EFFECTS OF A SEVERE COLD EVENT ON THE SUBTROPICAL, ESTUARINE—DEPENDENT COMMON SNOOK, *CENTROPOMUS UNDECIMALIS*

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ABSTRACT: The effects of infrequent disturbance events on marine fishes are often difficult to determine, due largely to lack of sufficient pre— and post—disturbance event data. In January 2010, subtropical southwestern Florida (USA) experienced extreme cold for 13 days, which caused extensive mortality of many fish species. The effect of this severe cold event on common snook (*Centropomus undecimalis*), an economically important gamefish, was assessed using three years (2007–2009) of pre—event and one year (2010) of post—event data from a tag—recapture program conducted over 28 km of Gulf of Mexico barrier islands of Florida. All metrics pointed to a significant effect of the severe cold event: post—disturbance apparent survival of marked fish was 96–97% lower than pre—disturbance, and post—disturbance common snook abundance was 75.57% and 41.88% less than in 2008 and 2009, the two years immediately pre—event. Although severe cold events have impacted subtropical Florida in the past, these events are infrequent (the previous recorded event was >30 years prior), and documentation of the impacts on common snook have not previously been published.

KEY WORDS: spawning habitat, survival, tag—recapture, thermal disturbance

INTRODUCTION

Disturbances play a fundamental role in shaping biological diversity (e.g., Cooper 1966, Connell 1978, Sousa 1979). Numerous non—mutually exclusive hypotheses have been proposed to explain how disturbances interact with competition, productivity, and life history strategies to maintain species abundance (e.g., Connell 1978, Huston 1994, White and Jentsch 2001). Given the importance of disturbances to biological organization, and the fortuitous nature of "natural experiments" provided by disturbances, studies that document ecological effects of disturbances are sorely needed.

With some notable exceptions (e.g., Sousa 1979, Hughes 1994, Syms and Jones 2000), studies of disturbances in marine systems have generally been opportunistic, whereby an ongoing study encompasses a disturbance event. Time—series are essential for drawing accurate pictures of species before a disturbance and determining the effects of the disturbance (Mackey and Currie 2001). For example, in a study of hurricane effects on coral reef fish assemblages, Adams (2001) first used a standard 'before vs. after' approach to data analysis, and found a decline in fish abundance and species richness after the hurricane. However, when the data were examined as a time series (17 months pre— and nine months post—hurricane census data), changes were shown to be long—term declines that were unaffected by the hurricane. Similarly, Lassig's (1983) time series data showed little effect of a tropical cyclone on adult fishes, but a notable effect on recruits – findings likely unattainable with only data 'snapshots.' More recently, however, issues of temporal scale have been addressed as more multi—year datasets are becoming available, and more studies have been able to address disturbances (e.g., Greenwood et al. 2006, Stevens et al. 2006). Multi—year studies provide data from before and after disturbance events that allow documentation of disturbance effects because the studies provide pre— and post—disturbance data.

Common snook, *Centropomus undecimalis*, is a tropical and subtropical, estuarine—dependent, euryhaline species that is ecologically and economically important throughout its range, especially in Florida (Taylor et al. 2000). Common snook are protandrous hermaphrodites, with sex ratio changing by size: < 553 mm standard length, the male:female ratio is ~ 1.9:1; at 553 mm the ratio is ~ 1:1; and at 750 mm the ratio is ~ 1:1.2 (Muller and Taylor 2006). The general life history is as follows: adult common snook spawn during summer in passes and inlets at the mouths of estuaries and along adjacent beaches (Taylor et al. 1998); larval planktonic stage is about 2 weeks (Peters et al. 1998); juvenile habitats are shallow, complex, meso— to oligohaline habitats (Peters et al. 1998), and adults use deeper estuarine and riverine habitats for overwintering (Blewett et al. 2009). Common snook in Florida can live for more than 20 yrs, with one to 7 yr olds being the most common age (Taylor 2000). The geographical distribution of common snook is restricted by temperature, with the northern edge of their range restricted by the 15°C winter isotherm; they stop feeding completely at 14.2°C, lose equilibrium at 12.7°C, and die at 12.5°C (Shafland 1983).

This manuscript reports the effects of a severe cold event on common snook in Florida (USA), using data gathered

from a multi–year study on snook movements on spawning grounds (Adams et al. 2009, 2011). After three years of study, an extended and severe period of cold temperatures impacted this subtropical region, causing extensive mortalities of common snook and many other fish species. Sampling that continued through the first year after the severe cold event allowed an estimate of the effects of the event on adult snook on spawning grounds.

