Spatio-temporal interactions between whale sharks, cetaceans and the European tropical tuna purse seine fishery in the Atlantic and Indian Oceans

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Introduction

Various natural and anthropogenic threats impact marine megafauna species worldwide. This denomination for large marine vertebrates includes several taxonomic groups, such as mammals, chondrichthyans (sharks and rays), turtles and seabirds (Lewison et al. 2004). The threats that their populations have to face consist of target and non-target fishing or harvesting, habitat destruction, pollution, ship traffic, pathogens, climate change and non-lethal human interactions (Hoffmann et al. 2010). Yet, in this array of threats from human activities, the major ones are considered to be targeted fisheries and bycatch (i.e. incidental capture of non-targeted species) (Read et al. 2006; Stevens et al. 2000; Wallace et al. 2011). This overall extensive and increasing pressure that is applied by humans has led to the decline of many species, especially species with particular inherent biological characteristics, such as late maturity, low fecundity and high longevity (Musick et al. 2000; Žydelis et al. 2009).

In the open ocean, tropical tuna purse seiners actively search for signs at the surface of the sea that can indicate the presence of tuna schools. These may include flocks of birds, the deformation of the water surface that is linked to tuna feeding behaviour, the presence of floating objects (natural or artificial) or the presence of marine megafauna species (i.e. cetaceans, or whale sharks, *Rhincodon typus*). Indeed, several marine species, including tropical tunas, aggregate under any floating object. Some tuna species may also associate with marine megafauna species – mainly to feed on the same prey species. Fishers use these known tuna behaviours in order to increase their fishing efficiency. For data management purposes, the various fishing modes are classified according to the cues for sighting a tuna school. In the eastern Atlantic Ocean and the western Indian Ocean, most fishing sets are made on free-swimming tuna schools ('free school set'), or associated with a floating object (natural or artificial drifting fish aggregating devices 'FAD set'). In both oceans, sets are also made in association with cetaceans and whale sharks. In the 1980s, these megafauna-associated fishing sets were estimated to represent 8% of the fishing sets in the eastern Atlantic Ocean (Stretta and Slepoukha 1986) but little information existed for the Indian Ocean (Romanov 2002). Nowadays, the whale shark- and whale-associated modes of fishing are considered relatively rare and are not well studied.

In the framework of the ecosystem approach to fishery (EAF) management, the impact of the tropical tuna purse seine fishery on targeted species – but also on incidentally captured and encircled species – should be investigated. In relation to cetaceans and whale sharks, the fact that all these marine species are referenced in international conventions for conservation (e.g. the International Union for Conservation of Nature, or the Convention on International Trade in Endangered Species of Wild Fauna and Flora) led regional tuna fishery organisations (the International Commission for the Conservation of Atlantic Tunas, and the Indian Ocean Tuna Commission), as well as ecological and non-governmental organisations, to call for detailed information on megafauna/purse seine fishery interactions.

The results presented in this newsletter are extracted from my PhD, which was completed at the French *Institut de Recherche pour le Développement* in Sète, France between 2013 and 2016.[2] The aims were to investigate the spatio-temporal interactions (fishing nets set in the vicinity of these species and potentially lead to encirclement) and/or co-occurrences (presence in the purse seine fishing grounds) between whale sharks, cetaceans and the tuna purse seine fishery in the eastern Atlantic and western Indian Oceans, and to assess the potential impacts on the species that are involved. To address these objectives, I have mainly used fishery data from European fleets (France and Spain): i) logbook records systematically filled out by vessel captains since 1980; and, ii) data from scientific observers onboard fishing vessels since 1995 (continuous data collection programmes since 2003). Observers tend to record more detailed and complementary information than captains. However, the number of purse seiners that carried an observer onboard was historically low (<10%), but has increased to 100% in the Atlantic Ocean and ~40% in the Indian Ocean since 2014.

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[2] In March 2017, I joined the Oceanic Fisheries Programme of the Pacific Community. I am now working on sustainable FAD fishing in the Western and Central Pacific Ocean (WCPO). My research focuses on i) identifying factors that lead to high juvenile bigeye tuna catch in FAD purse seine fishing sets; and, ii) investigating, and if possible quantifying, the operational use of FADs to increase our knowledge on FAD fishing dynamics and the ecosystem interactions that they drive.

