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Short communication

Mortality of marine megafauna induced by fisheries: Insights from the whale shark, the world's largest fish

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ABSTRACT

The expansion of human activities is endangering megafauna in both terrestrial and marine ecosystems. While large marine vertebrates are often vulnerable and emblematic species, many are considered to be declining, primarily due to fisheries activities. In the open ocean, certain fisheries improve their efficiency of detecting tuna schools by locating and fishing close to some macro-organisms, such as whale sharks or marine mammals. However, collecting accurate data on the accidental capture and mortality of these organisms is a complex process. We analyzed a large database of logbooks from 65 industrial vessels with and without scientific observers on board (487,272 and 16,096 fishing sets since 1980 and 1995 respectively) in both the Atlantic and Indian Oceans. Distribution maps of Sightings Per Unit of Effort highlights major hotspots of interactions between the fishery and whale sharks in the coastal area from Gabon to Angola in the Atlantic from April to September, and in the Mozambique Channel in the Indian Ocean between April and May. The incidence of apparent whale shark mortality due to fishery interaction is extremely low (two of the 145 whale sharks encircled by the net died, i.e. 1.38%). However, these two hotspots presented a relatively high rate of incidental whale shark capture. Thus, we underline the importance of estimating long-term post-release mortality rates by tracking individuals and/or by photographic identification to define precise conservation management measures.

1. Introduction

The rapid expansion of human activities threatens megafauna in both terrestrial and marine ecosystems (Schipper et al., 2008; Hoffmann et al., 2010). While the oceans encompass habitats of some of the earth's largest species and longest evolutionary history, there is increasing evidence of declines in populations of large marine vertebrates, including those of little or no commercial value such as marine mammals, sharks, rays, sea turtles and seabirds (Lewison et al., 2004; Read et al., 2006; Wallace et al., 2011; Dulvy et al., 2013; Senko et al., 2014). These declines can potentially impact ecosystem functioning, including extensive cascading effects on lower trophic levels (Ferretti et al., 2010; Estes et al., 2011), and/or further threaten species already considered at risk (Gilman, 2011). In addition, the recovery of these species may be difficult due to delayed life history features (e.g. slow growth, late maturity, and long life-spans).

In light of these declines, attention has focused on the ecological impacts of bycatch (i.e. catches of non-targeted species) in fisheries, which are emerging as the principle threat for several species (Polidoro et al., 2008; McClenachan et al., 2012), especially for rays and sharks (Stevens et al., 2000; Simpfendorfer and Kyne, 2009; Ferretti et al., 2010). Few explicit quantitative studies have estimated accidental capture and mortality induced by fisheries, although it is crucial for conservation planning (Lewison et al., 2004; Moore et al., 2013). Indeed, many at-risk vertebrate species live in the open ocean, making surveys expensive and difficult to undertake. In addition, the large spatial scales that fishing fleets

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and pelagic organisms cover make accurate assessments complex. Such quantification is, however, an important challenge in the frame of the Ecosystem Approach to Fisheries, which strives to apply an integrated approach to fisheries, taking into account ecosystem components (biotic, abiotic, human) and their interactions (Christensen and Maclean, 2011).

To improve their efficiency in the fairly homogenous open ocean, tropical tuna purse seine vessels actively search for signs that can indicate the presence of tuna schools (Dagorn et al., 2013). Tuna often aggregate under floating objects such as driftwood, artificial Fish Aggregation Devices (FADs, i.e. bamboo rafts), or associate with large marine species (e.g. whale shark, marine mammals) (Romanov, 2002; Dagorn et al., 2013). Fishing close to such macro-organisms, even sometimes involuntarily, can lead to their accidental capture and potentially impact their survival (Hall, 1998; Rowat and Brooks, 2012).

The whale shark (WHS) (*Rhincodon typus*, Smith 1828) is the world's largest living chondrichthyan (maximum length recorded of 20 m, see reference in Rowat and Brooks, 2012) and is an emblematic and sensitive species. It is listed as Vulnerable by the International Union for Conservation of Nature, in Appendix II of the Convention of Migratory Species of Wild Animals (IUCN; www.redlist.org), and is included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; www.cites.org). The species has a circum-global distribution and occurs in all tropical oceans and warm temperate seas except the Mediterranean (Rowat and Brooks, 2012). Although some studies have investigated the distribution of WHS sightings and related environmental conditions in areas of the Atlantic and Indian Oceans (Sequeira et al., 2012, 2014), little is known regarding their interactions with fisheries or fate when incidentally captured (Rowat et al., 2009; Rowat and Brooks, 2012). Regional Fisheries Management Organizations (RFMOs) and non-governmental environmental organizations have thus underlined the need to scientifically quantify these impacts.

