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Recovery bags reduce post-release impairments in locomotory activity and behavior of bonefish (*Albula* spp.) following exposure to angling-related stressors ☆

Jacob W. Brownscombe [a,*], Jason D. Thiem [a], Charles Hatry [a], Felicia Cull [a], Christopher R. Haak [c,d], Andy J. Danylchuk [c], Steven J. Cooke [b]

[a] *Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, 1125 Colonel By Dr., Ottawa, ON, Canada K1S 5B6*
[b] *Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental Science, Carleton University, 1125 Colonel By Dr., Ottawa, ON, Canada K1S 5B6*
[c] *Department of Environmental Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA 01003, USA*
[d] *Intercampus Marine Science Graduate Program, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA 01003, USA*

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ABSTRACT

Bonefish (*Albula* spp.) are a group of species targeted by recreational anglers in shallow tropical and sub-tropical seas worldwide. Although bonefish angling is almost entirely catch-and-release, mortality can occur because the stress associated with angling and handling causes locomotory impairment that promotes post-release predation. We used tri-axial accelerometer loggers to compare the locomotor activity and behavior of bonefish exposed to angling-related stressors and immediately released (n = 10, 39.9 ± 1.1 cm FL), to those retained in a recovery bag for 15 min prior to release (n = 10, 39.6 ± 1.0 cm FL) in a tidal creek in Eleuthera, The Bahamas. We also validated the use of reflex action mortality predictors (RAMP) as an impairment index for evaluating bonefish condition upon release. Following release, bonefish were visually tracked for 30 min with floats to evaluate short-term survival, after which the accelerometer was retrieved. Bonefish held in recovery bags exhibited significantly less locomotory impairment immediately post-release, and higher maximum tail beat frequencies and amplitudes up to 15 min post-release, which was likely due to the time spent in the recovery bag. Bonefish in the recovery bag treatment also spent more time resting in possible refuge areas, which may facilitate further recovery and avoidance from predation. RAMP provided a gradient of impairment scores that were correlated with stressor duration. Retaining bonefish in recovery bags improved swimming abilities during the critical time period where the majority of post-release predation occurs, and one fish that was not placed in the recovery bag was preyed upon during the monitoring period. Further testing is needed to determine if the locomotory and behavioral benefits of retaining bonefish in recovery bags translate into improved survival from predation in more predator rich environments.

1. Introduction

Catch-and-release angling (C&R) is highly popular worldwide, practiced voluntarily due to the conservation ethic of anglers or when mandated by harvest regulations (Cooke and Cowx, 2004; Cowx, 2002). It is a socially and economically important activity, as well as a conservation strategy that relies upon the assumption that released fish will ultimately survive (Arlinghaus et al., 2007; Wydoski, 1977). However, C&R angling can have detrimental effects on captured individuals, which could contribute to population level declines (Cooke and Schramm, 2007; Lewin et al., 2006). Physical injuries often result from various aspects of the angling process, including hooking, netting, and handling (Barthel et al., 2003; Danylchuk et al., 2008; Muoneke and Childress, 1994). Angling also causes physiological stress due to exhaustive physical exercise and air exposure (Arlinghaus et al., 2009; Cooke et al., 2002). These physical injuries and physiological impairments have the potential to cause post-release mortality, or even reduced growth and fitness (Cooke and Schramm, 2007). Behavioral impairments (reduced locomotory capabilities) can reduce reproductive potential or increase vulnerability to predation, while reduced fitness may result from the energy expenditure required to recover from physical and physiological disturbances (Cooke et al., 2000; Danylchuk et al., 2007a). However, the extent to which behavioral impairments affect the fitness of angled fish is not well understood, particularly in marine systems where predators are prevalent (Cooke et al., 2002).

A variety of angler behaviors and gear choices influence the outcome of a C&R event for a fish (reviewed in Cooke and Suski, 2005). The

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* Corresponding author. Tel.: +1 705 761 9012.
E-mail address: jakebrownscombe@gmail.com (J.W. Brownscombe).

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application of best angling practices, including using the appropriate gear, reducing fight time, and minimizing air exposure have been shown to reduce stress and improve survival for a variety of fish species (reviewed in Cooke and Suski, 2005; Cooke and Schramm, 2007; Arlinghaus et al., 2007). There is also growing interest in developing and testing strategies that have the potential to facilitate physiological and behavioral recoveries and thus improve survival. Recovery gears can range from special devices intended to facilitate ram ventilation by using water pumps (e.g., Beittinger et al., 2005; Farrell et al., 2001) to more simple gears where fish are held in static water (e.g., a cooler or portable bag). For species where post-release mortality is documented to be prevalent, use of recovery gears could be an effective strategy to enable fish to compensate for physiological and behavioral impairments and thus improve the ability of fish to evade predators. However, to our knowledge this idea has never been tested for marine fish that are subject to high levels of post-release predation.

