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Novel use of hook timers to quantify changing catchability over soak time in longline surveys

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ABSTRACT

Fishery-independent survey sampling programs frequently undergo changes in operational procedures, which have the capacity to alter the catchability coefficient, q. To preserve the continuity of the time series, changes in sampling protocol must be accounted for within the raw data. We used data from a long-standing shark longline survey as a case-study to demonstrate a method of estimating changing catch over variable soak times. Catches of longline sets with and without hook timers were modeled using generalized linear models (GLMs) to estimate catch conversion factors over varying soak times. Estimated conversion factors were used to correct the raw catch data, which were then analyzed with delta-lognormal GLMs to estimate indices of relative abundance. Uncertainty in conversion factor estimation was calculated via bootstrap resampling and propagated through to annual indices by correcting raw data using resampled conversion factors. Added variation introduced by implementation of correction factors was relatively small compared to the magnitude of the observation error of the resulting indices of relative abundance. In species where catch rate declined over soak time, the expected CPUE of shortened soak times increased relative to standard soak times. Contrarily, if catchability increased over soak time, expected CPUE decreased in shortened soak times. Thus, we showed that the predominant practice of treating each unit of sampling effort as equal in fixed, baited gear is not appropriate, and changes in soak time should be accounted for to preserve the longevity of the time series.

1. Introduction

Fishery-independent surveys are designed to estimate species relative abundance through the assumption that catch-per-unit-effort (CPUE) is proportional to abundance (N) via the catchability coefficient (q), such that CPUE = qN. Because q changes with time, space, and fishing power, survey CPUE data are often standardized by the use of generalized linear and additive models (GLMs/GAMs) structured to include covariates hypothesized to explain variation in q (Maunder and Punt, 2004). When surveys undergo operational procedure modifications, such as the use of a new gear or changes in sampling protocol, correction factors must be developed and applied to historic data to preserve the longevity of the time-series. Changes to survey operations can often affect catchability, and failure to account for those effects can lead to unreliable interpretations of CPUE data and target stock abundance.

Bottom longlines are static gear commonly used for surveys targeting large species such as sharks that may outswim mobile gear such as trawls and that are too large to be efficiently captured in gillnets. The Virginia Institute of Marine Science (VIMS) longline survey is a longstanding sampling program that targets various shark species inhabiting the lower Chesapeake Bay and mid-Atlantic Bight (Musick et al., 1993). The survey was initiated in 1973 and used primarily as a tool to collect requisite life history and ecological information on harvested shark populations. Consequently, soak times were not standardized until the mid-1990s when the emphasis of the program was augmented to provide survey data that could be used to estimate indices of relative abundance for incorporation into stock assessments (; 2011; 2013). Standardized longline soak time for this survey is currently four hours. However, within the historical VIMS longline data set (defined herein as prior to 1995), soak times ranged from 0.5 to 19 h.

Catch rates for static gears have been shown to vary as a function of soak time (Rotherham et al., 2006; Ward and Myers, 2007). Declining catch rate over the duration of a longline soak can sometimes be attributed to factors other than changes in abundance, including bait loss (deterioration, falling off hooks during sets, degradation of olfactory properties, removal by non-target species), escape of target species, predation of target species, and gear saturation (Grimes et al., 1982; High, 1980; Sigler, 2000; Ward et al., 2004). Longline CPUE are typically expressed as the number of individuals captured per k hooks per h

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hours of soak time ($k \times h$ hook-hours). However, catchability may change over time during a longline set, which calls into question the validity of treating each hour of effort the same. If catch rates decline over soak time, CPUE would be expected to decrease with increasing soak time. In other words, if catch rates do not proportionately increase with increasing soak time (i.e., catchability declines over soak time), estimated CPUE may be artificially deflated. For example, define $CPUE_1 = C_1/(100 \text{ hooks} \times h_1)$, where $CPUE_1$ is calculated from an observed catch of C_1 obtained from $100 \times h_1$ hook-hours. Assuming abundance is constant and catchability declines with soak time, a doubling of soak time ($h_2 = 2 \times h_1$) without a corresponding doubling in catch (say $C_2 = 1.5 \times C_1$) will decrease estimated $CPUE_2$ such that $CPUE_2 = 0.75 \times CPUE_1$.

In association with declining catch rates, increased soak times and protracted time spent on hooks have been shown to increase at-vessel fish mortality (Diaz and Serafy, 2005; Erickson and Berkeley, 2008; Marshall et al., 2015; Morgan and Burgess, 2007; Morgan and Carlson, 2010; Poisson et al., 2010). Post-release mortality of sharks is also positively related to time spent on hooks (Marshall et al., 2015). While it is apparent that decreasing soak times would decrease capture-related fish mortality, additional studies have suggested the existence of an optimal soak time that maximizes catch and replicability, while minimizing target and bycatch mortality (Erickson and Berkeley, 2008; Marshall et al., 2015; Rotherham et al., 2006). In an effort to quantify mortality rates of sharks caught using bottom longlines in Virginia waters, Marshall et al. (2015) noted that there exists a threshold soak time at three hours, after which total (at-vessel and post-release) mortality increases. By limiting soak times to less than three hours, total mortality would be reduced by approximately 46% in sandbar sharks (*Carcharhinus plumbeus*) and 60% in dusky sharks (*C. obscurus*; Marshall et al., 2015), two species commonly sampled by the VIMS longline survey.