Interactions between whale sharks and the tropical tuna purse seine fishery in the Atlantic and Indian Oceans

Whale shark sightings have mainly been recorded by captains and onboard scientific observers when directly interacting with purse seine fisheries, i.e. when whale sharks are encircled in tuna purse seine nets. According to these records, ~1,5% of all fishing sets were made in association with whale sharks in both oceans (8650 fishing sets recorded between 1980 and 2011 in the logbook datasets and 180 between 1995 and 2011 in the observer datasets) (Capietto et al. 2014). Whale shark-associated sets were mostly incidental, given that whale sharks were not seen prior to the setting of the net. Distribution maps of sightings per unit of effort (SPUE) highlight main areas of interactions between fisheries and whale sharks: i) in the coastal area from Gabon to Angola in the Atlantic from April to September; and, ii) in the Mozambique Channel in the Indian Ocean between April and May (Figure 1a). The incidence of apparent whale shark mortality due to fishery interaction is low (two of the 145 whale sharks encircled by the net between 1995 and 2011 died, i.e. 1.38%) (Figure 1b). Post-capture mortality rates in the longer term have then been investigated using pop-up archival tags. In 2014 and 2016, eleven large whale sharks (8–12 m in length) that were encircled in tuna purse seine nets were tagged before being released, in the area of the Atlantic Ocean and at the period that had been previously identified as having the highest rates of whale shark encirclements. These whale sharks were released from the encircling purse seine nets using, when possible, a 'good practice' method (see Escalle et al. 2016 for details). Seven individuals survived at least 21 days after release, three tags detached after 3 and 7 days and the fate of these individuals remains unknown, and one tag failed to provide a report. Although the sample size remains limited, the results indicate high post-encirclement survival rates. The tagging of additional individuals, including juveniles, should be pursued worldwide, such as in the Pacific and

