HABITAT PREFERENCES OF JUVENILE
COMMON SNOOK IN THE LOWER
RIO GRANDE, TEXAS

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CALEB G. HUBER, B.S.

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Approved

Reynaldo Patiño
Chairperson of the Committee

Kevin L. Pope

David R. Blankinship

Wilfrido M. Contreras Sánchez

Accepted

John Borrelli
Dean of the Graduate School
May, 2007
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ABSTRACT

The common snook, *Centropomus undecimalis*, is considered a euryhaline species that can tolerate a wide range of conductivity levels. This species also displays protandric hermaphroditism, in which all individuals first develop as males and then change sex to females as they reach a certain size range. Common snook were once abundant off the Texas coast and supported commercial and recreational fisheries. However, common snook populations are now characterized by low abundance and erratic recruitment that may be caused by habitat degradation and historical overfishing. Although the lower stretch of the Rio Grande is believed to provide nursery habitat for juvenile common snook in Texas, little is known about the specific biology and habitat needs of juvenile common snook along the Texas coastline. Knowledge of the general biology of common snook is a prerequisite for the development of management strategies designed to increase the numbers of wild snook. The primary objective of this study was to describe the habitat preferences of juvenile common snook in the lower portion of the Rio Grande, Texas. Fish were collected during January-March 2006 from the lower 51.5 km of the river using multiple gears; trawl was used to sample the river channel, and castnet, and boat electrofisher were used to sample the bank. Measurements of water quality (temperature, dissolved oxygen, conductivity, etc.) and other habitat traits (bank slope, presence of vegetation or woody debris, flow, etc.) were recorded at each sampling site. A total of 211 common snook were captured. Fish size-frequency distribution and otolith analyses revealed that most common snook collected were age-1 or age-2 fish of up to 303 mm SL, and histological analysis of the gonads indicated that these fish were
juvenile males (a single fish of 360 mm SL was caught that appeared to be of a larger size class). However, a single, incidental electroshock of the river channel clearly indicated that adult male and female common snook (up to 595 mm SL) are also present in the river. All common snook were captured in freshwater habitat above river kilometer 12.9. Because juvenile (age 1 and 2) common snook are able to withstand saline waters, their absence in the estuarine portion of the river suggests that they are choosing riverine habitat based on traits other than water salinity. Multivariate analyses revealed that the distribution of juvenile common snook within the freshwater portion of the river was not random but weakly associated with turbidity, temperature, conductivity, pH, and perhaps substrate type. This observation suggested that habitat preferences of juvenile common snook in the Rio Grande are dictated by a complex interaction of multiple environmental variables or by factors not included in the analysis such as available forage or predation pressure. It is concluded that nursery habitat for common snook is available only in the freshwater portion of the Rio Grande, and that riverine freshwater habitat may also be important to adult individuals.
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STATUS OF COMMON SNOOK IN TEXAS

Common snook, *Centropomus undecimalis*, have been the focus of both recreational and commercial fishing along the southern gulf coast of Texas (Matlock and Osburn 1987). Common snook are characterized as strong fighters that provide an adequate and palatable source of protein (Tucker et al. 1985). Unfortunately, common snook composed less than 0.1% of the sport landings in South Texas during 1985 and there have been no commercial landings since 1961 (Matlock and Osburn 1987). The current population of common snook in Texas is characterized by low abundance and erratic recruitment (Pope et al., in press). Decreased numbers of common snook in Texas may be the result of several factors including overfishing and loss or degradation of habitat. However, most research concerning common snook in North America has occurred in Florida and very little is known about the biology of common snook in Texas.

Common snook in the lower Rio Grande may have been first documented by surveys conducted during the late 1960s (Breuer 1970). The presence of this estuarine species in the lower stretch of the river has been interpreted as the abnormal result of increased water salinity caused by decreasing river flow rates (Edwards and Contreras 1991). Indeed, flow levels and patterns in the lower Rio Grande have been severely altered by the construction of dams and by use of the water for agricultural and municipal operations on both sides of the U.S.-Mexico border (Coastal Impact Monitoring Program 1995). However, there is evidence suggesting that the use of freshwater riverine habitat
by common snook can be a normal and even necessary occurrence. For example, a freshwater commercial fishery for common snook currently exists in the Usumacinta River (Mexico) approximately 150 km from its mouth (W.M. Contreras, personal communication); the Usumacinta River flows into the southern Gulf of Mexico uninterrupted by dams. In addition, when the mouth of Rio Grande was blocked by silt deposits in 2001-2002 (due to reduced water flows), recruitment of juvenile common snook in the lower Laguna Madre was negatively impacted (D.R. Blankinship, personal communication). Therefore, it seems likely that common snook occur naturally in the Rio Grande and that they migrate between freshwater and seawater at specific points in their life cycle. Consequently, blockage of the river mouth – such as it occurred during the early 2000s – can have potentially detrimental consequences to their population.

Based on the results of preliminary observations in the winter of 2005 (C.G. Huber, personal observations), the available habitat for common snook in the lower Rio Grande differs from what has been described in Florida (McMichael et al. 1989). In particular, there is little submerged mangrove habitat in the Rio Grande. Almost all mangrove habitat occurs within 0.5 km of the river mouth. Most of the habitat along the river shoreline contains mainly overhanging or submerged mesquite, *Prosopis glandulosa*, and other woody vegetation as well as emergent and floating mats of cane. This woody vegetation begins at a approximately river kilometer 5 and extends to the end of the study area. Given these differences in habitat, it is important to understand the habitat preferences of common snook in south Texas to design specific management strategies and restore snook populations.
Supplemental stocking of juvenile common snook is one possible strategy to increase population numbers (Tringali and Leber 1999). However, an understanding of the specific developmental patterns of common snook in Texas is also necessary for a stocking program to succeed. Snook display a unique life history in that they are protandric hermaphrodites that mature first as males and then change sex to females (Taylor et al. 2000). These developmental milestones have not been determined for common snook in Texas, and it is conceivable that these fish do not follow the same chronology as documented for snook in Florida (Taylor et al. 1998, 2000; Roberts et al. 1999). Knowledge of the length of fish at sexual differentiation and maturation as males is necessary to establish broodstock collection and management strategies.

**Scientific Background**

Snook belong to the family Centropomidae. Centropomidae is comprised of two sub-families, Centropominae and Latinae. Centropominae is represented by one genus, *Centropomus*, and is characterized by fishes with 24 vertebrae; no opercular spine, but 3 to 4 enlarged spines at the posterior angle of the operculum; no swimbladder-posttemporal ligament; and a distinct gap between the first and second dorsal fins. The common snook, *C. undecimalis*, is the most widely distributed and numerous of these species. Common names for *C. undecimalis* include snook, robalo, and saltwater pike. Rivas (1962) provided a key to this species and several other snook species residing along the Florida coast.

