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Potential impacts of emerging mahi-mahi fisheries on sea turtle and elasmobranch bycatch species

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ABSTRACT

Mahi-mahi (*Coryphaena hippurus*) is a resilient pelagic species that could provide long-term highly productive fisheries. Using FAO data we document enormous increases (746%) in reported global mahi-mahi landings since 1950. Detailed mahi-mahi fisheries records are limited, but an observer program monitoring Costa Rica's Pacific mahi-mahi pelagic longline fleet between 1999 and 2008 (n = 217 sets) provided a rare opportunity to quantify bycatch in these fisheries. Several sea turtles and sharks of global conservation concern were caught incidentally: olive ridley turtle (*Lepidochelys olivacea*; n = 1348, mean = 9.05 per 1000 hooks), silky shark (*Carcharhinus falciformis*; n = 402, mean = 2.96 per 1000 hooks), thresher sharks (*Alopias* sp.; n = 158, mean = 1.12 per 1000 hooks), green turtle (*Chelonia mydas*; n = 49, mean = 0.35 per 1000 hooks), and three other threatened sharks in small numbers. Pelagic stingray (*Pteroplatytrygon violacea*; a ray of low conservation concern) was also a common bycatch (n = 625, mean = 4.77 per 1000 hooks). Generalized linear models (GLMs) of catch rates showed increases in olive ridley turtles and decreases in mahi-mahi and silky sharks over the decade examined. The high hooking survival rates of olive ridley and green turtles in observed sets (95% and 96% respectively) suggest that widespread training of the fleet in careful gear removal and turtle release methods could be one effective bycatch mitigation strategy for these species. GLMs also provide evidence that closing the fishery during peak olive ridley nesting times (at least near nesting beaches), in combination with reduced gear soak times, could help minimize the fishery's impacts on threatened bycatch species while still maintaining a productive fishery.

1. Introduction

Declines in traditional food fishes, coupled with ever-rising global demand for seafood products (FAO, 2010), have led many fisheries to shift targets to new species and ecosystems (e.g. Morato et al., 2006). These newly developing fisheries typically outpace scientific knowledge about the fished populations and their broader ecosystem effects, thereby hindering effective management. Fisheries for mahi-mahi are a prime example. These circumtropical and subtropical pelagic fishes (*Coryphaena hippurus*, and a few other less abundant *Coryphaena* species of restricted distribution) should be able to sustain very high fishing mortality rates because of their exceptionally fast growth rates and early maturation (usually in the first year of life; Kraul, 1999; Oxenford, 1999; Schwenke and Buckel, 2008) and thus, in theory, could provide long-term productive fisheries. Globally, however, there is little information about the status of mahi-mahi populations or management of their fisheries (Mahon and Oxenford, 1999). Of conservation concern is the potential for high bycatch levels of marine megafauna in fisheries targeting mahi-mahi with longlines (Lewison et al., 2004a). Reflecting this concern, sustainable seafood guides recommend mahi-mahi caught in the US (where the fleet's bycatch is monitored) or in poll and line fisheries (which have minimal bycatch) as a 'best choice' or 'good alternative', but that consumers should avoid purchasing mahi-mahi caught by international longline fleets due to a lack of management and bycatch issues (Blue Ocean, 2010; Seafood Watch, 2010).

Indeed, many sea turtle and elasmobranch (shark and ray) species are already of conservation concern (Dulvy et al., 2008; IUCN, 2010), at least partially because of bycatch in other pelagic longline fisheries (FAO, 2009; Lewison et al., 2004b; Lewison and Crowder, 2007; Wallace et al., 2010). Sea turtles are often entangled or caught in pelagic longlines (Carranza et al., 2006; Donoso and Dutton, 2010; Lewison et al., 2004a,b; Pinedo and Polacheck, 2004; Watson et al., 2005), and this exploitation is thought to be impeding recovery efforts for leatherback and loggerhead turtles

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(Peckham et al., 2007; Spotila et al., 2000). Pelagic sharks and rays also are commonly caught as bycatch in pelagic longline fisheries (Gilman et al., 2008; Mandelman et al., 2008). Significant declines have been documented for many pelagic shark populations in the Pacific (Ward and Myers, 2005a but see Sibert et al., 2006) and northwest Atlantic Oceans (Baum et al., 2003; Musick et al., 1993; Myers et al., 2007).

Pelagic longline fisheries targeting mahi-mahi may be particularly detrimental to sea turtles and epipelagic elasmobranchs because of the high degree of spatial overlap of these species (Gilman et al., 2006, 2008). Mahi-mahi tend to reside in surface waters (Benetti et al., 1995), so longline sets targeting them are typically shallower than those targeting tunas. Previous studies have shown that sea turtles and sharks are both captured at higher rates on shallow pelagic longline sets: near-surface swordfish sets tend to catch far more sea turtles than deep sets targeting tuna (Lewison and Crowder, 2007); in the western and central Pacific, sharks are caught over twice as frequently on shallow longline sets (500,000 sharks/year) than on deep ones (200,000/year) (Molony, 2005); and, like mahi-mahi, the catchability of many epipelagic elasmobranchs declines rapidly with depth (Beverly et al., 2009; Ward and Myers, 2005b).

