A Comparative Study of Habitat Value for the Juvenile Blue Crab (*Callinectes sapidus*) Provided by Off-bottom Oyster Farming in the Northern Gulf of Mexico

by

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Abstract

In the northern Gulf of Mexico (nGOM), the quality and quantity of nursery habitat available for juvenile utilization is the most critical limiting factor affecting local populations of the blue crab, *Callinectes sapidus*. Though submerged aquatic vegetation (SAV) and oyster reefs (both natural and artificial) have been more-commonly acknowledged of late for their provisioning of this valuable habitat, each has also suffered decline recently throughout many areas. However, the gear used in off-bottom oyster farming (i.e. the culture of oysters within mesh containers held above the seafloor; OBOF) holds potential to provide additional habitat that is valuable for juvenile blue crabs (JBCs), especially in areas lacking other types of suitable habitat.

In order to make a qualitative assessment regarding the potential value of habitat that OBOF gear could provide for JBCs in the region, comparative field sampling and tethering experiments were performed to collect quantitative data from OBOF gear (specifically, the gear used in adjustable longline systems), along with bagged oyster shell, SAV, and unvegetated bottom habitats, during Summer and Fall 2013, at three spatially separated field sites within the coastal waters of Alabama and Louisiana. Following experimentation, an evaluation was made based on comparisons of average density, size, and percent survival data. Results showed that JBC densities, sizes, and survival rates were generally higher in the OBOF gear than in the other habitat types to which it was compared, though there appeared to be a functional change in its relative value over time. Consequently, OBOF gear seems to provide JBCs with valuable habitat which ranges by comparison from equivalent to significantly greater, depending on an exponentially based, size/density-dependent process, which resembles the Ricker function.

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List of Abbreviations

AD	Anderson-Darling (Test)
AIC	Akaike Information Criterion
AL	Alabama
ALS	Adjustable Longline System
ANOVA	Analysis of Variance
AUORDF	Auburn University Oyster Research and Demonstration Farm
AUSL	Auburn University Shellfish Laboratory
BDIL	Bay des Ilettes (Grand Isle), Louisiana
BIC	(Schwarz's) Bayesian Information Criterion
BOS	Bagged Oyster Shell
BST™	BST™ Oyster Supplies Pty. Ltd.
CI	(95.0 %) Confidence Interval
°C	Degrees Celsius
df	Degrees of Freedom
DW	Durbin Watson (D-Statistic)
FOA	First Order Autocorrelation
GH	Games-Howell (Test)
GLM	General Linear Model
HSD	(Tukey's) Honestly Significant Difference
JBC	Juvenile Blue Crab
KS	Kolmogorov-Smirnov (Lilliefors Test)

LA	Louisiana
LSGORDF	Louisiana Sea Grant Oyster Research and Demonstration Farm
LSM	Least Squares Means
LSU	Louisiana State University
MS	Mean Squares
MSE	Mean Standard Error
OBOF	Off-bottom Oyster Farm (ing)
OF	Oyster Farm
OFB	Oyster Farm Basket
PAP	Point aux Pins (Sandy Bay), Alabama
PBA	Portersville (Fowl River) Bay, Alabama
PVC	Polyvinyl chloride
SAV	Submerged Aquatic Vegetation
SBA	Sandy Bay (Point aux Pins), Alabama
SD	Standard Deviation
SG	Seagrass
SS	Sum of Squares
SW	Shapiro-Wilk (Test)
UVB	(Soft-sediment) Unvegetated Bottom

Chapter 1: Introduction and Literature Review

1.1 The Eastern Oyster

The Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), sometimes referred to as the American oyster (Turgeon *et al.*, 1988) occurs along the Atlantic and Gulf coasts of North America from the Gulf of St. Lawrence to the Yucatan Peninsula of Mexico in both subtidal areas and on the lower intertidal banks of mesohaline bays and bayous, occasionally extending into the edges of *Spartina alterniflora* marshes. Along the coast of the Gulf of Mexico, they are abundant in many estuaries, while the estuaries of Louisiana and Texas east of Corpus Christi have historically had the highest abundances (Kaplan, 1988). Eastern oysters can easily be identified by their irregularly oval shaped shells that are narrow at the upper end, their sharp outer valve edges, and their single, large adductor muscles which leave dark purple conspicuous scarring on the interior of their shells. They have been a popular food item for centuries, and because of their economic importance as seafood and their ecological significance, the Eastern oyster has been one of the most intensively studied bivalve mollusks in the world (Heard, 1982).

The North-Central Gulf of Mexico Oyster Fishery: Alabama and Louisiana

Oyster reefs (which are natural accumulations of oyster shell and living oysters that result from the successive growth of past oyster generations within the same area) have supported a historically important fishery along the Gulf coast. The commercial industry is thought to have first begun when aboriginal Americans established a trade market for smoked oysters around the same time that early European settlers began relying on local foods and needing to develop local economies.

As a consequence of the expansive fluvial nutrient input from the Mississippi and other coastal rivers, the north-central nearshore shelf is considered one of the most productive areas in the Gulf of Mexico. Gulf oysters now represent 80-90% of total U.S. eastern oyster production (Vanderkooy, 2012).

The north-central Gulf includes the Alabama, Mississippi, and Louisiana shorelines, which are dominated by sandy barrier islands, associated bays, and extensive inland marshes. Louisiana is the largest producer of oysters among the Gulf States representing about 56% of total Gulf production, which historically came from private leases. Louisiana has a very extensive public/private cooperative system where the public grounds are utilized for transplanting to privately leased beds. There are more than 9,000 individual, active leases of approximately 36 acres each. There are not any private oyster leases on state regulated bottom in Alabama or Mississippi, unless the bottom is within a waterfront property owner's riparian rights zone.

Harvest of oysters from public reefs in Alabama is limited to either raking them up by the use of tongs or by hand. These are the same basic techniques that have been used for hundreds of year, and there are only about 200 individuals who employ themselves as oyster tongers in Alabama. Over the last decade, even though the market demands for Gulf oysters have risen, the commercial landings in Alabama have instead decreased. This has mostly been attributed to the massive oyster drill proliferation that was experienced after a four year drought between 2005 and 2009, as well as the co-occurring widespread habitat loss caused by multiple major hurricane landfalls (Vanderkooy, 2012).

Figure 1.1 Photograph of traditional oyster harvest technique, at Cedar Point Reef in Alabama (April 2013). Photo credit: Alabama Gulf Seafood.

Oyster Reefs: Their Ecological Role in Providing Habitat

In addition to their role in sustaining the oyster fishery, oyster reefs, which can be very complex in their structural nature, are increasingly recognized for their potential habitat value, providing important habitat and food sources for transient and resident benthic fauna, many of which will go on to become a commercially valuable product. Oyster habitats have actually been found to support a higher density and biomass than vegetated marsh edges for some benthic crustaceans, and this distinct assemblage of decapods that they support may represent an ecologically important component to estuarine systems as habitat for other species as well (Glancy *et al*. 2003; Stunz *et al*. 2010; Shervette *et al*. 2011).

Oyster Restoration Efforts in Alabama

The largest problem facing the Gulf oyster fishery is oyster reef habitat loss, with the largest contributor being coastal development; followed by sedimentation, and contamination. Restoration efforts have been driven by a number of motives including that of both ecological and commercial interest (Coen and Luckenbach, 2000). With a decline in oyster reefs along much of the Atlantic coast, there had been increased attention to restoring oyster reefs through shell planting efforts over the last decade (Lenihan and Peterson, 1998).

These efforts provided mixed results however, as the planted shell can easily be lost by sedimentation and newly set spat were quite vulnerable to predation. Other efforts include providing more topographically complex structure in the benthos, often times constructed out of refuse oyster shell material that has been packaged into bags in order to help maintain its structural integrity. Created oyster habitat such as this does have the potential to provide organisms such as the blue crab with a supply of prey and a refuge from predation (Kellogg *et al*., 2006). Shell planting is still the most commonly used of these methods for oyster restoration efforts made in Alabama; however, Posey *et al*. (2006) suggests that if commercial harvest is permitted on these restored reefs, then restoration efforts might not be successfully achieved unless efficacious management precautions are imposed.

Figure 1.2 Photograph of shell planting restoration efforts in Portersville Bay, Alabama (May 2013). Photo credit: Alabama Marine Resources Division.

Oyster Aquaculture in Alabama and Louisiana

With the Gulf oyster industry still slowly recovering from challenges caused by habitat loss, commercially farming oysters off the bottom appears to be a sustainably viable means of providing a supplement for industry demands by reducing fishing pressure on the diminishing wild stocks, because raising them off the bottom decreases the risk of burial and the risk of mortality caused by benthic predators, while it increases the availability of food by being suspended in the photic zone where primary production is at its highest (Supan, 2002).

While only recently introduced to the northern Gulf of Mexico, innovative techniques for farming oysters off the bottom are proving to be effective methods for producing highly valuable, premium oysters for the half-shell market. The particular off- bottom technique used in this study, known as the adjustable longline system, only recently became an option available for use in Alabama waters. This system provides the means necessary for consistently producing large quantities of high-quality oysters, which feature characteristics desired by consumers accustomed to the niche market of high-dollar half-shells; a market which had generally not been considered for oysters grown in the Gulf of Mexico. The adjustable longline system was originally developed and manufactured by BST™ Oyster Supplies out of southern Australia.

It was designed for use in a bay system with relatively low nutrient input, and the adjustability enabled farmers to place the oysters where the food was. The same system is beneficial for use within our bay systems, only in a different way. Here in the southern US, as consequence of the expansive fluvial nutrient input from the Mississippi river, these waters promote rapid growth rates for oysters, but also for barnacles and other sessile filter feeding invertebrates, which can lead to massive amounts of bio-fouling accumulating on anything the water touches. This is where the system's adjustability comes into play for Gulf farmers, because they can easily desiccate this system allowing them to control the fouling issue which had always been the largest obstacle limiting success for farming ventures of the past.

The grow-out baskets housing the oysters in this system feature 12 millimeter hexagonal shaped mesh openings. These openings were engineered to maximize through-flow, while still providing enough protection to keep out large mobile predators such as the adult blue crab, which occasionally feed on juvenile oysters. However, smaller mobile organisms, which do not pose any threat to juvenile oysters, may easily enter and exit the baskets as they please through these 12 millimeter hexagonal shaped mesh openings. Just like the protection provided for the juvenile oysters, juveniles of other species may find that the complex interstitial spaces located among the oysters in these baskets can provide them with shelter for avoiding predation as well.

Though reef restoration may be necessary to the recovery of the local wild populations and the habitat that they create, oyster aquaculture could potentially provide many similar types of ecosystem services. Previous studies have suggested that oyster aquaculture gear can support populations of ecologically and economically important macrofauna comparable with that of an oyster reef, and can have substantially greater habitat value than shallow unvegetated bottom, and for some species, habitat value at least equal to and possibly superior to patchy beds of submerged aquatic vegetation (Dealteris *et al*., 2004; Erbland and Ozbay, 2008).

It is important to note that oyster farms in Alabama must be within waters that are at minimum, classified as "conditionally approved" for harvest by the Alabama Department of Public Health, and that permitting cannot be obtained in areas where submerged aquatic vegetation or seagrass is present (Walton *et al*., 2012). Therefore, the habitat that off bottom oyster aquaculture gear could provide for many organisms in their early life history stages, which could include recreationally and commercially important invertebrates such as the common blue crab, does not involve the removal or degradation of any existing habitat, other than unvegetated bottom.

Figure 1.3 Photograph of off-bottom adjustable long-line system in Sandy Bay (Point aux Pins), Alabama (November 2012). Photo credit: Auburn University Shellfish Laboratory.

1.2 The Blue Crab

The common blue crab, *Callinectes sapidus* (Rathbun, 1896), also referred to as the greater blue crab, in the family Portunidae, an estuarine and coastal dependent species, is the most common large estuarine crab in the north-central Gulf of Mexico and is one of the most commercially important species in the region. It is a swimming crab that occurs throughout all euryhaline estuarine intertidal and subtidal habitats along the East and Gulf coasts of North America, South America, and Central America from Massachusetts to southern Brazil, Bermuda, and the West Indies (Patillo *et al.*, 1997). They rarely exceed nine centimeters in carapace length, although they are much wider than they are long. They are easily recognizable by their last pair of legs having terminal segments that are flattened and oval shaped, resembling paddles which are modified for swimming. They also have four notches on the frontal margin between their eyes and a sharp posterior-most lateral spine, with bright blue palms and chelipeds with red tipped claw fingers. Blue crabs are omnivores and feed on a variety of foods including detritus, oysters, and other crabs including their own species (Heard, 1982; Kaplan, 1988).

Blue Crab Spawning and Settlement in Estuaries of the North-Central Gulf of Mexico

The population dynamics of marine species with complex life history patterns, like that of the blue crab which is subject to a wide range of rapidly changing environmental conditions such as pulses of freshwater and saltwater inflow, nutrient loading, and physical destruction of habitat, rely on a suite of physical and biotic forces (e.g., habitat structure and density-dependent predation or emigration) which control survival and abundance in early life history, particularly after settlement. Even though genetic evidence suggests that blue crab populations in the Gulf of Mexico are homogenous, exchange between geographic areas may be limited to dispersal by physical barriers such as the Mississippi River (Perry *et al*., 1997).

The blue crab typically has an annual peak spawning season in most areas; however, in Mobile Bay and other local estuaries off the coast of the north-central Gulf of Mexico, they will spawn year round. After blue crabs mate in these estuaries, egg-bearing females are observed to undergo a nocturnal ebb-tide transport during their seaward spawning migration into the higher salinity waters just offshore to release their larvae where salinities are optimal for egg hatching and larval survival. Eggs from local blue crab populations take about one day to hatch after spawning, and then the newly hatched planktonic blue crab zoea are dispersed by winds and currents for about one month before they will become able to swim vertically as megalopae (there are seven zoeal larval stages). Postlarval, or megalopal, blue crabs are transported from offshore areas for about two more months, eventually coming back into these estuaries where they will settle out of the plankton and metamorphose into juveniles in nursery areas (Forward and Cohen, 2004).

Importance of Habitat for Blue Crabs in the North-Central Gulf of Mexico

Blue crab larval recruitment to the estuaries is not a limiting factor affecting their recruitment into the fishery in Alabama, an area that has been documented to have a high supply of blue crab postlarvae. Exceptionally high levels of recruitment do not necessarily provide for greatly elevated numbers of juvenile blue crabs, thus recruitment that is in excess of estuarine carrying capacity is lost (Perry *et al*., 1998). Instead, the most critical limiting factor affecting their recruitment into the fishery is the quality and quantity of nursery habitat available for post-settlement stages, which can quickly become overcrowded and limiting for juvenile populations (Morgan *et al.*, 1996). Post-settlement survival for blue crabs is dependent on the availability of habitats that can provide shelter from predators, because their population dynamics are strongly influenced by a density-dependent three way interaction between body size, habitat, and predation (Heck *et al*. 1993; Heck *et al*. 2001).

Therefore, any substantial increase in the amount of available nursery habitat within the estuaries could ultimately help augment adult blue crab populations in the north-central Gulf of Mexico region. Structured benthic habitats such as salt marshes, vegetated beds, and oyster reefs are often recognized as the most valuable nursery habitats for blue crabs, but vegetation is more often considered the predominant settlement site and nursery habitat for megalopae (Eggleston *et al*., 1998). However, it has recently been documented that first molt juvenile instar blue crabs actually prefer live oysters over vegetation for habitat selection (Van Montfrans *et al*., 2003).

Blue Crab Habitat Case Studies: Effects on Density and Survival

Pile *et al*. (1996) conducted a long-term sampling effort accompanied by a series of field and laboratory experiments examining the joint effects of habitat type, body size, and population density upon abundance and survival of early juvenile blue crabs.

Instar	CW (mm)
First	2.2-3.0
Second	3.1-4.2
Third	4.3-5.9
Fourth	6.0-7.4
Fifth	7.5-9.1
Sixth	9.2-10.6
Seventh	10.7-12.6
Eighth	12.7-14.1
Ninth	14.2-16.1

Table 1.1) Size of benthic instars (spine-to–spine; CW) used to categorize juvenile blue crabs (Pile et al. 1996).

They quantified relationships between sequential life history stages in initial nursery habitats for blue crabs. Inter-instar relationships were defined as the densities of larger instars being dependent on the densities of smaller instars. Inter-instar relationships for the youngest instars were described by hyperbolic functions until crabs began to immigrate to unstructured habitats at approximately the fifth instar. While hyperbolic and parabolic functions were indicative of populations regulated by density-dependent processes (predation or emigration), the decay in the functions describing the relationships for crabs larger than the fifth instar indicated that the suite of processes regulating this segment of the population changed qualitatively (Pile *et al*., 1996).

In laboratory and field experiments, the effects of structured and unstructured habitats and size-specific predation on newly settled juveniles were also tested. Tethering was used to quantify relative rates of predation, and a laboratory study was conducted to determine if tethering induced treatment-specific bias. They found no statistically significant interactions between the tethering treatment and the factor treatments of crab size and habitat during the laboratory study, indicating that tethering did not produce treatment-specific bias. Tethering provided a relative measure of predation that allowed comparisons between treatments of habitat and crab size on crab survival. Survival was significantly higher in structured habitats and with increasing size until the ninth instar, when survival did not differ by habitat. This difference explained the dispersal from structured to unstructured habitats that occurred between the fifth and seventh instars (Pile *et al*., 1996).

In addition, survival of all crabs was significantly increased both during and after physical disturbance compared to pre-physical disturbance conditions. A model was developed that described juvenile survival as a function of crab size and habitat type. Survival curves in both habitats were represented by similar sigmoid functions with survival highest in structured habitats. Subsequently, the survival of newly settled blue crabs was likely dependent on the availability of complex habitat. Thus, they concluded that a suite of biotic and physical processes, both density-dependent and density-independent, control the early life history after settlement for the blue crab (Pile *et al*., 1996).

Moksnes and Heck (2006) assessed the relative role of three potentially important processes affecting the distribution of young juvenile blue crabs: (1) habitat selection at settlement, (2) selection of habitats by dispersing juveniles, and (3) habitat-specific predation rates, using cage experiments. The results suggest that active habitat selection by postlarvae and young juvenile crabs determines the habitat-specific distribution of juvenile blue crabs.

Densities of blue crab settlers (megalopae and first instar crabs) in caged habitat patches (i.e. excluded predators, settlers were not confined) were high and similar in artificial seagrass, live shoal grass, *Halodule wrightii*, and live oyster habitats, but significantly lower in mud, indicating active selection for any structurally complex habitat at settlement. Second and third instar juvenile blue crabs also colonized the structurally complex habitats in higher numbers, compared to mud, demonstrating that young juvenile blue crabs are highly mobile and redistribute soon after metamorphosis (Moksnes and Heck, 2006).

Blue crab densities in uncaged treatments were significantly lower in all habitats than in caged treatments, suggesting high predation mortality. However, the loss of settlers and juvenile crabs was similar in all habitats, and had no significant effect on the juvenile crab distribution (i.e. effect minimized by density-dependence). Densities of potential predators were on average five times higher in the structurally complex habitats than in mud. Thus, they concluded that an aggregation of predators in the refuge habitats, coupled with a refuge at low prey densities in unstructured habitats, appeared to decrease the proximate effect of predation on the distribution of juvenile crabs (Moksnes and Heck, 2006).

1.3 Project Goals and Objectives

The main objective of this study was to evaluate the relative habitat value for juvenile blue crabs provided by off-bottom oyster farming (OBOF) practices in the north-central Gulf of Mexico region, compared to more well-studied habitats: submerged aquatic vegetation (SAV), bagged oyster shell (BOS), and unvegetated, unconsolidated, soft-sediment bottom (UVB). The evaluation was conducted with the information gained by the two field studies presented below.

The primary field study, consisted of two complementary evaluations: one of three habitat types (OBOF, BOS, and UVB) in combination with three study site locations (Portersville (Fowl River) Bay, Alabama (PBA); Sandy Bay (Point aux Pins), Alabama (SBA); and Grand Isle (Bay Des Ilettes; BDIL), Louisiana) and another of four habitat types (OBOF, BOS, SAV, and UVB) in combination with two study site locations (PBA and SBA).

Objective 1) Investigate the potential abilities of the given habitat types within the given study site locations to support juvenile blue crabs, by determining if the given habitats and/or the given areas have a significant impact on the densities and sizes of juvenile blue crabs.

Hypothesis 1) Significant differences will occur in the densities and sizes of juvenile blue crabs based on the given habitat types and/or the given study site locations.

The relative predation intensity study consisted of an evaluation of four habitat types (OBOF, BOS, SAV, and UVB) in combination with two study site locations (PBA and SBA).

Objective 2) Investigate the potential abilities of the given habitat types within the given study site locations to support juvenile blue crabs, by determining if the given habitats and/or the given areas have a significant impact on the percent survival of juvenile blue crabs.

Hypothesis 2) Significant differences will occur in the percent survival of juvenile blue crabs based on the given habitat types and/or the given study site locations.

Chapter 2: Effects of Habitat and Site on Density, Size, and Survival

2.1 Introduction

The population dynamics of marine species with complex life histories involving larval dispersal and settlement rely on many physical and biotic processes which influence the fate of a cohort, both before and after settlement (Shervette *et al*., 2004; Wahle, 2003). Of the decapods, few have stronger evidence of the dominance of post-settlement processes than the blue crab, *Callinectes sapidus*. It is one of the few commercially exploited species with unchallenged spawner-recruit relationships in which strong compensatory processes lead to non-linear spawner-to-recruit or juvenile-to-recruit relationships (Wahle, 2003). The potential for blue crab post-settlement density-dependent controls during early benthic life is stronger in the Gulf of Mexico estuaries than those along the Atlantic coast (Kahn *et al.*, 1998; Lipcius & Van Engle, 1990; Lipcius & Stockhausen, 2002; Wahle, 2003). In Mobile Bay and several other estuaries off the north-central Gulf of Mexico, it has been reported that there is an exceptionally high level of blue crab larval supply. Van Montfrans *et al*. (1995) documented that larval settlement was "100-fold greater for the Gulf coast than the Atlantic coast ..." However, an exceptionally high level of larval recruitment does not automatically provide for a greatly elevated number of juvenile blue crabs (Perry *et al*., 1998); hence, "... implying greater population limitation by post-settlement processes in Gulf of Mexico estuaries and greater supply limitation in Atlantic estuaries" (Van Montfrans *et al*., 1995; Guillory *et al*., 1998). Recruitment that is in excess of the estuarine carrying capacity can be lost to post-settlement mortality (Perry *et al*., 1998); therefore, it can be assumed that increasing the estuarine carrying capacity (nursery habitat quality and quantity) is the only means that can provide for an elevated number of juvenile blue crabs in an estuary.

The most critical limiting factor influencing blue crab populations in the north-central Gulf of Mexico is the amount of nursery habitat that can offer protection from post-settlement loss to predation and/or cannibalism. Numerous field experiments have demonstrated that habitat complexity is critically important to benthic crustaceans, where different sized refuges within complex habitats are used to escape predation, in mitigating post-settlement mortality by cannibalistic individuals (Eggleston and Armstrong, 1995; Pile *et al*., 1996; Moksnes *et al*., 1998; Etherington and Eggleston, 2000). Therefore, juvenile blue crabs in the north-central Gulf of Mexico may benefit from the addition of complex habitat structure (Heck *et al*., 1993; Heck *et al*., 2001).

Active selection for any structurally complex habitat by postlarvae and young juvenile blue crabs determines the habitat-specific distribution of juvenile blue crabs, with patchy structure landscapes being the most valuable refuges for juveniles (Hovel and Fonseca, 2005). Survival post-settlement is determined not only by the size-specific probability of having shelter, but also by probability of mortality without having it. The importance and availability of refuge varies throughout the life history of organisms because of the increase in size of an organism as it grows. Refuge limitation acting on a specific size class may create a demographic bottleneck thereby limiting the production of a population through mortality, migration, or stunting of the affected size class. Lack of refuge can affect both population size structure and density of large juvenile crabs, and competition for available refuges may occur (Shervette *et al*., 2004). Post-settlement dispersal may also be an important means of mitigating crowding effects (Pile *et al*., 1996; Etherington and Eggleston, 2000), but distinguishing post-settlement dispersal from mortality remains a challenge (Pile *et al*., 1996; Moksnes and Wennhage, 2001; Etherington *et al*., 2003). In either case, refuge habitat is the limiting factor; especially among small individuals still vulnerable to predators (i.e. the bottleneck model predicts low survival for individuals that must leave shelter at a size still vulnerable to predation).

It is necessary to understand the nature of demographic bottlenecks (as described above) in terms of the joint effect of habitat availability and critical predator–prey interactions. If predation rates are relaxed, emergent prey (i.e. prey emigrating from shelter) may experience higher survival. There are numerous examples in which size-specific rates of survival have been related to the joint effects of habitat complexity and the type, size, and abundance of predators (Pile *et al*., 1996; Hovel and Lipcius, 2001).

Albeit the a priori goal of this research was to make assessments of habitat value; the term value in itself is rather ambiguous when used in the context of marine environments, since certain conditions may at times be more or less favorable than others, depending upon a suite of confounding factors. Especially when dealing with marine species that have such complex life histories like that of *C. sapidus*, whose population dynamics are heavily influenced by the ever-changing processes that occur within the surrounding estuarine systems. However, the regular interactions that ensue between these living organisms and their immediate surrounding habitat provide measureable conditions which constitute 'structure' within the substrata of these heterogeneous ecological systems of greater scale. These measurable conditions include biotic attributes such as the body size and/or mass of an organism, the densities of juveniles (which reflects recruitment, mortality and emigration; thus, can be an important indicator of nursery habitat value (Minello *et al.*, 2003) and the predation pressure exerted upon prey.

The overall purpose of this study was to determine how JBCs are being affected by the addition of structure being introduced with OBOF, relative to other available habitat types. Specifically, I tested the following hypotheses.

1. Across three coastal sites (one in LA and two in AL), JBC abundance and survival would be greater in OBOF habitat relative to UVB, but not differ from BOS.
2. Within Alabama's coastal waters (two sites that included SAV), JBC abundance and survival would be greater in OBOF habitat relative to UVB, but not differ from BOS or SAV.

2.2 Materials and Methods

2.2.1 Overview of Field Sites

Field study one was conducted in the following three separate salt water bodies on the Alabama and Louisiana coasts in the north central Gulf of Mexico: 1) Portersville (Fowl River) Bay, Alabama; 2) Sandy Bay (Point aux Pins), Alabama; and 3) Bay Des Ilettes (Grand Isle), Louisiana (Fig. 2.1) Field study two was conducted at the two sites in Alabama only.

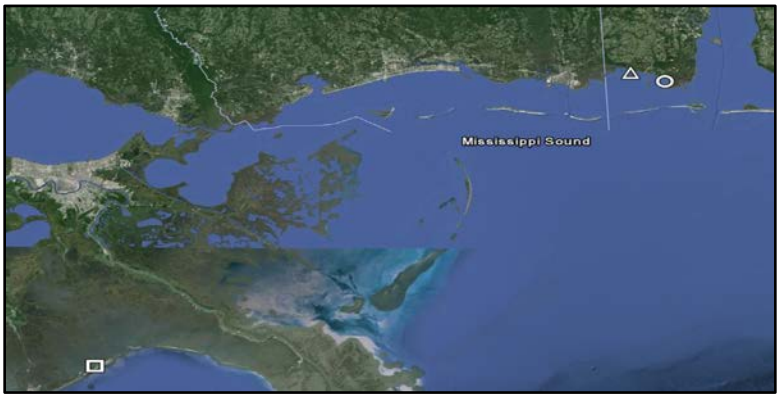


Figure 2.1 Satellite imagery map of the three field study site locations in coastal Alabama and Louisiana: Portersville (Fowl River) Bay, Alabama, (indicated by the white circle); Sandy Bay (Point aux Pins), Alabama, (indicated by the white triangle); and Bay des Ilettes (Grand Isle), Louisiana (indicated by the white square). Image credit: Google earth.

Portersville (Fowl River) Bay, Alabama

The first field site that was selected for this study, Portersville (Fowl River) Bay, Alabama, is a salt water body located to the south of Coden, Alabama, at the mouth of west Fowl River in the eastern portion of the Mississippi Sound. It is bordered on the east by the saltmarsh complexes of Mon Louis and Turtleback Islands and on the west by Coffee (Isle aux Herbes) and Terrapin Islands which are bordered by industrialized estuaries to the north.

The southern portion of Portersville (Fowl River) Bay contains the islands Raccoon, Lady, Cat, and Marsh from east to west. Portersville (Fowl River) Bay experiences diurnal tides with a typical tidal range of 0.5 meters. Water depth at mean high water is approximately 1.5 meters, and the bay is characterized by mixomesohaline salinities.

Common shallow habitats include vegetated *Spartina alterniflora* marsh edge, low profile *C. virginica* oyster shell, and unvegetated, unconsolidated bottom. Additionally, some subtidal *Ruppia maritima* occurs occasionally in small, sparse beds within some areas along the shorelines of Coffee (Isle aux Herbes) and Terrapin Islands. The substrate within Portersville (Fowl River) Bay consists mostly of semi-firm, unconsolidated sand, having little remaining oyster shell hash, due to a history of being cultivated for on-bottom oyster harvest.

Within Fowl River Bay, near the eastern shoreline of Portersville Bay, lying just southwest of the mouth of west Fowl River (30°21'11.56"N 88°11'28.45"W), operates the Auburn University Oyster Research and Demonstration Farm (AUORDF; Fig. 2.2).

Figure 2.2 Photograph of the AUORDF (Auburn University Oyster Research and Demonstration Farm) site in Portersville (Fowl River) Bay, Alabama (June 2013).

It is a 60-acre submerged lands riparian rights lease that was established in 2011 to help develop the OBOF industry in Alabama. A portion of the lease is currently operated by the Auburn University Shellfish Laboratory, part of which is maintained to conduct research, and another part of which is dedicated to an 'Oyster Farming Fundamentals' training program; while the remainder of the lease includes commercial farms and dedicated restoration areas.

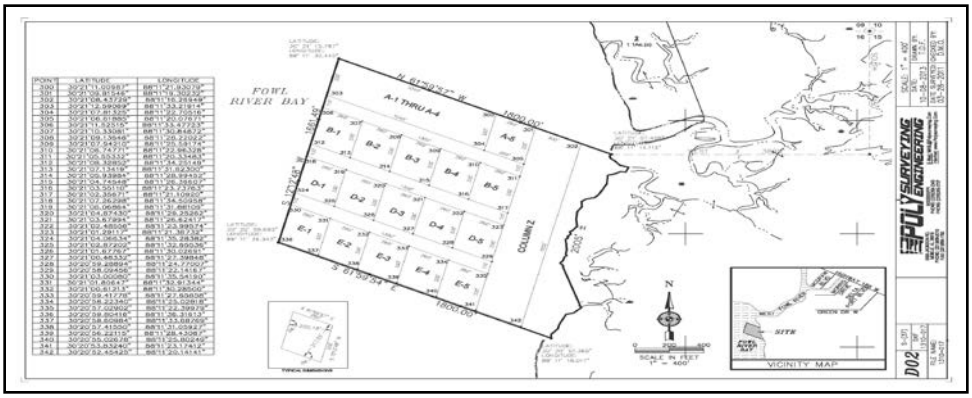


Illustration 2.1 Survey map of the AUORDF (Auburn University Oyster Research and Demonstration Farm) site in Portersville (Fowl River) Bay, Alabama.
Image credit: Bill Walton.

The observational field-based portions of this study related to oyster farming habitat value at the Portersville (Fowl River) Bay, Alabama site were conducted within this oyster farming lease, and those related to bagged oyster shell habitat value were conducted within close proximity (approximately 250 meters to the east). Since there is no submerged aquatic vegetation within the AUORDF oyster farming lease (Walton, 2011), the observational field-based portions of this study related to submerged aquatic vegetation and unvegetated bottom were conducted within the patchy *Ruppia maritima* beds along the shoreline of Coffee (Isle aux Herbes) and Terrapin Islands, approximately three miles to the west of the AUORDF oyster farming lease (Fig. 2.3).

Figure 2.3 Satellite imagery map of Portersville (Fowl River) Bay, Alabama (location of the adjustable longline system and bagged oyster shell study sites are indicated by the white circle; and location of the submerged aquatic vegetation and unvegetated bottom study sites are indicated by the white square). Image credit: Google earth.

Sandy Bay (Point aux Pins), Alabama

The next field site that was selected for this study, Sandy Bay, Alabama, is a salt water body located along the western shoreline of Point aux Pins (Isle aux Dames), Alabama, which is a peninsula that is an Alabama Forever Wild Land Trust area consisting mostly of saltmarsh complexes and low-lying forested wetlands, where there is little anthropogenic disturbance. This peninsula is bordered on the eastern shoreline by an industrialized estuary just south of Bayou La Batre. Towards the west of Sandy Bay, Alabama is Pascagoula, Mississippi, where Sandy Bay is adjoined by the salt water body of Grand Bay, Alabama. Sandy Bay experiences diurnal tides with a typical tidal range of 0.5 meters. Water depth at mean high water is approximately 1 meter, and the bay is characterized by mixomesohaline to mixopolyhaline salinities.

Common shallow habitats include vegetated *Spartina alterniflora* marsh edge, patchy to continuous subtidal *Ruppia maritima* beds (being more continuous during warmer seasonal conditions, and being patchier to sometimes sparse in colder seasonal conditions), low profile *C. virginica* oyster shell, and unvegetated, unconsolidated bottom. The substrate within Sandy Bay consists mostly of soft, unconsolidated sand, however within the shallows, the substrate consists moreso of nutrient enriched, unconsolidated muddy sediment.

Figure 2.4 Photograph of the farm site in Sandy Bay (Point aux Pins), Alabama (June 2013).

Within the eastern portion of Sandy Bay, along the western shoreline of Point aux Pins (Isle aux Dames; 30°22’59.45”N 88°18’46.24”W), operates a 4.5-acre submerged lands riparian rights lease commercial oyster farm known as the Point aux Pins oyster farm (Fig. 2.4). Specializing in the production of premium oysters for wholesale to the half shell market, it was established in 2010 as the first of the existing commercial oyster farming operations in Alabama.

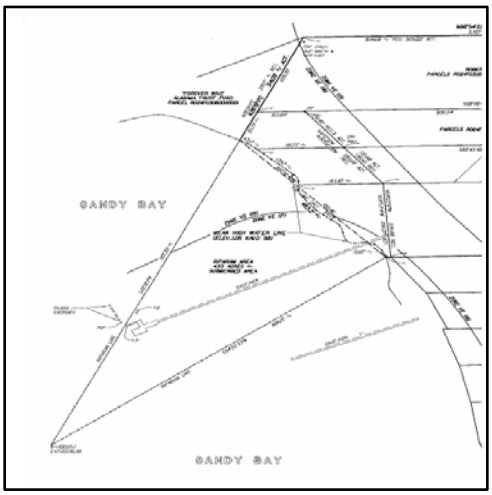


Illustration 2.2 Survey map of the Point aux Pins oyster farm site in Sandy Bay, Alabama, developed in 2007.
Image credit: Lawyer and Company. Date: 6/10/07. Project No.: 07-061-1.

The observational field-based portions of this study related to oyster farming and bagged oyster shell habitat were conducted within this lease, and the portions related to seagrass and unvegetated bottom habitat were conducted in its surrounding waters (Fig. 2.5).

Figure 2.5 Satellite imagery map of Sandy Bay (Point aux Pins), Alabama (location of the adjustable longline system and bagged oyster shell study sites are indicated by the white circle; and location of the submerged aquatic vegetation and unvegetated bottom study sites are indicated by the white square).
Image credit: Google earth.

Bay Des Ilettes (Grand Isle), Louisiana

The third field site that was selected for this study is located within the southernmost portion of the salt water body Bay Des Ilettes, Louisiana, bordered to the west by Caminada Bay, between Bayou Rigaud and Fifi Island (29°14'20.52"N 90°0'11.66"W). The site is well protected to the southeast by Grand Isle, which is a populated barrier island and to the north by man-made breakwaters formed of 'rip-rap' material. This study site has a typical diurnal tidal range of 0.5 meters and water depth at mean high water is approximately 1.5 meters. It is characterized by mixomesohaline salinities. Common shallow habitats include low profile *C. virginica* oyster shell, patches of coarse-grained sand beaches, sheltered rip-rap, and unvegetated, unconsolidated bottom. The substrate within the site consists of semi-soft unconsolidated sand and mud mixed sediment.

Figure 2.6 Photograph of the farm site in Bay des Ilettes (Grand Isle), Louisiana (July 2013).

Within this study site operates the Louisiana Sea Grant Oyster Research and Demonstration Farm (LSGORDF; Fig. 2.6). LSGORDF is a submerged lands riparian rights lease farm that is operated for research and demonstration purposes by a faculty member of Louisiana State University. Only the observational field-based portions of this study related to oyster farm, bagged oyster shell, and unvegetated bottom habitats were conducted within this oyster farming lease, because there is no seagrass located in this region.

Environmental Conditions

Environmental conditions including water temperature, depth, salinity (which can affect decapod larvae abundances; Bachelor *et al.*, 2006; and settlement on oyster reefs; Tolley *et al.*, 2012) , and dissolved oxygen (which can effect juvenile mortality; Eggleston *et al.*, 2005) were measured and recorded during each site visit. Water temperature and salinity were measured using a VitalSine Model SR-6 refractometer and a mercury thermometer, and water temperature, salinity, and dissolved oxygen were measured additionally using a Model 85 YSI Dissolved Oxygen and Conductivity Meter (Yellow Springs International, Yellow Springs, Ohio). Water depth was measured using a three meter long PVC pipe marked in increments of 10 centimeters. Field-based observation times and GPS coordinates were verified using a Garmin Model 72H GPS at the time and location of each occurrence.

2.2.2 Overview of Habitats

The habitat and system types of interest for this study were the following: 1) BST™ Adjustable Longline System gear (ALS; oyster farming baskets representing OBOF habitat); 2) bagged oyster shell (BOS; representing oyster reef restoration/supplementation habitat); 3) submerged aquatic vegetation (SAV; representing vegetated bottom habitat); and 4) non-vegetated, unconsolidated soft-sediment (UVB; representing unvegetated bottom habitat).

