Environmental Factors Affecting Blue Crab Abundance in the Hydrologically Altered Upper Barataria Estuary, Louisiana

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Abstract: The Barataria Estuary, Louisiana, is an interconnected hydrologic network of bayous, canals, lakes, and bays that stretches from freshwater swamps to the open Gulf of Mexico along a salinity gradient. Although the Barataria Estuary was built by sediment delivered via distributaries and interdistributaries of the Mississippi River, flood protection activities have blocked the historical connections between the Mississippi River and the upper estuary. Blue crabs (*Callinectes sapidus*) are abundant in the Barataria Estuary and seasonally occur in the upper estuary. To gain a better understanding of the blue crab seasonal dynamics in the upper Barataria Estuary, this study was designed to: 1) document the summer and fall abundance and distribution of blue crabs, 2) describe the size and condition of the blue crab population, and 3) determine if water quality affects blue crab abundance and distribution. Seven fixed sites were sampled at least biweekly with modified commercial crab traps from 11 July 2006 to 6 December 2006. Males ($n = 591$) were more abundant than females ($n = 58$). Although mean carapace width was greater for females than males, female and male blue crabs had a similar mean carapace length, total weight, and condition factor. Blue crabs were most abundant in July and August, decreased through the fall, and no crabs were collected after 7 November 2006, once temperature had dropped below 15 C. Low temperatures (15 C) and the occurrence of hypoxic conditions (dissolved oxygen ≤2.0 mg/L) limit summer and fall abundance of blue crabs in the upper Barataria Estuary. Future conservation and restoration activities should include strategies to reduce the periodic occurrence of hypoxia in the upper Barataria Estuary and maintain upper and lower estuary connectivity.

Key words: blue crab, nursery, floodplain, estuary, dissolved oxygen

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The Barataria Estuary, Louisiana, was formed approximately 3,500–4,000 years ago and is the most recently abandoned Mississippi River deltaic lobe (Bahr and Hebrard 1976). Characterized by forested wetlands (11.7%), fresh marsh (10.2%), intermediate marsh (4.2%), brackish marsh (3.9%), salt marsh (7.2%), and open saline waters of the Gulf of Mexico along a continuous hydrologic and salinity gradient (Braud et al. 2006), the interconnected hydrologic network of bayous, canals, and lakes extend inland from the Gulf of Mexico for approximately 120 km (Swenson et al. 2006, Jaworski 1972). The Barataria Estuary was historically connected to the Mississippi River by a series of distributaries and interdistributaries, which distributed nutrient and sediment rich water throughout the estuary during the annual Mississippi River floodpulse. However, the Barataria Estuary was disconnected from the Mississippi River early in the 20th century and no longer receives a predictable annual floodpulse, which has resulted in the highest rates of coastal land loss in the United States (Craig et al. 1979, Britsch and Dunbar 1993, Bernier et al. 2006).

Besides a few small (<12,000 cfs) Mississippi River diversions, local precipitation is the dominant source of freshwater for the Barataria Estuary (Sklar and Conner 1979, Swensen et al. 2006, Inoue et al. 2008). The upper-most reaches of the Barataria Estuary (east of Lac Des Allemands) are approximately 41% forested wetlands (swamps), 38% agricultural lands, and include a number of bayous and canals that rarely exceed salinities of 1.0 ppt (Braud et al. 2006). Bayou Chevreuil is the main waterway that drains the majority of the upper Barataria Estuary into Lac des Allemands, carrying leaf litter and other organic materials during rains and high water (Day et al. 1976). A major tenet of the River Continuum Concept (Vannote et al. 1980) is the downstream movement of energy and nutrients; however, many migratory species of coastal river systems transport energy and nutrients upstream (Deegan 1993, Garman and Macko 1998, MacAvoy et al. 2000).

Blue crabs (*Callinectes sapidus*) support a commercial and recreational fishery and are an economically important organism within the Barataria Estuary (Guillory et al. 2001). Blue crabs mate

