Deadliest Catch, Terra Australis Edition

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People are very familiar with Northern Hemisphere crab fisheries, to the point where there is a popular TV series about them (*Deadliest Catch*). However, king crab fisheries in the Southern Hemisphere are almost unknown, although they possess many of the characteristics that have made northern fisheries famous: remote fishing areas, rough and cold seas, bad weather, and a resource of high economic value. Here, we review the history of southern king crab fisheries at the "end of the world" and describe the current fishery in Patagonia.

At the southern tip of South America, there are two commercially valuable lithodids: the false king crab or centollon *Paralomis granulosa* and the southern king crab or centolla *Lithodes santolla*. The latter is the most valued of the two species and shows the largest body size and highest population abundance (Figure 1; Vinuesa 1991). These species have supported commercial fisheries in southern Argentina and Chile, first in the Beagle Channel and the Strait of Magellan region and then in other areas of the Pacific and Atlantic oceans (Figure 2). For many decades, southern fisheries remained at a low scale, but in recent years, the landings of these king crabs (mainly the southern king crab) have grown due to an increase in fishing effort (the number and size of the vessels have increased significantly) and the harvest of new stocks that were previously unexploited. Growth of the fisheries has been driven by the international demand that originated mostly in the United States and East Asia. Currently, the landings of these species represent almost 30% of worldwide king crab landings (Figure 3).

Figure 1. Male and female of the southern king crab.

In Argentina and Chile, commercial fisheries for southern king crab began during the 1920s in austral fjords and channels of Tierra del Fuego. The climate in this region is generally cold owing to the southern latitude. Fjords and channels provide shelters from the more hazardous conditions found in the open sea (strong winds, large waves, and strong currents). These weather conditions and the autonomy of the vessels constrained the expansion of the fisheries in the Beagle Channel and the Strait of Magellan region; thus, the fisheries remained at an artisanal scale for several years (Lovrich and Tapella 2014). In both Argentina and Chile, fisheries initially harvested only the southern king crab and then included the false king crab and became mixed fisheries (Vinuesa and Balzi 2002).

In Chile, southern king crab fishing was initially concentrated in the Strait of Magellan, southern Chilean fjords, and the Beagle Channel and was carried out by vessels that operated mainly from the Punta Arenas and Porvenir harbors. Fishing stocks near Punta Arenas collapsed in the early 1980s (Vinuesa 1991). After this collapse, the fishery in Punta Arenas began to be conducted in a framework of illegality, including catches obtained by diving or tangle nets and the capture of females and males under the legal minimum size (Guzmán et al. 2004). Despite the collapse of the fishing stocks near Punta Arenas, the landings of southern king crab in Chile have grown (Figure 4) due to the wide distribution of lithodids in Chilean coastal waters and because the vessels range further away to more distant areas to find unharvested stocks. At present, Puerto Toro, a remote harbor that is located 3 h from Puerto Williams, is the heart of the king crab fisheries at the southern end of Chile and serves to shelter fishers from inclement weather.

In Argentina, southern king crab fisheries began in the Beagle Channel, with vessels that operated from Ushuaia, the most austral city in the world. The fishery in the Beagle Channel was conducted with tangle nets until 1975, when the use of baited traps was phased in (Vinuesa 1991). Until the early 1990s, the southern king crab constituted the main component of this mixed crab fishery, but overexploitation of the resource caused

