

POTENTIAL FISHERIES IMPACT OF BALLAST WATER UPTAKE FROM LIQUEFIED
NATURAL GAS VESSELS AT THE SOUTHERN LNG-EL PASO, ELBA ISLAND
FACILITY IN SAVANNAH, GEORGIA

by

RANDI TYLER THOMPSON

A thesis submitted to the Graduate Faculty
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE IN MARINE SCIENCES

SAVANNAH STATE UNIVERSITY
MAY 2011

POTENTIAL FISHERIES IMPACT OF BALLAST WATER UPTAKE FROM LIQUEFIED
NATURAL GAS VESSELS AT THE SOUTHERN LNG-EL PASO, ELBA ISLAND
FACILITY IN SAVANNAH, GEORGIA

by

RANDI TYLER THOMPSON

Approved:

Thesis Advisor

Committee Members

Approved:

Director

Date of Thesis Defense

Dean, College of Sciences and Technology

Dean of Graduate Studies and Sponsored Research

ACKNOWLEDGEMENTS

Though there are many people to thank, I owe my adviser Dr. Matt Ogburn the biggest. Without his help, advice, support and cheering this project likely would have never finished. Dr. Jeff King and Dr. Matt Gilligan were also essential to this project, and as committee members I could not have asked for better. Captain Jay Rosenzweig designed, built, and put the sampling apparatus into place at Elba Island. SunBelt Rentals, who we rented the pump equipment from, were very accommodating and particularly Mr. Joe Crosby for giving me his time and patience with my lack of air compressor knowledge. Taxonomic assistance was generously provided by the RSMAS laboratory, particularly Dr. Joel Llopiz and Dr. Maria Criales.

Of course, without the funding from Southern LNG none of this would have been possible, so for that I am thankful. But in addition to that, the employees, the engineers, everyone at the Elba Island facility were inviting and very, very nice people. Without the staircase and plankton net holder they provided, my sampling would have been much, much harder. I will never forget my island and cryogenic tank tour, or my tour in the security boat around the island. I owe thanks to the security of Elba Island for being my photographers and keeping me company when sampling ran into the odd hours of the night.

Finally, my parents are due their thanks. They were pushing me to do my best, try my hardest, and make opportunities for myself since before kindergarten and this thesis has been no exception. Michael, my husband, turned our garage into a wet lab and our office into a taxonomy lab for me. He is the one that pushed me to go for this project, to make it happen, and to complete it – he has my love and gratitude always.

ABSTRACT

Southern Liquefied Natural Gas (SLNG) vessels offload their cargo of liquefied natural gas (LNG) at the SLNG-El Paso, Elba Island Facility in Savannah, Georgia. The vessels are required to withdraw 11.3 to 25.6 millions of gallons of Savannah River water as ballast at the SLNG-El Paso berthing slip prior to leaving port to maintain vessel stability. The purpose of this study was to determine if cumulative water uptake would have any impacts on local fisheries by removing fish, crab, or shrimp eggs, larvae, and/or juvenile stages from the river. Ballast water uptake was simulated on site at the Elba Island facility and entrained organisms were collected using a 200 μm mesh plankton net. Taxa were identified and analyzed for seasonal, tidal, and night/day differences. Seasonal and tidal phase differences were tested with a nonparametric Kruskal-Wallis One-Way ANOVA on Ranks, and all pairwise multiple comparisons were made using Dunn's Method. T-tests were performed for night and day data. Nine taxa of fish and nine invertebrate taxa were collected, but only three of these were somewhat commercially important and none were endangered or threatened. Fiddler crabs ($n = 6,797$) and mysids ($n = 5,659$) were the most abundant species in samples. Seasonal differences in abundance were the most common differences observed in this study with warmer months in having more organisms entrained. Crab larvae were also commonly more abundant at night. The LNG carriers could reduce fiddler crab entrainment by 96% and mud crab entrainment by 92% by avoiding night ballasting during summer months July-September. Fish entrainment could be reduced if ballasting was minimized to the maximum extent possible from February to May.

TABLE OF CONTENTS

BACKGROUND.....	1
INTRODUCTION	4
PROCEDURE	10
RESULTS	15
DISCUSSION	27
CONCLUSIONS	31
LITERATURE CITED	35

Background

In 2005, the Elba III Terminal Project was initiated and the review/approval process was completed in 2007 by the Federal Energy Regulatory Commission (FERC). The expansion adds 405,000 m³ storage capacity of liquefied natural gas (LNG) and it will require up to 299 additional ships annually. Because of the location of Elba Island within the Savannah River Estuary (SRE), the National Marine Fisheries Service (NMFS) and other resource agencies were concerned that the additional water intake from increased ship traffic could excessively impinge and entrain eggs or early larval stages of fish, crabs, and shrimp. As a part of the National Environmental Policy Act (NEPA), Southern LNG (SLNG) has agreed, to the maximum extent practicable, to use the results of this study to avoid the times of greatest potential fishery impact determined by time of day, tide phase, or season. Thus, the purposes of this study were to determine if the cumulative water uptake due to ballasting would have an impact on local fisheries, and if so what times are likely to have the least impact.

LNG is mostly methane (CH₄) that has been changed from the gaseous state to a liquid state by lowering the temperature to -162 °C (-260 °F). The liquid form occupies approximately 600 times less volume than that of the gaseous state, making LNG ideal for transportation and storage. LNG is typically transported from Algeria, Indonesia, Malaysia, Nigeria, Qatar, and Trinidad by ship to its destination in Savannah, Georgia.

SLNG is located on Elba Island, an 840-acre island, about five miles downstream of Savannah, Georgia, in Chatham County (Fig. 1). The Elba Island Terminal is a regasification and storage facility. Four major pipelines are directly connected to the facility, with two additional pipelines indirectly connected. The Elba Island LNG storage tanks are capable of holding 325,643,737,188 m³ and have 49,696,066 m³ per day of peak vaporization send-out capacity.

Once complete, the Elba Island expansion will allow for the facility to increase LNG storage to 444,574,493,378 m³ with a 59,890,131 m³ per day of peak vaporization send-out capacity.

LNG ships take on ballast water during offloading. The ballasting process is necessary to counteract the offloading LNG that exits the ship at a rate of approximately 10,000 m³/hr. A LNG vessel will take on ballast water for approximately 10 hours while offloading. The water is taken up through a dedicated ballast system that is typically located on the hull of the carrier. The amount of ballast water taken on board by a vessel is determined by the type and size of the ship and the amount of water it will take to keep the propellers immersed. Ranging from the smallest ship to the largest, LNG vessels will take on 11.3 to 25.6 millions of gallons of ballast water while berthed at the Elba Island facility. Additional water may be taken on if impending severe weather conditions exist that the vessel will experience upon departure.



Figure 1. Overhead view of the SLNG regasification facility on Elba Island, Savannah, Georgia.

Introduction

In the last few decades, the use of ballast water has generated considerable concern because of the transportation of invasive species by ships. However, ballasting also has the potential to adversely affect the sustainability of aquatic organisms in the location from which the ballast water was derived. Ballasting is the process by which ships take on water and store it in onboard tanks to balance out the weight loss from offloading cargo (Firestone and Corbett, 2005). The term ballast “water” can be a misnomer because the water contains organisms that were present in the aquatic environment (Firestone and Corbett, 2005). The use of ballast to stabilize ships started when the Phoenicians began to trade by sea (Firestone and Corbett, 2005). Two changes during the industrial era greatly increased the rate of species transfer from one aquatic environment to another (Firestone and Corbett, 2005). The first was a shift from the use of solid ballast, such as stones, to water ballast (Firestone and Corbett, 2005). The second was the globalization of trade and the associated increase in the number, size, and speed of ships that trade by sea (Firestone and Corbett, 2005).

Projects such as ship ballasting that divert water are a source of fish mortality and injury (NOAA, 1994). Since eggs and larval stages of fish are small and planktonic, these early life stages are most susceptible to ballast water uptake (NOAA, 1994). Withdrawal of water for long periods adds another source of mortality to early life stages of fish and invertebrates and may adversely affect their populations (Travnichek et al., 1993). Recruitment and year class strength may also be affected (Travnichek et al., 1993). The entrainment of fish and invertebrates that become entrained in ballast can have both immediate and future impacts to the river, estuary, and surrounding ecosystem (Rago, 1984). Entrainment is defined as the movement of aquatic organisms from their habitat into a surface diversion or through, under, or around screens that

results in the loss of the organisms from the population (USGS, 2006). The impacts of entrainment include loss of biomass from the aquatic system, loss of future reproductive potential, and the availability of food for predators (Rago, 1984).

Millions of gallons of water and the various life stages of invertebrates and fish are rapidly pulled from the river into ballast tanks of LNG carriers for hours at a time. A 200,000 m³ capacity LNG carrier could take on 19 million gallons of water in approximately 10 hours, taking large numbers of the organisms in the area along with the boarding water. A proposed offshore LNG degasification facility in Maine that uses a closed loop system similar to the Elba Island facility has the potential to entrain millions of eggs and larvae of Atlantic mackerel (*Scomber scombrus*) and pollock (*Pollachius virens*) annually due to ballast water uptake (USGS, 2006). I hypothesize that the Elba Island facility will also entrain a variety of estuarine organisms.