MATERIALS AND METHODS

Study area

Charlotte Harbor is a 700 km² coastal plain estuarine system in southwest Florida, USA (Figure 1, Hammett 1990). The Peace, Myakka, and Caloosahatchee Rivers, and many smaller creeks throughout the drainage, transport large amounts of fresh water into the harbor. The climate is subtropical; mean seasonal water temperatures range from 12 to 36°C, and freezes are infrequent (Poulakis et al. 2003). The estuary is separated from the Gulf of Mexico (GOM) by a string of barrier islands, with tidal exchange through five inlets that separate the barrier islands—Boca Grande Pass, Captiva Pass, Redfish Pass, and Blind Pass within the study area, and San Carlos Pass south of the study area. The GOM shorelines of the islands are comprised entirely of sandy beaches. The passes are a mixture of natural sand and anthropogenically hardened shorelines. The passes and barrier island beaches are classified as spawning grounds during summer (May through September) (Taylor et al. 1998, AJA pers. obs.).

Severe Cold Event

On 2 January 2010, a severe cold front followed by a reinforcing high pressure arrived in south Florida, creating abnormally cold conditions for 13 d. Daytime air temperatures were about 9°C below normal, and extended northerly winds kept temperatures low and caused water temperatures throughout the estuary to drop well below normal. Hourly water temperatures, averaged from 4 sensors from the Sanibel–Captiva Conservation Foundation Marine Laboratory's River, Estuary and Coastal Observing Network (SCCF RECON) (Figure 1), revealed that water temperature dropped from about 18°C on 1 January to 12°C by 6 January, and remained below 12°C through 16 January (Figure 2). This was well below the mean winter water temperature of 21°C for the estuary, and below the lethal thermal threshold of common snook (12.5°C) for at least 10 d. Severe cold events are infrequent but recurring in
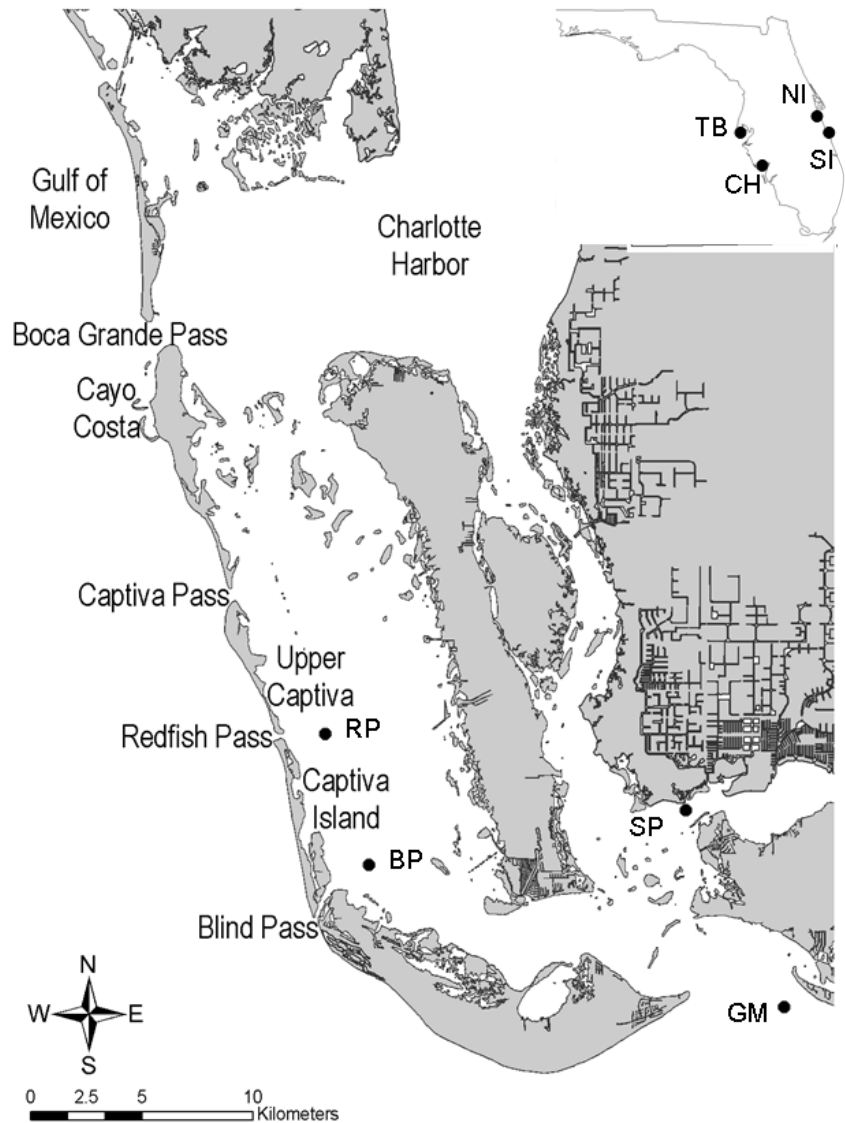

