2009
Final Report

Project Title: Developing Ecological Indicators for Managing Freshwater Inflows to the Loxahatchee River

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Background

Collapse of marine fisheries is widely acknowledged as one of the most critical global environmental crises. Many of these declines stem from aquatic habitat alteration and destruction, especially in estuarine ecosystems. The Loxahatchee River is no exception. Anthropogenic modifications to river habitats and the watershed as a whole have undoubtedly affected the quality of the river system as habitat for commercially and recreationally important fishes. Yet the river still has a diverse fish fauna and supports important fisheries (e.g., snook and gray snapper).

Fluctuations in abiotic conditions (e.g., salinity) likely have significant, yet extremely complex, effects on the ecology of the river system. For example, freshwater discharge into the Northwest Fork of Loxahatchee River is extremely variable from the wet to the dry season. The variable salinity patterns that result affect many specific ecological aspects of resident flora and fauna, but most of the results that currently exist are limited to long-term trends that have resulted following decadal-scale saltwater intrusion (see the Restoration Plan for the Northwest Fork of the Loxahatchee River for details).

Yet managing freshwater flows into the river requires a more detailed understanding of the short-term changes induced in the river/estuary following pulses of freshwater inflow. For example, do resident fishes respond behaviorally in predictable ways, such as distinct upstream or downstream movements? Do benthic organisms that reside in oyster reef habitat (and serve as critical prey species for gray snapper, snook and other commercially/recreationally important species) decline in abundance following freshwater inflows? And, if so, how predictable are these patterns? Are they directly in response to changes in salinity, or are they ingrained life history patterns? Without detailed baseline studies, and specific attempts to link these changes to underlying mechanisms that drive them, it will be impossible to adequately address the link between river/estuary ecology and freshwater discharges.

These questions are of pressing importance for management of the Loxahatchee River (and, more widely, throughout South Florida) because of planned "restoration" activities. In the case of the Loxahatchee, freshwater inflows are to be increased in the coming years in an effort to revert the system toward historical conditions. This research program is specifically designed to provide ecological information that will be critical to evaluate these proposed water management shifts.

We note that funding was designated for the support of Zachary Jud, a Ph.D. student at Florida International University. The project was designed to specifically examine ecological patterns in relation to freshwater inflow, yet still provide latitude for Zack to develop his own research directions. The contract from SFWMD was not initiated until February 2009, so we combined aspects of our long-term monitoring with data specifically collected under this contract from February-July 2009.

Research Components

Research under this contract focused around two core components in the Loxahatchee River: (1) benthic fauna associated with oyster habitat, and (2) the common snook (*Centropomus undecimalis*), perhaps the most important fishery in the river and estuarine system. The report is framed around these two components, and consists of the following sections:

I. Benthic fauna associated with oyster reef habitat
a. Bimonthly sampling of oyster-associated fauna in the Northwest Fork: seasonal patterns related to ambient salinity regimes.

b. Weekly sampling of oyster-associated fauna in relation to freshwater releases in the Southwest Fork.

c. Examine short-term behavioral observations to pulses of freshwater using individually-marked fauna.

II. Snook behavior in relation to freshwater inflows
a. Snook movement patterns in relation to freshwater inflows at an ecosystem scale.

b. Fish abundance in relation to freshwater inflow in the Southwest Fork.

c. *Snook feeding ecology in relation to freshwater inflow.*

I. Benthic fauna associated with oyster reef habitat

Benthic tray "traps" are a common approach to sample demersal fishes and invertebrates that utilize oyster reefs as habitat. These sampling units are plastic bakery trays (50 x 58 x 10 cm) with fiberglass sheet screening attached securely to the tray bottom. Prior to deployment, oyster shells were collected and dried in ambient air conditions. Shells were placed onto the bottom of each tray so that the entire tray bottom was covered. At each field site, an area equal to the dimensions of the tray trap was excavated and the trap placed into the excavated hole such that organisms can move laterally across the benthos and into a tray trap (Figure 1). Traps were left in place for 60 days and then collected. To collect organisms, the tray was lifted vertically, so that water ran through the fiberglass screening and the tray bottom, and benthic organisms and small demersal fishes remain within the tray trap among the oyster shells. All invertebrates were collected by hand, kept on ice in the field, and returned to the laboratory for identification and processing. Our focus was on assessing sessile (e.g., crabs) and motile (e.g., blennies) organisms that live among live and dead oyster shell.


Figure 1. A sampling tray filled with oyster shell (left) and a deployed tray at one of the river's natural oyster reefs (right).

a. Bimonthly sampling of oyster-associated fauna in the Northwest Fork: seasonal patterns related to ambient salinity regimes

Bimonthly sampling was conducted at three fixed locations across approximately two river miles: Boy scout Camp (BSC, Figure 2), Oyster Island (OI) and 7th Dock (7th). This sampling design allowed for both spatial and temporal pattern analysis. The "7th" dock site was added in January 2008. Collections were increased to monthly in May 2009, but results are presented here through March 2009. The more recent collections were not processed in time for this report.

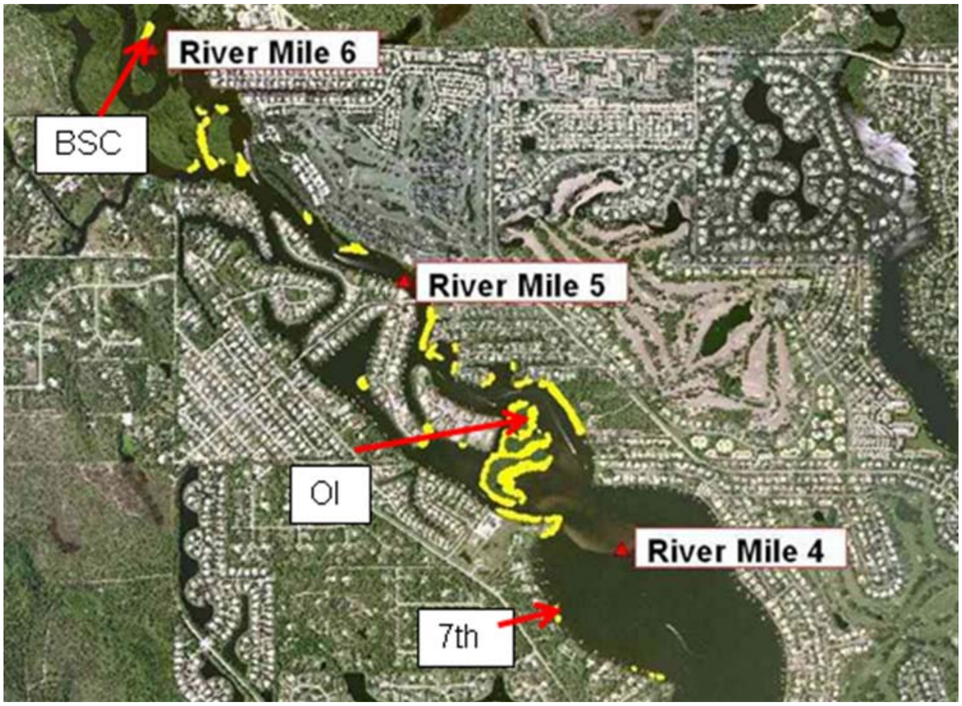

Figure 2. Sites sampled with the benthic tray methodology. Abbreviations are consistent with the following graphs.

