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## Review

# Chilean jagged lobster, *Projasus bahamondei*, in the southeastern Pacific Ocean: current state of knowledge

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**ABSTRACT.** The Chilean jagged lobster (*Projasus bahamondei*) is a deep-water crustacean (175-550 m) occurring in certain areas of the southeastern Pacific Ocean, including the Nazca Ridge, Desventuradas Islands, the Juan Fernandez archipelago and ridge, and the continental slope off the central coast of Chile. This review describes the taxonomic status, geographical and bathymetric distribution, some biological aspects and habitat characteristics of this species. Additionally, both artisanal and industrial exploitation attempts made within the region are detailed, as well as fishing operation results, chemical composition, different elaboration procedures and the destination of the catch. The main objectives of this review are to contribute to the knowledge of *P. bahamondei* as a component of the deep-sea ecosystem and to highlight its importance as a potential fishery resource.

**Keywords:** *Projasus bahamondei*, Chilean jagged lobster, distribution, biology, fishing, southeastern Pacific.

## Langosta enana, *Projasus bahamondei*, en el océano Pacífico suroriental: estado actual de conocimiento

**RESUMEN.** La langosta enana (*Projasus bahamondei*) es un crustáceo de aguas profundas (175-550 m) presente en el océano Pacífico suroriental: en la cordillera de Nazca, islas Desventuradas, archipiélago y cordón submarino de Juan Fernández y en el talud continental frente a la costa central de Chile. Se describe su estatus taxonómico, distribución geográfica y batimétrica, diferentes aspectos sobre su biología y las características del hábitat donde vive. Adicionalmente, se detallan los intentos de explotación realizados en la región, tanto a nivel artesanal como industrial, así como los resultados de las operaciones de pesca, su composición química, los diferentes procesos de elaboración y el destino de las capturas. El principal objetivo de esta revisión es contribuir al conocimiento de *P. bahamondei*, como componente del ecosistema de aguas profundas, así como destacar su relevancia como recurso pesquero potencial en el océano Pacífico suroriental.

**Palabras clave:** *Projasus bahamondei*, langosta enana, distribución, biología, pesca, Pacífico suroriental.

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## INTRODUCTION

The growing worldwide demand for seafood and the stagnation or even decline in the extraction levels of traditional fishery resources has motivated companies to focus part of their efforts in the search and capture of new pelagic and benthic species, concentrating exploration specifically on deep water in the Exclusive Economic Zone or in the open sea, the adjacent sea or far away from their traditional fishing areas (Arana, 2003). In this context, the southeast Pacific Ocean represents a vast marine area in which it is estimated that potential or

unknown resources that have not yet been properly investigated exist.

The "Chilean jagged lobster", "dalmacita" or "langosta de Valparaíso", described by George (1976) as *Projasus bahamondei*, is among the southeastern Pacific Ocean's known existing resources. It has been indicated that this lobster occurs around the Desventuradas Islands (Bahamonde, 1965) and specimens of this lobster have been found occasionally as by-catch of other species in trawl fishing off the central coast of Chile (George, 1976), and in the Nazca ridge where concentrations permit industrial exploitation.

*P. bahamondei* is one of three registered spiny lobsters in the southeastern Pacific Ocean, together with the Easter Island lobster (*Panulirus pascuensis*), present in this island and in Salas y Gómez Island, as well as the Juan Fernández lobster (*Jasus frontalis*), distributed in this archipelago and around the Desventuradas Islands (San Félix and San Ambrosio Islands) (Holthuis, 1991). The only species currently exploited in this oceanic region is *J. frontalis*, which is marketed in Chile and exported to various regions of the world, whereas *P. pascuensis* is only extracted for local consumption.

The optimum organoleptic characteristics and abundance of the Chilean jagged lobster in the Nazca ridge area motivated that, initially, ships from the former USSR and subsequently a Soviet-Chilean company to perform fishing operations with the use of a factory vessel between December 1990 and February 1991 (Weinborn, 1992; Parin *et al.*, 1997). Thereafter, the company Pesca Chile S.A. carried out an exploratory fishing campaign in the same area in order to determine the technical and economic feasibility of extracting this lobster, testing traps with a variety of designs (shape, size and functionality) in order to establish the most appropriate gear for extraction of this species (Arana & Venturini, 1991). The favorable prospects established in said exploration, led the company to decide on operating in the region with part of their fleet for a full year, fishing and marketing the aforementioned resource (Arana & Soto, 1994).

