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The impact of size truncation on reproductive success in the southern king crab (*Lithodes santolla*)

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Highlights

- Male size truncation affects functional reproduction in southern king crab (SKC).
- Functional reproduction ogive of female SKC indicates their reproductive health.
- Female functional reproduction of SKC must be estimated using the four parameters' Richards Function.
- Asymptotic values <0.99 would reflect a deteriorated condition of the stock.

- In SKC exploited stocks, asymmetry in functional reproduction ogive would indicate sperm limitation.

Abstract

Sex-biased fishing mortality caused by male-only fishing may result in sperm limitation and recruitment overfishing. These effects can be observed by studying the size at functional reproduction (SFR) of lithodid females. We studied changes in the ratio of males to females, size truncation, and changes in SFR in the southern king crab (SKC) in two areas experiencing different fishing pressures in southern Chile. SFR was estimated with the Richards Function, a generalized 4-parameter logistic model. The shrinking of SFR of females may occur due to the proportional shrinking of reproductive and non-reproductive females and/or because the shape of the ogive changes, setting the inflection point back to smaller sizes. In the region with low fishing pressure the functional reproductive ogive was symmetric (γ=1, and the asymptote was ~1, indicating a balance in male availability. In the region with high fishing pressure γ was 82% lower and the asymptote was 23% lower, an indicator of sperm limitation. The symmetric shape of the logistic curve, which is widely assumed when fitting maturity ogives, is not the most appropriate assumption in SKC and possibly in other males-only crab fisheries. More general shapes of the ogive should be estimated and studied.

Introduction

Sex-biased fishing mortality occurs in crab fisheries because fishers seek to catch larger-sized males and/or because regulations prohibit the landing of females or berried females (Di Salvatore et al., 2021, Kruse, 1993, Otto, 2014). When sex-biased fishing is strong and females prefer to mate with larger males, the reproductive success of stocks may be hampered due to sperm limitation caused by the inability to find suitable mates (Baker et al., 2022, Lovrich et al., 2002, Ogburn, 2019, Sato, 2012, Sato et al., 2007, Sato et al., 2005). Although unbalanced sex ratios have been observed in a number of crustacean fisheries, the impact of these biased sex ratios on reproductive success remains unknown in the majority of cases (Ogburn, 2019, Ogburn et al., 2014, Rains et al., 2018, Rains et al., 2016). Furthermore, spatial variations in fishing pressure may lead to dissimilar degrees of unbalanced sex ratio and sperm limitation in different areas (Sato, 2012, Ogburn, 2019, Di Salvatore et al., 2021). This article examines the aforementioned phenomenon in southern king crab (SKC) (*L. santolla)* by comparing a generalized functional reproduction model for

females in two distinct fishing areas with contrasting fishing pressures and size-truncated stocks in southern Chile.

Because female lithodid crabs attach their fertilized eggs to their pleopods, it is possible to directly monitor reproductive success by observing the presence of eggs in a wide size range of females, which is termed size at functional reproduction (SFR) (Di Salvatore et al., 2021). Accordingly, it is also possible to estimate model parameters of functional reproduction in females as a function of size (Kruse, 1993, Lovrich and Tapella, 2014). The estimation of size-maturity or reproduction models in female crustaceans is performed using logistic models that generally consider three parameters: one that represents the maximum ratio of mature individuals, and two that determine the shape of the logistic curve (Di Salvatore et al., 2021, Firpo et al., 2017, Jewett et al., 1985, Olson et al., 2018, Restrepo and Watson, 1991; Roa et al., 1999; Somerton, 1980; Webb, 2014). The variability in the forms that the fitted functions acquire for the different crustacean species studied, in addition to the temporal and spatial variability of the parameters obtained for the same species, have not been discussed in detail. The exception is Di Salvatore et al. (2021) who suggested the existence of at least two detectable phases within the *L. santolla* fishery in Argentina: a first phase of sperm limitation due to the exclusive extraction of males; and a second phase characterized by a low ratio of ovigerous females and an increase in SFR, but with no changes in the individual fecundity, resulting in recruitment overfishing. However, these phases have not been directly associated with a quantitative indicator or parameter. On the other hand, except for parameters representing mean size at maturity (such as size at 50% maturity), few results have been reported on i) the relationship between the parameters obtained and the reproductive biology of the species studied; ii) the criteria used to assign the stage of maturity; and iii) the selectivity of the fishing method used (Aguirre-Villaseñor et al., 2022). Further connections of sexual maturity with molting and growth in the SKC have been clarified by Lovrich and Tapella (2014): in the Beagle Channel and Golfo San Jorge gonadal maturity is attained between 65 and 75 mm CL (Following Vinuesa 1984). After the gonad maturity males probably molt twice a year until they are 100 mm CL, then they could molt annually and males larger than 130 mm LC could molt biennially. Females could molt annually since their maturity, because of the 10-month egg-bearing.

This article explores the effects of changes in the ratio of males and females and size truncation on alterations in reproductive success and the quantification thereof in SKC fisheries in two areas with different fishing pressures in southern Chile. We studied the SFR in female SKC by applying a generalized 4-parameter logistic model, known as the Richards Function (Giraldo et al., 2002). It is argued that parameters of the generalized logistic

maturity models serve as indicators of the reproductive health status of the population studied.

Section snippets

Study area and fishery description

The study area included *L. santolla* fisheries located on the continental shelf (oceanic zone) and in the north Patagonian channels and fjords between 41º 30′ S and 46º S, which includes the Los Lagos and Aysén Regions (zones 117, 118, 121 and 122, see Fig. 1). Samples were collected from this area from: i) fishery sampling, which included on-board scientific observers (zones 117, 118 and 122), and ii) fishery-independent sampling (zones 121 and 122).

The bathymetry of the fjords and inland…

Results

During the study period, 21,522 specimens of *L. santolla* were sampled in the Los Lagos region (67% males, 33% females) and 5316 specimens in the Aysén region (46% males, 54% females), 80% of which were obtained from the fishery (see Table A1, Appendix). In Aysén, data from the fishery were obtained between January and March 2019, while in Los Lagos the data were recorded between May 2018 and December 2019.

For fecundity estimation in the laboratory, 495 females were captured in Los Lagos…

Discussion

The contrasting differences observed in the size distribution of male and female *L. santolla* caught in the Los Lagos and Aysén regions resulted in distinct functional reproduction patterns of the females from each region, as well as differential fecundity between regions

due to the size differences of females. A response through the Richards function was observed, most likely caused by the different fishing histories and intensities between the regions. In the more pristine conditions of the *L.* …

Conclusions

We study the female functional reproduction ogive in two stocks of SKC in southern Chile. The northern more intensively exploited of Los Lagos region stock shows size truncation in both males and females, in addition to diminished fecundity. In contrast, the southern less exploited stock of Aysén region shows a robust size distribution in both male and female components. The four parameters Richards Function for the maturity ogive in the less exploited stocks is symmetrical ($\gamma = 1$, inflection…

CRediT authorship contribution statement

All authors contributed to the study conception and design, Data collection was performed by: Carlos Molinet, Katherine Espinoza, Manuel Diaz, Patricio Díaz, Thamara Matamala, José Valenzuela, Yohnatan Jaramillo, Sampling and fecundity were performed by: Paulina Gebauer, Oscar de Lázaro, Thamara Matamala, Katherine Espinoza, Daniela Uribe, Data analysis and modelling were performed by: Carlos Molinet, Rubén Roa-Ureta, Jorge Henríquez, The first draft of the manuscript was written by: Carlos…

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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