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Behavior and mortality of caught-and-released bonefish (*Albula* spp.) in Bahamian waters with implications for a sustainable recreational fishery

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Abstract

Bonefish (*Albula* spp.) are a widely distributed group of morphologically indistinguishable marine fish species, that provide a recreational sport fishery, that is important for many local economies. Although the majority of angled bonefish are released following capture, little is known about their behavior or post-release survival. Using ultrasonic transmitters and small visual floats, we assessed behavior and mortality of bonefish following catch-and-release angling at spring water temperatures (25.5–27.3 °C) in two regions of the Bahamas with differing shark abundances. All observed mortality occurred within 30 min of release and was a direct result of predation by sharks. In the low shark abundance areas, all released bonefish survived, whereas in the high shark abundance areas, some mortality (39%) was observed. Exhaustively angled fish exposed to air had problems maintaining equilibrium following release. These fish typically spent substantial periods of the first 30 min post-release remaining stationary, then moved in rapid bursts. The results of this study, highlight the benefits of angling and releasing bonefish quickly, minimizing handling and particularly air exposure. Furthermore, when shark predation threat is high, anglers should avoid releasing bonefish in the immediate area. The conservation of exploited recreational bonefish fisheries will depend upon the development and dissemination of science-based catch-and-release strategies.

Keywords: Bonefish; Recreational fishery; Catch-and-release; Behavior; Mortality; Conservation; Predation

1. Introduction

Over the past several decades, there has been an explosion in the literature on the effects of catch-and-release angling on freshwater species, including assessments of injury, physiological disturbance, mortality and fitness impairments (e.g., Muoneke and Childress, 1994; Wilde, 1998; Cooke et al., 2002). Many marine fish also support important recreational angling industries that provide substantial benefit to local economies. It is surprising, therefore, that few studies have examined the biological effects of catch-and-release angling practices on marine fisheries (Edwards, 1998; Taylor et al., 2001; Cooke et al., 2002). Bonefish (*Albula* spp.) are a widely distributed group of tropical marine fishes that occupies shallow coastal and inshore habitats (Alexander, 1961). Until recently, bonefish were considered to be a single species (*Albula vulpes*), however, new molecular genetic information indicates that there are at least eight morphologically indistinguishable, but genetically distinct species (Colborn et al., 2001). We will use the term bonefish to represent all *Albula* spp. in aggregate. Anglers target bonefish using both spin and fly fishing gear (Kaufmann, 2000; Samson, 2001). Bonefish are admired by anglers for their wariness, as well as, their strong swimming ability and as such, form specialized recreational fisheries important for many regional and national economies (McIntosh, 1983; Mojica et al., 1995).

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In the state of Florida alone, bonefish recreational fisheries are valued at approximately several billion US dollars per anum through direct and indirect expenditures (Humston, 2001).

Although bonefish are consumed opportunistically by locals (usually captured in nets), in the recreational fishery most fish are released alive after capture. In fact, in certain areas rates of release following capture by recreational anglers are thought to approach 100% (Humston, 2001). There is mounting evidence, however, that at least some local populations are experiencing substantial declines in abundance and shifts in size structure resulting in conservation concerns (Bruger and Haddad, 1986; Anon, 2001; Ault et al., 2002). Because, release rates are high, it is presumed that changes in local abundance are due to other factors such as habitat degradation or overharvest by artisanal fishers. Because, bonefish fight themselves to exhaustion, they are often in poor condition at time of release and this fact raises questions about the behavior and survival of fish post-release. Only one study has examined the effects of catch-and-release angling on injury and mortality of bonefish (Crabtree et al., 1998). These authors provide good information on the mortality, that results to bonefish from injury and physiological disturbance of bonefish, but only in an artificial lagoon and in the absence of predators. There is no information on the effects of catch-and-release angling on bonefish in the wild and in the presence of predators.

