SUMMER FEEDING ECOLOGY OF JUVENILE COMMON SNOOK IN SOUTHWEST FLORIDA TIDAL CREEKS

By

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To my family for their continued support in all that I aspire to accomplish

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Diel feeding periodicity and diet shifts were examined for common snook *Centropomus undecimalis* from May-August 2004 and 2005 in tidal creeks flowing into Sarasota Bay on the west coast of Florida. Snook were sampled throughout a 24-hr period during May and June 2005 to assess diel feeding periodicity. Using a digestive index to characterize the condition of each prey item, it was determined that juvenile snook from 85-415 mm standard length (SL) had peak feeding activity from dusk, throughout the night, and then tapering off around dawn. Juvenile snook were therefore found to be both crepuscular and nocturnal foragers, with little feeding occurring diurnally. Teleost fishes (especially clown goby *Microgobius gulosus* and mojarra *Eucinostomus* spp.) and grass shrimp (*Palaemonetes* spp.) dominated the diet of snook overall. Mysids were important prey items for smaller (<130 mm SL) snook and were replaced by larger prey items (clown goby, mojarra, and grass shrimp) in larger snook (≥130 mm SL). However, small prey (mysids, amphipods, and isopods) were present in all size classes. Blue crabs *Callinectes sapidus* were important prey items in the largest snook size class (≥265 mm SL). Snook underwent ontogenetic and spatial shifts in their diet. Specifically, niche breadth increased with ontogeny, and the niche breadth of snook was narrower in tidal creeks with

natural or undeveloped shorelines, and as the degree of urbanization increased so did niche breadth of juvenile snook. Significant predator-prey size relationships were found between snook and their teleost prey, especially mojarras. Snook consumed teleosts that were mostly <20% of their SL. During the summer in tidal creeks of southwest Florida, juvenile snook were primarily crepuscular/nocturnal predators, feeding mostly on relatively large fishes and crustaceans.

CHAPTER 1
GENERAL INTRODUCTION

The Common Snook

The common snook *Centropomus undecimalis* (herein referred to as "snook") is an important contributor to a US$7.6 billion saltwater recreational fishing industry in the state of Florida (NOAA, 2009). Despite size and bag limits and closed seasons, snook are considered over-fished (Muller and Taylor 2006). In response to increased recreational fishing pressure and concerns over the status of snook, a stock enhancement research program was initiated in 1986. Since 1997, Mote Marine Laboratory (Sarasota, FL), in cooperation with the Florida Fish and Wildlife Conservation Commission, has performed experimental stock enhancement studies with hatchery-reared juvenile snook tagged and released into local estuarine habitats throughout Sarasota Bay on the west coast of Florida (Tringali and Leber, 1999; Brennan et al. 2005, 2006). Experimentation with snook stock enhancement has stimulated further research on snook ecology to evaluate potential impacts of released hatchery fish on native wild fish stocks.

Feeding ecology studies (e.g., Gilmore et al. 1983, McMichael et al. 1989, Luczkovich et al. 1995, and Blewett et al. 2006) have focused either on early juvenile (<100 mm standard length; SL) or adult life stages (>300 mm SL) in open bays and estuaries (Gilmore et al. 1983; McMichael et al. 1989; Blewett et al. 2006) and freshwater impoundments (Luczkovich et al. 1995). Blewett et al. (2006) indicated research is needed concerning both diel feeding periodicity and diet of snook in other locations, such as the tidal creek habitats chosen for this study. Research on late juveniles (100-300 mm SL) is also lacking. Examining the summer feeding ecology of juvenile snook is important as they are currently used in stock enhancement studies, with releases occurring primarily in late spring and early summer (Brennan et al. 2005, 2006).

Snook is one of several Centropomids found in the state of Florida. Others include tarpon snook *C. pectinatus*, sword spine snook *C. ensiferus*, and fat snook *C. parallelus* (Aliaume et al. 1997). Common snook is by far the most abundant Centropomid in U.S. waters. Snook range from north Florida, throughout the Gulf of Mexico, west to Texas in the U.S., and south to southern Brazil in South America. Snook inhabit primarily coastal waters with mangrove systems, brackish pools, tidal canals, and rivers (Meek and Hildebrand 1925; Marshall 1958; Fore and Schmidt 1973; Gilmore et al. 1983; Shafland and Foote 1983; Rivas 1986; McMichael et al. 1989; Aliaume et al. 1997; Aliaume et al. 2000; Taylor et al. 2000). These habitats have often undergone extensive anthropogenic alterations and are characterized by high productivity, diverse floral and faunal communities, and strong daily and seasonal environmental fluctuations (Brennan et al. 2005).

Snook are euryhaline, spend most of their life in fresh or brackish water and migrate to saltwater to spawn (Gilmore et al. 1983; McMichael et al. 1989; Aliaume et al. 1997). After spawning near shore, tidal currents carry newly hatched fry into estuaries, rivers, and creeks where snook generally remain until reaching sub-adulthood. Juvenile snook primarily inhabit low salinity estuaries and creeks with tidal flow. Adult snook inhabit the same rivers and estuaries, the shores of barrier islands, and mangrove coastlines (McMichael et al. 1989). Snook are protandric hermaphrodites; they begin life immature and mature into males and later in life most will change sex from male to female (Taylor et al. 2000). Snook are active predators, seeking out and hunting elusive prey items. The feeding mode used by snook, ram feeding, results in prey items being consumed whole (Luczkovich et al. 1995).

Several studies have noted the importance to fish communities of natural unaltered shorelines compared to altered shorelines. These often include increased diversity, species richness, abundance, and differing community structures compared to areas with altered shorelines (Bryan and Scarnecchia 1992; Laegdsaard and Johnson 2001; Huxam et al. 2004). In general, species richness is higher in areas with unaltered natural shoreline compared to areas with altered shoreline. In Florida, juvenile snook associate with shoreline habitats (Marshall 1958; Gilmore et al. 1983; McMichael et al. 1989) thus making them dependent on areas that may be subject to anthropogenic habitat alterations (Muller and Taylor 2005). Examining how the diet of juvenile snook may differ between altered and unaltered creeks is important as it may influence juvenile survival and affect the selection of future release locations.

The main goal of this thesis was to quantify the feeding ecology of juvenile snook in tidal creeks of southwest Florida. The specific objectives were to determine diel feeding periodicity, quantify the diet composition, and assess ontogenetic and spatial differences in diets of juvenile snook in tidal creeks of varying anthropogenic disturbance. Feeding periodicity was evaluated by performing 24-h collections and analyzing the digestive state of each prey item using a digestive index (Chapter 2). Determining feeding periodicity allowed for the collection of diet samples during (or soon after) peak foraging period(s). Ontogenetic and spatial differences in diet were assessed by quantifying the diet, niche breadth, and dietary (niche) overlap of various size classes of snook and sampling locations from developed and non-developed tidal creeks (Chapter 3). In conclusion, Chapter 4 focuses on the new discoveries concerning snook feeding ecology, specifically feeding periodicity, new prey taxa, and ontogenetic and spatial shifts in the diet of juvenile snook.

CHAPTER 2
DIEL FEEDING PERIODICITY OF JUVENILE COMMON SNOOK
IN SOUTHWEST FLORIDA TIDAL CREEKS

Introduction

Diet analysis is an integral component of many fish research or management investigations (Light et al. 1983). In turn, a crucial aspect of any diet analysis study should be feeding periodicity, as feeding may occur not only during multiple periods throughout a 24-h day but also change seasonally, spatially, and/or through ontogeny (Bowen 1996). In addition, differential digestion rates may result in over- or under-representation of certain prey types depending on the difference between when the fish fed versus when it was captured and thus potentially bias the importance of quickly digested prey in the diet (Kennedy 1969; Mann and Orr 1969; Gannon 1976). The effects of these behaviors and processes can be minimized if samples are taken during (or soon after) foraging. Hence, it is important to determine the feeding periodicity of any species before beginning a diet analysis study (Bowen 1996).

Relatively little information exists on feeding periodicity in the wild for the genus *Centropomus*. McMichael et al. (1989), using mean stomach fullness values, suggested small juvenile snook (10-70 mm SL) feed during the day in Tampa Bay, Florida. However, diel feeding periodicity was not determined. Later studies by Luczkovich et al. (1995, snook size range: 29-123 mm SL), Aliaume et al. (1997, 10-300 mm SL), and Blewett et al. (2006, 300-882 mm SL) describe the diet of common snook but do not address feeding periodicity. Although Luczkovich et al. (1995) performed both day and night collections, samples were pooled for analysis so diel differences were not assessed. However, among fishers, it is generally accepted that the best time to catch snook in the summer is during and after dusk and around dawn.

The objective of this chapter was to determine the diel feeding periodicity of wild juvenile and sub-adult snook (85-415 mm SL) during the summer when they are in tidal creeks on the southwest coast of Florida. Specifically, the objectives were to 1) determine the digestive state of prey items in the stomach throughout a 24-h day, 2) determine when during a 24-h day snook stomachs were empty, 3) evaluate when snook were most abundant in the study area during a 24-h day, and 4) determine the types of prey in snook stomachs throughout a 24-h day.

Methods

Study Site

Snook were sampled from North Creek (27°12.93 N, 82°29.99 W) and South Creek (27°10.13 N, 82°29.22 W), tidal creeks opening into Sarasota Bay, Florida (Fig. 2-1). Mangrove islands and shallow oyster bars obscure the mouth of North Creek, which opens into a large lagoon area before constricting in the middle and upper reaches. Depth throughout the creek varies from 0 to 2 m, with most areas <1 m. The lower lagoon and middle reach are separated by a series of shallow oyster bars. Due to these bathymetric features, there is little boat traffic within North Creek. Also absent from the creek are seawalls and docks with unnatural lighting that may influence fish feeding behavior. South Creek is a tidal creek with light boat traffic from local residents near the mouth, and with a comparatively deeper channel at the mouth (~3 m) than at North Creek. Creek depth varies from 0 to 3 m, with most areas <1 m. The lower reach of South Creek is highly developed with residential homes throughout the shoreline, channelized waterways, docks, shoreline riprap, and trimmed mangrove vegetation. The middle and upper reaches are encompassed by Oscar Sherer State Park, where the creek is relatively unaltered, devoid of any boat traffic, and the shoreline free of unnatural lighting. Shoreline vegetation in both creeks consists mainly of red mangrove *Rhizophora mangle* in the lower reaches, which is gradually replaced by rushes *Juncus* spp., Brazilian pepper *Schinus terebinthifolius*, leather fern *Acrostichum danaeifolium*, pines *Pinus* spp., and oaks *Quercus* spp. in the middle and upper reaches.

Snook Collections

Snook were sampled for 1h, during all odd numbered hours, for two 24-h observation periods per creek. The 24-h periods were not continuous, but divided into three 8h blocks and spread out over several days so each period was sampled during both incoming and outgoing tides.

Snook were collected using a 73 x 3-m bag seine with 1-cm nylon mesh from 26 May-28 June 2005. Seines were hauled towards the shoreline and sampled approximately 650-m^2. All captured snook were initially placed into floating net pens, measured for SL, fork length (FL), and total length (TL) (± 1 mm), and sampled for stomach contents using a modification of the pulsed gastric lavage (PGL) technique (Waters et al. 2004). Water quality parameters were measured immediately after each net pull. At each location, surface and bottom readings were taken for dissolved oxygen (DO), pH, salinity, and temperature.

Stomach Content

The PGL technique involved using a modified garden sprayer with a removable tapered plastic pipette (2.8 mm outside diameter at terminal end) placed on the end of the hose. The pipette decreased the outside diameter of the hose so the apparatus could be used on smaller fish with narrower esophageal openings (Hartleb and Moring 1995). Slightly pressurized water was pulsed through the esophageal opening to fill the stomach while the fish was in a head up position. The fish was then turned downward at a 45° angle allowing any food items to flow out of the stomach onto a 350µm mesh collection net. The underbelly of the snook was massaged as the stomach was flushed with a continuous flow of water, allowing any remaining food items to be removed. This process was repeated 2-3 times until the stomach was presumed empty (Waters et al. 2004). This method was 94.6% effective in removing stomach contents from wild snook (n=46) ranging in size from 62-438 mm SL (J. E. Rock, unpublished data). Snook, with empty stomachs, were held in a floating net pen for recovery and released as soon as they began trying to swim away, usually <1 min post lavage. No immediate mortalities were observed as a result of the PGL procedure; fish were not held to assess latent PGL-associated mortality. The entire process from capture to release typically took less than 20 min.

Stomach contents were placed into individually labeled plastic bags, returned to the laboratory on ice, and frozen. Prior to examination, stomach contents were thawed, sorted into gross food categories of either fish, shrimp, crab, mysid, or amphipods/isopods, blotted dry, weighed to the nearest 0.01g, and identified to the lowest possible taxon. All prey items were fixed in 10% buffered formalin and stored in 70% isopropanol.

Feeding Periodicity

The 1-h sampling periods were pooled into broader periods for analyses: (1) diurnal: 0730-1859 h, (2) nocturnal: 2200-0459 h, (3) dawn: 0500-0729 h, and (4) dusk: 1900-2159 h. The dawn and dusk periods were set to encompass periods of twilight that preceded sunrise and followed sunset (U.S. Naval Observatory 2006). Diel feeding periodicity was determined by examining (1) relative catch per unit effort (CPUE), (2) percent of snook with prey, (3) a digestive index to approximate the digestive state of prey items recovered (Table 1) (adapted from Berens 2005), and (4) mean numbers of each prey type per snook. CPUE was calculated as the mean number of snook caught per seine haul within each period. Differences in CPUE and percentage of snook with prey among periods were analyzed using a non-parametric one-way

ANOVA; significant differences between periods were evaluated with a Kruskal-Wallace (KW) chi-square test (α=0.05) (SAS Institute 1998). Differences in mean numbers of each prey type among periods for large ($\geq$130 mm SL) and small ($\leq$129 mm SL) snook, and means of large and small snook within each period, were also analyzed using a non-parametric one-way ANOVA followed by KW chi-square tests if warranted by significance to detect where differences occurred.

Digestion codes were assigned to each prey item on a scale from 0 to 5, with 0 representing nearly whole prey items with little to no digestion (0-10%) and increasing to 5 (>90%) nearly completely digested and unrecognizable (Berens 2005). Digestion codes were used to assess whether snook were feeding continuously or if feeding was concentrated around a particular time(s). Prey items assigned a digestion code of 5 were excluded from the analysis, as they were most likely left over from a previous feeding event (Jobling and Breiby 1986).

Individual digestive indices for all prey recovered from snook stomachs were plotted as a function of collection time to determine the minimum (or minima), which would indicate active feeding by snook. These preliminary plots showed a bimodal distribution during nocturnal hours (i.e., freshly digested items as well as prey items in the late stages of digestion), which indicated that averaging digestion index as a function of time would be inappropriate. Therefore, to model the digestive index over time, digestion data with a code$\leq$2 (i.e., $\leq$50% digested) in the period from 2100-2300 h was assigned to the previous day, and digestion data with a code >2 during the period of 0000-0900 h was assigned to the following day. This method assumed that highly digested items recovered in the stomachs were from a previous meal when found in conjunction with relatively non-digested food items. Given this assumption, it was possible to fit a logistic regression model $Y=A/(1+e^{[B(t+C)]})$ to the digestion data over a continuous period of time, where

Y is the digestive index at time *t*, A is the estimated parameter, B is the scale parameter, C is the *x*-ordinate of the point of inflection of the curve, and *t* is elapsed time after ingestion (Berens 2005). The model was fit with a nonlinear-regression (NLIN) procedure (SAS Institute 1998).

Results

Snook Collections

A total of 166 snook were sampled for the presence of stomach contents, 55 from North Creek and 111 from South Creek, respectively. Snook sampled ranged in size from 90 to 430 mm SL with the majority (81%) <200 mm SL (Fig. 2-3). DO in North Creek ranged from 1.5 to 9.1 parts per million (ppm) with a mean of 5.5 ppm ± 0.3 (mean ±1 SE). In South Creek DO ranged from 0.5 to 10.9 ppm with a mean of 5.2 ppm ± 0.5. Temperature ranged from 25.7 to 33.2°C with a mean of 29.9°C ± 0.4 in North Creek and ranged from 26.4 to 31.8°C with a mean of 29.1°C ± 0.3 in South Creek. In North Creek, pH ranged from 3.7 to 5.7 with a mean of 4.7 ± 0.1 and ranged from 3.5 to 8.4 with a mean of 5.3 ± 0.2 in South Creek. Salinity in North Creek ranged from 0.16 to 12.12 ‰ with a mean of 2.4 ‰ ± 0.4 and in South Creek from 0.16 to 30.52 ‰ with a mean of 4.0 ‰ ± 1.1. Salinities >11 ‰ in North Creek were recorded only once during the study and were <7 ‰ on all but one other occasion. Salinities >18 ‰ in South Creek were recorded three times during the study period and were <6 ‰ on all but two other occasions. Tidal influence on feeding periodicity was not tested as heavy rains during the sampling period often resulted in water flowing out of the creeks during the predicted rising tidal period.

Feeding Periodicity

Overall, CPUE was significantly different among periods (P<0.01) (Fig. 2-3), and was greater nocturnally (6.8 snook/seine ± 1.2) compared to diurnal (1.5 snook/seine ± 0.4) (P<0.01) and dawn (1.6 snook/seine ± 0.8) (P<0.01) periods. CPUE was also greater during dusk (6.6

snook/seine ± 1.6) compared to diurnal (*P*<0.01) and dawn (*P*<0.01) periods, there was no significant difference between nocturnal and dusk periods (*P*=0.9) or diurnal and dawn periods (*P*=0.8). Prey items were retrieved from 113 snook (68%), 42 from North Creek (76%) and 71 from South Creek (64%). The percentage of snook with prey was significantly different among periods (*P*=0.003). Dusk (44.2% ± 7.7) was significantly lower than dawn (100% ± 0) (*P*=0.004), diurnal (70% ± 7.3) (*P*=0.02), and nocturnal (77.3% ± 4.3) (*P*=0.0003) periods. There was no significant difference between diurnal and dawn (*P*=0.08), diurnal and nocturnal (*P*=0.4), or nocturnal and dawn (*P*=0.1) periods (Fig. 2-4).

