Is the tiger shark (*Galeocerdo cuvier*) a coastal species? Expanding its distribution range in the Atlantic Ocean using at-sea observer data

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Abstract

The occurrence of tiger shark (*Galeocerdo cuvier*) in the Atlantic Ocean was assessed using at-sea observer data from multiple pelagic longline fisheries (Japan, Portugal, Spain, United States and Uruguay). Geographic positions of 2,764 tiger sharks, recorded between 1993 and 2013 and covering a wide area of the Atlantic were compared with the currently accepted distribution ranges of the species. Most of our records fell outside the accepted distribution ranges in both the Southern and Northern hemispheres. These results strongly suggest that the distribution range of the tiger shark is considerably wider than previously described, particularly over the open ocean.

Key-words

Tiger shark; distribution; longline fisheries; observer data

Introduction

The tiger shark, *Galeocerdo cuvier* (Peron & LeSueur, 1822), is one of the most unique species of the family Carcharhinidae. It reaches the largest size among its congeners (up to 5.5 m total length) and is also the only carcharhinid with aplacental viviparous reproduction (Randall, 1992; Hamlett, 2005; Whitney & Crow, 2007). Tiger sharks are regularly described as costal pelagic predators with circumglobal distribution in warm and temperate waters of all oceans (Ebert *et al.*, 2013). Although commonly associated with coastal areas and continental and insular shelves (Holland *et al.*, 1999; Hazin *et al.*, 2013; Afonso & Hazin, 2014), tiger sharks are also capable of traveling long distances, even across oceanic waters (Kohler *et al.*, 1998; Heithaus *et al.*, 2007; Hammerschlag *et al.*, 2012). They perform occasional extended vertical migrations diving up to 500 m deep (Vaudo *et al.*, 2014; Werry *et al.*, 2014). The distribution range of the tiger shark in the western Atlantic Ocean comprises coastal and shelf waters from Massachusetts, USA, to Uruguay, including the Gulf of Mexico, the Caribbean and Bermuda. On the eastern Atlantic tiger sharks occur from Angola to Morocco, including the Canary and Azores archipelagos, but have also been occasionally reported close to Iceland and England, possibly advected along with warm waters of the Gulf Stream (Compagno, 1984; Ebert *et al.*, 2013). To date, the presence of tiger sharks in the Mediterranean Sea remains uncertain and further confirmation is needed (Serena, 2005). Despite the existence of two records from Spanish and Italian waters (Pinto de la Rosa, 1994; Celona, 2000), at-sea observers of the Spanish longline fishery in the western Mediterranean have not observed this species for over two decades (D. Macias pers. Com. 10/October/2014) suggesting that its regular occurrence in the Mediterranean Sea is doubtful.

Sub-population structure within the Atlantic is currently unknown, but long distance migrations inferred from several tagging studies (Kohler *et al.*, 1998; Hammerschlag *et al.*, 2012) suggest that there may be connections between different regions.

Tiger sharks have been regularly captured in some directed commercial shark fisheries (Bonfil, 1997; Simpfendorfer, 2009), recreational fisheries (Stevens, 1984), and shark control programs (Dudley, 1997; Cliff & Dudley, 2011; Sumpton *et al.*, 2011), but also as by-catch in several fisheries (Bonfil, 1994; Beerkircher *et al.*, 2008). In the Atlantic Ocean, tiger sharks are captured as by-catch in pelagic longline fisheries across their entire distribution range. They are presently ranked as Nearly Threatened in global assessment by the International Union for the Conservation of Nature (IUCN) red lists (Simpfendorfer, 2009). Population trends for this species are currently unknown worldwide (Simpfendorfer, 2009), but its conservation would be relevant since they are apex predators and are considered key species in some marine ecosystems, potentially having a considerable influence on community dynamics (Heithaus *et al.*, 2009, 2012).

This note revises data collected on board pelagic longline vessels operating throughout the Atlantic Ocean within the scope of observer programs or research developed in five of major longline fleets (Japan, Portugal, Spain, Uruguay and the United States of America). It aims at updating and expanding the distribution of the tiger shark over the Atlantic Ocean.