In this context, the aims of this study were to (i) update the spatio-temporal location of hotspots of interactions between tuna purse seine fisheries and WHS considering complementary fishing fleets and years in the Atlantic and Indian Oceans (AO and IO) (ii) document the number and fate of encircled animals (mortality or apparent survival when released).

2. Materials and methods

Since the start of the European tropical tuna fishery in the early 1960s in the AO and 1980s in the IO, the French and Spanish components (presently 23 and 42 purse seine vessels) have been monitored by the Institut de Recherche pour le Développement (IRD), and the Instituto Espagñol de Oceanografía (IEO) and AZTI Tecnalia, respectively (Fonteneau, 2009, 2010). For both oceans we analyzed two principle data types to complementarily assess the impact of fisheries, each with their own advantages and limitations (Lewison et al., 2004): (i) logbook declarations of fishing vessels completed by skippers, and (ii) data from scientific observer programs (i.e. «data collection plans in which independent observers collect data aboard fishing vessels on catch of target and bycatch species»). While observer coverage may be low relative to the total fishing effort, owing to the cost of such programs and the need for well-trained observers, they provide the highest quality bycatch data (Lewison et al., 2004).

Logbooks contain declarative data for 31-years (1980–2011) covering nearly 100% of the French and Spanish fleets in both oceans (captured by IRD and IEO, respectively). We define an "activity" as a record declared by skippers with: (i) geographic position, (ii) fishing set characteristics (time and catch composition) and (iii) association information (e.g. WHS sighting). If no fishing set is made during the day, one record is registered at midday with geolocation and association information if any. Additionally, observer data contain scientific observations and provide location and fate of WHS in case of capture (apparent survival or immediate mortality when released). French (IRD) and Spanish (AZTI and IEO) observer datasets span 16 years between 1995 and 2011, with coverage low relative to logbook data (approximately 10% of fleet activities). Observations are recorded during all fishing days (day time hours) for each modification in activities (e.g. new clue identified, fishing set, fish aggregating device operations). When no modification in activity occurred, one record is made each hour; any sighting made when not fishing (e.g. ship cruising) is also recorded. Spatio-temporal comparison between the two datasets was checked for accuracy (Supplementary Table A.1). An interaction between the fishery and a WHS is defined as any WHS sighting (e.g. observation during ship cruising, fishing activities) and any individual caught (i.e. encircled by the net), with mortality or apparent survival recorded.

Due to variability in hydro-climatic factors that may drive both WHS and fishery distributions, each year was divided into different periods for each ocean. In the AO, we considered four trimesters starting from January (numbered 1–4). For the IO, we defined two main monsoons periods [north–east (NE) from December to March (1) and south–west (SW) from June to September (3)], and two inter-monsoons periods [south–west (ISW), April–May (2) and north–east (INE), October–November (4)].

In order to produce accurate maps of interaction hotspots, we used a Poisson kriging method (Goovaerts, 2005; Monestiez et al., 2006) to take the spatial heterogeneity of observation effort into account and computed Sightings Per Unit of Effort (SPUE, i.e. number of WHS sightings per fishery activities). Kriging parameterizations were carefully performed (Appendix B). Note that mapping of SPUE by kriging could not be performed in the Caribbean Sea nor for each season separately due to low sighting numbers precluding the computation of the experimental variogram (maps of raw data available in Appendix C). All analyses were conducted using the R software (version 2.15.2, R Development Core Team 2013).

3. Results

In the logbook dataset 468,181 activities were registered in the AO with 6673 WHS sightings. Similarly, a total of 393,404 activities were registered in the IO with 2142 WHS sightings. In the observer dataset, there were 169,546 activities registered in the AO and 114,581 in the IO with 198 and 90 WHS sightings respectively (see Table A.2 for main data characteristics).

The WHS sightings declared by skippers in both oceans were located in specific areas and periods (see Fig. C.1 for maps with absolute sightings values), with a matching of hotspots of fishery and WHS interactions when based on absolute sightings or standardized by fishing effort (WHS SPUE) (Fig. 1a). Areas presenting high SPUE are concentrated in the eastern part of the Gulf of Guinea in the AO, and in the Mozambique Channel in the IO. Although a relatively high number of WHS sightings were observed in the Seychelles (Fig. C.1), the high number of fishing activities in this area accounted for the low SPUE.

