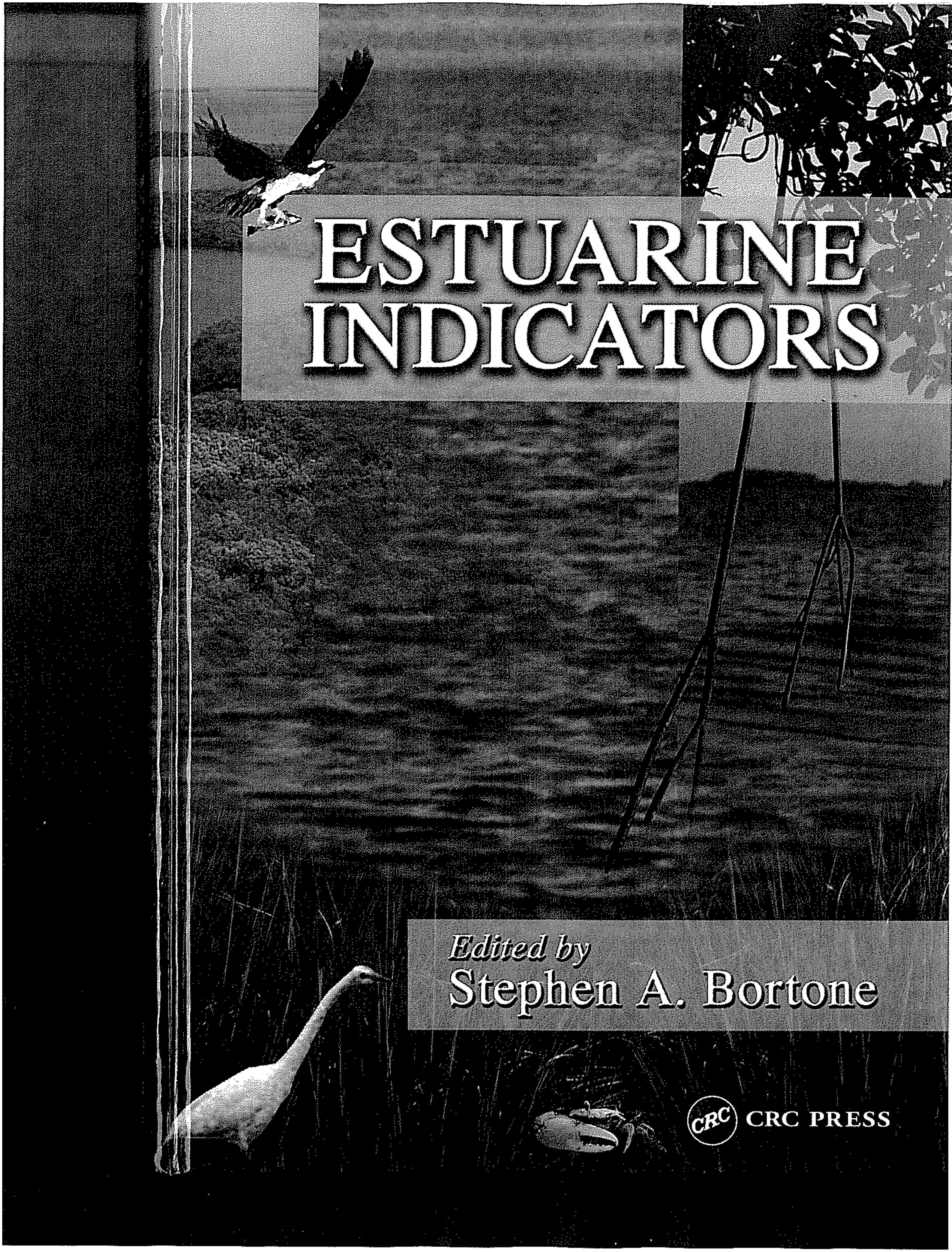

ESTUARINE INDICATORS

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Habitat Affinities of Juvenile Goliath Grouper to Assess Estuarine Conditions

Anne-Marie Eklund

CONTENTS

Introduction

The overall goal in managing and monitoring an estuarine ecosystem should be a "healthy" system. Ecosystem health and ecosystem integrity have been variously defined as synonyms of each other and as synonyms of stability, sustainability, resilience, balance, and productivity (Simberloff, 1998; Jordan and Smith, Chapter 30, this volume). A healthy ecosystem is one that also supports reasonable human uses through the long term (Simberloff, 1998). To maintain a healthy estuarine system or to restore a degraded system to a stable and functioning state, it is essential to be able to measure that system's health. When managing or restoring an estuary to a better condition, it is important to understand its present state, what the current trends are in the ecosystem's status and how long it will take to achieve a healthy system (Simberloff, 1998).

In Chapter 30, Jordan and Smith describe two different paths in assessing ecosystem health. One method is to describe effects of stressors on the sediment, habitat, nutrients, etc. and then define the relationships between abiotic and biotic components of an estuary, by means of a complex conceptual model. The model would then have outputs as response variables that describe ecosystem health. Another method to assess the status of an ecosystem is to define direct relationships between stressors and responses. Using the second method does not require a complete understanding of a conceptual model and all of the interrelationships and components of a complex food web (Jordan and Smith, Chapter 30, this volume). It does require the use of a suitable indicator that integrates the system's responses to stressors and predicts changes in ecosystem status.

As outlined by Jordan and Smith, indicators of ecological integrity can be from population, community, or ecosystem levels. They can be species groups, broad taxa, or indices that reflect an attribute of a community, such as species composition, diversity, evenness, or richness. Often, however, a single species may be designated an indicator of ecosystem function, particularly as it may be more practical and possible to monitor and manage a single species, rather than to monitor and manage a suite of species or many components of an ecosystem.

Of course, using indicator species in conservation biology is not without problems. First, it is difficult to choose one and hard to understand just what it is supposed to indicate. Species are chosen for monitoring and management if their presence or abundance gives us a better understanding of the system. Often a flagship or high-profile species is chosen for its political "palatability," but it may not be a good indicator of the status of a community or ecosystem (Zacharias and Roff, 2000).

If one is to use a single species as an indicator of ecosystem health, restoration success, or change, it is imperative to choose an effective one. First, the indicator species needs to be abundant in the area that is being studied and it must be relatively easy to catch or observe, to ensure some success at monitoring. Of course, the species must be measurably affected by changes that are occurring and there must be some understanding of the mechanisms affecting the species and causing the observed changes.

