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The Impact of Varying Productivity Levels on Abundance and Feeding Patterns of Callinectes sapidus: What does Blue Crab Behavior Tell us About Wetlands Restoration?

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Problem Statement: How does an estuarine productivity gradient, which varies with distance from the Gulf of Mexico as well as seasonal freshwater inputs, affect blue crab abundance and feeding patterns?

Abstract

The Everglades is a unique wetland ecosystem characterized by high species diversity, yet has been negatively impacted by anthropogenic activities. The Everglades has been the target of conservation efforts to restore it to its original state. A major aspect of the restoration is the reestablishment of hydrologic connectivity across the wetlands ecosystem.

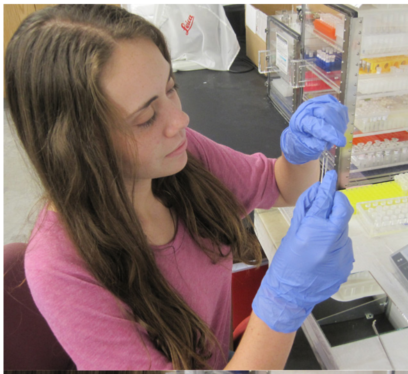
The coastal Everglades is characterized by a productivity gradient, with higher productivity closer to the Gulf. Adult male blue crabs (Callinectes sapidus) are only somewhat affected by factors such as salinity, but are sensitive to varying productivity levels, which could make them excellent indicators of how restoration will affect the southern coastal Everglades as productivity dynamics change.

The purpose of this study was to investigate how an estuarine productivity gradient, which also varies seasonally, affects blue crab abundance and feeding patterns. Using crab-trapping surveys, blue crab abundance was measured across four sites, each with differing productivity levels, as well as across wet and dry seasons. Feeding patterns were also examined using stable isotope analysis of crab muscle tissue.

The results largely supported the hypothesis that crab abundance and feeding patterns would correlate with productivity and would shift seasonally with productivity changes. This suggests that studying blue crab distribution and abundance could be useful for monitoring restoration progress as it relates to altered productivity dynamics. Continued monitoring of blue crab populations could be important in determining whether costly restoration efforts are ultimately successful.

