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Effects of recreational angling on the post-release behavior and predation of bonefish (*Albula vulpes*): The role of equilibrium status at the time of release

Sascha E. Danylchuk[a,b,c,*], Andy J. Danylchuk[a,b], Steven J. Cooke[a,b,d],
Tony L. Goldberg[a,b,e], Jeff Koppelman[a,b], David P. Philipp[a,b,c]

[a] *Cape Eleuthera Institute Flats Ecology and Conservation Program, 498 SW 34th Street, Ft. Lauderdale, FL 33315 USA*
[b] *Illinois Natural History Survey, Center for Aquatic Ecology and Conservation, 1816 S, Oak Street, Champaign, IL 61820 USA*
[c] *University of Illinois, Department of Natural Resources and Environmental Sciences, 1102 South Goodwin Avenue, Urbana, Illinois 61801 USA*
[d] *Fish Ecology and Conservation Physiology Laboratory, Institute of Environmental Science and Department of Biology, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario, Canada K1S 5B6*
[e] *University of Illinois Department of Pathobiology, 2001 South Lincoln Avenue, Urbana, IL 61802 USA*

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Abstract

Even though the recreational fishery for bonefish (*Albula* spp) is predominantly catch-and-release, the effects of angling on individual behavior and survival are poorly understood. We used visual tracking to measure the short-term post-release behavior and survival of bonefish (*Albula vulpes*) in Eleuthera, The Bahamas, to determine if any specific aspects of the angling event were linked to post-release mortality, particularly via predation. Bonefish ($n=88$) were angled and landed using fly fishing equipment, affixed with a small float, and exposed to four treatments (released near or far from cover, with or without equilibrium). Following release, each fish was observed for up to 1 h, and specific swimming behaviors and incidences of predation were recorded. As a reference, a second group of bonefish ($n=20$) was caught using a seine net and treated in a similar manner as angled fish. Fifteen (17%) of the angled bonefish suffered post-release predation by either lemon sharks (*Negaprion brevirostris*) or great barracuda (*Sphyraena barracuda*), while only one (5%) bonefish caught via seine was preyed upon. Released bonefish that had lost equilibrium were six times more likely to suffer predation than those released without losing equilibrium. In addition, longer durations of air exposure and handling times positively influenced the loss of equilibrium in bonefish. Proximity to mangrove cover, however, did not influence the susceptibility of released bonefish to predation. These findings suggest that post-release mortality of bonefish and potentially other marine fish released in high predator regions could be reduced by ensuring that fish are handled and released without leading to the loss of equilibrium.

Keywords: *Albula vulpes*; Bonefish; Catch-and-release angling; Mangroves; Post-release mortality; Predation

1. Introduction

Catch-and-release is increasingly becoming a popular form of recreational angling that can have widespread and positive effects on fisheries (Cowx, 2002;

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* Corresponding author. Cape Eleuthera Institute, 498 SW 34th Street, Ft. Lauderdale, FL 33315 USA. Tel.: +1 609 945 0710; fax: +1 954 337 3799.
E-mail address: saschaclark@ceibahamas.org (S.E. Danylchuk).

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Cooke and Cowx, 2004). The potential benefits of catch-and-release angling could be overestimated, however, if the angling event results in the mortality of at least some released fish (Wydoski, 1977; Cooke et al., 2002). In general, studies on the effects of catch-and-release angling have focused predominately on freshwater species (Cooke et al., 2002), and only a few have attempted to quantify which aspects of the angling event contribute to post-release mortality (Ferguson and Tufts, 1992; Wilde, 1998; Cooke et al., 2001, Cooke et al., 2002; Cooke et al., 2003; Meka and McCormick, 2005). In marine systems, a relatively high number of predators inhabit areas where recreational angling is popular, posing an additional threat to physiologically stressed fish following catch-and-release (Edwards, 1998; Cooke and Philipp, 2004). Despite the lucrative nature of recreational angling in marine systems, especially in tropical developing countries, the role of catch-and-release angling in these areas is only now beginning to be addressed (Cooke et al., 2006).