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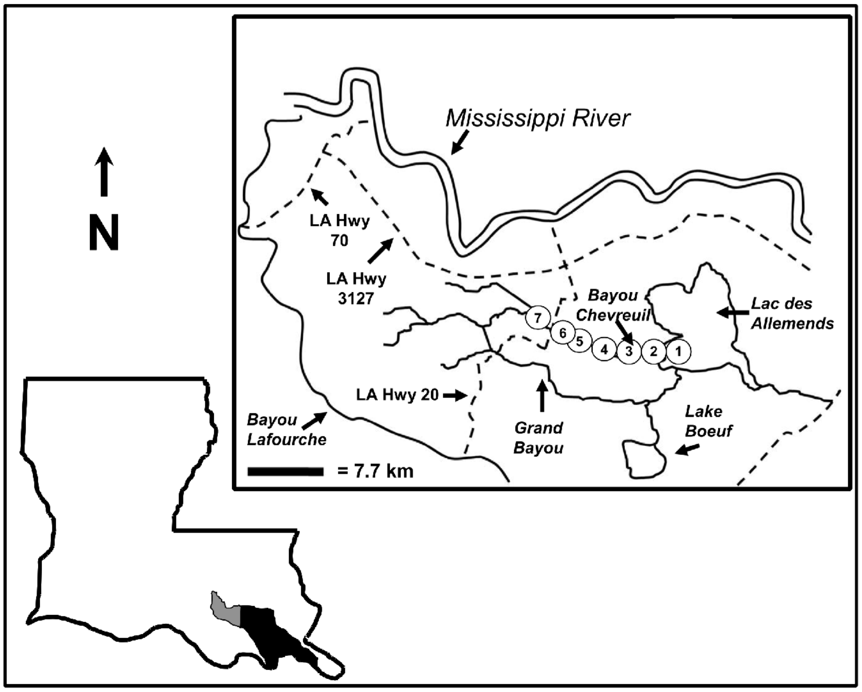

Figure 1. Location of the seven study sites in Lac des Allemands and Bayou Chevreuil in the upper Barataria Estuary (gray shaded area).

in brackish estuary waters, after which females migrate down estuary to spawn in more saline waters (Van Engel 1987, McClintock et al. 1993, Hines 2003). Hatching and early development usually occurs in saline waters, but many juvenile blue crabs migrate up estuary into lower saline and even fresh waters (Van Engel 1987), where they continue to grow and mature into adults after approximately 18–20 post-larval molts (Miller and Smith 2003). The occurrence of blue crabs in freshwater areas of estuaries is seasonal because crabs vacate low saline waters when temperatures drop to 15 C to seek out warmer waters near the coast (Jaworski 1972, Miller and Smith 2003).

The southernmost portion of Lac des Allemands has been described as the most inland blue crab nursery habitat in the Barataria Estuary (Jaworski 1972), which is a nutrient and detritus-rich eutrophic system (Hopkinson and Day 1980, Stow et al. 1985, Conner and Day 1992). Because the blue crab diet can consist of terrestrial-derived detritus (Laughlin 1982, Reichmuth et al. 2009), the crabs may be an important link between the terrestrial and aquatic systems. Blue crabs are prey for many organism in freshwater habitats including American eel (*Anguilla rostrata*), alligator gar (*Atractosteus spatula*), spotted gar (*Lepisosteus oculatus*), channel catfish (*Ictalurus punctatus*), and blue catfish (*I. furcatus*) (Darnell 1961; Goodyear 1967; K. DiBenedetto, U.S. Fish and Wildlife Service, personal communication). Also, due to the migratory nature of blue crabs, they transport energy and nutrients upstream from the lower estuary to the upper estuary.

There is little published information on blue crabs in the freshwater areas of the upper Barataria Estuary (Jaworski 1972, Guillory et al. 2001). Conservation and restoration activities associated with coastal land loss in the Barataria Estuary may include the construction of additional freshwater diversions from the Mississippi River, which may in turn affect the current abundance and distribution of some species within the estuary. Understanding how conservation and restoration activities may affect local biota will aid in the design of conservation and restoration projects that minimize the negative impacts on local biota. To gain a better understanding of the blue crab seasonal dynamics in the upper Barataria Estuary, this study was designed to: 1) document the summer and fall abundance and distribution of blue crabs, 2) describe the size and condition of the blue crab population, and 3) determine if water quality affects blue crab abundance and distribution.

