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Historical reconstruction of Gulf of California shark fishery landings and species composition, 1939–2014, in a data-poor fishery context

Luz Erandi Saldaña-Ruiz[a], Oscar Sosa-Nishizaki[a,*], Daniel Cartamil[b]

[a] Departamento de Oceanografía Biológica, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), No. 3918 Carretera Tijuana-Ensenada, Ensenada, Baja California CP 22860, Mexico

[b] Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA 92093-0204, United States

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ABSTRACT

The Gulf of California (GC) is one of the most historically important regions in Mexico for shark fisheries. However, detailed historical shark landings are not available, making it difficult to plan adequate management strategies. This study analyses historical trends in GC shark fishery landings in a data-poor environment to establish a baseline for future research and assessments. The total shark landings for the artisanal fishery from 1939 to 2014, middle-size vessel fishery landings for the 1988–2014, and species composition from 1960 to 2014 were estimated, and we assessed the uncertainty inherent in the data sources and subsequent analyses. Thirty-eight shark species were identified in the GC artisanal fishery, of which *Mustelus* spp., *Sphyrna lewini*, *Rhizoprionodon longurio, Squatina californica, Carcharhinus falciformis, Sphyrna zygaena,* and *Carcharhinus limbatus* were the taxa with the greatest landings. A noticeable decline in landings was observed for *Carcharhinus leucas, Nasolamia velox, Negaprion brevirostris, Sphyrna* spp., *Carcharhinus altimus, Carcharhinus obscurus, Galeocerdo cuvier, Carcharhinus porosus, Triakis semifasciata,* and *Carcharhinus brachyurus*. Landings of the pelagic sharks *Prionace glauca, Alopias pelagicus,* and *Isurus oxyrinchus* increased after 1986, mainly due to the development of the middle-size vessel fishery. The history of GC shark fisheries and implications for management of sustainable shark fisheries are discussed.

1. Introduction

Most shark species have been described as vulnerable to overfishing because of their unique life history characteristics, which include low fecundity, slow growth, late age at maturity and long lifespan (Musick, 1999; Stevens et al., 2000). Sustainable management of shark fisheries has been recognized as a global priority to ensure the conservation of commercially harvested sharks. However, typical parameters used in shark fishery management require adequate fishery data, including catch and effort statistics and species composition information (Punt et al., 2000). The lack of such data has jeopardized the assessment of shark populations, particularly in developing countries such as Mexico.

Mexico is the worlds sixth-largest producer of shark fishery products (Dent and Clarke, 2015). More specifically, northwestern Mexico is the most important region in the country for shark fisheries, accounting for 62% (17,615 metric tons) of total shark landings (SAGARPA, 2015). Two types of shark fisheries operate in this region: the artisanal fishery, composed of < 10 m length vessels with outboard engines known as 'pangas' (Holts et al., 1998); and the middle-sized vessel fishery, composed of industrial longline fishing boats, 10–27 m in length, that mainly target pelagic sharks (DOF, 2007). In Mexico, artisanal fisheries account for about 97% of the marine fleet (Fernández et al., 2011).

An area of special biological significance in northwestern Mexico is the Gulf of California (GC), a highly productive sea with great biodiversity, that has been recognized as the most important fishing region in Mexico (Lluch-Cota et al., 2007), and designated as a Large Marine Ecosystem (Sherman, 1994). Shark fishing became important in the GC during World War II, when large shark species were targeted to provide shark liver oil to the United States as sources of vitamin A (McGoodwin, 1976; Applegate et al., 1979). This fishery has since evolved into a multi-species, multi-gear fishery with high socio-economic value (Castillo-G & niz et al., 1998; Holts et al., 1998; Sosa-Nishizaki, 2008; Cartamil et al., 2011).

To improve management of the GC shark fishery, and to understand the potential vulnerability of harvested species, it is necessary to identify species-specific landing trends through time (Camhi et al., 1998; Musick, 1999; Bizzarro et al., 2007). Unfortunately, incomplete documentation of GC shark fishery landings limits our understanding of

* Corresponding author.
E-mail addresses: lsaldana@cicese.edu.mx, luzerandisr@gmail.com (L.E. Saldaña-Ruiz), ososa@cicese.mx, ososa1103@gmail.com (O. Sosa-Nishizaki), dcartamil@mail.ucsd.edu (D. Cartamil).

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historical trends. The available official landing records have three major deficiencies. First, historical shark landings records are not available for some years. Second, species composition data are lacking. And third, there is no differentiation between the landings from the artisanal and the middle-sized vessel fisheries.

Several previous studies have highlighted the importance of using of all available fishery data, as well as qualitative information, to estimate and reconstruct historical fisheries landings (Pauly, 1998; Zeller et al., 2007; Harper et al., 2014; Leitão et al., 2014). Reconstruction of landings time series in data-poor situations requires interpolations and strong assumptions (Zeller et al., 2006). Although imperfect, reconstruction of past landings and species composition can provide a reasonable approximation of changes in marine fisheries over time, and help elucidate the current status of shark populations (Pauly, 1998). Thus, this information is fundamental to evaluating the effectiveness of current management.

In light of the ecological importance of the GC and the magnitude of its shark fisheries, this study analyses historical trends in GC shark fishery landings in a data-poor environment. Based upon an exhaustive review of extant literature and alternative data sources, we have reconstructed total shark landings from GC shark fisheries for the period 1939–2014, species composition of the landings for the period 1960–2014, and assessed the uncertainty inherent in our data sources and subsequent analyses. We discuss the history of GC shark fisheries, and implications for management of sustainable shark fisheries in the GC.