Figure 1. *Map of the Charlotte Harbor (CH) study area in southwestern Florida, USA. Tag and recapture by seine occurred along barrier island beaches from the northern end of Cayo Costa (at Boca Grande Pass) to the southern end of Captiva (at Blind Pass). Four SCCF RECON monitoring stations (Redfish Pass (RP), Blind Pass (BP), Shell Point (SP) and Gulf of Mexico (GM)) were used to obtain water temperatures for January 2010. The other estuaries sampled by Florida Fish and Wildlife Conservation Commission Fisheries Independent Monitoring program (see inset) are Tampa Bay (TB), North Indian River Lagoon (NI), and South Indian River Lagoon (SI).*

Florida, with multiple historical reports (e.g., Storey 1937). Though there has usually been at least one severe cold disturbance per decade recorded for terrestrial ecosystems (Miller and Downtown 1993), the most recent documented marine cold event of similar magnitude to the 2010 disturbance was in 1977 (Gilmore et al. 1978, Bohnsack 1983), and prior to that in 1940 (Galloway 1941), both of which caused significant fish mortalities. Few published reports document more than a species list of moralities (but see Gilmore et al. 1978, Bohnsack 1983).

Sampling protocol

As part of a study to examine levels of site fidelity of adult common snook to spawning grounds (Adams et al. 2009, 2011), adult snook were captured by seine along GOM beaches of Florida during the summer spawning season from 2007 through 2010. Tag—recapture methods were used to estimate common snook use of spawning grounds within and among years. Snook exhibited >97% fidelity to spawning grounds over this 4 y time period (Adams et al. 2009, 2011). In this paper we compare 3 years of seine and tag—recapture data from prior to the severe cold event (2007 – 2009) to one year of data after the event (2010) to estimate the effects of the cold event on abundance of adult common snook on the spawning grounds.

During the summer spawning season from 2007 through 2010, adult common snook were sampled with seine nets along beaches of 3 barrier islands – Cayo Costa (12.4 km long), Upper Captiva (8 km), and Captiva (8.9 km) – between Boca Grande Pass and Blind Pass (Figure 1). Sampling occurred from May through September in 2007 and from May through August of 2008 through 2010. Sampling effort was similar among years and islands (Table 1).

Sampling procedures were carried out according to Adams et al. (2009). To summarize, sampling occurred between 0700 hrs (onset of suitable sunlight for sighting fish) and 1200 hrs. Sampling did not take place after 1200 hrs due to increase in the volume of human activity on beaches and water temperatures that reached stressful levels for common snook. Sampling occurred as conditions allowed – onshore winds or high surf prevented sampling, as did proximity of hurricanes – and did not focus on a particular lunar phase. On each sample day, the entire length of beach that could be sampled on each island (e.g., free of trees and other debris) was searched if time allowed. A shallow—draft boat was used to set seine nets around schools of common snook that were spotted along the beach. The procedure was to steer the boat along the beach and, when common snook were spotted, one end of the net was deployed off the back of the boat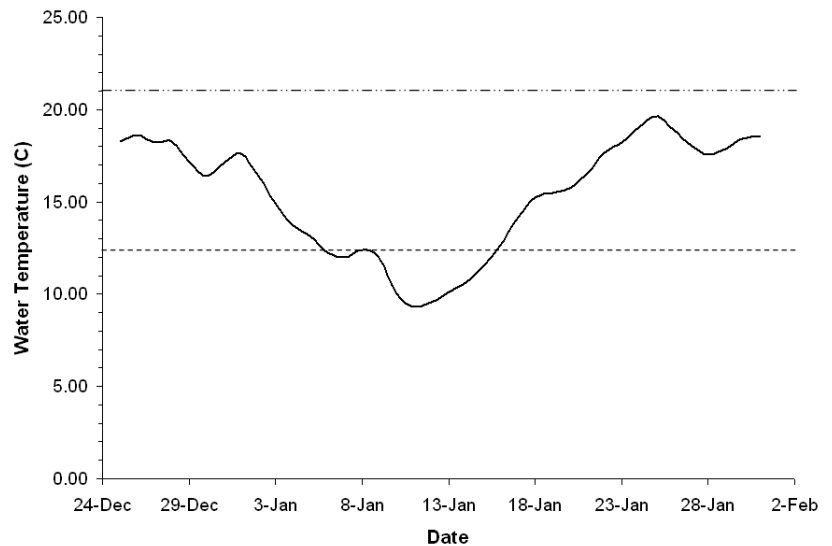 and the boat was used to set the net around the school. During summer, common snook are typically found within 2 m of shore, so this method is very effective. Three center—bag seine nets were used during this study: 91.44 m x 2.44 m with 19.05 mm mesh was used in 2007 and 2010; 182.88 m x 2.44 m with 15 mm mesh was used in 2007, 2008, 2009; and 152.40 m x 2.44 m with 35 mm mesh was used in 2007 and 2010. The nets were hauled onto shore, and the fish captured in the center bag. Once captured, the common snook were placed in mesh holding pens until tagged.