Extensive numbers of organisms have been found in ballast in previous research. Ballast water from 159 vessels that originated from Japan was sampled from Coos Bay, Oregon (Carlton and Gellar, 1993). The ballast from these ships contained 16 animal and 3 protist phyla (Carlton and Gellar, 1993). Most of the observed taxa had a planktonic phase in their life cycle (Carlton and Gellar, 1993). Organisms with short planktonic life history stages are not as likely to be dispersed by ballast because they spend less time in the water column (Carlton and Gellar, 1993). The dispersal of early life stages is important to the population dynamics of mature organisms with limited dispersal (Largier, 2003). Therefore, if vessels are taking up ballast during these specific early life history stages increments, organisms could possibly be entrained and killed. A taxonomically diverse community of organisms is captured and moved in ballast water from ports throughout the world (Carlton and Gellar, 1993). Hebert and Cristescu (2002) projected that the rate of human-mediated spreading of crustacean zooplankton to the Great Lakes

surpasses the natural rate by up to 50,000 fold. Kolar and Lodge (2002) suggested that changes in the seasonal timing and site of ballasting could lessen the risk of introducing new invasive species to the Great Lakes. The risk of entrainment might also be reduced if ballast water could be drawn from the upper part of the water column (Kolar and Lodge, 2002).

The Elba Island LNG terminal is located in the Savannah River Estuary (SRE). The SRE is home to several federally managed estuarine species, as well as Essential Fish Habitats (EFH) (Jennings, 2002). NMFS defines an EFH within estuaries as emergent vegetation (salt marsh and brackish marsh), estuarine shrub/scrub (mangroves), seagrass, oyster reefs and shell banks, intertidal flats, palustrine emergent and forested (freshwater wetlands), and the estuarine water column. Estuarine fishes vary in their use of these habitats both spatially and temporally (Jennings, 2002). Estuaries are inhabited by some species year-round (Nelson, 1991). Other species only use the estuaries for certain life stages (Nelson, 1991). Nelson (1991) characterized the latter organisms into four categories: 1) diadromous species and those species that use the estuary as nurseries, 2) species that use the estuary for spawning, 3) species that release their eggs or young at the mouth of the estuary and depend on tidal and wind currents to carry the plankton to the nursery areas, and 4) species that enter the estuary to feed or live during certain optimal times of the year. The uptake of estuarine water in ballast hinders the immigration and retention of early life history stages (Olm III, 1994), and is most likely to affect types 1-3.

The Center for Coastal Monitoring and Assessment (CCMA) database compiled by NOAA's Estuarine Living Marine Resources (ELMR), suggests that a number of fish and invertebrate species should be present in the SRE in varying stages of their life history. In it, species are ranked from not present (given the value 0) to highly abundant (given the value 5). At salinities ranging from 0.5-25 ppt and life stages of eggs, larvae, and juveniles, several fish and

invertebrate species are expected to be abundant or highly abundant in the sample area of Elba Island (Table 1). All three life stages of the bay anchovy, daggerblade grass shrimp, sheephead minnow and the juveniles of Atlantic croaker, spotted seatrout, silversides, spot, white shrimp and striped mullet, among other species, are projected to be present at various times of year in the SRE at Elba Island.

Additionally, the SRE is habitat to the shortnose sturgeon (*Acipenser brevirostrum*). The shortnose sturgeon is listed as endangered, meaning it is in danger of extinction throughout all or a significant portion of its range. Shortnose sturgeon populations have been depleted because of dams, pollution, and over-harvesting (Kuga, 1998).

NMFS is a federal agency under NOAA and a division of the Department of Commerce. NMFS is responsible for the management, conservation, and protection of the marine resources of the U.S. The expansion at Elba Island falls under the jurisdiction of NMFS, among other resource agencies. The expansion is also governed by the Magnuson-Stephenson Act, which assesses impacts to fishery resources. This includes the different life stages of all relevant species, their habitats, and their food sources. To meet NMFS requirements, SLNG prepared an Essential Fish Habitat Assessment (EFHA). The data from the EFHA and additional sources provided that at any given time of year, the facility had a potential to impact fishery resources, especially when temperatures are warmer (Goldstein and Goldstein, 2008).

The main objective of this study was to find windows that may have adverse effects to the estuarine organisms in the SRE around Elba Island. Daylight and nighttime hours were considered as a factor, since planktonic organisms will migrate in the water column corresponding with the presence or absence of sunlight. The tidal influence in the SRE is large with mean tidal range of 2.5 m (8.1 ft). I hypothesize that species present in samples will be

influenced by the tide. Lastly, seasonal differences are expected to be found in this study. Most species are present and absent during certain times of the year, but seasonal differences in organismal abundance in the SRE around Elba Island at a depth of 9 m (30 ft) are not known.

The specific objectives of this study were as follows:

1. To collect samples of water at the approximate location and depth of ballast water uptake at SLNG
2. To identify times when entrained organisms were most abundant
3. To make recommendations on times when LNG vessels should avoid ballast water uptake to minimize fisheries impacts

Table 1. Savannah River Estuary species that are present at salinities of 0.5-25ppt. where 5 is highly abundant, 4 is abundant, 3 is common, 2 is rare, and 0 is not present.*

Common Name	life stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
bay anchovy	eggs	0	0	0	0	5	5	5	5	5	5	0	0
daggerblade grass shrimp	eggs	0	0	0	0	4	4	4	4	4	4	0	0
sheephead minnow	eggs	0	0	4	4	4	4	4	4	4	4	0	0
Atlantic croaker	larvae	4	4	4	4	0	0	0	0	0	0	3	3
Atlantic menhaden	larvae	4	4	4	4	3	2	0	0	0	0	0	4
bay anchovy	larvae	0	0	0	0	5	5	5	5	5	5	5	0
daggerblade grass shrimp	larvae	0	0	0	0	4	4	4	4	4	4	4	0
hogchoker	larvae	0	0	0	0	3	3	4	3	3	3	0	0
sheephead minnow	larvae	0	0	4	4	4	4	4	4	4	4	4	0
spot	larvae	4	4	4	4	3	3	0	0	0	0	0	0
weakfish	larvae	0	0	0	4	4	4	4	4	4	3	3	0
Atlantic croaker	juveniles	3	3	4	5	5	5	5	5	5	5	4	3
Atlantic menhaden	juveniles	3	3	4	4	4	4	4	4	4	4	3	3
bay anchovy	juveniles	5	5	5	5	5	5	5	5	5	5	5	5
blue crab	juveniles	3	3	4	4	4	4	4	4	4	4	4	3
brown shrimp	juveniles	3	3	3	3	3	4	4	4	3	3	3	3
daggerblade grass shrimp	juveniles	4	4	4	4	4	4	4	4	4	4	4	4
hardhead catfish	juveniles	0	0	0	3	4	4	4	4	4	4	3	0
pinfish	juveniles	2	2	2	2	3	4	4	4	3	3	3	2
red drum	juveniles	3	3	3	3	3	3	3	3	4	4	4	4
sheephead	juveniles	3	3	3	3	3	3	3	3	4	4	4	3
sheephead minnow	juveniles	4	4	4	4	4	4	4	4	4	4	4	4
silver perch	juveniles	3	3	3	4	4	4	4	4	4	4	4	3
silversides	juveniles	4	4	4	4	4	4	4	4	4	4	4	4
southern flounder	juveniles	3	3	3	4	4	4	4	4	4	4	4	3
southern kingfish	juveniles	3	3	4	4	4	4	4	4	4	3	3	3
spot	juveniles	3	4	4	5	5	5	5	5	5	4	4	3
spotted seatrout	juveniles	4	4	3	3	3	4	4	4	4	4	4	4
star drum	juveniles	3	3	4	4	4	4	4	4	4	4	4	3
striped mullet	juveniles	4	4	4	5	5	5	5	5	5	5	5	4
weakfish	juveniles	3	3	3	3	3	3	5	5	5	3	3	3
white shrimp	juveniles	3	3	3	4	4	5	5	5	5	5	4	3

*Table from the Center for Coastal Monitoring and Assessment (CCMA) database compiled by NOAA's ELMR.

Procedure

A 3" air diaphragm pump was installed on the deck of the north dock where some of the SLNG carriers dock at the Elba Island site on the Savannah River, Georgia (Fig. 2). The pump was powered by a 185 CFM (ft³/minute) diesel-powered air compressor and was connected to a sampling apparatus using 2 suction hoses. The sampling apparatus, consisting of a fiberglass tank and associated piping, was stationed on the adjacent bank (Fig. 3). The water intake hose (0.152 m diameter opening) was submerged 9 m below the surface of the water for all sampling. A float was attached to the hose to ensure that the intake of the hose remained at 9 m depth with the rise and fall of the tides. The LNG carriers typically have 5 mm screen to protect larger marine organisms from being sucked into the ballast tanks, so a similar 5 mm screen was placed on the end of the intake hose. This setup approximated the depth in the water column and intake equipment of most of the LNG carriers. To collect each sample, the pump was turned on and the flow of water was sampled for two-hour increments for each sample. The pump was set to take water from the estuary at a rate between 5,100 gal/hr and 3,730 gal/hr, which is comparable to the rate that the ships take on water via sea chests.

The flow of water from the berthing slip was directed into a 0.5 m diameter, 2 m long plankton net (200 µm mesh size) that was suspended in the sampling apparatus (Fig. 3). The net was mostly submerged into the tank, but the rim remained resting above the water line. Positioning the plankton net in the tank of water helped keep the organisms intact for later identification. At the end of each collection period, the net was removed from the water and then the contents of the net were washed down into the cod end using a portable pressure washer.

After washing the organisms down, the water was drained off using a 200 μm mesh size sieve. The organisms were preserved in a 90% ethanol solution on site.

Samples were collected during an approximately 1-week period in each of the four seasons (fall: 22-29 October 2008; winter: 6-16 February 2009; spring: 12-22 May 2009; summer: 31 August – 7 September 2009). A total of sixty-four samples were collected. Samples were collected during both day and night, with forty-three samples collected during daylight hours and twenty-one samples collected after dark. Sampling targeted different tide stages including high ($n = 13$), low ($n = 12$), flood ($n = 18$), and ebb tides ($n = 21$). Water quality measurements, temperature, salinity, dissolved oxygen, and percent oxygen saturation, were taken using a YSI 85 before, during, and at the end of all sample collection times from the water pumped into the fiberglass tank.

