EXAMINING SEASONAL MOVEMENT AND HABITAT USE PATTERNS OF ADULT COMMON SNOOK

By

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To my mother, father, and sisters for their unconditional love and support.

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The common snook, *Centropomus undecimalis*, is an ecologically and economically important estuarine dependent predatory fish species found throughout south Florida. Despite increasingly restrictive management actions over the past 50 years, common snook populations are thought to have declined. Possible reasons for this decline are high harvest rates and loss of essential habitat related to coastal development. I evaluated habitat use and movement patterns for adult snook in seasons with and without large-scale environmental (red tide blooms) and anthropogenic (dredging) disturbance events. Results of my study support much of the literature on snook life history while providing new behavioral information regarding movement, site fidelity, and habitat disturbances. My study provides important information for conservation management purposes and improves the understanding of direct and indirect effects of habitat threats associated with anthropogenic and environmental disturbances on snook populations. This understanding of habitat-species relationships is important because of the emphasis placed on managing habitat by various State and Federal agencies for the conservation of fish and wildlife resources.

CHAPTER 1
INTRODUCTION

Development and implementation of successful conservation and management strategies for terrestrial and aquatic organisms relies on a sound understanding of their ecological requirements. In recent years, increasing attention has been given to the habitat conservation approach with the motivation that protecting habitat will ensure population viability. This approach, in fact, is a major component of many State and Federal mandates, including the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) for essential fish habitat (EFH), which requires using a habitat-oriented and ecosystem-based approach to develop effective management and conservation plans.

Sufficient habitat is a necessary requirement for survival of wildlife and aquatic populations (Morrison et al. 1992). Management of fisheries resources typically follows two approaches: (1) regulating harvest to maintain sustainable populations and (2) preserving and improving species' habitats through protective or restoration measures. In the United States, the development of "ecosystem based management", where these two approaches are integrated into a single management strategy, has become the mandate for fisheries management (NRC 2006).

For ecosystem based management to be successful, an adequate understanding of the relationships between species and their habitat is necessary (Knapp and Owens 2005). This requires a thorough understanding of the types of habitats required for a species to live at all life stages, preferably through quantitative exploration of the species' resource use patterns (Oppel et al. 2004). As resources may include anything that an animal may ultimately require, such as foraging, refuge, and rearing habitats, monitoring patterns of interaction between species and their habitat may ultimately provide insight into the dynamic factors that drive viable populations. These patterns are directly related to individual behavioral choices regarding movement and habitat interactions.

In developing effective management strategies for a fishery, it is important to identify the linkages between individual fish behavior and habitat resources in order to understand the implications of anthropogenic and environmental disturbances on populations. Physical disturbances related to coastal development, such as dredging and shoreline modification, are readily visible and obvious examples of habitat modification. However, less consideration is given to environmental disturbances such as harmful algal blooms (HABs e.g.; "red tide blooms"). HABs have been linked to widespread fish and marine mammal mortality events and are thought to be increasing in frequency and duration across much of southwest Florida (Mahadevan et al. 2005).

HABs represent a unique case of habitat loss as they do not necessarily result in the loss of structural habitat. However, HABs may make otherwise suitable habitat unusable (or even lethal) for extended periods of time. Red tide blooms, because of their toxic nature, are likely to force fish and other species to occupy sub-optimal habitats or elicit emigration from the system to areas not affected by the HAB event.

Physical habitat alterations that result from dredging and development and other environmental disturbances such as HABs can have large impacts on fish populations. Reductions in growth, for example, can lead to lower fecundity and even survival rates which, in turn, can have marked population-level consequences. To understand the mechanisms that cause these population-level impacts, it is important to recognize behavioral choices and potential bet-hedging strategies demonstrated by individuals. Individual choices related to survival may include variable movement patterns or the use of alternative habitats to reduce an individual's risk of predation, vulnerability to fishing, or susceptibility to lethal conditions. Thus, it is critical to understand the interactions between a species and its habitat for effective conservation and management purposes.

In general, the best method to identify habitat use and movement by an animal is through direct observation (White and Garrott 1990). When this is not feasible, which is often the case with aquatic organisms, acoustic tracking techniques via telemetry can provide an adequate substitute. Telemetry studies provide insight into spatial and temporal use of habitats and can be a first step in identifying EFH (Arendt et al. 2001). In the case of fishes, telemetry provides spatial and temporal tracking of individual movement and habitat use patterns which may ultimately reveal the most ecologically important habitats (Savitz et al. 1983). This method provides insight about key behaviors such as foraging (Heithaus et al. 2002), activity patterns (Jadot et al. 2006), seasonal movement and site fidelity (Jackson and Hightower 2001). It also provides a means to estimate home ranges (Morrissey and Gruber 1993) and mortality rates (Bennett 2006). Ultimately, combining seasonal movement and site fidelity information with habitat-specific mortality estimates (both natural, M, and fishing, F) can facilitate predictions regarding the effects of habitat alterations on survivorship.

Acoustic telemetry was used in this study to examine seasonal movement and habitat use patterns of adult common snook, *Centropomus undecimalis.* Common snook are an ecologically and recreationally important apex predator found throughout the tropical Caribbean basin including south Florida. In Florida, snook are abundant along the Gulf of Mexico coast from Tampa Bay south to the Florida Keys and north to Cape Canaveral along the Atlantic coast (Muller and Taylor 2006). Throughout different life stages snook use a range of habitats from offshore reefs to inland lakes and are generally considered diadromous (Rivas 1986). As snook grow they tend to move from shallow riparian habitats to seagrass meadows, mangrove fringe, and deeper estuarine areas (Gilmore et al. 1983). Adult snook often make use of passes from estuarine waters into the open ocean for spawning (Muller and Taylor 2006). Despite the species' broad use of habitat types, the overall distribution of adult snook has been found to be highly correlated with the distribution of mangrove habitat (Gilmore et al. 1983). In addition, snook are considered to be a cold water sensitive species with lower lethal temperature limits between 6-13°C (43-55°F) (Marshall 1958; Howells et al. 1990). To avoid these lethal temperatures during cool winter months, snook tend to seek thermal refuge in the warmer waters of creeks and canals.

Acoustic telemetry was used in this study to examine seasonal movement and habitat use patterns with the ultimate goal of gaining a better understanding of the ecological relationships between a population of adult common snook and a variety of habitats within a large estuary in southwest Florida. Relocations of individual adult snook were used to identify "key" habitats that provide essential information needed to improve conservation management plans. I was particularly interested in answering the following research questions:

- **Question 1**: Do snook demonstrate variable seasonal movement and habitat use patterns?
- **Question 2**: Do individual snook exhibit site fidelity in specific habitat type and location?
- **Question 3**: What are the impacts of large scale disturbance events on movement patterns and habitat use?
- **Question 4**: Can inferences be made regarding survivorship by examining individual movement and habitat use patterns of fish with known mortality fates?

Questions 3 and 4 were specifically related to an unusually large red tide bloom (*Krenia brevis*) that occurred in summer 2005, and a dredging project in a tidal creek system (Whitaker Bayou) that began in late fall 2005. The red tide event provided a natural experiment to examine snook movement and habitat use patterns before, during, and after the red tide bloom.

Concurrent with this study and the red tide bloom it was found that annual natural mortality rates were much greater than the natural mortality rates currently used in the snook stock assessment (Pine et al. 2007). Similarly, the dredging project provided an experimental opportunity to examine snook movement and habitat use patterns in relation to physical habitat alteration. From previous quantitative sampling, Whitaker Bayou is thought to be a prominent nursery habitat and wintering area for both juvenile and adult snook (Brennan et al., in press). A layer of flocculent organic material in this system provides warmth during winter months due to decomposition and solar warming. Both “experiments” provided the opportunity to examine the impacts of environmental and anthropogenic disturbance events on habitat use and movement patterns of adult snook, which may have affected an individual’s likelihood of survival.

CHAPTER 2
MATERIALS AND METHODS

Study Site

Sarasota Bay (Figure 2-1) is a moderately sized, subtropical estuary located along the southwest Florida coast. Sarasota Bay was identified as an Estuary of National Significance in 1987 by the United States Congress and has since been included in the National Estuary Program. Sarasota Bay is approximately 44 km in the north-south direction and includes an area of about 114 km^2. Sarasota Bay and its associated tidal tributaries, sub-bays, and canals are separated from the Gulf of Mexico by a series of narrow barrier islands, including Casey Key, Siesta Key, and Longboat Key, and connect with the Gulf through a series of narrow passes.

All sampling for this study was conducted between Cortez Bridge (Cortez, Florida) and Albee Bridge (Venice, Florida) at the southernmost extent of the bay, just north of Venice Inlet (Figure 2-1). Within Sarasota Bay proper, there are three passes connecting Sarasota Bay and the Gulf of Mexico (Longboat Pass, New Pass, and Big Pass), as well as five major tidal tributaries (Bowlees Creek, Whitaker Bayou, Phillippi Creek, North Creek, and South Creek, Figure 2-1). This study focused only on the waters of Sarasota Bay and did not include nearshore areas of the Gulf of Mexico.

Determining Movement and Habitat Occupancy

During fall 2004, 75 adult common snook were surgically implanted with a uniquely coded, long-life (700-day), Vemco® acoustic telemetry tag (Vemco Ltd., Shad Cay, Nova Scotia, Canada). Three angler returned tags were later reused and implanted in newly caught snook (April 2005). These fish were referred to as “batch 1”. In summer 2006, five angler returned tags and one tag retrieved from a fish believed to have died of natural causes (red tide bloom), were reused to tag other adult snook. During this time, an additional 25 adult snook were tagged with 180-day tags. The group of fish (n=31) tagged in the summer 2006 was referred to as "batch 2". All snook were tagged and released at the original site of capture.

Tagged snook were relocated using an array of underwater, autonomous VEMCO® VR2 receivers (Vemco Ltd., Shad Cay, Nova Scotia, Canada). Acoustic receivers were programmed to record the unique tag code, date, and time when a tagged snook was within the monitoring range of the VR2. Listening stations were positioned strategically throughout Sarasota Bay including the northern and southern extreme portions of the bay, passes, and major tidal tributaries (Figure 2-2). Data from the VR2s was retrieved on an 8 to 12 week schedule between October 2004 and March 2007. At least 29 receivers were constantly deployed in Sarasota Bay during the study period as part of this and other cooperative projects with Mote Marine Laboratory, Sarasota, Florida.

