Fisheries Research 145 (2013) 66–75

Contents lists available at SciVerse ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Application of Generalized Linear Models and Generalized Estimation Equations to model at-haulback mortality of blue sharks captured in a pelagic longline fishery in the Atlantic Ocean

Rui Coelho[a,*], Paulo Infante[b], Miguel N. Santos[a]

[a] Instituto Português do Mar e da Atmosfera (IPMA I.P.), Avenida 5 de Outubro s/n, 8700-305 Olhão, Portugal
[b] Centro de Investigação em Matemática e Aplicações (CIMA-UE) e Departamento de Matemática, ECT da Universidade de Évora, Rua Romão Ramalho 59, 7000-671 Évora, Portugal

ARTICLE INFO

Article history:
Received 31 July 2012
Received in revised form 29 January 2013
Accepted 16 February 2013

Keywords:
Generalized Estimation Equations
Generalized Linear Models
At-haulback mortality
Longline fisheries
Pelagic sharks

ABSTRACT

At-haulback mortality of blue shark (*Prionace glauca*) captured by the Portuguese pelagic longline fishery targeting swordfish in the Atlantic was modeled. Data was collected by onboard fishery observers that monitored 762 fishing sets (1 005 486 hooks) and recorded information on 26 383 blue sharks. The sample size distribution ranged from 40 to 305 cm fork length, with 13.3% of the specimens captured dead at-haulback. Data modeling was carried out with Generalized Linear Models (GLM) and Generalized Estimation Equations (GEE), given the fishery-dependent source of the data. The explanatory variables influencing blue shark mortality rates were year, specimen size, fishing location, sex, season and branch line material. Model diagnostics and validation were performed with residual analysis, the Hosmer–Lemeshow test, a receiver operating characteristic (ROC) curve, and a 10-fold cross validation procedure. One important conclusion of this study was that blue shark sizes are important predictors for estimating at-haulback mortality rates, with the probabilities of dying at-haulback decreasing with increasing specimen sizes. The effect in terms of odds-ratios are non-linear, with the changing odds-ratios of surviving higher for the smaller sharks (as sharks grow in size) and then stabilizing as sharks reach larger sizes. The models presented in this study seem valid for predicting blue shark at-haulback mortality in this fishery, and can be used by fisheries management organizations for assessing the efficacy of management and conservation initiatives for the species in the future.

1. Introduction

In the Atlantic Ocean several pelagic shark species are common bycatch on pelagic longline fisheries (e.g. Buencuerpo et al., 1998; Petersen et al., 2009; Simpfendorfer et al., 2002) but information on their life history, population parameters and the effects of fisheries on these populations is still limited. Generally, elasmobranchs have K-strategy life cycles, characterized by slow growth rates and long lives, and reduced reproductive potential with few offspring and late maturity. The natural mortality rates are usually low, and increased fishing mortality may have severe consequences on these populations with declines occurring even at relatively low levels of fishing mortality (Smith et al., 1998; Stevens et al., 2000). Of the several elasmobranch species caught in surface pelagic longline fisheries, the blue shark (*Prionace glauca*, L. 1758), is the most frequently caught species, and can represent more than 50% of the total fish catch, and 85–90% of the total elasmobranch catch (Coelho et al., 2012a).

Previous studies have focused elasmobranch mortality during fishing operations, with many carried out for coastal species caught in trawl fisheries (e.g. Mandelman and Farrington, 2007; Rodriguez-Cabello et al., 2005). For pelagic elasmobranchs, Campana et al. (2009) analyzed blue sharks captured by the Canadian pelagic longline fleet and studied both the short term mortality (recorded at-haulback) and the longer term mortality (recorded with satellite telemetry). Also for the NW Atlantic, Diaz and Serafy (2005) worked with data from the U.S. pelagic fishery observer program and analyzed factors affecting the live release of blue sharks. Additionally, several authors have addressed the possible effects of gear modifications such as hook style and leader material on both the catch rates and mortalities of pelagic elasmobranchs (e.g. Afonso et al., 2011, 2012; Kerstetter and Graves, 2006; Yokota et al., 2006).

Knowledge on the at-haulback mortality (recorded at time of fishing gear retrieval) can be used to evaluate conservation and management measures that include the prohibition to retain particular vulnerable species, such as those recently implemented

* Corresponding author. Tel.: +351 289 700 520; fax: +351 289 700 535.
E-mail addresses: rpcoelho@ipma.pt, coelho.ruip@gmail.com (R. Coelho).

0165-7836/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fishres.2013.02.010

by some tuna Regional Fisheries Management Organizations (tRFMOs). In particular and for the Atlantic Ocean, the International Commission for the Conservation of Atlantic Tunas (ICCAT) has recently implemented mandatory discards for the bigeye thresher (ICCAT Rec. 09-07), the oceanic whitetip (ICCAT Rec. 10-07), hammerheads (ICCAT Rec. 10-08) and silky sharks (ICCAT Rec. 11-08). However, at-haulback fishing mortality remains largely unknown, and therefore the efficiency of such measures also remains unknown. Considering that all specimens of these particular species are now being discarded, fishing mortality is still occurring due to at-haulback mortality, as part of the catch is already dead at time of fishing gear retrieval and is therefore being discarded dead (Coelho et al., 2012b).