Common snook occur from $\approx 34^\circ$ N to $\approx 25^\circ$ S latitude in the western Atlantic Ocean, which includes waters off Galveston and the southern tip of Texas south to Rio de
Janeiro (Robins and Ray 1986). Common snook distribution is primarily restricted by
cold weather and freeze events (Storey and Gudger 1936). Shafland and Foote (1983)
reported that laboratory reared common snook stopped feeding when temperatures fell
below 14.2 °C and that juvenile fish began dying when temperatures fell to 12.5 °C.
Shafland and Foote's (1983) data suggest that prolonged exposure to temperatures below
14.2 °C or brief exposure to temperatures below 12.5 °C result in juvenile mortality.
Common snook have been observed as far north as New York (Schaefer 1972), but their
sensitivity to cold weather prevents establishment of a permanent population further
north than the winter 15.0 °C isotherm (Shafland and Foote 1983). The lower Laguna
Madre and its respective estuaries appear to be the northern-most permanent range for
common snook along the Texas-Mexico gulf coast.

Common snook spawn near mouths of coastal rivers (Marshall 1958) or in or near
bay and lagoon inlets (Taylor et al. 1998). Spawning sites in Florida have heavy currents,
adequate structure to provide protection for larvae, and adjacent grass flats (Taylor et al.
1998). The salinity at these spawning areas must be at least 28 ppt to activate sperm
(Ager et al. 1976) and to provide buoyancy for eggs (Chapman et al. 1982). Spawning
takes place from late spring to early autumn. The majority of spawning in Florida occurs
from April to September with a peak spawning period from July to August (Taylor et al.
1998). Spawning in Latin America occurs slightly earlier in the year as a result of
warmer water temperatures. Tucker and Campbell (1988) observed spawning at
temperatures from 20 to 31 °C. Spawning is most likely triggered by tidal or lunar
effects. Spawning coincides with strong afternoon ebb tides that occur with the new and
full moons (Peters et al. 1998). Taylor et al. (1998) reported that females were capable of
spawning every 1.4 (post ovulatory follicle method) to 1.9 (hydrated oocyte method) d.

Fecundity of common snook has been estimated at 1,440,000 eggs from an individual of 584-mm fork length (FL) (Volpe 1959) and 1,648,000 from an individual of 795-mm FL (Beebe and Tee-Van 1928).

Hatching of common snook occurs 17-18 h after fertilization and larvae quickly move from more open spawning areas to near-shore nursery habitat. Austin and Austin (1971) captured common snook larvae in areas that had salinity ranging from 4 to 46 ppt. Once larvae reach a length of 5 to 20-mm standard length (SL), they become pelagic and are found in near-shore vegetation and riverine backwaters. At 100 to 300-mm SL, common snook disperse more widely and become more difficult to document in faunal surveys (Peters et al. 1998). Juveniles in this size range also begin to transition from pelagic feeding to a more demersal lifestyle.

Peters et al. (1998) have provided details of early-stage juvenile common snook habitat usage in Florida. They reported that basin shape, size and depth, as well as submerged structure, water flow, and dissolved oxygen (DO) levels all play a role in habitat usage. Common snook juveniles seemed to prefer basins that were relatively small in size (<100,000 m²) with narrow and protected access. Basins with moderately sloping banks also harbored more juveniles than steeper banks because the shallow depths lessen wave action and facilitate increased DO levels. Juvenile common snook have been observed in waters with DO ranging from 0.3 to 8.1 mg/L. According to the literature, juvenile common snook are able to withstand low DO levels, but there are no data stating a preferred range (Peters et al. 1998). Juveniles (<300 mm SL) tend to show a preference for underwater vegetation (Gilmore et al. 1983). Small juveniles (<100-mm
SL) prefer habitats located along the shoreline with both submerged and overhanging vegetation. Larger juveniles (150 to 300-mm SL) are found almost exclusively in seagrass habitats (Gilmore et al. 1983).

McMichael et al. (1989) studied the early life history of common snook in Tampa Bay, Florida. They found that juvenile common snook typically grow at a rate of 0.06 to 0.07-mm SL/d, but there were instances when growth occurred as quickly as 1.2-mm SL/d. They also observed ontogenetic shifts in common snook diets that were initiated when the juvenile was ≈45-mm SL. The juvenile fish switched from a diet of predominately mysids and copepods to one of fish (cyprinodontids and poecilids) and shrimp. Austin and Austin (1971) measured the stomach contents of two snook species in western Puerto Rico and found that common snook consumed primarily crustaceans (64% volumetrically of the total diet) and fishes (36%). The swordspine snook, Centropomus enciferus, consumed primarily crustaceans (68%), plant material (25%), and fish (7%). Austin and Austin (1971) proposed that the plant intake could have been accidental and that adult snook do not feed on vegetation. Sazima (2002) has shown that three species of snook, guinan snook, C. mexicanus, fat snook, C. parallelus, and union snook, C. unionensis, feed by acting as aggressive mimics of mojarras, Euncinostomus spp. Mimicry of mojarras by snook species is based on similar morphology and visual records of snooks feeding within schools of mojarras. Mimicry allows snook to approach their target prey fish undetected because mojarras feed primarily on benthic crustaceans and do not pose a predation threat to other fishes. As adults, common snook feed exclusively on fishes captured by ambush (Moyle and Cech 2004).
Peters et al. (1998) stated that all common snook are hatched with indifferent gonads that then develop into testes, but it is unclear if they all mature as males before transitioning to females or if females could arise directly from immature males. According to Marshall (1958), relatively few male common snook mature at 350-mm FL, approximately 50% mature by 400-mm FL, and all mature by 500 to 512-mm FL (about 5 years of age). Fifty percent of fish with ovaries mature at 630 to 718-mm SL. Common snook have lobular testes that consist of germinal compartments that terminate at the periphery of the testis (Grier and Taylor 1998). Common snook gonads (testes and ovaries) have been classified as follows: regressed, early maturation, mid-maturation, late maturation, and regressing (Grier and Taylor 1998; Taylor et al. 1998). Roberts et al. (1999) have published correlations between the hormones estradiol-17β (E₂), testosterone (T), and 11-ketotestosterone (11-KT) and gonadal recrudescence based on the preceding classification. They found elevated levels of E₂ and T in females during mid and late maturation stages and significantly depressed levels during early maturation and regressing stages. Males had similar patterns of hormone levels, with increased levels during mid and late maturation stages and decreased levels during early maturation and regressing stages. Roberts et al. (1999) also reported increased levels of alkali-labile protein phosphorous, which varies with the egg yolk precursor, vitellogenin, during mid and late maturation. Alkali-labile protein phosphorous levels in males did not vary significantly throughout the year.
Conceptual Framework and Specific Objectives

We expected that habitat preferences of juvenile common snook in the lower Rio Grande would be different than those of snook in other geographic areas such as Florida (Seaman and Collins 1983; McMichael et al. 1989; Peters et al. 1998). The reason for this expectation is that the available habitat in the Rio Grande was different than the typical snook habitat described in Florida waters. Thus, our primary objective was to examine and describe the habitat preferences of juvenile common snook in the lower Rio Grande, Texas.