Snook were also relocated manually using a Vemco® VR100 receiver and directional hydrophone. These active searches were designed to "sweep" major areas of Sarasota Bay not covered by the VR2 array. Two tracking methods were used: (1) a "hopscotch" method in which tracking was conducted along the entire shoreline of the bay at 300 m intervals and (2) a search method in which random GPS points were selected to monitor all areas of the bay. Manual tracking efforts were conducted opportunistically from fall 2004 to winter 2006 with the largest amount of effort occurring during summer 2005.

Defining and Monitoring Available Habitats

An existing classification of available habitat types in Sarasota Bay, developed for the Sarasota Bay National Estuary Program (SBNEP) (Serviss and Sauers 2003) was used to define four distinct habitat types: creek, mangrove, open bay, and pass (Table 2-1). Habitat types for individual VR2 monitoring stations were assigned by overlaying VR2 GPS coordinates onto pre-existing GIS data layers. Each VR2 was given a numerical assignment based on its location, a descriptive name and an associated habitat type (Table 2-2). The percent area of each habitat type monitored was calculated as:

$$\frac{area_{VR2habitatX}}{total\_area\_monitored} * 100 \qquad (2\text{-}1)$$

where $\text{area}_{\text{VR2habitatX}}$ is the area of a monitored habitat type *X* with VR2 receiver coverage and total area monitored is the sum of the area of all habitats monitored within theVR2 array (Table 2-3). The variable $\text{area}_{\text{VR2habitatX}}$ was calculated as:

$$N * \pi * r^2 \qquad (2\text{-}2)$$

where N is the number of receivers in the specific habitat, and r was the radius of the VR2 detection range (150 m) as determined from a series of range tests (Bennett 2006).

Analyses

Assessing Seasonal Movement and Habitat Use Patterns

I summarized seasonal movement for individually tagged snook using relocation data from the VR2 array. Relocation data was infrequent from the manual tracking efforts, therefore, I did not include it in the analyses. I plotted individual movement patterns within the bay system to determine if snook exhibit distinct seasonal movements. I used individual movement patterns to describe generalized patterns exhibited by the population. I also used the relocation data to compare seasonal habitat use patterns for the population of tagged snook in Sarasota Bay with previously documented snook life history information. Habitat use was characterized by "fish-days". A fish-day was defined as an individual date that a fish was recorded by a VR2 in a given habitat location (creek, mangrove, open bay, or pass). Consequently, as it was possible for a fish to occupy the four different habitat types in one day, an individual fish could have potentially contributed up to four fish-days per 24 hour time period. Figure 2-3 depicts an example of fish-days, based on daily relocations, for an individual fish over a three month time period. An example where this particular fish, 1936, contributed two fish-days to the analyses, were on December 25, 2004 and March 15, 2005, where this fish was relocated in two different habitat types (mangrove and pass) on the same day. Two or more relocations, or "hits" at a VR2 were required to count as a fish-day to eliminate spurious detections that are sometimes recorded by a VR2 from electronic equipment, marine mammals, or other noise sources (Clements et al. 2005; Heupel et al. 2006; Klimley et al. 1998).

A series of χ^2 analyses were conducted to determine: (1) if there was a seasonal effect on habitat type use, i.e. were habitat use and season independent, and (2) if there was a difference between observed and expected habitat use for each season and year. Expected habitat use was defined as:

$$\frac{area_{VR2\,habitatX}}{total\_area\_monitored} * N_{fish-days} \tag{2-3}$$

where $N_{\text{fish-days}}$ was the total number of observed fish-days in a season. Observed habitat use was the sum of the total number of fish-days recorded for each habitat per season.

The χ^2 test statistic was calculated as:

$$\chi^2 = \sum_{i=1}^{k} \frac{(f_i - \hat{f}_i)^2}{\hat{f}_i} \tag{2-4}$$

where f_i is the frequency, or number of counts, observed in class i (habitat type), and $\hat{f}_i$ is the frequency expected in class i if the null hypothesis is true (Zar 1999). All χ^2 tests were conducted using the Statistical Analysis System (SAS Institute 1996) and Microsoft Excel.

Seasons were defined by average monthly water temperatures (Table A-1). Year 1 began in fall 2004 and included the winter, spring and summer seasons that followed. Relocations during this time were from batch 1 fish only. Year 2 began in fall 2005 and included the following winter, spring and summer seasons. Relocations during this time were from batch 1 fish and batch 2 fish (beginning in the summer season). Year 3 began in fall 2006 and included the following winter season. Relocations during this time were primarily from batch 2 fish as the battery life of the tags from the majority of batch 1 fish had expired.

Site Fidelity

Relocations of individual fish were examined to determine if site fidelity was evident based on the original capture habitat and location compared to other similar and different habitat types. Relocations were grouped by habitat type and characterized by fish-days per individual fish. To determine site fidelity at the original capture location, I required that only fish released within the detection range of a VR2 be considered in the analysis. I calculated percent fish-days spent at the site of capture for each individual snook included in the analysis. I inferred high site fidelity if the percent of fish-days was highest at the original capture habitat and location, for the entire time a fish was monitored. I also assessed individual creek site fidelity for fish captured specifically in Bowlees Creek (n=6 fish) and Whitaker Bayou (n=9 fish) and the single fish captured in South Creek.

Impacts of Habitat Disturbance on Movement and Habitat Use

I estimated habitat use by summing the total number of fish-days in each habitat per season to determine if there was a difference in habitat use, based on percent fish-days, that may be related to the red tide bloom or the dredging treatments. For the red tide bloom, I examined habitat use within passes between the summer of this event (2005) and the summer of the following year (2006) when the duration of elevated red tide cell counts was shorter (Figure A-1). Snook use pass habitats as spawning sites in the summer and are known to aggregate in these areas for several weeks each year. Pass habitats also often have high red tide cell count levels because of their proximity to the Gulf of Mexico. I expected percent habitat use in passes to increase in summer 2006 relative to 2005 because the duration of red tide cell counts exceeding a level that is considered lethal to fish (200,000 cells/liter) was higher in 2005 than in 2006. I expected snook to avoid passes during the high red tide events.

To assess the impact of dredging, I examined if the dredging event which occurred in Whitaker Bayou led to differences in percent habitat use before and after the event between the five tidal creeks. Snook are a cold water sensitive species (Marshall 1958) and Whitaker Bayou is a prominent wintering area for snook (Brennan et al., in press). Therefore, I expected habitat use to increase in other creek systems and decrease in Whitaker Bayou, particularly due to the lower water temperatures within Whitaker Bayou compared to other creek systems, after dredging began (Figure 2-4).

Relating Movement and Habitat Use Patterns with Survivorship

I examined habitat use and movement patterns of fish with known mortality fates (fishing or natural). This included nine fish that were caught and had tags returned by anglers, and one fish believed to have died as a result of the red tide bloom in summer 2005. I calculated the mean "days-at-liberty" for the fish harvested by anglers and compared patterns among fish with fewer days-at-liberty (<150 days) to those with a mean days-at-liberty ≥ 150 days. Days-at-liberty was defined as the number of days a fish was known to be alive post-capture, tagging, and release.

Table 2-1. Total area (m2) and percent available for each habitat type in Sarasota Bay, Florida.

Habitat type	Area m^2	Percent available
Creek	4236249	2.95
Mangrove	9470858	6.58
Open Bay	127673723	88.78
Pass	2425627	1.69
Total	143806459	100.00

Table 2-2. VR2 habitat location with assigned numerical location, indicating geographical position around Sarasota Bay, and associated VR2 habitat type.

VR2 site	Numerical assignment	Habitat type
Longboat Moorings (LBMM)	1	Open bay
Longboat Pass	2-4	Pass
Cortez Pass	5-7	Pass
Tidy Island	8	Mangrove
Bayshore	9	Mangrove
Bowlees Creek (mouth)	10	Creek
Bowlees Creek (inside)	11	Creek
Haunted House	12	Open bay
Johnny Pilings	13	Open bay
Whitaker (mouth)	14	Creek
Whitaker (inside)	15	Creek
Fountain	16	Open bay
Hudson Bayou	17	Mangrove
Siesta Islands	18	Mangrove
Phillippi ICW	19	Mangrove
Phillippi Creek	20	Creek
Coral Cove	21	Open Bay
North Creek Outer	22	Mangrove
North Creek Tunnel	23	Creek
North Creek Pilings	24	Creek
North Creek Upper	25	Creek
Spanish Point	26	Mangrove
South Creek (mouth)	27	Creek
South Creek (inside)	28	Creek
Pops Dock	29	Pass
Big Pass	30-32	Pass
Sunken Barge	33	Mangrove
Backdock	34	Mangrove
New Pass	35-36	Pass

Table 2-3. Area (m^2) and percent area monitored by VR2s for each habitat type in Sarasota Bay, Florida.

Habitat type	Number of VR2s	Monitored area m^2	Percent Monitored
Creek	10	706500	16.68
Mangrove	9	635850	6.71
Open Bay	4	282600	0.22
Pass	12	847800	34.95
Total	35	2472750	1.71