In marine systems mortality resulting from predation can represent a large component of the mortality following catch-and-release angling (e.g., Atlantic sailfish, *Istiophorus platypterus*, Jolley and Irby, 1979; tarpon, *Megalops atlanticus*, Edwards, 1998). Numerous marine predators occupy habitats similar to bonefish, including barracuda, *Sphyraena barracuda*, lemon shark, *Negaprion brevirostris*, black tip reef shark, *Carcharhinus limbatus*, nurse shark, *Ginglymostoma cirratum*, tiger shark, *Galeocardo cuvier* and bonnet head shark, *Sphyrna tiburo*, all of which are known on occasion to consume bonefish (Hess, 1962; Gruber et al., 1988; Wetherbee et al., 1990; Castro, 2000). Although Colton and Alevizon (1983a), noted that following intraperitoneal implantation of ultrasonic transmitters, bonefish survived if they were not released in the immediate vicinity of sharks, the magnitude and source of this catch-and-release angling-induced predation has not been assessed.

This study was conducted in response to concerns over the sustainability of bonefish populations in the face of expanding recreational fishing in the Bahamas. Our objective was to characterize the injury, post-release behavior and levels of predation of angled bonefish. Our results are intended to provide direction to anglers, fishing guides and resource managers for minimizing mortality that can result from catch-and-release angling, a possible conservation issue associated with bonefish sustainability in the Bahamas and elsewhere.

2. Materials and methods

2.1. Study sites

This study was conducted at two sites within the Bahamas. The first site was a tidal flats lagoon referred to as Pigeon Creek, located in the southeast corner of San Salvador (24°1′ 60N, 74°31′ 0W). The tidally influenced lagoon had a central channel that was ~1–3 m deep. Dense mangroves (predominantly red mangrove, *Rhizophora mangle* and black mangrove, *Avicennia germinans*) lined the many smaller branches of Pigeon Creek. Extensive sand and silt flats with sparse grass (principally turtle grass, *Thalassia testudium* and shoal grass, *Halodule wrightii*), provided substantial amounts of habitat used by bonefish for feeding. A visual survey (on foot and by boat) in March 2000 determined that Pigeon Creek had low densities of predators that were able to consume bonefish. The potential predators that were observed in Pigeon Creek included barracuda, lemon shark and nurse shark. Additional details on this site are given elsewhere (Diehl et al., 1988; Boardman and Carney, 1996).

The second site were the waters off the southeast tip of Grand Bahama Island in the vicinity of Deep Water Cay (26°37′ 0N, 77°55′ 0W). The region was composed of numerous cays with tidal creeks and harbors extending between closely aligned cays (with deeper channels in the center) and, shallow flats surrounding smaller, more diffuse and distant cays. The creek regions were characterized by mangrove lined banks with grasses (principally turtle grass and shoal grass) sparsely distributed over shallow sand substrates. The sand flats surrounding all cays were covered with patchy regions of turtle grass interspersed with deeper cuts. Consultation with staff of the Deep Water Cay Club prior to choosing this study site revealed that it had reasonably high densities of bonefish predators including good populations of barracuda, lemon shark, black tip reef shark, nurse shark, tiger shark and bonnet head shark. Additional detail on this study site can be found in Colton and Alevizon (1983b). Water temperatures at both study sites ranged between 25.5 and 27.3 °C during the study period.

2.2. Fish capture and handling

Bonefish at Pigeon Creek were angled by wading or from a canoe and at Deep Water Cay by wading or from a guided flats boat. Anglers used a variety of medium action spinning gear (2.7–4.5 kg (6–10 lb) line) and fly fishing gear (7–9 weight rods). Fly anglers used flys in crab imitation, crazy Charlie, or pink puff patterns on barbed conventional hooks. Spin anglers used small 7 g (1/4 oz) jigs with soft plastic or bucktail bodies for lures or 3/0 straight shank hooks with dead shrimp as bait.

For each bonefish angled, the duration of the angling event (to the nearest 15 s), the number of sharks observed during the angling event and the time that the fish was held out of water were recorded. At San Salvador, fish were held by hand in water at the site of capture for attaching visual tags or placed in 40 l coolers in the canoe for implanting transmitters. At Deep Water Cay, for the safety of both anglers and fish, all fish were held in 40 l coolers in the boat following capture. The anatomical location of the hook and presence/absence of bleeding was determined and fish were measured (total length in cm). Captured bonefish were then either affixed with a visual tag to monitor short-term release behavior and survival for up to 1 h or implanted with acoustic transmitters to monitor longer-term release behavior and survival for 24 h.