Bonefish (*Albula* spp.) are a group of benthivorous fish species that occupy shallow tropical and subtropical seas worldwide (Alexander, 1961), and are highly popular for recreational anglers, generating important revenue for many local economies (Danylchuk et al., 2008; Humston, 2001). Despite the fact that angling for bonefish is almost entirely C&R, the stress of angling causes locomotory impairment that often leads to predation (Cooke and Philipp, 2004; Danylchuk et al., 2007a). Cooke and Philipp (2004) noted that post-release mortality of bonefish was influenced by predator abundance and could be as high as 40%. Danylchuk et al. (2007a) revealed that bonefish that lost equilibrium (a reflex impairment; Davis, 2010) prior to release had behavioral impairments and were six times more likely to be preyed upon than angled fish that had not lost equilibrium. These studies also found that the majority of mortality occurred in the first 20 min post-release, suggesting that this is the critical period for survival after angling events. Therefore it has been theorized that retaining bonefish for a short period may reduce mortality, especially in areas of high predator abundance (Cooke and Philipp, 2008), although this has not yet been validated as an effective practice.

The primary objective of this study was to evaluate the effectiveness of retaining bonefish in recovery bags for reducing short-term locomotory impairment when subjected to angling-related stressors, and whether potential improvements in swimming ability translated to increased survival. We used physiological stressors and did not inflict physical injuries that are often associated with angling events because previous studies have shown that it is the former that lead to behavioral impairments and post-release predation (see Cooke and Philipp, 2004; Danylchuk et al., 2007a). We used recovery bags given that they are inexpensive and could be easily carried by anglers when walking or wading rather than gears that required electricity or were otherwise less likely to be embraced by anglers due to practicality and expense. To quantify post-release behavior we used novel high-resolution tri-axial accelerometer loggers, which allowed for the measurement of body acceleration in three axes to quantify tail beat frequencies and amplitudes. We also tested reflex impairment indices as indicators of bonefish condition given that previous work by Danylchuk et al. (2007a) revealed that loss of equilibrium was associated with post-release predation. Reflex indicators have recently been deemed effective predictors of mortality (Davis, 2010; Raby et al., 2012), and could be used by anglers to evaluate in which instances fish would benefit from recovery. We predicted that fish retained in recovery bags would exhibit lower reflex impairment, as well as higher locomotory ability and survival than those immediately released.

2. Methods

2.1. Study site and fish collection

This study was conducted in Kemps Creek, Eleuthera, The Bahamas (24° 48.9′N, 76° 18.1′W). Kemps is a tidal creek with mainly coarse sand substrate, and sparse vegetation, including primarily Halimeda (*Halimeda* spp.), and Penicillus (*Penicillus* spp.). The shoreline is lined with red mangrove (*Rhizophora mangle*), and sharp calcium carbonate rock. Preliminary genetic analysis indicated that all bonefish in this area were *Albula vulpes* (Danylchuk et al., 2007a). Bonefish were collected by block netting (see Danylchuk et al., 2011) in Kemps Creek on 23rd February 2012, and were held in a mesh pen (1.3 m × 0.8 m × 1.25 m, 3.1 cm extruded plastic mesh) for up to 48 h prior to experimentation.

2.2. Validation of reflex impairment indices

We validated the use of reflex action mortality predictors (RAMP) (Davis, 2005, 2010) to assess bonefish vitality after 0, 2, 4 and 6 min of air exposure. The 0-minute assessments (n = 30) occurred prior to air exposure on fish from all treatments, while bonefish in the 2-minute treatment (n = 20) were those used in recovery bag experiments (see below), and 4, 6 min treatments (n = 5) were conducted on alternate fish. Five predictors were measured; tail grab, equilibrium (orientation), body flex, head complex, and vestibular-ocular response (VOR). These predictors were chosen because Raby et al. (2012) found that they were strong predictors of coho salmon (*Oncorhynchus kisutch*) mortality after being caught in commercial nets, and all these predictors can be easily and quickly measured by bonefish anglers. RAMP was assessed in the same manner by Raby et al. (2012). The presence of a tail grab response was assessed by grabbing the fish's tail while it is submerged in water; it was considered impaired if the fish did not attempt to swim away from the handler. Equilibrium was assessed by rolling the fish upside down in water; impairment was indicated when the fish was unable to right itself within 3 s. Body flex was tested by holding the fish by the middle of the body in air; it was considered impaired if the fish made no attempt to struggle free. Head complex was considered impaired if while holding fish in air, a regular pattern of ventilation of the fish's operculum was not observed for at least 5 s. VOR was assessed by rolling the fish back and forth in air; it was considered impaired if its eyes did not roll to maintain the same pitch and track the angler. Higher RAMP scores indicated greater impairment.

2.3. Post-release activity experiments

Bonefish were retrieved from the holding pen by dip net and held in a trough filled with seawater for attachment of tri-axial accelerometer loggers (model X6-2, 20 g in air, 25 Hz recording frequency; model X6-2mini, 500 mAh battery, 15 g in air, or 250 mAh battery, 10 g in air, 20 Hz recording frequency; Gulf Coast Data Concepts, Waveland, MS). Tri-axial accelerometers measure dynamic and static accelerations in units of gravity (g), equivalent to 9.8 m s^{-2} (Wilson et al., 2008). Larger tags were used on larger individuals, and an equal number of each tag type was used for each treatment. Devices were attached externally, secured through the dorsal musculature below the dorsal fin to plastic frontal and backing plates (2 g each) with 36 kg strength braided Dacron line (Fig. 1). Tags were oriented with the y-axis facing longitudinally. A cylindrical foam float was also attached to the frontal plate with 2.5 m of 7 kg strength monofilament line for visual tracking of the fish (as per Cooke and Philipp, 2004; Danylchuk et al., 2007a) and retrieval of the accelerometer loggers. The attachment procedure lasted less than 1 min.

