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Bycatch of the Southern King Crab (*Lithodes santolla*) in the Patagonian shrimp fishery in the Southwestern Atlantic Ocean. Can it contribute to the depletion of its population?

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ABSTRACT

The Southern King Crab (SKC), *Lithodes santolla*, has supported a growing fishery in San Jorge Gulf (Patagonia, Argentina) since 2011. This fishery is developed by vessels called crabbers. SKC is also caught as bycatch in the Patagonian shrimp fishery, a major crustacean fishery in the Southwestern Atlantic Ocean. In this work, we characterized SKC bycatch in shrimp fishery and compared 1994–1996 data (which reflected little fishing impact) and 2011–2012 data (at the beginning of the current SKC fishery by crabbers in San Jorge Gulf), to determine the particular effects of bycatch on the SKC population. The frequency of occurrence of SKC in shrimp hauls was 84.08%. However, the relative abundance was low, in most of the hauls SCK represented less than 5% of the capture. Between 2006 and 2011, the estimated SKC bycatch was 2432 tn/year. Frequency of occurrence and abundance were higher in the same area where crabbers operate. SKC bycatch is commonly discarded, but, in 18% of the hauls, SKC are processed on board, although this is illegal. Mortality estimated at the beginning of handling was 19%, but this value may be greater due to the long time of onboard handling. SKC bycatch include critic stages of its life cycle such as juveniles, ovigerous females and molting individuals. Juveniles represented 26.9% of the total SKC bycatch, while ovigerous females represented 28.1%. Sex ratios and male size showed no differences between 1994–1996 and 2011–2012, whereas the proportion of ovigerous females decreased between both periods. This decrease can be related to the interference of trawlings in their reproductive migration to coastal waters or in their mating grounds. We consider that the main problem of SKC bycatch is the detrimental effects on its reproductive potential due to the increase in the proportion of non-ovigerous females and the mortality of ovigerous females along with extensive handling, which can also result in a significant egg loss.

1. Introduction

Bycatch has ecological, legal and socio-economic implications and becomes a particularly important problem when it involves target species of other fisheries. Trawling has been the focus of many studies due to its low selectivity and high incidental catch (Andrew and Pepperell, 1992; Stobuzki et al., 2001). In this respect, shrimp (and prawn) fisheries contribute largely to bycatch around the world, because they account for 35% of global commercial fisheries discards. The Patagonian shrimp fishery is the main crustacean fishery in the Southwestern Atlantic Ocean (Boschi, 1997) and its bycatch includes several commercially valuable species such as the hake (*Merluccius hubbsi*) and the southern king crab (SKC), *Lithodes santolla*.

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Some king crab species, which support many lucrative fisheries in the world, are caught as bycatch in many trawling fisheries (Stevens, 2014). Information about trawling fisheries and their interaction with commercially valuable king crabs refers mainly to species of the northern hemisphere. Moreover, it is well known that king crab populations are vulnerable to depletion (Orensanz et al., 1998; Otto, 2014), due to their longevity, late maturity and population changes by large male-only fishing. Several fisheries of king crabs collapsed in the past (Guzmán et al., 2004; Lovrich and Tapella, 2014; Otto, 2014; Vinuesa and Balzi, 2002). The most known case was that of the red king crabs (*Paralithodes camtschaticus*) in Bristol Bay, Alaska, in the early 1980s. Many causes have been proposed to explain red king crab population decline: overfishing, parasite-associated brood mortality, climate change and changes in predator abundance, among others (see Otto, 2014, and references therein). According to Dew and McConnaughey (2005), bycatch of the red king crab in trawling fisheries could have played a key role in the depletion of its population in the early 1980s.

In South America, there are two commercially valuable lithodids: the stone crab, (*Paralomis granulosa*) and the SKC, being the latter the most valued species because of its larger body size and higher meat yield per crab. Fishing of SKC began in the Strait of Magellan (Chile) and Beagle Channel (Argentina) in the 1920s. Landings of SKC in both areas were fairly constant during many decades, but local stocks showed a depletion due to overfishing and illegal procedures as on-board processing of females and sub-commercial males or the use of prohibited fishing gears (Guzmán et al., 2004; Lovrich and Tapella, 2014). In consequence, landings decreased drastically. However, in the last decades, Chilean landings of lithodids have increased due to the wide distribution range of SKC in Chilean coasts and because the vessels range further away to more distant areas to exploit unharvested stocks. In Argentina, the decrease in SKC landings in the Beagle fishery promoted *P. granulosa* exploitation and the development of the SKC fishery in San Jorge Gulf (SJG) (Lovrich and Tapella, 2014). Exploitation of SKC in SJG has been discontinuous in time and has been developed to different levels. SKC was initially caught by small coastal bottom trawlers (coastal fleet) as well as bycatch in the Patagonian red shrimp (*Pleoticus muelleri*) and hake fisheries. In 2003, an exploratory SKC fishery started in an area adjacent to SJG by using vessels known as crabbers and since 2011, SKC fishing has been performed inside the gulf. Landings of SKC in the shrimp fishery were banned in 2006 so as not to interfere with this emerging SKC exploratory fishery. However, SKC is usually processed on board and illegally marketed by fishers. In the last seasons, the exploratory fishery showed a decrease in yield, so the implementation of very conservative policies should be adopted in the next seasons.