2.3. Visual tagging

Because bonefish reside in shallow environments, we were able to use small visual markers to monitor immediate post-release behavior. For this, captured fish were held by hand in the water (San Salvador) or in a 40 l cooler (Deep Water Cay) and a curved suture needle and monofilament nylon line (1–2 m long, 0.9 kg (2 lb) test line) was used to attach a small oval colored styrofoam float to the soft tissue portion of the posterior origin of the dorsal fin. For up to 1 h following release, observers collected detailed notes on the behavior of the fish and its habitat use (classified broadly as sand flat, channel, or mangrove). Stopwatches and maps were used to estimate rates of movement and distance traveled during that period. We also recorded the depth at which the fish was captured and released (to nearest 0.1 m) and the distance to the nearest shore (to nearest 5 m). We also recorded the total distance the fish had moved in the first 30 min and, the duration within that 30 min period that the fish was stationary.

2.4. Ultrasonic telemetry

Although the visual tags were useful for determining short-term behavior and survival (i.e., up to 1 h), longer-term assessment of movement and survival required the use of ultrasonic transmitters. Because, we wanted to minimize handling disturbance immediately following catch-and-release angling, we chose to use forced intragastric transmitter implantation, a technique recognized as one of the most viable and least obtrusive for short-term studies of catch-and-release (e.g., Bendock and Alexandersdottir, 1993) and, one that had been used previously on bonefish (Colton and Alevizon, 1983a). This method of implantation does not produce drag and places the transmitter near the fish's center of gravity. Furthermore, the procedure can be completed rapidly and without anesthetic, resulting in minimal handling and expedient recovery (Winger and Walsh, 2001). We used two types of gastrically implanted ultrasonic transmitters for this study (a V8SC-6L continuous pinger, 3.1 g in air, 22 × 9 mm and a V8-2L 12 h duty cycle pinger, 6.0 g in air, 40 × 9 mm; both made by Vemco Inc., Shad Bay, NS). Both types were encased in epoxy packages with plasti-dip (Plasti-Dip International, Blaine, MN) covering the activation wires and both broadcast at frequencies ranging from 63.0 to 84.0 kHz. The 12-h duty cycle transmitters were set to emit pulses from 07:00–19:00 daily.

For implantation, smooth plastic tubes with inner diameters sized to that of the transmitter were gently pushed down the esophagus until the end of the tube was within the stomach. A plunger was used to expel the transmitter from the tube and into the stomach (Mellas and Haynes, 1985). The tube and plunger were withdrawn, leaving the transmitter within the stomach. The entire procedure generally required less than 30 s and could be accomplished while keeping the body of the fish underwater in the cooler. Following their release, transmitter-implanted fish were located using a wide band manual tracking receiver (USR-5W, Sonotronics Inc., Tucson, AZ) and a directional hydrophone (DH-4, Sonotronics Inc., Tucson, AZ) mounted on a piece of PVC pipe (1.25 m long, 2.4 cm diameter). At San Salvador, fish were tracked on the shallow flats carrying the tracking gear on foot or in the deeper water by canoe. Fish were followed for up to 1 h post-release and then located 24 h later. Habitat use and behavior was monitored as described for visual tags, except that measurements of habitat and distance from release were made for transmitter-implanted fish 24 h post-release. Fish were located visually to determine if they were still alive or were being digested by predators.

2.5. Data analysis

We used *t*-tests to assess differences in continuous variables among the two study sites and the two possible fates of released bonefish. Similar comparisons on categorical data were conducted using contingency table analyses. Where appropriate, we also used logistic regression and one way analysis of variance. Linear regression was used to evaluate the relationship between two continuous variables. All analyses were conducted using JMPIN V. 4.0 (SAS, Inc.). Test results were interpreted using $\propto = 0.05$ and values presented are means (±1 SE).