Tagged bonefish were then assessed for RAMP, and air exposed in a moistened rubber net or recovery bag (not submerged) for 2 min. This elicited physical exercise as the fish struggled in the net, as well as air exposure, which cumulatively results in the depletion of tissue energy stores (e.g., PCr, ATP, glycogen of white muscle) and elevations of lactate in white muscle and plasma, similar to the stress of angling events (Suski et al., 2004). Our stressor duration (2 min) was similar to a relatively quick angling event for bonefish (Cooke and Philipp, 2004; Danylchuk et al., 2007a,b). However, over 90% of fish lost equilibrium post-stress in this study, indicating it was more

Fig. 1. Location of accelerometer attachment on bonefish for quantifying behavior after simulated angling stress.

similar to a highly stressful angling event (Cooke and Philipp, 2004; Danylchuk et al., 2007a).

RAMP was reassessed after air exposure, and bonefish were either immediately released (n = 10) or held in a recovery bag (Dynamic Aqua Ltd., Vancouver, BC; 75 cm length, 15 cm width with 0.5 cm mesh on both ends and a plastic zipper; see Fig. 2) for 15 min prior to release (n = 10). Immediately released fish were manually resuscitated for up to 1 min prior to release; a common practice amongst recreational anglers. Resuscitation involved holding bonefish upright, facing tidal currents to allow water to flow through the mouth and over the gills. Swimming data were collected for only nine bonefish in the immediate release treatment because data from one bonefish was lost due to a predation event, while all ten accelerometers were recovered from the fish in the recovery treatment. For bonefish held in recovery bags, RAMP was reassessed prior to release. Releases occurred at water depths of 25–70 cm.

Tagged bonefish were visually tracked by wading, following the attached float at a distance of at least 15 m for 30 min. Accelerometers were retrieved by using rod and reel to hook the float line and recapture the fish. Trials were conducted between 0700 and 1500 h on February 24th and 0700–1000 h on 25th February 2012. Treatments were alternated to achieve similar environmental conditions between treatment groups. Water temperatures ranged from 24 to 30 °C during this time period, which is a typical temperature range for these environments during this time of year (Murchie et al., 2011).

2.4. Data analysis

Accelerometers were set to continuously record total acceleration (g) at intervals of 20 or 25 Hz in three (x, y and z) planes, where total acceleration was the sum of both static (due to gravity) and dynamic (due to animal movement) acceleration with maximum values of ±6 g. Device output was calibrated by rotating the device through known angles to real g (9.8 m s^{-2}) prior to deployment (Gleiss et al., 2010). Static and dynamic accelerations were separated by weighted smoothing at an interval of 2 s. The ideal smoothing interval was determined following the method of Shepard et al. (2008), and smoothing was conducted by using OriginPro 8 software (OriginLab, Northampton, MA).

To quantify bonefish behavior, as well as tail beat frequencies and amplitudes, continuous wavelet transformation was used to decompose acceleration data based on the amplitudes and frequencies of oscillations in the sway axis (following the method of Sakamoto et al., 2009). Cycles ranging in frequency from 0.1 to 1 s were included in the analysis, and the non-dimensional frequency parameter was set to eight to best identify oscillations in the sway axis acceleration for bonefish. Data were then clustered into similar spectra by using the *k*-means algorithm. Spectra were categorized into a maximum of 10 clusters, as higher numbers were found to add no resolution to swimming behaviors, but instead separated resting behaviors (defined by low amplitude, non-cyclic movements; Whitney et al., 2010). For clusters that represented swimming behavior (cyclic movements), tail beat frequency and amplitude were determined from the cycle frequency and amplitude of clusters (Fig. 3). This was not a measure of actual tail beat amplitudes, but relative amplitudes of sine waves derived from acceleration data in units of acceleration (g). Spectra were further categorized into resting (low frequency, non oscillating movements), slow (<2 tail beats/s, and/or <0.1 g amplitudes), moderate (2–3 tail beats/s, 0.1–0.2 g amplitudes) or fast (>3 tail beats/s, >0.2 g amplitudes) swimming speeds (Fig. 3). Behavioral analysis was conducted by using Igor Pro 6.0 software (WaveMetrics Inc., Lake Oswego, OR), and Ethographer (see Sakamoto et al., 2009).

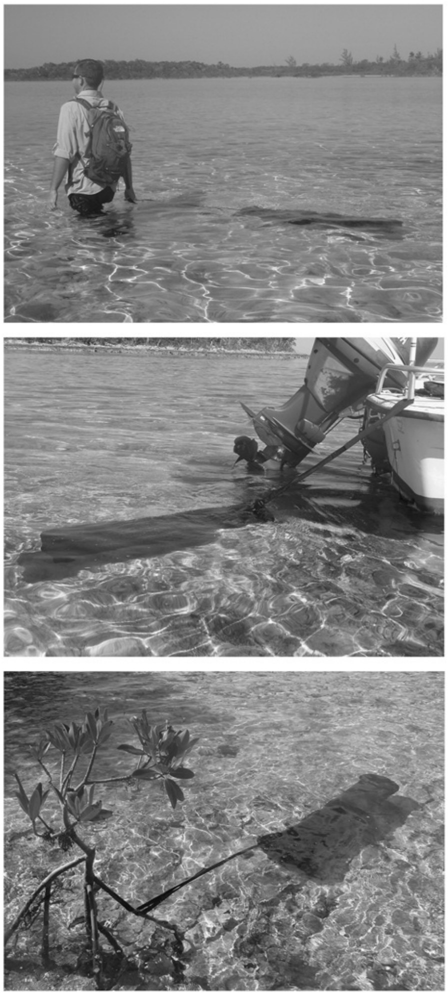

Fig. 2. Recovery bag being used to retain bonefish after angling by wading, behind a boat, and fastened to a mangrove.