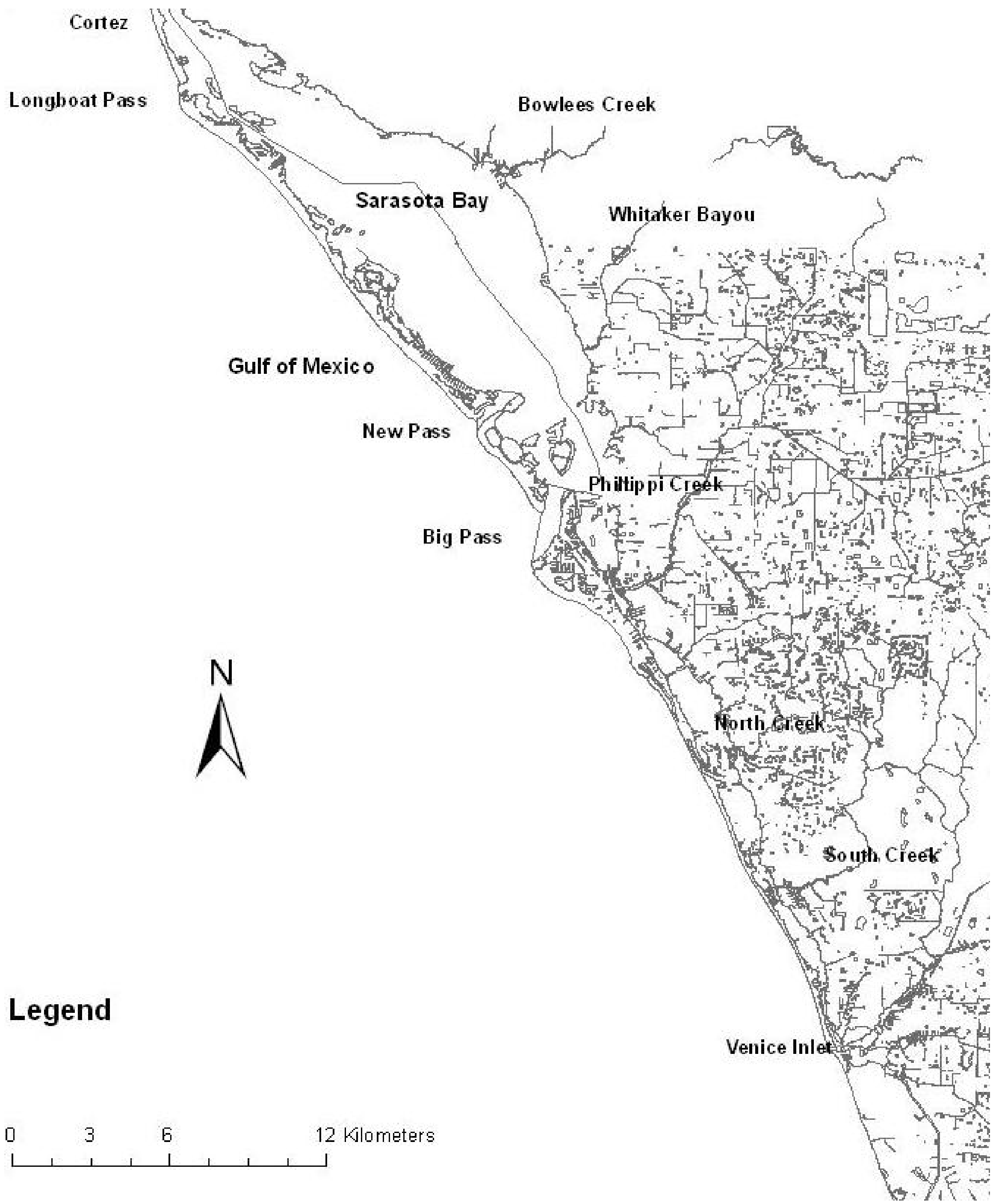

Figure 2-1. Sarasota Bay, Florida highlighted with major tidal tributaries and passes.

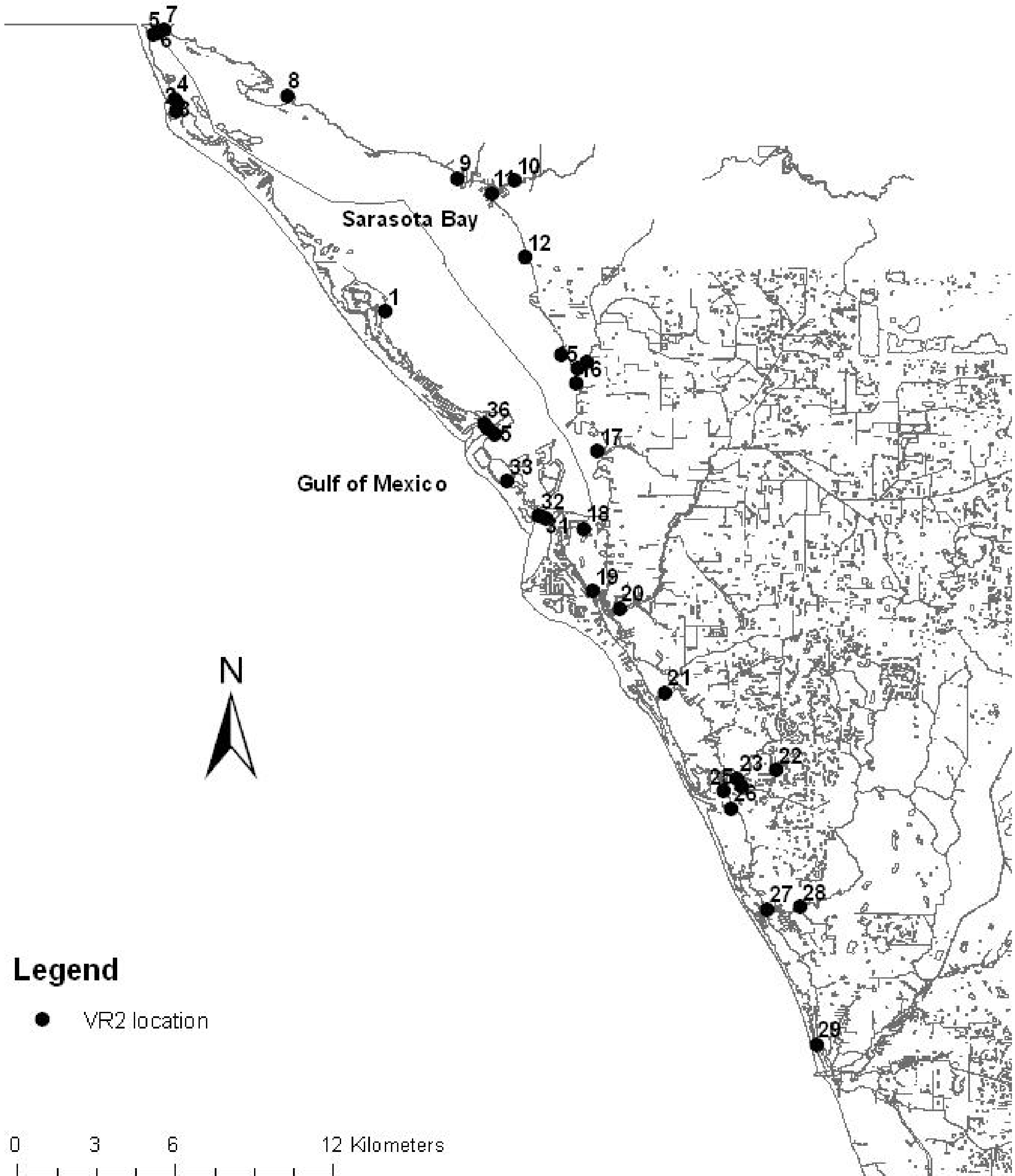

Figure 2-2. The VEMCO® VR2 numbers and locations in Sarasota Bay, Florida. Table 2-2 gives the VR2 numbers with corresponding name and associated habitat type.

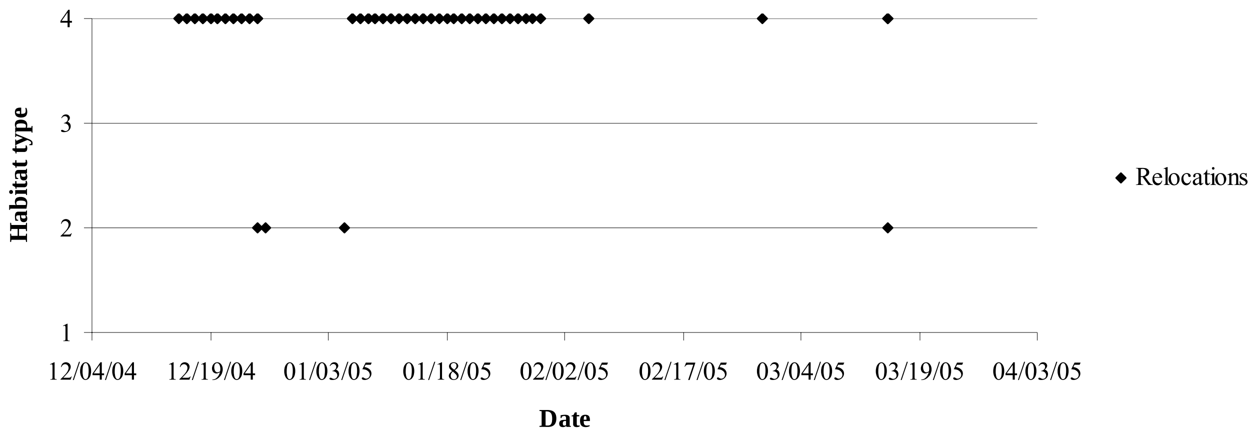

Figure 2-3. This graph which shows relocations for an individual fish, 1936, depicts an example of fish-days based on daily relocation data. Overlapping relocations in various habitat types, (1: creek, 2: mangrove, 3: open bay, 4: pass) on a specific date, constitute multiple fish-days contributed by an individual fish.

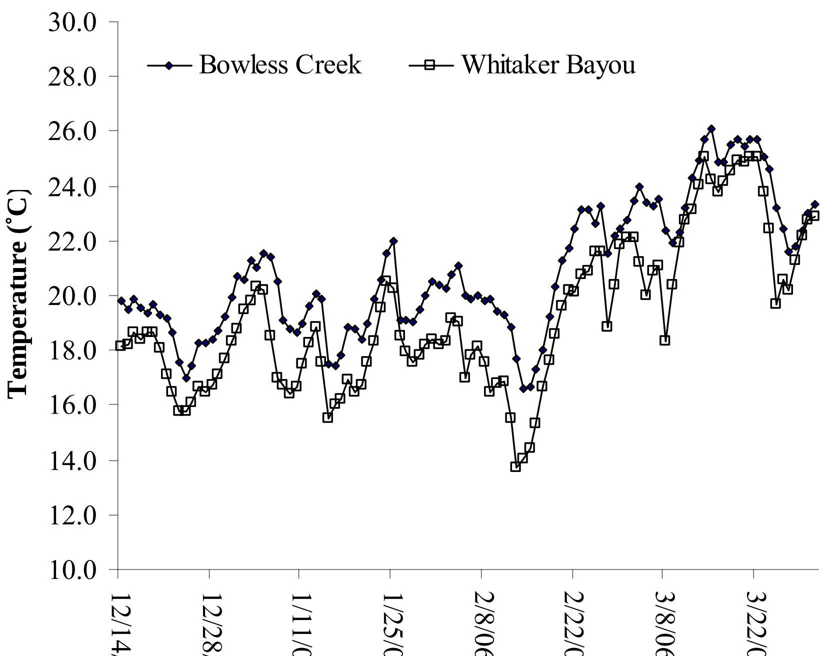

Figure 2-4. Water temperature, following a dredging event which occurred in Whitaker Bayou in late fall 2004, for two creek systems.