The number of samples per day ranged from one to 7 and depended on the number of common snook spotted and captured. For example, if a large number of common snook was captured in a sample, the time to measure and tag the fish reduced the amount of time available for more samples on that day. On days in which few common snook were spotted, the net was set 'blind' (i.e., set without seeing fish) to ensure samples were obtained on that day.

Tag—Recapture

Tagging. Prior to tagging, common snook were removed from the holding pens and placed in a cooler with a seawater and Alka—Seltzer mix (1–1.5 tabs/4 L seawater) to immobilize the fish. Once immobilized, a 23 mm HDX Passive Integrated Transponder (PIT) tag (TIRFID 2000, Texas Instruments) with a unique 16—digit identification number was inserted into the abdominal cavity through a 3 mm incision (*sensu* Adams et al. 2006). Additionally, during 2007 through 2009, common snook were also marked with external T—bar anchor or dart tags (Floy Tag and Manufacturing) to increase probability of angler recapture. Standard length (SL) in millimeters, PIT and external tag number, and latitude—longitude were recorded for each fish. After tagging, fish were

Figure 2. *January 2010 water temperature in Charlotte Harbor. Water temperature was averaged from hourly readings from 4 SCCF RECON sensors (Shell Point, Redfish Pass, Blind Pass, GOM; see Figure 1). The upper dashed line is the mean winter water temperature in Charlotte Harbor (21°C) and the lower dotted line is the lethal temperature threshold of the common snook (12.5°C).*

TABLE 1. *Number of sampling days by island and year.*

Island	Year				Total
	2007	2008	2009	2010	
Cayo Costa	12	7	8	15	42
Upper Captiva	13	7	13	15	48
Captiva	8	7	7	11	33
Total	33	21	28	41	123

placed in a recovery pen for about 5 minutes and released at the site of capture. Tagging experiments with juvenile snook reported low or no mortality (Adams et al. 2006), so post–tagging mortality in this study was assumed to be minor. Of the 3,315 snook tagged during this study, one post–tagging mortality occurred in the recovery pen. A necropsy was conducted and there were no apparent signs of injury due to tag insertion, disease or macro–parasitic infection.

Recapture. Recapture occurred by seine during tagging efforts along the GOM beaches of the barrier islands, and by recreational anglers using hook and line. During seine sampling and prior to tagging, all common snook were scanned with an Allflex ISO compatible RFID portable reader for PIT tags (model number RS601, Allflex). In addition, on numerous sampling days common snook were not tagged, and all captured fish were scanned for tags and released. For recaptures, SL, PIT tag number, and latitude–longitude were recorded and the fish were released. Three Allflex RFID portable readers were also distributed to local recreational fishing charter captains who frequently targeted common snook. If PIT tags were detected, the guides recorded location of the recapture, length of the fish and the PIT tag identification number. Only 3 PIT tagged common snook were recaptured by these charter captains. Recreational anglers who caught common snook with external tags reported the catch to the phone number listed on the tag, and provided tag identification number, length of the fish, and the location of capture.

Data Analysis

Three different metrics were used to compare pre– and post–cold event data: apparent survival, length–frequency, and catch (expressed as abundance). Apparent survival (1 – (mortality + emigration)) was calculated between each summer for n =3,275 marked fish (41 marks were found to be mislabeled in the tagging database, and therefore excluded from survival analysis). We combined marking information with recaptures from seine netting and angler recaptures near spawning grounds (n = 211: 189 seine net recaptures; 22 angler recaptures) from May to September and created a capture history for each marked fish. Capture histories were constructed on a yearly basis (2007, 2008, 2009, 2010), with fish being assigned a '1' in years they were marked or recaptured, and a '0' in years they were not seen. To analyze

the data, a Cormack–Jolly–Seber open population model (Cormack 1964, Jolly 1965, Seber 1965) was used in the computer program MARK (White and Burnham 1999). The Cormack–Jolly–Seber model calculates 2 parameters: (1) apparent survival probability (Φ = 1 – mortality – emigration), and (2) capture probability (p). Unique apparent survival values were calculated between each year in order to investigate the impact of the disturbance on survival of common snook that used the study area as spawning grounds. Capture probability was kept constant as the same sampling methods were used each year, which likely resulted in a nearly identical probability of capturing fish present during sampling. Lower survival between the summer of 2009 and the summer of 2010 as compared to previous years would indicate a significant effect of the severe cold event.