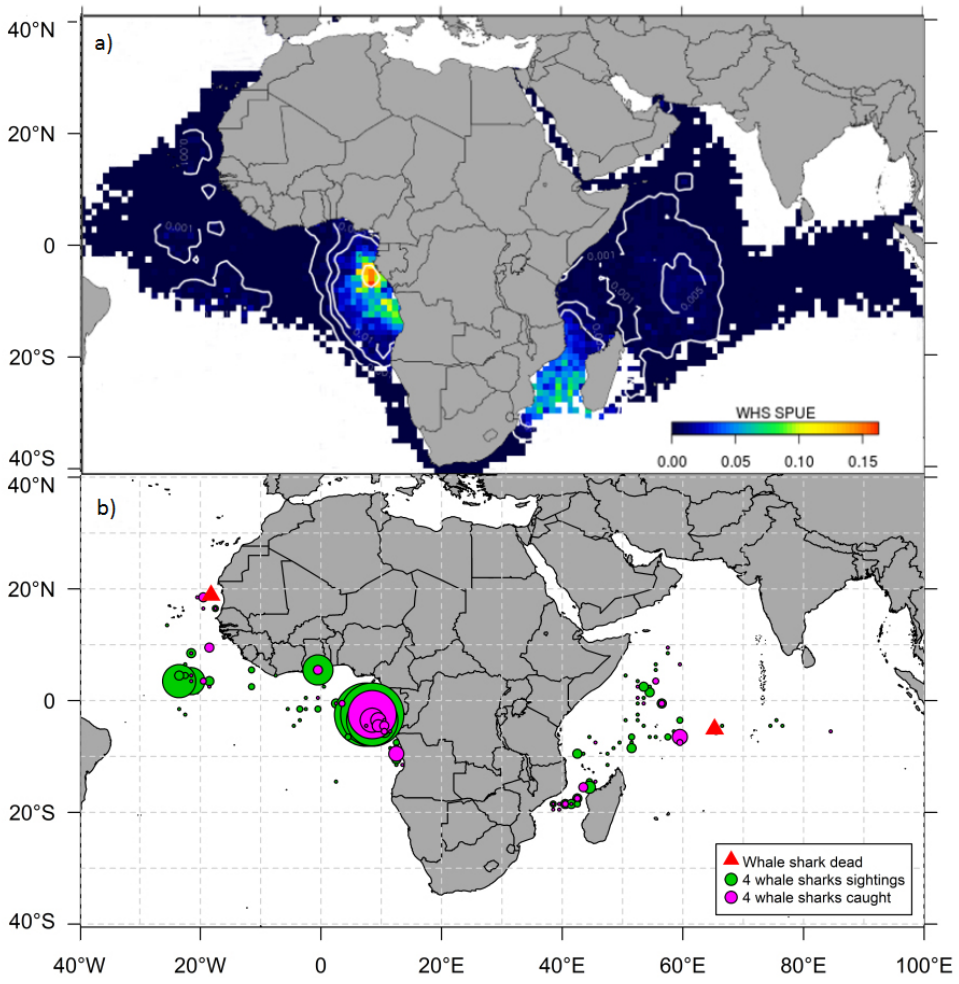

Figure 1. a) Distribution maps of sighting per unit effort (SPUE) of whale sharks in the Atlantic and Indian Oceans from 1980 to 2011 (logbook data) estimated using Poisson kriging. b) Distribution of sightings, encirclements and mortalities of whale sharks in the Atlantic and Indian Oceans from 1995 to 2011 (scientific observers' data). (source: Figure 1 in Capietto et al. 2014).

A whale shark (*Rhincodon typus*) stranded in a closed purse seine (image: L. Escalle, ©Orthongel-IRD, 2014).

Indian Oceans, to precisely assess whale shark post-release survival rates in tuna purse seine fisheries and to develop, if needed, management measures to limit fishery impact on whale shark populations.

Interactions between cetaceans and tropical tuna purse seine fisheries in the Atlantic and Indian Oceans

As was done for whale sharks, the co-occurrence and interaction between various cetaceans species (divided in three groups: baleen whales, dolphins and the sperm whale *Physeter macrocephalus*) and tuna purse seine fisheries has been studied in the Atlantic and Indian Oceans. In these oceans, the majority of cetacean sightings involved baleen whales (94% of the cetacean sightings recorded in the logbook dataset), which are mostly observed during a fishing set and therefore are directly interacting with purse seine fisheries. In both oceans, whale-associated fishing sets represented ~3% of all fishing sets (14,900 fishing sets recorded between 1980 and 2011 in the logbook dataset, and 450 between 1995 and 2011 in the observer dataset) (Escalle et al. 2015). Baleen whales are, however, rarely encircled, as most of the time they escape by themselves by diving before the closure of the net or by going through the net. It should be noted that in the case of whale-associated fishing, the sets are intentional in the way that fishing crews use baleen whales as indicator of tuna schools before setting nets in their vicinity. While dolphins are also present in fishing areas, very few interactions with fisheries were detected (258 and 85 dolphin-associated fishing sets recorded in the logbook and observer datasets), which highlights the striking difference between the eastern Pacific Ocean where half the sets are associated with dolphin pods (Hall 1998). Distribution maps of cetacean SPUE highlighted main areas of relatively high co-occurrence: i) east of the Seychelles from December to March); ii) the Mozambique Channel from April to May; and, iii) offshore waters of Gabon from April to September (Figure 2a). Finally, the mortality of eight pantropical spotted dolphins (*Stenella attenuata*) and three humpback whales (*Megaptera novaeangliae*) has been recorded by observers in the Atlantic Ocean (Figure 2b) leading to relatively low immediate apparent mortality rates following encirclement (Atlantic Ocean: 8%, Indian Ocean: 0%). These high survival rates suggest setting nets close to cetaceans has a low immediate apparent impact on the species involved. It is important to note that the non-lethal impacts of cetacean-associated sets have not been assessed and would be very difficult to measure. Overall, these findings, as those related to whale sharks, should contribute to the development of EAF management and accurate cetacean conservation measures.

Humpback whale (*Megaptera novaeangliae*) encircled in a purse seine (image: L. Escalle, ©Orthongel-IRD, 2014).

