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Relative importance of fishing and natural mortality for spotted seatrout (*Cynoscion nebulosus*) estimated from a tag-return model and corroborated with survey data

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ABSTRACT

The spotted seatrout (*Cynoscion nebulosus*) is one of the most economically important sportfish in the U.S. South Atlantic and Gulf of Mexico, including at its northern distributional extent in North Carolina and Virginia. The recent stock assessment for this region used an assumed fixed rate of natural mortality (*M*), obtained from a general life-history relationship based on weight. However, biased estimates of fishing mortality (*F*) could result if the life-history proxy failed to capture either the magnitude or temporal variation in *M*. Data from the first comprehensive tag-return study of spotted seatrout in this region were used in a Bayesian statistical modeling framework to estimate *F* and *M*. Both laboratory and field studies, including high-reward and double tagging, were conducted to obtain estimates of auxiliary parameters (i.e., tag-reporting rate, tag loss, and tagging mortality) necessary for the tag-return model. There was no measured mortality associated with tagging, but reporting rate and loss of internal anchor tags limited returns in this study. From 2008 to 2012, tag-return model estimates of bimonthly instantaneous mortality rates ranged from 0.003 to 0.067 2-mo^{-1} for *F* and from 0.002 to 2.850 2-mo^{-1} for *M*. Annual estimates of *F* were much lower than *M* for the three years studied, and annual *M*-estimates were higher than those used for spotted seatrout in this region's recent stock assessment. Bimonthly estimates of total mortality rate (*Z*) from tag-return data were similar to bimonthly estimates of *Z* from an independent analysis of concurrent gill net survey data, which corroborates the variability and magnitude of mortality estimates determined from tagging. A strong seasonal influence (i.e., winter severity) on annual loss of spotted seatrout was observed, suggesting that future assessments and management measures for this stock would be improved by explicitly accounting for temporal variation in *M* in models of fishery population dynamics.

1. Introduction

Determining the relative importance of the fishing and natural components of mortality on population dynamics is a complex, but fundamental objective of fishery stock assessments. Fishery influence on a stock is frequently measured through a variety of age-structured modeling techniques that require long-term survey (abundance) and composition (age) data from fishery-dependent and fishery-independent sampling (Gulland, 1983; Hilborn and Walters, 1992; Haddon, 2001). These estimates of fishing mortality rate (*F*) are used to establish management guidelines for allowable exploitation rate and invoke statutory directives (e.g., rebuilding criteria) to fishery managers, particularly when current harvest levels are unsustainable. Natural mortality rate (*M*) is a principal parameter of most fishery stock assessment models because of its direct relationship with population productivity. However, unlike harvest, natural deaths are rarely observed and therefore inherently more difficult to quantify (Quinn and Deriso, 1999). The general approaches to estimating *M* have been extensively reviewed and include both direct (i.e., species/stock specific) and indirect (i.e., meta-analyses or life-history correlates) methods (e.g., Brodziak et al., 2011; Then et al., 2015). Indirect estimates of *M*, such as the Hoenig (1983) longevity-based or the Lorenzen (1996) weight-based approximations, are frequently used in stock assessments because often they are the only estimates available. However, the accuracy at which these and other life-history correlates predict *M* is generally unknown (Vetter, 1988; Pascual and Iribarne, 1993;

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Kenchington, 2014). Furthermore, these proxy estimates of *M* are often assumed to be constant across age and time, though this assumption is unrealistic for most species. For example, temporal variability in natural mortality due to factors such as episodic environmental disturbances (e.g., harmful algal blooms: Gannon et al., 2009; Flaherty and Landsberg, 2011) is a major challenge for fisheries stock assessment scientists and managers (Johnson et al., 2015). Erroneous estimates of *M* can significantly bias an assessment and result in misguided management recommendations (Williams, 2002; Legault and Palmer, 2016). For example, underestimates of *M* will negatively bias estimates of population size and positively bias subsequent estimates of *F* (Clark, 1999; Maunder and Wong, 2011).

An alternative approach to estimating *F* and *M* in exploited fish populations is to model the mortality of marked fish (reviewed by Pine et al., 2012). Using auxiliary estimates of the tag-reporting rate (λ) (i.e., the fraction of tags from harvested and caught-and-released fish that are reported by the fishery), tag loss (Ω), and survival from the tagging procedure (ϕ), tag-return models can partition the instantaneous total mortality rate (*Z*) into estimates of *F* and *M* (i.e., $Z = F + M$) (Hoenig et al., 1998a). Although inaccuracies in these key auxiliary parameters will bias mortality estimates determined from tag-return data (Pollock, 1991; Pollock et al., 2001; Miranda et al., 2002; Brenden et al.,2010), appropriately designed and implemented tagging studies have generated reliable estimates of mortality for numerous fishes (e.g., den Heyer et al., 2013; Kerns et al., 2015). Another important advantage of tag-return models is the ability to estimate mortality parameters at time-scales (e.g., monthly) that can be informative about the timing and sources of mortality affecting abundance, such as a relationship between *M* and seasonal variability in temperature (e.g., Ellis et al., 2017a; Harris and Hightower, 2017).