Material & Methods

Records from several observer and research programs were pooled to assess tiger shark distribution. Between 1993 and 2013, scientific observers on board pelagic longline fishing vessels recorded interactions with tiger sharks over a wide geographical area throughout the Atlantic Ocean, including waters over continental and insulars shelves and slopes, and especially large expanses of the open ocean.

Tiger sharks were identified on board fishing vessels by trained observers. Morphologically, the tiger shark is easily recognized by its short and blunt head, the presence of long upper labial furrows, low keels on the caudal peduncle, a prominent interdorsal ridge, distinctive strongly combed teeth with heavy serrations and distal cusplets, and a characteristic trunk pigmentation of dark vertical tiger-like stripe markings that become less conspicuous in adults (Compagno, 1984; Ebert *et al.*, 2013; see also Fig. 1).

Brief description of each longline fleet and observer program

Japan

Japan started placing observers on-board tuna longline vessels since 1995 mainly at bluefin tuna fishing ground in the temperate Atlantic as well as bigeye tuna fishing ground in the tropical Atlantic (Matsumoto and Miyabe, 1998). In recent years, observers are also placed in the fishing ground of southern bluefin tuna (National Research Institute of Far Seas Fisheries, 2014). Japanese longliners target bluefin tuna mainly in off Ireland and off Grand Bank with relatively shallow day sets whose number of hooks per basket is between 4 and 13 (Kimoto et al., 2014), and target southern bluefin tuna mainly in off Cape Town with similar sets as bluefin tuna. Tropical bigeye tuna fishing ground is off western Africa with deep day sets whose number of hooks per basket is 12 or larger (Yokawa, 2001). In the tuna targeting day set, Japanese longliner usually start gear setting after mid night and finish after sun rise, and start gear retrieving start around noon and finish after sunset. Shallow sets covers water column above and below thermocline, and deep sets covers mainly in the depth between 150m and 350m or more (Yokawa and Takeuchi, 2003; Yokawa et al., 2005). All longliners use Japanese tuna hook whose shape is similar to J style hook.

Portugal

The Portuguese longline Fishery Observer Program started in 2000 and became fully implemented in 2003.IPMA (*Portuguese Institute for the Ocean and Atmosphere*) is responsible for maintaining the Program as part of the European Union Data Collection Framework (DCF). This Program covers Portuguese pelagic longliners that operate over a wide area of the Atlantic Ocean in both hemispheres (Coelho *et al.*, 2012a). The fleet targets mainly swordfish, even though in certain areas and seasons tropical tunas and sharks (mainly blue shark, *Prionace glauca*) may also be targeted. Fishing is usually carried out at depths of 20-50 m, with gear deployment beginning usually at around 17:00 h and haulback starting the next day from about 06:00 h. The traditional hooks used by the fishery are stainless steel J-style hooks, and the baits are usually either squid or mackerel (Coelho *et al.*, 2012b; Santos *et al.*, 2012; 2013). Both monofilament and wire branch lines are used.

Spain

The Spanish surface longline fishery targeted swordfish (*Xiphias gladius*), but in recent years it has been targeting swordfish and/or blue shark (*Prionace glauca*) in some areas and seasons. The gear traditionally used was multifilament longline style until the introduction of monofilament-nylon or “American style” at the end of the 20th century. Fishing is carried out in oceanic epipelagic areas usually at depths in the range of 20-50 m, with gear deployment beginning at night and haulback starting the next day (night sets).

Traditionally stainless steel J-style hooks or derivatives baited with mackerel were used. With the introduction of the monofilament-nylon style various hook types baited either with mackerel or squid began to be used (Mejuto and De la Serna, 2000; García-Cortés *et al*., 2014). Several research projects and studies on large pelagic shark species (Mejuto *et al.* 2009a, 2013) as well as on other less prevalent species such as the tiger shark (Castro *et al*. 2000, Mejuto 1985, Mejuto *et al*., 2009b) Have been developed since 1983. Records of the sporadic bycatch of tiger sharks were obtained by onboard during 1994-2013 for scientific purposes.