Fish length frequencies were $\log_{10}$ transformed and examined by year with ANOVA to determine whether snook size differed between pre– and post–cold event years. Abundance (number of common snook per 100 m of shoreline) was calculated as the number of individuals caught per day over the total length of beach sampled that day (length of net x number of sets). Combining all samples from a day reduced the problem caused by zero catches (especially high in 2010), which precluded reasonable statistical approaches. To determine whether the different nets resulted in different catch rates, we compared common snook abundance (number of snook per 100 m of shoreline sampled) for different nets used within the same year. The comparisons were: 91.44 m x 152.4 m in 2007 and 2010; 91.4 m x 182.8 m in 2008. There was no comparison of gears in 2009 because only the 182.8 m net was used. For each comparison, we used a one–way ANOVA on log transformed abundance (number of snook per 100 m of shoreline). If results were nonsignificant for each comparison, we combined abundance data from all nets for analysis. We used a two–way ANOVA to determine whether abundance differed by year and island, with a focus on whether abundance in 2010 differed from previous years on all islands.

Results

Samples were conducted over a total of 123 d during the 4 year study (Table 1). Abiotic parameters were well within requirements for common snook spawning in all years (Table 2). All metrics indicated a significant negative effect of the severe cold event.

The Cormack–Jolly–Seber apparent survival estimates for the first 2 years validate the model by aligning with the mortality estimates used in the most recent stock assessment for common snook (see Figure 4.3.2.3 in Muller and Taylor 2006). In this study, apparent survival dropped substantially from 0.45 (upper 95% Confidence Interval = 0.23, lower 95% CI = 0.21) and 0.65 (upper 95% CI = 0.26, lower 95% CI = 0.39) for the years prior to the cold event, to 0.01 (upper 95% CI = 0.05, lower 95% CI = 0.01) for the time period

TABLE 2. *Mean (± SE) of dissolved oxygen, water temperature and salinity recorded during net sampling from May through August of each year.*

Year	Dissolved Oxygen (mg/L)	Water Temperature (°C)	Salinity
2007	6.20±0.09	30.00±0.22	36.71±0.07
2008	5.80±0.11	29.96±0.28	35.63±0.03
2009	5.44±0.05	30.29±0.40	36.59±0.25
2010	5.46±0.06	29.84±0.09	34.66±0.06

encompassing the cold event (i.e., 2009 to 2010). The 96–97% decrease in apparent survival indicates that few common snook returned to the spawning grounds in the spawning season that followed the cold event. The significant difference in length by year (ANOVA on $\log_{10}$ transformed SL: $F_{3,3310}$ = 53.993, p < 0.001, Figure 3) was not associated with the cold event, but was instead due to a relatively larger size distribution in 2007, followed by a decrease in 2008 and 2009.

Results of gear comparisons were nonsignificant: 91.4 m x 152.4 m in 2007 (F = 0.516, p = 0.482); 91.4 m x 152.4 m in 2010 (F = 0.509, p = 0.48); 91.4 m x 182.8 m in 2008 (F = 0.11, p = 0.744) and thus abundance data were combined for all nets. There was a Year x Island interaction effect for the analysis of log transformed abundance (number of common snook per 100 m of shoreline) (Table 3). However, on all islands abundance was lowest in the year following the cold event when compared to previous years (Figure 4). Therefore, we focused on the abundance estimates for all islands combined. For all islands combined, non transformed abundance in 2010 was 75.57% and 41.88% lower than in 2008 and 2009. The Florida Fish and Wildlife Conservation Commission (FWC) Fisheries Independent Monitoring sampling program saw similar trends in multiple estuaries (Table 4) (FWRI 2010). In addition, one author (AJA) counted 1,132 dead, floating adult snook in a known wintering location (about 1 ha) at the end of the cold event. Conversations with numerous recreational fishermen suggested that some snook may have died during the weeks following the cold event; they reported seeing common snook with external lesions and fungal growth during this time period. Statewide data collected by FWC also indicated significant mortalities of other species, with more than 27 species reported killed on the FCW Fish Kill Hotline (http://research.myfwc.com/fishkill/), representing 21 families (see Appendix A).