2.5. Statistical analysis

The fork length of bonefish was compared between recovery and immediate release treatments by using an independent *t*-test. To compare the locomotory activity between treatments during equivalent time periods post-release, mean and maximum tail beat frequency, as well as mean and maximum tail beat amplitude were compared

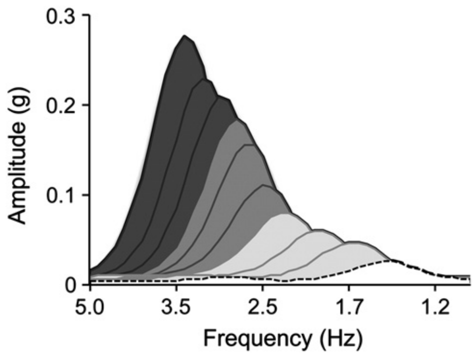

Fig. 3. Example of behavior clusters derived from continuous wavelet transformation and *k*-means cluster analysis, categorized into resting (hatched line), slow swimming (light gray), moderate swimming (gray), and fast swimming (dark gray) behaviors from one bonefish during 30 min post-release after simulated angling stress.

by using mixed measures ANOVA with treatment as the fixed effect, and time as the repeated measure in 1-minute intervals for the first 10 min post-release. Due to interaction effects, these variables were compared between treatments within each minute by using independent *t*-tests. To compare the locomotory activity between treatments during equivalent time periods post-stressor, the same variables were compared from 15 to 25 min post-stressor in 1-minute intervals by using the mixed measures ANOVA. Due to interaction effects, mean tail beat amplitudes were compared within each minute by using independent *t*-tests. All variables were tested for assumptions of normality, homogeneity of variance, and in the case of the mixed measures ANOVA, sphericity prior to analysis. Where data did not meet the assumption of sphericity, a Greenhouse–Geisser correction factor was applied (Field et al., 2012). All statistical analyses were conducted in R (v.2.15 R Foundation for Statistical Computing, Vienna, Austria). All data are presented as mean ± SE.

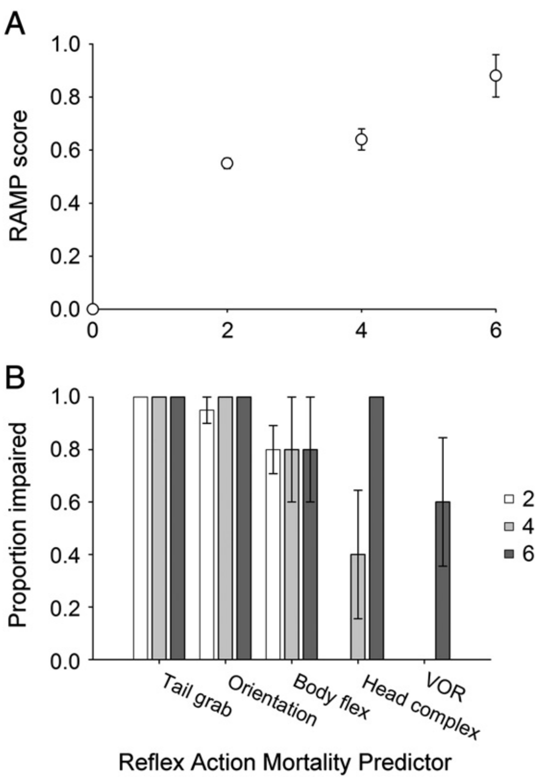

Fig. 4. (A) Reflex action mortality predictor impairment scores (mean ± SE), and (B) proportion of impairment for five impairment predictors in bonefish after 0 min (n = 30), 2 min (n = 20), 4 min (n = 5), and 6 min (n = 5) of air exposure ± SE.

3. Results

3.1. Validation of reflex impairment indices

Bonefish exhibited no reflex impairment prior to air exposure, and impairment scores increased with longer air exposure times (Fig. 4A). Air exposure times of 2–6 min resulted in all bonefish lacking a response to tail grabbing, while nearly all lacked equilibrium, and 80% of fish lacked body flex response (Fig. 4B). No impairment of head complex or VOR was observed after 2 min of air exposure. Impairment of head complex was observed after 4 min of air exposure, and VOR impairment was observed after 6 min.

Based on the responsiveness of bonefish to the RAMP indices, we used them to evaluate the utility of the recovery bags. After air exposure, bonefish released with accelerometers had similar RAMP scores between immediate release (2.8 ± 0.14) and recovery (2.7 ± 0.14) treatments. However, after retention in a recovery bag for 15 min, all bonefish had RAMP scores of zero (i.e., full recovery).