When assessing the effects of anthropogenic or natural changes in an estuary, species or species groups from lower trophic levels may be used as indicators, because they are more abundant than those from the higher trophic groups. Furthermore, using a higher tropic-level species as an indicator can be problematic. Effects on higher trophic levels can be more difficult to understand, because there are many steps in the food web that link to the top-trophic levels. Abiotic effects may be mitigated (or exacerbated) by intermediate steps in the food chain. In addition, highly mobile organisms may respond quickly to suboptimal conditions by leaving those environments. Another complicating factor is that bottom-up effects (such as water quality and pollution) may or may not be as important as top-down effects such as fishing and other human-extractive activities. For example, in Chapter 30, Jordan and Smith present information on the striped bass in Chesapeake Bay and the fact that the top-down forces of fishery management affected the species to the extent that any bottom-up relationship between the fish and habitat restoration was not measurable.

Despite these difficulties, it is vitally important to try to understand the relationships between the natural and anthropogenic perturbations of the system and the effects of such perturbations on fish and other higher trophic-level organisms, particularly because there is often an inherent interest in them by managers and the general public. Furthermore, the ultimate success in restoration is to revive the natural system, so that all trophic levels — including the highest levels — benefit from restoration activities.

Using fish as indicators of estuarine ecosystem health may turn out to be ecologically important to other areas as well. Many predatory fish and other species that are the target of fisheries use estuaries as nursery areas. Their success in the nursery will affect the ecology of other systems as they grow and recruit to their adult habitats (e.g., coral reefs). Many commercially and recreationally valuable species depend on estuaries for some part of their life history. In the southeastern United States, more than 95% of the fish that are landed commercially and the majority of the recreational species caught are dependent on estuaries for some part of their life cycle (Nakamura et al., 1980). Estuaries benefit juveniles, in particular, because they provide rich food resources with fewer predators and less competition from adults of the same species (Colby et al., 1985).

The juvenile goliath grouper, *Epinephelus itajara* (formerly referred to as jewfish before a proposed common name change by Nelson et al., 2001) thrives in the estuary of the Ten Thousand Islands of southwest Florida. It is an important species in the estuarine ecosystem as a top-level predator, and the system is important to the goliath grouper as its primary nursery habitat. Goliath grouper can be easily caught, tagged, measured, and recaptured (Eklund and Schull, 2001) in the same general area, and their abundance is affected by certain variables that are changing with habitat restoration. Because the only known predators of goliath grouper (even as juveniles) are sharks and humans and because there currently is no harvest of goliath grouper allowed, total mortality is probably quite low and top-down effects on the species are minimal to nonexistent.

In this chapter I explain how goliath grouper can be used as an indicator of estuarine condition. I describe what we can learn about the restoration of an ecosystem and the recovery of a protected species and how the two are related.

Goliath Grouper

The goliath grouper is the largest grouper in the western North Atlantic. As adults they inhabit shallow reefs, wrecks, canals, seawalls, bridges, and piers, although they are also found on offshore wrecks and reefs down to at least 70 m (Sadovy and Eklund, 1999). The larvae settle in the fall in the estuaries of Florida (Bullock and Smith, 1991), including the Ten Thousand Islands (personal observation). They grow up in the estuary and are found along mangrove-lined creeks and mangrove islands in tidal passes from settlement size up to about 1 m, and ages 0 to 6 or 7 years (Bullock et al., 1992). The fish are site faithful (Eklund and Schull, 2001) based on mark–recapture data, making it possible to assess habitat preferences and describe microhabitats.

According to Bullock and Smith (1991), the species' center of abundance along Florida's west coast is in the Ten Thousand Islands estuary, due to the extensive habitat of mangrove swamps for juveniles. The juveniles have been collected in poorly oxygenated canals (Lindall et al., 1975) and in mangrove swamps with tidal currents that are strong enough to scour holes in the bottom and undercuts in the ledges (Bullock and Smith, 1991). Goliath grouper appear to tolerate a large range of salinity (Sadovy and Eklund, 1999), but are susceptible to cold water-induced mortality (Gilmore et al., 1978) and red tide (Smith, 1976).

Goliath grouper are europhagic carnivores, but they are more likely to consume crustaceans and slow-moving benthic fishes (Odum et al., 1982; Bullock and Smith, 1991; Sadovy and Eklund, 1999; personal observation). Even as juveniles, goliath grouper are top predators in the estuarine system, because they grow to a size greater than most other fish in the area, within their first 2 years of life (Bullock and Smith, 1991).

The U.S. fishery for goliath grouper expanded rapidly in the 1980s, until the populations were overexploited to the point of economic extinction (Sadovy and Eklund, 1999). In the early 1990s, the Gulf of Mexico, South Atlantic, and Caribbean Fishery Management Councils passed amendments to prohibit retention of goliath grouper in U.S. waters. Their stocks may be recovering due to fishing prohibitions that have been in place since that time (Porch et al., 2003); however, it is not clear how variable year-class strengths are and how vulnerable juvenile goliath grouper are to environmental perturbations in their nursery habitats.

In the Ten Thousand Islands of southwest Florida, the proximity of natural riverine habitat to that of dredged canals with altered freshwater flow patterns enables one to compare the abundance of juveniles in altered and unaltered habitats. This comparison has set the stage for long-term monitoring of goliath grouper abundance in order to indicate the health of the Ten Thousand Islands estuary and the success of the restoration of that system. These rivers and canals link the upstream freshwater system of the Big Cypress Basin to the system of bays, which empty into the Gulf of Mexico through a series of channels around mangrove islands. Most of the area is completely undeveloped and protected, yet it is downstream from areas in the Big Cypress Basin that have been subjected to massive changes in water delivery, timing, and quantity over the years. The entire area is included in the Comprehensive Everglades Restoration Project (CERP) (U.S. Army Corps of Engineers/South Florida Water Management District, 2000), which is an attempt to restore the system, as much as possible, to historical conditions.

Ten Thousand Islands Estuary

The Ten Thousand Islands is one of the largest estuaries in the United States (Browder et al., 1986) and is composed of a series of shallow bays that are separated from the Gulf of Mexico by thousands of small mangrove islands stretching approximately 30 km from Goodland to Chokoloskee, Florida (Figure 25.1). Several tidally influenced rivers empty into the bays, and each bay is connected to the Gulf of Mexico through convoluted passes.