Later, attempts to develop an artisanal fishing industry for this species have been made, taking advantage of its presence in certain places off the central coast of Chile (Arancibia, 2001). Despite acceptable results were obtained in experimental and exploratory fishing with the help of artisanal vessels, high operating costs and low abundances have prevented the consolidation of permanent fishing activity for this resource.

The main available data on this species is described in this paper. The principal objective of this review is to contribute to the biological and fishery knowledge of *P. bahamondei*, as a component of the deep-sea ecosystem and its importance as a potential fishery resource in the southeastern Pacific Ocean.

## MATERIALS AND METHODS

Articles that refer to this species were collected for the preparation of this review, as well as published reports and records obtained from the worldwide web. The search included both domestic documents and foreign sources.

Unpublished information on biological aspects of these lobsters and on fishing operations conducted off the coast of Chile, particularly in the Nazca ridge, is also included, as these fishing operations constitute the only available source of information on catch, effort, and catch per unit of effort (CPUE) of *P. bahamondei* in this oceanic region.

## BIOLOGICAL AND ENVIRONMENTAL ASPECTS

### Description

The carapace of the Chilean jagged lobster has four longitudinal rows of long, slender and curved spines. The two central rows are slightly divergent towards the front or proximal region, where there is a central spine; the spines of the latero-marginal rows are smaller, except for the two proximal. On both sides of the carapace, a spine is located in the proximal region, between the latero-marginal and center rows. On the thoracic somite of legs 1-4 there are four tubers, and at the end of the somite, two central tubers can be found. The abdomen has a central carina, represented in the first segment by a depressed tuber, which is low and obtuse in the second segment and low on the 2nd, 3rd, 4th and 5th segments, and ends in a spine on the 4th and 5th segments. The pleural surface of somites 2-6 has oblique areas equipped with 3-4 granules. The pleural thorns in the second segment are straight, while in the 3-5 segments are moderately curved (George, 1976; Báez & Ruiz, 1985; Retamal & Arana, 2000).

While fresh, the specimens are a soft, yellow-orange to pink-violet color. In specimens maintained in formalin, the color is light brown uniform with golden spines. In ovigerous females, the eggs are generally brown and some golden when mature.

### Classification

From Chan (2010):

Kingdom: Animalia

Phylum: Arthropoda

Class: Crustacea

Order: Decapoda

Suborder: Macrura Reptantia

Infraorder: Achelata

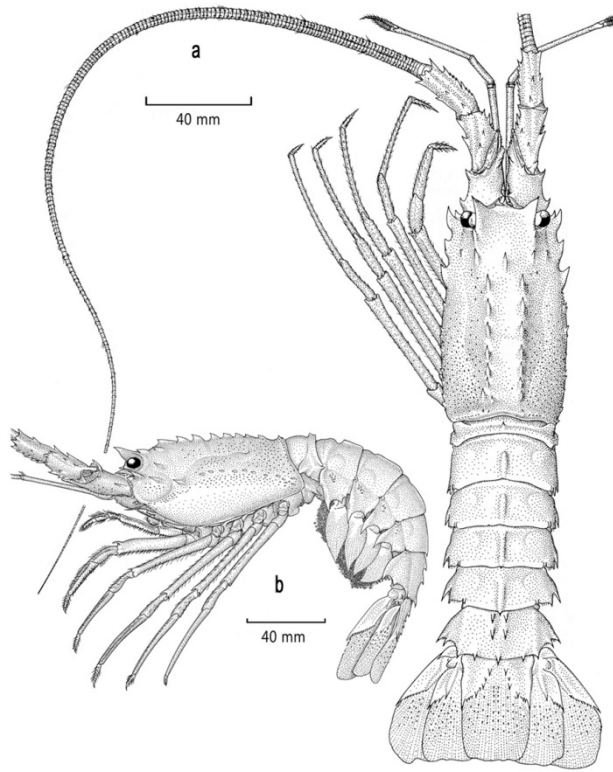
Family: Palinuridae

Genus: *Projasus*

Species: *Projasus bahamondei*

### Species

*Projasus bahamondei* George, 1976. Crustaceana, 30(1): 27, text-fig. 1, pl. 1. (Fig. 1).



**Figure 1.** *Projasus bahamondei* (Stebbing, 1902). a) Male, dorsal view, b) berried female, lateral view (after Weber & Booth, 1988).

Holotype: a female, 71 mm carapace length measured from the tip of the rostrum in the midline to the posterior margin of the carapace, and 174 mm total length. Specimen deposited in Western Australian Museum, N°104-72.