Fresh prey items, with a digestive index ≤ 2 were primarily found during dusk and nocturnal periods (Fig. 2-5). When the bimodal digestion data, observed primarily during dusk and nocturnal periods (Fig. 2-6), was corrected for highly digested stomach contents from a previous meal, the resulting model of digestion of stomach contents as a function of collection time was: $Y=4.7989/(1+e^{[-0.1764(t-18.1106)]})$; adj-$r^2$=0.81, N=893, $P \leq 0.0001$. Applying this logistic model to the original digestion data indicated that, within a 24-h day, there were portions of three separate feeding cycles: 1) the end of a previous feeding cycle, upper mode of 0100-0900 time periods, as most fish within this segment contained highly digested prey items; 2) a more "complete" feeding cycle in which fresh prey items are found in the lower mode of the 0100 and 0300h time periods with a gradual increase in digestion indices to more highly digested prey in the upper mode of the 1900, 2100, and 2300h time periods; and 3) the beginning stage of another feeding cycle as fresh prey items are present in the lower mode of the 2100 and 2300h time periods.

During this study, several prey types were found in snook stomachs (Table 2-2). Numerically, mysids made up 71%, fish 15%, shrimp 3%, crab 1%, and all other prey 10% of all prey items. By mass, mysids comprised 1%, fish 83%, shrimp 5%, crab 5%, and all other prey 5% of all prey items. Mysids were found in 27%, fish 77%, shrimp 17%, crabs 4%, and all other prey in 9% of all snook containing at least one prey item. Other prey items included amphipods, isopods, and freshwater crayfish. Significant differences were found in mean number of mysids between periods for both small and large snook (Fig. 2-7). Significantly more mysids (predominantly *Mysidopsis almyra*) were found nocturnally than diurnally for both large (P=0.007) and small snook (P=0.002).

Discussion

Capture rates of snook, percentage of snook with prey, and mean number of each prey type per snook among periods, all strongly suggest that juvenile and sub-adult snook adopt a mixture of crepuscular and nocturnal foraging behavior, feeding primarily during dusk and nocturnal hours. In addition, the digestive index of prey throughout the diel cycle showed that fresh (i.e., recently ingested) prey were principally found during dusk and nocturnal periods (Fig. 2-5). Thus, our analyses show that juvenile snook began feeding around dusk, fed throughout the night, and then reduced their feeding around dawn and into the daytime. This foraging pattern classifies juvenile and sub-adult snook as both crepuscular and nocturnal foragers during the summer.

The majority (72%) of snook sampled were caught during dawn, dusk, and nocturnal periods. Differences in CPUE (Fig. 2-3) among collection periods were likely due to diel differences in snook behavior. The main hindrance to seine net efficiency with snook is structure and whereas a seine net can surround a structure, it cannot physically capture snook hiding in and around the structure itself (pers. obs.). Differences in CPUE imply that (1) snook moved into the area during dusk and nocturnal periods to forage, (2) low tide forced snook out of their refugia making them more catchable during dusk and nocturnal periods, or (3) snook became more active during dusk and nocturnal periods, presumably moving away from daytime refugia or resting areas to forage, thus becoming more susceptible to capture.

The percentage of snook with prey (Fig. 2-4) was greatest during dawn (100%), nocturnal (77%), and diurnal (70%) periods and lowest during dusk (44%). Coupled with the bimodal distribution of fresh and highly digested prey (Fig. 2-6), the abundance of fresh prey during the nocturnal period (Fig. 2-5) would suggest that snook are primarily crepuscular and nocturnal foragers. Our findings therefore do not support the suggestion of McMichael et al. (1989) that juvenile snook feed diurnally. Previous snook diet studies may have under- or over-represented the importance of some prey species by performing collections solely during the day (e.g., Gilmore et al. 1983, McMichael et al. 1989; Aliaume et al. 1997; Blewett et al. 2006). Luczkovich et al. (1995) did perform diel collections but all samples were pooled and any differences in prey occurrence between day and night samples were not reported.

Differences in mean number of certain prey types in snook stomachs between periods support primarily dusk and nocturnal foraging behavior by the juvenile snook sampled here. During diurnal and dawn periods, mysids and other small-bodied crustaceans (amphipods and isopods) were virtually absent from diet samples (Fig. 2-7). These prey were primarily consumed nocturnally and because of their small body size most likely digested at a faster rate than larger prey items, hence their absence in our diurnal and dawn samples. The majority of mangrove/shoreline associated crabs (*Neopanope* spp.) were collected from large snook diurnally suggesting that some feeding occurs within their daytime refuge areas. Small snook fed mainly on mysids and fish whereas the diet of large snook was more diverse and included crabs, shrimp, amphipods, and isopods.

Most juvenile fishes, and to some extent small adult fishes, reduce their vulnerability to visual predators by spending most of the day in refuge (Helfman 1993; Walters and Juanes 1993). Feeding opportunities are often limited in such refuges, and so juveniles must forage elsewhere in higher risk habitats but reduce that risk by foraging at night (Walters and Juanes 1993; Walters and Martell 2004). Juvenile snook also appear to be capitalizing on behaviors of other fish and invertebrates acting in a similar manner. As snook are active predators, it is likely difficult to capture prey that congregate in and around complex structures. In the study creeks, these structures often included broken tree limbs, fallen trees, *Juncus* spp., shell bottom, and extensive complexes of mangrove roots. During evening and overnight hours, prey species presumably move out of refugia in search of food (e.g., grass shrimp, *Palaemonetes pugio* [Clark et al. 2003]).

To live in aquatic environments, teleosts are equipped with a variety of different sensory systems. Visual systems adapted to dynamic fluctuations in light intensity can accommodate complex interactions of light transmission through the water column (Richmond et al. 2004). In general, most species are active by day or night and can be classified as either diurnal, nocturnal or crepuscular, since visual adaptations for activity at one light level often reduce efficiency at others. Diurnal species generally are adapted for improved spatial and temporal acuity as well as color sensitivity; in contrast, nocturnal species may enhance their visual sensitivity at low light levels by compromising on some of these aspects (Douglas and McGuigan 1989; Douglas and Hawryshyn 1990; Munz 1990; Fraser and Metcalfe 1997).

Juvenile snook primarily inhabit tidal creeks, impoundments, streams, rivers, or estuaries that are usually turbid from runoff, re-suspension of particles by wind events, tannins from vegetation, or algal blooms (Ecklebarger et al. 1980; McMichael et al. 1989; Peters et al. 1998).

Combined with the darkness of night, this creates a difficult visual environment for snook to detect and capture prey efficiently. Snook, as a visual predator, have advanced adaptations in their eye morphology to aid in prey detection at low-light levels. The outer segment of the retina of snook contains a high density of rods and an unusually low ratio of ganglion cells to photoreceptors (Ecklebarger et al. 1980), both indicative of adaptations for scotopic (low-light) vision. In addition, under low-light conditions, the tapetum lucidum is exposed and enhances quantal catch by a factor of 1.5 (Ecklebarger et al. 1980; Nicol 1981). Alternatively, under high-light (photopic) conditions, the tapetal spheres become obscured by retinal pigments. The tapetum, which enhances light absorption in the retina, increases visual sensitivity and can be advantageous to fishes feeding under low-light conditions. These features, present in snook, are characteristic of a nocturnal-type eye (Ecklebarger et al. 1980). The feeding data presented, along with the morphological characteristics of the snook eye, characterize snook as crepuscular and nocturnal foragers.

It was also apparent that individual snook varied in their time of feeding, as some snook contained fresh prey during the diurnal period (Fig. 2-5). These instances consisted mainly of large juvenile and sub-adult snook with mangrove associated crabs (*Neopanope* spp.) in their stomachs (Fig. 2-7). This suggests that diurnal feeding by large juvenile/sub-adult snook was taking place in their daytime refugia (or they were possibly using these areas as forage grounds). Some temperate species have shown flexibility in the timing of their feeding rhythms. Contrasting diel activity schedules occur in different populations of Atlantic salmon (Fraser et al. 1995; Valdimarsson et al. 2000), age cohorts within a population (Gries et al. 1997), the same individuals at different temperatures (Fraser et al. 1993), and between individuals of the same cohort in the same population at the same time (Sanchez-Vazquez et al. 1995; Alanärä and

Brännäs 1997; Brännäs and Alanärä 1997; Metcalfe et al. 1998; Sanchez-Vazquez and Tabata 1998; Metcalfe and Steele 2001). Ultimately, organisms foraging in risky habitat should exhibit daily timing of feeding activity that reflects temporal variation in both predation risk while foraging and the rate of food intake. The optimal period of foraging activity should minimize predation risk per unit of food obtained (Werner et al. 1983; Clark and Levy 1988; Metcalfe et al. 1999; Metcalfe and Steele 2001). For juvenile and sub-adult snook, this would appear to be during dusk and nocturnal periods during summer months. Future research should be undertaken to determine if diel feeding periodicity differs among habitat types, seasons, and snook sizes not covered by this research.

Table 2-1. Prey digestion indices for fish and crustacean prey of juvenile common snook (adapted from Berens 2005).

Code	Approximate percentage of total prey digested	Fish	Crustacean
0	<10	Whole or mostly whole fish, complete vertebral column (VC), <10% skin and meat missing, head intact, otoliths present, all guts and bones present, most fin rays, no chyme/digesta.	Whole, complete, and hard carapace, all spines, <10% meat and guts missing, legs and eyes attached, no chyme/digesta.
1	10-30	Recognizable fish, complete VC, 10-50% of skin missing, complete or partial head, otoliths present, 10-20% of meat and guts missing, <30% finrays missing, very little chyme/digesta.	Recognizable crab/shrimp, whole or partial soft carapace possibly folded in, spines soft if present, 10-20% meat and guts missing, most legs, eyes possibly attached, no chyme/digesta.
2	30-50	May or may not be a recognizable fish, complete VC, 50-80% skin missing, complete or partial head, otoliths present, 20-40% meat and guts missing, bones may be exposed, few or no finrays, little chyme/digesta.	May or may not be a recognizable crab/shrimp, partial soft carapace, carapace usually folded in or partially detached in shrimp, spines soft if present, 20-40% meat and guts missing, few to no legs, eyes detached, no chyme/digesta.
3	50-70	May or may not be a recognizable fish, complete or incomplete VC, >80% skin missing, no head, partial or no skull, otoliths present or absent, 40-70% meat and guts missing, bones exposed, no finrays, some chyme/digesta.	Partial crab/shrimp, possibly recognizable to species, partial soft carapace, carapace folded or portions missing, no spines, 40-70% meat and guts missing, no legs or eyes, little chyme/digesta.
4	70-90	No longer a recognizable fish, incomplete VC, bits of or no skin, head, or otoliths, 70-90% meat and guts missing, loose bones present, no finrays, more chyme/digesta.	No longer a recognizable crab/shrimp, partial very soft carapace, carapace folded or portions missing, 70-90% meat and guts missing, no legs, no eyes, more chyme/digesta.
5	>90	Recognizable as a fish, incomplete VC, no skin, head, or otoliths, >90% meat and guts missing, no finrays, loose bones present, much chyme/digesta.	Still recognizable as a crab/shrimp based on carapace parts, partial very soft carapace, carapace in pieces, no spines, >90% meat and guts missing, no legs or eyes, much chyme/digesta.

Table 2-2. Diet of juvenile common snook by percent occurrence (%O), percent numerical abundance (%N), percent weight (%W), and percent index of relative importance (%IRI), n=113 non-empty stomachs, all sizes.

Prey Category	Common Name	%O	%N	%W	%IRI
Teleosts[1]		**24.8**	**7.3**	**82.7**	**23.6**
Ariidae					
UID Ariidae	Catfish	0.9	0.1	0.2	<0.1
Gerreidae					
Eucinostomus spp.	Mojarra	2.7	0.3	39.9	4.7
Gobiidae					
Microgobius gulosus	Clown Goby	11.5	2.7	16.6	9.7
UID Gobiidae	Goby	13.3	3.9	9.8	7.9
Poecilliidae					
Poecilia latipinna	Sailfin Molly	1.8	0.3	16.2	1.3
Unidentified Teleosts		46.9	7.1		
Decapoda[1]		**11.5**	**2.2**	**13.4**	**2.3**
Palaemonidae					
Palaemonetes spp.	Grass Shrimp	7.7	1.5	3.7	1.8
Penaeidae					
Farfantepenaeus duorarum	Pink Shrimp	1.8	0.2	0.5	0.1
Unidentified Shrimp		7.1	1.8		
Xanthidae					
Neopanope spp.	Mud Crab	0.9	0.3	4.8	0.2
Unidentified Crab		3.5	0.8		
Cambaridae					
UID Cambaridae	Crawfish	0.9	0.2	4.4	0.2
Mysida		**26.5**	**71.0**	**2.0**	**72.6**
Mysidae					
Mysidopsis almyra	Mysid Shrimp	1.8	5.9	0.2	0.5
UID Mysidae		24.8	65.1	1.8	72.1
Amphipoda		**4.4**	**9.2**	**0.6**	**1.5**
Corophiidae					
Grandidierella bonneroides		0.9	0.1	<0.1	<0.1
UID Corophiidae		3.5	9.1	0.6	1.5
Isopoda[1]		**2.7**	**0.3**	**1.6**	**0.2**
Sphaeroma terebrans	Mangrove Isopod	2.7	0.3	1.6	0.2
Unidentified isopods		0.9	0.1	<0.1	<0.1
Total n		**113**	**882**	**32.5**	**23.0**
Total %		**(100)**	**(100)**	**(100)**	**(100)**

[1]Values do not include unidentified teleosts, crabs, shrimp, or isopods.

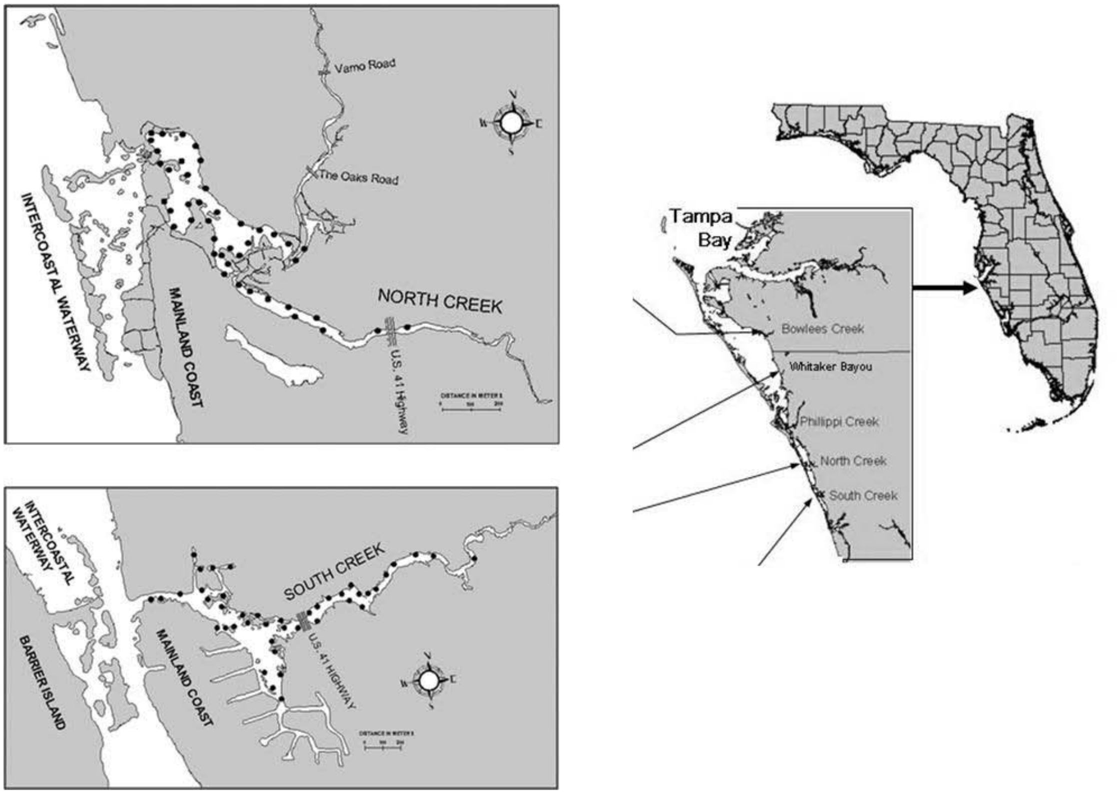


Figure 2-1. Map of study creeks in Sarasota, Florida. Black circles indicate locations of common snook sampled for stomach contents.

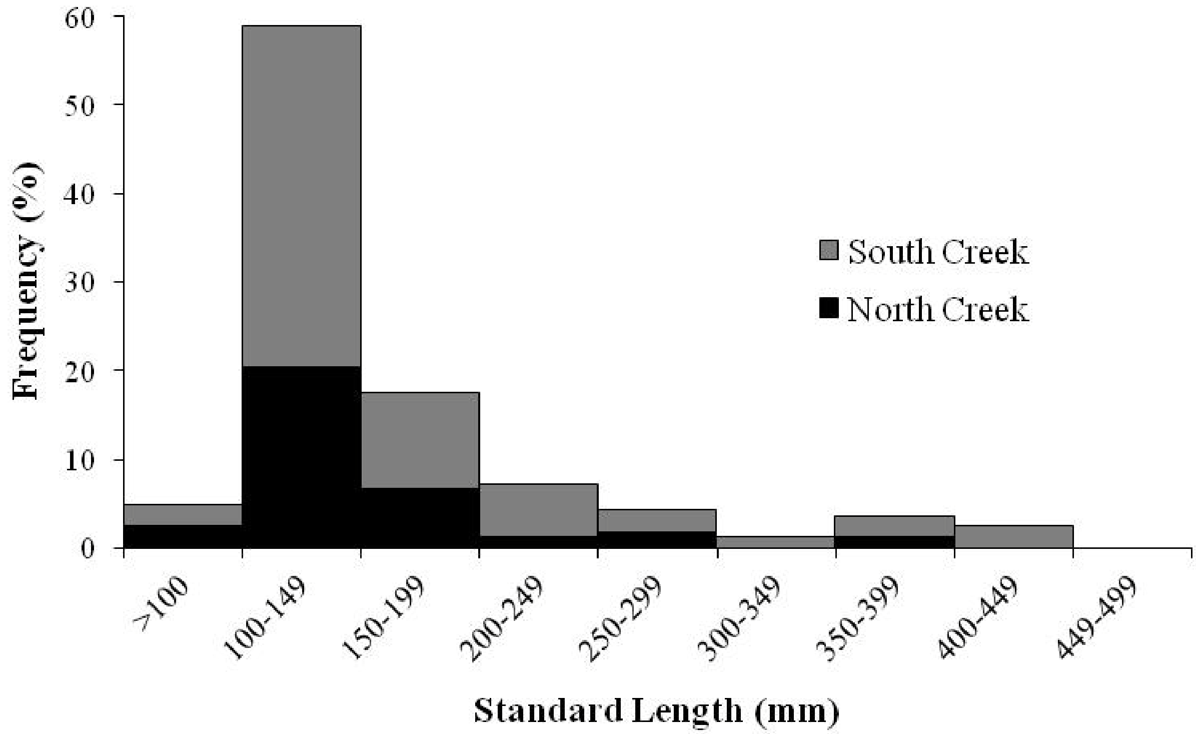


Figure 2-2. Length frequency distribution of all common snook sampled for stomach contents (empty and non-empty stomachs included) in North Creek (n=55) and South Creek (n=111).

