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Assessing the effects of demersal fishing and conservation strategies of marine mammals over a Patagonian food web

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ABSTRACT

The San Matías Gulf (SMG) is a semi-enclosed ecosystem where the Argentine hake *Merluccius hubbsi* (AH) has been the main fishery resource since 1971. During the 20th century the South American sea lion *Otaria flavescens* (SASL) population was severely reduced in this ecosystem due an intense hunting, but in the 1970's conservation was promoted and hunting was banned. As a consequence SASL have been slowly recovering, until the 1990's when rapidly rebuilt their populations. Recent studies indicate that they feed mostly over commercially profitable medium-sized AH. Also, medium-sized and large hake are well-known cannibals that feed heavily over smaller AH. Fishing trawlers affect juvenile and medium-sized AH and artisanal long-liners capture exclusively large AH. The objective of this study was to evaluate the effect of a growing SASL population over the AH in the SMG, considering the changes in the fishing activity as well as the size-structured cannibalism within the AH population. The evaluations were based on time series of hake and SASL biomass using the "Ecopath with Ecosim" dynamic modelling approach. The analyses show that over 4 decades the increase in Sea Lions biomass has not generated a significant increase in the predation mortality over AH. On the other hand, an increase and subsequent variations in the fishing mortality seems to be related with long-term variations in large AH abundance, and a decrease in medium-sized AH abundance, constraining the cannibalism mortality. This led to a positive effect over juvenile AH abundance due to a released cannibalism pressure, even considering that the less abundant larger AH are also the main spawners of the population. In this scenario, where it seems that trawlers and long-liners have replaced several predators over the SMG food web, SLAS population is still growing but they may not reach the pristine abundance levels of the time before hunting.

1. Introduction

Marine ecosystems are currently under change due to different reasons: intensive fishing, climate change and pollution, among others. Fishing is a widely known activity that usually targets a few components of the ecosystems; other components are often discarded (Kelleher, 2005; Rochet and Trenkel, 2005) or affected indirectly through food web effects (Crespo et al., 1997). For instance, in some heavily fished ecosystems top predator biomass has declined substantially, inducing major changes in ecosystem structure and function through the release of top-down control (Christensen et al., 2014). Marine mammals are examples of these top-down controllers and are often considered as competitors of humans, since they share the same food (Kaschner and Pauly, 2005; Morissette, 2007; Plagányi and Butterworth, 2002; Read, 2008). In current scenarios, where fishing frontiers are moving further and many marine mammal species are recovering, the perception of a significant competition between marine mammals and fisheries has motivated different studies in order to understand how

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they interact and to prevent future conflicts (Cronin et al., 2014; DeMaster et al., 2001; Harkonen et al., 2012; Harwood and Croxall, 1988). Although competition between marine mammals and fishing fleets is difficult to quantify, previous studies have shown some degree of direct impact between them (Bergamino et al., 2012; Morissette, 2007). However, this competition is entangled in a more complex web of interactions where indirect competition may be relevant (Trites et al., 1997; Yodzis, 1998).

On the Argentine Continental Shelf (ACS), the Argentine hake (AH) *Merluccius hubbsi* is one of the most important fishery resources in terms of landings volumes and its two main stocks were severely fished and are considered overexploited (Aubone et al., 2004; Vaz-dos-Santos et al., 2010). The San Matías Gulf (SMG) is a semi-enclosed fished ecosystem that hosts a third stock of Argentine hake. Several studies have shown that this stock completes its life cycle within the gulf, constituting an independent demographic unit (Di Giácomo et al., 1993; González et al., 2007; Machado Schiaffino et al., 2011; Sardella and Timi, 2004). This species has also shown a size-structured intraspecific predation, where the larger cannibals prey over the commercially profitable medium-sized hakes and the latter actively feed over young-of-the-year juvenile hake (Ocampo-Reinaldo et al., 2011). The hake fishery started in 1971 with medium-sized industrial bottom trawlers, while industrial and artisanal long-liners joined 25 years later (González et al., 2007). While both fleets are aimed to capture hake, they affect a different range of fish sizes: trawlers catch all the size range from juveniles (which are discarded) to larger hakes (Ocampo Reinaldo, 2010; Romero et al., 2010), long-liners catch mostly large hakes with no significant discards (González et al., 2003, 2007; Romero, 2011).

The SMG also hosts several permanent settlements of South American sea lions (SASL) *Otaria flavescens* and one temporary settlement of South American fur seals *Arctocephalus australis* (Svendsen et al., 2013). During the 20th century the SASL population was severely reduced in this ecosystem due to intense hunting, but in the 1970's conservation was promoted and hunting was banned (Crespo and Pedraza, 1991; Dans et al., 2004). As a consequence, SASL have been slowly recovering, until the 1990's when rapidly rebuilt their populations (overall ~5.7% per year). Recent studies indicate that they have high consumption rates and feed mostly over commercially profitable medium-sized and juvenile hakes (Drago et al., 2009; Romero et al., 2011).

