Fisheries Research 102 (2010) 229–239

Contents lists available at ScienceDirect

Fisheries Research

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

Inferring shark population trends from generalized linear mixed models of pelagic longline catch and effort data

Julia K. Baum[a,*], Wade Blanchard[b]

[a] Department of Biology, Dalhousie University, Halifax, Nova Scotia B3H 4J1, Canada
[b] Department of Mathematics and Statistics, Dalhousie University, Chase Building, Halifax, Nova Scotia B3H 3J5, Canada

ARTICLE INFO

Article history:
Received 18 September 2009
Received in revised form
13 November 2009
Accepted 19 November 2009

Keywords:
Bycatch
Blue shark
Catch per unit effort
Generalized linear mixed models
Pelagic longline

ABSTRACT

We estimate recent (1992–2005) trends in relative abundance for Northwest Atlantic oceanic and large coastal sharks, using generalized linear mixed models to standardize catch rates of eight species groups as recorded by U.S. pelagic longline fishery observers. Models suggest precipitous (76%) declines in hammerhead (*Sphyrna* species) and large coastal (dusky, night, and silky shark, genus *Carcharhinus*) species, and moderate declines (53%) in blue and oceanic whitetip sharks over this period. In contrast, mako and thresher sharks appear to have stabilized, and the tiger shark population appears to be increasing. A comparison of nominal shark catch rates from this fleet's observer and logbook data (to evaluate the veracity of trends previously estimated from the latter) showed a high degree of concordance for each species group, both in individual sub-areas and overall. Models of these two datasets for the common time period (1992–2000) show that compared to the observer data the logbook data indicate greater declines for some species, but lesser declines for others. Signs of recovery for some shark species are encouraging, but must also be set in the context of the significant declines that occurred in previous decades.

1. Introduction

Concern about increased exploitation of sharks, coupled with the inherent vulnerability to overexploitation of many of these species, has brought this group of fishes to the forefront of marine conservation in recent years (FAO, 1998, 2000; Musick et al., 2000; ICCAT, 2004; CITES, 2006; Anon, 2009). Large pelagic sharks are circumglobally distributed top predators and among the most heavily exploited sharks (Camhi et al., 2008a; Dulvy et al., 2008). Species in this group, which includes wide-ranging oceanic sharks such as blue (*Prionace glauca*) and mako (*Isurus* species) and more coastal tiger (*Galeocerdo cuvier*) and hammerhead (genus *Sphyrna*) species, comprise the majority of those traded in Asia's shark fin trade (Clarke et al., 2006) and are also increasingly sought after for their meat (Hareide et al., 2007).

Quantifying the impacts of exploitation remains a challenge for most shark populations because of a paucity of data (Camhi et al., 2008a). Few stock assessments have been conducted for sharks, and results for many of those that have been were uncertain (e.g. ICCAT, 2008). Indices of abundance are key components of the complex population dynamics models used in stock assessments (Maunder and Punt, 2004), and also important indicators of the direction and magnitude of changes in abundance for the many shark species for which there are inadequate catch records and biological information to conduct stock assessments.

Estimating unbiased indices of abundance for large pelagic sharks is, however, complicated by several factors (Camhi et al., 2008b). Distributed in epipelagic and upper mesopelagic waters, these species are rarely caught in fishery-independent research surveys. Surveys that have sampled sharks often are limited by low sample size to provide estimates only for the most frequently caught coastal species. Conversely, fisheries sample intensely over large regions closer in size to the geographic ranges of shark populations, but are much more variable than designed research surveys making standardization of the catch rates a challenge (Maunder and Punt, 2004; Bishop, 2006). What is more, there is a dearth of long-term fishery-dependent data for sharks: most commercial fisheries began recording shark catches at the species level only in the 1990s, and reliable species identification remains a challenge. There also is a tradeoff between logbook data, which are self-reported by fishermen, and scientific observer data, which should be more accurate but often monitor only a small proportion of commercial fleets. The situation is exacerbated for oceanic sharks because much of their exploitation occurs on the high seas, where their catches are unrestricted and often un- or under-reported (Camhi et al., 2008b).