Despite the potential threats, a paucity of data has limited assessment of bycatch in mahi-mahi fisheries to date. In this paper, we aimed to document recent global trends in mahi-mahi landings and quantify sea turtle and elasmobranch bycatch in these fisheries. Onboard records from most of the world's mahi-mahi fisheries are poor, but Costa Rica's fleet has had an onboard observer program since 1999 (initiated and led by co-author Arauz, 2002, 2004). Data from this program thus provide a rare opportunity to assess bycatch levels in a commercial mahi-mahi longline fishery. Costa Rica's Pacific waters are home to several pelagic shark species, and its shores are host to two of the largest known mass synchronous olive ridley turtle (*Lepidochelys olivacea*) nesting aggregations (hundreds of thousands of turtles) in the world, Nancite in Santa Rosa National Park and the Ostional National Wildlife Refuge (Cornelius, 1986). We examined the observer data for associations between catch rates of the different species and the temporal, spatial, and operational characteristics of the fishery with the goal of identifying fishing strategies that could potentially minimize bycatch while maintaining attractive catch rates of mahi-mahi.

2. Methods

2.1. Global mahi-mahi landings

We first documented trends in mahi-mahi landings within each ocean and globally between 1950 and 2009, using data pooled for all countries from the UN Food and Agriculture Organization's (FAO) Global Capture Production Database (FAO, 2011). We cross-checked the US portion of these data with US imports and landings data from the National Marine Fisheries Service database over the same time period (NOAA-NMFS, 2011). Although we searched for similar information from other countries, including Canada, UK, and Australia, no other data source isolated mahi-mahi in sufficient taxonomic detail for comparison.

2.2. Case study: Costa Rica's mahi-mahi fishery

Costa Rican authorities classify their Pacific pelagic longline vessels as being part of either the "medium scale" or "advanced scale" fleet. Vessels in the "medium scale" fleet ($n = 350$), which is the focus of this paper, usually have only 10–15 ton capacity and iced holds. They typically undertake two-week trips using approximately 18-mile longlines and wire leaders, with 650 hooks per set and 12–16 sets per trip (Table 1). This fleet targets mainly mahi-mahi, but also catch tunas and sailfish, and operates throughout the Exclusive Economic Zone (EEZ). In contrast, "advanced scale" vessels are capable of deploying 150 mile longlines, and operate within and beyond the EEZ targeting swordfish, marlins and tunas (Arauz, 2004; Arauz, pers. obs.). Sharks are considered a complementary catch in both fleets and are typically retained (Rojas et al., 2000). There are currently no spatial or temporal restrictions on longlining in Costa Rica.

Observers began onboard monitoring of a small proportion of the medium-scale fleet in 1999. All observations have been made onboard six vessels owned by Papagayao Seafood S.A., which operates from Playas del Coco. In total, the observer data consist of 217 mahi-mahi targeted fishing sets spanning the years 1999–2008 (Table 1). The highest proportion of observed sets occurred in 1999 (29%), 2003 (33%), and 2006 (12%). Within years, fishing effort typically was highest in December and January because of seasonal increases in mahi-mahi, and observer coverage increased correspondingly, with 20% and 15% of total observed sets in these months, respectively, compared to between 1% and 10% in other months.

Two species of mahi-mahi occur in this area, *C. hippurus* and *C. equiselis*, known as the common and pompano dolphinfish, respectively. *C. hippurus* is thought to comprise the vast majority of the catch (Lasso and Zapatta, 1999). These species are also referred to as dorado, but are generally sold under their Hawaiian name mahi-mahi; herein we refer to them collectively as mahi-mahi.

Bycatch in this fishery includes at least 14 pelagic teleost species, 14 elasmobranch species, and two sea turtles (Table 2). We focused on the latter two groups, because their life history characteristics (e.g. late age at sexual maturity, low fecundity) typically render them more vulnerable to overexploitation than teleost fishes, and modeled the four most commonly caught of these species (Table 2).

2.3. Data analyses

Following initial data checks and exploratory analyses, we plotted maps of the observer data to visualize and compare the spatial distribution of the fishing effort and the catch rates for the target species with those of the most commonly caught sea turtle and elasmobranch species.

We then fitted generalized linear models (GLM) to the observer data for mahi-mahi and for each of our focal bycatch species, using a negative binomial error distribution and a log link. For each species, s, the initial model of the expected mean catch, μ_i on set i is

Table 1
Variables included in initial models of observed sets in Costa Rica's mahi-mahi targeted pelagic longline fishery.

Variable	Class	Description (mean ± 1SD)
Years fished	Continuous	1999, 2002–2008
Day of year fished	Continuous (sines, cosines)	Year-round
Soaktime (h) per set	Continuous	11.03 h ± 1.86
Set period*	Categorical	Day ($n = 205$); night ($n = 12$)
Distance from shore	Continuous	143 km ± 112.5
Hooks per set	Continuous, offset	647.7 ± 156.30

* Although only 12 sets were fished at night, we included this variable in the models because it has been shown to significantly affect sea turtle and shark catch rates (Watson et al., 2005; Ward and Myers, 2005b).