Etymology: the name of this species was dedicated in honor of Dr. Nibaldo Bahamonde N., of the Museo Nacional de Historia Natural and the Universidad de Chile, Santiago de Chile.

### Synonyms

*Isopuerulus* (n.g.) *parkeri*: the first citation of this species in Chilean waters is owed to Bahamonde (1963), who classified the species with that name upon obtaining three specimens from trawl fishing operations, between 300 and 350 m depth offshore from the Valparaíso Region (Quintero Bay and Punta Ritoque). Based on the location where they were captured, the analyzed specimens were denominated as "Valparaíso lobster". A few years later, Bahamonde (1965) noted the presence of *I. parkeri* in Islas Desventuradas (San Felix and San Ambrosio Islands), indicating the necessity for knowing their abundance in this archipelago, with the possibility that they could be exploited in the future.

*Projasus parkeri*: prior to this species being described as *P. bahamondei*, Dupré (1975) mentioned this lobster among the species inhabiting the archipelago of Juan Fernández, whereas Báez (1973) used this same name for the lobsters present in Chilean waters.

*Projasus bahamondei*: this lobster was described as a new species by George (1976), comparing a specimen captured in San Ambrosio Island (Chile) with material from East Africa, determining that the specimens differ from *P. parkeri* principally in the position of the carapace spines, abdomen, legs and third maxilliped, the median carina of the abdomen and the relative size of the eye.

### Affinities

The first species described in the genus *Projasus* was *Projasus parkeri* (Stebbing, 1902). The genus *Projasus* was described by George & Grindley (1964), modifying previous classifications that were given to this species: *Jasus parkeri* (Stebbing, 1902) and *Puerulus parkeri* (Holthuis, 1946).

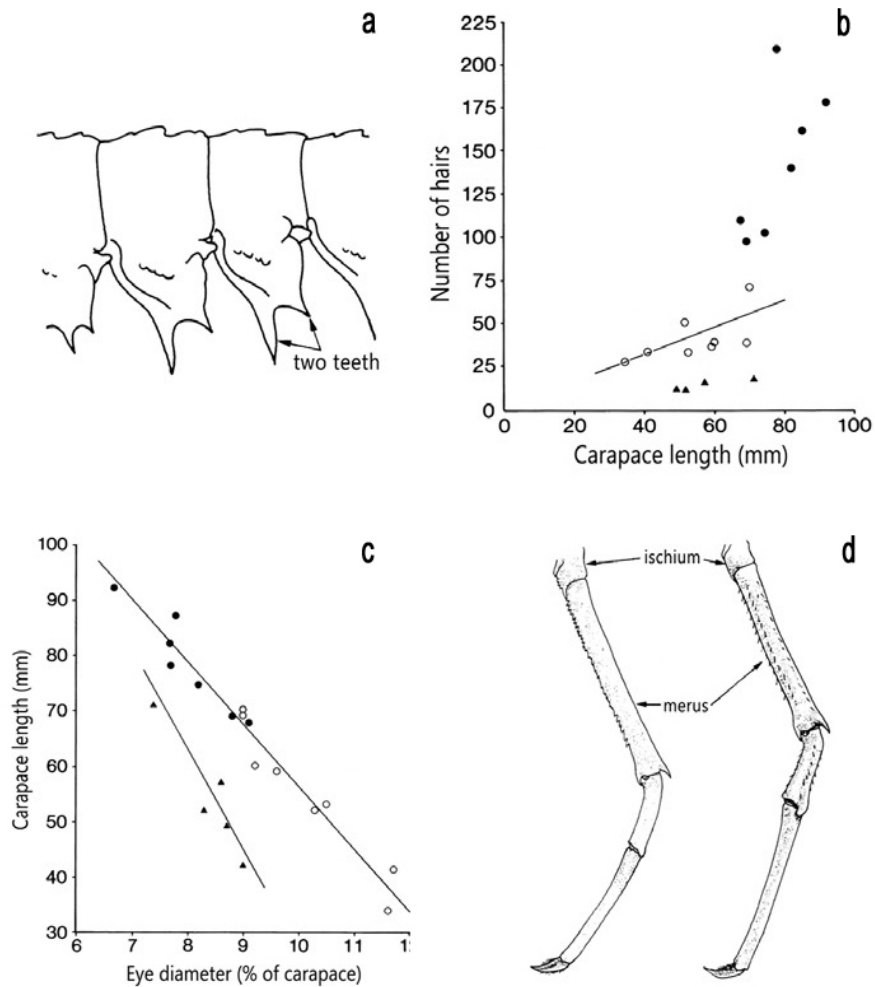
The genus is represented by two species (*P. parkeri* and *P. bahamondei*), each living in widely separated regions of the Southern Ocean. It should be highlighted that both species of this genus have a circumpolar Antarctic distribution, between 15°S and 48°S. The spiny lobsters (family Palinuridae) possibly invaded the deep-sea from shallower rocky reef areas and then radiated, suggesting a southern hemisphere origin for the group. Subsequent diversification appears to have been driven by the closure of the Thethys Sea and the formation of the Antarctic Circumpolar Current (Tsang *et al.*, 2009; Palero *et al.*, 2009).

