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Catch-and-Release Fishing on a Spawning Aggregation of Common Snook: Does It Affect Reproductive Output?

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Abstract.—Interactions between fishing and the reproductive biology of an exploited stock are broader than the parameters historically considered (e.g., spawning seasonality, spawning biomass, and size or age at maturity). However, few studies address these broader interactions. Here we characterize a spawning aggregation of common snook *Centropomus undecimalis*, evaluate the feasibility of acoustic telemetry for monitoring the movement of released fish out of the spawning aggregation, and determine whether the stress of capture and release affects reproductive output. A spawning aggregation of common snook was studied in Lake Worth Inlet, Florida, during summer 1998 and 1999. The aggregation was made up of large, mature fish that were actively spawning, as indicated by females with hydrated oocytes or postovulatory follicles and males with flowing milt. Individual courtship behaviors by a few fish were observed by divers, but no spawning events were observed. Acoustic telemetry indicated that the stress of capture and release did not cause fish to immediately leave the aggregation. However, some individual movement into and out of the aggregation site was observed during the spawning season. Fish implanted with either live or dummy ultrasonic tags continued to spawn. Histological evidence suggested that the stress of being caught on hook and line and then released did not cause females to interrupt or terminate spawning. Released females were consistently recaptured from the aggregation, and levels of ovarian atresia and spawning activity were similar for both recaptured and control fish.

Understanding reproductive processes and how they interact with fishing is becoming increasingly important (Sadovy 1996). Fisheries biologists have traditionally estimated size at maturity, spawning seasonality, and fecundity or spawning biomass in order to evaluate the effect of fishing mortality on reproductive output. However, biologists have rarely addressed other aspects of reproduction, such as reproductive behavior or the effect of no-take (i.e., catch-and-release) fishing on reproductive output. Determining where and when a species spawns is necessary to protect reproductive output, ensure that reproductive behavior is undisturbed, and help in the decision process associated with the placement and size of marine protected areas (Sadovy 1996; Zeller 1998). Similarly, knowledge of whether a species forms spawning aggregations or is hermaphroditic is important, as these attributes may make a species more susceptible to overexploitation (Coleman et al. 1996).

In Florida, spawning aggregations of common snook *Centropomus undecimalis* are heavily targeted by catch-and-release fisheries. Common snook are protandric hermaphrodites that are euryhaline. In spring, they migrate from upper rivers and backwaters to river mouths and passes to form spawning aggregations (Marshall 1958; Volpe 1959; Chapman et al. 1982). Common snook spawn multiple times (approximately once every 1.1–1.5 d) during a protracted spawning season, which occurs from approximately May through September (Taylor et al. 1998, 2000). The common snook fishery in Florida is strictly regulated, including a closed season from June to August and the use of only hook-and-line gear. However, fishing effort continues to increase in the common snook fishery, and 70% of the catch occurs during the summer closed season, when spawning is at its peak (Taylor et al. 2001). During the closed season, fishing is permitted but retention is not.

To understand how fishing may affect common

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snook reproduction, we first need a better understanding of their reproductive behavior. Common snook spawning aggregations have been reported to coincide with periods of strong afternoon ebb tides, which occur around the time of the new and full moons (Chapman et al. 1982; Peters et al. 1998), but no supporting data have been presented. Based on gonadal developmental stages over time, it has been documented that spawning occurs at dusk (Taylor et al. 1998), but spawning activity has never been observed (Peters et al. 1998). Only general spawning areas have been documented, based on the collection of gravid females and running ripe males (Taylor et al. 1998). In addition, it is not known whether individuals remain within the aggregation throughout the spawning season or whether there is movement to and from the aggregation (Taylor et al. 1998).

There also is concern that stress from catch-and-release fishing on spawning aggregations may adversely affect common snook reproduction. Stress has been shown to adversely affect reproductive physiology in fish by causing changes in reproductive hormone levels, fecundity, egg size, and survival of eggs and larvae (Billard et al. 1981; Campbell et al. 1994; McCormick 1998). In addition, Hutchings et al. (1999) suggested that fishing might disrupt spawning or courtship behavior and thus indirectly affect fertilization rates. For example, Atlantic cod *Gadus morhua* that were subjected to the simulated stress of capture and release under laboratory conditions initiated fewer courtships and produced more abnormal larvae than did control fish (Morgan et al. 1999).

This research was conducted to study a spawning aggregation of common snook on the Atlantic coast of Florida and to determine the influence of catch-and-release, hook-and-line fishing on spawning. Our objectives were to (1) characterize the spawning aggregation and observe it for potential spawning activity, (2) collect preliminary acoustic telemetry data on individuals from the aggregation, and (3) determine whether the stress of capture and release causes fish to interrupt or cease spawning.