Bonefish (*Albula* spp) are a group of marine fish that inhabit shallow tropical and subtropical environments worldwide (Alexander, 1961). The wariness and speed of bonefish make them one the most sought after group of fishes among recreational anglers (Kaufmann, 2000). Because of their popularity, bonefish are the focus of a tourism-based recreational angling industry that provides substantial revenue to coastal communities. Interestingly, although the consumption of bonefish does occur in some regions, most anglers targeting bonefish voluntarily practice catch-and-release (Humston et al., 2005).

Despite the importance of bonefish to the recreational angling industry, few studies have focused on how catch-and-release angling influences the survival of bonefish. Cooke and Philipp (2004) found that the short-term (<24 h) post-release mortality of bonefish could be as high as 40% and was dependent on the abundance of predators in the area. At sites with intermediate predator densities to those studied by Cooke and Philipp (2004), Danylchuk et al. (2007) found that although the short-term (<48 h) post-release mortality of bonefish was 8%, if bonefish were able to avoid predation for the first few minutes following release, then delayed mortality (>48 h) was minimal. These authors concluded that at intermediate predator abundances, specific aspects of the angling event likely influence the susceptibility of bonefish to predation post-release (Danylchuk et al., 2007).

The purpose of our study was to determine which elements of an angling event influenced the likelihood of predation on bonefish during the first hour following catch-and-release. We postulated that angling practices that lead to a loss of equilibrium would negatively affect the behavior of bonefish following release, leading to higher rates of predation. We also hypothesized that refuge from predators may also influence the post-release susceptibility of bonefish to mortality. Given that mangroves are common to nearshore tropical flats where bonefish reside and offer intricate root structure that can provide shelter to many fish and invertebrates (Kieckenbusch et al., 2004), we further postulated that bonefish released close to mangroves would be less susceptible to predation following release than those released far from mangrove cover.

2. Methods

2.1. Study area

This study was conducted in shallow flats and coastline embayments off Cape Eleuthera and Rock Sound, Eleuthera, The Bahamas (18 364035 E, 2747609 N) and included some of the same study sites as Danylchuk et al. (2007). The shoreline in this area is composed of tidal creeks, sandy bays, mangroves, and sharp calcium carbonate outcroppings. The area contains many tidal creeks characterized by a mosaic of sandy beach and turtle grass beds (*Thalassia testudium*) surrounded by tracts of red mangroves (*Rhizophora mangle*).

Preliminary genetic analysis of the bonefish used in this study indicated that all specimens were *Albula vulpes* (Danylchuk et al., unpublished data); this is important since multiple, outwardly similar species of bonefish potentially occur in The Bahamas (Colborn et al., 2001). Other species of fish common to our study area were lemon sharks (*Negaprion brevirostris)*, great barracuda (*Sphyraena barracuda)*, and yellowfin mojarra (*Gerres cinereus)* (Danylchuk et al., unpublished data).

2.2. Capture and release

Bonefish were angled from a skiff or by wading using conventional fly fishing gear (7–9 wt rod and reel, barbed bonefish flies). For angled bonefish we measured fight time, duration of handling, duration of air exposure (all to the nearest 5 s), the presence/absence of blood, total length of the fish, and whether or not the fish was able to maintain equilibrium at the time of release. Because water temperature can affect the physiology of fish and their response to stress (Meka and McCormick, 2005), we measured water temperatures by deploying temperature data loggers (Hobo 8K, Onset Computer

Corporation, Pocasset, MA, USA) on the substrate at several locations throughout our study area. Tidal regimes in our study area were determined using regional tide charts and visual observations.