In the Northwest Atlantic Ocean, one of the most data-rich regions for sharks, many large pelagic shark species appear to

* Corresponding author at: National Center for Ecological Analysis and Synthesis, UCSB, 735 State St. Suite 300, Santa Barbara, CA 93101, USA.
Tel.: +1 805 892 2517, fax: +1 805 892 2510.
E-mail addresses: juliakbaum@gmail.com (J.K. Baum), wade.blanchard@dal.ca (W. Blanchard).

0165-7836/$ – see front matter
doi:10.1016/j.fishres.2009.11.006

have declined significantly (Musick et al., 1993; Simpfendorfer et al., 2002; Baum et al., 2003; Ha, 2006; Myers et al., 2007; Aires-da-Silva et al., 2008). For example, two dedicated shark-targeted longline surveys conducted annually on the U.S. east coast since 1972 and 1974 respectively, have provided valuable multi-decadal records for many large coastal shark species; analyses of these data indicate substantial declines in dusky, tiger, blacktip and sandbar sharks (Ha, 2006; Myers et al., 2007). Examination of fisheries logbooks from 1986 to 2000 also suggested significant changes in large pelagic shark population abundance in this region, ranging from 40% declines for two mako shark species up to 89% declines for three hammerhead species (Baum et al., 2003). In those analyses, generalized linear models (GLM) were fitted to the non-zero catches with the truncated negative binomial distribution to avoid the potential bias of any change in fishermen's tendency to record shark catches over time (Baum et al., 2003). Six additional analyses using different statistical distributions and subsets of the data (based on the tendency of sharks to be recorded on different vessels) led to some quantitative differences in trends, but similar conclusions of significant declines in abundance (Baum et al., 2003, Supplementary Online Material). That research has, however, been criticized for inferring trends in abundance from a single data source, particularly since the data were from logbooks (Burgess et al., 2005, but see rebuttal in Baum et al., 2005, and analyses of additional data sources in Myers et al., 2007).

To address these concerns and to examine more recent changes, here we build upon this earlier research by using the U.S. Atlantic pelagic longline fishery's observer monitoring program data: (i) to describe the spatial distribution and concentrations of large pelagic sharks in the Northwest Atlantic Ocean, (ii) to estimate trends in their relative abundance using the most recent available observer data (1992–2005), (iii) to compare these data and estimates to those from the same fleet's logbook data, and (iv) to suggest improvements for future observer data collection and models.

Table 1
Total number of each shark species recorded in the U.S. Atlantic pelagic longline observer program between 1992 and 2005. Analyzed species are classified as either oceanic or large coastal sharks according to the U.S. Atlantic Highly Migratory Species Fishery Management Plan (NMFS, 2006). Species are grouped as in analyses. Species recorded fewer than 5 times not shown.