Methods

Study area.—Two known spawning aggregations of common snook (Taylor et al. 1998) were sampled on the southern Atlantic coast of Florida (Figure 1). The main study site was Lake Worth Inlet. Water depths in the inlet ranged from 5 m along the rock jetty on the south side to 13.7 m in the main channel. The bottom was sand with shell hash (bits of broken shell), and there were numerous limestone outcroppings. The inlet is bordered by jetties, which extend seaward outside the inlet mouth. To allow for the maximum number of fish to be tagged and released in Lake Worth Inlet, we sampled control fish (those that had an ovarian sample taken immediately after landing) from a second known spawning aggregation in Jupiter Inlet (Figure 1). This inlet is similar to Lake Worth Inlet in bottom type and in the presence of seawalls that maintain the channel to the ocean. Jupiter Inlet is somewhat shallower, ranging from 3.5 to 6 m.

Collection of samples.—Baseline sampling of the aggregation occurred during the summer closed season (late July–August 1998 and June–August 1999) in Lake Worth Inlet and consisted of two types of events. In catch-and-release events, fish were first captured on hook and line, females were tagged with Hallprint extended-barb plastic tipped dart tags (PDL), and all fish were released. Recapture events were then conducted 1–3 d and 7–9 d (roughly 1 week) after the fish were released to determine whether the stress of capture and release affected ovarian condition. To increase our sample size of recaptured females, additional females were recaptured during nontargeted postrelease periods (18–73 d and 391 d). In 1999, this sampling schedule was supplemented with extra catch-and-release and recapture events because of low catch rates (Table 1). Also in 1999, the following environmental parameters were recorded during recapture events: surface and bottom salinity and temperature, water depth, moon phase, and underwater visibility range.

Our goal was to capture 30 females during each catch-and-release event. The aggregation was located via depth recorder or color echosounder and/or a snorkeler's observations, but it was generally found at one of four stations near the mouth of the inlet (Figure 1). A minimum of four anglers participated and fished from 0630 to 1200 hours. The anglers used the same bait, tackle, and techniques used by recreational anglers in the area. Fish were measured (nearest mm total length [TL]), and were sexed based on the appearance of the urogenital pore and on the presence or absence of flowing milt, following Neidig et al. (2000). Females from each event were tagged uniformly, and tags unique to each event were used so that the appropriate females could be targeted in subsequent recapture events. Times from hooking to landing and from landing to fish release were recorded for 111 females and 124 males.

Tagged fish were recaptured by divers with spear guns. Time of recapture alternated between morn-

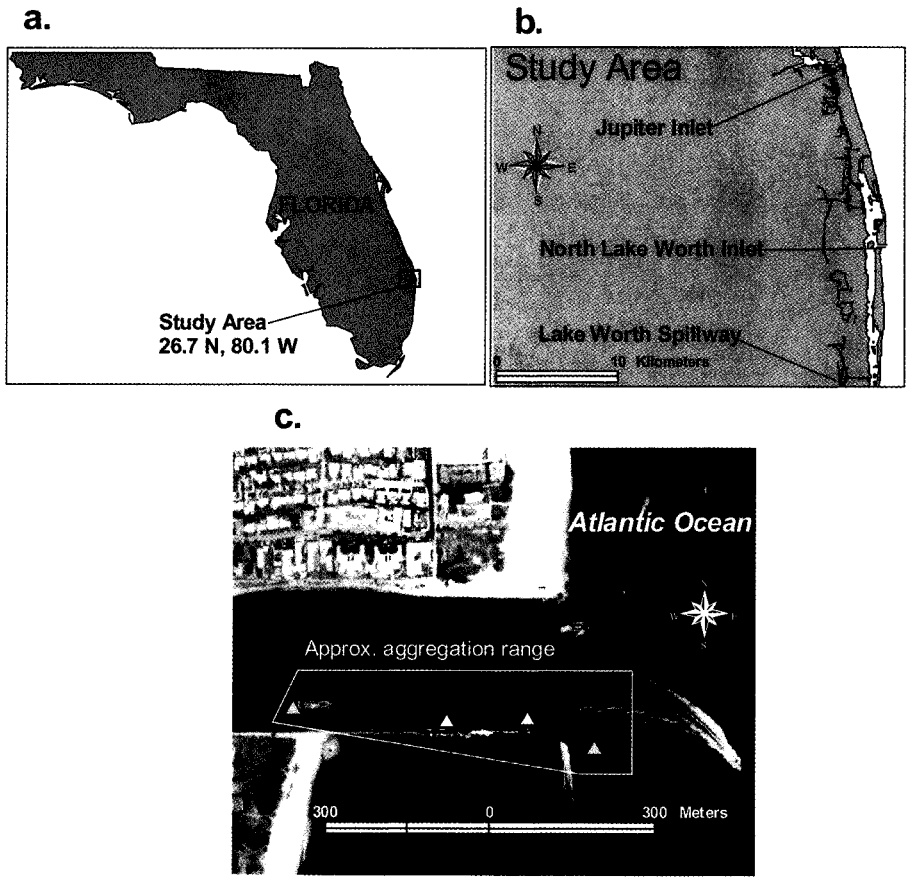

FIGURE 1.—**(a)** Map of the Florida study area where the spawning aggregation of common snook was examined for the effects of catch-and-release fishing, **(b)** study area, enlarged to show sampling and relocation sites, and **(c)** aerial photograph of Lake Worth Inlet. The triangles in panel (c) indicate four stations where the aggregation was most frequently located and where acoustic telemetry monitoring sites were located.