Once bonefish were landed, a visual float was attached just below the posterior origin of their dorsal fin. Visual floats consisted of a fishing hook tied to 3–4 m of 4 lb test monofilament fishing line and attached to a 3 cm brightly colored, oval fishing bobber at the opposite end. Cooke and Philipp (2004) found no significant differences in the post-release mortality rates between bonefish attached with visual floats and those implanted with gastric ultrasonic transmitters, however, tracking bonefish with visual floats provided more accurate and detailed assessments of post-release survival and behavior. Using light monofilament line allowed bonefish to break the line if they became entangled in shoreline vegetation or other structures. At the time of release it was noted whether the location of release was adjacent to (<10 m) or far from (≥10 m) mangrove cover and whether or not bonefish lost equilibrium. Loss of equilibrium was defined in this study as a fish unable to swim away immediately upon release but instead rolling on its side and/or "nose diving" toward the substrate. Such loss of equilibrium indicates a generalized breakdown of systemic homeostatic mechanisms (Beitinger et al., 2000). These fish often had to be retrieved, righted and hand held for a short period of time (<2 min) before they were capable of swimming on their own. Any such revival of bonefish that were released without equilibrium was not included as part of handling time.

To provide a non-angled reference group, we also collected bonefish using a seine net (45.72 m × 1.22 m seine with a 1.22 m bag, 0.95 cm mesh). To capture these fish, the seine was employed as a block net that was stretched across narrow channels in tidal flats, and bonefish were ushered into the net as they entered or exited the creek system. Duration of handling, duration of air exposure (both to the nearest 5 s), total lengths of fish, tide, and water temperature were measured for each fish. Prior to release, a visual float was affixed to bonefish in a manner identical to that employed for fish captured via angling. All non-angled bonefish were released with equilibrium and far from mangrove cover due to logistic restraints of the seining locations.

2.3. Tracking

Once released, all fish were visually tracked (by foot or by boat) for up to 1 h, and their locations during this time period were noted on a site map. Successful predation events were recorded, as well as the species and approximate size of the predator. Behaviors, including swimming non-directionally, swimming directionally, and resting, were recorded at 30 s intervals for up to 1 h following release. We defined swimming non-directionally as swimming with a lack of bearing and at a slow speed. Conversely, swimming directionally was defined as swimming steadily at a faster speed. Resting was distinguished by a lack of movement. Tracking ceased once a bonefish was followed for 1 h, when a fish was attacked and killed by a predator, or when the visual float became detached from the fish or when sight of it was lost by the observer. Following the tracking period, we attempted to remove the float from as many bonefish as possible by hooking the line and pulling gently to free the hook from the fin tissue. Floats were successfully removed from more than 50% of the fish that were tracked.

2.4. Data analysis

Multivariate survival analysis (Cox proportional hazard regression) was used to determine if angling-related factors were predictors of mortality risk (see Castro-Santos and Haro, 2003). Multivariate linear and logistic regression was then used to determine which aspects of the angling event contributed to the loss of equilibrium and various behaviors following release. Comparisons of distances from mangroves were done using Mann Whitney *U*-test. All statistical analyses were performed using Systat v 10.2 and SAS v 9.1. Associations were considered statistically significant at $P \leq 0.05$.

3. Results

A total of 107 fish were collected from March 2005 to February 2006 (non-angled fish $n=20$, angled fish released with equilibrium and adjacent to mangroves $n=23$, angled fish released with equilibrium and far from mangroves $n=21$, angled fish that had lost equilibrium and released adjacent to mangroves $n=22$, angled fish that had lost equilibrium and released far from mangroves $n=21$). One fish was preyed upon during the angling event and was subsequently excluded from the analysis.