All organisms were sorted, identified, and counted in the laboratory with the aid of a lighted magnifying glass and a dissecting scope. The samples were separated into major groups first, such as fish, crabs, and shrimp, and then further separated by species. Larvae and juveniles were identified to the lowest possible taxon (Richards, 2005; Williams, 1984; SERTC, 2005; Ogburn et al., 2011) and grouped together for analyses. No eggs were collected, although this cannot rule out the possibility that they may have broken apart in the sampling process.

Statistical Analyses

Data were tested for normality, but as is expected for count data, they were not normally distributed. The data were square root transformed, which is the standard transformation for count data. After the data were square root transformed, they were still not normally distributed, nor did they have equal variance. Therefore, seasonal and tidal phase differences were tested

with the nonparametric Kruskal-Wallis One-Way ANOVA on Ranks, and all pairwise multiple comparisons were made using Dunn's Method. Mann-Whitney Rank Sum Tests were performed for night and day data.

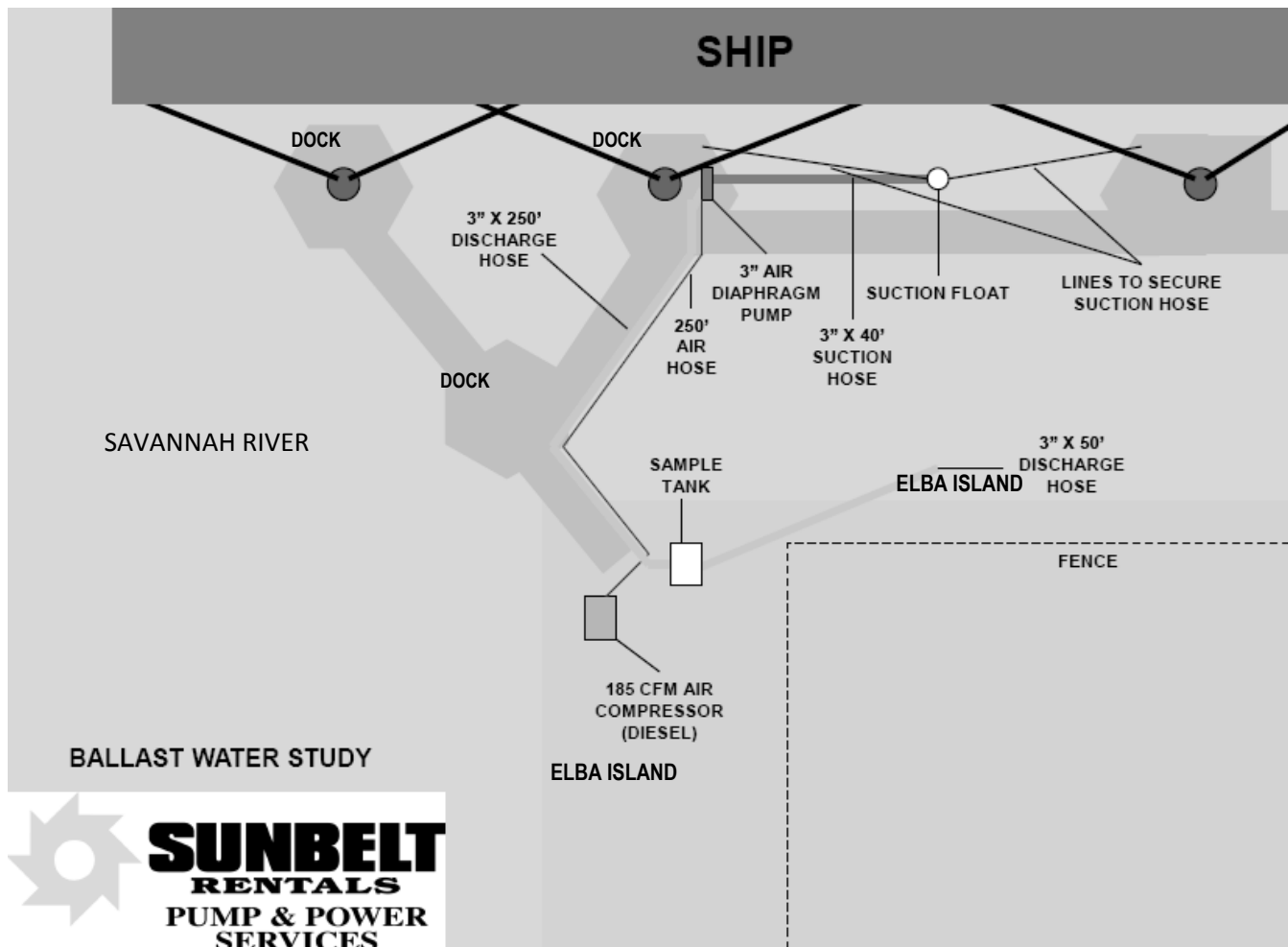


Figure 2. Diagram of sample collection site and equipment (plan view).



Figure 3. Side view of the sampling apparatus showing water flowing into the center of the tank.

Results

Nine fish and nine invertebrate taxa were collected (Table 3,4). A total of 15,375 individuals were identified in this study, in 126.25 hours of sampling. Some taxa were collected too sparingly to perform statistical analyses and only organisms that appeared in five or more samples were analyzed. Of the fish taxa, Atlantic croakers (*Micropogonias undulates*) (n = 16), silver perch (*Bairdiella chrysoura*) (n = 96), Atlantic silversides (*Menidia menidia*) (n = 410), and an unidentified species (n = 212) were abundant enough for statistical analysis. Mysids (*Mysidopsis bahia*) (n = 5,659), daggerblade grass shrimp (*Palaemonetes pugio*) (n = 663), fiddler crabs (*Uca spp*) (n = 6,797), mud crabs (*Panopeus spp*) (n = 1,364), and stone crabs (*Menippe mercenaria*) (n = 99) were analyzed statistically. Larvae and juveniles were grouped together for analysis. No eggs were collected in any samples.

Invertebrates

Season

Invertebrate densities varied by season. All invertebrates except the stone crab ($h = 7.1$, $df = 3$, $p = 0.068$) showed seasonal differences. Mysids were found in all seasons, with the highest densities occurring in fall (10 ± 12 per sample) and the second highest in winter (6 ± 9 per sample) and spring (6 ± 8 per sample) (Fig. 4). There was a significant difference in mysid density between fall and summer ($h = 12$, $df = 3$, $p = 0.007$). Daggerblade grass shrimp were present in all seasons, but densities were significantly higher in spring (4 ± 3 per sample) and summer (3 ± 2 per sample) ($h = 17.4$, $df = 3$, $p = <0.001$) than fall (1 ± 1 per sample) and winter (1 ± 1 per sample) (Fig. 4). Fiddler crabs were predominantly found in samples in the summer (9 ± 18 per sample) and very few in the winter (1 ± 0 per sample) ($h = 16.5$, $df = 3$, $p = 0.001$) (Fig.

3). Mud crabs densities were significantly higher in summer (5 ± 7 per sample), than in fall (1 ± 0 per sample) ($h = 8$, $df = 3$, $p = 0.047$) (Fig. 4).

Night/Day

Three of the 9 species analyzed showed differences in density among day and night. Fiddler crab megalopae (8 ± 17 per sample at night, 1 ± 2 per sample during day), mud crab megalopae (4 ± 7 per sample at night, 1 ± 1 per sample during day), and stone crab megalopae (1 ± 1 per sample at night, 1 ± 0 per sample during day), were significantly more abundant [($t = -2.6$, $df = 62$, $p = 0.013$); ($t = -2.8$, $df = 62$, $p = 0.007$); ($t = -2.6$, $df = 62$, $p = 0.001$), respectively] in the night time samples (Fig. 5). Mysids (6 ± 7 per sample at night, 5 ± 9 per sample during day) and grass shrimp (3 ± 3 per sample at night, 2 ± 2 per sample during day) showed no statistical differences between night and day.

Tide phase

Few differences were observed in any taxa among tide phases. Mysids were the only taxa to show a statistically different density, with more mysids being captured in high (7 ± 9 per sample at high tide) and ebb (8 ± 11 per sample at ebb tide) tides than low tides (2 ± 2 per sample at low tide) ($h = 9.1$, $df = 3$, $p = 0.027$) (Fig. 6). Fiddler and mud crabs were also collected in high densities during high tide (8 ± 20 per sample at high tide, 4 ± 8 per sample at high tide, respectively), but these differences were not statistically significant ($h = 1.9$, $df = 3$, $p = 0.59$; $h = 1.6$, $df = 3$, $p = 0.65$).

Lunar cycles

The four sampling weeks captured two full moons, one new moon, and one three quarters moon. 67% of all crabs were captured in a single sampling that coincided with the full moon on September 2009. The full moon sample from February 2009, however, only had 4 mud crabs, but this may be because crab megalopae were primarily collected in summer.

Fish

Season

Most fish taxa were only caught in one season, so seasonal statistical differences were absent (Fig. 7). Atlantic croaker was found in fall (1 ± 1 per sample) and winter (1 ± 0 per sample), but not statistically different ($h = 10.3$, $df = 3$, $p = 0.096$). Silversides and silver perch were only present in spring samples (3 ± 1 per sample, 7 ± 10 per sample, respectively). The unidentified species samples were collected only in the summer with 89.6% occurring in a single sample taken on 7 September 2009 (12 ± 43 per sample).

Night/Day

No fish taxa showed any statistical difference between night and day capture (Fig. 8). Atlantic croaker were present in both night (1 ± 0 per sample at night) and day (1 ± 0 per sample during day). Almost all of the unknown taxa were caught in a single sample during among the day samples (5 ± 29 per sample during day) and were not statistically different from the night samples (1 ± 2 per sample at night).

