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Clutch fullness index as an early indicator of overexploitation of the Southern King Crab: Implications for fisheries management

Carla Firpo [a], María Inés Militelli [a b c], Mauro Alejandro Eduardo Chaparro [b d], Cecilia Mauna [a], Pablo Lértora [a]

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Highlights

- *Lithodes santolla* Clutch fullness index varied among years.
- The variation of the CFI was opposite to the fishing effort.
- The implementation of management measures allowed the recovery of CFI values.
- Two indicators of *L. santolla* reproductive status are proposed.

Abstract

Southern king crab is a high-value fishing resource commercially exploited in the Argentine Patagonia (south 44° S) since 2004. The ovigerous mass size of females, estimated as the clutch fullness index (CFI), has been used as a proxy for qualitative fecundity and an indicator of population health. In 2015, the use of CFI allowed the early detection of signs of overexploitation of the Southern king crab. This study aimed to assess temporal variations in the CFI in relation to fishing effort and management measures. Data were collected from commercial vessels between January and May from 2012 to 2020 in the Central Patagonian Sector (comprising the San Jorge gulf and adjacent shelf waters, 43°30′- 48°S). The Correspondence Analysis and hierarchical cluster analysis showed that the CFI varied among years. The variation of the CFI was opposite to the fishing effort. The CFI decreased between 2015 and 2017 (from 80% of females with 100% CFI in 2014 to 43% in 2017), and increased since 2018 (from 57% in 2018 to 78% in 2020). This is probably due to the implementation of two new management measures (extended closed season and the regulation of an annual catch quota). Two indicators of *L. santolla* reproductive status are proposed based on empirical data. The first one is the proportion of non-ovigerous mature females during the incubation period, which could reflect a male shortage during the mating period must not exceed 10% and the second one is the proportion of females with a complete clutch must be greater than 40%. The CFI variations and the proposed indicators can constitute an alternative to the crabs traditional management.

Introduction

Variation in population recruitment is perhaps one of the main factors to consider in fisheries evaluation and management. In species under intense commercial exploitation, the extractive activity usually generates changes in the population structure, affecting different reproductive variables (Dvoretsky and Dvoretsky, 2015) and subsequently influencing the renewal potential of the resource. This has led to intensifying the study of these aspects, incorporating new indices into traditional evaluation models that allow decision-makers to explain, and even predict variations in abundance patterns.

Lithodids support important fisheries in higher-latitude regions in the northern and southern hemispheres. King crabs are vulnerable to overfishing, in part due to their slow growth and late sexual maturity (Olson et al., 2018), their spatial distribution confined to restricted geographic regions (Armstrong et al., 1998; Orensanz and Jamieson, 1998; Firpo, 2020), and on the other hand, to the fisheries regulation applied. Most management of lithodid fisheries is based on the 3S (size, sex, season) strategy, which consists of the selective exploitation of males above a certain size and regulation of a limited fishing season (e.g., Alaska Department of Fish and Game, 1993). These measures aim to preserve

reproductive potential since the legal minimum fishing size allows males to mate for at least one season (Orensanz et al., 1998). In addition, the sex restriction protects females that carry embryos for much of the year and the fishing season prevents capture in "biologically sensitive periods" such as mating and moulting (Kruse, 1993). However, the overfishing has led to a substantial decline in lithodid catches in many regions (Otto et al., 1989; Orensanz et al., 1998; Zaklan, 2002; Hebert et al., 2009; Pirtle et al., 2012).

In South America, the southern king crab (*Lithodes santolla*) fishery is developed in the Southern Pacific and Atlantic oceans (Otto and MacIntosh, 1996). In the Magellan Strait and on the Pacific coast near Chiloé (Chile), southern king crab fisheries reported recruitment overfishing associated with an increasing fishing effort (Vinuesa et al., 1991; Molinet et al., 2020). In the Beagle Channel, *L. santolla* overexploitation since the 1970s led to prolonged close fishing, between 1992 and 2012 (Lovrich, 1997; Lovrich and Tapella, 2014) but the stock did not reach the expected recovery (Di Salvatore et al., 2021). Several factors have been proposed to explain the collapse of the king crab fisheries, such as overfishing, recruitment linked to climate change, variations in predator abundances, a decline of reproductive potential, and increased embryonic mortality (Otto, 2014).

L. santolla is a highly valuable resource, ranking among the 10 most important species in Argentine marine fishery exports (1.5% of exports, Firpo et al., 2021a, Firpo et al., 2021b). Currently this fishery has three main fishing areas: Central Patagonian Sector (CPS, Central Area) located between 43° 30′ S and 48° S, South Patagonian Sector (SPS, South Area) between the 48°-55°S, and the Beagle Channel in Tierra del Fuego. The CPS fishery was opened in 2004 and represents the most important area in terms of catch volume and fishing effort (almost 2,000t per year, Firpo et al., 2021a, Firpo et al., 2021b) and SPS is a new area that opened in 2016. In these areas the fishing fleet is composed of freezer and fresher vessels, whereas the Beagle Channel fishing is artisanal.