Of all bonefish caught-and-released via angling, 15 (17%) were preyed upon within the first hour post-release by either lemon sharks (*N. brevirostris*, $n=13$) or barracuda (*S. barracuda*, $n=2$; Table 1). Interestingly, almost all of the predation events occurred within the first 20 min after release (Fig. 1). Of the bonefish caught

Table 1
Fish size, aspects of the angling event, and the incidence of predation for bonefish following catch-and-release angling and seining (non-angled fish)

Treatment	n	Total length (cm) (±SE)	Angling time[1] (s) (±SE)	Handling time[2] (s) (±SE)	Air exposure[3] (s) (±SE)	Predation[4]
Non-angled	20	45.6 (2.8)	N/A	8880 (90)^{a}	4 (2)^{a}	5.0^{a}
Angled, released with equilibrium	44	47.2 (0.6)	158 (13)	253 (19)^{b}	23 (7)^{a}	4.5^{a}
Angled, released without equilibrium	43	49.1 (0.9)	172 (13)	354 (35)^{b}	60 (5)^{b}	30.2^{b}

Differences in lettered superscripts indicate significant differences among treatment groups.

[1] Amount of time between hooking and landing of a fish.

[2] Amount of time between landing or netting and release; handling time includes air exposure.

[3] Amount of time of exposure to air during handling.

[4] Percentage of fish observed to suffer mortality via predation following release.

via seining, however, only one (5%) was preyed upon within the first hour post-release. The level of predation for non-angled bonefish was similar to that of angled bonefish that had not lost equilibrium ($t=0.452$, $P=0.65$) and not (significantly) different than the angled fish that had lost equilibrium at release ($t=-0.970$, $P=0.11$; Fig. 1). The only bonefish that suffered mortality from means other than predation occurred on the hottest day of our study when water temperatures were >35 °C. Following release, this bonefish swam for 52 min before losing equilibrium and ceasing to respire.

Whether a bonefish had or had not lost equilibrium was a significant predictor of predation, with bonefish losing equilibrium being over six times more likely to suffer predation than those that did not lose equilibrium (Cox proportional hazard regression, $t=-2.397$, $P=0.017$; hazard ratio$=6.24$). All other variables measured during the study (total length, angling time, handling time, air exposure time, bleeding, and water temperature) were not directly related to predation risk. Fish that were preyed upon did not spend significantly more time further from mangroves than fish that were not preyed upon ($P=0.36$). In fact, following release 17 (20%) bonefish were observed swimming into open water (>2.5 m deep) rather than staying in close proximity to the shore line or in shallow water.

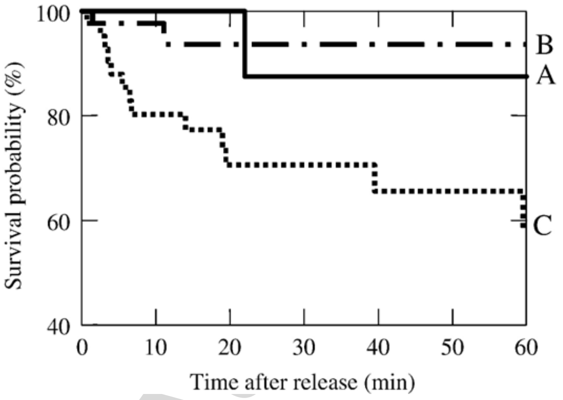

Fig. 1. Bonefish mortality due to predation following capture and release for each of the three treatments. Treatment A consisted of non-angled fish (captured by soft beach seine; $n=20$). Treatment B consisted of fish ($n=44$) that were angled and that were able to maintain equilibrium at the time of release. Treatment C consisted of fish ($n=43$) that were angled and that were not able to maintain equilibrium at the time of release. Mortality rates did not differ significantly between treatments A and B and were not (significantly) different between treatments A and C. However, the mortality rate associated with treatment C differed significantly from B.

Longer air exposure and overall handling times were significant predictors of the loss of equilibrium in angled bonefish (aOR$=5.58$, $t=3.611$, $P<0.001$, and aOR$=1.22$, $t=2.155$, $P=0.031$ respectively). Angling time, total length, water temperature, and bleeding at the hooking site were not significant predictors of equilibrium loss (all $P>0.05$).