In the AO, 77% of WHS sightings were concentrated in the Gulf of Guinea, off the Gabon coast between April and September (6207 sightings) (Fig. C.1). In the Caribbean Sea, WHS observations were concentrated between October and December (189 sightings), but mostly occurred in a single year (2008, 127 sightings). In the IO, WHS sightings were particularly high in the Mozambique Channel during the ISW monsoon (1115 sightings) and to a lesser extent in a 10° square East of Seychelles (from 0°N–10°S and 55°E–65°E)

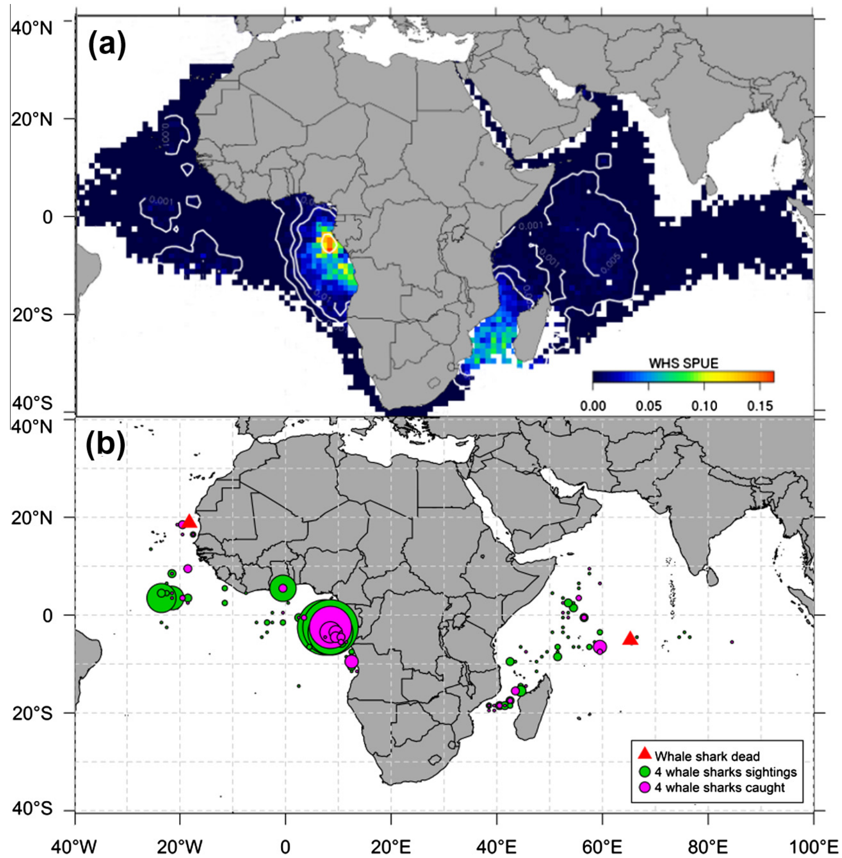

Fig. 1. (a) Distribution maps of Sighting Per Unit Effort (SPUE) of whale sharks in the Atlantic and Indian Oceans from 1980 to 2011 (logbook data) estimated using Poisson kriging. (b) Distribution of observations, catches and mortality of whale sharks in the Atlantic and Indian Oceans from 1995 to 2011 (scientific observers' data).

during the NE and INE monsoons (815 sightings). A more northerly distribution was also detected during the SW monsoon, but related to fewer observations (212 sightings).

According to the scientific observer dataset (available in the overall study area but excluding the Caribbean Sea), the rate of WHS sighting during all recorded activities is very low (0.1%); whereas the percentage of WHS sighting during fishing activity (1.12%) as well as the capture of WHS (0.88%) in fishing sets are around 1% in both oceans (Table A.2, Fig. A.1). The immediate impact of fishing on apparent WHS mortality was low in both oceans. In the AO, one case of WHS mortality from 107 records of known fate was reported by a scientific observer in 1998 off the Mauritanian coast (Fig. 1b, Table A.2). In the IO, one mortality in 38 records of known fate was reported in the east of the Seychelles in 1999 (Fig. 1b, Table A.2). In other capture events, 25 WHS escaped from the net alive (16 and 9 in the AO and IO, respectively), and 118 were released from the net or removed alive without being brought onboard (90 and 28 in the AO and IO). Thus, observed WHS apparent survival rate was 99.07% and 97.37% of the WHS caught in the AO and IO, respectively. It is noteworthy that WHS sightings, capture and apparent survival probabilities were similar between AO and IO (Table A.2, Fig. A.1).

4. Discussion

Hotspots of high frequency of co-occurrence between WHS sightings and purse seine fishing were identified during specific periods of time and areas, particularly in the coastal zone between Gabon and Angola from April to September for the AO, and in the Mozambique Channel during the ISW monsoon (April–May) for the IO. This is in agreement with previous studies on WHS distribution focused on French logbooks of 1991–2007 in the IO (Sequeira et al., 2012) and 1980–2010 in AO (Sequeira et al., 2014).