ing (0700–1200 hours) and afternoon or evening (1400–1930 hours) to ensure enough light to identify tagged fish. These times were also chosen to maximize sampling of active spawners, as common snook reportedly spawn at dusk (Taylor et al. 1998). Active spawners were defined as fish with either 0-d (Hunter and Macewicz 1985) postovulatory follicles (POFs), indicating they had spawned the night before, or oocytes undergoing final oocyte maturation (FOM; defined as those oocytes which exhibited either germinal vesicle migration, germinal vesicle breakdown, or yolk coalescence/hydration), indicating they would spawn that evening (Figure 2).

Recaptured fish were brought on board and killed. Time of capture and dart tag number(s) were recorded. An ovarian tissue sample was taken immediately and fixed in 10% formalin for histology. After each recapture event, fish were taken to the laboratory, measured (nearest mm fork length [FL] and TL), and weighed (nearest g). Histological samples were later washed and stored in 70% ethanol. Samples were embedded in glycol methacrylate, sectioned to 3–5-μm thickness, stained with periodic acid–Schiff's hematoxylin, and then counterstained with metanil yellow (Quintero-Hunter et al. 1991). Sagittal otoliths were removed and stored dry. They were processed and aged following the methods of Taylor et al. (2000).

Characteristics of the aggregation.—In addition to the recapture event dives, four dives were conducted to document whether fish in the aggregation demonstrated courtship or spawning behavior. These dives were made on August 9, 23, 24, and 25, 1999, during the new and full lunar phases,

TABLE 1.—Description of catch-and-release and recapture of common snook in Lake Worth Inlet, Florida. Data include catch-and-release event and date, sex ratio, (number of females caught out of total captures), date of recapture events, time of day of recapture, and number of females recaptured at targeted postrelease periods. Events from 1998 are designated with letters and those from 1999 with numbers to make them easily distinguishable.

Catch-and-release event	Date of catch-and-release event	Sex ratio	Date of recapture event(s)	Time of day	Number of females recaptured	Targeted postrelease period (d)
A	Jul 29, 1998	29/50	Jul 30, 1998	PM	2	1
			Aug 7, 1998	AM	2	8
B	Aug 12, 1998	28/101	Aug 13, 1998	PM	3	1
			Aug 20, 1998	AM	0	8
1	Jun 15, 1999	31/49	Jun 16, 1999	AM	0	1
			Jun 23, 1999	PM	3	8
2	Jun 29, 1999	6/12	Jun 30, 1999	AM	0	1
3	Jul 6, 1999	12/21	Jul 7, 1999	PM	0	8
4	Jul 12, 1999	17/35	Jul 13, 1999	AM	0	1
			Jul 21, 1999	PM	2	9
5	Jul 25, 1999	5/10				
5	Jul 26, 1999	8/16	Jul 27, 1999	AM	1	1
6	Aug 3, 1999	21/73	Aug 4, 1999	PM	0	1
			Aug 5, 1999	PM	2	2
			Aug 11, 1999	AM	2	8
			Aug 12, 1999	AM	2	9
7	Aug 9, 1999	3/8				
7	Aug 10, 1999	1/13	Aug 11, 1999	AM	0	1
8	Aug 17, 1999	6/30				
8	Aug 18, 1999	6/13	Aug 19, 1999	PM	1	1
					1	2
			Aug 20, 1999	PM	0	2
			Aug 25, 1999	AM	2	8
9	Aug 24, 1999	24/57	Aug 25, 1999	AM	2	1
			Aug 26, 1999	AM	3	2
			Aug 27, 1999	AM	2	3

for which peak spawning activity has been reported (Chapman et al. 1982). Two scuba divers monitored the behavior of individuals and that of the school from about 3 h before sunset to 20 min after sunset (which occurred at approximately 2000 hours). Divers specifically looked for the prespawning behaviors that have been previously reported for common snook: (1) large fish escorted by several smaller fish and (2) females losing equilibrium or floating on their sides at the surface (Peters et al. 1998). Divers also looked for spawning or courtship behaviors described for other broadcast spawners, such as (1) mounting and/or release of gametes, (2) flaunting (exaggerated lateral bends of the body), (3) prodding (the male's snout nudging the female's ventral trunk region [Brawn 1961]), and (4) color changes (Domeier and Colin 1997). Any courtship-like behaviors observed during either morning or evening recapture events also were recorded.