Uruguay

The Uruguayan Observer Program (Programa Nacional de Observadores a bordo de la Flota Atunera, PNOFA) started operating in 1998 in the pelagic longline fleet, which targets mainly swordfish (*Xiphias gladius*) and tunas, but also some sharks (mainly blue shark, *Prionace glauca*) (Mora & Domingo, 2006). This fishery operates since 1981 over a wide region of the southwest Atlantic Ocean. During the last decade the fleet has operated mainly between 20º and 40ºS and 20º and 55ºW (Forselledo et al., 2008; Jimenez et al., 2014). The longline is set over the vessel’s stern, up to 100 m deep. The set usually starts after sunset and is completed before midnight. Haulback takes place the following morning (Domingo *et al.*, 2011).

USA

The US Pelagic Longline Observer Program (PLLOP) started operating in 1992 by placing scientific observers aboard commercial longline vessels targeting large-bodied pelagic fishes in the western North Atlantic Ocean. The pelagic longline fleet targets primarily yellowfin tuna (*Thunnus albacares*), bigeye tuna (*T. obesus*) and swordfish, but other tunas and the shortfin mako are also retained (Keene 2011). This fishery has been operating since the late 1950s, first by Japanese longliners, then by US and Canadian fishermen since the 1960s. By the late 1970s, the gear consisted of monofilament nylon. The fishery operates over a wide region in the western North Atlantic Ocean, including the Gulf of Mexico and extending north to the Grand Banks and south as far as the equator. Average hook depth is 45 m. Fishing strategy varies according to the target species: for sets targeting swordfish, the longline is set in the evening and hauled back in the morning; for sets targeting yellowfin tuna, the gear is deployed in the early morning and hauled back from evening into the night; for sets targeting bigeye tuna, the gear is deployed at slower speeds causing the hooks to fish in deeper water (Keene 2011).

Data use and analysis

Data regarding the currently accepted distribution range of *G. cuvier* in the Atlantic Ocean were obtained from the IUCN Red List (IUCN 2012) and from Ebert et al. (2013) (Fig. 2). Observer information collectively covers the period 1992-2013. The study is based on data for positive sets (*i.e.* fishing sets where at least one tiger shark was captured). A buffer area of 600 km was created around the positive sets, which was then smoothed using a Polynomial Approximation with the Exponential Kernel algorithm (Bodansky et al. 2002). Finally, the outer 200 km of the resulting polygons were clipped out in order to obtain a conservative extension of the distribution range. All spatial analysis and maps were produced using ESRI ArcGis 10.1.

Results

In total, 2,764 tiger sharks were reported during the study period. These were caught throughout the Atlantic Ocean, both over shelf and slope waters and their vicinity, as well as in international waters in the open ocean. Most of the records were reported by USA (86.4%, n = 2,387), followed by Japan (8.7%, n = 240), Spain (2.9%, n = 81), Portugal (1.3%, n = 35) and Uruguay (0.7%, n = 21).

Of all observed tiger sharks, 86.4% (n = 2,388) and 19.4% (n = 537) were reported outside the distribution ranges currently proposed by the IUCN (2012) and Ebert *et al.*, (2013), respectively (Figs. 2 and 3). Furthermore, all tiger sharks reported by the Japanese, Spanish, Portuguese and Uruguayan observer programs occurred outside the IUCN (2012) distribution ranges, as well as every single individual captured over the South Atlantic Ocean. Reported catches that fell inside the currently proposed distribution ranges occurred along the US east and southeast coast, the Gulf of Mexico and the Caribbean, respectively. However, several reported captures also occurred over distant waters and far away from currently accepted distribution ranges in the Northern hemisphere (Fig. 3).