Although water temperature did not seem to directly affect the susceptibility of bonefish to predation, bonefish spent significantly more time resting as water temperatures increased ($R^2=0.055$, $t=2.443$, $P=0.017$). Bonefish released during periods of elevated water temperatures often rested for up to 1 min shortly after release, however no bonefish in our study were preyed upon when they were at rest.

Lemon sharks that preyed on bonefish did so by tracing the path of bonefish. In four cases, bonefish carcasses that were quickly recovered after a successful predation event revealed that the lemon sharks had targeted bonefish posterior to the dorsal fin, and, in two cases, severed the caudal fin from the body prior to attempting to consume the rest of the fish. Conversely, the great barracuda that preyed on bonefish post-release did so using rapid burst swimming, and in both cases ate the bonefish whole. Relative size differences, however, between predators and prey (i.e., the barracuda were larger than most of the lemon sharks) could account for differences in predation strategies.

Bonefish that were released without equilibrium and those of smaller body sizes spent significantly more time

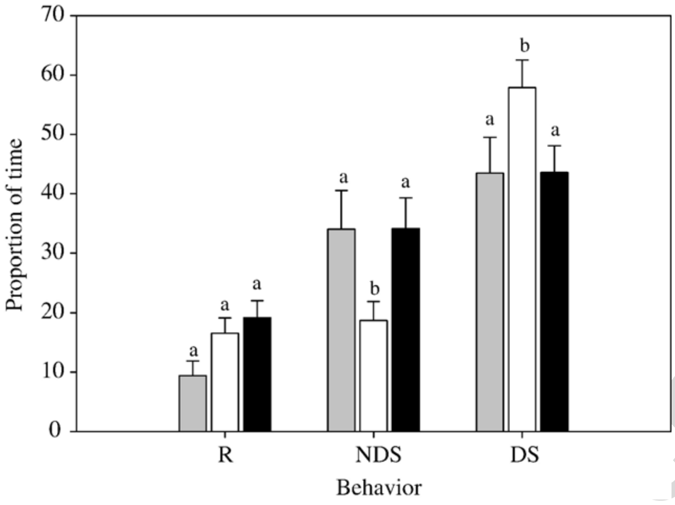

Fig. 2. Proportions of time that bonefish displayed three behaviors (resting (R), non-directional swimming (NDS), and directional swimming (DS)) following capture and release. Fish were captured and released according to three treatments: non-angled (grey), angled and released with equilibrium (white), angled and released without equilibrium (black). Differences in letters indicate statistically significant differences among treatment groups for each behavior. Error bars represent standard errors of the mean.

swimming non-directionally than bonefish released with equilibrium or those with larger body sizes ($R^2 = 0.217$, $P < 0.001$ and $P = 0.001$ respectively). Conversely, fish released with equilibrium and larger fish spent significantly more time swimming directionally ($R^2 = 0.128$, $P = 0.006$ and $P = 0.008$ respectively). When the swimming behaviors of seine-captured fish were compared to those of angled fish released without equilibrium no significant differences were found (Fig. 2).

4. Discussion

Our study indicates that angled bonefish that lost equilibrium at the time of release were over six times more likely to be killed by predators than bonefish that did not lose equilibrium at the time of release. Our study also demonstrates that certain aspects of the angling event, specifically the duration of air exposure and total handling time, influence the probability that a released bonefish will lose equilibrium. Although not significant predictors of predation, water temperature and body size were shown to affect the movements of bonefish following angling and release. The proximity to mangrove cover did not influence the susceptibility of bonefish to predation following catch-and-release angling.

