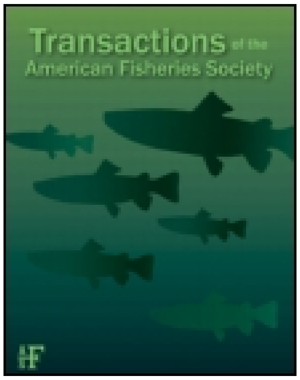

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Fishing-Related Stressors Inhibit Refuge-Seeking Behavior in Released Subadult Great Barracuda

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ARTICLE

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Abstract

Fisheries interactions that result in the capture and release of fish can cause behavioral impairments that increase the risk of postrelease predation. Increased predation risk has been attributed to reduced swimming capabilities; however, the role of refuge (structural shelter) use is still poorly understood. We examined the effect of fishing-related stressors on the ability of subadult Great Barracuda *Sphyraena barracuda* to attain refuge in an experimental wetland in Eleuthera, The Bahamas. Twenty-two Great Barracuda were either treated as controls with minimum stress, chased to exhaustion, or chased to exhaustion and air exposed for 90 s. Reflex action mortality predictors (RAMP) including ability to maintain equilibrium and bursting response were assessed prior to release at a standardized location. The prop roots of red mangrove *Rhizophora mangle* provided refuge about 5 m from the release point. Great Barracuda were visually monitored for up to 30 min postrelease to quantify behavior (resting, swimming, directional changes) and the time when refuge was reached. The RAMP scores increased with the degree of stressor, and fish in both fishing-related stressor treatments took significantly longer to reach refuge than control fish, while air exposed fish took significantly longer than fish that were only chased. Prior to reaching refuge, fish exposed to fishing-related stressors spent less time swimming, and changed directions more frequently than control fish, indicating that impaired locomotory capabilities and disorientation inhibited refuge use. The inability to find refuge after an acute stressor such as capture and release fisheries may be an important factor contributing to postrelease mortality for relevant species.

No matter the fisheries sector, a component of the catch is released. In commercial fisheries, nontarget individuals are often regarded as bycatch and, thus, discarded (Hall et al. 2000; Hall and Mainprize 2005), a phenomenon that is exceedingly common (Davies et al. 2009). In the recreational sector, catch-and-release angling is increasing in popularity due to a combination of harvest regulations and the conservation ethic of anglers (Cowx 2002; Cooke and Cowx, 2004; Arlinghaus et al. 2007). Although the release of fish from various fisheries is certainly a conservation strategy (Cooke and Cowx 2006), released fish may have reduced fitness due to physical injuries, energetic costs of recovery from physiological disturbance,

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or behavioral impairments (Davis 2002; Arlinghaus et al. 2007; Cooke and Schramm 2007). In certain environments, these behavioral impairments cause some species to be more vulnerable to predators (reviewed in Raby et al., in press).

Fisheries interactions are often associated with elevations in oxygen consumption, depletion of tissue energy stores, and associated physiological alterations (reviewed in Davis 2002; Cooke and Suski 2005) that can cause behavioral impairment postrelease (Cooke et al. 2014). Negative behavior al impacts are often attributed to reduced locomotory capabilities (Cooke et al. 2000) although recent studies on Bonefish *Albula vulpes*, suggest that refuge (structural shelter) use may also be affected, contributing to predation risk (Danylchuk et al. 2007; Brownscombe et al. 2013). Cooke et al. (2014) found that fisheries-related stressors caused cognitive impairment in Spanish Flag Snapper *Lutjanus carponotatus*, which precluded their ability to locate or evaluate potential refuge habitats up to 30 min post stressor. In general, behavior has rarely been used as an endpoint in capture and release fisheries, which is probably driven by the fact that most studies focus solely on injury or mortality as endpoints. Clearly there is opportunity to extend studies of fisheries interactions to consider potential behavioral impairments in both laboratory and field environments, given the need to improve our understanding of ecologically relevant endpoints such as behavior (Cooke et al. 2014).

Great Barracuda *Sphyraena barracuda* are a common predatory fish in tropical and subtropic oceans worldwide (de Sylva 1963). It is a popular species for recreational anglers, caught as a target species and incidentally. In addition, commercial and artisanal fisheries frequently capture barracuda using a variety of gear types, including hook and line (e.g., rod and reel, handlining). Barracuda have the potential to biomagnify ciguatera bacteria, further elevating release rates (Villareal et al. 2007; O'Toole et al. 2010). Great Barracuda live in environments with high predator burden, and smaller individuals in particular may be more vulnerable to predation postrelease by larger Great Barracuda or sharks. Subadult Great Barracuda often occupy shallow nearshore areas such as reefs and mangrove creeks, using these structurally complex habitats for refuge (de Sylva 1963; Paterson 1998). Therefore subadult Great Barracuda offered a good model for testing if and how fishing-related stressors influence refuge-seeking behavior.

