (Office of Technology Assessment, 1993). In general, species tend to be more successful when native species do not occupy similar niches, they are often native to continents and to extensive, nonisolated habitats within continents, and inhabit disturbed environments and those with a history of close association with humans (Brown, 1989). The following additional biological characteristics are often exhibited by successful invading species (Williams & Meffe, 1999):

- High reproductive rates
- Broad diet
- Wide tolerance range for environmental conditions
- Long-lived
- High dispersal rates
- Single parent reproduction
- Vegetative or clonal reproduction
- High genetic variability
- Broad native range
- Occur in groups

Table 32 presents molluskan (two freshwater, 12 marine), crustacean (one freshwater, 9 marine) and polychaete (ten marine) species that have become invasive in certain parts of the world and have the potential to be introduced to the waters of the South Atlantic Bight. Most of these invasions occurred through shipping vectors (ballast water and hull fouling). Brief notes are also provided on these species native and introduced distributions, habitat, life history and invasive impacts.

Species	**Common name**	**Classification**	**Habitat**	**Native region**
Dreissena polymorpha	Zebra mussel	Mollusk	Freshwater	Europe
Potamopyrgus antipodarum	New Zealand mud snail	Mollusk	Freshwater	New Zealand
Anomia nobilis	Jingle shell	Mollusk	Marine	Indo-Pacific
Bedeva paivae	Australian whelk	Mollusk	Marine	Australia
Godiva quadricolor	Nudibranch	Mollusk	Marine	South Africa
Musculista senhousia	Asian date mussel	Mollusk	Marine	Siberia to Red Sea
Mytilopsis salleii	Black striped mussel	Mollusk	Marine	Indo-Pacific
Mytilus galloprovincialis	Mediterranean mussel	Mollusk	Marine	Mediterranean & Black Seas
Ostrea sandvichensis	Hawaiian rock oyster	Mollusk	Marine	Indo-Pacific
Perna perna	Brown mussel	Mollusk	Marine	Tropical & Subtropical Atlantic
Potamocorbula amurensis	Marine clam	Mollusk	Marine	China, Japan & Korea
Theora lubrica	Asian semele	Mollusk	Marine	Western Pacific
Varicorbula gibba	European clam	Mollusk	Marine	Europe
Rapana venosa	Veined rapa whelk	Mollusk	Marine	Eastern Pacific
Platychirograpsus spectabilis	Saber crab	Crustacean	Freshwater	Central America & W. Africa
Carcinus maenas	European green crab	Crustacean	Marine	Europe & North Africa
Eriocheir sinensis	Chinese mitten crab	Crustacean	Marine	Asia
Megabalanus coccopoma	Acorn barnacle	Crustacean	Marine	Pacific Central America
Megabalanus rosa	Acorn barnacle	Crustacean	Marine	Japan, China & Taiwan
Megabalanus tintinnabulum	Acorn barnacle	Crustacean	Marine	Unknown
Megabalanus zebra	Barnacle	Crustacean	Marine	Singapore
Notomegabalanus algicola	Barnacle	Crustacean	Marine	South Africa
Scylla serrata	Serrated swimming crab	Crustacean	Marine	Indo-Pacific
Sphaeroma quoyanum	Australasian isopod	Crustacean	Marine	Australia
Boccardia proboscidea	Spionid mud worm	Polychaete	Marine	EasternPacific
Boccardiella hamata	Spionid mud worm	Polychaete	Marine	Japan
Boccardiella ligerica	Spionid mud worm	Polychaete	Marine	Western Europe
Euchone limnicola	Fanworm	Polychaete	Marine	California
Ficopomatus enigmatica	Tubeworm	Polychaete	Marine	Indo-Pacific
Hydroides ezoensis	Tubeworm	Polychaete	Marine	Japan
Janua brasiliensis	Tubeworm	Poluychaete	Marine	Brazil
Pileolaria berkeleyana	Tubeworm	Polychaete	Marine	Japan
Pseudopolydora paucibranchiata	Spionid mud worm	Polychaete	Marine	Japan & Indo-Pacific
Sabella spallanzanii	Mediterranean fanworm	Polychaete	Marine	E. Atlantic & Mediterranean

Table 32 Molluskan, crustacean and polychaete species with potential for introduction to the SAB through shipping activities.

6.4.4.2. Potential Mollusks

Dreissena polymorpha (Pallas, 1771) – Zebra Mussel

Native distribution: Black, Azov, and Caspian Seas.
Introduced distribution: Europe, western Asia, Turkey, and North America.
Introduction vectors: Ballast water and hull fouling.
Impacts of introduction: Filter out the majority of plankton in the water which decreases the food available to planktivorous fish. Their introduction has also extirpated native mussels from the Great Lakes. They also cause damage to water pipes, shipping buoys, and ship motors.
Habitat: Usually found in the littoral and sublittoral zones attached to plants, other mollusks, crustaceans, and man made objects such as water pipes and dock pilings. They are found in fresh water but can tolerate salinities up 12 ppt and temperature range of 0-32°C.
Life history: Fertilization is external; the free-swimming larva begins to form its shell after 6-20 hours and remains part of the plankton for one week to one month. Once the shell is large enough the mussel settles and attaches by byssal threads to the substrate.

References:

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GSMFC. 2005. *Dreissena polymorpha* (Pallas, 1771). Gulf and South Atlantic Regional Panel on Aquatic and Invasive Species. Retrieved June 15, 2006. http://nis.gsmfc.org/nis_factsheet.php?toc_id=131

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Potamopyrgus antipodarum (Gray, 1843) - New Zealand mudsnail

Native distribution: New Zealand.

Introduced distribution: Europe, Australia and North America.

Introduction vectors: Recreational water users, ship ballast, transfer in sea freight, fish stocking.

Impacts of introduction: Provides food and space competition for native species. Heavy populations alter primary production, impacting trout feeding. Also a potential biofouler.

Habitat: Found in rivers, reservoirs, lakes and estuaries. Can tolerate up to 17-26% salinity. Has a broad temperature tolerance and is able to withstand desiccation.

Life history: Populations may consist of parthenogenic, ovoviviparous females or diploid sexual females and males. Embryos range from 20-120 per female. Reaches sexual maturity at approximately three mm.

References:

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Winterbourn, M. 1970. The New Zealand Species of *Potamopyrgus* (Gastropoda: Hydrobiidae). *Malacologia*, 10(2): 283-321.

Anomia nobilus (Reeve, 1859) - Jingle shell

Native distribution: Indo-Pacific region.

Introduced distribution: Introduced to the Hawaiian Islands and to the Red Sea.

Introduction vectors: Fouling from hulls of ships.

Impacts of introduction: Currently impact studies have not been conducted but it is thought to compete with native fouling organisms.

Habitat: Found in the intertidal zone on the surface of rocks, floating docks, and pier pilings where they are found stacked on top of each other.

Life history: They are gonochoristic and fertilization occurs externally. The larvae are initially planktonic and then settle to the bottom.

References:

HBS. 2002. Guide book of introduced marine species of Hawaii. Bishop Museum and University of Hawaii. Retrieved June 15, 2006. http://www2.bishopmuseum.org/HBS/invertguide/species/anomia_nobilis.htm

Vine, P. 1986. Red Sea Invertebrates. London: Immel Publishing. 224 pp.

Bedeva paivae (Crosse, 1864) - Paiva's dwarf triton, Australian whelk

Native distribution: Australia.
Introduced distribution: South Africa prior to 1968 (population now extinct) and the Canary Islands.
Introduction vectors: Accidental introduction by shipping.
Impacts of introduction: No impact in S. Africa due to population extinction in that country.
Habitat: Found in the intertidal zone and estuaries in sea grass and oyster beds.
Life history: Deposits egg masses on natural estuarine substrata among oysters.

References:
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Robinson, T. B., C. L. Griffiths, C. D. McQuaid, & M. Rius. 2005. Marine alien species of South Africa — status and impacts. African Journal of Marine Science 27(1):297-306.

Corbula amurensis (Schrenck, 1861), also know as *Potamocorbula amurensis* (Reeve 1861) – Marine clam

Native distribution: China, Japan, and Korea
Introduced distribution: United States – San Francisco Bay
Introduction vectors: Ballast water
Impacts of Introduction: Has become the dominant benthic species in San Francisco Bay. It filters large amounts of phytoplankton and zooplankton which starves native bivalves and removes their larvae, and is believed responsible for the crash of some fisheries in the Bay. Asian clams also accumulate selenium at high concentrations which could affect the reproduction success of birds and fish that feed upon them.
Habitat: Found on a wide range of sediments including clay, mud, peat, and sand in the subtidal zone and occasionally in the intertidal. Can live in salinities from 1-33 ppt. and can tolerate temperatures from zero to 28° C.
Life history: Asian clams reach maturity at a few months of age and can release anywhere from 45,000 to 220,000 eggs. Spawning can occur all year and once the eggs are fertilized the larvae are part of the plankton for 17-19 days before attaching to the substrate.

References:

Anonymous. n.d. Asian clam (*Potamocorbula amurensis)* – Marine pest guide. New Zealand Ministry of Fisheries. Retrieved June 19, 2006. http://www.fish.govt.nz/sustainability/biosecurity/pests/guide_potamocorbula.pdf

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Godiva quadricolor (Barnard, 1927)

Native distribution: South Africa.

Introduced distribution: Australia.

Introduction vectors: Hull attachment and/or ballast water.

Impact of introduction: Unknown.

Habitat: Found on wharf pilings in the intertidal zone.

Life history: Nudibranchs live for about a year and are hermaphrodites. They can lay up to 1 million eggs which are fertilized internally. When the eggs hatch they release either larvae that feed in the plankton until they settle or small adults.

References:

AM. 2006. Sea slug forum: *Godiva quadricolor* (Barnard, 1927). Austrialian Museum. Retreived June 28, 2006. http://www.seaslugforum.net/factsheet.cfm?base=godiquad

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Willan, R.C. 1987. Phylogenetic systematics and zoogeography of Australian nudibranchs. 1. The presence of the aeolid *Godiva quadricolor* (Barnard) in Western Australia. Journal. Malacological Society Australia, 8: 71-85.

Musculista senhousia (Benson in Cantor, 1842) - Asian date mussel

Native distribution: China, Korea, Japan, Siberia, and Singapore.
Introduced distribution: West coast of Canada, Mexico, and the United States, Mediterranean coast of Egypt, France, Israel, Italy, and Slovenia, and in Australia and New Zealand.
Introduction vectors: Ballast water and food trade.
Impacts of introduction: Decreases populations of native bivalves through food competition and by smothering with mats of dense threads. Affects the growth of eel grass in San Francisco Bay.
Habitat: Found from the intertidal to 30 m deep on hard and soft substrates. Its temperature range is approximately 1-31°C and can tolerate salinities from 18-35 ppt.
Life history: Spawns in the summer months and females can release up to 137,000 eggs. The hatching larvae remain as plankton up to 55 days after which they settle and attach to the substrate. They reach sexual maturity at nine months and live for approximately two years.

References:
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Mytilopsis salleii (Recluz, 1849) – Black-striped mussel

Native distribution: Central and South America.
Introduced distribution: Fiji, Hong Kong, India, Japan, and Taiwan.
Introduction vectors: Ballast water and hull fouling.
Impacts of introduction: Can attach to wide range of substrates in high densities and foul pipes, piers, and other structures. They out compete native bivalves by forming dense monocultures.
Habitat: Typically found in estuarine and inshore areas and tolerate temperatures from five to 40°C and salinities from zero up to 50 ppt).
Life history: Reproduction is external and females can release eggs that number in the 10,000's that are fertilized in the water column. Once eggs are fertilized and hatch the larvae are planktonic for approximately a day or two before they settle. They reach maturity at approximately nine mm and live for up to two years.

References:

CRIMP. 2001. Black-Striped Mussel (*Mytilopsis sallei*). Marine Pest Information Sheet #10. Retrieved June 15, 2006. http://www.marine.csiro.au/crimp/Reports/Infosht10_Mytil0201S3.pdf

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Mytilus galloprovincialis (Lamarck, 1819) – Mediterranean mussel

Native distribution: Adriatic, Black, and Mediterranean Seas.
Introduced distribution: Asia, North America, Hawaii, and Southern Africa.
Introduction vectors: Aquaculture, ballast water, hull fouling, live food trade.
Impacts of introduction: Can outcompete indigenous mussels due to their rapid growth and ability to survive long periods of air exposure (approximately seven days).
Habitat: Found in estuarine or marine areas on sandy substrates and exposed rocky areas with high water flow.
Life history: Spawns when water temperatures are highest for that region. Once fertilization occurs the larvae spends approximately two to four weeks as part of the plankton and then settles and attaches by byssal threads to the substrate as a juvenile.

References:

ISSG. 2006. *Mytilus galloprovincialis* (mollusk). Invasive Species Specialist Group, Global Invasive Species Database. Retrieved June 15, 2006. http://www.issg.org/database/species/ecology.asp?si=102&fr=1&sts=

Perna perna (Linnaeus, 1758) – Brown mussel

Native distribution: Africa, Europe, and South America.
Introduced distribution: North America in the Gulf of Mexico.
Introduction vectors: Ballast water.
Impacts of introduction: Can affect shipping by attaching to shipping buoys and causing them to sink. Also fouls pipes and water system in power plants.
Habitat: Prefers rocky shores and artificial substrates. Can tolerate temperatures from 7.5 - 30°C and salinities from 15 – 50 ppt.
Life history: Spawning occurs during the winter. The larvae are part of the plankton for the first ten to 14 days during which they develop byssal threads. They then settle onto the substrate and permanently attach to the substrate by the byssal threads.

References:
GSMFC. 2003. Fact Sheet: *Perna perna* (Linnaeus, 1758). Gulf and South Atlantic Regional Panel on Aquatic Invasive Species. Retrieved June 15, 2006. http://nis.gsmfc.org/nis_factsheet.php?toc_id=149

NBII. 2005. *Perna perna* (mollusk). Global Invasive Species Database. Retrieved June 15, 2006. http://www.issg.org/database/species/ecology.asp?si=742&fr=1&sts=

Theora lubrica (Gould, 1861) – Asian semele

Native distribution: Western Pacific.
Introduced distribution: California, Australia & New Zealand.
Introduction vectors: Ballast water.
Impacts of introduction: Can occur in high densities, providing competition for native species.
Habitat: Muddy sand.
Life history: Unable to locate information.

References:

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Varicorbula gibba (Olivi, 1792) – European Clam

Native distribution: Europe.

Introduced distribution: Australia.

Introduction vectors: Ballast water and fouling.

Impacts of introduction: High densities provide competition for native species.

Habitat: Shallow water, burrows in mud and sand or attaches to substrates with a single byssal thread. Tolerant of pollution and low oxygen levels.

Life history: Sexes separate. Broadcast spawners in the summer and fall. Maximum size is 15-20 mm, lives up to two years.

References:

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Rapana venosa (Valenciennes, 1846) – Rapa whelk

Native distribution: China, Japan, Korea, Russia, and Taiwan.
Introduced distribution: Argentina, Bulgaria, France, Romania, Turkey, United States, & Uruguay.
Introduction vectors: Ballast water.
Impacts of Introduction: Has caused declines to native bivalves in the Black Sea.
Habitat: Subtidal sandy areas that allow it to bury itself easily. Tolerates polluted water with low amounts of dissolved oxygen, temperatures from four to 27 °C, and a wide range of salinities.
Life history: Is dioecious and lays 50–500 capsules in mats. Each capsule can contain anywhere from 200-1000 eggs. The eggs hatch within 14-21 days and the larvae are pelagic for 14-21 days after which they settle to the bottom. They reach maturity at two years of age.

References:

CIESM. 2003. *Rapana venosa* (Valenciennes, 1846). The Mediterranean Science Commission. Retrieved June 19, 2006. http://www.ciesm.org/atlas/Rapanavenosa.html#top

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6.4.4.3. Potential Crustaceans

Platychirograpsus spectabilis (de Man, 1896) – Saber crab

Native distribution: Mexico and western Africa
Introduced distribution: United States – only in Florida
Introduction vectors: Shipping – imported logs from Mexico
Impacts of Introduction: Not known at this time.
Habitat: Live in holes made in the clay, mud, or on rocky banks on the edges of rives above the water line. Typically found in fresh water but observed in brackish with a salinity of two to three ppt.
Life history: May breed during the winter months in brackish or salt water or release their eggs in salt water for the larvae to develop like other species in the genus *Platychirograpsus*.

References:

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Schubart, C. D., H. Liu, & J. A. Cuesta. 2003. A new genus and species of tree-climbing crab (Crustacea: Brachyura: Sesarmidae) from Taiwan with notes on its ecology and larval morphology. The Raffles Bulletin on Zoology 51(1):49-59.

Carcinus maenas (Linnaeus, 1758) – European Green Crab

Native distribution: Europe and N. Africa.
Introduced distribution: Australia, South America, and the United States.
Introduction vectors: Aquaculture, aquarium and live food trade, ballast water, and hull fouling.
Impacts of introduction: Has caused a 40% drop in the Manila clam harvest in Humbolt Bay, CA and has forced shellfish growers to use nets to protect their stocks. It has also been linked to the destruction of soft-shell clam stocks, and to declines in scallop and northern quahog stocks in the Northeast U.S. and has the potential to damage the Dungeness crab fishery if populations increase in WA State.
Habitat: European green crab can tolerate a wide range of salinity (four to 54 ppt) and temperature (zero to 33°C). They are found on a variety of habitats including cobble beaches, rocky shores, sand flats, and tidal marshes.
Life history: Mating takes place from late spring to early fall after the females molt. Egg bearing females then move to deeper water due to stable salinity and temperature and extrude their eggs in the spring.

References:

Gollasch S. 2005. *Carcinus maenas* (crustacean). Institute for Marine Research, Kiel, Germany, & Invasive Species Specialist Group (ISSG). Retrieved June 15, 2006. http://www.issg.org/database/species/ecology.asp?si=114&fr=1&sts=

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Eriocheir sinensis (Milne-Edwards, 1854) – Chinese mitten crab

Native distribution: China and Korea.
Introduced distribution: Europe and North America including Hawaii.
Introduction vectors: Ballast water, deliberate introduction, hull fouling, and live food trade.
Impacts of introduction: Causes erosion by burrowing in the banks of rivers, estuaries, and coastal marshes. Reduces native invertebrate populations, damages rice crops, and interferes with fishing industry by damaging nets, increasing handling time, and eating fish caught in nets. It also an intermediate host of the oriental mammalian lung fluke (*Paragonimus* sp).
Habitat: Found around vegetation in rivers, estuaries, lagoons, riparian zones, and wetlands; can also tolerate a wide range in temperature and salinity.
Life history: Is a catradomous species that lives most of its life in fresh water but breeds in brackish and salt water. After mating the males die and the females brood the eggs in salt water. After the eggs hatch the larvae metamorphose into juvenile crabs which then migrate into fresh water to mature.

References:
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Megabalanus coccopoma (Darwin, 1854) – Barnacle

Native distribution: Pacific Coast of Central America.
Introduced distribution: Brazil, North Sea, Louisiana.
Introduction vectors: Hull fouling.
Impacts of introduction: Biofouling.
Habitat: Inhabits low-intertidal zone.
Life history: Studies are ongoing to determine if this species is *Megabalanus rosa*, which would result in reconsideration of native range and introduced distribution of the species.

References:

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Megabalanus rosa (Pilsbry, 1916) - Acorn barnacle

Native distribution: Japan, China, Taiwan.
Introduced distribution: Australia and New Zealand.
Introduction vectors: Ballast water and hull fouling.
Impacts of introduction: Attaches to pipes, ships, and other man made objects and can be a nuisance when in high numbers.
Habitat: Lives to depths of 300 m and tolerates temperatures from 15-28°C and can be found on artificial structures (i.e. wharf pilings, pipes, ship hulls, etc.).
Life history: Reproduction occurs when temperatures begin to rise and fertilization is internal. After brooding nauplius larvae are released into the water to develop into cyprid larvae before attaching to the substrate.

References:
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Megabalanus tintinnabulum (Linnaeus, 1758) – Acorn barnacle

Native distribution: Cosmopolitan.
Introduced distribution: Possibly introduced to Belgium, Australia, and Brazil.
Introduction vectors: Hull fouling.
Impacts of introduction: Most common fouling barnacle on ships, but no affects known.
Habitat: Found in the intertidal zone to 40 m deep attached to a variety of substrates including bivalves and algae, and can also tolerate temperatures up to 35°C.
Life history: Fertilization is internal and after brooding, the eggs are released as cyprid larvae into the water before they settle and attach to the substrate.

References:
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Megabalanus zebra (Darwin, 1854)
Species has not been studied in detail (Pitombo, 2004)

Native distribution: Singapore.
Introduced distribution: Australia, Japan, and New Zealand.
Introduction vectors: Vessel and equipment fouling.

References:

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Pitombo, F. B. 2004. Phylogenetic analysis of the Balanidae (Cirripedia, Balanomorpha) Zoologica Scripta 33(3):261–276

Notomegabalanus algicola (Unable to locate authority) – Barnacle

Native distribution: South Africa.

Introduced distribution: Australia.

Introduction vectors: Hull fouling.

Impacts of introduction: This species is a biofouler, and impacts native encrusting communities.

Habitat: Temperate climates, sublittoral on rocks and pilings.

Life history: Unable to locate.

References:

Hayes, K., C. Sliwa, S. Migus, F. McEnnulty & P. Dustan. 2005. National priority pests: Part II Ranking of Australian Marine Pests. An independent report undertaken for the Department of Environment and Heritage by CSIRO Marine Reseach.

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Scylla serrata (Forskål, 1775) – Serrated swimming crab

Native distribution: Indo-Pacific.

Introduced distribution: Florida, Hawaii, Japan, China, Taiwan, Philippines, to Australia, Red Sea and East and South Africa.

Introduction vectors: Intentional introduction to establish commercial crab fishery.

Impacts of introduction: Aggressive, carnivorous species, feeds on native invertebrates.

Habitat: Muddy bottoms in brackish water along the shoreline, mangrove areas, and river mouths.

Life history: Females migrate offshore from estuaries to spawn with up to two million eggs at a time attached to the pleopods. Larvae are intolerant of estuary conditions, requiring temperatures in the range of 10-25°C and salinities above 17.5ppt.

References:

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Sphaeroma quoyanum (H. Milne-Edwards) – Australasian isopod

Native distribution: Australia.
Introduced distribution: California and Oregon.
Introduction vectors: Hull fouling.
Impacts of introduction: Horizontal burrows weakens vertical and undercut banks, eventually resulting in collapse and severe erosion.
Habitat: Found mainly in the high intertid zone on bay-front rather than creek edge marsh banks where it burrows into wood, rock, and marsh peat.
Life history: Fertilization is internal and after brooding the eggs they are released as cyprid larvae into the water before they settle and attach to the substrate.