CHAPTER 3
RESULTS

Assessing Seasonal Movement and Habitat Use Patterns

In examining the movement patterns of all individually tagged snook between fall 2004 and winter 2007 I observed two general movement patterns: (1) "transient" fish that traveled long distances to multiple habitats throughout the year, and (2) "resident" fish that moved infrequently between habitats within a small geographic area. For example, fish 1947 was tagged and released in a mangrove habitat in the southern portion of the bay along the eastern shoreline in fall 2004. This fish was repeatedly relocated for over a year and a half in various habitat types throughout the entire bay system including multiple creek, mangrove, and open bay areas in both the northern and southern portion of Sarasota Bay (Figure 3-1). This fish was last detected at an open bay VR2 in summer 2006. In contrast, fish 1966 was tagged and released in a creek habitat in the northeastern portion of the bay and was relocated primarily in its original capture creek and nearby mangrove habitat for approximately seven and a half months until it was last detected on a pass receiver. Thus, I assumed that the fish emigrated from the study system (Figure 3-2).

Larger scale movement patterns tended to occur primarily during the late spring and summer months for most fish. These travel patterns typically involved a fish transitioning from a creek habitat in the northern portion of Sarasota Bay and moving to a southern pass habitat. During the spring and early summer of 2005, 14 of 35 tagged fish demonstrated this type of movement patterns as fish would move out of a creek habitat in the northern bay to nearby habitats including other creeks, mangroves and open bay areas (e.g., fish 1913, Figure 3-3). Distances traveled to the nearby habitats during this time, ranged between 0.6-3.0 km. The transitional movement to nearby habitats typically lasted for one month. During late June and early July these fish traveled to the southernmost portion of the bay where they were detected on a VR2 that was located in the Intracoastal Waterway (ICW) just north of the entrance to Venice Inlet for varying time intervals. In most cases these fish would return to the same northern bay habitats where they were located earlier in the year. For a few fish ($n=3$), this pattern was demonstrated on an annual basis over a two-year time period. Straight-line, one-way distances for all tagged snook, between recorded relocations, ranged from zero (fish that were only detected at one receiver location) to >30 km.

All four monitored habitat types classified by SBNEP were used by adult snook throughout this study, although patterns of habitat use varied among seasons and years (Figures 3-4, 5, and 6). Results from chi-square analyses ($\alpha = 0.05$) indicated a significant dependence between habitat and season for Year 1 ($\chi2 = 2024.69$, df = 9, p = < 0.0001), Year 2 ($\chi2 = 334.43$, df = 9, p = < 0.0001), and Year 3 ($\chi2 = 55.12$, df = 3, p = <0.0001). Hence, there was a general association of snook habitat use patterns with both habitat type and season. There was also a significant difference in the $\chi2$ analysis ($\alpha = 0.05$) between expected and observed habitat occupancy for each season in years 1, 2, and 3 (Table 3-1).

Throughout fall and winter, when water temperatures in creek habitats were typically warmer than open water areas (Figure 3-7) habitat use, determined by fish-days from relocation data, for the tagged snook was highest in creeks. Over fifty-percent of all fall and winter observations during years 1 and 2 were in creek habitats. In spring, Year 1, habitat use was highest in mangroves and accounted for 39% of all observations. In spring, Year 2, habitat use was highest in creeks and accounted for 52% of all observations. Habitat use differed between the summers in years 1 and 2. In summer, Year 1, use was greatest in passes (34%). In summer, Year 2, mangrove habitat was used most often, accounting for 51% of all observations. Fall and winter of Year 3 were the last two seasons included in this study and during this time period habitat use was highest in creek and mangrove habitats (fall: 38% creeks, 36% mangroves, winter: 37% creeks, 36% mangroves). Snook habitat use in open bay varied within a range of 0-21% among seasons and between years.

Site Fidelity

A table was constructed which included the date of capture, size, capture location (VR2), capture habitat, and the percentage of fish-days at the original capture location for the 48 fish captured, tagged and released within the detection range of a VR2 (Table 3-2). Data from this table was used to graph habitat use, based on percent fish-days, to examine site fidelity for a specific habitat and location (Figure 3-8). Overall, when all tagged fish released within the vicinity of a VR2 were included in the analysis, I found that site fidelity was highest among fish captured in creeks (63%) and open bay (69%) habitats.

There were a total of sixteen fish captured and released in three of the five creek habitats. Six of these fish were from Bowlees Creek. The mean proportion of relocated fish-days for these fish was 0.63 (SE ± 0.15). Nine fish were released in Whitaker Bayou. Habitat use based on the mean proportion of fish-days within Whitaker was 0.53 (SE ± 0.08). One fish was captured and released in South Creek. The proportion of relocated fish-days within South Creek was 0.95. Although definitive conclusions are limited to the small numbers of fish captured within specific creeks, this data suggests that snook may demonstrate high year round site fidelity to the specific creeks in which they were first captured.

Impacts of Habitat Disturbance on Movement and Habitat Use

I observed a large decrease in percent habitat use, based on fish-days, for snook in pass habitat between summer Year 1 (34%) and summer Year 2 (9%). During the summer, use of creek and mangrove habitats by snook was higher in Year 2 than in Year 1 (Figures 3-4 and 3-5).

In the summer of Year 2, mangrove habitat was used most often, accounting for 51% of all observed fish-days.

Percent habitat use, based on fish-days within creeks, decreased in Whitaker Bayou following the start of the large dredging event at the end of fall Year 2 (Figure 3-9). Percent habitat use in Whitaker Bayou decreased from 44% in fall and 39% in winter of Year 2 to 13% in fall and 0% in winter of Year 3. Simultaneously, percent habitat use in other creeks increased over the seasons following the dredging event. This was most dramatically observed within Phillippi Creek where percent habitat use increased from 13% in fall Year 2 to 53% in the fall Year 3. This pattern was also observed between the winter seasons where percent habitat use increased from 16% to 76%, between years 2 and 3, respectively.

Relating Movement and Habitat Use Patterns with Survivorship

Nine fish were harvested by anglers during this study. The number of days-at-liberty from the original capture date to harvest ranged from approximately 100 to 340 days. All fish were originally captured, tagged, and released in the northern portion of Sarasota Bay. Relocations from these fish were also all in the northern portion of the bay. Appreciable movement was not observed for four of the harvested fish as they were relocated nearly 100% of the time at one open bay VR2 location (Longboat Marina and Moorings, VR2 1). Three of these fish were originally tagged near this VR2 (1907, 1917, and 1963). The other fish, 1937, was tagged approximately 2 km north of this location. Two fish, (1902 and 1909) were tagged in mangrove habitat near VR2 33 between Lido Key and Big Pass. Fish 1909 was relocated 100% of the time at VR2 33. Fish 1902 utilized Big Pass until January 26, 2005. This fish was not detected again until March 6, 2005 in Big Pass which suggests that it may have moved into the Gulf of Mexico during that time. Following this, habitat use was among mangroves near VR2 33 and Big Pass. The last detection of this fish before it was harvested in April 2005 was at VR2 33. Fish 1930 was tagged in October 2004 approximately 650 m northeast of a VR2 adjacent to Siesta Key. This fish was relocated in a mangrove habitat near this VR2 a month later during manual tracking efforts. Following this relocation, the fish was detected on VR2s moving north until it entered Whitaker Bayou. All subsequent relocations were within Whitaker Bayou prior to harvest (February 2, 2005). The mean number of days-at-liberty for these seven fish was 128 days.

The final two fish that were harvested had a higher number of mean days-at-liberty (310 days) than the other seven fish. Both fish were tagged on the same date in early November 2004. Fish 1932 was tagged in an open bay habitat in the northwest portion of the bay. While at liberty, this fish exhibited considerable movement between its original capture location and several pass habitats. It was last relocated in late August 2005 near the area in which it was first captured. Fish 1962 was tagged in a mangrove habitat in the northeast portion of the bay. This fish moved between its original capture location and a creek habitat (Bowlees Creek) throughout the fall, winter, and early spring seasons. This fish was also relocated in various pass habitats throughout the summer, and returned to Bowlees Creek and surrounding mangrove habitats in the late summer. This fish was last relocated in late September 2005 within Bowlees Creek.

One fish, 1916, was assumed to have died as a result of the red tide bloom in summer 2005. This fish was originally tagged in an open bay habitat in the northwest portion of the bay in November 2004. Relocations of this fish were infrequent within the first two months of when it was first captured with one to two fish-days near a VR2 where it was originally captured. Relocations remained infrequent during spring near a VR2 in mangrove habitat adjacent to Siesta Key. In the summer, relocations were concentrated in New Pass. This fish was found dead on a

Gulf side beach in July 2005 outside of New Pass while sampling snook carcasses of fish that died during the red tide bloom.

Table 3-1. Chi-square test (α=0.05) results to determine if there was a significant difference between observed and expected habitat use based on percent fish-days.

Year	Season	X^2 value	d.f.	p-value
1	fall	423.4	3	< 0.0001
	winter	2857.5	3	< 0.0001
	spring	395.7	3	< 0.0001
	summer	8.9	3	0.0300
2	fall	41 5.9	3	< 0.0001
	winter	1075.9	3	< 0.0001
	spring	146.8	3	< 0.0001
	summer	450.3	3	< 0.0001
3	fall	140.4	3	< 0.0001
	winter	106.7	3	< 0.0001

Table 3-2. Original capture habitat and location data for snook released within the detection range of a VR2.