Common snook are generally protandric hermaphrodites. However, this developmental pattern has not been confirmed for common snook in Texas and there is also some evidence suggesting that a small percentage of juvenile common snook in Tabasco (Mexico) begin gonadal sex differentiation as females (Guadalupe Morales-Lara, unpublished data). In addition, for management purposes it was important to determine age-at-first maturity. Thus, our secondary objective was to document gonadal development in relation to the age of juvenile common snook.

Considerations of Experimental Design and Analytical Approach

Results of ecological studies are often complicated and vary over space and time; thus, their interpretation can be difficult. One approach to simplify analyses of these data is by multivariate ordination techniques. Ordination techniques allow the arrangement of observations along axes so that complex relationships can be summarized from an infinite number of possible patterns into one or few dominant patterns (McCune et al. 2002). Principle component analysis (PCA) is often used for this type of analysis. PCA is an
eigenvalue-based ordination technique that reduces the original variables into groups (principle components) of composite variables (McCune et al. 2002). After these relationships are assigned, subsequent analyses are used to determine which component or components best explain the variability in the data collected. PCA also generates factor or case scores on each axis, which can be subsequently used in standard parametric multivariate statistics (McGarigal et al. 2000). The following three recent publications addressed questions similar to those of the present study and influenced our data analysis or interpretation.

Spanjer and Cipollini (2006) recently published a paper describing the relationship between water chemistry and the presence or absence of stygobitic crayfish (Cambaridae). They determined the presence or absence of crayfish at a number of caves throughout their study area. At each cave they also recorded a host of physicochemical data. Using PCA and multivariate analysis of variance (applied on factor scores using presence or absence of crayfish as the independent variable), they reported that stygobitic crayfish were found in caves with no externally originating streams. Crayfish also preferred increased DO and decreased ammonia levels and water temperature.

Smith and Kraft's (2005) recent publication integrates landscape position, stream order, and environmental data as a way to predict stream assemblage structure in the Beaverkill-Willowemac watershed, New York. They found an increase in species richness with stream order and downstream link and decreased species richness with confluence link. They emphasized the use of landscape positioning as broad but coarse predictor of stream assemblage within a specific watershed. Landscape positioning is also very useful for temporal comparisons because unlike most microhabitat
measurements, they are very stable. This study noted that, because of the complexity of ecological relationships, explanations that account for even only a small proportion of the observed variability are very useful to understand and manage ecosystems.

Erös et al. (2003) recently examined the relationship between habitat patches that differ physically and fish assemblage structure in a central European submontane stream composed entirely of native species. The authors used PCA to describe and compare microhabitats. They then used correspondence analysis to ordinate assemblages on habitat patches. There was no clear difference in the physical characteristic of identified patches, but rather a riffle-pool continuum. In fact, the only clear difference found among patches was seasonal. They also found marginal evidence that the fish assemblage displayed a continuum that paralleled the habitat continuum rather than displaying habitat specific guilds. There was, however, no difference in fish abundance between habitat types, and the documented seasonal difference was attributed to juvenile recruitment.


CHAPTER II

HABITAT PREFERENCES OF JUVENILE COMMON SNOOK IN THE LOWER RIO GRANDE, TEXAS

Introduction

The common snook, *Centropomus undecimalis*, is the most widely distributed and numerous of the snook species. Common snook range from $\approx 34^\circ$ N to $\approx 25^\circ$ S latitude in the western Atlantic Ocean, which includes waters off Galveston and the southern tip of Texas south to Rio de Janeiro (Robins and Ray 1986). Common snook distribution is primarily restricted by cold weather and freeze events (Storey and Gudger 1936; Shafland and Foote 1983). The lower Laguna Madre and its respective estuaries appear to be the northern-most permanent range of the Texas-Mexico snook population.

Common snook have been the target of recreational and commercial fisheries along the southern gulf coast of Texas (Matlock and Osburn 1987). However, common snook composed less than 0.1% of the sport landings in South Texas during 1985 and there have been no commercial landings since 1961 (Matlock and Osburn 1987). Currently, the Texas population of common snook is characterized by low abundance and erratic recruitment (Pope et al., in press). The reason for the decline in the Texas snook population is unclear but may be associated with habitat loss or degradation, or overfishing. Most research concerning common snook in North America has occurred in Florida (e.g., Peters et al. 1998; Taylor et al. 1998, 2000) and very little is known about the specific biology and habitat needs of common snook in Texas.
Common snook are protandric hermaphrodites that mature first as males and then transform into females as they grow and age (Peters et al. 1998; Taylor et al. 1998, and Taylor et al. 2000). In Florida, common snook spawn from April to September with a peak spawning period of July to August (Taylor et al. 1998). Juvenile common snook in Florida seem to prefer estuarine basins of relatively small size (<100,000 m$^2$) with narrow and protected access (Peters et al. 1998). Small juveniles (<100-mm standard length [SL]) prefer habitats located along the shoreline with overhanging vegetation or marsh grasses (McMichael, Florida Department of Environmental Protection; unpublished data cited in Peters et al. [1998]), whereas larger juveniles (150 to 300-mm SL) are found almost exclusively in seagrass habitats (Gilmore et al. 1983).

Common snook in the lower Rio Grande may have been first documented by surveys conducted during the late 1960s (Breuer 1970). The presence of this estuarine species in the lower stretch of the river has been interpreted as the abnormal result of increased water salinity caused by decreasing flow rates (Edwards and Contreras 1991). A pilot study conducted in January-March 2005 (C. G. Huber et al., unpublished data) also revealed the presence of juvenile common snook in the same portion of the river as in previous studies (Breuer 1970; Edwards and Contreras 1991). Although habitat preferences for juvenile common snook in the Rio Grande (or elsewhere in Texas) have not been described, this riverine habitat is clearly different (e.g., little or no mangroves) than the habitat previously described for juvenile common snook in Florida (Seaman and Collins 1983; Peters et al. 1998; McMichael et al. 1989). Knowledge of the habitat preferences of juvenile common snook in the Rio Grande may provide management agencies opportunities to increase recruitment by manipulating habitat and providing
additional nursery areas. Also, because of the size-dependent protandric development of this species, knowledge of the size (age) at sexual differentiation and maturation may be useful to the design of optimal management practices for the recreational fishery. Thus, the primary objective of this study was to describe the habitat preferences of juvenile common snook in the lower Rio Grande, and a secondary objective was to document the relationship between age and juvenile reproductive development.