References:
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6.4.4.4. Potential Polychaetes

Boccardiella hamata (Webster, 1879) – Spionid mud worm

Native distribution: Japan.
Introduced distribution: Introduced to North America in British Columbia, the Chesapeake Bay and the Gulf of Mexico.
Introduction vectors: Introduction by ballast water is the most likely vector for spionid polychaetes.
Impacts of introduction: May bore into commercially important bivalve shells or inhabit pre-existing shell crevices affecting the shells appearance and marketability. Can also attain high densities and become dominant members of the benthic infauna.
Habitat: Occurs in a wide variety of substrata usually with high salinities (>23ppt) where it lives in U-shaped burrows.
Life history: *B. hamata* produce ten to 100 pelagic larvae, brooded through part of development.

References:

Baker, P., S. M. Baker, & J. Fajans. 2004. Nonindigenous marine species in the greater Tampa Bay. Final Report to the Tampa Bay Estuary Program. 1-131 pp.

Cohen, A. N., & J. T. Carlton. 1995. Nonindigenous aquatic species in a United States estuary: A case study of the biological invasions of the San Francisco Bay and Delta. A Report for the United States Fish and Wildlife Service and the National Sea Grant College Program, Connecticut Sea Grant. Retrieved June 15, 2006. http://nas.er.usgs.gov/Publications/SFBay/sfinvade.html

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Boccardiella ligerica (Ferronnière, 1898) – Spionid mud worm

Native distribution: Brackish water of France, Holland, and Germany.
Introduced distribution: Introduced to the U.S.A. in California in 1935 and Florida in 1997. Also found on both coasts of South America.
Introduction vectors: Ballast water.
Impacts of introduction: Can form dense populations in introduced areas, but no studies have indicated any ecological or economic impacts.
Habitat: Occurs in a wide variety of substrata usually with a salinity <23ppt where it lives in U-shaped burrows.
Life history: Produce ten to 100 pelagic larvae.

References:
Baker, P., S. M. Baker, & J. Fajans. 2004. Nonindigenous marine species in the greater Tampa Bay. Final Report to the Tampa Bay Estuary Program. 1-131 pp.

Cohen, A. N., & J. T. Carlton. 1995. Nonindigenous aquatic species in a United States estuary: A case study of the biological invasions of the San Francisco Bay and Delta. A Report for the United States Fish and Wildlife Service and the National Sea Grant College Program, Connecticut Sea Grant. Retrieved June 15, 2006. http://nas.er.usgs.gov/Publications/SFBay/sfinvade.html

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Boccardia proboscidea (Hartman, 1940) – A spionid worm

Native distribution: Eastern Pacific including Canada, the United States and Mexico.
Introduced distribution: Australia
Introduction vectors: Ballast water
Impacts of Introduction: Not known
Habitat: Sand tubes on many substrates such as mud, rock, and sand in the intertidal zone, common around sewage pipes.
Life history: Fertilization is internal and bead like egg capsules are kept inside the females tube. When the eggs hatch they are either planktotrophic larvae that remain in the plankton for 2 weeks or are juveniles.

References:

Gibson, G. D. & H. L. Smith From embryos to juveniles: morphogenesis in the spionid *Boccardia proboscidea* (Polychaeta). Invertebrate Biology 123(2): 136-145.

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NOO. n. d. Impact of shipping: Port environs. National Oceans Office. http://www.oceans.gov.au/impacts_shipping/page_002.jsp

Euchone limnicola (Reish, 1959) - Fanworm

Native distribution: California.
Introduced distribution: Australia.
Introduction vectors: Hull fouling, mariculture, and ballast water.
Impacts of Introduction: Filter feeding can ecologically affect an area when in high densities.
Habitat: Sedentary worm found in muddy substrates in dense populations.
Life history: External fertilization; larvae are part of the plankton for <4 days before settling.

References:

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Thompson, B., S. Lowe, & M. Kellogg. 2000. Results of the benthic pilot study 1994-1997: Part 1–Macrobenthic assemblages of the San Francisco Bay-Delta, and their responses to abiotic factors. San Francisco Estuary Regional Monitoring Program for Trace Substances. Technical Report 39. 39 pp. http://www.sfei.org/rmp/reports/benthicpilot/94-97_benthic.pdf

Ficopomatus enigmatica (Fauvel 1923) – A tubeworm

Native distribution: Indo-Pacific.
Introduced distribution: Argentina, Europe, Japan, New Zealand, Uruguay, and United States including Hawaii, and the Black and Caspian Seas.
Introduction vectors: Ballast water and hull fouling.
Impacts of introduction: Problems with the working of locks in the Netherlands and clogged pipes in New Zealand.
Habitat: Found as single tubes or as aggregations on hard substrates in the intertidal and shallow subtidal areas where salinities are between ten and 30 ppt.
Life history: Fertilization is external and the larvae remain in the plankton for 20-25 days. They then settle and attach to the substrate where they begin building calcareous tubes.

References:

Blanchet, A. 2005. Dynamics and health of coastal and estuarine ecosystems –Ficopomatus. IFREMER. Retrieved June 12, 2006. http://www.ifremer.fr/delec-en/projets/ficopomatus/ficopoma.htm

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Cohen, A. N. 2005. Guide to the exotic species of San Francisco Bay. San Frisco Estuary Institute, Oakland, CA. http://www.exoticsguide.org/

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Read, G. B., & D. Gordon. 1991. Adventive occurrence of the fouling serpulid *Ficopomatus enigmaticus* (Polychaeta) in New Zealand. New Zealand Journal of Marine and Freshwater Research 25: 269-273. http://www.rsnz.org/publish/nzjmfr/1991/29.pdf

Hydroides ezoensis (Okuda 1934) – A tubeworm

Native distribution: Japan.

Introduced distribution: Australia, China, England, France, and Russia.

Introduction vectors: Hull fouling and ballast water.

Impact of introduction: Can affect the buoyancy of buoys and ships.

Habitat: Found in estuarine and sublittoral areas on rocks and other hard substrates where the water has an abundance of plankton.

Life history: Forms calcareous tubes and needs water 20° C or warmer to spawn.

References:

DEH. n.d.. Australian biological resource study: Hydroides ezoensis Okuda, 1934. Australian Government, Department of the Environment and Heritage. http://www.deh.gov.au/cgi-bin/abrs/fauna/details.pl?pstrVol=POLYCHAETA;pstrTaxa=4275;pstrChecklistMode=2

JNCC. n.d. *Hydroides ezoensis*. Joint Nature Conservation Committee, Advisor to Government. Retreived June 28, 2006. http://www.jncc.gov.uk/page-1699

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Janua brasiliensis (Grube, 1872) – A tubeworm

Native distribution: Brazil.

Introduced distribution: England, France, and the Netherlands.

Introduction vectors: Ballast water or natural distribution by attachment to *Sargassum muticum.*

Impact of introduction: Attaches to eel grass which causes leaves to lie on the sediment.

Habitat: Found on vegetation and hard substrates in warm water.

Life history: It reaches maturity in one season and has a reduced brooding period in warm water. The larvae are motile for a brief period before they attach on plants of hard substrates.

References:

JNCC. n.d. *Janua brasiliensis*. Joint Nature Conservation Committee, Advisor to Government. Retrieved June 28, 2006. http://www.jncc.gov.uk/page-1701

Marrs, R. n.d. Invasive non-native marine species *Janua brasiliensis*. Retrieved June 28, 2006. http://138.253.199.114/IAAP%20Web/IAAPwebsite/Marinesppintro2.asp?ID=32

Pileolaria berkeleyana (Rioja 1942) – A tubeworm

Native distribution: Japan and the Kamchatka Peninsula.

Introduced distribution: United Kingdom and the North Sea.

Introduction vectors: Hull fouling or on Japanese seaweed (*Sargassum muticum*).

Impact of introduction: Not known.

Habitat: Attaches to hard substrates.

Life history: Can reproduce and live in a wide range in temperatures.

References:

JNCC. 1997. Non-native marine species in British waters: a review and directory. N. C. Eno, R. A. Clark, & W. G. Sanderson, editors. Petersborough, UK. Joint Nature Conservation Committee. Retrieved June 28, 2006. http://www.jncc.gov.uk/page-1702

Pseudopolydora paucibranchiata (Okuda, 1937) – A spionid worm

Native distribution: Japan and Indo-Pacific.
Introduced distribution: Australia, west coast United States.
Introduction vectors: Ballast water, hull fouling, and aquaculture.
Impacts of Introduction: Not known.
Habitat: Lives in mud tubes in soft sediments in the intertidal zone.
Life history: Brood 100-250 larvae in tubes. Once larvae are released they are planktonic for 7-40 days before settling to the bottom.

References:

AMBS. 2002. Port Survey for Introduced Marine Species – Sydney Harbour. Australian Museum Business Services. 71 pp.

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Sabella spallanzanii (Gmelin, 1791) – European fan worm

Native distribution: Found in the eastern Atlantic, in western Africa, the Canary Islands, Spain, France, and throughout the Mediterranean Sea.
Introduced distribution: Australia, Jakarta Harbor, Indonesia, and Rio de Janeiro and Ilha Sao Sebastio, Brazil.
Introduction vectors: Ballast water, hull fouling and as accidental bait.
Impacts of introduction: Feeds at a higher rate than the native tube worms and can alter the structure of the habitat by forming a canopy with their filamentous feeding structures. This change in habitat has caused a population increase in the fish Neodax balteatus in the Port Phillip Bay, Australia.
Habitat: Protected shallow sub-tidal areas (i.e. harbors and bays) on either soft or hard substrate 1-30 m deep.
Life history: Male and female forms which reach sexual maturity at 150 mm in length. Spawning occurs when water temperatures reach between 11 and 22°C. They can grow approximately 15 mm/month in Australia and 100 mm/year in Italy.

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APPENDIX 1. Literature Review References for GIS Database

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APPENDIX 2. Published Water Quality for Ports During 2003.

Location	Water temp. (°Celcius)	Salinity (ppt)	Date
Wilmington N 33.9456 W -77.9696	28.4	32.7	7/2002
	28.5	30.7	8/2002
	28.0	26.4	9/2002
	26.5	27.9	10/2002
	17.8	25.1	11/2002
	10.7	23.8	12/2002
	9.0	11.4	1/2003
	8.7	28.1	2/2003
	10.9	15.2	3/2003
	14.8	10.1	4/2003
	23.4	10.6	5/2003
	24.0	6.3	6/2003
Location	**Water temp. (°Celcius)**	**Salinity (ppt)**	**Date**
Wilmington N 34.2138 W -77.9787	29.6	15.0	7/2002
	30.0	14.5	8/2002
	27.4	2.2	9/2002
	26.7	10.1	10/2002
	16.1	1.5	11/2002
	9.1	2.1	12/2002
	8.0	0.1	1/2003
	7.1	0.2	2/2003
	9.8	0.1	3/2003
	14.3	0.0	4/2003
	23.5	0.1	5/2003
	21.0	0.0	6/2003

Source: Mallin *et al*. 2002-2003.

Location	Water temp. (°Celcius)	Salinity (ppt)	Date
Charleston N 32.76953 W -79.8755	8.59	32.76	1/22/2003
	12.1	28.71	2/26/2003
	14.94	30.25	3/19/2003
	20.7	26.73	4/17/2003
	22.24	26.34	5/7/2003
	27.9	23.91	6/26/2003
	27.88	23.39	7/23/2003
	28.71	26.88	8/26/2003
	22.09	30.3	10/16/2003
	19.49	25.46	11/13/2003
	11.8	25.99	12/17/2003
Location	**Water temp. (°Celcius)**	**Salinity (ppt)**	**Date**
Charleston N 32.89036 W -79.9629	11.08	14.32	1/21/2003
	8.77	15.29	2/4/2003
	14.4	10.16	3/13/2003
	21.12	9.33	4/29/2003
	24.33	10.4	5/28/2003
	29.23	7.66	7/9/2003
	25.33	9.8	9/16/2003
	19.65	11.81	11/12/2003
	11.59	11.66	12/16/2003

Source: U.S. Environmental Protection Agency STORET Database, November 2005.
http://www.epa.gov/storet/dbtop.html

Location	Water temp. (°Celcius)	Salinity (ppt)	Date
Savannah N 32.0394 W -80.9231	10.6	26.87	1/9/2003
	11.3	26.23	2/20/2003
	12.9	13.95	2/26/2003
	12.3	24.89	3/3/2003
	13.9	22.43	3/13/2003
	19.4	23.13	4/17/2003
	20.4	8.91	4/22/2003
	20	7.65	4/24/2003
	21.4	13.95	4/30/2003
	22.8	27.23	5/14/2003
	27.4	23.27	6/26/2003
	28.1	21.39	7/10/2003
	27.6	24.04	8/21/2003
	28.3	24.25	8/27/2003
	25.6	27.02	9/10/2003
	26	25.17	9/17/2003
	23	26.94	10/16/2003
	22.5	25.66	11/6/2003
	20.2	18.16	11/13/2003
	20.1	24.25	11/19/2003
	15.1	17.35	12/3/2003
Savannah N 32.1658 W -81.1539	10.5	4.81	1/8/2003
	11.2	no record	2/19/2003
	13.3	no record	2/26/2003
	12.8	0.55	3/3/2003
	14.8	2.23	3/12/2003
	17.1	0.08	4/16/2003
	19.1	0.04	4/22/2003
	18.1	0.04	4/24/2003
	19.2	0.10	4/29/2003
	22.4	0.63	5/13/2003
	24.1	0.05	6/25/2003
	24.9	0.05	7/9/2003
	26.7	5.40	8/20/2003
	27.2	0.58	8/27/2003
	24.9	2.07	9/10/2003
	25.5	5.37	9/18/2003
	23.3	5.15	10/15/2003
	21	3.42	11/5/2003
	20.6	4.26	11/13/2005
	19.3	5.52	11/19/2003
	14.3	2.11	12/3/2005

Source: USGS NWISWeb Data, November 14, 2005. http://waterdata.usgs.gov/nwis/

Location	Water temp. (°Celcius)	Salinity (ppt)	Date
Jacksonville N 30.4019 W -81.4022	13.1	14.75	1/8/2003
	12.71	20.31	2/10/2003
	19.24	8.25	3/12/2003
	19.45	32.61	4/15/2003
	22.33	33.83	5/15/2003
	25.15	35.45	6/12/2003
	22.7	33.09	7/14/2003
	20.92	31.88	8/13/2003
	24.79	34.09	9/9/2003
	24.8	30.58	10/8/2003
	21.83	32.2	11/10/2003
	15.89	26.82	12/15/2003

Source: Unpublished data, SJRWMD, received December 7, 2005

Location	Water temp. (°Celcius)	Salinity (ppt)	Date
Jacksonville N 30.3223 W -81.6588	13.4	1.2	1/6/2003
	9.6	0.5	1/27/2003
	12.6	0.4	2/10/2003
	17.2	0.4	2/24/2003
	18.5	0.3	3/10/2003
	22.4	0.3	3/24/2003
	21	5.2	4/14/2003
	29.9	7.7	4/28/2003
	25.8	7.8	5/5/2003
	27.3	14.7	5/19/2003
	28.2	2.3	6/9/2003
	28.9	5.5	6/23/2003
	29.7	0.5	7/7/2003
	29.6	0.4	7/22/2003
	29.1	0.6	8/4/2003
	29.8	0.3	8/18/2003
	26.3	15.5	9/9/2003
	27.5	3.7	9/22/2003
	25.2	3	10/6/2003
	23.7	0.4	10/22/2003
	24.5	6.2	11/4/2003
	20.7	1.4	11/17/2003
	16.1	11.1	12/10/2003
	12.8	10.1	12/22/2003

Source: Florida STORET, November 15, 2005. http://storet.dep.state.fl.us/

APPENDIX 3. Sampling Dates, Sample ID, and Water Quality.

LOCATION ID	Port	Zone	Gear	Water temperature (°Celcius)	Salinity (ppt)	Date
WIL01	Wilmington	1		20	9	
WIL01CO	Wilmington	1	Core			10/20/2003
WIL01CR	Wilmington	1	Crab trap			10/31/2003
WIL01MI	Wilmington	1	Minnow trap			10/31/2003
WIL01TR	Wilmington	1	Trawl			9/29/2003
WIL02	Wilmington	2		19	11	
WIL02CO	Wilmington	2	Core			10/22/2003
WIL02CR	Wilmington	2	Crab trap			10/28/2003
WIL02HD	Wilmington	2	Hester-Dendy plate			12/16/2003
WIL02MI	Wilmington	2	Minnow			10/28/2003
WIL02SC	Wilmington	2	Scraping			10/30/2003
WIL02TR	Wilmington	2	Trawl			9/15/2003
WIL03	Wilmington	3		17.5	1	
WIL03CO	Wilmington	3	Core			10/13/2003
WIL03CR	Wilmington	3	Crab trap			10/17/2003
WIL03MI	Wilmington	3	Minnow trap			10/17/2003
WIL03TR	Wilmington	3	Trawl			9/16/2003
CHA01	Charleston	1		27.28	26	
CHA01CO	Charleston	1	Core			8/28/2003
CHA01CR	Charleston	1	Crab trap			8/29/2003
CHA01MI	Charleston	1	Minnow trap			8/29/2003
CHA01TR	Charleston	1	Trawl			8/28/2003
CHA01SED	Charleston	1	Sediment			8/28/2003
CHA02	Charleston	2		28.84	22	
CHA02CO	Charleston	2	Core			8/28/2003
CHA02CR	Charleston	2	Crab trap			8/29/2003
CHA02HD	Charleston	2	Hester-Dendy plate			1/23/2004
CHA02MI	Charleston	2	Minnow			8/29/2003
CHA02SC	Charleston	2	Scraping			8/30/2003
CHA02TR	Charleston	2	Trawl			8/28/2003
CHA02SED	Charleston	2	Sediment			8/28/2003
CHA03	Charleston	3		29.58	9	
CHA03CO	Charleston	3	Core			8/28/2003
CHA03CR	Charleston	3	Crab trap			8/29/2003
CHA03MI	Charleston	3	Minnow trap			8/29/2003
CHA03TR	Charleston	3	Trawl			8/28/2003
CHA03SED	Charleston	3	Sediment			8/28/2003
SAV01	Savannah	1		28.47	15	
SAV01CO	Savannah	1	Core			8/26/2003
SAV01CR	Savannah	1	Crab trap			8/25/2003

LOCATION ID	Port	Zone	Gear	Water temperature (°Celcius)	Salinity (ppt)	Date
SAV01MI	Savannah	1	Minnow trap			8/25/2003
SAV01TR	Savannah	1	Trawl			8/25/2003
SAV01SED	Savannah	1	Sediment			8/26/2003
SAV02	Savannah	2		27.2	12	
SAV02CO	Savannah	2	Core			8/26/2003
SAV02CR	Savannah	2	Crab trap			8/25/2003
SAV02HD	Savannah	2	Hester-Dendy plate			10/12/2003
SAV02MI	Savannah	2	Minnow			8/25/2003
SAV02SC	Savannah	2	Scraping			8/27/2003
SAV02TR	Savannah	2	Trawl			8/26/2003
SAV02SED	Savannah	2	Sediment			8/26/2003
SAV03	Savannah	3		27.64	0	
SAV03CO	Savannah	3	Core			8/26/2003
SAV03CR	Savannah	3	Crab trap			8/25/2003
SAV03MI	Savannah	3	Minnow trap			8/25/2003
SAV03TR	Savannah	3	Trawl			8/26/2003
SAV03SED	Savannah	3	Sediment			8/26/2003
JAX01	Jacksonville	1		27.52	24	
JAX01CO	Jacksonville	1	Core			9/23/2003
JAX01CR	Jacksonville	1	Crab trap			9/24/2003
JAX01MI	Jacksonville	1	Minnow trap			9/24/2003
JAX01TR	Jacksonville	1	Trawl			9/23/2003
JAX01SED	Jacksonville	1	Sediment			9/23/2003
JAX02	Jacksonville	2		27.75	13	
JAX02CO	Jacksonville	2	Core			9/24/2003
JAX02CR	Jacksonville	2	Crab trap			9/24/2003
JAX02HD	Jacksonville	2	Hester-Dendy plate			11/13/2003
JAX02MI	Jacksonville	2	Minnow			9/24/2003
JAX02SC	Jacksonville	2	Scraping			9/24/2003
JAX02TR	Jacksonville	2	Trawl			9/24/2003
JAX02SED	Jacksonville	2	Sediment			9/24/2003
JAX03	Jacksonville	3		27.72	7	
JAX03CO	Jacksonville	3	Core			9/24/2003
JAX03CR	Jacksonville	3	Crab trap			9/24/2003
JAX03MI	Jacksonville	3	Minnow trap			9/24/2003
JAX03TR	Jacksonville	3	Trawl			9/24/2003
JAX03SED	Jacksonville	3	Sediment			9/24/2003

APPENDIX 4. Species Occurrence and Abundance per Gear Type, Zone and Port

Wilmington Zone One Core Samples	
Species	**Abundance**
Streblospio benedicti	41
Leitoscoloplos fragilis	12
Heteromastus filiformis	10
Parandalia sp. A	10
Harpacticoida sp.	8
Parandalia (americana)	8
Laeonereis culveri	6
Geukensia demissa	4
Hargeria rapax	3
Ostracoda	3
Edotia sp.	2
Marenzelleria viridis	2
Neanthes succinea	2
Streptosyllis pettiboneae	2
Ampelisca verrilli	1
Aricidea suecica	1
Bivalvia sp.	1
Capitella capitata	1
Cirrophorus sp.	1
Apocorophium lacustre	1
Glycera dibranchiata	1
Glycera sp.	1
Nassarius obsoletus	1
Monoculodes edwardsi	1
Pagurus longicarpus	1
Paraprionospio pinnata	1
Wilmington Zone One Crab Traps	
Species	**Abundance**
Callinectes sapidus	40
Wilmington Zone One Minnow Traps	
Species	**Abundance**
Palaemonetes vulgaris	9
Callinectes sapidus	3
Litopenaeus setiferus	1
Wilmington Zone One Trawl Samples	
Species	**Abundance**
Litopenaeus setiferus	68

Callinectes similis	1
Callinectes sapidus	3
Wilmington Zone Two Core Samples	
Species	**Abundance**
Marenzelleria viridis	18
Balanus juv sp.	15
Harpacticoida sp.	15
Gammarus tigrinus	6
Edotia sp.	5
Parandalia (americana)	4
Mediomastus sp.	2
Parandalia sp.	2
Chiridotea caeca	1
Monoculodes edwardsi	1
Streptosyllis pettiboneae	1
Wilmington Zone Two Crab Traps	
Species	**Abundance**
Callinectes sapidus	27
Wilmington Zone Two Hester-Dendy Plates	
Species	**Abundance**
Balanus juv sp.	2865
Gammarus tigrinus	1152
Listriella barnardi	703
Melita nitida	456
Apocorophium lacustre	228
Cassidinidea lunifrons	58
(Modiolus juv sp.)	35
Rhithropanopeus harrisii	13
Bivalvia sp.	3
Boccardia sp. A	2
Laeonereis culveri	1
Neanthes succinea	1
Synidotea (nebulosa)	1
Uca juv. Sp.	1
Wilmington Zone Two Minnow Traps	
Species	**Abundance**
Litopenaeus setiferus	8
Callinectes sapidus	2
Wilmington Zone Two Scraping Samples	
Species	**Abundance**