DISCUSSION

The severe cold event of January 2010 had a major effect on common snook in southwest Florida. There was a 96–97% post–cold event decrease in apparent survival estimates and a 41.88% decline in nominal abundance from
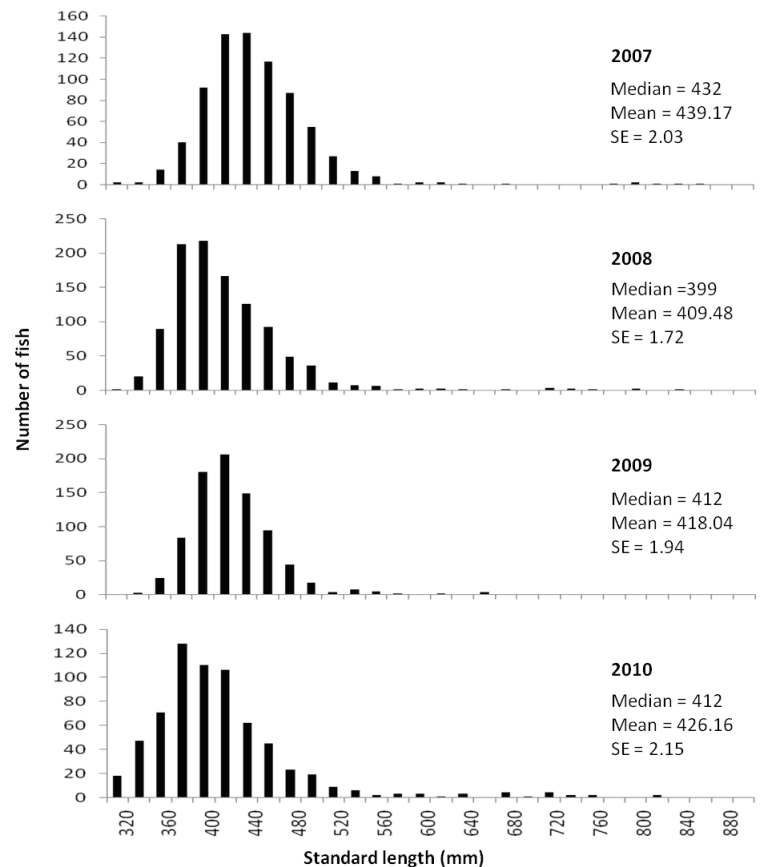

Figure 3. *Size frequency of common snook by year for all islands combined. SE = standard error.*

2009 and a 75.57% decline from 2008. The event appeared to affect all sizes classes sampled in spawning grounds similarly, suggesting a widespread effect on adults. That all of the metrics examined in this study show the same trend provides a compelling argument for a strong negative effect of the cold event. Moreover, although the estimates of abundance are somewhat confounded by an increase in blind sets in the post–disturbance year, this in itself is a strong indicator of the extremely low abundance of common snook after the cold event.

The clumped distribution of common snook on spawning grounds during the spawning season likely biased our data toward underestimating abundance declines, suggesting that even though we found a major effect, our findings are likely conservative. This is because analyzing abundance based on aggregating fish can be misleading as the numbers are prone to hyperstability (Sadovy and Domeier 2005). Hyperstability occurs with fish that commonly aggregate, because an aggregation that is repeatedly targeted or sampled continues to result in high catches even though the overall abundance may have declined. The northern cod, *Gadus morhua*, fishery, for example, had an increasing catch–per–unit–effort while, in fact, the population was being overfished for decades (Rose and Kulka 1999) because of this bias.

TABLE 3. *Summary of a two-way ANOVA by year and island on $\log_{10}$ transformed abundance.*