Fish ID	Capture date	Size (TL) mm	Capture location (VR2)	Capture habitat	Percent fish-days at capture habitat and location
1646	8/18/2006	734	32	pass	3.0
1647	8/18/2006	694	32	pass	34.0
1648	6/23/2006	856	8	mangrove	0.0
1649	8/18/2006	739	32	pass	23.0
1650	6/23/2006	917	8	mangrove	57.0
1654	8/18/2006	817	32	pass	5.0
1656	6/23/2006	910	8	mangrove	27.0
1662	6/23/2006	662	8	mangrove	3.0
1663	8/18/2006	710	32	pass	43.0
1666	6/23/2006	644	8	mangrove	4.0
1906	10/12/2004	721	34	mangrove	12.0
1912	10/26/2004	663	18	mangrove	86.0
1913	12/2/2004	856	14	creek	53.0
1916	11/3/2004	689	1	open bay	81.6
1917	11/3/2004	714	1	open bay	97.8
1918	11/3/2004	707	1	open bay	99.5
1920	10/20/2004	932	11	creek	54.0
1922	11/3/2004	750	1	open bay	28.0
1923	11/3/2004	683	1	open bay	60.0
1924	10/28/2004	1100	8	mangrove	5.6
1926	11/3/2004	705	1	open bay	33.3
1931	10/20/2004	853	11	creek	20.0
1932	11/3/2004	720	1	open bay	87.9
1935	12/2/2004	819	14	creek	39.0
1936	10/21/2004	668	35	pass	81.0
1938	10/20/2004	816	11	creek	97.0
1941	11/3/2004	748	1	open bay	93.6
1943	12/2/2004	700	14	creek	81.0
1945	11/3/2004	683	1	open bay	63.8
1949	10/28/2004	712	8	mangrove	37.0
1950	10/20/2004	850	11	creek	92.0
1951	12/2/2004	722	14	creek	69.0
1955	12/2/2004	845	14	creek	71.0
1956	12/2/2004	670	14	creek	26.0
1957	11/3/2004	687	1	open bay	100.0
1958	10/26/2004	681	18	mangrove	85.0
1959	12/2/2004	761	14	creek	79.0
1961	11/2/2004	776	8	mangrove	6.6
1962	11/3/2004	856	13	open bay	13.0

Table 3-2. Continued

Fish ID	Capture date	Size (TL) mm	Capture location (VR2)	Capture habitat	Percent fish-days at capture habitat and location
1963	11/3/2004	666	1	open bay	100.0
1965	11/22/2004	855	28	creek	95.0
1966	10/20/2004	896	11	creek	23.0
1967	10/21/2004	596	35	pass	82.0
1969	10/7/2004	596	10	creek	94.0
1971	12/2/2004	615	14	creek	1.0
1973	12/2/2004	851	14	creek	46.0
1975	12/3/2004	655	18	mangrove	89.0
51937	4/15/2005	741	1	open bay	0.0

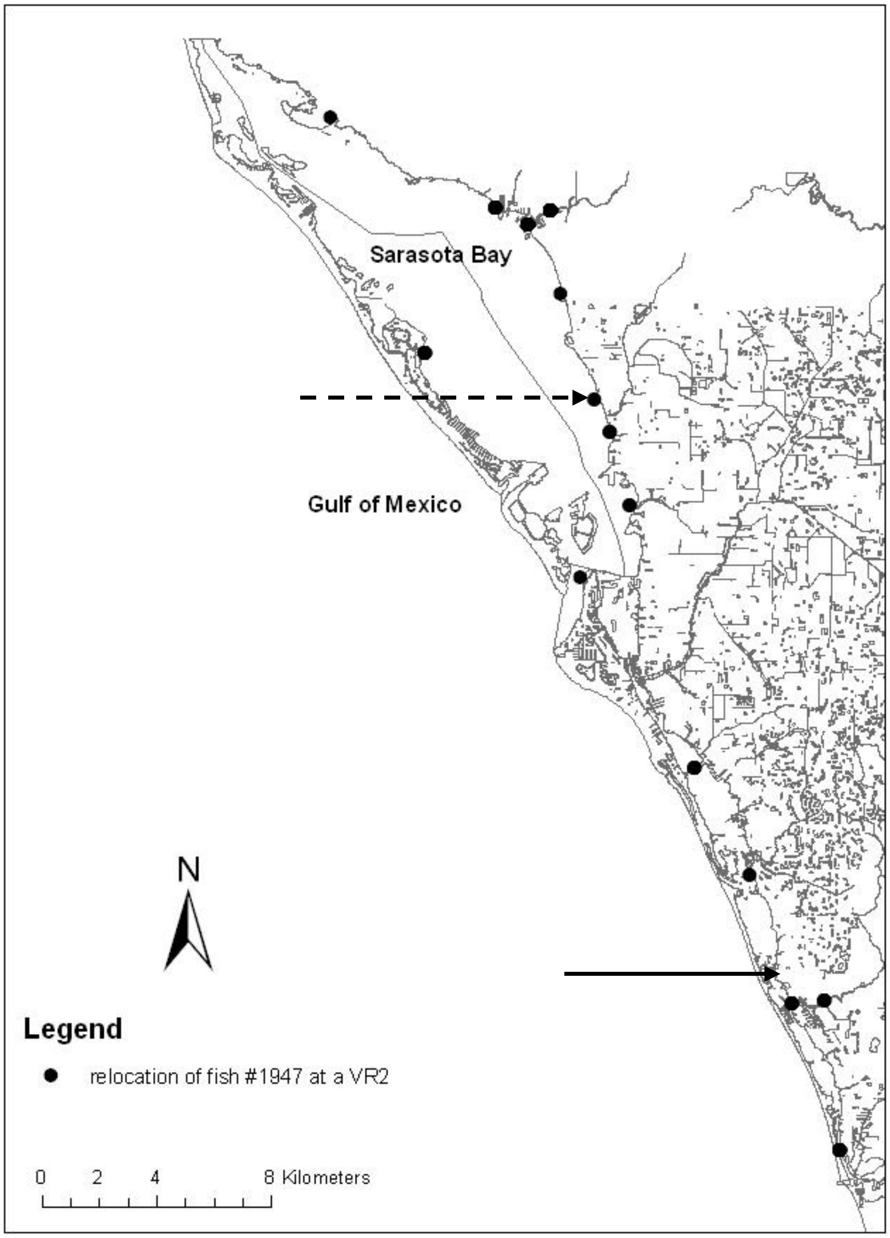

Figure 3-1. Observed relocations of fish 1947 in Sarasota Bay, Florida. The solid arrow indicates where the fish was originally captured, tagged, and released. The dashed arrow indicates where the fish was last detected.

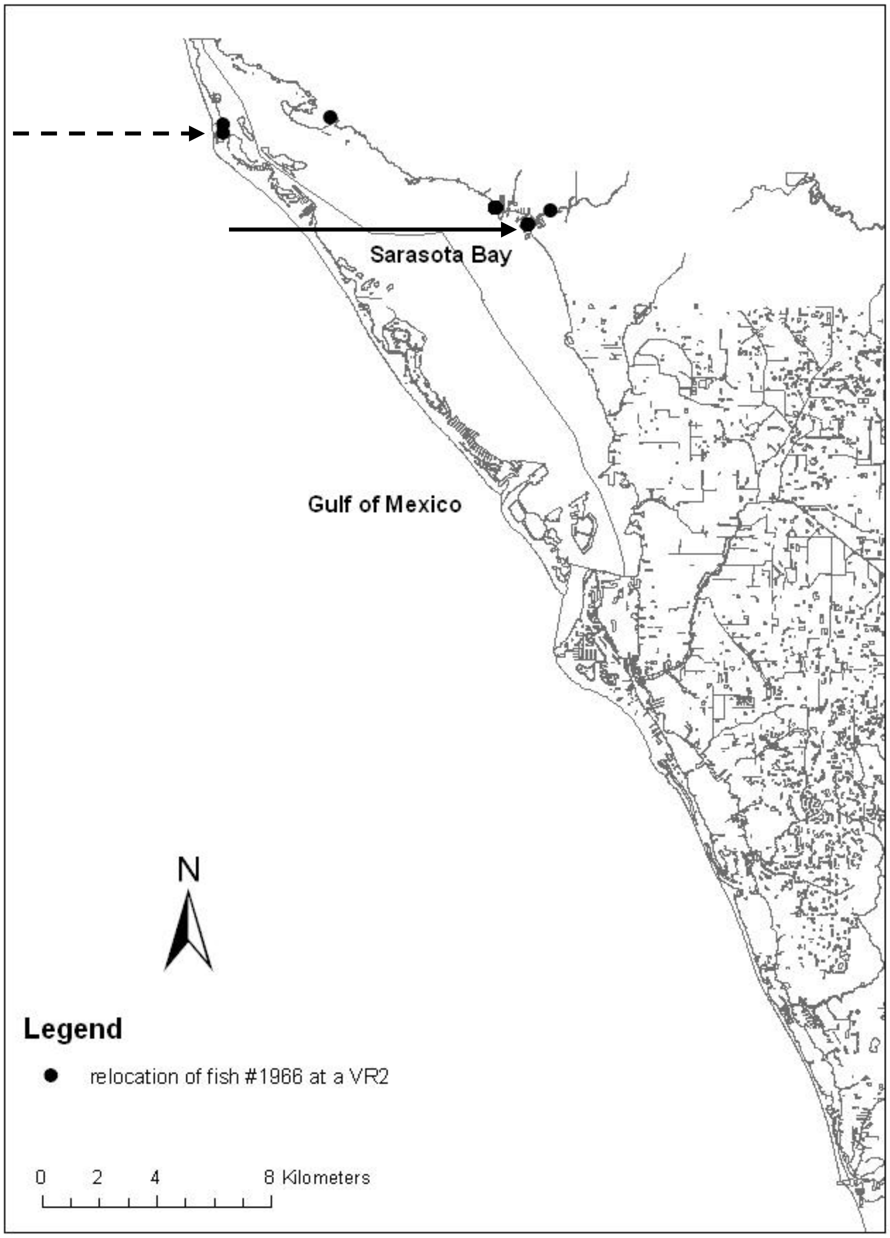

Figure 3-2. Observed relocations of fish 1966 in Sarasota Bay, Florida. The solid arrow indicates where the fish was originally captured, tagged, and released. The dashed arrow indicates where the fish was last detected.