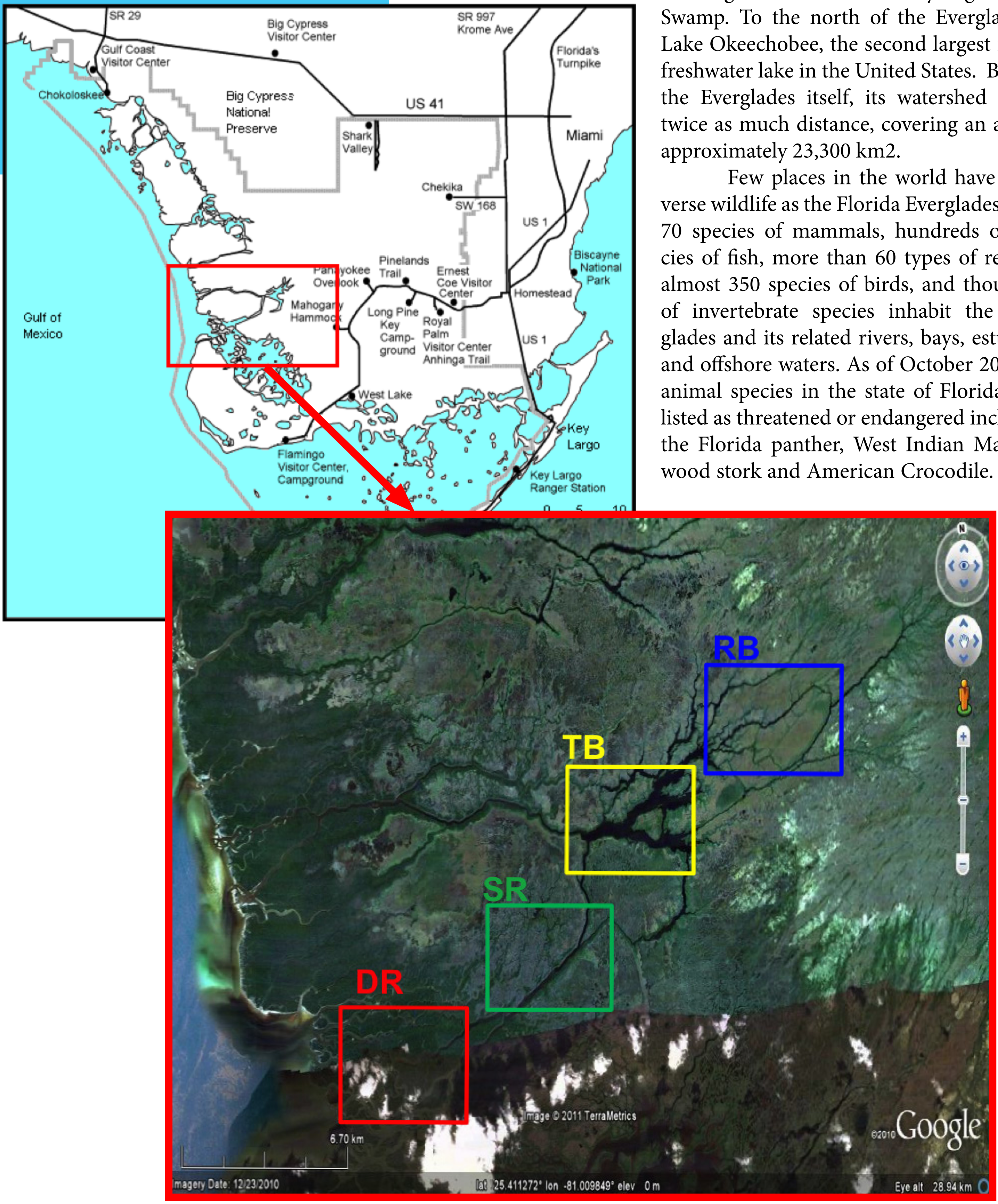
What is so special about the Wetlands of South Florida?

The Everglades is a complex wetland ecosystem at the southern end of the Florida peninsula, and is heavily impacted by human development. It is the only subtropical National Park in North America,



and the largest sawgrass prairie in the world. It is bounded on the east by the Atlantic Costal Ridge and on the west by Big Cypress Swamp. To the north of the Everglades is Lake Okeechobee, the second largest inland freshwater lake in the United States. Beyond the Everglades itself, its watershed covers twice as much distance, covering an area of approximately 23,300 km2.

Few places in the world have as diverse wildlife as the Florida Everglades. Over 70 species of mammals, hundreds of species of fish, more than 60 types of reptiles, almost 350 species of birds, and thousands of invertebrate species inhabit the Everglades and its related rivers, bays, estuaries, and offshore waters. As of October 2011, 85 animal species in the state of Florida were listed as threatened or endangered including the Florida panther, West Indian Manatee, wood stork and American Crocodile. It has



been estimated that since the 1930's, up to 90% of the wading birds such as wood storks and white ibises have been lost. Plant populations have also been hurt. Exotic pest plants such as melaleuca, Brazilian pepper, and Australian pine have invaded natural areas, competing with native plants and altering the habitat. Deaths of seagrass beds in Florida Bay have caused a significant loss of wading birds, fish, shrimp, sponges, and mangroves.