The most obvious pattern that emerged from the first two years of data is that total organism biomass peaks at the onset of the wet season in July. The lowest biomass was typically found in November, the end of the wet season. This suggests that reduced salinity may be affecting the densities of certain oyster-associated fauna, perhaps through mortality, or a behavioral response in which the organisms migrate downstream. Six taxonomic groupings accounted for >96% of biomass across all sampling dates: *Panopeus* mud crabs, *Eurypanopeus* mud crabs, crested goby (*Lophogobius cyprinoides*), frillfin goby (*Bathygobius fuscus*), green porcelain crabs (*Petrolisthes armatus*), and *Alpheid* snapping shrimp. Two of these groups seem especially sensitive to salinity changes, the green porcelain crab and the frillfin goby (Figure 4 on following page). The most downstream site, "7th Dock", was characterized by the least temporal variation. This spatial pattern also suggests that salinity may drive abundance patterns, as the most downstream site would be exposed to the least freshwater influence.

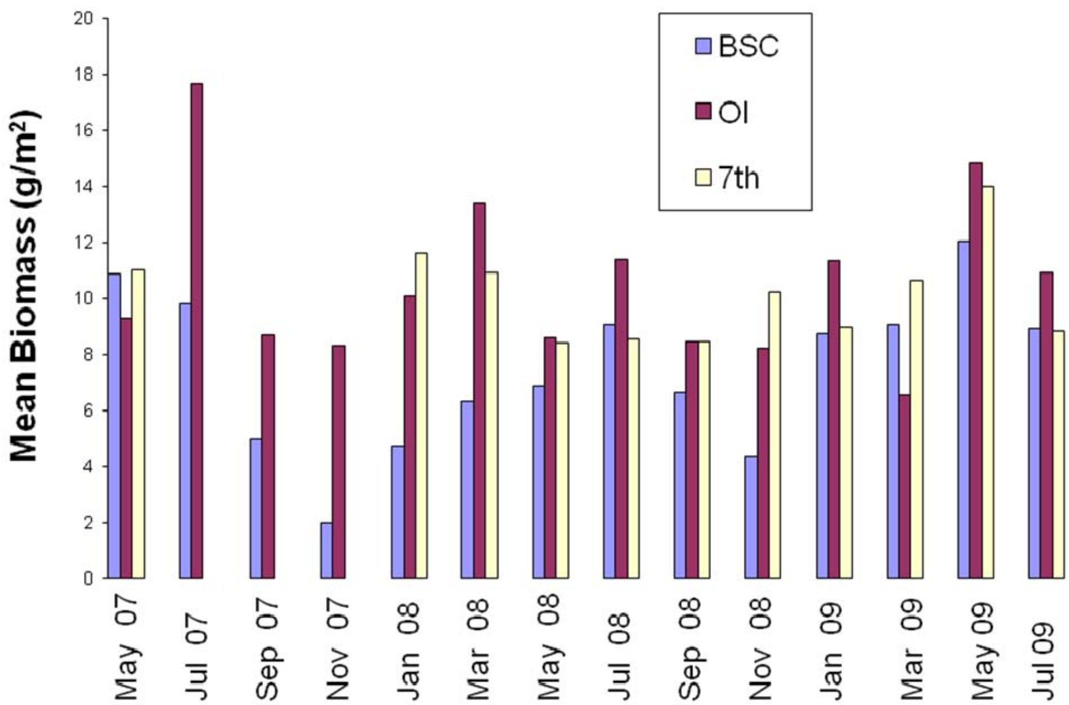

Figure 3. Mean biomass of benthic organisms in oyster reef habitat as estimated by the benthic sampling tray methodology. Color codes correspond to our three long-term monitoring sites spread across ~2 river miles (Boy Scout Camp, Oyster Island, and 7th Dock). Note that "7th Dock" became part of our regular sampling in January 2008.

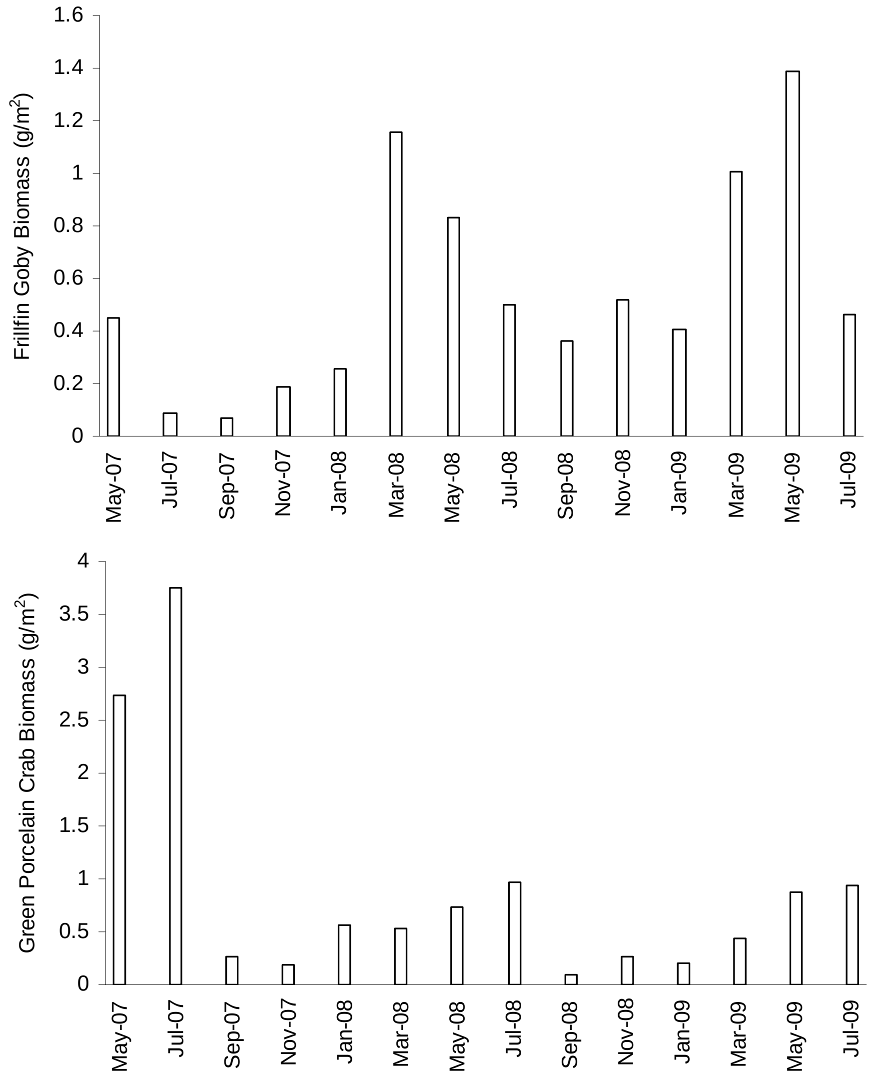

Figure 4. Mean biomass of frillfin goby (top panel) and green porcelain crab (bottom panel) summed across the three long-term oyster reef monitoring sites, as estimated by the benthic sampling tray methodology.