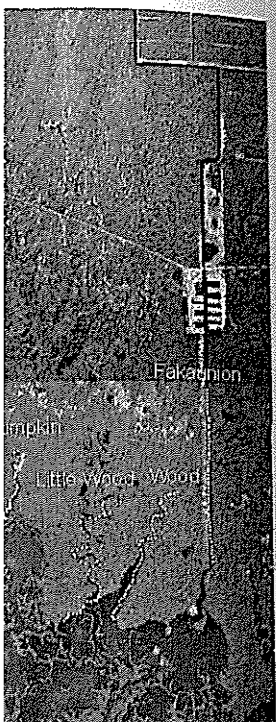
The natural, undeveloped freshwater system of southwest Florida was one in which fresh water slowly flowed as a broad sheet over gently sloping prairies and eventually into the estuary, with a lag of several months between upstream rainfall and inflow into the bays (Browder et al., 1986). Although the area is under the protection of the Ten Thousand Islands National Wildlife Refuge, Rookery Bay Estuarine Research Reserve, and Everglades National Park, it has been, and continues

FIGURE 25.1 (Color figure follows p. 266.) Six natural, tidally influenced rivers and three canals in the Ten Thousand Islands of southwest Florida. Canals on either side of U.S. Highway 92 are labeled 92 Canal West and 92 Canal East. The dots on the river and canal transects designate locations where fish traps and crab traps were placed to catch juvenile goliath grouper, *Epinephelus itajara*, from 1999–2000.

to be, adversely affected by upstream water management practices. The natural slough system of freshwater sheet flow is no longer active, due to the vast network of canals that are actually deeper than the groundwater table (Popowski et al., 2003). The most drastic drainage activity in the area was that of the Southern Golden Gate Estates (SGGE) Canal system, which includes more than 294 canals that were built for a housing project that never materialized (Browder et al., 1986). As a result of the canal network, more than 600 km^2 of wetlands are drained into Faka Union Bay (U.S. Army Corps of Engineers/South Florida Water Management District, 2000). Pre-drainage, the flow would occur over land much more broadly and would drain into a larger area of the estuary. As a result, Faka Union Bay receives about five times more water annually than it did historically, but the nearby bays receive much less water because water is lost from surface flow and from the groundwater as well.

The excessive drainage of the SGGE has made the area a target for restoration. The Golden Gates Estates Feasibility Study and the CERP include immediate plans for restoring the system by disassembling the canals, removing roads, and adding spreader canals and pumps (U.S. Army Corps of Engineers/South Florida Water Management District, 2000). If canals are plugged, sheet flow restored, and upland water storage increased, then estuarine systems are expected to improve. Discharges into Faka Union Bay should decrease in the wet season, the base flow to the entire system should increase in the dry season, and a more natural salinity gradient should be reestablished (U.S. Army Corps of Engineers/South Florida Water Management District, 2000; Popowski et al., 2003).

Browder et al. (1989) and Sklar and Browder (1998) reviewed the few studies that had been conducted in the bays of the Ten Thousand Islands and found that every study that compared animal abundances among or between bays found lower numbers of the study organisms in the Faka Union system than in adjacent systems (Carter et al., 1973; Colby et al., 1985; Browder et al., 1986). Reasons for the lower numbers in Faka Union Bay could be less area of suitable salinity for many organisms or the difficulty



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in larval transport against high canal flow rates. These studies found depressed numbers of fishes and invertebrates throughout the year, indicating that the large, wet-season discharges had long-term effects. None of the above-mentioned studies detected any changes in species composition, however. Thus, using species composition alone as an indicator of ecosystem health would fail, in this case, to detect any changes in the altered system.

The tidal streams and rivers of the Ten Thousand Islands have received considerably less attention and little research activity. Colby et al. (1985) is the only published study that covers the entire area of embayments of the Ten Thousand Islands. However, neither that study nor any of the others included an investigation of the tidal rivers. Those rivers are primarily fringed with red mangroves (*Rhizophora mangle*) and connect the freshwater marshes with the shallow bays.

Mangrove communities, in general, are characterized by turbid surface water with low dissolved oxygen (DO), low concentrations of macronutrients (mainly phosphorus), and extreme ranges in salinity from 0 to 40 ppt (or above) (Odum et al., 1982). Typically, DO concentrations are between 2 and 4 ppm and often approach zero when waters are stagnant or after heavy storm runoff (Odum et al., 1982).

Mangrove swamps provide habitat for many organisms through the tree canopy, the aerial roots, and the associated muddy substrates in the adjacent creeks and embayments. The riverine mangrove forest system of southwest Florida supports a dense and speciose fish assemblage, with 47 to 60 species per river system (Odum et al., 1982). The mangrove shorelines include vast undercuts of eroded banks that provide shelter for many species of invertebrates and fishes. Personal observations include goliath grouper, gag grouper (*Mycteroperca microlepis*), snook (*Centropomis undecimalis*), and gray snapper (*Lutjanus griseus*) co-occurring in high densities under the mangrove overhangs. Invertebrate species diversity is moderately high and includes such organisms as spiny lobsters, barnacles, sponges, polychaetes, gastropods, oysters, mussels, isopods, amphipods, mysids, crabs, shrimp, copepods, ostracods, coelenterates, nematodes, insects, bryozoans, and tunicates (Odum et al., 1982). The leaf litter forms the basis of a detrital food web.

The fish assemblages of mangrove communities have not been studied extensively as a result of inherent gear limitations (Serafy et al., 2003). Comparisons of fish abundance inside and outside of mangrove habitats are rare, and those comparisons are often problematic due to the difficulty in sampling in the mangroves (Beck et al., 2001). Often different gears are used in and out of mangrove habitats, making comparisons difficult. Most studies have collected fish adjacent to the mangrove forests, not actually within the flooded forest (Beck et al., 2001).

With Everglades restoration efforts under way, water quality, quantity, and timing of water delivery will soon be altered due to restoration. The SGGE project has already begun. If we can predict the response of a top-level predator to the changes in the water quality of the system, then we may be able to successfully monitor, manage, and shape decisions about future restoration activities. The objectives of this study were to estimate the abundance, size distribution, site fidelity, and movement patterns of juvenile goliath grouper in altered and unaltered rivers and canals in the Ten Thousand Islands of southwest Florida and to ascertain whether that species could be used as an indicator of ecosystem restoration.