3. Results

3.1. Capture characteristics

In total, we landed 35 fish that were used for this study ($N = 17$ at San Salvador; $N = 18$ at Deep Water Cay). Six fish at each site were implanted with ultrasonic transmitters, the remaining fish were affixed with visual float tags. The mean total length of all bonefish captured and released at San Salvador (51.2 ± 1.4 cm) was similar ($t = -0.51$, $p = 0.614$) to those at Deep Water Cay (50.2 ± 1.4 cm). Of the 35 fish captured in this study, 38% were hooked in the lower lip, 59% in the upper lip and 3% in the tongue. Because none of these locations are vital organs, very little bleeding was observed. Of the 17% that did exhibit some bleeding, none was considered to be potentially lethal.

Comparing the two sites, there was no significant difference in the time that it took to land bonefish once they were hooked ($t = -1.32$, $p = 0.195$). At Deep Water Cay, there was a positive relationship between the size of the fish and the duration of the angling event ($F = 10.13$, $p = 0.006$, $R^2 = 0.388$). At San Salvador, however, there was no significant relationship between the size of the fish and the duration of the fight ($F = 0.75$, $p = 0.399$, $R^2 = 0.048$). Air exposure times were significantly longer at San Salvador than at Deep Water Cay ($t = -5.91$, $p < 0.001$). Combining the angling duration and air exposure duration resulted in significantly longer total handling times at San Salvador (269 ± 20 s), than at Deep Water Cay (169 ± 16 s) ($t = -3.87$, $p < 0.001$). As a result of the protracted handling, which included more exposure to air, most fish (77%) at San Salvador had problems maintaining equilibrium following release, whereas only one (6%) at Deep Water Cay had that problem ($X^2 = 16.70$, $p < 0.001$). Logistic regression analysis revealed that chances of losing equilibrium increased when total handling times exceeded ~180 s ($X^2 = 22.82$, $p < 0.001$).

3.2. Post-release behavior

After initially swimming away from the angler, most released fish at San Salvador (some of which had lost equilibrium and required revival by hand) stopped often for extended periods to rest. Most released fish at Deep Water Cay (after spending some recovery time in a cooler of water) swam away immediately and more steadily. The distance travelled by bonefish in the first 30 min after release at San Salvador (357 ± 56 m) was similar to that for bonefish released at Deep Water Cay (263 ± 34 m; $t = -1.32$, $p = 0.202$; Fig. 1(a)). Bonefish at San Salvador, however, spent more of the initial 30 min following release resting in a stationary position (11.3 ± 2.1 min) compared to bonefish at Deep Water Cay (1.8 ± 1.4 min; $t = -3.54$, $p = 0.002$; Fig. 1(b)). During the first 30 min following release, when bonefish were not stationary, they swam faster at San Salvador ($N = 12$, 0.70 ± 0.13 bl/s), than at Deep Water Cay ($N = 9$, 0.29 ± 0.11 bl/s; $t = -2.46$, $p = 0.024$; Fig. 1(c)).