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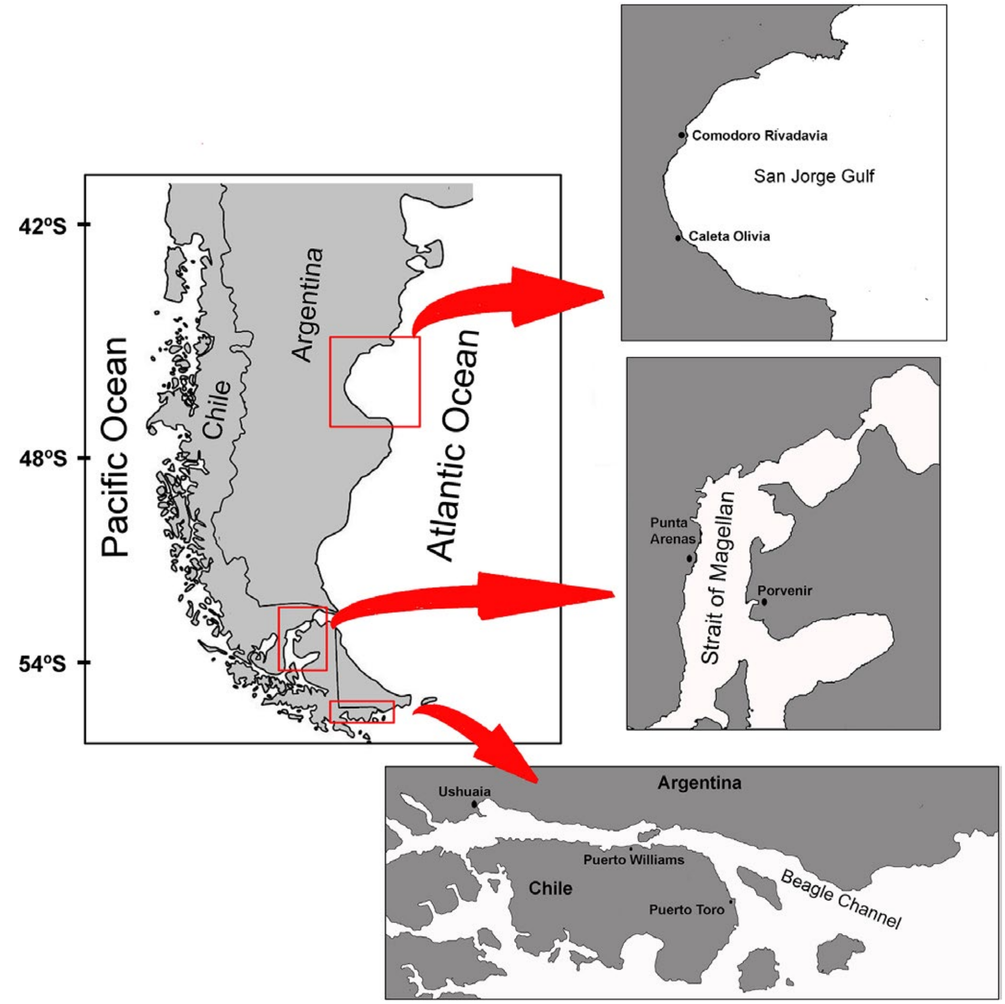

Figure 2. Fishing areas for southern king crabs in Patagonia and the southern end of South America.

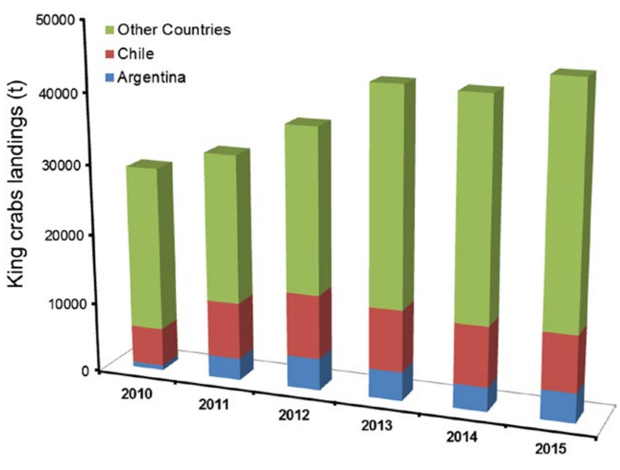

Figure 3. World landings (metric tons) of king crab species, with particular contribution of Chilean and Argentinian fisheries (based on data extracted from FAO 2017).

a drastic decrease in the landings of this species (Figure 4). Currently, the false king crab constitutes the main target species of this fishery because southern king crabs in the Beagle Channel have not yet recovered (Lovrich and Tapella 2014). Nowadays, the harvest of southern king crabs in the western area of the Beagle Channel (i.e., Argentinean side) is forbidden, whereas landings of false king crabs are allowed. However, in the eastern area of the channel, landings of both species are allowed. This complex framework and the absence of adequate controls favor illegal landings of southern king crabs.

The decrease of landings in the Beagle Channel promoted the development of exploratory fisheries for the southern king crab in southern waters of the Argentine Sea. A low-scale fishery was developed along the Atlantic coast of Tierra del Fuego but was considered nonviable (Lovrich and Tapella 2014), probably due to high operation costs and low yields. An exploratory fishery in San Jorge Gulf and the surrounding area started in 2003, and this is currently the main fishing area for southern king crabs in the Argentine Sea (Figure 4). More recently, large crabbing vessels have been allowed to operate over the Argentinean continental shelf between the 48°S parallel and the Strait of Magellan.