Methods

For a pre-restoration "baseline" data assessment, in 1999 and 2000, the abundance of juvenile goliath grouper in natural tidal passes, or rivers, was compared to their abundance in channelized canals (Figure 25.1). The natural rivers should provide optimal microhabitat for the juvenile goliath grouper, including mangrove overhangs along eroded shorelines (Figure 25.2) and rocky depressions in tidal passes. Oppositely, canals tend to have straightened shorelines with little to no eroded banks and mangrove overhangs. Because they are dredged, canals are also of relatively uniform bathymetry, lacking the natural depressions that rivers contain. The hypothesis was that the physical features of the two habitat types would differ and that the goliath grouper would be more abundant in the natural rivers.

In each river and canal, 40 crab traps and 10 fish traps were placed every 92.6 m (0.05 nautical miles) along a linear transect. Two rivers and one canal were sampled concurrently for 3 weeks with the traps

FIGURE 25.2 **(Color figure follows p. 266.)** Photographs of typical eroded shorelines in the Ten Thousand Islands of southwest Florida. The erosion along the mangrove shorelines provides for underwater habitat underneath the mangrove overhangs.

inspected and sampled weekly within the 3-week period. At the end of 3 weeks, traps were moved to new locations. At the end of 9 weeks, all locations had been sampled and the first sites were sampled again. In the second year, YSI® datasondes were deployed to continuously measure temperature, salinity, DO, and depth. A datasonde was secured to a fish trap in each river, so that the water quality parameters measured would reflect the water quality adjacent to and inside the traps that were currently fishing. One datasonde was placed in a fish trap either in the upper, middle, or lower part of a river/canal and remained deployed for 1 week. When the traps were inspected, the water quality data were downloaded, the datasonde was calibrated, if necessary, and subsequently moved to another part of the river/canal. At the end of the 3-week sampling period, the datasonde would have acquired water quality information at all three sections of the river/canal.

The amount of eroded (vs. depositional or straight) shoreline was measured by taking Global Positioning System (GPS) waypoints at the beginning and end of each section of eroded shoreline and measuring the distance between the two points using Geographic Information System (GIS) ArcView® software. The heterogeneity of the bottom (i.e., the presence/absence of rocky depressions and other obstructions) was estimated by taking a depth reading every 185.2 m (0.1 nautical miles) along each side of the river/canal. The change in depth from each reading was then calculated and averaged for the entire river/canal.

The duration of hypoxic events was determined for each datasonde deployment by calculating the percent of time that the datasonde recordings (made every 15 min) were below 2 parts per million (ppm). The percentage was calculated for each datasonde deployment and averaged for each river for the year.

Because goliath grouper are found at a broad range of salinity and appear to tolerate even fresh water to a certain degree, it was appropriate to look at the rate of salinity change rather than the absolute value of salinity. Thus, the change in salinity from one reading to the next (15 min between readings) was calculated. This difference between each reading was averaged for each deployment. The average change in salinity for all the deployments in each river was then calculated for a grand mean for each river.

A multilinear regression analysis was used with catch-per-unit-effort (CPUE) as the dependent variable, and two physical habitat variables (meters of eroded shoreline and bathymetric complexity) and

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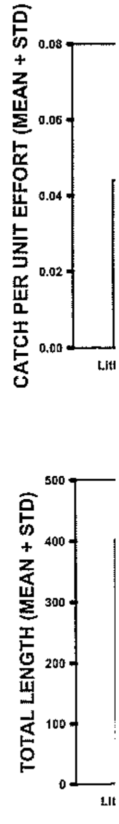

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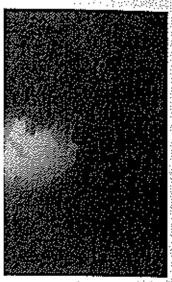

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two chemical variables (percent of time that DO was below 2 ppm and mean change in salinity) were the independent variables. A Pearson's rank correlation coefficient was calculated between CPUE and the four above-listed habitat variables.

In addition to the analysis made on an annual and entire river basis, analysis of CPUE was also divided into parts of the river/canal (upper, middle, lower), so that a comparison of CPUE and water quality could be made for each sampling period and each river/canal section.

Results

A total of 687 juvenile goliath grouper were caught in nine rivers and canals of the Ten Thousand Islands from 1999 to 2000. Many of these fish were recaptured at least once, with previously tagged fish comprising 38% of the total catch. Fish demonstrated movement within rivers but not among river/canal systems. In only a few cases ($n < 5$) were marked fish recaptured outside their original river or canal. Goliath grouper CPUE and total catch were highest in Little Wood River, Palm River, and Blackwater River, and few goliath grouper were caught in the Wood, Pumpkin, and Whitney Rivers (Table 25.1 and Figure 25.3A). While two of the canals, Faka Union and 92 West Canal, had lower CPUE and total catch of goliath grouper than in several rivers, 92 East Canal had higher CPUE and total catch than many of the natural rivers (Figure 25.3A).

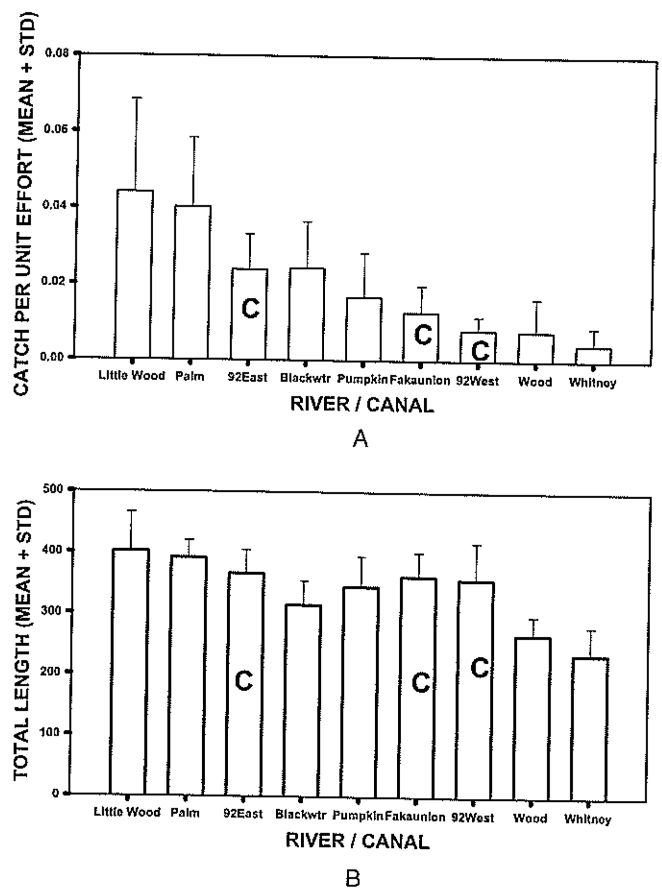


FIGURE 25.3 Mean + standard error (A) CPUE and (B) total length (in millimeters) of juvenile goliath grouper, *Epinephelus itajara*, caught in fish traps and crab traps in six tidal rivers and three canals (designated with a C) of the Ten Thousand Islands of southwest Florida from 1999–2000.