b. Weekly sampling of oyster-associated fauna in relation to freshwater releases in the Southwest Fork

Beginning in June 2009, oyster reef fauna was sampled weekly in the Southwest Fork. The purpose of this component of our study was to measure biomass and abundance of oyster-associated organisms at various freshwater inflow levels. Our monthly monitoring identified shifts in species composition between the wet season and dry season. We hoped to identify similar patterns on a much finer temporal scale. Five benthic tray traps were each filled with five gallons of live oysters (collected from adjacent oyster reefs). The trays were then pressed into the substrate every 25 m along a section of oyster-covered shoreline in the lower Southwest Fork. Trays were sampled each week, refilled with new live oysters, and returned to the river bottom. All samples were processed at Florida International University. Due to the timing of the planned and unplanned inflow events, we were not able to provide results in this report from additional weekly samples were collected during July and August 2009.

We were unable to establish a clear pattern between biomass of oyster-associated organisms and freshwater inflow (Figure 5). We plan to continue the study through the remainder of the wet season, with the hope capturing additional freshwater inflow events. A salinity data logger was installed just above the substrate at this study site to determine how salinity fluctuates along the benthos during freshwater release events. Based on field observations, it appears that short duration/moderate flow discharge events create a salt wedge in the Southwest Fork. From an adaptive management standpoint, we hope to identify a specific minimum discharge rate that causes salinity to decrease along the river's bottom. This flow rate may represent the point at which freshwater inflow becomes detrimental to oyster-associated fauna.

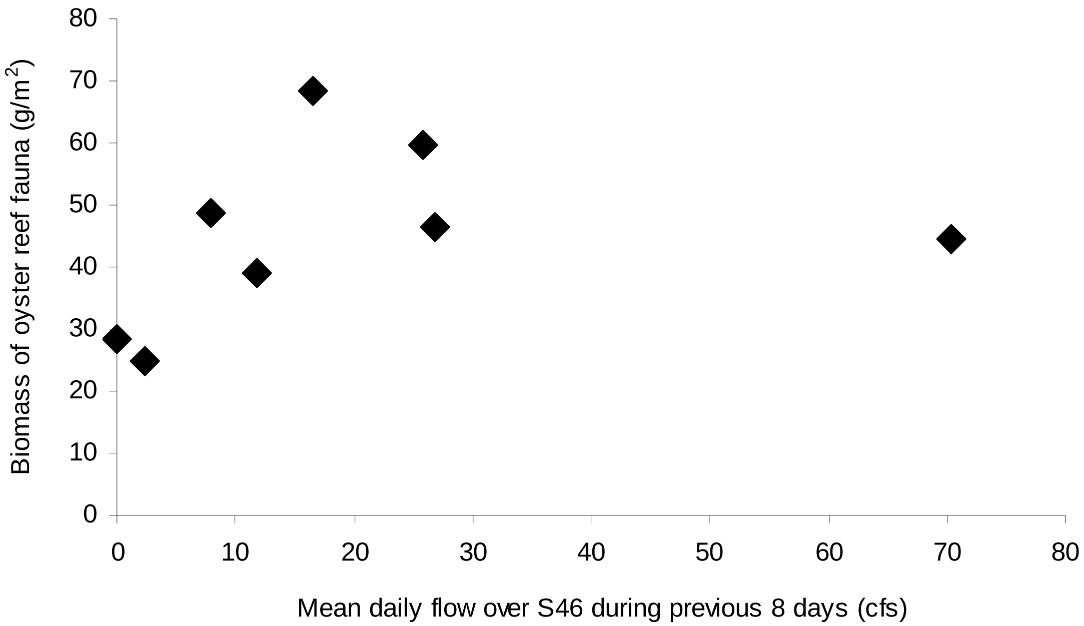

Figure 5. Freshwater inflow versus biomass of oyster reef fauna in the Southwest Fork of the Loxahatchee River. These data were obtained through our weekly benthic tray sampling in the lower Southwest Fork.

c. Using individually-marked fauna to examine short-term behavioral observations to pulses of freshwater

The bimonthly data (part a) suggested that particular organisms were especially sensitive to freshwater inflows. That is, in periods of high freshwater discharge into the Northwest Fork of the River, the abundance of some taxa (e.g., frillfin gobies, green porcelain crabs) decreased. As such, these taxa may be ideal "biological indicators" of the effects of longer-term changes of freshwater inflow into the system. Our monitoring design, however, did not provide the resolution with which to explicitly link organism abundance to freshwater flows (because the patterns may simply be seasonal life history phenomena that occur irrespective to the quantity of flow into the system). We plan to evaluate this possibility with a newly-developed protocol.

We collected (using additional trays deployed in other areas) two taxa that, based on our long-term monitoring data, appeared sensitive to inflows (porcelain crabs, frillfin gobies), and two that seemed insensitive to the ambient salinity regime (xanthid crabs, crested gobies). Each crab was marked with a dab of super glue and a color-coded thread, and the fishes were marked with a fin clip. This protocol was developed and tested throughout this summer. Ten individuals of each crab and four individuals of each fish were placed in each of five trays, and the trays deployed in oyster habitat of the Southwest Fork of the river. After three days, trays were sampled (by lifting them vertically so water runs through the screen lining and organisms remain in the trays), and samples returned to Florida International University for processing. We plan to test the hypothesis that "freshwater sensitive" organisms will decrease in abundance in periods of high inflow, but "freshwater tolerant" species abundance will remain relatively constant during the experimental periods (or slightly increase due to immigration from the surrounding oyster matrix). Our first paired trial suggested no impact of the freshwater release event, but this assessment was preliminary, and will require additional testing at various inflow levels.