Until 1997, the population traits of SKC in SJG reflected parameters of a healthy population with little fishing impact (Balzi, 2005). However, in subsequent years, a decrease in the proportion of ovigerous females was observed in a small coastal area of SJG where small trawlers (coastal fleet) operate (Vinuesa and Balzi, 2002). No subsequent studies were conducted to determine the health of the SKC population in SJG. The failure of king crab fisheries in the past, the significant increase in the fishing effort in the SKC fishery in SJG, and the overlapping of SKC with a large trawling fishery have determined a negative scenario for the sustainability of SKC. Thus, knowing and characterizing SKC bycatch is the first step to understand, and eventually manage, the impact of bycatch in SKC population. Moreover, the study of the SKC population structure may allow early detection of problems in the reproductive health of the population.

Therefore, the aims of this study were: 1- to describe spatial and temporal trends in SKC bycatch in the Patagonian shrimp fishery and 2- to analyze the SKC population structure before the development of the SKC exploratory fishery in order to identify a negative effect on the SKC population due to bycatch in shrimp fisheries. Bycatch description was based on haul monitoring between 2006 and 2011. Frequency of occurrence, relative abundance and fate of SKC bycatch was analyzed and annual SKC bycatch was quantified. To assess the negative impact on SKC population, we compared data from 1994 to 1996, when the SKC population showed healthy traits, with data from 2011 to 2012, prior to the development of the intensive SKC fishery by crabbers inside the gulf.

2. Material and methods

2.1. Study area

San Jorge Gulf (SJG) is the widest sea entry in the Southwestern Atlantic Ocean; it extends from Dos Bahías Cape in the north to Tres Puntas Cape in the south (Fig. 1). The waters of SJG are a mixture of subantarctic waters from the Malvinas (Falkland) current and low-salinity waters from the Magellanic plume. The latter, formed by the discharge from the Strait of Magellan, extends along the inner shelf of southern Patagonia (Palma et al., 2008). Its maximum depth is approximately 100 m. The maximum and minimal temperatures oscillate between 6 °C and 20 °C in the Leones Island (45°10′S) and between 1.2 °C and 15 °C in Tres Puntas Cape (47°20′S). There are two management areas, limited by 46° S: the Provinces of Chubut and Santa Cruz. The jurisdictions of these provinces extend for approximately 22 km outside the gulf. Towards the east, the area is under National government jurisdiction. This last area was included in this study because it is directly linked to the management of the gulf.

2.2. Fisheries of San Jorge Gulf

SJG is one the most important fishing areas of the Southwestern Atlantic Ocean. The following fleets operate in the gulf: a crabber fleet, whose target species is the SKC, and three trawler fleets: a- coastal fleet, b- a high-sea ice trawler fleet and c- a double-beam trawler fleet.

The SKC exploratory fishery is developed by five large vessels (50 m). Crabbers use truncated conical pots (inkpots), and each vessel can operate until 4500 pots throughout the season. Like other crab fisheries, regulations of the SKC fishery are based on the so-called 3S rules: size–sex–season. Under this rule, only males larger than 110 mm of carapace length can be landed. Currently, the regulations establish that the fishery is open from September to June.

Among trawlers, the double-beam trawler fleet is the largest fleet in the gulf. The double-beam trawler fleet includes some 80 vessels with lengths approximately between 23 and 50 m. The Patagonian red shrimp is the target species of this fleet. Vessels are provided with two trawling nets with a mesh size of 45 mm in the cod end. The nets have vertical openings of 1.2–1.5 m and horizontal openings of 30–50 m. The fishery begins in the south of the gulf in February–March and then follows the migration of the resource to the central - eastern gulf and towards national waters during autumn and winter. During spring, the fleet moves to the north of the gulf, where it remains until the closure of the fishing season, in November–December (Góngora et al., 2012). The shrimp fishery is the most profitable fishery of Argentina. In 2015, this fishery was responsible for exporting more than 120,000 t of shrimp and producing 763 M US$ (Ministry of Agroindustry of Argentina, 2016). Landings of SKC in the shrimp fishery were related to the low availability of shrimp, but landings never exceeded 55 t. Since 2006, fishing rules and regulations have

