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Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean

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ABSTRACT

Pelagic fishes are well known to aggregate in large numbers under floating objects and this behavior is frequently exploited by purse seine fisheries targeting tunas. Non-target species (e.g., sharks) are often caught as well, but they are typically discarded as they do not have sufficient commercial value. To investigate the total mortality of pelagic sharks in the equatorial Eastern Pacific Ocean associated with the tuna purse seine fishery deploying drifting fish aggregating devices (FADs), we measured rates of at-vessel mortality and deployed pop-up satellite archival tags (PSATs) to monitor post-release survival and behavior. Between 2011 and 2012, at-vessel mortality rate ranged from 15% to 70%, and total mortality rate (i.e. the combination of at-vessel and post-release mortalities) ranged from 80% to 95%. Taken together, our findings document the high mortality of sharks incidentally captured in the tuna purse seine fishery that employs drifting FADs, indicate a correlation to set size, and suggest the need to develop methods that minimize shark bycatch in this fishery.

1. Introduction

The association of pelagic fishes with natural (e.g., logs, debris) or man-made (e.g., buoys, rafts) floating objects in oceanic waters commonly results in aggregating behavior that is exploited by commercial, recreational, and artisanal fishers to increase catches (e.g., Dagorn et al., 2000; Ohta et al., 2001). During the last several decades, purse seine fleets targeting tuna have increasingly relied on deploying man-made fish aggregating devices (FADs) for this purpose (Fonteneau et al., 2000; Girard et al., 2004). By the late 1990's, these fishing methods reached landings of 1×10^6 tons per year and accounted for more than 50% of global tuna landings (Fonteneau et al., 2000). The landings of the tuna fleets using FADs in the Eastern Pacific Ocean (EPO) now surpass 3×10^5 tons per year (Gerrodette et al., 2012). Although the EPO purse seine fishery employing drifting FADs primarily targets market-sized skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus alalunga),* and bigeye (*T. obesus*) tunas, they frequently encounter unwanted species (i.e., bycatch). This bycatch includes pelagic teleosts such as rainbow runners (*Elagatis bipinnulata*) and oceanic triggerfish (*Canthidermis maculates*), undersized tunas, silky (*Carcharhinus falciformis*) and scalloped hammerhead (*Sphyrna lewini)* sharks, and sea turtles (Hall, 1996; Hall et al., 1999). Between 2005 and 2009, the total bycatch in the EPO-based tuna purse seine fishery was ~2.3% of the overall landings, with about half being comprised of non-tuna species (Restrepo, 2011). This is comparable to bycatch rates estimated in other purse seine fisheries using drifting FADs (Gerrodette et al., 2012), but it is markedly lower than that of other fishing gear targeting tunas (e.g., 7.5% for longline, 30% for mid-water trawls; Kelleher, 2005). Despite this relatively low bycatch rate, the large total landings of the purse seine fleets, which account for the majority of tuna caught annually across the globe, result in a substantial amount of bycatch, both in terms of numbers and tonnage (IATTC, 2013). For this reason, reducing overall bycatch in purse seine fisheries has become an important goal as a means to decrease the potentially adverse ecological impact of this fishing practice and to increase resource sustainability (Hall et al., 2000; Garcia et al., 2003; Watson et al., 2008).

While debate continues on the status of global shark populations (Burgess et al., 2005), it is well-known that sharks are, in general, particularly vulnerable to exploitation due to their low fecundities,

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Table 1
Data for each deployment of the purse seine over drifting FADS in the Eastern Pacific Ocean, in which sharks were captured.

Date	Set	Sharks	Tonnage	Latitude (N)	Longitude (W)	SST (C°)	Thermocline (m)
31/05/11	2	5	75	04° 20′	104° 11′	28.0	53
01/06/11	3	3	22	04° 03′	104° 11′	26.8	58
04/06/11	4	4	147	03° 46′	104° 03′	27.8	34
09/06/11	5	1	39	05° 00′	104° 10′	28.0	46
23/06/11	7	17	182	03° 21′	100° 40′	27.7	58
30/06/11	8	4	142	02° 04′	102° 17′	27.3	37
10/07/11	9	6	72	04° 52′	103° 29′	27.5	37
07/04/12	2	3	12	01° 35′	101° 05′	27.8	10
20/04/12	6	4	15	01° 17′	95° 56′	28.7	19
20/04/12	7	2	79	01° 19′	96° 02′	28.7	19
21/04/12	8	3	22	01° 13′	94° 48′	28.7	24
23/04/12	10	1	95	00° 41′	93° 30′	–	–
24/04/12	12	6	25	01° 22′	94° 07′	28.7	23
25/04/12	14	1	17	01° 57′	96° 57′	28.8	23

slow growth rates, and late maturity (Musick et al., 2000). Thus, their inherent biology may limit their overall resilience to high rates of fishing mortality, and some studies argue that shark population levels have already been markedly affected worldwide (Myers and Worm, 2003; Baum and Myers, 2004; Worm et al., 2013). Recent estimates from the EPO-based tuna purse seine fleets show that between 1994 and 2004 silky shark bycatch (the most common bycatch shark species in tuna purse seine fisheries worldwide) has decreased considerably (Menard et al., 2000; Minami et al., 2007; Watson et al., 2008; Filmalter et al., 2011). During this period in the EPO, there was an increase in both the total catch of tunas by purse seiners that employ drifting FADs and the number of FADs deployed (IATTC, 2008). Because the distribution of fishing effort and landings appear to be consistent during this time period (http://www.iattc.org/AnnualReportsENG.htm), and as observer coverage is at or close to 100% for large vessels (Watson et al., 2008), it is possible that a decrease in silky shark bycatch may be due to a lower overall shark abundance.