II. Snook behavior in relation to freshwater inflows

In addition to seasonal patterns of abundance in resident benthic organisms, mobile organisms may also respond in specific ways to different levels of freshwater inflow. Accordingly, different flow regimes may induce fundamental changes in the basic ecology of the river food web. FIU explored this potential link using common snook (*Centropomus undecimalis*) as a model study organism. Because of the recreational and ecological relevance of this species in the Loxahatchee River system, more detailed information on factors that affect its behavior and population dynamics were needed. Three main research components were developed in 2009.

a. Snook movement patterns in relation to freshwater inflows at an ecosystem scale

As part of our 2008 pilot study, 16 common snook were acoustically tagged and tracked in the Loxahatchee River (many additional snook were tagged by FWC which we are monitoring as well). Based on preliminary data obtained during the pilot study, upstream movements in common snook may be related to increases in freshwater discharge. Snook tagged in the lower section of the estuary frequently made forays into the upper reaches of all three river forks. It was not uncommon for snook to make roundtrip movements on the order of several miles in a single day. Brief migrations to upstream sections of the river were often observed in conjunction with periods of increased freshwater inflow.

To follow up on these preliminary findings, an additional 10 common snook were acoustically tagged in late June and early July of 2009 (Table 1). All of these fish were tagged in the upriver section of the Southwest Fork, immediately downstream of the S46 structure. By tagging fish that were known to utilize the Southwest Fork, we hoped to increase the likelyhood of observing upstream movements while still maintaining a small sample size (due to the cost of tags). The 10 newly-tagged snook, as well as the 16 that were tagged last summer (and numerous snook tagged by FWC) were tracked throughout the summer of 2009. The number of individual snook present in the upper Southwest Fork during five day time intervals was plotted against mean daily freshwater inflow through the S46 flood control structure from February 19 – August 3 (Figure 6). Since we tagged numerous snook in the Southwest Fork during this time period, only previously-tagged snook (pilot study and FWC) were included in this data set. During the dry season, very few snook entered the Southwest Fork. Snook numbers began to increase following the first freshwater inflow event in early June. The greatest snook abundance in the upper Southwest Fork was observed in conjunction with the planned freshwater release event that occurred on July 6 – 8. Many of the snook that entered the Southwest Fork during the release event left shortly after freshwater inflow was cut off. To increase the spatial resolution of our acoustic monitoring, two new underwater receivers were installed in the Southwest Fork in July.

Table 1. Snook acoustically tagged in the upper Southwest Fork, summer 2009.

Tagging Date	Standard Length
June 30	870
June 30	475
June 30	800
July 3	840
July 3	890
July 3	625
July 3	570
July 3	670
July 7	630
July 7	915

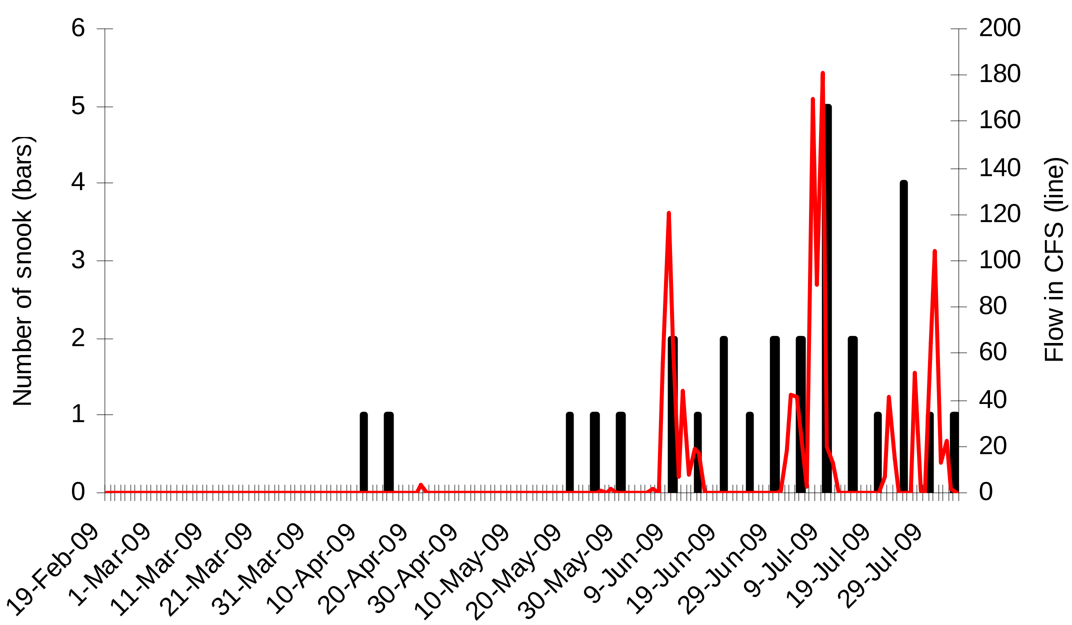

Figure 6. Number of acoustically-tagged snook present in the upper reaches of the Southwest Fork of the Loxahatchee River plotted against mean daily freshwater inflow through the S46 flood control structure, from February 19 – August 3, 2009. Each vertical bar represents the total number of unique snook detected in the area over the previous five days. See map below for the exact location of the acoustic receiver used to calculate snook abundance in this section of the river. All snook shown in this figure were tagged prior to 2009.

A similar movement pattern was observed in the lower and middle sections of the Northwest Fork. Unlike the Southwest Fork, water is supplied to the Northwest Fork through a flood control structure (G92) as well as a number of tributaries. Changes to inflow level in the Northwest Fork tend to occur more gradually, and remain elevated during most of the wet season. The number of individual snook present during five-day time blocks in the lower Northwest Fork, near Island Way Bridge, was plotted against mean daily freshwater flow over Lainhart Dam from February 19 – July 30 (Figure 7). A similar comparison was made further up in the Northwest Fork, within the boundaries of Jonathan Dickinson State Park (Figure 8). Since no new snook were tagged in the Northwest Fork during the summer of 2009, all snook detections were counted as snook moving up into the fork from downstream portions of the estuary. During the dry season, very few snook were present in either section of the Northwest Fork. As flow increased at the onset of the wet season, snook abundance in the Northwest Fork increased. This pattern was most apparent in the lower Northwest Fork; however snook do appear to move further into the fork during periods of increased freshwater inflow. It is important to note that the maximum flow over Lainhart Dam during this study period was less than 180 CFS. Much greater flow levels can occur during storm events. The response of snook to unusually high flows has yet to be determined.