Discussion

Tiger sharks are infrequently captured by high-seas longline fisheries (e.g. Amorim *et al.*, 1998; Miller *et al.* 2006; Mejuto *et al.*, 2009), probably due to their low abundance there, the observation of several hundred individuals over oceanic waters suggests that this species has a more widespread distribution in the open ocean than previously accounted for. Regional satellite tagging studies in both the Atlantic (Hammerschlag *et al.*, 2012) and Pacific oceans (Meyer *et al.*, 2010) support our more general finding. Catches of tiger sharks were recorded over the entire Equatorial area, whereas it does not appear to be the case for higher latitudes (Fig. 3). This may suggest that the Equatorial area could be acting as a connecting corridor between the East and West Atlantic, where tiger sharks may take advantage of both the North and South Equatorial Current and the North Equatorial Counter current (*sensu* Philander, 2001) advection as natural pathways to cross the Atlantic. Advection of tiger sharks by oceanic currents has also been proposed by Compagno (1984), who suggested that the isolated records reported form the United Kingdom could be of vagrant individuals following the Gulf and North Atlantic stream northwards. A recent telemetry study on tiger sharks conducted in the Northwestern Atlantic (Hammerschlag *et al.*, 2012) provides further evidence of long-distance migrations into the open ocean associated with waters of the Gulf Stream, and hypothesizes that these movements could be related to feeding behavior.

Based on data provided by several Observer Programs developed by countries that target large pelagic fish in the high-seas Atlantic Ocean, we propose to expand the distribution range for this species (Fig. 4). This expansion is towards the open ocean, and the area doubles the one previously recognized. Though the extent of observers` coverage did not allow to confirm it is highly possible that the apparently isolated areas appearing to the north and south are also part of the distribution range, at least during certain times of the year a as a consequence of migratory cycles. Expanded distribution ranges, as shown here, have direct implications for management and conservation. These findings raise questions about long-distance migrations, population or sub-population connectivity, and the identification and delimitation of different stocks. Furthermore, expanded distribution ranges also imply potentially larger availability and susceptibility to fisheries, which may result in higher vulnerability in ecological risk assessments (see e.g., Cortés et al. 2010). Future evaluations, such as stock and ecological risk assessments, should take into account this new information on distribution to provide more realistic and up-to-date results.

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Figure 1. Tiger shark morphological characters. **A**:short and blunt head, **B**: presence of long upper labial furrows, **C**: strongly combed teeth with heavy serrations and distal cusplets, **D**: characteristic trunk pigmentation of dark vertical tiger-like stripe markings that become less conspicuous in adults.

This photography it's provided by Tunna team, I.E.O. Coruña, Spain (Author: Antonio Corgos)

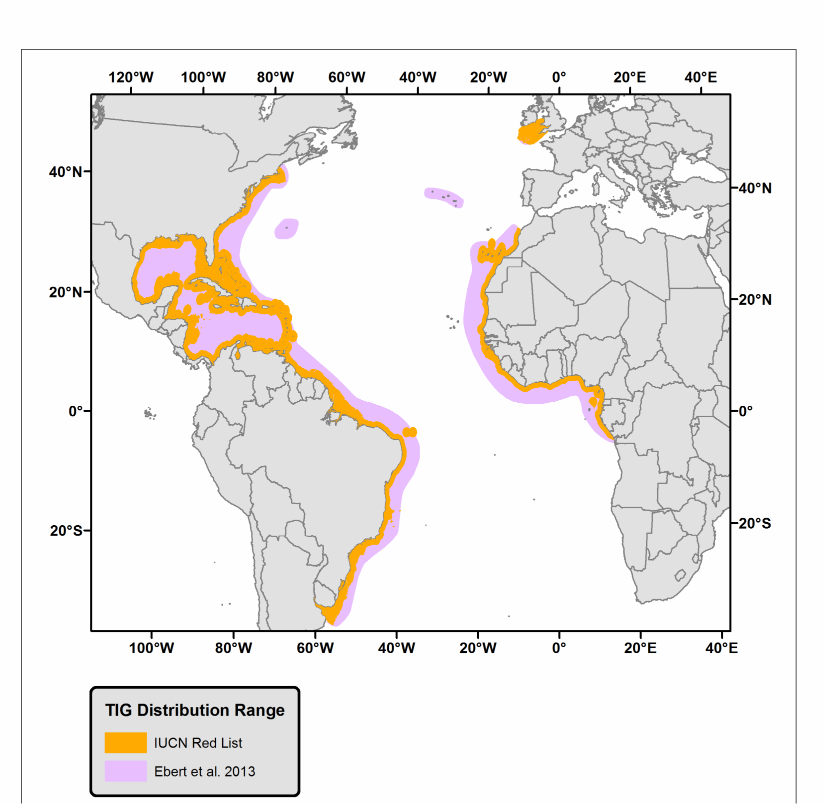

Figure 2. Currently accepted distribution range of the tiger shark in the Atlantic Ocean.