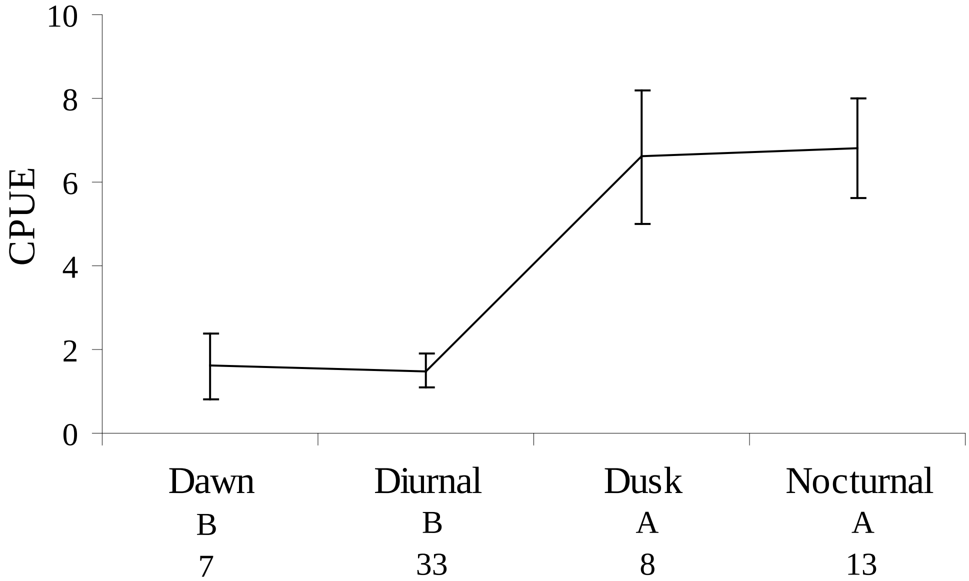


Figure 2-3. CPUE (snook/seine) of common snook during each period. Error bars indicate one standard error. Periods with the same letter are not significantly different. Numbers below x-axis represent number of seines pulled during each period.

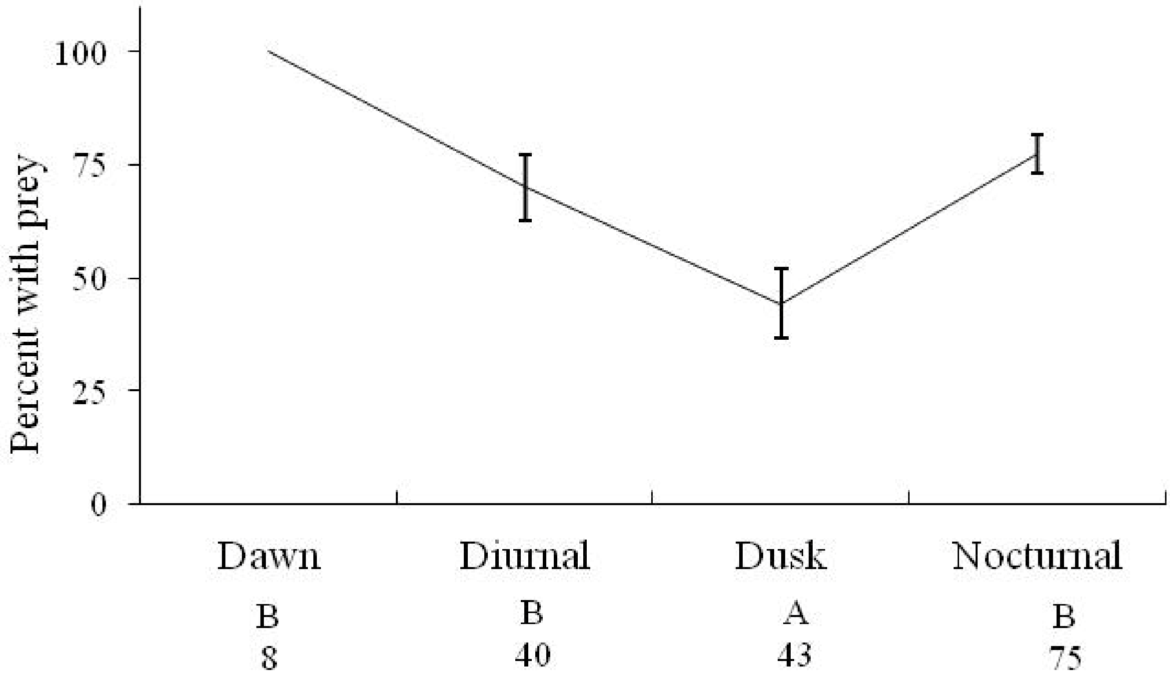


Figure 2-4. Percent of common snook with prey during each period. Error bars indicate one standard error. Periods with the same letter are not significantly different. Numbers below x-axis represent number of snook sampled for prey during each period.

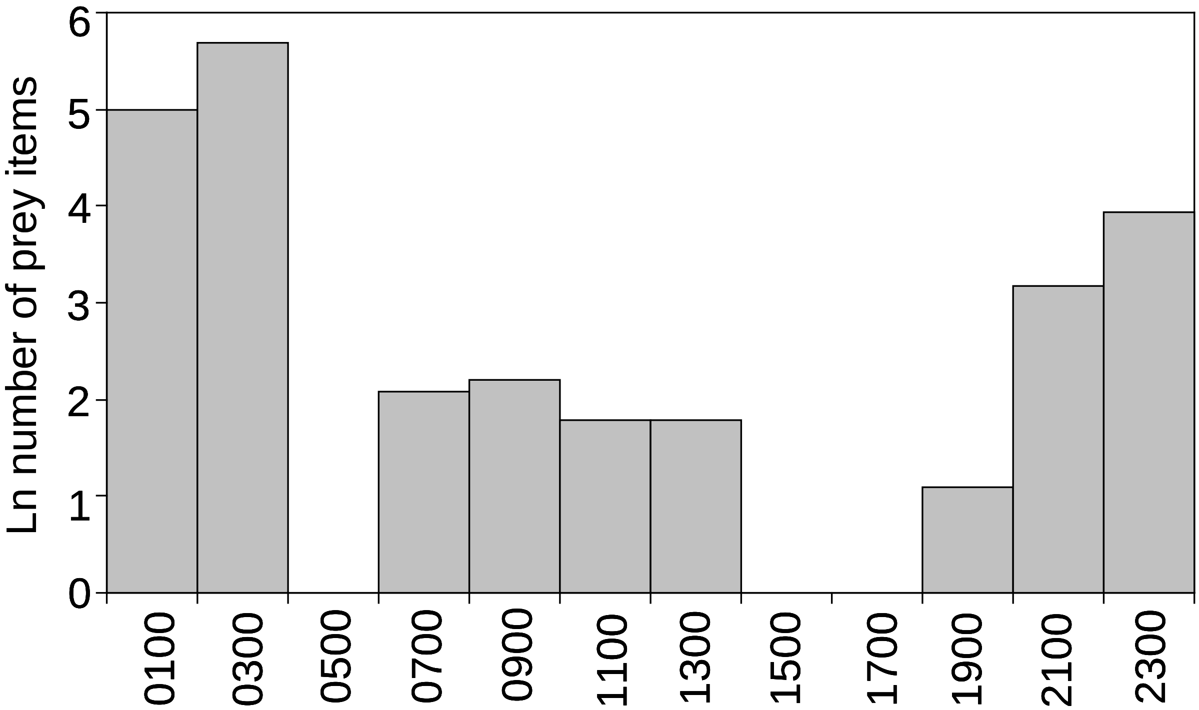


Figure 2-5. Ln number of fresh prey items (digestive index <2) in common snook stomachs by sampling period.

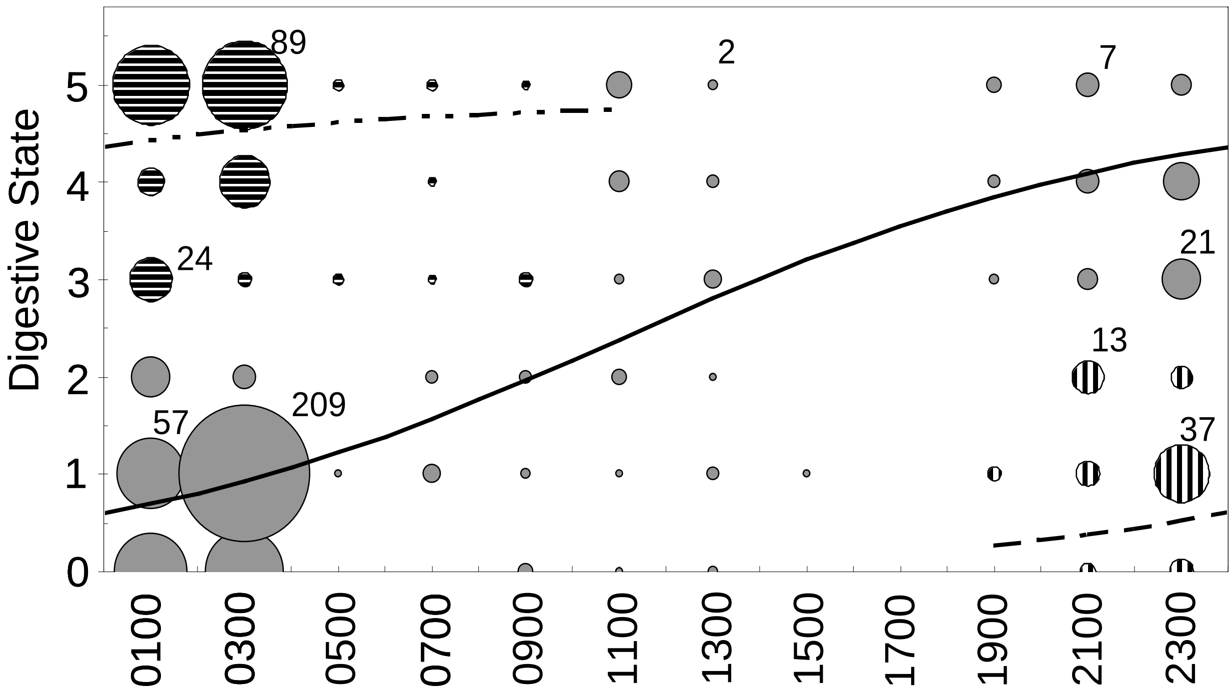


Figure 2-6. Bubble plot of individual prey digestive indices by collection period for common snook. Large bubbles contain more prey items than small bubbles; some N values have been included for scale. Lines represent logistic model fit to the three partial feeding cycles predicting the most likely digestive state of prey throughout the diel cycle. Logistic regression model: Y=4.7989/(1+$e^{[-0.1764(t-18.1106)]}$); adj-r^2=0.81, n=893, $P\leq 0.0001$.

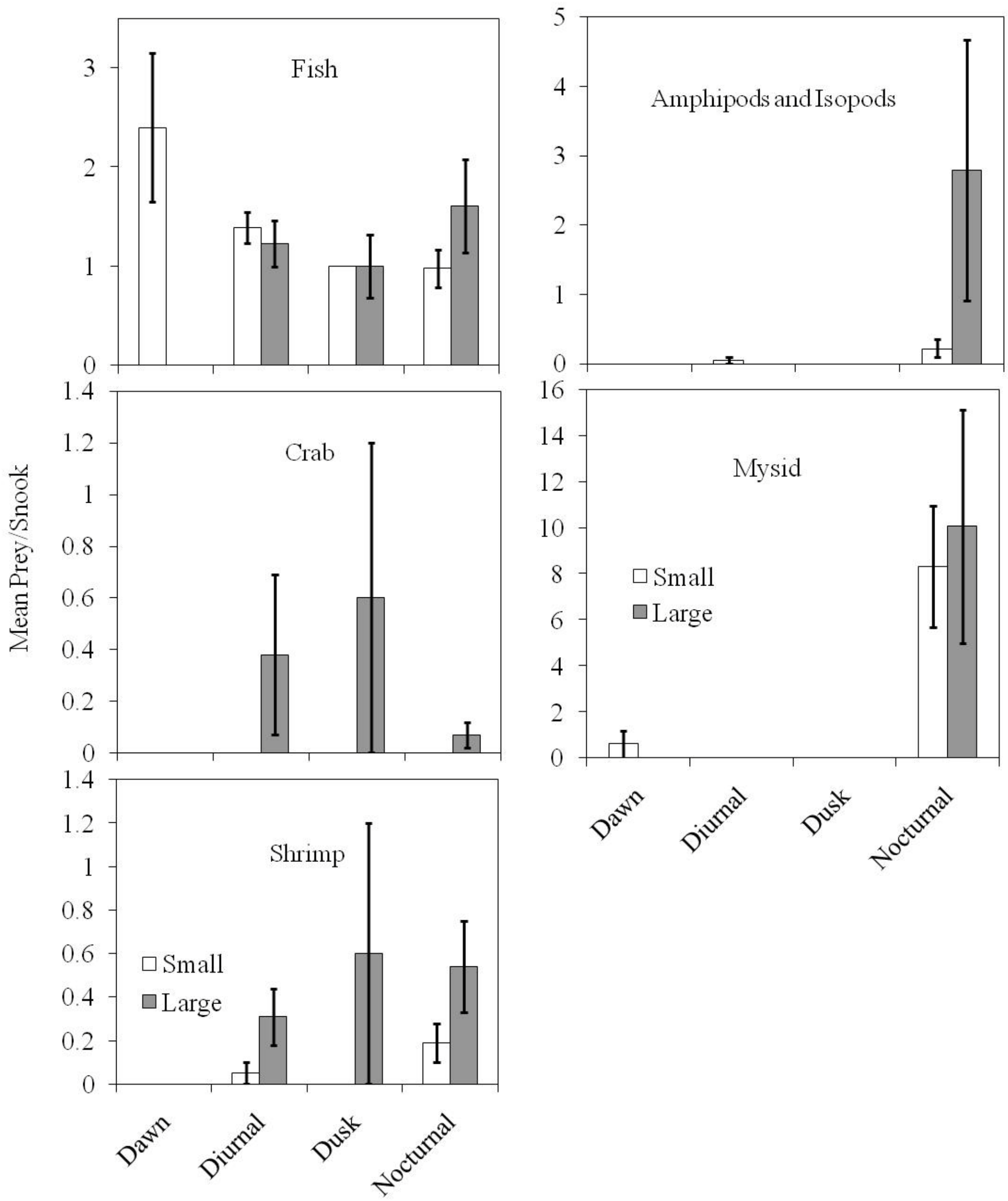


Figure 2-7. Mean number of each prey type per common snook during each period. Error bars indicate one standard error.

CHAPTER 3

ONTOGENETIC DIETARY SHIFTS AND DIETARY OVERLAP OF JUVENILE COMMON SNOOK

Introduction

Typically, marine fishes undergo significant changes in body size through time, ending up as adults that are often orders of magnitude larger than their post-hatch larval size (Winemuller 1989). Often associated with these changes are corresponding shifts in resource use (Osenberg et al. 1992) that may strongly affect an organism's capacity to avoid predation and/or use different habitat types (Schmitt and Holbrook 1984; Walton et al. 1992; Mueller et al. 1994). Ecological compromises may be involved in the timing of these shifts; i.e., habitats with higher prey abundance and availability may also carry a greater risk of predation, particularly for juvenile fish (Werner and Hall 1988; Walters and Juanes 1993), which may be ameliorated with faster growth, owing to size-escape from predation (Paine 1976).

Habitat shifts and changes in body size can be associated with significant shifts in diet, as prey availability and prey selection change (e.g., Stoner, 1980; McCormick 1998), Changes in food habits with increasing body size have been observed in many fish species (e.g. Keast 1970; Murie 1995; Blewett et al. 2006). In carnivorous fishes, younger, smaller fish typically feed on smaller food items and have narrower niche breadths compared to older, larger fish (Nikolosky 1963; Keast 1970; Murie 1995). In Florida, size related differences in feeding have previously been studied for snook ranging from 300-882 mm SL (Blewett et al. 2006) and from 8-120 mm SL (McMichael et al. 1989). However, knowledge of feeding habits for juvenile snook ranging from 100-300 mm SL is lacking.

Few studies have examined the diet of juvenile snook, and all of these studies sampled snook from open bays and estuaries. Marshall (1958) and Fore and Schmidt (1973) examined snook diet of 128 and 454 stomachs, respectively, collected from the Ten Thousand Islands area of southern Florida and found that snook at those sites consumed shrimp, crabs, and fish. Fore and Schmidt (1973) examined ontogenetic shifts but grouped prey only into categories of shrimp, fish, or crab; so the importance of individual species or taxa was not determined. McMichael et al. (1989) studied the diet of juvenile snook in Tampa Bay, Florida, with ~75% of all fish between 10-70 mm SL and most fish (45%) in the 30-45 mm SL size class. They found an ontogenetic shift in diet when snook approached 45 mm SL; juvenile snook <45 mm SL fed mostly on mysids and copepods and snook >45 mm SL, while still feeding on mysids, consumed mostly fish and shrimp.

Aliaume et al. (1997) also studied the diet of juvenile snook in four Puerto Rico estuaries. In their study, stomachs from 268 common snook ranging from <50 mm to 300 mm SL were examined and contents were grossly identified as either fish, shrimp, crab, plankton, or other; hence the importance of individual prey taxa were not reported. They reported snook undergo major ontogenetic changes in diet between the 10-30 mm SL and the 30-60 mm SL size classes. Within the 10-30 mm SL size class, common snook were mainly planktivorous, and at 30-60 mm, their diet began to diversify and include fish and shrimp. Upon reaching 60 mm SL, they no longer preyed upon zooplankton and fed primarily on fish and crustaceans.

Luczkovich et al. (1995) examined the diet of 258 juvenile snook, ranging in size from 5-119 mm SL, in a mangrove impoundment. They found that small snook (<15 mm SL) primarily consumed calanoid and cyclopoid copepods whereas larger juveniles (>15 mm SL) primarily fed on fish. In addition, shrimp, amphipods, and polychaete worms were found in snook stomachs, though no size classes were listed for these prey types.