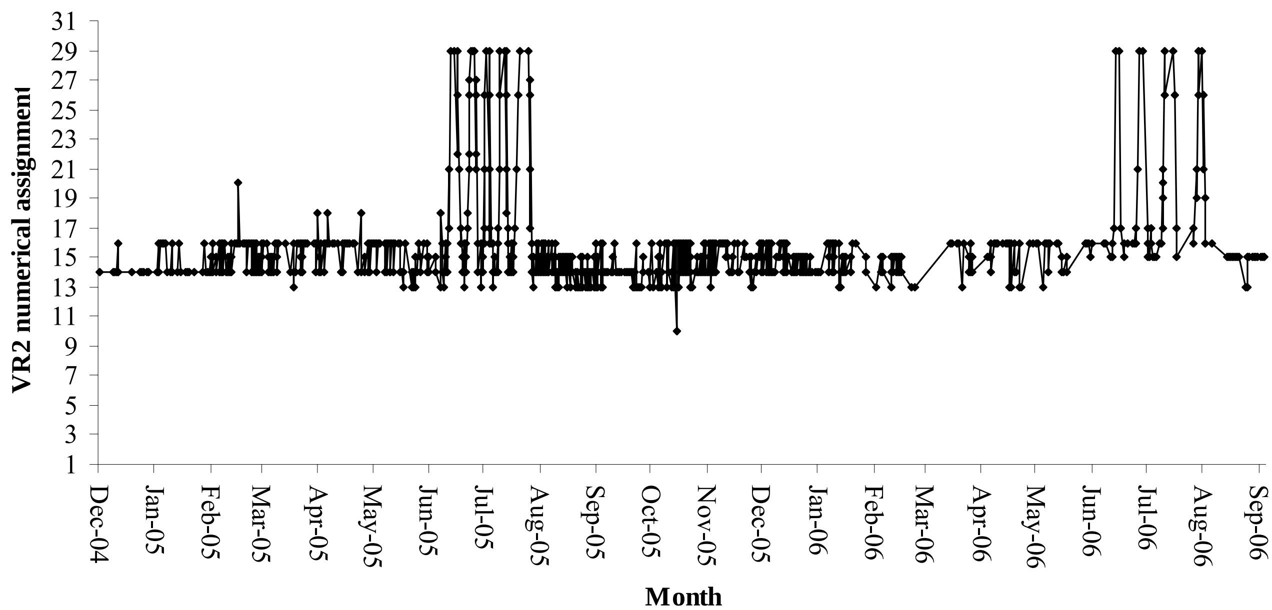

Figure 3-3. Movement pattern based on relocations from VR2s for fish 1913. Refer to Table 2-2 for VR2 habitat location with assigned numerical location, indicating geographical position around Sarasota Bay, and associated VR2 habitat type.

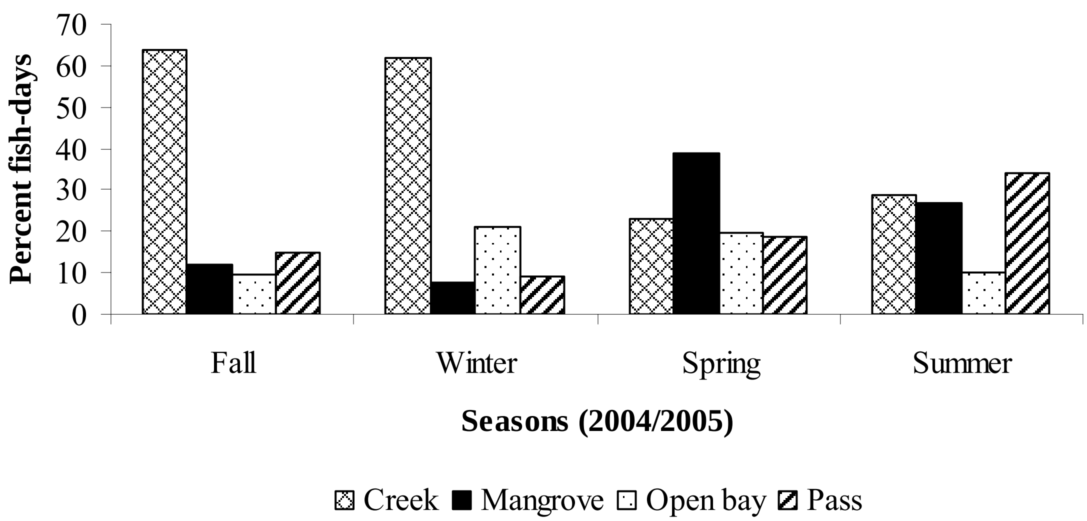

Figure 3-4. Habitat use (percent fish-days) per season for Year 1 (2004/2005).

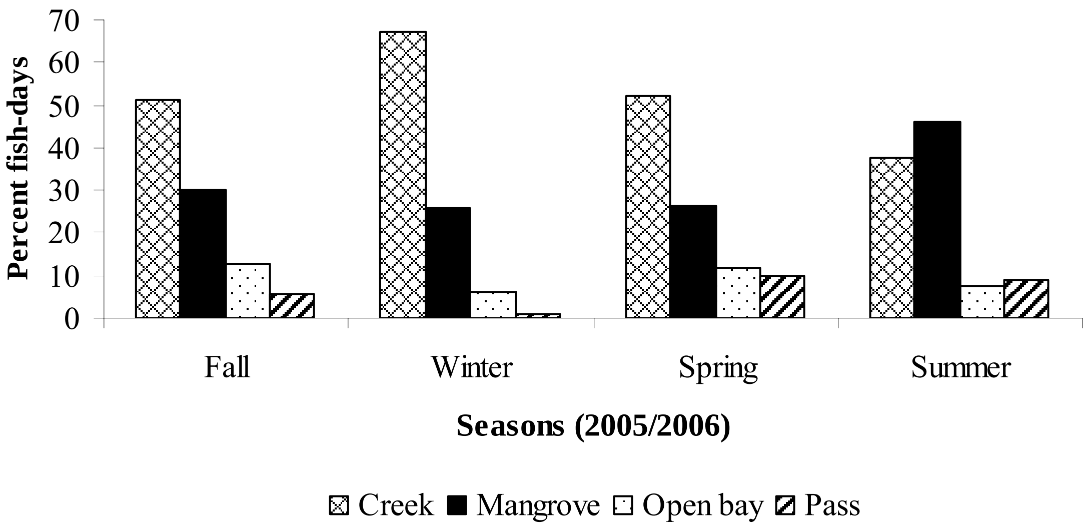

Figure 3-5. Habitat use (percent fish-days) per season for Year 2 (2005/2006).

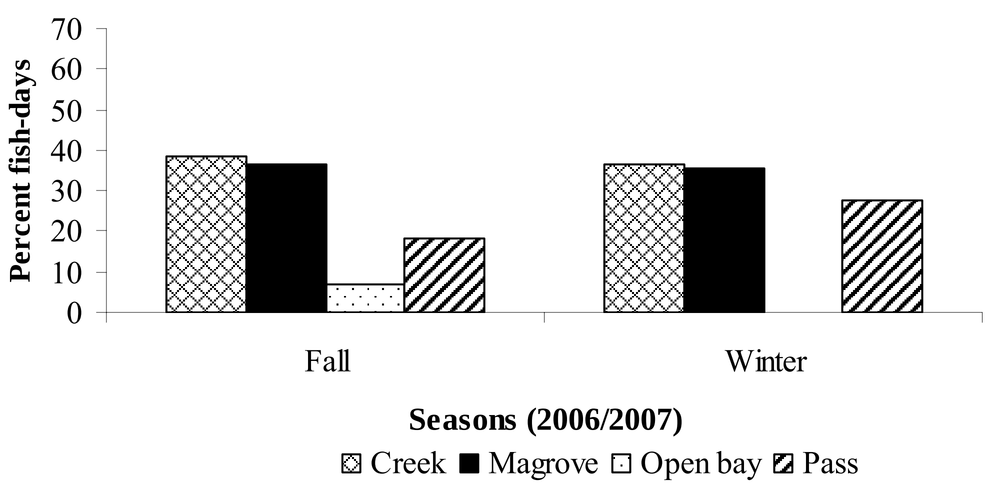

Figure 3-6. Habitat use (percent fish-days) per season for Year 3 (2006/2007).

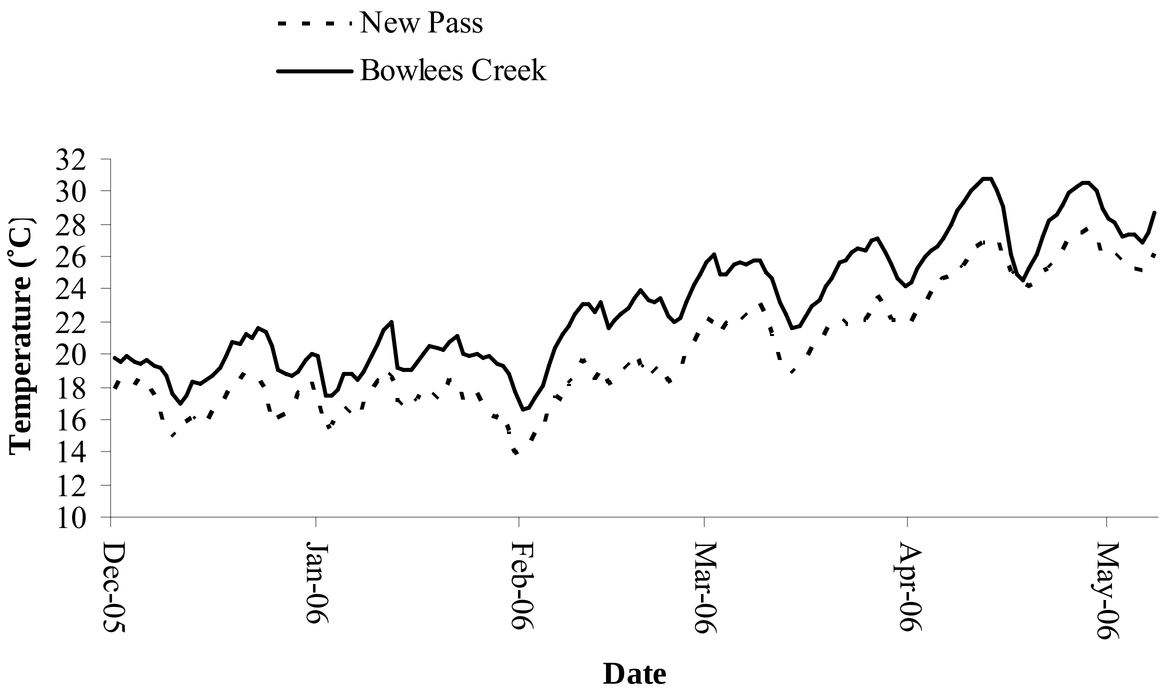

Figure 3-7. Average monthly water temperatures (˚C) for an open bay area (New Pass) and a creek habitat (Bowlees Creek) in Sarasota Bay, Florida.