TABLE 25.1

CPUE and Total Catch of Goliath Grouper, *Epinephelus itajara*, and Dead Bycatch from Crab and Fish Traps Set in Rivers and Canals of the Ten Thousand Islands of Southwest Florida[a]

River/Canal	Mean CPUE 1999	Mean CPUE 2000	Total Catch 1999	Total Catch 2000	Dead Organisms 1999	Dead Organisms 2000	Eroded Shoreline (m)	Eroded Shoreline %	Depth Change (per 0.1 nmi)	Time Hypoxic % of time	Salinity Change per 15 min	Temperature (C) Mean	Temperature (C) Range	Salinity (ppt) Mean	Salinity (ppt) Range	DO (ppm) Mean	DO (ppm) Range
92 Canal W.	0.006	0.009	11	15	0	3	2.6	42	0.61	29.41	0.60	25.69	16.4–32.5	24.79	0.1–38.0	3.63	0.17–10.22
92 Canal E.	0.024	0.020	43	20	3	1	4.6	59	0.47	32.63	0.35	27.00	17.1–32.6	26.67	2.1–36.7	2.90	–0.33–7.88
Palm R.	0.040	0.040	81	65	1	2	3.4	51	3.45	8.56	0.29	27.59	21.1–34.0	25.34	0.1–35.0	4.19	0.77–10.24
Blackwater R.	0.026	0.020	59	36	10	6	1.3	20	1.98	25.49	0.29	27.66	23.4–25.6	28.46	8.8–36.6	3.44	0.13–8.49
Whitney R.	0.003	0.006	9	13	78	29	3.0	48	2.16	49.84	0.19	26.73	15.0–33.1	27.81	12.1–37.4	2.21	0.03–7.85
Pumpkin R.	0.013	0.015	31	20	73	11	0.7	22	1.28	31.76	0.16	26.17	14.9–33.4	29.00	0.55–39.2	3.97	–0.31–13.03
Little Wood R.	0.045	0.043	119	87	1	6	4.7	70	4.31	16.52	0.10	27.09	16.6–33.0	25.68	0.64–33.8	3.44	0.21–8.75
Wood R.	no data	0.007	no data	18	no data	34	0.6	10	1.08	23.76	0.12	25.89	17.1–33.5	22.34	0.40–36.7	4.03	0.29–9.68
Faka Union	0.011	0.015	27	33	6	0	0	0	0.63	4.05	0.55	27.78	22.5–33.0	17.05	0.40–37.1	4.16	0.92–7.99

[a] Along with measurements of length of eroded shoreline, percent of shoreline with eroded banks, mean change in depth (per 185 m or 0.1 nautical mile along the length of the river/canal, percent of time that DO concentration was below 2 ppm, mean change in salinity per 15-min period, and the mean, minimum, and maximum temperature, salinity, and DO measured in each river and canal from June to December 2000.

Within each river and canal, certain sections were more productive, in terms of goliath grouper CPUE. In general, the upper sections of the Little Wood River and Palm River, the lower sections of the Whitney and Wood, and the middle section of the Pumpkin River/Bay area were more productive than the other sections of the respective rivers. The Blackwater River and the canals were more variable in where the highest CPUE occurred (see Eklund et al., 2002, for details on each section of river and canal).

The goliath grouper caught in the Ten Thousand Islands ranged in length from 133 to 903 mm total length (TL), practically the entire range of the juvenile life-history stage (Sadovy and Eklund, 1999). Consistently, the largest fish were caught in the Palm and Little Wood Rivers, and only small fish were caught in the Whitney and Wood Rivers (Figure 25.3B). The canals and Blackwater and Pumpkin Rivers were more temporally varied in the sizes caught. There did not seem to be a consistent pattern with size distribution along sections of the rivers, and there was no indication of ontogenetic migration upstream or downstream.

Goliath Grouper Habitat Description

The amount of erosion along the shorelines of the meandering rivers should be a good measure of the amount of suitable or optimal habitat for goliath grouper, as the erosion provides for a mangrove-undercut area where the fish can reside (Figure 25.2). The Little Wood River and the 92 East Canal have the greatest length of eroded shoreline (more than 4.5 km), comprising 70 and 59% of those systems, respectively (Table 25.1). Very little of the shorelines of the Blackwater, Pumpkin, and Wood Rivers is undercut (1.3, 0.7, 0.6 km, respectively; less than 25% of the system) (Table 25.1), and Faka Union Canal is a completely straight canal with no meandering and resultant erosion/deposition along the shorelines (Table 25.1).

All three canals have uniform depths, with a change of 0 to 1 m between readings (data were recorded 185.2 m apart) (Table 25.1). Little Wood River and Palm River had the greatest variation in depth, with an overall mean change in depth readings equal to 4.31 and 3.45 m, respectively. The Whitney, Blackwater, and Pumpkin Rivers were intermediate in depth variation, and the Wood River was more similar to the canals with a mean change just slightly greater than 1 (Table 25.1).

Water depth varied with time, due to tidal changes and upstream flow. The rivers and canals appeared to experience similar changes in depth over time, with all nine systems having a mean depth change between 1.0 and 1.3 m, within the week's sampling period.

While currents were not directly measured, it was possible to gather a relative description of overall flow, based on movement of the traps. The Palm and Little Wood Rivers and parts of the Blackwater River had the strongest flow, based on the fact that the traps had to be secured to trees along the riverbanks to prevent their loss. The Highway 92 Canals also had high water flow at times, probably due to pulses of upstream water releases. Thus, traps had to be secured to the banks of those two canals as well. Faka Union Canal also received upstream water pulses, but that canal is very wide with the overall flow dampened somewhat across the stream. The other rivers received such little flow that the traps did not move appreciably, unless there was a storm event.