CPS landings presented 3 stages according to fleet growth and the management measures: between 2004 and 2009 an exploratory fishery was carried out with one vessel (1,000t on average per season), between 2010 and 2016 there was full development with growth in landings and fleet (3,800t on average and 5 vessels), and since 2017 a recovery stage has been implemented with restrictive management measures (1,300t on average). At present 6 freezer vessels provide much of the catch and 2–3 fresher vessels land lower catches and fish inshore waters (Varisco et al., 2018; Firpo, 2020).

In Argentina, the *L. santolla* fishery management is based on selective exploitation of legal male size (≥110mm carapace length, CL), a fishery closed season and the prohibition of female landings according to 3S management strategy (Firpo et al., 2018). Since L. *santolla*

mate once a year, lack sperm-storage structures, and carry eggs for an extended period, the egg production and the clutch size are the direct and indirect measure of reproductive success in the previous reproductive season (Di Salvatore et al., 2021). In the CPS adult females moult during spring (between November and December), in synchrony with the mating season, while adult males moult between late autumn and early winter (Balzi, 2005). Until 2017 landings were not restricted, and then a quota catch estimated from survey and fishing data was regulated. At the same time, the start of fishing was changed from October 1 to January 1 and therefore the season was reduced. Another important regulation is the presence of on-board observers on all vessels and fishing trips since the opening of the fishery, reaching a coverage of ~85%, which provides the necessary information for stock assessment and management of the fishery (Firpo, 2020).

Selective fishing protects females; however, it can affect their reproductive potential due to sex ratio changes and/or reduction in males' size (Pillans et al., 2005; Hjelset, 2014; Pardo et al., 2015). Other non-natural factors that may also contribute to a reproductive potential reduction are: limited sperm production because small males dominate (Sato et al., 2005; 2006; 2007) or low abundance of large males (Powell et al., 1973), handling and discarding of females and eggs mortality due to air exposure during the capture selection (Gowland-Sainz et al., 2015). Natural factors include advanced age, deterioration in physiological conditions, loss of unfertilized eggs, abrasion, diseases, and predation (Kuris et al., 1991). The ability of females to carry eggs allows the detection of spatial and temporal variability in reproductive potential, so the clutch fullness index (CFI) has been proposed as an indirect estimate of egg production. CFI has been reported in several crab fisheries such as red king crab (*Paralithodes camtschaticus*), snow crab (*Chionoecetes opilio*), Tanner crab (*C. bairdi*) and *L. santolla*, based on a limited number of categories (Donaldson and Byersdorfer, 2005; Johnson et al., 2001; Orensanz et al., 2005; Militelli et al., 2019; Molinet et al., 2020). In this sense, the CFI is useful for fisheries management since it allows the detection of signs of recruitment overfishing and, as an indicator of the population status, it can be used to define biological reference points (Orensanz et al., 1998; Webb, 2014).

In the CPS, an increase in fishing effort and reported catches between 2010 and 2015 caused a decline in yields and fecundity (Firpo et al., 2015a, 2015b; Varisco et al., 2019). These early overexploitation signs lead to the implementation of a longer closed season in 2017 to protect the moulting and mating season of females (Wyngaard et al., 2016). The main objective of this study was to assess the temporal variation in the CFI of the southern king crab in relation to fishing effort and management measures.

Section snippets

Study area and fishery characteristics

The Central Patagonian Sector (CPS) comprises the San Jorge gulf and adjacent shelf waters. The San Jorge gulf is an ocean basin that's open to the Atlantic Ocean, with a shoreline spanning from Chubut to Santa Cruz province (Fig. 1). Due to its geography, more than 70% of the gulf basin is between 50 m and 75 m deep with a maximum of 110 m in the centre. The southern king crab fishing area is divided into four management zones: Northern sector of National jurisdiction (NN), Southern sector of…

Results

The presence of on-board observers in the CPS management zone allowed us to register CL and CFI for between 6,370 and 35,000 mature females per year (Table 1).

Before carrying out the CA analysis, a mosaic graph was made to represent the relevance of each CFI category (Fig. 4). Each mosaic height corresponds with each CFI category relative proportion and the width represents the relative proportion of the number of samples, for each year. In this way, it is possible to observe that 2019 and 2016 …

Discussion

The annual analysis of the southern king crab population made it possible to detect temporal CFI variations in the Central Patagonian Sector. A decrease in reproductive potential was detected between 2015 and 2018. This result coincided with Varisco et al. (2019) who determined that the fecundity of the species in the San Jorge gulf was lower in 2014–2016 than in 1994–1996 when fishing had not yet started. In the subsequent years, the recovery in the proportion of ovigerous females with…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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