Several factors may dictate the spatio-temporal patterns observed. Seasonal distributions could be linked to modifications in the environmental conditions, such as variation in current, temperature and/or in primary production as previously observed (Rowat and Brooks, 2012; Sequeira et al., 2012). Similarly, reproductive behavior might affect distribution but little is known about WHS reproductive behavior. In the AO, the primary interaction area is located between Cape Lopez (≈0°) and the Angola Benguela Front (10°S) from April to September; corresponding to the local wet season, with significant input of fresh water and dissolved organic substances from rivers into the marine environment (e.g. Ogooué, Congo rivers). Furthermore, the area is characterized by seasonal upwelling from July to September, followed by high chlorophyll levels (Hardman-Mountford et al., 2003). In the IO, the Mozambique Channel circulation pattern is influenced by anticyclonic gyres (Schott et al., 2009); current circulations reverse between seasons and the upwelling areas changes from South (January) to North (July), which may drive WHS movements. The area seems to present suitable characteristic for WHS, especially during the ISW monsoon, including optimal sea surface temperatures and local productivity, as noted by Sequeira et al. (2012). There is a need for improved knowledge on WHS migrations in relation to the above environmental factors and potential interactions with fisheries, which can be obtained through tracking studies (Rowat and Brooks, 2012).

Whale sharks are placid organisms, swimming slowly, and aggregating several species of fishes, including tunas. This feature may be used by purse seiners to locate tuna, and nets are sometimes set around them, even involuntarily (Rowat and Brooks, 2012; Dagorn et al., 2013). In the Pacific fleets, high WHS mortality has already been recorded from fishing activities (60 individuals died in 2009) (WCPFC, 2010). This prompted management measure from the Western and Central Pacific Fisheries Commission to ban the intentional setting of nets around WHS (WCPFC, 2012), implemented at the beginning of 2014. In the IO, this activity has also been prohibited since September 2013 (IOTC, 2013). These recent management measures have been implemented as precautionary approach because the WCPFC and IOTC (Indian Ocean Tuna Commission) consider that WHS are vulnerable, ecologically important and emblematic. In addition they admitted that accurate data on the interaction between purse seine operations and WHS are lacking. In contrast, in the AO, ICCAT (International Commissions for the Conservation of Atlantic Tunas) have not yet proposed any management measures for WHS.

Our results highlight the very low immediate apparent impact of the purse seine fishery on WHS in both the eastern AO and western IO (0.91% and 2.56% apparent WHS mortality, respectively). Recently, best practices for the safe release of WHS have been developed for fishermen when a WHS is accidentally caught, such as cutting out a section of net to release it and avoiding towing it by the caudal peduncle (Poisson et al., 2014). The IOTC now requires these guidelines to be followed when a WHS is accidentally encircled, which should contribute to the maintenance of this high apparent survival rate. It is important to note that the two recorded mortality events occurred outside of the hotspots of interaction between WHS and fishery (Fig. 1b). However, the main hotspots presented a relatively high rate of WHS capture (Fig. 1b). Thus, it is important to assess the long-term post-release survival of WHS, in order to produce appropriate fisheries management measures for WHS conservation, such as a FAD moratorium, prohibiting the intentional setting of nets on WHS or restricted fishing around these hotspots during the periods identified.

While immediate apparent survival rates of WHS in European purse seine fishery were based on the scientific observers' dataset, which only cover 10% of this fleet, there are plans to increase this coverage to 100% by 2016 (since July 2013 coverage has already increased to 50%). In addition, even though improved coverage will provide more data interactions and health status at the time of release, investigating the effective post-capture survival rates for longer periods remains essential. This would be feasible through satellite tracking, using Pop-Up Satellite Archival Tags (considering the practical constraints of tagging a WHS at surface when the fishing set is ended and most tunas have been removed from the net, and by approaching the WHS from the purse seiner speedboat under calm conditions). Similarly, photographic identification could be used alongside, using existing photo-ID databases (Arzoumanian et al., 2005). Overall, collecting and analyzing both logbooks, observers, electronic tagging and photo-ID data would strengthen fishery impact studies and help define conservation management for marine megafauna.

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Appendices. Supplementary material

Main statistics of logbook and scientific observers datasets on the European purse seine fishery (Appendix A), details on the Poisson Kriging method and parameterizations (Appendix B), and seasonal distribution maps of WHS sightings from 1980 to 2011 in the AO and IO (Appendix C) are available online. Supplementary material associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2014.03.024.

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