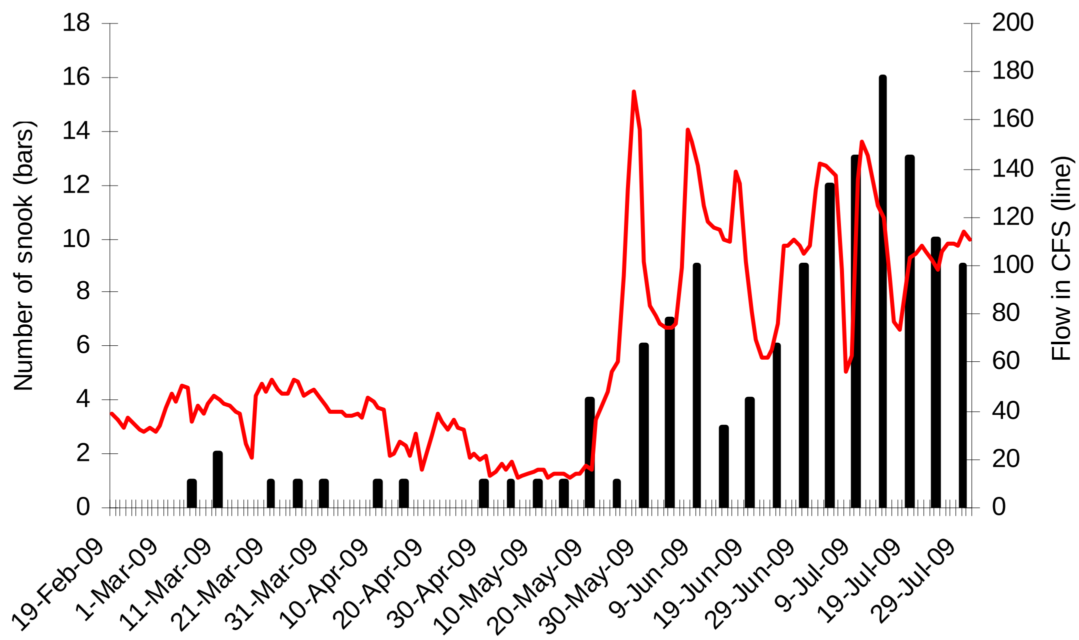

Figure 7. Number of acoustically-tagged snook present in the lower Northwest Fork of the Loxahatchee River near Island Way Bridge. Snook abundance is plotted against mean daily freshwater flow over Lainhart Dam, from February 19 – July 30, 2009. Each vertical bar represents the total number of unique snook detected in the area over the previous five days. See map for the exact location of the acoustic receiver used to calculate snook abundance.

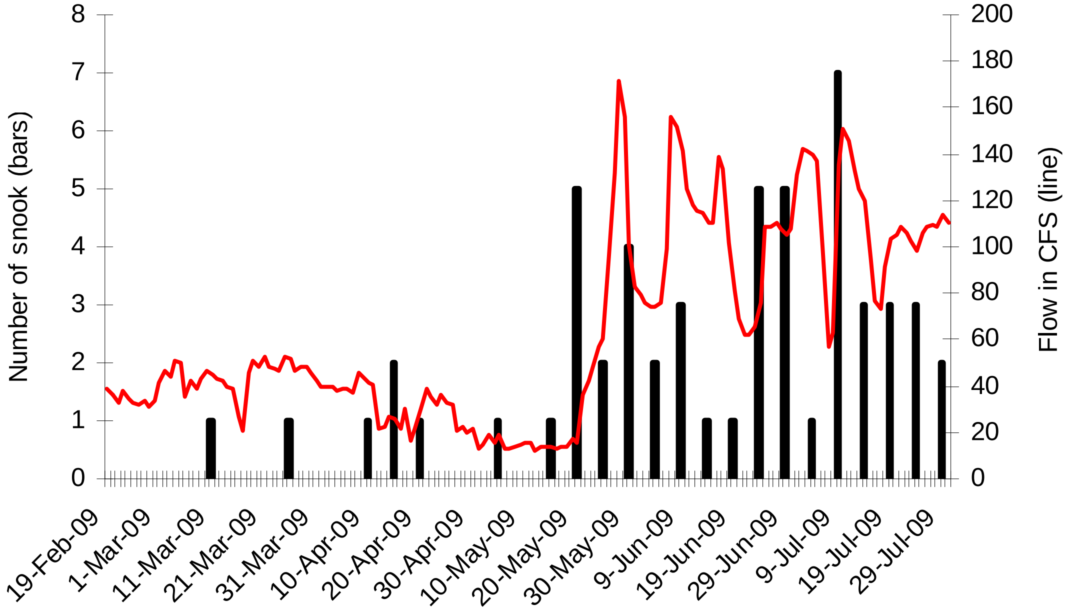

Figure 8: Number of acoustically-tagged snook present in the middle section of the Northwest Fork of the Loxahatchee River, in Jonathan Dickinson State Park. Snook abundance is plotted against mean daily freshwater flow over Lainhart Dam, from February 19 – July 30, 2009. Flow measurements include freshwater inflow through the G92 flood control structure, as well as contributions from upstream tributaries. Each vertical bar represents the total number of unique snook detected in the area over the previous five days. See map for the exact location of the acoustic receiver used to calculate snook abundance.

In addition to using acoustic telemetry to identify snook movement patterns in the Loxahatchee River, we deployed a 350 foot center bag seine (Figure 9) in the upper Southwest Fork on five occasions to directly measure snook abundance in that section of the river. The mean number of snook captured in each pull of the net was compared to the mean freshwater inflow level during the proceeding 72 hours (Figure 10). Although the acoustic telemetry data presented above are compelling, we were unable to establish a relationship between snook abundance and freshwater inflow in the Southwest Fork based on data collected while seining. A number of variables, including boat traffic, time of day, and operator error, can greatly reduce the number of snook captured in a seine net. Continued use of the seine at different levels of inflow may provide a more accurate estimate of snook abundance in the upper Southwest Fork.

Figure 9. Deploying the 350foot seine net in the upper Southwest Fork of the Loxahatchee River.