Blewett et al. (2006) examined the diet of 432 larger snook (300-882 mm SL) in Charlotte Harbor, Florida. Their study revealed a significant positive relationship between predator size and prey size, presented as an explanation for the ontogenetic changes in diet observed. Smaller snook in their samples (300-550 mm SL) consumed primarily pink shrimp *Farfantepenaeus duorarum*, pinfish *Lagodon rhomboides* and grass shrimp *Palaemonetes* spp. whereas larger snook (550-882 mm SL) primarily consumed pinfish, pigfish *Orthopristis chysoptera*, silver perch *Bairdiella chrysoura*, and hardhead catfish *Ariopsis felis*.

Juvenile nursery habitat of many species is associated with shorelines where development and pollution are concentrated (Brennan et al. 2008). In Florida, juvenile snook associate with shoreline habitats (Marshall 1958; Gilmore et al. 1983; McMichael et al. 1989) thus making them dependent on areas that may be subject to anthropogenic habitat alterations (Muller and Taylor 2005). In Southwest Florida, these areas are tidal creeks and estuarine backwaters where natural shorelines consist mainly of red mangrove *Rhizophora mangle* in the lower reaches, and is gradually replaced by rushes *Juncus* spp., Brazilian pepper *Schinus terebinthifolius*, leather fern *Acrostichum danaeifolium*, pines *Pinus* spp., and oaks *Quercus* spp., in the middle and upper reaches (pers. obs.). Several studies have noted the importance to fish communities of natural unaltered shorelines compared to altered shorelines. These often include increased diversity, species richness, abundance, and different community structures compared to altered shorelines (Bryan and Scarnecchia 1992; Laegdsaard and Johnson 2001; Huxam et al. 2004). Because of this, it is easy to speculate there may be differences in diet between altered and unaltered shoreline environments.

The objectives of this study were to 1) describe the diet of juvenile snook in tidal creeks, 2) determine if snook diet changes with ontogeny in the 100 to 300 mm SL size range not previously studied, 3) examine predator size-prey size relationships, and 4) determine if snook diet varies between creeks with altered and unaltered shorelines.

Methods

Data Collection

In addition to those stomachs from Chapter 2, snook stomachs were also collected during July and August 2005 during the peak feeding period identified in Chapter 2. A total of 344 snook were sampled for stomach contents (North=150, South=194). To increase sample sizes and provide a better description of the diet of snook in tidal creeks, samples collected from May-August 2004 (collected in the same manner and during the peak feeding period established in Chapter 2) were also analyzed. An additional 184 samples were added from 2004 to supplement the 2005 samples. Percent empty stomachs was not determined for the 2004 samples. The 2004 samples were distributed among four creeks as follows: Bowlees Creek=67, Whitaker Bayou=44, North Creek=29, and South Creek=39 (Fig. 3-1). Snook were caught, stomachs sampled, and contents identified and processed in the same manner as in Chapter 2.

All of these creeks are partially influenced by anthropogenic shoreline alterations but to differing degrees. Percentages of altered shorelines for each creek were North<2%, South=7%, Bowlees=65%, and Whitaker=14%. Percent altered shoreline in Whitaker was estimated lower than expected due to sedimentation along sea walled shorelines, resulting in a more natural bank slope (Brennan et al. 2008). North and South creeks were designated as unaltered systems and Bowlees Creek and Whitaker Bayou as altered systems.

Stomach Content Analysis

Stomach contents were used to evaluate 1) frequency of occurrence, 2) numerical abundance, 3) weight (Hyslop 1980), and 4) index of relative importance (%IRI) (after Pinkas et al. 1971; Cortés 1997) for each prey taxa. Weight values were back-calculated to the original wet weight of the prey item when possible using regression equations (Murie 1985). Morphometric regression equations were formed by collecting species previously listed as prey items and other potential prey items caught in the same nets as snook. A subsample of these species was weighed (0.01g wet weight), measured to 1 mm for SL, FL, TL, body depth (BD), vertebral column length (base of the skull to the beginning of the caudal fin rays) (VC), post orbital head length (POHL), and carapace width (CW). For prey species not collected with snook, regression equations were provided by the Florida Fish and Wildlife Research Institute in St. Petersburg, Florida (Table 3-1). Weight values for gross prey categories (e.g., teleosts, decapods, mysids, amphipods, and isopods) were calculated using identified prey items only; IRI values for those prey categories were calculated with %O and %N values for all.

Prey items were assigned a digestion code as in Chapter 2. To reduce inclusion of prey items from previous feeding cycles, all samples assigned a digestion code of 5 were excluded from all analyses. Snook were subdivided into four size categories of approximately equal sample sizes. Cumulative prey-species curves were constructed for snook size classes A (80-129 mm SL), B (130-174 mm SL), C (175-264 mm SL), and D (≥265 mm SL), and for each creek (e.g., Bowlees, Whitaker, North, and South). The curves were constructed using a random number generator (in MS Excel) to randomize the order in which stomach samples were analyzed 10 times to count the number of new prey items per randomization. Cumulative prey-species curves were used to identify adequate stomach sample size for this study. An adequate number of stomachs was considered to have been analyzed when the percent of new prey items increased less than 5% over the last 10 stomachs analyzed (Ferry and Cailliet 1996).

Ontogenetic and Spatial Diet Shifts

Niche breadth and niche overlap in snook diets were calculated using %N because %O does not account for multiple prey items of the same type in individual stomachs and %W and %IRI could not be calculated for all prey items. Prey items were summarized by family; unidentified teleosts, shrimps, and crabs were excluded from analyses.

Changes in snook diet with ontogeny and between creek types (developed and undeveloped) were assessed using Levins's niche breadth index (B) (Levin 1968) as standardized (B_A) by Hurlbert (1978). This was used to determine if each size class adopted a generalized (no discrimination among prey types) or specialized (discrimination among prey types) foraging strategy (Murie 1995). Niche breadth was expressed on a scale from 0 to 1. When B_A=0, all individuals, items, or mass occur in one food category, indicating maximum specialization. When B_A=1, an equal number of individuals, items, or mass occurs in each food category indicating no discrimination or a generalist behavior (Murie 1995, Krebs 1999):

$$B_A = \frac{B-1}{n-1}$$

where B is equal to $1/\sum p^2_{ij}$ and p^2_{ij} is the proportion of the diet of predator i that contains prey j and n is the number of prey categories.

Niche overlap was calculated using Morisita's index of similarity, C (Morisita 1959, Krebs 1999). The index ranges from 0 (no similarity) to 1 (complete similarity) and was used to assess diet overlap among size classes and between creek types. Morisita's index of similarity was used because it gives almost no bias regardless of sample size or number of resources (Smith and Zaret 1982, Krebs 1999):

$$C = \frac{2 \sum_i^n p_{ij}\, p_{ik}}{\sum_i^n p_{ij}[(n_{ij} - 1)/(N_j - 1)] + \sum_i^n p_{ik}[(n_{ik} - 1)(N_k - 1)]}$$

where, C is Morisita's index of niche overlap between species j and k, p_{ij} is equal to the proportion resource i is of the total resources used by species j, p_{ik} is the proportion resource i is of total resources used by species k, n_{ij} is number of individuals of species j that use resource category i, n_{ik} is number of individuals of species k that use resource category i, and N_j and N_k are equal to the total number of individuals of each species in the sample.

Prey Size

Predator size-prey size relationships were examined by plotting snook length against prey length for teleosts and for the three most abundant prey taxa (mojarras, clown gobies, and grass shrimp). Pearson correlations were used to determine any significant relationship between snook length and prey length. Prey size ratios (prey SL/snook SL) were also calculated for teleosts to examine the relationship between prey size and snook size.

Results

Diet Analysis

Of the 344 snook sampled in 2005 (including those from Chapter 2), 228 (66%) contained at least 1 prey item and 180 (52%) contained at least 1 prey item with a digestion code <5. In total, of the 412 stomach samples with at least 1 prey item (2004=184, 2005=228), 353 (86%) samples contained at least one prey item with a digestion code <5 and were used in this study. Snook ranged in size from 88 to 414 mm SL. Of those 353 samples, 62 (18%) were from Bowlees Creek, 43 (12%) from Whitaker Bayou, 105 (30%) from North Creek, and 143 (41%) were from South Creek. Larger snook (>265 mm SL) had the highest proportion of nearly digested prey (digestion code of 5), and this proportion generally decreased as size decreased

(Fig. 3-2). Snook from North Creek and South Creek had the highest proportion of stomachs with nearly digested prey (Fig. 3-3).

Cumulative prey plots showed the diet was well described overall with a 0.3% increase in new prey items over the last 10 stomachs analyzed (Fig. 3-4). The diet was well described for snook <175 mm SL (size classes A and B), with a 3.0% and 3.8% increase in new prey items over the last 10 stomachs analyzed (Fig. 3-5a, b). The diets of snook ≥175 mm SL in size categories C and D were not adequately described as new prey items increased 9.3% and 28.3%, respectively, over the last 10 stomachs analyzed (Fig. 3-5c, d). Additionally, the diet was well described for North and South Creeks, with a 3.6% and 3.1% increase in new prey items (Fig. 3-6a, b), but diets in Bowlees Creek and Whitaker Bayou were not well described as new prey items increased 7.0% and 13.0% over the last 10 stomachs analyzed (Fig. 3-6c, d).

When possible, weight values were back calculated to original prey weights using regression equations (Table 3-1). Teleosts were the most common prey item encountered in snook stomach contents, occurring in 69.7% O, 29.4% N, 76.3% W, and 44.2% IRI of stomachs containing food (Table 3-2). Clown gobies *Microgobius gulosus* were the most abundant teleost prey overall (9.3% O, 4.6% N, 4.3% W, 8.4% IRI), followed by mojarras *Eucinostomus* spp. (9.9% O, 2.6% N, 33.6% W, 25.2% IRI), other gobies (11.3% O, 4.6% N, 4.3% W, 7.0% IRI), and cyprinids (3.7% O, 1.3% N, 6.4% W, 2.0% IRI). Other important prey items were grass shrimp *Palaemonetes* sp. (18.7% O, 7.1% N, 8.2% W, 20.1% IRI), mysids (12.2% O, 39.1% N, 0.5% W, 27.9% IRI), and amphipods (5.1% O, 16.7% N, 1.0% W, 4.4% IRI).

Teleosts also dominated the diet of snook based on size. Teleosts made up 63.9%, 71.3%, 84.8%, and 57.6% occurrence and 21.7%, 33.7% 49.0%, and 15.7% numerical abundance in the diets of size classes A, B, C, and D, respectively (Fig. 3-3). Decapods were also common, making up 20.6%, 36.3%, 36.2%, and 42.4% occurrence and 6.6%, 16.4%, 17.3%, and 10.5% numerical abundance for size classes A, B, C, and D. Mysids (26.8% O, 68.1% N, 2.2% W, 58.8% IRI) were the most important single prey item for size class A, followed by mojarras (10.3% O, 2.7% N, 40.2% W, 17.4% IRI), clown gobies (11.3% O, 4.6% N, 20.1% W, 11.0% IRI), and grass shrimp (15.5% O, 5.0% N, 8.1% W, 8.0% IRI). Grass shrimp (28.6% O, 10.3% N, 14.8% W, 36.8% IRI) and mojarras (11.5% O, 3.2% N, 43.8% W, 27.7% IRI) were the most common prey items for size class B, followed by mysids (8.9% O, 40.8% N, 0.4% W, 18.8% IRI) and clown gobies (7.6% O, 4.1% N, 7.1% N, 4.4% IRI). Grass shrimp (19.7% O, 8.2% N, 6.3% W, 20.1% IRI) were the most common prey item for size class C, followed by mojarras (9.1% O, 2.9% N, 27.9% W, 19.7% IRI) and clown gobies (13.6% O, 7.2% N, 12.7% W, 19.0% IRI). Amphipods (family Corophiidae, 9.1% O, 69.5% N, 3.1% W, 53.3% IRI) were the most common prey item for size class D, followed by blue crabs *Callinectes sapidus* (9.1% O, 1.4% N, 22.4% W, 17.5% IRI), silver jennies *Eucinostomus gula* (9.1% O, 1.4% N, 5.9% W, 5.4% IRI), and the mangrove boring isopod *Sphaeroma terebrans* (15.2% O, 3.8% N, 0.4% W, 5.1% IRI).

In Bowlees Creek, mojarras (22.6% O, 9.8% N, 49.2% W, 54.3% IRI) were the most important prey item consumed, followed by grass shrimp (19.4% O, 20.3% N, 10.0% W, 23.9% IRI) and cyprinids (9.7% O, 8.5% N, 18.2% W, 10.5% IRI). Amphipods (9.3% O, 66.5% N, 9.7% W, 48.2% IRI) were the most important prey item consumed in Whitaker Bayou, followed by mojarras (9.3% O, 1.7% N, 37.0% W, 24.5% IRI) and grass shrimp (14.0% O, 3.9% N, 10.0% W, 13.2% IRI). Mysids (27.6% O, 67.0% N, 1.5% W, 74.3% IRI) were the most important prey item in North Creek, followed by clown gobies (7.6% O, 1.8% N, 16.8% W, 6.6% IRI) and mojarras (4.8% O, 1.0% N, 17.8% W, 4.2% IRI). In South Creek, grass shrimp

(25.2% O, 13.1% N, 8.6% W, 32.3% IRI) were the most important prey item, followed by clown gobies (16.1% O, 12.3% N, 10.9% W, 22.1% IRI) and mojarras (8.4% O, 3.4% N, 31.5% W, 17.3% IRI).

Ontogenetic and Spatial Diet Shifts

Niche breadth generally increased with ontogeny, with Levins standardized niche values of 0.08, 0.15, 0.37, and 0.04 for size classes A (85-129 mm SL), B (130-174 mm SL), C (175-264 mm SL), and D (≥265 mm SL), respectively. These values indicated that small snook were specialized foragers (size classes A and B) and diet diversity increased as snook grew larger (size class C). Niche breadth decrease between size classes C and D was likely a result of small sample size for size class D (n=33) and the presence of one snook that consumed 143 corophiids. With this snook excluded, niche breadth rose to 0.66. Niche overlap estimates indicated ontogenetic shifts in diet. Morisita's index of similarity was highest between size classes A and B (0.92) and between C and D (0.60). Size classes A and D (0.05) and B and D (0.14) had the lowest niche overlap estimates. Niche overlap estimates for size classes A and C were low (0.26) and estimates were higher for B and C (0.48). Niche overlap was highest between contiguous size classes and decreased as size classes became further apart.

Niche breadth values for unaltered creeks were 0.06 for North and 0.25 for South. Altered creeks had niche breadth values of 0.06 for Whitaker and 0.49 for Bowlees. The low values for Whitaker Bayou and North Creek indicate snook in those systems were highly specialized. The values for South and Bowlees Creeks indicate snook in those systems were less specialized and had diets that are more diverse compared to snook in North Creek and Whitaker Bayou. Diet overlap between the altered creeks was low (0.06). The low overlap value is most likely related to the large difference in niche breadth between the two systems. Overlap estimates between the unaltered creeks was moderate (0.56). Overlap estimates between Bowlees Creek and the unaltered creeks was moderate for North Creek (0.56) and high for South Creek (0.74). Overlap estimates for Whitaker Bayou was low for North Creek (0.16) and South Creek (0.14).

Prey Size

Snook ranging from 88-414 mm SL consumed fishes ranging in size from 6.5-92.1 mm SL, shrimp 2.7-10.5 mm POHL, and crabs 7.0-39.5 mm CW. The size of teleosts consumed generally increased with snook size (Fig. 3-7A), and the predator size-prey size relationship was significant ($r=0.41$, $p<0.0001$). In general, larger snook consumed both small and larger fishes, whereas smaller snook primarily consumed smaller fishes. Most (56.2%) teleosts consumed by snook were < 15% of snook SL and 93% were < 25% snook SL (Fig. 3-7B); the average teleost prey consumed was 15% of snook SL. The smallest teleost consumed in relation to snook size was a 11.1 mm SL unidentified fish consumed by a 288 mm SL snook (4% body length), and the largest was a 92.1 mm SL needlefish (*Strongylura* sp.) consumed by a 280 mm SL snook (33% body length). The mean SL of fish prey was 22.8 ± 1.1 (S.E.), 23.0 ± 1.0, 24.5 ± 1.3, and 44.0 ± 8.2 for size classes A, B, C, and D, respectively. Mojarras (*Eucinostomus* spp.) consumed by snook displayed a significant predator size-prey size relationship ($r=0.42$, $p=0.009$). No significant predator size-prey size relationship was found for clown gobies ($r=-0.16$, $p=0.3$) or grass shrimp ($r=0.09$, $p=0.5$).

Discussion

The percentage of snook collected during 2005 with at least one prey item in their stomach (66%) is higher in this study compared to previous studies. Marshall (1958) reported 48% of snook with stomach contents, and Fore and Schmidt (1973) reported 46% of snook to contain food in their stomach. Overall percentage of snook with stomach contents in the present study corresponded with Blewett et al. (2006) who found 62% of snook with food (when only summer samples were considered, the percentage of snook with food rose to 75% in that study). Although the percent of snook with prey was similar, the condition of the prey may have differed, as they collected samples during the day when snook had generally ceased feeding. Blewett et al. (2006) suggested their method minimized stress during capture and therefore likelihood of regurgitation, resulting in the high percentage of snook with food. Similarly to Blewett et al. (2006), only on a couple of occasions were snook observed regurgitating in the net pen. Snook <100 mm SL are generally absent during this time of year and were not included in this study.

Numerically, overall diet composition of fish (29%), shrimp (11%), and crabs (2%) in this study was different from that reported by Marshall (1958) (50% fish, 38% shrimp, 6% crab), Fore and Schmidt (1973) (25% fish, 26% shrimp, 48% crab), and Blewett et al. (2006) (71% fish, 19% shrimp, 7% crab). This was likely due to the high percentage of mysids (39%) and amphipods (17%) found in the stomach contents of snook in the present study; mysids were previously reported in the diet by McMichael et al. (1989) and amphipods were found by McMichael et al. (1989) and Luczkovich et al. (1995). Collections for the present study were done during the peak feeding period (1900-0500) for snook in tidal creeks identified in Chapter 2 compared with McMichael et al. (1989) and Blewett et al. (2006), which was carried out during the daytime. Due to differential digestion rates, small-bodied prey (e.g., mysids) are digested more rapidly than larger prey items (e.g., fish, shrimp, and crabs) (Kennedy 1969; Mann and Orr 1969; Gannon 1976). By sampling during the dusk and nocturnal hours, these prey groups were more easily detected and therefore more accurately represented in the diet of snook in the present study.