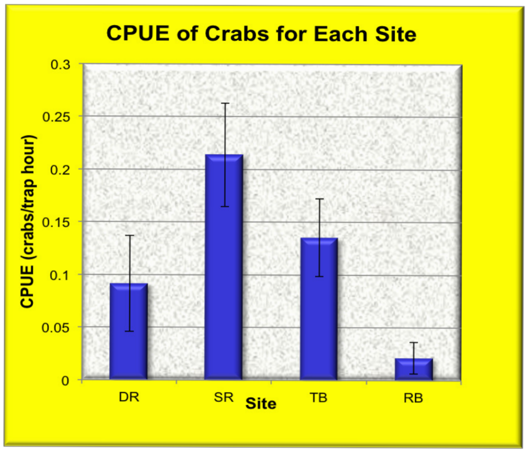
How have we hurt the Everglades and how have we affected productivity levels?

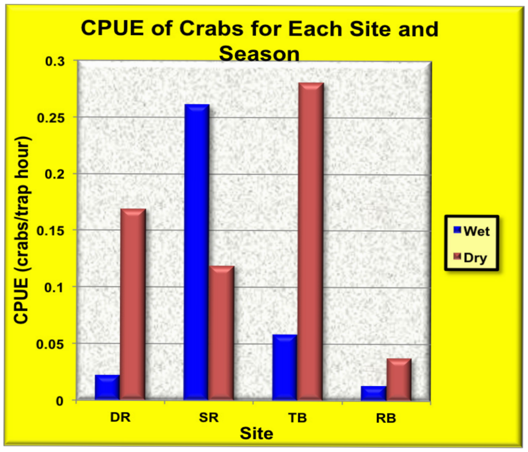
There has been so much growth of the human population in South Florida that it has caused tremendous strain on the Everglades ecosystem. More than 1600 kilometers of man-made canals, over 1100 kilometers of levees, and 16 pump stations have diverted over 6,000,000m3 of water daily away from its natural flow through the Everglades in an effort to dry up land areas. More than half of the original Everglades have been drained. Over 4,000 km2 of the Everglades south of Lake Okeechobee have been converted to agricultural land. Other areas have been changed for industrial uses, resulting in 8,000 km2 more of lost habitat. The redirection of freshwater from its original flow patterns has not only lead to decreased freshwater levels in the southern Everglades but also has likely altered patterns of productivity (the amount of biomass in a given area), especially in the coastal southern Everglades. Animals tend to congregate in areas that have high productivity levels because those areas are characterized by high food abundance. Historically, productivity in this area was fueled by nitrogen (N), carbon (C), and detrital inputs that flowed in with freshwater from the north and phosphorous (P) inputs that flowed in with the tides from the Gulf of Mexico. Currently, freshwater inputs to the coastal Everglades have been drastically decreased by human activities and thus less N, C, and detritus is available for production in this system, while P from the Gulf of Mexico has pushed farther up into coastal areas. Altered freshwater flow patterns have likely led to changes in the nutrient dynamics of the costal Everglades and productivity patterns. The decreased productivity in the coastal Everglades has likely affected the animals that inhabit this system both behaviorally and in terms of population dynamics.

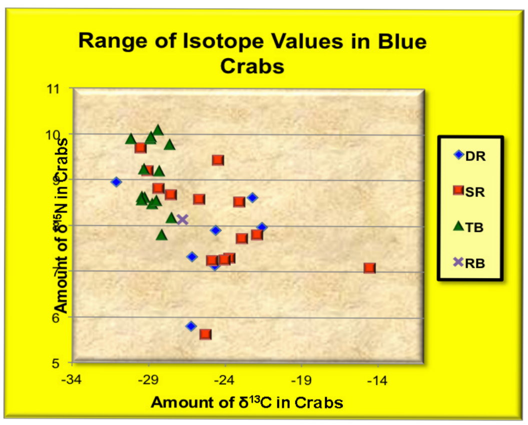
Why are blue crabs significant to Everglades Restoration Research?