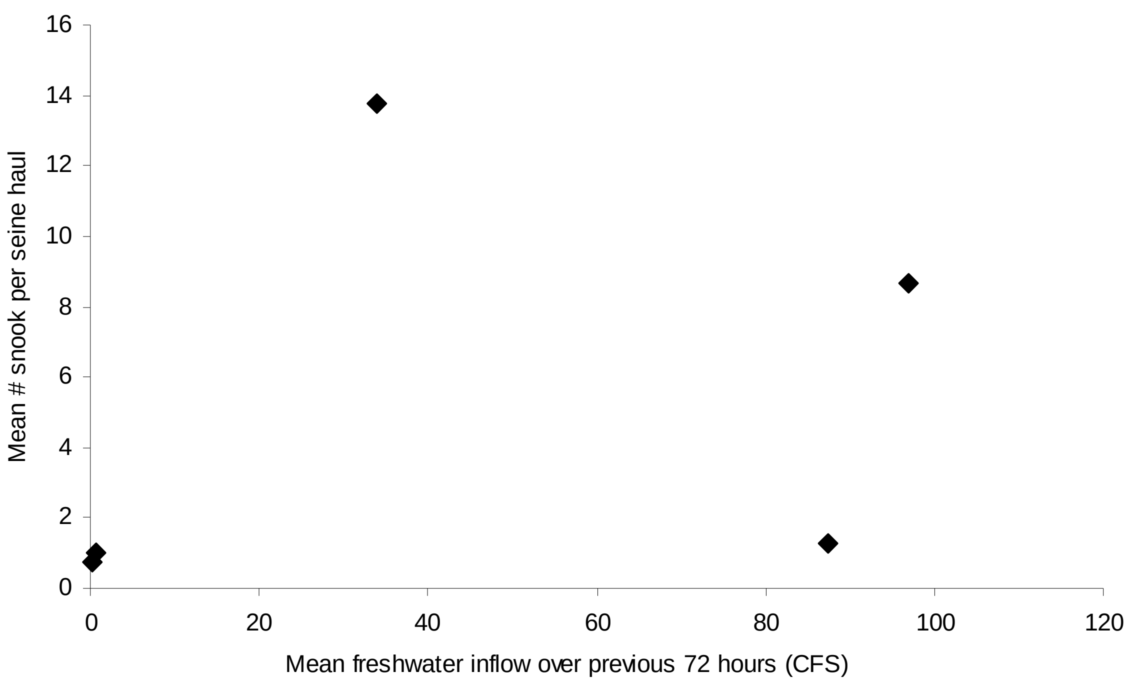

Figure 10. Mean number of snook captured in each seine haul in the upper Southwest Fork, as a function of freshwater inflow through the S46 flood control structure. Flow values refer to mean daily discharge over the previous 72 hours.

The 10 snook tagged during the summer were detected throughout the Loxahatchee River estuary. In order to better describe the movements of these fish, the river was broken down into seven different sections (Figure 11). In Figure 12, each horizontal row of symbols represents the movements of a single tagged snook. Each color-coded symbol represents a different section of the estuary. This format allows for simplified visualization of a single snook's movements throughout the river. It also permits us to compare the locations of multiple snook on a single date. It is interesting to note that the majority of the newly-tagged snook initially left the Southwest Fork between July 8 and July 10. These dates fell immediately after the controlled freshwater release event (July 6-8). Six of the tagged snook returned to the upper Southwest Fork between July 18 and July 20. All but one of the tagged snook spent time in Jupiter Inlet. Additionally, snook tagged in the Southwest Fork appear to spend time in the vicinity of Oyster Island.

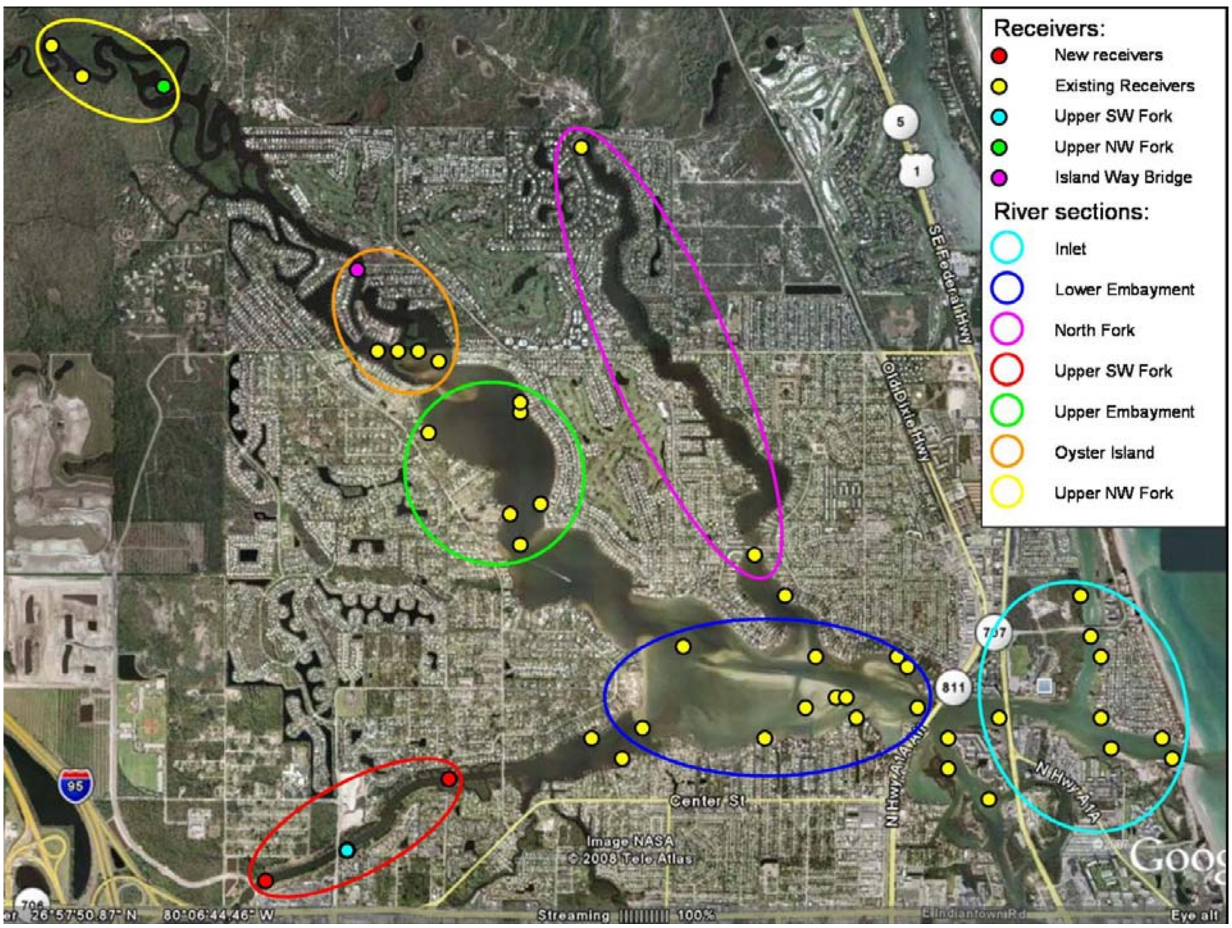

Figure 11: Map of the Loxahatchee River Estuary, showing the location of acoustic receivers. Receivers in the upper Southwest Fork (blue), middle Northwest Fork (green) and at Island Way Bridge (pink) were used to examine snook movement patterns with respect to freshwater inflow. Colored ellipses indicate distinct sections of the river for the benefit of discussing snook movements.