Teleosts occurred more frequently than other prey items, followed by shrimp and mysids. Grass shrimp (*Palaemonetes* spp.) were the most frequently consumed individual species identified in stomachs. Clown gobies were the most common teleost species, followed by mojarras and sailfin mollies (*Poecilia latipinna*). The %IRI value for mysids was high (27.9%), though was likely inflated by the absence of back-calculated weights for unidentified fish, shrimp, and crab prey items. The high number of mysids in smaller snook (size classes A and B) and in North and South Creeks suggests they are important prey items in those systems for snook 85-174 mm SL. This was supported by the high niche overlap value (0.92) for size classes A and B.

A wide variety of prey items were collected from snook stomachs in tidal creeks, suggesting snook have diverse feeding habits; 25 taxa were recorded, five of which were not reported in previous studies (Marshall 1958, Fore and Schmidt 1973, Gilmore et al. 1983, McMichael et al. 1989, Blewett et al. 2006). Snook fed on species throughout the water column and in various habitats. For example, *Anchoa* spp. and clupeids are pelagic, xanthid (mud) crabs are demersal, clown gobies are burrowers, grass shrimp and pinfish are associated with seagrasses, and silversides and sailfin mollies are commonly associated with mangrove habitats (Thayer et al. 1987; Sheridan 1992; Poulakis et al. 2003; Blewett et al. 2006).

Niche breadth values between 0.08 and 0.37 indicate that snook of all sizes studied here were more specialists than generalists, though they appeared to become less specialized through ontogeny. The low niche breadth values in size classes A and B may be attributed to the high number of mysids in the diet. Additionally, the low niche breadth value for size class D was due to the presence of a single snook that consumed 143 corophiids; when excluded from the analysis, niche breadth rose to 0.66. The cumulative prey curve showed the diet was possibly not well described for this size class so more research is needed to determine if this low niche breadth value is valid. While niche overlap estimates cannot directly measure competition, they can give an idea of the potential for competition to occur if prey resources become limiting (Murie 1995). Niche overlap estimates indicate smaller snook are more likely to compete with snook similar, or only slightly larger, in size and less likely to compete with larger snook for prey resources. McMichael et al. (1989) also found that overlap estimates decreased with increasing differences in snook size. Ontogenetic shifts in diet likely can be attributed to larger snook incorporating more diversity into their diet (Nikolosky 1963; Keast 1970; Murie 1995).

Snook most frequently consumed fishes that were < 15% of their SL. The maximum length of fish prey consumed increased with snook length, but snook of all sizes consumed relatively small prey items. This is relatively common and has been shown previously for snook (Blewett et al. 2006) and for other species, including Atlantic angel sharks *Squantina dumeril* (Baremore 2007) and juvenile fringed flounder *Etropus crossotus* (Reichert 2003). It was also consistent with many marine fishes selecting smaller prey items than were predicted by optimal diet models alone (Juanes 1994).

Snook consumed mainly teleost fishes, though shrimp and mysids were also important items in the diet. Snook showed an ontogenetic shift in diet, with teleosts and shrimp becoming more important with increasing size. Niche breadth increased with snook size indicating the smallest snook were the most specialized foragers. Diet overlap between the altered creeks was low suggesting more factors than shoreline alteration influence snook feeding. Bowlees Creek (altered) had high overlap values with both unaltered creeks. Examination of the food habits table shows snook consumed many of the same species in these creeks, but perhaps the most influential prey source was mysids, as they were found in the diet of snook from every system except Whitaker Bayou (which had low overlap values with the three other creeks). Snook of all sizes consumed relatively small prey items with size class A (85-129 mm SL) consuming the largest teleost prey in relation to body size. This research is an important first step in describing the diet of intermediate-size juvenile snook in tidal creeks and examining differences in snook diet between altered and unaltered habitats. More research is needed to determine what other biotic and abiotic factors affect snook diet in these nursery areas.

Table 3-1. Regression equations used to back-calculate lengths and weights of partially digested prey items. W=weight (g), SL=standard length (mm), TL=total length (mm), VCL=vertebral column length, POHL=post-orbital head length, CW=carapace width. Ranges of x values are listed from minimum to maximum. All regressions were significant at $P \leq 0.05$.

Prey Species	**Regression Equation**	**r^2**	**n**	**Min(x)**	**Max(x)**
Blue crab[1] *Callinectes sapidus*	$W=0.0002(CW)^{2.7623}$	0.99	152	10	209
Clown goby[1] *Microgobius gulosus*	$W=0.00002(SL)^{2.8724}$	0.93	266	12	65
	$W=0.00002(TL)^{2.7123}$	0.92	90	14	82
	$TL=1.2618(SL)-0.3607$	0.99	90	12	65
Crested goby *Lophogobius cyprinoides*	$W=0.00002(SL)^{3.1656}$	0.97	9	28	64
Eastern mosquitofish[1] *Gambusia holbrooki*	$W=0.0000055(TL)^{3.189}$	0.98	198	10	40
Grass shrimp *Palaemonetes spp.*	$W=0.0024(POHL)^{2.5357}$	0.93	22	3	23
	$W=0.00003(TL)^{2.8037}$	0.97	22	13	87
Pink Shrimp[1] *Farfantepenaeus duorarum*	$W=0.0032(POHL)^{2.3015}$	0.90	222	2	43
Sailfin molly[1] *Poecilia latipinna*	$W=0.00001(TL)^{3.141}$	0.99	450	15	59
Silver jenny[1] *Eucinostomus gula*	$W=0.00005(SL)^{3.0652}$	0.96	613	22	128
	$SL=2.0563(VCL)^{0.8902}$	0.99	20	14	75

[1] Denotes equations provided by Florida Fish and Wildlife Research Institute.

Table 3-2. Diet of common snook by percent occurrence (%O), percent number (%N), percent weight (%W), and percent index of relative importance (%IRI). Weight was back-calculated for fish species when possible. N=353 non-empty stomachs, all sizes and locations.

Prey Category	Common Name	%O	%N	%W	%IRI
Teleosts[1]		**69.7**	**29.4**	**76.3**	**44.2**
Ariidae					
UID Ariidae	Catfish	0.3	0.1	<0.1	<0.1
Atherinopsidae					
Menidia spp.	Silverside	0.6	0.2	0.5	<0.1
Belonidae					
Strongylura spp.	Needlefish	0.3	0.1	0.8	<0.1
Clupeidae					
Harengula spp.	Sardine	0.6	0.5	1.0	0.1
UID Clupeidae		0.3	0.1	0.2	<0.1
Cyprinodontidae					
Cyprinodon variegatus	Sheepshead Minnow	0.3	0.1	1.1	<0.1
UID Cyprinodontidae		3.7	1.3	6.4	2.0
Engraulidae					
Anchoa spp.	Anchovy	0.8	0.3	0.4	<0.1
Gerreidae					
Eucinostomus gula	Silver Jenny	1.1	0.3	1.6	0.2
Eucinostomus spp.	Mojarra	9.9	2.6	33.6	25.2
Gobiidae					
Lophogobius cyprinoides	Crested Goby	0.3	0.1	2.1	<0.1
Microgobius gulosus	Clown Goby	9.3	4.2	8.7	8.4
UID Gobiidae	Goby	11.3	4.6	4.3	7.0
Mugilidae					
Mugil spp.	Mullet	0.6	0.1	<0.1	<0.1
Poeciliidae					
Gambusia holbrooki	Eastern Mosquitofish	0.8	0.7	0.8	0.1
Poecilia latipinna	Sailfin Molly	2.0	0.6	5.3	0.8
UID Poeciliidae		0.8	0.3	0.6	0.1
Sparidae					
Lagodon rhomboides	Pinfish	0.3	0.1	8.8	0.2
Unidentified teleosts		38.8	13.3		
Decapoda[1]		**33.7**	**12.9**	**21.9**	**21.8**
Palaemonidae					
Palaemonetes spp.	Grass Shrimp	18.7	7.1	8.2	20.1
Penaeidae					
Farfantepenaeus duorarum	Pink Shrimp	0.6	0.2	0.5	<0.1
UID Penaeidae		3.4	1.2	2.6	0.9
Unidentified shrimp		7.4	2.4		
Grapsidae					
Aramases cinereum	Squareback Marsh Crab	0.6	0.1	1.4	0.1
Porcellanidae					
Porcellana sayana	Porcelain Crab	0.3	0.1	0.3	<0.1
Portunidae					
Callinectes sapidus	Blue Crab	1.4	0.3	6.5	0.7
Xanthidae					
Neopanope spp.	Mud Crab	0.3	0.2	0.9	<0.1
Pilumnus spp.	Mud Crab	0.3	0.1	0.8	<0.1
Unidentified crabs		3.7	1.1		

Table 3-2. Continued.

Prey Category	Common Name	%O	%N	%W	%IRI
Cambaridae					
UID Cambaridae	Crawfish	0.3	0.1	0.8	<0.1
Mysida		**12.2**	**39.1**	**0.5**	**27.9**
Mysidae	Mysid Shrimp				
Bowmaniella spp.		0.6	0.2	<0.1	<0.1
Mysidopsis almyra		0.6	3.5	<0.1	0.1
UID Mysidae		11.0	35.4	0.4	27.8
Amphipoda		**5.1**	**16.7**	**1.0**	**4.4**
Corophiidae					
Grandidierella bonneroides		1.4	0.7	0.1	0.1
UID Corophiidae		3.7	16.0	0.9	4.4
Isopoda[1]		**3.4**	**1.0**	**0.3**	**0.3**
Sphaeromatidae					
Sphaeroma terebrans	Mangrove Isopod	3.4	1.0	0.3	0.3
Unidentified isopods		0.6	0.1		
Total n		**353**	**1491**	**173.4**	**1406.5**
Total %		**100**	**100**	**100**	**100**

[1]Values do not include unidentified teleosts, crabs, shrimp, or isopods.

Table 3-3. Diet of common snook by size classes: A (SL<130 mm, N=97), B (130-174, N=157), C (175-264, N=66), and D (SL≥265, N=33), by %O, %N, %W, and %IRI.

	Size Class A				Size Class B				Size Class C				Size Class D			
Prey Category	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**
Teleosts[1]	**63.9**	**21.7**	**86.4**	**32.5**	**71.3**	**33.7**	**78.0**	**42.4**	**84.8**	**49.0**	**78.1**	**67.2**	**57.6**	**15.7**	**66.2**	**20.4**
Ariidae																
UID Ariidae					0.6	0.2	0.1	<0.1								
Atherinopsidae																
Menidia spp.					1.3	0.5	1.5	0.1								
Belonidae																
Strongylura spp.													3.0	0.5	2.2	0.7
Clupeidae																
Harengula spp.	1.0	0.6	2.7	0.1					1.5	2.4	2.5	0.5				
UID Clupeidae					0.6	0.2	0.5	<0.1								
Cyprinodontidae																
Cyprinodon variegatus									1.5	0.5	4.5	0.5				
UID Cyprinodontidae	2.1	0.4	3.8	0.3	4.5	1.9	7.8	2.2	6.1	3.4	13.1	7.1				
Engraulidae																
Anchoa spp.					1.3	0.7	0.9	0.1					3.0	0.5	0.4	0.2
Gerreidae																
Eucinostomus gula									1.5	0.5	0.5	0.1	9.1	1.4	5.9	5.4
Eucinostomus spp.	10.3	2.7	40.2	17.4	11.5	3.2	43.8	27.7	9.1	2.9	27.9	19.7	3.0	0.5	23.5	5.8
Gobiidae																
Lophogobius cyprinoides					0.6	0.2	6.2	0.2								
Microgobius gulosus	11.3	4.6	20.1	11.0	7.6	4.1	7.1	4.4	13.6	7.2	12.7	19.0				
UID Gobiidae	8.2	2.5	2.5	1.6	12.7	6.6	4.6	7.3	16.7	7.7	7.4	17.7				
Mugilidae																
Mugil spp.					0.6	0.2	<0.1	<0.1	1.5	0.5	0.1	<0.1				
Poeciliidae																
Gambusia holbrooki	2.1	1.2	2.9	0.3	0.6	0.7	1.1	0.1								
Poecilia latipinna	3.1	0.8	10.6	1.4	1.3	0.3	4.3	0.3	3.0	1.4	9.2	2.2				
UID Poeciliidae	2.1	0.4	3.7	0.3					1.5	1.0	0.3	0.1				
Sparidae																
Lagodon rhomboides													3.0	0.5	34.2	8.4
Unidentified teleosts	32.0	8.5			40.8	15.1			43.9	21.6			39.4	11.4		

Table 3-3. Continued.

Prey Category	Size Class A				Size Class B				Size Class C				Size Class D			
	%O	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**
Decapoda[1]	**20.6**	**6.6**	**11.1**	**8.1**	**36.3**	**16.4**	**21.3**	**37.9**	**36.2**	**17.3**	**20.8**	**26.6**	**42.4**	**10.5**	**30.3**	**21.2**
Palaemonidae																
Palaemonetes spp.	15.5	5.0	8.1	8.0	28.6	10.3	14.8	36.8	19.7	8.2	6.3	20.1	6.1	1.0	0.6	0.8
Penaeidae																
Farfantepenaeus duorarum					1.3	0.5	1.5	0.1								
UID Penaeidae					3.2	1.2	5.0	1.0	7.6	4.3	3.7	4.3	6.1	1.0	0.8	0.9
Unidentified shrimp	5.2	1.2			10.2	3.9			3.0	1.0			9.1	2.4		
Grapsidae																
Aramases cinereum									3.0	1.0	5.6	1.4				
Porcellanidae																
Porcellana sayana									1.5	0.5	1.0	0.2				
Portunidae																
Callinectes sapidus	1.0	0.2	3.1	0.1					1.5	0.5	1.2	0.2	9.1	1.4	22.4	17.5
Xanthidae																
Neopanope spp.													3.0	1.4	3.5	1.2
Pilumnus spp.													3.0	0.5	2.9	0.8
Unidentified crabs	1.0	0.2			4.5	1.2			3.0	1.0			9.1	2.9		
Cambaridae																
UID Cambaridae									1.5	1.0	3.3	0.5				
Mysida	**26.8**	**68.1**	**2.2**	**58.8**	**8.9**	**40.8**	**0.4**	**18.8**	**4.5**	**6.3**	**<0.1**	**0.8**				
Mysidae																
Bowmaniella spp.									3.0	1.4	<0.1	0.3				
Mysidopsis almyra	2.1	10.8	0.2	0.9												
UID Mysidae	24.7	57.6	2.0	57.9	8.9	40.8	0.4	18.8	1.5	4.8	<0.1	0.5				

Table 3-3. Continued.

Prey Category	Size Class A				Size Class B				Size Class C				Size Class D			
	%O	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**
Amphipoda	**5.2**	**3.5**	**0.2**	**0.6**	**3.8**	**6.4**	**0.2**	**0.8**	**4.5**	**23.1**	**0.3**	**2.7**	**9.1**	**69.5**	**3.1**	**53.3**
Corophiidae																
Grandidierella bonneroides	1.0	0.2	<0.1	<0.1	1.3	0.7	0.1	0.1	3.0	2.4	0.1	0.5				
UID Corophiidae	4.1	3.3	0.1	0.5	2.5	5.8	0.1	0.8	1.5	20.7	0.2	2.2	9.1	69.5	3.1	53.3
Isopoda[1]					**1.9**	**1.5**	**0.2**	**0.1**	**7.6**	**4.3**	**0.7**	**2.7**	**18.2**	**4.3**	**0.4**	**5.1**
Sphaeromatidae																
Sphaeroma terebrans					1.3	1.4	0.2	0.1	7.6	4.3	0.7	2.7	15.2	3.8	0.4	5.1
Unidentified isopods					0.6	0.2	<0.1	<0.1					3.0	0.5		
Total n	**97**	**483**	**24.9**	**2542.3**	**157**	**590**	**58.8**	**1952.8**	**66**	**208**	**43.2**	**1420.9**	**33**	**210**	**44.7**	**1240.1**
Total %	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

[1] Values do not include unidentified teleosts, crabs, shrimp, or isopods.

Table 3-4. Diet of common snook by creek: Bowlees (N=62), Whitaker (N=43), North (N=105), and South (N=143) by %O, %N, %W, and %IRI.

	Bowlees				**Whitaker**				**North**				**South**			
Prey Category	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**	**%O**	**%N**	**%W**	**%IRI**
Teleosts[1]	**71.0**	**49.7**	**85.7**	**68.6**	**79.1**	**25.7**	**75.5**	**37.4**	**58.1**	**15.2**	**67.2**	**15.7**	**74.8**	**50.7**	**75.4**	**58.3**
Ariidae																
UID Ariidae													0.7	0.3	0.1	<0.1
Atherinopsidae																
Menidia spp.									1.9	0.4	2.4	0.2				
Belonidae																
Strongylura spp.	1.6	0.7	2.9	0.2												
Clupeidae																
Harengula spp.					4.7	3.5	12.4	5.1								
UID Clupeidae					2.3	0.4	2.1	0.4								
Cyprinodontidae																
Cyprinodon variegatus	1.6	0.7	4.2	0.3												
UID Cyprinodontidae	9.7	8.5	18.2	10.5	4.7	0.9	5.6	2.1	2.9	0.4	2.5	0.4	1.4	0.5	1.5	0.2
Engraulidae																
Anchoa spp.	4.8	3.3	1.5	0.9												
Gerreidae																
Eucinostomus gula									1.0	0.1	6.5	0.3	2.1	0.8	0.6	0.2
Eucinostomus spp.	22.6	9.8	49.2	54.3	9.3	1.7	37.0	24.5	4.8	1.0	17.8	4.2	8.4	3.4	31.5	17.3
Gobiidae																
Lophogobius cyprinoides									1.0	0.1	9.7	0.5				
Microgobius gulosus	3.2	1.3	0.8	0.3					7.6	1.8	16.8	6.6	16.1	12.3	10.9	22.1
UID Gobiidae	4.8	2.0	2.4	0.9	7.0	1.3	4.4	2.7	7.6	3.2	3.2	2.3	18.2	10.2	5.9	17.3
Mugilidae																
Mugil spp.													1.4	0.5	0.1	0.1
Poeciliidae																
Gambusia holbrooki					2.3	2.2	4.9	1.1	1.0	0.1	0.1	<0.1	0.7	1.0	0.9	0.1
Poecilia latipinna	3.2	2.0	5.5	1.0	2.3	0.4	5.8	1.0	2.9	0.6	7.7	1.1	0.7	0.3	3.9	0.2
UID Poeciliidae	1.6	0.7	1.0	0.1	2.3	0.4	3.2	0.6	1.0	0.3	0.3	<0.1				
Sparidae																
Lagodon rhomboides													0.7	0.3	20.1	0.8
Unidentified teleosts	32.3	20.9			46.5	14.8			37.1	7.2			40.6	21.1		

Table 3-4. Continued.