3.2. Locomotory activity

There was no significant difference in the length of bonefish in the immediate release (39.9 ± 1.1 cm fork length; mean ± SD) and recovery (39.6 ± 1.0 cm fork length; mean ± SD) treatments ($t = 0.20$ $df = 18$ $p = 0.86$). Upon release, recovered bonefish exhibited less locomotory impairment (Fig. 5) and left the release site faster than those released immediately. Bonefish held in recovery bags had a greater number of tail beats and higher tail beat amplitudes in the first 5 min post-release than those released immediately (Fig. 6). When comparing mean tail beat frequencies between treatments in 1-minute intervals for the first 10 min, there was a significant interaction between treatment and time ($F_{3,\ 45} = 4.13$, $p = 0.014$). There was also a significant interaction when comparing maximum tail beat frequencies ($F_{4,67} = 4.97$, $p = 0.002$), mean tail beat amplitudes ($F_{2.6,45} = 3.92$, $p = 0.018$), and maximum tail beat amplitudes ($F_{4,68} = 6.14$, $p < 0.001$). Bonefish retained in recovery bags exhibited significantly higher mean tail beat frequencies in the first 2 min post release, higher maximum tail beat frequencies in the first 3 min, higher mean tail beat amplitudes in the first 3 min, and higher maximum tail beat amplitudes in the first 4 min ($t > 1.74$, $df = 17$, $p < 0.05$ in all cases). Maximum tail beat frequencies and amplitudes remained higher for recovered bonefish than those immediately released for 15 min post-release (Fig. 6). One bonefish from the immediate release treatment suffered mortality from predation by a ~1.2 m great barracuda (*Sphyraena barracuda*) 9 min, 40 s post-release. No bonefish from the recovery treatment experienced mortality within 30 min post-release.

When comparing the locomotory activity between treatments during the equivalent time period post-stressor (15–25 min post-stressor), there were no significant differences between treatments in tail beat frequencies ($F_{1,\ 17} = 0.17$, $p = 0.69$), maximum tail beat frequencies ($F_{1,\ 17} = 0.85$, $p = 0.37$), mean tail beat amplitudes ($F_{1,\ 17} = 0.81$, $p = 0.38$), or maximum tail beat amplitudes ($F_{1,\ 17} = 0.85$ $p = 0.37$). However, there was an interaction effect when comparing mean tail beat amplitudes ($F_{3,\ 50} = 3.7$, $p = 0.02$). Bonefish held in recovery bags exhibited significantly higher mean tail beat amplitudes 16–17 min post-stressor ($t = 2.12$, $df = 17$, $p = 0.049$).

3.3. Post-release behavior

Upon release, recovered fish spent relatively more time swimming fast (>3 tail beats/s, >0.2 g amplitudes), while immediately released fish spent more time resting (>30% of first minute) and swimming slowly (<2 tail beats/s, and/or <0.1 g amplitudes) (Figs. 7, 8). Approximately 4–5 min post release, behavioral patterns changed. Bonefish from both treatment groups exhibited similar levels of slow and fast swimming behaviors, while immediately released fish spent more time swimming at moderate speeds (2–3 tail beats/s, 0.1–0.2 g amplitudes) while located primarily in the main creek channel. Recovered fish began spending more time resting (Fig. 8), and the majority of this resting behavior occurred while bonefish were located along the northern shoreline of the Kemps Creek, near rocky outcroppings or a red mangrove.

4. Discussion

Bonefish that were retained in recovery bags for 15 min after angling-related stress exhibited significantly greater locomotory activity in the first 4 min post-release than those immediately released, as well as higher maximum tail beat frequencies and amplitudes up to 15 min post-release. However, there was little difference in locomotory abilities between treatments when comparing equivalent time periods post-stressor, suggesting that recovery bags do not accelerate recovery rates, but provide a means for retaining bonefish; protecting them from predators for the short time period while they recover. Previous studies have shown that nearly all angling-related bonefish predation occurs within 20 min post-release, and the majority occurs within the first few minutes (Cooke and Philipp, 2004; Danylchuk et al., 2007a,b). Our results demonstrate that retaining bonefish in recovery bags for 15 min reduced locomotory impairment upon release during the critical time period where most predation occurs, and this practice has the potential to increase survival after catch-and-release angling. Presumably, retaining bonefish in a live well with ambient oxygen levels (Shultz et al., 2011) would have a similar benefit if an angler had access to a boat.

Previous studies have shown that post-release predation of bonefish varies greatly (0–40%) due to predator abundance (Cooke and Philipp, 2004; Danylchuk et al., 2007a). Predator abundance and thus risk to bonefish post-release appear to vary extensively among sites, seasons, and even years. We observed relatively few potential predators for bonefish during the study aside from a single large barracuda, which is likely the primary reason why little post-release predation was observed. Further testing is required to determine whether the reduced behavioral impairments observed here translate into improved survival in more predator rich environments. Similarly, predator abundance is an important consideration for anglers when deciding where and when to release captured bonefish.

Bonefish experience predation after being caught by anglers due to impaired swimming capabilities, and an increased ability of predators to target them through chemical cues (Dallas et al., 2010; Danylchuk et al., 2007a). Given that bonefish excrete the majority of these chemicals shortly after angling events (Dallas et al., 2010), it would be necessary to determine if predators were attracted to recovery bags when holding fish to ensure angler safety. Predators avoided researchers retaining bonefish in recovery bags during this study, however; the only predators present in the study area were juvenile lemon sharks and one large barracuda. Should there be an issue with angler safety in areas with larger sharks, recovery bags could be equipped with magnets, which are effective shark repellants (O'Connell et al., 2010; Robbins et al., 2011.).