Adjustable Longline System

The BST™ Adjustable Longline System (ALS) is an oyster mariculture system developed and manufactured in Cowell, South Australia by BST™ Oyster Supplies Pty. Ltd. This system was chosen due to the recent development of the oyster aquaculture industry within the region, and the ecological effects of this system have not yet been explored in the region. Oysters that are cultured using this system which suspends them in baskets off of the bottom can be kept free from fouling and predators that can create oyster mortality issues for oyster farmers.

The baskets used in this system are triangular shaped cylinders that are approximately 71 centimeters in length by 21 centimeters in width. They are made out of ultra-violet light stabilized plastic with 12 millimeter hexagonal mesh openings. These openings can allow transient organisms entry where they may find shelter from predation.

Figure 2.7 Photograph of BST™ ALS oyster baskets (June 2013).

The ALS baskets are suspended within the water column by being clipped onto 5 millimeter diameter monofilament wire longlines that have been sleeved with rigid dripper tubing and tensioned between two pilings on either end, generally spaced 100 meters apart from one another. These longlines are typically deployed in pairs. The ALS baskets are additionally supported by riser clips which have been affixed at incrementally spaced heights to PVC posts that are spaced 100 centimeters apart from one another running the length of the longlines and approximately 72 centimeters apart from one another between each of the longlines.

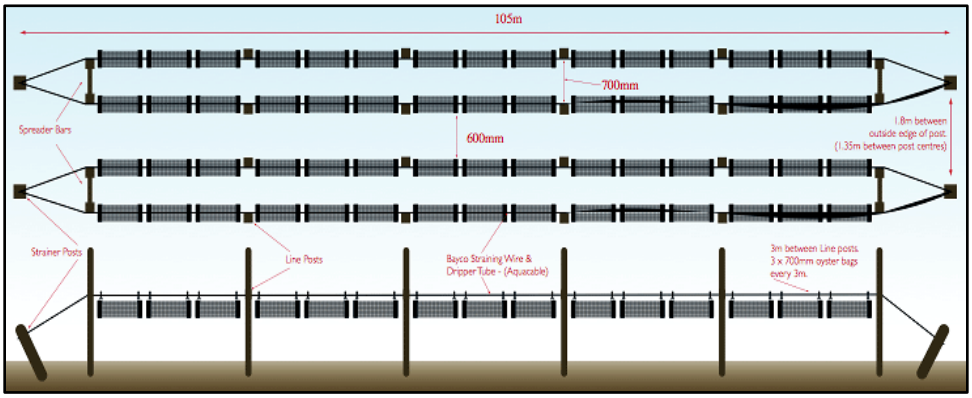


Illustration 2.3 Example configurations depicting an ALS deployed using an in-line basket arrangement. Image credit: BST™ Oyster Supplies Pty. Ltd.

In the Gulf of Mexico, oyster farmers will typically desiccate this system once weekly by placing the longlines into the clips which have been affixed at the highest increments on the PVC riser posts. This routine operation increases meat quality as well as shell quality (Ring, 2012; Davis, 2013).

Bagged Oyster Shell

Bagged oyster shell is commonly used for oyster reef restoration projects in the coastal waters of Alabama (Fig. 2.8). These bags are typically stacked in groupings of wide mounds having low-profiles in subtidal and intertidal areas arranged in a parallel orientation with the shoreline. They are generally used in areas where there are scarce amounts of naturally occurring oyster reefs.

Bagged oyster shell was included in this study, because this man-made structure may serve as valuable habitat for populations of reef oriented species that have suffered from declining availability of naturally occurring oyster populations, as documented in a recent report by The Nature Conservancy (Kroeger, 2012).

Figure 2.8 Photograph of oyster shell bags used for oyster reef restoration in Portersville Bay, Alabama.

Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV, also sometimes referred to as seagrasses, although not necessarily interchangeable) occurs in the shallow waters along the north-central Gulf of Mexico coastline, mostly consisting of wigeon grass, *Ruppia maritima*, and shoal grass, *Halodule wrightii*, the latter of which is more commonly considered a true seagrass. In well-sheltered areas, this vegetation can densely cover the bottom and stabilize the sediment with their rhizomes. Another species which can sometimes be found in the region is turtle grass, *Thalassia testudinum*, which invades the Gulf to its northern shores. However, being a tropical species, its erect clumps of flattened broad blades are generally killed by colder winters (Kaplan, 1988). Submerged vegetation is being included in this study of habitat value for comparison purposes, because it is commonly viewed as excellent nursery habitat for juvenile estuarine organisms seeking shelter.

Unvegetated Bottom

Unvegetated, soft sediment bottom habitats cover more area than any other estuarine habitat in the Gulf of Mexico (Kaplan, 1988). Unvegetated bottom can serve as habitat for a variety of marine epibenthic organisms; however, in many cases the adult life stage is better suited for this habitat type than is the juvenile life stage. In this study, unvegetated bottom was included in order to better understand the effects of placing new structure within the benthos.

2.2.3 Field Study Setup and Design

For the primary field study, two different but related analyses were done. First, a two factor complete factorial test of habitat type (three levels of habitat) by site (three levels of site) was conducted to address the hypotheses developed for this field study where there were three sites that had three common habitats, but over a greater spatial extent. Second, another two factor complete factorial test of habitat type (four levels of habitat) by site (two levels of site, both in Alabama) was conducted to allow a comparison of all four habitat types.

The primary field study was conducted over 122 days, with the first deployment occurring on June 25th 2013, and the final sample collection occurring on November 4th, 2013. Of the four habitat types (ALS, BOS, SAV, and UVB), only the ALS and BOS required deployment or installation.

	Time	PBA	SBA	BDIL
Adjustable Longline System	**1**	07/18/2013	07/16/2013	NO SAMPLE
	2	08/06/2013	08/08/2013	08/03/2013
	3	08/26/2013	08/28/2013	NO SAMPLE
	4	09/18/2013	09/23/2013	09/13/2013
	5	10/09/2013	10/14/2013	NO SAMPLE
	6	11/02/2013	11/04/2013	10/25/2013
Bagged Oyster Shell	**1**	07/18/2013	07/16/2013	NO SAMPLE
	2	08/06/2013	08/08/2013	08/03/2013
	3	08/26/2013	08/28/2013	NO SAMPLE
	4	09/18/2013	09/23/2013	09/13/2013
	5	10/09/2013	10/14/2013	NO SAMPLE
	6	11/02/2013	11/04/2013	10/25/2013
Submerged Aquatic Vegetation	**1**	07/18/2013	07/16/2013	NO SAMPLE
	2	08/06/2013	08/08/2013	NO SAMPLE
	3	08/26/2013	08/28/2013	NO SAMPLE
	4	09/18/2013	09/23/2013	NO SAMPLE
	5	10/09/2013	10/14/2013	NO SAMPLE
	6	NO SAMPLE	11/04/2013	NO SAMPLE
Unvegetated Bottom	**1**	07/18/2013	07/16/2013	NO SAMPLE
	2	08/06/2013	08/08/2013	08/03/2013
	3	08/26/2013	08/28/2013	NO SAMPLE
	4	09/18/2013	09/23/2013	09/13/2013
	5	10/09/2013	10/14/2013	NO SAMPLE
	6	11/02/2013	11/04/2013	10/25/2013

Table 2.1 Primary field study sampling dates.

		PBA	SBA	BDIL
Adjustable Longline System	Description	(Off-Bottom) ALS	(Off-Bottom) ALS	(Off-Bottom) ALS
	Sampling Freq.	once every third week	once every third week	once every sixth week
	Sampling Mode	collection bag	collection bag	collection bag
	Replicates	30	30	15
Bagged Oyster Shell	Description	(On-Bottom) BOS	(On-Bottom) BOS	(On-Bottom) BOS
	Sampling Freq.	once every third week	once every third week	once every sixth week
	Sampling Mode	collection bag	collection bag	collection bag
	Replicates	30	30	15
Submerged Aquatic Vegetation	Description	*Ruppia maritima*	*Ruppia maritima*	Not Applicable
	Sampling Freq.	once every third week	once every third week	Not Applicable
	Sampling Mode	suction	suction	Not Applicable
	Replicates	30	30	Not Applicable
Unvegetated Bottom	Description	Soft Bottom	Soft Bottom	Soft Bottom
	Sampling Freq.	once every third week	once every third week	once every sixth week
	Sampling Mode	suction	suction	suction
	Replicates	30	30	15

Table 2.2 a) Primary field study design testing effects of site and habitat on density and size.

		PBA	SBA
ALS	Description	(Off-Bottom) ALS	(Off-Bottom) ALS
	Replicates	3	3
BOS	Description	(On-Bottom) BOS	(On-Bottom) BOS
	Replicates	3	3
SAV	Description	*Ruppia maritima*	*Ruppia maritima*
	Replicates	3	3
UVB	Description	Soft Bottom	Soft Bottom
	Replicates	3	3

Table 2.2 b) Relative predation intensity field study design testing effects of site and habitat on survival.

Adjustable Longline System

A BST™ ALS had already been installed at each of the sites prior to the beginning of this study; therefore, the existing gear was utilized. For the purposes of this study, seven empty ALS bays were required at each site in Alabama and five empty ALS bays were required at the site in Louisiana (bays required at each site were approximately three meters long by one meter wide). Each empty bay was later be occupied by three BST™ ALS oyster baskets per line in an in-line orientation (i.e. six per bay for the two line runs at each site in Alabama, and three per bay for the one line run at the site in Louisiana) for a total of 99 BST™ ALS oyster baskets. Prior to deployment, the BST™ ALS oyster baskets (12 millimeter mesh-size; equipped with BST™ T-clips and pins for in-line orientation) were cleaned of all existing fouling and debris using a mechanical pressure washer, and then individually tagged using Hasco™ cattle tags (style number 402).

Figure 2.9 Photograph of the QuickTube Sorter™ rotary grader at AUSL.

All oysters used for this study were initially processed through a QuickTube Sorter™ mechanical grader manufactured by the Chesapeake Bay Oyster Company (Fig. 2.9). This rotary style grader uses a rotating aluminum grading tube, manufactured with two sections of holes sized for grading single shell oysters, equating to three size sorts. Only oysters of the largest grade were used for this study. The grader was additionally equipped with a spray bar wash down connection attached to a freshwater supply that sprayed a constant stream of water across the oysters as they were graded, leaving them clean of fouling and other debris by the end of the process.

All of the BST™ ALS oyster baskets for the two Alabama sites were stocked each with 85 sub-adult (< 75 millimeters; mean shell height = 50 millimeters) oysters (*C. virginica*). These oysters were spawned at the Auburn University Shellfish Laboratory (AUSL) on July 27th, 2012. For the Louisiana site, each BST™ ALS oyster basket was stocked with 85 sub adult/adult (< 75 - 90 millimeters; mean shell height = 72 millimeters) oysters (*C. virginica*). The stocked BST™ ALS oyster baskets were deployed on June 26th, 2013 at the two sites in Alabama, and on July 8th, 2013 at the site in Louisiana.

Bagged Oyster Shell

For preparation of BOS deployment, oyster shells were first removed by shovel from a shell-stock pile at AUSL. Oyster shells were then placed into a bucket that had been measured and marked to accommodate approximately 150 oyster shells (50 - 75 millimeters in shell height). Each load of approximately 150 oyster shells was then packed into a 30.5 centimeters wide by 61 centimeters long oyster setting bag (16 millimeter mesh-size) that had an overhand knot tied at each end. At each of the two sites in Alabama, 40 oyster shell bags were deployed on June 25th, 2013, and at the site in Louisiana, 15 oyster shell bags were deployed on July 8th, 2013.

At each of the sites, oyster shell bags were placed on the sediment in five groups of three to eight bags, depending upon the frequency of sampling, and each bag within a grouping was spaced approximately 0.5 meters from another, while each grouping was spaced approximately five meters from another. Each grouping was marked by a tagged floating buoy attached by rope to an anchor driven into the sediment.

Figure 2.10 Photograph of bagged oyster shell ready to be deployed at Auburn University Shellfish Laboratory (June 2013).

2.2.4 Data Collection

2.2.4.1 Primary Field Study

After an initial period of three weeks had passed (for community establishment post-deployment) the density and size structure data necessary for estimating habitat utilization of juvenile blue crabs was obtained by collecting five randomly selected replicate samples from each of the four habitat treatments present at each of the three sites repeatedly over a course of five months spanning the summer and fall seasons of 2013.

Sampling was randomly allocated (within each time, habitat type, and location). It was necessary to use two types of sampling techniques due to the different characteristics of the sub strata in this field study. These techniques involved using collection bag enclosure devices (for adjustable longline system and bagged oyster shell) and suction sampling enclosure devices (for submerged aquatic vegetation and unvegetated bottom).

Enclosure devices such as these (including both collection bag and suction sampling) have few variables influencing catch efficiency (i.e. sampling methodology allows for consistent catch efficiency) ; and although the area enclosed by these samplers is small, increasing the sample number can generally compensate for this limitation. For estimating densities of blue crabs in shallow estuarine habitats, it is recommended to use enclosure samplers because these samplers provide the most reliable quantitative data, and the results of studies using these samplers (i.e. enclosure samplers) should be comparable, because there are common units of number per area (Rozas and Minello, 1997).

Adjustable Longline System

For each field sampling effort, five randomly selected submerged BST™ ALS oyster baskets (no more than one from each bay) were quantitatively sampled for juvenile blue crabs using the following methodology: First, a randomly selected ALS basket was carefully approached and sampled by raising a collection bag (0.5 millimeter mesh-size; Fig. 2.11) from underneath, and then enclosing the ALS basket and removing it from the longline.

Figure 2.11 Photograph of sample collection bag (0.5 millimeter mesh).

The ALS basket would then be carefully transferred from the collection bag onto a wooden collection platform within the boat or on nearby land (Fig. 2.12). The ALS basket and collection bag were then both emptied and rinsed onto the collection platform, where each oyster would be rinsed and then placed into a bucket for volumetric displacement measurements, and all fauna would be rinsed into the collection tray underneath the collection platform.

The collected fauna would then be rinsed from the collection tray onto a smaller 500 micron mesh screen from which the fauna could then be easily rinsed into a labeled sample bag to be stored inside a cooler for sorting purposes that would be performed upon return to the laboratory. The ALS basket would then have the oysters placed back inside, and returned to the longline. Once an individual BST™ ALS oyster basket was sampled, it would not be sampled again.

Figure 2.12 Photograph of collection platform and sample processing gear.

Bagged Oyster Shell

For each field sampling effort, five randomly selected submerged oyster shell bags (no more than one from each grouping) were quantitatively sampled for juvenile blue crabs using the following methodology: First, a randomly selected oyster shell bag would be carefully approached and sampled by lowering a collection bag (0.5 millimeter mesh-size; Fig. 2.11) from above, and then enclosing the oyster shell bag and removing it from the benthos. The oyster shell bag would then be carefully transferred from the collection bag onto a wooden collection platform (Fig. 2.12). The oyster shell bag and collection bag were then both emptied and rinsed onto the collection platform, where oyster shell material would be rinsed and then placed into a bucket for volumetric displacement measurements, and all fauna would be rinsed into the collection tray underneath the collection platform.

The collected fauna would then be rinsed from the collection tray onto a smaller 500 micron mesh screen from which the fauna could then be easily rinsed into a labeled sample bag to be stored inside a cooler for sorting purposes that would be performed upon return to the laboratory. The oyster shell would then be returned to the benthos from where it came.

Submerged Aquatic Vegetation

For each field sampling effort, five randomly selected areas of submerged aquatic vegetation were quantitatively sampled for juvenile blue crabs using a suction sampling technique that follow the methodology of Spitzer *et al*. (2003) as follows: A PVC cylinder (diameter = 0.604 meters; Fig. 2.13 (a), left), which is open at both ends, was placed within the desired subsection of habitat. Taking care not to disturb the sampling area prior to cylinder placement, a tight seal was created following placement by twisting the cylinder into the sediment (due to water depth and cylinder height, the cylinder always reached the surface). Once the seal was formed, the contents of the substrate enclosed by the cylinder were evacuated via suction using a trash pump and suction manifold (Fig. 2.13 (b)) through a PVC suction sampling wand (Fig. 2.13 (a), right) into a collection bag (0.5 millimeter mesh-size) for two minute durations.

The collection bag was then removed and placed into a collection tray aboard the sampling vessel where it was then emptied of all contents and rinsed. To ensure that the cylinder was empty, a dip net was used to remove any remaining juvenile blue crabs, which were also placed into the same collection tray. The cylinder was checked using the dip net until at least three dips returned no fauna. The collected fauna were then rinsed from the collection tray onto a smaller 500 micron mesh screen from which the fauna were then easily rinsed into a labeled sample bag and stored inside a cooler for sorting purposes that were performed upon return to the laboratory. Once an individual subsection was sampled, it was not sampled again.

Figure 2.13 a) Photograph of suction sampling chamber (left); and suction sampling wand (right).

Figure 2.13 b) Photograph of suction sampling manifold.

Unvegetated Bottom

For each field sampling effort, five randomly selected areas of unvegetated bottom sediment were quantitatively sampled for juvenile blue crabs using a suction sampling technique that follow the methodology of Spitzer *et al*. (2003) as follows: A PVC cylinder (diameter = 0.604 meters; Fig. 2.13 (a), left), which is open at both ends, was placed within the desired subsection of habitat. Taking care not to disturb the sampling area prior to cylinder placement, a tight seal was created following placement by twisting the cylinder into the sediment.

Once the seal was formed, the contents of the substrate enclosed by the cylinder were evacuated via suction using a trash pump and suction manifold (Fig. 2.13 (b)) through a PVC suction sampling wand (Fig. 2.13 (a), right) into a collection bag (0.5 millimeter mesh-size) for two minute durations. The collection bag was then removed and placed into a collection tray aboard the sampling vessel where it was then emptied of all contents and rinsed. To ensure that the cylinder was empty, a dip net was used to remove any remaining juvenile blue crabs, which were also placed into the same collection tray. The cylinder was checked using the dip net until at least three dips returned no fauna. The collected fauna were then rinsed from the collection tray onto a smaller 500 micron mesh screen from which the fauna were then easily rinsed into a labeled sample bag and stored inside a cooler for sorting purposes that was performed upon return to the laboratory. Once an individual subsection was sampled, it was not sampled again.

Sample Processing

After sample collection, each sample was returned to the laboratory where they were frozen briefly until being transferred into individual containers of 70% isopropyl alcohol for sorting purposes (Fig. 2.14). Each sample was closely examined for the removal of all *C. sapidus* specimens; each was then photographed and counted. Carapace width (to the nearest hundredth of a millimeter) and gender were also recorded for each.

Figure 2.14 Photograph of stored samples.

2.2.4.2 Estimation of Relative Predation Intensity

In order to estimate relative predation intensity, juvenile blue crab field-tethering studies were performed in July 2013 at SBA and September 2013 at PBA by quantifying survival rates between habitat and site treatments. Techniques used were followed similarly to those used in previous studies (Minello, 1993; Heck and Coen, 1995; Spitzer *et al*., 2003).

Juvenile blue crabs were first collected in the field from vegetated habitats using beach seines, and then returned to the laboratory. After measuring carapace width for each crab collected (range: 18 - 33 mm), a 0.5 meter long segment of monofilament fishing line (20 lb. test) containing a loop and slipknot at one end was prepared for each to be used as a tether. Each tether was affixed around the carapace of a juvenile blue crab by securing the looped end between the last pair of walking legs and the swimming legs using cyanoacrylate cement. They were then allowed to acclimate to the tethers in the laboratory for 24 hours before being deployed in the field (Fig. 2.15).

Five individually tethered blue crabs were deployed into each of the four habitat treatments. For the ALS and BOS habitat treatments, the tethered crabs were placed within the basket/bag interior and the opposite end of the tethers were tied onto the basket/bag exterior; and for the vegetated and unvegetated bottom habitat treatments, the opposite end of the tether was tied to a stake that was driven into the sediment. Once every 24 hours, the tethered crabs were examined to see if they were missing (i.e. escaped or preyed upon). Results were recorded and missing crabs were replaced so that a full set of crabs was deployed for the next 24 hours.

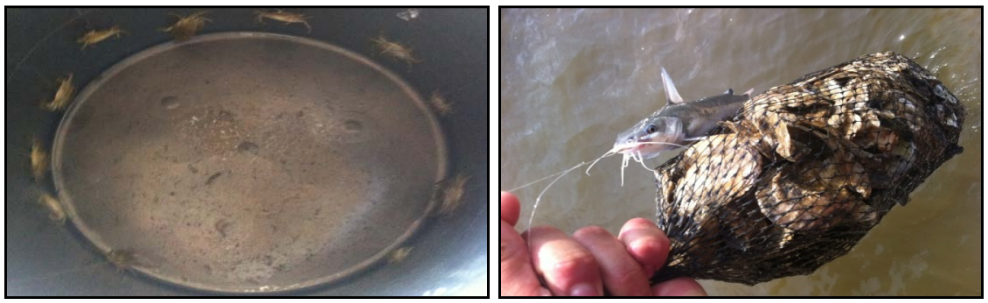


Figure 2.15 Juveniles acclimating to tethers (left); juvenile blue crab predator, hardhead catfish (*Arius felis*; right).

The study ran for three consecutive days at each site. Crabs were classified as having been preyed upon rather than as having had escaped by the presence of carapace fragments remaining attached to the tether. Whereas, if had they escaped, then only a complete loop with no carapace would have remained. If a tether was found without any carapace attached, it was not included in the analysis.

2.2.5 Data Analysis

2.2.5.1 Primary Field Study

There were two approaches used in analyzing the data for the primary field study.

Approach 1			Approach 2		
Sites	**Habitats**	**Time**	**Sites**	**Habitats**	**Time**
PBA	ALS, BOS, UVB	2, 4, 6	PBA	ALS, BOS, UVB, SAV	1, 2, 3, 4, 5
SBA	ALS, BOS, UVB	2, 4, 6	SBA	ALS, BOS, UVB, SAV	1, 2, 3, 4, 5
BDIL	ALS, BOS, UVB	2, 4, 6			

Table 2.3 A comparison of the two approaches used for data analysis in the primary field study.

Analytical Approach 1

In the first approach used for analyzing the data for this portion of the study, there were nine treatments (three habitats x three sites) with five replicates per treatment at three separate sampling times (analyzed one at a time), where the SAV habitat data were excluded, but the BDIL site data were included. Therefore, for this analysis, conclusions are across all three study sites. Data were analyzed by habitat (2 df), site (2 df), and any interaction between the two (4 df) for all the response variables. Response variables were: average relative abundance (density A; i.e. number of juvenile blue crabs per sample bottom surface area), average relative abundance (density B; i.e. number of juvenile blue crabs per sample bottom and bag interior surface area), and average carapace width of juvenile blue crabs per sample (Table 2.4 (a)).

The following hypotheses, and their interactions, were tested:

H_0: $\mu_{ALS} = \mu_{BOS} = \mu_{UVB}$ $\quad$ H_0: $\mu_{PBA} = \mu_{SBA} = \mu_{BDIL}$

H_a: $\mu_{ALS} \neq \mu_{BOS} \neq \mu_{UVB}$ $\quad$ H_a: $\mu_{PBA} \neq \mu_{SBA} \neq \mu_{BDIL}$

Analytical Approach 2

In the second approach used for analyzing the data for this portion of the study, there were eight treatments (four habitats x two sites) with five replicates per treatment at five separate sampling times (analyzed one at a time) for a total of 200 replicates, where the BDIL data were excluded due to the lack of SAV habitat. Therefore, for this analysis, conclusions are confined to the two Alabama study sites. Data were analyzed by habitat (3 df), site (1 df), and any interaction between the two (4 df) for all the response variables.

Response variables were: average relative abundance of juvenile blue crabs per sample bottom surface area (density A), average relative abundance of juvenile blue crabs per sample total interior surface area (density B), and average carapace width of juvenile blue crabs per sample (Table 2.4 (a)). The following hypotheses, and their interactions, were tested:

H_0: $\mu_{ALS} = \mu_{BOS} = \mu_{SAV} = \mu_{UVB}$ $\quad$ H_0: $\mu_{PBA} = \mu_{SBA}$

H_a: $\mu_{ALS} \neq \mu_{BOS} \neq \mu_{SAV} \neq \mu_{UVB}$ $\quad$ H_a: $\mu_{PBA} \neq \mu_{SBA}$

Response Variable	Description
Mean Density (A)	Average number of juvenile blue crabs per bottom surface area of sample
Mean Density (B)	Average number of juvenile blue crabs per total interior surface area of sample
Mean Carapace Width	Average carapace width of juvenile blue crabs per sample

Table 2.4 a) Primary field study response variables.

Statistical Methods: Approaches 1 and 2

Systat® 12 and Microsoft® Excel® 2010 software were used to analyze the data (Systat Software Inc., Chicago, IL; Microsoft, Redmond, WA). Shapiro-Wilk Tests and Levene's Tests were used to verify the assumptions of normality and homogeneity of variance, respectively. Data were considered normally distributed and variances homogenous at $p > 0.05$.

Where these assumptions were not met, data were transformed using the appropriate transformation for the type of data (Underwood, 1997). We were unable to achieve normality in all but three analyses of the data (Tables A-6 (d), A-17 (d), and A-22 (d)). However, since we had a relatively large number of samples, we could safely interpret the analysis even with non-normal distributions (Underwood, 1997).

A two-factor analysis of variance (ANOVA) was used to determine effects of habitat, site, and any interaction between the two for each response variable. When no interactions were detected single factors were pooled across treatments. All tests were performed with $\alpha = 0.05$ and means were considered significantly different if $p < 0.05$. *Post-hoc* pairwise comparison using Tukey's Honestly Significantly Difference Test ($p < 0.05$) was used to further investigate significant effects identified by the ANOVA.

2.2.5.2 Test of Relative Predation Intensity

In the approach used for analyzing the relative predation intensity data for this portion of the study, there were eight treatments (four habitats x two sites) replicated on the level of day for a total of 24 replicates. Data were analyzed by effect of habitat (3 df), site (1 df), and any interaction between the two (4 df) on the response variable. The response variable was predation pressure expressed as percent survival. The following hypotheses, and their interactions, were tested (where S = percent survival):

H_0: $S_{ALS} = S_{BOS} = S_{SAV} = S_{UVB}$ $\quad\quad$ H_0: $S_{PBA} = S_{SBA}$
H_a: $S_{ALS} \neq S_{BOS} \neq S_{SAV} \neq S_{UVB}$ $\quad\quad$ H_a: $S_{PBA} \neq S_{SBA}$

Response Variable	Description
Predation Pressure	Average percent survival of juvenile blue crabs per sample.

Table 2.4 b) Test of relative predation intensity response variable.

Statistical Methods

Systat® 12 and Microsoft® Excel® 2010 software were used to analyze the data (Systat Software Inc., Chicago, IL; Microsoft, Redmond, WA). Differences in predation rates between sites, habitat types, and their interactions were examined using a two-factor analysis of variance (ANOVA). When no interactions were detected, single factors were pooled across treatments. All tests were performed with $\alpha = 0.05$ and means were considered significantly different if $p < 0.05$.

A priori tests were run to test for normality and heteroscedasticity (using the Kolmogorov-Smirnov or Shapiro-Wilk Test and the Levene's Test, respectively). Data were considered normally distributed and variances homogenous at $p > 0.05$. If either failed, then the data were transformed (arcsin square root) to correct the violations. If assumptions could not be met with data transformations, then we relied on the robustness of the test for safe analysis interpretation. *Post-hoc* pairwise comparison using Tukey's Honestly Significantly Difference Test ($p < 0.05$) was used to further investigate significant effects identified by the ANOVA. Although effects of seasonality/month (either July 2013 or September 2013) were nested within each respective site treatment, differences between environmental factors for each site were analyzed; therefore, the presence or absence of seasonality effects could be gathered from these analyses.

2.3 Results: Primary Field Study

2.3.1 Environmental Conditions

Mean seawater temperature at the Portersville (Fowl River) Bay, Alabama (hereafter, PBA) site, was 27.7 °C (range: 20.0 - 33.8 °C); at the Sandy Bay (Point aux Pins), Alabama (hereafter, SBA) site, mean seawater temperature was 27.9 °C (range: 20.0 - 34.3 °C); and at the Bay des Ilettes (Grand Isle), Louisiana (hereafter, BDIL) site, mean seawater temperature was 27.5 °C (range: 19.0 - 34.6 °C; Fig. 2.16).

Mean salinity at PBA was 15.7 PSU (range: 8.8 - 24.2 PSU); at the SBA site, mean salinity was 20.8 PSU (range: 13.8 - 32.0 PSU); and at the BDIL site, mean salinity was 22.5 PSU (range: 19.2 - 26.8 PSU; Fig. 2.17).

Mean dissolved oxygen at PBA was 6.75 mg L^{-1} (range: 4.41 - 9.03 mg L^{-1}); at the SBA site, mean dissolved oxygen was 7.06 mg L^{-1} (range: 3.58 - 11.50 mg L^{-1}); and at the BDIL site, mean dissolved oxygen was 6.83 mg L^{-1} (range: 5.02 - 7.95 mg L^{-1}; Fig. 2.18).

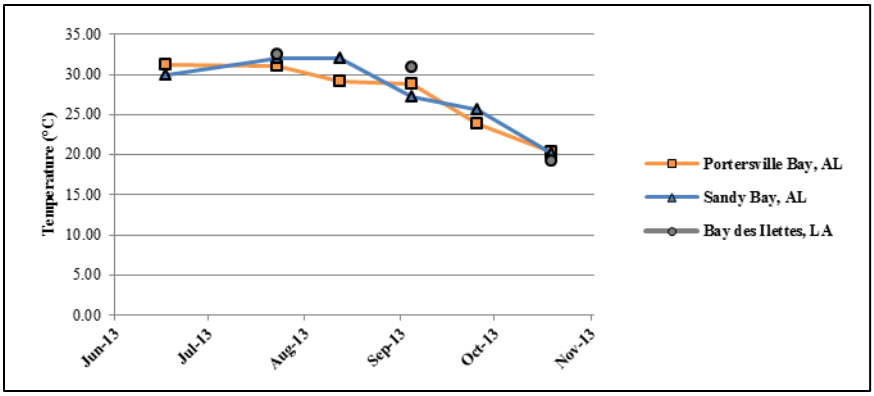


Figure 2.16 Physical seawater temperature (°C) data for each field site during 2013.

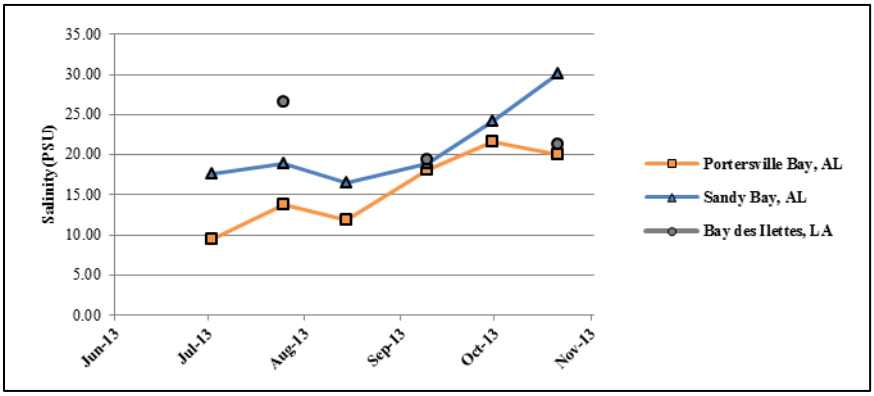


Figure 2.17 Physical seawater salinity (PSU) data for each field site during 2013.

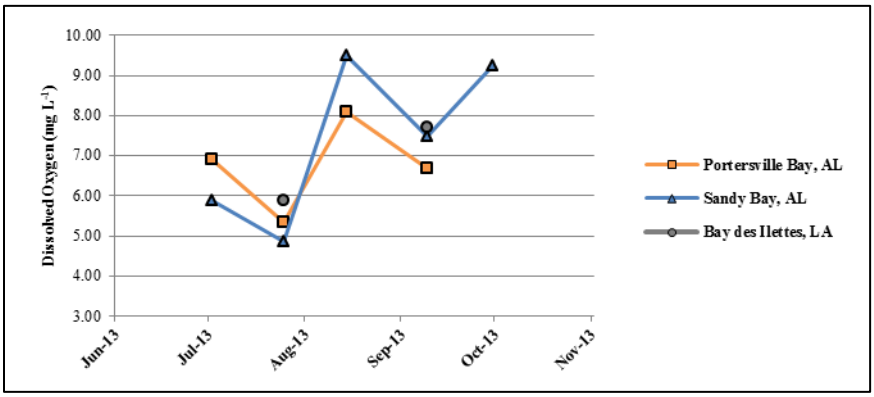


Figure 2.18 Physical seawater dissolved oxygen (mg L^{-1}) data for each field site during 2013.

Environmental conditions were tested for significant differences between sites (analyzed by site; 2 df). Seawater temperature and dissolved oxygen were not significantly different between sites (ANOVA: seawater temperature, $p = 0.885$, Table 2.5; dissolved oxygen, $p = 0.424$, Table 2.7; Fig. 2.19). Salinity was significantly lower at the PBA site than at both the SBA and BDIL sites (ANOVA: $p < 0.001$, Table 2.6; Fig. 2.19), but salinity was not significantly different between the SBA and BDIL sites (Tukey's HSD: $p = 0.094$; Fig. 2.19; see App. A: Chapter Two Supporting Data, Table A-1 (a-e), Table A-2 (a-f), and Table A-3 (a-e) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
SITE	4.944	2	2.472	0.122	0.885
Error	5,620.708	277	20.291		

Table 2.5 ANOVA results related to physical seawater temperature data.

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
SITE	2,196.646	2	1,098.323	49.759	0.000
Error	6,114.193	277	2,.073		

Table 2.6 ANOVA results related to physical seawater salinity data.

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
SITE	4.281	2	2.141	0.861	0.424
Error	511.880	206	2.485		

Table 2.7 ANOVA results related to physical seawater dissolved oxygen data.

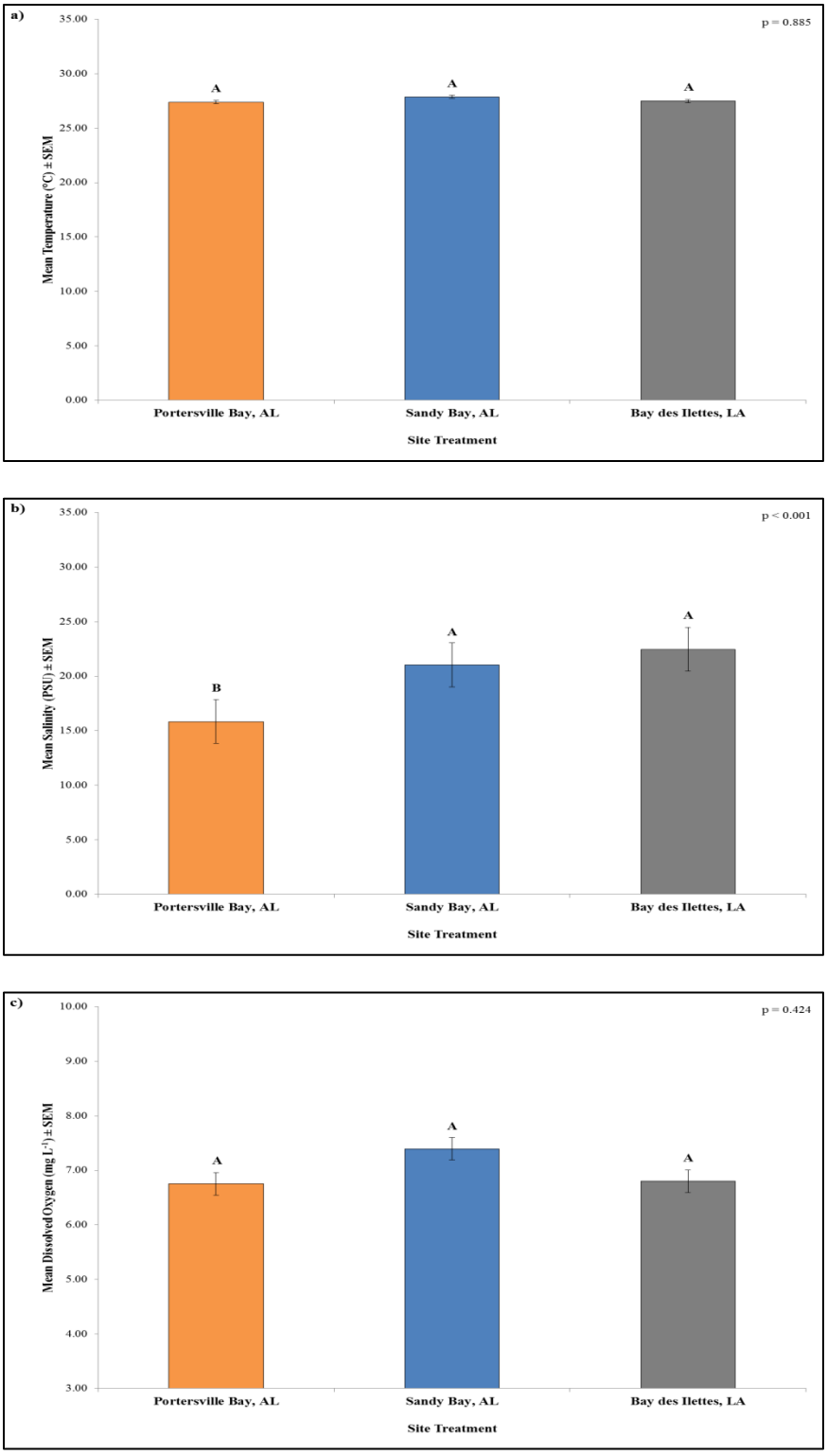


Figure 2.19 Comparison of physical seawater parameters: a) mean temperature (°C); b) mean salinity (PSU); and c) mean dissolved oxygen (mg L^{-1}). Different letters indicate a statistically significant difference ($p < 0.05$). P-values were derived from general linear models and statistically significant differences were calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.2 Effects of Habitat and Site: Analytical Approach 1

The following results were obtained by using the first analytical approach to address the hypotheses developed for this study, where there were three sites that had three common habitats, over a spatial extent spanning Alabama to Louisiana. Analysis was performed using nine treatments (three habitats x three sites) with five replicates per treatment at three separate sampling times (analyzed one at a time) for a total of 135 replicates.