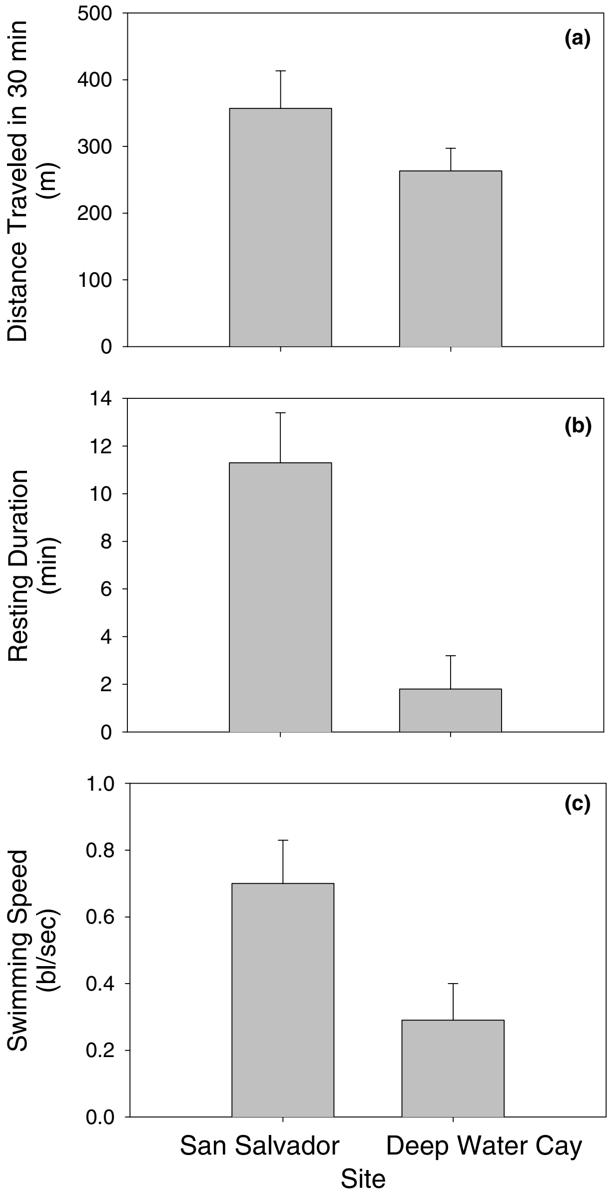

Fig. 1. Release behavior of bonefish at Pigeon Creek, San Salvador and Deep Water Cay. (a) Distance moved in the first 30 min of release. (b) Resting duration expressed as the number of minutes resting during the first 30 min of release. (c) Swimming speed of bonefish during the first 30 min after release during periods of time that the fish were not resting in a stationary manner. Data are visualized for both transmitter and visual tag fish, however, only those monitored for at least 30 min.

Even 30 min after release, most bonefish at both San Salvador and Deep Water Cay were located within 300 m of the release site (Fig. 2). Using ultrasonic transmitters to locate bonefish 24 h after release, we observed that most fish at San Salvador were still generally located near the release site. Interestingly, one individual

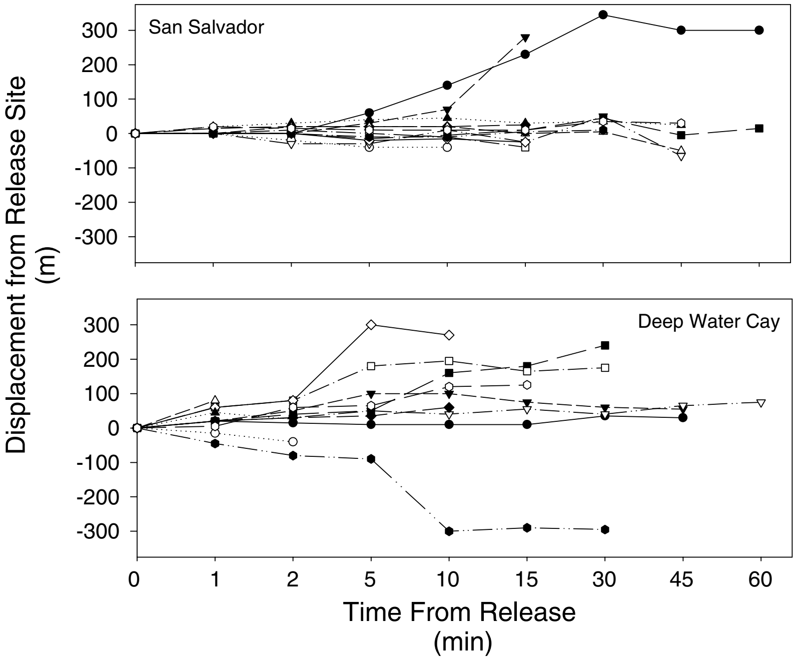

Fig. 2. Displacement of bonefish affixed with visual floats from release site at Pigeon Creek (upper panel) and the waters adjacent to Deep Water Cay (lower panel). Fish were monitored from periods ranging from 2 to 60 min. Location of release was set as (0) and fish movements that resulted in a net upstream or downstream movement are plotted.

moved upstream 3.2 km to the head of the tidal inlet, but by 48 h after release, that fish had returned to the release site vicinity. At Deep Water Cay, excluding two fish that were attacked and consumed by sharks shortly after release, released bonefish made short-term movements similar to those we observed at San Salvador. With the exception of 1 fish that moved 2400 m, the distance moved by fish implanted with transmitters 24 h after release was similar for fish at San Salvador ($N = 6$, 493 ± 383 m) and Deep Water Cay ($N = 4$, 175 ± 46 m; $t = -0.66$, $p = 0.527$).