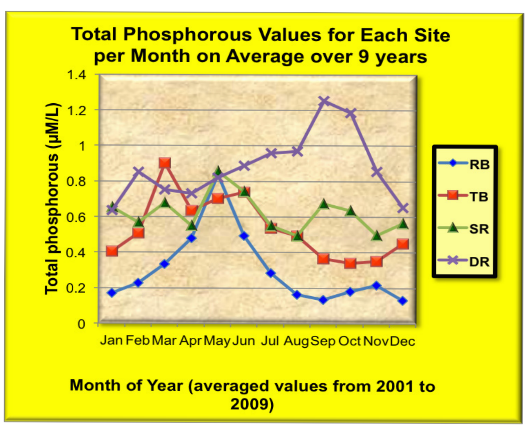
As a result of its unique characteristics, the Everglades has been the focus of major restoration efforts, mostly directed at improving the effects of human use of the surrounding land. The Comprehensive Everglades Restoration Plan (CERP) was created in 2000 to try to restore the natural flow of water through the Everglades and to improve the quality of the water in Lake Okeechobee. It is expected to cost at least $10.5 billion and to take more than 35 years. It is the largest hydrologic restoration project ever undertaken in the U.S. CERP is in the process of reconnecting the hydrology between the coastal and central Everglades in order to deliver a higher volume of freshwater to the coastal Everglades in the future. Increased freshwater inputs to the system are also intended to increase inputs of N, C, and detritus to help return the coastal Everglades to its historical productivity levels. New freshwater inputs are hypothesized to push the phosphorous-rich saltwater back towards the Gulf of Mexico and reduce seasonal variations of productivity in upstream areas.

The coastal Everglades is anticipated to be one of the habitats most heavily impacted by CERP because of changes to salinity and freshwater flow patterns along with the productivity gradient. Blue crabs currently inhabit the coastal Everglades over a wide range of salinities because they are able to tolerate varying salinity levels, therefore they will most likely not be heavily impacted by changes to salinity patterns in the ecosystem. However, blue crabs may be sensitive to changes in productivity levels because, like all animals, they need nutrients to survive. Since blue crabs are not affected by salinity but may be responsive to differences in resources and productivity patterns, ecosystem managers may be able to use blue crab abundance and behaviors specifically as indicators of changes in productivity patterns caused by CERP, making blue crabs useful for tracking successful progress over the next 30 years. However, to accurately predict how blue crab populations will respond to changes in coastal Everglades productivity levels both demographically and behaviorally so that ecosystem managers can use the information, we must strive to understand how blue crabs respond to current productivity patterns in the coastal Everglades.









Results

Average phosphorous concentration between 2001 and 2009 varied in the Shark River Estuary across testing sites as well as seasons. During the wet season (July to December) phosphorous levels decreased as distance from the Gulf of Mexico increased (Down River (DR) site > Shark River (SR) site > Tarpon Bay (TB) site > Rookery Branch (RB) site), with phosphorous concentration during August, September, and October almost twice as high at the DR site as it was at the SR site. During the dry season (January to June) phosphorous levels peaked in the TB site during March and TB had the highest peak of all the sites in the dry season. The phosphorous levels peaked in RB during the month of May and this peak was the highest of all the sites during May along with SR. The phosphorous concentration at the DR site stayed relatively high, even during the dry season.

The average blue crab abundance (catch per unit effort or CPUE) aggregated across seasons was significantly different between sites (Kruskal-Wallis ANOVA on Ranks: $H_3 = 15.361$, $p = 0.002$) and showed an increasing pattern as site distance from the Gulf of Mexico decreased, except for the site closest to the Gulf of Mexico. At the RB site the average CPUE was 0.02 (± 0.01 SE), at the TB site the average CPUE was 0.13 (± 0.04 SE), at the SR site the average CPUE was 0.21 (± 0.05 SE), and at the DR site, the average CPUE was 0.09 (± 0.05 SE). Interestingly, the DR site, closest to the Gulf of Mexico, displayed the second lowest CPUE despite containing the highest year-round average levels of phosphorous. The SR site held the highest year-round average CPUE of adult male blue crabs in total. T-tests revealed that CPUE at SR was significantly higher than CPUE at DR and RB ($T_{17,21} = 256$, $p = 0.02$ and $T_{18,21} = 239$, $p < 0.001$, respectively), and very close to significantly higher than CPUE at TB ($T_{21,29} = 619$, $p = 0.088$). TB also had a significantly higher CPUE than RB ($T_{18,29} = 340.5$, $p = 0.016$).