Not only is the risk of increased mortality of sharks intrinsically harmful, it is particularly damaging given the population declines that several shark species experienced in the 1980s (Cortés, 2002; Musick et al., 1993, 2000; Peterson et al., 2017). Out of the seven most common species captured by the VIMS longline survey, one is listed on the IUCN Red List (IUCN, 2016) as least concern (Atlantic sharpnose shark, *Rhizoprionodon terraenovae*), three are near threatened (blacktip shark, *Carcharhinus limbatus*; spinner shark, *C. brevipinna*; tiger shark, *Galeocerdo cuvier*), and three are listed as vulnerable and currently are prohibited from commercial and recreational harvest (sandbar shark; dusky shark; sand tiger shark, *Carcharias taurus*). Further, given the capacity of the VIMS longline to interact with additional endangered and threatened species (e.g., sea turtles, several threatened shark species), effort has recently been directed at better understanding the distribution of capture times during survey operations. Data on time-at-capture can aid in optimization of field protocols and provide an analytical foundation for understanding the relationship between soak time and relative abundance.

Physical event timers, or hook timers, are extremely useful and informative tools for longline surveys. Historically, hook timers have been used to assess feeding time (Young et al., 2010), stress physiology (Brooks et al., 2012), and at-vessel (Berkeley and Edwards, 1998; Marshall et al., 2012; Morgan and Carlson, 2010) and post-release mortality due to extended hook time (Marshall et al., 2015) in an effort to minimize bycatch and target species mortality. In the current study, we utilize hook timers in a novel way to quantify and correct for changing catchability over soak time. With the use of hook timers, we present a methodology that can be used to generate correction factors for converting expected longline catches among differing levels of effort (soak times). The VIMS longline dataset will serve as a case-study to demonstrate the approach and convert total shark catch obtained from non-standard sets (soak times ≠ 4 h) to expected catch in a standard set (soak time = 4 h). While several catch comparison studies have previously been conducted (e.g., Benoit and Swain, 2003; Casey and Myers, 1998; Holst and Revill, 2009; Maki et al., 2006), few account for the increased uncertainty generated by applying correcting factors (e.g., Miller, 2013). We propose a method for uncertainty propagation, and characterize the effect of standardizing catch on resulting VIMS longline annual indices of abundance and corresponding coefficients of variation (CVs). Secondarily, in addition to converting catch to what would be expected in a standard four-hour set, we also investigated the effect of assuming a shortened standard set, defined as two hours.

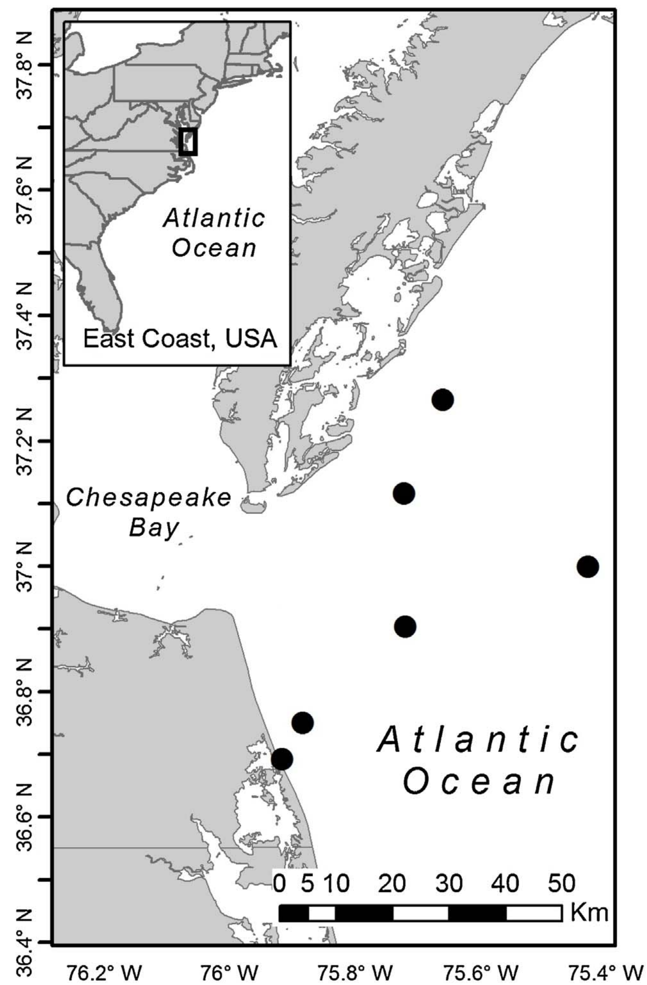

Fig. 1. The six standard, fixed stations from the VIMS longline, denoted by black dots. The VIMS longline survey samples coastal waters of Virginia, USA.

2. Materials and methods

2.1. VIMS longline survey

The VIMS longline survey is a fishery-independent sampling program that targets large and small coastal sharks in the lower Chesapeake Bay and coastal waters of Virginia using bottom longline gear. A fixed station survey design is implemented, in which one or two longlines are set for four hours within six standard sampling areas annually primarily during the months of June-September (Fig. 1). Each set consists of approximately 2400 m of 4.8 mm diameter tarred, braided nylon mainline, with 100 equally spaced gangions. Each gangion is constructed of two meters of 4.8 mm diameter tarred, braided nylon mainline attached via an 8/0 barrel swivel to one meter of 1.6 mm diameter stainless steel leader, terminating with a 9/0 Mustad J hook (model 7698 B DT). Gangions are fastened to the mainline via an 8/0 stainless steel longline snap. Norwegian buoys are placed between every 20 gangions, and each end of the mainline is anchored. Atlantic