Balanus juv sp.	22545
Apocorophium lacustre	118
Cassidinidea lunifrons	97
Mytilopsis leucophaeata	3
Sinelobus stanfordi	2
Acetes americanus carolinae	1
Gammarus tigrinus	1
Laeonereis culveri	1
Rhithropanopeus harrisii	1
Tanaidacea sp.	1
Wilmington Zone Two Trawl Samples	
Species	**Abundance**
Litopenaeus setiferus	77
Farfantepenaeus duorarum	6
Callinectes sapidus	5
Wilmington Zone Three Core Samples	
Species	**Abundance**
Harpacticoida sp.	22
Bivalvia sp.	4
Gammarus tigrinus	4
Corophium volutator	2
Marenzelleria viridis	1
Monoculodes edwardsi	1
Wilmington Zone Three Crab Traps	
Species	**Abundance**
Callinectes sapidus	22
Wilmington Zone Three Minnow Traps	
Species	**Abundance**
Palaemonetes pugio	14
Rhithropanopeus harrisii	9
Macrobrachium acanthurus	4
Palaemonetes vulgaris	3
Probopyrus pandalicola	2
Callinectes sapidus	1
Wilmington Zone Three Trawl Samples	
Species	**Abundance**
Litopenaeus setiferus	33
Callinectes sapidus	4

Charleston Zone One Core Samples	
Species	**Abundance**
Nassarius obsoletus	14
Aricidea suecica	6
Tharyx dorsobranchialis	5
Mediomastus californiensis	3
Angulus texana	3
Cirratulidae sp.	2
Cyathura polita	2
Eteone heteropoda	2
Scoletoma tenuis	2
Neanthes succinea	2
Abra aequalis	1
Anaitides mucosa	1
Chione elevata	1
Drilonereis longa	1
Glycera americana	2
Laeonereis culveri	1
Orbinia ornata	1
Pagurus longicarpus	1
Pagurus sp.	1
Raeta plicatella	1
Spiophanes bombyx	1
Streblospio benedicti	1
Charleston Zone One Crab Traps	
Species	**Abundance**
Callinectes sapidus	23
Callinectes similis	2
Menippe mercenaria	2
Charleston Zone One Minnow Traps	
Species	**Abundance**
Palaemonetes vulgaris	7
Callinectes sapidus	6
Callinectes similis	3
Farfantepenaeus aztecus	3
Panopeus herbstii	2
Charleston Zone One Trawl Samples	
Species	**Abundance**
Balanus juv. sp.	3205
Acetes americanus carolinae	231
Litopenaeus setiferus	147

Brachidontes exustus	91
Balanus venustus	76
Balanus sp.	74
Sphenia sp.	57
Sabellaria vulgaris beaufortensis	59
Lolliguncula brevis	36
Farfantepenaeus aztecus	28
Sphenia fragilis	20
Musculus lateralis	15
Sabella sp. A	11
Callinectes similis	10
Pista palmata	10
Batea catharinensis	9
Dulichiella appendiculata	9
Lysmata wurdemanni	9
Neanthes succinea	9
Pagurus longicarpus	8
Xiphopenaeus kroyeri	7
Eupolymnia sp. A	5
Melita nitida	5
Mitrella sp.	5
Nereis falsa	5
Pagurus pollicaris	5
Cerithiopsis sp.	4
Nereiphylla fragilis	4
Cymothoa excisa	3
Decapoda sp.	3
Ericthonius brasiliensis	3
Lembos smithi	3
Polycirrus sp. B	3
Squilla empusa	3
Caprellidae sp.	2
Crassostrea virginica	2
Diopatra cuprea	2
Eurypanopeus depressus	2
Menippe mercenaria	2
Ovalipes sp.	2
Sabellaria vulgaris vulgaris	2
Synalpheus (townsendi)	2
Urosalpinx sp.	2
Ampelisca abdita	1
Anadara transversa	1
Autolytus cornutus	1
Barnea truncata	1

Crangonyx pseudogracilis	1
Cumingia tellinoides	1
Demonax microphthalmus	1
Elasmopus levis	1
Exhippolysmata oplophoroides	1
Geukensia demissa	1
Leucothoe spinicarpa complex	1
Libinia dubia	1
Livoneca reniformis	1
Loimia medusa	1
Marphysa sanguinea	1
Nerocila sp.	1
Odontosyllis enopla	1
Pagurus sp.	1
Palaemonetes pugio	1
Periclimenes longicaudata	1
Podarke obscura	1
Polynoidae sp.	1
Portunus gibbesii	1
Stenothoe minuta	1
Triphora sp.	1
Charleston Zone Two Core Samples	
Species	**Abundance**
Leitoscoloplos fragilis	124
Mediomastus californiensis	6
Capitella capitata	5
Mediomastus sp.	2
Caulleriella killariensis	1
Glycera americana	1
Glycera dibranchiata	1
Hesionura sp. A	1
Heteromastus filiformis	1
Parandalia (americana)	1
Prionospio cristata	1
Tagelus plebeius	1
Charleston Zone Two Crab Traps	
Species	**Abundance**
Menippe mercenaria	6
Callinectes sapidus	1
Charleston Zone Two Hester-Dendy Plates	
Species	**Abundance**

Caprella equilibra	204
Melita nitida	75
Ampithoe valida	65
Pleusymtes glaber	43
Neanthes succinea	28
Jassa marmorata	16
Balanus improvisus	13
Monocorophium acherusicum	13
Xanthidae juv. sp.	13
Balanus eburneus	12
Corophium sp.	6
Panopeus herbstii	6
Elasmopus levis	4
Sphenia fragilis	4
Stenothoe minuta	4
Petrolisthes armatus	3
Amphipoda spp.	2
Synidotea sp.	2
Crangonyx richmondensis richmondensis	1
Dulichiella appendiculata	1
Dyspanopeus sayi	1
Ericthonius brasiliensis	1
Hyale plumulosa	1
Hydroides dianthus	1
Neomysis americana	1
Potamilla cf reniformis	1
Charleston Zone Two Minnow Traps	
Species	**Abundance**
Panopeus herbstii	104
Litopenaeus setiferus	22
Balanus eburneus	10
Callinectes similis	9
Palaemonetes vulgaris	6
Portunus gibbesii	4
Brachidontes exustus	2
Pagurus longicarpus	1
Charleston Zone Two Scraping Samples	
Species	**Abundance**
Brachidontes exustus	1528
Geukensia demissa	576
Genetyllis castanea	417
Neanthes succinea	159

Melita nitida	100
Balanus eburneus	97
Zaops ostreum	91
Eurypanopeus depressus	45
Ligia exotica	36
Polydora ligni (cornuta)	30
Sphaeroma quadridentatum	26
Panopeus herbstii	24
Balanus amphitrite amphitrite	18
Hyale plumulosa	18
Ampithoe valida	17
Balanus sp.	16
Sphenia fragilis	9
Petrolisthes armatus	8
Hydroides dianthus	5
Balanus spp.	4
Boonea impressa	4
Ischadium recurvum	4
Xanthidae spp.1	3
Armases (cinereum)	2
Bivalvia sp.	2
Littoraria irrorata	1
Marphysa sp.B	1
Nereiphylla fragilis	1
Ostrea equestris	1
Sphenia sp.	1
Streblospio benedicti	1
Charleston Zone Two Trawl Samples	
Species	**Abundance**
Litopenaeus setiferus	277
Leucothoe spinicarpa complex	102
Leucothoe spinicarpa	60
Acetes americanus carolinae	33
Lolliguncula brevis	33
Farfantepenaeus aztecus	18
Squilla empusa	10
Portunus gibbesii	9
Dulichiella appendiculata	8
Libinia dubia	8
Eurypanopeus depressus	7
Rimapenaeus constrictus	7
Parapenaeus politus	6

Geukensia demissa	5
Sphenia fragilis	5
Callinectes similis	4
Balanus venustus	3
Latreutes parvulus	3
Synalpheus (townsendi)	3
Alpheus heterochaelis	2
Cymothoa excisa	2
Diopatra cuprea	2
Melita nitida	2
Palaemonetes pugio	2
Panopeus herbstii	2
Petrolisthes armatus	2
Progebiophilus upogebiae	2
Rocinela americana	2
Sabellaria vulgaris beaufortensis	2
Anadara ovalis	1
Balanus eburneus	1
Balanus trigonus	1
Brachidontes exustus	1
Capitellidae sp.	1
Cleantioides planicauda	1
Cronius sp.	1
Lepidonotus sublevis	1
Livoneca reniformis	1
Menippe mercenaria	1
Nereis falsa	1
Pagurus longicarpus	1
Pagurus pollicaris	1
Sabella sp. A	1
Sabellaria vulgaris vulgaris	1
Squilla juv. sp.	1
Thor sp.	1
Upogebia affinis	1
Charleston Zone Three Core Samples	
Species	**Abundance**
Parandalia (americana)	43
Nassarius obsoletus	16
Balanus sp.	11
Callinectes sapidus	1
Neanthes succinea	1
Charleston Zone Three Crab Traps	

Species	Abundance
Callinectes sapidus	36
Charleston Zone Three Minnow Traps	
Species	**Abundance**
Palaemonetes vulgaris	72
Panopeus herbstii	16
Callinectes similis	8
Litopenaeus setiferus	7
Callinectes sapidus	2
Farfantepenaeus aztecus	1
Charleston Zone Three Trawl Samples	
Species	**Abundance**
Balanus juv. sp.	387
Litopenaeus setiferus	147
Brachidontes exustus	129
Balanus improvisus	28
Farfantepenaeus aztecus	19
Crassostrea virginica	10
Lolliguncula brevis	7
Callinectes similis	6
Callinectes sapidus	2
Acetes americanus carolinae	1
Geukensia demissa	1
Pagurus carolinensis	1
Pagurus longicarpus	1
Rhithropanopeus harrisii	1
Savannah Zone One Core Samples	
Species	**Abundance**
Leitoscoloplos fragilis	317
Parahaustorius holmesi	7
Uca sp.	1
Savannah Zone One Crab Traps	
Species	**Abundance**
Sabellaria vulgaris	49
Balanus eburneus	44
Clibanarius vittatus	6
Sphenia fragilis	4
Neanthes succinea	3
Anadara floridana	1

Savannah Zone One Minnow Traps	
Species	**Abundance**
Panopeus herbstii	30
Palaemonetes vulgaris	16
Litopenaeus setiferus	15
Clibanarius vittatus	2
Callinectes similis	3
Savannah Zone One Trawl Samples	
Species	**Abundance**
Litopenaeus setiferus	886
Balanus sp.	653
Balanus eburneus	46
Lolliguncula brevis	44
Acetes americanus carolinae	18
Callinectes similis	15
Geukensia demissa	11
Farfantepenaeus aztecus	10
Sphenia sp.	9
Sphenia fragilis	6
Pagurus longicarpus	5
Rimapenaeus constrictus	5
Brachidontes exustus	4
Pagurus sp.	4
Cymothoa excisa	3
Palaemonetes vulgaris	3
Dentatisyllis carolinae	2
Marphysa sanguinea	2
Streblosoma hartmanae	2
Cleantioides planicauda	1
Neanthes succinea	1
Penaeidae sp.	1
Rhithropanopeus harrisii	1
Savannah Zone Two Core Samples	
Species	**Abundance**
Marenzelleria viridis	46
Laeonereis culveri	4
Cyathura polita	1
Parandalia (americana)	1
Spionidae sp.	1
Savannah Zone Two Crab Traps	
Species	**Abundance**

Callinectes sapidus	48
Savannah Zone Two Hester-Dendy Plates	
Species	**Abundance**
Balanus sp.	257
Mytilopsis leucophaeata	61
Melita nitida	23
Panopeus herbstii	23
Pleusymtes glaber	11
Neanthes succinea	10
Palaemonetes pugio	10
Bivalvia sp.	7
Synidotea sp.	6
Mytilopsis sp.	5
Xanthidae juv. sp.	5
Apocorophium lacustre	3
Boccardiella sp. A	2
Brachidontes exustus	2
Gammarus fasciatus	2
Hyale plumulosa	2
Ischadium recurvum	2
Amphilochus (spencebatei)	1
Cassidinidea lunifrons	1
Geukensia demissa	1
Sphenia fragilis	1
Stenothoe minuta	1
Savannah Zone Two Minnow Traps	
Species	**Abundance**
Palaemonetes pugio	52
Litopenaeus setiferus	50
Panopeus herbstii	42
Callinectes sapidus	4
Palaemonetes vulgaris	1
Savannah Zone Two Scraping Samples	
Species	**Abundance**
Brachidontes exustus	1958
Ischadium recurvum	1682
Geukensia demissa	1570
Sphenia fragilis	427
Hyale plumulosa	407
Neanthes succinea	351
Genetyllis castanea	322

Mytilopsis leucophaeata	108
Zaops ostreum	105
Cassidinidea lunifrons	89
Petrolisthes armatus	54
Eurypanopeus depressus	40
Balanus eburneus	37
Panopeus herbstii	21
Balanus amphitrite amphitrite	11
Ligia exotica	7
Melita nitida	5
Sphenia sp.	5
Polydora ligni (cornuta)	4
Ampithoe valida	3
Armases (cinereum)	3
Rhithropanopeus harrisii	3
Balanus sp.	2
Mediomastus californiensis	2
Syllis sp.	2
Xanthidae spp.	2
(Dynamene sp.)	1
Bivalvia sp.	1
Cassidinidea ovalis	1
Apocorophium lacustre	1
Marphysa sp.	1
Pachygrapsus transversus	1
Sphaeroma quadridentatum	1
Savannah Zone Two Trawl Samples	
Species	**Abundance**
Litopenaeus setiferus	220
Anilocra (acuta)	3
Rhithropanopeus harrisii	2
Callinectes similis	1
Cymothoa excisa	1
Ischadium recurvum	1
Savannah Zone Three Core Samples	
Species	**Abundance**
Marenzelleria viridis	32
Laeonereis culveri	1
Savannah Zone Three Crab Traps	
Species	**Abundance**
Callinectes sapidus	53

Savannah Zone Three Minnow Traps	
Species	**Abundance**
Panopeus herbstii	18
Palaemonetes pugio	10
Litopenaeus setiferus	6
Savannah Zone Three Trawl Samples	
Species	**Abundance**
Litopenaeus setiferus	239
Palaemonetes sp.	1
Mytilopsis leucophaeata	1
Caridea sp.	1
Jacksonville Zone One Core Samples	
Species	**Abundance**
Leitoscoloplos fragilis	15
Parahaustorius holmesi	10
Emerita talpoida	7
Paraonis fulgens	2
Dispio uncinata	1
Marenzelleria viridis	1
Jacksonville Zone One Crab Traps	
Species	**Abundance**
Balanus calidus	600
Balanus eburneus	86
Callinectes sapidus	38
Clibanarius vittatus	32
Brachidontes exustus	24
Neanthes succinea	16
Sphenia fragilis	16
Balanus amphitrite	15
Menippe mercenaria	14
Lepidonotus sublevis	6
Melita nitida	4
Sabellaria vulgaris	3
Anadara floridana	1
Chelonibia testudinaria	1
Musculus lateralis	1
Pagurus pollicaris	1
Jacksonville Zone One Minnow Traps	
Species	**Abundance**

Portunus gibbesii	40
Pagurus longicarpus	15
Callinectes similis	7
Portunus sp.	7
Panopeus herbstii	4
Callinectes sapidus	2
Balanus venustus	1
Clibanarius vittatus	1
Jacksonville Zone One Trawl Samples	
Species	**Abundance**
Balanus juv. sp.	636
Ostrea equestris	287
Balanus venustus	233
Farfantepenaeus aztecus	108
Brachidontes exustus	67
Crassostrea virginica	60
Portunus gibbesii	45
Lolliguncula brevis	32
Parapenaeus politus	24
Callinectes similis	22
Petrolisthes armatus	9
Sphenia fragilis	8
Eurypanopeus depressus	7
Litopenaeus setiferus	7
Pagurus longicarpus	6
Libinia dubia	5
Portunus sp.	4
Spisula solidissima similis	4
Acetes americanus carolinae	3
Nereis falsa	3
Amygdalum papyrium	2
Anadara floridana	2
Anadara notabilis	2
Corbula contracta	2
Pelia mutica	2
Balanus eburneus	1
Batea catharinensis	1
Cleantioides planicauda	1
Conopea galeata	1
Emerita talpoida	1
Geukensia demissa	1
Latreutes parvulus	1
Lepidonotus sublevis	1

Marphysa sanguinea	1
Mysidacea sp.	1
Pagurus pollicaris	1
Penaeidae sp.	1
Sabella sp. A	1
Sabellaria vulgaris vulgaris	1
Simnialena uniplicata	1
Sphenia sp.	1
Jacksonville Zone Two Core Samples	
Species	**Abundance**
Leitoscoloplos fragilis	16
Laeonereis culveri	4
Parahaustorius holmesi	4
Eteone heteropoda	2
Nassarius obsoletus	2
Uca pugilator	1
Jacksonville Zone Two Crab Traps	
Species	**Abundance**
Callinectes sapidus	5
Balanus calidus	3
Clibanarius vittatus	2
Jacksonville Zone Two Hester-Dendy Plates	
Species	**Abundance**
Balanus sp.	104
Pleusymtes glaber	66
Corophium sp.	35
Balanus improvisus	26
Balanus eburneus	25
Sinelobus stanfordi	25
Melita nitida	11
Amphilochus (spencebatei)	6
Polydora ligni (cornuta)	6
Xanthidae juv. sp.	3
Amygdalum papyrium	2
Balanus venustus	2
Apocorophium lacustre	2
Neanthes succinea	2
Synidotea sp.	2
Callinectes sapidus	1
Caprella equilibra	1
Panopeus herbstii	1

Stenothoe minuta	1
Jacksonville Zone Two Minnow Traps	
Species	**Abundance**
Panopeus herbstii	18
Callinectes similis	5
Palaemonetes vulgaris	5
Callinectes sapidus	4
Clibanarius vittatus	1
Jacksonville Zone Two Scraping Samples	
Species	**Abundance**
Geukensia demissa	651
Brachidontes exustus	456
Ischadium recurvum	367
Hyale plumulosa	285
Genetyllis castanea	120
Neanthes succinea	113
Melita nitida	94
Ligia exotica	51
Eurypanopeus depressus	42
Sphenia fragilis	23
Balanus eburneus	11
Balanus sp.	5
Amygdalum papyrium	4
Boonea impressa	3
Pachygrapsus transversus	3
Panopeus herbstii	3
Polydora ligni (cornuta)	3
Mytilopsis leucophaeata	2
Petrolisthes armatus	2
Balanus amphitrite amphitrite	1
Sinelobus stanfordi	1
Zaops ostreum	1
Jacksonville Zone Two Trawl Samples	
Species	**Abundance**
Farfantepenaeus aztecus	202
Litopenaeus setiferus	57
Callinectes similis	53
Callinectes sapidus	25
Mytilus edulis	6
Palaemonetes pugio	6
Squilla empusa	5
Parapenaeus politus	4
Balanus eburneus	3

Decapoda sp.	2
Panopeus herbstii	2
Alpheus heterochaelis	1
Geukensia demissa	1
Libinia dubia	1
Rocinela americana	1
Jacksonville Zone Three Core Samples	
Species	**Abundance**
Laeonereis culveri	46
Marenzelleria viridis	1
Jacksonville Zone Three Crab Traps	
Species	**Abundance**
Callinectes sapidus	22
Jacksonville Zone Three Minnow Traps	
Species	**Abundance**
Callinectes sapidus	25
Palaemonetes vulgaris	3
Callinectes similis	2
Jacksonville Zone Three Trawl Samples	
Species	**Abundance**
Synidotea sp.	308
Amygdalum papyrium	204
Callinectes sapidus	85
Litopenaeus setiferus	82
Melita nitida	26
Neomysis americana	23
Farfantepenaeus aztecus	14
Callinectes similis	10
Panopeus herbstii	5
Stenothoe minuta	4
Balanus improvisus	3
Bowmaniella juv sp.	2
Brasilomysis castroi	1
Cymothoa excisa	1
Mytilus edulis	1
Nereis falsa	1

HIGHER TAXA	SPECIES / LOCATION II	WIL01CO	WIL01CR	WIL01MI	WIL01TR	WIL02CO	WIL02CR	WIL02HD	WIL02MI	WIL02SC	WIL02TR	WIL03CO	WIL03CR	WIL03MI	WIL03TR	CHA01CO	CHA01CR	CHA01MI	CHA01TR	CHA02CO	CHA02CR	CHA02HD	CHA02MI	CHA02SC	CHA02TR	CHA03CO	CHA03CR	CHA03MI	CHA03TR	SAV01CO	SAV01CR	SAV01MI	SAV01TR	SAV02CO	SAV02CR	SAV02HD	SAV02MI	SAV02SC	SAV02TR	SAV03CO	SAV03CR	SAV03MI	SAV03TR	JAX01CO	JAX01CR	JAX01MI	JAX01TR	JAX02CO	JAX02CR	JAX02HD	JAX02MI	JAX02SC	JAX02TR	JAX03CO	JAX03CR	JAX03MI	JAX03TR
PHYLUM ANNELIDA CLASS POLYCHAETA																																																									
Capitellidae	*Capitella capitata*	•																		•																																					
	Capitellidae sp.																								•																																
	Heteromastus filiformis	•																		•																																					
	Mediomastus californiensis															•				•																		•																			
	Mediomastus sp.					•														•																																					
Cirratulidae	*Caulleriella killariensis*																			•																																					
	Cirratulidae sp.															•																																									
	Tharyx dorsobranchialis															•																																									
Eucinidae	*Marphysa sanguinea*																		•														•														•										
	Marphysa sp.																																					•																			
	Marphysa sp.B																							•																																	
Glyceridae	*Glycera americana*															•				•																																					
	Glycera dibranchiata	•																		•																																					
	Glycera sp.	•																																																							
Hesionidae	*Podarke obscura*																		•																																						
Lumbrineridae	*Scoletoma tenuis*															•																																									
Nereididae	*Laeonereis culveri*	•						•		•						•																		•						•								•						•			
	Neanthes succinea	•						•								•			•			•		•		•					•		•			•		•							•					•		•					
	Nereis falsa																		•						•																						•										•
Oenonidae	*Drilonereis longa*															•																																									
Onuphidae	*Diopatra cuprea*																		•						•																																
Orbiniidae	*Leitoscoloplos fragilis*	•																		•										•														•				•									
	Orbinia ornata															•																																									
Paraonidae	*Aricidea suecica*	•														•																																									
	Cirrophorus sp.	•																																																							
	Paraonis fulgens																																											•													
Phyllodocidae	*Anaitides mucosa*															•																																									
	Eteone heteropoda															•																																•									
	Genetyllis castanea																							•														•														•					
	Hesionura sp. A																			•																																					
	Nereiphylla fragilis																		•					•																																	
Pilargidae	*Parandalia (americana)*	•				•														•						•								•																							
	Parandalia sp. A	•																																																							
	Parandalia sp.					•																																																			
Polynoidae	*Lepidonotus sublevis*																								•																				•		•										
	Polynoidae sp.																		•																																						
Sabellariidae	*Sabellaria vulgaris*																														•														•												
	Sabellaria vulgaris beaufortensis																		•						•																																
	Sabellaria vulgaris vulgaris																		•						•																						•										
Sabellidae	*Demonax microphthalmus*																		•																																						
	Potamilla cf reniformis																					•																																			
	Sabella sp. A																		•						•																						•										
Serpulidae	*Hydroides dianthus*																					•		•																																	
Spionidae	*Boccardia sp. A*							•																																																	
	Boccardiella sp. A																																			•																					
	Polydora ligni (cornuta)																							•														•												•		•					
	Dispio uncinata																																											•													
	Marenzellaria viridis	•				•						•																						•						•				•										•			
	Paraprionospio pinnata	•																																																							
	Prionospio cristata																			•																																					
	Spionidae sp.																																	•																							
	Spiophanes bombyx															•																																									
	Streblospio benedicti	•														•								•																																	
Syllidae	*Autolytus cornutus*																		•																																						
	Dentatisyllis carolinae																																•																								
	Odontosyllis enopla																		•																																						
	Streptosyllis pettiboneae	•				•																																																			
	Syllis sp.																																					•																			