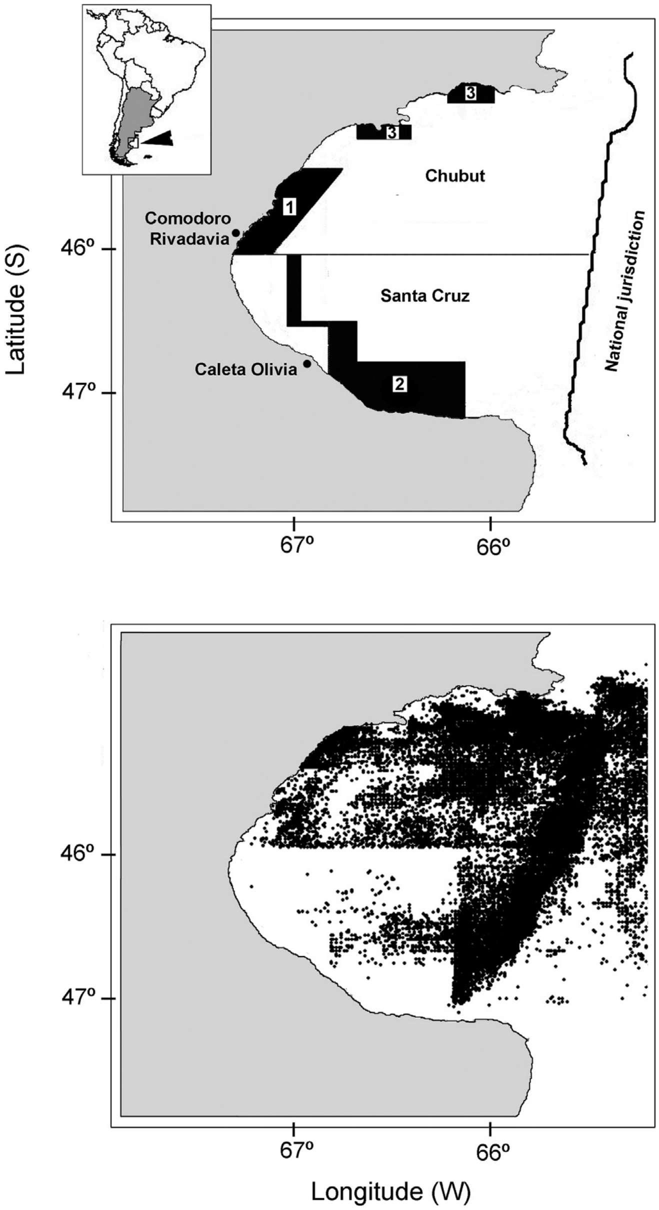

Fig. 1. San Jorge Gulf, Southwestern Atlantic Ocean. Three jurisdiction (Chubut, Santa Cruz and national) are shown. 1- Restricted fishing effort area. 2 - Closure of Mazarredo (nursery area of Patagonian red shrimp). 3 and 4 - Temporal closure in the north of the gulf. Hauls of the double-beam trawler fleet between 2006 and 2011 are shown.

prohibited the landings of SKC by this double-beam trawler fleet, so all SKC bycatch should be returned to the sea.

2.3. SKC bycatch characterization

2.3.1. Definitions

The term bycatch has been used to name different things by different investigators. In line with Eliasen et al. (2014), in the present study, we used the term bycatch to refer to non-target catch, meaning the incidental catch which is retained and the fraction which is discharged back overboard, either live or dead.

2.3.2. Data collection

Chubut government has an On-Board Observer Program (POBCh), which monitors hauls of the double-beam trawler fleet. The staff of the POBCh recorded SKC bycatch in a sub-sample of this fleet between 2006 and 2011. The relative abundance (RA) of SKC bycatch was recorded according to the following scale: a- uncommon (lower than 5% of the capture in terms of number of individuals), b- common (5–25%), c- abundant (25–50%) and d- very abundant (over 50%). The fate of the captures was recorded as: a- fully boxed, b- partially boxed, and c- discarded. These procedures were also used in earlier works (Bovcon et al., 2013; Góngora et al., 2009; Varisco et al., 2015). The frequency of occurrence [FO = (hauls with presence of SKC/total of hauls). 100%] was calculated for different depths, years and jurisdictions. In randomly selected hauls, the weight of the SKC catch was estimated by using the following categories: a- 0 – 5 kg of SKC; b- 5 – 25 kg; c- 25 – 50 kg; d- 50 – 100 kg; e- 100 – 200 kg; f- 200 – 500 kg; g- 500 – 1000 kg. The annual weight of the SKC bycatch (AW) was estimated as:

$$AW = \sum i\left[\left(H\cdot\frac{FO}{100}\right)\cdot\frac{Fi}{100}\cdot CMi\right]$$

where H is the total number of hauls of the fleet, FO is the frequency of occurrence in a given year; Fi is the frequency of hauls of the category i and CM is the midpoint of category i.

In September 2011 and April and June 2012, hauls were randomly selected to assess the negative impact of bycatch on the structure population of SKC. Individuals were sexed and carapace length (CL) was measured using a digital caliper (±0.01 mm). The presence of ovigerous females and molting stages (intermolt, molting or postmolt) in all SKC were also recorded. Sex ratio, ovigerous proportion and mean male size were estimated and these data were compared with data of hauls of 1996–1997. These traits are related to reproductive success of king crab populations, and could contribute to identifying reproductive failures. Moreover, molting stages were recorded because crabs are more vulnerable to injuries (or dead) during molting and posmolting stages.

Also, mortality was assessed as: 1- alive, individuals showing spontaneous movements, 2- dying, individuals showing slow movements in response to handling, and 3- dead. Carapace injuries, cheliped appendages and leg loss were also recorded.

2.3.3. Geographical analysis

The GVSIG 10.1 software was used to identify spatial trends in SKC occurrence, its relative abundance and fate of bycatch. The nautical chart of SJG (Servicio de Hidrografía Naval, Argentina) was georeferenced (datum WGS 84) and used for the mapping of hauls. The 50 and 90 m isobaths, based on the nautical chart, were also georeferenced. A 6′ × 6′ grid was used to represent the FO in the hauls of the double-beam trawler fleet. National and provincial jurisdictions were also georeferenced.

2.3.4. Statistical analysis

The non-parametric Chi-square test was used to analyze the independence between FO and years, depth and jurisdictions. Yates's correction for continuity was used to improve the accuracy of the null-condition sampling distribution of Chi-square (Zar, 2010). This test was also used to assess the independence between RA and depth, fishing areas or fate of bycatch.