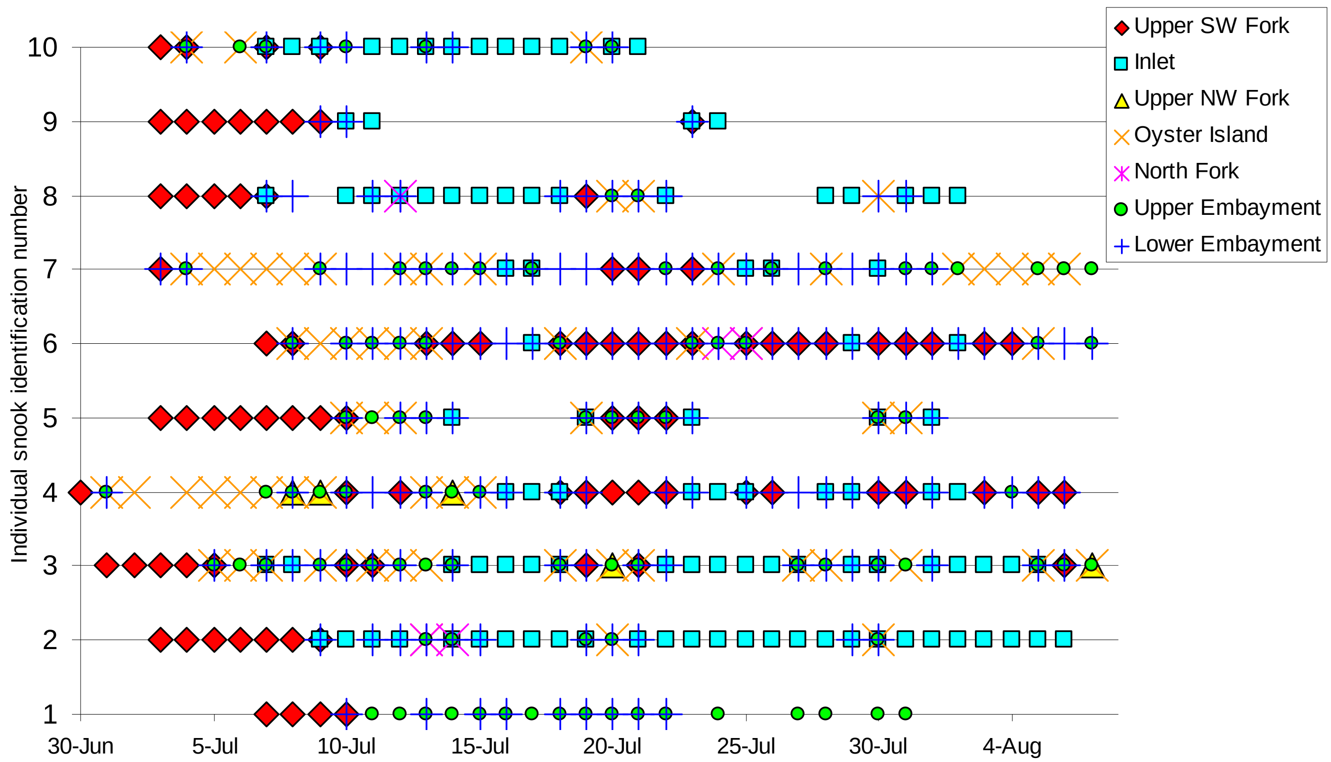

Figure 12. Individual movement patterns of the ten snook that were acoustically tagged in the upper Southwest Fork in summer. Each horizontal row of symbols represents the movements of a single snook. The color-coded symbols indicate different sections of the estuary. By following a single horizontal row from left to right, an individual snook's movements through the estuary can readily visualized. Looking vertically above a given date can reveal the location of all 10 fish at that particular time. Dates with multiple symbols correspond to rapid snook movement through the estuary. See map to identify the locations of the river sections referred to above.

b. Fish abundance in relation to freshwater inflow in the Southwest Fork

While the original intent of the 350foot seine was to capture snook for acoustic tagging and dietary analysis, we also used it to characterize the fish community in the upper Southwest Fork (Figure 13). During each seining event, all fish species were identified and measured. Fish community structure was observed to change over time. In samples collected on June 30th (before any major freshwater inflow) and July 3rd (during an initial period of low freshwater inflow), fish diversity and richness were high. A number of marine associated species were identified on these dates. During periods of high freshwater inflow (July 7th and July 9th), most of the marine associated species were absent from the upper reaches of the Southwest Fork. It appears that the initial pulse of freshwater through the system at the start of the wet season greatly affected fish community structure. Many of the species that were present prior to the reduction in salinity caused by freshwater inflow did not return to the upper Southwest Fork even after discharge had ceased (August 4th). Richness and diversity were much lower following periods of freshwater inflow.