SOUTHERN KING CRAB FISHERY IN SAN JORGE GULF

The fishery in San Jorge Gulf is being developed at two scales: an industrial fishery that involves five large crabbing vessels (called "crabbers") and an artisanal-scale fishery involving two or three boats less than 10 m in length (Figure 5). There are also illegal fishers who use small boats to catch crabs, which are then traded

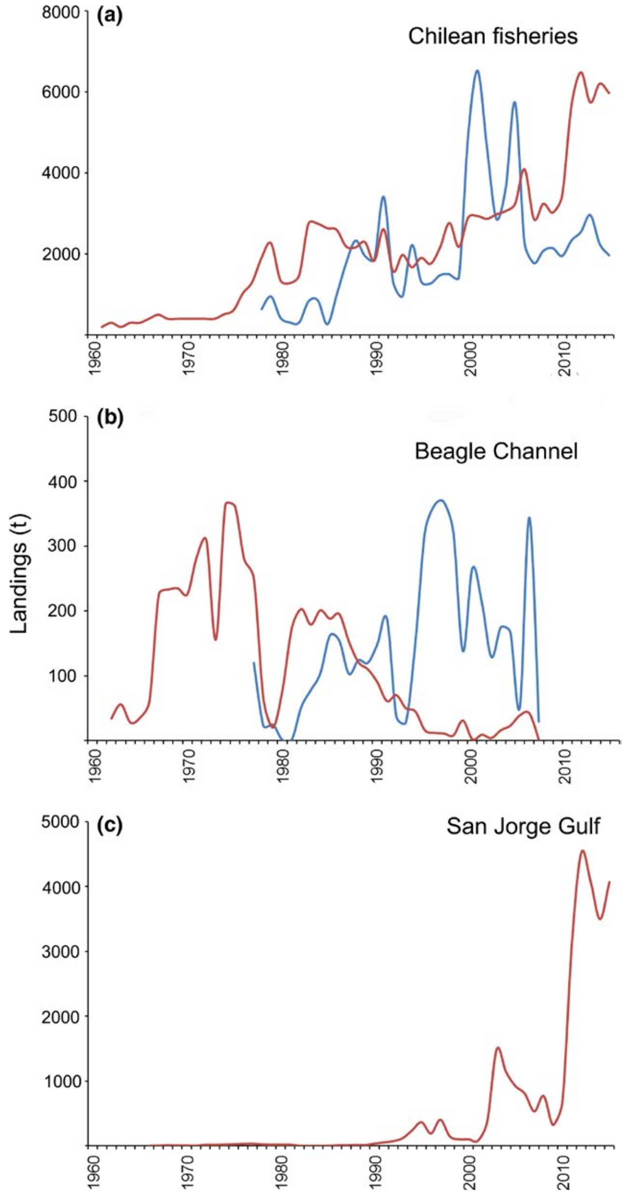

Figure 4. Landings (metric tons) of the southern king crab (red line) and the false king crab (blue line) in Argentinean and Chilean fisheries: (a) Chilean fishery landings (extracted from FAO 2017); (b) landings from Beagle Channel, Argentina; and (c) landings from San Jorge Gulf, Argentina (Ministry of Agroindustry of Argentina 2016).

locally on the black market, although their activity is marginal compared with the fisheries mentioned above. Although the sea in mid-Patagonia is warmer than Tierra del Fuego waters, operations of vessels are also affected by adverse climatic conditions. The strong westerly winds found in Patagonia between 40°S and 50°S constrain the operation of vessels, mainly the small vessels belonging to the artisanal fleet.

Crabbers use truncated conical pots ("inkpots") with a main opening of up to 0.5 m at the top and two escape rings of 0.13 m (Figure 5). Traps are arranged in lines of 150 traps on average and remain in the water for 4–5 d (Figure 6). Each vessel can operate up to 4,500 traps throughout the season and can process nearly 600 traps daily. Traps are baited with hake or anchovy discard. Unlike most Alaskan vessels, crabbers process and cook crabs onboard to produce a frozen block of leg meat or clusters, which include right and left chelipeds and legs (Varisco et al. 2016).