The Kruskal-Wallis test was used to compare the CL of each sex between depths and periods (1996/1997–2011/2012). *A-posteriori* comparisons between depths were performed with Mann–Whitney U tests with Bonferroni correction for multiple comparisons. The Kruskal-Wallis test was also used to compare the CL of males between 1996/1997 and 2011/2012. An Exact test was used to compare the proportion of ovigerous females between both periods.

3. Results

3.1. Characterization of the SKC bycatch

A total of 28,957 hauls, representing 7.18% of the hauls of the fleet, were analyzed between 2006 and 2011. The FO ranged between 41.3 and 95.09%, and it was different between years ($\chi = 3546$, df = 8; $p < 0.01$) and depths analyzed ($\chi = 106.4$, df = 2; $p < 0.01$). *A-posteriori* comparisons showed that the FO was lower in depths less than 50 m (Table 1). The spatial pattern of SKC occurrence was similar in all the periods analyzed. The FO showed no differences among the three jurisdictions where double-beam trawler fleet operates ($\chi = 4.34$, df = 2; $p = 0.12$). The FO of SKC was higher in the central area and near the mouth of the gulf (Fig. 2).

The RA of SKC on hauls was low in the entire period. In most hauls, SCK represented lower than 5% of the capture in terms of the number of individuals. SKC represents higher than 50% of the capture in terms of number of individuals in only 0.17% of hauls. The RA was related to depths ($\chi = 1933$, df = 6; $p < 0.01$), and a slight increase in the RA was recorded in larger depths (Table 2). The RA was higher in Santa Cruz than in Chubut and national jurisdictions ($\chi = 785.5$, df = 6; $p < 0.01$). Hauls in which SKC was abundant were concentrated in the central area near the mouth of the gulf (Fig. 3). The estimated SKC bycatch ranged between 1275 t in 2011 and 3433 t in 2008 (Table 3).

Although SKC landings have been banned since 2006, SKC individuals were fully boxed in 1.43% of the hauls and partially boxed in 16.71% of the hauls. The fate of the bycatch was related to the RA of SKC in the hauls ($\chi = 89.7$, df = 6; $p < 0.01$); discarded SKC was higher when SKC were rare or very abundant. Trends in bycatch use were not influenced by the area of fishing ($\chi = 6.58$ df = 4; $p = 0.15$).

3.2. Sex, size structure, and injuries

The overall sex ratio was 1: 0.81 (♂:♀) and the mature sex ratio was (1:1.05). A significant deviation from the 1:1 sex ratio was observed in several hauls. The proportion of ovigerous females was 75.57% in September 2011 and 74.81% in April–June 2012. These data include two different reproductive seasons. Ovigerous females represented 28.1% of the total SKC bycatch (in terms of number of individuals), while juveniles represented 26.9%. The size (CL) of SKC ranged between 34 and 169 mm for males and between 32 and 138 mm for females. The size of both sexes was related to depth: the CL of males was lower in depths <50 m, while that of females was lower in depths >90 m. Consequently, the proportion of juveniles decreased at larger depths (Fig. 4).

The sex ratios ($\chi = 0.02$, df = 1; $p = 0.88$) and male size structure (Kruskall-Wallis, $H = 1.75$, $p = 0.18$) of the SKC bycatch showed no differences between 1994–1996 and 2011–2012. A significant decrease in the proportion of ovigerous females was recorded between periods ($\chi = 120.0$, df = 1; $p < 0.01$). The proportion of ovigerous females decreased from 90.6% (N = 922) in 1994–1996 to 72.2% (N = 2880) in 2011–2012 (Fig. 5).

Carapace injuries and appendage losses were recorded in 23.5% of the SKC caught, injuries in carapace were the most frequent injuries recorded. Mortality by fishery (only due to the net discharge in the processing plant) in trawler vessels was 19% (dead and dying). Injuries and mortality were higher in postmolted individuals. In addition, 28% of males were in postmolt stage in June 2006. Samples did not include the female molting period.

4. Discussion

The relative abundance of SKC in the hauls of the shrimp fishery was low along the studied period However, given the magnitude of the double-beam trawler fleet and high frequency of SKC in its hauls, SKC bycatch has a significant impact on the SKC population. The annual mean of SKC bycatch was 2432 t between 2006 and 2011. These data are similar to the 2600 tn/year estimated for 1998–2002 and the 2000 t/year for 2003–2011 (Iorio et al., 2003, 2013). It's interesting to note that SKC bycatch is higher than those reported by fisheries of the northern hemisphere: 500 t of the red king crab in the Gulf of Alaska or 250 t in the Bering Sea (Stevens, 2014). However, SKC bycatch may be overestimated, given the aggregative pattern of the double beam trawler fleet and the recapture rates possibly related to this pattern. Further studies should be developed to calculate a recapture ratio in this fishery. Moreover, the main problem to estimate the actual impact of bycatch on the SKC population is that assessment of stock size is imprecise.

The abundance of SKC was higher in the central area of the gulf near the mouth of the gulf, where the main caughts in the SKC fishery by crabbers occur. The double-beam trawler fleet operates in this area during late autumn and winter, and then, in spring and summer, the crabbers fish in the area. This determines that there is an almost continuous disturbance by fishing in the area of greatest abundance of SKC.