2.3.2.1 Analytical Approach 1 (August 2013)

Adjustable Longline System

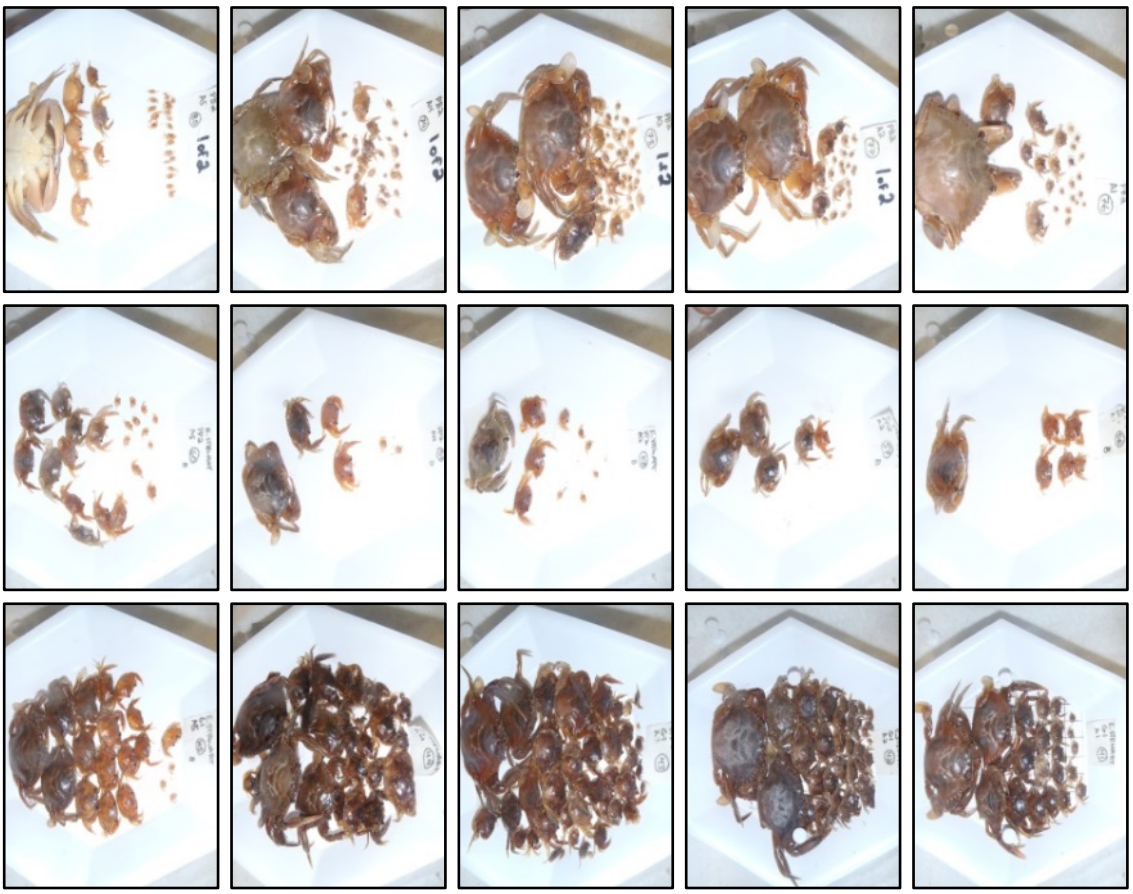


Figure 2.20 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during August 2013. Top row: Portersville (Fowl River) Bay, Alabama; middle row: Sandy Bay (Point aux Pins), Alabama; and bottom row: Bay des Ilettes (Grand Isle), Louisiana.

Bagged Oyster Shell

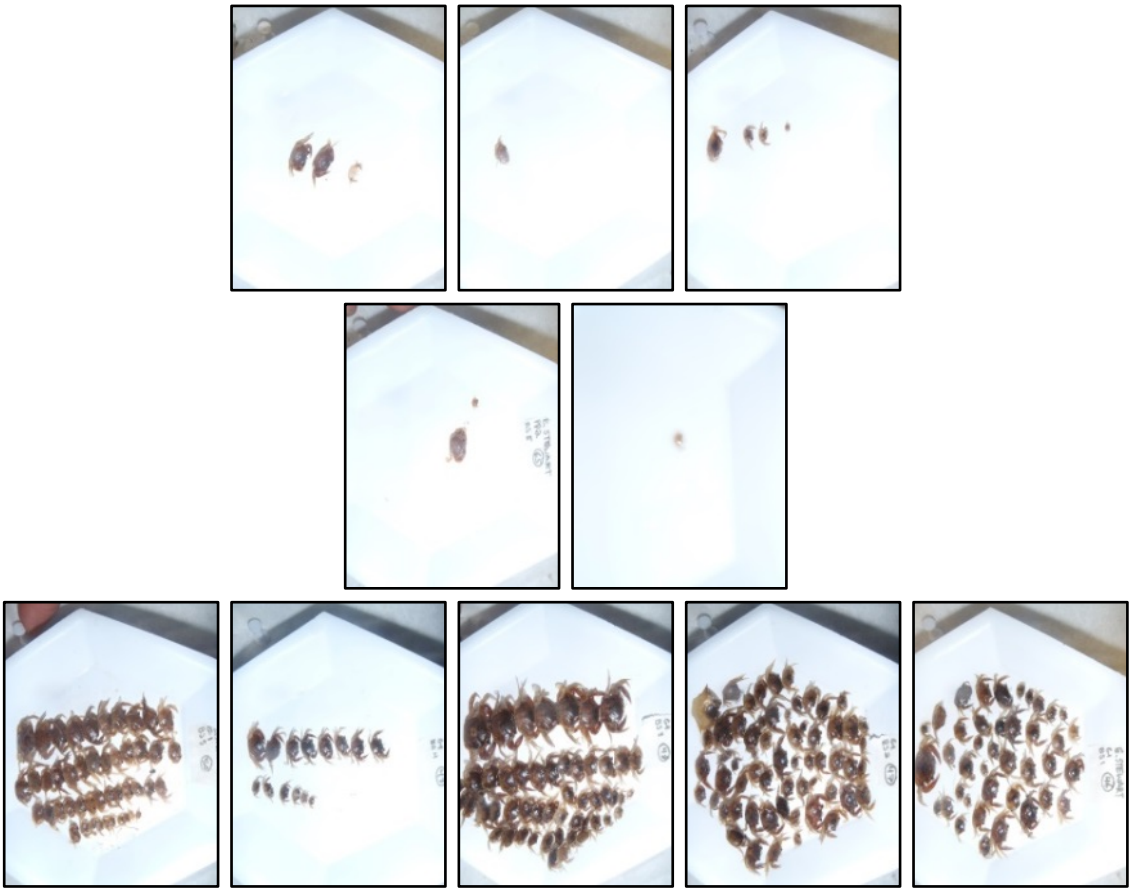


Figure 2.21 Each individual photograph above is of the juvenile blue crabs collected from an oyster shell bag sample during August 2013. Top row: Portersville (Fowl River) Bay, Alabama; middle row: Sandy Bay (Point aux Pins), Alabama; and bottom row: Bay des Ilettes (Grand Isle), Louisiana.

Unvegetated Bottom

Figure 2.22 Each individual photograph above is of the juvenile blue crabs collected from an unvegetated bottom sample during August 2013. Top row: Portersville (Fowl River) Bay, Alabama; middle row: Sandy Bay (Point aux Pins), Alabama; and bottom row: Bay des Ilettes (Grand Isle), Louisiana.

Juvenile Blue Crab Density (A)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (A) in August 2013 (ANOVA: $p < 0.001$; Table 2.8). Juvenile blue crab mean density was significantly greater in the adjustable longline system gear (hereafter, ALS) samples at PBA and BDIL, and in the oyster shell bag (hereafter, BOS) samples at BDIL than in all other treatments (Fig. 2.23; see App. A: Chapter Two Supporting Data, Table A-4 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	175,764.405	2	87,882.202	40.064	0.000
SITE	101,630.111	2	50,815.056	23.166	0.000
HABITAT*SITE	130,483.670	4	32,620.918	14.871	0.000
Error	78,966.982	36	2,193.527		

Table 2.8 ANOVA results for mean density (A) in August 2013, using analytical approach 1.

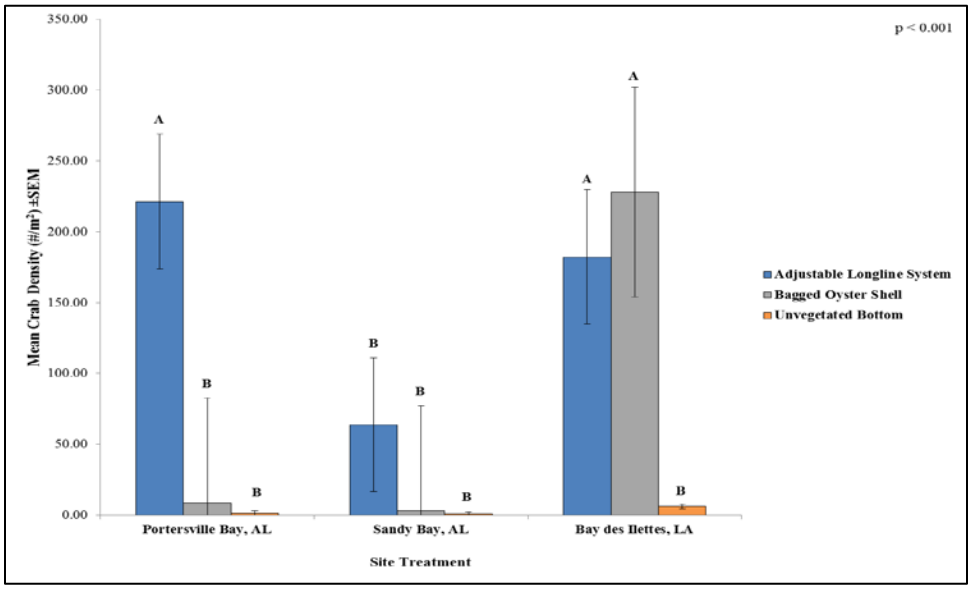


Figure 2.23 Effect of habitat type and site upon juvenile blue crab mean density (A) ± SEM in August 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (B) in August 2013 (ANOVA: $p < 0.001$; Table 2.9). Juvenile blue crab mean density was significantly greatest in the BOS samples at BDIL compared to all other treatments. Additionally, the lowest densities were observed in the BOS samples at the two Alabama sites and all three unvegetated bottom (hereafter, UVB) samples. Intermediate densities were observed in the ALS samples at each site (Fig. 2.24; see App. A: Chapter Two Supporting Data, Table A-5 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	25,725.492	2	12,862.746	21.388	0.000
SITE	34,483.790	2	17,241.895	28.670	0.000
HABITAT*SITE	48,591.050	4	12,147.762	20.200	0.000
Error	21,649.970	36	601.388		

Table 2.9 ANOVA results for mean density (B) in August 2013, using analytical approach 1.

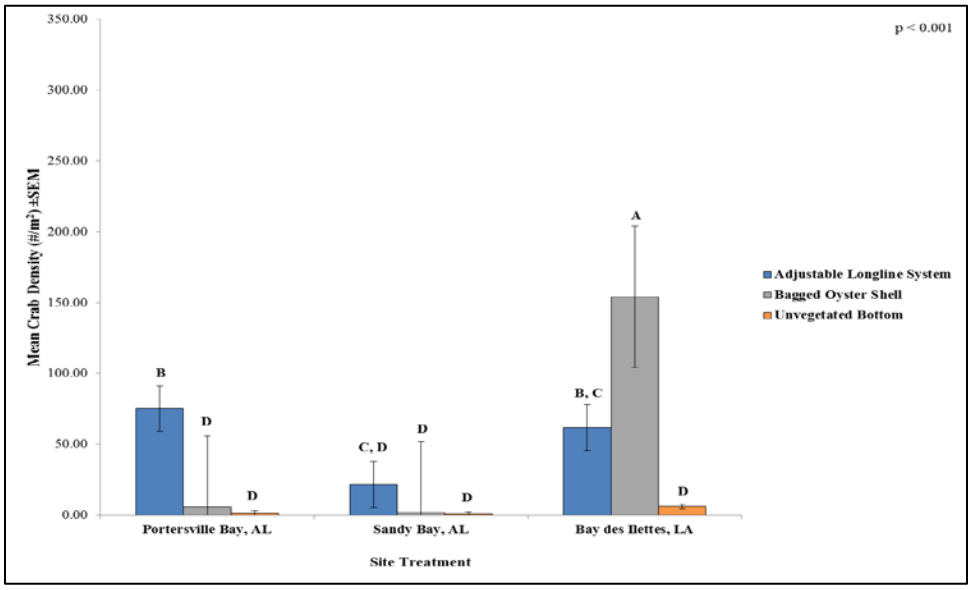


Figure 2.24 Effect of habitat type and site upon juvenile blue crab mean density (B) ± SEM in August 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean carapace width in August 2013 (ANOVA: $p < 0.005$; Table 2.10). Juvenile blue crab mean carapace width was significantly greatest in the ALS gear samples at SBA and BDIL compared to all other treatments (except for the BOS samples at BDIL). Additionally, the lowest mean carapace widths were observed in the UVB samples at the two Alabama sites. Intermediate mean carapace widths were observed in the ALS samples at PBA, BOS samples at the two Alabama sites, and the UVB samples at BDIL (Fig. 2.25; see App. A: Chapter Two Supporting Data, Table A-6 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	979.826	2	489.913	51.957	0.000
SITE	395.040	2	197.520	20.948	0.000
HABITAT*SITE	184.093	4	46.023	4.881	0.003
Error	339.453	36	9.429		

Table 2.10 ANOVA results for mean CW in August 2013, using analytical approach 1.

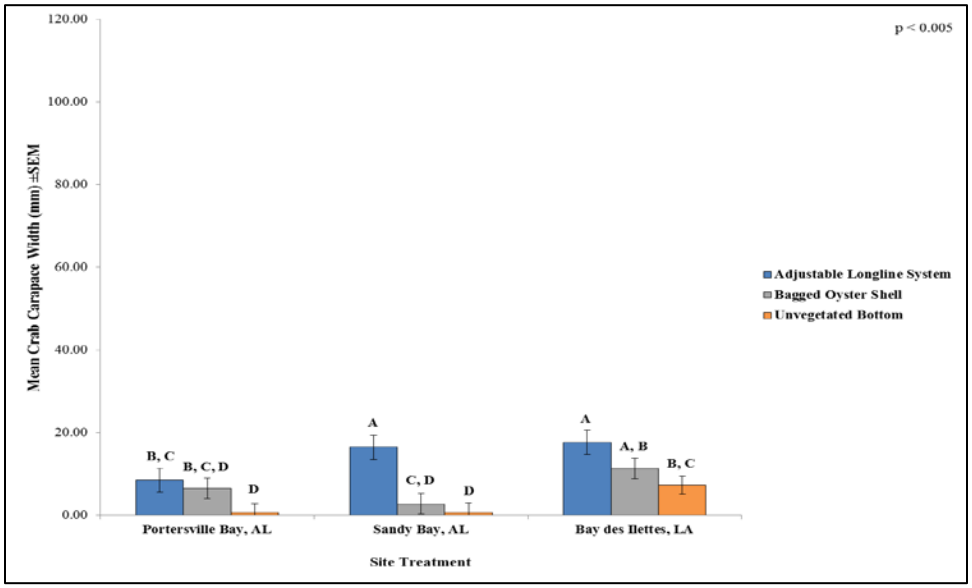


Figure 2.25 Effect of habitat type and site upon juvenile blue crab mean carapace width ± SEM in August 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.2.2 Analytical Approach 1 (September 2013)

Adjustable Longline System

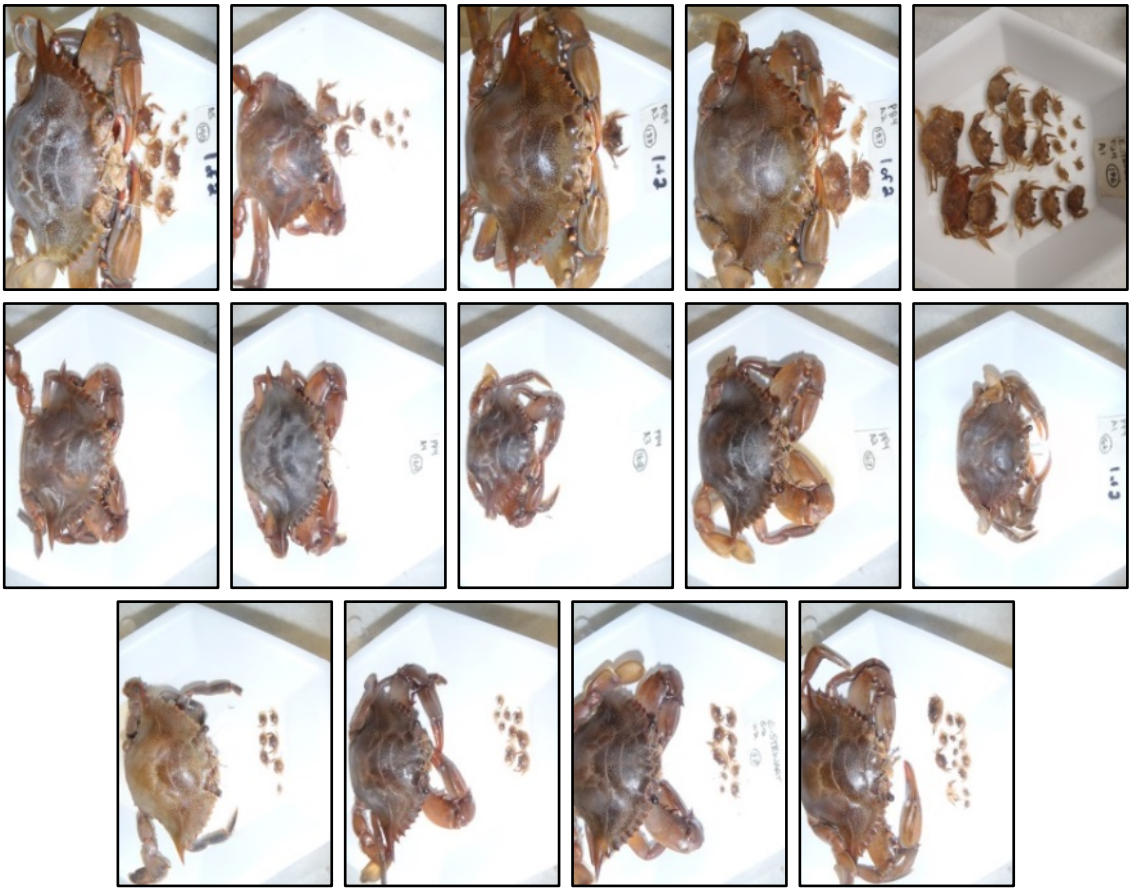


Figure 2.26 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during September 2013. Top row: Portersville (Fowl River) Bay, Alabama; middle row: Sandy Bay (Point aux Pins), Alabama; and bottom row: Bay des Ilettes (Grand Isle), Louisiana.

Bagged Oyster Shell

Figure 2.27 Each individual photograph above is of the juvenile blue crabs collected from an oyster shell bag sample during September 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Bay des Ilettes (Grand Isle), Louisiana.

Unvegetated Bottom

Figure 2.28 Each individual photograph above is of the juvenile blue crabs collected from an unvegetated bottom sample during September 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Juvenile Blue Crab Density (A)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (A) in September 2013 (ANOVA: $p < 0.005$; Table 2.11). Juvenile blue crab mean density was significantly greater in the ALS samples at PBA and BDIL, than all other treatments (Fig. 2.29; see App. A: Chapter Two Supporting Data, Table A-7 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	14,367.236	2	7,183.618	23.474	0.000
SITE	4,338.390	2	2,169.195	7.088	0.003
HABITAT*SITE	6,245.297	4	1,561.324	5.102	0.002
Error	11,016.854	36	306.024		

Table 2.11 ANOVA results for mean density (A) in September 2013, using analytical approach 1.

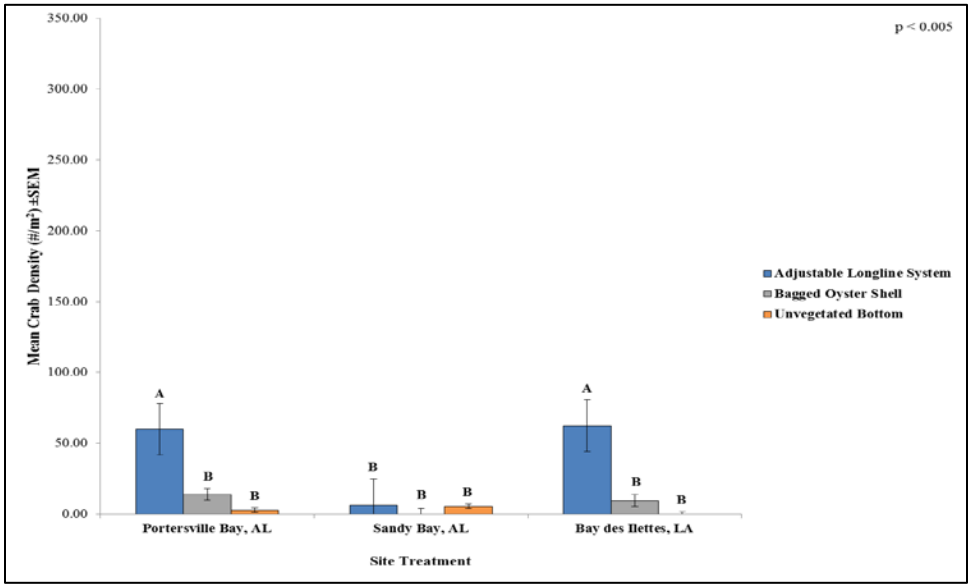


Figure 2.29 Effect of habitat type and site upon juvenile blue crab mean density (A) ± SEM in September 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (B) in September 2013 (ANOVA: $p < 0.05$; Table 2.12). Juvenile blue crab mean density was significantly greater in the ALS samples at PBA and BDIL, than in the ALS samples at SBA, the BOS samples at SBA, and the UVB samples at PBA and BDIL (Fig. 2.30; see App. A: Chapter Two Supporting Data, Table A-8 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	1,159.087	2	579.543	10.868	0.000
SITE	576.793	2	288.397	5.408	0.009
HABITAT*SITE	887.597	4	221.899	4.161	0.007
Error	1,919.776	36	53.327		

Table 2.12 ANOVA results for mean density (B) in September 2013, using analytical approach 1.

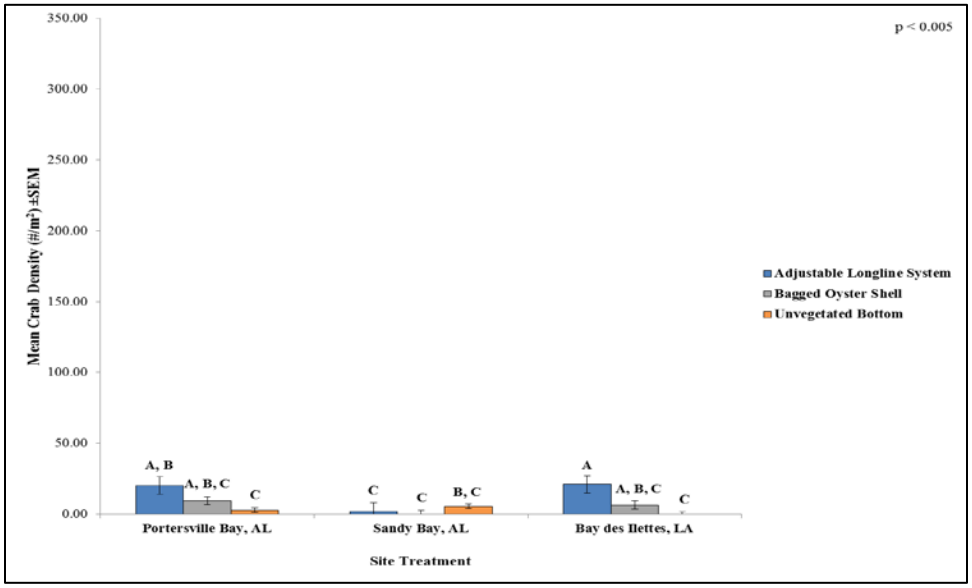


Figure 2.30 Effect of habitat type and site upon juvenile blue crab mean density (B) ± SEM in September 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean carapace width in September 2013 (ANOVA: $p < 0.001$; Table 2.13). Juvenile blue crab mean carapace width was significantly greatest in the ALS samples at SBA, with the smallest juvenile blue crabs in the BOS and UVB treatments (Fig. 2.31; see App. A: Chapter Two Supporting Data, Table A-9 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	16,061.501	2	8,030.750	100.745	0.000
SITE	3,881.423	2	1,940.712	24.346	0.000
HABITAT*SITE	7,221.654	4	1,805.413	22.649	0.000
Error	2,869.686	36	79.714		

Table 2.13 ANOVA results for mean CW in September 2013, using analytical approach 1.

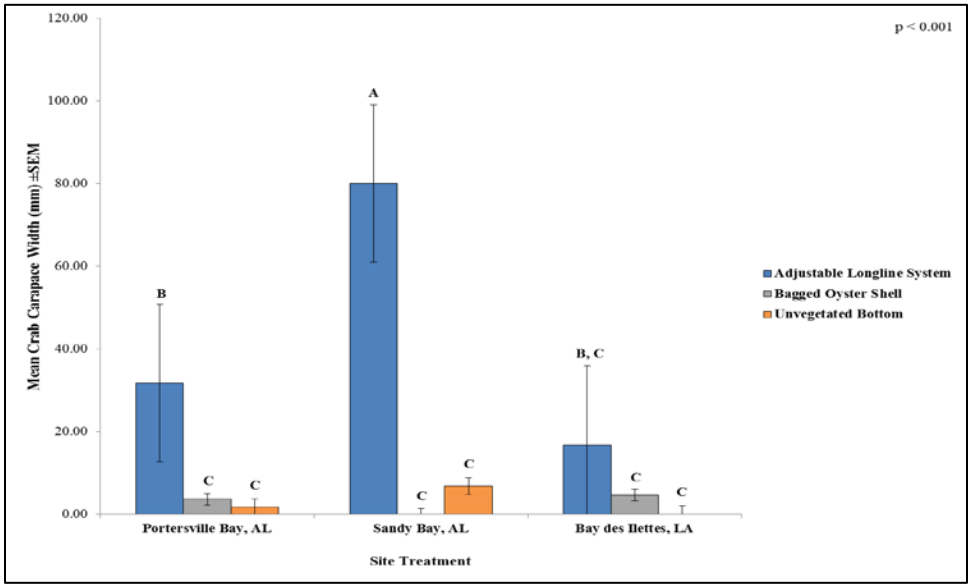


Figure 2.31 Effect of habitat type and site upon juvenile blue crab mean carapace width ± SEM in September 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.2.3 Analytical Approach 1 (November 2013)

Adjustable Longline System

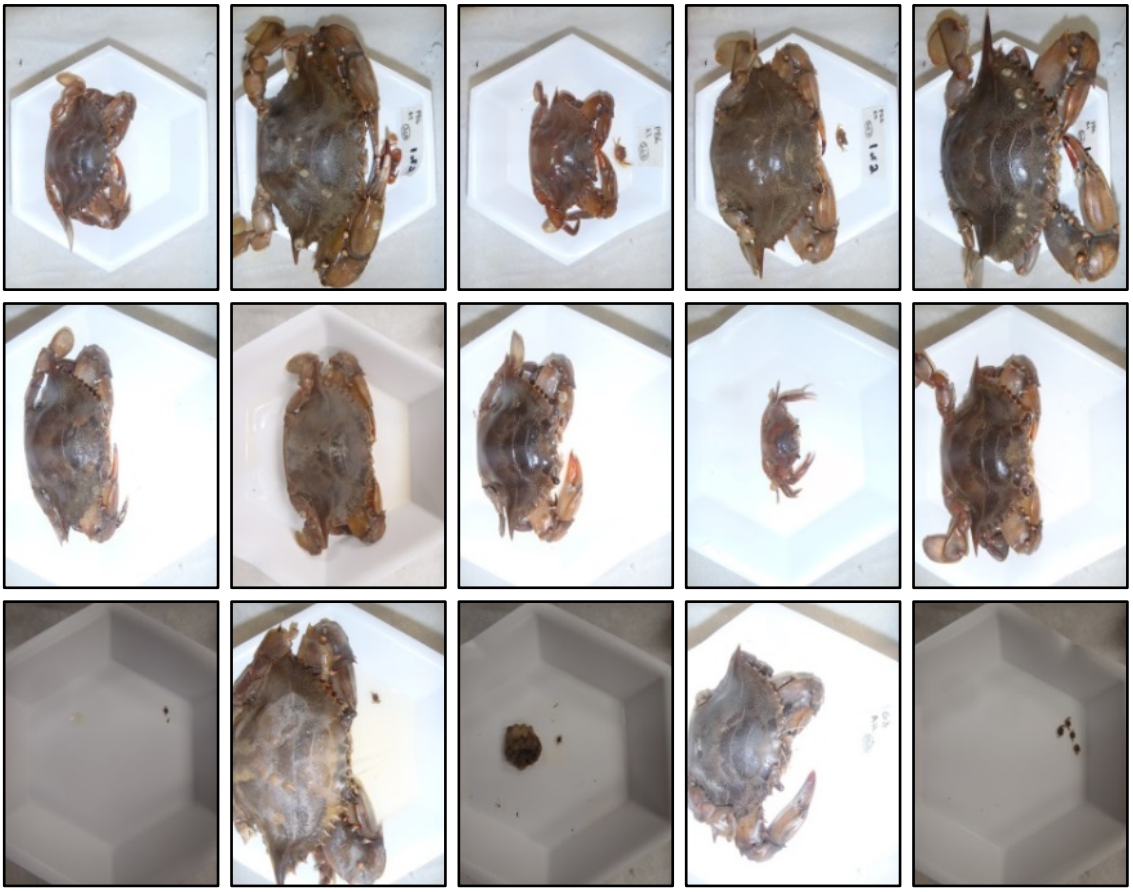


Figure 2.32 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during November 2013. Top row: Portersville (Fowl River) Bay, Alabama; middle row: Sandy Bay (Point aux Pins), Alabama; and bottom row: Bay des Ilettes (Grand Isle), Louisiana.

Bagged Oyster Shell

Figure 2.33 The photograph above is of the juvenile blue crab collected from an oyster shell bag sample during November 2013 in Bay des Ilettes (Grand Isle), Louisiana.

Unvegetated Bottom

Figure 2.34 The photograph above is of the juvenile blue crab collected from an unvegetated bottom sample during November 2013 in Portersville (Fowl River) Bay, Alabama.

Juvenile Blue Crab Density (A)

There were no significant interactions between habitat type and site with respect to juvenile blue crab mean density (A) in November 2013 (ANOVA: $p = 0.407$; Table 2.14); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean density (ANOVA: $p = 0.380$; Table 2.14); therefore, site factors were pooled across habitat treatments (Fig. 2.35). There was a significant effect of habitat upon juvenile blue crab mean density (ANOVA: $p < 0.001$; Table 2.14); specifically, there were significantly more juvenile blue crabs present in ALS samples than those present in BOS samples and UVB samples (Fig. 2.38; see App. A: Chapter Two Supporting Data, Table A-10 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	835.558	2	417.779	32.227	0.000
SITE	25.766	2	12.883	0.994	0.380
HABITAT*SITE	53.227	4	13.307	1.026	0.407
Error	466.688	36	12.964		

Table 2.14 ANOVA results for mean density (A) in November 2013, using analytical approach 1.

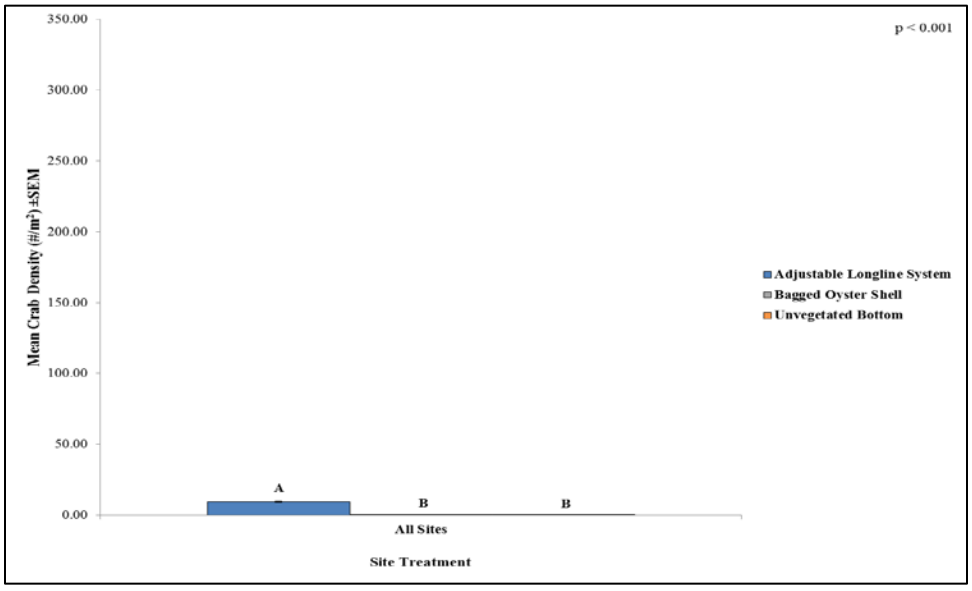


Figure 2.35 Effect of habitat type upon juvenile blue crab mean density (A) ± SEM in November 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There were no significant interactions between habitat type and site with respect to juvenile blue crab mean density (B) in November 2013 (ANOVA: $p = 0.407$; Table 2.15); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean density (ANOVA: $p = 0.527$; Table 2.15); therefore, site factors were pooled across habitat treatments (Fig. 2.36). There was a significant effect of habitat upon juvenile blue crab mean density (ANOVA: $p < 0.001$; Table 2.15); specifically, there were significantly more juvenile blue crabs present in ALS samples than those present in BOS samples and UVB samples (Fig. 2.36; see App. A: Chapter Two Supporting Data, Table A-11 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	83.912	2	41.956	19.149	0.000
SITE	2.858	2	1.429	0.652	0.527
HABITAT*SITE	8.999	4	2.250	1.027	0.407
Error	78.877	36	2.191		

Table 2.15 ANOVA results for mean density (B) in November 2013, using analytical approach 1.

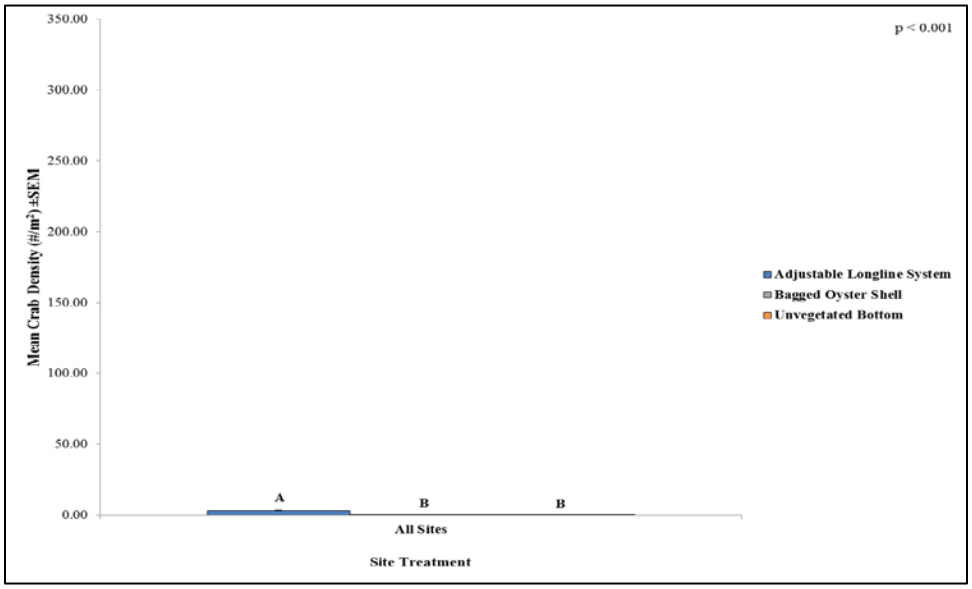


Figure 2.36 Effect of habitat type upon juvenile blue crab mean density (B) ± SEM in November 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There were no significant interactions between habitat type and site with respect to juvenile blue crab mean carapace width in November 2013 (ANOVA: $p = 0.332$; Table 2.16); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean carapace width (ANOVA: $p = 0.381$; Table 2.16); therefore, site factors were pooled across habitat treatments (Fig. 2.37). There was a significant effect of habitat upon juvenile blue crab mean carapace width (ANOVA: $p < 0.001$; Table 2.16); specifically, juvenile blue crabs present in ALS samples had a significantly higher mean carapace width than those present in BOS samples and UVB samples (Fig. 2.37; see App. A: Chapter Two Supporting Data, Table A-12 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	49,862.741	2	24,931.370	38.744	0.000
SITE	1,274.049	2	637.025	0.990	0.381
HABITAT*SITE	3,059.924	4	764.981	1.189	0.332
Error	23,165.890	36	643.497		

Table 2.16 ANOVA results for mean CW in November 2013, using analytical approach 1.