Tide phase

No fish species were found in one particular tide more often than another (Fig. 9). High tide for Atlantic croaker was not statistically different from low tide (1 ± 0 per sample at high tide, 1 ± 0 per sample at low tide, $h = 1.9$, $df = 3$, $p = 0.6$). Silversides were mostly found in ebb tide samples (2 ± 4 per sample at ebb tide) and silver perch were mostly among low tide samples (6 ± 12 per sample at low tide).

Water Quality

Most of the variability in salinity, temperature, and oxygen was due to seasonal differences. Salinity ranged from 16.5 ± 3.5 per sample in the spring to 21.6 ± 2.1 per sample in the fall (Table 5), indicating that the estuary around the Elba Island facility is brackish. Oxygen saturation was nearly 100% (98.8 ± 5.1 ml/l) in the winter, when the average water temperature was 11.8 ± 1.03 °C (Table 5). Low dissolved oxygen was never observed (Table 5).

Table 3: Total number of individual fish collected in all samples at Elba Island site, Savannah, Georgia.

Family	Species	Common Name	fall (n = 11)	winter (n = 18)	spring (n = 16)	summer (n = 19)
Sciaenidae	<i>Micropogonias undulatus</i>	Atlantic croaker	7	9	0	0
	<i>Leiostomus xanthurus</i>	spot	0	2	0	0
	<i>Bairdiella chrysoura</i>	silver perch	0	0	96	0
	<i>Cynoscion nebulosus</i>	spotted seatrout	0	0	12	1
Atherinidae	<i>Menidia menidia</i>	Atlantic silverside	0	0	410	0
Carangidae	<i>Chloroscombrus chrysurus</i>	Atlantic bumper	0	0	1	0
Sparidae	<i>Stenotomus caprinus</i>	longspine porgy	0	0	1	0
Mugilidae	<i>Mugil curema</i>	silver mullet	0	1	0	0
unknown	unknown	unknown species	0	0	0	212

Table 4: Total number of individual invertebrates collected in all samples at Elba Island site, Savannah, Georgia.

Family	Species	Common name	fall (n = 11)	winter (n = 18)	spring (n = 16)	summer (n = 19)
Mysidae	<i>Mysidopsis bahia</i>	mysid	2,295	1,840	1,409	115
Palaemonidae	<i>Palaemonetes spp</i>	daggerblade grass shrimp	12	42	372	237
Ocypodidae	<i>Uca spp</i>	fiddler crab	1	0	84	6,712
Panopeidae	<i>Panopeus</i>	mud crab	1	24	30	1,309
Menippidae	<i>Menippe mercenaria</i>	stone crab	30	0	5	64
Porcellanidae	<i>Petrolisthes armatus</i>	green porcelian crab	1	7	0	1
Portunidae	<i>Callinectes similis</i>	lesser blue crab	0	0	1	1
Pinnotheridae	<i>Parapinnixa hendersoni</i>		0	0	18	0
	<i>Zaops ostreus</i>	oyster crab	12	0	0	0

Table 5: Average temperature, salinity, dissolved oxygen, and oxygen saturation % for ballast water simulation samplings at Elba Island Site, Savannah, Georgia.

	temp (C°)	salinity	dissolved oxygen (mg/l)	oxygen saturation %
fall 2008 (n = 11)	19.9 ± 1.1	21.6 ± 2.1	7.5 ± 0.7	92.2 ± 5.7
winter 2009 (n = 18)	11.8 ± 1.0	19.5 ± 2.8	9.1 ± .1	98.8 ± 5.1
spring 2009 (n = 16)	23.6 ± 1.6	16.5 ± 3.5	7.2 ± 0.2	82.4 ± 2.7
summer 2009 (n = 19)	28.2 ± 0.7	18.7 ± 2.5	6.2 ± 0.4	86.7 ± 5.5

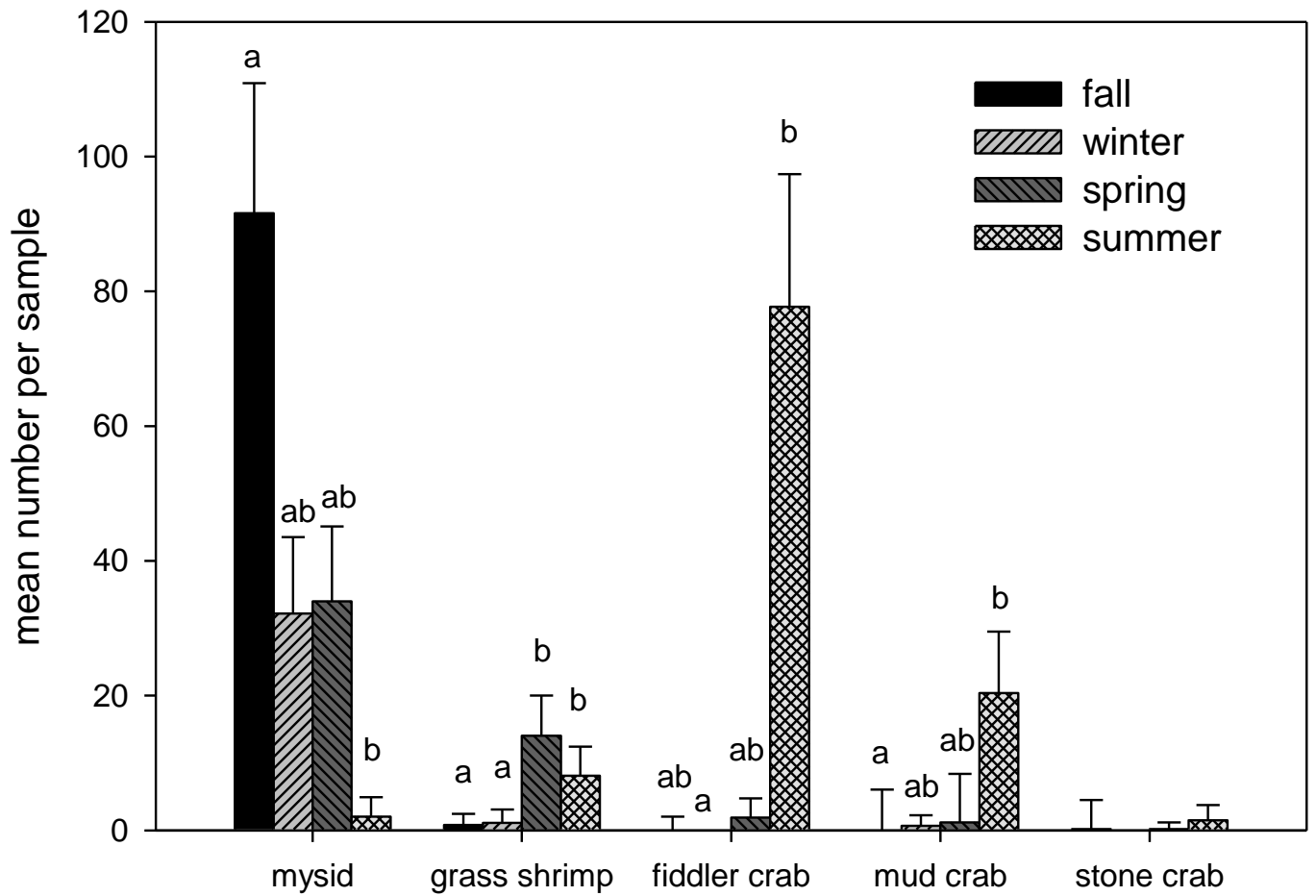


Figure 4. Mean number of invertebrate taxa collected in each season. Letters indicate statistically significant difference among seasons for each taxon. Species labeled with a are statistically different from those labeled b, but different from those labeled ab.