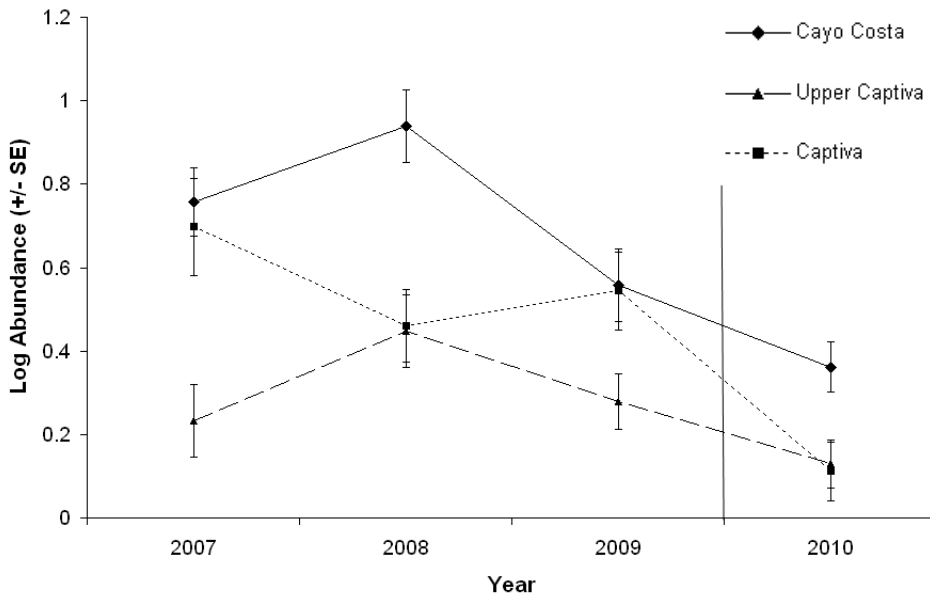| Source	SS	df	MS	F	P
Year	3.134	3	1.045	19.529	< 0.001
Island	2.565	2	1.283	23.979	< 0.001
Year x Island	0.851	6	0.142	2.65	<0.05
Error	5.082	95	0.053		

Figure 4. *Log abundance (number of common snook per 100 m of shoreline) by year and island. Values are means ± standard error. There was a significant year x island interaction effect (Table 3), but this interaction was not associated with the cold event. The vertical line between 2009 and 2010 indicates the occurrence of the severe cold event.*

It is not possible to partition mortality and emigration in the calculation of apparent survival for this study, so we suggest two possible causes for the decline in common snook abundance on spawning grounds – lethal and sublethal effects. In either case, the cold event caused a severe reduction in abundance of common snook on spawning grounds in the year following the cold event.

We suggest that lethal effects resulting from thermal stress from the severe cold was the primary cause of the decline of adult common snook on spawning grounds. Immediate lethal effects likely occurred for common snook when water temperature dropped below their lower thermal limit (12.5°C) for 10 d, leading to cellular functions ceasing and, ultimately, mortality. Although it is possible that some common snook found thermal refuges (e.g., freshwater springs of constant temperature) in which the water temperature did not reach lethal levels, reports of dead common snook were frequent and widespread during and immediately following the cold event, indicating extremely high, immediate lethal effects. The data from the FWRI (2010) report also support the argument that lethal effects were the dominant cause for the observed decline in common snook abundance on spawning grounds. It is also likely that the ability of common snook to avoid predators (sharks, dolphins, birds) was also compromised; when declining water temperatures approach the lethal limit of 12.5°C, common snook become very lethargic and lose some of their mobility, thus making them more susceptible to predation. Finally, delayed lethal effects, such as reduced immune response due to stress, may have also contributed to common snook mortalities caused by the

cold event.

A probable secondary cause of adult common snook abundance decline on spawning grounds was sublethal effects. Sublethal effects occur when fish survive a stressful event, but experience reduced fitness that impairs processes such as spawning. In this scenario, surviving common snook most likely utilized available resources to fortify their immune systems, contribute to somatic growth, and to counter other stress–related effects that impacted their reproductive fitness (Schreck et al. 2001). This leaves fewer resources to allocate to spawning, which can result in no or a severely reduced spawning season for these individuals (McCullough et al. 2001). The scenario of skipping a spawning season is somewhat likely for common snook as even in normal years only a portion of the mature population spawns (Blewett 2009). Similarly, individuals of barramundi, *Lates calcarifer*, a Pacific species with a similar life history, do not spawn in every year (Milton 2005). Spawning can be a stressful event for fishes resulting in death for individuals of some species (e.g., Pyron and Beitinger 1993), and progeny of physiologically stressed fishes are often deformed or have low survival (McCullough et al. 2001). Therefore, investing in somatic rather than gonadal growth may be an effective bet–hedging strategy for the common snook, especially following a disturbance.