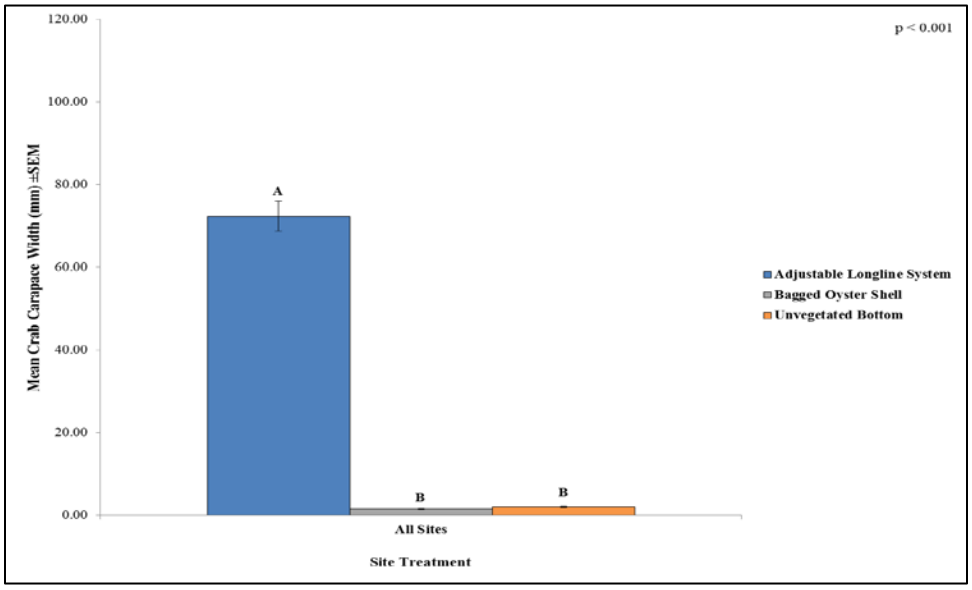


Figure 2.37 Effect of habitat type upon juvenile blue crab mean carapace width ± SEM in November 2013 using Approach 1. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.3 Effects of Habitat and Site: Analytical Approach 2

The following results were obtained using the second analytical approach (some portions of the data were used in the first analytical approach) to address the hypotheses developed for this study, where there were two sites (both in Alabama) that had four common habitats, to allow a comparison of all four habitat types. Analysis was performed using eight treatments (four habitats x two sites) with five replicates per treatment at five separate sampling times (analyzed one at a time) for a total of 200 replicates.

2.3.3.1 Analytical Approach 2 (July 2013)

Adjustable Longline System

Figure 2.38 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during July 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Bagged Oyster Shell

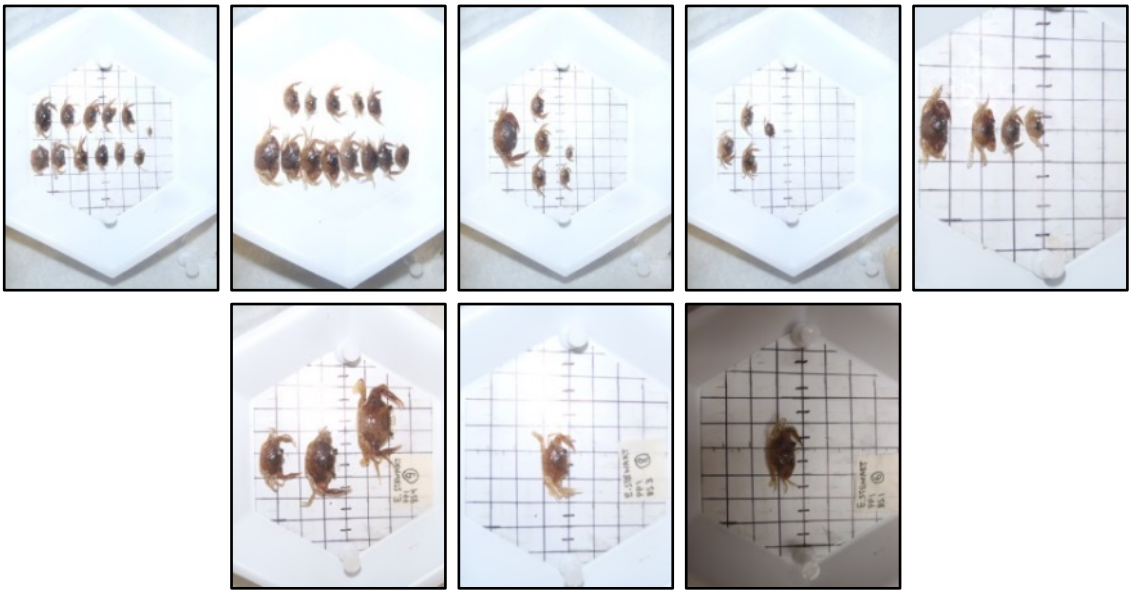


Figure 2.39 Each individual photograph above is of the juvenile blue crabs collected from an oyster shell bag sample during July 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Submerged Aquatic Vegetation

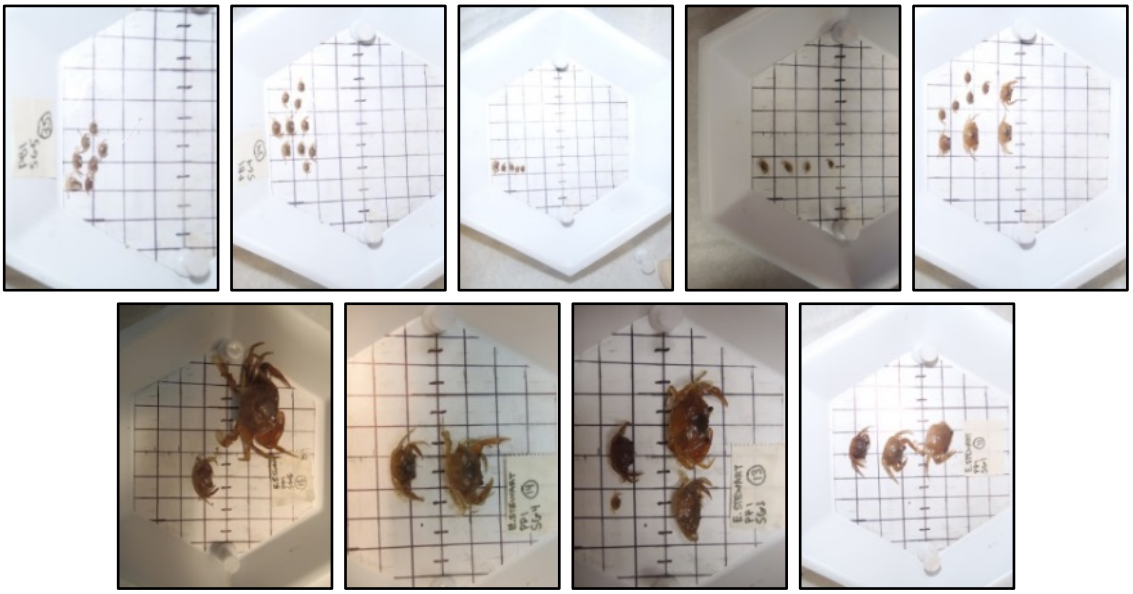


Figure 2.40 Each individual photograph above is of the juvenile blue crabs collected from a submerged aquatic vegetation sample during July 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Unvegetated Bottom

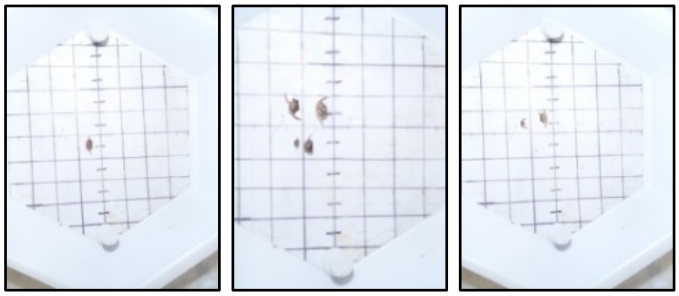


Figure 2.41 Each individual photograph above is of the juvenile blue crabs collected from an unvegetated bottom sample during July 2013 in Portersville (Fowl River) Bay, Alabama.

Juvenile Blue Crab Density (A)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (A) in July 2013 (ANOVA: $p < 0.001$; Table 2.17). Juvenile blue crab mean density was significantly greatest in the ALS samples at PBA (Fig. 2.42; see App. A: Chapter Two Supporting Data, Table A-13 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	15,116.118	3	5,038.706	25.133	0.000
SITE	10,112.782	1	10,112.782	50.443	0.000
HABITAT*SITE	5,905.129	3	1,968.376	9.818	0.000
Error	6,415.320	32	200.479		

Table 2.17 ANOVA results for mean density (A) in July 2013, using analytical approach 2.

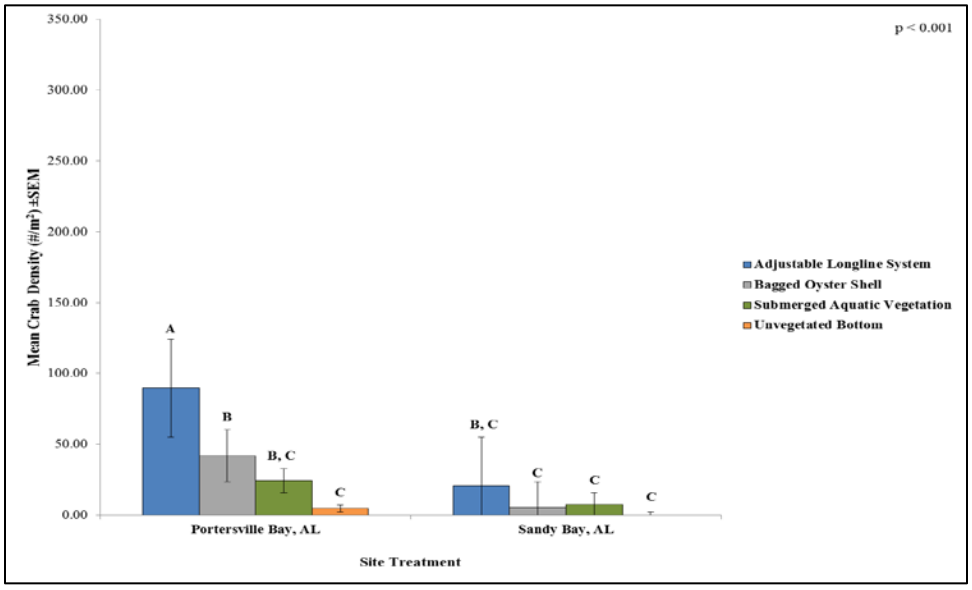


Figure 2.42 Effect of habitat type and site upon mean juvenile blue crab density (A) ± SEM in July 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (B) in July 2013 (ANOVA: $p < 0.05$; Table 2.18). Juvenile blue crab mean density was significantly greater at PBA than SBA in all habitats except UVB, where there was no difference between the two sites (Fig. 2.43; see App. A: Chapter Two Supporting Data, Table A-14 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	1,628.924	3	542.975	8.470	0.000
SITE	3,040.860	1	3,040.860	47.435	0.000
HABITAT*SITE	618.983	3	206.328	3.219	0.036
Error	2,051.387	32	64.106		

Table 2.18 ANOVA results for mean density (B) in July 2013, using analytical approach 2.

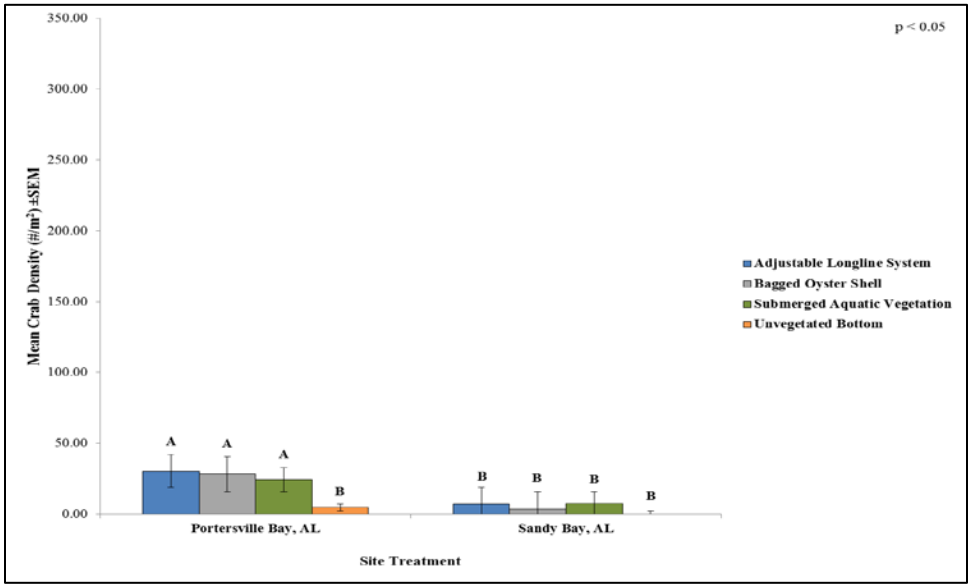


Figure 2.43 Effect of habitat type and site upon juvenile blue crab mean density (B) ± SEM in July 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There were no significant interactions between habitat type and site with respect to juvenile blue crab mean carapace width in July 2013 (ANOVA: $p = 0.083$; Table 2.19); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean carapace width (ANOVA: $p = 0.132$; Table 2.19); therefore, site factors were pooled across habitat treatments (Fig. 2.44). There was a significant effect of habitat upon juvenile blue crab mean carapace width (ANOVA: $p < 0.001$; Table 2.19); specifically, juvenile blue crabs present in ALS samples had a significantly higher mean carapace width than those present all other treatments (Fig. 2.44; see App. A: Chapter Two Supporting Data, Table A-15 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	1,823.703	3	607.901	20.211	0.000
SITE	71.757	1	71.757	2.386	0.132
HABITAT*SITE	219.207	3	73.069	2.429	0.083
Error	962.471	32	30.077		

Table 2.19 ANOVA results for mean CW in July 2013, using analytical approach 2.

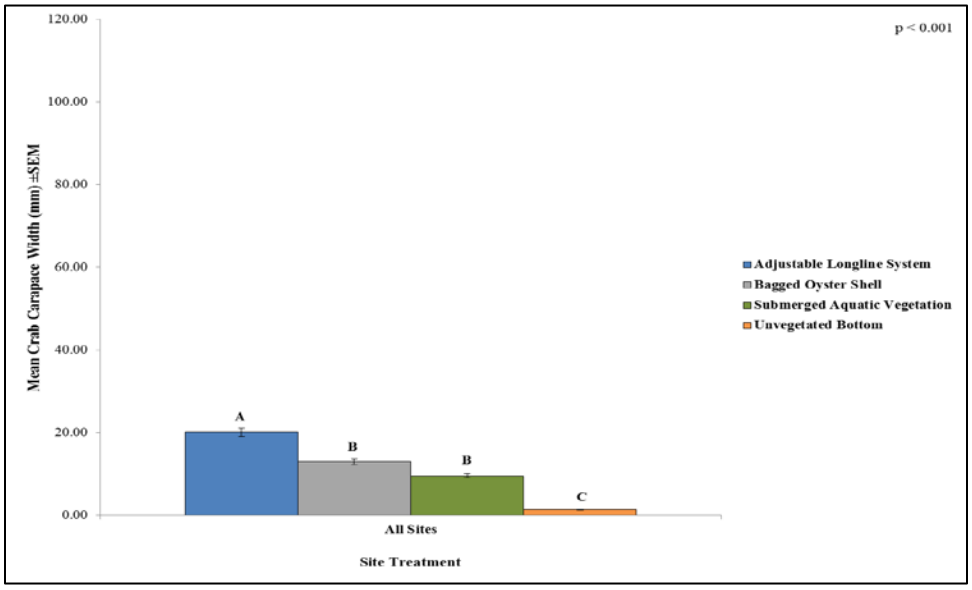


Figure 2.44 Effect of habitat type upon juvenile blue crab mean carapace width ± SEM in July 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.3.2 Analytical Approach 2 (Early August 2013)

Adjustable Longline System

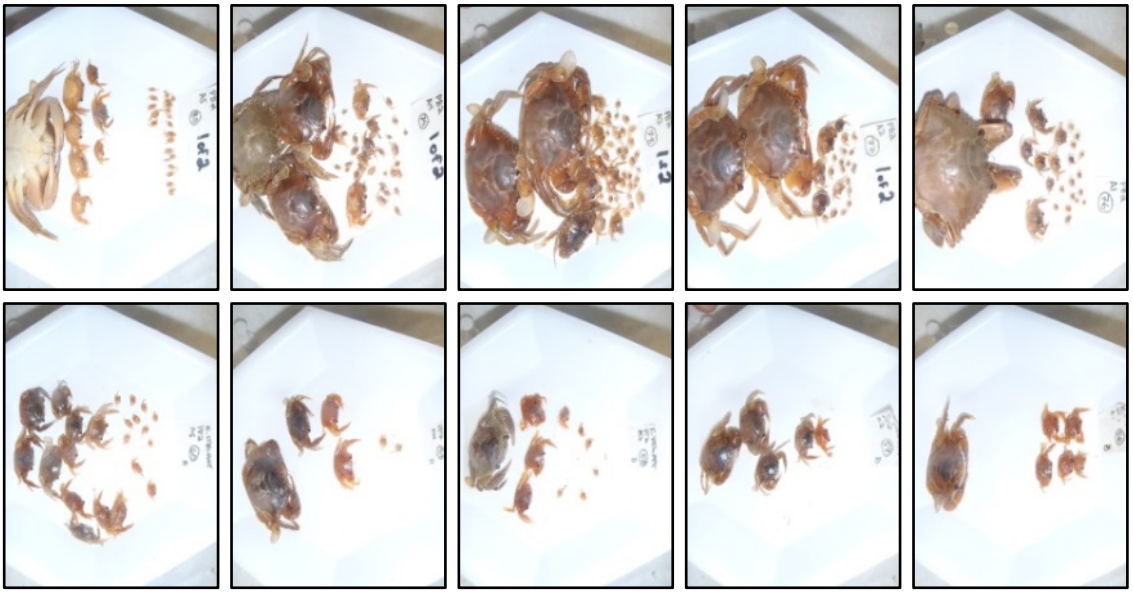


Figure 2.45 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during early August 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Bagged Oyster Shell

Figure 2.46 Each individual photograph above is of the juvenile blue crabs collected from an oyster shell bag sample during early August 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Submerged Aquatic Vegetation

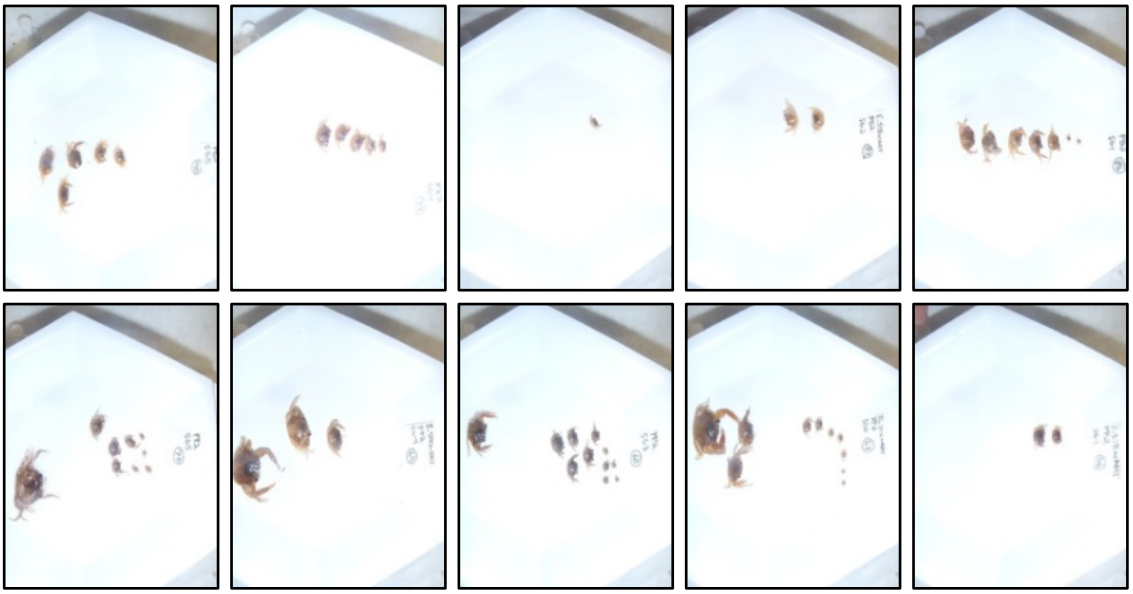


Figure 2.47 Each individual photograph above is of the juvenile blue crabs collected from a submerged aquatic vegetation sample during early August 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Unvegetated Bottom

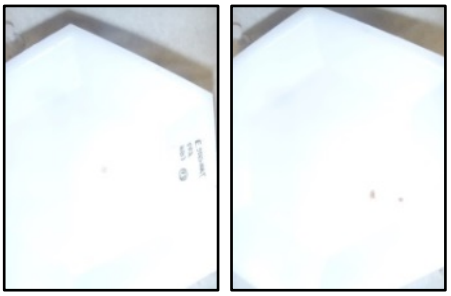


Figure 2.48 Each individual photograph above is of the juvenile blue crabs collected from an unvegetated bottom sample during early August 2013. Left: Portersville (Fowl River) Bay, Alabama; and right: Sandy Bay (Point aux Pins), Alabama.

Juvenile Blue Crab Density (A)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (A) in early August 2013 (ANOVA: $p < 0.001$; Table 2.20). Juvenile blue crab mean density was significantly greatest in the ALS samples at PBA compared to all other treatments (Fig. 2.49; see App. A: Chapter Two Supporting Data, Table A-16 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	136,271.064	3	45,423.688	44.050	0.000
SITE	14,676.361	1	14,676.361	14.233	0.001
HABITAT*SITE	47,768.482	3	15,922.827	15.441	0.000
Error	32,997.854	32	1,031.183		

Table 2.20 ANOVA results for mean density (A) in early August 2013, using analytical approach 2.

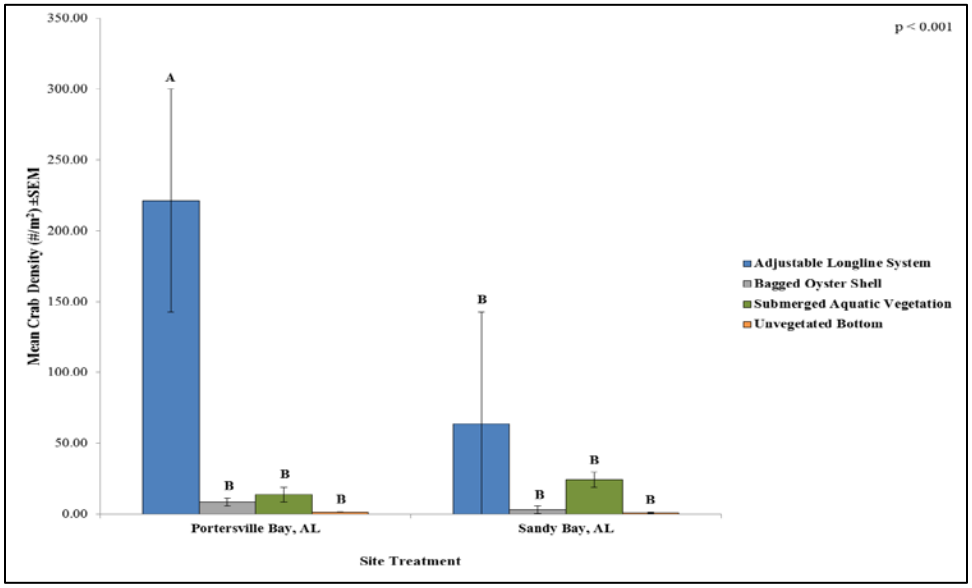


Figure 2.49 Effect of habitat type and site upon juvenile blue crab mean density (A) ± SEM in early August 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (B) in early August 2013 (ANOVA: $p < 0.001$; Table 2.21). Juvenile blue crab mean density was significantly greatest in the ALS samples at PBA compared to all other treatments (Fig. 2.50; see App. A: Chapter Two Supporting Data, Table A-17 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	14,109.272	3	4,703.091	29.992	0.000
SITE	1,404.821	1	1,404.821	8.959	0.005
HABITAT*SITE	6,063.187	3	2,021.062	12.889	0.000
Error	5,017.918	32	156.810		

Table 2.21 ANOVA results for mean density (B) in early August 2013, using analytical approach 2.

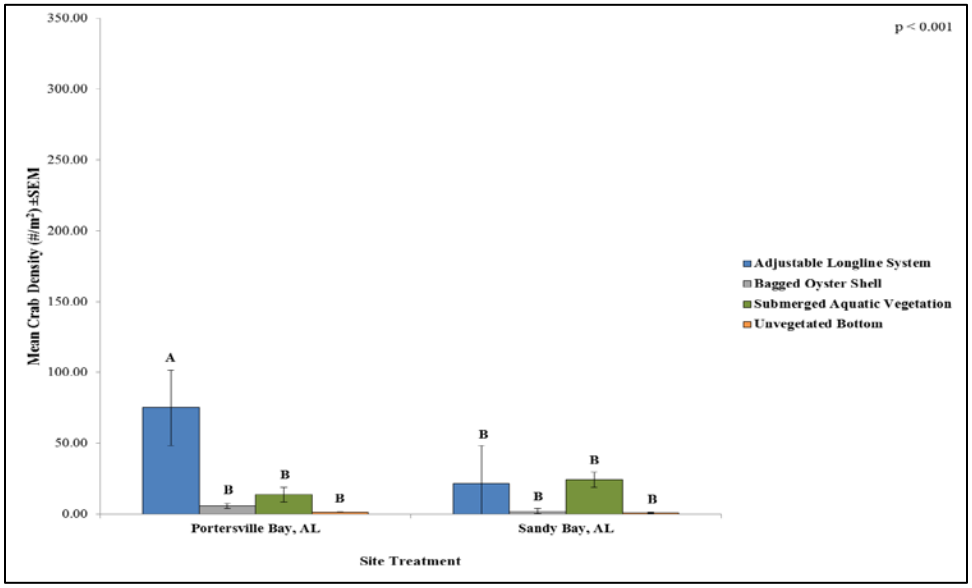


Figure 2.50 Effect of habitat type and site upon juvenile blue crab mean density (B) ± SEM in early August 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean carapace width in early August 2013 (ANOVA: $p < 0.05$; Table 2.22). Juvenile blue crab mean carapace width was significantly greater in the ALS samples at SBA than in all other treatments except SAV samples at SBA (Fig. 2.51; see App. A: Chapter Two Supporting Data, Table A-18 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	804.923	3	268.308	20.290	0.000
SITE	18.534	1	18.534	1.402	0.245
HABITAT*SITE	179.312	3	59.771	4.520	0.009
Error	423.151	32	13.223		

Table 2.22 ANOVA results for mean CW in early August 2013, using analytical approach 2.

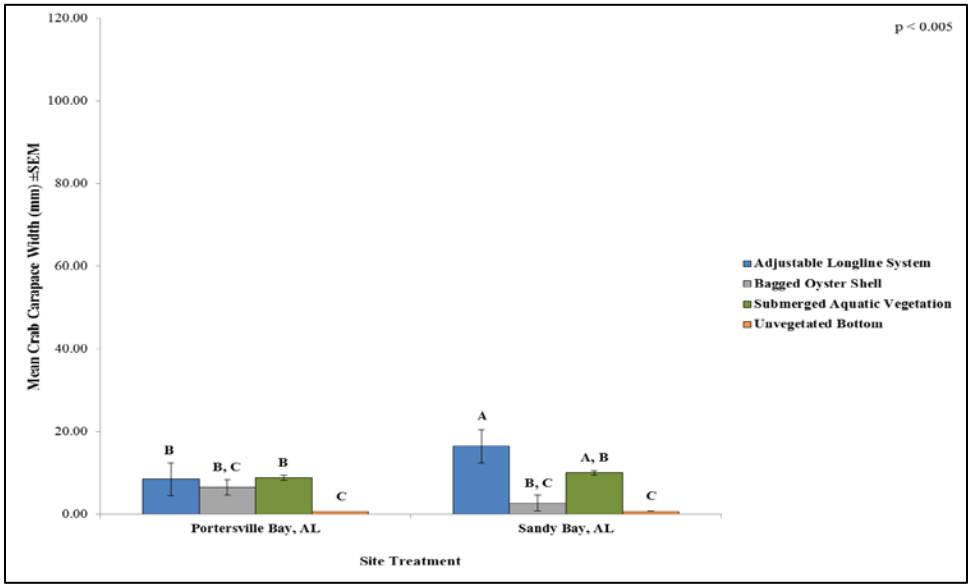


Figure 2.51 Effect of habitat type and site upon juvenile blue crab mean carapace width ± SEM in early August 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.3.3 Analytical Approach 2 (Late August 2013)

Adjustable Longline System

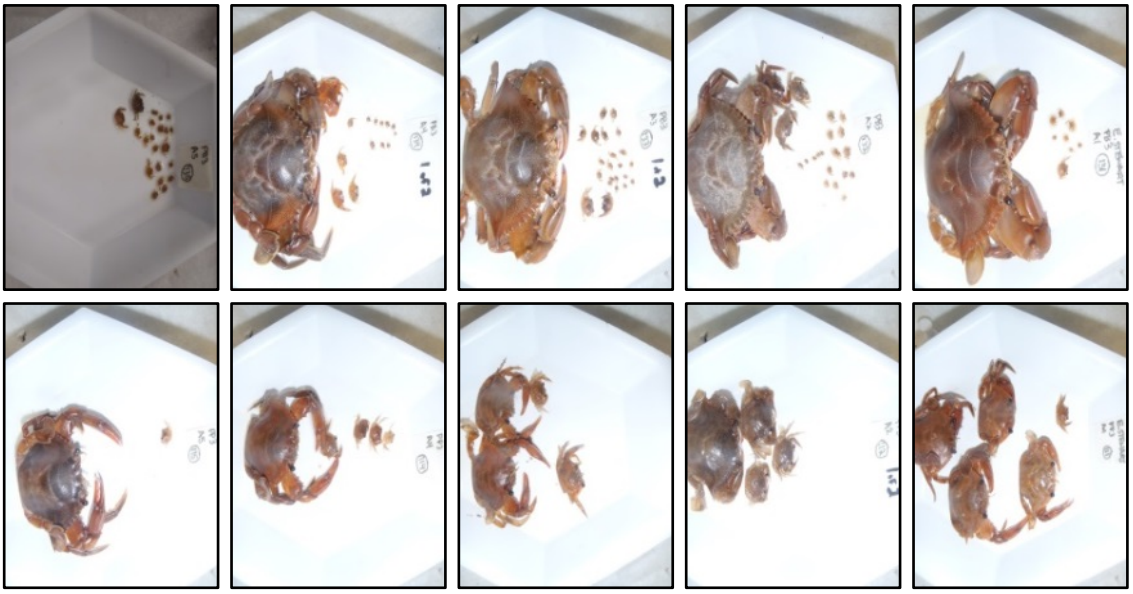


Figure 2.52 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during late August 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Bagged Oyster Shell

Figure 2.53 Each individual photograph above is of the juvenile blue crabs collected from an oyster shell bag sample during late August 2013 in Portersville (Fowl River) Bay, Alabama.

Submerged Aquatic Vegetation

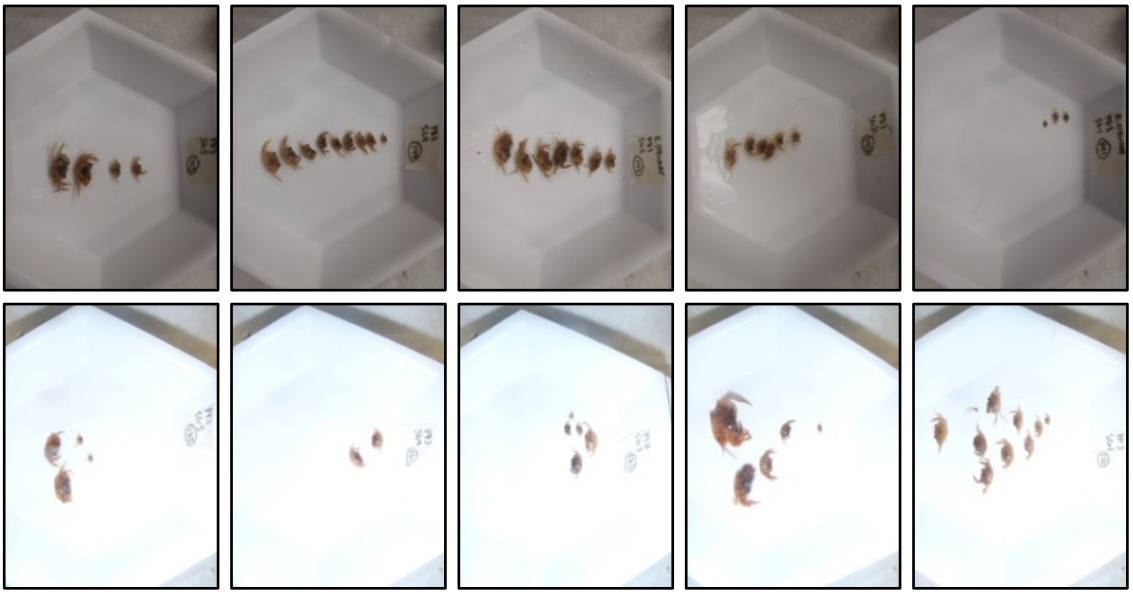


Figure 2.54 Each individual photograph above is of the juvenile blue crabs collected from a submerged aquatic vegetation sample during late August 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Unvegetated Bottom

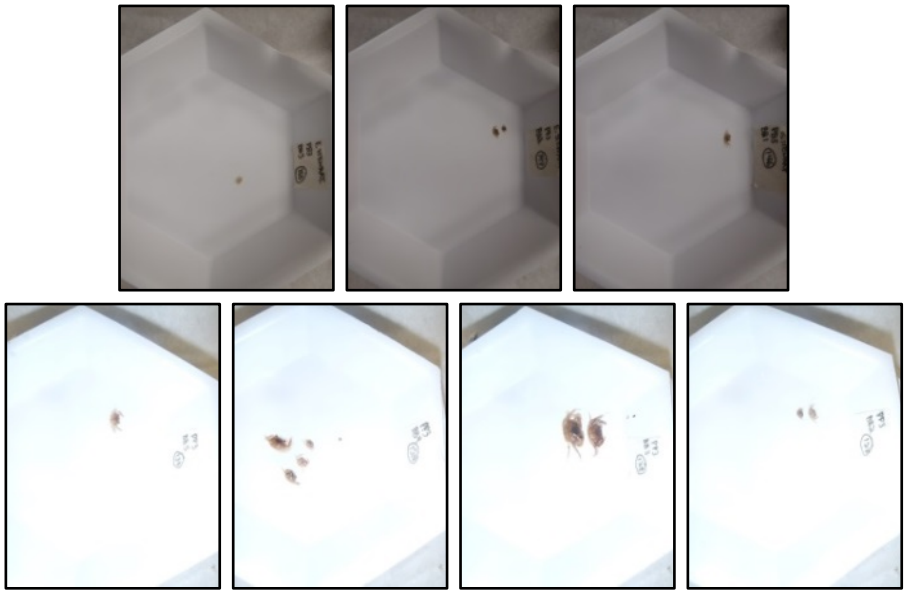


Figure 2.55 Each individual photograph above is of the juvenile blue crabs collected from an unvegetated bottom sample during late August 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Juvenile Blue Crab Density (A)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (A) in late August 2013 (ANOVA: $p < 0.001$; Table 2.23). Juvenile blue crab mean density was significantly greatest in the ALS samples at PBA (Fig. 2.56; see App. A: Chapter Two Supporting Data, Table A-19 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	31,395.730	3	10,465.243	50.981	0.000
SITE	5,213.240	1	5,213.240	25.396	0.000
HABITAT*SITE	15,041.418	3	5,013.806	24.425	0.000
Error	6,568.884	32	205.278		

Table 2.23 ANOVA results for mean density (A) in late August 2013, using analytical approach 2.

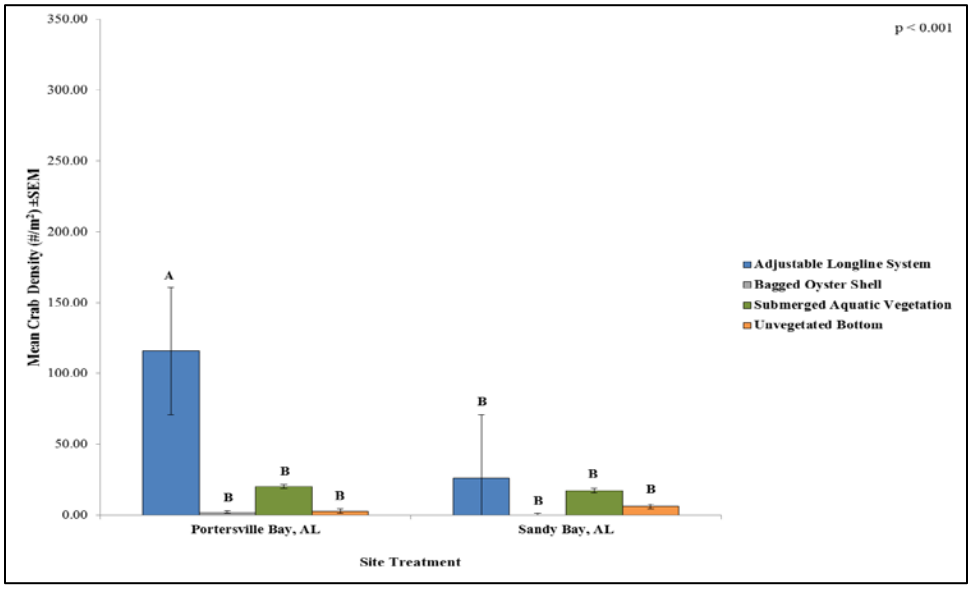


Figure 2.56 Effect of habitat type and site upon juvenile blue crab mean density (A) ± SEM in late August 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (B) in late August 2013 (ANOVA: $p < 0.001$; Table 2.24). Juvenile blue crab mean density was significantly greatest in the ALS samples at PBA (Fig. 2.57; see App. A: Chapter Two Supporting Data, Table A-20 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	3,757.065	3	1,252.355	28.285	0.000
SITE	611.457	1	611.457	13.810	0.001
HABITAT*SITE	1,772.179	3	590.726	13.342	0.000
Error	1,416.858	32	44.277		

Table 2.24 ANOVA results for mean density (B) in late August 2013, using analytical approach 2.