The objective of this research was to examine the influence of fishing-related stressors on behavior and refuge use in subadult Great Barracuda. To do so, we used two common fishing-related stressors, exhaustive physical exercise and air exposure, and quantified behavioral impairment with a well-established index, reflex action mortality predictors (RAMP; Davis 2010; Raby et al. 2012) prior to release in an enclosed experimental wetland environment. We predicted that Great Barracuda exposed to fishing-related stressors would take longer to reach refuge due to reduced locomotory abilities, as well as nondirectional swimming associated with disorientation.

METHODS

Fish collection.—Subadult Great Barracuda were collected by seine from Page Creek (24.8212°N, −76.3106°W) in Eleuthera, The Bahamas on January 19, 2013 and brought to the Cape Eleuthera Institute for experimental testing. Great Barracuda were held in circular tanks (3.7 m diameter, 1.25 m height; 13,180 L) for 24–48 h prior to experimentation.

Stress and refuge experiments.—Great Barracuda were subjected to one of three treatments prior to release into an enclosed wetland (about 2500 m^2; see Murchie et al. 2011) via an 8-m waterslide: (1) control fish ($n = 7$; mean = 29 cm FL, SD = 3.0) were released with minimal stress (aside from handling) prior to release, (2) fish chased to exhaustion ($n = 8$; mean = 28.4 cm FL, SD = 3.4) were chased by hand in a tote (0.8 × 0.5 × 0.5 m) until they no longer responded to tail grabbing, (3) fish chased and exposed to air ($n = 7$; mean = 27.1 cm FL, SD = 5.4) were chased by hand to exhaustion and exposed to air for 90 s in a rubberized mesh net. Prior to release, Great Barracuda were assessed for five RAMP indicators, including tail grab, equilibrium, body flex, head complex, and vestibular-ocular response (VOR) (see Brownscombe et al. 2013). Tail-grab response was assessed by grabbing the fish's tail while in water; it was considered impaired if the fish did not attempt to swim away. Fish were considered to have lost equilibrium if, when rolled upside down, they failed to right themselves within 3 s. Body flex was assessed by holding the fish in air by the middle of body; a lack of attempt to struggle indicated impairment. While held in air, a lack of regular opercular beats indicated impairment of head complex. Lastly, VOR was assessed by rolling fish side to side; fish were considered impaired if their eyes did not maintain the same pitch and track the handler. Each indicator was scored as either 1 (impaired) or 0 (unimpaired), higher RAMP scores indicating greater impairment. Upon entry to the wetland, Great Barracuda were visually monitored from a raised walk bridge that stretches across the wetland for up to 30 min to record behavior (resting, swimming, directional changes) and time to refuge. Directional changes were defined as a 90° alteration in bearing by the fish. Distance to potential refuge was about 5 m in all directions, which was red mangrove *Rhizophora mangle*, in three directions, and the walking bridge in the fourth.

Data analysis.—One-way analysis of variance (ANOVA) was used to compare the fork lengths of treated fish, and there were no significant differences between treatments ($F_{2,19} = 0.33$, $P = 0.72$). Cox proportional hazard regression analysis was used to determine whether the amount of time until the fish attained refuge varied significantly between treatments. The percentage of time spent swimming prior to reaching cover, as well as the number of direction changes made by Great Barracuda were compared across treatments using Kruskal–Wallis ANOVAs with Bonferonni-corrected pairwise comparisons. Assumptions of normality and, for Cox regression, proportionality and nonlinearity, were checked prior to analysis, the level of significance was $\alpha = 0.05$. All analysis was conducted using RStudio (R Core Team 2012).

RESULTS

Great Barracuda RAMP scores increased consistently with the degree of stressor; mean scores were 0 (SD, 0) for control fish, 2.4 (SD, 0.5) for fish chased to exhaustion, and 3.4 (SD, 0.5) for fish chased to exhaustion and air-exposed (Figure 1). All but one individual found refuge in the red mangrove within 30 min postrelease. The time until Great Barracuda reached refuge varied significantly between treatments ($\chi^2 = 19.7$, $P < 0.001$; Figure 2). Great Barracuda in the chase treatment took significantly longer to reach refuge than the control treatment ($z = 2.7$, $P = 0.006$, hazards ratio = 7.5), as did Great Barracuda that were chased and air-exposed ($z = 3.8$, $P < 0.001$, hazards ratio = 44.3). Chased and air-exposed fish also took longer to reach refuge than fish that were only chased ($z = 2.2$, $P = 0.03$, hazards ratio = 5.9).