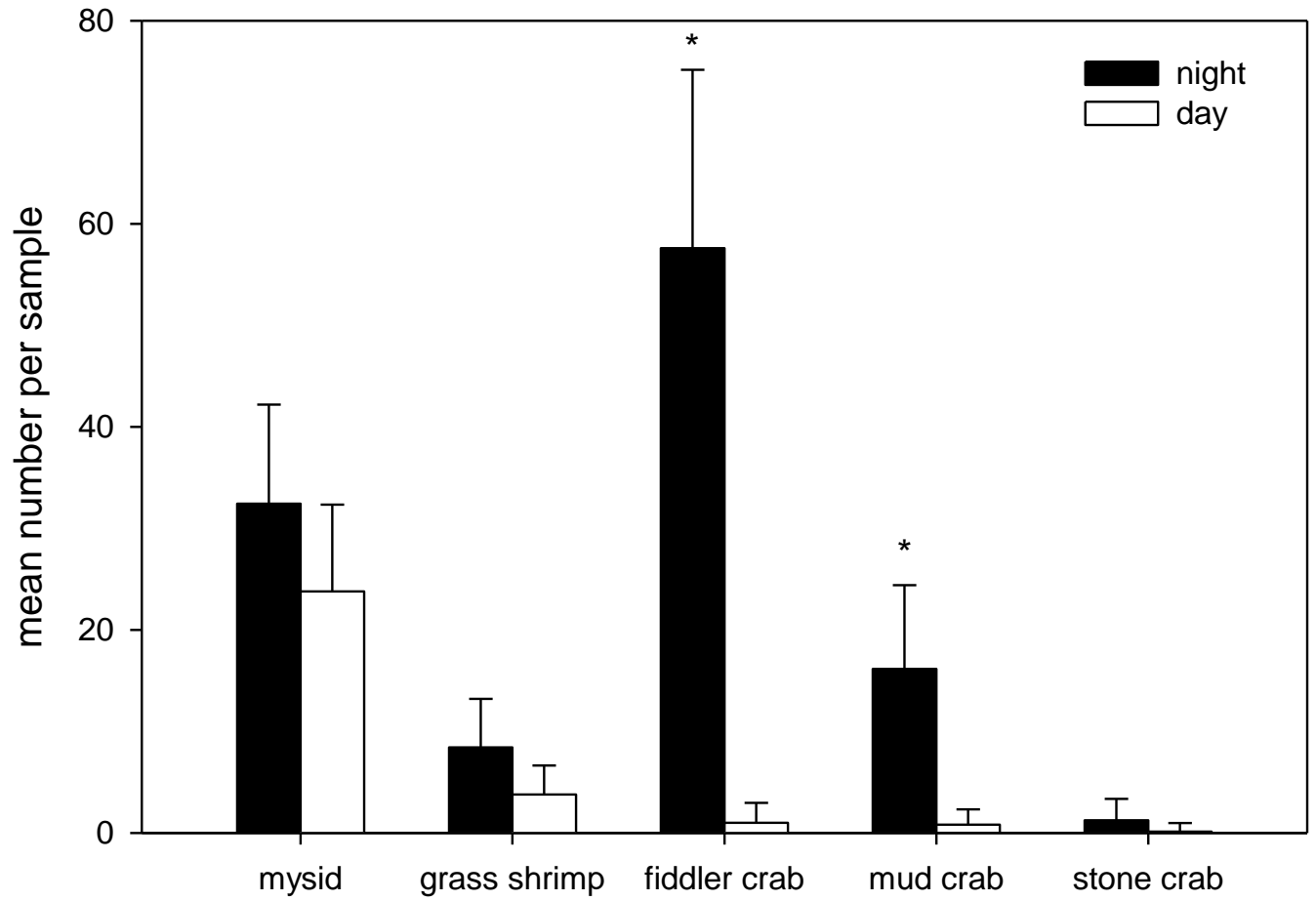


Figure 5. Mean number of the most abundant taxa during night and day. Statistically significant differences are indicated by asterisks.

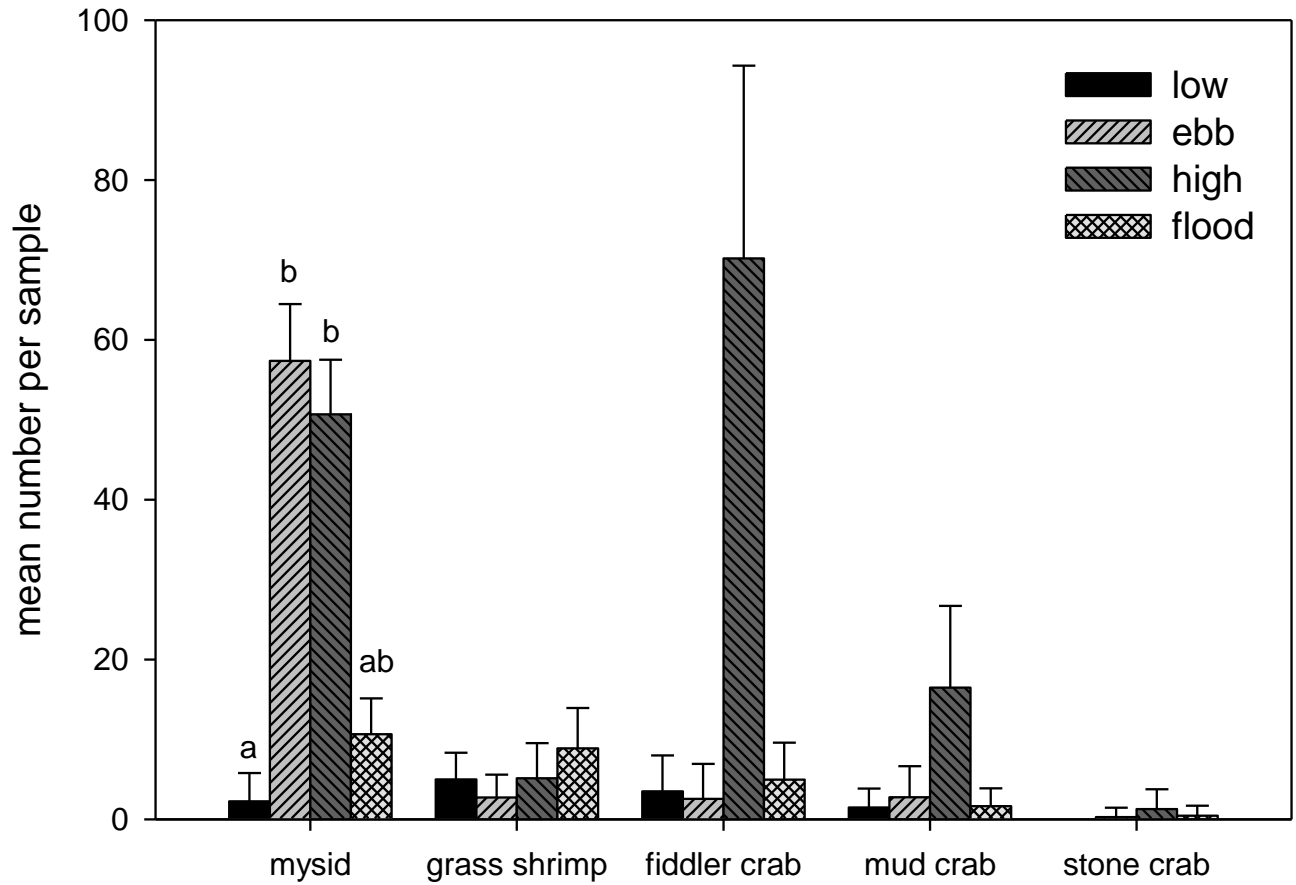


Figure 6. Mean number of invertebrate taxa collected during each tide phase. Letters indicate statistically significant difference among seasons for each taxon. Species labeled with a are statistically different from those labeled b, but different from those labeled ab.

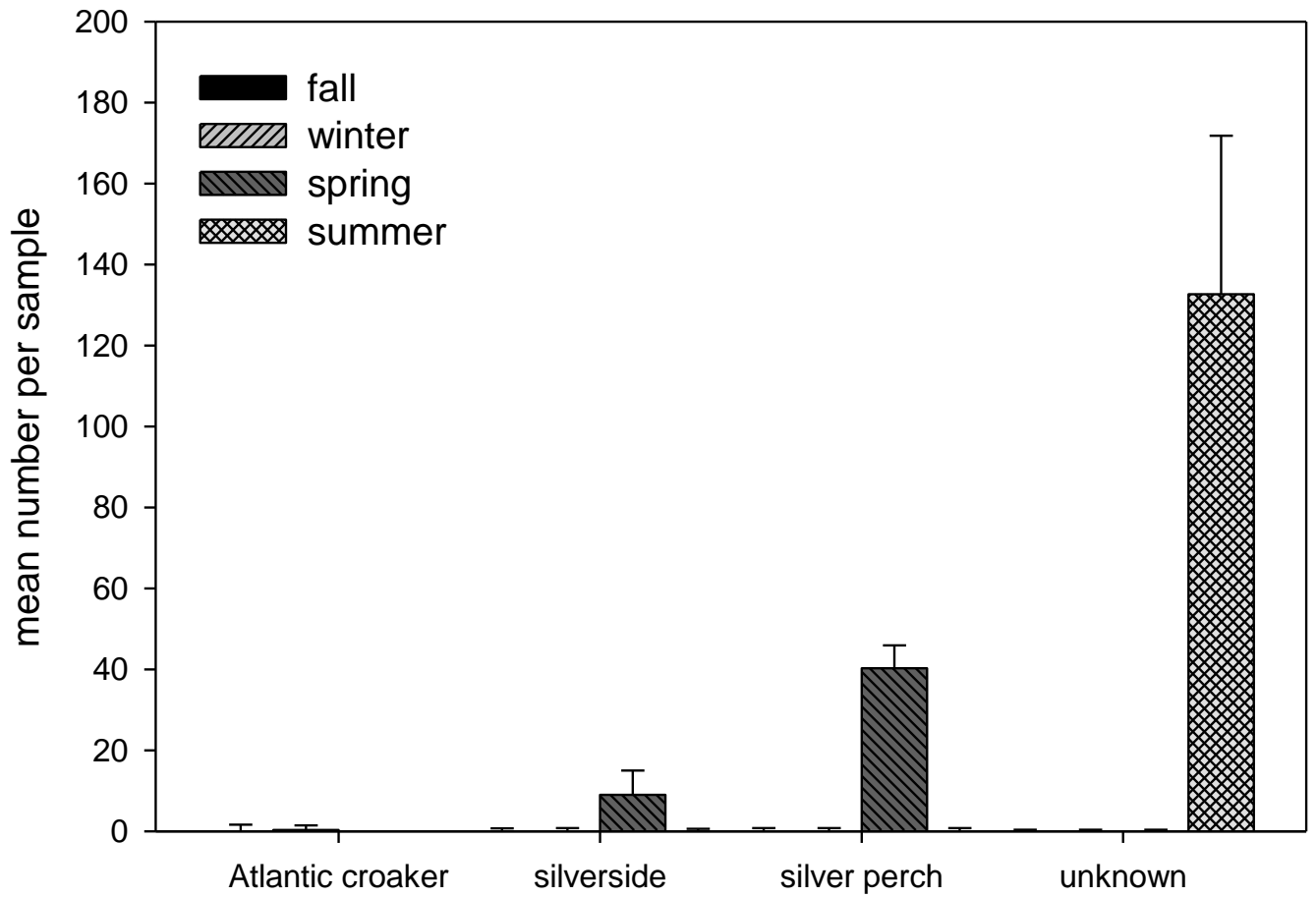


Figure 7. Mean number of of fish taxa collected in each season. Although there were no statistical differences, silversides, silver perch, and the unknown species were only caught during one season.