Materials and Methods

Study area

The study area began at the mouth of the Rio Grande, which connects to the Gulf of Mexico, and extended 51.5-km upstream (Figure 2.1). Sampling effort was confined to the U. S. side of the river. The banks near the river mouth were not well defined and in some areas resembled tidal flats and pools with a sandy substrate. There was little submerged vegetation, and shoreline vegetation consisted primarily of Poaceae grass and two small patches of black mangrove, *Avicennia germinans*. The habitat gradually changed up-river to a substrate of silt and mud with more channelized banks and shrubby vegetation (mesquite, *Prosopis glandulosa*, and Texas ebony *Pithecolobium flexicaule*) along the shoreline. Agriculture is the predominant land use practice beyond the river banks.

Sampling Design

Fish were collected from 1 January 2006 through 25 March 2006. These months were selected for sampling because a pilot study conducted in 2005 suggested that both
age-1 and age-2 juvenile common snook are present in the river simultaneously during this time of the year (C. G. Huber et al., unpublished data). Samples were collected during standard work hours (8:00-17:00) during the week (Monday-Friday) for safety and logistic reasons. Three different gears (trawl, castnet and eletrofisher) were used to capture fish in the various river habitats.

When sampling with the trawl and castnet, the study area was divided into 16 sections that were each 3218-m long. Sections were divided into two groups, eight upper and eight lower sections, in order to limit daily travel and maximize sampling effort. Within each group, we typically sampled four sections (randomly chosen) per day. We chose the initial group randomly and then alternated sampling days between groups until sampling of all sections was completed. One trawl haul and four castnet throws were performed within each section at each sampling time. The exact location of trawl sites could not be predetermined because of the need for a relatively straight stretch of river and the existence of underwater obstructions, changing water levels, and other unforeseen obstacles. Thus, we subjectively chose each trawl site within each section while sampling with the castnet. Castnet sites were chosen at random by treating each section as a transect. Random distances from 0 to 3218 m were generated, and the GPS's trip function (see later description of equipment) was used to determine the distance traveled from the beginning of the target section of the river. Once the desired site (distance) was reached, the boat was turned perpendicular to the shoreline. The boat was slowly moved toward the shoreline, and the castnet was thrown on the downstream side of the boat as soon as the boat reached the shoreline. Approximately 4 days were required to
completely sample sampling all 16 river sections with the trawl and castnet. Sampling with the electrofisher was then initiated.

The increased water conductivity (salinity) in the lower sections of the river restricted the use of the electrofisher to the upper 38.6 km of the study area. This area was stratified into a single group of 3218-m sections that corresponded to sections 4-16 sampled with trawl and castnet. The sampling order of sections was randomly determined. Within each section, four sampling sites were selected for daily sampling in the same manner as the castnet sites. It took approximately 3 days to completely sample all 13 river sections (4-16) with the electrofisher. After sampling with the electrofisher was completed, the entire process (all three gears) was repeated with unique randomizations.

Bottom Trawl

A bottom trawl was used to sample the mid-channel habitat. The trawl dimensions were 3-m X 1.5-m mouth and 450-mm square green-dip multifilament netting. Trawls were attached to a 30-m bridle made of 20-mm twisted nylon rope. Trawls were pulled downstream for 10 min at approximately 1.0 m • sec⁻¹. It was not uncommon for a trawl to be stopped before 10 min had elapsed because of stochastic events such as the trawl hanging on a bottom obstruction. If the trawl was deployed for at least 5 min, the duration was noted and the catch was processed. If the trawl was deployed for less than 5 min, the trawl was retrieved and emptied immediately, and the procedure repeated in another area within the same section of the study area. Non-fish species (crabs, turtles, shrimp, etc.) were counted and released immediately; all fish
Captured were placed into a bucket of water and processed following procedures described later.

Castnet

A castnet was used to sample near-shore areas where the use of the trawl was not practical. The castnet was 4.3-m diameter with 10-mm square monofilament mesh. The net was deployed from the boat and allowed to sink completely before it was retrieved. If the castnet hung on the bottom or did not open greater than approximately 75%, it was quickly retrieved and redeployed in an undisturbed area adjacent to the random site. If the site was unsuitable for castnetting (e.g., because of presence of emergent vegetation or woody debris), the castnet was deployed in the nearest suitable site. All fish captured were placed into a bucket of water and processed following procedures described later.

Electrofisher

A boat-mounted electrofisher (Smith-Root 5.0 GPP with twin booms) was used to sample all freshwater shoreline habitats. Fish were collected using pulsed DC and one dip-netter. At each site, we sampled a single habitat by nosing the boat into the randomly selected site and then activating the electrofisher. A strenuous attempt was made to net all fish before they were able to escape the electric field. All fish captured were placed into a bucket of water and processed following procedures described later.
Field Processing of Fish

The mass and length of all common snook caught were recorded, whereas only the abundance (numbers) of non-target species was recorded. Several common snook were euthanized immediately upon capture and sagittal otoliths and gonadal tissue were collected from those individuals. Sagittal otoliths were removed and stored in clean, dry vials until read in the laboratory. Gonads were removed and preserved following one of two procedures depending on fish size. For smaller fish, the entire carcass was fixed in 10% buffered formalin to maintain integrity of the gonadal tissue. For fish that were too large for whole fixation, the gonadal tissue was removed in the field and fixed in 10% buffered formalin solution. The tissues were processed in the laboratory for histological examination.

Geographical Coordinates, Water Quality, and Flow

Geographical coordinates and water-quality measurements were taken at all sampling sites. These data were collected after captured specimens had been processed; when sampling shoreline habitat, measurements were taken on the upstream (undisturbed) side of the boat. Latitude and longitude (decimal degrees) coordinates were determined using a Magellan Navigator 500 GPS receiver (Magellan, San Dimas, California). Water flow (m/sec) was measured using a Flowmate 2000 flowmeter (Marsh-McBirney, Frederik, Maryland). Turbidity (NTU) was measured using an Oakton T-100 turbidimeter (Oakton Instruments, Vernon Hills, Illinois). Water conductivity (µS/cm), pH, dissolved oxygen (DO, mg/L), temperature (°C), and oxidation-reduction potential (ORP, mV/cm) were measured using an YSI 556
multiparameter meter (YSI Incorporated, Yellow Springs, Ohio). The YSI 556-based measurements were collected every 0.3 m down the water column from surface to bottom, and depth was also recorded at each site. All other observations were collected only once per site (within 1 m of the surface).