HIGHER TAXA	SPECIES LOCATION II	WIL01CO	WIL01CR	WIL01MI	WIL01TR	WIL02CO	WIL02CR	WIL02HD	WIL02MI	WIL02SC	WIL02TR	WIL03CO	WIL03CR	WIL03MI	WIL03TR
Terebellidae	*Eupolymnia sp. A*														
	Loimia medusa														
	Pista palmata														
	Polycirrus sp. B														
	Streblosoma hartmanae														
PHYLUM ARTHROPODA SUBPHYLUM CRUSTACEA ORDER SESSILIA															
Archaeobalanidae	*Conopea galeata*														
Balanidae	*Balanus sp.*														
	Balanus amphitrite														
	Balanus amphitrite amphitrite														
	Balanus calidus														
	Balanus eburneus														
	Balanus improvisus														
	Balanus juv. sp.					•		•		•					
	Balanus spp.														
	Balanus trigonus														
	Balanus venustus														
Chelonibiidae	*Chelonibia testudinaria*	•													
ORDER HARPACTICOIDA	*Harpacticoida sp.*					•						•			
ORDER AMPHIPODA															
	Amphipoda spp.														
Ampeliscidae	*Ampelisca abdita*														
	Ampelisca verrilli	•													
Amphilochidae	*Amphilochus (spencebatei)*														
Ampithoidae	*Ampithoe valida*														
Aoridae	*Lembos smithi*														
Bateidae	*Batea cathariensis*														
Caprellidae	*Caprella equilibra*														
	Caprellidae sp.														
Corophiidae	*Apocorophium lacustre*	•						•		•					
	Corophium sp.														
	Corophium volutator											•			
	Monocorophium acherusium														
Crangonyctidae	*Crangonyx pseudogracilis*														
	Crangonyx richmondensis richmondensis														
Gammaridae	*Gammarus fasciatus*														
	Gammarus tigrinus					•		•		•		•			
	Monoculodes edwardsi	•				•						•			
Haustoriidae	*Parahaustorius holmesi*														
Hyalidae	*Hyale plumulosa*														
Ischyroceridae	*Ericthonius brasiliensis*														
	Jassa marmorata														
Leucothoidae	*Leucothoe spinicarpa*														
	Leucothoe spinicarpa complex														
Liljeborgiidae	*Listriella barnardi*							•							
Melitidae	*Dulichiella appendiculata*														
	Elasmopus levis														
	Melita nitida							•							
Pleustidae	*Pleusymtes glaber*														
Stenothoidae	*Stenothoe minuta*														
ORDER DECAPODA															
	Caridea sp.														
	Decapoda sp.														
Alpheidae	*Alpheus heterochaelis*														
	Synalpheus (townsendi)														
Diogenidae	*Clibanarius vittatus*														
Grapsidae	*Pachygrapsus transversus*														
Hippidae	*Emerita talpoida*														

HIGHER TAXA	SPECIES	CHA01CO	CHA01CR	CHA01MI	CHA01TR	CHA02CO	CHA02CR	CHA02HD	CHA02MI	CHA02SC	CHA02TR	CHA03CO	CHA03CR	CHA03MI	CHA03TR
Terebellidae	*Eupolymnia sp. A*				•										
	Loimia medusa				•										
	Pista palmata				•										
	Polycirrus sp. B				•										
	Streblosoma hartmanae														
PHYLUM ARTHROPODA SUBPHYLUM CRUSTACEA ORDER SESSILIA															
Archaeobalanidae	*Conopea galeata*														
Balanidae	*Balanus sp.*				•					•		•			
	Balanus amphitrite														
	Balanus amphitrite amphitrite									•					
	Balanus calidus														
	Balanus eburneus							•	•	•	•				
	Balanus improvisus							•							•
	Balanus juv. sp.				•										•
	Balanus spp.									•					
	Balanus trigonus										•				
	Balanus venustus				•						•				
Chelonibiidae	*Chelonibia testudinaria*														
ORDER HARPACTICOIDA	*Harpacticoida sp.*														
ORDER AMPHIPODA															
	Amphipoda spp.							•							
Ampeliscidae	*Ampelisca abdita*				•										
	Ampelisca verrilli														
Amphilochidae	*Amphilochus (spencebatei)*														
Ampithoidae	*Ampithoe valida*							•		•					
Aoridae	*Lembos smithi*				•										
Bateidae	*Batea cathariensis*				•										
Caprellidae	*Caprella equilibra*							•							
	Caprellidae sp.				•										
Corophiidae	*Apocorophium lacustre*														
	Corophium sp.							•							
	Corophium volutator														
	Monocorophium acherusium							•							
Crangonyctidae	*Crangonyx pseudogracilis*				•										
	Crangonyx richmondensis richmondensis							•							
Gammaridae	*Gammarus fasciatus*														
	Gammarus tigrinus														
	Monoculodes edwardsi														
Haustoriidae	*Parahaustorius holmesi*														
Hyalidae	*Hyale plumulosa*							•		•					
Ischyroceridae	*Ericthonius brasiliensis*				•			•							
	Jassa marmorata							•							
Leucothoidae	*Leucothoe spinicarpa*										•				
	Leucothoe spinicarpa complex				•						•				
Liljeborgiidae	*Listriella barnardi*														
Melitidae	*Dulichiella appendiculata*				•			•			•				
	Elasmopus levis				•			•							
	Melita nitida				•			•		•	•				
Pleustidae	*Pleusymtes glaber*							•							
Stenothoidae	*Stenothoe minuta*				•			•							
ORDER DECAPODA															
	Caridea sp.														
	Decapoda sp.				•										
Alpheidae	*Alpheus heterochaelis*										•				
	Synalpheus (townsendi)				•						•				
Diogenidae	*Clibanarius vittatus*														
Grapsidae	*Pachygrapsus transversus*														
Hippidae	*Emerita talpoida*														

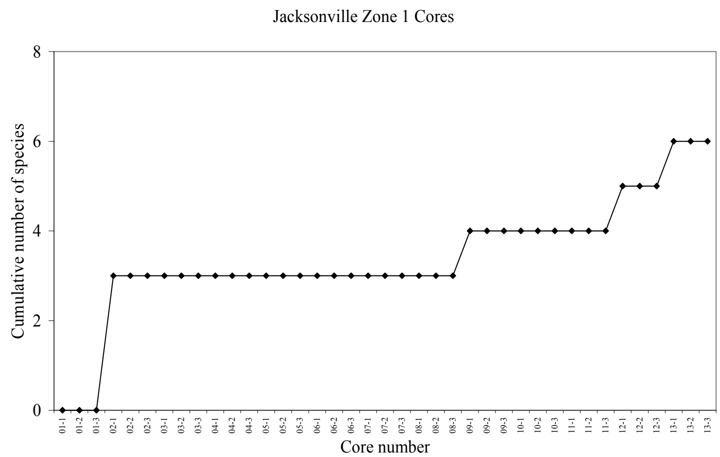
HIGHER TAXA	SPECIES	SAV01CO	SAV01CR	SAV01MI	SAV01TR	SAV02CO	SAV02CR	SAV02HD	SAV02MI	SAV02SC	SAV02TR	SAV03CO	SAV03CR	SAV03MI	SAV03TR
Terebellidae	*Eupolymnia sp. A*														
	Loimia medusa														
	Pista palmata														
	Polycirrus sp. B														
	Streblosoma hartmanae				•										
PHYLUM ARTHROPODA SUBPHYLUM CRUSTACEA ORDER SESSILIA															
Archaeobalanidae	*Conopea galeata*														
Balanidae	*Balanus sp.*				•			•		•					
	Balanus amphitrite														
	Balanus amphitrite amphitrite									•					
	Balanus calidus														
	Balanus eburneus		•		•					•					
	Balanus improvisus														
	Balanus juv. sp.														
	Balanus spp.														
	Balanus trigonus														
	Balanus venustus														
Chelonibiidae	*Chelonibia testudinaria*														
ORDER HARPACTICOIDA	*Harpacticoida sp.*														
ORDER AMPHIPODA															
	Amphipoda spp.														
Ampeliscidae	*Ampelisca abdita*														
	Ampelisca verrilli														
Amphilochidae	*Amphilochus (spencebatei)*							•							
Ampithoidae	*Ampithoe valida*									•					
Aoridae	*Lembos smithi*														
Bateidae	*Batea cathariensis*														
Caprellidae	*Caprella equilibra*														
	Caprellidae sp.														
Corophiidae	*Apocorophium lacustre*							•		•					
	Corophium sp.														
	Corophium volutator														
	Monocorophium acherusium														
Crangonyctidae	*Crangonyx pseudogracilis*														
	Crangonyx richmondensis richmondensis														
Gammaridae	*Gammarus fasciatus*							•							
	Gammarus tigrinus														
	Monoculodes edwardsi														
Haustoriidae	*Parahaustorius holmesi*	•													
Hyalidae	*Hyale plumulosa*							•		•					
Ischyroceridae	*Ericthonius brasiliensis*														
	Jassa marmorata														
Leucothoidae	*Leucothoe spinicarpa*														
	Leucothoe spinicarpa complex														
Liljeborgiidae	*Listriella barnardi*														
Melitidae	*Dulichiella appendiculata*														
	Elasmopus levis														
	Melita nitida							•		•					
Pleustidae	*Pleusymtes glaber*							•							
Stenothoidae	*Stenothoe minuta*							•							
ORDER DECAPODA															
	Caridea sp.														•
	Decapoda sp.														
Alpheidae	*Alpheus heterochaelis*														
	Synalpheus (townsendi)														
Diogenidae	*Clibanarius vittatus*		•	•											
Grapsidae	*Pachygrapsus transversus*									•					
Hippidae	*Emerita talpoida*														

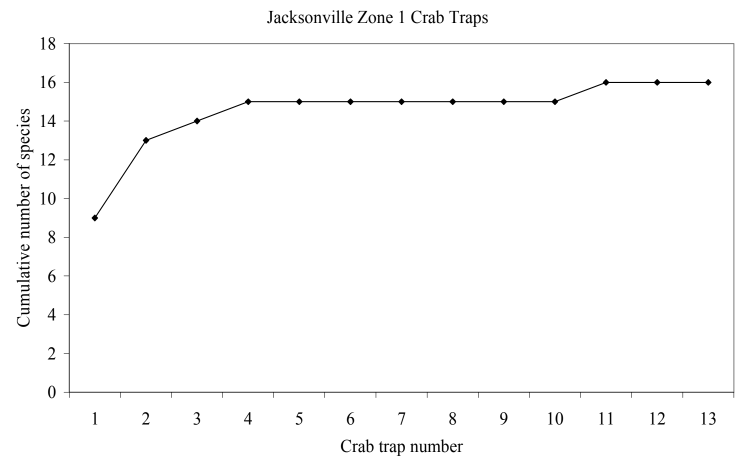
HIGHER TAXA	SPECIES	JAX01CO	JAX01CR	JAX01MI	JAX01TR	JAX02CO	JAX02CR	JAX02HD	JAX02MI	JAX02SC	JAX02TR	JAX03CO	JAX03CR	JAX03MI	JAX03TR
Terebellidae	*Eupolymnia sp. A*														
	Loimia medusa														
	Pista palmata														
	Polycirrus sp. B														
	Streblosoma hartmanae														
PHYLUM ARTHROPODA SUBPHYLUM CRUSTACEA ORDER SESSILIA															
Archaeobalanidae	*Conopea galeata*				•										
Balanidae	*Balanus sp.*							•		•					
	Balanus amphitrite		•												
	Balanus amphitrite amphitrite									•					
	Balanus calidus		•				•								
	Balanus eburneus		•		•			•		•	•				
	Balanus improvisus							•							•
	Balanus juv. sp.				•										
	Balanus spp.														
	Balanus trigonus														
	Balanus venustus			•	•			•							
Chelonibiidae	*Chelonibia testudinaria*		•												
ORDER HARPACTICOIDA	*Harpacticoida sp.*														
ORDER AMPHIPODA															
	Amphipoda spp.														
Ampeliscidae	*Ampelisca abdita*														
	Ampelisca verrilli														
Amphilochidae	*Amphilochus (spencebatei)*							•							
Ampithoidae	*Ampithoe valida*														
Aoridae	*Lembos smithi*														
Bateidae	*Batea cathariensis*				•										
Caprellidae	*Caprella equilibra*							•							
	Caprellidae sp.														
Corophiidae	*Apocorophium lacustre*							•							
	Corophium sp.							•							
	Corophium volutator														
	Monocorophium acherusium														
Crangonyctidae	*Crangonyx pseudogracilis*														
	Crangonyx richmondensis richmondensis														
Gammaridae	*Gammarus fasciatus*														
	Gammarus tigrinus														
	Monoculodes edwardsi														
Haustoriidae	*Parahaustorius holmesi*	•				•									
Hyalidae	*Hyale plumulosa*									•					
Ischyroceridae	*Ericthonius brasiliensis*														
	Jassa marmorata														
Leucothoidae	*Leucothoe spinicarpa*														
	Leucothoe spinicarpa complex														
Liljeborgiidae	*Listriella barnardi*														
Melitidae	*Dulichiella appendiculata*														
	Elasmopus levis														
	Melita nitida		•					•		•					•
Pleustidae	*Pleusymtes glaber*							•							
Stenothoidae	*Stenothoe minuta*							•							•
ORDER DECAPODA															
	Caridea sp.														
	Decapoda sp.										•				
Alpheidae	*Alpheus heterochaelis*										•				
	Synalpheus (townsendi)														
Diogenidae	*Clibanarius vittatus*		•	•			•		•						
Grapsidae	*Pachygrapsus transversus*									•					
Hippidae	*Emerita talpoida*	•			•										

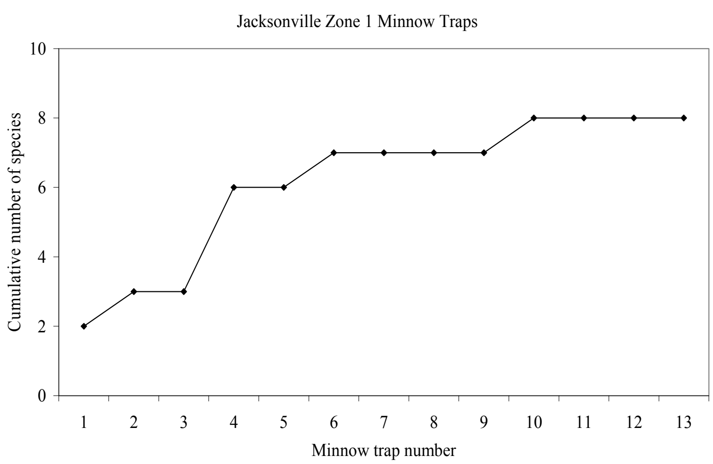
HIGHER TAXA	SPECIES (LOCATION II)	WIL01CO	WIL01CR	WIL01MI	WIL01TR	WIL02CO	WIL02CR	WIL02HD	WIL02MI	WIL02SC	WIL02TR	WIL03CO	WIL03CR	WIL03MI	WIL03TR	CHA01CO	CHA01CR	CHA01MI	CHA01TR	CHA02CO	CHA02CR	CHA02HD	CHA02MI	CHA02SC	CHA02TR	CHA03CO	CHA03CR	CHA03MI	CHA03TR	SAV01CO	SAV01CR	SAV01MI	SAV01TR	SAV02CO	SAV02CR	SAV02HD	SAV02MI	SAV02SC	SAV02TR	SAV03CO	SAV03CR	SAV03MI	SAV03TR	JAX01CO	JAX01CR	JAX01MI	JAX01TR	JAX02CO	JAX02CR	JAX02HD	JAX02MI	JAX02SC	JAX02TR	JAX03CO	JAX03CR	JAX03MI	JAX03TR
Hippolytidae	*Exhippolysmata oplophoroides*																		•																																						
	Latreutes parvulus																								•																						•										
	Lysamata wurdemanni																		•																																						
	Thor sp.																								•																																
Majidae	*Libinia dubia*																		•						•																						•						•				
Ocypodidae	*Uca pugilator*																																															•									
	Uca juv. sp.							•																																																	
	Uca sp.																													•																											
Paguridae	*Pagurus carolinensis*																												•																												
	Pagurus longicarpus	•														•			•				•		•				•				•													•	•										
	Pagurus pollicaris																		•						•																				•		•										
	Pagurus sp.															•			•														•																								
Palaemonidae	*Macrobrachium acanthurus*																																																								
	Palaemonetes pugio													•					•						•											•	•						•												•				
	Palaemonetes sp.																																										•														
	Palaemonetes vulgaris			•										•				•						•					•				•	•					•															•					•	
	Periclimenes longicaudata																		•																																						
Panopeidae	*Dyspanopeus sayi*																					•																																			
	Eurypanopeus depressus																		•					•	•													•									•					•					
	Panopeus herbstii																	•				•	•	•	•			•				•				•	•	•				•				•				•	•	•	•				•
	Rhithropanopeus harrisii							•		•				•															•				•					•	•																		
Penaeidae	*Farfantepenaeus aztecus*																	•	•						•			•	•				•															•						•				•
	Farfantepenaeus duorarum										•																																														
	Litopenaeus setiferus			•	•				•		•				•				•				•		•			•	•			•	•				•		•			•	•				•						•				•
	Parapenaeus politus																								•																						•						•				
	Penaeidae sp.																																•														•										
	Xiphopenaeus kroyeri																		•																																						
	Rimapenaeus constrictus																								•								•																								
Pinnotheridae	*Zaops ostreum*																							•													•														•					
Pisidae	*Pelia mutica*																																														•										
Porcellanidae	*Petrolisthes armatus*																					•		•	•													•									•					•					
Portunidae	*Callinectes sapidus*		•	•	•		•		•		•		•	•	•		•	•			•						•	•	•	•						•		•				•				•	•			•	•	•		•		•	•	•
	Callinectes similis				•												•	•	•				•		•			•	•			•	•						•							•	•				•		•			•	•
	Cronius sp.																								•																																
	Ovalipes sp.																		•																																						
	Portunus gibbesii																		•				•		•																				•	•										
	Portunus sp.																																												•	•										
Sergestidae	*Acetes americanus carolinae*									•									•						•				•				•														•										
Sesarmidae	*Armases (cinereum)*																							•													•																			
Upogebiidae	*Upogebia affinis*																								•																																
Xanthidae	*Menippe mercenaria*																•		•		•				•																				•												
	Xanthidae juv. sp.																				•														•														•							
	Xanthidae spp.																																				•																			
	Xanthidae spp.1																						•																																	
ORDER ISOPODA																																																									
Aegidae	*Rocinela americana*																							•																												•				
Anthuridae	*Cyathura polita*															•																		•																							
Bopyridae	*Probopyrus pandilicola*													•																																											
	Progebiophilus upogebiae																								•																																
Chaetilidae	*Chiridotea caeca*					•																																																			
Cymothoidae	*Anilocra (acuta)*																																					•																		
	Cymothoa excisa																		•						•								•						•																		•
	Livoneca reniformis																		•						•																																
	Nerocila sp.																		•																																						
Holognathidae	*Cleantioides planicauda*																								•								•														•										
Idoteidae	*Edotia sp.*	•				•																																																			
	Synidotea (nebulosa)							•																																																	
	Synidotea sp.																					•														•														•							•
Ligiidae	*Ligia exotica*																							•													•														•					
Sphaeromatidae	*(Dynamene sp.)*																																				•																			
	Cassidinidea lunifrons							•		•																									•		•																			
	Cassidinidea ovalis																																				•																			
	Sphaeroma quadridentatum																						•														•																			