Relative to tunas, the market value of sharks is often low and they are mostly discarded (dead or alive) by the majority of the fishing fleets around the world (Clarke et al., 2006; Dulvy et al., 2008). Currently, the tuna purse seine fleets, unlike other fisheries (e.g., Skomal, 2007; Mandelman et al., 2008; National Marine Fisheries Service, 2008; Skomal and Bernal, 2010), have no current mandate to reduce the capture of non-target fish (e.g., sharks and teleosts). Nonetheless, during the last decade, individual purse seine vessels, encouraged by the Inter-American Tropical Tuna Commission (Roman-Verdesoto and Orozco-Zoller, 2005), have begun a self-imposed campaign to actively decrease bycatch, particularly sharks (pers. comm. Captain Ricardo Diaz, 2011). One of the principal methods employed to decrease the capture effect on sharks has been to quickly sort the catch and, when sharks are present, promptly return them to the ocean. The overall assumption is that releasing sharks will allow their future contribution to the overall biomass and growth of the population. For this to occur, released sharks must survive the trauma and stress inherent in the capture event and subsequent handling. Unfortunately, the rate of post-release survival of sharks captured by tuna purse seines using drifting FADs is poorly understood. Due to the uncertain fate of released sharks, it is also critical to quantify the at-vessel condition of incidentally captured sharks to determine if there are species–specific differences, or if there are correlations between parameters associated with the capture event (e.g., quantity of tuna surrounded by the purse seine, time to remove sharks from the net) and the at-vessel condition. Recent work in the Indian Ocean by Poisson et al. (2014) showed that silky sharks captured by tuna purse seiners have over 72% at-vessel mortality, with released individuals experiencing an additional 48% mortality. It remains unknown, however, if the high total mortality of silky sharks in the Indian Ocean purse seine tuna fishery is ocean-basin specific or if it is associated with this fishing technique.

While silky sharks comprise about 90% of the shark bycatch in the tuna purse seine fishery (Gillman, 2011), other species (e.g., scalloped hammerhead) also interact with this fishery (Menard et al., 2000; Roman-Verdesoto and Orozco-Zoller, 2005; Amande et al., 2010). The recent classification by the International Union for the Conservation of Nature (IUCN) of silky sharks as "Near Threatened" and scalloped hammerheads as "Endangered" (Baum et al., 2007; Bonfil et al., 2009) has resulted in efforts to minimize any fishing-related interactions and to promote their release if captured. While this is a positive step, the post-release survival of sharks after being captured by tuna purse seines remains unknown.

There is growing evidence that interactions with fishing gear result in significant physiological disruptions, the extent of which are species-specific and depend on the capture method (i.e., fishing gear), duration of capture, and handling time (Manire et al., 2001; Mandelman and Farrington, 2007; Skomal, 2007; Mandelman and Skomal, 2009; Frick et al., 2010; Heberer et al., 2010). For example, some shark species are either dead or moribund upon reaching the fishing vessel, while others have low at-vessel-mortality (Marshall et al., 2012). In purse seine fisheries, as the net is retrieved and a sack is formed alongside the fishing vessel, the extremely high density of the fish reduces the ability of sharks to swim and ram ventilate (i.e., to force water over the gills by forward motion). This occurs simultaneously with a likely reduction in dissolved oxygen (DO), both of which exacerbate physiological stress levels (e.g., metabolic acidosis) (Mandelman and Skomal, 2009). In addition, during brailing (i.e., transfer of the catch from the "sack" to the vessel with a large mechanically-assisted dip net) the possibility of physical trauma (e.g., crushing, scraping, and cutting) is increased. The objectives of this study were therefore to quantify rates of at-vessel and post-release mortality of silky and scalloped hammerhead sharks associated with drifting FADs in the equatorial EPO and incidentally captured by a tuna purse seiner.

2. Methods

2.1. Shark collection and PSAT attachment

All sharks were captured during routine tuna purse seine operations aboard two Ecuadorian fishing vessels (F/V *Yolanda L*, May-July 2011 and F/V *Via Simoun*, April 2012) in the EPO (0–5° N, 93–104° W). The purse seine nets (approximately 175 m deep) were set around drifting FADs that were deemed by the captain to have sufficient tuna aggregations. Encircling the drifting FAD and associated tuna took 5–10 min, with an additional 60–120 min required to haul the net back aboard and create the sack. After the net was mostly recovered and a sack formed alongside the vessel, fish were