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Egg loss in females of two lithodid species following different return-to-the-water protocols

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ABSTRACT

Coastal waters of the southern tip of South America have sustained a mixed king crab fishery since the 1930s, with two target species: the southern king crab *Lithodes santolla* and the stone crab *Paralomis granulosa*. The fisheries are managed with the so-called 3S rule (Sex, Season, and Size) and females must be returned to the water. In king crabs, fecundity can be reduced by several mechanisms, but those related to fishing activities are only partially known. In this article, we tested experimentally whether egg loss is caused by the return of *L. santolla* and *P. granulosa* ovigerous females to the water. To do so, we performed experiments for each species with a 3 × 2 different return-to-the-water conditions: free fall, ramp, or a no-fall (control), with or without previous aerial exposure of females. Our experiments demonstrate that free fall impacts, similar to the normal practice in the fishery of the Beagle Channel, result in egg loss in both the species. Female *L. santolla* lost more eggs if females were exposed to air prior to the dropping. Also, eggs with more developed embryos were likely to be lost as a result of tumbling. In both the species, the use of a ramp for the returning of crabs to water caused an egg loss similar to those of the experimental controls. In *P. granulosa* fecundity from three areas with different fishing effort suggest that the return of females to the water may be a negative effect that could be detected at a population level. To our knowledge, this is the first study that demonstrates the egg loss of female crabs returned to the water in a fishery.

1. Introduction

In the southern tip of South America, a mixed crab fishery has developed since the 1930s. The two target species are the southern king crab *Lithodes santolla* and the false southern king crab or stone crab *Paralomis granulosa*. Both species are frequently captured in the same trap. *L. santolla* is bigger and its meat yield higher than *P. granulosa* and therefore *L. santolla* has been preferred as the target species. In Chile a fishery for *L. santolla* developed near Chiloé island (44°S) and another mixed fishery extends south of 49°S, mainly inside the numerous fjords and channels, including the Straits of Magellan and the Cape Horn area (Fig. 1). Landings of the Chilean fisheries are approximately 3000 t per year for *P. granulosa* and 4000 t per year for *L. santolla*. Argentine fisheries are less extensive geographically and hence less productive. The king crab fishery was first developed in the Beagle Channel with maximum landings of 300 and 400 t of *L. santolla* and *P. granulosa* respectively, but currently yields of *L. santolla* have cropped less than 80 t per year (Lovrich and Tapella, 2014). The current major Argentine fishery is based off the Golfo San Jorge (ca. 46°S, Fig. 1) targeting exclusively for *L. santolla* with landings of ca. 3000 t per year, during the last 2 years.

In Argentina, fisheries are managed by using the '3S' rule (Sex, Season, and Size) where all females must be returned to the water. There is also a closed season and a legal minimum size of 110 mm and 80 mm of carapace length (CL) for *L. santolla* and *P. granulosa* males respectively. For decades the closed season in the Beagle Channel was November and December to protect female molting, mating and eventually the production of offspring. Female *L. santolla* attain larger sizes (140 mm CL) and reproduce once a year compared to the biennial reproductive cycle of *P. granulosa* (maximum size of 90 mm CL), resulting in *L. santolla* having much higher egg production than that of *P. granulosa* (Lovrich and Vinuesa, 1999). In both species, the abdomen completely covers the egg mass during all of the embryogenesis period. In all the South American fisheries except in continental shelf off the Golfo San Jorge, crab

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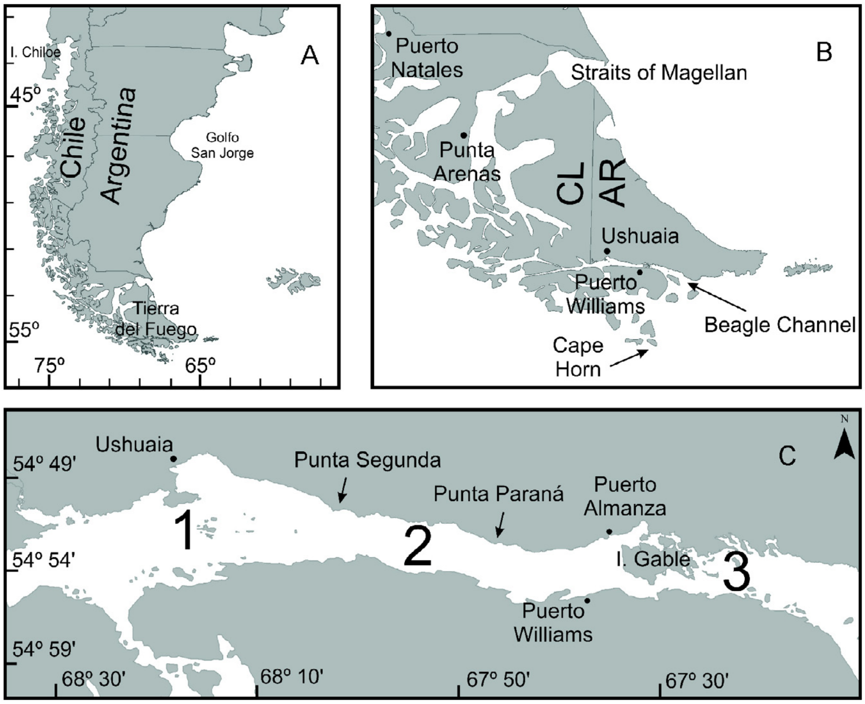