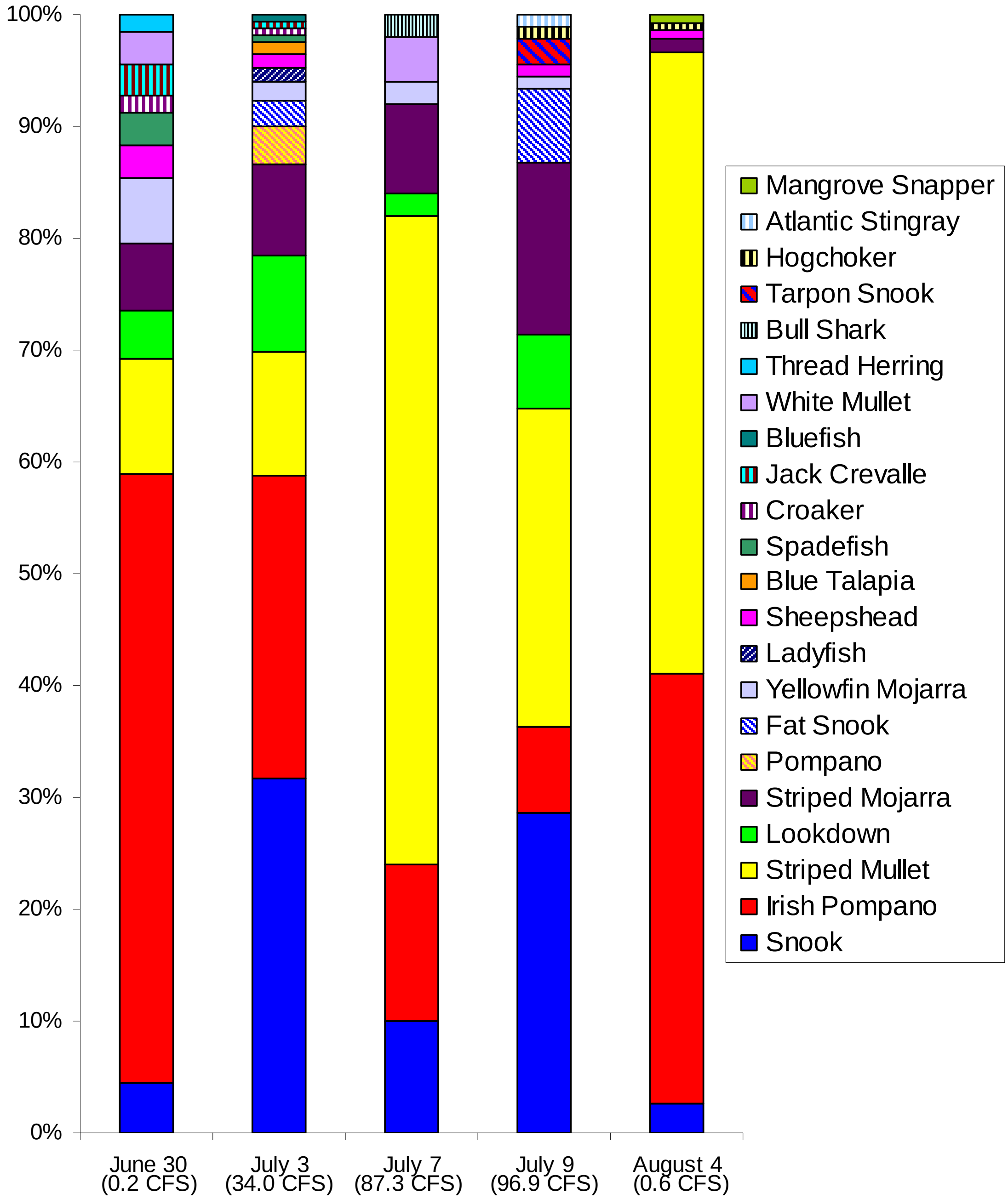

Figure 13: Fish species composition in the upper Southwest Fork at varying levels of freshwater inflow. Vertical bars represent the proportional contribution of each species to the total catch. Fishes were captured in a 350 foot seine net. Flow values refer to mean daily discharge over the previous 72 hours.

c. *Snook feeding ecology in relation to freshwater inflow*

A final component of our research in conjunction with the freshwater inflows was the collection of diet data from common snook, and the collection of fin clips from snook and many other fish species for stable isotope analysis. Snook and other fish species were collected in the upper Southwest Fork using a 350 foot seine net. Fin clips were taken from a subset of each species for stable isotope analysis (Table 2). Direct dietary analysis by means of non-lethal gastric lavage was also carried out on common snook captured in the seine (Figure 14). A semi-rigid plastic tube was introduced through the fish's esophagus and into the stomach. Ambient sea water was then pumped into the stomach, dislodging all stomach contents and forcing them out through the mouth. Prey items were collected in a sieve and frozen for later laboratory analysis. Preliminary analysis revealed that snook diets were dominated by anchovies, small herrings, and penaeid shrimp. The largest snook examined frequently had empty stomachs. Large mullet were the most abundant prey item consumed by snook larger than 700 mm.

Figure 14. Gastric lavage pump designed to dislodge stomach contents without harming snook.

Table 2. Complete list of all fish species captured while seining in the upper Southwest Fork of the Loxahatchee River. Fin clips were taken from a subset of each species for stable isotope analysis. Gastric lavage was attempted on 41 common snook. Fourteen of these fish contained food items in their stomachs.

	Total # captured	**# of fin clips taken for isotope analysis**	**Gastric lavage attempted**	**Stomach contents obtained**
Striped Mullet	166	49		
Irish Pompano	157	62		
Common Snook	93	81	41	14
Striped Mojarra	38	29		
Lookdown	25	21		
Fat Snook	10	8		
Yellowfin Mojarra	9	9		
Pompano	6	6		
Sheepshead	6	6		
White Mullet	4	4		
Spadefish	3	3		
Jack Crevalle	3	2		
Ladyfish	2	1		
Blue Talapia	2	2		
Croaker	2	2		
Tarpon Snook	2	2		
Hogchoker	2	2		
Bluefish	1	1		
Thread Herring	1	1		
Bull Shark	1	1		
Atlantic Stingray	1	1		
Mangrove Snapper	1	1		
Total:	**535**	**294**		

Because many of the isotope and diet samples were collected around the time of the freshwater release events (i.e., mid to late summer), there was not sufficient time for analysis. These samples will be analyzed this fall in our laboratory at FIU

FIU will also use the $\delta^{13}C$ gradient as a means to estimate what proportion of both adult common and fat (*Centropomus parallelus)* snook utilize freshwater habitats in their post-larval and early juvenile stage. This is especially important for fat snook, as their habitat utilization during this ontogenetic period is unknown. To explore this habitat utilization we will follow the approach of Verweij et al. 2008 (*Limnology and Oceanography* 53:1540-1547). The early juvenile portion of the otolith (i.e., the portion of the otolith laid down during growth in the post-larval stage) from adult common and fat snook will be isolated and analyzed for $\delta^{13}C$. At present, the otoliths of 13 fat snook have been obtained through collaboration with FWC, and we have standardized the protocol with the Yale Stable Isotope Laboratory. Based on the clear gradient of isotopic signatures from marine to freshwaters, FIU will be able to estimate the proportion of adult fishes that utilized different portions of the river habitat as juveniles.

Conclusion

An intensive summer of field and laboratory work allowed us to begin to elucidate the role that freshwater inflow plays in the lower Loxahatchee River ecosystem. While our long-term monitoring of oyster-associated fauna suggested that organismal biomass declines during the wet season, this pattern was not as apparent in our weekly results. Within the range of freshwater inflow experienced during the summer of 2009, the per $meter^2$ biomass of oyster-associated fauna appeared to remain relatively stable. We attribute this to the continuous presence of a salt wedge in the lower Southwest Fork, which essentially shielded benthic organisms from the overlying freshwater layer. Since oysters and oyster-associated organisms are often sensitive to low salinity, the exclusion of this salt wedge during periods of extremely high freshwater inflow may have detrimental effects on the oyster reef ecosystem. In our continuing research, we hope to identify critical inflow rates that correspond to declining biomass in oyster-associated organisms.

While benthic organisms were relatively unaffected by the freshwater inflow rates experienced during the summer of 2009, fish community structure varied considerably at different inflow levels. Fish diversity in the upper Southwest Fork was greatest prior to the onset of the wet season. Following the first freshwater inflow event during the summer of 2009, the number of fish species found in the upper Southwest Fork declined. The fish community in the upper Southwest Fork was dominated by just a few species during the wet season. Acoustic telemetry data suggest that common snook responded acutely to each increase in freshwater discharge, moving upriver during or shortly after periods of higher inflow. Although continued sampling is required to fully understand the effects of freshwater inflow on fishes, it is immediately clear that fish community structure is strongly driven by salinity and inflow levels. As we continue to monitor fish abundance and snook movements in response to freshwater inflow, we hope to identify patterns that may allow for enhancement of the fishery through adaptive management of freshwater inflow.