At-haulback mortality studies are also important as they can be incorporated into stock assessments, such as the study by Cortés et al. (2010), which used an ecological risk assessment analysis for eleven species of elasmobranchs captured in pelagic longlines in the Atlantic Ocean. With this analysis, both the susceptibility and the productivity of each species are analyzed in order to rank and compare their vulnerability to the fishery. One of the parameters that can be included in the susceptibility component is the probability of survival after capture, which can in part be calculated from the mortality at-haulback.

This study had two main objectives: (1) to predict at-haulback mortality of blue sharks captured in the Portuguese pelagic longline fishery targeting swordfish in the Atlantic Ocean, comparing GLM and GEE models and, (2) to identify and interpret variables that significantly influence the blue shark at-haulback mortality rates.

2. Materials and methods

2.1. Data collection

Data for this study was collected by fishery observers from the *Portuguese Sea and Atmospheric Research Institute* (*IPMA*, *I.P.*) placed onboard Portuguese longliners targeting swordfish along the Atlantic Ocean. The fishing gear typically used by this fleet consists of a standard monofilament polyamide mainline set for fishing at depths of 20–50 m below the surface. Usually the line is set with five branch lines between pairs of buoys, with each branch line having approximately 18 m in length and a hook in the terminal tackle. The hooks used by the fleet are typically stainless steel J-style hooks, baited either with squid (*Illex* spp.) or mackerel (*Scomber* spp.). Both monofilament and multifilament wire branch lines are used, but only one type is used per fishing set. Gear deployment traditionally begins at around 17:00, with haulback starting the next day from about 06:00. Data was collected between August 2008 and December 2011, and during that period information from a total of 762 longline sets, corresponding to 1 005 486 hooks, was collected. The study covered a wide geographical area (from both hemispheres) of the Atlantic Ocean (Fig. 1).

For every specimen caught, the onboard fishery observers recorded the species, specimen size (FL, fork length measured to the nearest lower cm), sex and at-haulback condition (alive or dead at time of fishing gear retrieval). The condition of the sharks at fishing gear retrieval (alive or dead) was categorized based on any responsiveness from the sharks indicating that specimens were alive. For each longline set carried out some additional information was recorded, including date, geographic location (coordinates: latitude and longitude), number of hooks deployed in the set, and branch line material used (monofilament or wire). Sea Surface Temperature (SST) was interpolated from satellite data using the known date and location of each fishing set, applying the algorithm described by Kilpatrick et al. (2001), and using the Marine Geospatial Ecology Tools (MGET) developed by Roberts et al. (2010).

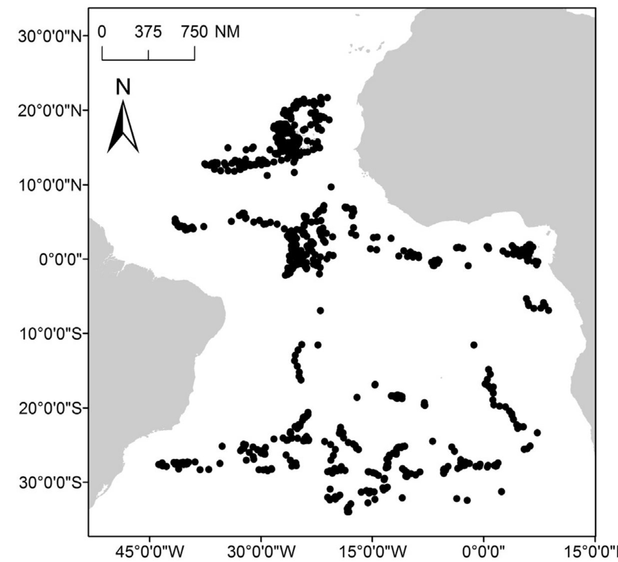

Fig. 1. Location of the longline fishing sets analyzed in this study along the Atlantic Ocean. The scale bar is represented in nautical miles (NM).

2.2. Description of the data

The length frequency distribution of male and female blue sharks was analyzed, and compared with a 2-sample Kolmogorov–Smirnov test and a Mann Whitney rank sum test. Those non-parametric tests were chosen after calculating the skewness and kurtosis coefficients, and confirming that the data were non-normal with a Lilliefors test. The proportions of dead and alive blue sharks were calculated for each level of each categorical variable (trip, sex, year, quarter, vessel, branch line material), and the differences in the proportions were compared with contingency tables and chi-square statistics (using Yates' continuity correction in the cases of 2 × 2 tables). For this preliminary contingency table data analysis, the continuous variables FL, latitude, longitude and SST were categorized by their quartiles.

2.3. Data modeling

Generalized Linear Models (GLMs) and Generalized Estimation Equations (GEEs) were used to model blue shark at-haulback mortality, and compare the odds of a shark being dead at-haulback given the various variables considered. The response variable was the condition of the specimens at time of haulback (Y_i: binominal variable, i.e., dead or alive), and for this study we considered that the event occurred if the shark died during the fishing operation. Therefore, the response variable was coded with 1 for sharks dead at-haulback and with 0 for sharks alive at-haulback.

Each captured shark (Y_i) follows a Bernoulli distribution with p_i (probability of success/dying at-haulback = π_i), and can be specified as:

$$Y_i \sim B(1, \pi_i)$$

With the expected value and the variance defined by:

$$E(Y_i) = \pi_i$$

$$Var(Y_i) = \pi_i \times (1 - \pi_i)$$