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Factors affecting the operational interaction between the South American sea lions and the artisan gillnet fishery in Chile

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ABSTRACT

The South American sea lion (SASL, *Otaria byronia*) is one of the species of pinnipeds that display the strongest level of conflict with fishing activities throughout its distribution range. However, little is known about potential temporal and/or spatial variations in the magnitude and effects of SASL and fishing interactions over an entire year and at different sites simultaneously. This study examines the factors that affect the intensity of the operational interaction between SASL and the artisan gillnet fishery in central Chile. Between 2014 and 2016, a total of 145 hauls at three artisan fishing coves were analyzed. South American sea lion interactions were observed in 82 of the 145 (56.6%) hauls analyzed, most frequently at the coves of San Antonio and El Membrillo. From the examined factors, Predation per Unit Effort increased with the number of SASL, however it decreased both during the summer and with greater distance from the nearest SASL colony. Artisan deterrent systems used by fishermen were found to be inefficient in avoiding the interactions with sea lions. Although the intensity of the interaction has increased in recent years (compared with previous studies in the area), the observed Catch per Unit Effort did not differ significantly during fishing trips with or without interaction, indicating that SASL is not a determining factor in the variation of artisan fishery catches. These results demonstrate that the intensity of interactions is not produced at random but rather it is related to factors that obey biological and ecological aspects of the SASL. These factors should be considered for the development of effective actions to prevent, or at least to reduce the interaction between SASL and artisan fisheries.

1. Introduction

According to the FAO (2012), the majority of global fisheries are overexploited or fully exploited, which has led to a marked decrease in fish stocks in recent decades (Sanchirico and Wilen, 2007). The decrease of these resources has generally resulted in the intensification of fishing effort, which increases the probability of interactions with other marine predators, such as marine mammals (Read et al., 2006). Pinnipeds (seals, sea lions and walruses) in particular are one of the groups that display the highest levels of interaction with fisheries given by the fact that they prey upon the same resources ("biological interaction") and their foraging areas overlap with fishing activities (Lavigne, 2003; Hückstädt and Krautz, 2004; Machado et al., 2016). This leads to damage of catch and fishing gear, injury and fatalities of sea lions, as well as possible injuries to fishermen ("operational interaction", Wickens et al., 1992). Whether caused by operational or biological interaction, it can lead to a decrease in the relative abundance of pinnipeds and/or to changes in their diet composition due to the advantage of accessible prey (Machado et al., 2016). Fish landings for fishermen may also drop, thus leading to a situation where both fishermen and sea lions incur losses (Lavigne, 2003; Machado et al., 2016).

One of the species of pinnipeds that display the strongest level of conflict with fishing activities throughout its distribution range is the South American sea lion (SASL, *Otaria byronia*) (e.g. Szteren and Páez,

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2002; Hückstädt and Antezana, 2003; Sepúlveda et al., 2007; Goetz et al., 2008; Reyes et al., 2013; Machado et al., 2016). This species is widely distributed in both ocean basins off South America (Cappozzo and Perrin, 2009; Crespo et al., 2012). It displays generalist and opportunist feeding habits, with a highly variable diet and easy adaptation to exploit the resources that are most widely available in their foraging environment (Cappozzo and Perrin, 2009; Muñoz et al., 2013). In Chile, a large part of the prey species that are part of the SASL diet are of commercial importance (Neira and Arancibia, 2004; Parada et al., 2013), which generates a conflict with artisan and industrial fisheries (e.g. Hückstädt and Antezana, 2003; Sepúlveda et al., 2007; Goetz et al., 2008; Reyes et al., 2013; González et al., 2015), given that these animals have learnt to take advantage of prey that is concentrated and vulnerable inside fishing gear (De la Torriente et al., 2010).

The degree of the interaction between SASL and fishing activities is not constant, but varies spatially and temporally (De María et al., 2014; González et al., 2015). Spatial variation in interaction intensity has been reported off the coast of the Pacific (e.g. González et al., 2015) and Atlantic Oceans (e.g. Szteren and Páez, 2002), and is associated mainly with the distance between fishing activities and SASL colonies, where the shorter the distance, the greater the intensity of interaction with the fishery. In a similar way, temporal variations in interaction intensity have been recorded throughout SASL distribution, with greater intensities during the months of autumn and winter (March to September) (Sepúlveda et al., 2007; De la Torriente et al., 2010; De María et al., 2014; Machado et al., 2016).

The strong operational interaction between different species of marine mammals and artisan and industrial fisheries has motivated the development of a range of deterrent devices worldwide, such as the use of acoustics systems, albeit with mixed results (Götz and Janik, 2013). Moreover it has an unaffordable implementation cost for artisan fishermen. In Chile, fishermen have created their own artisan deterrent methods with noisemakers, shortguns and pyrotechnics. However, to our knowledge, these systems have not been assessed for their efficiency in reducing interaction with SASL.