SKC bycatch is largely higher than the landings reported by the double-beam trawler fleet before the SKC landings were banned. Landings of the double-beam trawler fleet never exceeded 55 t, suggesting that SKC was traditionally an untapped resource by double-beam trawlers. Until 2006, SKC landings were related to the low availability of target species. After the ban, no SKC landings were recorded by the double beam-trawler fleet (Ministry of Agroindustry of Argentina, 2016). Nonetheless, our results show that SKC is processed on-board several times, although this is an illegal practice. Apostle (1998) noted that the decision about the fate of bycatch is influenced by the perceived incentives of various capitals pooled in three spheres: community (social framework), state (control, policies, rules), and market. In line with this approach, the use of SKC bycatch in the shrimp fishery can recognize incentives of the three spheres. There is a large tradition about

Table 1
Annual variation of frequency of occurrence (%) of the southern king crab *Lithodes santolla* in the Patagonian shrimp fishery, pooled by depths. + hauls with *L. santolla*. N; number of hauls.

	<50 m			50–90 m			>90 m			Total		
	+	N	FO	+	N	FO	+	N	FO	+	N	FO
2006	24	28	85.71	1011	1149	87.98	1309	1545	84.72	2344	2722	86.11
2007	64	75	85.33	1866	2063	90.45	791	913	86.63	2688	3051	88.10
2008	258	329	78.41	3024	3426	88.26	1833	2136	85.81	5115	5891	86.82
2009	520	655	79.38	2764	3185	86.78	2971	3314	89.64	6491	7154	90.73
2010	162	213	76.05	2342	3399	68.90	1315	2090	62.91	3819	5702	66.97
2011	628	749	83.8	1877	2094	89.63	1301	1594	81.61	3806	4437	85.77

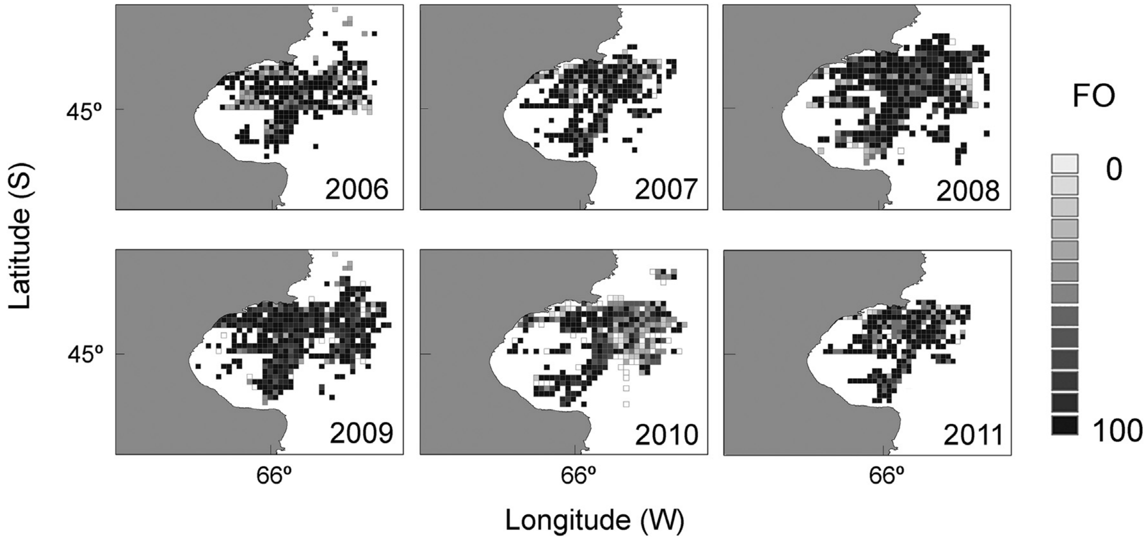

Fig. 2. Frequency of occurrence of the southern king crab in hauls of the double-beam trawler fleet between 2006 and 2011.

Table 2
Annual variation in relative abundance of the southern king crab *Lithodes santolla* in the Patagonian shrimp fishery, pooled by depths. Numbers correspond to number of hauls under each category. Uc, uncommon; Co, common; Ab, abundant; Va, very abundant.

	<50 m				50–90 m				>90 m			
	Uc	Co	Ab	Va	Uc	Co	Ab	Va	Uc	Co	Ab	Va
2006	24	–	–	–	921	86	4	–	1163	143	3	–
2007	59	3	1	3	1478	370	10	8	637	143	8	3
2008	241	10	–	–	2605	390	24	5	1521	283	27	2
2009	501	16	–	3	2471	276	10	7	2398	515	45	13
2010	158	2	2	–	2253	82	5	2	907	62	1	–
2011	606	19	2	1	1843	33	1	–	1279	17	5	–

use of bycatch species (not only SKC) for personal trade of fishers in this fishery. The absence of an adequate control of landings and the possibility to market SKC in an illegal path promote the on-board processes and landings of SKC in the Patagonian shrimp fishery. The decision to either use (boxed and processed) or discard the SKC bycatch is a haul-to-haul decision, which is mainly influenced by the abundance of SKC in the hauls. When SKC is common or abundant, it is usually boxed and processed by fishers. However, if SKC is the main species of the hauls (very abundant), the discard increases, probably because the double-beam trawlers are not equipped to process large amounts of SKC. In addition, large amounts of SKC are not easy to land and market illegally. Spatial trends in use of bycatch were similar in the three jurisdictions, so efforts to reduce illegal landings of SKC require coordinated policies and controls of provincial and national governments.