The water temperature range in the Ten Thousand Islands rivers and canals was from 15 to 34°C, with mean water temperatures similar among rivers and canals, between 26 and 28°C (Table 25.1). The rivers and canals that were sampled concurrently yielded almost the exact mean temperatures, meaning that water temperature changes were reflective of greater environmental conditions and not of the individual river/canal systems.

There was a lot of fluctuation in salinity readings in the Ten Thousand Islands (Table 25.1). The lowest overall mean salinity was found in Faka Union Canal. The Palm River and all three canals often experienced a large range of salinities, at times the readings went from completely fresh water (less than 5 ppt) to almost salt water (greater than 30 ppt) within 1 week. The lower section of the 92 East Canal and the lower Blackwater River, on the other hand, maintained higher salinity with minimal variation. Overall, most of the rivers experienced a 10 ppt change in salinity within a week's period.

Perhaps more germane to the survival or habitat preference of goliath groupers and other organisms in the area is the rate of salinity change during the week. In general, the canals experienced more rapid changes in salinity over short time periods (Table 25.1), with Faka Union Canal and 92 West Canal

[a] Along with measurements of length of eroded shoreline, percent of shoreline with eroded banks, mean change in depth (per 185 m or 0.1 nautical mile along the length of the river/canal, percent of time that DO concentration was below 2 ppm, mean change in salinity per 15-min period, and the mean, minimum, and maximum temperature, salinity, and DO measured in each river and canal from June to December 2000.

having much faster rates of change than 92 East Canal. Blackwater River and Palm River also experienced relatively high rates of salinity changes. The other rivers had much lower rates of change, particularly the Wood and Little Wood Rivers (Table 25.1).

Although the rivers differed in their patterns of DO concentration, their overall means were similar (Table 25.1), except for the Whitney River and 92 East Canal, whose means were less than 3.0 ppm. The Whitney River had the lowest overall mean DO concentration; all sections of that river had minimum DO less than 0.30 throughout the year, except for the lower Whitney in midsummer, which had a minimum DO of 1.01. The upper Pumpkin and Wood Rivers always had minimum DO less than 0.35 and, until toward the end of the wet season, the middle sections also had minimums less than 1.0. The only parts of the Pumpkin and Wood Rivers that consistently had high DO were the lower sections, which were really part of the bay systems and less riverine in their physical nature (Figure 25.1). The 92 East Canal also had low DO levels (actually becoming anoxic) in the upper and middle sections during the middle of the summer, but those low levels did not persist.

More important to sustaining most life in the rivers is the length of time that hypoxic conditions persisted. The datasonde in Whitney River measured DO concentrations below 2 ppm over 49% of the time that the probes were in the water. The Wood, Blackwater, and Pumpkin Rivers and both of the Highway 92 Canals were hypoxic one fourth to one third of the time that they were sampled. The Little Wood River, Palm River, and Faka Union Canal had fewer periods of hypoxic conditions (Table 25.1).

Perhaps indicative of anoxic conditions, the traps from the Wood, Whitney, and Pumpkin Rivers often contained dead blue crabs (*Callinectes sapidus*), hardhead catfish (*Arius felis*), *Tilapia* spp., and various other fish. Dead crabs or fish were a rare occurrence in the other rivers and canals (Table 25.1).

No significant relationships were found between any abiotic variables and CPUE when examined by specific river section or time period. However, much stronger relationships were revealed when CPUE and abiotic factors were averaged for each river for the entire year of sampling (Figure 25.4). A Pearson product-moment correlation coefficient indicated a significant ($\alpha < 0.05$) positive correlation between bathymetric complexity and CPUE. The multilinear regression had an $r^2 = 0.92$ when all four factors were used in the analysis:

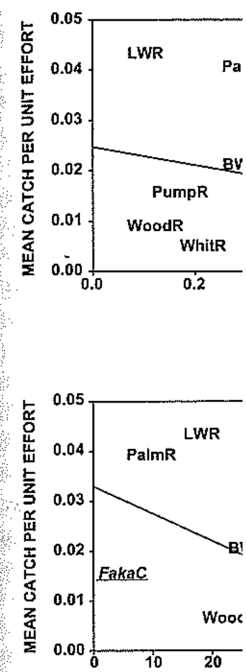
$$\text{CPUE} = 0.0218 + (0.00367 \times \text{meters of eroded shoreline}) + (0.00364 \times \text{bathymetric complexity}) - (0.000591 \times \text{percentage of time hypoxic}) - (0.00938 \times \text{salinity change})$$

Salinity change had the lowest r^2 (0.058; Figure 25.4A), and the least effect on the regression when it was removed from the equation. Bathymetric complexity had the strongest relationship with CPUE ($r^2 = 0.639$; Figure 25.4B), explaining more than half the variation among rivers. Percent of hypoxic conditions and length of eroded shoreline each explained about one third of the variation in CPUE ($r^2 = 0.313$ and 0.312, respectively; Figure 25.4C and D).

Discussion

Goliath grouper catch was variable among the rivers in the Ten Thousand Islands, making direct comparisons of rivers and canals more difficult than anticipated. These differences, however, illuminated differences in physical-chemical habitat and underscored how restoration success could be indicated by the abundance of these juvenile fish. Goliath grouper were most abundant in the Little Wood and Palm Rivers, and those rivers also had the greatest amount of bathymetric heterogeneity and eroded shoreline, and neither river experienced many periods of hypoxia. In addition, the Little Wood River had less variation in salinity than that of the other rivers. The presence of both bathymetric complexity and eroded shoreline are indications of good physical habitat for these fish. Rocky holes and mangrove undercuts provide optimal habitat for goliath grouper in the form of shelter from current and an ideal location for ambush predator activities. In addition, the lack of hypoxic events and extreme salinity changes helped maintain a quality habitat for the fish.

