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A novel method for determining post-release mortality, behavior, and recovery period using acceleration data loggers

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ABSTRACT

Recent declines in global fish stocks have raised questions regarding the sustainability of both extractive and catch-and-release fishing activities, and prompted efforts to quantify the total impact of fishing pressure. While at-vessel mortality rates are relatively easy to obtain, accurately assessing post-release mortality and sub-lethal behavioral effects has proven difficult. Acceleration data loggers (ADLs) represent a useful tool in post-release studies, but have yet to be fully utilized. The goal of this paper is to demonstrate the utility of ADLs in identifying mortality events, and to provide an example of recovery period quantification methods using acceleration-based swimming metrics. To illustrate the application of this method, we use sample data from blacktip sharks (*Carcharhinus limbatus*) captured and released in the Florida recreational shark fishery. Mortality events were inferred from stationary depth traces and the eventual cessation of all tailbeat activity, while posture information confirmed that the tag was still attached to the animal. We also detail how ADL data from surviving individuals were used to calculate 58 metrics of fine-scale swimming behavior. Using nonlinear mixed modeling, we found 19 of these metrics displayed a significant logistic relationship with time post-release, indicative of a recovery period. Calculated recovery periods ranged from 5.1 to 19.5 h, with a mean of 10.54 ± 3.78 h. The low cost of ADLs and their capacity for multiple deployments allows for relatively large sample sizes at a fraction of the cost of satellite tag studies. ADLs provide definitive evidence of post-release mortality, and also allow for the quantification of sub-lethal effects which can be used to measure the impact of different gear types or handling methods, even in species for which mortality events are rare.

1. Introduction

The creation and maintenance of sustainable fisheries are global challenges (Kleisner et al., 2013; Watson et al., 2013). In recent years, management initiatives that impose size restrictions and catch quotas have been considered positive steps toward conservation and sustainability (NMFS 2006; Morgan and Carlson, 2010; NOAA, 2010). However, these policies may increase bycatch (Ferretti et al., 2010; Lewison et al., 2004) and discards (Biery and Pauly, 2012; Gilman et al., 2008), and cannot be viewed as successful without a full evaluation of total fishing mortality (Molina and Cooke, 2012; Skomal, 2007; Skomal and Bernal, 2010). In fact, high bycatch mortality is often the factor preventing fisheries from being sustainable (Pelc et al., 2015). Although catch-and-release angling has been touted as a sustainable alternative to extractive fishing (Arlinghaus et al., 2007; Cooke et al., 2014), animals in these fisheries may be subjected to exhaustive exercise and stress before release, resulting in anaerobic respiration, elevated lactate levels, and respiratory acidosis (Skomal and Bernal, 2010). To better assess the ecological impacts of fishing (Hobday et al., 2011) and ensure sustainable harvest (Simpfendorfer et al., 2005), a combined assessment of immediate and post-release (cryptic) mortality is needed.

Abbreviations: ADL, acceleration data logger; VHF, very high frequency; ODBA, overall dynamic body acceleration; PSAT, pop-up satellite archival tag; VV, vertical velocity; TBAA, tailbeat acceleration amplitude; TBC, tailbeat cycle; LMM, linear mixed model; BIC, bayes information criteria; AIC, akaike information criteria.

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In addition to documenting mortality, quantifying sub-lethal behavioral changes following the stress of capture may also provide critical information for resource managers. These effects have been shown to impact mating or foraging success in some species, with possible population- and ecosystem-level implications (Arlinghaus et al., 2007; reviewed by Lewin et al., 2006). For instance, longer recovery periods may lead to increasing susceptibility of depredation following release, and could impair energy intake causing temporary starvation or mortality (Donaldson et al., 2008; Olla et al., 1995). Stress from capture may also negatively impact the immune system, growth, and reproduction (see Lewin et al., 2006 for a review). Studies that have investigated post-release behavior have done so only at low resolution; e.g., inferring recovery time from brief acoustic tracks (Gurshin and Szedlmayer, 2004; Holts and Bedrofd, 1993), Crittercam deployments (Heithaus et al., 2002; Skomal et al., 2008), or from broad-scale changes in swimming depth in pelagic species that are unlikely to be detected in coastal species (Campana et al., 2009; Skomal, 2006).