Bonefish from the respective treatments exhibited very different temporal patterns in post-release behavior. Bonefish retained in recovery bags initially spent the majority of time swimming at moderate or fast speeds, while those immediately released spent relatively more time resting and swimming slowly. As previously discussed, this difference was likely due to greater locomotory impairment in immediately released fish. Behavioral patterns changed around 4–5 min post-release, where immediately released bonefish began to spend relatively more time swimming at moderate speeds, and recovered fish spent more time resting. During this time period, bonefish in the recovery treatment spent the majority of their time close to the shoreline, near rocky outcroppings or mangroves. It seems that recovered bonefish were using these areas as a refuge for rest and recovery. Conversely, immediately released fish spent the majority of their time swimming at

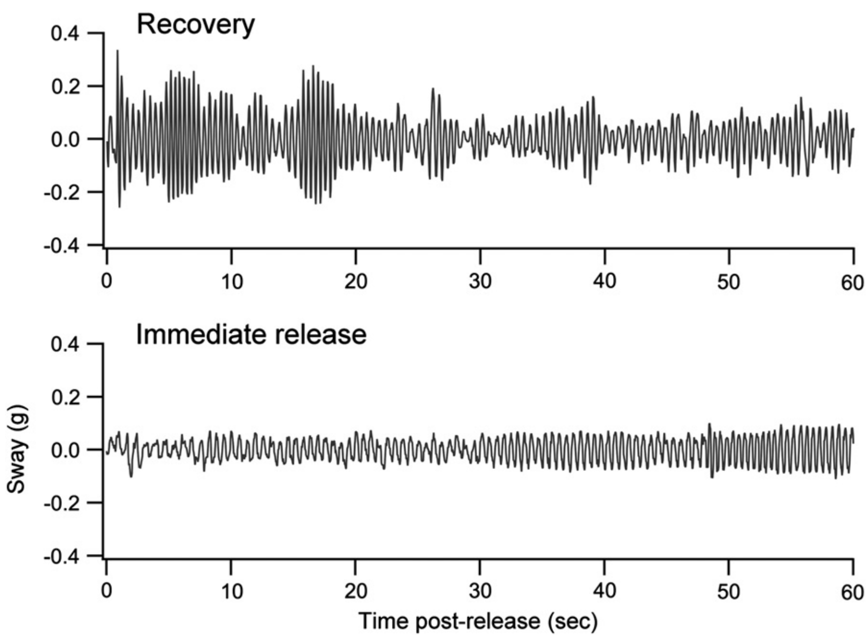

Fig. 5. Bonefish swimming activity (dynamic acceleration, g) in the sway axis measured using tri-axial accelerometers during the first minute post-release after exposure to simulated angling stress and (A) retained in a recovery bag for 15 min prior to release, or (B) immediately released. Oscillations represent individual tail beats. Data shown are from the individual bonefish that exhibited median activity levels for their respective treatments in the first minute post-release.

moderate speeds in the main creek channel, or on the flat adjacent to the creek. Indeed, the one bonefish that was depredated during this study was located in the main creek channel. A previous study also found that immediately released bonefish did not use available structures for refuge (Danylchuk et al., 2007a). Animals are known to exhibit inhibited decision-making abilities after acute stress (Shafiei et al., 2012; Starcke and Brand, 2012). Our results suggest that retaining bonefish for a short period prior to release may actually facilitate improved decision-making in terms of improving recovery and reducing predation risk. Previous studies have shown that angled northern pike (*Esox lucius*) also rest in refuge habitats after release, and experience little short-term mortality (Klefoth et al., 2008; Arlinghaus et al., 2009). However, in the case of bonefish, the ability to utilize shoreline structures for refuge likely depends on the size and location of predators, and the complexity of shoreline habitats (Danylchuk et al., 2007a).

Accelerometer loggers are novel instruments for measuring fine-scale behavior and energy expenditure of animals in the wild (Sakamoto et al., 2009; Whitney et al., 2010; Wilson et al., 2008, 2012). To our knowledge, this study is the first to use tri-axial accelerometry to measure the effects of a disturbance event on animal behavior, and in relation to angling interactions (Donaldson et al., 2008). Accelerometer loggers provided detailed and quantifiable information on bonefish activity after angling-related stress, which allowed for greater insight into how retaining bonefish in recovery bags reduces behavioral impairments. To accomplish this, we applied recently developed data analysis techniques to estimate tail beat