Bycatch mortality and injuries are related to fisheries procedures and handling of catch. In trawling fisheries of the Bering Sea and Aleutians Islands, red king crab mortality has been estimated to be 80% (Stevens, 2014). In this work, mortality and injuries of SKC were evaluated at the beginning of catch handling. However, in most vessels, discarding takes place 2 h after the catch is brought to the processing plant; so, mortality and injury may be significantly greater. Iorio et al. (2013) estimated 37% mortality of SKC in winter, when thermal stress is lower. Moreover, the Patagonian shrimp fishery extends for several months and includes the SKC male molting period; so, an increase in immediate mortality is expectable Other two aspects that can contribute to increase the mortality

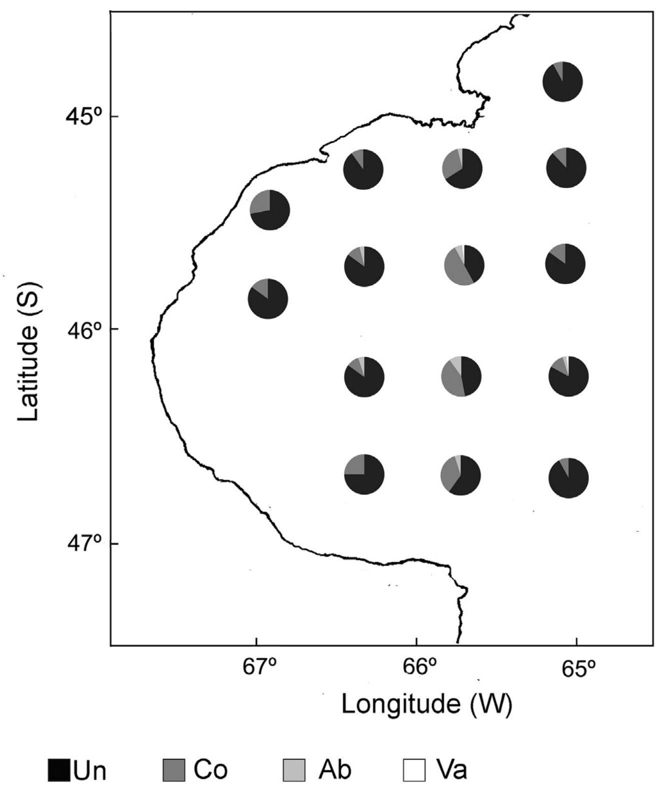

Fig. 3. Relative abundance of southern king crabs in San Jorge Gulf and adjacent area. Un, uncommon; Co, Common; Ab, Abundant, Va, very abundant.

Table 3
Estimated bycatch of the southern king crab *Lithodes santolla* in the Patagonian shrimp fishery between 2006 and 2011.

Year	Recorded hauls	Total hauls	SKC bycatch (t)	Bycatch/hauls (Kg)
2006	2722	65,544	2490	37.98
2007	3051	78,534	2789	35.51
2008	5891	73,327	3433	46.81
2009	7154	69,663	2953	42.38
2010	5702	61,907	1275	20.59
2011	4437	53,796	1656	30.78