In addition to the standard suite of water-quality variables collected at trawl and castnet sites, we recorded several other habitat variables at electrofisher sites. Collection of these variables began approximately two weeks after sampling began. These variables described physical traits of the shoreline habitat including substrate type (mud, sand, or mixed) and bank slope (shallow, medium, steep, or cliff), as well as submerged vegetation type (grass, cane, woody, other, or none) and presence or absence of overhanging vegetation (shade). These data were only collected at electrofisher sites because the electrofisher was the only sampling gear that could be used effectively regardless of shoreline structure.

Fish Age and Otolith Processing

Fish age was initially determined using a length-frequency histogram (DeVries and Frie 1996). We were able to easily distinguish age-1 and age-2 juvenile common snook (all fish were assigned a 1 January birthdate). We then processed a subsample of otoliths in order to verify our initial age estimations. Whole otoliths were read using reflected light and a dissecting scope (10X magnification) as described by Taylor et al. (2000) for common snook. Otoliths were used to develop an age-length key to classify juvenile common snook into age groups. Otoliths were aged by two readers independently. If the readers disagreed on the age of an otolith, they were re-read by
both readers again. If a consensus could not be reached, a third reader was used; in these instances, fish age was assigned based on agreement of two readers.

Histological Procedures

Gonads were processed according to standard histological procedures (Luna 1992). Tissues collected in the field were post-fixed in Bouin's fixative for 48 h, rinsed in tap water overnight, dehydrated in a series of ethanol baths, cleared in xylene, and infiltrated with paraffin. Paraffin blocks were sectioned (6-8 µm) using a microtome. Central cross-sections of each gonad were placed on pre-cleaned slides and stained using Weigert's hematoxylin and eosin. Gonad sections were viewed with a compound microscope and classified into ad hoc stages according to size and tissue organization.

Data Analysis

All statistical analyses were conducted with the Statistica® Data Miner software package (StatSoft, Tulsa, Oklahoma) with a statistical level of significance of \( \alpha = 0.05 \). At each sampling site, common snook were categorized as either present or absent. When multiple measurements of water quality were taken at different depths for each site (i.e., conductivity, pH, DO, temperature, and ORP), the mean profile value was used for analyses. Overhanging vegetation (shade) and underwater structure were binomial variables and all physical data were categorical variables. Quantitative data were log\(_{10}\) transformed to normalize distributions. Chi-square analysis was used as a preliminary (low-resolution) test of the pattern of presence of common snook (random versus non-random) along the study area. These tests were conducted on the entire study area.
(sections 1-16; trawl and castnet), on sections where juvenile common snook were present (sections 4-16; all gears), and along the shoreline where juvenile common snook were present (sections 4-16; electrofisher only).

The multivariate ordination technique, Principle Component Analysis (PCA) was used to describe the sampled habitat (Statistica® Data Miner does not use rotation). Sections 1-3 were excluded from this analysis because it was evident that snook were not present in these sections (see Results) and, consequently, the purpose of the PCA analysis became the description and analysis of the area of the river where common snook were found in at least one site per section (sections 4-16). A second PCA was performed for electrofisher data only; this PCA also included the categorical data describing shoreline habitat. In both cases, factor scores from the PCAs were used as independent variables in a parametric one-way multiple analysis of variance (MANOVA; McGarigal et al. 2000) to assess the association of principle components with the presence or absence of juvenile common snook. Tukey's tests for pairwise comparisons were then performed to determine which principle components were significantly associated with the presence or absence of common snook.

Results

Fish Age and Gonadal Development

We sampled 77 trawl, 323 castnet, and 258 electrofisher sites (n = 658) during the sampling period. A total of 211 common snook was collected, all from sections 4-16 (Figure 2.2). At least two size groups were evident from the length-frequency histogram: 46 to 156 and 198 to 303-mm SL; and a single fish was caught that appeared to be of a
larger size class (360 mm SL) (Figure 2.3). We performed otolith and gonadal analysis on 41 individuals. These analyses confirmed that otoliths from the smaller size class (46 to 156-mm SL) contained a single annulus still in the process of formation (age 1) and also had relatively small gonads (Figure 2.4). A cavity could be recognized near the hilar region of the gonads of these fish that resembled a sperm duct (Figure 2.4). Age-1 common snook were therefore classified as juvenile males. Otoliths taken from the second size class (198 to 303 mm SL) showed two annuli (age 2) and their gonads were larger but still classified as juvenile males (Figure 2.4). Otoliths and gonads from the 360-mm fish were not analyzed, but separate analyses of common snook of similar size suggested that this fish was age-3 or older and may have been a mature adult (see later discussion).

General Aquatic Habitat

Water conductivity was high at the river mouth, dropped sharply through section 5 (14.5 km), and became low and stable thereafter (Figure 2.5, top). Depth was variable throughout the study area with a slight trend to deeper water upstream (Figure 2.6, top). The DO exhibited a bimodal distribution with peak values at about sections 5 and 11 (Figure 2.7, top). Flow rates increased and became less variable with increasing river section (Figure 2.8, top). The ORP was variable throughout the entire study area, but seemed to exhibit a parabolic distribution with minimum values near section 8 (Figure 2.9, top). The pH increased sharply from the river mouth through section 4 and then slowly decreased upriver (Figure 2.10, top). Water temperature seemed to be especially variable in sections 2-4, but values were relatively consistent through most of the study.
area (Figure 2.11, top). Turbidity was relatively low near the river mouth, increased sharply through section 6, and slowly decreased upstream (Figure 2.12, top).

General Fish Distribution

The distribution of juvenile common snook throughout the study area (sections 1-16; trawl and castnet) was not random \((\chi^2 = 29.83, \text{df} = 15, P = 0.013)\). In fact, no common snook were captured in the first three sections of the river (up to 9654 m from mouth) (Figure 2.2). These sections were eliminated from subsequent analyses. When the analysis was restricted to sections 4-16 (all gears), common snook continued to exhibit a non-random distribution \((\chi^2 = 25.30, \text{df} = 12, P = 0.013)\). After analyses were further restricted to electrofisher sites only (shoreline habitat in sections 4-16), juvenile common snook distribution appeared to be random \((\chi^2 = 17.8, \text{df} = 12, P = 0.122)\).