Loss of equilibrium could make bonefish more susceptible to predation by lemon sharks and great barracuda that co-inhabit nearshore flats. A post-release loss of equilibrium in fish represents a breakdown of body systems that normally function to allow fish to avoid life-threatening situations (Beitinger et al., 2000). For black bass (*Micropterus* spp), Cooke et al. (2000) found that caught-and-released fish exhibited a period of hyperactivity followed by a period of lower than normal activity, and that catch-and-release angling causes significant locomotory impairment. In our study, we found that bonefish that lost equilibrium upon release spent significantly more time swimming non-directionally, which likely made them more susceptible to predation. Independent of loss of equilibrium at the time of release, body size and water temperature were shown to affect the post-release behavior of bonefish in this study. Body size and water temperature are two factors that can influence the physiology and behavior of fishes (see Schmidt-Nielsen, 1975; Brett, 1979; Goolish, 1991), and may thus contribute indirectly to the probability of post-release survival.

Chemical metabolites produced by fishes as a result of excessive physiological stress could also increase the likelihood of predation for bonefish, especially by predators with sensitive chemoreception, such as sharks. For example, Ellis et al. (2005) showed that cortisol, a hormone excessively produced by vertebrates during stressful events, was excreted by rainbow trout at levels detectable in the water column. Sharks have an acute sense of smell and are able to detect minute concentrations of organic compounds in seawater (Moss, 1977). The acute sense of smell in sharks has been shown to greatly assist in the localization of prey (Kleerekoper et al., 1975; Johnsen and Teeter, 1985). As such, it is possible that juvenile lemon sharks in shallow mangrove creeks use chemical cues excreted by stressed bonefish to home in on potential prey. During our study, we often observed juvenile lemon sharks that eventually preyed on bonefish following nearly the same serpentine route as the bonefish rather than swimming in a relatively straight path towards its prey.

It has been documented that certain aspects of an angling event can cause disruptions that negatively impact the physiology, behavior, and post-release survival of fish (Ferguson and Tufts, 1992; Philipp et al., 1997; Cooke et al., 2001; Cooke et al., 2002). For example, Philipp et al. (1997) found that male black bass exposed to air after angling took at least twice as long to return to their spawning nests as fish not exposed to air after angling. Cooke et al. (2001) found that rock bass (*Ambloplites rupestris*) exposed to air took significantly longer for cardiac output, stroke volume, and heart rate to return to basal levels than rock bass not exposed to air. Danylchuk et al. (2007) showed that the only bonefish preyed upon within the first hour following catch-and-release angling was one that was treated roughly, including extensive air exposure and handling. In our study, extended air exposure and long handling times likely caused the excessive physiological stress leading to the loss of equilibrium post-release.

Although the proximity to mangrove cover did not influence the susceptibility of bonefish to predation, other properties of the flats habitat may offer refuge following catch-and-release angling. In our study, some released bonefish were observed swimming into deeper water, away from conspecifics and the structure of mangrove prop roots. Studies have shown that shallow flats and mangrove creeks are important nursery grounds for juvenile lemon sharks (Gruber et al., 1988) and that most juvenile lemon sharks are found within 200 m of mangroves (B. Franks, Drexel University, pers. comm.). Although the spatial ecology of bonefish is poorly understood, it is reasonable to postulate that bonefish move away from cover following catch-and-release angling as a way to reduce the risk of predation by juvenile lemon sharks that are present in such habitat.

Overall, our results indicate that the handling practices of recreational anglers can influence the susceptibility of bonefish to predation following release, and, therefore the effectiveness of catch-and-release angling as a conservation measure to maintain populations. Understanding the physiological mechanisms that increase the susceptibility of bonefish to the loss of equilibrium may lead to novel ways to allow fish to recover from the angling event prior to release. The interactions of bonefish and their prey will also potentially allow for site or situation-specific guidelines to be developed that can reduce the likelihood of their post-release mortality (Cooke and Suski, 2005). Furthermore, finding ways to decrease the post-release mortality of bonefish may make catch-and-release bonefishing more compatible with the goals of no-take marine protected areas (Cooke et al., 2006) and lead to greater chances of ecological and economic sustainability in places like The Bahamas.

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