Prey Category	Bowlees				Whitaker				North				South			
	%O	%N	%W	%IRI	%O	%N	%W	%IRI	%O	%N	%W	%IRI	%O	%N	%W	%IRI
Decapoda[1]	**35.5**	**30.1**	**14.0**	**26.1**	**23.3**	**7.8**	**14.7**	**14.3**	**21.0**	**4.0**	**29.5**	**5.8**	**45.5**	**25.6**	**24.3**	**35.2**
Palaemonidae																
Palaemonetes spp.	19.4	20.3	10.0	23.9	14.0	3.9	10.0	13.2	11.4	2.2	4.6	3.6	25.2	13.1	8.6	32.3
Penaeidae																
Farfantepenaeus duorarum	1.6	0.7	0.6	<0.1									0.7	0.5	0.8	0.1
UID Penaeidae	6.5	4.6	3.3	2.1	2.3	1.7	1.6	0.5					4.9	1.8	3.5	1.5
Unidentified shrimp	4.8	2.0			4.7	0.9			4.8	1.0			11.2	6.3		
Grapsidae																
Aramases cinereum									1.9	0.3	6.4	0.6				
Porcellanidae																
Porcellana sayana					2.3	0.4	3.2	0.6								
Portunidae																
Callinectes sapidus									1.9	0.3	15.1	1.4	2.1	0.8	7.4	1.0
Xanthidae																
Neopanope spp.													0.7	0.8	2.0	0.1
Pilumnus spp.									1.0	0.1	3.5	0.2				
Unidentified crabs	6.5	2.6			4.7	0.9			1.0	0.1			4.2	2.3		
Cambaridae																
UID Cambaridae													0.7	0.5	1.9	0.1
Mysida	**6.5**	**19.6**	**0.3**	**5.3**					**27.6**	**67.0**	**1.5**	**74.3**	**7.0**	**17.5**	**0.1**	**5.6**
Mysidae																
Bowmaniella spp.													1.4	0.8	<0.1	0.1
Mysidopsis almyra									1.9	7.2	0.1	0.7				
UID Mysidae	6.5	19.6	0.3	5.3					25.7	59.9	1.4	73.7	5.6	16.7	0.1	5.6
Amphipoda	**1.6**	**0.7**	**<0.1**	**<0.1**	**9.3**	**66.5**	**9.7**	**48.2**	**4.8**	**11.2**	**0.4**	**2.6**	**5.6**	**3.7**	**0.2**	**0.7**
Corophiidae																
Grandidierella bonneroides													3.5	2.6	0.1	0.6
UID Corophiidae	1.6	0.7	<0.1	<0.1	9.3	66.5	9.7	48.2	4.8	11.2	0.4	2.6	2.1	1.0	0.1	0.1

Table 3-4. Continued.

Prey Category	Bowlees				Whitaker				North				South			
	%O	%N	%W	%IRI	%O	%N	%W	%IRI	%O	%N	%W	%IRI	%O	%N	%W	%IRI
Isopoda[1]									**8.6**	**2.6**	**1.4**	**1.6**	**2.1**	**1.6**	**0.1**	**0.2**
Sphaeromatidae																
Sphaeroma terebrans									8.6	2.6	1.4	1.6	2.1	1.6	0.1	0.2
Unidentified isopods													1.4	0.5		
Total n	**62**	**153**	**45.6**	**2455.3**	**43**	**230**	**14.0**	**1469.0**	**105**	**725**	**37.7**	**2137.7**	**143**	**383**	**76.2**	**1690.3**
Total %	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

[1]Values do not include unidentified teleosts, crabs, shrimp, or isopods.

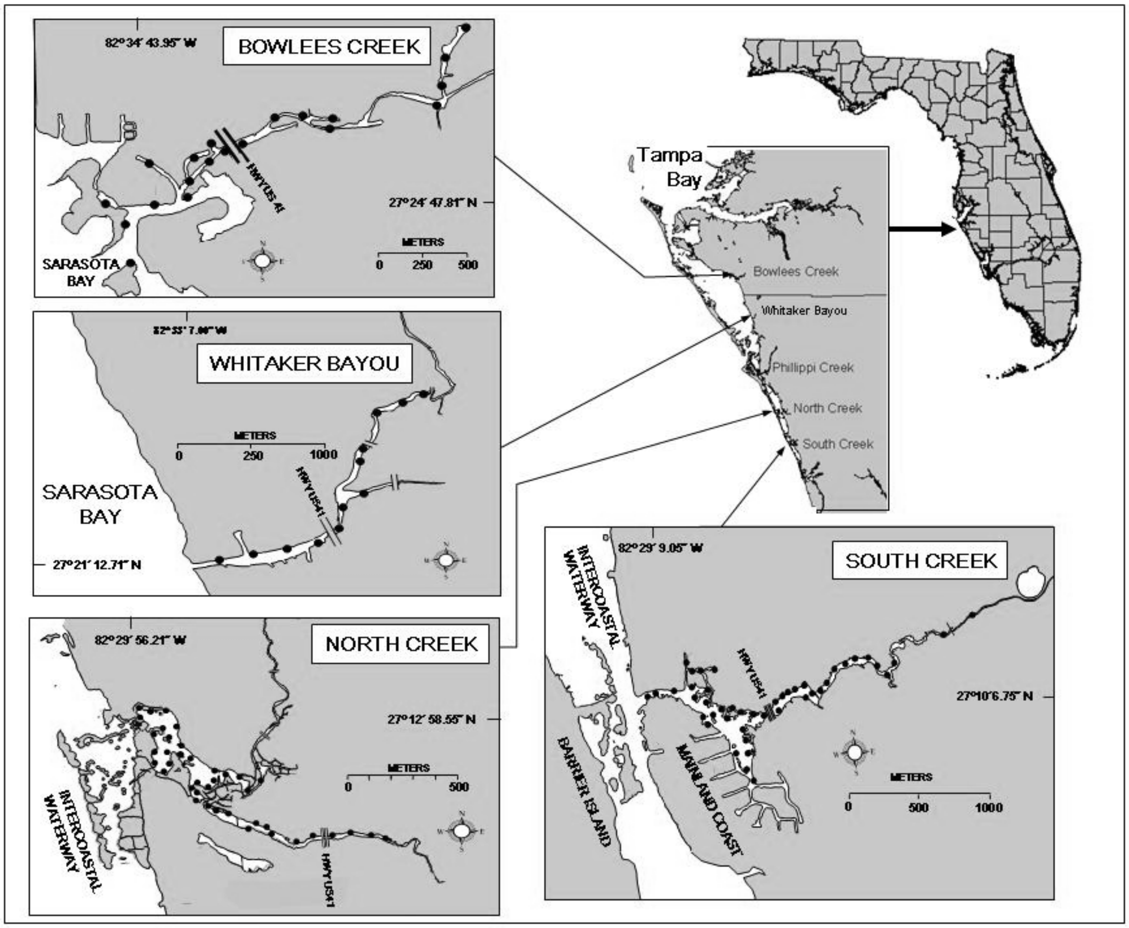


Figure 3-1. Map of four study creeks in Sarasota, Florida, where common snook were sampled in 2004 and 2005 (sample sites represented by black dots).

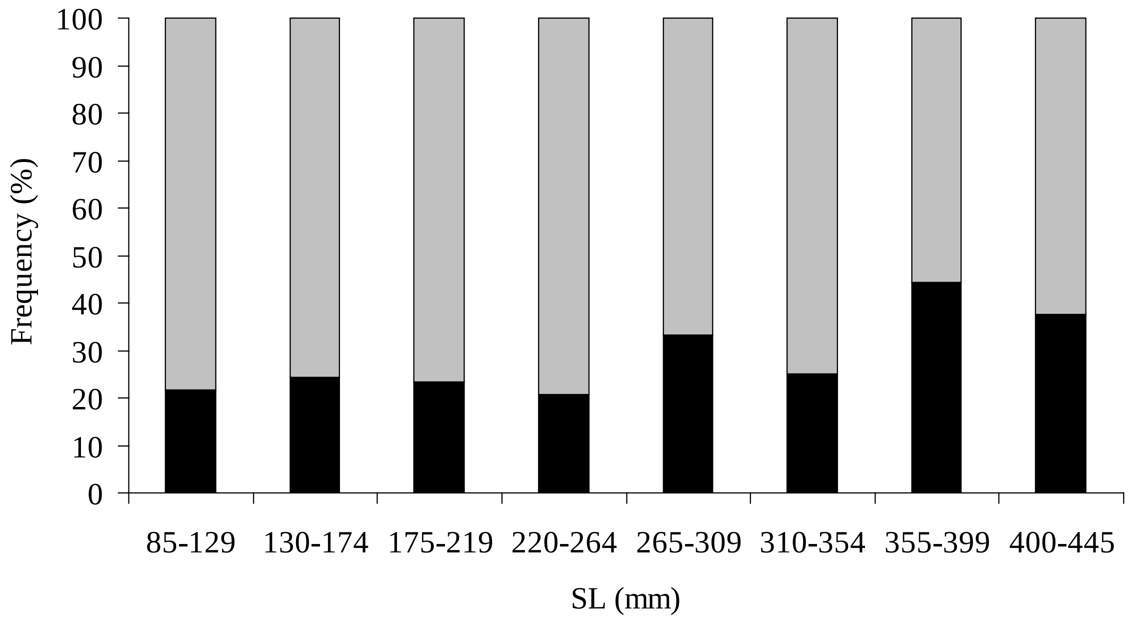


Figure 3-2. Frequencies of common snook with non-empty stomachs containing prey items coded <5 (gray) and prey items coded 5 (black) by size group.

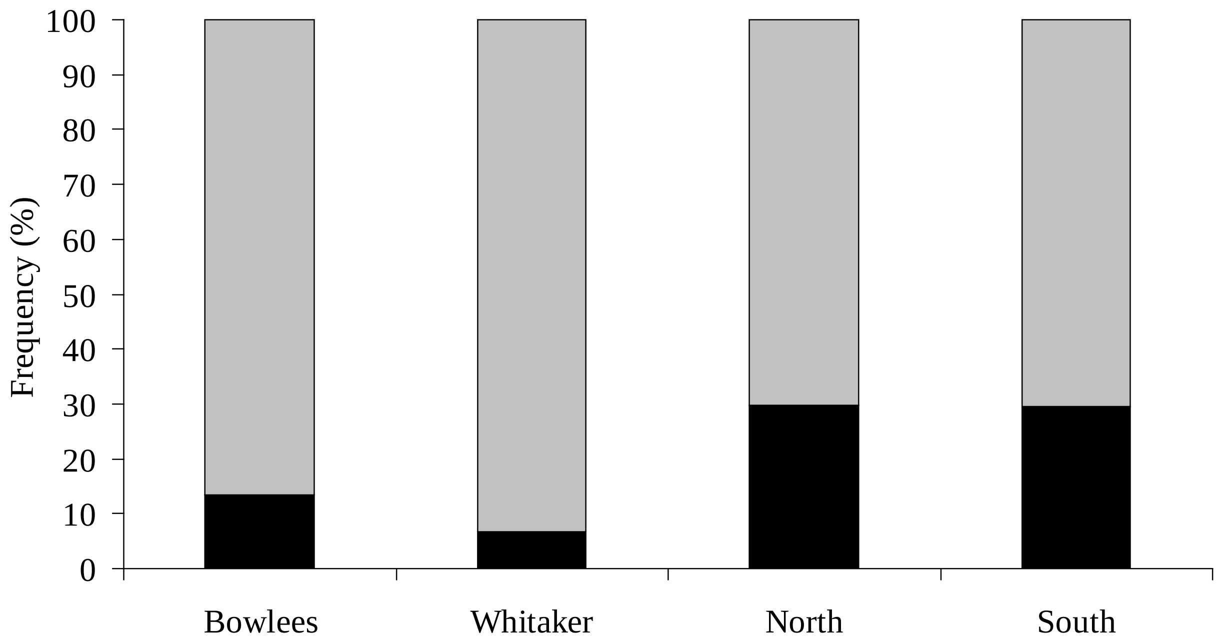


Figure 3-3. Frequency of common snook with non-empty stomachs containing prey items coded <5 (gray) and prey items coded 5 (black) by creek.

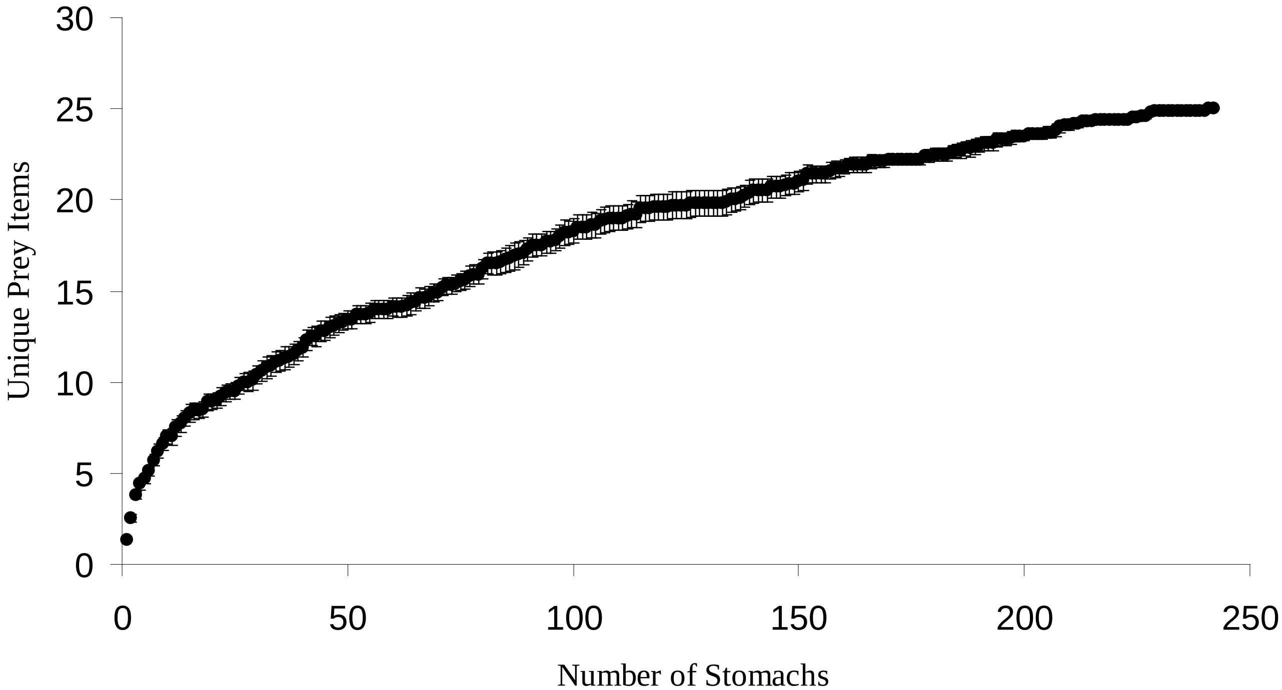


Figure 3-4. Cumulative prey curve for all common snook from all creeks for 2004 and 2005 showing the overall diet was well described.

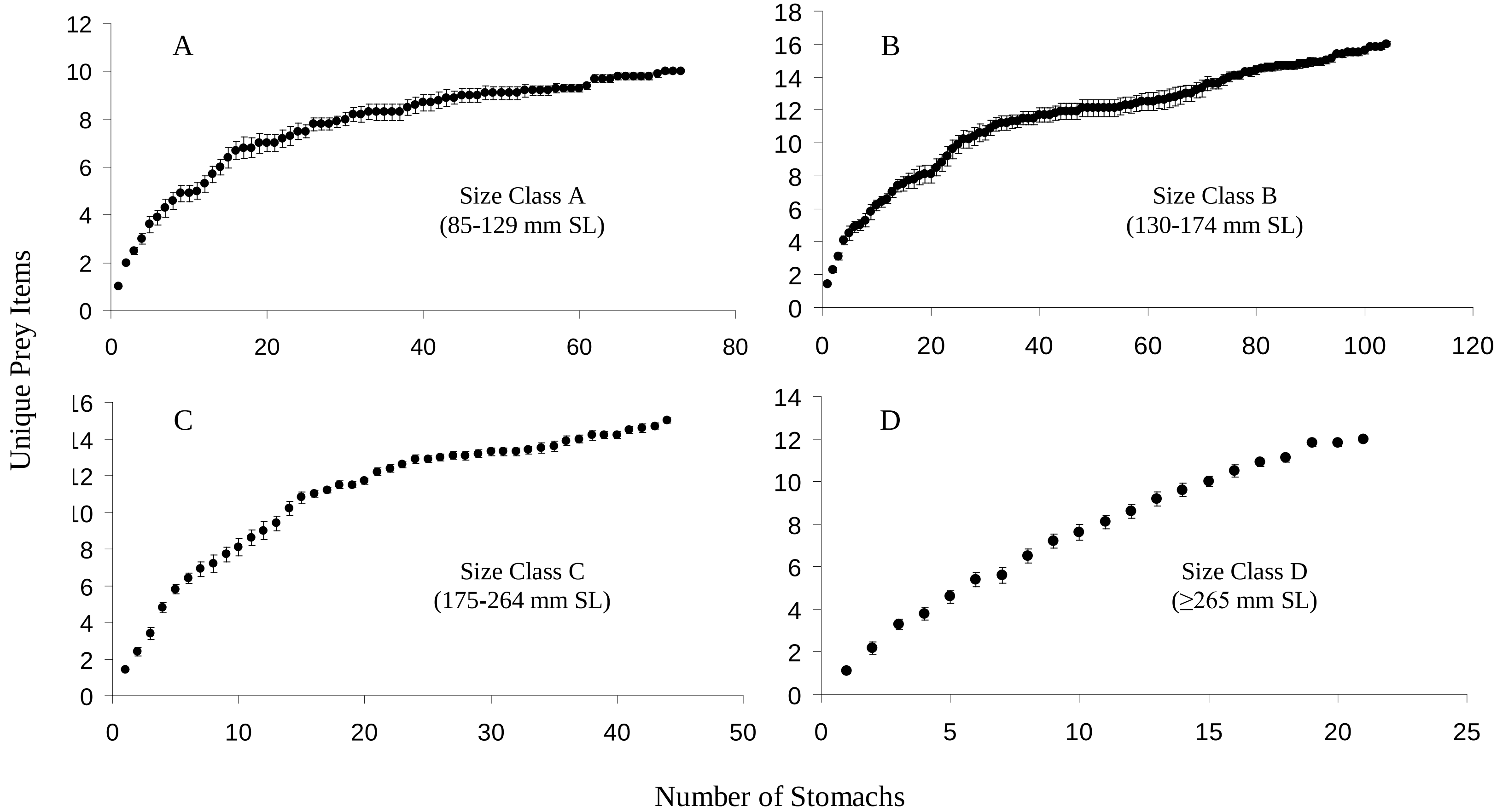


Figure 3-5. Cumulative prey curves for common snook within size classes A, B, C, and D, showing the diet was well described for snook ≤174 mm SL, nearly well described for common snook 175-264 mm SL, and not adequately sampled for common snook ≥265 mm SL.