*P. parkeri* has been reported in the Atlantic Ocean: South-West Africa (Stebbing, 1902, 1910); Indian Ocean: south-east Africa and St. Paul Island; Pacific Ocean: southeastern Australia and New Zealand; at depths of 370 to 880 m.

### Diagnosis

The presence of a tooth in the mid-anterior region of the cephalothorax as well as two longitudinal rows of sub-central spines and two lateral rows on the carapace, smooth and without spinules, is a characteristic for the genus. Furthermore, there are two simple sharp teeth in the pleural extremities (Fig. 2a).

The differentiation between *P. bahamondei* and *P. parkeri* is possible because in the former species there is less pilosity on the shell (Fig. 2b), the gill region is inflated, and the diameter of the eye relative to



**Figure 2.** a) Pleura of third and four abdominal somites of *Projasus* (Holthuis, 1991), b) number of hairs in relation to carapace length in *Projasus parkeri* from New Zealand (●) and Indian Ocean (○) and *P. bahamondei* (▲) (Webber & Booth, 1988), c) eye diameter in relation to carapace length in *P. parkeri* from New Zealand (●) and Indian Ocean (○) and *P. bahamondei* (▲) (Webber & Booth, 1988), d) pereopods of *P. bahamondei* and *P. parkeri* (Holthuis, 1991).

carapace length is smaller (Fig. 2c) (Webber & Booth, 1988). Also, there are morphological differences between both species in the spinules present on the ventral margin of merus and ischium of pereopods (Fig. 2d) (George, 1976; Holthuis, 1991).

#### Local names

Chile: Dalmacita (Báez, 1973; Retamal, 1981; Bahamonde, 1987; Weinborn *et al.*, 1992), langosta de Valparaíso (George, 1976; Báez & Ruiz, 1985, 2000; Báez *et al.*, 2005), langosta enana (Báez, 1973; Retamal, 1981; Bahamonde, 1987; SERNAPESCA, 1999; Arana & Venturini, 1991; Arancibia, 2001; Arana, 2003).

#### English names

Chilean jagged lobster (FAO); baby lobster (Arancibia, 2001).

The other species in this genus (*P. parkeri*) is known internationally as Cape jagged lobster and Parker's crayfish (George & Grindley, 1964).

#### Distribution

Type locality: San Ambrosio Island (Desventuradas Islands), south-east Pacific, 26°21.5'S, 79°47'W, at 175 m depth (George, 1976) (Fig 3).

Geographical distribution: this species is abundant in the Nazca submarine ridge, especially east of 84°W, off Peru (Prosvirov, 1990; Rudjakov *et al.*, 1990; Parin *et al.*, 1997) where it has been commercially fished by industrial vessels (Parin *et al.*, 1997; Arana & Venturini, 1991). It is also found around the Desventuradas Islands and the Juan Fernández Archipelago (Dupré, 1975; George, 1976; Retamal, 1981, 1994; Andrade, 1985; Báez & Ruiz, 1985;

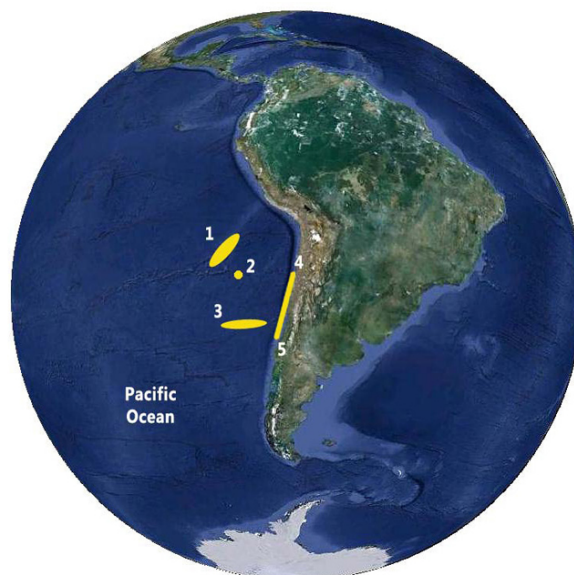


**Figure 3.** Chilean jagged lobsters (*Projasus bahamondei*) photographed from the submarine DeepSee at about 300 m deep in a seamount north of the Roca Catedral (Desventuradas Islands). Photograph by Klapfer Avi, National Geographic and Oceana Expedition, February 2013.