At Deep Water Cay, for short-term recovery released bonefish used habitats similar to those in which they were captured and released ($X^2 = 0.89$, $p = 0.344$). At San Salvador, there was also no difference in habitat type used for short-term recovery and the habitat where they were caught and released, however, the test was only marginally nonsignificant ($X^2 = 9.14$, $p = 0.058$). At Deep Water Cay, the habitat type where fish were captured was similar to the habitat type where they were located 24 h after release (100% flats in both instances). The habitat type where fish were captured in San Salvador, was also similar to the habitat type where they were located 24 h after release ($X^2 = 3.82$, $p = 0.148$).

3.3. Predation during the angling event

The predator abundance was quite different at the two different study sites. During the 204 h spent angling at San Salvador only 12 sharks (0.059 sharks/h) and 18 barracuda (0.088 barracuda/h) large enough to attack bonefish were observed. At Deep Water Cay, however, during the 126 angling h spent angling 184 sharks (1.46 sharks/h) and 8 barracuda (0.064 barracuda/h) large enough to attack bonefish were observed. While on the line, none of the 17 bonefish (0%) landed at San Salvador was attacked by sharks. Consistent with this, no sharks were observed in the immediate vicinity during the time that any of the fish were on the line. Two of the 33 bonefish (6%) hooked at Deep Water Cay, however, were attacked by lemon sharks while they were on the line. In addition, when bonefish were actually on the line, sharks were observed frequently by anglers (3.2 sharks observed per bonefish landed), significantly more so than was observed at San Salvador ($t = -5.61$, $p < 0.001$).

3.4. Predation following release

All 17 bonefish caught and released at San Salvador (with visual tags and transmitters) were still alive after 30 min. In addition, the six bonefish implanted with transmitters ($N = 6$) were all still alive after 24 h (Fig. 3). In contrast, at Deep Water Cay, two of the six bonefish implanted with ultrasonic transmitters and, five of twelve fish monitored with visual markers were attacked by lemon sharks shortly after release (Fig. 3). Significantly more fish were eaten in Deep Water Cay (39%), than in San Salvador (0%) ($X^2 = 10.97$, $p < 0.001$). Most fish were attacked within the first few

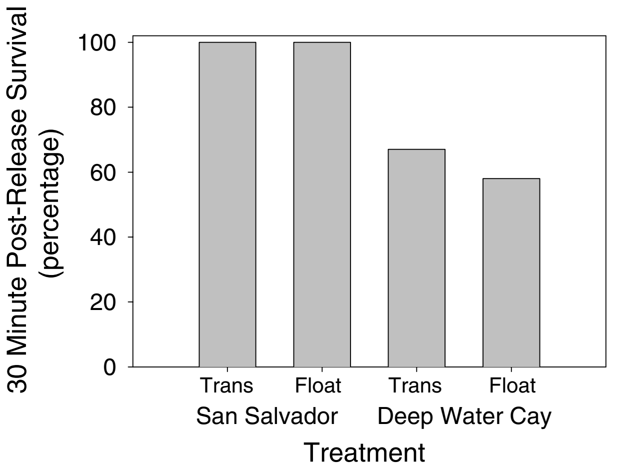

Fig. 3. Rates of survival for bonefish captured and released in regions of the Bahamas with low shark predation threat (Pigeon Creek, San Salvador) and high shark predation threat (waters adjacent to Deep Water Cay) 30 min after release. Data are visualized for fish gastrically implanted with ultrasonic transmitters ($N = 6$ at each site) and affixed with visual tags ($N = 11$ at San Salvador, $N = 12$ at Deep Water Cay). All mortality was observed within this 30 min period.

minutes after release. Not surprisingly, at Deep Water Cay there were significantly more sharks (5.0 ± 0.7) observed while angling those fish that were eaten than for those fish that survived (2.1 ± 0.6 sharks; $t = 3.14$, $p = 0.006$).