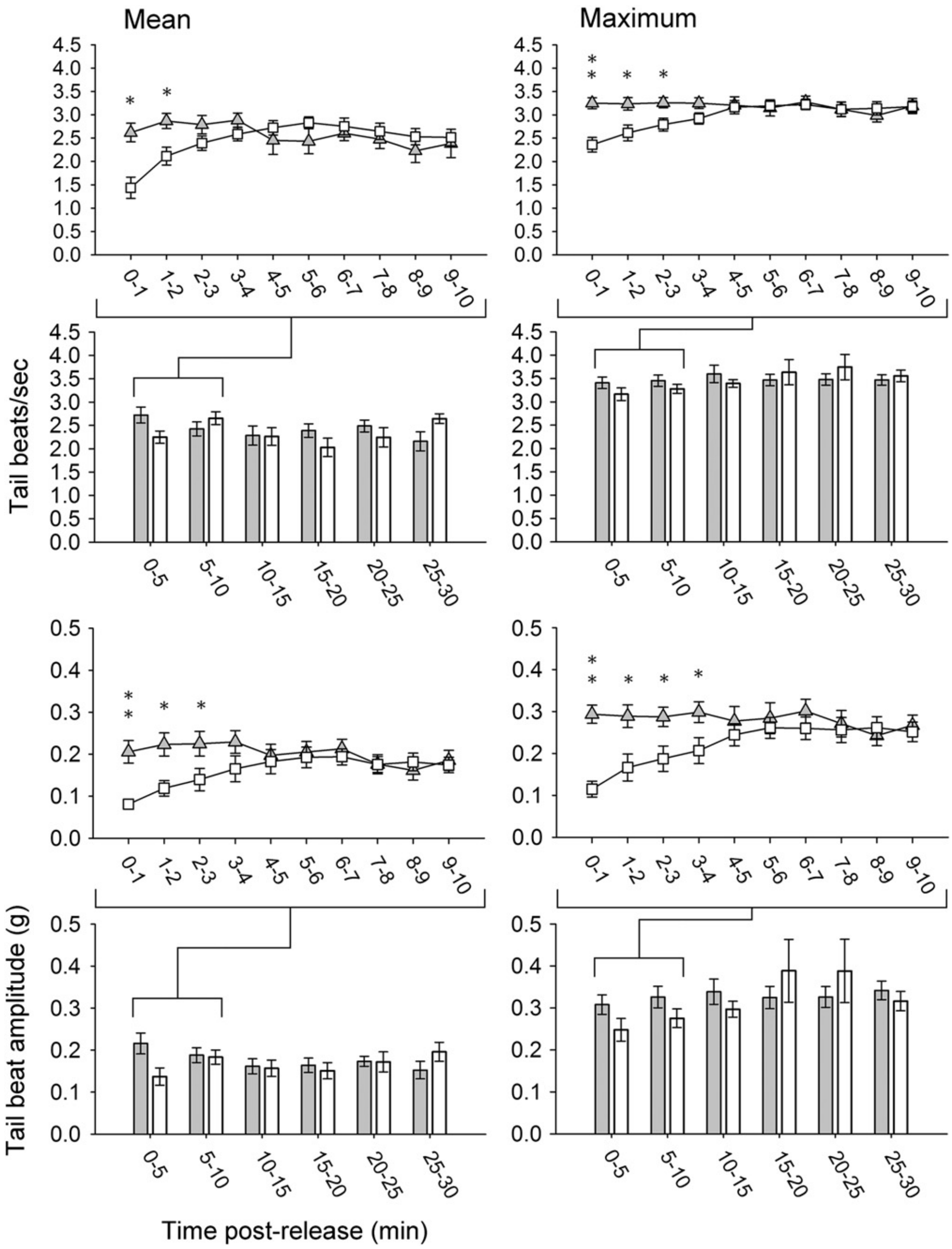

Fig. 6. Mean and maximum tail beat frequencies and amplitudes of bonefish for 30 min post-release after exposure to simulated angling stress and retained in a recovery bag for 15 min prior to release (gray; n = 10), or immediately released (white; n = 9) ± SE. * indicates $p<0.05$, ** $p<0.001$. Tail beat metrics were measured with tri-axial accelerometers and derived from continuous wavelet transformation.

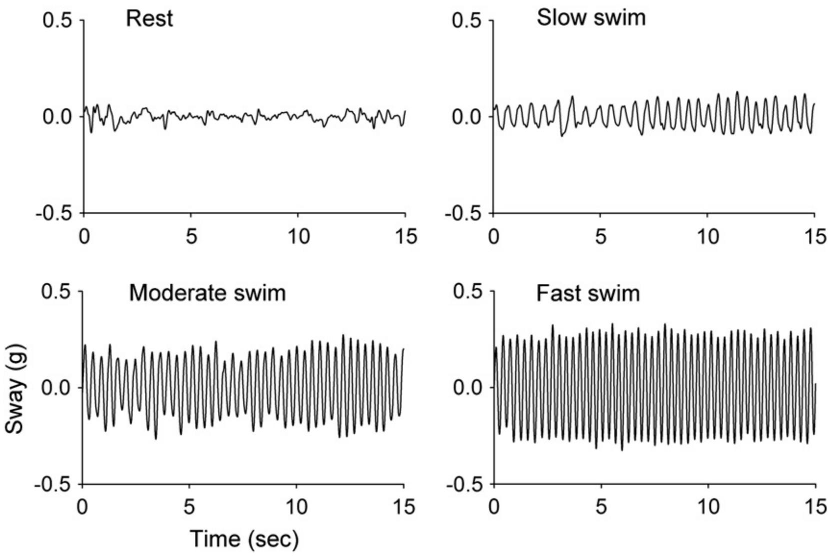

Fig. 7. Dynamic acceleration (g) in the sway axis (tail beats) categorized as resting, slow, moderate, and fast swimming behaviors. Data shown is from one bonefish; collected within 30 min after angling-related stress.

frequencies and amplitudes, and grouped this information into behavior types. While overall dynamic body action (ODBA) is currently the best proxy for energy expenditure (Gleiss et al., 2011), we elected to use tail beat metrics as an indication of bonefish vitality because post-release predation is due to behavioral impairments (Cooke and Philipp, 2004; Danylchuk et al., 2007a). The ability of bonefish to evade predators likely depends not only on their ability to move and expend energy, but to swim in a coordinated manner.