Acoustic telemetry.—We implanted 26 fish captured in Lake Worth Inlet with either live ($N = 5$) or dummy ($N = 21$) ultrasonic coded tags (IT-95-2, frequency range 36–40 kHz, continuous pulse interval of approximately 1 s; Sonotronics Co., Tucson, Arizona). Each tag was 45 mm long and 14 mm in diameter, weighed 5.0 g in water, and had a battery life of 12 months. Fish to be tagged were held in a 168.5-L cooler filled with fresh seawater while their air bladders were deflated. After FL and TL were measured, each fish was placed ventral side up in an angled cradle within the cooler so that the fish's head and gills were submerged in oxygenated water but the incision site was left dry. Tags were surgically implanted into the peritoneal cavities of unanaesthetized fish. Incisions approximately 2 cm long were made just posterior to the pelvic girdle along the midventral line, and were closed with cyanoacrylate adhesive (Petering and Johnson 1991). The tagging procedure took approximately 3–5 min.

To evaluate the effects of the implantation process on the fish, 21 females were implanted with dummy tags. Three of these were immediately sacrificed to assess the implantation procedure. The remaining 18 fish were released and targeted for recapture to evaluate wound healing and ovarian developmental stage. Seven of these fish were re-

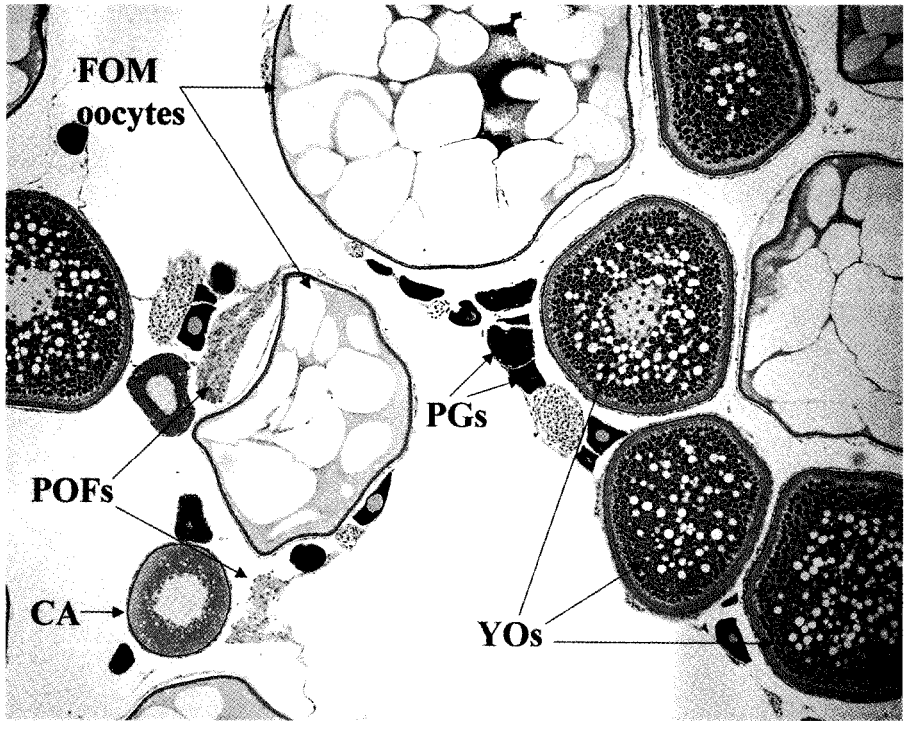

FIGURE 2.—Histological ovarian sample from the fish with tag 46, showing signs of continued spawning activity and no atresia (PG = primary growth oocyte; CA = cortical alveoli oocyte; YO = yolked oocyte; POF = post-ovulatory follicle; and FOM = final oocyte maturation stage). The fish was recaptured 28 d after implantation with a dummy sonic tag.

captured 27–62 d postrelease and were examined externally for evidence of infection and/or healing at the wound site. They were then dissected and examined for (1) inflammation of tissue and organs, (2) transmitter position, (3) healing of the internal surface of the incision (Moore et al. 1990), and (4) ovarian developmental stage. Ovarian developmental stage was determined histologically by the methods described in the next section. Additional data, as described for recaptured fish from catch-and-release events, were also collected from these fish.

To evaluate the feasibility of acoustic telemetry as a method for determining whether released fish left the spawning aggregation, we tagged five females with ultrasonic transmitters. These fish were captured in Lake Worth Inlet in 1999 by hook and line and were tagged on June 18 (N = 1 fish), June 28 (N = 3), and July 22 (N = 1). Each fish was released at its capture site immediately after tagging. To determine whether fish had survived the implantation process, each individual was tracked for 20 min postrelease. If the fish showed signs of movement, it was assumed to be alive and functioning.