Alternatively, the observed decline in common snook abundance on spawning grounds may have been caused by common snook moving to other locations. For example, it might be argued that abiotic conditions on the spawning grounds in the year following the cold event may not have been suitable for spawning. During this study, however, water temperature, salinity and dissolved oxygen on the GOM beaches during the summer months following the severe cold event had little variation and were within the required

TABLE 4. *Catches of common snook,* Centropomus undecimalis, *by Florida Fish and Wildlife Conservation Commission Fisheries Independent Monitoring program for 4 estuaries. See Figure 1 for locations. Values are total number of common snook captured during January through June of each year.*

Year	Tampa Bay	Charlotte Harbor	North Indian River Lagoon	South Indian River Lagoon
2008	639	223	190	341
2009	347	123	144	449
2010	90	28	30	154

physiological range of common snook (Table 3; Peters et al. 1998), so were not likely factors influencing the decrease in abundance of the common snook on the summer spawning grounds. In addition, since we sampled 28 km of coastal beach habitat, we would have detected long–distance movement as well as any tendency toward increased dispersal over time or with fish size. Even if common snook dispersed to other spawning locations outside the study area, for example, if such movement was common it would have also resulted in movements among islands sampled in this study, but such movement was rare.

It is also possible that common snook that previously spawned along beaches moved offshore to spawn in the year following the cold event. Common snook apparently also spawn on offshore reefs (Taylor et al. 1998), habitats which were not sampled in this study. However, if this occurred, this would still be considered a major effect of the cold event in that the location of spawning changed dramatically for a large portion of the adult population. This is significant because hydrodynamic conditions affecting larval distribution would differ between the beach spawning grounds and purported offshore locations. One would expect a spawning site to, on average, provide larvae to a particular location, thus connecting specific spawning and nursery habitats. If this area contains suitable nursery habitat, then that spawning location can expect some reproductive success. On the other hand, if the larval settlement area contains no or poor quality nursery habitat, then reproductive success of that spawning site will be low. Therefore, under this scenario, a change in spawning location might impact recovery due to a change in coastal habitats that receive common snook larvae.

The decline in common snook abundance from 2008 to 2009, prior to the disturbance, might indicate that other factors are influencing regional populations. However, the extensive reports of region–wide common snook mortalities associated with the cold event, reports from recreational fishermen of low common snook catch rates in the year af-ter the cold event, and the rather dramatic decline in abundance in the year following the cold event suggest that the disturbance effect was severe even in the context of a possible longer term trend of population decline. If other factors are also influencing common snook abundance over the longer term, these factors may synergistically interact with the disturbance to affect the recovery trajectory of the common snook population.

Infrequent, severe cold disturbances recur regularly in subtropical southwest Florida, with published reports of cold–related fish kills from as early as the 1800's (e.g., Storey 1936, Galloway 1941). More recently, notable cold disturbances occurred in 1977 (Gilmore et al. 1978, Bohnsack 1983) and throughout the 1980's (Miller and Downtown 1993), though not all appear to have impacted fishes. However, these events generally occur infrequently enough that the common snook population has been able to recover to pre–event levels before the next cold event occurs (Storey and Gudger 1936).

Since common snook exhibit nearly 100% site fidelity to spawning grounds (Adams et al. 2009, 2011), there may be spawning–based population segregation that effectively creates numerous smaller spawning populations distributed along the coastline, which may affect recovery. Too few tagged common snook were recaptured in 2010 to determine whether the disturbance altered their site fidelity behavior, but continued study of the response to this disturbance would address that issue. Spawning site fidelity may slow recovery from disturbances; the slower than expected response of Atlantic cod may be in part due to a greater degree of spawning segregation than had been recognized, because site fidelity impedes recolonization of spawning grounds (Robichaud and Rose 2001). The degree to which this will occur is likely linked to the type of spawning site fidelity exhibited by common snook (philopatry, spawning–group fidelity, or socially learned fidelity). As this mechanism is of yet unknown for common snook it should be a focus for future studies.

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APPENDIX A. List of fishes killed by the January 2010 cold event reported to the Florida Fish and Wildlife Conservation Commission Fish Kill Hotline (http://research.myfwc.com/fishkill).

Family	Species
Elopidae	*Elops saurus*
Megalopidae	*Megalops atlanticus*
Albulidae	*Albula* spp.
Clupeidae	unidentified
Ariidae	unidentified
Mugilidae	*Mugil* spp.
Atherinidae	unidentified
Belonidae	unidentified
Serranidae	*Epinephelus* spp.
	Mycteroperca spp.
Carangidae	*Caranx hippos*
	Seriola dumerili
	Trachinotus carolinus
	Trachinotus falcatus
Lutjanidae	unidentified
Gerreidae	*Diapterus plumieri*
Haemulidae	unidentified
Sparidae	*Archosargus probatocephalus*
	Lagodon rhomboides
Sciaenidae	*Cynoscion nebulosus*
	Sciaenops ocellatus
Pomacanthidae	unidentified
Scaridae	unidentified
Sphyraenidae	*Sphyraena barracuda*
Ostraciidae	unidentified
Tetraodontidae	unidentified