The spotted seatrout (*Cynoscion nebulosus*) is a warm-temperate estuarine-dependent species of high economic importance throughout the U.S. South Atlantic and Gulf of Mexico. The species is most notably a valued sportfish for recreational anglers, but is also harvested commercially using primarily gill nets and haul seines in states where such fisheries are allowed, including in North Carolina where a large majority of the U.S. commercial landings of spotted seatrout originate (NCDMF, 2012; NOAA Fisheries Statistics Division open data portal). Spotted seatrout are caught year-round by both fishing sectors in North Carolina, but targeted effort and landings tend to be higher during fall and winter seasons as fish become more aggregated in overwintering areas of the upper estuary (NCDMF, 2012, 2015). Throughout the species' geographic range, episodic mass mortalities of spotted seatrout have been attributed to periods of low temperature extremes (Storey and Gudger, 1936; Gunter and Hildebrand, 1951; Moore, 1976; McEachron et al., 1994; NCDMF, 2012). In North Carolina and Virginia specifically, spotted seatrout are at the species' northern latitudinal limits and are therefore regularly exposed to lethal winter conditions (Ellis et al., 2017a). A recent stock assessment completed by the North Carolina Division of Marine Fisheries (NCDMF), where age-specific *M* was fixed across time using a general life-history relationship based on weight, concluded that the spotted seatrout population in North Carolina and Virginia was not overfished during the 22-year time series (1991–2012) (NCDMF, 2015). However, biased estimates of *F* could result if the life-history proxy failed to capture either the magnitude or temporal variation in *M*. Understanding the relative importance of harvest and winterkill on population dynamics is essential for effective management of the spotted seatrout fishery in this region.

We used data from the first comprehensive tag-return study of spotted seatrout in North Carolina and Virginia to estimate bimonthly *F* and *M* between 2008 and 2012. Both laboratory and field studies were conducted to obtain estimates of auxiliary parameters (e.g., λ, Ω, and ϕ) necessary for the tag-return model. Using recent advancements in the Hoenig et al. (1998a, 1998b) instantaneous rates formulation of the Brownie et al. (1985) model, we developed an integrated tag-return model in which mortality rates and auxiliary parameters were estimated jointly to more adequately assess model uncertainty (e.g., Polacheck et al., 2006; Jiang et al., 2007a; Bacheler et al., 2009). We also use eight years (2008–2015) of fishery-independent survey data collected monthly by the NCDMF to estimate bimonthly and annual *Z* for comparison to tag-return estimates. The estimates of mortality from this study provide managers with new critical information about temporal variation in and the relative importance of *F* and *M* for spotted seatrout in the northern extent of the species' geographic range.

2. Methods

Data from two independent, but concurrent studies were used in separate models of spotted seatrout mortality: (1) a multiyear, reward-based external tagging initiative by North Carolina State University (NCSU) and (2) a coastwide fishery-independent gill net survey conducted by the NCDMF. The methodologies used to collect and analyze these data are detailed below. Symbols used throughout this article are listed and defined in Appendix A.

2.1. NCSU multiyear tag-return study

2.1.1. Tagging procedure

From September 2008 through October 2012, spotted seatrout were continually tagged and released each month throughout North Carolina and Virginia. With the assistance of ten guide-service professionals who were compensated, spotted seatrout were predominantly captured using standard hook-and-line methods. Only mouth-hooked individuals that did not exhibit any physical signs of trauma (e.g., bleeding or visible tissue damage) were considered candidates for tagging. A limited number of spotted seatrout were also captured for tagging using electrofishing. All taggers were trained and periodically assessed to help ensure consistency in handling and tagging methodology.

Internal anchor tags (Model FM-95W; Floy Tag, Inc.) were inserted ventrally through a small incision just posterior of the pelvic fin. All tags were labeled with a unique identification number, a toll-free phone number, the name of the research organization (i.e., NCSU), and instructions to return the tag for a reward. The tag number, date, fish total length (TL; mm), and location associated with each individual release were recorded.

Approximately 15% of released individuals received a red, high-reward (US $100) tag, specifically labeled with "CUT TAG $100 REWARD", to estimate tag-reporting rate. All other individuals were released with a yellow, standard-reward (US $5, hat, or t-shirt) tag bearing the label "CUT TAG REWARD." Approximately 25% of fish with standard rewards received two internal anchor tags, one on either side of the body, to allow for estimation of the tag-loss rate. The order of tag types (i.e., reward value and number of tags per fish) was randomized; see Section 2.1.2 for further details regarding the high-reward and double-tagging methods.

Information on recaptured spotted seatrout with tags was obtained directly from fishery participants. Reporting of tagged fish was promoted by advertising across several media outlets throughout the study. Data consisting of the tag number(s), date and location of recapture, fish TL, general condition and number of tags, fishery sector, and fate of the fish and tag (i.e., kept, released with tag intact, or released with tag cut off) were determined during a follow-up phone interview.

2.1.2. Tag-return model

One major advantage of using tag-return studies to estimate mortality rates is that they allow for a known cohort size (i.e., initial number of tag releases). Numerous assumptions regarding the tagged population relative to the untagged population must be met to use tag-return data to estimate *F* and *M* (Ricker, 1975; Youngs and Robson, 1975):

1. Tagged individuals mix completely with the untagged population