Four stations, corresponding to the areas where the aggregation was consistently located, (Figure 1) were monitored once per week (from June 14 through September 9, 1999) with a mobile Sonotronics Model USR-96 ultrasonic receiver and a Sonotronics Model DH-2 directional hydrophone. At each station, the hydrophone was lowered to approximately 1 m below the surface. A technician then listened for a period of 30 s to 1 min in each direction for each of the tag frequencies. Individual fish were identified by frequency and pulse codes.

Effect of catch and release on reproduction.—To evaluate whether catch-and-release fishing decreased the reproductive output of the common snook in our study, histological samples from recaptured females were compared to those from control females in terms of atresia and percentage of active spawners. Ovarian developmental stage was classified histologically (Wallace and Selman 1981; Hunter et al. 1992) based on four stages of

oocyte development: (1) the primary growth stage, (2) the cortical alveoli stage, (3) the yolked stage, and (4) the FOM−hydrated stage. The POFs were noted and aged by determining the difference between the time of peak spawning activity and the time when fish were recaptured (Alheit et al. 1984). The percentages of active spawners in these two groups were compared by means of a chi-square test at an α level of 0.05. Control females were those from whom an ovarian sample was taken immediately after hook-and-line capture (23 fish and 7 ovarian biopsies from Jupiter Inlet and 3 fish from Lake Worth Inlet). Recaptured females were those collected by spear gun during targeted ($N = 30$ fish) and nontargeted ($N = 20$) postrelease periods. Both recaptured and control females were collected well within the spawning season (from June through August) and in morning and afternoon−evening samples to target active spawners. Biopsy samples were excluded from any analysis based on POFs, because it has not yet been demonstrated whether POFs can be identified with this sampling method.

We categorized the level of atresia in terms of the atretic states defined by Hunter and Macewicz (1985), with a few slight modifications. Early beta-stage atretic oocytes were noted, because they were easily identified and were the only means of identifying the resorption of a previous batch of fully yolked oocytes in ovaries with a newly developing batch of healthy yolked oocytes. Cortical alveoli were also included, as healthy cortical alveoli indicate recruitment of new batches of oocytes to the yolked stage. Biopsy samples were excluded from the atresia analysis due to the potential for damage to yolked oocytes during the extraction process.

Results

Characterization of the Aggregation

An aggregation of large adult common snook consistently occurred either inside Lake Worth Inlet or adjacent to the southern jetty during our sampling periods in 1998 and 1999 (Figure 1). We located a school in the sampling area during 95% ($N = 38$) of the sampling events. Although no formal method of estimating school size was used, divers observed that school size fluctuated from week to week, with what appeared to be a maximum of 1,000–2,000 fish. Occasionally, more than one group of fish was observed in the area. In addition, there were recapture events during which the school broke up into smaller groups or moved away and was difficult to relocate on the second dive. Visibility ranged from 2.4 to 12.2 m and affected the divers' ability to observe and quantify the aggregation.

The number of tagged fish observed during recapture dives varied. A total of 140 females were tagged in 1999. The percentage of tagged fish observed and/or recaptured during any one recapture event, out of the number of tagged fish released from all events prior to that date, ranged from 0% ($N = 31$ total releases) on June 16, 1999 to 20.3% ($N = 79$ total releases) on July 27, 1999. With one exception, tagged fish were not captured in later hook-and-line events.

Strong current, medium depth, and fairly high salinity characterized the area where the aggregation was located. Depths where common snook were located ranged from 7 to 13.7 m and averaged 10.9 m ($N = 16$, SE = 0.447). Average bottom water temperature was 28.9°C ($N = 16$, range = 27.6–29.9°C, SE = 0.184), and average bottom salinity was 35.2 ppt ($N = 16$, range = 34.2–36.5‰, SE = 0.523).

Aggregations were observed during all lunar phases and throughout the day (from 0615 to 2020 hours), but at dusk they often broke up into smaller groups. Recapture events in 1999 were assigned to lunar weeks, and aggregations were located during all phases (new moon, $N = 5$; first quarter, $N = 6$; full moon, $N = 7$; last quarter, $N = 5$) throughout the sampling period. Actively spawning females (those with hydrated oocytes or 0-d POFs) were also recaptured during all lunar phases (Table 2).

The aggregation was made up of large, mature fish. A total of 492 fish were caught by hook and line. Lengths ranged from 690 to 1,103 mm TL (mean = 880 mm, SE = 3.57 mm). Length differed significantly between sexes (t-test, $N = 492$, $P < 0.001$). The average length for males was 853 mm TL (690–1,038 mm, $N = 294$, SE = 3.68 mm) and for females was 921 mm TL (720–1,103 mm, $N = 198$, SE = 5.85 mm). The age range of the 80 fish kept for dissection was 4–16 years, and the mean age was 8 years (SE = 0.25). Sex ratios of fish captured on hook and line varied across sampling dates (Table 1), but starting in August, they were consistently skewed towards males. The overall sex ratio (1.5 males to 1 female) was also significantly skewed towards males ($\chi^2 = 18.8$, $N = 492$, $P < 0.001$). The external sex classification method was 96% accurate (2 of 55 recaptured fish classified as females were male). Most males extruded milt upon pressure, and all recap-

TABLE 2.—Number of female common snook recaptured from Lake Worth Inlet, Florida, with the percentage that were active spawners in parentheses, by lunar phase; all dates are in 1999.