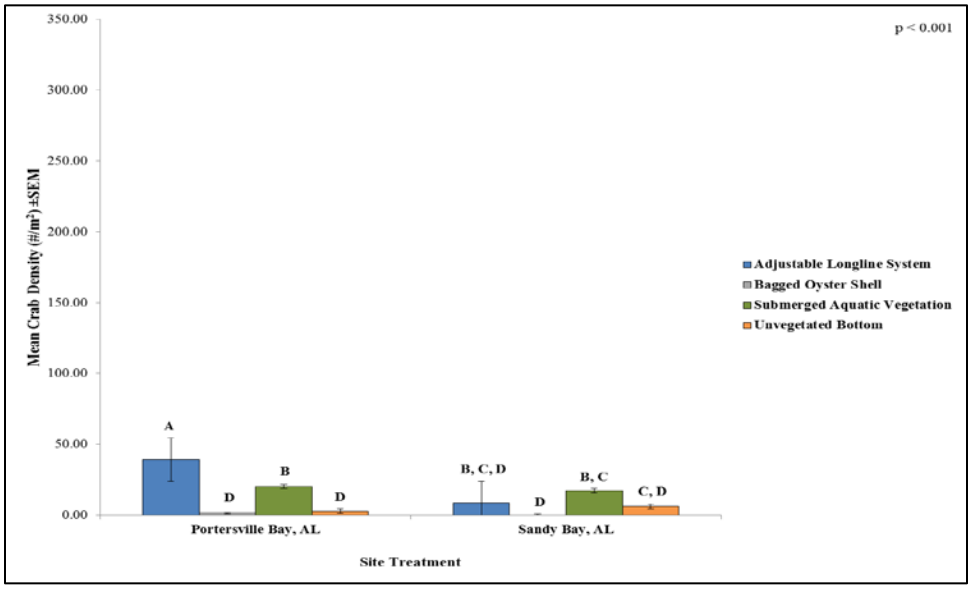


Figure 2.57 Effect of habitat type and site upon juvenile blue crab mean density (B) ± SEM in late August 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean carapace width in late August 2013 (ANOVA: $p < 0.001$; Table 2.25). Juvenile blue crab mean carapace width was significantly greatest in the ALS samples at SBA, while the smallest mean carapace widths were observed in the BOS samples and UVB samples at both sites (Fig. 2.58; see App. A: Chapter Two Supporting Data, Table A-21 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	1,838.547	3	612.849	41.874	0.000
SITE	358.550	1	358.550	24.498	0.000
HABITAT*SITE	732.949	3	244.316	16.693	0.000
Error	468.339	32	14.636		

Table 2.25 ANOVA results for mean CW in late August 2013, using analytical approach 2.

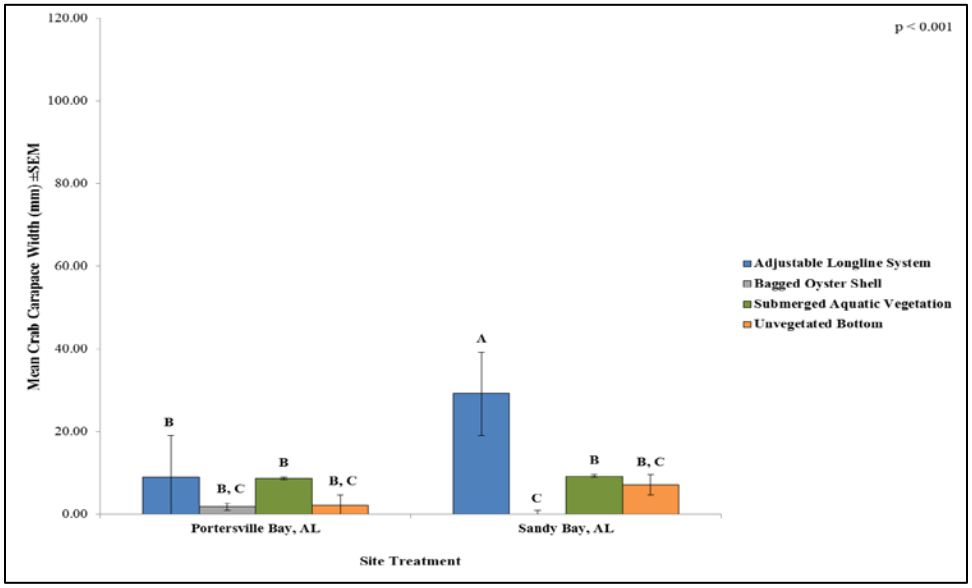


Figure 2.58 Effect of habitat type and site upon juvenile blue crab mean carapace width ± SEM in late August 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.3.4 Analytical Approach 2 (September 2013)

Adjustable Longline System

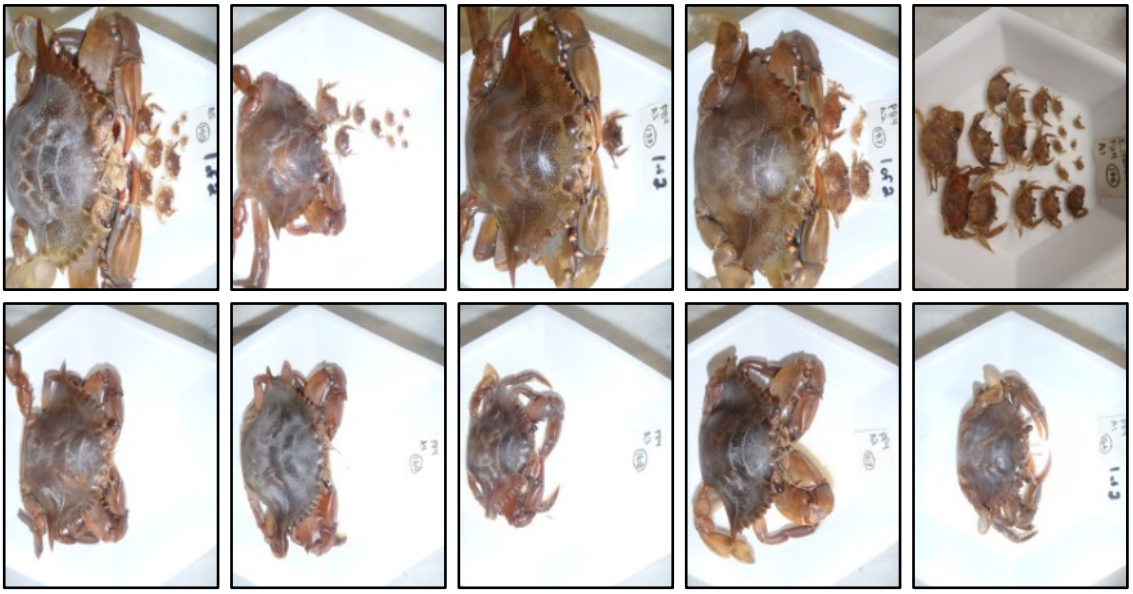


Figure 2.59 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during September 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Bagged Oyster Shell

Figure 2.60 Each individual photograph above is of the juvenile blue crabs collected from an oyster shell bag sample during September 2013 in Portersville (Fowl River) Bay, Alabama.

Submerged Aquatic Vegetation

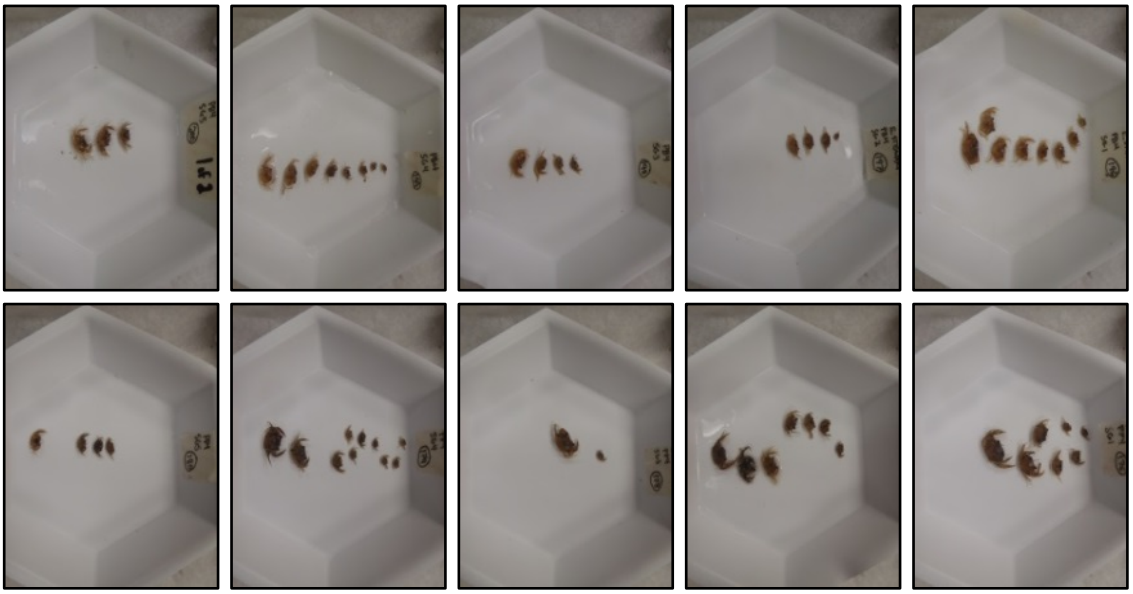


Figure 2.61 Each individual photograph above is of the juvenile blue crabs collected from a submerged aquatic vegetation sample during September 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Unvegetated Bottom

Figure 2.62 Each individual photograph above is of the juvenile blue crabs collected from an unvegetated bottom sample during September 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Juvenile Blue Crab Density (A)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (A) in September 2013 (ANOVA: $p < 0.005$; Table 2.26). Juvenile blue crab mean density was significantly greatest in the ALS samples at PBA compared to all other treatments (Fig. 2.63; see App. A: Chapter Two Supporting Data, Table A-22 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	5,319.574	3	1,773.191	6.670	0.001
SITE	2,442.895	1	2,442.895	9.190	0.005
HABITAT*SITE	5,206.452	3	1,735.484	6.528	0.001
Error	8,506.694	32	265.834		

Table 2.26 ANOVA results for mean density (A) in September 2013, using analytical approach 2.

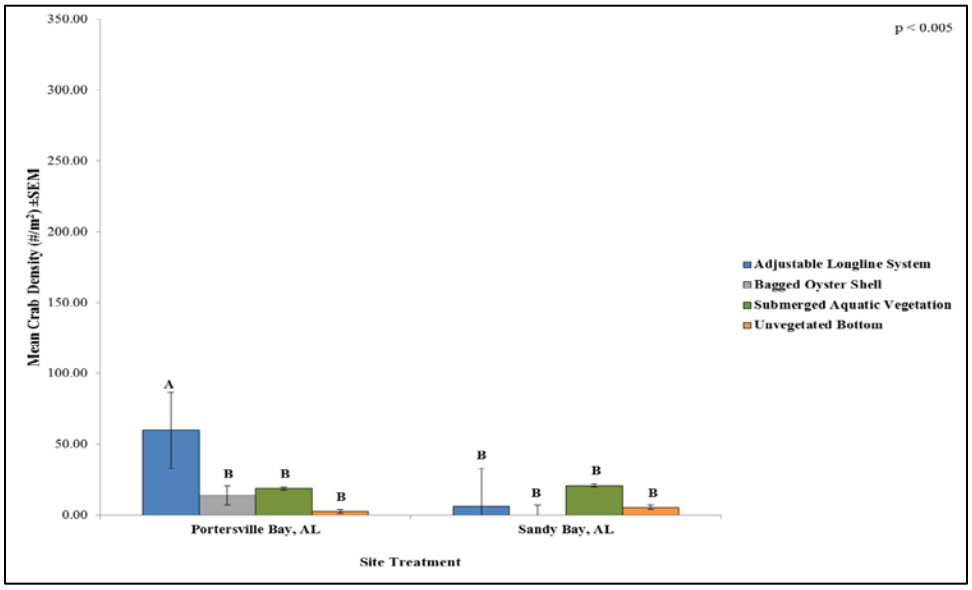


Figure 2.63 Effect of habitat type and site upon juvenile blue crab mean density (A) ± SEM in September 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean density (B) in September 2013 (ANOVA: $p < 0.05$; Table 2.27). Juvenile blue crab mean density was significantly greater in the ALS samples at PBA and the SAV samples at SBA than the ALS samples at SBA, the BOS samples at SBA, and the UVB samples at PBA (Fig. 2.64; see App. A: Chapter Two Supporting Data, Table A-23 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	1,602.006	3	534.002	8.059	0.001
SITE	322.516	1	322.516	4.867	0.035
HABITAT*SITE	753.447	3	251.149	3.790	0.020
Error	2,120.304	32	66.259		

Table 2.27 ANOVA results for mean density (B) in September 2013, using analytical approach 2.

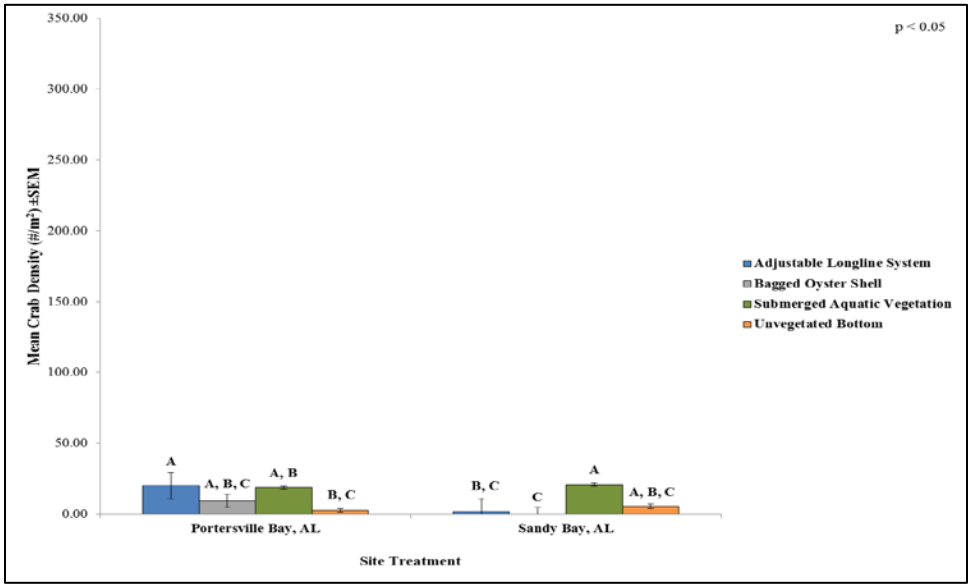


Figure 2.64 Effect of habitat type and site upon juvenile blue crab mean density (B) ± SEM in September 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There was a significant interaction between habitat type and site with respect to juvenile blue crab mean carapace width in September 2013 (ANOVA: $p < 0.001$; Table 2.28). Juvenile blue crab mean carapace width was significantly greater in the ALS samples at SBA than in all other treatments; although, the blue crabs with the greatest individual carapace width occurred within the ALS samples at PBA (Fig. 2.65; see App. A: Chapter Two Supporting Data, Table A-24 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	19,709.961	3	6,569.987	78.326	0.000
SITE	1,560.721	1	1,560.721	18.607	0.000
HABITAT*SITE	4,363.417	3	1,454.472	17.340	0.000
Error	2,684.172	32	83.880		

Table 2.28 ANOVA results for mean CW in September 2013, using analytical approach 2.

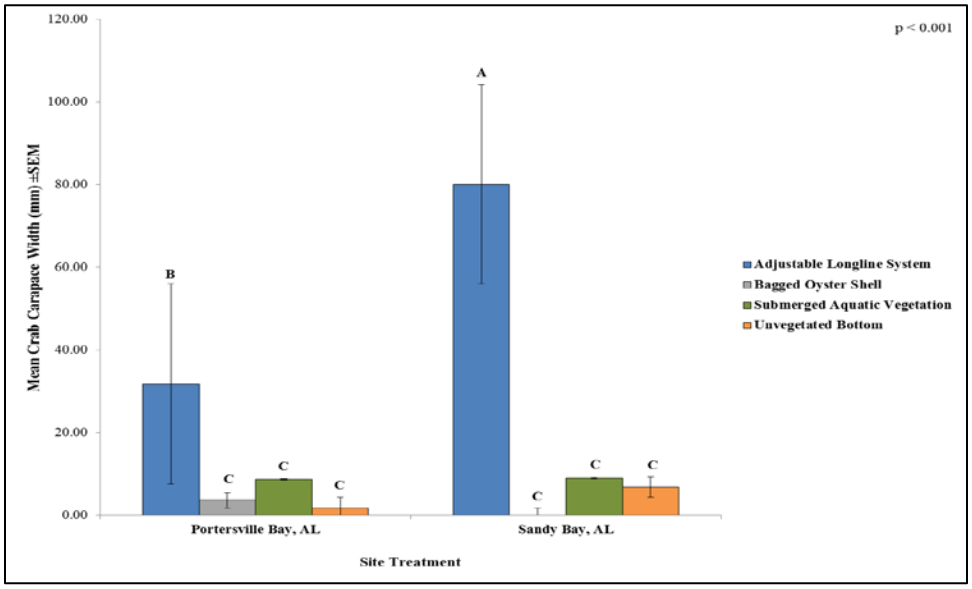


Figure 2.65 Effect of habitat type and site upon juvenile blue crab mean carapace width ± SEM in September 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.3.3.5 Analytical Approach 2 (October 2013)

Adjustable Longline System

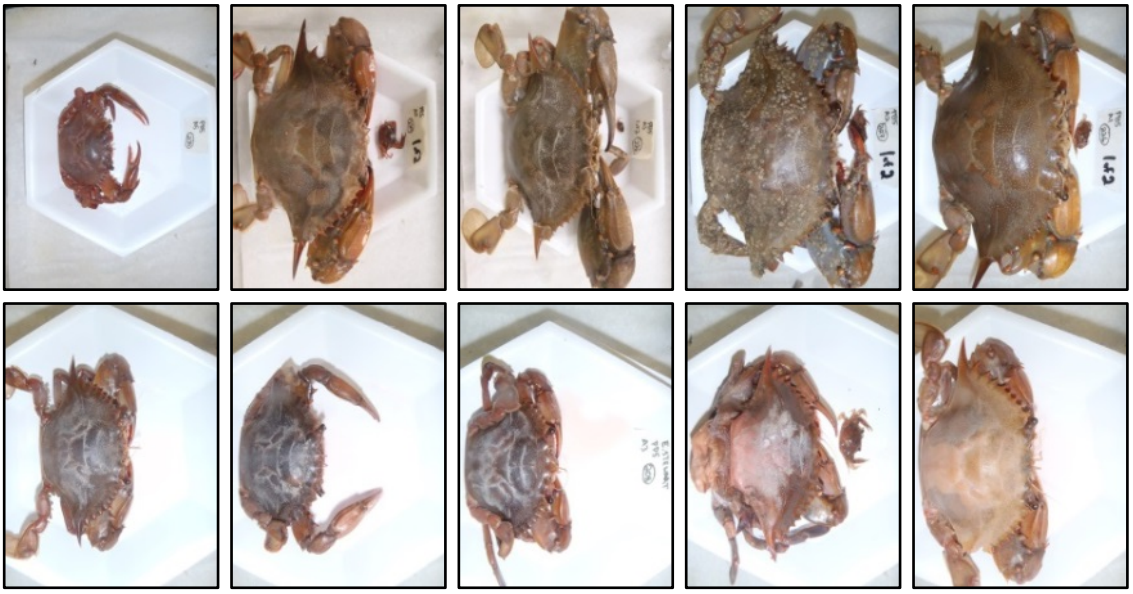


Figure 2.66 Each individual photograph above is of the juvenile blue crabs collected from an adjustable longline system basket sample during October 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Submerged Aquatic Vegetation

Figure 2.67 Each individual photograph above is of the juvenile blue crabs collected from a submerged aquatic vegetation sample during October 2013. Top row: Portersville (Fowl River) Bay, Alabama; and bottom row: Sandy Bay (Point aux Pins), Alabama.

Unvegetated Bottom

Figure 2.68 The photograph above is of a juvenile blue crab collected from an unvegetated bottom sample during October 2013 in Sandy Bay (Point aux Pins), Alabama.

Juvenile Blue Crab Density (A)

There were no significant interactions between habitat type and site with respect to juvenile blue crab mean density (A) in October 2013 (ANOVA: $p = 0.217$; Table 2.29); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean density (ANOVA: $p = 0.138$; Table 2.29); therefore, site factors were pooled across habitat treatments (Fig. 2.69). There was a significant effect of habitat upon juvenile blue crab mean density (ANOVA: $p < 0.001$; Table 2.29); specifically, juvenile blue crab mean density was significantly greater in the SAV samples than the other habitat treatments (Fig. 2.69; see App. A: Chapter Two Supporting Data, Table A-25 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	9,044.367	3	3,014.789	24.634	0.000
SITE	283.890	1	283.890	2.320	0.138
HABITAT*SITE	574.623	3	191.541	1.565	0.217
Error	3,916.312	32	122.385		

Table 2.29 ANOVA results for mean density (A) in October 2013, using analytical approach 2.

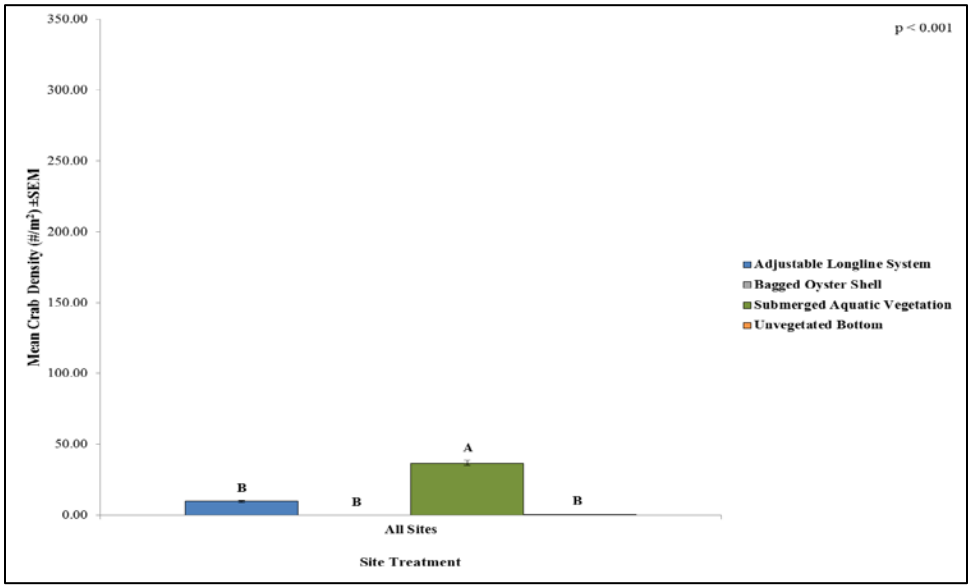


Figure 2.69 Effect of habitat type upon juvenile blue crab mean density (A) ± SEM in October 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Density (B)

There were no significant interactions between habitat type and site with respect to juvenile blue crab mean density (B) in October 2013 (ANOVA: $p = 0.192$; Table 2.30); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean density (ANOVA: $p = 0.187$; Table 2.30); therefore, site factors were pooled across habitat treatments (Fig. 2.70). There was a significant effect of habitat upon juvenile blue crab mean density (ANOVA: $p < 0.001$; Table 2.30); specifically, juvenile blue crab mean density was significantly greater in the SAV samples than the other habitat treatments (Fig. 2.70; see App. A: Chapter Two Supporting Data, Table A-26 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	9,612.655	3	3,204.218	26.589	0.000
SITE	219.303	1	219.303	1.820	0.187
HABITAT*SITE	605.440	3	201.813	1.675	0.192
Error	3,856.276	32	120.509		

Table 2.30 ANOVA results for mean density (B) in October 2013, using analytical approach 2.

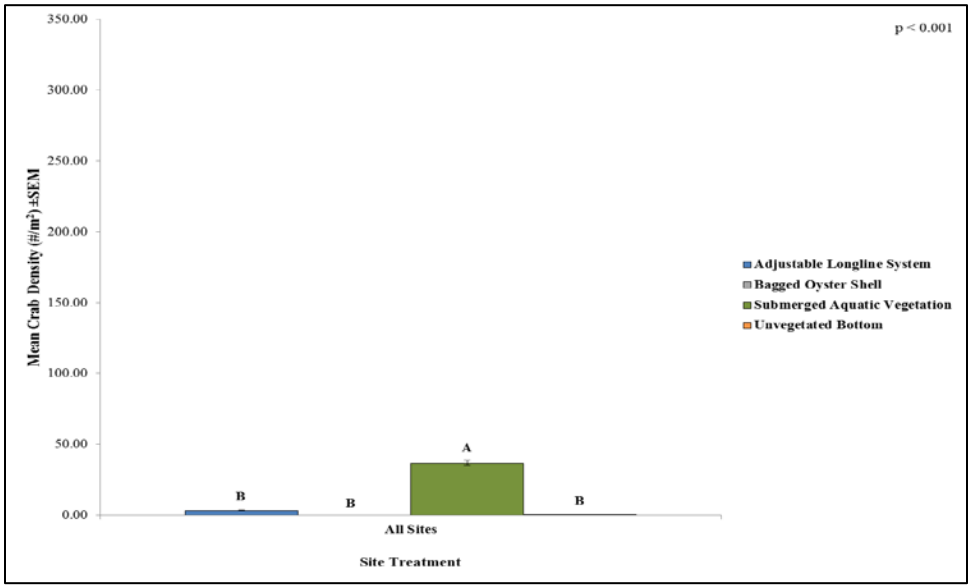


Figure 2.70 Effect of habitat type upon juvenile blue crab mean density (B) ± SEM in October 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

Juvenile Blue Crab Carapace Width

There were no significant interactions between habitat type and site with respect to juvenile blue crab mean carapace width in October 2013 (ANOVA: $p = 0.943$; Table 2.31); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean carapace width (ANOVA: $p = 0.795$; Table 2.31); therefore, site factors were pooled across habitat treatments (Fig. 2.71). There was a significant effect of habitat upon juvenile blue crab mean carapace width (ANOVA: $p < 0.001$; Table 2.31); specifically, juvenile blue crab mean carapace width was significantly greater in the ALS samples than the other habitat treatments (Fig. 2.71; see App. A: Chapter Two Supporting Data, Table A-27 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	49,728.535	3	16,576.178	248.771	0.000
SITE	4.568	1	4.568	0.069	0.795
HABITAT*SITE	25.633	3	8.544	0.128	0.943
Error	2,132.235	32	66.632		

Table 2.31 ANOVA results for mean CW in October 2013, using analytical approach 2.

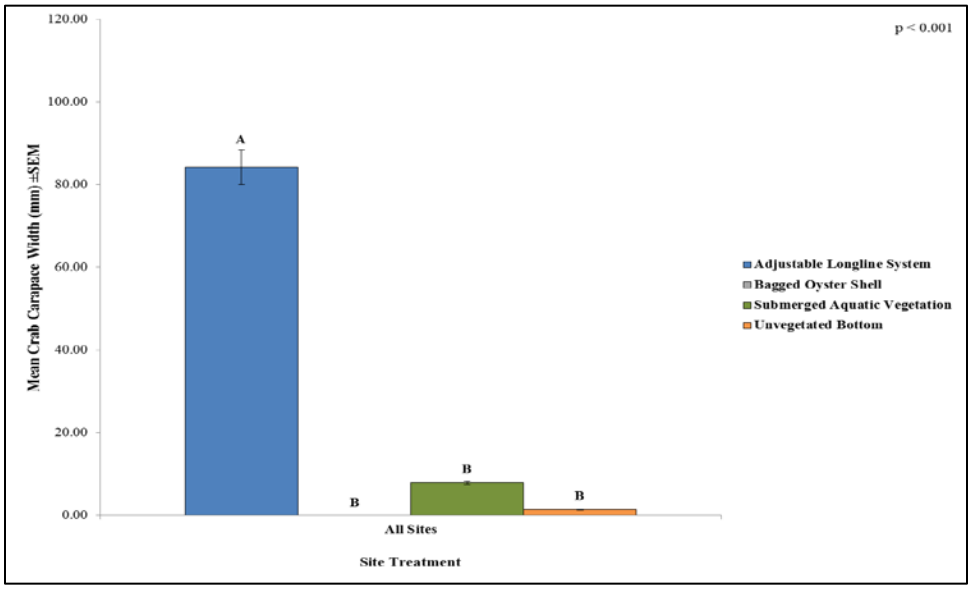


Figure 2.71 Effect of habitat type upon juvenile blue crab mean carapace width ± SEM in October 2013 using Approach 2. Different letters indicate a statistically significant difference ($p < 0.05$). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.4 Results: Estimation of Relative Predation Intensity

2.4.1 Environmental Conditions

Mean seawater temperature at the PBA site was 29.6 °C (range: 26.6 - 33.9 °C); and at the SBA site, mean seawater temperature was 32.0 °C (range: 30.1 - 33.3 °C; Fig. 2.72). Mean salinity at the PBA site was 13.2 PSU (range: 10.7 - 15.6 PSU; 2.73); and at the SBA site, mean salinity was 16.7 PSU (range: 15.1 - 17.9 PSU; Fig. 2.73). Mean dissolved oxygen at the PBA site was 7.93 mg L^{-1} (range: 5.7 - 10.34 mg L^{-1}; Fig. 2.74); and at the SBA site, mean dissolved oxygen was 10.6 mg L^{-1} (range: 7.16 - 18.1 mg L^{-1}; Fig. 2.74).

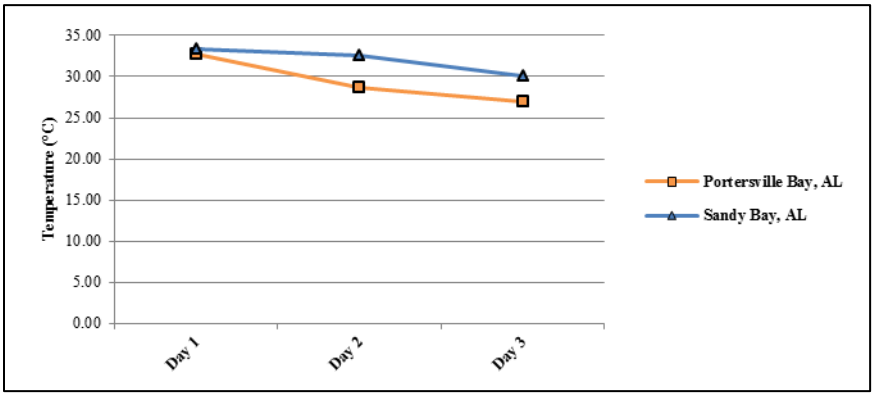


Figure 2.72 Physical seawater temperature (°C) data for each field site during 2013 (Portersville Bay, AL: September 2013; Sandy Bay, AL: July 2013).

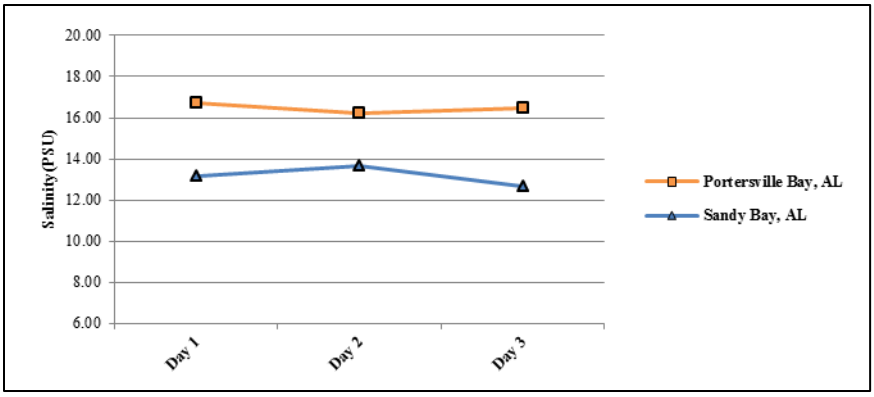


Figure 2.73 Physical seawater salinity (PSU) data for each field site during 2013 (Portersville Bay, AL: September 2013; Sandy Bay, AL: July 2013).

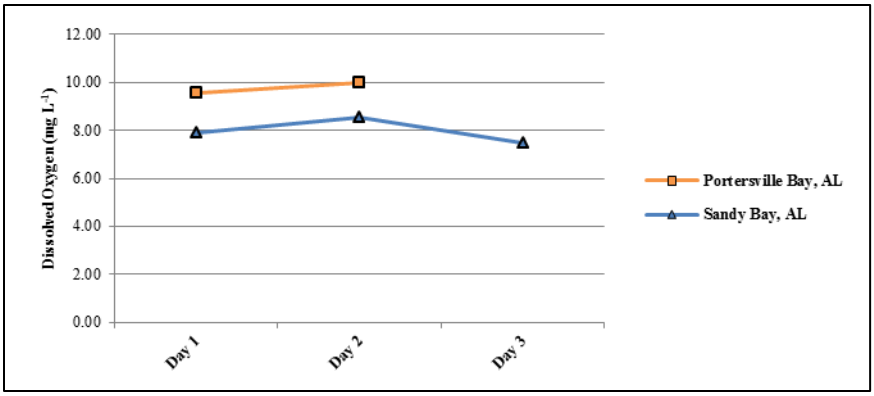


Figure 2.74 Physical seawater dissolved oxygen (mg L^{-1}) data for each field site during 2013 (Portersville Bay, AL: September 2013; Sandy Bay, AL: July 2013).

Seawater temperature was significantly lower at the PBA site than at the SBA site (ANOVA: $p < 0.001$; Table 2.32; Fig. 2.75). Salinity and dissolved oxygen both were significantly lower at the SBA site than at the PBA site (ANOVA: salinity, $p < 0.001$, Table 2.33; dissolved oxygen, $p < 0.001$; Table 2.34; Fig. 2.75; see App. A: Chapter Two Supporting Data, Table A-28 (a-e), Table A-29 (a-f), and Table A-30 (a-e) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
SITE	225.625	1	225.625	68.747	0.000
Error	518.550	158	3.282		

Table 2.32 ANOVA results related to physical seawater temperature data.

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
SITE	435.481	1	435.481	315.965	0.000
Error	203.982	148	1.378		

Table 2.33 ANOVA results related to physical seawater salinity data.

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
SITE	208.260	1	208.260	52.704	0.000
Error	466.277	118	3.951		

Table 2.34 ANOVA results related to physical seawater dissolved oxygen data.

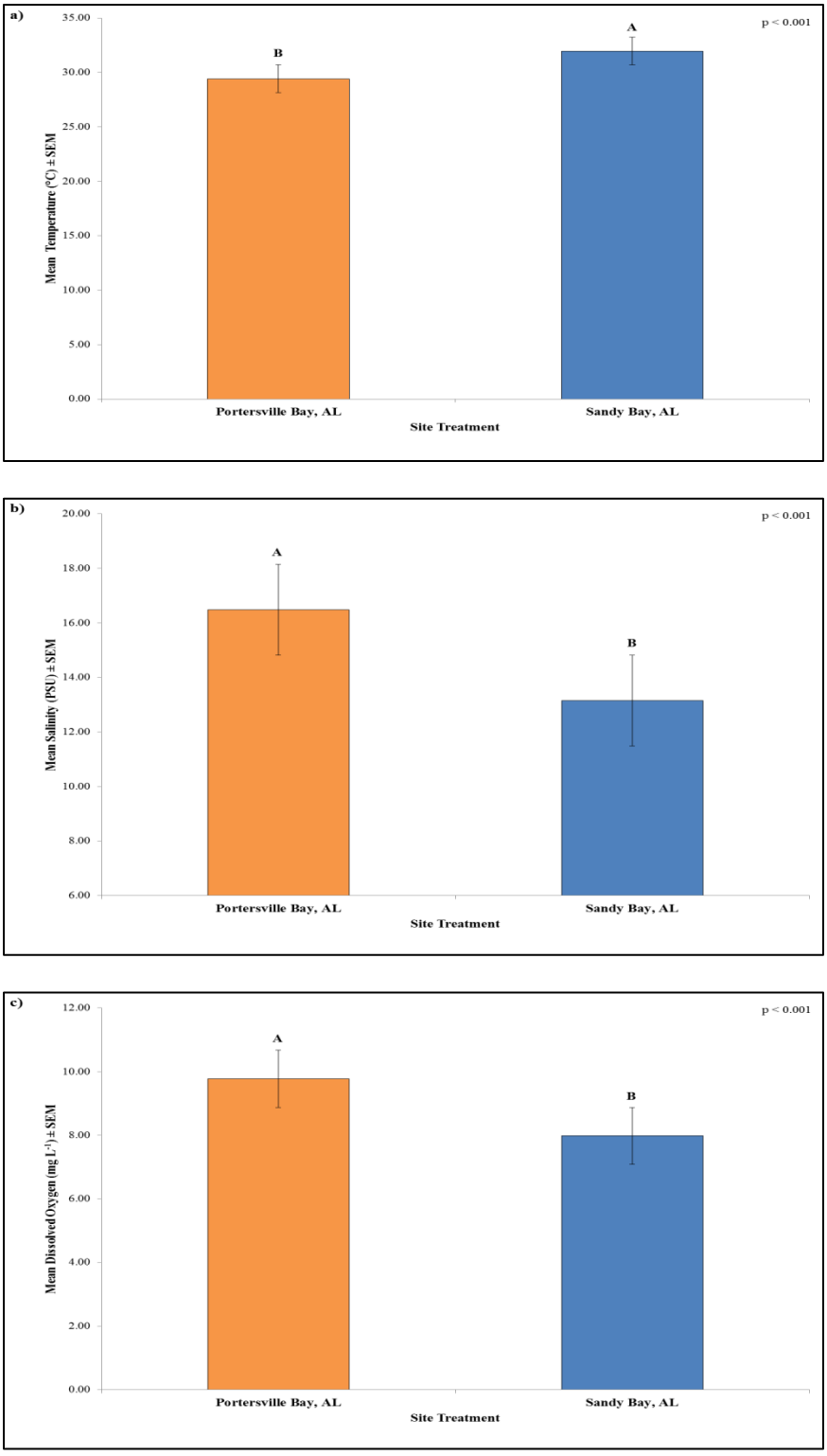


Figure 2.75 Comparison of physical seawater parameters: a) mean temperature (°C); b) mean salinity (PSU); and c) mean dissolved oxygen (mg L^{-1}). Different letters indicate a statistically significant difference ($p < 0.05$). P-values were derived from general linear models and statistically significant differences were calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.4.2 Effects of Habitat and Site: Predation Pressure (Percent Survival)

There were no significant interactions (ANOVA: p = 0.058) between habitat type and site with respect to juvenile blue crab mean percent survival in July 2013 and September 2013 (Table 2.35); therefore, we consider each of these factors separately. There was no significant effect of site upon juvenile blue crab mean percent survival (ANOVA: p = 0.837; Table 2.35); therefore, site factors were pooled across habitat treatments (Fig. 2.76). There was a significant effect of habitat upon juvenile blue crab mean percent survival (ANOVA: p < 0.001; Table 2.35); specifically, juvenile blue crabs tethered in ALS samples had a significantly higher percent survival than all other treatments (Fig. 2.76; see App. A: Chapter Two Supporting Data, Table A-31 (a-f) for more information).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
HABITAT	1.072	3	0.357	9.319	0.001
SITE	0.002	1	0.002	0.043	0.837
HABITAT*SITE	0.352	3	0.117	3.058	0.058
Error	0.613	16	0.038		

Table 2.35 ANOVA results for mean percent survival in July 2013 at Sandy Bay (Point aux Pins), Alabama and September 2013 at Portersville (Fowl River) Bay, Alabama.