Prior to reaching cover, there was a significant difference between treatments in time spent swimming ($H_2 = 6.0$, $P = 0.04$). Control fish spent significantly more time swimming than fish chased and air-exposed ($P < 0.05$; Figure 3*a*) but not fish that were only chased. There was also a significant difference in the number of direction changes made prior to reaching cover across treatments ($H_2 = 7.2$, $P = 0.03$). Both fish chased to exhaustion and those chased and air-exposed made significantly more direction changes per minute than did control fish ($P < 0.05$; Figure 3*b*).

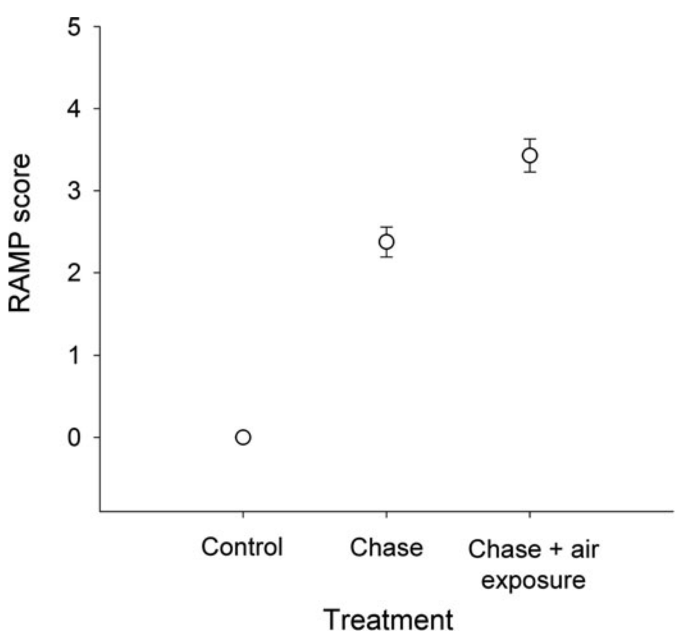

FIGURE 1. Mean and SD reflex action mortality predictor (RAMP) scores for Great Barracuda across three treatments prior to release into the wetland.

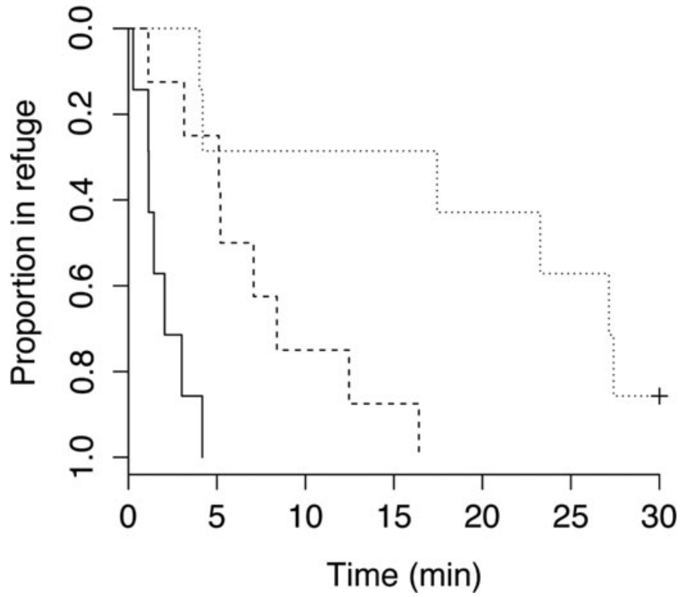

FIGURE 2. Proportion of Great Barracuda finding red mangrove refuge in the wetland across time postrelease by treatment: control (solid line), chased only (dashed), and chase + air-exposed (dotted).

DISCUSSION

Great Barracuda exposed to fishing-related stressors had higher reflex impairment (RAMP) scores and took significantly longer to reach refuge in the wetland than did control fish. Juvenile and subadult Great Barracuda are known for using mangrove and reef structure for refuge (de Sylva 1963; Paterson 1998). Indeed, the Great Barracuda in our study were collected from red mangrove habitat, and fishing-related behavioral impairment had a significant impact on their ability to return to similar refuge upon release in the experimental wetland. It is well established that fishery-related stressors cause behavioral impairment that is often correlated with mortality (Davis 2010; Raby et al. 2012), which in some ecosystems commonly involves opportunistic predators (Raby et al., in press). While there were no predators of Great Barracuda in the wetland during this study, the longer they spend in open areas away from refuge, the greater the potential risk of predation (e.g., birds, conspecifics, sharks) in the wild. Our findings support previous assertions that behavioral impairments can impact refuge use, which may contribute to higher predation risk, particularly in environments with high predator burden (e.g., shallow tropical or subtropical seas; Danylchuk et al. 2007; Brownscombe et al. 2013; Cooke et al. 2014).