Date of recapture event	Time of day	New moon	First quarter	Full moon	Last quarter
Jun 23	PM				3 (33%)
Jul 21	PM				2 (50%)
Jul 27	AM			3 (0%)	
Aug 5	PM		3 (100%)		
Aug 11	AM	4 (25%)			
Aug 12	AM	4 (25%)			
Aug 19	PM				3 (100%)
Aug 20	PM				1 (100%)
Aug 25	AM			7 (43%)	
Aug 26	AM			7 (57%)	
Aug 27	AM			7 (57%)	
Total		8 (25%)	3 (100%)	24 (46%)	9 (67%)

tured females had fully yolked oocytes, indicating they were mature and capable of spawning. In addition, 51% of the recaptured females had either POFs or oocytes in FOM, indicating active spawning.

Although individual courtship behaviors were observed, no large, aggregate courtship or spawning was seen. An aggregation of large fish was located within the inlet on the north side of the south jetty during all four courtship evaluation dives. Smaller fish were also observed in close proximity to the rocks of the jetty during each of these dives. Behaviors observed included (1) large fish escorted by one to five smaller fish, (2) flaunting, and (3) nudging. However, these behaviors were always limited to only a few fish in the aggregation (one to two large fish for behavior 1, and one to two individuals for behaviors 2 and 3). Loss of female equilibrium, ventral mounts, or the release of gametes were never observed. Attempts to identify color changes were inconclusive. On several occasions, a large, relatively dark fish was escorted or nudged by smaller fish. However, we observed groups exhibiting courtship behavior in which the larger fish showed no changes in color. During morning dives, we also observed large, dark individuals even when no courtship behavior was apparent. The three observed courtship behaviors were also seen during afternoon–evening recapture dives but not during morning dives.

The histology of recaptured females was consistent with the observed prespawning behavior in terms of ovarian condition and diel periodicity of spawning. Although the very earliest stage of germinal vesicle migration (GVM) was observed in three fish collected before noon (0900–1153 hours), well-advanced GVM was observed only in fish collected after 1330 hours. Three females contained hydrated oocytes in which germinal vesicle breakdown had been completed, presumably indicating they were close to ovulation. These fish were collected at 1550, 1614, and 1912 hours. No fish from afternoon–evening collections ($N = 17$) were in the process of ovulation or had fresh POFs, which would have indicated they had just spawned (most of these fish were collected from 1400 to 1600 hours; three were collected after 1800 hours).

Acoustic Telemetry

Recaptured, implanted fish had well-healed wounds and were capable of spawning. Of the seven recaptured, implanted fish, none showed signs of either internal or external infection or inflammation, and all the incisions were healed. The sonic tag was encapsulated in a clear layer of tissue between the ovaries, just posterior to the wound scar. All of the ovaries from recaptured, implanted fish had minimal atresia (categories 0 or 1) and had healthy, fully yolked oocytes or oocytes in FOM (Table 3). The two fish recaptured in the afternoon/evening (tags 28 and 46) were going through FOM and would have spawned that evening. In addition, one of these also had POFs, indicating it had spawned the night before (Figure 2). Of the five fish recaptured in the morning, one had 0-d POFs and another had an atretic hydrated oocyte, indicating both had previously spawned.

Four of the five fish implanted with acoustic tags were relocated in the aggregation the day after implantation (Table 4), suggesting that the stress of capture and release did not cause an immediate migration out of the area. One fish was relocated 2 d after implantation, and another was relocated in the aggregation approximately 2 weeks after

TABLE 3.—Ovarian development of recaptured common snook females implanted with ultrasonic tags, by tag type and number of days between release and recapture (days out) in Lake Worth Inlet, Florida. All wounds were healed by the time of recapture. In ovarian development descriptions, FOM is final oocyte maturation and POFs are post-ovulatory follicles. Under atresia category, category 0 indicates no alpha or beta atresia of yolked or cortical alveoli oocytes, and category 1 indicates that less than 50% of yolked and cortical alveoli oocytes are atretic. All dates are in 1999.

Fish number	Tag type	Implant date	Days out	Ovarian development	Atresia category
22	Dummy	Jun 10	47	Healthy, fully yolked oocytes	0
33	Dummy	Jun 10	62	Healthy, fully yolked oocytes and 0-d POFs	1
1	Dummy	Jun 17	21	Healthy, fully yolked oocytes	1
36	Dummy	Jun 17	55	Healthy, fully yolked oocytes	0
28	Dummy	Jun 17	49	Healthy FOM oocytes	0
21	Live	Jun 28	29	Healthy, fully yolked oocytes	1
46	Dummy	Jul 22	28	Healthy FOM oocytes and 0-POFs	0

implantation. The fish with tag 38 (Table 4) was relocated 1 d after implantation (June 28, 1999) and was then recaptured by spear gun on July 27, 1999, when it was determined that its tag was faulty and not transmitting. The fish with tag 40 was implanted later in the season than were the other fish and was never relocated.