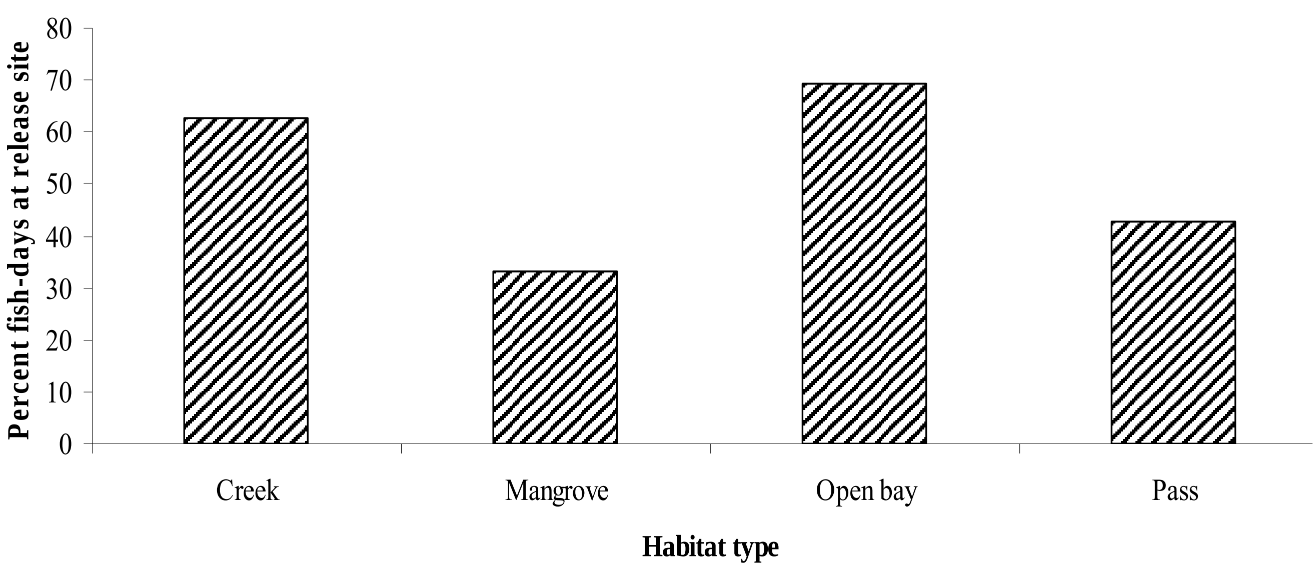

Figure 3-8. Habitat use (percent fish-days) at the original capture habitat and location for snook (n=48). This graph is showing high site fidelity demonstrated by snook captured and released at specific habitat types (creeks and open bay).

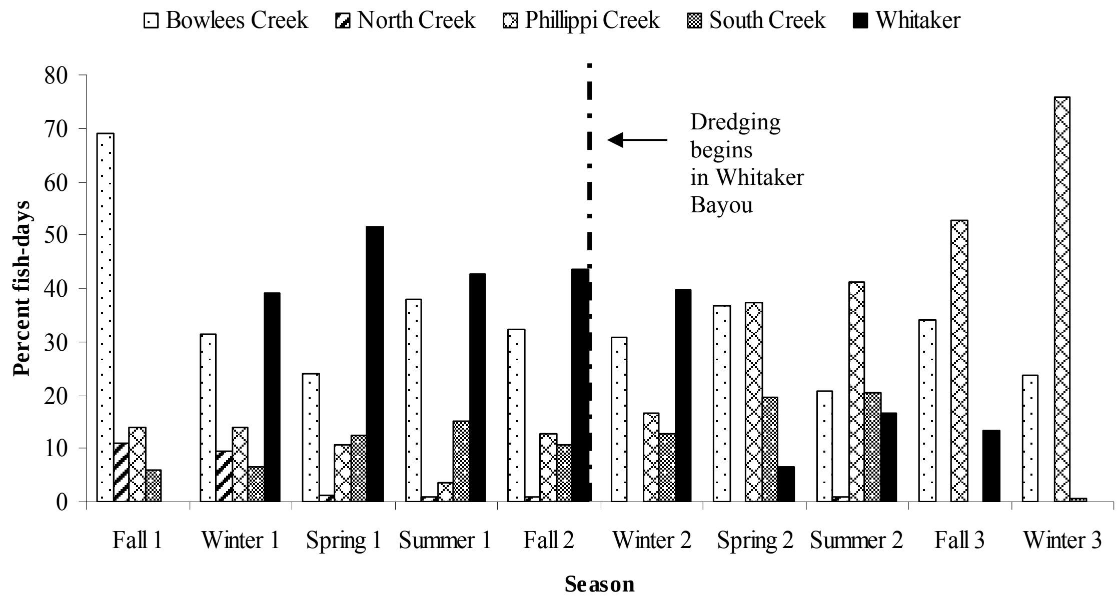

Figure 3-9. Seasonal habitat use (percent fish-days) in each of the tidal creeks before and after the dredging event in Whitaker Bayou, Sarasota Bay, Florida.

CHAPTER 4
DISCUSSION

Along with confirming results from several life history studies, including the association of habitat use with specific habitat types (e.g., Gilmore et al. 1983 and Muller and Taylor 2006), new insights have been gained regarding habitat site fidelity and variable movement patterns of adult common snook. These new findings provide insight into individual behaviors of snook which may be adaptive strategies that increase an individual's chance of survival by decreasing susceptibility to possible sources of mortality (harvest, HABs, and displacement from refuge habitats). For example, it appeared that there was a distinct seasonal movement and habitat use pattern demonstrated by individual snook which may have increased the likelihood of these fish surviving the large scale red tide bloom in Sarasota Bay, during summer 2005.

Survivors of the red tide bloom generally spent extended periods of time through the fall and winter in the creek habitats found in northern Sarasota Bay. However, during summer 2005 many of these fish were found in the most southern areas of Sarasota Bay around Venice Inlet. This may have increased the probability of these fish surviving the red tide bloom during summer 2005 because southern Sarasota Bay appeared to have lower levels of fish kills (Bennett 2006), likely due to the higher exchange rate with the Gulf of Mexico, and increased availability of freshwater over areas in the southern regions of Sarasota Bay from creeks. Some fish were last detected at the Venice Inlet location during the summer 2005 and were not relocated until several months later at this same location. These fish may have either exited the bay system into the Gulf of Mexico or traversed out of the VR2 array detection range from the Venice area of Sarasota Bay to other bay and creek systems located further to the south (Roberts Bay, Curry Creek, Lemon Bay and Alligator Creek, for example). This would not be unlikely as this study has shown a number of individual fish moving distances $\geq$ 30 km. In addition, at least three fish exhibited the previously described pattern (northern creeks to southern passes in the summer) for two consecutive years. This suggests a potentially beneficial behavioral strategy for these individual fish making them less susceptible to mortality associated with major red tide blooms in pass habitats in the summer spawning months. Overall, fish that were identified as natural mortalities from the red tide bloom in Bennett (2006) were most frequently relocated on pass receivers in the northern bay. During the summer 2005 red tide bloom, it appeared that fish kills were greatest in the northern portion of Sarasota Bay.

Fish that were detected in pass habitat in Year 1 (red tide bloom) that survived to the following summer were part of the group of fish that showed increased utilization of creek and mangrove habitats in the summer of Year 2. This decline in pass habitat use may be related to a decrease in the number of fish that were available to be monitored in the system, but it could also indicate that individual fish may not return to spawning areas with the same frequency each year. Jorgensen (2006) showed that Atlantic cod *Gadus morhua* are annual spawners when young. However, as the fish mature they exhibit skip-year spawning. Older fish, in fact, spawn only every second or third year. Female Gulf sturgeon, *Acipenser oxyrhincys desotoi*, may also skip spawn as they are thought to spawn on 3-4 year intervals (Pine et al. 2001).

A multi-year spawning interval such as this could be advantageous for common snook for several reasons. First, spawning is energetically very costly, particularly for females (Jorgensen 2006) and the energetic demands of producing the large gametes of adult snook are likely high. Second, pass habitats are likely the “most risky” habitats that adult snook occupy. Pass habitats of Sarasota Bay are generally the first to be exposed to red tide blooms originating from the Gulf of Mexico. Additionally, pass habitats are more likely than other habitats in the bay to support potential predators of adult snook including a variety of shark species (C. Simpfendorfer, Mote

Marine Laboratory, personal communication) and dolphins (R. Wells, Mote Marine Laboratory, personal communication). Thus, it seems reasonable that adult snook would minimize their time in the risky habitats. Although further research is required to confirm this, skip-spawning may be a potentially advantageous evolutionary trait exhibited by some snook in Sarasota Bay, especially during periods when environmental conditions are unfavorable.

Unfavorable habitat conditions that are a result of anthropogenic disturbances, such as dredging, may lead to displacement. This displacement could potentially have negative population level impacts by increasing an individual's susceptibility to sources of mortality including exposure to predators (Walters and Juanes 1993) or lethal environmental conditions. Cederholm and Reid (1987) summarized the impacts of forest management via logging on Northwest coho salmon *Oncorhynchus kisutch* populations. They describe decreases in resilience mechanisms (e.g. excess spawning and abundant fry) and survival over a variety of life stages which resulted from an increase in suspended sediments and a decrease in refuge habitats. A decrease in resiliency and survival from anthropogenic habitat degradation such as this, combined with overfishing, resulted in an overall decrease in coho salmon stocks. This result led Cederholm and Reid (1987) to suggest an integrated approach to natural resource management which includes the protection of habitats used by fish through the combined efforts of the fishery and forestry industries.

During this project, Whitaker Bayou was subject to a major physical modification when a channel was dug to increase boat access to a new marina complex. This dredging project removed a layer of flocculent organic material that helped to keep Whitaker Bayou warm during winter months due to decomposition and solar warming. Before dredging began, the percent of habitat use in Whitaker Bayou was relatively high, ranging between 44%, in fall Year 2, and

39% in winter Year 2. After dredging began, habitat use decreased within Whitaker Bayou and increased among other creek systems, most notably in Phillippi Creek. This, however, may be an affect of a decrease in batch 1 fish (due to mortality and emigration), that had site fidelity towards Whitaker Bayou, still alive and monitored in 2006. Additionally, most of the 25 fish tagged in summer 2006 were initially captured in mangrove and pass habitat approximately 4km or less from the mouth of Phillippi Creek. Nevertheless, four of the nine fish relocated in Whitaker Bayou in winter Year 1 were relocated the following winter in other habitats. Three of these fish were relocated in other creek systems (Bowlees Creek or Phillippi Creek). The fourth fish was relocated primarily in a mangrove habitat near Siesta Key Island. Therefore, it appeared that some individual snook demonstrated adaptive strategies in response to displacement by moving to other creek or habitat areas.