We carried out a 2-year study at three artisan fishing coves in central Chile, with the following two aims: (1) to analyze the factors that affect the intensity of the interaction between SASL and artisan fisheries; and (2) to describe and analyze the efficiency of the deterrent devices developed by artisan fishermen to reduce interactions with SASL.

2. Material and methods

2.1. Area and study period

This study was carried out at three artisan fishing coves in central Chile: Higuerillas (32°55′S–71°32′W), El Membrillo (33°1′S–71°37′W) and San Antonio (33°35′S–71°36′W) (Fig. 1). The vessels are open boats mainly made of fiberglass with an outboard four-stroke engine. The vessel length is between 8 and 9 m (Range: 7.4–11.5 m), with an engine power of about 50 Hp (Range: 40–140 Hp). Two observers performed fishing trips. The observers recorded a total of 122 fishing trips and 145 hauls onboard artisan fishing boats between May 2014 and January 2016, spanning four seasons.

This study examined the artisan gillnet fishing fleet targeting South Pacific hake (SPH, *Merluccius gayi*), since most interactions with SASL have been described for this fishery in Central Chile (Sepúlveda et al., 2007; Goetz et al., 2008). This fishery uses monofilament and multifilament nylon gillnets, with a length from 150 to 3000 m. Total annual landings of SPH in the study area are 2270 t (Sernapesca, 2016).

2.2. Interaction with sea lions

During each haul, the following information was recorded: (1) geographic position, (2) number and surface area of nets, (3) number and weight of SPH caught, (4) immersion time of the fishing net, (5) number of SASL observed near the fishing vessel, including animals within 20 m of the vessel, a distance which provides a clear view of animals around the boat (Sepúlveda, obs. pers.), (6) number and weight of fish damaged by attacks from sea lions, and (7) mortality of sea lions (intentional, by direct action by fishermen; or accidental, due to entanglement in the net or during fishing operations).

In 74 of the 145 hauls, information about the use of artisanal deterrent systems was collected. A total of seven different systems were identified by the observers: (1) Strobes; (2) Musical triangle; (3) Steel poles or oars; (4) Steel spheres; (5) Firecrackers; (6) Sound blasts; and (7) Shortguns. These systems were used in the presence of sea lions during fishing activities to emit sounds that would attempt to ward off sea lions from vicinity of fishing. For each trip, the observer registered if the fishermen used a deterrent system, identifying which of these systems were used.

An interaction event was defined by the presence of sea lions and/or whether fishes were taken or damaged (Szteren and Páez, 2002). We considered that a fish had been damaged by a sea lion when the scar had a characteristic semicircular shape and one or more sea lions were observed within 20 m of the vessel (Szteren and Páez, 2002).

Catch from all trips was standardized as Catch per Unit Effort (CPUE). CPUE was calculated as: $CPUE = C\ t^{-1} s^{-1}$, where C is the biomass of SPH (kg), t is the immersion time of the fishing net (h), and s is the total surface area of the fishing net (m^2) (Szteren and Páez, 2002). In a similar way, depredation rates were standardized according to Predation per Unit Effort (PPUE), which was calculated with the equation: $PPUE = C_{df} t^{-1} s^{-1}$, where C_{df} is the biomass of SPH damaged by SASL (Szteren and Páez, 2002).

2.3. Data analysis

We compared the CPUE in the presence or absence of interactions using a Kruskal-Wallis nonparametric test, since CPUE departed from normality, and calculated the relation between CPUE and the number of SASL around the boat using a Spearman's nonparametric correlation. We also calculated the relative frequency of occurrence of the interactions, i.e. the number of interactions with sea lions divided by the total number of fishing operations, expressed as a percentage (FO%) (Machado et al., 2016). Differences in FO among local coves were calculated, as well as seasonal differences at each cove using a chi-squared (χ^2) test.

We modeled the potential explanatory factors in order to assess the causes of sea lion predation. The variables considered for this analysis were: year, season, number of sea lions, and the distance to the nearest sea lion colony. A large proportion of zeros occurred in our database because many of the observations did not register any interaction (see Section 3). To deal with these distributional characteristics, we formulated a 'two-part' (or 'Hurdle') model (Lambert, 1992). We first constructed a logistic regression model to test which variables may potentially influence the PPUE. After that we modeled the PPUE using a Zero-inflated Gamma regression model as a function of the covariables mentioned above. A zero-inflated model is recommended when analyzing data that have a larger proportion of zeros (Barry and Welsh, 2002; Yau et al., 2003).

Finally, we analyzed separately the effects of the use of deterrent systems because they were only monitored in 74 hauls. For this analysis we conducted a two-sample Wilcoxon rank-sum (Mann-Whitney) test to analyze whether the use of deterrent systems by fishermen influenced the number of fish that were damaged by SASL. All statistical analyses were performed using the program Systat 13.0 (SYSTAT, 2009), Stata 14.0 and R-project software (http://www.R-project.org).

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