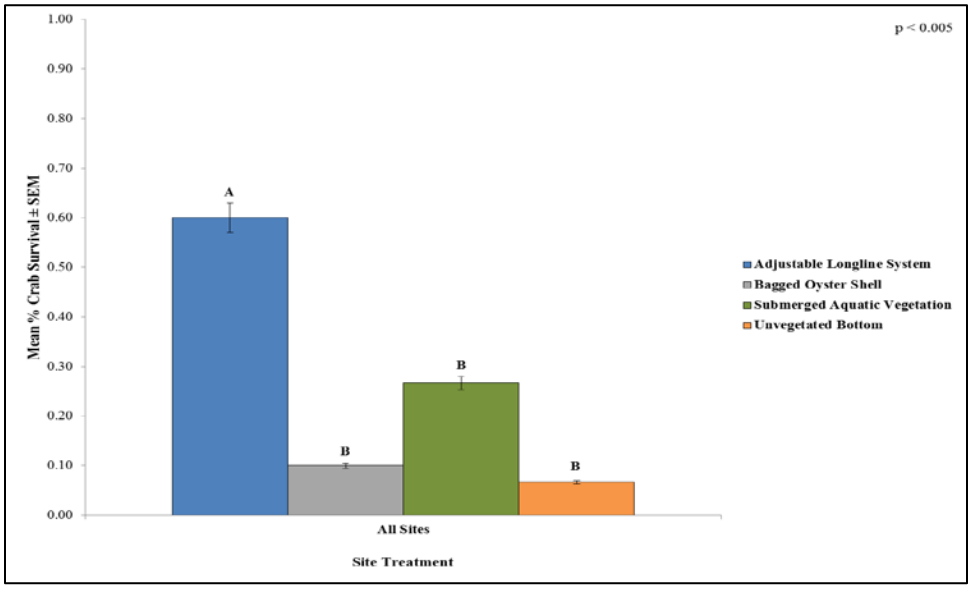


Figure 2.76 Effect of habitat type upon juvenile blue crab mean percent survival ± SEM in July 2013 at SBA and in September 2013 at PBA. Different letters indicate a statistically significant difference (p < 0.05). P-values are derived from general linear models with groups calculated using Tukey's HSD *post-hoc* multiple comparisons at 95% confidence.

2.5 Discussion

2.5.1 Comparing Relative Habitat Value

The a priori goal of this research was to make an assessment of habitat value. Habitat value can be defined as 'the potential ability of a given area or environment to support a fishery resource or any one of its life stages'. The regular interactions that ensue between fishery resource organisms and their immediate surrounding areas or environments can provide measureable conditions which constitute 'the ecological structure' within the substrata (i.e. defined habitats) of the larger-scale systems (i.e. surrounding estuaries). These measurable conditions include biotic attributes such as the density of organisms, the body size and/or mass of the organisms, and their survival rate in the presence of predators.

For the purposes of this study, a given area or environment (i.e. habitat type) is assumed to provide a measurable 'value' for a fishery resource to some degree, as long as the fishery resource of interest (*C. sapidus*; juvenile life stage) is present at a given time in the given habitat type. Generally, habitat types are considered to provide organisms with a greater habitat value if the organisms demonstrate lower average mortality rates, higher average densities, and larger average body sizes than before or than they do in other habitat types.

Thus, the following discussion compares the results for juvenile blue crab density, size structure, and survival rates within each of the four habitat types (ALS, BOS, SAV, and UVB) in order to make a conclusive evaluation of relative habitat value (the potential ability of a given area or environment to support a fishery resource or any one of its life stages). Not surprisingly, habitat value is affected by different environmental conditions and different life history stages, and the interactions among these. In comparing relative habitat values among the four tested habitat types, there appears to be a pronounced effect of the size of the blue crab juveniles, with a sharp change in habitat value around carapace widths where the juveniles are not able to freely move between the outside and inside of the ALS baskets.

2.5.2 Density

Comparison of Methods to Calculate Density

Juvenile blue crab densities for ALS and BOS were calculated by using two different, yet related methods. The first method was calculated using the mean number of juvenile blue crabs collected from within replicate samples of each particular habitat treatment and site combination, and dividing the resulting numbers by the area (m^2) of seafloor that the respective treatments occupy without regard to internal structure.

The second method was calculated using again the mean number of juvenile blue crabs collected from within replicate samples of each particular habitat treatment and site combination, but dividing the resulting numbers by the area (m^2) of seafloor that the respective treatments would occupy if the total sample internal surface area were expanded out onto the seafloor (i.e. if the basket or bag were split open and laid out flat).

Although the same general trends are apparent between the two methods, the frequency and magnitude of statistical differences are minimized when using the second method, as the larger divisor reduces the calculated densities in the ALS and BOS treatments. While the second approach provides more conservative results (mostly by reducing the ALS density) the first method may actually provide more ecologically relevant results. ALS and BOS are typically only allowed to be deployed in unstructured environments (UVB), where densities are assumed to be essentially two dimensional; thus, for a comparison of relative habitat value, it is worthwhile to ask how these habitats affect density for given square footage of seafloor. Therefore, this discussion will be based on the results of the first density calculation method.

General Trends and Changes in Density over Time (Approach 1)

Where juvenile blue crab density was compared for three types of habitat (ALS, BOS, and UVB with no SAV included) over three sites (PBA, SBA, and BDIL), density was always lowest in UVB and highest in ALS at all sampling times except during August 2013, where the density in BOS at BDIL was not significantly different than the density in ALS at PBA and SBA (Tukey's HSD: $p > 0.05$). These results support the findings of Moksnes and Heck (2006), where densities of juvenile blue crabs were highest in structurally complex habitats, though the addition of suspension of the structure off the seafloor of the ALS habitat may be important relative to BOS. Although ALS and BOS habitats share some characteristics, such as the presence of complex interstitial spaces provided by the oysters/shells, the environments amidst ALS baskets are unique in that they exist just below the water's surface rather than on the bottom.

As such, ALS habitats and any organisms within them are not affected by conditions commonly occurring on the bottom such as episodic hypoxia; instead, organisms within ALS are most affected by the dynamics associated with surface current and tidal flow changes. Additionally, the structural nature of ALS habitats are inherently unique, because unlike BOS and other types of oyster reefs (which are comprised of oyster shells that have clumped up and bonded to one another forming stagnant clumps of solidified structure), the oysters (generally hatchery produced single-sets) can be moved around within the baskets by wave action, and the baskets themselves also move with the wave action (due to the method of attachment on the horizontal longlines on which they are suspended). Therefore, ALS habitats are not necessarily more structurally complex than BOS habitats; rather they are similar in structural complexity (i.e. similar in the amount of interstitial space available for shelter), but more unique in both location within the water column and structural plasticity, and mobile species such as blue crabs (which commonly redistribute themselves throughout the water column) may find this unique habitat more suitable at times.

Furthermore, juvenile blue crab densities decreased over time in all three habitats included in this analysis (ALS, BOS, UVB, but see below for SAV). This trend could be explained by either post-settlement dispersal, or by post-settlement mortality. Post-settlement dispersal may be an important way to mitigate crowding effects that could occur in BOS and ALS (Pile *et al.*, 1996; Etherington and Eggleston, 2000; Etherington *et al.*, 2003; Moksnes and Wennhage, 2001). The most significant decrease in density over time occurred in BOS, possibly related to the high abundances of other benthic decapod species often found in BOS (Fig. 2.77; which were rarely found in the other habitat types), and the resulting interspecific interactions.

Figure 2.77 Example of benthic crustaceans in BOS at Portersville (Fowl River) Bay, Alabama in September 2013.

General Trends and Changes in Density over Time (Approach 2)

In a second analysis, the effects of all four habitat types (ALS, BOS, UVB and SAV) over the two Alabama sites (PBA and SBA) were examined. In this analysis, juvenile blue crab density was always lowest in UVB and was highest in ALS except during the October 2013 sampling, where the density in SAV exceeded the density in ALS. This result supports the conclusion that ALS provides important structure for juvenile blue crabs, but highlights that this result is dependent upon time (but not strongly dependent; i.e. only one month out of many) at least in regards to SAV. While densities of blue crab juveniles decreased in all treatments over time, there appeared to be a functional change in the relative habitat value provided by ALS baskets. Based on qualitative observations and changes in size structure of blue crab juveniles over time, it appears that there was a tipping point (see below) during the sampling period where lower densities (often one) of larger juvenile blue crabs began to dominate the ALS baskets.

2.5.3 Size

Regardless of the analysis, the highest juvenile blue crab mean carapace width was in the ALS at all sampling time points and all sites. Of course, there is a limiting body size at which blue crabs can enter or exit the ALS baskets due to the defined hexagonal mesh size of the ALS baskets (12 millimeters). While carapace length was not measured in this study, Gokce *et al.* (2006) found that blue crab carapace length and carapace width generally have a relationship of 1:2, so it is assumed for the sake of this discussion that 24 mm is this maximum carapace width for juveniles that were able to move freely through the basket mesh.

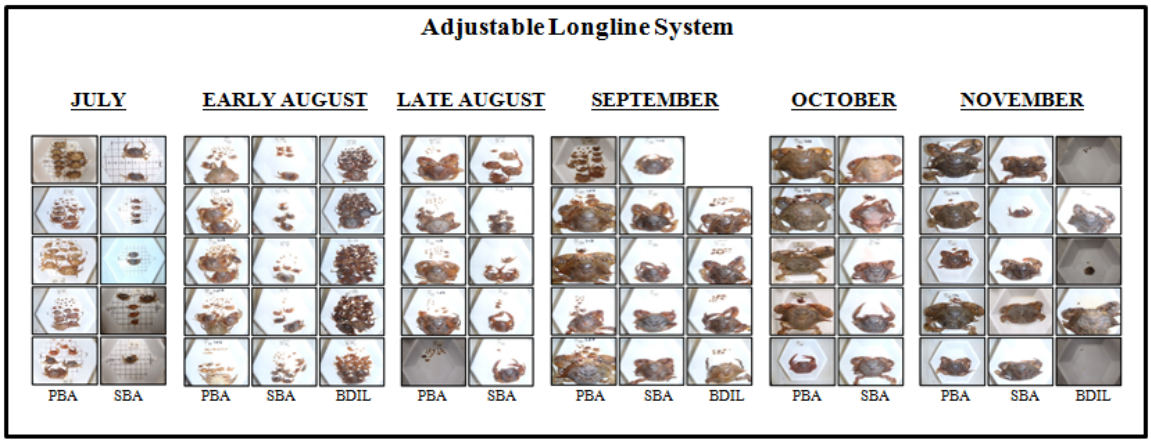


Figure 2.78 Changes in average blue crab size (and density) over time.

This artifact could have affected mean carapace width in several ways. The mesh size presumably protected juvenile blue crabs inside the basket from larger predators, allowing individuals within the basket to survive and grow, which would be expected if the ALS habitat were providing improved relative habitat. Though not tested in this study, it would be interesting to measure growth rates of individuals within baskets to see if molting occurs more frequently and/or if growth is faster, relative to individuals outside the ALS baskets.

In contrast, at least two additional artifacts may have affected mean carapace width. First, once juvenile blue crabs inside the ALS molted and could not leave the basket, these individuals were effectively trapped in the basket. Whereas larger juvenile blue crabs may have emigrated from the other habitats, they could not leave ALS, potentially inflating the mean carapace width.

Second, the presence of a larger juvenile blue crab could have reduced the abundance of smaller juvenile blue crabs in at least two ways, either through active avoidance of the ALS baskets by smaller juveniles (Diaz *et al.*, 2001) or by reduction through cannibalism (Moksnes *et al.*, 1997). Further experimentation is required to tease apart the benefits of protection from predators provided by ALS on carapace width versus the price of increased cannibalism.

2.5.4 Survival

Post-settlement survival for blue crabs is dependent on the availability of habitats that can provide shelter from predators, because their population dynamics are strongly influenced by a density-dependent three-way interaction between body size, habitat, and predation (Heck *et al.*, 1993; Heck *et al.*, 2001).

In the tethering experiments (Fig. 2.76), relative survival was highest in ALS, suggesting relatively high predation mortality in the other habitat types, supporting the findings of Moksnes and Heck (2006), where blue crab densities in uncaged treatments were significantly lower in all habitats than in caged treatments. Notably, crabs used in the tethering experiments in both the ALS and BOS were all able to move in and out of the baskets and bags (CW: < 25 mm). Again, the mesh size of the ALS baskets appears to provide a distinct refuge for the juvenile crabs.

2.5.5 Conclusions

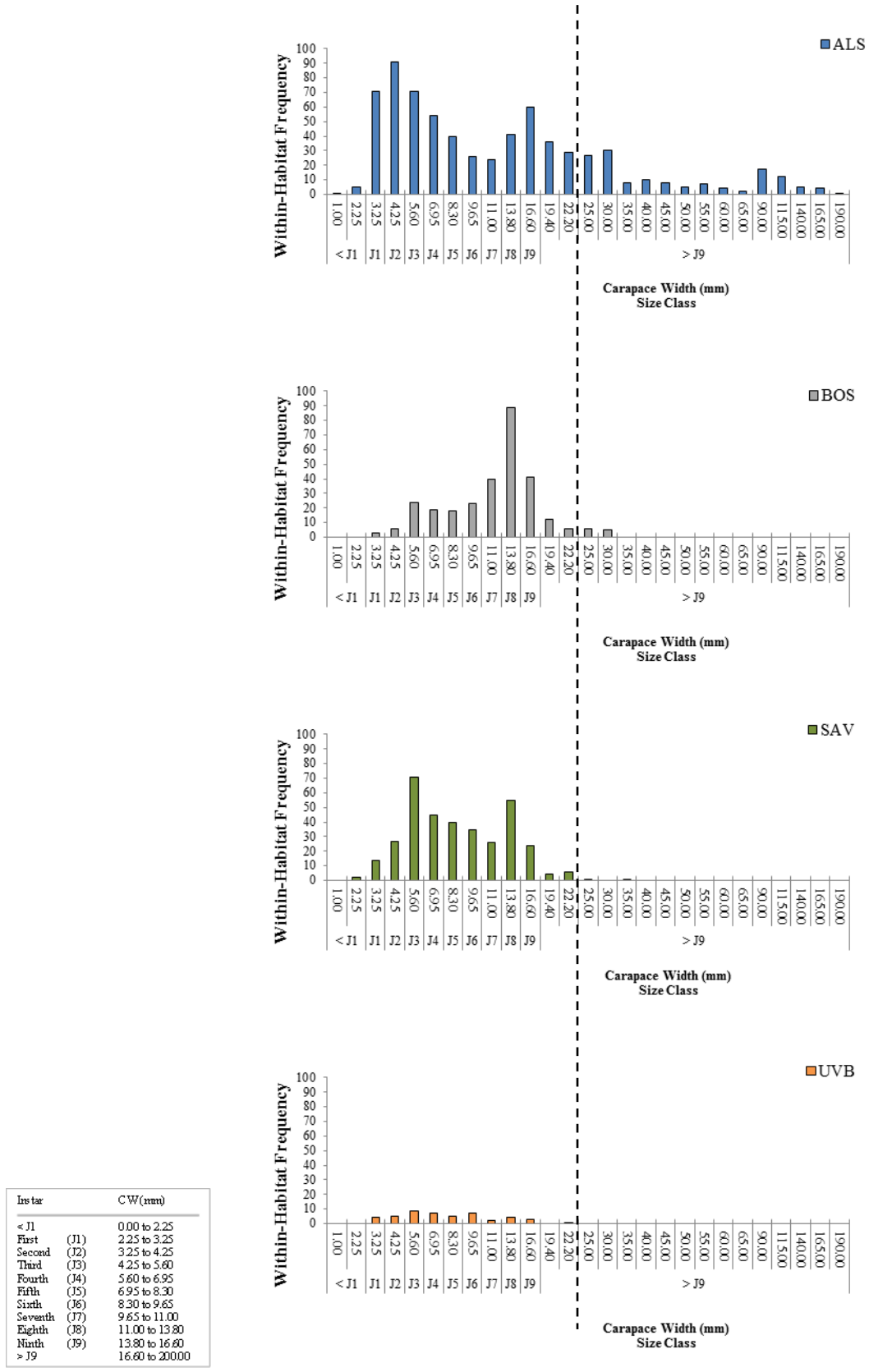
ALS baskets are essentially cylindrical structures featuring lateral holes and complex interstitial spaces (Fig. 2.79); habitats with these characteristics have been documented to support the highest degree of enhancement for shelter seeking individuals (whose survival is somewhat dependent upon shelter availability), due to the large amount of shelter cavities and surface area that that the spaces between and among the oysters within them can provide (Pickering and Whitmarsh, 1997).

Many estuarine-dwelling organisms display a preference for shelter cavities similar to their body size (Shulman, 1984; Hixon and Beets, 1989), however, if these organisms for some reason do not emigrate from the structured habitats before they outgrow the available space, then elevated mortality rates will result among the following cohorts of juvenile settlers, due to the increased predation/cannibalism risk brought about by the larger remaining individuals (West *et al.*, 1994), which appears to be occurring in ALS.

Figure 2.79 Interior of ALS basket.

Relative Habitat Value of ALS

Drawing together the results for density, size, and survival, ALS provides the most valuable habitat for juvenile blue crabs below an average carapace width of approximately 25 mm. For juvenile crabs larger than this size, there appears to be a tipping point in the manner in which the ALS serves as habitat. Interestingly, over the course of the study, each ALS basket typically became dominated by a single larger juvenile blue crab, which appeared to thrive in the basket (Fig. 2.79), and this was not observed in the other tested habitats. Of course, the presence of this single larger crab in the ALS makes this habitat much less valuable to juvenile crabs in the size range vulnerable to cannibalism. Therefore, the relative habitat value of ALS is a product of the size of the juvenile blue crabs and the 'state of the basket' (occupied or not by a larger blue crab), which, in turn is at least partially a function of time. Still, it can be concluded that ALS (which is not occupied by a single large crab) can provide an extremely valuable habitat to juvenile blue crabs, relative to the other tested habitats in this study.



Instar		CW (mm)
< J1		0.00 to 2.25
First	(J1)	2.25 to 3.25
Second	(J2)	3.25 to 4.25
Third	(J3)	4.25 to 5.60
Fourth	(J4)	5.60 to 6.95
Fifth	(J5)	6.95 to 8.30
Sixth	(J6)	8.30 to 9.65
Seventh	(J7)	9.65 to 11.00
Eighth	(J8)	11.00 to 13.80
Ninth	(J9)	13.80 to 16.60
> J9		16.60 to 200.00

Figure 2.80 *C. sapidus* size frequencies by habitat; chart displays sizes of benthic instars (CW: mm; spine-to-spine) used to categorize crabs; dotted line indicates size which crabs can no longer move through ALS cage mesh (24 mm).

It is difficult to determine whether any habitat 'enhancements' are augmenting recruitment or simply causing a concentration of existing individuals. There are two commonly-recognized (opposing) hypotheses regarding observations of increased organismal densities within structured habitats such as ALS. One of them suggests that observations of increased densities within structured habitats are caused merely by the attraction and redistribution of existing individuals, with no net increase in overall abundance (Bohnsack, 1989). In this scenario, individuals that move into (or settle into) structured habitats are unable to be replaced due to other limiting factors affecting the abundance of organisms in the area, such as a finite larval or food supply (density-independent). Thus, the observed increase of *C. sapidus* densities following ALS and BOS deployment may be due to a short-term concentration, yet the observed individuals are likely seeking shelter from the highly localized predation pressure outside of ALS (Brickhill *et al.*, 2005).

The other scenario suggests that observations of increased densities within structured habitats may be due to the addition of new individuals, where the additional habitat is enhancing production by increasing an area's carrying capacity, leading to a net increase in overall abundance (Bohnsack, 1989; Brickhill *et al.*, 2005). In the case of production, not only are greater number of juveniles able to settle, but also greater numbers of juveniles are able to survive to adulthood, later contributing new individuals to local populations. Structured habitats may provide additional surface area for the development of encrusting epibenthic assemblages that can provide food for residents (Rezak *et al.,* 1990; Johnson *et al.,* 1994); and as discussed previously, *C. sapidus* larval supply does not appear to be limiting in the north-central GOM (Heck *et al.*, 1993; Van Montfrans *et al.*, 1995; Heck *et al.*, 2001; Wahle, 2003), but if food is limiting, increased structure would not increase K (carrying capacity). The structured habitat thereby promotes a net increase in local abundance of organisms, because future individuals can be accommodated by the new habitat (Brickhill *et al.*, 2005).

In order to determine whether attraction or production is responsible for observations of increased densities within ALS, two approaches are recommended for future studies. These approaches are: 1) using control sites, both interspersed among the ALS and at structured and non-structured locations outside of the study area containing the OBOF, to allow testing of hypotheses that predict the extent of influence of the ALS, and to allow testing of hypotheses that assess the productive potential of OBOF (i.e. where only attraction of existing individuals is occurring, the net abundance of juvenile blue crabs at the OBOF and surrounding areas should not change; where production is occurring, there should be a net increase in juvenile blue crab abundance observed at the OBOF and in the surrounding areas because the surrounding areas would encompass all exchanges of blue crabs to and from the ALS); and 2) blue crab age (obtained using extractable lipofuscin techniques; Ju *et al.*, 1999; Bosley and Dumbauld, 2010) and size data over time (length-frequency histogram modal analysis; Jennings *et al.*, 2003) to allow testing of hypotheses that predict the extent of temporal influence of the OBOF (i.e. the extent of influence over longer periods of time). Additionally, determining the spawning-potential per-recruit would be useful for estimating secondary production (Bunnell and Miller, 2005). Lastly, techniques such as those used previously in mark and recapture tagging studies (Davis *et al.*, 2004) and stable isotope analysis studies (Bucci *et al.*, 2007; Hoeninghaus *et al.*, 2007; Abeels *et al.*, 2009; Llewellyn and Peyre, 2011) could be used to help resolve movement mechanisms driving attraction and production (i.e. site fidelity; Brickhill *et al.*, 2005).

2.5.6 Management Implications

The degree of attraction and production can also influenced by management protocols, such as whether or not sexually mature individuals are able to emigrate from the structured habitat (Brickhill *et al.*, 2005). With ALS, if the regular removal and release of larger blue crabs were incorporated into the operational routine for oyster farmers using ALS, then the unique structure could enhance overall production in the area.

Released crabs (which would no longer need the shelter) would be able to make their offshore spawning migrations, possibly returning to unstructured areas previously uninhabited. In addition, the removal of the resident larger crab, would then allow the next cohort of juvenile blue crabs to settle into the ALS, free of a larger cannibalistic individual which they might normally avoid (Grabowski and Kimbro, 2005; Macreadie *et al.*, 2012). Additionally, removal of larger crabs is already a recommended practice for oyster farmers to minimize oyster losses to predation, but due to the rapid growth rates of oysters grown using ALS in this region, subsequent *C. sapidus* settlement events that occur (after the removal of large crabs that initially settled post-deployment) would not be expected to negatively impact the farmed oysters, because the oysters would be expected to have outgrown the size which is most vulnerable to predation by these smaller newly-settled crabs, and oyster harvest should occur shortly hereafter. Ideally, this simple management protocol could eventually enhance the local crab populations.

This raises the question of how large an effect this might have. Previous studies have estimated production enhancement resulting from restoring oyster reef habitat (Peterson *et al.*, 2003); a recent report by The Nature Conservancy estimated a regional oyster reef restoration project to enhance the local *C. sapidus* population production by 229 g/10 m^2 of oyster reef/yr. (Kroeger, 2012). The same general methods could be applied to ALS. For example, if one blue crab (CW > 60 mm) is released from each of six ALS baskets per bay (10 m^2) once every four months (during peak growing seasons) on a farm using an ALS, then based on the relationship which was observed between carapace width (mm) and wet weight (g) obtained from *C. sapidus* specimens collected in this study (n = 541; $R^2 = 0.97$; Fig. 2.81), an estimated production enhancement of 216 g/10 m^2 could be annually provided from ALS systems in the region, managed to maximize this benefit, following the assumption that these larger crabs would have otherwise not survived had they not been caged (which can be supported by the results for ALS mean percent survival increase; Fig. 2.76).

Considering that the average ALS off-bottom oyster farm consists of 16 longline runs (on two acres), each with 34 bays, and that at least half of the farm is utilized at any given time throughout the year, an approximate estimation for annual production enhancement of *C. sapidus* provided by an average ALS farm is 118 kg/yr.

Previous studies have also taken this a step further by making an economic valuation of the potential ecosystem services provided by habitat enhancements such as those proposed here (Grabowski *et al.*, 2012). A conservative estimate for the potential economic gain resulting from blue crab habitat provisioning offered by an OBOF using the ALS is $205.52/yr./OBOF in Alabama and $244.54/yr./OBOF in Louisiana. These estimates are based on the 2012 Alabama and Louisiana dockside prices for blue crab per pound, sourced within a 2014 report assessing the economic value of shellfish habitat for commercial and recreational fish species in the Gulf of Mexico (Northern Economics, Inc., 2014). Thus, ALS appears to provide valuable habitat for juvenile blue crabs, and if oyster farmers implement simple husbandry practices, then there lies greater potential for substantially enhancing/improving blue crab recruitment to the locally fished populations.

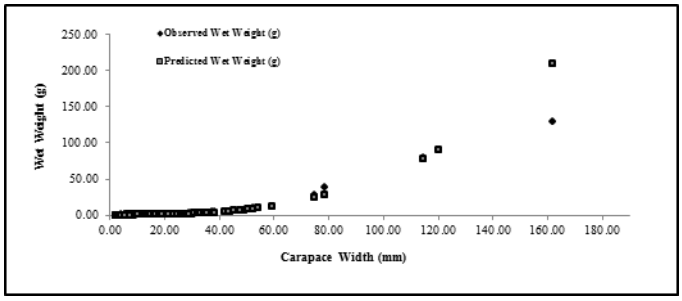


Figure 2.81 a) Relationship between carapace width and weight.

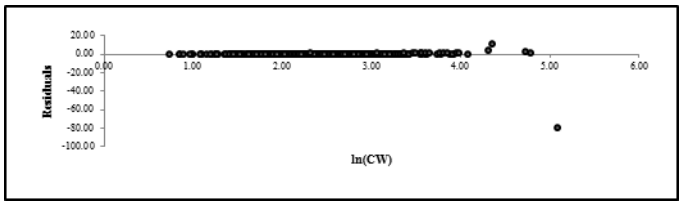


Figure 2.81 b) Relationship between carapace width and weight (residuals).

The overall purpose of this study was to determine how juvenile blue crabs are being affected by the addition of structure being introduced with off-bottom oyster farming, relative to other available habitat types. Specifically, I tested the following hypotheses.

1. Across three coastal sites (one in Louisiana and two in Alabama), juvenile blue crab abundance and survival would be greater in off-bottom oyster farming habitat relative to unvegetated bottom, but not differ from bagged oyster shell.
2. Within Alabama's coastal waters (two sites that included submerged aquatic vegetation), juvenile blue crab abundance and survival would be greater in off-bottom oyster farming habitat relative to unvegetated bottom, but not differ from bagged oyster shell or submerged aquatic vegetation.

In conclusion, across three coastal sites (one in Louisiana and two in Alabama), juvenile blue crab abundance and survival was greater in off-bottom oyster farming habitat relative to unvegetated bottom, and differed from bagged oyster shell. Within Alabama's coastal waters (two sites that included submerged aquatic vegetation), juvenile blue crab abundance and survival was greater in off-bottom oyster farming habitat relative to unvegetated bottom, and differed from bagged oyster shell and submerged aquatic vegetation.

References

Abeels, H. A., A. K. Volety, A. N. Loh and S. G. Tolley. 2009. Trophic transfer and habitat use of oyster (*Crassostrea virginica*) reefs in southwest Florida using stable isotope analysis: Are oyster reefs used for refuge, food or both? *J. Shellfish Res.* 28(3):677-677.

Bachelor, B. M., S. G. Tolley and S. E. Burghart. 2006. Influence of salinity on the distribution and abundance of larvae of dominant oyster-reef decapods in southwest Florida. *J. Shellfish Res.* 25(2):709-710.

Bohnsack, J. A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioural preference? *Bull. Mar. Sci.* 44:631-645.

Bosley, K. M. and B. R. Dumbauld. 2010. Use of extractable lipofuscin to estimate age structure of ghost shrimp populations in west coast estuaries of the USA. *Mar. Ecol.-Prog. Ser.* 428:161-176.

Brickhill, M. J., S. Y. Lee and R. M. Connolly. 2005. Fishes associated with artificial reefs: Attributing changes to attraction or production using novel approaches. *J. Fish Bio.* 67(Supplement B):53-71.

Bucci, J. P., S. Rebach, D. DeMaster and W. J. Showers. 2007. A comparison of blue crab and bivalve delta super (15) N tissue enrichment in two North Carolina estuaries. *Environmental Pollution* 145(1):299-308.

Bunnell, D. B. and T. J. Miller. 2005. An individual-based modeling approach to spawning-potential per-recruit models: An application to blue crab (*Callinectes sapidus*) in Chesapeake Bay. *Canadian Journal of Fisheries and Aquatic Sciences* 62:2560-2572.

Clark, M. E., T. G. Wolcott, D. L. Wolcott and A. H. Hines. 1999. Intraspecific interference among foraging blue crabs *Callinectes sapidus*: Interactive effects of predator density and prey patch distribution. *Mar. Ecol.-Prog. Ser.* 178:69-78.

Coen, L. D. and M. W. Luckenbach. 2000. Developing success criteria and goals for evaluating oyster reef restoration: Ecological function or resource exploitation? *Ecological Engineering* 15:323-343.

Cohen, J. 1969. Statistical power analysis for behavioral sciences. NY: Academic Press.

Davis, J. E. 2013. Effects of basket arrangement and stocking density when using the adjustable long-line system for oyster grow-out. In. United States -- Alabama: Auburn University. pp. 82.

Davis, J. L. D., A. C. Young-Williams, A. H. Hines and O. Zmora. 2004. Comparing two types of internal tags in juvenile blue crabs. *Fisheries Research* (Amsterdam) 67:265-274.

Dealteris, J. T., B. D. Kilpatrick and R. B. Rheault. 2004. A comparative evaluation of the habitat value of shellfish aquaculture gear, submerged aquatic vegetation, and a non-vegetated seabed. *J. Shellfish Res.* 23:867-874.

Diamond, J. M. 1986. Overview: laboratory experiments, field experiments, and natural experiments. Pages 3-22 in J. M. Diamond and T. J. Case (eds.), Community Ecology. Harper and Row, New York.

Diaz, H., B. Orihuela, R. B. Forward, Jr. and D. Rittschof. 2001. Effects of chemical cues on visual orientation of juvenile blue crabs, *Callinectes sapidus* (Rathbun). *J. Exp. Mar. Biol. Ecol.* 266(1):1-15.

Eggleston, D. B. and D. A. Armstrong. 1995. Pre- and post-settlement determinants of estuarine dungeness crab recruitment. *Ecological Monographs* 65(2):193-216.

Eggleston, D. B., G. W. Bell and A. D. Amavisca. 2005. Interactive effects of episodic hypoxia and cannibalism on juvenile blue crab mortality. *J. Exp. Mar. Biol. Ecol.* 325(1):18-26.

Eggleston, D. B., L. L. Etherington and W. E. Elis. 1998. Organism response to habitat patchiness: Species and habitat-dependent recruitment of decapod crustaceans. *J. Exp. Mar. Biol. Ecol.* 223:111-132.

Erbland, P. J. and G. Ozbay. 2008. A comparison of the macrofaunal communities inhabiting a *Crassostrea virginica* oyster reef and oyster aquaculture gear in Indian River Bay, Delaware. *J. Shellfish Res.* 27:757-768.

Etherington, L. L. and D. B. Eggleston. 2000. Large-scale blue crab recruitment: Linking postlarval transport, post-settlement planktonic dispersal, and multiple nursery habitats. *Mar. Ecol. -Prog. Ser.* 204:179-198.

Etherington, L. L., D. B. Eggleston and W. T. Stockhausen. 2003 Partitioning loss rates of early juvenile blue crabs from seagrass habitats into mortality and emigration. *Bull. Mar. Sci.* 72(2):371-392.

Forward, R. B., Jr. and J. H. Cohen. 2004. Factors affecting the circatidal rhythm in vertical swimming of ovigerous blue crabs, *Callinectes sapidus*, involved in the spawning migration. *J. Exp. Mar. Biol. Ecol.* 229:255-266.

Garson, G. D. 2012. Testing statistical assumptions. Asheboro, NC: Statistical Associates Publishing. 52 pp.

Gillanders, B. M., K. W. Able, J. A. Brown, D. B. Eggleston and P. F. Sheridan. 2003. Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: An important component of nurseries. *Mar. Ecol.-Prog. Ser.* 247:281-295.

Glancy, T. P., T. K. Frazer, C. E. Cichra and W. J. Lindberg. 2003. Comparative patterns of occupancy by decapod crustaceans in seagrass, oyster, and marsh-edge habitats in a northeast Gulf of Mexico estuary. *Estuaries* 26:1291-1301.

Gmelin, J. F. 1791. Caroli a Linné, systema naturae. Tom. I. Pars VI:3021-3910. Lipsiae (Beer).

Grabowski, J. H., R. D. Brumbaugh, R. F. Conrad, A. G. Keeler, J. J. Opaluch, C. H. Peterson, M. F. Piehler, S. P. Powers and A. R. Smyth. 2012. Economic valuation of ecosystem services provided by oyster reefs. *Bioscience* 62:900-909.

Grabowski, J. H., A. R. Hughes, D. L. Kimbro and M. A. Dolan. 2005. How habitat setting influences restored oyster reef communities. *Ecology* 86:1926-1935.

Grabowski, J. H. and D. L. Kimbro. 2005. Predator-avoidance behavior extends trophic cascades to refuge habitats. *Ecology* 86:1312-1319.

Gregalis, K. C., M. W. Johnson and S. P. Powers. 2009. Restored oyster reef location and design affect responses of resident and transient fish, crab, and shellfish species in Mobile Bay, Alabama. *Transactions of the American Fisheries Society* 138(2):314-327.

Guillory, V., H. M. Perry, P. Steele, T. Wagner, P. Hammerschmidt, S. Heath and C. Moss. 1998. The Gulf of Mexico blue crab fishery: Historical trends, status, management, and recommendations. *J. Shellfish Res.* 17(2):413-424.

Harding, J. M. and R. Mann. 2010. Observations of distribution, size, and sex ratio of mature blue crabs, *Callinectes sapidus*, from a Chesapeake Bay tributary in relation to oyster habitat and environmental factors. *Bulletin of Marine Science* 86:75-91.

Heard, R. W. 1982. Guide to Common Tidal Marsh Invertebrates of the Northeastern Gulf of Mexico. Booneville, MS: Reinbold Lithographing and Printing Company. 82 pp.

Heck, K. L., Jr., and L. D. Coen. 1995. Predation and abundance of juvenile blue crabs: A comparison of selected east and Gulf coast studies. *Bull. Mar. Sci.* 57:877-883.

Heck, K. L., Jr., L. D. Coen and S. G. Morgan. 2001. Pre- and post-settlement factors as determinants of juvenile blue crab *Callinectes sapidus* abundance: Results from the north-central Gulf of Mexico. *Mar. Ecol.-Prog. Ser.* 222:163-176.

Heck, K. L., Jr., L. D. Coen, S. G. Morgan and R. K. Zimmer-Faust. 1993. Recruitment and habitat utilization by the blue crab, *Callinectes sapidus*: The importance of juvenile nursery habitats to the fishery. Marine Fisheries Initiative (MARFIN) Final Rep.

Hixon, M. A. and J. P. Beets. 1989. Shelter characteristics and Caribbean fish assemblages: Experiments with artificial reefs. *Bull. Mar. Sci.* 44:666-680.

Hoeinghaus, D. J. and S. E. Davis, III. 2007. Size-based trophic shifts of saltmarsh dwelling blue crabs elucidated by dual stable C and N isotope analyses. *Mar. Ecol.-Prog. Ser.* 334:199-204.

Hovel, K. A. and M. S. Fonseca. 2005. Influence of seagrass landscape structure on the juvenile blue crab habitat -survival function. *Mar. Ecol.-Prog. Ser.* 300:179-191.

Hovel, K. A. and R. N. Lipcius. 2001. Habitat fragmentation in a seagrass landscape: Patch size and complexity control blue crab survival. *Ecology* 82:1814-1829.