Species		Number caught
Common name	Latin name	
Oceanic sharks		
Blue	*Prionace glauca*	28,317
Mako sharks	*Isurus* species	3,433
Shortfin mako	*I. oxyrinchus*	2,705
Longfin mako	*I. paucus*	217
Unidentified makos	*I.* species	511
Thresher sharks	*Alopias* species	921
Bigeye thresher	*A. superciliosus*	627
Common thresher	*A. vulpinus*	148
Unidentified thresher	*A.* species	146
Oceanic whitetip	*Carcharhinus longimanus*	506
Porbeagle[a]	*Lamna nasus*	192
Large coastal sharks		
Hammerhead sharks	*Sphyrna* species	1,292
Scalloped hammerhead	*S. lewini*	742
Great hammerhead	*S. mokarran*	93
Smooth hammerhead	*S. zygaena*	15
Unidentified hammerhead	*S.* species	442
Tiger shark	*Galeocerdo cuvier*	1,190
Coastal group 1[b]	*Carcharhinus* species	7,212
Dusky shark	*C. obscurus*	1,924
Night shark	*C. signatus*	1,649
Silky shark	*C. falciformis*	3,639
Coastal group 2[b]	*Carcharhinus* species	9,799
Bignose shark	*C. altimus*	47
Blacktip shark	*C. limbatus*	125
Bull shark	*C. leucas*	42
Sandbar shark	*C. plumbeus*	550
Spinner shark	*C. brevipinna*	31
Sand tiger shark[a]	*Carcharias taurus*	6
Other shark species		
Atlantic sharpnose shark[a]	*Rhizoprionodon terraenovae*	20
Collared dogfish[a]	–	6
Crocodile shark[a]	*Pseudocarcharias kamoharai*	162
Reef shark[a]	–	7
Smooth dogfish[a]	*Mustelus canis*	59
Spiny dogfish[a]	*Squalus acanthias*	95
Unidentified dogfish[a]	–	38
		Unidentifiedsharks
Unidentified requiem sharks	*Carcharhinus* species	179
Unidentified sharks	–	1,613
Total (all sharks)		46,052

[a] Species not included in analysis because of small sample size.
[b] Coastal group 1 includes dusky, night, silky shark. Coastal group 2 includes Coastal group 1, plus bignose, blacktip, bull, sandbar, spinner and all unidentified sharks.

2. Methods

2.1. Data and shark species

The U.S. Atlantic pelagic longline fishery is the major source of exploitation for large pelagic fishes off North America's east coast (Hoey and Moore, 1999; Beerkircher et al., 2002; Mandelman et al., 2008). The fleet primarily targets swordfish (*Xiphias gladius*) and yellowfin tuna (*Thunnus albacares*); substantial numbers of sharks are also caught, mainly as bycatch.

We obtained the observer and logbook data for this fleet, both of which include counts of the sharks caught per longline set. The logbook dataset used here is identical to that of Baum et al. (2003), spanning from 1986 to 2000, and comprising over 214,000 sets and 110 million hooks. Scientific sampling of the fleet was initiated in 1992 under the National Marine Fisheries Service's (NMFS) Pelagic Observer Program (POP), and observers have monitored between 2.2 and 11.5% of the sets (mean = 5.5%) in the fishery each year since (Beerkircher et al., 2004). We obtained the observer data from NMFS Southeast Fisheries Science Center (SEFSC), and met with and emailed POP staff to discuss the fishery, observer program, and dataset. These data were available from 1992 to 2005 and (excluding sets in the experimental fishery conducted to test measures for reducing sea turtle bycatch) totaled 6952 sets and over 4.8 million hooks. Detailed information on this observer program is available on the NMFS SEFSC website (http://www.sefsc.noaa.gov/pop.jsp).

Both datasets underwent extensive checks prior to analyses. Logbook data corrections and selection criteria are detailed in Baum (2002) and Baum et al. (2003); notable among these was the exclusion of sets that used bottom longline gear (to target large coastal sharks) or pelagic longline gear to directly target sharks. There were no bottom longline sets in the observer data, and we excluded the few shark-targeted pelagic sets ($n = 32$) because their uneven distribution in the time series and high shark catches could have biased conclusions about shark population trends. We performed summary statistics, plots, and range checks on all variables of interest in the observer data, and corrected obvious errors. For example, implausible dates and locations (e.g. on land) could often be corrected using information from other sets on the same fishing trips. Any outstanding queries were discussed with POP staff and corrected wherever possible.

Observers have recorded over twenty-five shark species in this fishery (Table 1). Blue, tiger, and oceanic whitetip sharks are easily identified and were caught in sufficient numbers to model their catch rates (Table 1). Hammerhead (*Sphyrna* spp.), thresher (*Alopias* spp.), mako (*Isurus* spp.), and requiem (*Carcharhinus* spp.) sharks