Preliminary results indicated that individuals moved into and out of the spawning aggregation during the spawning season. The fish with tag 37 was present in the aggregation the day after implantation but could not be relocated the following day (June 29, 1999). It was caught and released by an angler at Lake Worth Spillway on July 1, 1999 (a low-salinity, nonspawning area located 14.6 km from the study area; Figure 1), and was then relocated in the aggregation in Lake Worth Inlet on August 19, 1999. A similar pattern was seen for the fish with tag 36, although we have no corroborating evidence to confirm this individual exited the inlet. Fish 36 was implanted on June 18 and relocated through June 30, 1999. This fish was not located in early July, but was again relocated in the aggregation on July 13, 1999 (Table 4). In addition, a dummy-tagged fish was implanted on June 17, 1999, in Lake Worth Inlet and recaptured on July 8, 1999, in Jupiter Inlet (approximately 19 km from the study area).

TABLE 4.—Dates (1999) when female common snook were implanted with five ultrasonic tags and dates when the fish were monitored for possible relocations at four listening stations within Lake Worth Inlet, Florida. (***) Asterisks indicate dates of relocation.

Date	Tag 36	Tag 37	Tag 38	Tag 39	Tag 40
Jun 18	Implanted				
Jun 23	***				
Jun 28	***	Implanted	Implanted	Implanted	
Jun 29	***	***	***	***	
Jun 30	***			***	
Jul 1					
Jul 6					
Jul 7					
Jul 13	***				
Jul 21					
Jul 22					Implanted
Jul 25					
Jul 27			Recaptured		
Aug 4					
Aug 5					
Aug 11					
Aug 12					
Aug 19		***			
Aug 20					
Aug 25					
Aug 26					
Sep 9					

Effect of Catch and Release on Reproduction

Catch and release of common snook from the spawning aggregation caused some observable stress. The average hooking-to-landing time was 66.6 s (N = 235 fish, SE = 2.2), and the average landing-to-release time was 45.0 s (N = 235, SE = 2.9 s). A large number of the fish floated when they were released because of the rapid depressurization associated with capture in relatively deep water. These fish had to have their swim bladders punctured before they could return to the depths at which the school was located (11 m). Of the 492 fish caught and released, one mortality was observed. This fish was found in the rocks of the jetty during the following day's recapture event.

A total of 50 females was captured by spear gun in Lake Worth Inlet during recapture events. Fish were recaptured from all of the catch-and-release events except one (7 with only four females; Table 1). Thirty of these recaptured fish were collected at the targeted times postrelease (17 fish at 1–3 d postrelease; 13 fish at 8–9 d postrelease). The average recapture rate per catch-and-release event for fish 1–3 d postrelease was 6.7% (N = 11 events) and ranged from 0% to 29.2%. For females recaptured 8–9 d postrelease, the average recapture rate per catch-and-release event was 6.3% (ranging from 0% to 21.1%; N = 11 events). Of the remaining 20 recaptured fish, 19 were collected 18–73 d postrelease, and one was recaptured the following season (393 d postrelease). In addition, two males, misidentified as females, were recaptured at 1 and 11 d postrelease, and another female was recaptured during a subsequent catch-and-release event (21 d postrelease).

Recaptured females (N = 50) had low levels of ovarian atresia. The majority of the fish (59%) had category-0 atresia (no atretic oocytes observed), and all of the fish had healthy, fully yolked oocytes. No fish had category-2 atresia (50% or more of yolked and cortical alveoli oocytes are atretic), which would have indicated that cessation of spawning was imminent (Table 5). However, three females had relatively high numbers of early beta-stage atretic yolked oocytes, as well as healthy yolked oocytes, indicating the resorption of a batch of oocytes but not the cessation of spawning. There was no observable trend between the level of atresia and the number of days between release and recapture (Table 5). The percentage of recaptured fish with category-0 or category-1 atresia was not significantly different from that of control fish (χ^2 = 0.21, P = 0.65, N = 76).

TABLE 5.—Number of female common snook recaptured by spear gun by number of days between release and recapture (days out), categorized by level of ovarian atresia. Atresia category 0 indicates no alpha or beta atresia of yolked or cortical alveoli oocytes, category 1 indicates that less than 50% of yolked and cortical alveoli oocytes are atretic, and category 2 indicates 50% or more of yolked and cortical alveoli oocytes are atretic.