2. Methods

2.1. Study area

The GC is a semi-enclosed sea in the eastern North Pacific Ocean. It is located between the eastern coasts of the Mexican states of Baja California (BC) and Baja California Sur (BCS), and the western coasts of Sonora (SON), Sinaloa (SIN), and Nayarit (NAY) (Fig. 1). The southern limit of the GC is taken as a line connecting Cabo San Lucas (BCS) and Cabo Corrientes (Jalisco), a delineation based on faunal and oceanographic features, and Mexican official marine territorial planning (Roden, 1964; Brusca et al., 2005; DOF, 2006; Álvarez-Borrego, 2010). The GC is 1130 km long, ranges in width from 80 to 209 km, with an area of approximately 200,000 km^2, and reaches depths greater than 3000 m (Lluch-Cota et al., 2007). Due to overfishing and resource sustainability concerns, the GC is closely monitored by conservation groups (Lluch-Cota et al., 2007; Álvarez-Romero et al., 2013).

Dynamic oceanographic processes of the GC include gyres, fronts and upwelling, that produce elevated sea surface temperature variability and primary productivity (mostly in the north and central zones) during winter and spring (Álvarez-Romero et al., 2013). The GC has three natural fertilization mechanisms: wind-induced upwelling, tidal mixing, and thermohaline circulation. (Álvarez-Borrego, 2010). In winter conditions (December–May), upwelling occurs off the eastern coast of the GC with northwesterly winds, and off the BC coast with southeasterly winds in summer conditions (July–October). Upwelling and the gyres increase the phytoplankton communities (Álvarez-Borrego, 2010; Santamaría-del-Ángel et al., 1994). These processes allow the GC to support a great diversity of sharks and other ichthyofauna, which in turn support several commercial fisheries (Lara-Lara et al., 2008; Álvarez-Romero et al., 2013). For example, Hastings et al. (2010) reported 87 species of cartilaginous fish within the GC, and around 72 species (83%) are caught in the GC artisanal fishery (Bizzarro et al., 2007). Fish diversity is higher in southern latitudes of the GC, due to elevated temperatures, greater habitat diversity, and increased connection with Pacific waters (Lehner, 1979; Álvarez-Borrego, 2010; Brusca et al., 2005).

2.2. Reconstruction of GC total shark landings: 1939–2014

This study reconstructs total GC shark landings during the period 1939–2014 using a variety of available data sources. In addition, we estimate species composition for the artisanal fishery catch from 1960 to 2014, and assess the uncertainty associated with our analyses. Reconstruction of total landings and species composition followed the approach of Harper et al. (2014); Zeller et al. (2007, 2015), and fundamentals for reconstructing catch time series of Pauly (1998).

2.2.1. Data sources

Details of all data sources used in this study are reported in Table 1. The baseline data used for the reconstruction consist of Mexican official landings statistics that have been compiled since 1940 by several agencies of the Mexican Federal Government (Arreguín-Sánchez and Arcos-Huitrón, 2007). This process begins with fishery permit holders, who regularly submit landing slips to local fishery offices (FOs) of the Mexican National Commission of Fisheries and Aquaculture (CONAPESCA). FOs are typically located at major ports or close to important fishing communities (Escobar-Fernandez, 1989). Landing data are then compiled at CONAPESCA's central office, and reported annually through the Fisheries Statistics Yearbook (Anuario Estadístico de Pesca), which includes landings in dressed (i.e., headed and gutted) weight and rounded weight (kg) by species or species group for each state (Secretaría de Marina, 1940–1969; Departamento de Pesca, 1979–1981; Secretaría de Pesca, 1982–1994; Secretaría del Medio Ambiente, Recursos Naturales y Pesca, 1995–2001; Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, 2002–2015). We used only rounded weight. Yearbooks do not report shark catch by species, and shark landings have historically been reported under two categories: "Tiburon" [sharks > 150 cm TL (Total Length)] and "Cazon" (sharks ≤150 cm TL). The categories were pooled to generate historical total shark landings series for each state, and are referred to hereafter as total shark landings (TSL), expressed in metric tons (t).

Total shark landings for the GC (TSL-GC) were compiled from official yearbook statistics recorded at 26 local FOs from the five states bordering the GC (Table 1). In the case of BC and BCS (states with both Pacific and GC coasts), only records from the six FOs on the GC coast were used (Fig. 1). However, official catch statistics contain data gaps (missing years of FOs data), requiring the reconstruction of an estimated TSL-GC for each type of fishery (artisanal and middle-sized vessel), and for several time periods, each with unique characteristics and requiring different analytical approaches and assumptions, as described below:

2.2.1.1. Artisanal fishery.

(a) 1939–1950: Shark liver was the main product during this period due to high demand for vitamin A during World War II, with most of the meat discarded (Hernández-Carvallo, 1971; Alcalá-Moya, 1999). Shark landings during this period were reported only in terms of liver weight (Secretaría de Marina, 1940–1969), which was converted to rounded weight using an FAO conversion factor of 8.13 (Vannuccini, 1999).
(b) 1951–1960: Shark meat becomes the main shark fishery product due to the advent of synthetic vitamin A production (Ferreira, 1958; Hernández-Carvallo, 1971). For BC and BCS, all landings reported before 1960 were assumed to correspond to fishing in the GC, because Pacific coast fisheries did not begin until the early 1960s (Alcalá-Moya, 1999).
(c) 1961–1976: During this period, TSL was reported only for the entire country. To estimate landings from the GC only, we used the relative proportions (72%) of TSL-GC to TSL found in the first available regional data (1977–1979), assuming a similar fishing dynamic.