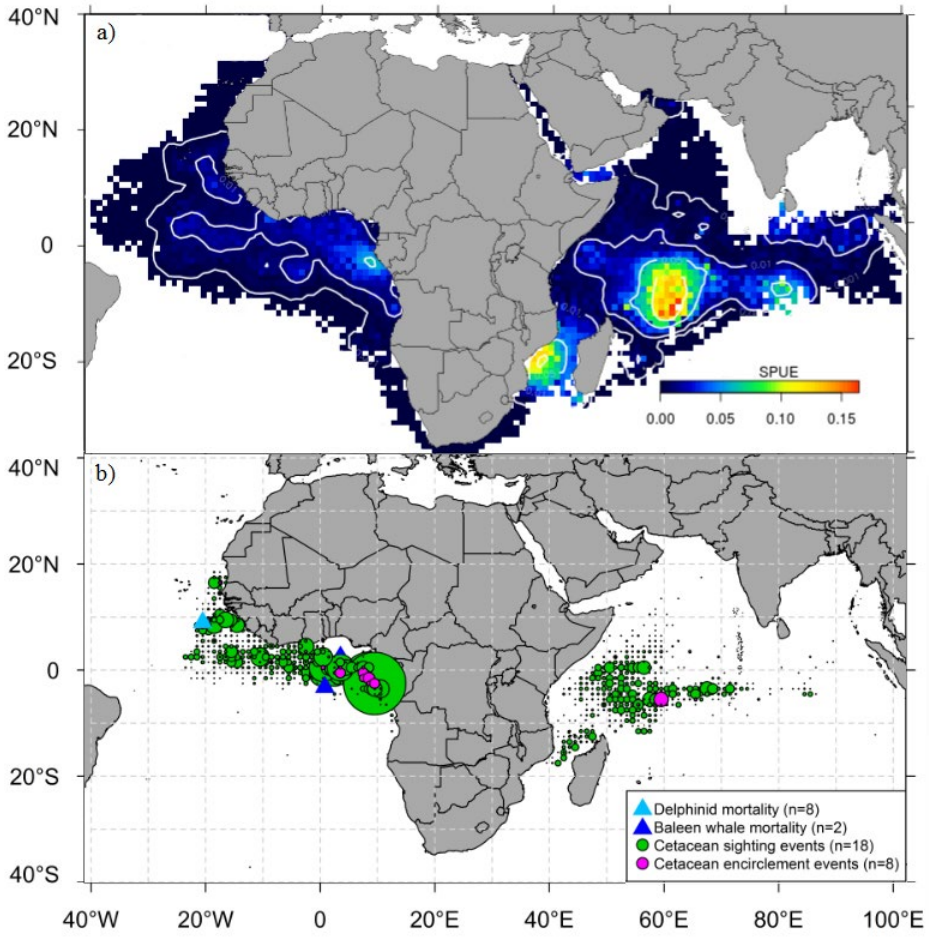

Figure 2 a) Distribution maps of Sighting Per Unit Effort (SPUE) of all cetaceans combined, in the Atlantic and Indian Oceans from 1980 to 2011 (logbook data) estimated using Poisson kriging. b) Distribution of sightings, encirclements and mortalities of cetaceans in the Atlantic and Indian Oceans from 1995 to 2011 (scientific observers' data). (source: Figure 2 in Escalle et al. 2015).

Environmental factors and megafauna spatio-temporal co-occurrence with tropical tuna purse seine fisheries

Following the identification of specific areas and periods with high whale shark and cetacean co-occurrence with purse seine fisheries, it was then relevant to investigate possible links between these main areas of co-occurrence and specific environmental conditions. In fact, various environmental variables such as water temperature or primary production may directly influence the distribution of megafauna species, as well as tuna distribution (and therefore fishery distribution), or indirectly affect them through influences on the distribution of their prey. To investigate these hypotheses, we analysed a ten-year (2002–2011) dataset from logbooks in the Atlantic and Indian Oceans, with the aim of identifying the principle environmental variables under which the megafauna/fishery co-occurrence appears. We applied statistical models (Delta-model approach using Generalized Additive Models and Boosted Regression Trees models) separately by ocean and megafauna group. The variables that contributed most in the models were chlorophyll-a concentration in the Atlantic Ocean, as well as depth and monsoons in the Indian Ocean (Escalle et al. 2016c). It was therefore highlighted that high co-occurrence between whale sharks, baleen whales and tuna purse seine fisheries were mostly observed in productive areas during the particular seasons that are previously mentioned, which was expected as both megafauna groups are filter feeders.