In this situation, with SASL apparently competing with the fishery for the same resources is important to quantify the potential synergistic effects of SASL conservation, fishing activity and hake cannibalism over the food web. In this sense, the assessment of the SMG ecosystem needs to address these effects using the same framework. The construction of an ecosystem energy flow model in a "pristine condition" provides such a framework where baseline interactions between components of the ecosystem can be quantified. Changes in the ecosystem state and structure from the past to the present can be simulated to better understand the processes that underlie the observed patterns of abundance of important species.

This study is based on a reference steady state model of the SMG, for the time when the demersal fishery had not been developed yet and the SASL population was severely depleted (1970). Also, the model was then used to explore along four decades the ecosystem effects of a new and growing hake fishery paralleled by the rise of SASL population due to conservation measures.

The aim of this study was to evaluate the effect of a growing SASL population over the Argentine hake resource of SMG, considering the changes in the fishing activity as well as the size-structured cannibalism within the hake population. The evaluations were based on long-term time series of AH and SASL biomass using the "Ecopath with Ecosim" dynamic modelling approach.

2. Methods

2.1. Study area

The study area has been set for modelling purposes over the operative area of the San Matías Gulf (SMG) trawl fishery (41°30′S and 64°30′W at the centre of the area, approximately 10,000 km^2), which covers almost the entire gulf from the coasts to its entrance (Fig. 1). This semi-enclosed area is deeper than 90 m, with a maximum of 200 m in the central area, and the continental shelf on the eastern side forms an open basin with a mean depth of 50–70 m at the entrance. The general circulation pattern in spring-summer is dominated by a cyclonic gyre, located at the northern half of the basin (70 km diameter approximately, Piola and Scasso, 1988), which in combination with a seasonal frontal system in summer determines the relative isolation of the gulf water masses (Gagliardini and Rivas, 2004; Piola and Scasso, 1988; Scasso and Piola, 1988; Williams et al., 2010).

In terms of biological components, the SMG sustains a diverse food web. Zooplankton is dominated by sub-antarctic euphausiids (*Euphausia lucens, E. vallentini)* and the sub-tropical *Nematoscelis megalops* and tropical *Thysanoessa gregaria*, which are found with different abundances and frequencies of larval stages in relation to the ACS waters, supporting the isolation hypothesis of the SMG waters (Curtolo et al., 1990).

Similarly, over 23 species of planktonic cnidarians have been found with a characteristic assemblage composition, highlighting the presence of a siphonophore *Pyrostephos vanhoeffeni*, previously known as endemic to Antarctic and sub-Antarctic waters (Guerrero et al., 2013). On the other hand, as additional evidence of the isolation of this ecosystem, the Argentine red shrimp *Pleoticus muelleri* have not been a significant benthic component within the SMG, while over other coastal areas of the ACS (e.g. San Jorge Gulf) it is a very important fishery resource. Small pelagic fishes such as anchovy *Engraulis anchoita* are present with a high biomass, but no fishery has been developed to target them (González et al., 2004; Hansen, 2007; Rojo and Silvosa, 1969). The demersal fish community is dominated by the Argentine hake (AH) both in terms of biomass and landings. Alongside with its highly intra-cohort and inter-cohort cannibalistic behaviour, this species feeds over a variety of preys changing its diet during its lifetime (Prenski and Angelescu, 1993; Ocampo-Reinaldo et al., 2011). Many other fishery species that are likely to play an important role in the food web (e.g. short-finned squid *Illex argentinus*) show dramatic inter-anual abundance variations for unclear reasons (Romero, 2011). The SMG ecosystem also represents an independent management unit, with their demersal fisheries and conservation areas managed exclusively by the Río Negro Province Administration. Within this ecosystem, the fishing activity is performed mainly by industrial bottom trawlers aimed to catch the AH (up to 80% of the annual landings) followed by the silver warehou *Seriolella porosa* in recent years (Ocampo Reinaldo et al., 2013; Romero et al., 2013). However, more than 15 other fish species have commercial and/or ecological value and are mostly captured by trawlers as by-catch. The landings composition has changed a few times in the fishery history, due to market drivers and/or variations in the fishing strategies rather than changes in the abundance of the target resources (Romero, 2011; Romero et al., 2013). A mid-water near-bottom long-liners industrial fleet joined in 1996, but after 4 years was banned, allowing thereafter only artisanal smaller boats with similar gears (González et al., 2007). A third industrial jigger fleet has operated sporadically over the SMG, with highly variable inter-annual effort depending on the occasional abundance of short-finned squid (1994–1999, 2000 and 2003) (Fig. 2; Official logbook records of the Fishery Directorate of Río Negro province, Millán, 2009).

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