Like other crab fisheries, regulations for the southern king crab fishery are based on the so-called "3 S" rule: size, sex, and season. Under this rule, only males with a carapace length larger than 110 mm can be landed. This size should ensure that males left in the population reach sexual maturity (which occurs at a carapace length of 68 mm) and can mate at least once before they recruit to the fishery (Lovrich and Tapella 2014). Currently, the regulations establish that the fishery is open from January to mid-May, but in practice, the fishery closes earlier (i.e., mid-April) due to a decrease in yields. Fishery closure protects the males during their molt, and during this period the meat yield of adult males is very poor.

The southern king crab fishery in San Jorge Gulf did not have a total allowable catch (TAC) limit until the 2016–2017 season. Before the adoption of TAC, the fishery was closed only when the closure period began or when the fishery reached some indicators, such as the proportion of non-commercial individuals in the catch, the proportion of molting crabs, and the proportion of ovigerous females; however, in practice, the indicators were never reached. Measures such as TACs and individual fishing quotas (IFQs), which are used in most Alaskan fisheries, have helped to prevent overfishing (Otto 2014) and can contribute to the sustainability of the San Jorge Gulf fishery. The use of these management tools requires accurate stock assessment. Therefore, the imprecise estimation of southern king crab abundance probably explains why TACs and IFQs were not used in the past. Wyngaard and Iorio (2003) suggested a TAC of 600 metric tons/year for this fishery, which has largely been surpassed since the fishery began. Recently, based on fishery-independent data, a TAC of 2,000 metric tons for the San Jorge Gulf fishery has been suggested by the Argentinean National Institute for Fisheries Research and Development. This represents a significant decrease in landings for the fishery.

Since the start of the fishery in San Jorge Gulf, landings increased to a peak of 4,317 metric tons in 2012, associated with a significant increase in fishing effort (Figure 4). Interestingly, all crabbers' production is destined for export. For example, between 2011 and 2013, this fishery as a whole was responsible for exporting more than 11,000 metric tons of southern king crab meat (worth US$83.5 million), 90% of which was exported to the United States (Ministry of Agroindustry of Argentina 2016). The southern king crabs marketed in Argentina come from the artisanal fishery, bycatch in trawlers, illegal activities, or Chilean-origin imports.

Since the southern king crab fishery is an exploratory fishery, vessels are monitored by the national and provincial governments through onboard observer programs. Both observers and scientists collect data and samples to contribute to the biological knowledge of the species. The main effort of scientists is invested in assessing the reproductive health of the resource and the fishery impacts on it, as this knowledge is an important factor to ensure the fishery's sustainability.

Artisanal boats also use inkpots, and can deploy between 20 and 60 traps, depending on boat size. The small size of vessels and the strong winds constrain the artisanal fleet's operations to a small area near Comodoro Rivadavia harbor. Data on the landings made by this fishery are generally informal (thus, no statistics are available); however, according to the artisanal fishers' own estimates, landings constitute approximately 15 metric tons per season. All catch obtained by the artisanal fleet is destined for domestic trade.

Figure 5. Vessels involved in southern king crab fisheries operating within San Jorge Gulf, Argentina: (a) large vessel (“crabber”) operating in the industrial fishery; (b) example of an inkpot used in the industrial fishery; and (c), (d) artisanal boats used in coastal fishing.