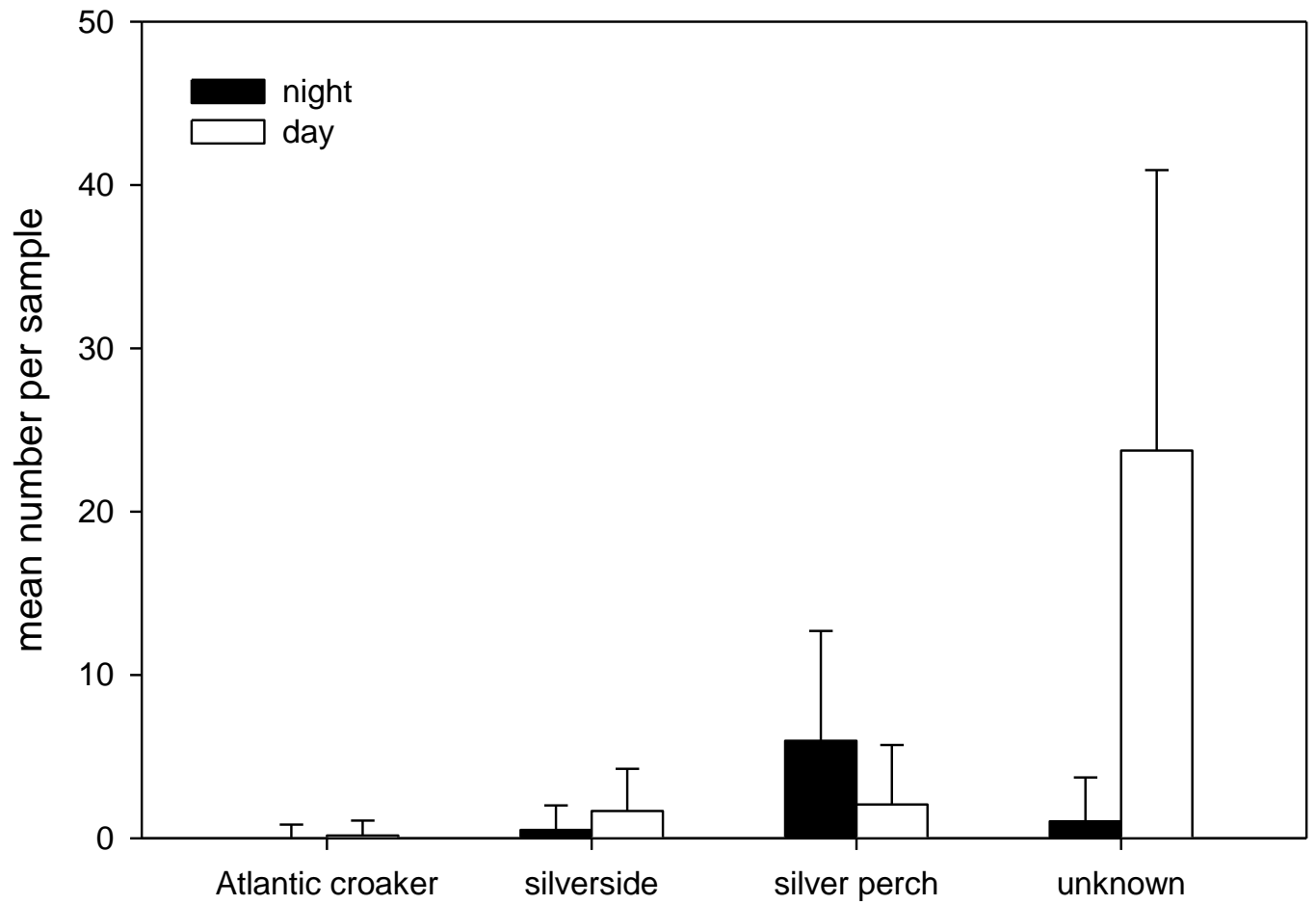


Figure 8. Mean number of fish taxa during night and day.

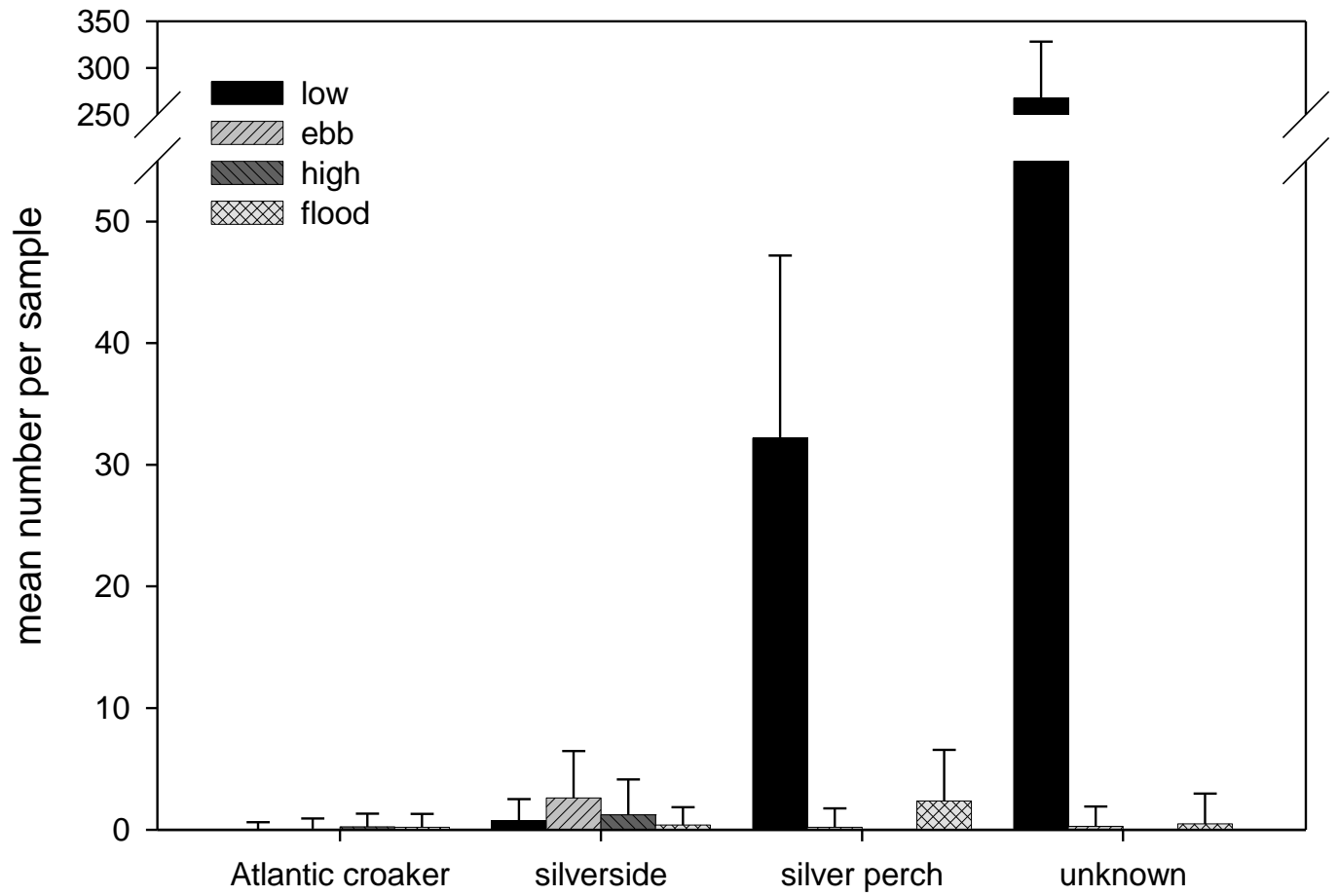


Figure 9. Mean number of fish taxa collected during each tide phase

Discussion

A variety of fish and invertebrate taxa were collected, but few of these were commercially important and none were endangered or threatened. One longspine porgy was found in the 29 August 2009 sample. The longspine porgy is managed by the South Atlantic Fishery Management Council and has minor commercial value. No other federally managed species were captured. Atlantic croaker and spotted sea trout were also collected and both have some commercial and recreational importance (DNRCRD, 2010). Few stone crabs were collected, and although the stone crab is not a regulated species, they are commercially caught for their claws (DNRCRD, 2010). Thus, the direct impacts to the important protected and commercial species by entrainment appear to be small.

Fiddler crab megalopae were the most abundant taxa found in this study. This is in keeping with Montague (1980), who said that in many salt marshes, the fiddler crab was the most abundant and prominent invertebrate. Fiddler crabs are important contributors to the biomass in an estuary, with their byproducts and various activities contributing to the energy and nutrient of the surrounding ecosystem (Montague, 1980). Young fiddler crabs are flushed in and out of the estuary by the tides (Tankersley and Forward, 1994). Lopez-Duarte and Tankersley (2007) reported a peak in upward swimming of first zoea stages about three hours after high tide, aiding them in leaving the estuary for larval development. Upon reentry to the estuary, the megalopae stages begin a circatidal vertical migration (Tankersley and Forward, 1994). The fiddler crabs will swim up into the water column during flood tides at night and return to the bottom during ebb tides and daytime flood tides (Tankersley and Forward, 1994). Most fiddler crab megalopae were collected at night, although the difference between night and day samples was not

statistically significant. The LNG carriers take on ballast water approximately 9 m below the surface where there is no light penetrating and may be catching the crabs as they move up into the water column.