The Little Wood and Palm Rivers also had the largest goliath grouper caught, another indication of optimal habitat. The two rivers that had the lowest goliath grouper catch, the Wood and Whitney Rivers, also had the smallest fish caught. In some instances, catching more small fish could be an



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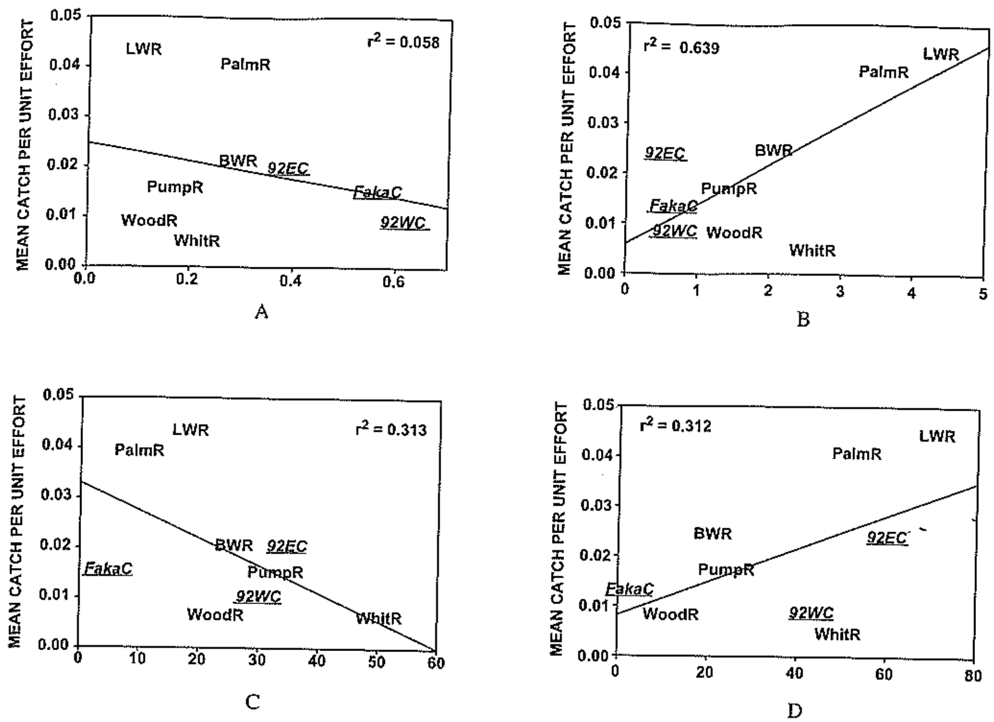

FIGURE 25.4 The relationship between juvenile goliath grouper CPUE and (A) mean change in salinity between each 15-min datasonde recording period; (B) bathymetric complexity (as determined by averaging the change in depth between each 0.1 nautical mile of river/canal bank); (C) the percentage of time that hypoxic conditions (<2 ppm DO concentration) were recorded; and (D) the percentage of the river/canal shoreline that was eroded in each river and canal in the Ten Thousand Islands. LWR = Little Wood River, PalmR = Palm River, BWR = Blackwater River, PumpR = Pumpkin River, WoodR = Wood River, WhitR = Whitney River, 92EC = 92 Canal East, 92WC = 92 West Canal, and FakaC = Faka Union Canal.

artifact of low sample size, since younger fish are usually more abundant than older fish due to natural mortality. However, in this case, the trend is real, since the blue crab traps do not select for the smallest size classes. Rather, the blue crab traps used in this study selected for fish between 300 and 400 mm TL. The fact that the few fish caught at Whitney and Wood Rivers were smaller than the selected size range indicates that the fish in those rivers really were smaller. The goliath grouper were likely settling throughout the system, and then either emigrating or suffering mortality in those areas of suboptimal habitat. In Chapter 2 of this volume, Adams accentuates the need to notice and measure physiological affects of animals as an alarm before there is a response to population levels. However, highly mobile animals will emigrate as a response to environmental change, before a physiological response can be detected. Thus, a change in abundance is what we need to measure, not a change in physiology.

The hypothesis that natural rivers would provide better and more habitat than canals for juvenile goliath grouper was based on the assumption that the shorelines and bathymetry would be vastly different between rivers and canals. Our visual assessment of Faka Union Canal bore out that hypothesis, as the canal is completely straight with no eroded shorelines and a uniform bathymetry. The two other canals, however, are not completely straight and the slight meanders have resulted in some shoreline erosion, providing undercut habitat for goliath grouper and other fish (Table 25.1). In fact, the 92 East Canal had more eroded shoreline than all of the natural rivers, except the Little Wood River, with large tracts of erosion along its eastern bank, away from the roadbed. The Faka Union Canal and the Wood, Pumpkin, and Blackwater Rivers had shorelines with little erosion. None of the canals had heterogeneous bathymetry, as expected, because the canals are created by dredging activities. Also as expected, the canals all received much greater fluctuations in salinity (but the 92 East Canal did not fluctuate as much as the other two); yet these results contradict the assumption that salinity would be the main driving affect on fish distribution (Browder et al., 1989; Popowski et al., 2003).

The Whitney River is the biggest outlier in the relationships between physical habitat characteristics and CPUE, but the low CPUE is explained by the extremely low DO concentrations that occurred in the Whitney River almost half the time it was measured. The Pumpkin River was intermediate to low in physical and chemical habitat values and contained a low abundance of goliath grouper as well. In addition, our qualitative observations revealed that there was much less water flow in the Pumpkin, Wood, and Whitney Rivers than there was in the Little Wood, Palm, and Blackwater Rivers and in all the canals.

The rivers with consistently low DO (Pumpkin, Wood, and Whitney) had consistently low CPUE of goliath grouper. The datasonde measured the conditions on the bottom of the rivers and canals, and it is likely that the systems are stratified in oxygen concentration. Mobile animals, such as fish and crabs, can move easily when the water becomes anoxic. Thus, systems such as the 92 East Canal and the Little Wood River, which experienced anoxia or hypoxia for short time periods, could still sustain healthy populations of goliath grouper. Systems that appeared to maintain an extremely low DO throughout the sampling period were the rivers that had low catch of goliath grouper. The number of dead fish and crabs is another indication of the unsuitability of these rivers. It is apparent that catfish and crabs were living in the rivers, but they were caught in the traps during bad water quality time periods and subsequently died. The low number of dead (or live) goliath grouper caught with the dead organisms indicates that the grouper either move out very quickly during low DO events, or more likely, they do not inhabit the areas at all.