The five impairment indicators we tested on bonefish provided a gradient in impairment scores that related to the degree of stressor (i.e., 0–6 min of air exposure). RAMP scores have been correlated with stressor duration and mortality for a number of fish species (Davis, 2005, 2007; Davis and Ottmar, 2006; Humborstad et al., 2009; Raby et al., 2012). Indeed, the duration of a stressful event increases the level of physiological disturbance in bonefish (Suski et al., 2007; Donaldson et al., 2008), while longer handling times and air exposure durations result in higher post-release predation rates (Danylchuk et al., 2007a). In this study, bonefish that were equipped with accelerometers exhibited moderate impairment scores after 2 min of air exposure, while no impairment was detected after 15 min of retention in a recovery bag, and fish from the recovery treatment exhibited significantly higher levels of activity upon release. Therefore RAMP scores appear to be a good indication of bonefish vitality. Bonefish anglers may be able to use RAMP to assess bonefish condition, and make educated decisions on whether to release the fish, or retain it for a short period to facilitate recovery. Likewise, if water temperatures and bonefish impairment scores are very high, responsible anglers can recess until conditions are more favorable.

The impairment indicators tail grab, equilibrium, and body flex were the first to become impaired in bonefish, and impairment levels within these predictors did not vary with increased stress duration. This was likely because bonefish were all highly impaired at the lowest level of stress we inflicted. Indeed, a previous study found roughly that 50% of bonefish lose equilibrium after angling events (Danylchuk et al., 2007a), while 95% of bonefish lost equilibrium after simulated angling stress (2 min of air exposure) in this study. These three predictors may provide an indication of impairment levels with lesser degrees of stress. Head complex was the next to become impaired at 4 min of air exposure, followed by VOR at 6 min. Therefore head complex and VOR predictors are indicative of very high levels of physiological disturbance in bonefish. This predictor-specific pattern of impairment in bonefish is nearly identical to that of coho salmon (see Raby et al., 2012).

In conclusion, retaining bonefish in recovery bags for 15 min prior to release after simulated angling stress reduced locomotory impairment during the critical time period where post-release predation normally occurs. This practice may also promote resting behavior in possible refuge areas, further facilitating recovery and avoidance of predation. Recovery bags may also have potential to reduce mortality for other species that experience mortality after angling due to predation, such as the red snapper (*Lutjanus campechanus*) (Parker, 1985). They also have potential for improving survival after other stress events, and have been shown to reduce reflex impairment and improve survival of migrating salmonids after being caught in commercial fishing nets (Donaldson et al., in press). The impairment index tested here provided a gradient of impairment scores that were correlated to the level of stressor. Further testing should use real angling events rather than angling-related stressors (as we used here) to evaluate the extent to which these findings apply to C&R angling (Cooke et al. in press). Moreover, work to identify the optimal duration of recovery would be useful to ensure maximal benefit to the fish while minimizing effort by the angler. Finally, the use of tri-axial accelerometer loggers served as a novel tool for documenting behavioral impairments associated with angling interactions and is worthy of consideration for future C&R studies.

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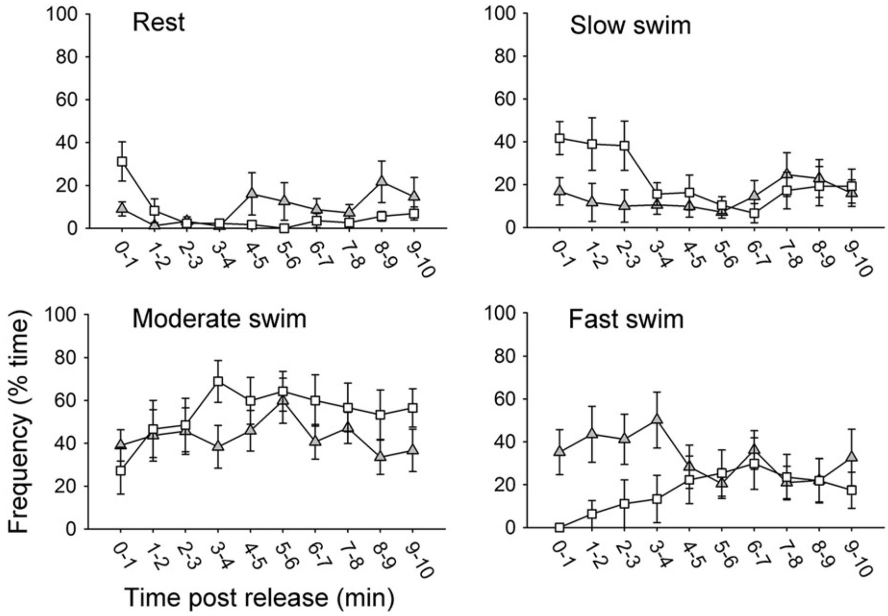

Fig. 8. Frequency of bonefish behaviors (mean ± SE) for 10 min post-release after exposure to simulated angling stress and retained in a recovery bag for 15 min prior to release (gray; n = 10), or immediately released (white; n = 9).

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