The mean value of all water variables measured in sections 4-16 for all gears were slightly lower, except ORP, at sites where juvenile common snook were present than sites where they were absent (Table 2.1). The mean value of all water variables measure in sections 4-16 for electrofisher sites only were slightly greater, except flow, at sites where juvenile common snook were present than sites where they were absent (Table 2.2). The proportions of shoreline structure used by juvenile common snook in sections 4-16 for electrofisher sites only were slightly greater for shallow and moderate slope, mud and mud/sand substrate, shade (overhanging vegetation), and cane, grass or no submerged vegetation (Table 2.3).

Associations between Water Quality and Presence or Absence of Juvenile Snook
Approximately 68% of the variability in water-quality parameters for sections 4-16 (all gears) was accounted by the first 4 principle components with eigenvalues ≥ 1.0 (Table 2.4). The first component classified sampled sites (factor loading ≥ 0.60 or ≤ -0.60) mainly by section, pH, turbidity, and temperature. The second component classified sites mainly by conductivity. The third component classified sites mainly by flow and ORP. The fourth component classified sites mainly by depth.

The MANOVA analysis using factor scores generated by the PCA yielded a Wilk's Lambda of 0.97 ($F_{4, 574} = 4.22, P = 0.002$) for the overall model. Post hoc tests indicated that only the first component was significantly related to the presence or absence of juvenile common snook. Thus, based on the raw mean data measured (Table 2.1), juvenile common snook were present in sites with composite patterns of relatively lower pH, turbidity, and temperature.

Associations between Shoreline Structure and Water Quality and Presence or Absence of Juvenile Snook

Approximately 60% of the variability in shoreline structure and water quality in sections 4-16 for electrofisher sites only was accounted for by the first 4 principle components with eigenvalues ≥ 1.0 (Table 2.5). The first component classified sampled sites (factor loading ≥ 0.60 or ≤ -0.60) mainly by section, DO, pH, turbidity, flow, and temperature. The second component classified sites mainly by presence of shade and bank slope. The third component classified sites mainly by conductivity and substrate type. The fourth component classified sites mainly by ORP.
The MANOVA analysis using factor scores from the PCA yielded a Wilk's Lambda of 0.94 ($F_{4, 234} = 3.99, P = 0.003$) for the overall model. Post hoc tests indicated that only the third component was significantly related to the presence or absence of juvenile common snook. Thus, based on the raw mean data measured (Table 2.2 and Table 2.3), juvenile common snook were more likely to be found in sites with composite patterns of decreased conductivity and mud or mud/sand substrate.

**Discussion**

Our sampling design allowed the capture of mostly of age-1 (2005 year class) and age-2 (2004 year class) juvenile common snook as determined by length-frequency histogram and otolith analysis. Histological examination of the gonads indicated that age-1 fish (<160 mm SL) were immature males with very small, pre-spermatogenic testes recognizable mainly by the presence of what appeared to be an early sperm duct. Age-2 fish (>160 to 303-mm SL) also had immature testes but at more advanced stages. Differences in size within each age group were presumably due to the protracted spawning period that is typical for common snook (April through September; Taylor et al. 1998). Given the small size and early developmental stage of age-1 testes, it is highly unlikely that any age-2 males reached breeding condition during their first potential spawning season as age-1 fish (spring-summer 2005). However, it is possible that age-2 fish reached maturity and bred for the first time during the 2006 breeding season. A previous study with common snook in Florida showed that spermatogenesis does not begin until late winter or spring (Grier and Taylor 1998), sometime following the sampling period for the present study. Because all age-1 and age-2 common snook
captured in the present study were males, the results of the present study are consistent with the previous conclusion that common snook are protandric hermaphrodites (Taylor et al. 2000).

Juvenile common snook were not distributed randomly in the present sampling area of the lower Rio Grande when all river sections (1-16; trawl and castnet sites) were included in a $\chi^2$ analysis. Notably, no juvenile common snook were captured in the first three sections of the study area (from the mouth of the river to 9654 m upstream). Water conductivity in this stretch of the river was 1598-54386 µS/cm (0.81-36.05 ppt), whereas the conductivity in the upstream sections (4-16) where juvenile common snook were found was generally 1419 µS/cm (0.71 ppt). The cutoff between freshwater and brackish water is generally considered to be 0.5 ppt; however, the salinity of sections 4-16 is representative of the upstream reaches of the Rio Grande (e.g., Patiño et al., unpublished observations) and for the purposes of this study it was considered as freshwater. The absence of juvenile common snook in the brackish water sections of the river is notable because these fish can tolerate water salinities ranging from freshwater to 22 ppt (Peters et al. 1998). No other water-quality variable measured in this study seemed to explain the absence of juvenile common snook in the lower portion of the study area. Therefore, we conclude that the reason behind their absence in sections 1-3 of the river is outside the suite of variables measured in this study or that juvenile common snook are selecting for certain habitat variables that are absent in sections 1-3. Although juvenile common snook need to return to a marine environment in order to mature and spawn, thus completing their life cycle (Ager et al. 1976; Chapman et al. 1982), our observations also
indicated that their downstream migration in the Rio Grande would occur outside the sampling period of this study (January-March).

Juvenile common snook were only found in the freshwater portion of the study area (sections 4-16; overall mean conductivity <1565 µS/cm), both in the river channel and along the shoreline. When all sites sampled within this stretch of the river were included in the PCA-MANOVA, river section, pH, turbidity, and temperature were the best descriptors of habitat preferred by juvenile common snook. The finding that river section helped describe the habitat preferred by juvenile common snook is in agreement with the results of the $\chi^2$ analysis for this stretch of the river indicating that their distribution by section is not random. Water pH generally decreased with distance from the river mouth, but its upper and lower extremes were within a range that juvenile common snook are expected to tolerate. Overall, juvenile common snook chose sites with slightly lower mean pH (8.1 in snook-positive sites versus 8.2 in snook-negative sites). Water turbidity was fairly constant in sections 4–11, but declined in the upstream sections (12-16). Common snook are visual, ambush-type predators (Moyle and Cech 2004); therefore, sites with less turbidity may improve their foraging efficiency. Overall, juvenile common snook chose sites that had slightly lower mean turbidity levels (47.9 NTU in snook-positive sites versus 49.6 NTU in snook-negative sites). In the present study, the lowest water temperature recorded was 14.4 °C, but juvenile common snook were never observed at temperatures below 16.3 °C. Nonetheless, juvenile common snook chose sites that had a slightly cooler mean temperature (19.8 °C in snook-positive sites versus 20.5 °C in snook-negative sites). Overall, these various observations suggest that juvenile common snook distribution in the freshwater portion of the sampled area is
not random and is partially explained by specific combinations of water-quality conditions (pH, turbidity, and temperature) that presumably optimize the fish’s foraging ability and metabolic activities.