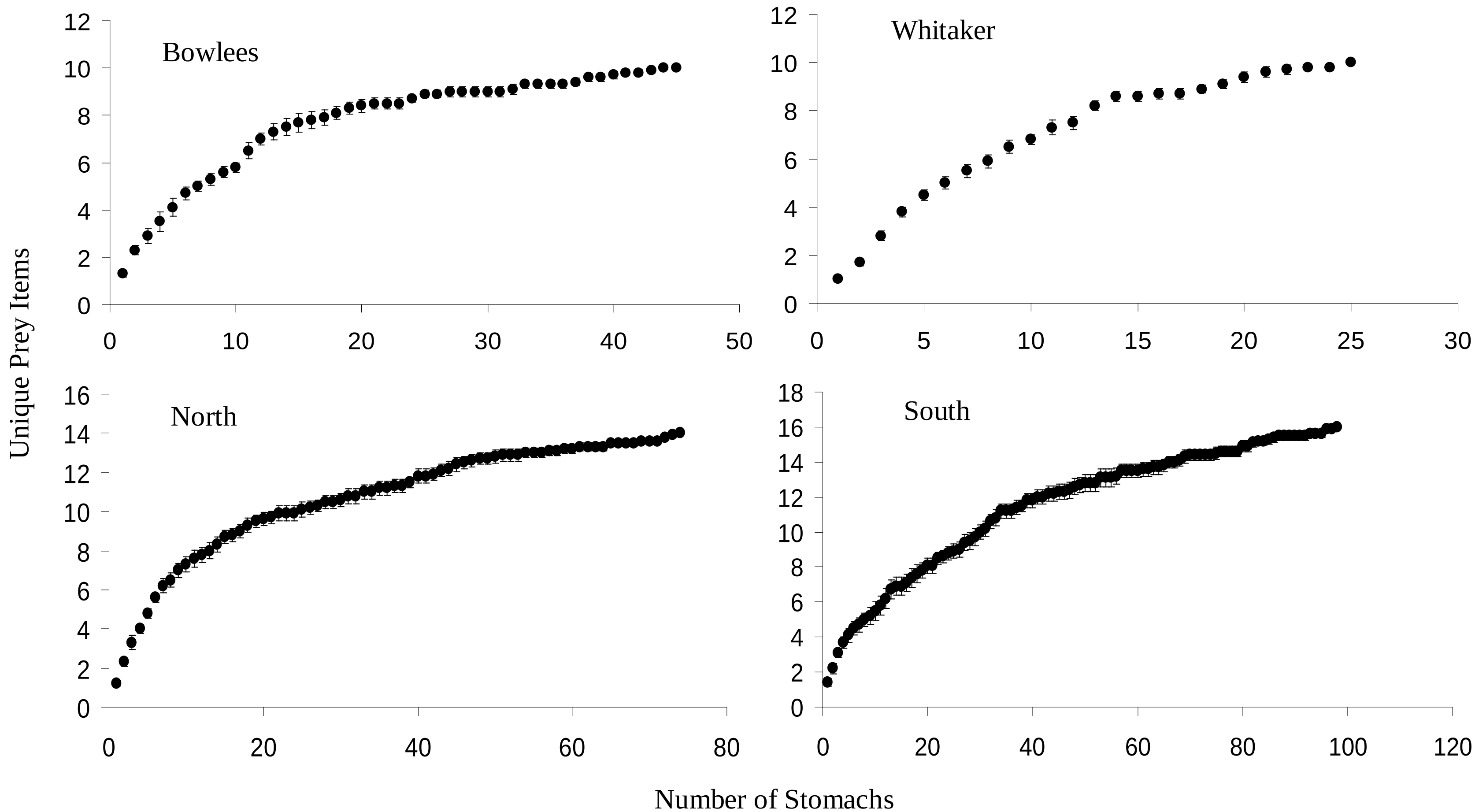
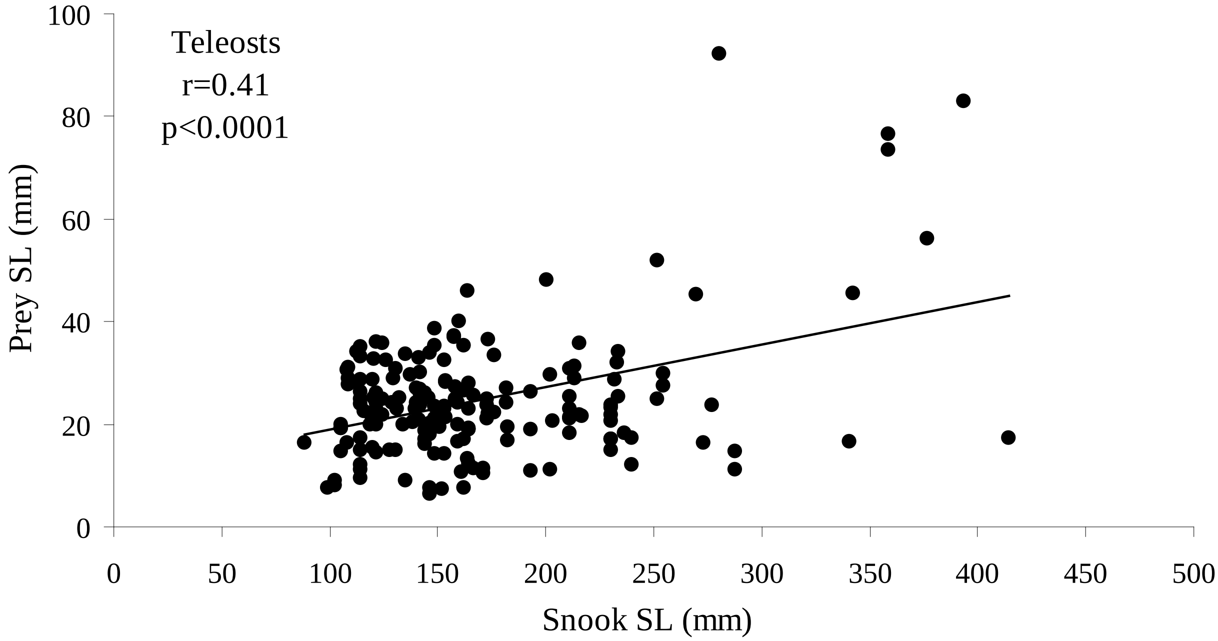


Figure 3-6. Cumulative prey curves for common snook by creek showing the diet was well described for North and South Creeks and possibly not adequately sampled for Bowlees Creek and Whitaker Bayou.

A



B

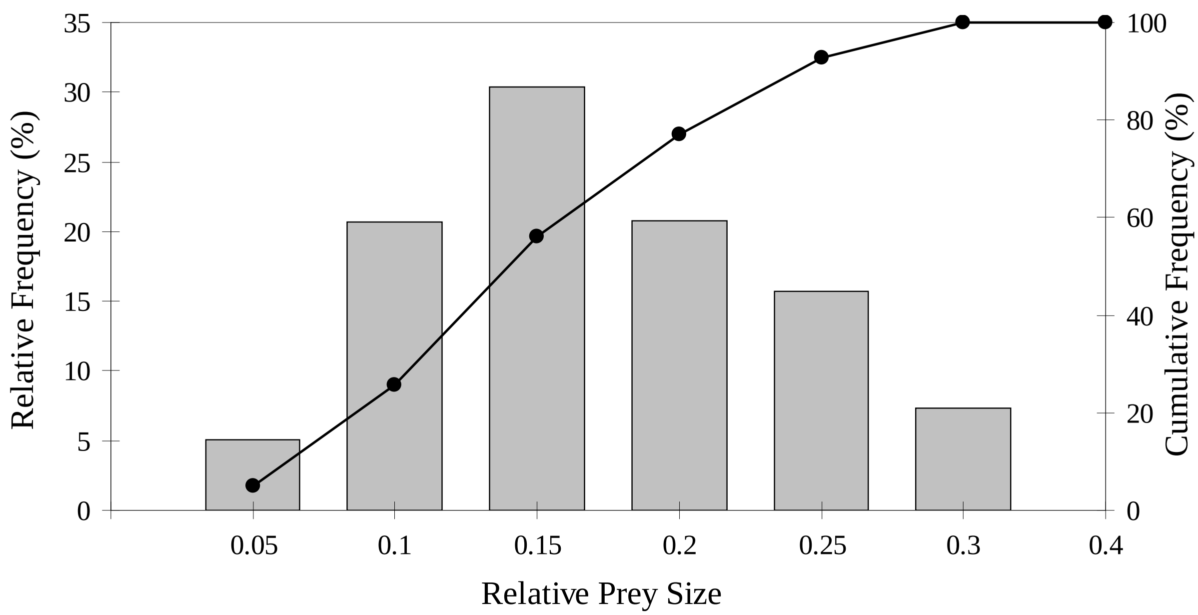


Figure 3-7. A) All teleost prey found in all common snook stomachs, showing a general increase in prey size with common snook size; and B) relative and cumulative frequencies of relative teleost prey size (prey SL/snook SL) in common snook stomach contents. Most prey items were 0.15 common snook SL.

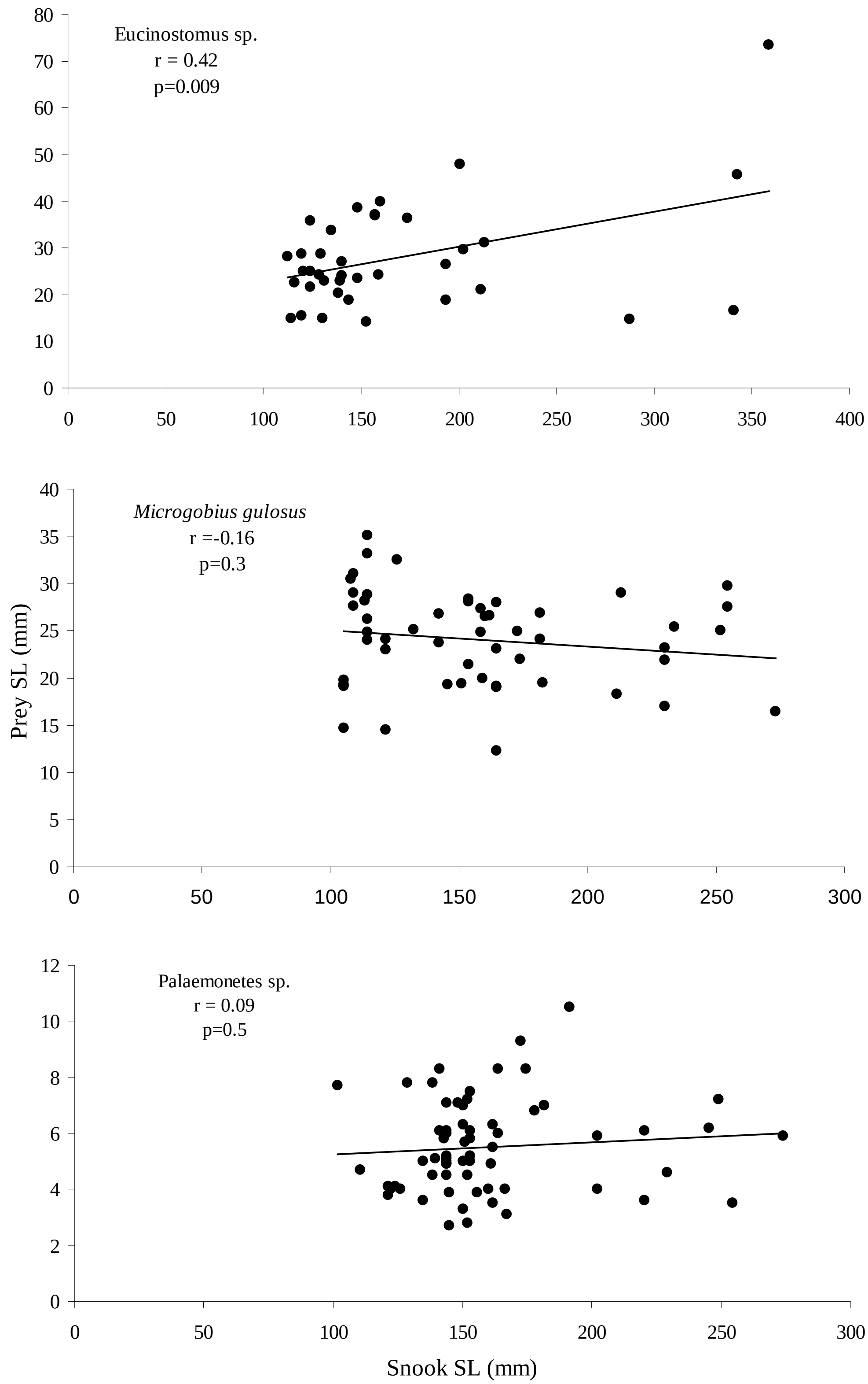


Figure 3-8. Scatter diagram showing the relationship between prey size and common snook size for three important prey taxa.

CHAPTER 4
CONCLUSION

Current and detailed biological data are needed for the proper management of fish stocks and even more so when considering a species for stock enhancement (Leber 1999). This study is the first to provide information concerning the feeding ecology of juvenile snook in tidal creek habitats and the first to compare the diet of juvenile snook in areas with altered and unaltered shoreline. The objectives of this study were to determine diel feeding periodicity, quantify the summer diet of juvenile snook in tidal creek habitats, and to assess ontogenetic and spatial differences in diet of snook in tidal creeks of varying development.

This is the first study to characterize diel feeding periodicity of snook of any size or age. Juvenile snook are primarily nocturnal foragers with feeding beginning around dusk and ceasing before dawn during the summer in tidal creeks in southwest Florida (Chapter 2). The presence of some fresh prey items diurnally suggests some feeding occurs during the day. These occurrences consisted mainly of larger snook (>250mm SL) with crabs or shrimp in their stomachs. Differential digestion rates may account for some of these instances. Grass shrimp have been shown to have a lag phase in digestion, presumably due to their exoskeleton, with up to 50% of prey mass present in snook stomachs up to 6 h after ingestion (Brennan, unpublished data). Additionally, differing diel activity schedules have been shown to occur in different populations of Atlantic salmon (Fraser et al. 1995; Valdimarsson et al. 2000), age cohorts within a population (Gries et al. 1997), the same individuals at different temperatures (Fraser et al. 1993), and among individuals of the same cohort in the same population at the same time for several fish species (Sanchez-Vazquez et al. 1995; Alanärä and Brännäs 1997; Brännäs and Alanärä 1997; Metcalfe et al. 1998; Sanchez-Vazquez and Tabata 1998; Metcalfe and Steele 2001) and should be investigated for snook. Further studies on feeding periodicity are needed to determine how habitat/location, lunar phase, tidal phase, seasons (determined by water temperature), prey assemblages, and ontogeny may affect diel feeding periodicity.

Feeding periodicity has long been known to be an important part of any diet analysis study (Bowen 1996). This thesis emphasizes the importance of feeding periodicity studies to describe the diet of snook accurately (Chapter 3). Of the new prey taxa identified in this study, *Grandidierella bonneroides* (amphipod) and *Sphaeroma terebrans* (isopod) are small-bodied organisms. While amphipod and isopod remains were found by McMichael et al. (1989) and Blewett et al. (2006), they were not able to identify the species. As small-bodied prey, differential digestion rates often result in these prey items being absent from stomach samples if they are collected several hours after the fish has fed (Kennedy 1969; Mann and Orr 1969; Gannon 1976). Blewett et al. (2006) listed isopods as incidental prey, but this study suggests these small-bodied prey items may not be merely incidental prey items for juvenile snook. In most cases these prey were found in snook that had no other prey types in their stomach. Other new prey items identified by this study were needlefish *Strongylura* sp., crested goby *Lophogobius cyprinoides*, and crawfish (Cambaridae).

Throughout ontogeny, feeding habits are likely to shift with changes in size or life history stage (Luczkovich et al. 1995). Ecologically and evolutionarily, body size is one of the most important attributes of an organism. Body size influences energetic requirements, potential for resource use, and susceptibility to predation. Since resource use and predation risk are typically related to body size, many species undergo ontogenetic shifts in habitat use and/or prey resources. In fish, ontogenetic change in prey resources is almost universal (Werner and Gilliam 1984). Size-related shifts in prey resources have been well documented in many studies (e.g., Larkin et al. 1957; Martin 1970; Keast 1978; Ross 1978; Grossman 1980; Persson 1983; Stoner and Livingston 1984; McMichael 1989; Blewett et al. 2006). As fish increase in size, they tend to broaden their diet to include larger and different prey items (Osenberg 1992; Juanes 1994; Bowen 1996). This held true for juvenile snook as niche breadth increased with size from 0.06 in size class A (85-129 mm SL) to 0.37 in size class C (175-264 mm SL); niche breadth for size class D (≥265 mm SL) was also higher (0.66) when the snook with 143 corophiids was excluded.

Several studies have noted the importance to fish communities of natural unaltered shorelines compared to altered shorelines. These often include increased diversity, species richness, abundance, and different community structures compared to altered shorelines (Bryan and Scarnecchia 1992; Laegdsaard and Johnson 2001; Huxam et al. 2004). In general, species richness is higher in areas with unaltered natural shoreline compared to areas with altered shoreline. Based on this, it would be logical to assume that niche breadth would be lower in tidal creeks with a higher percentage of altered shoreline, and niche overlap between creeks with altered and unaltered shoreline would be relatively high as altered habitats generally contain a subset of the ichthyofauna present in unaltered habitats (Bryan and Scarnecchia 1992). Niche breadth in both altered and unaltered creeks was generally low indicating that juvenile snook are more specialists than generalists regardless of shoreline type. This study showed high niche overlap between Bowlees Creek (altered) and South Creek (unaltered) and between Bowlees Creek and North Creek (unaltered). This indicates these systems have similar prey assemblages and factors other than the presence/absence of unaltered shoreline may influence snook prey selection.