While at-vessel mortality rates are relatively easy to obtain, quantifying post-release mortality and sub-lethal behavioral effects is more difficult. Previous studies have relied on proxies of stress such as blood stress chemistry (e.g., Brooks et al., 2011; Hyatt et al., 2011) and hormone levels (Barton, 2002), tag and recapture data (e.g., Francis, 1989; Hueter et al., 2006) or satellite and acoustic telemetry (e.g., Holts and Bedrofd, 1993; Hoolihan et al., 2011; Sepulveda et al., 2015; Skomal, 2006). Although the physiological proxies have revealed high inter-specific variability in the response to capture stress (Frick et al., 2010; Hyatt et al., 2011; Mandelman and Skomal, 2009; Marshall et al., 2012), very few studies have correlated these stress values to actual animal outcomes, and the ability of these proxies to predict post-release mortality or sub-lethal effects is largely untested. Tag-recapture studies require large sample sizes of frequently caught species and may take years of recapture data collection to provide an assessment (Hueter et al., 2006). While acoustic or satellite telemetry methods can be effective for assessing post-release mortality, cost limitations may result in small sample sizes, particularly in studies of highly mobile species. Additionally, these techniques may not be well suited for analyzing sub-lethal behavioral impacts of capture stress due to track duration or data resolution. For instance, active acoustic telemetry is labor-intensive, so track durations are often limited to a few hours (e.g., Gurshin and Szedlmayer, 2004; Holts and Bedrofd, 1993; Skomal and Chase, 2002), whereas passive acoustic telemetry requires that animals remain within the limited range of stationary receiver stations (e.g., Afonso and Hazin, 2014; Kneebone et al., 2013). Satellite tag studies typically cost 5–8 times more than those using acoustic tags (excluding boat and man hours), and infer mortality by comparing tag reporting rates between species (e.g., fin-mounted platform terminal transmitters, Gallagher et al., 2014) or more directly when a negatively buoyant animal sinks to the seafloor and remains there for a predetermined time limit assumed to indicate mortality (e.g., pop-up satellite archival tags; PSATs; Campana et al., 2009; Hoolihan et al., 2011; Moyes et al., 2006; Musyl et al., 2011; Sepulveda et al., 2015). All of these telemetry methods typically involve one-time use of each tag deployed, and some may confound mortality events with tag shedding or malfunction (e.g., when mortality is inferred from a lack of detection). At best, these technologies infer mortality from a lack of vertical and/or horizontal displacement, and do not incorporate data from the physical movement or posture of the animal.

A novel, relatively inexpensive method that shows great potential for studying post-release effects is accelerometry. Acceleration data loggers (ADLs) measure tri-axial acceleration, indicating fine-scale movement and body orientation, and provide high-resolution information on a tagged animal's behavior. ADLs have been applied to a wide range of aquatic species to quantify fine-scale details of swimming dynamics and identify specific behaviors (e.g., Gleiss et al., 2009, 2010; Kawabe et al., 2003; Nakamura et al., 2011; Whitney et al., 2007, 2010), and can also be used to study energy expenditure and metabolic rate based on an animal's overall dynamic body acceleration (ODBA; Gleiss et al., 2011; Whitney et al., 2012; Wilson et al., 2006). Because of the large amount of high-resolution swimming data obtainable with ADLs, they have the potential to provide not only definitive measures of mortality, but also detailed information regarding sub-lethal behavioral effects. ADLs have been applied to the study of captive-held bonefish after angling (Brownscombe et al., 2013), but have not been widely used to study post-release behavior in free-swimming animals.

The goal of this paper is to demonstrate the utility of ADLs in identifying mortality events and quantifying recovery periods using acceleration-based swimming metrics. To illustrate the application of this methodology in a real-world context, we use sample data from blacktip sharks (*Carcharhinus limbatus*) captured and released in the Florida recreational shark fishery. Specifically, we describe the definitive evidence of mortality provided by accelerometers and demonstrate a method to use fine-scale metrics of swimming performance to test empirically for and quantify a recovery period for this species.

2. Materials and methods

2.1. Model species and tagging

Blacktip sharks are found in tropical to sub-tropical waters, and are prevalent along the southeast U.S. coast (Castro, 1996) where they have been a main target of both recreational and commercial fisheries for decades (NMFS 2006). For this study, sharks were caught by rod and reel in and around Charlotte Harbor (26° 47′ 18″ N, 82° 7′ 23″ W) and Cape Canaveral (28° 19′ 8″ N 80° 20′ 6″ W), Florida between January 2011 and April 2013. Angled sharks were secured alongside the boat with the leader and a tail rope while still in the water, at which point they were quickly measured and blood sampled via caudal venipuncture as part of another study. Two holes were drilled into the first dorsal fin to allow attachment of a custom-designed data-logger package (Fig. 1; see Whitmore et al., 2016) containing a G6a ADL (CEFAS Ltd., Lowestoft UK) set to record tri-axial acceleration at 25 Hz, depth at 1 Hz, and temperature at 0.033 Hz, as well as a VHF transmitter (MM180B, Advanced Telemetry Services, Isanti, MN, USA) for package relocation and recovery. The entire tag-float package was approximately 7 × 11 cm in size and weighed 125 g in air (70 g positively buoyant in seawater; <0.5% body mass). The tag package was secured to the left side of the dorsal fin using monofilament or plastic cable ties and a galvanic timed release (International Fishing Devices Inc., Northland, New Zealand). The galvanic release dissolved in seawater after 1–7 days, releasing the tag package and allowing it to float to the surface for recovery. In an assessment of release timing accuracy, Whitmore et al. (2016) found an overall mean variance of 1% in actual GTR release time compared to expected time. Floating tag packages were detected using a hand-held VHF receiver (R45-20C, Advanced Telemetry Systems, USA), and retrieved by vessel (see Lear and Whitney 2016).

2.2. Data processing

We analyzed the ADL data using Igor Pro ver. 6.22 (Wavemetrics, Inc. Lake Osewego, OR, USA) and Ethographer (Sakamoto et al., 2009). As certain tags displayed large depth sensor drift over the deployment, a user-defined function was created to correct the depth trace by the minimum value (assumed to represent