Jennings, S. M. J. Kaiser and J. D. Reynolds. 2003. Marine Fisheries Ecology. Malden, MA: Blackwell Publishing. pp. 417.

Johnson, T. D., A. M. Barnett, E. E. DeMartini, L. L. Craft, R. F. Ambrose and L. J. Purcell. 1994. Fish production and habitat utilization on a Southern Californian artificial reef. *Bull. Mar. Sci.* 55:709-723.

Ju, S. J., D. H. Secor and H. R. Harvey. 1999. Use of extractable lipofuscin for age determination of blue crab *Callinectes sapidus*. *Mar. Ecol.-Prog. Ser.* 185:171- 179.

Kahn, D. M., R. W. Cole, S. F. Michels and W. H. Whitmore. 1998. Development of life-stage-specific indices of relative abundance and stock-recruitment relationships for the Delaware Bay blue crab stock. *J. Shellfish Res.* 17:529-541.

Kaplan, E. H. 1988. A Field Guide to Southeastern and Caribbean Seashores: Cape Hatteras to the Gulf Coast, Florida, and the Caribbean. New York, NY: Houghton Mifflin Company. 425 pp.

Kellogg, M. L., C. McIntyre, K. C. Paynter and K. T. Paynter. 2006. Enhanced blue crab abundance on restored oyster reefs. In: National Shellfisheries Association, Dept. Marine Sciences, U. Conn. 1080 Shennecossett Road Groton, CT 06340 (USA). pp. 744.

Kroeger, T. 2012. Dollars and Sense: Economic benefits and impacts from two oyster reef restoration projects in the northern Gulf of Mexico. The Nature Conservancy. pp. 101. Retrieved from http://www.nature.org/science-in-action/science-features/1-dollars-and- sense.pdf

Lenihan, H. S. and C. H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. *Ecological Applications* 9:128-140.

Lipcius, R. N. and W. T. Stockhausen. 2002. Concurrent decline of the spawning stock, recruitment, larval abundance, and size of the blue crab in Chesapeake Bay. *Mar. Ecol. - Prog. Ser.* 226:45-61.

Lipcius, R. N. and W. A. Van Engle. 1990. Blue crab population dynamics in Chesapeake Bay, variation in abundance (York River 1972-1988) and stock–recruit functions. *Bull. Mar. Sci.* 46:180-194.

Llewellyn, C. and M. Peyre. 2011. Evaluating ecological equivalence of created marshes: Comparing structural indicators with stable isotope indicators of blue crab trophic support. *Estuaries and Coasts* 34(1):172-184.

Macreadie, P. I., N. R. Geraldi and C. H. Peterson. 2012. Preference for feeding at habitat edges declines among juvenile blue crabs as oyster reef patchiness increases and predation risk grows. *Mar. Ecol.-Prog. Ser.* 466:145-153.

McCue, T., Carruthers, E., Dawe, J., Liu, S., Robar, A. and K. Johnson. 2008. Evaluation of generalized linear model assumptions using randomization. Unpublished manuscript. Retrieved from http://www.mun.ca/biology/dschneider/b7932/B7932Final10Dec2008.pdf

Minello, T. J. 1993. Chronographic tethering: A technique for measuring prey survival time and testing predation pressure in aquatic habitats. *Mar. Ecol.-Prog. Ser.* 101(1-2):99-104.

Minello, T. J., K. W. Able, M. P. Weinstein and C. G. Hays. 2003. Salt marshes as nurseries for nekton: Testing hypotheses on density, growth and survival through meta-analysis. *Mar. Ecol.-Prog. Ser.* 246:39-59.

Moksnes, P-O. and K. L. Heck, Jr. 2006. Relative importance of habitat selection and predation for the distribution of blue crab megalopae and young juveniles. *Mar. Ecol.-Prog. Ser.* 308:165-181.

Moksnes, P-O. and H. Wennhage. 2001. Methods for estimating decapod larval supply and settlement: Importance of larval behavior and development stage. *Mar. Ecol. -Prog. Ser.* 209:257-273.

Moksnes, P-O., L. Phil and J. Van Montfrans. 1998. Predation on postlarvae and juveniles of the shore crab *Carcinus maenas*: Importance of shelter, size and cannibalism. *Mar. Ecol. -Prog. Ser.* 166:211-225.

Moksnes, P-O., R. N. Lipcius, L. Pihl and J. van Montfrans. 1997. Cannibal-prey dynamics in young juveniles and postlarvae of the blue crab. *J. Exp. Mar. Bio. Ecol.* 215(2):157-187.

Morgan, S. G., R. K. Zimmer-Faust, K. L. Heck, Jr. and L. D. Coen. 1996. Population regulation of blue crabs *Callinectes sapidus* in the northern Gulf of Mexico: Postlarval supply. *Mar. Ecol.-Prog. Ser.* 133:73-88.

Northern Economics, Inc. *Assessment of the value of shellfish aquaculture in Gulf of Mexico as habitat for commercial and recreational fish species*. Prepared for Auburn University School of Fisheries, Aquaculture and Aquatic Sciences and Alabama Cooperative Extension. March, 2014.

Patillo, M.E., T. E. Czapla, D. M. Nelson, and M. E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume II: Species life history summaries. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. pp. 377.

Perry, H. M., J. Warren and C. Trigg. 1997. Fishery independent sampling for megalopae and juvenile blue crabs in Mississippi coastal waters. *J. Shellfish Res.* 16(1):317-318.

Perry, H. M., J. Warren, C. Trigg and T. Van Devender. 1998. The blue crab fishery of Mississippi. *J. Shellfish Res.*17 (2):425-433.

Peterson, C. H., J. H. Grabowski, S. P. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: Quantitative valuation. *Mar. Ecol.-Prog. Ser.* 264:249-264.

Pickering, H. and D. Whitmarsh. 1997. Artificial reefs and fisheries exploitation; a review of the 'attraction versus production' debate, the influence of design and its significance for policy. *Fisheries Research* 31:39-59.

Pile, A. J., R. N. Lipcius, J. Van Montfrans and R. J. Orth. 1996. Density-dependent settler-recruit- juvenile relationships in blue crabs. *Ecological Monographs* 66(3):277-300.

Posey, M. H., T. D. Alphin, L. Coen, K. Walters and D. Wilber. 2006. Measuring success in oyster reef restoration: Application of standardized measures and tests of approaches. In: National Shellfisheries Association, Dept. Marine Sciences, U. Conn. 1080 Shennecossett Road Groton, CT 06340 (USA). pp. 763.

Rathbun, M. J. 1896. The Genus *Callinectes*. Washington, D.C. Smithsonian Institution. Government Printing Office. pp. 425.

Rakocinski, C. F., H. M. Perry, M. A. Abney and K. M. Larsen. 2003. Soft-sediment recruitment dynamics of early blue crab stages in Mississippi Sound. In: Rosenstiel School of Marine and Atmospheric Science. pp. 393-408.

Rezak, R., S. R. Gittings and T. J. Bright. 1990. Biotic assemblages and ecological controls on reefs and banks of northwest Gulf of Mexico. *American Zoologist* 30:23-35.

Ring, C. C. 2013. Evaluation of a mechanical grader for the improvement of the aquaculture production of the eastern oyster, *Crassostrea virginica*, in the northern Gulf of Mexico. In. United States -- Alabama: Auburn University. pp. 221.

Rozas, L. P. and T. J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: A review of sampling design with focus on gear selection. *Estuaries* 20:199-213.

Shervette, V. R., F. Gelwick and N. Hadley. 2011. Decapod utilization of adjacent oyster, vegetated marsh, and non-vegetated bottom habitats in a Gulf of Mexico estuary. *Journal of Crustacean Biology* 31:660-667.

Shervette, V. R., H. M. Perry, C. F. Rakocinski and P. M. Biesiot. 2004. Factors influencing refuge occupation by stone crab *Menippe adina* juveniles in Mississippi Sound. *Journal of Crustacean* Biology 24:652-665.

Shulman, M. J. 1984. Resource limitation and recruitment patterns in a coral reef fish assemblage. *J. Exp. Mar. Bio. Ecol.* 74:85-109.

Spitzer, P. M., K. L. Heck, Jr. and J. F. Valentine. 2003. Then and now: A comparison of patterns in blue crab post-larval abundance and post-settlement mortality during the early and late 1990s in the Mobile Bay system. *Bull. Mar. Sci.* 72:435-452.

Stunz, G. W., T. J. Minello and L. P. Rozas. 2010. Relative value of oyster reef as habitat for estuarine nekton in Galveston Bay, Texas. *Mar. Ecol.-Prog. Ser.* 406:147-159.

Supan, J. 2002. Extensive culture of *Crassostrea virginica* in the Gulf of Mexico regions. Southern Regional Aquaculture Center, Pub. No. 4300.

Tolley, S. G., B. M. Brosious, J. T. Evans, J. L. Nelson, L. H. Haynes, L. K. Smith, S. E. Burghart and E. B. Peebles. 2012. Freshwater inflow effects on larval fish and crab settlement onto oyster reefs. *J. Shellfish Res.* 31(3):895-908.

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 and J. D. Williams. 1988. Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks. *Am. Fish. Soc. Spec. Pub.* 16. AFS, Bethesda, MD. pp. 277.

Underwood, A. J. 1997. Experiments in ecology: Their logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge, UK. pp. 195.

Vanderkooy, S. (editor). 2012. The oyster fishery of the Gulf of Mexico, United States: A regional management plan - 2012 Revision. Publication No. 202, Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

Van Montfrans, J., C. E. Epifanio, D. M. Knott, R. N. Lipcius, D. J. Mense, K. S. Metcalf, E. J. Olmi, R. J. Orth, M. H. Posey and E. L. Wenner. 1995. Settlement of blue crabs postlarvae in western North Atlantic estuaries. *Bull. Mar. Sci.* 57:834-854.

Van Montfrans, J., C. H. Ryer and R. J. Orth. 2003. Substrate selection by blue crab *Callinectes sapidus* megalopae and first juvenile instars. *Mar. Ecol.-Prog. Ser.* 260:209-217.

Wahle, R. A. 2003. Revealing stock–recruitment relationships in lobsters and crabs: Is experimental ecology the key? *Fisheries Research* 65:3-32.

Walton, W.C. 2011. Survey of submerged aquatic vegetation at proposed oyster farm site in Portersville Bay, AL. In, US Army Corps of Engineers Application SAM-2011-00283-DEM. pp. 6.

Walton, W. C., J. E. Davis, G. I. Chaplin, F. S. Rikard, T. R. Hanson, P. J. Waters and D. L. Swann. 2012. Off-bottom oyster farming. Agriculture and Natural resources Timely information: Fisheries and Aquaculture Series. Alabama Cooperative Extension System. pp. 8.

West, J., R. Buckley and D. Doty. 1994. Ecology and habitat use of juvenile rockfishes (*Sebastes* spp.) associated with artificial reefs in Puget Sound, Washington. Bull. Mar. Sci. 55:344-350.

Williams, A. H., L. D. Coen and M. S. Stoelting. 1990. Seasonal abundance, distribution, and habitat selection of juvenile *Callinectes sapidus* (Rathbun) in the northern Gulf of Mexico. *J. Exp. Mar. Biol. Ecol.* 137(3):165-183.

Appendix A: Chapter Two Supporting Data

Table A-1 a)

General Linear Model			
Variables	**Levels**		
SITE (3 levels)	BDIL	PBA	SBA

Table A-1 b)

General Linear Model	
Dependent Variable	Seawater Temperature
N	280
Multiple R	0.030
Squared Multiple R	0.001

Table A-1 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	16.294	0.000

Table A-1 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.175	0.000
Shapiro-Wilk Test	0.903	0.000
Anderson-Darling Test	9.719	<0.01
Durbin-Watson D Statistic	0.106	
First Order Autocorrelation	0.937	

Table A-1 e)

Information Criteria	
AIC	1,642.444
AIC (Corrected)	1,642.590
Schwarz's BIC	1,656.983

Table A-1 (a-e): Supporting data for seawater temperature in 2013.

Table A-2 a)

General Linear Model			
Variables	**Levels**		
SITE (3 levels)	BDIL	PBA	SBA

Table A-2 b)

General Linear Model	
Dependent Variable	Salinity
N	280
Multiple R	0.514
Squared Multiple R	0.264

Table A-2 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	7.309	0.001

Table A-2 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.155	0.000
Shapiro-Wilk Test	0.939	0.000
Anderson-Darling Test	5.776	<0.01
Durbin-Watson D Statistic	0.090	
First Order Autocorrelation	0.949	

Table A-2 e)

Information Criteria	
AIC	1,666.008
AIC (Corrected)	1,666.153
Schwarz's BIC	1,680.547

Table A-2 f)

Tukey's Honestly-Significant-Difference Test					
SITE	**SITE**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
BDIL	PBA	6.810	0.000	4.784	8.746
BDIL	SBA	1.707	0.094	-0.217	3.632
PBA	SBA	-5.103	0.000	-6.540	-3.666

Table A-2 (a-f): Supporting data for seawater salinity in 2013.

Table A-3 a)

General Linear Model			
Variables	**Levels**		
SITE (3 levels)	BDIL	PBA	SBA

Table A-3 b)

General Linear Model	
Dependent Variable	Dissolved Oxygen
N	209
Multiple R	0.091
Squared Multiple R	0.008

Table A-3 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	11.893	0.000

Table A-3 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.132	0.000
Shapiro-Wilk Test	0.951	0.000
Anderson-Darling Test	6.490	<0.01
Durbin-Watson D Statistic	0.160	
First Order Autocorrelation	0.914	

Table A-3 e)

Information Criteria	
AIC	788.329
AIC (Corrected)	788.525
Schwarz's BIC	801.699

Table A-3 (a-e): Supporting data for seawater dissolved oxygen in 2013.

Table A-4 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-4 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	45
Multiple R	0.915
Squared Multiple R	0.838

Table A-4 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	6.284	0.000

Table A-4 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.229	0.000
Shapiro-Wilk Test	0.859	0.000
Anderson-Darling Test	2.839	<0.01
Durbin-Watson D Statistic	2.064	
First Order Autocorrelation	-0.059	

Table A-4 e)

Information Criteria	
AIC	483.860
AIC (Corrected)	490.331
Schwarz's BIC	501.927

Table A-4 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*BDIL	ALS*PBA	-39.076	0.919	-136.740	58.588
ALS*BDIL	ALS*SBA	118.530	0.008	20.865	216.194
ALS*BDIL	BOS*BDIL	-45.774	0.827	-143.439	51.890
ALS*BDIL	BOS*PBA	173.745	0.000	76.081	271.409
ALS*BDIL	BOS*SBA	179.125	0.000	81.461	276.789
ALS*BDIL	UVB*BDIL	176.088	0.000	78.423	273.752
ALS*BDIL	UVB*PBA	180.961	0.000	83.297	278.625
ALS*BDIL	UVB*SBA	181.657	0.000	83.993	279.321
ALS*PBA	ALS*SBA	157.605	0.000	59.941	255.270
ALS*PBA	BOS*BDIL	-6.699	1.000	-104.363	90.965
ALS*PBA	BOS*PBA	212.820	0.000	115.156	310.485
ALS*PBA	BOS*SBA	218.201	0.000	120.537	315.865
ALS*PBA	UVB*BDIL	215.163	0.000	117.499	312.827
ALS*PBA	UVB*PBA	220.037	0.000	122.372	317.701
ALS*PBA	UVB*SBA	220.733	0.000	123.069	318.397
ALS*SBA	BOS*BDIL	-164.304	0.000	-261.968	-66.640
ALS*SBA	BOS*PBA	55.215	0.641	-42.449	152.879
ALS*SBA	BOS*SBA	60.595	0.524	-37.069	158.260
ALS*SBA	UVB*BDIL	57.558	0.590	-40.106	155.222
ALS*SBA	UVB*PBA	62.431	0.484	-35.223	160.095
ALS*SBA	UVB*SBA	63.127	0.469	-34.537	160.792
BOS*BDIL	BOS*PBA	219.519	0.000	121.855	317.183
BOS*BDIL	BOS*SBA	224.899	0.000	127.235	322.564
BOS*BDIL	UVB*BDIL	221.862	0.000	124.198	319.526
BOS*BDIL	UVB*PBA	226.735	0.000	129.071	324.399
BOS*BDIL	UVB*SBA	227.432	0.000	129.767	325.096
BOS*PBA	BOS*SBA	5.380	1.000	-92.284	103.045
BOS*PBA	UVB*BDIL	2.343	1.000	-95.321	100.007
BOS*PBA	UVB*PBA	7.216	1.000	-90.448	104.880
BOS*PBA	UVB*SBA	7.912	1.000	-89.752	105.577
BOS*SBA	UVB*BDIL	-3.038	1.000	-100.702	94.627
BOS*SBA	UVB*PBA	1.836	1.000	-95.828	99.500
BOS*SBA	UVB*SBA	2.532	1.000	-95.132	100.196
UVB*BDIL	UVB*PBA	4.873	1.000	-92.791	102.538
UVB*BDIL	UVB*SBA	5.570	1.000	-92.095	103.234
UVB*PBA	UVB*SBA	0.696	1.000	-96.968	98.360

Table A-4 (a-f): Supporting data for mean density (A) in August 2013, using analytical approach 1.

Table A-5 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-5 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	45
Multiple R	0.913
Squared Multiple R	0.834

Table A-5 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	4.986	0.000

Table A-5 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.201	0.000
Shapiro-Wilk Test	0.747	0.000
Anderson-Darling Test	3.405	<0.01
Durbin-Watson D Statistic	2.246	
First Order Autocorrelation	-0.135	

Table A-5 e)

Information Criteria	
AIC	425.629
AIC (Corrected)	432.099
Schwarz's BIC	443.695

Table A-5 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*BDIL	ALS*PBA	-13.270	0.994	-64.407	37.868
ALS*BDIL	ALS*SBA	40.251	0.224	-10.887	91.389
ALS*BDIL	BOS*BDIL	-92.257	0.000	-143.395	-41.120
ALS*BDIL	BOS*PBA	56.106	0.023	4.969	107.244
ALS*BDIL	BOS*SBA	59.743	0.012	8.605	110.880
ALS*BDIL	UVB*BDIL	55.659	0.024	4.521	106.796
ALS*BDIL	UVB*PBA	60.532	0.011	9.394	111.670
ALS*BDIL	UVB*SBA	61.228	0.009	10.091	112.366
ALS*PBA	ALS*SBA	53.520	0.034	2.383	104.658
ALS*PBA	BOS*BDIL	-78.988	0.000	-130.125	-27.850
ALS*PBA	BOS*PBA	69.376	0.002	18.238	120.514
ALS*PBA	BOS*SBA	73.012	0.001	21.875	124.150
ALS*PBA	UVB*BDIL	68.928	0.002	17.791	120.066
ALS*PBA	UVB*PBA	73.802	0.001	22.664	124.939
ALS*PBA	UVB*SBA	74.498	0.001	23.360	125.636
ALS*SBA	BOS*BDIL	-132.508	0.000	-183.646	-81.371
ALS*SBA	BOS*PBA	15.855	0.981	-35.282	66.993
ALS*SBA	BOS*SBA	19.492	0.937	-31.646	70.629
ALS*SBA	UVB*BDIL	15.408	0.984	-35.730	66.545
ALS*SBA	UVB*PBA	20.281	0.923	-30.857	71.419
ALS*SBA	UVB*SBA	20.977	0.908	-30.160	72.115
BOS*BDIL	BOS*PBA	148.364	0.000	97.226	199.501
BOS*BDIL	BOS*SBA	152.000	0.000	100.862	203.138
BOS*BDIL	UVB*BDIL	147.916	0.000	96.778	199.054
BOS*BDIL	UVB*PBA	152.789	0.000	101.652	203.927
BOS*BDIL	UVB*SBA	153.486	0.000	102.348	204.623
BOS*PBA	BOS*SBA	3.636	1.000	-47.501	54.774
BOS*PBA	UVB*BDIL	-0.448	1.000	-51.585	50.690
BOS*PBA	UVB*PBA	4.426	1.000	-46.712	55.563
BOS*PBA	UVB*SBA	5.122	1.000	-46.016	56.260
BOS*SBA	UVB*BDIL	-4.084	1.000	-55.222	47.054
BOS*SBA	UVB*PBA	0.789	1.000	-50.348	51.927
BOS*SBA	UVB*SBA	1.486	1.000	-49.652	52.623
UVB*BDIL	UVB*PBA	4.873	1.000	-46.264	56.011
UVB*BDIL	UVB*SBA	5.570	1.000	-45.568	56.707
UVB*PBA	UVB*SBA	0.696	1.000	-50.441	51.834

Table A-5 (a-f): Supporting data for mean density (B) in August 2013, using analytical approach 1.

Table A-6 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-6 b)

General Linear Model	
Dependent Variable	Mean CW
N	45
Multiple R	0.906
Squared Multiple R	0.821

Table A-6 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	8.643	0.000

Table A-6 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.132	0.048
Shapiro-Wilk Test	0.962	0.149
Anderson-Darling Test	0.737	0.051
Durbin-Watson D Statistic	2.683	
First Order Autocorrelation	-0.343	

Table A-6 e)

Information Criteria	
AIC	238.635
AIC (Corrected)	245.105
Schwarz's BIC	256.701

Table A-6 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*BDIL	ALS*PBA	9.166	0.001	2.763	15.569
ALS*BDIL	ALS*SBA	1.186	0.999	-5.217	7.589
ALS*BDIL	BOS*BDIL	6.290	0.057	-0.113	12.693
ALS*BDIL	BOS*PBA	11.136	0.000	4.732	17.539
ALS*BDIL	BOS*SBA	14.888	0.000	8.485	21.292
ALS*BDIL	UVB*BDIL	10.319	0.000	3.915	16.722
ALS*BDIL	UVB*PBA	16.932	0.000	10.529	23.336
ALS*BDIL	UVB*SBA	16.887	0.000	10.484	23.291
ALS*PBA	ALS*SBA	-7.980	0.006	-14.383	-1.576
ALS*PBA	BOS*BDIL	-2.876	0.857	-9.279	3.528
ALS*PBA	BOS*PBA	1.970	0.982	-4.433	8.373
ALS*PBA	BOS*SBA	5.723	0.111	-0.681	12.126
ALS*PBA	UVB*BDIL	1.153	1.000	-5.250	7.556
ALS*PBA	UVB*PBA	7.767	0.008	1.363	14.170
ALS*PBA	UVB*SBA	7.722	0.009	1.318	14.125
ALS*SBA	BOS*BDIL	5.104	0.211	-1.299	11.507
ALS*SBA	BOS*PBA	9.950	0.000	3.546	16.353
ALS*SBA	BOS*SBA	13.702	0.000	7.299	20.106
ALS*SBA	UVB*BDIL	9.133	0.001	2.729	15.536
ALS*SBA	UVB*PBA	15.746	0.000	9.343	22.150
ALS*SBA	UVB*SBA	15.701	0.000	9.298	22.105
BOS*BDIL	BOS*PBA	4.846	0.268	-1.558	11.249
BOS*BDIL	BOS*SBA	8.598	0.002	2.195	15.002
BOS*BDIL	UVB*BDIL	4.029	0.505	-2.375	10.432
BOS*BDIL	UVB*PBA	10.642	0.000	4.239	17.046
BOS*BDIL	UVB*SBA	10.597	0.000	4.194	17.001
BOS*PBA	BOS*SBA	3.753	0.597	-2.651	10.156
BOS*PBA	UVB*BDIL	-0.817	1.000	-7.220	5.586
BOS*PBA	UVB*PBA	5.797	0.102	-0.607	12.200
BOS*PBA	UVB*SBA	5.752	0.107	-0.652	12.155
BOS*SBA	UVB*BDIL	-4.570	0.339	-10.973	1.834
BOS*SBA	UVB*PBA	2.044	0.977	-4.359	8.447
BOS*SBA	UVB*SBA	1.999	0.980	-4.404	8.402
UVB*BDIL	UVB*PBA	6.614	0.038	0.210	13.017
UVB*BDIL	UVB*SBA	6.569	0.041	0.165	12.972
UVB*PBA	UVB*SBA	-0.045	1.000	-6.448	6.358

Table A-6 (a-f): Supporting data for mean CW in August 2013, using analytical approach 1.

Table A-7 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-7 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	45
Multiple R	0.833
Squared Multiple R	0.694

Table A-7 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	3.734	0.003

Table A-7 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.256	0.000
Shapiro-Wilk Test	0.774	0.000
Anderson-Darling Test	4.055	<0.01
Durbin-Watson D Statistic	2.217	
First Order Autocorrelation	-0.294	

Table A-7 e)

Information Criteria	
AIC	395.228
AIC (Corrected)	401.698
Schwarz's BIC	413.294

Table A-7 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*BDIL	ALS*PBA	2.605	1.000	-33.874	39.084
ALS*BDIL	ALS*SBA	56.009	0.000	19.530	92.487
ALS*BDIL	BOS*BDIL	52.836	0.001	16.358	89.315
ALS*BDIL	BOS*PBA	48.532	0.003	12.053	85.011
ALS*BDIL	BOS*SBA	62.521	0.000	26.042	99.000
ALS*BDIL	UVB*BDIL	62.521	0.000	26.042	99.000
ALS*BDIL	UVB*PBA	59.736	0.000	23.257	96.215
ALS*BDIL	UVB*SBA	56.952	0.000	20.473	93.430
ALS*PBA	ALS*SBA	53.403	0.001	16.925	89.882
ALS*PBA	BOS*BDIL	50.231	0.002	13.753	86.710
ALS*PBA	BOS*PBA	45.927	0.005	9.448	82.406
ALS*PBA	BOS*SBA	59.916	0.000	23.437	96.395
ALS*PBA	UVB*BDIL	59.916	0.000	23.437	96.395
ALS*PBA	UVB*PBA	57.131	0.000	20.652	93.610
ALS*PBA	UVB*SBA	54.347	0.001	17.868	90.825
ALS*SBA	BOS*BDIL	-3.172	1.000	-39.651	33.307
ALS*SBA	BOS*PBA	-7.476	0.999	-43.955	29.003
ALS*SBA	BOS*SBA	6.513	1.000	-29.966	42.991
ALS*SBA	UVB*BDIL	6.513	1.000	-29.966	42.991
ALS*SBA	UVB*PBA	3.728	1.000	-32.751	40.207
ALS*SBA	UVB*SBA	0.943	1.000	-35.536	37.422
BOS*BDIL	BOS*PBA	-4.304	1.000	-40.783	32.175
BOS*BDIL	BOS*SBA	9.685	0.993	-26.794	46.164
BOS*BDIL	UVB*BDIL	9.685	0.993	-26.794	46.164
BOS*BDIL	UVB*PBA	6.900	0.999	-29.579	43.379
BOS*BDIL	UVB*SBA	4.115	1.000	-32.364	40.594
BOS*PBA	BOS*SBA	13.989	0.935	-22.490	50.468
BOS*PBA	UVB*BDIL	13.989	0.935	-22.490	50.468
BOS*PBA	UVB*PBA	11.204	0.982	-25.275	47.683
BOS*PBA	UVB*SBA	8.419	0.997	-28.059	44.898
BOS*SBA	UVB*BDIL	0.000	1.000	-36.479	36.479
BOS*SBA	UVB*PBA	-2.785	1.000	-39.264	33.694
BOS*SBA	UVB*SBA	-5.570	1.000	-42.048	30.909
UVB*BDIL	UVB*PBA	-2.785	1.000	-39.264	33.694
UVB*BDIL	UVB*SBA	-5.570	1.000	-42.048	30.909
UVB*PBA	UVB*SBA	-2.785	1.000	-39.264	33.694

Table A-7 (a-f): Supporting data for mean density (A) in September 2013, using analytical approach 1.

Table A-8 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-8 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	45
Multiple R	0.760
Squared Multiple R	0.577

Table A-8 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	3.060	0.010

Table A-8 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.256	0.000
Shapiro-Wilk Test	0.891	0.001
Anderson-Darling Test	2.238	<0.01
Durbin-Watson D Statistic	2.399	
First Order Autocorrelation	-0.322	

Table A-8 e)

Information Criteria	
AIC	316.603
AIC (Corrected)	323.074
Schwarz's BIC	334.670

Table A-8 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*BDIL	ALS*PBA	0.885	1.000	-14.343	16.112
ALS*BDIL	ALS*SBA	19.020	0.006	3.792	34.247
ALS*BDIL	BOS*BDIL	14.686	0.066	-0.542	29.914
ALS*BDIL	BOS*PBA	11.777	0.243	-3.451	27.005
ALS*BDIL	BOS*SBA	21.231	0.002	6.003	36.459
ALS*BDIL	UVB*BDIL	21.231	0.002	6.003	36.459
ALS*BDIL	UVB*PBA	18.446	0.008	3.219	33.674
ALS*BDIL	UVB*SBA	15.662	0.040	0.434	30.889
ALS*PBA	ALS*SBA	18.135	0.010	2.907	33.363
ALS*PBA	BOS*BDIL	13.801	0.101	-1.427	29.029
ALS*PBA	BOS*PBA	10.892	0.336	-4.336	26.120
ALS*PBA	BOS*SBA	20.347	0.003	5.119	35.574
ALS*PBA	UVB*BDIL	20.347	0.003	5.119	35.574
ALS*PBA	UVB*PBA	17.562	0.014	2.334	32.790
ALS*PBA	UVB*SBA	14.777	0.063	-0.451	30.005
ALS*SBA	BOS*BDIL	-4.334	0.989	-19.562	10.894
ALS*SBA	BOS*PBA	-7.243	0.815	-22.471	7.985
ALS*SBA	BOS*SBA	2.212	1.000	-13.016	17.439
ALS*SBA	UVB*BDIL	2.212	1.000	-13.016	17.439
ALS*SBA	UVB*PBA	-0.573	1.000	-15.801	14.655
ALS*SBA	UVB*SBA	-3.358	0.998	-18.586	11.870
BOS*BDIL	BOS*PBA	-2.909	0.999	-18.137	12.319
BOS*BDIL	BOS*SBA	6.545	0.884	-8.682	21.773
BOS*BDIL	UVB*BDIL	6.545	0.884	-8.682	21.773
BOS*BDIL	UVB*PBA	3.761	0.996	-11.467	18.988
BOS*BDIL	UVB*SBA	0.976	1.000	-14.252	16.204
BOS*PBA	BOS*SBA	9.455	0.523	-5.773	24.682
BOS*PBA	UVB*BDIL	9.455	0.523	-5.773	24.682
BOS*PBA	UVB*PBA	6.670	0.873	-8.558	21.898
BOS*PBA	UVB*SBA	3.885	0.995	-11.343	19.113
BOS*SBA	UVB*BDIL	0.000	1.000	-15.228	15.228
BOS*SBA	UVB*PBA	-2.785	0.999	-18.013	12.443
BOS*SBA	UVB*SBA	-5.570	0.950	-20.797	9.658
UVB*BDIL	UVB*PBA	-2.785	0.999	-18.013	12.443
UVB*BDIL	UVB*SBA	-5.570	0.950	-20.797	9.658
UVB*PBA	UVB*SBA	-2.785	0.999	-18.013	12.443

Table A-8 (a-f): Supporting data for mean density (B) in September 2013, using analytical approach 1.

Table A-9 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-9 b)

General Linear Model	
Dependent Variable	Mean CW
N	45
Multiple R	0.951
Squared Multiple R	0.904

Table A-9 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	4.993	0.000

Table A-9 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.193	0.000
Shapiro-Wilk Test	0.776	0.000
Anderson-Darling Test	2.734	<0.01
Durbin-Watson D Statistic	2.484	
First Order Autocorrelation	-0.289	

Table A-9 e)

Information Criteria	
AIC	334.693
AIC (Corrected)	341.163
Schwarz's BIC	352.759

Table A-9 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*BDIL	ALS*PBA	-14.936	0.204	-33.553	3.682
ALS*BDIL	ALS*SBA	-63.224	0.000	-81.842	-44.606
ALS*BDIL	BOS*BDIL	12.206	0.450	-6.412	30.824
ALS*BDIL	BOS*PBA	13.211	0.347	-5.407	31.829
ALS*BDIL	BOS*SBA	16.838	0.103	-1.780	35.456
ALS*BDIL	UVB*BDIL	16.838	0.103	-1.780	35.456
ALS*BDIL	UVB*PBA	15.005	0.199	-3.613	33.623
ALS*BDIL	UVB*SBA	10.042	0.695	-8.576	28.660
ALS*PBA	ALS*SBA	-48.288	0.000	-66.906	-29.670
ALS*PBA	BOS*BDIL	27.142	0.001	8.524	45.760
ALS*PBA	BOS*PBA	28.146	0.000	9.529	46.764
ALS*PBA	BOS*SBA	31.774	0.000	13.156	50.392
ALS*PBA	UVB*BDIL	31.774	0.000	13.156	50.392
ALS*PBA	UVB*PBA	29.941	0.000	11.323	48.559
ALS*PBA	UVB*SBA	24.978	0.002	6.360	43.596
ALS*SBA	BOS*BDIL	75.430	0.000	56.812	94.048
ALS*SBA	BOS*PBA	76.435	0.000	57.817	95.052
ALS*SBA	BOS*SBA	80.062	0.000	61.444	98.680
ALS*SBA	UVB*BDIL	80.062	0.000	61.444	98.680
ALS*SBA	UVB*PBA	78.229	0.000	59.611	96.847
ALS*SBA	UVB*SBA	73.266	0.000	54.648	91.884
BOS*BDIL	BOS*PBA	1.005	1.000	-17.613	19.622
BOS*BDIL	BOS*SBA	4.632	0.995	-13.986	23.250
BOS*BDIL	UVB*BDIL	4.632	0.995	-13.986	23.250
BOS*BDIL	UVB*PBA	2.799	1.000	-15.819	21.417
BOS*BDIL	UVB*SBA	-2.164	1.000	-20.782	16.454
BOS*PBA	BOS*SBA	3.627	0.999	-14.990	22.245
BOS*PBA	UVB*BDIL	3.627	0.999	-14.990	22.245
BOS*PBA	UVB*PBA	1.794	1.000	-16.823	20.412
BOS*PBA	UVB*SBA	-3.169	1.000	-21.786	15.449
BOS*SBA	UVB*BDIL	0.000	1.000	-18.618	18.618
BOS*SBA	UVB*PBA	-1.833	1.000	-20.451	16.785
BOS*SBA	UVB*SBA	-6.796	0.951	-25.414	11.822
UVB*BDIL	UVB*PBA	-1.833	1.000	-20.451	16.785
UVB*BDIL	UVB*SBA	-6.796	0.951	-25.414	11.822
UVB*PBA	UVB*SBA	-4.963	0.993	-23.581	13.655

Table A-9 (a-f): Supporting data for mean CW in September 2013, using analytical approach 1.

Table A-10 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-10 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	45
Multiple R	0.814
Squared Multiple R	0.662

Table A-10 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	5.579	0.000

Table A-10 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.344	0.000
Shapiro-Wilk Test	0.684	0.000
Anderson-Darling Test	4.884	<0.01
Durbin-Watson D Statistic	2.222	
First Order Autocorrelation	-0.140	

Table A-10 e)

Information Criteria	
AIC	252.959
AIC (Corrected)	259.430
Schwarz's BIC	271.026

Table A-10 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	9.193	0.000	5.979	12.407
ALS	UVB	9.088	0.000	5.874	12.301
BOS	UVB	-0.105	0.996	-3.319	3.108

Table A-10 (a-f): Supporting data for mean density (A) in November 2013, using analytical approach 1.

Table A-11 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-11 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	45
Multiple R	0.741
Squared Multiple R	0.548

Table A-11 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	4.153	0.001

Table A-11 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.344	0.000
Shapiro-Wilk Test	0.739	0.000
Anderson-Darling Test	4.442	<0.01
Durbin-Watson D Statistic	2.283	
First Order Autocorrelation	-0.162	

Table A-11 e)

Information Criteria	
AIC	172.960
AIC (Corrected)	179.431
Schwarz's BIC	191.027

Table A-11 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	3.001	0.000	1.680	4.322
ALS	UVB	2.780	0.000	1.458	4.101
BOS	UVB	-0.222	0.912	-1.543	1.099

Table A-11 (a-f): Supporting data for mean density (B) in November 2013, using analytical approach 1.

Table A-12 a)

General Linear Model			
Variables	**Levels**		
HABITAT (3 levels)	ALS	BOS	UVB
SITE (3 levels)	BDIL	PBA	SBA

Table A-12 b)

General Linear Model	
Dependent Variable	Mean CW
N	45
Multiple R	0.837
Squared Multiple R	0.701

Table A-12 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	8.754	0.000

Table A-12 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.266	0.000
Shapiro-Wilk Test	0.793	0.000
Anderson-Darling Test	3.988	<0.01
Durbin-Watson D Statistic	2.370	
First Order Autocorrelation	-0.315	

Table A-12 e)

Information Criteria	
AIC	428.674
AIC (Corrected)	435.145
Schwarz's BIC	446.741

Table A-12 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	70.892	0.000	48.250	93.534
ALS	UVB	70.332	0.000	47.690	92.974
BOS	UVB	-0.560	0.998	-23.202	22.082

Table A-12 (a-f): Supporting data for mean CW in November 2013, using analytical approach 1.