Analysis of the electrofisher sites indicated that physical characteristics of the shoreline habitat may also contribute to the habitat preferences of juvenile common snook; the best descriptors of habitat preferred by juvenile common snook were conductivity and substrate type. Although conductivity was relatively constant throughout sections 4-16 at the electrofisher sites, juvenile common snook seemed to choose sites with slightly increased mean conductivity (1555 µS/cm in snook-positive sites versus 1289 µS/cm in snook-negative sites). The primary substrate type in sections 4-16 was mud, and sites where mud-sand or sand was present was limited to sections 4 and 5. Also, there appeared to be little overall differences in substrate type between sites where snook were present or absent. Thus, the biased distribution of substrate type in this stretch of the river may have biased the results of the PCA-MANOVA and it is possible that environmental variable did not contribute significantly to the habitat preferences of juvenile common snook.

Peters et al. (1998) found that juvenile common snook in Florida preferred habitats with a predominance of red mangrove, *Rhizophora mangle* (Peters et al. 1998), an estuarine plant that has a complicated prop-root system and an overhanging canopy that provides both overhanging vegetation and submerged cover. The only mangrove species present in the Rio Grande is black mangrove (*Avicenna germinans*), which is found further up the shoreline and has a less complex prop root system than red mangrove. Also, black mangrove was restricted to isolated patches near the river mouth.
where common snook were not found. In fact, further upstream juvenile common snook did not seem to choose sites base on either submerged or overhanging cover. A possible explanation for this observation is that the available overhanging and submerged vegetation (primarily provided by mesquite) may not be a limiting resource in the area of the river (section 4-16) where juvenile common snook occurred.

It should be noted that the multivariate analysis yielded only weak associations between the environmental parameters measured in the present study and the presence or absence of snook (as indicated by the high [>0.9] values for the Wilk’s lambda statistic). This observation suggested that habitat preferences of juvenile common snook in the Rio Grande are dictated by a complex interaction of multiple environmental variables or by other factors not included in the analysis, such as available forage or predation pressure. However, as by noted Smith and Kraft (2005), even a small degree of explanatory power is useful to better understand and manage fish habitats in complicated systems such as large rivers.

Although not evident from our results, flow may be an important aspect of riverine habitat for both juvenile and adult common snook. Juvenile common snook in the freshwater portion of the lower Rio Grande may have been first documented by surveys conducted during the late 1960s (Breuer 1970). The presence of this estuarine species in the lower stretch of the river has been interpreted as the abnormal result of increased water salinity caused by decreasing river flow rates (Edwards and Contreras 1991). Indeed, flow levels and patterns in the lower Rio Grande have been severely altered by the construction of dams and by use of the water for agricultural and municipal operations on both sides of the U.S.-Mexico border (Coastal Impact Monitoring Program
1995). However, there is evidence suggesting that the use of freshwater riverine habitat by common snook can be a normal and even necessary occurrence. For example, a freshwater commercial fishery for common snook currently exists in the Usumacinta River (Mexico) approximately 150 km from its mouth (W.M. Contreras, personal communication); the Usumacinta River flows into the southern Gulf of Mexico uninterrupted by dams. In addition, when the mouth of Rio Grande was blocked by silt deposits in 2001-2002 (due to reduced water flows), recruitment of juvenile common snook in the lower Laguna Madre was negatively impacted (D.R. Blankinship, personal communication). Therefore, it seems likely that common snook occur naturally in the Rio Grande and that they migrate between freshwater and seawater at specific points in their life cycle. Consequently, blockage of the river mouth – such as it occurred during the early 2000s – can have potentially detrimental consequences to their population.

It is of interest to note that several large males (395 to 595-mm SL; older than 4 years as determined by otolith analysis) and one female (544 mm SL; older than 4 years) were also caught in the freshwater portion of the sampling area (at river-kilometer 24.1) by electroshocking the river channel on a single occasion outside of the present study plan (unpublished observations). Although these fish did not show advanced stages of gametogenesis, gonadal recrudescence in common snook reportedly begins during late winter or spring (Grier and Taylor 1998). This observation suggests that adult common snook also use the freshwater portion of the lower Rio Grande, at least seasonally.

In conclusion, although common snook have been previously reported in the same stretch of the Rio Grande examined by this study (Breuer 1970; Edwards and Contreras 1991), the present study is the first to methodically examine the habitat preferences of
juvenile common snook in freshwater riverine habitat. This study found that juvenile
common snook were uncommon (none captured) in the estuarine section of the study area
(sections 1-3), and fairly common in the freshwater sections of the river up to 51.5 km
from the rivermouth (sections 4-16) during the winter months (January-March). Also, the
presence of adult common snook was incidentally documented in freshwater. Therefore,
it is concluded that the Rio Grande provides nursery habitat for common snook and
perhaps feeding habitat for adult individuals.
Table 2.1. Descriptive statistics for physical and chemical variables of water from sites sampled with trawl, castnet, and electrofisher where common snook were present ($n = 112$) or absent ($n = 467$) from sections 4 through 16 of the lower Rio Grande, Texas during January-March 2006.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present</th>
<th>Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (m/s)</td>
<td>Mean ± SE 0.06 ± 0.01</td>
<td>Min. – Max. -0.11 – 0.30</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>47.9 ± 1.3</td>
<td>Min. – Max. 21.4 – 108.0</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>19.78 ± 0.23</td>
<td>Min. – Max. 16.31 – 25.50</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>1418 ± 57</td>
<td>Min. – Max. 713 – 6710</td>
</tr>
<tr>
<td>Dissolved O$_2$ (mg/L)</td>
<td>8.51 ± 0.12</td>
<td>Min. – Max. 5.29 – 13.75</td>
</tr>
<tr>
<td>pH</td>
<td>8.14 ± 0.04</td>
<td>Min. – Max. 6.22 – 9.30</td>
</tr>
<tr>
<td>ORP (mV)</td>
<td>89.9 ± 6.5</td>
<td>Min. – Max. -179.4 – 233.2</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>1.4 ± 0.2</td>
<td>Min. – Max. &lt;0.3 – 3.6</td>
</tr>
</tbody>
</table>
Table 2.2. Descriptive statistics for physical and chemical variables of water from sites sampled with the electrofisher where common snook were present ($n = 68$) or absent ($n = 190$) from sections 4 through 16 of the lower Rio Grande, Texas during January-March 2006.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present Mean ± SE</th>
<th>Min. – Max.</th>
<th>Absent Mean ± SE</th>
<th>Min. – Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (m/s)</td>
<td>0.04 ± 0.01</td>
<td>-0.18 – 0.27</td>
<td>0.30 ± 0.01</td>
<td>-0.10 – 0.21</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>49.9 ± 1.2</td>
<td>20.3 – 103.0</td>
<td>46.1 ± 1.5</td>
<td>21.4 – 86.0</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>20.92 ± 0.18</td>
<td>16.42 – 25.54</td>
<td>19.94 ± 0.26</td>
<td>16.65 – 25.50</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>1555 ± 101</td>
<td>903 – 13491</td>
<td>1289 ± 29</td>
<td>713 – 2061</td>
</tr>
<tr>
<td>Dissolved O₂ (mg/L)</td>
<td>8.69 ± 0.08</td>
<td>5.81 – 12.40</td>
<td>8.34 ± 0.13</td>
<td>6.03 – 11.68</td>
</tr>
<tr>
<td>pH</td>
<td>8.26 ± 0.03</td>
<td>5.81 – 9.43</td>
<td>8.16 ± 0.05</td>
<td>6.22 – 9.30</td>
</tr>
<tr>
<td>ORP (mV)</td>
<td>99.7 ± 4.8</td>
<td>-32.3 – 275.3</td>
<td>96.4 ± 8.5</td>
<td>-24.6 – 233.2</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>4.2 ± 0.2</td>
<td>1.0 – 16.0</td>
<td>3.6 ± 0.2</td>
<td>&lt;0.3 – 11.0</td>
</tr>
</tbody>
</table>
Table 2.3. Proportion of physical habitat variables for sites sampled with the electrofisher where juvenile common snook were absent (A, \(n = 176\)) or present (P, \(n = 63\)) from sections 4 through 16 of the lower Rio Grande, Texas during January-March 2006.