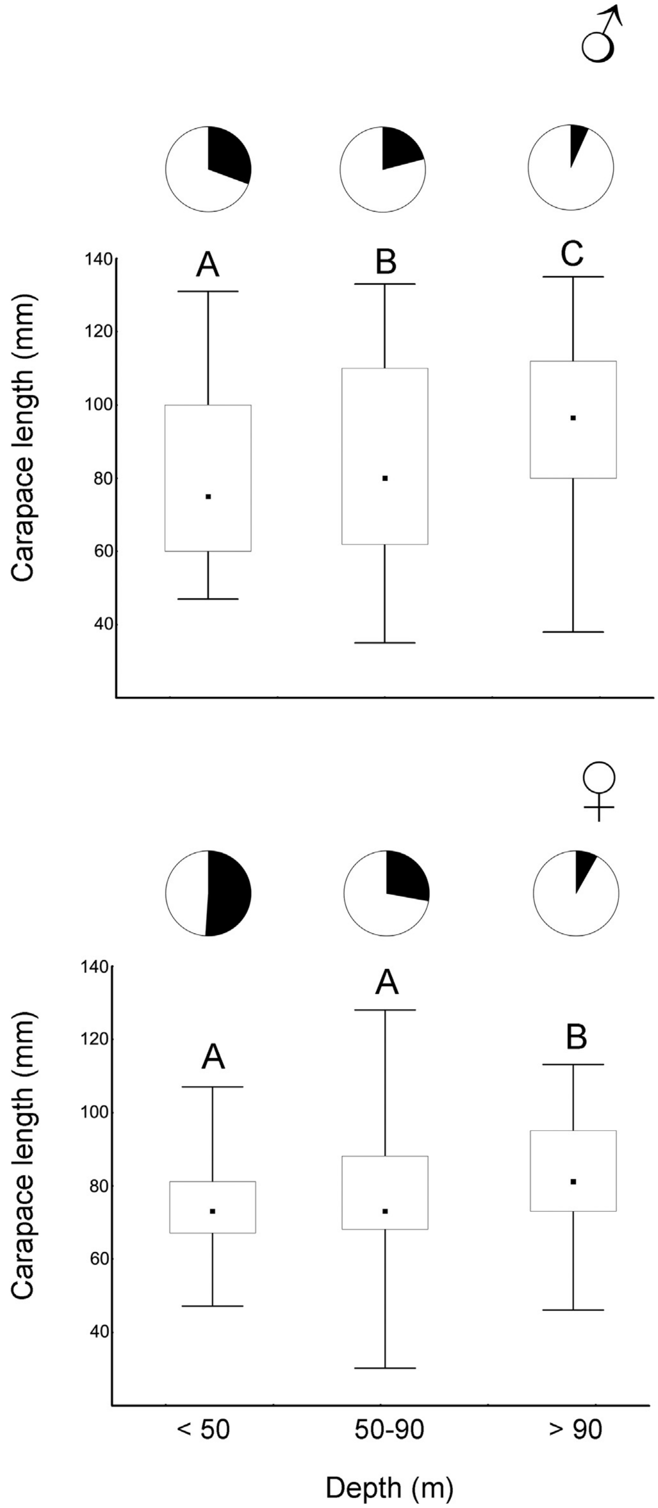

Fig. 4. Carapace length of the southern king crab related to depth. The letters indicate significant differences in pairwise comparisons (Mann-Whitney post hoc test). The pie chart shows the proportion of juveniles (black).

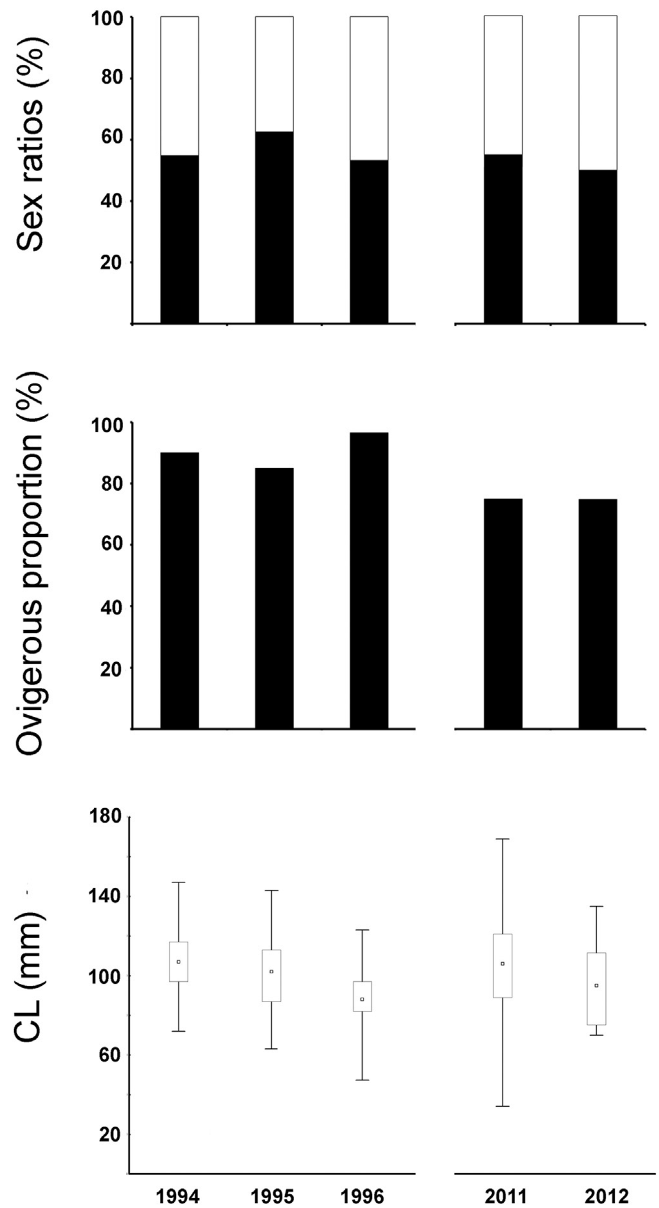

Fig. 5. Sex ratio, ovigerous proportion and carapace length (median CL) of southern king crab males in Patagonian shrimp bycatch.

in this fishery are: 1- the aggregative pattern of the fleet, which can contribute to accumulating injuries and thus increasing mortality, and 2- the unobserved mortality due to encounters with trawls on the bottoms. King crabs are more vulnerable than other crabs to mortality due to encounters with trawl gear components (mainly the footrope) because of their body shape (Rose et al., 2013). Due to the size of the double beam trawler fleet and its high fishing effort (mean of 74,166 hauls/year for the study period), unobserved mortality could be significant. Moreover, injuries may have negative effects on the SKC fishery because loss or damage of appendages reduce the exploitable biomass available and individuals spend energy to regenerate damaged appendages at the expense of molt increment (see Emery et al., 2016).