Management considerations

Management conservation measures for whale sharks and cetaceans have been implemented in the Indian Ocean (resolution IOTC 13/04 and 13/05), which prohibit the intentional setting of purse seine nets around these animals. This has been implemented due to the ecological importance and vulnerability of these species, as shown by their inclusion in various conservation lists. It should be noted that as whale sharks are often not seen prior the setting of the net, this measure will have relatively low consequences on the number of encirclements and 'good practice' methods that are carried out to release encircled whale sharks should be mandatory in case of incidental encirclements. On the contrary, no conservation measures toward whale sharks and cetaceans exist in the Atlantic Ocean. To investigate the consequences that such measures may have on the number of megafauna-associated fishing sets, as well as on the tuna catch and bycatch, we simulated the ban of whale or/and whale shark-associated fishing sets in both oceans. These could lead to an increase in the number of FAD and free school sets but no change in the tuna catch, as well as a slight decrease in bycatch (Escalle et al. 2016a). Similarly, management measures toward FAD fishing (no take zones or moratoria, i.e. area and period where all FAD activities are prohibited) have been implemented in both oceans to protect stocks of tropical tunas. However, the fishing effort relocation toward other fishing modes (i.e. free school, whale-associated and whale shark-associated fishing sets) may lead to increasing impacts on encircled megafauna species, but also on bycatch species. The potential side effects and consequences of these FAD fishing management measures were therefore also investigated. Real and simulated (larger and longer than the existing ones) FAD moratoria showed limited impacts on the number of megafauna-associated fishing sets. This is due to the fact that in both oceans the main FAD fishing seasons and areas do no correspond with the areas and periods with higher megafauna-associated fishing sets (Escalle et al. 2016a, 2017). However, the large six-months FAD moratoria that have been simulated in each of the oceans could be beneficial for juvenile tuna and some bycatch species, by highly decreasing the number of FAD-associated fishing sets at the scale of the whole ocean during a fishing year (Escalle et al. 2017). Nevertheless, it should be noted that contrasted results were found depending on the ocean and the fleet considered (i.e. French or Spanish).

Conclusion and comparison with the Western and Central Pacific Ocean (WCPO)

Overall, this study led to an increase in the knowledge on megafauna/fishery interactions, which is essential for the general framework of setting up EAF management in for tropical tuna purse seine fisheries. While megafauna-associated fishing sets were relatively high before 2000 in the Atlantic and Indian Oceans they have become less frequent in recent years. However, whale shark- and baleen whale-associated fishing sets are localised in specific areas and periods that are characterised by highly productive environments. In addition, in the Atlantic and Indian Oceans, purse seine fisheries appear to have a relatively low apparent impact on these megafauna species. In relation to whale sharks, post-release mortality rates also appear low but additional studies are needed to precisely estimate survival in the longer term. In relation to baleen whales, while encirclement and mortality rates appear low, the non-lethal impacts of whale-associated fishing sets have not been assessed. However, given the ecological importance and vulnerability of these species, intentional setting of purse seine nets around whale sharks and cetaceans has been prohibited in the Indian Ocean.

In the Western and Central Pacific Ocean (WCPO), whale- and whale shark-associated fishing sets have also been recorded. Whale shark-associated sets represent 0.3–0.7% and whale-associated sets 1.6–2.5% of the total number of sets performed between 1980 and 2014 (Molony 2005; WCPFC 2010; Clarke 2015). These megafauna-associated fishing sets are mostly located in the Papua New Guinea Economic Exclusive Zone (i.e. Bismarck and Solomon

Seas) (WCPFC 2010). In addition, onboard observers have recorded the mortality of two Bryde's whales (*Balaenoptera edeni*) between 2007 and 2010 (WCPFC 2010) and 88 whale sharks between 2007 and 2014 (WCPFC 2010; Clarke 2015). This corresponds to apparent mortality rates of 6% for baleen whales and 7–14% for whale sharks, which is higher than in the Atlantic and Indian Oceans. This has prompted the Western and Central Pacific Fisheries Commission (WCPFC) to ban the intentional setting of nets on cetaceans and whale sharks since January 2013 (CMM-2011-03) and January 2014 (CMM-2012-04), respectively. In addition, WCPFC has drafted 'good practice' method guidelines on how to release whale sharks that are incidentally encircled.

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