Fig. 1. Study area. Map of the southern tip of South America (A and B) and the Beagle Channel (C), with areas of different fishing pressure shown. References 1: No fishing, 2: Moderate fishing effort and 3: High fishing effort.

fishing is conducted with small boats of a maximum of 15 m length. The common practice of fishing is to empty all of the 10 truncated conical traps that constitute a fishing line on deck, to then change the bait and to redeploy the traps. Fishers then sort out the capture, retain the legal males, and return undersized males and all females to the water. Crabs spend between 0.2 and 2 h on deck exposed to the air (annual average temperature range 1–10 °C) and are returned to the water in different fashions, somewhat violent. When catches are small, animals are picked up by hand from the deck and twirled to the water. In contrast, when catches are large crabs to be discarded are dragged along the deck to the freeboard or shoveled to the water. In all cases crabs fell into the water from a height of at least 1.5 m.

Previous studies have focused on handling king crabs on deck, which can be one of the causes of injury and mortality in captured sublegal animals returned to the sea during the discarding process, (reviewed by Stoner, 2012; Stevens, 2014b). Injuries can range from onboard imperceptible physiological trauma to broken carapace or limbs (e.g., Bergmann et al., 2001; Stoner, 2012). Handling on deck and air exposure seems to be the most important mortality factors associated with crab fishing (Zhou and Shirley, 1995; Warrenchuk and Shirley, 2002). King crabs captured as bycatch of the toothfish fishery off South Georgia (ca. 55°S; 42°W) have differential mortality depending on how pots are emptied: crabs discharged down on a conveyor belt have a higher survival rate than those falling down a vertical chute (Purves et al., 2003). Extreme conditions from high latitudes, such as low temperatures and strong winds increasing the windchill, and long exposures to this environment also reduce growth, produce incomplete ecdysis, increase crab limb-loss, and mortality (Carls and O'Clair, 1989). Furthermore, crabs may become more vulnerable to predation due to impaired mobility after being exposed to air on deck and returning to water (Warrenchuk and Shirley, 2002).

In crabs, fecundity can be reduced by several reasons, but those related to fishing activities are only partially known. Predation is one of the natural causes of egg loss (Shields et al., 1989; Kuris et al., 1991). Nemerteans are the main predators of king crabs eggs of the northern hemisphere, to the point of being responsible for the loss of an entire year class in the population of *Paralithodes camtschaticus* (cf. Shields et al., 1989; Kuris et al., 1991). However, in the southern Hemisphere, there are no records of any king crab egg predators (Lovrich and Tapella, 2014). Fecundity can be variable through the years, seasons, and locations (Swiney et al., 2010; Hjelset et al., 2012; Swiney et al., 2012; Stevens, 2014a). Another source of reduction in fecundity is the male-only fishing. This practice can cause sperm limitation derived from a biased sex ratio towards females, which in turn may result in a low proportion of ovigerous females, individuals with partial clutches or low fertilization rate because fewer females have access to an appropriate sized male for mating (Paul and Paul, 1989; Sato et al., 2007; Van Son and Thiel, 2007). In lithodids, differences in fecundity during the long brooding period, between the recently extruded eggs and those near to hatch, was attributed to egg loss or brood mortality (see reviews by Kuris, 1991; Stevens, 2014a). For example egg loss account for 8–13% in *L. aequispina* (Jewett et al., 1985) and 14% in *P. granulosa* (Lovrich and Vinuesa, 1993), but the cause was never explored. In brachyuran crabs egg losses due to ventilation are substantial and are between 10% and 13% throughout the brooding period (Fernández et al., 2000). Egg losses were also verified at the time of hatching that eventually diminishes the actual birth rate and the consequent contribution of new individuals to the population, as for example it occurs in the hermit crab *Pagurus comptus* (Lovrich and Thatje, 2006) or *L. santolla* (Tapella pers. obs.).

Study or monitoring of fecundity is essential in a king crab fishery because it is indicative of the reproductive health of the population, since the presence of eggs is the direct evidence of successful mating during the last reproductive time that offspring for the season (Orensanz et al., 1998). The spatial and temporal variation in the proportion of ovigerous females can provide direct indication of the reproductive potential of the fished population and allows early detection of problems associated with fishing extraction that may have occurred during the previous reproductive season. Hence