There were also seasonal differences in CPUE at each site. Blue crabs were 7.5, 4.8, and 2.8 times more abundant during the dry season at DR, TB, and RB, respectively. In contrast, blue crabs were 2.2 times less abundant during the dry season at the SR site. In the dry season, the phosphorous levels increased near the SR and TB sites.

The carbon isotope values differed between crabs caught at different sites. The average crab $\delta^{13}C$ value was -25.3 (± 1.2 SE), -24.7 (± 1.0 SE), and -28.8 (± 0.2 SE) at DR, SR, and TB respectively. Mean and SE could not be calculated for RB because only one value was available for that site. The isotope data shows that some of the blue crabs migrated between different sites. The crabs caught at the TB site displayed tightly clustered $\delta^{13}C$ values, indicating they most likely did not move very far from where they were caught. In contrast, most of the crabs caught at the SR and DR sites displayed widely dispersed $\delta^{13}C$ values, indicating probable migratory movement between different sites.

Conclusions

This study was conducted to investigate how an estuarine productivity gradient, which varies with seasons and distance from the Gulf of Mexico, affects the abundance, distribution, and feeding patterns of adult

Type of Test	Test statistic	Degrees of Freedom
ANOVA comparing all sites	15.361	3
T-test DR vs. SR	256	17,21
T-test DR vs. TB	364	17,29
T-test DR vs. RB	336	17,18
T-test DR vs. TB	619	21,29
T-test DR vs. RB	239	18,21
T-test DR vs. RB	340.5	18,29

male blue crabs. My hypothesis stated that there would be more crabs closer to the Gulf of Mexico in the wet season because of higher rates of productivity in that area, whereas in the dry season crabs would reside further upstream due to productivity gradient shifts upstream with reduced freshwater flow patterns. I also predicted that the feeding patterns of the crabs would reflect the crabs' movements based on the prediction for the abundance data. The data supported the hypothesis in that crab abundance during the wet season increased as distance from the Gulf of Mexico decreased, with the exception of the site closest to the Gulf of Mexico (which was the most marine-influenced and had the highest productivity). In addition, the differences between seasons mostly supported the hypothesis; crab abundance increased along with productivity levels at the sites furthest away from the Gulf in the dry season, and in the area closest to the Gulf in the dry season as well.

The deviations from the hypotheses could possibly be explained by non-productivity related factors, specifically predator abundance and distribution patterns. Blue crab behaviors are not only driven by the search for food and mates, but also by the need to avoid predators. Blue crabs are prey for a wide variety of predators in the coastal Everglades and surrounding waters, including the American alligator (Alligator mississippiensis) and bonnethead shark (Sphyrna tiburo). Previous studies have shown that relatively large numbers of alligators inhabit the DR habitat during the wet season, suggesting that blue crabs reside mostly in the SR habitat rather than the DR in the wet season to avoid alligators while still being able to exploit areas of high productivity. However, in the dry season the salinity levels become unbearable for alligators because they lack functioning salt glands, thus they are forced to move upstream to TB and RB. Also, during the dry season, the decline of water levels in the surrounding marshes causes fish to congregate in upstream areas which alligators may be able to take advantage of. The data also shows that the crabs in the dry season become more abundant in DR because there is still a lot of productivity that they would not have access to in the wet season due to the presence of alligators. The crabs are more abundant in TB during the dry season because they are not as affected by salinity, like the alligators, and TB is where the productivity levels spike in the dry season.