Large-male-only fishing is a rule in king crab fisheries. Changes in the population structure such as a decrease in male size, a sex ratio biased toward females, and/or an increase in the proportion of non-ovigerous females or the occurrence of females with incomplete clutches are related to this kind of fisheries and have been widely reported (Hjelset, 2014; Lovrich and Tapella, 2014; Orensanz et al., 1998; Otto, 2014; Sato et al., 2005). Conversely, effects of trawling bycatch in the population structure of king crabs have been poorly analyzed. The sex ratios and the mean size of males of the SKC population in SJG showed no differences between 1994–1996 and 2011–2012. These effects are related to a selective large-male extraction, but not expectable due to bycatch. These results suggest that mortality due to bycatch is not related to size or sex.

The detrimental effects of bycatch on the SKC population are related to the increase in the number of non-ovigerous females. This constrains the contribution of larvae and juveniles to the population and can lead to a stock reduction. Population depletions in several king crabs species were preceded by a decrease in the proportion of ovigerous females (Lovrich and Tapella, 2014; Orensanz et al., 1998). In these cases, decreases in the proportion of ovigerous females were related to changes in male size and sex ratio. Male-only extraction determines that at a time when the number (and/or size) of males is insufficient to mate with all females, females without eggs or with incomplete clutches begin to appear. In this work, the increase in the number of non-ovigerous females would not be related to these changes in population structure. The increase in the number of non-ovigerous females would result from intensive trawling in shrimp fishing grounds. Trawling can disrupt population movements related to reproduction and could contribute to explaining the proportion of ovigerous females observed. High densities of SKC in coastal areas during the reproductive period and at greater depths in winter suggest a migration related to reproduction (Vinuesa and Balzi, 2002). About 60% of hauls in November and early December (if the fishery is still open) are performed in coastal areas where the SKC reproductive stock occurs. In consequence, Vinuesa and Balzi (2002) have reported a drastic reduction (near 50%) in the frequency of non-ovigerous females in hauls of a small area of SJG where the coastal fleet operates (restricted fishing effort area, see Fig. 1). Interference of trawling in population movements has also been suggested as a cause of depletion of the red king crab in Alaska Gulf (Dew and McConnaughey, 2005).

Ovigerous mortality and egg loss due to fishing procedures can also contribute to a reduction in the reproductive potential of SKC. Dew and McConnaughey (2005) proposed that high mortality of ovigerous females in trawling fisheries could have contributed to the depletion in Alaska fisheries in the early 1980s. In the present study, the annual bycatch of SKC was higher than 2000 t/year, and near 30% of the catch (in number of individuals) were ovigerous females; so, a significant mortality of ovigerous females is expectable. Moreover, handling and fishing procedures can lead to a significant egg loss. Gowland-Sainz et al. (2015) demonstrated that discard of SKC females results in egg loss in the fishery of the Beagle Channel and increases if females are exposed to the air before being returned to the sea. In this research, egg loss due to discard procedures was not evaluated; however, these may have a negative impact. Air exposure can be particularly important in double-beam trawlers because females may be on board for a few hours before being discarded. Moreover, the aggregative pattern of the double-beam trawler fleet should increase the negative effects on SKC fecundity.

In the Patagonian shrimp fishery, the main efforts to describe, and eventually reduce, the bycatch have been directed mainly towards the Argentine hake, other commercial fishes and charismatic fauna such as birds, penguins or dolphins (Bovcon et al., 2013; Dans et al., 2003 Gandini et al., 1999; González-Zevallos et al., 2011). Traditionally, SKC bycatch has not been perceived as a problem by shrimp fishers, scientists or politicians. Moreover, the shrimp fishery is the most profitable fishery of Argentina and the shrimp industry employs thousands of workers along the Argentine coasts. So, it is difficult to think that steps are being taken to reduce SKC bycatch if this means a reduction in the fishing effort. Unfortunately, modifications of gears do not appear to be a solution to the bycatch problem. Several trawl modifications to reduce bycatch of crabs have been tested in trawling fisheries of the Bearing Sea, but they were not a solution to crabs bycatch (Stevens, 2014). We consider that the focus of policies to reduce the impact of bycatch on the SKC population should be placed in: 1- reducing the trawl in areas where SKC is abundant and 2- improving the on-board handling and discard. Mobile closures in space and time could be established against the high abundances of SKC in hauls, and fishing efforts could be redirected to areas with lower abundance of SKC. These closures have been used in the Patagonian shrimp fishery in order to reduce hake bycatch. Improving the on-board handling and reducing the time from the moment the animals come aboard and that when they are discarded would also lead to a decrease in the number of SKC injuries and mortality. Also, the use of a ramp to return SKC to the sea can result in a reduction of injuries and mortality. In addition, egg loss decreases significantly when ramps are used to discard ovigerous females (Gowland-Sainz et al., 2015).

In the last years, the SKC fishery has shown a significant decrease in yield. This decrease may be due to negative impacts of the SKC fishery as well as to a large bycatch of SKC in the shrimp fishery. Our results show that bycatch has negative impacts on the SKC population. We consider that the main effect of bycatch on the SKC population is the reduction of its reproductive potential due to: 1- a decrease in the ovigerous proportion due to trawling interference in mating and reproductive-associated migrations, 2- high ovigerous mortality, and 3- egg loss, which is expectable due to extensive handling. The continuous expansion of the SKC fishery and the overlapping of SKC with the double-beam trawler fleet determine a negative scenario for the sustainability of SKC in SJG and adjacent areas.

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