These are important findings because Whitaker Bayou is a rearing habitat for juvenile snook and a known wintering location for snook of all sizes (Brennan et al., in press). The loss of this flocculent bottom material likely led to the cooler winter temperatures in Whitaker Bayou which potentially eliminated this creek habitat as a winter refuge. The decrease in water temperature in Whitaker Bayou compared to Bowlees Creek post-dredging (Figure 2-4) is suggested as a factor leading snook to seek thermal refuge in other creek systems. The possibility of impacts at the individual level, which affect populations, such as reduced growth, recruitment, and survival due to habitat degradation and/or loss, should be considered when making management decisions regarding habitat and species protection.

Issues regarding habitat protection, as well as fisheries management, are often closely linked to individual habitat site fidelity. Evidence of site fidelity has been widely documented in relation to the importance in developing management strategies of spatially explicit populations in reservoirs (e.g., Jackson and Hightower 2001) and marine reserves (e.g., Meyer et al. 2000). The suggestion that snook demonstrate high site fidelity to specific habitats in a bay system poses a concern to either maintain or improve these habitats which ultimately provide advantageous resources (e.g., food sources and/or refuge) during certain life history stages. In particular, it appeared that snook exhibit high site fidelity toward specific creeks primarily during winter seasons and specific pass habitats during summer seasons. This suggests the significance of individual habitat types and locations as potentially important year-round habitats for feeding, breeding, and refuge.

High site fidelity may also prove to be disadvantageous in certain instances. For example, it appeared that the majority of snook harvested by anglers demonstrated high site fidelity to the open bay habitat near VR2 1, located in the northern portion of the bay. A stationary strategy such as this may be beneficial to conserving energy while foraging. These fish, however, may ultimately be more susceptible to harvest by anglers. Fish that exhibited high site fidelity to open bay areas and creeks had fewer days-at-large than fish that moved between habitat types. Therefore, potential inferences could be made regarding increased chances of survival based on site fidelity although data such as angler effort would also need to be examined to make more concrete predications about survivorship.

Another possibly disadvantageous habitat use strategy was related to pass site fidelity during the spawning season (summer 2005). The one fish that was found dead, presumably as a result of the red tide bloom, most likely came to New Pass to spawn but was unable to survive the extremely exaggerated red tide cell counts during that time. Natural mortality due to the red tide bloom was also suspected, but not confirmed, for seven other fish. These latter fish were last detected within northern bay passes in summer 2005. Snook that did not utilize passes in the northern portion of the bay during summer 2005 to spawn had perhaps increased their chances of survival by escaping areas of the bay with the most concentrated red tide cell counts. This demonstrates how site fidelity, as in the case of spawning location, could have large-scale population impacts, i.e., genetic diversity of the population could be lowered over time if fish that spawn in the northern passes are more susceptible to mortality events while fish who spawn in southern pass are less impacted.

Overall, I found that snook use a variety of habitat types and spatial locations, and exhibit a range of seasonal movement patterns. This diversity in behavior reduces the likelihood of any one cataclysmic event, such as a massive red tide bloom, killing all adult snook in Sarasota Bay. However, at least one tagged fish (1965) tagged in fall 2004 remained in the original creek where it was captured throughout the two year time period this fish was monitored. That creek habitat (South Creek) is located in the southern portion of Sarasota Bay. Occasionally this fish was relocated on the pass VR2 near Venice Inlet during the summer seasons, but generally this fish appeared to move very little from the creek where it was originally captured. This type of behavior may have ultimately contributed to the survival of this fish by decreasing its exposure to both fishing and natural (red tide) mortality. Similar variation in individual fish behavior has been noted in other systems (Gilliam and Fraser 2001).

Adult snook used habitats in varying proportion compared to available habitat. This, however, was based on the analysis that the available habitat, as well as the expected habitat use, was equal to the proportion of each habitat type monitored by the VR2 array. VR2s were not randomly placed throughout the bay as this study was originally designed to estimate snook mortality rates and therefore necessary to relocate fish (see Bennett 2006). For example, open bay, which makes up the majority of all available habitats in Sarasota Bay, had the smallest amount of VR2 coverage. This led to open bay becoming the smallest proportion of monitored habitat, in terms of receiver coverage and total available habitat. Although this contributed a bias within the analysis, it appeared from the movement relocation data that open bay habitat was "used" primarily as transitional habitat or as a movement corridor, as opposed to the other habitat types where relocations occurred more often and for longer periods of time. In addition, only four habitat types (creek, mangrove, open bay, and pass) classified by SBNEP were considered in this study. Other more fine scale habitat types such as oyster bars or seagrass may be considered for future work.

CHAPTER 5
CONCLUSIONS

This telemetry study provides insight into spatial and temporal patterns of habitat use and may serve as a first step towards identifying essential fish habitat (Arendt et. al 2001) for snook in Sarasota Bay, Florida. In this study, the relocations of individual fish were used as a metric to identify key habitats used by common snook. This is particularly important in linking the use of critical seasonal habitats, such as winter creek systems and summer spawning habitats, with environmental and anthropogenic threats in Sarasota Bay. Both scenarios of physical and environmental disturbances can lead to population level impacts within an aquatic ecosystem. These impacts may include reduced growth of individuals, recruitment, and survival in an area where a disturbance has occurred. It is therefore important to recognize behavioral choices and potential bet-hedging strategies demonstrated by individuals, such as movement and habitat use, as they may ultimately provide insight into factors contributing survival.

These new findings provide insight into individual behaviors of snook which may be adaptive strategies that contribute to an individual's chance of survival by increasing or decreasing susceptibility to possible sources of mortality (e.g., harvest, HABs, and displacement from refuge habitats). For example, it appeared that there was a distinct seasonal movement and habitat use pattern demonstrated by individual snook which may have increased the likelihood of these fish surviving the large scale red tide bloom in Sarasota Bay. The fish that survived the bloom transitioned from northern creek habitats to the southern extent of the bay at Venice Inlet during the summer months whereas the fish that most likely died as a result of the red tide bloom used passes in the northern bay.

The significance of this study is that it improves our understanding of spatial and temporal relationships between an aquatic species and a variety of habitats. This study also documents findings on movement and habitat use in relation to anthropogenic and environmental sources of habitat loss. Implications of habitat loss can include displacement from wintering refuge habitats, as in the case of dredging, or impacts on spawning cycles that may result in adaptive strategies to compensate for unfavorable habitat conditions. By identifying key habitat areas combined with mortality information, we can begin to shift to an ecosystem based management strategy which ultimately requires an understanding of how the two traditional management arenas, harvest regulation and habitat protection, interact.

APPENDIX
ADDITIONAL TABLES AND FIGURES

Table A-1. Months included in each season, characterized by average monthly water temperature (°C) for Sarasota Bay, Florida.

Season	Months	Average water temperature (˚C)
Fall	October, November	24.6
Winter	December, January February, March	18.1
Spring	April, May	24.1
Summer	June, July August, September	29.6

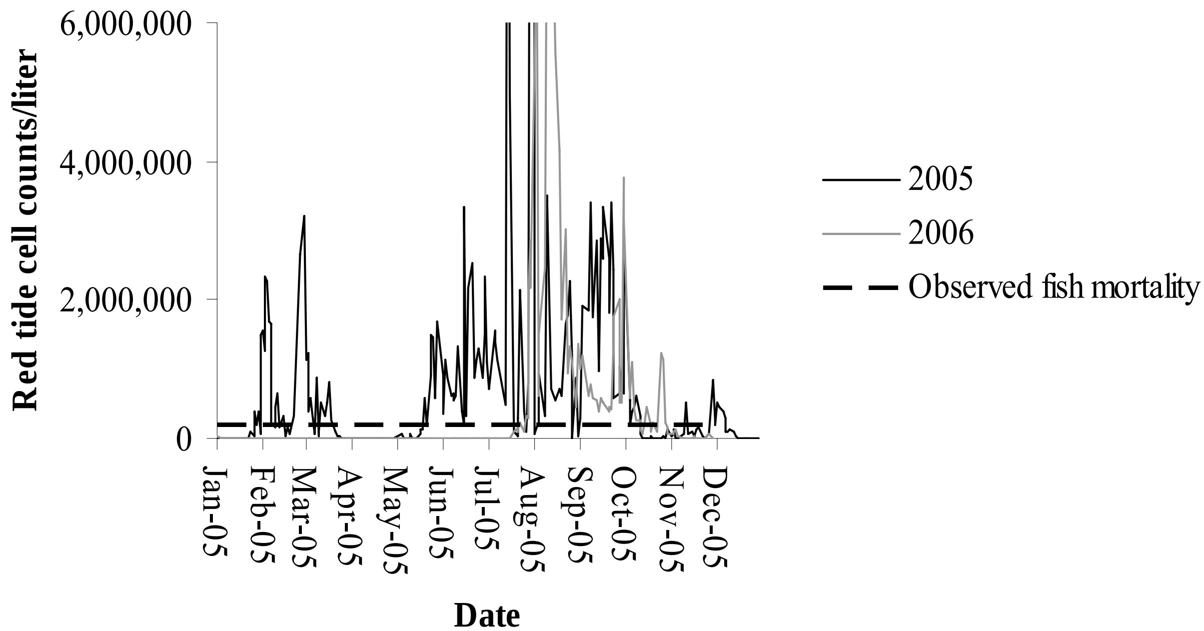

Figure A-1. 2005 and 2006 red tide (*K. brevis)* cell counts for New Pass in Sarasota Bay, Florida.

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BIOGRAPHICAL SKETCH

Lauren Lee Marcinkiewicz was born in Miami, Florida. However, she grew up primarily in Massachusetts. Lauren received her B.S. in marine biology from the University of California, Santa Cruz, in 2001. After graduation, she returned to Massachusetts and worked as an observer on commercial ground fishing boats. In 2004, Lauren moved to Sarasota, Florida, where she worked as a technician under the supervision of Dr. William E. Pine, III at Mote Marine Laboratory. In August 2004, Lauren joined Dr. Pine to begin her master's research at the University of Florida, Department of Fisheries and Aquatic Sciences. Lauren completed her master's research in 2007.