Table A-13 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-13 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	40
Multiple R	0.911
Squared Multiple R	0.829

Table A-13 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	6.195	0.000

Table A-13 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.150	0.024
Shapiro-Wilk Test	0.933	0.021
Anderson-Darling Test	0.990	0.011
Durbin-Watson D Statistic	1.928	
First Order Autocorrelation	-0.012	

Table A-13 e)

Information Criteria	
AIC	334.618
AIC (Corrected)	340.618
Schwarz's BIC	349.818

Table A-13 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	69.034	0.000	40.026	98.042
ALS*PBA	BOS*PBA	47.907	0.000	18.899	76.915
ALS*PBA	BOS*SBA	84.494	0.000	55.486	113.502
ALS*PBA	SAV*PBA	65.507	0.000	36.499	94.515
ALS*PBA	SAV*SBA	82.216	0.000	53.208	111.224
ALS*PBA	UVB*PBA	85.001	0.000	55.993	114.009
ALS*PBA	UVB*SBA	89.874	0.000	60.866	118.882
ALS*SBA	BOS*PBA	-21.127	0.295	-50.135	7.881
ALS*SBA	BOS*SBA	15.460	0.671	-13.548	44.468
ALS*SBA	SAV*PBA	-3.527	1.000	-32.535	25.481
ALS*SBA	SAV*SBA	13.182	0.816	-15.826	42.190
ALS*SBA	UVB*PBA	15.967	0.635	-13.041	44.975
ALS*SBA	UVB*SBA	20.840	0.311	-8.168	49.848
BOS*PBA	BOS*SBA	36.587	0.006	7.579	65.595
BOS*PBA	SAV*PBA	17.600	0.519	-11.408	46.608
BOS*PBA	SAV*SBA	34.309	0.012	5.301	63.317
BOS*PBA	UVB*PBA	37.094	0.005	8.086	66.102
BOS*PBA	UVB*SBA	41.967	0.001	12.959	70.975
BOS*SBA	SAV*PBA	-18.987	0.424	-47.995	10.021
BOS*SBA	SAV*SBA	-2.278	1.000	-31.286	26.730
BOS*SBA	UVB*PBA	0.507	1.000	-28.501	29.515
BOS*SBA	UVB*SBA	5.380	0.999	-23.628	34.388
SAV*PBA	SAV*SBA	16.709	0.583	-12.299	45.717
SAV*PBA	UVB*PBA	19.494	0.391	-9.514	48.502
SAV*PBA	UVB*SBA	24.367	0.153	-4.641	53.375
SAV*SBA	UVB*PBA	2.785	1.000	-26.223	31.793
SAV*SBA	UVB*SBA	7.658	0.988	-21.350	36.666
UVB*PBA	UVB*SBA	4.873	0.999	-24.135	33.881

Table A-13 (a-f): Supporting data for mean density (A) in July 2013, using analytical approach 2.

Table A-14 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-14 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	40
Multiple R	0.849
Squared Multiple R	0.721

Table A-14 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	6.826	0.000

Table A-14 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.151	0.023
Shapiro-Wilk Test	0.966	0.260
Anderson-Darling Test	0.580	0.125
Durbin-Watson D Statistic	1.715	
First Order Autocorrelation	0.125	

Table A-14 e)

Information Criteria	
AIC	289.011
AIC (Corrected)	295.011
Schwarz's BIC	304.211

Table A-14 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	23.443	0.001	7.039	39.846
ALS*PBA	BOS*PBA	2.156	1.000	-14.247	18.560
ALS*PBA	BOS*SBA	26.884	0.000	10.480	43.287
ALS*PBA	SAV*PBA	6.153	0.921	-10.250	22.556
ALS*PBA	SAV*SBA	22.862	0.002	6.458	39.265
ALS*PBA	UVB*PBA	25.647	0.000	9.243	42.050
ALS*PBA	UVB*SBA	30.520	0.000	14.117	46.923
ALS*SBA	BOS*PBA	-21.287	0.004	-37.690	-4.883
ALS*SBA	BOS*SBA	3.441	0.997	-12.963	19.844
ALS*SBA	SAV*PBA	-17.290	0.033	-33.693	-0.886
ALS*SBA	SAV*SBA	-0.581	1.000	-16.984	15.822
ALS*SBA	UVB*PBA	2.204	1.000	-14.200	18.607
ALS*SBA	UVB*SBA	7.077	0.852	-9.326	23.480
BOS*PBA	BOS*SBA	24.727	0.001	8.324	41.131
BOS*PBA	SAV*PBA	3.997	0.993	-12.407	20.400
BOS*PBA	SAV*SBA	20.705	0.006	4.302	37.109
BOS*PBA	UVB*PBA	23.490	0.001	7.087	39.894
BOS*PBA	UVB*SBA	28.364	0.000	11.960	44.767
BOS*SBA	SAV*PBA	-20.731	0.006	-37.134	-4.327
BOS*SBA	SAV*SBA	-4.022	0.992	-20.425	12.382
BOS*SBA	UVB*PBA	-1.237	1.000	-17.640	15.166
BOS*SBA	UVB*SBA	3.636	0.996	-12.767	20.040
SAV*PBA	SAV*SBA	16.709	0.043	0.305	33.112
SAV*PBA	UVB*PBA	19.494	0.011	3.090	35.897
SAV*PBA	UVB*SBA	24.367	0.001	7.964	40.770
SAV*SBA	UVB*PBA	2.785	0.999	-13.619	19.188
SAV*SBA	UVB*SBA	7.658	0.795	-8.745	24.062
UVB*PBA	UVB*SBA	4.873	0.977	-11.530	21.277

Table A-14 (a-f): Supporting data for mean density (B) in July 2013, using analytical approach 2.

Table A-15 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-15 b)

General Linear Model	
Dependent Variable	Mean CW
N	40
Multiple R	0.829
Squared Multiple R	0.687

Table A-15 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	10.112	0.000

Table A-15 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.216	0.000
Shapiro-Wilk Test	0.892	0.000
Anderson-Darling Test	1.706	<0.01
Durbin-Watson D Statistic	2.602	
First Order Autocorrelation	-0.309	

Table A-15 e)

Information Criteria	
AIC	258.740
AIC (Corrected)	264.740
Schwarz's BIC	273.940

Table A-15 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	7.149	0.031	0.503	13.794
ALS	SAV	10.631	0.001	3.986	17.276
ALS	UVB	18.765	0.000	12.120	25.410
BOS	SAV	3.482	0.497	-3.163	10.127
BOS	UVB	11.617	0.000	4.971	18.262
SAV	UVB	8.134	0.012	1.489	14.779

Table A-15 (a-f): Supporting data for mean CW in July 2013, using analytical approach 2.

Table A-16 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-16 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	40
Multiple R	0.926
Squared Multiple R	0.858

Table A-16 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	15.177	0.000

Table A-16 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.241	0.000
Shapiro-Wilk Test	0.797	0.000
Anderson-Darling Test	3.313	<0.01
Durbin-Watson D Statistic	1.858	
First Order Autocorrelation	0.007	

Table A-16 e)

Information Criteria	
AIC	400.128
AIC (Corrected)	406.128
Schwarz's BIC	415.328

Table A-16 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	157.605	0.000	91.817	223.394
ALS*PBA	BOS*PBA	212.820	0.000	147.032	278.609
ALS*PBA	BOS*SBA	218.201	0.000	152.412	283.990
ALS*PBA	SAV*PBA	207.505	0.000	141.716	273.294
ALS*PBA	SAV*SBA	197.062	0.000	131.273	262.851
ALS*PBA	UVB*PBA	220.037	0.000	154.248	285.825
ALS*PBA	UVB*SBA	220.733	0.000	154.944	286.522
ALS*SBA	BOS*PBA	55.215	0.154	-10.574	121.004
ALS*SBA	BOS*SBA	60.595	0.089	-5.193	126.384
ALS*SBA	SAV*PBA	49.900	0.250	-15.889	115.688
ALS*SBA	SAV*SBA	39.457	0.534	-26.332	105.245
ALS*SBA	UVB*PBA	62.431	0.073	-3.357	128.220
ALS*SBA	UVB*SBA	63.127	0.067	-2.661	128.916
BOS*PBA	BOS*SBA	5.380	1.000	-60.408	71.169
BOS*PBA	SAV*PBA	-5.315	1.000	-71.104	60.473
BOS*PBA	SAV*SBA	-15.758	0.993	-81.547	50.030
BOS*PBA	UVB*PBA	7.216	1.000	-58.573	73.005
BOS*PBA	UVB*SBA	7.912	1.000	-57.876	73.701
BOS*SBA	SAV*PBA	-10.696	0.999	-76.484	55.093
BOS*SBA	SAV*SBA	-21.139	0.964	-86.927	44.650
BOS*SBA	UVB*PBA	1.836	1.000	-63.953	67.625
BOS*SBA	UVB*SBA	2.532	1.000	-63.257	68.321
SAV*PBA	SAV*SBA	-10.443	0.999	-76.232	55.346
SAV*PBA	UVB*PBA	12.532	0.998	-53.257	78.320
SAV*PBA	UVB*SBA	13.228	0.998	-52.561	79.016
SAV*SBA	UVB*PBA	22.975	0.945	-42.814	88.763
SAV*SBA	UVB*SBA	23.671	0.936	-42.118	89.459
UVB*PBA	UVB*SBA	0.696	1.000	-65.093	66.485

Table A-16 (a-f): Supporting data for mean density (A) in early August 2013, using analytical approach 2.

Table A-17 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-17 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	40
Multiple R	0.901
Squared Multiple R	0.811

Table A-17 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	10.891	0.000

Table A-17 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.124	0.118
Shapiro-Wilk Test	0.939	0.032
Anderson-Darling Test	0.874	0.023
Durbin-Watson D Statistic	2.106	
First Order Autocorrelation	-0.102	

Table A-17 e)

Information Criteria	
AIC	324.791
AIC (Corrected)	330.791
Schwarz's BIC	339.991

Table A-17 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	53.520	0.000	27.866	79.175
ALS*PBA	BOS*PBA	69.376	0.000	43.721	95.031
ALS*PBA	BOS*SBA	73.012	0.000	47.357	98.667
ALS*PBA	SAV*PBA	61.270	0.000	35.615	86.925
ALS*PBA	SAV*SBA	50.827	0.000	25.172	76.482
ALS*PBA	UVB*PBA	73.802	0.000	48.147	99.457
ALS*PBA	UVB*SBA	74.498	0.000	48.843	100.153
ALS*SBA	BOS*PBA	15.855	0.496	-9.800	41.510
ALS*SBA	BOS*SBA	19.492	0.248	-6.163	45.147
ALS*SBA	SAV*PBA	7.750	0.974	-17.905	33.405
ALS*SBA	SAV*SBA	-2.693	1.000	-28.348	22.962
ALS*SBA	UVB*PBA	20.281	0.208	-5.374	45.936
ALS*SBA	UVB*SBA	20.977	0.176	-4.678	46.632
BOS*PBA	BOS*SBA	3.636	1.000	-22.019	29.291
BOS*PBA	SAV*PBA	-8.106	0.967	-33.761	17.549
BOS*PBA	SAV*SBA	-18.549	0.303	-44.204	7.106
BOS*PBA	UVB*PBA	4.426	0.999	-21.229	30.081
BOS*PBA	UVB*SBA	5.122	0.998	-20.533	30.777
BOS*SBA	SAV*PBA	-11.742	0.811	-37.397	13.913
BOS*SBA	SAV*SBA	-22.185	0.130	-47.840	3.470
BOS*SBA	UVB*PBA	0.789	1.000	-24.865	26.444
BOS*SBA	UVB*SBA	1.486	1.000	-24.169	27.141
SAV*PBA	SAV*SBA	-10.443	0.885	-36.098	15.212
SAV*PBA	UVB*PBA	12.532	0.757	-13.123	38.186
SAV*PBA	UVB*SBA	13.228	0.705	-12.427	38.883
SAV*SBA	UVB*PBA	22.975	0.106	-2.680	48.629
SAV*SBA	UVB*SBA	23.671	0.088	-1.984	49.326
UVB*PBA	UVB*SBA	0.696	1.000	-24.959	26.351

Table A-17 (a-f): Supporting data for mean density (B) in early August 2013, using analytical approach 2.

Table A-18 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-18 b)

General Linear Model	
Dependent Variable	Mean CW
N	40
Multiple R	0.839
Squared Multiple R	0.703

Table A-18 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	4.824	0.001

Table A-18 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.130	0.089
Shapiro-Wilk Test	0.967	0.288
Anderson-Darling Test	0.565	0.137
Durbin-Watson D Statistic	2.618	
First Order Autocorrelation	-0.310	

Table A-18 e)

Information Criteria	
AIC	225.869
AIC (Corrected)	231.869
Schwarz's BIC	241.069

Table A-18 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	**HABITAT * SITE**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS*PBA	ALS*SBA	-7.980	0.029	-15.430	-0.530
ALS*PBA	BOS*PBA	1.970	0.988	-5.480	9.420
ALS*PBA	BOS*SBA	5.723	0.237	-1.727	13.173
ALS*PBA	SAV*PBA	-0.356	1.000	-7.806	7.094
ALS*PBA	SAV*SBA	-1.530	0.997	-8.980	5.920
ALS*PBA	UVB*PBA	7.767	0.036	0.317	15.217
ALS*PBA	UVB*SBA	7.722	0.038	0.272	15.172
ALS*SBA	BOS*PBA	9.950	0.003	2.500	17.400
ALS*SBA	BOS*SBA	13.702	0.000	6.252	21.152
ALS*SBA	SAV*PBA	7.623	0.042	0.173	15.073
ALS*SBA	SAV*SBA	6.450	0.129	-1.000	13.900
ALS*SBA	UVB*PBA	15.746	0.000	8.296	23.196
ALS*SBA	UVB*SBA	15.701	0.000	8.251	23.151
BOS*PBA	BOS*SBA	3.753	0.728	-3.697	11.203
BOS*PBA	SAV*PBA	-2.326	0.969	-9.776	5.124
BOS*PBA	SAV*SBA	-3.500	0.790	-10.950	3.950
BOS*PBA	UVB*PBA	5.797	0.223	-1.653	13.247
BOS*PBA	UVB*SBA	5.752	0.231	-1.698	13.202
BOS*SBA	SAV*PBA	-6.079	0.178	-13.529	1.371
BOS*SBA	SAV*SBA	-7.252	0.061	-14.702	0.198
BOS*SBA	UVB*PBA	2.044	0.985	-5.406	9.494
BOS*SBA	UVB*SBA	1.999	0.987	-5.451	9.449
SAV*PBA	SAV*SBA	-1.174	1.000	-8.624	6.276
SAV*PBA	UVB*PBA	8.123	0.025	0.673	15.573
SAV*PBA	UVB*SBA	8.078	0.026	0.628	15.528
SAV*SBA	UVB*PBA	9.296	0.007	1.846	16.746
SAV*SBA	UVB*SBA	9.251	0.007	1.801	16.701
UVB*PBA	UVB*SBA	-0.045	1.000	-7.495	7.405

Table A-18 (a-f): Supporting data for mean CW in early August 2013, using analytical approach 2.

Table A-19 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-19 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	40
Multiple R	0.942
Squared Multiple R	0.887

Table A-19 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	10.697	0.000

Table A-19 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.219	0.000
Shapiro-Wilk Test	0.773	0.000
Anderson-Darling Test	2.861	<0.01
Durbin-Watson D Statistic	1.988	
First Order Autocorrelation	-0.244	

Table A-19 e)

Information Criteria	
AIC	335.564
AIC (Corrected)	341.564
Schwarz's BIC	350.764

Table A-19 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	89.874	0.000	60.521	119.227
ALS*PBA	BOS*PBA	113.772	0.000	84.419	143.126
ALS*PBA	BOS*SBA	115.925	0.000	86.571	145.278
ALS*PBA	SAV*PBA	95.735	0.000	66.382	125.088
ALS*PBA	SAV*SBA	98.520	0.000	69.167	127.873
ALS*PBA	UVB*PBA	113.140	0.000	83.787	142.493
ALS*PBA	UVB*SBA	109.659	0.000	80.306	139.012
ALS*SBA	BOS*PBA	23.898	0.180	-5.455	53.251
ALS*SBA	BOS*SBA	26.050	0.112	-3.303	55.404
ALS*SBA	SAV*PBA	5.861	0.998	-23.492	35.214
ALS*SBA	SAV*SBA	8.646	0.978	-20.708	37.999
ALS*SBA	UVB*PBA	23.266	0.205	-6.087	52.619
ALS*SBA	UVB*SBA	19.785	0.388	-9.568	49.138
BOS*PBA	BOS*SBA	2.152	1.000	-27.201	31.505
BOS*PBA	SAV*PBA	-18.038	0.503	-47.391	11.316
BOS*PBA	SAV*SBA	-15.253	0.697	-44.606	14.100
BOS*PBA	UVB*PBA	-0.633	1.000	-29.986	28.720
BOS*PBA	UVB*SBA	-4.114	1.000	-33.467	25.240
BOS*SBA	SAV*PBA	-20.190	0.363	-49.543	9.163
BOS*SBA	SAV*SBA	-17.405	0.548	-46.758	11.948
BOS*SBA	UVB*PBA	-2.785	1.000	-32.138	26.568
BOS*SBA	UVB*SBA	-6.266	0.997	-35.619	23.087
SAV*PBA	SAV*SBA	2.785	1.000	-26.568	32.138
SAV*PBA	UVB*PBA	17.405	0.548	-11.948	46.758
SAV*PBA	UVB*SBA	13.924	0.782	-15.429	43.277
SAV*SBA	UVB*PBA	14.620	0.739	-14.733	43.973
SAV*SBA	UVB*SBA	11.139	0.917	-18.214	40.492
UVB*PBA	UVB*SBA	-3.481	1.000	-32.834	25.872

Table A-19 (a-f): Supporting data for mean density (A) in late August 2013, using analytical approach 2.

Table A-20 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-20 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	40
Multiple R	0.901
Squared Multiple R	0.813

Table A-20 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	4.292	0.002

Table A-20 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.157	0.015
Shapiro-Wilk Test	0.934	0.022
Anderson-Darling Test	1.133	<0.01
Durbin-Watson D Statistic	1.959	
First Order Autocorrelation	-0.116	

Table A-20 e)

Information Criteria	
AIC	274.208
AIC (Corrected)	280.208
Schwarz's BIC	289.408

Table A-20 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	30.520	0.000	16.888	44.152
ALS*PBA	BOS*PBA	37.912	0.000	24.279	51.544
ALS*PBA	BOS*SBA	39.366	0.000	25.734	52.999
ALS*PBA	SAV*PBA	19.177	0.002	5.544	32.809
ALS*PBA	SAV*SBA	21.961	0.000	8.329	35.594
ALS*PBA	UVB*PBA	36.581	0.000	22.949	50.214
ALS*PBA	UVB*SBA	33.101	0.000	19.468	46.733
ALS*SBA	BOS*PBA	7.392	0.652	-6.241	21.024
ALS*SBA	BOS*SBA	8.846	0.435	-4.786	22.479
ALS*SBA	SAV*PBA	-11.343	0.161	-24.976	2.289
ALS*SBA	SAV*SBA	-8.559	0.477	-22.191	5.074
ALS*SBA	UVB*PBA	6.062	0.832	-7.571	19.694
ALS*SBA	UVB*SBA	2.581	0.998	-11.052	16.213
BOS*PBA	BOS*SBA	1.455	1.000	-12.178	15.087
BOS*PBA	SAV*PBA	-18.735	0.002	-32.368	-5.103
BOS*PBA	SAV*SBA	-15.950	0.013	-29.583	-2.318
BOS*PBA	UVB*PBA	-1.330	1.000	-14.963	12.302
BOS*PBA	UVB*SBA	-4.811	0.942	-18.444	8.821
BOS*SBA	SAV*PBA	-20.190	0.001	-33.822	-6.557
BOS*SBA	SAV*SBA	-17.405	0.005	-31.037	-3.773
BOS*SBA	UVB*PBA	-2.785	0.997	-16.417	10.848
BOS*SBA	UVB*SBA	-6.266	0.808	-19.898	7.367
SAV*PBA	SAV*SBA	2.785	0.997	-10.848	16.417
SAV*PBA	UVB*PBA	17.405	0.005	3.773	31.037
SAV*PBA	UVB*SBA	13.924	0.043	0.292	27.556
SAV*SBA	UVB*PBA	14.620	0.029	0.988	28.253
SAV*SBA	UVB*SBA	11.139	0.177	-2.493	24.772
UVB*PBA	UVB*SBA	-3.481	0.990	-17.113	10.151

Table A-20 (a-f): Supporting data for mean density (B) in late August 2013, using analytical approach 2.

Table A-21 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-21 b)

General Linear Model	
Dependent Variable	Mean CW
N	40
Multiple R	0.929
Squared Multiple R	0.862

Table A-21 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	1.792	0.123

Table A-21 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.150	0.024
Shapiro-Wilk Test	0.924	0.010
Anderson-Darling Test	1.092	<0.01
Durbin-Watson D Statistic	2.347	
First Order Autocorrelation	-0.198	

Table A-21 e)

Information Criteria	
AIC	229.928
AIC (Corrected)	235.928
Schwarz's BIC	245.128

Table A-21 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	**HABITAT * SITE**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS*PBA	ALS*SBA	-20.190	0.000	-28.028	-12.352
ALS*PBA	BOS*PBA	7.116	0.097	-0.722	14.954
ALS*PBA	BOS*SBA	8.970	0.016	1.132	16.808
ALS*PBA	SAV*PBA	0.319	1.000	-7.518	8.157
ALS*PBA	SAV*SBA	-0.279	1.000	-8.117	7.558
ALS*PBA	UVB*PBA	6.815	0.126	-1.023	14.653
ALS*PBA	UVB*SBA	1.798	0.995	-6.040	9.636
ALS*SBA	BOS*PBA	27.306	0.000	19.468	35.144
ALS*SBA	BOS*SBA	29.160	0.000	21.322	36.998
ALS*SBA	SAV*PBA	20.509	0.000	12.672	28.347
ALS*SBA	SAV*SBA	19.911	0.000	12.073	27.748
ALS*SBA	UVB*PBA	27.005	0.000	19.167	34.843
ALS*SBA	UVB*SBA	21.988	0.000	14.150	29.826
BOS*PBA	BOS*SBA	1.854	0.994	-5.984	9.692
BOS*PBA	SAV*PBA	-6.797	0.128	-14.634	1.041
BOS*PBA	SAV*SBA	-7.395	0.076	-15.233	0.442
BOS*PBA	UVB*PBA	-0.301	1.000	-8.139	7.537
BOS*PBA	UVB*SBA	-5.318	0.379	-13.156	2.520
BOS*SBA	SAV*PBA	-8.651	0.022	-16.488	-0.813
BOS*SBA	SAV*SBA	-9.249	0.012	-17.087	-1.412
BOS*SBA	UVB*PBA	-2.155	0.985	-9.993	5.683
BOS*SBA	UVB*SBA	-7.172	0.093	-15.010	0.666
SAV*PBA	SAV*SBA	-0.599	1.000	-8.436	7.239
SAV*PBA	UVB*PBA	6.496	0.164	-1.342	14.333
SAV*PBA	UVB*SBA	1.479	0.998	-6.359	9.316
SAV*SBA	UVB*PBA	7.094	0.099	-0.743	14.932
SAV*SBA	UVB*SBA	2.077	0.988	-5.760	9.915
UVB*PBA	UVB*SBA	-5.017	0.452	-12.855	2.821

Table A-21 (a-f): Supporting data for mean CW in late August 2013, using analytical approach 2.

Table A-22 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-22 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	40
Multiple R	0.777
Squared Multiple R	0.604

Table A-22 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	3.593	0.006

Table A-22 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.225	0.000
Shapiro-Wilk Test	0.741	0.000
Anderson-Darling Test	3.461	<0.01
Durbin-Watson D Statistic	1.883	
First Order Autocorrelation	-0.181	

Table A-22 e)

Information Criteria	
AIC	345.904
AIC (Corrected)	351.904
Schwarz's BIC	361.104

Table A-22 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	53.403	0.000	20.000	86.807
ALS*PBA	BOS*PBA	45.927	0.002	12.524	79.330
ALS*PBA	BOS*SBA	59.916	0.000	26.513	93.319
ALS*PBA	SAV*PBA	41.119	0.008	7.715	74.522
ALS*PBA	SAV*SBA	39.030	0.013	5.627	72.433
ALS*PBA	UVB*PBA	57.131	0.000	23.728	90.535
ALS*PBA	UVB*SBA	54.347	0.000	20.943	87.750
ALS*SBA	BOS*PBA	-7.476	0.996	-40.880	25.927
ALS*SBA	BOS*SBA	6.513	0.998	-26.891	39.916
ALS*SBA	SAV*PBA	-12.285	0.929	-45.688	21.119
ALS*SBA	SAV*SBA	-14.373	0.853	-47.777	19.030
ALS*SBA	UVB*PBA	3.728	1.000	-29.675	37.131
ALS*SBA	UVB*SBA	0.943	1.000	-32.460	34.346
BOS*PBA	BOS*SBA	13.989	0.870	-19.414	47.392
BOS*PBA	SAV*PBA	-4.808	1.000	-38.212	28.595
BOS*PBA	SAV*SBA	-6.897	0.997	-40.300	26.506
BOS*PBA	UVB*PBA	11.204	0.955	-22.199	44.607
BOS*PBA	UVB*SBA	8.419	0.991	-24.984	41.823
BOS*SBA	SAV*PBA	-18.797	0.610	-52.201	14.606
BOS*SBA	SAV*SBA	-20.886	0.482	-54.289	12.517
BOS*SBA	UVB*PBA	-2.785	1.000	-36.188	30.618
BOS*SBA	UVB*SBA	-5.570	0.999	-38.973	27.834
SAV*PBA	SAV*SBA	-2.089	1.000	-35.492	31.315
SAV*PBA	UVB*PBA	16.013	0.773	-17.391	49.416
SAV*PBA	UVB*SBA	13.228	0.899	-20.176	46.631
SAV*SBA	UVB*PBA	18.101	0.653	-15.302	51.504
SAV*SBA	UVB*SBA	15.316	0.809	-18.087	48.720
UVB*PBA	UVB*SBA	-2.785	1.000	-36.188	30.618

Table A-22 (a-f): Supporting data for mean density (A) in September 2013, using analytical approach 2.

Table A-23 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-23 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	40
Multiple R	0.747
Squared Multiple R	0.558

Table A-23 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	2.947	0.017

Table A-23 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.225	0.000
Shapiro-Wilk Test	0.932	0.018
Anderson-Darling Test	1.272	<0.01
Durbin-Watson D Statistic	2.540	
First Order Autocorrelation	-0.382	

Table A-23 e)

Information Criteria	
AIC	290.332
AIC (Corrected)	296.332
Schwarz's BIC	305.532

Table A-23 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	HABITAT * SITE	Difference	p-value	95.0% Confidence Interval	
				Lower	Upper
ALS*PBA	ALS*SBA	18.135	0.025	1.458	34.812
ALS*PBA	BOS*PBA	10.892	0.427	-5.785	27.569
ALS*PBA	BOS*SBA	20.347	0.008	3.670	37.023
ALS*PBA	SAV*PBA	1.549	1.000	-15.127	18.226
ALS*PBA	SAV*SBA	-0.539	1.000	-17.216	16.137
ALS*PBA	UVB*PBA	17.562	0.033	0.885	34.238
ALS*PBA	UVB*SBA	14.777	0.113	-1.900	31.454
ALS*SBA	BOS*PBA	-7.243	0.847	-23.920	9.434
ALS*SBA	BOS*SBA	2.212	1.000	-14.465	18.888
ALS*SBA	SAV*PBA	-16.586	0.052	-33.262	0.091
ALS*SBA	SAV*SBA	-18.674	0.020	-35.351	-1.998
ALS*SBA	UVB*PBA	-0.573	1.000	-17.250	16.103
ALS*SBA	UVB*SBA	-3.358	0.998	-20.035	13.319
BOS*PBA	BOS*SBA	9.455	0.601	-7.222	26.131
BOS*PBA	SAV*PBA	-9.343	0.615	-26.019	7.334
BOS*PBA	SAV*SBA	-11.431	0.367	-28.108	5.245
BOS*PBA	UVB*PBA	6.670	0.894	-10.007	23.346
BOS*PBA	UVB*SBA	3.885	0.994	-12.792	20.562
BOS*SBA	SAV*PBA	-18.797	0.018	-35.474	-2.121
BOS*SBA	SAV*SBA	-20.886	0.006	-37.563	-4.209
BOS*SBA	UVB*PBA	-2.785	0.999	-19.461	13.892
BOS*SBA	UVB*SBA	-5.570	0.956	-22.246	11.107
SAV*PBA	SAV*SBA	-2.089	1.000	-18.765	14.588
SAV*PBA	UVB*PBA	16.013	0.067	-0.664	32.689
SAV*PBA	UVB*SBA	13.228	0.204	-3.449	29.904
SAV*SBA	UVB*PBA	18.101	0.026	1.425	34.778
SAV*SBA	UVB*SBA	15.316	0.090	-1.360	31.993
UVB*PBA	UVB*SBA	-2.785	0.999	-19.461	13.892

Table A-23 (a-f): Supporting data for mean density (B) in September 2013, using analytical approach 2.

Table A-24 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-24 b)

General Linear Model	
Dependent Variable	Mean CW
N	40
Multiple R	0.951
Squared Multiple R	0.905

Table A-24 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	5.419	0.000

Table A-24 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.241	0.000
Shapiro-Wilk Test	0.736	0.000
Anderson-Darling Test	3.253	<0.01
Durbin-Watson D Statistic	2.493	
First Order Autocorrelation	-0.297	

Table A-24 e)

Information Criteria	
AIC	299.765
AIC (Corrected)	305.765
Schwarz's BIC	314.965

Table A-24 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT * SITE	**HABITAT * SITE**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS*PBA	ALS*SBA	-48.288	0.000	-67.052	-29.525
ALS*PBA	BOS*PBA	28.146	0.001	9.383	46.910
ALS*PBA	BOS*SBA	31.774	0.000	13.010	50.537
ALS*PBA	SAV*PBA	23.127	0.008	4.364	41.891
ALS*PBA	SAV*SBA	22.779	0.009	4.016	41.543
ALS*PBA	UVB*PBA	29.941	0.000	11.177	48.704
ALS*PBA	UVB*SBA	24.978	0.003	6.214	43.741
ALS*SBA	BOS*PBA	76.435	0.000	57.671	95.198
ALS*SBA	BOS*SBA	80.062	0.000	61.299	98.825
ALS*SBA	SAV*PBA	71.415	0.000	52.652	90.179
ALS*SBA	SAV*SBA	71.067	0.000	52.304	89.831
ALS*SBA	UVB*PBA	78.229	0.000	59.466	96.992
ALS*SBA	UVB*SBA	73.266	0.000	54.503	92.029
BOS*PBA	BOS*SBA	3.627	0.998	-15.136	22.391
BOS*PBA	SAV*PBA	-5.019	0.987	-23.783	13.744
BOS*PBA	SAV*SBA	-5.367	0.981	-24.131	13.396
BOS*PBA	UVB*PBA	1.794	1.000	-16.969	20.558
BOS*PBA	UVB*SBA	-3.169	0.999	-21.932	15.595
BOS*SBA	SAV*PBA	-8.647	0.806	-27.410	10.117
BOS*SBA	SAV*SBA	-8.995	0.773	-27.758	9.769
BOS*SBA	UVB*PBA	-1.833	1.000	-20.596	16.930
BOS*SBA	UVB*SBA	-6.796	0.934	-25.559	11.967
SAV*PBA	SAV*SBA	-0.348	1.000	-19.111	18.416
SAV*PBA	UVB*PBA	6.814	0.933	-11.950	25.577
SAV*PBA	UVB*SBA	1.851	1.000	-16.913	20.614
SAV*SBA	UVB*PBA	7.162	0.915	-11.602	25.925
SAV*SBA	UVB*SBA	2.199	1.000	-16.565	20.962
UVB*PBA	UVB*SBA	-4.963	0.988	-23.726	13.800

Table A-24 (a-f): Supporting data for mean CW in September 2013, using analytical approach 2.

Table A-25 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-25 b)

General Linear Model	
Dependent Variable	Mean Density (A)
N	40
Multiple R	0.847
Squared Multiple R	0.717

Table A-25 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	7.798	0.000

Table A-25 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.298	0.000
Shapiro-Wilk Test	0.662	0.000
Anderson-Darling Test	5.353	<0.01
Durbin-Watson D Statistic	2.995	
First Order Autocorrelation	-0.498	

Table A-25 e)

Information Criteria	
AIC	314.876
AIC (Corrected)	320.876
Schwarz's BIC	330.076

Table A-25 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	9.769	0.219	-3.636	23.173
ALS	SAV	-27.130	0.000	-40.534	-13.725
ALS	UVB	9.421	0.246	-3.984	22.825
BOS	SAV	-36.898	0.000	-50.303	-23.494
BOS	UVB	-0.348	1.000	-13.753	13.056
SAV	UVB	36.550	0.000	23.146	49.955

Table A-25 (a-f): Supporting data for mean density (A) in October 2013, using analytical approach 2.

Table A-26 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-26 b)

General Linear Model	
Dependent Variable	Mean Density (B)
N	40
Multiple R	0.855
Squared Multiple R	0.730

Table A-26 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	8.262	0.000

Table A-26 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.332	0.000
Shapiro-Wilk Test	0.618	0.000
Anderson-Darling Test	6.422	<0.01
Durbin-Watson D Statistic	3.005	
First Order Autocorrelation	-0.503	

Table A-26 e)

Information Criteria	
AIC	314.258
AIC (Corrected)	320.258
Schwarz's BIC	329.458

Table A-26 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	3.317	0.906	-9.984	16.619
ALS	SAV	-33.581	0.000	-46.882	-20.280
ALS	UVB	2.969	0.930	-10.332	16.271
BOS	SAV	-36.898	0.000	-50.200	-23.597
BOS	UVB	-0.348	1.000	-13.649	12.953
SAV	UVB	36.550	0.000	23.249	49.852

Table A-26 (a-f): Supporting data for mean density (B) in October 2013, using analytical approach 2.

Table A-27 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-27 b)

General Linear Model	
Dependent Variable	Mean CW
N	40
Multiple R	0.979
Squared Multiple R	0.959

Table A-27 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	3.678	0.005

Table A-27 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.271	0.024
Shapiro-Wilk Test	0.709	0.010
Anderson-Darling Test	4.436	<0.01
Durbin-Watson D Statistic	2.971	
First Order Autocorrelation	-0.499	

Table A-27 e)

Information Criteria	
AIC	290.557
AIC (Corrected)	296.557
Schwarz's BIC	305.757

Table A-27 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	84.186	0.000	74.295	94.077
ALS	SAV	76.374	0.000	66.483	86.265
ALS	UVB	82.863	0.000	72.972	92.754
BOS	SAV	-7.812	0.162	-17.703	2.079
BOS	UVB	-1.323	0.983	-11.214	8.568
SAV	UVB	6.489	0.302	-3.402	16.380

Table A-27 (a-f): Supporting data for mean CW in October 2013, using analytical approach 2.

Table A-28 a)

General Linear Model		
Variables	**Levels**	
SITE (2 levels)	PBA	SBA

Table A-28 b)

General Linear Model	
Dependent Variable	Seawater Temperature
N	160
Multiple R	0.551
Squared Multiple R	0.303

Table A-28 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	26.248	0.000

Table A-28 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.176	0.000
Shapiro-Wilk Test	0.923	0.000
Anderson-Darling Test	4.339	<0.01
Durbin-Watson D Statistic	0.103	
First Order Autocorrelation	0.938	

Table A-28 e)

Information Criteria	
AIC	648.198
AIC (Corrected)	648.352
Schwarz's BIC	657.424

Table A-28 (a-e): Supporting data for seawater temperature in July 2013 and September 2013.

Table A-29 a)

General Linear Model		
Variables	**Levels**	
SITE (2 levels)	PBA	SBA

Table A-29 b)

General Linear Model	
Dependent Variable	Salinity
N	150
Multiple R	0.825
Squared Multiple R	0.681

Table A-29 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	2.881	0.092

Table A-29 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.109	0.000
Shapiro-Wilk Test	0.954	0.000
Anderson-Darling Test	2.277	<0.01
Durbin-Watson D Statistic	0.097	
First Order Autocorrelation	0.932	

Table A-29 e)

Information Criteria	
AIC	477.791
AIC (Corrected)	477.955
Schwarz's BIC	486.823

Table A-29 f)

Tukey's Honestly-Significant-Difference Test					
SITE	**SITE**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
GIL	PBA	6.810	0.000	4.784	8.746
GIL	SBA	1.707	0.094	-0.217	3.632
PBA	SBA	-5.103	0.000	-6.540	-3.666

Table A-29 (a-f): Supporting data for seawater salinity in July 2013 and September 2013.

Table A-30 a)

General Linear Model		
Variables	**Levels**	
SITE (2 levels)	PBA	SBA

Table A-30 b)

General Linear Model	
Dependent Variable	Dissolved Oxygen
N	120
Multiple R	0.556
Squared Multiple R	0.309

Table A-30 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	1.567	0.212

Table A-30 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.212	0.000
Shapiro-Wilk Test	0.745	0.000
Anderson-Darling Test	10.090	<0.01
Durbin-Watson D Statistic	0.304	
First Order Autocorrelation	0.829	

Table A-30 e)

Information Criteria	
AIC	509.420
AIC (Corrected)	509.627
Schwarz's BIC	517.782

Table A-30 (a-e): Supporting data for seawater dissolved oxygen in July 2013 and September 2013.

Table A-31 a)

General Linear Model				
Variables	**Levels**			
HABITAT (4 levels)	ALS	BOS	SAV	UVB
SITE (2 levels)	PBA	SBA		

Table A-31 b)

General Linear Model	
Dependent Variable	% Survival
N	24
Multiple R	0.836
Squared Multiple R	0.699

Table A-31 c)

Test for Homogeneity		
	Test Statistic	**p-value**
Levene's Test	1.829	0.150

Table A-31 d)

Test for Normality		
	Test Statistic	**p-value**
K-S Test (Lilliefors)	0.283	0.000
Shapiro-Wilk Test	0.907	0.030
Anderson-Darling Test	1.265	<0.01
Durbin-Watson D Statistic	1.957	
First Order Autocorrelation	-0.159	

Table A-31 e)

Information Criteria	
AIC	-1.897
AIC (Corrected)	10.961
Schwarz's BIC	8.706

Table A-31 f)

Tukey's Honestly-Significant-Difference Test					
HABITAT	**HABITAT**	**Difference**	**p-value**	**95.0% Confidence Interval**	
				Lower	**Upper**
ALS	BOS	0.500	0.002	0.177	0.823
ALS	SAV	0.333	0.042	0.010	0.657
ALS	UVB	0.533	0.001	0.210	0.857
BOS	SAV	-0.167	0.475	-0.490	0.157
BOS	UVB	0.033	0.991	-0.290	0.357
SAV	UVB	0.200	0.323	-0.123	0.523

Table A-31 (a-f): Supporting data for mean percent survival in July 2013 and September 2013.