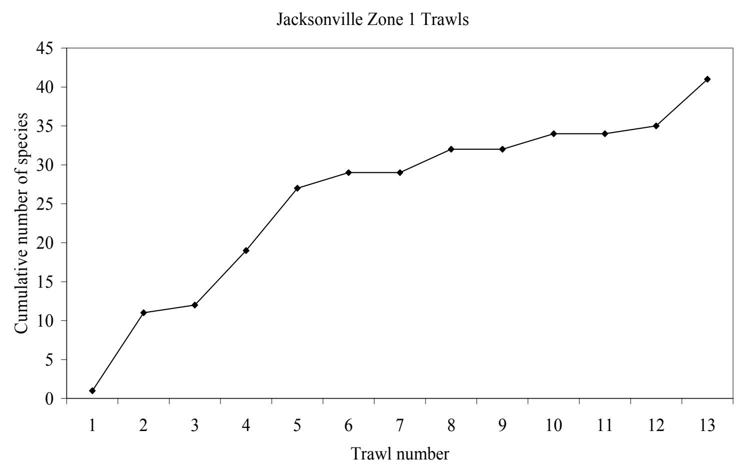
HIGHER TAXA	SPECIES	LOCATION II WIL01CO	WIL01CR	WIL01MI	WIL01TR	WIL02CO	WIL02CR	WIL02HD	WIL02MI	WIL02SC	WIL02TR	WIL03CO	WIL03CR	WIL03MI	WIL03TR	CHA01CO	CHA01CR	CHA01MI	CHA01TR	CHA02CO	CHA02CR	CHA02HD	CHA02MI	CHA02SC	CHA02TR	CHA03CO	CHA03CR	CHA03MI	CHA03TR	SAV01CO	SAV01CR	SAV01MI	SAV01TR	SAV02CO	SAV02CR	SAV02HD	SAV02MI	SAV02SC	SAV02TR	SAV03CO	SAV03CR	SAV03MI	SAV03TR	JAX01CO	JAX01CR	JAX01MI	JAX01TR	JAX02CO	JAX02CR	JAX02HD	JAX02MI	JAX02SC	JAX02TR	JAX03CO	JAX03CR	JAX03MI	JAX03TR
ORDER MYSIDA																																																									
	Mysidacea sp.																																														●										
Mysidae	*Bowmaniella juv sp.*																																																								●
	Brasilomysis castroi																																																								●
	Neomysis americana																					●																																			●
ORDER STOMATOPODA																																																									
Squillidae	*Squilla empusa*																		●						●																												●				
	Squilla juv. sp.																								●																																
ORDER TANAIDACEA																																																									
	Tanaidacea sp.									●																																															
Leptocheliidae	*Hargeria rapax*	●																																																							
Tanaidae	*Tanais cavolinii*									●																																								●		●					
CLASS OSTRACODA																																																									
	Ostacoda sp.	●																																																							
PHYLUM MOLLUSCA																																																									
CLASS BIVALVIA																																																									
	Bivalvia sp.	●						●				●												●												●		●																			
Arcidae	*Anadara floridana*																														●														●		●										
	Anadara notabilis																																														●										
	Anadara ovalis																								●																																
	Anadara transversa																		●																																						
Corbulidae	*Corbula contracta*																																														●										
Dreissenidae	*Mytilopsis leucophaeata*									●																										●		●					●									●					
	Mytilopsis sp.																																			●																					
Mactridae	*Raeta plicatella*															●																																									
	Spisula solidissima similis																																														●										
Myidae	*Sphenia fragilis*																		●			●		●	●						●		●			●		●							●		●					●					
	Sphenia sp.																		●					●									●					●									●										
Mytilidae	*Amygdalum papyrium*																																														●			●		●					●
	Brachidontes exustus																		●				●	●	●				●				●			●		●							●		●					●					
	Geukensia demissa	●																	●					●	●				●				●			●		●									●					●	●				
	Ischadium recurvum																							●												●		●	●													●					
	Modiolus juv. sp.							●																																																	
	Musculus lateralis																		●																										●												
	Mytilus edulis																																																				●				●
Ostreidae	*Crassostrea virginica*																		●										●																		●										
	Ostrea equestris																							●																							●										
Pholadidae	*Barnea truncata*																		●																																						
Semelidae	*Abra aequalis*															●																																									
	Cumingia tellinoides																		●																																						
Solecurtidae	*Tagelus plebius*																			●																																					
Tellinidae	*Angulus texana*															●																																									
Veneridae	*Chione elevata*															●																																									
CLASS CEPHALOPODA																																																									
Loliginidae	*Lolliguncula brevis*																		●						●				●				●														●										
CLASS GASTROPODA																																																									
Cerithiopsidae	*Cerithiopsis sp.*																		●																																						
Columbellidae	*Mitrella sp.*																		●																																						
Littorinidae	*Littoraria irrorata*																							●																																	
Muricidae	*Urosalpinx sp.*																		●																																						
Nassariidae	*Nassarius obsoletus*	●														●										●																						●									
Ovulidae	*Simnialena uniplicata*																																														●										
Pyramidellidae	*Boonea impressa*																							●																												●					
Triphoridae	*Triphora sp.*																		●																																						

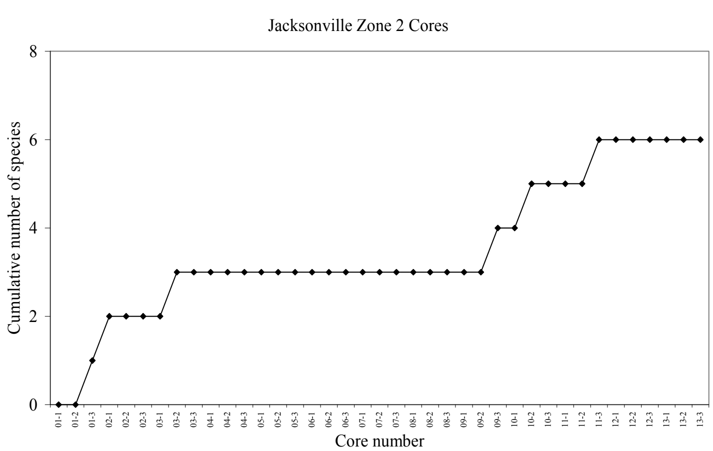
APPENDIX 5. Cumulative Species Curves per Gear Type, Zone and Port

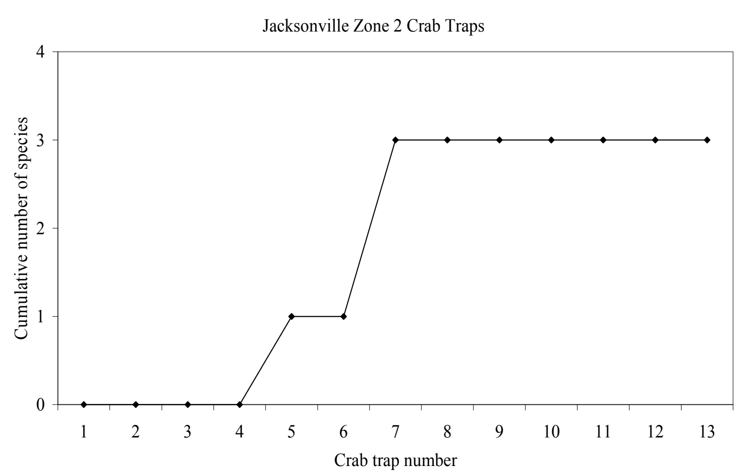




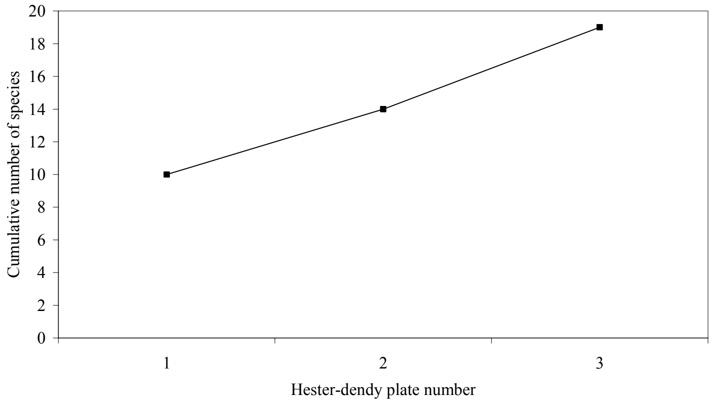




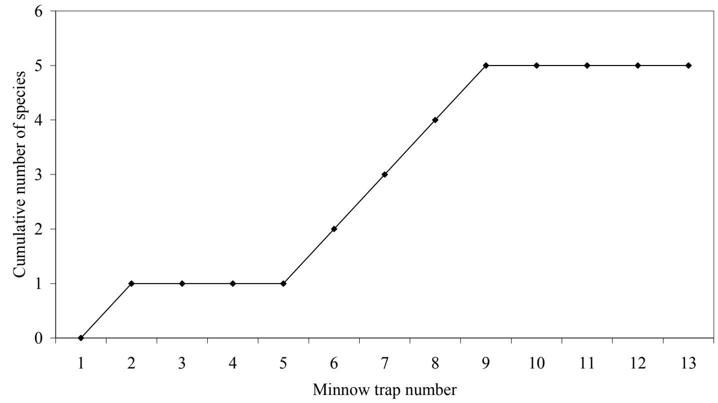




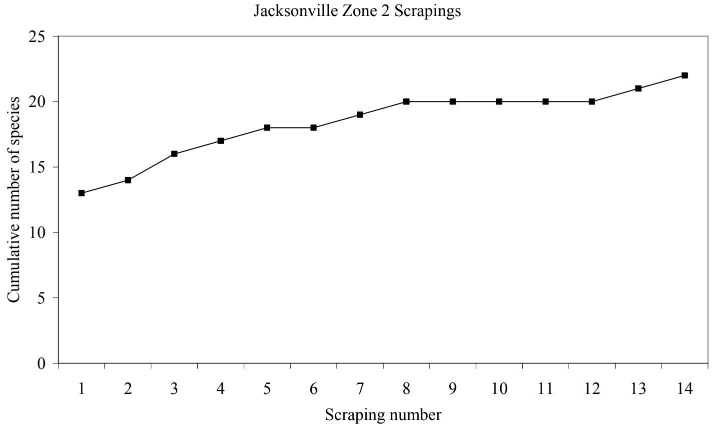
Jacksonville Zone 2 Hester-Dendy Plates



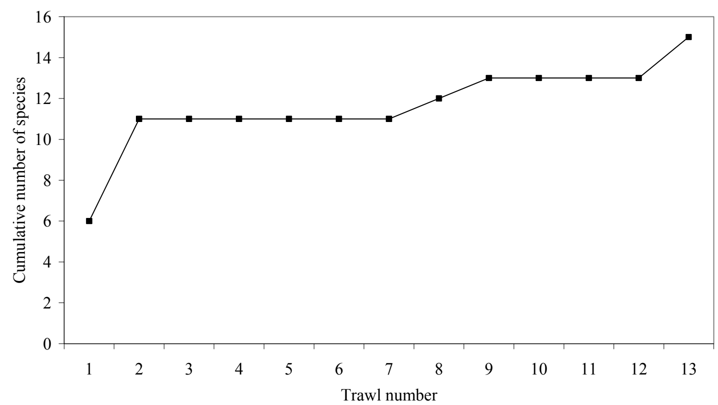
Jacksonville Zone 2 Minnow Traps



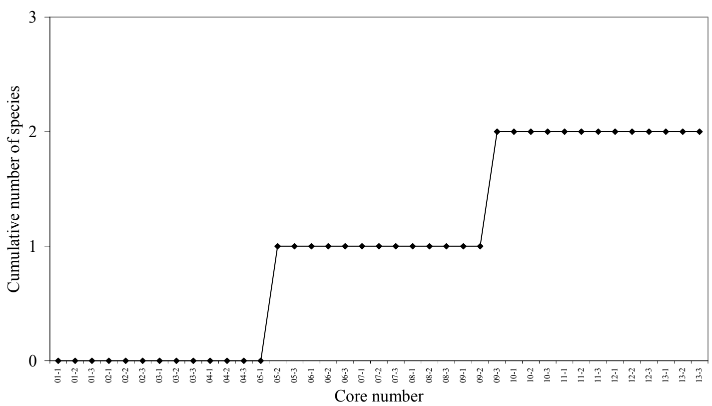
Jacksonville Zone 2 Scrapings



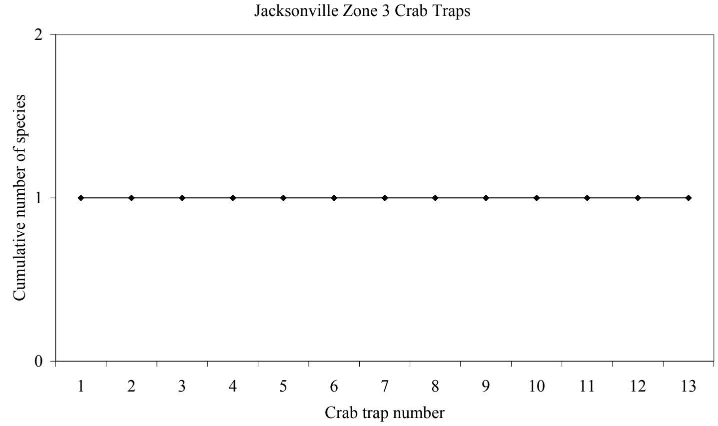
Jacksonville Zone 2 Trawls

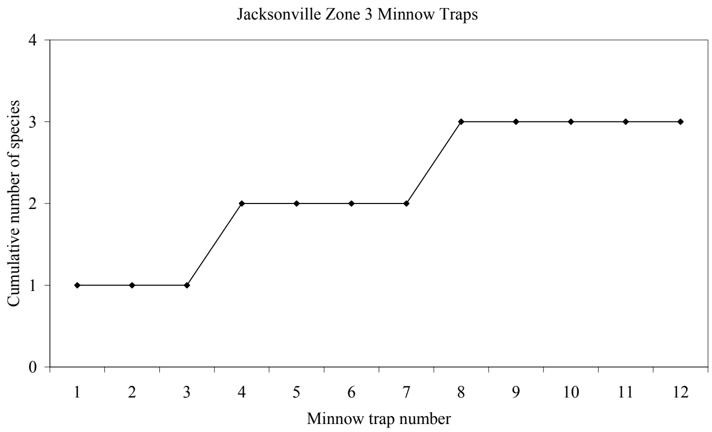


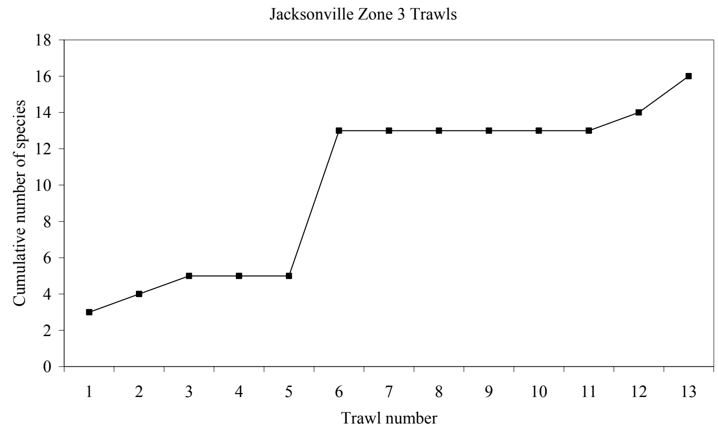
Jacksonville Zone 3 Cores

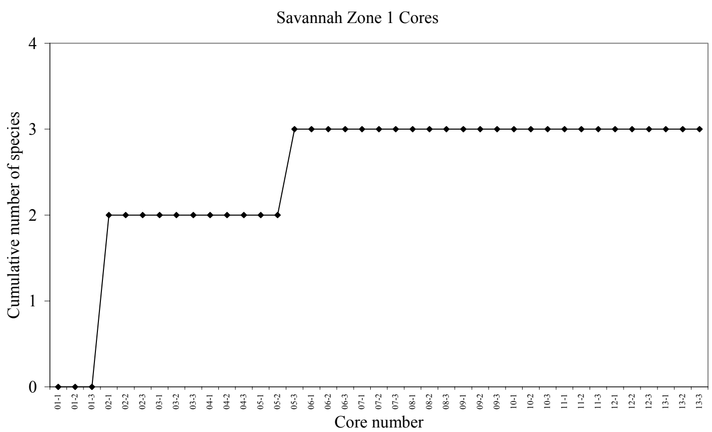


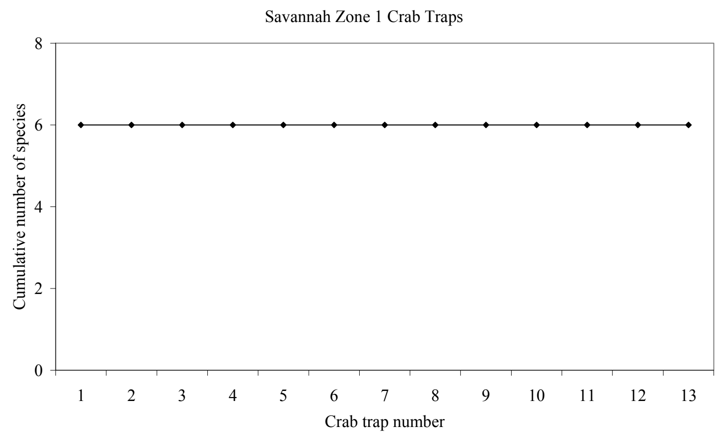
Jacksonville Zone 3 Crab Traps

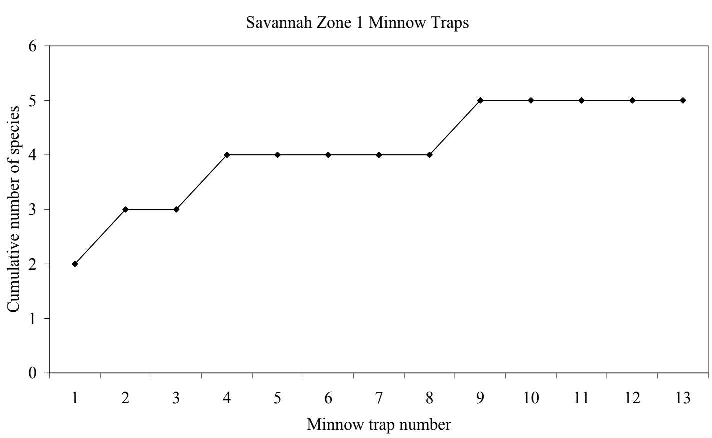


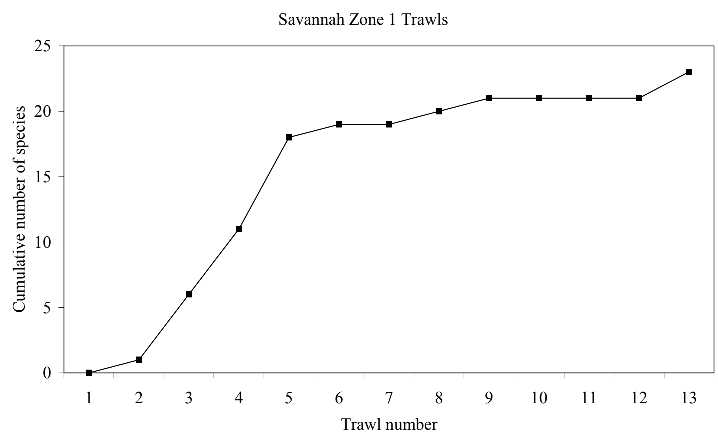

Jacksonville Zone 3 Minnow Traps
Cumulative number of species
0
1
2
3
4
1 2 3 4 5 6 7 8 9 10 11 12
Minnow trap number

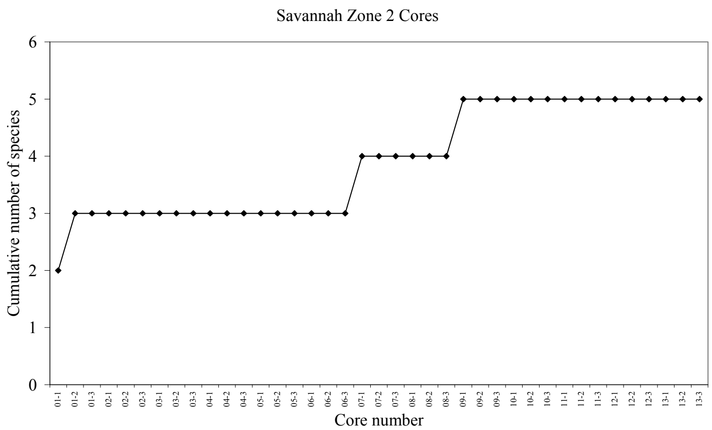

Jacksonville Zone 3 Trawls
Cumulative number of species
0
2
4
6
8
10
12
14
16
18
1 2 3 4 5 6 7 8 9 10 11 12 13
Trawl number

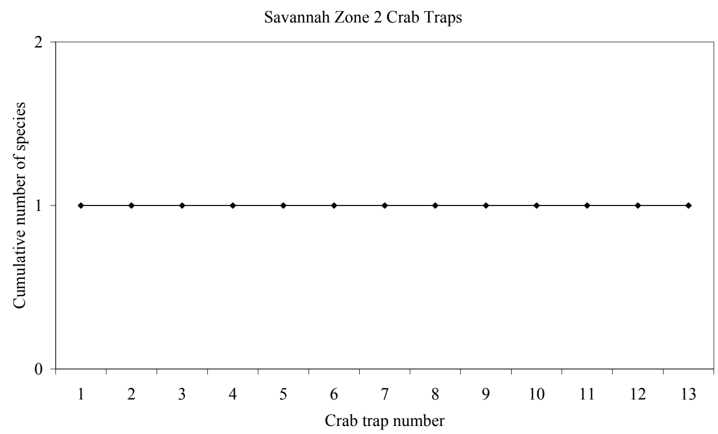

Savannah Zone 1 Cores
Cumulative number of species
0
1
2
3
4
Core number

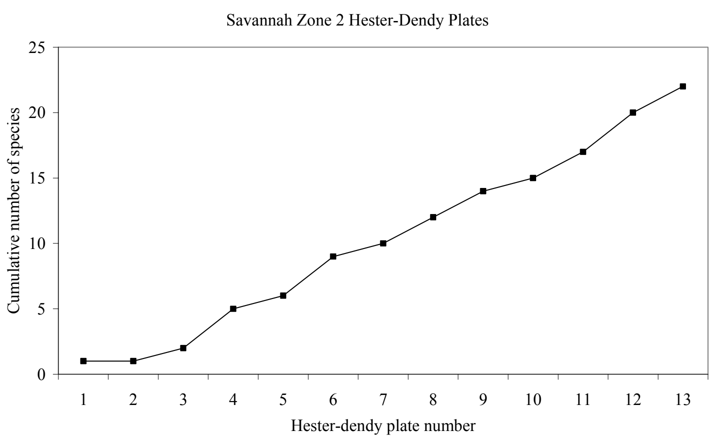

Savannah Zone 1 Crab Traps
Cumulative number of species
0
2
4
6
8
1 2 3 4 5 6 7 8 9 10 11 12 13
Crab trap number

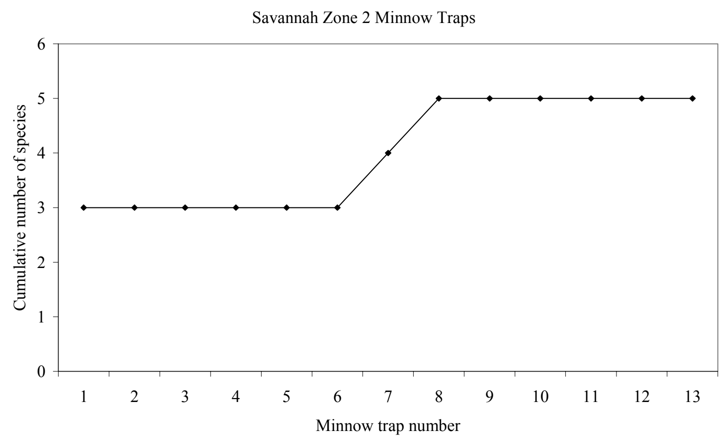

Savannah Zone 1 Minnow Traps
Cumulative number of species
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13
Minnow trap number

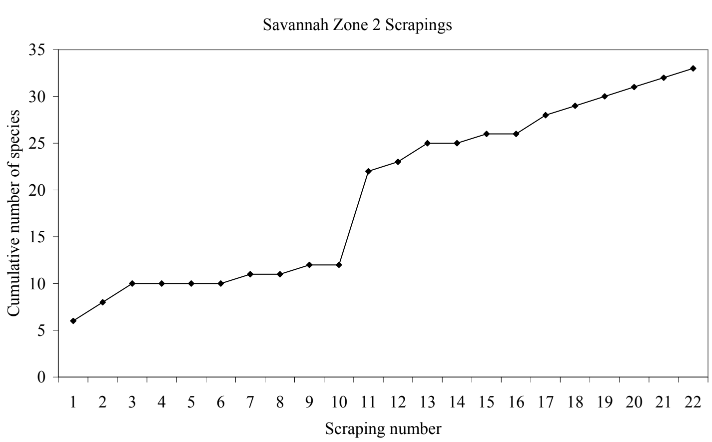

Savannah Zone 1 Trawls
Cumulative number of species
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13
Trawl number