Methods

Blue crabs were sampled weekly to biweekly from 11 July 2006 to 6 December 2006 using modified commercial crab traps (60.9 x 60.9 x 43.2 cm) from seven fixed sites in the upper Barataria Estuary, Louisiana (Figure 1). Each trap was constructed of vinyl-coated 3.8 cm mesh wire and two escape rings (5.9 cm inner diameter), which were closed with plastic zip-ties to prevent escapement of smaller (≤ 127 mm carapace width) individuals. Four traps per site were baited either with gizzard shad (*Dorosoma cepedianum*) or chicken (*Gallus domesticus*) pieces and remained

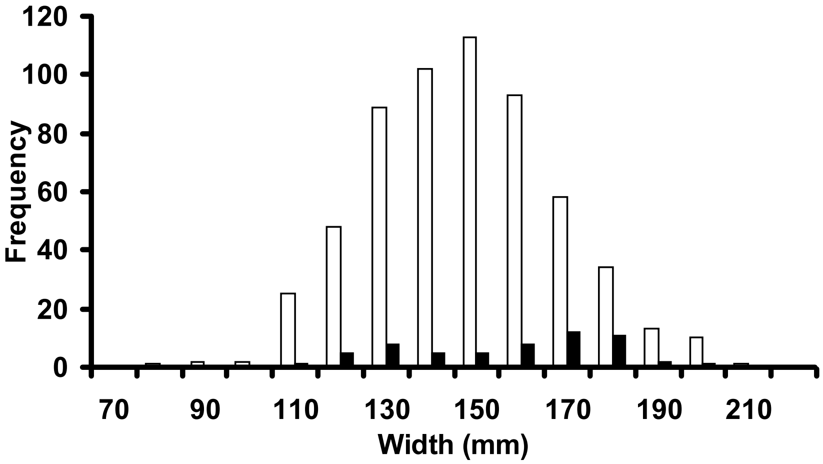

Figure 2. Size frequency distribution for female (solid bars; n = 58) and male (open bars; n = 591) blue crabs collected in the upper Barataria Estuary from 11 July 2006 to 6 December 2006.

deployed for 24 hours. A preliminary study indicated no difference (ANOVA $P>0.05$) for blue crab catch rates using either chicken or gizzard shad as bait. The number of blue crabs caught per trap at each site was recorded and site specific blue crab catch per unit effort (CPUE) was determined as the mean number of crabs collected per trap per 24 hour period. Catch per unit effort was used as a measure of relative abundance. The blue crabs were kept on ice until processing.

Water temperature (C), dissolved oxygen (DO; mg/L), and salinity (ppt) were measured at the bottom of the water column with a hand-held oxygen-conductivity-salinity-temperature meter at each site for each sample date (Yellow Springs Instruments, Yellow Springs, Ohio). A sample was designated as hypoxic if DO was ≤2.0 mg/L. Multiple regression analysis (alpha = 0.05) was used to determine the relationship among the water quality variables and CPUE. Mean water quality values and CPUE were calculated for each sample date to describe changes in the relative abundance of blue crabs and water quality of the upper Barataria Estuary during our study period.

Principal components analysis (PCA; Clarke and Gorley 2006) was used to assess CPUE and water quality differences among the seven sites sampled. Only those variables with loadings greater than 0.4 were used to interpret the PCA (Johnson and Wichern 1992). Mean scores and 95% confidences intervals for each site were plotted on the first two principle components to graphically examine differences among sites.

Each crab was sexed and females were designated as mature or immature based on the shape of the abdominal apron. Total weight (TW; g), carapace width (CW; distance between the two outermost lateral spines; mm), and carapace length (CL; distance from the anterior of the carapace to the posterior of the carapace centered between the two outermost lateral spines; mm) was measured. Condition (C) was calculated for males and females

$$C = (TW / CL^3) * 1{,}000$$

based on Atar and Secer (2003). Analysis of variance (alpha = 0.05) was used to compare TW, CW, CL, and C between male and female blue crabs.

Results

Of the 649 blue crabs collected from 11 July 2006 to 7 November 2006, male blue crabs ($n = 591$; 91%) were more abundant than female blue crabs ($n = 58$; 9%; Figure 2). Although mean CW was greater for females (153 ± 2.9 mm; mean ± SE) than males (143 ± 0.9 mm), female and male blue crabs had a similar mean CL (65 ± 0.3 mm), TW (146 ± 2.2 g), and C (0.5 ± 0.002). Twenty four female blue crabs (41.4% of females) were classified as immature (CL = 59 ± 5.3 mm; CW = 131 ± 13.0 mm; TW = 102 ± 23.7 g).