Number of females	Days out	Atresia category		
		0	1	2
9	1	5	4	
6	2	3	3	
2	3	2		
7	8	6	1	
6	9	2	4	
2	18		2	
1	21		1	
1	22	1		
1	24		1	
1	28	1		
1	29		1	
1	30	1		
1	32	1		
1	45		1	
2	46	2		
1	47	1		
1	49	1		
1	55	1		
1	58		1	
1	62		1	
1	72	1		
2	73	2		

The percentages of actively spawning fish were similar for both recaptured and control fish. Nineteen percent of recaptured females (N = 50) and 18% of control females (N = 33) had FOM–hydrated oocytes, indicating they would spawn that evening. These percentages were not significantly different (χ^2 = 0.000, P = 0.983, N = 83). The percentages of fish recaptured with 0-d POFs were also not significantly different for the two groups (χ^2 = 0.003, P = 0.957, N = 76): 34% (N = 50) of the recaptured fish and 34.6% (N = 26) of the control fish had fresh POFs.

Discussion

Characteristics of the Aggregation

We considered the aggregation of common snook in Lake Worth Inlet to be a spawning aggregation. This was based on the consistent collection of reproductively active females, the large increase in the numbers of common snook in the inlet during the spawning season (J. A. Whittington, unpublished data), and published information

indicating that common snook travel relatively long distances from estuaries and freshwater tributaries to aggregation sites at ocean inlets (Tucker and Campbell 1988).

However, not all fish in the aggregation spawn on any given night. Thus, we suggest a two-stage model to explain this spawning aggregation. An aggregation of reproductively ready fish (i.e., those that are capable of spawning either that night or over the next several days) occurs at the inlet throughout the spawning season. This aggregation persists throughout daylight hours and during all lunar phases. A subset of the reproductively ready aggregation spawns on a given night, as indicated by the fact that only 19% of the females collected in afternoon/evening samples were in spawning condition (i.e., had FOM−hydrated oocytes). The divers in our study observed the aggregation breaking up into smaller groups just as light faded. We suggest that these small groups represented the active spawners and that they may be spawning in areas adjacent to the larger, reproductively ready group.

Individual fish move into and out of the aggregation. An individual was relocated in the aggregation several days after implantation, then 2 d later it was caught and released in a low salinity, nonspawning habitat situated 14.6 km from the aggregation site. This same individual returned to the aggregation 6 weeks later. This type of movement indicates that, although the aggregation itself is present over the protracted spawning season (roughly May through September), the individuals making up the aggregation may change. In addition, another individual was found to move from the Lake Worth Inlet aggregation site to the Jupiter Inlet aggregation site, indicating that there is at least some connectivity between these sites.

In addition to the reproductively ready aggregation, small common snook (presumably males) were consistently observed near the jetty. Common snook are protandric hermaphrodites, and the male population is 50% sexually mature at approximately 400 mm FL and 2–3 years of age (Taylor et al. 2000). However, the size range of males in the aggregation (690–1,038 mm TL, mean = 853 mm TL) was considerably larger than this. It is not yet clear where or whether the smaller males spawn.

The release of gametes by common snook was never observed in Lake Worth Inlet, possibly due to the alteration of normal spawning behavior by diver presence. In general, the common snook aggregation allowed divers to get within 4.6–15.2 m with no obvious change in behavior. However, the few smaller groups exhibiting prespawning behavior appeared more affected by the divers, with one such group stopping its behavior and rejoining the larger aggregation when divers tried to follow it.

Acoustic Telemetry

Common snook appear to be ideal candidates for further research to determine movements associated with spawning. Although it has generally been recommended that fish not be implanted with tags during the spawning season (Nielsen 1992), our results indicated that female common snook with developed ovaries (i.e., containing yolked oocytes) could be implanted with ultrasonic tags and continue to spawn. In addition, the goal of immobilizing the fish and inserting the tag with minimum stress could be met simply by turning the fish ventral side up. This practice negated the need for a 21-d recovery period (required when tricaine methanesulfonate [MS-222] is used) and avoided the possible effects of captivity on gonad development.

Effect of Catch and Release on Reproduction

Although the reported short-term catch-and-release mortality rates for common snook are quite low (2.13%; Taylor et al. 2001), we did observe stress associated with rapid depressurization. Taylor et al. (2001) did not address this problem because most common snook caught in Florida are caught in relatively shallow water. However, common snook caught in Lake Worth Inlet often need their swim bladders punctured before they can regain neutral buoyancy and return to the depths at which they were caught. Keniry et al. (1996) found that puncturing the swim bladders in yellow perch *Perca flavescens* caught in relatively deep water reduced the mortality associated with swim bladder overinflation. He also suggested decompression (fish brought to the surface in stages) as a less invasive means of handling depressurization problems. Another possible solution, already used by some fishing guides in the Lake Worth area, is a weighted release hook. With this device, the fish is brought to the bottom before being released.

The stress of capture and release did not appear to cause the common snook to cease spawning. In some species, a stress-induced decrease in plasma levels of gonadal steroids causes a

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