It is important to realize that the correlations between the abiotic variables and CPUE were not significant when viewed on a small spatial (river section) and temporal (specific sampling run) scale; yet the physical habitat variables and the degree of hypoxia exhibited stronger relationships with CPUE when viewed from the scale of an entire river or canal and whole sampling season. These results are indicative of the integrative properties of a mobile, predatory fish. The effect of antecedent conditions are demonstrated by the fact that abiotic conditions for a particular time and space do not indicate what the abundance and distribution of goliath grouper will be. Although each river was subject to great variations in abiotic factors, it is the average value that has greater meaning with regard to fish abundance. As DO, salinity, water depth, and temperature vary, so does the fish's behavioral response and resulting fish abundance, but it is the integration of these responses throughout the year that result in the establishment of a home site for the goliath grouper and in the effectiveness of goliath grouper as an ecological indicator.

What is most surprising about this study is that the biggest differences in goliath grouper abundance were not between the canals and the rivers, considering the huge impact of the canals (particularly the Faka Union Canal) on freshwater input into the system. Rather, there was wide variation among the natural rivers, which leads to the question of why one river would provide more suitable habitat than an adjacent river. All the rivers in the study are downstream of the same Big Cypress Basin, but aerial photographs of the area help explain the differences among the rivers (see Figure 25.1). The rivers with the highest goliath grouper catch rate (Little Wood, Palm, and Blackwater) obviously separate from the rivers of low catch rate (Pumpkin, Wood, and Whitney). Little Wood, Palm, and Blackwater Rivers are all connected to natural bodies of water upstream. Mud bay connects Blackwater and Palm Rivers to each other and the upper Blackwater River is navigable almost all the way to U.S. Highway 41 (Figure 25.1). The upstream source of the Little Wood River is a rich labyrinth of streams and ponds within the mangrove forest, providing a vehicle for greater overall flow of oxygen and nutrients (Figure 25.1). These upstream areas may also be providing more habitat for goliath grouper to settle and/or grow over time. In addition, the productivity, while not measured in this study, is probably much higher in these upstream areas, yielding a rich food web that can better support juvenile goliath grouper and other fishes. The Pumpkin, Wood, and Whitney Rivers, on the other hand, all appear to lead to upstream dead ends, with little water flow coming into the rivers (Figure 25.1).

The CERP and specifically the SGGE restoration projects will have direct impacts on the habitat of the juvenile goliath grouper, as well as other juvenile fishes, in the Ten Thousand Islands. Precious little is known concerning the animals in the natural rivers and canals in the area, with the bulk of the research be the main driving affect on

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activities taking place in upland and freshwater areas. However, the restoration activities will surely affect areas downstream.

As the CERP and SGGE projects proceed, there will be an increase in the freshwater flow and somewhat of a return to the sheet flow of the natural system (Popowski et al., 2003). As canals are plugged and the freshwater flow is increased over time and space, there will be an immediate change in the patterns of salinity and DO. It is the increase in flow, providing more oxygen-rich waters to the rivers, that may result in an increase in goliath grouper. As the juveniles appear to settle throughout the system (personal observation) and then either emigrate from or die in the suboptimal habitats, there is potential for immediate effects of an improvement of water quality (DO and flow).

An increase in flow should also have longer-term effects, by changing the physical nature of the tidal rivers and providing new physical habitats (undercuts and rocky depressions). These physical changes will occur very slowly, however, as evidenced by the Whitney River that still retains its undercuts and holes, even though flow has been absent there for a long time. Possible medium-term effects may occur with an increase in upstream linkages throughout the system, as more water is allowed to fill dried-up depressions and creek beds. Eventually, if sheet flow is restored somewhat, other rivers, besides the Little Wood River, will have more extensive and productive upstream linkages.

Conclusions and Research Needs

There is a direct relationship between goliath grouper abundance and certain habitat and water quality variables that are integrated over time. As the Ten Thousand Islands estuary is restored somewhat to a more natural system, more freshwater flow should provide more oxygen, more productivity, and eventually the creation of more physical habitat for goliath grouper and other fishes. Although top-level predators may be at times difficult to use as indicators, the juvenile life history stage of this species is showing a direct response to water management. The fish is probably not limited by food resources but is limited by the quality of available habitat; therefore, changes in habitat should be reflected in changes in distribution and abundance of this species. It is easy to measure this effect because abundance alone can serve as the metric, and it is not necessary to measure physiological stresses. Also, by using a single species as an indicator of restoration, cause–effect relationships can be predicted and measured without using a complex food web or conceptual model.

It may be unexpected that a top-level predator's abundance would reflect the differences in attributes of these rivers, but it is reasonable to believe that when conditions are good enough for goliath grouper to thrive in an area, they are good enough for a number of yet-unstudied estuarine species to thrive also. Thus, the abundance of juvenile goliath grouper can be used as a performance measure of the Big Cypress Basin restoration work.

Much more information is needed, however, to understand restoration effects on goliath grouper and other co-occurring species. Baseline (pre-restoration) conditions must be quantified, particularly flow patterns in the rivers. Currently, only one of the rivers and one of the canals are being monitored for flow (Popowski et al., 2003). This study has demonstrated that each river is unique and that all have undoubtedly been affected by upstream water management. The entire system is "altered," not just the canals, and we cannot adequately compare one or two altered canals with one or two "natural" rivers without understanding whether the natural river is healthy or how it compares to the other rivers.

The study on goliath grouper in the tidal rivers and canals of the Ten Thousand Islands has provided some insight on how increased freshwater flow may affect the estuary's biota. This baseline information can be used to structure hypotheses to be tested as restoration activities proceed, even without a complete understanding of the complexity and variability of the system. Indeed, we will never comprehend all of the intricacies of a complex ecosystem. However, knowledge of the relationships between abiotic variables and the abundance of an important top-level predator, the juvenile goliath grouper, is a huge step forward in the ability to assess restoration success.

This study has demonstrated that discovering a few direct relationships between stressors (DO, bathymetry, erosion) and response variables (fish abundance) has given us information to predict responses to habitat change and ecosystem restoration. Although an estuary is a complex ecosystem with a large food web of interconnecting organisms, it is possible to find direct links between a predatory fish species and its nursery habitat. As a result, we can predict changes to fish distribution based on habitat changes. Fish are integrators of environmental change on different spatial and temporal scales, and while such integration may appear to cloud the situation, it actually provides us a more accurate depiction of the biological effects of habitat alteration and restoration.

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