<table>
<thead>
<tr>
<th>Proportion</th>
<th>Bank Slope</th>
<th>Substrate</th>
<th>Shade</th>
<th>Submerged Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>P</td>
<td>A</td>
<td>P</td>
</tr>
<tr>
<td>Shallow</td>
<td>0.40</td>
<td>0.44</td>
<td>Mud</td>
<td>0.95</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.20</td>
<td>0.23</td>
<td>Mud/Sand</td>
<td>0.01</td>
</tr>
<tr>
<td>Steep</td>
<td>0.06</td>
<td>0.00</td>
<td>Sand</td>
<td>0.01</td>
</tr>
<tr>
<td>Cliff</td>
<td>0.32</td>
<td>0.31</td>
<td>Unknown</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Table 2.4. Factor loading matrix for the first four factors of principle component analysis of habitat variables for sites sampled with the trawl, castnet and electrofisher within sections 4 through 16 of the lower Rio Grande, Texas during January-March 2006.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>0.61</td>
<td>-0.51</td>
<td>-0.17</td>
<td>-0.07</td>
</tr>
<tr>
<td>Flow</td>
<td>0.46</td>
<td>-0.07</td>
<td>-0.62</td>
<td>-0.22</td>
</tr>
<tr>
<td>Turbidity</td>
<td>-0.69</td>
<td>-0.36</td>
<td>-0.14</td>
<td>-0.10</td>
</tr>
<tr>
<td>Temperature</td>
<td>-0.62</td>
<td>-0.46</td>
<td>-0.04</td>
<td>-0.08</td>
</tr>
<tr>
<td>Conductivity</td>
<td>-0.04</td>
<td>0.83</td>
<td>-0.29</td>
<td>-0.06</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>-0.57</td>
<td>0.24</td>
<td>-0.43</td>
<td>-0.11</td>
</tr>
<tr>
<td>pH</td>
<td>-0.78</td>
<td>-0.04</td>
<td>-0.16</td>
<td>-0.18</td>
</tr>
<tr>
<td>ORP</td>
<td>0.13</td>
<td>-0.20</td>
<td>-0.68</td>
<td>0.48</td>
</tr>
<tr>
<td>Depth</td>
<td>0.29</td>
<td>-0.06</td>
<td>-0.08</td>
<td>-0.85</td>
</tr>
</tbody>
</table>

Eigenvalue        | 2.47     | 1.40     | 1.20     | 1.07     |

% Variance        | 27.41    | 15.52    | 13.32    | 11.89    |

Cumulative % Variance | 27.41 | 42.93 | 56.25 | 68.14 |

Note: Factors with values ≥ 0.60 or ≤ -0.60 are in bold print
Table 2.5. Factor loading matrix for the first four factors of the principle component analysis of habitat variables for sites sampled with the electrofisher (with physical data included) from sections 4 through 16 of the lower Rio Grande, Texas during January-March 2006.

<table>
<thead>
<tr>
<th>Variable</th>
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Note: Factors with values ≥ 0.60 or ≤ -0.60 are in bold print.
Figure 2.1. The lower 51.5 km of the Rio Grande, Texas including hydrology (dark grey) and urban (light grey; Brownsville) areas. Numbered points indicate the beginning of each river section (3.2 km) from the mouth to the end of the study area (section 1 extends from the river mouth to point 2 and section 16 extends from point 16 to end of the study area).
Figure 2.2 Number of sites within each river section (3218 m) where juvenile (age 1 and 2) common snook were captured in the lower 51.5 km of the Rio Grande, Texas using trawl, castnet, and electrofisher (top) and electrofisher only (bottom) during January-March 2006.
Figure 2.3. Length-frequency histogram of all common snook captured in the lower 51.5 km of the Rio Grande, Texas using trawl, castnet and electrofisher during January-March 2006.
Figure 2.4. Gonad cross section (left) and whole sagittal otolith (right) from an age-1 (A and C) and an age-2 (B and D) common snook captured in the lower 51.5 km of the Rio Grande, Texas during January-March 2006. Asterisks indicate the sperm ducts, black arrows indicate germinal epithelium, and white arrows indicate annuli.
Figure 2.5. Mean (± SE) water conductivity for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Figure 2.6. Mean (± SE) water depth for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Figure 2.7. Mean (± SE) water dissolved oxygen for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Figure 2.8. Mean (± SE) water flow for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Figure 2.9. Mean (± SE) water oxidation-reduction potential for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Figure 2.10. Mean (± SE) water pH for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Figure 2.11. Mean (± SE) water temperature for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Figure 2.12. Mean (± SE) water turbidity for sites sampled with trawl, castnet, and electrofisher (top) and for sites sampled only with electrofisher (bottom) within each section (3218 m) of the lower 51.5 km of the Rio Grande, Texas during January-March 2006.
Literature Cited


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Student Signature          Date

Disagree  (Permission is not granted.)

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Student Signature          Date