Determining the trophic linkages between fish and their prey is crucial to understanding daily ration, growth, prey mortality, prey selection, and competition among predators (Breck 1993). The differences in dominant prey type in this study and previous studies (Gilmore et al.

1983; McMichael et al. 1989; Blewett et al. 2006), and the ability of snook to consume prey in a variety of habitats and throughout the water column, indicate snook are highly adaptable to different environments and prey assemblages. Gilmore et al. (1983) suggests snook simply exploit the most dominant suitable prey taxa. Without quantifying prey resources, it was not possible to determine if snook in the present study were selecting specific prey types but their increasing niche breadth through ontogeny suggests they tend to become more generalist predators with size.

LIST OF REFERENCES

Alanärä, A. and E. Brännäs. 1997. Diurnal and nocturnal feeding activity in arctic char and rainbow trout. Canadian Journal of Fisheries and Aquatic Sciences 54: 2894-2900.

Aliaume, C., A. Zerbi, and J. M. Miller. 1997. Nursery habitat and diet of juvenile *Centropomus* species in Puerto Rico estuaries. Gulf of Mexico Science 15: 77-87.

Aliaume, C., A. Zerbi, J. C. Joyeux, and J. M. Miller. 2000. Growth of juvenile *Centropomus undecimalis* in a tropical island. Environmental Biology of Fishes 59: 299-308.

Baremore, I. E. 2007. Feeding ecology of the Atlantic angel shark in the northeastern Gulf of Mexico. Master's thesis, Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, Florida.

Berens, E. J. 2005. Gastric evacuation and digestion state indices for gag, *Mycteroperca microlepis*, consuming fish and crustacean prey. Master's thesis, Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, Florida.

Blewett, D. A., R. A. Hensley, and P. W. Stevens. 2006. Feeding habits of common snook, *Centropomus undecimalis*, in Charlotte Harbor, Florida. Gulf and Caribbean Research 18: 1-13.

Bowen, S. H. 1996. Quantitative description of the diet. Pages 513-529 *in* B.R. Murphy and D.W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Brännäs, E. and A. Alanärä. 1997. Is diel dualism in feeding activity influenced by competition between individuals? Canadian Journal of Zoology 75: 661-669.

Breck, J. E. 1993. Foraging theory and piscivorous fish: Are forage fish just big zooplankton? Transactions of the American Fisheries Society 122: 902-911.

Brennan, N. P., K. M. Leber, H. L. Blankenship, J. M. Ransier, and R. DeBruler, Jr. 2005. An evaluation of coded wire and elastomer tag performance in juvenile common snook under field and laboratory conditions. North American Journal of Fisheries Management 25: 437-445.

Brennan, N. P., M. C. Darcy, and K. M. Leber. 2006. Predator-free enclosures improve post-release survival of stocked common snook. Journal of Experimental Marine Biology and Ecology 335(2): 302-311.

Clark, C. W. and D. A. Levy. 1988. Diel vertical migrations by juvenile sockeye salmon and the anti-predation window. American Naturalist 131: 271-290.

Clark, K. L., G. M. Ruiz, and A. H. Hines. 2003. Diel variation in predator abundance, predation risk and prey distribution in shallow-water estuarine habitats. Journal of Experimental Marine Biology and Ecology 287: 37-55.

Douglas, R. H. and C. M. McGuigan. 1989. The spectral transmission of freshwater teleost ocular media-an interspecific comparison and a guide to potential ultraviolet sensitivity. Vision Research 29: 871-879.

Douglas, R. H. and C. W. Hawryshyn. 1990. Behavioural studies of fish vision: an analysis of visual capabilities. Pages 373-518 *in* R. H. Douglas and M. B. A. Djangoz, editors. The visual system of fish. Chapman and Hall, London.

Ecklebarger, K. J., R. Scalan, and J. A. C. Nicol. 1980. The outer retina and tapetum lucidum of the snook *Centropomus undecimalis* (Teleostei). Canadian Journal of Zoology 58: 1042-1051.

Ferry, L. A. and G. M. Calliet. 1996. Sample size and data: Are we characterizing diet properly? Pages 70-81 *in* Mackinlay D, Shearer K, editors. Feeding ecology and nutrition in fish. Proceedings of the Symposium on the Feeding Ecology and Nutrition in Fish. International Congress on the Biology of Fishes. San Francisco, California.

Fore, P. L. and T. W. Schmidt. 1973. Biology of juvenile and adult snook, *Centropomus undecimalis*, in the Ten Thousand Islands, Florida. U. S. Environmental Protection Agency, Surveillance and Analysis Division, EPA 904/9-74-002, Atlanta, Georgia.

Fraser, N. H. C., N. B. Metcalfe, and J.E. Thorpe. 1993. Temperature-dependent switch between diurnal and nocturnal foraging in salmon. Proceedings of the Royal Society of London Series B 252: 135-139.

Fraser, N. H. C., J. Heggenes, N. B. Metcalfe, and J. E. Thorpe. 1995. Low summer temperatures cause juvenile Atlantic salmon to become nocturnal. Canadian Journal of Zoology 73: 446-451.

Fraser, N. H. C. and N. B. Metcalfe. 1997. The costs of becoming nocturnal: feeding efficiency in relation to light intensity in juvenile Atlantic salmon. Functional Ecology 11: 385-391.

Gannon, J. E. 1976. The effects of differential digestion rates of zooplankton by alewife, *Alosa pseudoharengus*, on determinations of selective feeding. Transactions of the American Fisheries Society 105: 89-95.

Gilmore, R. G., C. J. Donohoe, and D. W. Cooke. 1983. Observations on the distribution and biology of east-central Florida populations of the common snook, *Centropomus undecimalis* (Bloch). Florida Scientist 46: 313-336.

Gries, G., K. G. Whalen, F. Juanes, and D. L. Parrish. 1997. Nocturnal activity of juvenile Atlantic salmon (*Salmo salar*) in late summer: evidence of diel activity partitioning. Canadian Journal of Fisheries and Aquatic Sciences 54: 1408-1413.

Grossman, G. D. 1980. Ecological aspects of ontogenetic shifts in prey size utilization in the bay goby (Pisces: Gobiidae). Oceologia 47: 233-238.

Hartleb, C. F. and J. R. Mooring. 1995. An improved gastric lavage for removing stomach contents from live fish. Fisheries Research 24: 261-265.

Helfman, G. S. 1993. Fish behaviour by day, night, and twilight. Pages 285-305 *in* T. J. Pitcher, editor. Behaviour of teleost fishes, 2nd edition. Chapman and Hall, New York, New York.

Hurlbert, S. H. 1978. The measurement of niche overlap and some relatives. Ecology 59: 67-77.

Jobling, M. and A. Brieby 1986. The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. Sarsia 71: 265-274.

Juanes, F. 1994. What determines prey size selectivity in piscivorous fishes? Pages 79-100 *in* D. J. Strouder, K. L. Fresh, and R. J. Feller, editors. Theory and Application in Fish Feeding Ecology. University of South Carolina Press, Colombia, South Carolina.

Keast, A. 1978. Trophic and spatial interrelationships in the fish species of an Ontario temperate lake. Environmental Biology of Fishes 3: 7-31.

Kennedy, C. R. 1969. Tubificid oligochaetes as food of dace. Journal of Fish Biology 1: 11-15.

Krebs, C. J. 1999. Ecological Methodology, 2nd edition. Addison-Wesley Longman, Menlo Park, California.

Larkin, P. A., J. G. Terpenning, and R. R. Parker. 1957. Size as a determinant of growth rate in rainbow trout *Salmo gairdneri*. Transactions of the American Fisheries Society 86: 84-96.

Leber, K. M. 1999. Rationale for an experimental approach to stock enhancement. In: Stock Enhancement and Sea Ranching. Fishing News Books, Blackwell Science, Oxford, UK, pp. 63-75.

Levins, R. 1968. Evolution in changing environments. Princeton University Press, Princeton, New Jersey.

Light, R. W., P. H. Adler, and D. E. Arnold. 1983. Evaluation of gastric lavage for stomach analyses. North American Journal of Fisheries Management 3: 82-85.

Luczkovich, J. J., S. F. Norton, and R. G. Gilmore, Jr. 1995. The influence of oral anatomy on prey selection during ontogeny of two percoid fishes, *Lagodon rhomboids* and *Centropomus undecimalis*. Environmental Biology of Fishes 44: 79-95.

Mann, R. H. K., and D. R. Orr. 1969. A preliminary study of the feeding relationships of fish in a hard-water and a soft-water stream in southern England. Journal of Fish Biology 1: 31-44.

Marshall, A. M. 1958. A survey of the snook fishery of Florida, with studies of the biology of the principal species, *Centropomus undecimalis* (Bloch). Florida State Board of Conservation, St. Petersburg Marine Laboratory, Technical Series 22, St. Petersburg. Florida.

Martin, N. V. 1970. Long-term effects of diet on the biology of the lake trout and the fishery in Lake Opeongo, Ontario. Journal of the Fisheries Research Board of Canada 27: 125-146.

McCormick, M.I. 1998. Ontogeny of diet shifts by a microcarnivorous fish, *Cheilodactylus spectabilis*: relationship between feeding mechanics, microhabitat selection and growth. Marine Biology 132:9-20.

McMichael, R. H., K. M. Peters, and G. R. Parsons. 1989. Early life history of the snook, *Centropomus undecimalis*, in Tampa Bay, Florida. Northeast Gulf Science 10: 113-125.

Meek, S. E. and S. F. Hildebrand. 1925. The marine fishes of Panama. Field Museum of Natural History, Zoological Service 15:331-707.

Metcalfe, N. B., N. H. C. Fraser, and M. D. Burns. 1998. State-dependent shifts between nocturnal and diurnal foraging in salmon. Proceedings of the Royal Society of London Series B 265: 1503-1507.

Metcalfe, N. B., N. H. C. Fraser, and M. D. Burns. 1999. Food availability and the nocturnal vs. diurnal foraging tradeoff in juvenile salmon. Journal of Animal Ecology 68: 371-381.

Metcalfe, N. B. and G. I. Steele. 2001. Changing nutritional status causes a shift in the balance of nocturnal to diurnal activity in European minnows. Functional Ecology 15: 304-309.

Mueller, K. W., G. D. Dennis, D. B. Eggleston, and R. I. Wicklund. 1994. Size-specific social interactions and foraging styles in a shallow water population of mutton snapper, *Lutjanus analis*, (Pisces: Lutjanidae), in the central Bahamas. Environmental Biology of Fishes 40: 175-188.

Muller, R. G. and R. G. Taylor. 2006. The 2006 Stock assessment update of common snook, *Centropomus undecimalis*. Fish and Wildlife Conservation Commission, Florida Marine Research Institute, St. Petersburg, Florida.

Munz, W. R. A. 1990. Stimulus, environment and vision in fishes. Pages 491-511 *in* R. H. Douglas and M. B. A. Djangoz, editors. The visual system of fish. Chapman and Hall, London.

Murie, D. J. 1995. Comparative feeding ecology of two sympatric rockfish congeners, *Sebastes caurinus* (copper rockfish) and *S. maliger* (quillback rockfish). Marine Biology 124: 341-353.

Nicol, J. A. C. 1981. Tapeta lucida of vertebrates. Pages 401-431 *in* J. M. Enoch and F. L. Toby Jr., editors. Vertebrate photoreceptor optics. Springer-Verlag, New York, New York.

Nikolsky, G. V. 1963. The ecology of fishes. Academic Press, New York, New York.

NOAA, 2009. Fisheries Economics of the U.S., 2006. http://www.st.nmfs.noaa.gov/st5/publication/economics_communities.html.

Osenberg, C. W., G. G. Mittlebach, and P. C. Wainwright. 1992. Two-stage life histories in fish: the interaction between juvenile competition and adult performance. Ecology 73: 255-267.

Paine, R.T. 1976. Size-limited predation: an observational and experimental approach with the *Mytilus-Pisaster* interaction. Ecology 57: 858-873.

Persson, L. 1983. Food consumption and the significance of detritus and algae to intraspecific competition in roach *Rutilus rutilus* in a shallow eutrophic lake. Oikos 41: 118-125.

Peters, K. M., R. E. Matheson, Jr., and R. G. Taylor. 1998. Reproduction and early life history of the common snook, *Centropomus undecimalis*, (Bloch), in Florida. Bulletin of Marine Science 62: 509-529.

Poulakis, G. R., D. A. Blewett, and M. E. Mitchell. 2003. The effects of season and proximity to fringing mangroves on seagrass-associated fish communities in Charlotte Harbor, Florida. Gulf of Mexico Science 21: 171-184.

Reichert, M. J. M. 2003. Diet, composition, and growth of juvenile fringed flounder (*Etropus crossotus*); a test of the 'maximum growth/optimum food hypothesis' in a subtropical nursery area. Journal of Sea Research 50: 97-116.

Richmond, H. E., T. R. Hrabik, and A. F. Mensinger. 2004. Light intensity, prey detection and foraging mechanisms of age 0 year yellow perch. Journal of Fish Biology 65: 195-205.

Rivas, L. R. 1986. Systematic review of the perciform fishes of the genus *Centropomus*. Copeia 3: 576-611.

Ross, S. T. 1978. Trophic ontogeny of the leopard searobin, *Prionotus scitulus* (Pisces: Triglidae). Fisheries Bulletin 76: 225-234.

Sánchez-Vázquez, F. J., J. A. Madrid, and S. Zamora. 1995. Circadian rhythms of feeding activity in sea bass, *Dicentrarchus labrax*, L. dual phasing capacity of diel demand-feeding pattern. Journal of Biological Rhythms 10: 256-266.

Sánchez-Vázquez, F. J. and M. Tabata. 1998. Circadian rhythms of demand-feeding and locomotor activity in rainbow trout. Journal of Fish Biology 52: 255-267.

SAS Institute. 1998. SAS Procedures Guide, Version 8.11, 3rd edition. Cary, North Carolina.

Shafland, P. L., and K. J. Foote. 1983. A lower lethal temperature for fingerling snook, *Centropomus undecimalis*. Northeast Gulf Science 6: 175-177.

Sheridan, P. F. 1992. Comparative habitat utilization by estuarine macrofauna within the mangrove ecosystem of Rookery Bay, Florida. Bulletin of Marine Science 50: 21-39.

Schmidt, R. J. and S. J. Holbrook. 1984. Ontogeny of prey selection by black surfperch *Embiotoca jacksoni* (Pisces: Embiotocidae): the roles of fish morphology, foraging behavior, and patch selection. Marine Ecology Progress Series 18: 225-239.

Stoner, A.W. 1980. Feeding ecology of *Lagodon rhomboids* (Pisces: Sparidae): variation and functional responses. Fishery Bulletin 78:337-352.

Stoner, A. W. and R. J. Livingston. 1984. Ontogenetic patterns in diet and feeding morphology in sympatric sparid fishes from seagrass meadows. Copeia 1984: 174-187.

Taylor, R. G., J. A. Whittington, H. J. Grier, and R. E. Crabtree. 2000. Age, growth, maturation, and protandric sex reversal in common snook, *Centropomus undecimalis*, from the east and west coasts of south Florida. Fishery Bulletin 98:612-624.

Thayer, G. W., D. R. Colby, and W. F. Hettler, Jr. 1987. Utilization of the red mangrove prop root habitat by fishes in south Florida. Marine Ecology Progress Series 35: 25-38.

Tringali, M.D. and K. M. Leber. 1999. Genetic considerations during the experimental and expanded phases of snook stock enhancement. Bulletin of the National Research Institute Aquaculture (Japan) Suppl. 1:109-119.

Valdimarsson, S. K., S. Skúlason, and N. B. Metcalfe. 2000. Experimental demonstration of differences in sheltering behaviour between Icelandic populations of Atlantic salmon (*Salmo salar*) and Arctic char (*Salvelinus alpinus*). Canadian Journal of Fisheries and Aquatic Sciences 57: 719-724.

U.S. Naval Observatory. 2006. Duration of daylight/darkness table for one year. U.S. Naval Observatory, Astronomical Applications Department. Available: http://aa.usno.navy.mil/ (May 2006).

Walton, W. E., N. G. Hairston, and J. K. Wetterer. 1992. Growth related constraints on diet selection by sunfish. Ecology 73: 429-437.

Waters, D. S., T. J. Kwak, J. B. Arnott, and W. E. Pine III. 2004. Evaluation of stomach tubes and gastric lavage for sampling diets from blue catfish and flathead catfish. North American Journal of Fisheries Management 24: 258-261.

Walters, C. J. and F. Juanes. 1993. Recruitment limitation as a consequence of natural selection for use of restricted feeding habitats and predation risk taking by juvenile fishes. Canadian Journal of Fisheries and Aquatic Sciences 50: 2058-2070.

Walters, C. J. and S. J. D. Martell. 2004. Fisheries Ecology and Management**.** Princeton University Press, Princeton, New Jersey.

Werner, E. E. and J. F. Gilliam. 1984. The ontogenetic niche and species interactions in size-structured populations. Annual Review of Ecology and Systematics 15: 393-426.

Werner, E. E., J. F. Gilliam, D. J. Hall, and G. G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540-1548.

Werner, E. E. and D. J. Hall. 1988. Ontogenetic habitat shifts in bluegill: the foraging rate-predation risk trade-off. Ecology 69: 1352-1366.

Winemiller, K. O. 1989. Ontogenetic diet shifts and resource partitioning among piscivorous fishes in the Venezuelan ilanos. Environmental Biology of Fishes 26: 177-199.

BIOGRAPHICAL SKETCH

Jason E. Rock was born in San Diego, CA and raised in Chesapeake, VA. Jason earned his bachelor's degree in biological sciences in 2002 from Old Dominion University in Norfolk, VA. From there he accepted a position at Mote Marine Laboratory (Sarasota, FL) in 2003 as a technician working on stock enhancement projects with common snook and red snapper. This afforded him the opportunity to hone his scientific skills and interests and ultimately allowed him to attend the University of Florida in 2004 to begin work on his master's degree. In the fall of 2006, he accepted a position with the Florida Fish and Wildlife Conservation Commission monitoring the health of marine finfish species throughout the state. Jason is currently working for the North Carolina Division of Marine Fisheries in Washington, NC monitoring finfish populations in Pamlico Sound and its' surrounding estuaries.