Levels of bleeding observed at Deep Water Cay differed significantly between fish that lived (33% bleeding) and those that were eaten (67% bleeding; $X^2 = 9.93$, $p = 0.002$). Although non-significant ($t = -1.17$, $p = 0.259$), there was a trend towards more sharks being observed upon releasing bleeding bonefish (4.4 ± 2.0 sharks), than non-bleeding individuals (2.9 ± 0.5 sharks). There was also no significant difference between the total length of fish that were attacked by sharks at Deep Water Cay (47.6 ± 2.2 cm) and, those that were not (51.5 ± 1.1 cm; $t = -1.64$, $p = 0.111$), although there was a trend towards those that died being smaller. There were no significant differences in angling duration ($t = -0.77$, $p = 0.449$), air exposure duration ($t = -1.19$, $p = 0.253$) and total handling time ($t = -1.05$, $p = 0.310$) between bonefish at Deep Water Cay that survived (angle, 150 ± 17 s air; 33 ± 8 s; total, 183 ± 24 s) and those attacked by sharks (angle, 129 ± 17 s, air, 19 ± 5 s, total, 148 ± 18 s).

4. Discussion

To date, only one other study has examined the effects of catch-and-release angling practices on bonefish (Crabtree et al., 1998). In that study, bonefish were held in a large lagoon with no large predators and repeatedly captured by rod and reel using baited hooks. Mortality rates were only 4.1% despite the fact that some fish were released as many as 10 times. The authors attributed those instances of mortality to the cumulative effects of repeated catch-and-release events and suggested that these mortality rates were, therefore, inflated. Although reducing the low level of mortality that results from hooking injury or physiological disturbance at intermediate water temperatures may not be critical, minimizing sublethal physiological disturbances and releasing fish in suitable conditions to avoid predators may be important.

Because bonefish are such strong swimmers (Colton and Alevizon, 1983a) and so wary, it is unlikely that under normal, non-angled conditions bonefish would be easy prey for sharks. Sharks may only feed opportunistically on injured, or otherwise impaired bonefish that are not capable of out-swimming sharks for extended periods of time. Sharks have a series of specialized sensory adaptations that make them extremely efficient at locating injured prey (Bleckmann and Hofmann, 1999). Only when a bonefish is on the line and unable to swim away from the shark, separated from other individuals, exhausted, or in an impaired state due to handling and air exposure is the shark able catch and consume bonefish easily. In our study, all of the mortality that we observed was due to predation by sharks. The degree of exhaustion (Gustaveson et al., 1991; Kieffer, 2000; Schreer et al., 2001; Thorstad et al., 2003) and duration of air exposure (Ferguson and Tufts, 1992; Cooke et al., 2001) are known to influence the magnitude of physiological disturbance, recovery rates and potential for mortality following angling. At San Salvador, where the shark predation pressure was low, even those bonefish that were extremely exhausted (as evidenced by a loss of equilibrium) all survived the post-release monitoring period. Following release, many of the bonefish at San Salvador spent substantial periods of time in stationary positions. Although located close to cover, but still potentially vulnerable to sharks, no shark attacks were observed.

Because of the greater abundance of sharks at Deep Water Cay, we processed fish in coolers inside the flats boats. This procedure resulted in less air exposure during handling and consequently, the fish were less exhausted when they were released. Despite the fact that all but two of the fish were exposed to air for less than 1 min, nearly 40% of the bonefish released at Deep Water Cay were dead from shark attacks within the first hour of release. We only observed two instances in which sharks were in the immediate vicinity and released bonefish were able to evade capture. In the first instance, we created splashing disturbances around the boat to distract the predator. We also did this with no apparent benefit for all releases when sharks were present near the boat. In the second instance, because the largest bonefish we captured was exhausted, it was revived manually in the water prior to having to evade capture by a lemon shark, that came into the vicinity. In this case, the size of the fish combined with the revival may have allowed it to swim more rapidly than the shark. This large transmitter-implanted bonefish was observed feeding with conspecifics 24 h after capture and release. Although not significant, we did observe a strong trend towards smaller fish being attacked more frequently than larger fish which may reflect the ability of larger fish to evade predators more effectively.