Mysids were the second most abundant species found in this study. They are shrimp-like crustaceans that may add up to approximately 40% of the biomass of omnivores in coastal systems (Heard et al., 2006). Mysids are a food source to estuarine fish, particularly to hake, southern flounder, bluefish, striped bass, Atlantic croaker, bay anchovy, and silver perch (Mauchline, 1980). Mysid occurrence is irregular and depends on physical, chemical, and topographical environmental attributes and the general behavior of the species (Mauchline, 1980). The results from this study were consistent with both high abundance and the irregularity and lack of pattern. Mysids were found in all seasons, on high and ebb tides, and during both day and night time samplings.

Grass shrimp are of little commercial importance (Stenth, 1976). However, they are an important prey item for fish of the estuary (SAMFC, 1998). The grass shrimp peaked in the spring and were nearly absent from fall samples, mirroring when the fish of this study were most abundant.

Green porcelain crabs, an invasive species, were found in a few samples. Most of the specimens were juveniles, and all but two were found in the winter. This species recruits thousands of juveniles from the plankton during summer (Hollebone and Hay, 2007; Tilburg et al., 2010), which is contrary to the winter findings of juveniles in this study.

Silversides were the most abundant fish found in this study. This corresponded with Nelson (1991) that says silversides are often one of the most abundant fish species in an estuary. They are schooling fish that feed at or near the surface (Middaugh and Hemmer, 1987).

Silversides have massive spawning that are timed to the tides and lunar cycles (Middaugh and Hemmer, 1987). Spawning occurs in the spring and summer months. The only season silversides were captured in this study was spring, and 64% of those were captured in a single sample on 15 May 2009. That sample was a day time sample obtained at 14:35-16:35 on an ebb tide.

Silversides are important food for larger commercial and recreational fisheries (Marcy et al., 2005).

The South Carolina Department of Natural Resources (DNR) (2001) completed a study in the SRE using acoustics to find spawning grounds and populations of Sciaenidae. Four species of Sciaenidae (Atlantic croaker, spot, silver perch, and spotted seatrout) showed up in samples from all four seasons. The DNR found the greatest numbers of spotted seatrout at the Elba Island site (DNR, 2001). From May to September, the spotted seatrout spawn repeatedly and peak in July (DNR, 2001). The DNR (2001) reported the area past the jetties to be the spawning area, so the eggs must be washed out of the area by the tides and the older fish return when they are too large to be caught up in the ballast. Alternatively, the eggs may have broken apart during sampling. In this study, only twelve spotted seatrout were found in the spring and one in the summer samples. Sciaenidae larvae typically are juvenile size before they enter the estuary (Nelson et al., 1991). Sciaenidae life spans can be lengthy and they will spend several years in estuaries as juveniles (Nelson et al., 1991). Sciaenidae move into deeper waters as temperatures drop in the winter (Nelson et al., 1991). These species are recreationally sought after by anglers in the Savannah River (DNRCRD, 2010).

The area around Elba Island has been dredged many times. The disruptions in the water and the inevitable sedimentation may cause fish to choose another more suitable area for spawning (NOAA, 2008). Larvae and juvenile fish are also sensitive to noise (NOAA, 2008)

and with ships and equipment in the water around the LNG facility, the fish may move to quieter areas. Construction of piers and docks also affect fishery habitat (SAFMC, 2009), and the Elba Island facility has constructed several dolphins (i.e., piers used as a fender at a dock) for the LNG carriers.

Though only a few commercially important fish and stone crabs were entrained, it does not mean that LNG vessels have no adverse effects on fisheries in the SRE. The prey of the commercially and recreationally species were abundant in certain seasons. The success of the larger, commercial and recreational species is dependent on the presence and viability of prey.

Conclusions

Though it would appear relatively low numbers of individuals were taken from the SRE during this study, perspective should not be lost when considering the size and frequency of LNG carriers ballasting in the SRE. Tens of thousands of gallons were used sampled in this study, whereas each LNG carrier takes millions of gallons of water out of the SRE in a single ballasting event. Additionally, samples for this study were collected in two hour increments and LNG carriers typically offload LNG for ten hours.

Even though only seven Atlantic croaker were captured for the fall sample (Table 3) many more would have been entrained by each ship (Table 6,7). The smallest LNG carrier will take on approximately 11.3 million gallons of ballast water while offloading, so multiplying the number of Atlantic croaker up to reflect the actual gallons estimates up 712 Atlantic croaker caught in ballast water. Furthermore, the Elba Island had 5 LNG carriers to their facility in October 2007 and also in 2008. Assuming all of these ships were the smallest vessels that were using the fastest uptake rate, 3,560 Atlantic croaker juveniles would be lost out of the SRE around Elba Island. The inverse of this scenario, assuming the largest ships (25.6 million gallons) and slowest rate of 3,730 gal/hr, results in 2,202 Atlantic croaker from a single ship, and 11,010 Atlantic croaker taken up from 5 ships. In this study, Atlantic croaker were caught in both day and night samples and among most tides. It is also important to remember that the facility in 2007-2008 was not to full expansion, so 5 ships may not be reflective of actual ships coming to Elba Island.

Fiddler crabs and stone crabs, the most abundant species in the summer samples (Table 4), are taken from the SRE in the tens of thousands when one million gallons of water is

considered (Table 7). Assuming the fastest uptake rate (5,100 gal/hr), the largest ship (25.6 million gallons of ballast water) would presumably take up 886,630 fiddler crabs and 172,902 mud crabs during summer months.

Impacts of entrainment from ballast water from an individual ship may be considered minor, but when considering the cumulative impacts of multiple ships the effects become potentially major. In 2007, the Elba Island facility received 64 ships and offloaded 167,781 million standard cubic foot (MMSCF) in product (FERC, 2007). Forty-nine ships were received in 2008 and 127,466 MMSCF of product were offloaded (FERC, 2008). The expanded plant projects that it will receive from 142 to 299 ships annually (EIS, 2007), or an average of 95 additional ships per year. Though few commercial species were seen in this study, the prey of these species were abundant in certain seasons. Drake et al. (2005) suggested that the number of individuals it takes to have a thriving population will be inversely proportional to the body size of the organism. This accounts for the higher numbers of prey found in this study, but also shows that the success of the larger, commercial and recreational species are heavily dependent on the presence and viability of prey.

It was suggested that using larger ships could reduce overall impacts by reducing the number of ships that will visit the port (EIS, 2007). Larger ships have a LNG capacity of 266,000 m³ and the smaller ships 125,000 m³. But if only small ships are used, the 181 additional ships would take up 2,045 million gallons annually and if only large ships are used, the 86 additional ships would take up 2,200 million gallons annually. Thus, ship size has little impact on annual ballast water uptake.

To reduce the impacts to the SRE by LNG vessels at Elba Island, ballasting should be avoided when possible at night during July, August, and September. This would also likely

reduce blue crab (Bishop et al., 2010) and white shrimp (Pearson, 1939) entrainment because it is possible some of their megalopae and larvae could also be entrained, even though they were not collected in this study. Using the data from this study, 96% reduction in fiddler crab entrainment could be achieved by avoiding night ballasting. Mud crab entrainment could be reduced by 92% in the summer months by avoiding night ballasting.

The Elba Island facility should avoid ballasting from February to May to the maximum extent possible to avoid fish entrainment. Many of the larval fish species found in the Savannah River, though not necessarily in this study, have shown periods of high abundance from mid February to mid April (Hettler et al., 1997; Warlen and Burke, 1990, Rice et al., 1999). Larval Atlantic croaker has shown a peak abundance in early February and spot the same for early March (Hettler et al., 1997; Warlen and Burke, 1990). Reducing the number of vessels during these late winter and early spring months would reduce fish entrainment.

In conclusion, the LNG carriers would do the least direct damage to the fish taxa present in early life stages by using the Elba Island facility more frequently in the fall and winter months, and only during the daylight hours. Invertebrate taxa are most impacted by LNG carriers in the summer and at night. The LNG carriers take on ballast for hours, through more than one tidal phase, but because this study found no significant difference in species presence among tide phases, it can be negated as a factor for ballasting.

Table 6: Family, species, and estimated number of individual fish per million gallons assuming flow rate of 3,730 gal/hr collected at Elba Island site, Savannah, Georgia. These numbers can be used for easy calculations of the approximate # of individuals that would entrained by each ship.

Family	Species	Common Name	fall	winter	spring	summer
Sciaenidae	<i>Micropogonias undulatus</i>	Atlantic croaker	86	67	0	0
	<i>Leiostomus xanthurus</i>	spot	0	15	0	0
	<i>Bairdiella chrysoura</i>	silver perch	0	0	807	0
	<i>Cynoscion nebulosus</i>	spotted seatrout	0	0	101	7
Atherinidae	<i>Menidia menidia</i>	Atlantic silverside	0	0	3,447	0
Carangidae	<i>Chloroscombrus chrysurus</i>	Atlantic bumper	0	0	8	0
Sparidae	<i>Stenotomus caprinus</i>	longspine porgy	0	0	8	0
Mugilidae	<i>Mugil curema</i>	silver mullet	0	8	0	0
unknown	<i>unknown</i>	unknown species	0	0	0	1,501

Table 7: Family, species, and estimated number of individual invertebrates per million gallons assuming flow rate of 3,730 gal/hr collected at Elba Island site, Savannah, Georgia. These numbers can be used for easy calculations of the approximate # of individuals that would entrained by each ship.