Mean temperature ranged from 31.5 to 9.7 C for the duration of this study (Figure 3). Mean dissolved oxygen levels ranged from 0.4 to 4.8 mg/L and were hypoxic on eight occasions during this study (Figure 3). With the exception of a spikes in salinity on 11 October 2006 (0.6 ± 0.05 ppt) and 18 October 2006 (0.9 ± 0.35 ppt), mean salinity (± SE) remained below 0.4 throughout the sample period. Mean CPUE was greatest in July and early August, declined sharply in late August and continued to decline throughout the summer and fall, reaching zero by the end of November after water temperature had decreased to below 15 C (Figure 3). Temperature and DO were positively related to CPUE, but salinity was not (Table 1).

The PCA yielded two principle components (PC1 and PC2) that explained 84.8% of the CPUE and water quality variation among sites (Figure 4). Temperature, DO, salinity, and CPUE were all negatively loaded on PC1 and accounted for 58% of the total

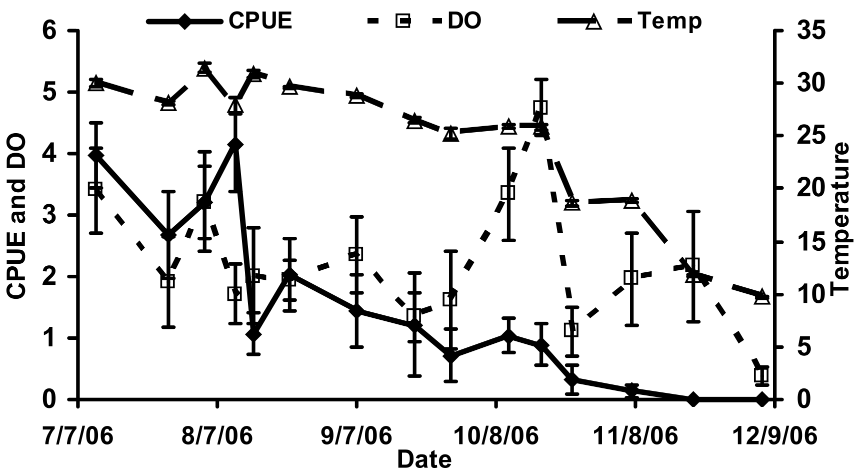

Figure 3. Mean (±SE) catch per unit effort (CPUE; number/day; solid line), dissolved oxygen (mg/L; small-dashed line), and temperature (C; long-dashed line) for each sample date from 11 July 2006 to 6 December 2006.

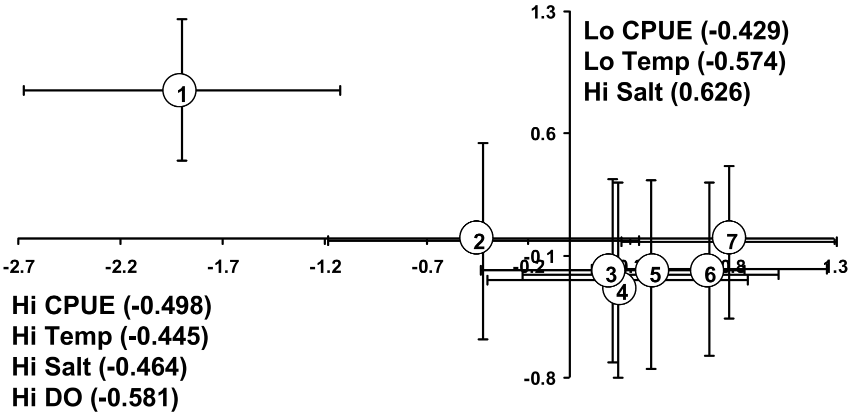

Figure 4. Mean (±95% CI) principal components score for each site on PC1 (x-axis) and PC2 (y-axis). The variable loadings for principal components 1 (PC1) and PC2 are listed for each variable on each axis.

variation. Temperature and CPUE were negatively loaded and salinity was positively loaded on PC2, which accounted for 26.8% of the total variation (Figure 4). The plot of loadings for each site indicate that there was a trend in decreasing temperature, DO, specific conductance, and CPUE along a gradient from site 1 to site 7 for PC1 (Figure 4).

Table 1. Results of the multiple regression analysis comparing CPUE to temperature (C), dissolved oxygen (mg/L) and salinity (ppt).