Previous studies of post-release behavior have reported a variety of different behaviors ranging from occupying the general release site for an extended period (i.e., days to weeks, smallmouth bass, *Micropterus dolomieu*, Bunt et al., 2002) to leaving the release site immediately and traveling long-distances (e.g., Atlantic salmon, *Salmo salar*, Whoriskey et al., 2000). In our study, most bonefish stayed within ~300 m of the release site. At San Salvador, where handling times were greater, bonefish spent substantial periods not moving, usually resting adjacent to mangroves. At Deep Water Cay, released bonefish spent very little time stationary and engaged in more slow, but steady swimming. It is not possible to determine whether this difference was due to the fact that the bonefish at Deep Water Cay were in better physiological condition, due to the abundance of sharks and the risks associated with remaining stationary, or due to intra- or inter-specific variation (e.g., Nelson et al., 1994). However, the erratic behavior of fish at San Salvador (i.e., swim away quickly, then rest) is most likely indicative of hyperactivity, a phenomenom previously observed in other species following extreme catch-and-release angling related disturbances (e.g., Black, 1958; Cooke et al., 2000). An alternative explanation is related to predation risk and availability of resting habitat. At San Salvador, bonefish may have been swimming quickly to locate suitable resting habitat and would traverse more risky habitat rapidly resulting in elevated swimming speeds. Bonefish at Deep Water Cay were in better condition, because, they were handled for less time and were kept in a cooler of water while in the boat. Furthermore, because abundance of sharks was higher at Deep Water Cay, their best strategy to avoid predation may have been to rejoin the feeding aggregations to diffuse the risk of predation during recovery. Indeed, six of the twelve bonefish affixed with visual float tags joined/rejoined aggregations within the first hour following release.

Crabtree et al.'s (1996) estimated range for total mortality including natural and angler-generated mortality (0.2–0.3) suggested that little of this mortality resulted from commercial and/or recreational harvest in the Florida Keys. Furthermore, because total mortality was low, the authors concluded that the mortality rate for caught-and-released bonefish was also low. Shark attacks on angled fish will likely elevate total mortality rates in regions where sharks are abundant; indeed, the abundance of sharks may also elevate natural mortality rates as well. Although harvest rates for bonefish may be extremely low, our research suggests that mortality arising from catch-and-release angling could be substantial. Future assessments of bonefish populations must therefore account for this source of mortality when developing management and conservation strategies if recreational angling for bonefish is to be a sustainable activity.

5. Conclusion

The results of our study suggest that there are opportunities for anglers, guides, resource managers and conservationists to enhance the sustainability of recreational bonefish angling. The material presented here can serve as a starting point for the development of species-specific catch-and-release guidelines (see Cooke and Suski, in press) for bonefish. Species-specific guidelines for catch-and-release angling are required to conserve diverse fisheries resources threatened by recreational angling. Our first recommendation would be for anglers to land fish as quickly as possible and to minimize air exposure during the hook removal and release phase. A cooler or live-well aboard boats may provide an appropriate holding unit to minimize air exposure for this procedure. In fact, we recommend allowing all captured fish to recover for 2–3 min in a cooler or live-well prior to release. Fish that are returned to the water without losing their equilibrium should be better able to avoid predators and resume normal activities more rapidly. Because the likelihood that a bonefish will survive after release is substantially reduced in regions where sharks are abundant, distracting a shark by splashing may be helpful, but will not prevent all predation. We also recommend, that when sharks are in the immediate vicinity of release, anglers hold their bonefish in a cooler or live-well and transport it to an alternate release location. This action may not be possible for anglers that are wading. If sharks are present and the likelihood that a shark will attack either angled or released fish is high, we encourage anglers and guides to relocate to an alternate location. If a captured bonefish is bleeding, we recommend that it be held in a live-well/cooler for 2 min to allow clotting before release or moved to an area with complex cover such as mangroves. The conservation of bonefish will depend upon anglers using strategies to release fish in good condition, such that they can avoid predators. Educational material related to proper fish handling needs to be disseminated to stakeholders around the globe that are involved in catch-and-release bonefish angling, or management of these fisheries resources.

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