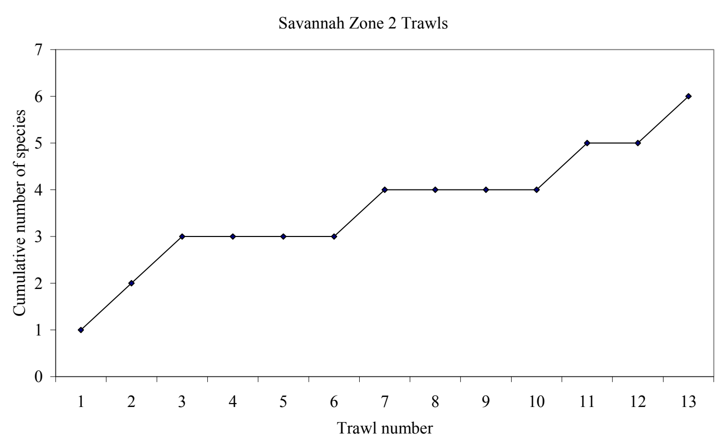

Savannah Zone 2 Cores
Cumulative number of species
0
1
2
3
4
5
6
Core number

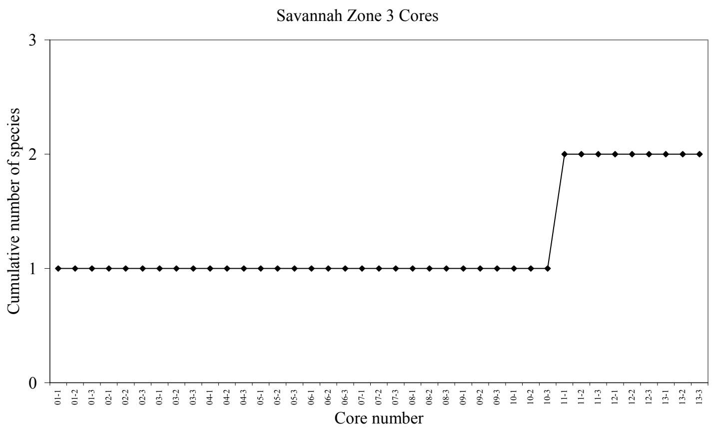

Savannah Zone 2 Crab Traps
Cumulative number of species
0
1
2
1 2 3 4 5 6 7 8 9 10 11 12 13
Crab trap number

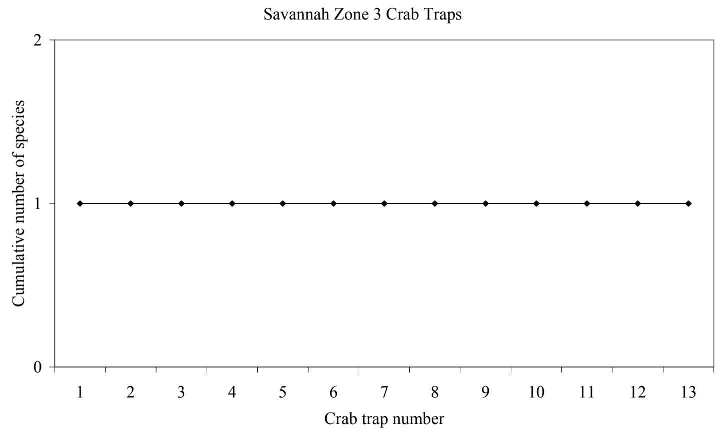

Savannah Zone 2 Hester-Dendy Plates
Cumulative number of species
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13
Hester-dendy plate number

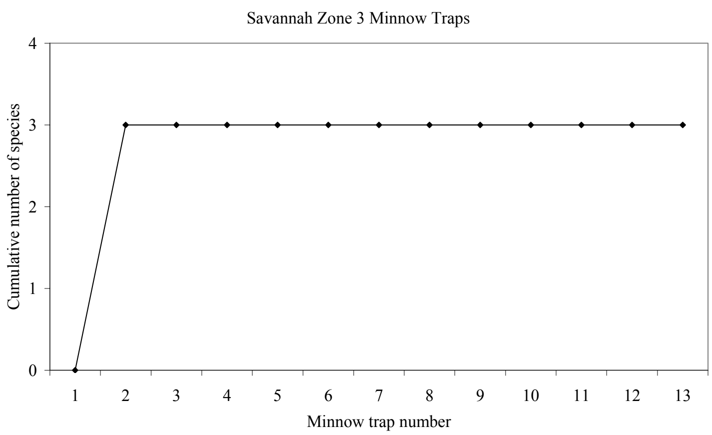

Savannah Zone 2 Minnow Traps
Cumulative number of species
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13
Minnow trap number

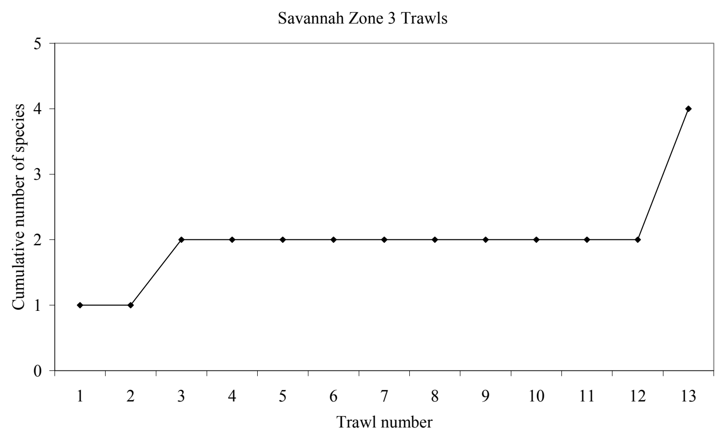

Savannah Zone 2 Scrapings
Cumulative number of species
0
5
10
15
20
25
30
35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Scraping number

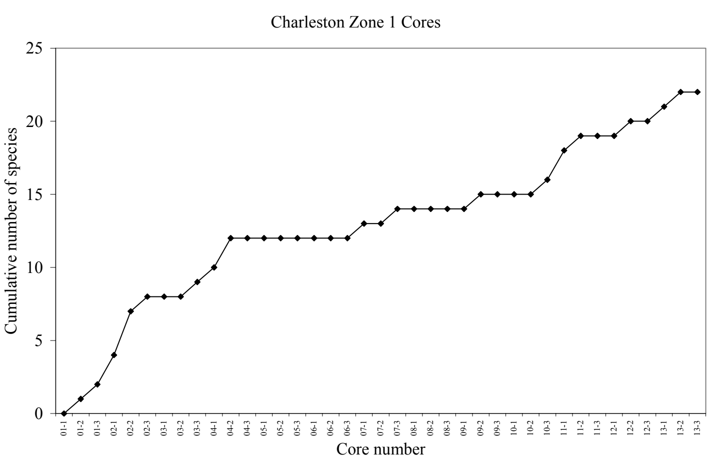

Savannah Zone 2 Trawls
Cumulative number of species
0
1
2
3
4
5
6
7
1 2 3 4 5 6 7 8 9 10 11 12 13
Trawl number

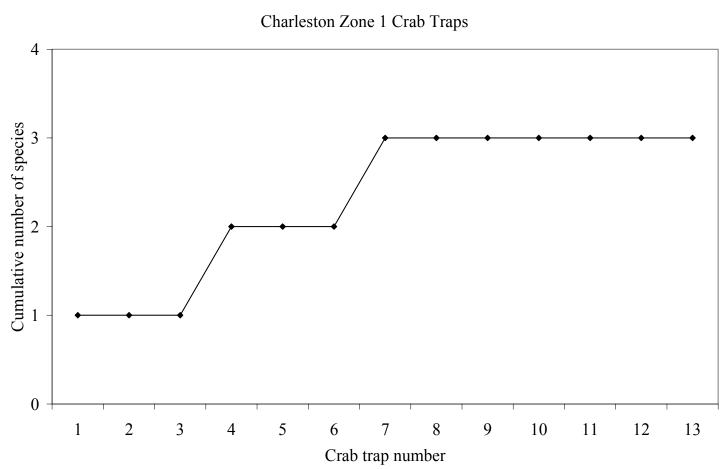

Savannah Zone 3 Cores
Cumulative number of species
Core number

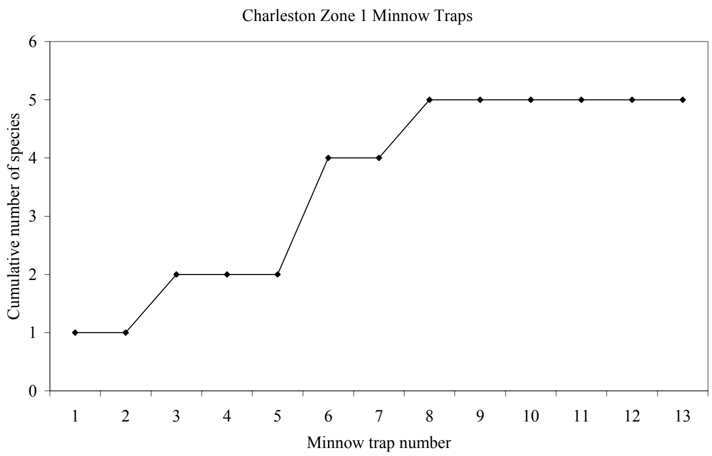

Savannah Zone 3 Crab Traps
Cumulative number of species
Crab trap number

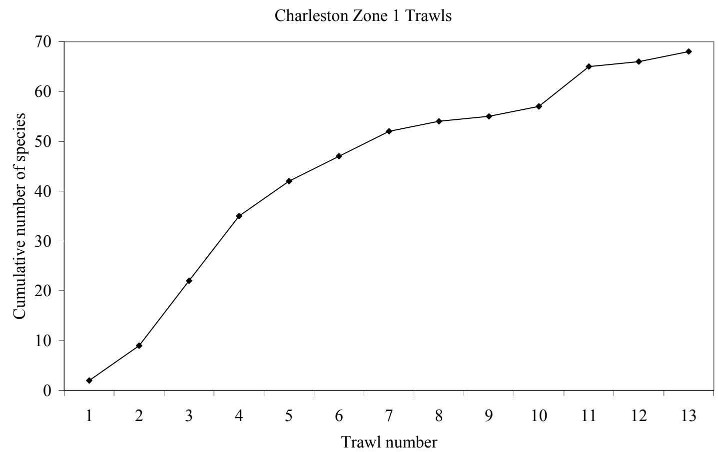

Savannah Zone 3 Minnow Traps
Cumulative number of species
Minnow trap number

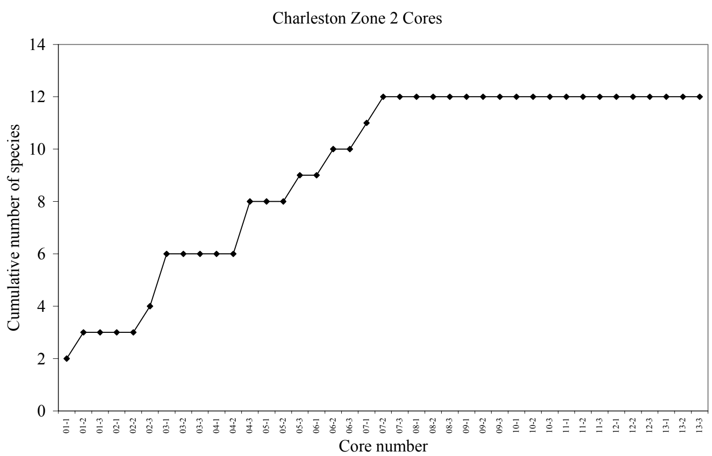

Savannah Zone 3 Trawls
Cumulative number of species
Trawl number

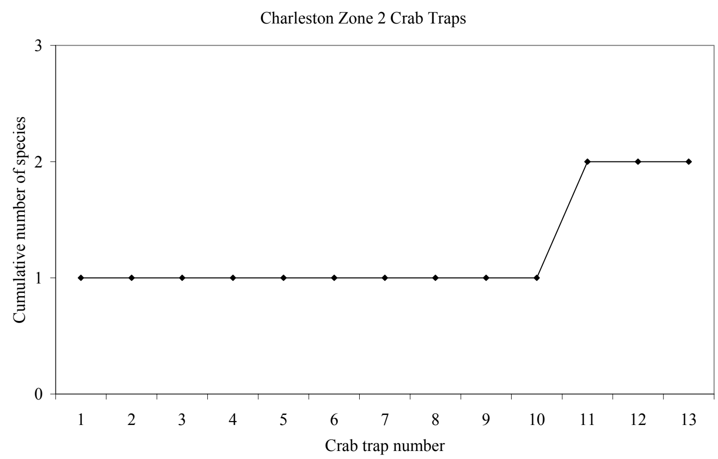

Charleston Zone 1 Cores
Cumulative number of species
Core number

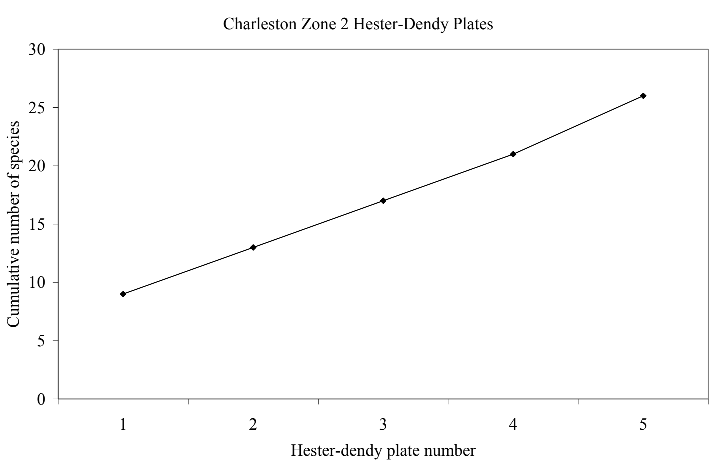

Charleston Zone 1 Crab Traps
Cumulative number of species
Crab trap number

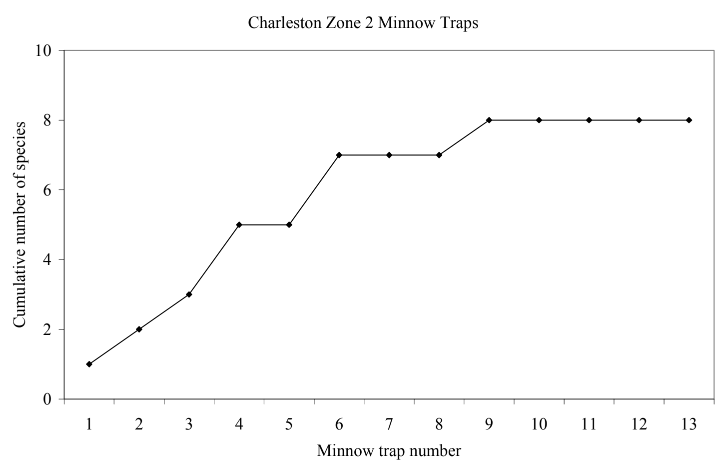

Charleston Zone 1 Minnow Traps
Cumulative number of species
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13
Minnow trap number

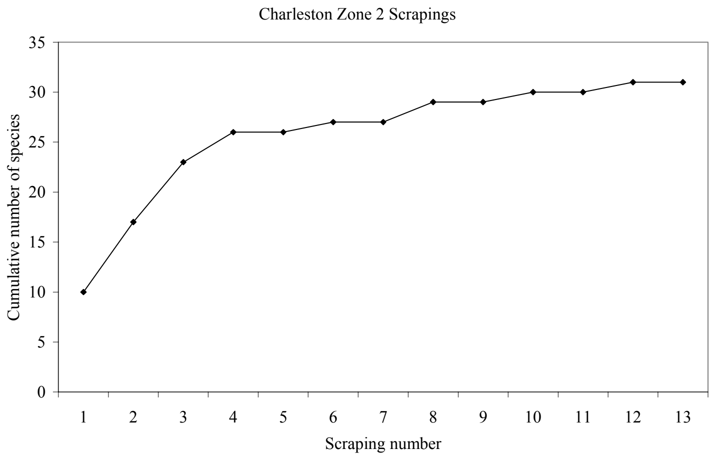

Charleston Zone 1 Trawls
Cumulative number of species
0
10
20
30
40
50
60
70
1 2 3 4 5 6 7 8 9 10 11 12 13
Trawl number

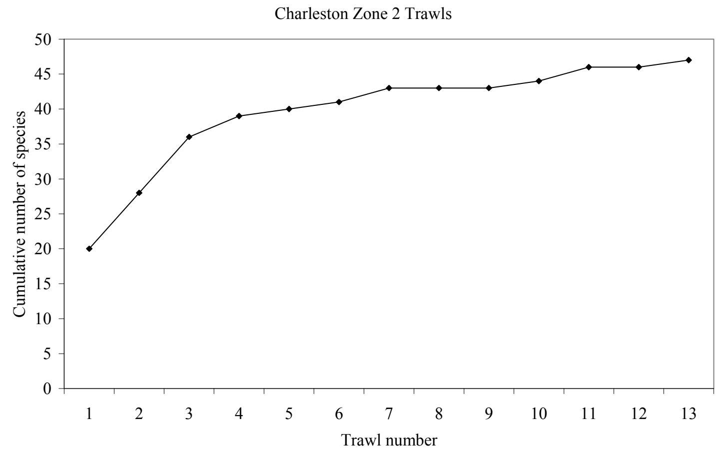

Charleston Zone 2 Cores
Cumulative number of species
0
2
4
6
8
10
12
14
Core number

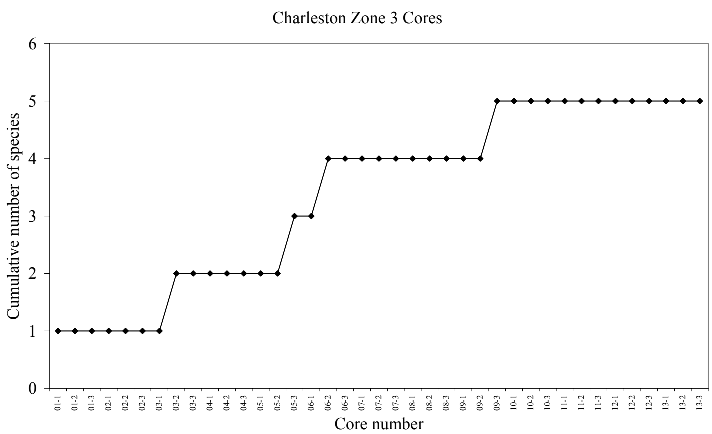

Charleston Zone 2 Crab Traps
Cumulative number of species
0
1
2
3
1 2 3 4 5 6 7 8 9 10 11 12 13
Crab trap number

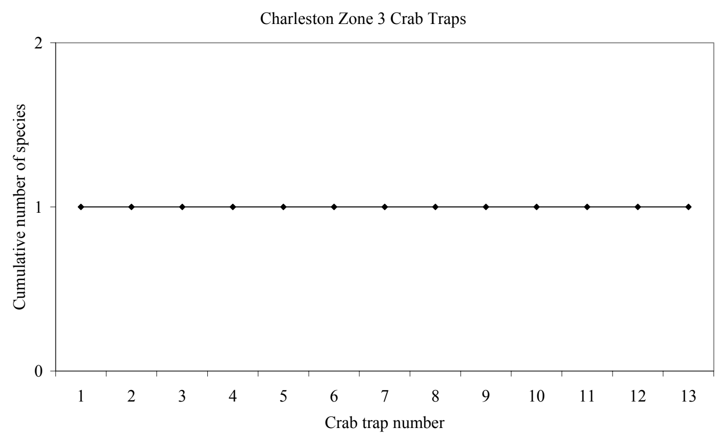

Charleston Zone 2 Hester-Dendy Plates
Cumulative number of species
0
5
10
15
20
25
30
1 2 3 4 5
Hester-dendy plate number

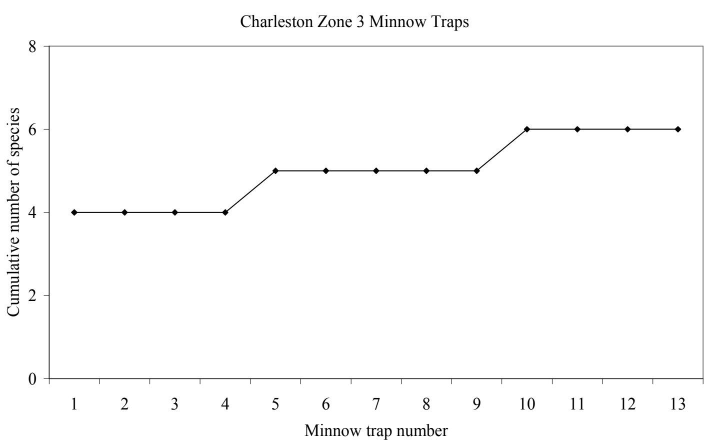

Charleston Zone 2 Minnow Traps
Cumulative number of species
0
2
4
6
8
10
1 2 3 4 5 6 7 8 9 10 11 12 13
Minnow trap number

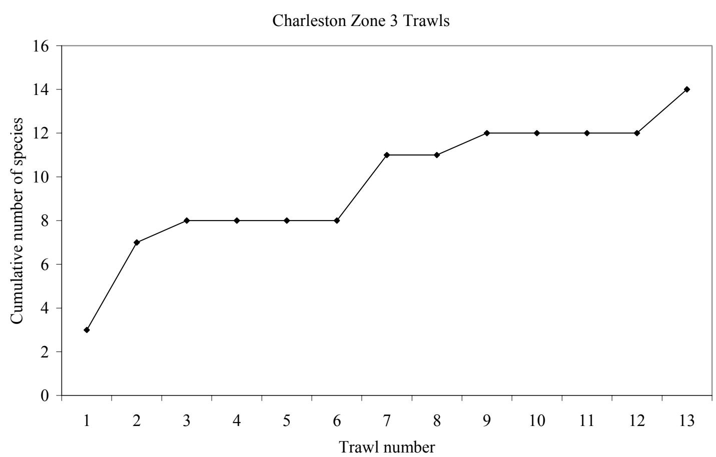

Charleston Zone 2 Scrapings
Cumulative number of species
0
5
10
15
20
25
30
35
1 2 3 4 5 6 7 8 9 10 11 12 13
Scraping number

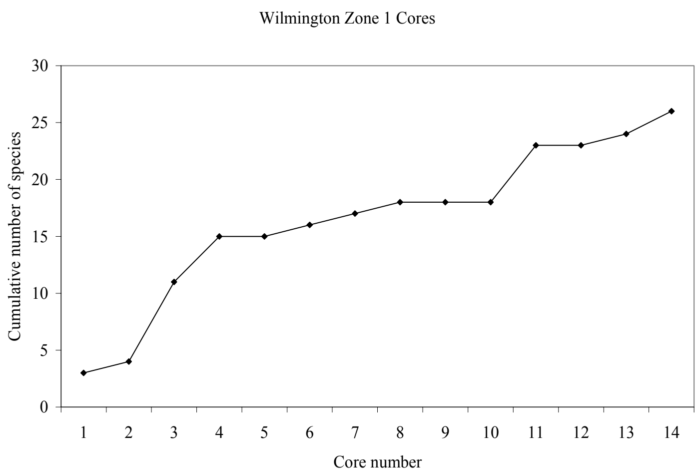

Charleston Zone 2 Trawls
Cumulative number of species
0
5
10
15
20
25
30
35
40
45
50
1 2 3 4 5 6 7 8 9 10 11 12 13
Trawl number