Stable carbon isotopes can be used to determine the source(s) of nutrients for a consumer. Carbon isotopes vary across the Shark River Estuary with higher $\delta 13C$ values closer to the Gulf of Mexico and lower $\delta 13C$ values in the freshwater areas. Stable isotopes may remain in a crab's system for about two years, so an isotope analysis is able to determine where the crab has been feeding for most of that time. The results supported the hypothesis that blue crabs migrated with varying productivity levels throughout the Shark River Estuary. Like the abundance data for the wet season, the isotope data shows that SR, the second to farthest site from the Gulf, had the highest average δ13C values, which was higher than the area closest to the Gulf, DR. This phenomenon can also be explained by the presence of alligators in the DR area in the wet season that may cause an influx of DR crabs into the SR site. In the dry season, once Alligators move farther upstream due to their aversion to salinity, SR crabs may be free to move into areas such as DR and TB (third site from the Gulf) which contain high levels of productivity at that time of year. The crabs caught in DR and SR were shown to have highly variable δ13C values even though they were caught in areas characterized by high δ13C values, which supports the results of the abundance data that crabs migrate to areas based on varying productivity levels and that they feed in multiple food webs across the different sites.

These findings suggest that blue crab abundance and feeding patterns are indeed affected by the productivity gradient present in the Shark River Estuary. However, the results also suggest that blue crab behaviors may be simultaneously affected by the presence and abundance of their predators. Therefore, blue crab abundance and feeding patterns alone may not be a useful indicator of changing productivity levels in the Everglades as restoration efforts continue, but changes in blue crab abundance and feeding patterns analyzed alongside changes in predator abundance and distribution could still be used to track future changes in productivity. These results also suggest that as restoration efforts increase hydrologic connectivity between the northern and southern Everglades, blue crab productivity surveys along with predator behavior surveys can assist in determining whether or not the costly and time-consuming efforts of CERP are effective in benefitting the overall Everglades ecosystem and if they are proceeding as planned.

Importance and Application

The government is planning on spending more than \$10.5 billion on the Comprehensive Everglades Restoration Plan (CERP), the largest hydrologic restoration project ever undertaken in the United States. It is expected to take more than 35 years to restore as much of the Florida Everglades to its natural state as possible. To assess the progress and success of CERP, ecosystem managers must have measurable goals and targets to track the expected responses from the Everglades ecosystem, including animal species responses to increased water levels, shifts in plant community composition, and changes in productivity patterns. Once the water flow between the northern and southern parts of the Everglades is greatly increased, the main area of productivity in the coastal Everglades is expected to shift toward the Gulf of Mexico because phosphorous is expected to become less abundant in the upstream areas of the southern estuaries. To track the expected changes in the productivity gradient, CERP needs to focus on indicator species that are sensitive to shifts in productivity but not as sensitive to shifts in salinity, which is a factor also expected to change with restoration.

The current study has several important practical applications related to the ability of CERP to track changes in productivity. The results show that blue crab abundance and feeding pattern surveys combined with predator distribution surveys could be an effective way of monitoring shifting productivity patterns as restoration activities progress over the next three decades. By describing the current abundance and distribution of adult male blue crabs across estuarine habitats with varying productivity levels, and by monitoring these populations throughout hydrologic restoration efforts, this study, and other research like it, could serve as an important indicator of whether these expensive, time consuming efforts are economically and ecologically effective, and provide recommendations for changes and modifications to the components of CERP if necessary.

In addition to the important implications of this study with regards to Everglades restoration, blue crabs are also an important seafood species for human consumption. All along the east coast of the United States and in the Gulf of Mexico, blue crabs are heavily fished and populations of blue crabs have been drastically reduced across their entire range as a result. In some areas, such as the Chesapeake Bay, there are many restoration efforts currently underway to revive the local blue crab population along with the ecosystems they inhabit. The results from this study could also be useful for predicting how blue crab populations in heavily fished areas will respond to local restoration efforts if those efforts will lead to changes in productivity patterns.