Family	Species	Common name	fall	winter	spring	summer
Mysidae	<i>Mysidopsis bahia</i>	mysid	28,111	13,719	11,849	814
Palaemonidae	<i>Palaemonetes spp</i>	daggerblade grass shrimp	148	313	3,127	1,681
Ocypodidae	<i>Uca spp</i>	fiddler crab	12	0	706	47,519
Panopeidae	<i>e.g. Panopeus</i>	mud crab	12	175	256	9,266
Menippidae	<i>Menippe mercenaria</i>	stone crab	367	0	42	113
Porcellanidae	<i>Petrolisthes armatus</i>	green porcelian crab	12	54	0	7
Portunidae	<i>Callinectes similis</i>	lesser blue crab	0	0	8	7
Pinnotheridae	<i>Parapinnixa hendersoni</i>		0	0	151	0
	<i>Zaops ostreus</i>	oyster crab	148	0	0	0

Literature Cited

- Bishop, T.D., H.L. Miller III, R.L. Walker, D.H. Hurley, T. Menken, and C.E. Tilburg. 2010. Blue crab (*Callinectes sapidus*) settlement at three Georgia (USA) estuarine sites. Estuaries and Coasts 33:688–698.
- Carlton, J.J. and B. Gellar. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science 261:78-82.
- Drake, J.M., D.M. Lodge, and M. Lewis. 2005. Theory and Preliminary Analysis of Species Invasions from Ballast Water: Controlling Discharge Volume and Location. American Midland Naturalist 154:459-470.
- [DNR] Spawning aggregations of recreationally important sciaenid species in the Savannah Harbor: spotted seatrout *Cynoscion nebulosus*, red drum *Sciaenops ocellatus*, weakfish *Cynoscion regalis*, and black drum *Pogonias cromi*. 2001. South Carolina Department of Natural Resources Final Report to Georgia Ports Authority.
- [DNRCRD] Georgia's Commercial Saltwater Fishing Regulations. 2010. Department of Natural Resources Coastal Resources Division.
<http://crd.dnr.state.ga.us/Assets/Documents/2010ComRegWeb.pdf>
- Duarte-Lopes, P.C. and R.A. Tankersley. 2007. Circatidal swimming behaviors of fiddler crab *Uca pugnator* from different tidal regimes. Marine Ecology Progress Series 343:207-220.
- [EIS] Federal Energy Regulatory Commission. 2007. Elba III Project Environmental Impact Statement. Final Environmental Impact Statement. Savannah, Georgia.
- [FERC] Federal Energy Regulatory Commission. 2007. Southern LNG Inc. Semi-Annual Operating Report January 1, 2007- June 30, 2007 Docket#: CP71-264-000.
- [FERC] Federal Energy Regulatory Commission. 2007. Southern LNG Inc. Semi-Annual Operating Report July 1, 2007 – December 31, 2007 Docket#: CP71-264-000.
- [FERC] Federal Energy Regulatory Commission. 2007. Southern LNG Inc. Semi-Annual Operating Report January 1, 2008- June 30, 2008 Docket#: CP71-264-000.
- [FERC] Federal Energy Regulatory Commission. 2007. Southern LNG Inc. Semi-Annual Operating Report July 1, 2008- December 30, 2008 Docket#: CP71-264-000.
- [FERC] Federal Energy Regulatory Commission. 2005. Draft environmental impact statement, Down Landing LNG and Logan Lateral projects. Washington (DC): FERC Office of Energy Projects.

- Firestone, J. and J. Corbett. 2005. Coastal and port environments: international legal and policy responses to reduce ballast water introductions of potentially invasive species. Ocean Development & International Law 36:291-316.
- Garland, E., C. Zimmer, S. Lentz. 2002. Larval distributions in inner-shelf waters: the roles of wind-driven cross-shelf currents and diel vertical migrations. Limnology and Oceanography. 40:803:817.
- Goldstein, J.M., and R. F. Goldstein. 2008. Numerous steps required to gain permits for an LNG terminal expansion. Pipeline & Gas Journal p 54-60.
- Heard, R. W., W.W. Price, D.M. Knott, R. A. King, and D.M. Allen. 2006. A taxonomic guide to the mysids of the South Atlantic Bight. NOAA Professional Paper NMFS 4, 37 p.
- Hebert, P.D.N. and M.E.A. Cristescu. 2002. Genetic perspectives on invasions: the case of the Cladocera. Canadian Journal of Fisheries and Aquatic Sciences 59:1229-1234.
- Hettler Jr., W.F., D.S. Peters, D.R. Colby, E.H. Laban. 1997. Daily variability in abundance of larval fishes inside Beaufort Inlet. Fishery Bulletin 95:477-493.
- Hollebone, A.L. and M.E. Hay. 2007. Propagule pressure of an invasive crab overwhelms native biotic resistance. Marine Ecology Progress Series 342:191-196.
- Jennings, C.A. 2002. Temporal and Spatial Distribution of Estuarine-Dependent Species in the Savannah River Estuary. Annual Report.
http://sav-harbor.com/Study%20Reports/SRE_EST-DEP_ANL-RPT_01.pdf
- Kolar, C.S. and D.M. Lodge. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science 298:1233-1236.
- Kuga, H.A. 1998. Endangered and Threatened Wildlife and Plants; Notice of Availability or the Final Recovery Plan for Shortnose Sturgeon. Federal Register Vol. 63, No. 242.
- Largier, J. 2003. Considerations in estimating larval dispersal distances from oceanographic data. Ecological Applications 71-89.
- Lellis-Dibble, K. A., K.E. McGlynn, and T.E. Bigford. 2008. Estuarine Fish and Shellfish Species in U.S. Commercial and Recreational Fisheries: Economic Value as an Incentive to Protect and Restore Estuarine Habitat. U.S. Dep. Commerce, NOAA Tech. Memo. NMFSF/ SPO-90, 94 p.
- Mauchline, J. 1980. The biology of mysids and euphausiids. Advances in Marine Biology 18: 143-246.

- Marcy, B.C., D.E. Fletcher, F.D. Martin, M.H. Paller, and M.J.M. Reichert. 2005. Fishes of the Middle Savannah River Basin, with emphasis on the Savannah River Site. University of Georgia Press pp 280-282.
- Middaugh, D.P. and M.J. Hemmer. 1987. Reproductive Ecology of the Tidewater Silverside, *Menidia peninsulae* (Pisces: Atherinidae) from Santa Rosa Island, Florida. Copeia 3:727-732.
- Montague, C.L. 1980. A natural history of temperate Western Atlantic fiddler crabs (Genus *Uca*) with reference to their impact on the salt marsh. Contrib. Mar. Sci. 23:25-55.
- Nelson, D.M., E.A. Irlandi, L.R. Settle, M.E. Monaco, and L. Coston-Clements. 1991. Distribution and Abundance of Fishes and Invertebrates in Southeast Estuaries. ELMR Rep. No. 9. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. pp 167
- [NOAA] National Oceanic and Atmospheric Administration. 1994. Experimental fish guidance devices. Long Beach (CA): National Marine Fisheries Service, Southwest Region. <http://swr.nmfs.noaa.gov/hcd/exprscrn.pdf>.
- [NOAA]. 2008. NOAA Technical Memorandum NMFS-NE-209: Impacts to marine fisheries habitat from nonfishing activities in the Northeastern United States. 2008. US Department Of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service Northeast Regional Office Gloucester, MA.
- Pearson, J.C. 1939. *Penaeus Setiferus* (Linn.), The Common Shrimp. U.S. Bureau of Fisheries, Bulletin 30, Vol 49 pp 5-6.
- Ogburn, M.B., K.C. Stuck, R.W. Heard, S.Y. Wang, and R. B. Forward, Jr. 2011. Seasonal variability in the morphology of blue crab, *Callinectes sapidus*, megalopae and early juvenile stage crabs, and distinguishing characteristics among co-occurring portunidae. Journal of Crustacean Biology 31:106-113.
- Olmi III, E. 1994. Vertical migration of blue crab *Callinectes sapidus* megalopae: implications for transport in estuaries. Marine Ecology Progress Series 113: 39-54.
- Rago PJ. 1984. Production forgone: an alternative method for assessing the consequences of fish entrainment and impingement losses at power plants and other water intakes. Ecological Modeling 24(1-2):79-111.
- Rice, J.A., J.A. Quinlan, S.W. Nixon, W.F. Hettler Jr., S.M. Warlen, and P. M. Stegmann. 1999. Spawning and transport dynamics of Atlantic menhaden: inferences from characteristics of immigrating larvae and predictions of a hydrodynamic model. Fisheries Oceanography 8:93-110.
- Richards, W. 2005. Early Stages of Atlantic Fishes: An Identification Guide for the Western Central North Atlantic, Volume II. CRC Press, Boca Raton, FL. pp. 1670-1723

[SAFMC] Final habitat plan for the south Atlantic region: Essential fish habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. 1998.

[SAFMC] Fishery ecosystem plan of the South Atlantic region. 2009. Volume IV: threats to the South Atlantic ecosystem and recommendations.

<http://www.safmc.net/Portals/0/FEP/VolIV%20Intro%20and%20Non-Fishing%20impacts.pdf>

Stenth, N. E. 1976. A Review of the Systematics and Zoogeography of the Freshwater Species of *Palaemonetes* Heller of North America (Crustacea, Decapoda). Smithsonian Contributions to Zoology 228: 1-2.

Tankersley, R.A., and R.B. Forward. 1994. Endogenous swimming rhythms in estuarine crab megalopae: implications for flood-tide transport. Marine Biology 118:415–423.

Tilburg, C.E., J.E. Seay, T.D. Bishop, H.L. Miller III, and C. Meile. 2010. Distribution and retention of *Petrolisthes armatus* in a coastal plain estuary: The role of vertical movement in larval transport. Estuarine, Coastal and Shelf Science 88: 260-266.

Travnichek, V.H., A.V. Zale, W.L. Fisher. 1993. Entrainment of ichthyoplankton by a warm water hydroelectric facility. Transactions of the American Fisheries Society 122:709.

[USCG] US Coast Guard. 2006. Environmental impact statement/environmental impact report for the Neptune LNG deepwater port license application. Washington (DC): USCG-2005-22611.

Warlen, S. M. and J.S. Burke. 1990. Immigration of Larvae of fall/winter spawning marine fishes into a North Carolina estuary. Estuaries 13: 453-461.