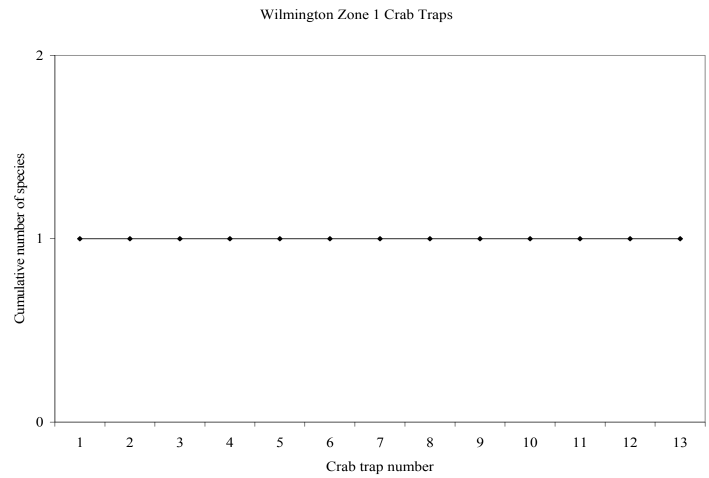

Charleston Zone 3 Cores
Cumulative number of species
0
1
2
3
4
5
6
01-1 01-2 01-3 02-1 02-2 02-3 03-1 03-2 03-3 04-1 04-2 04-3 05-1 05-2 05-3 06-1 06-2 06-3 07-1 07-2 07-3 08-1 08-2 08-3 09-1 09-2 09-3 10-1 10-2 10-3 11-1 11-2 11-3 12-1 12-2 12-3 13-1 13-2 13-3
Core number

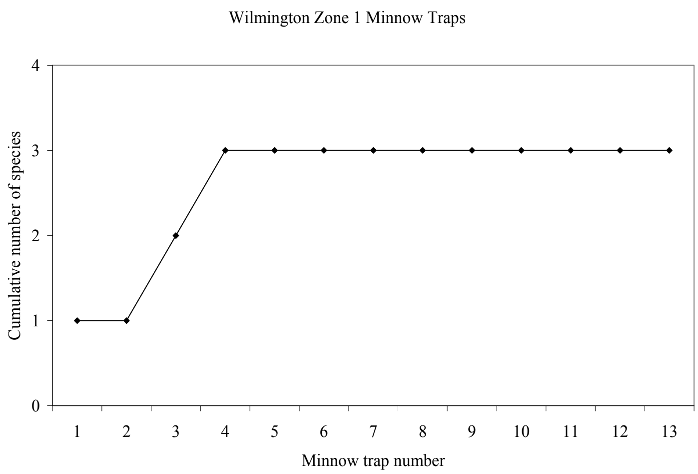

Charleston Zone 3 Crab Traps
Cumulative number of species
0
1
2
1 2 3 4 5 6 7 8 9 10 11 12 13
Crab trap number

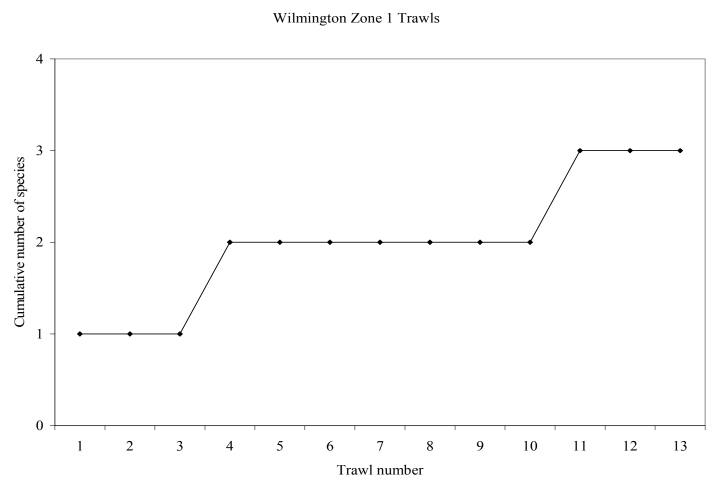

Charleston Zone 3 Minnow Traps
Cumulative number of species
0
2
4
6
8
1 2 3 4 5 6 7 8 9 10 11 12 13
Minnow trap number

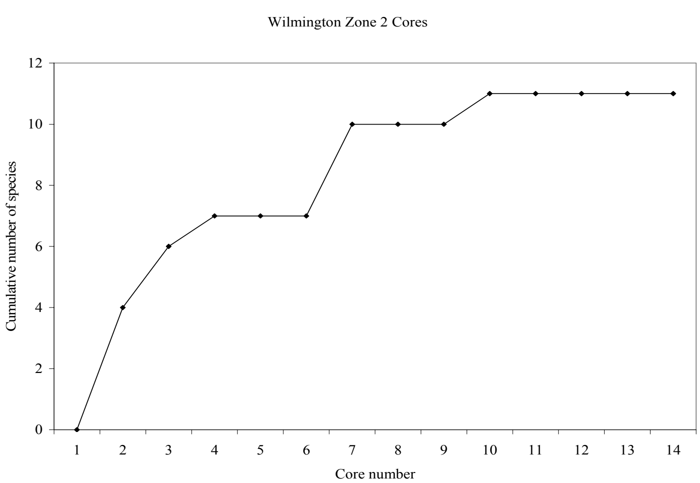

Charleston Zone 3 Trawls
Cumulative number of species
0
2
4
6
8
10
12
14
16
1 2 3 4 5 6 7 8 9 10 11 12 13
Trawl number

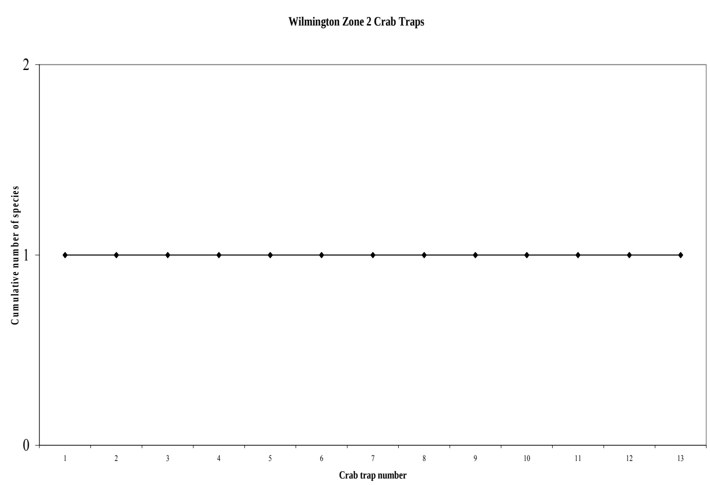

Wilmington Zone 1 Cores
Cumulative number of species
Core number

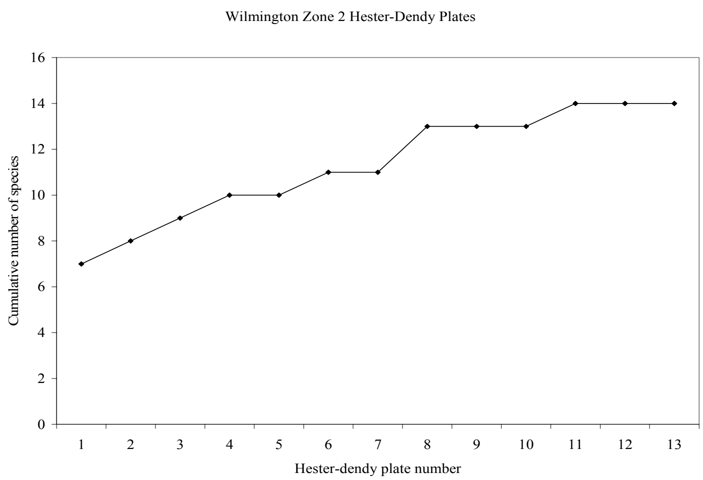

Wilmington Zone 1 Crab Traps
Cumulative number of species
Crab trap number

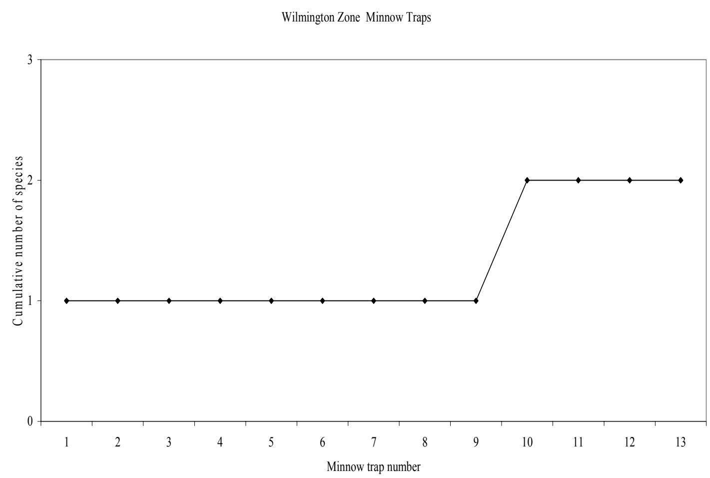

Wilmington Zone 1 Minnow Traps
Cumulative number of species
Minnow trap number

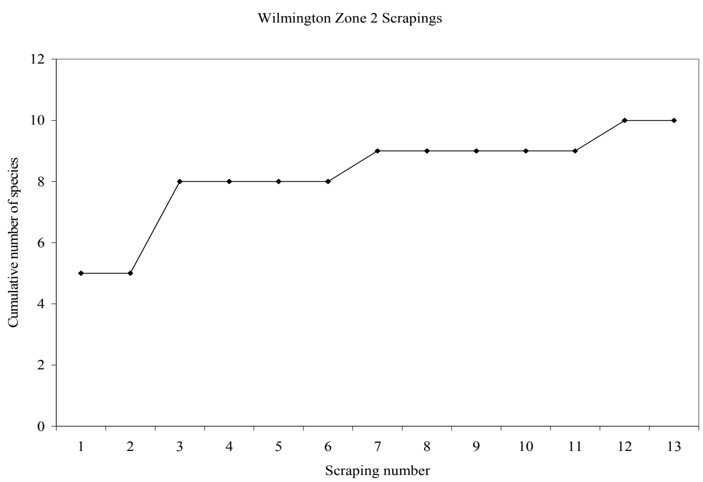

Wilmington Zone 1 Trawls
Cumulative number of species
Trawl number

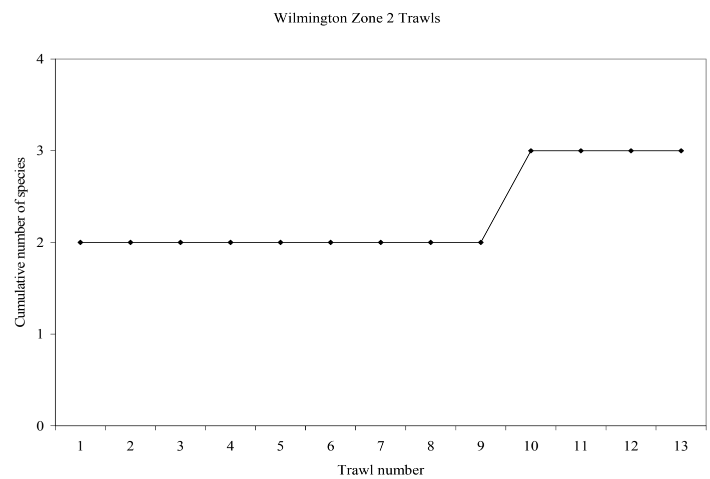

Wilmington Zone 2 Cores
Cumulative number of species
Core number

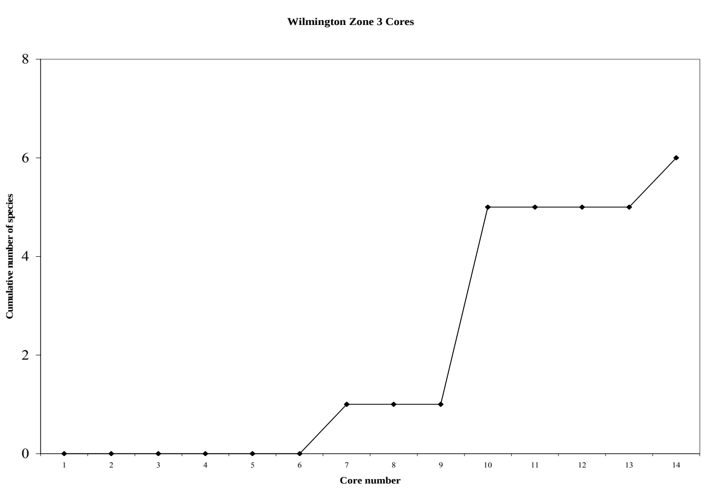

Wilmington Zone 2 Crab Traps
Cumulative number of species
Crab trap number

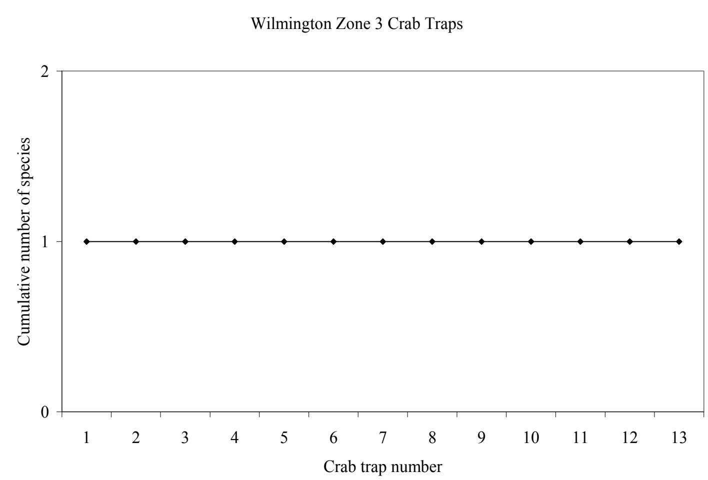

Wilmington Zone 2 Hester-Dendy Plates
Cumulative number of species
Hester-dendy plate number


Wilmington Zone Minnow Traps
Cumulative number of species
Minnow trap number

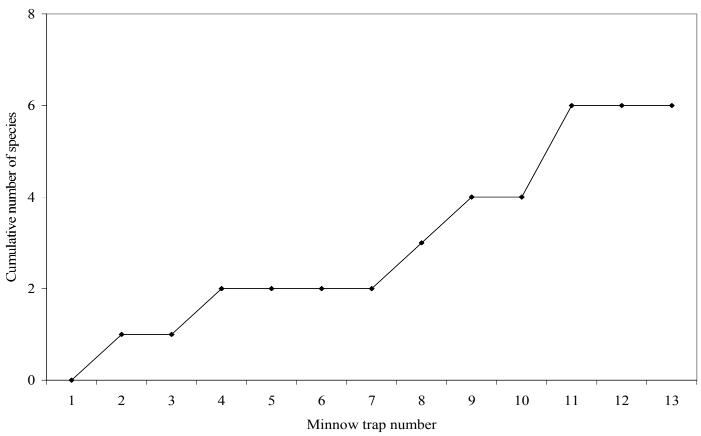

Wilmington Zone 2 Scrapings
Cumulative number of species
Scraping number


Wilmington Zone 2 Trawls
Cumulative number of species
Trawl number

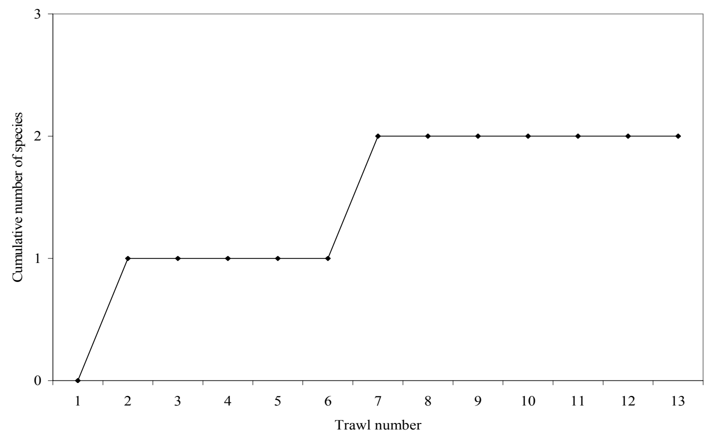

Wilmington Zone 3 Cores
Cumulative number of species
Core number


Wilmington Zone 3 Crab Traps
Cumulative number of species
Crab trap number

Wilmington Zone 3 Minnow Traps



Wilmington Zone 3 Trawls



APPENDIX 6. Biological Indices per Gear Type, Zone and Port.

LOCATION ID	Species Richness	Species Evenness	Shannon-Wiener Diversity Index
WIL01CO	26	0.770286643	2.509668245
WIL01CR	1	0	0
WIL01MI	3	0.719332904	0.790267968
WIL01TR	3	0.223736799	0.245799997
WIL02CO	11	0.816257242	1.957299382
WIL02CR	1	0	0
WIL02HD	14	0.520992759	1.374929759
WIL02MI	2	0.721928095	0.500402424
WIL02SC	10	0.028037163	0.064557953
WIL02TR	3	0.659535229	0.724573507
WIL03CO	6	0.64702544	1.159313959
WIL03CR	1	0	0
WIL03MI	6	0.819164624	1.467745971
WIL03TR	2	0.494182935	0.342541508
CHA01CO	22	0.867208033	2.680576845
CHA01CR	3	0.475301292	0.522171841
CHA01MI	5	0.934519555	1.504051202
CHA01TR	68	0.292359856	1.233614665
CHA02CO	12	0.287882702	0.71536164
CHA02CR	2	0.591672779	0.410116318
CHA02MI	8	0.57338766	1.19232612
CHA02TR	47	0.573262887	2.207146728
CHA02HD	26	0.651411745	2.122362351
CHA02SC	31	0.530171542	1.820602292
CHA03CO	5	0.651107993	1.047917889
CHA03CR	1	0	0
CHA03MI	6	0.581277304	1.041509114
CHA03TR	14	0.524589062	1.38442061
SAV01CO	3	0.113569711	0.12476908
SAV01CR	6	0.642596973	1.151379212
SAV01MI	5	0.798481175	1.285105875
SAV01TR	23	0.389812547	1.222254985
SAV02CO	5	0.337194832	0.542694146
SAV02CR	1	0	0

LOCATION ID	Species Richness	Species Evenness	Shannon-Wiener Diversity Index
SAV02MI	5	0.758924654	1.221442111
SAV02TR	6	0.114095956	0.204432509
SAV02HD	22	0.523576563	1.618397383
SAV02SC	33	0.567471855	1.984169631
SAV03CO	2	0.195909271	0.135793959
SAV03CR	1	0	0
SAV03MI	3	0.912733241	1.002739954
SAV03TR	4	0.05797053	0.080364218
JAX01CO	6	0.780617124	1.398678123
JAX01CR	16	0.446819963	1.238847991
JAX01MI	8	0.700255896	1.4561412
JAX01TR	41	0.540665487	2.00780025
JAX02CO	6	0.75878442	1.359559169
JAX02CR	3	0.937230563	1.029653014
JAX02MI	5	0.785489766	1.26419701
JAX02TR	15	0.54055792	1.463857985
JAX02HD	19	0.703477215	2.071345733
JAX02SC	22	0.646697172	1.998968413
JAX03CO	2	0.14854949	0.10296666
JAX03CR	1	0	0
JAX03MI	3	0.512218756	0.56272982
JAX03TR	16	0.606073901	1.680393663

APPENDIX 7. Federal Ballast Water Management Regulations

Mandatory Practices

For All Vessels with Ballast Tanks on All Waters of the United States, Regardless of Exclusive Economic Zone (EEZ) Entry (33 CFR 151.2035(a))

- Avoid ballast operations in or near marine sanctuaries, marine preserves, marine parks, or coral reefs.
- Avoid or minimize ballast water uptake:
    - Where infestation, harmful organisms and pathogens are located.
    - Near sewage outfalls.
    - Near dredging operations.
    - Where tidal flushing is poor or when a tidal stream is known to be more turbid.
    - In darkness when organisms may rise up in the water column.
    - In shallow water or where propellers may stir up the sediment.
    - Areas with pods of whales, convergence zones and boundaries of major currents
- Clean ballast tanks to remove sediment regularly.
- Only discharge minimal amounts of ballast water in coastal and internal waters.
- Rinse anchors and anchor chains during retrieval to remove organisms and sediments at their place of origin.
- Remove fouling organisms from hull, piping, and tanks on a regular basis and dispose of any removed substances in accordance with local, state and federal regulations.
- Maintain a vessel specific ballast water management plan.
- Train vessel personnel in ballast water and sediment management and treatment procedures.

Additional Mandatory Practices

For All Vessels transiting to U.S. Waters with ballast water that was taken on within 200 NM of any coast after operating beyond the U.S. EEZ (33 CFR151.2035(b))

Conduct one of the following:

a. conduct mid-ocean ballast water exchange prior to entering U.S. waters;
b. retain the ballast water on board while in U.S. water; or
c. use a Coast Guard approved alternative environmentally sound to treat the ballast water

Safety ─ BWM practices shall not jeopardize the safety of a vessel, its crew, or its passengers. Therefore, the master of a vessel will not be prohibited from discharging unexchanged ballast, in areas other than the Great Lakes and the Hudson River, if the master decides the practices would be a threat to safety, stability, or security due to adverse weather, vessel design equipment failure, or any other extraordinary condition. All vessels, however, must discharge only the minimal amount of ballast water operationally necessary and ensure ballast water records accurately reflect any reasons for not complying with the mandatory requirements.

Reporting and Recordkeeping Requirements ─ The master, owner, operator, person in charge, or vessel agent of any vessel equipped with ballast water tanks that is bound for ports or places of the United States, must ensure complete and accurate Ballast Water reporting Forms are submitted in accordance with 33 CFR 151.2041, and signed ballast water records the kept on board the vessel for a minimum of two years in accordance with 33 CFR 151.2045. All vessels, both foreign and domestic, that are bound for port or places in the U.S. and are equipped with ballast water tanks, must submit BWM reports, regardless of whether the vessels operated either 24 hours before arrival to each U.S. port or place of destination when a voyage is more than 24 hours; or before departing each port or place of departure when a voyage is less than 24 hours Penalties for failing to comply with the Mandatory BWM Requirements: Max. $27,500 per day; Willful violations= Class C felony.