Variable	DF	Estimate	SE	t-value	Pr > |t|
Intercept	1	-2.077	0.5835	−3.56	0.0006
Dissolved oxygen	1	0.125	0.1317	2.80	0.0062
Temperature	1	0.368	0.0236	5.29	<0.0001
Salinity	1	−0.920	0.8757	−1.05	0.2958

Discussion

Blue crabs may be seasonally abundant in the upper Barataria Estuary due to up-estuary movement during development (Jaworski 1972, Van Engel 1987, Guillory et al. 2001). Megalops and small juveniles are found in the more saline waters of the lower estuary and large juveniles and adults are found throughout the upper Barataria Estuary as far inland as freshwater swamps (Jaworski 1972). The size distribution of blue crabs ranged from 80–210 mm CW. Blue crabs <80 mm CW may be present in the upper Barataria Estuary but were not collected due to the mesh size of the traps, which may have allowed for the escapement of smaller individuals (<80 mm CW). The presence of juvenile male and female blue crabs suggests that the upper Barataria Estuary serves as a blue crab nursery area.

Temperature was positively correlated to blue crab abundance. Blue crabs do not tolerate low temperatures and may practice autotomy (sacrificing limbs for survival) at water temperatures below 5 C to conserve energy (Rome et al. 2005). Blue crabs do not acclimate well to low temperatures with tolerance to low temperatures further reduced at low salinities, and significant mortality occurs if blue crabs are exposed to extended periods (≥15 days) of water temperatures below 3 C (Rome et al. 2005). Blue crab tolerance to low temperatures is reduced at low salinities (Rome et al. 2005). Water temperature was below 15 C on the two dates that no blue crabs were collected from the upper Barataria Estuary. Jaworski (1972) also noted that blue crabs vacate lower saline waters of the upper estuary when temperatures drop to 15 C to seek out warmer waters near the coast. Although low temperatures preclude blue crabs from being year-round residents, the upper Barataria Estuary serves as a seasonal nursery area.

Dissolved oxygen was positively correlated to blue crab abundance. Although tolerance to hypoxic waters increases with an increase in age, blue crabs are sensitive to low levels of dissolved oxygen (Tankersley and Wieber 2000, Das and Stickle 1993). Bell et al. (2003a) observed telemetered blue crabs swimming near the surface of the water column or moving out of an area in an attempt to escape hypoxic conditions, and a decline in feeding and molting rates of blue crab occurs during hypoxic events (Bell et al. 2003b, Seitz et al. 2003, Das and Stickle 1993). It appears that hypoxic conditions and low temperatures (<15 C) force blue crabs out of the upper Barataria Estuary.

Males dominated the blue crab population of the upper Barataria Estuary. A possible explanation for the lack of females is that females migrate towards the coast after maturation to spawn in saline waters (Hines 2003, McClintock et al. 1993, Van Engel 1987, Adkins 1972). Another possible explanation is the difference in osmotic regulation between male and female blue crabs. Osmotic regulation demands are greater at low salinities (≤8.0 ppt), and require greater energy expenditure (Rome et al. 2005). At low salinities as low as 2.0 ppt, osmotic regulation demands are greater for females than males, and the greatest for ovigerous females (Tagatz 1971, Tan and Van Engel 1966). Additionally, oxygen consumption increases with decreasing ambient salinity (Findley et al. 1978). The combination of low salinity (≤1.0 ppt) and low dissolved oxygen and the resulting increased oxygen demand may prevent migration of the majority of female blue crabs into the upper Barataria Estuary. However, there are benefits to living in low salinities for blue crabs. Water uptake during molting is greater in low salinity waters than in high salinity waters, resulting in higher blood volume, which may shorten the time required to complete ecdysis, thus reducing vulnerability to predation (deFur 1990). Because of warmer temperatures, predation on blue crabs is greater in the U.S. Gulf of Mexico than along the Atlantic coast (Heck and Coen 1995). Estuarine waters with low DO and low salinity, such as the upper Barataria Estuary, may serve as a refuge for blue crabs from larger predatory organisms that cannot withstand such conditions.

The principal components analysis revealed that sites characterized by higher temperature, DO, and salinity were also characterized by higher blue crab abundance. The upper Barataria Estuary is a viable blue crab nursery as long as temperature remains above 15 C; however, the periodic occurrence of hypoxic conditions limits the amount of blue crab nursery habitat in the upper Barataria Estuary. The seasonal migration of blue crabs into freshwater areas of estuaries provides a lower estuary-derived source of energy and nutrients to the freshwater residents of inland estuary species, such as alligator gar, spotted gar, and blue catfish. Conservation and restoration activities within estuary systems should include strategies to reduce the periodic occurrence of hypoxia that can occur. By decreasing the occurrence rate of hypoxic events, the connectivity and nutrient and energy exchanges between the saline and fresh water areas of estuaries will be enhanced.

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