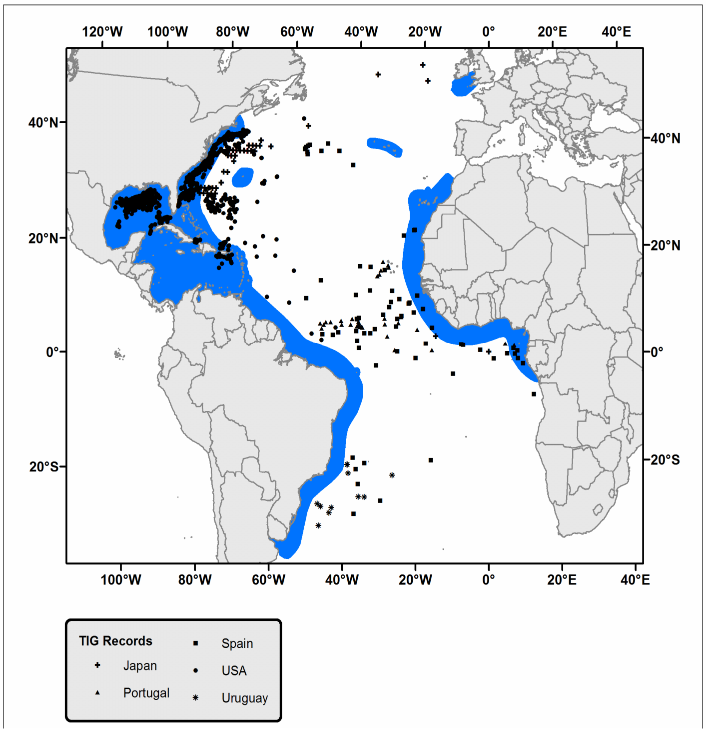

Figure 3. Tiger shark records from Observer Programs overlaid with the currently accepted distribution range in the Atlantic Ocean.

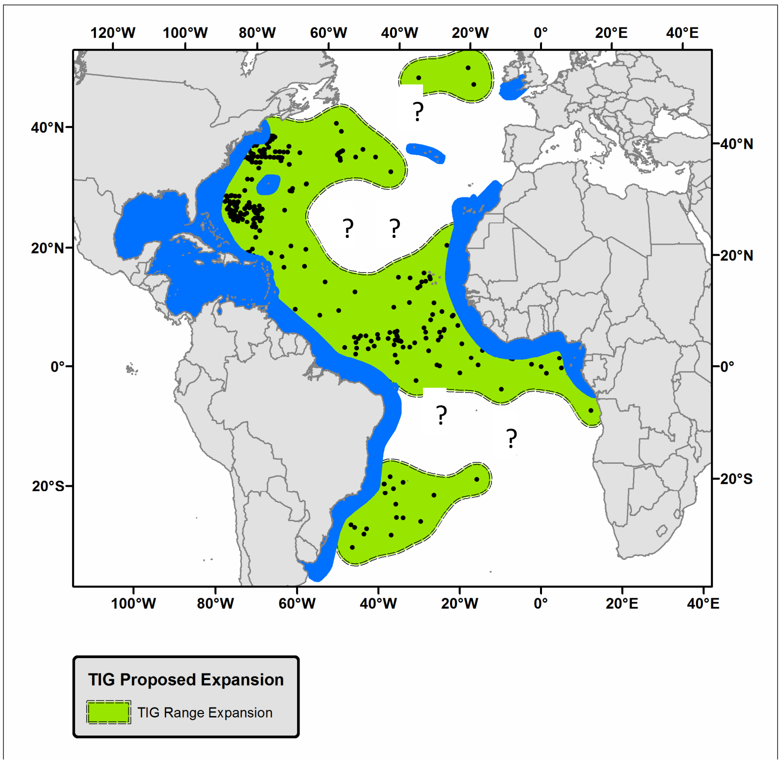

Figure 4. Proposed extended distribution range of tiger sharks in the Atlantic Ocean.