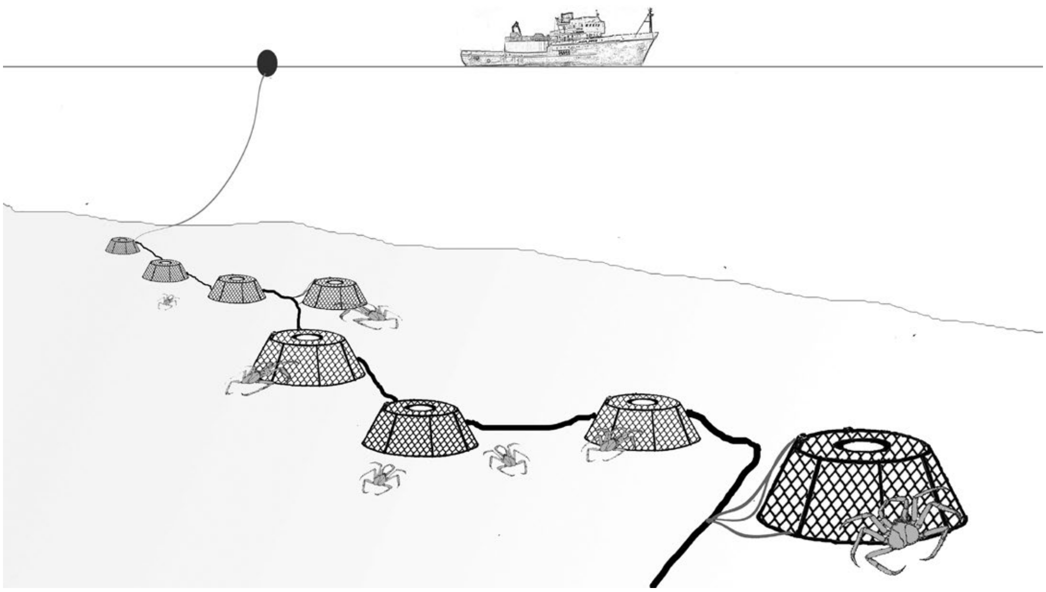

Figure 6. Schematic depicting a line of truncated conical pots (inkpots) used in the southern king crab commercial fishery.

SOUTHERN KING CRAB HEALTH IN SAN JORGE GULF

Several king crab fisheries have collapsed in both the Northern Hemisphere (Otto 2014) and the Southern Hemisphere (Lovrich and Tapella 2014). The most well-known cases include the red king crab *Paralithodes camtschaticus* fishery in the eastern Bering Sea or whole regional collapse of demersal crustacean resources (king crabs, crabs, and shrimps) in the Gulf of Alaska during the early 1980s (Orensanz et al. 1998). Many potential causes of red king crab population decline have been proposed, including overfishing, parasite-associated brood mortality, climate change, variations in predator abundance, and trawling bycatch effects, among others (Otto 2014; Stevens 2014). Moreover, Vinuesa and Balzi (2002) indicated that the continual violation of regulations, which has characterized the Argentinean and Chilean fisheries, was the main factor explaining the collapse of fisheries in the Beagle Channel and the Strait of Magellan. Regardless of the causes, the experience in these fisheries has provided a lesson in prudent management, demonstrating that some stock should be preserved as broodstock (Orensanz et al. 1998; Otto 2014).

The reproductive success of the southern king crab population depends on the social context (sex ratios, male size distribution, and relative sizes of males and females). As in other king crab species, southern king crab mating pairs are generally composed of an intermolt male and a pre-molt female. The male embraces the female until she molts; mating and egg extrusion occur immediately after the female molts. The male then releases the female and is available to mate with other females (Lovrich and Tapella 2014). The large-male-only fishing used in king crab fisheries can have important implications for their reproductive success (Sato and Goshima 2006). Excessive removal of large, potentially dominant males can lead to reproductive failure due to a scarcity of large males and a preponderance of small males (with low reproductive potential and mating ability) available for mating. This can result in an increased number of barren females or females with incomplete clutches (Weeb 2014).

Studies on southern king crab biology in San Jorge Gulf showed a healthy population with little fishing impact until 1997 (Vinuesa and Balzi 2002). The first warning signs have recently appeared due to an increase in the proportion of ovigerous females with incomplete clutches in areas where the industrial fleet operates. Moreover, southern king crabs are captured as bycatch in trawl fisheries targeting Patagonian red shrimp *Pleoticus muelleri* and Argentine Hake *Merluccius hubbsi*. Annually, Patagonian shrimp fisheries average 2,000 metric tons of southern king crab bycatch, which is returned to the sea (Varisco et al. 2017). This bycatch has a negative impact on the southern king crab population due to direct effects such as high mortality, injuries, and egg loss and could interfere in the reproductive-related migration and mating process, thereby leading to reproductive failure. The mortality of southern king crabs in the shrimp fishery was 19% (estimated at the beginning of onboard handling), but this value may be greater due to the long handling time on deck (Varisco et al. 2017). Gowland-Sainz et al. (2015) demonstrated that discard procedures led to egg loss in southern king crabs, whereas we (Varisco et al. 2017) recently suggested that the increased proportion of barren females in coastal areas may be explained by the interference of trawling in the reproductive process. In some years, during the precopulatory period of the southern king crab, about 60% of hauls in the shrimp fishery (when this fishery is still open) are performed in coastal areas where the southern king crab reproductive stock occurs.

In summary, after 14 years of exploratory fishing targeting southern king crabs in San Jorge Gulf, the population shows some signs of overfishing. However, recent measures aimed at significantly reducing the TAC can contribute to the sustainability of the fishery.

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