Vessels <u>Exempt</u> from the Mandatory BWM Requirements: Crude oil tankers engaged in coastwise trade; Vessels of the Department of defense, Coast Guard, or any of the Armed Services as defined within 33 USC 1322 (a) and (n); Vessels that operate exclusively within one COTP zone

Source: http://www.uscg.mil/hq/g-m/mso/ans.htm

APPENDIX 8. Taxonomic Classification of Collected Species

Source (www.itis.usda.gov)

Phylum Annelida
- Class Polychaeta
  - Subclass Palpata
    - Order Aciculata
      - Suborder Eunicida
        - Family Eucinidae
          - *Marphysa sanguinea*
          - *Marphysa sp.*
          - *Marphysa sp. B*
        - Family Lumbrineridae
          - *Scoletoma tenuis*
        - Family Oenonidae
          - *Drilonereis longa*
        - Family Onuphidae
          - *Diopatra cuprea*
      - Suborder Phyllodocida
        - Family Glyceridae
          - *Glycera americana*
          - *Glycera dibranchiata*
          - *Glycera sp.*
        - Family Hesionidae
          - *Podarke obscura*
        - Family Nereididae
          - *Laeonereis culveri*
          - *Neanthes succinea*
          - *Nereis falsa*
        - Family Phyllodocidae
          - *Anaitides mucosa*
          - *Eteone heteropoda*
          - *Genetyllis castanea*
          - *Hesionura sp. A*
          - *Nereiphylla fragilis*
        - Family Pilargidae
          - *Parandalia (americana)*
          - *Parandalia sp.*
          - *Parandalia sp. A*
        - Family Polynoidae
          - *Lepidonotus sublevis*
          - *Polynoidae sp.*
        - Family Syllidae
          - *Autolytus cornutus*
          - *Dentatisyllis carolinae*
          - *Odontosyllis enopla*
          - *Streptosyllis pettiboneae*
          - *Syllis sp.*

Phylum Annelida Class Polychaeta Subclass Palpata

Order Canalipalpata
- Suborder Sabellida
  - Family Sabellariidae
    - *Sabellaria vulgaris*
    - *Sabellaria vulgaris beaufortensis*
    - *Sabellaria vulgaris vulgaris*
  - Family Sabellidae
    - *Demonax microphthalmus*
    - *Potamilla cf reniformis*
    - *Sabella sp. A*
  - Family Serpulidae
    - *Hydroides dianthus*
- Suborder Spionida
  - Family Spionidae
    - *Boccardia sp.*
    - *Boccardiella sp. A*
    - *Dispio uncinata*
    - *Marenzelleria viridis*
    - *Polydora ligni (cornuta)*
    - *Prionospio cristata*
    - *Spionidae sp.*
    - *Spiophanes bombyx*
    - *Streblospio benedicti*
- Suborder Terebellida
  - Family Cirratulidae
    - *Caulleriella killariensis*
    - *Cirratulidae sp.*
    - *Tharyx dorsobranchialis*
- Family Terebellidae
    - *Eupolymnia sp. A*
    - *Loimia medusa*
    - *Pista palmata*
    - *Polycirrus sp. B*
    - *Streblosoma hartmanae*

Subclass Scolecida
  - Family Capitellidae
    - *Capitella capitata*
    - *Capitellidae sp.*
    - *Heteromastus filiformis*
    - *Mediomastus californiensis*
    - *Mediomastus sp.*
  - Family Orbiniidae
    - *Leitoscoloplos fragilis*
    - *Orbinia ornata*
  - Family Paraonidae
    - *Aricidea suecica*
    - *Paraonis fulgens*
    - *Cirrophorus sp.*

Phylum Arthropoda
- Subphylum Crustacea
  - Class Maxillopoda
    - Subclass Copepoda
      - Infraclass Neocopepoda
        - Superorder Podoplea
          - Family Harpacticoida
            - *Harpacticoida sp.*
    - Subclass Thecostraca
      - Infraclass Cirripedia
        - Superorder Thoracica
          - Order Sessilia
            - Suborder Balanomorpha
              - Superfamily Balanoidea
                - Family Archaeobalanidae
                  - *Conopea galeata*
                - Family Balanidae
                  - *Balanus sp.*
                  - *Balanus amphitrite*
                  - *Balanus amphitrite amphitrite*
                  - *Balanus calidus*
                  - *Balanus eburneus*
                  - *Balanus improvisus*
                  - *Balanus juv. sp.*
                  - *Balanus spp.*
                  - *Balanus trigonus*
                  - *Balanus venustus*
              - Superfamily Coronuloidea
                - Family Chelonibiidae
                  - *Chelonibia testudinaria*
  - Class Malacostraca
    - Subclass Eumalacostraca
      - Superorder Percarida
        - Order Amphipoda
          - *Amphipoda spp.*
          - Suborder Gammaridea
            - Family Ampeliscidae
              - *Ampelisca abdita*
              - *Ampelisca verrilli*
            - Family Amphilochidae
              - *Amphilochus (spencebatei)*
            - Family Ampithoidae
              - *Ampithoe valida*
            - Family Aoridae
              - *Lembos smithi*
            - Family Bateidae
              - *Batea catharinensis*
            - Family Corophiidae
              - *Apocorophium lacustre*
              - *Corophium sp.*
              - *Corophium volutator*

Phylum Arthropoda
Subphylum Crustacea
Class Malacostraca
Subclass Eumalacostraca
Superorder Percarida
Order Amphipoda
Suborder Gammaridea

Family Corophiidae
- *Monocorophium acherusicum*

Family Crangonyctidae
- *Crangonyx pseudogracilis*
- *Crangonyx richmondensis*

Family Gammaridae
- *Gammarus fasciatus*
- *Gammarus tigrinus*

Family Haustoriidae
- *Parahaustorius holmesi*

Family Hyalidae
- *Hyale plumulosa*

Family Ischyroceridae
- *Ericthonius brasiliensis*
- *Jassa marmorata*

Family Leucothoidae
- *Leucothoe spinicarpa*
- *Leucothoe spinicarpa complex*

Family Liljeborgiidae
- *Listriella barnardi*

Family Melitidae
- *Dulichiella appendiculata*
- *Elasmopus levis*
- *Melita nitida*

Family Oedicerotidae
- *Monoculodes edwardsi*

Family Pleustidae
- *Pleusymtes glaber*

Family Stenothoidae
- *Stenothoe minuta*

Infraorder Caprellida
- Superfamily Caprelloidea
  - Family Caprellidae
    - *Caprella equilibra*
    - *Caprellidae sp.*

Superorder Eucarida
- Order Decapoda
  - *Decapoda sp.*
  - Suborder Dendrobranchiata
    - Superfamily Penaeoidea
      - Family Penaeidae
        - *Farfantepenaeus aztecus*
        - *Farfantepenaeus duorarum*
        - *Litopenaeus setiferus*
        - *Parapenaeus politus*
        - *Penaeidae sp.*
        - *Rimapenaeus constrictus*
        - *Xiphopenaeus kroyeri*

Phylum Arthropoda
Subphylum Crustacea
Class Malacostraca
Subclass Eumalacostraca
Superorder Eucarida
Order Decapoda

- Superfamily Sergestidae
  - Family Sergestidae
    - *Acetes americanus carolinae*
- Suborder Pleocyemata
  - Infraorder Anomura
    - Superfamily Galatheoidea
      - Family Porcellanidae
        - *Petrolisthes armatus*
    - Superfamily Hippoidea
      - Family Hippidae
        - *Emerita talpoida*
    - Superfamily Paguroidea
      - Family Diogenidae
        - *Clibanarius vittatus*
      - Family Paguridae
        - *Pagurus carolinensis*
        - *Pagurus longicarpus*
        - *Pagurus pollicaris*
        - *Pagurus sp.*
  - Infraorder Brachyura
    - Superfamily Grapsoidea
      - Family Grapsidae
        - *Pachygrapsus transversus*
      - Family Sesarmidae
        - *Armases (cinereum)*
    - Superfamily Majoidea
      - Family Majidae
        - *Libinia dubia*
      - Family Pisidae
        - *Pelia mutica*
    - Superfamily Ocypodoidea
      - Family Ocypodidae
        - *Uca juv. sp.*
        - *Uca pugilator*
        - *Uca sp.*
    - Superfamily Panopeidae
      - Family Panopeidae
        - *Dyspanopeus sayi*
        - *Eurypanopeus depressus*
        - *Panopeus herbstii*
        - *Rhithropanopeus harrisii*
      - Family Xanthidae
        - *Menippe mercenaria*
        - *Xanthidae juv. sp.*
        - *Xanthidae spp.*
        - *Xanthidae spp.1*
    - Superfamily Pinnotheroidea
      - Family Pinnotheridae
        - *Zaops ostreum*

Phylum Arthropoda
Subphylum Crustacea
Class Malacostraca
Subclass Eumalacostraca
Superorder Eucarida
Order Decapoda
Suborder Pleocyemata

- Superfamily Portunoidea
  - Family Portunidae
    - *Callinectes sapidus*
    - *Callinectes similis*
    - *Cronius sp.*
    - *Ovalipes sp.*
    - *Portunus gibbesii*
    - *Portunus sp.*
- Infraorder Caridea
  - *Caridea sp.*
  - Superfamily Alpheoidea
    - Family Alpheidae
      - *Alpheus heterochaelis*
      - *Synalpheus (townsendi)*
    - Family Hippolytidae
      - *Exhippolysmata oplophoroides*
      - *Latreutes parvulus*
      - *Lysmata wurdemanni*
      - *Thor sp.*
  - Superfamily Palaemonoidea
    - Family Palaemonidae
      - *Macrobrachium acanthurus*
      - *Palaemonetes pugio*
      - *Palaemonetes sp.*
      - *Palaemonetes vulgaris*
      - *Periclimenes longicaudata*
- Infraorder Thalassinidea
  - Superfamily Callianassoidea
    - Family Upogebiidae
      - *Upogebia affinis*
- Superorder Percarida
  - Order Isopoda
    - Suborder Anthuridea
      - Family Anthuridae
        - *Cyathura polita*
    - Suborder Epicaridea
      - Superfamily Bopyroidea
        - Family Bopyridae
          - *Probopyrus pandalicola*
          - *Progebiophilus upogebiae*
    - Suborder Flabellifera
      - Family Aegidae
        - *Rocinela americana*
      - Family Cymothoidae
        - *Anilocra (acuta)*
        - *Cymothoa excisa*
        - *Livoneca reniformis*
        - *Nerocila sp.*

Phylum Arthropoda Subphylum Crustacea Class Malacostraca Subclass Eumalacostraca Superorder Percarida Order Isopoda

Family Sphaeromatidae
- *Dynamene sp.*
- *Cassidinidea lunifrons*
- *Cassidinidea ovalis*
- *Sphaeroma quadridentatum*

Suborder Oniscidea
- Infraorder Ligiamorpha
  - Family Ligiidae
    - *Ligia exotica*

Suborder Valvifera
- Family Chaetilidae
  - *Chiridotea caeca*
- Family Holognathidae
  - *Cleantioides planicauda*
- Family Idoteidae
  - *Edotia sp.*
  - *Synidotea (nebulosa)*
  - *Synidotea sp.*

Order Mysida
- Family Mysidae
  - *Bowmaniella juv sp.*
  - *Brasilomysis castroi*
  - *Neomysis americana*

Order Mysidacea
- *Mysidacea sp.*

Subclass Hoplocarida

Order Stomatopoda
- Suborder Unipeltata
  - Superfamily Squilloidea
    - Family Squillidae
      - *Squilla empusa*
      - *Squilla juv. sp.*

Order Tanaidacea
- *Tanaidacea sp.*
- Suborder Tanaidomorpha
  - Superfamily Paratanaoidea
    - Family Leptocheliidae
      - *Hargeria rapax*
  - Superfamily Tanaoidea
    - Family Tanaidae
      - *Sinelobus stanfordi*

Class Ostracoda
- *Ostracoda sp.*

Phylum Molluska
- Class Bivalvia
  - Subclass Heterodonta
    - Order Arcoida
      - Family Arcidae
        - *Anadara floridana*
        - *Anadara notabilis*
        - *Anadara ovalis*
        - *Anadara transversa*
    - Order Myoida
      - Superfamily Myoidea
        - Family Corbulidae
          - *Corbula contracta*
        - Family Myidae
          - *Sphenia fragilis*
          - *Sphenia sp.*
      - Superfamily Pholadoidea
        - Family Pholadidae
          - *Barnea truncate*
  - Subclass Pteriomorphia
    - Order Mytiloida
      - Family Mytilidae
        - *Amygdalum papyrium*
        - *Brachidontes exustus*
        - *Geukensia demissa*
        - *Ischadium recurvum*
        - *Modiolus juv. sp.*
        - *Musculus lateralis*
        - *Mytilus edulis*
    - Order Ostreoidae
      - Family Ostreidae
        - *Crassostrea virginica*
        - *Ostrea equestris*
    - Order Veneroida
      - Superfamily Dreissenoidea
        - Family Dreissenidae
          - *Mytilopsis leucophaeata*
          - *Mytilopsis sp.*
      - Superfamily Mactroidea
        - Family Mactridae
          - *Raeta plicatella*
          - *Spisula solidissima similis*
      - Superfamily Tellinoidea
        - Family Semelidae
          - *Abra aequalis*
          - *Cumingia tellinoides*
        - Family Solecurtidae
          - *Tagelus plebeius*
        - Family Tellinidae
          - *Angulus texana*

Phylum Molluska
Class Bivalvia
Subclass Heterodonta

Superfamily Veneroidea
Family Veneridae
Chione elevate

Class Cephalopoda
Subclass Coleoidea
Superorder Decabrachia
Order Teuthida
Suborder Myopsina
Family Loliginidae
Lolliguncula brevis

Class Gastropoda
Order Heterostropha
Family Pyramidellidae
Boonea impressa

Order Neogastropoda
Family Columbellidae
Mitrella sp.
Family Muricidae
Urosalpinx sp.
Family Nassariidae
Nassarius obsoletus

Order Neotaenioglossa
Family Cerithiopsidae
Cerithiopsis sp.
Family Littorinidae
Littoraria irrorata
Family Ovulidae
Simnialena uniplicata
Family Triphoridae
Triphora sp.

APPENDIX 9 . Publications and Meeting Presentations

Scientific Journal Articles

Power, A.J., Walker, R.L., Payne, K. & Hurley, D. 2004. First occurrence of the nonindigenous green mussel, *Perna viridis* (Linnaeus, 1758) in coastal Georgia. Journal of Shellfish Research 23(3): 741-744.

News Articles:

- Interview broadcast on Georgia National Public Radio in early October 2003.
- http://www.savannahnow.com/stories/100603/LOC_invasives.shtml
- http://www.savannahnow.com/stories/100803/LOC_mussel.shtml
- http://www.thebrunswicknews.com/front/278823634242670.php
- http://www.islandpacket.com/news/local/story/3084920p-2805072c.html
- http://gce-lter.marsci.uga.edu/lter/research/pr/highlights.htm#mussels

Workshops & Meetings

South Georgia Invasive Species Workshop sponsored by the National Estuarine Research Reserve and The Nature Conservancy at the Coastal Georgia Community College, Brunswick Georgia on October 1, 2003.

Triennial Meeting of the National Shellfish Association, World Aquaculture Society, and American Fisheries Society in Honolulu, Hawaii on March 1-5, 2004.

Gulf & South Atlantic States Shellfish Conference sponsored by the Georgia Department of Agriculture and the Florida Department of Agriculture & Consumer Service, Division of Aquaculture at the Buccaneer Beach Resort on Jekyll Island on April 18-21, 2004.

Tidal Freshwater and Estuary Wetlands Restoration Workshop at DeSoto Hilton in Savannah, GA on June 22, 2004.

International Conference on Aquatic Invasive Species, Sonesta Beach Resort in Key Biscayne, FL on May 14-19, 2006.

APPENDIX 10. Abbreviations and Acronyms

ANSRP	Aquatic Nuisance Species Research Program
BMNV	Baculoviral midgut gland necrosis virus
BP	*Baculovirus penaei*
BSASP	Baltic Sea Alien Species Database
C	Carbon
CA	California
CHA	Charleston
CD	Compact disk
CIESM	International Commission for the Scientific Exploration of the Mediterranean Sea
C/N	Carbon to Nitrogen ratio
CO	Core sample
CR	Crab trap
CRIMP	CSIRO Research on Introduced Marine Pests
DDT	dichloro-diphenyl-trichloroethane
EIS	Environmental Impact Study
EPA	Environmental Protection Agency
EEZ	Exclusive Economic Zone
FL	Florida
FY	Fiscal Year
GA	Georgia
GPA	Georgia Ports Authority
GIS	Geographical Information System
GSMFC	Gulf States Marine Fisheries Commission
FEC	Florida East Coast Railway
HBS	Hawaii Biological Survey
HD	Hester Dendy Plate
HPV	Hepatopancreatic parvo-like virus
ICES	International Council for the Exploration of the Sea
ID	Identifier
IHHNV	Infectious hypodermal and hematopoietic necrosis virus

IMO	International Maritime Organization
ISSG	Invasive Species Specialist Group
JAA	Jacksonville Airport Authority
JAX	Jacksonville
JAXPORT	Jacksonville Seaport Authority
JPA	Jacksonville Port Authority
JSA	Joint Subcommittee on Aquaculture
LPV	Lymphoidal parvo-like virus
MBV	*Monodon baculovirus*
MEDML	Marine Ecosystem Dynamics Modeling Laboratory
MI	Minnow trap
MIT	Massachusetts Institute of Technology
MLW	Mean low water
MSL	Mean sea level
N	Nitrogen
NANCPA	Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990
NAS	Nonindigenous Aquatic Species
NBIC	National Ballast Information Clearing House
NBII	National Biological Information Infrastructure
NC	North Carolina
NCDENR	North Carolina Department of Environmental and Natural Resources
NEANS	Northeast Aquatic Nuisance Species Panel
NEMESIS	National Exotic Marine and Estuarine Species Information System
NIMPIS	National Introduced Marine Pest Information System
NIS	Nonindigenous species
NISA	National Invasive Species Act of 1996
NOAA	National Oceanic and Atmospheric Administration
NSWF	New South Wales Fisheries
NTG	Northern Territory Government
NZMF	New Zealand Ministries of Fisheries
OR	Oregon

ORTEP	Organotin Environmental Programme
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
RAS	Rapid Assessment Surveys
RLV	Reo-like virus
RO/RO	Roll-on/Roll-off
SAB	South Atlantic Bight
SAS	Statistical Analysis Software
SAV	Savannah
SC	Scraping sample
SC	South Carolina
S.E.	Standard error
SEAMAP	Southeast Area Monitoring and Assessment Program
SED	Sediment
SEQ	State of the Environment Queensland
SERC	Smithsonian Environmental Research Center
SPA	South Carolina State Ports Authority
SRS	Savannah River Site
SWIM	Surface Water Improvement and Management Act
TED	Turtle Exclude Device
TEUs	Twenty Foot Equivalent Unit
TR	Trawl
TSV	Taura Syndrome virus
USDOT	United States Department of Transportation
U.S.A.	United States of America
U.S.	United States
US	United States
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WA	Washington

WDFW Washington Department of Fish and Wildlife

WIL Wilmington

WGITMO Working Group on Introductions and Transfers of Marine Organisms

YHV Yellow-head virus

°C °Celsius

cm centimeter

cm/s centimeters per second

°F °Fahrenheit

ft feet

$/ft^2$ per square foot

g gram

hr hour

km kilometer

m meter

m^2 square meter

m/s meters per second

m^3/s cubic meters per second

m/km meters per kilometer

mg/l milligrams per liter

mm millimeter

mt metric tons

nm nautical mile

ppm parts per million

ppt parts per thousand

Φ phi

APPENDIX 11. New Barnacle in Coastal Georgia?

On June 22nd Captain Fendig collected unusual barnacles from the hull of a vessel that was being cleaned/surveyed in the Brunswick Landing boat yard. Ten specimens were collected; however these were among several noted. He passed the barnacles onto Mr. Henry Ansley with the Coastal Resources Division, Georgia Department of Natural Resources (CRD, GADNR). For the previous five months, the vessel had been at the Golden Isles Marina in Glynn County, GA, and prior to this was in West Florida.

On June 27th Mr. Brooks Good (CRD, GA DNR) contacted Dr. Alan Power with the Marine Extension Service (MAREX) with a request to identify the barnacles. They appeared to be a species of acorn barnacle, genus *Megabalanus*. Their basal diameter ranged from 5.2 mm to 18.5 mm, and height ranged from 2.8 mm to 13.8mm.

On June 28th Mr. John Crawford, a MAREX educator reported that he had recently observed dead specimens of these barnacles on two separate sea buoys that had washed ashore, one on Wassaw Island and the other on Ossabaw Island (see images below). We know that the No. 4 buoy on Ossabaw Island was previously anchored in the South Channel of Ossabaw Sound (81° 15", 31° 48' 15"). Some of the barnacles growing on these buoys apparently measured in the range of 60-80mm in diameter.

On June 29th numerous small (<3 mm diameter) specimens were also noted on the hull of our small research vessel which sits adjacent to our facilities in the Skidaway River on Skidaway Island near Savannah. This seems to indicate that the species has become established throughout coastal Georgia.

Based on the images taken below by Mr. Fran Lapolla (MAREX), Dr. William A. Newman (Professor of Biological Oceanography & Curator of Benthic Invertebrates, Emeritus, University of California, San Diego) has suggested that the species might be *Megabalanus coccopoma* (see page 179). A species native to the Pacific Coast of Central America, it is not known from the South Atlantic Bight region. The only published record of the species in the Gulf of Mexico, or the

Caribbean is Perreault (2004)[3] who describes an introduction in Louisiana.

Using the same photos, Mr. John Lewis (Head, Environmental Compliance & Biotechnology, Maritime Platforms Division, Defence Science & Technology Organisation, Australia) has identified the barnacle as *Megabalanus tintinnabulum*, one of the commonest megabalanids he is seeing on Australian ships. A cosmopolitan fouling species it is reported to have been introduced to Belgium, Australia, and Brazil (see page 182). This would be the first reported occurrence of this species in the South Atlantic Bight.

As of the completion of this report the species identity has not yet been confirmed.

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[3] Perreault, Ray T, 2004. An exotic tropical barnacle, *Megabalanus coccopoma* (Darwin, 1854), in Louisiana: its probable arrival and environmental implications. Proceedings of the Louisiana Academy of Sciences 66, 16 November 2003(2004): 13-16.

HAVE YOU SEEN ME?

A new acorn barnacle (genus *Megabalanus*) has been introduced to coastal Georgia, and has the potential to cause economical and ecological harm. The species has a conspicuous pink color. If found please record as much of the following information as possible to help document the invasion pattern:

Date

Location (GPS if available)

Approximate Number of Barnacles

Living or Dead

Attached to

Approximate Depth

Water Temperature & Salinity

Approximate Size (Width and Height)

Collectors Name & Contact information

Please send information to:
Dr. Alan Power
University of Georgia
Marine Extension Service
20 Ocean Science Circle
Savannah, GA 31411
Tel: (912) 598 2348
Fax: (912) 598 2399
Email: alanpowr@uga.edu

MAREX
The University of Georgia Marine Extension Service

Images Courtesy Fran Lapolla

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