While in search of refuge, Great Barracuda exposed to fishing-related stressors spent less time swimming and made more directional changes than control fish, suggesting that delayed refuge use results from both locomotory impairment and disorientation. Indeed, Cooke et al. (2014) also found fishing-related stressors affected refuge-seeking behavior of Spanish Flag Snapper, a predatory reef fish, which took longer to find

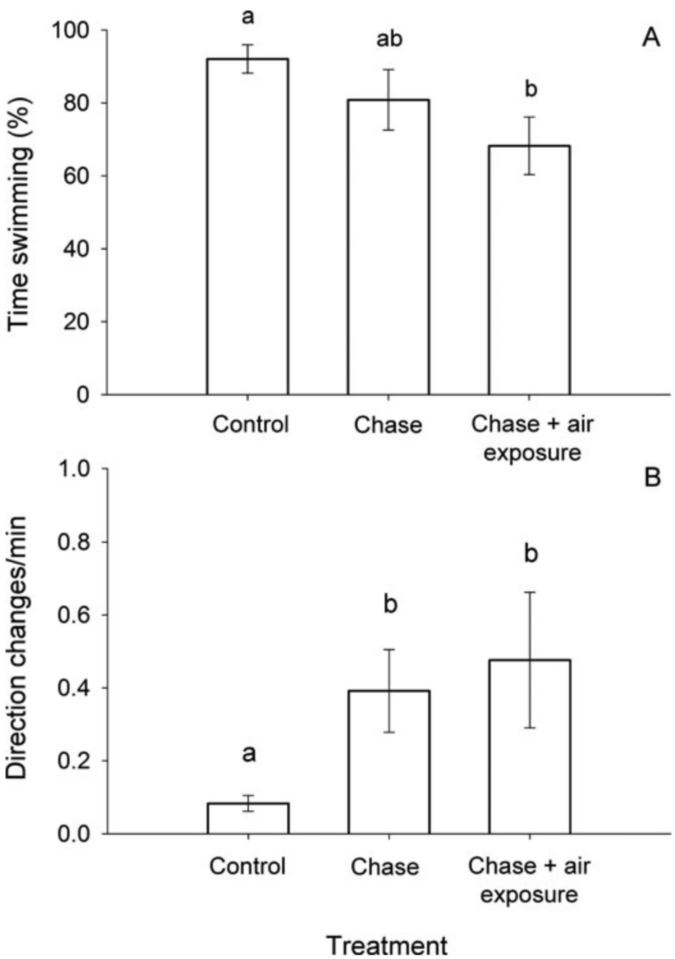

FIGURE 3. For each of three Great Barracuda treatments released in the wetland, the (**A**) time spent swimming, and (**B**) number of direction changes/min prior to reaching red mangrove cover. Bars with dissimilar letters indicate significant differences.

refuge and were more apprehensive to utilize it. Stress causes physiological disturbances that impact the function of cognitive, sensory, and locomotory systems (Wendelaar Bonga 1997; de Kloet et al. 1999; Starcke and Brand 2012). Fishing-related stressors can reduce the ability of fish to locate refuge areas, in addition to being less physically capable of swimming to refuge and to avoid predatory attack.

Great Barracuda that were only chased to exhaustion were intended to represent a relatively gentle fishing-related stressor. This treatment exhibited moderate reflex impairment (25% losing equilibrium), which has been shown to be a significant predictor of predation risk in Bonefish (Danylchuk et al. 2007). Furthermore, while fish in this treatment did not spend significantly less time swimming than control fish, they made significantly more directional changes. Impaired cognitive or visual acuity may be an important contributor to predation risk in even moderately stressed individuals. Great Barracuda that were also air-exposed, representing a harsher fishing stressor, had higher reflex impairment and took significantly longer to reach cover (due to impaired locomotory capabilities and disorientation) than did both control and chased treatments. Cooke et al. (2014) revealed that even highly stressed Spanish Flag Snapper regain the ability to attain refuge 30 min postrelease, regardless of maintaining high levels of physiological stress. This agrees with our findings, where all but one highly stressed barracuda found cover within a 30 min period. When fish exhibit high levels of reflex impairment after fishing-related stress, retention in live wells, recovery bags, or even simple plastic containers with ambient oxygen levels for a short period may improve survival by providing period for recovery of locomotory, cognitive, and visual faculties (Shultz et al. 2011; Brownscombe et al. 2013; Donaldson et al. 2013; Cooke et al. 2014).

In summary, fishing-related stressors caused behavioral impairment that influenced the ability of Great Barracuda to reach refuge habitat, probably due to a combination of impaired locomotion and disorientation. This effect is consistent with the degree of fishing-related stress, which can be effectively measured with reflex impairment indices. Disorientation may be a particularly important factor contributing to inhibited refuge use and higher predation risk in fish with moderate impairment.

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