Retamal & Arana, 2000; National Geographic-Oceana, 2014) and in the O'Higgins Seamount ( $39^{\circ}55'S$ ,  $73^{\circ}52'W$ ), off the central coast of Valparaíso, Chile (Báez & Weinborn, 1983). This lobster was also recorded in the Juan Fernández ridge during exploratory fishing operations for orange roughy (*Hoplostetys atlanticus*), but was misclassified as *Sclerocangron atrox* (Lillo *et al.*, 1999).

The presence of *P. bahamondei* is registered sporadically in areas adjacent to the Chilean continental coast, approximately between Huasco ( $28^{\circ}28'S$ ) and Constitución ( $35^{\circ}20'S$ ) (Andrade & Baez, 1980; Andrade, 1987; Retamal, 1981, 1994) (Fig. 4), being caught mainly in trawl fishing operations targeting nylon shrimp or “camarón nailon” (*Heterocarpus reedi*), yellow squat lobster or “langostino amarillo” (*Cervimunida johni*) and red squat lobster or “langostino colorado” (*Pleuroncodes monodon*) (Arana & Ahumada, 2005). According to Acuña *et al.* (2008), the frequency of occurrence for the Chilean jagged lobster in 29 evaluation cruises for demersal crustaceans off the central Chilean coast was 27.6%.

Depth distribution: in the Nazca ridge, this species has been recorded at depths between 225 and 420 m (Arana & Venturini, 1991; Arana & Soto, 1994; Parin *et al.*, 1997). Around the Desventuradas Islands between 286-406 m (National Geographic-Oceana, 2014), and in the Robinson Crusoe and Santa Clara islands some Chilean jagged lobsters have been



**Figure 4.** Distribution of *Projasus bahamondei* in the southeastern Pacific Ocean. 1) Nazca Ridge, 2) Desventuradas Islands, 3) Juan Fernández Ridge, 4) Huasco ( $28^{\circ}28'S$ ), and 5) Constitución ( $35^{\circ}20'S$ ).

captured at depths of approximately 250 m (Arana & Vega, 2000). In the South American continental slope the bathymetric range of this species is between 175 and 550 m (Dupré, 1975; Andrade & Baez, 1980; Baez & Weinborn, 1983).



## Environment

Bottom morphology: the dorsal or submarine Nazca Ridge constitutes the most highlighted southwestern Pacific prominence. This ridge is made up of numerous seafloor elevations, extending towards the southeast-northeast for about 1100 km and is 200 km wide, being subducted under the South American plate off the coast of Peru. It includes several seamounts differing greatly in form, summit depth, degree of isolation and oceanographic conditions (Parin *et al.*, 1997). This ridge attaches to the Salas y Gómez Ridge, at around 83°W, running east to west up to the junction with East Pacific dorsal, with Easter Island (27°08'S, 109°25'W) and Salas y Gómez Island (26°27'S, 105°28'W) as emerging peaks near the Nazca Ridge, are the Desventuradas Islands, comprised of the San Felix (26°17.2'S, 80°05.5'W), and San Ambrosio islands; the González islet and the Roca Peterborough.

The Nazca Ridge is of volcanic origin, by effect of eruptions recorded in the Easter hotspot and the displacement of the oceanic plate moving eastward at a speed of about 10-18 cm yr<sup>-1</sup>. The presence of this ridge divides the ocean floor in two basins; the Peruvian basin and the Chilean basin. A detailed description of the seamounts is provided, among others, in Woods & Okal (1994), Naar *et al.* (2002), and Galvez-Larach (2009).

According to Parin *et al.* (1997), the summits of the Nazca ridge seamounts show remnants of coral atolls, suggesting that after the Miocene, these summits would have been 300-375 m higher than at present, so that many of the peaks would have formed islands. At present, several of these mountains possess the shape of guyots with vast flat summits, possibly caused by abrasion during the sinking process. In the central part of the ridge some of the mountains have summits at depths of 240-500 m and other at depths of 850-950 m, with depths of over 3500 m between them.

Based on the experience accumulated in fishing operations conducted on these mountains (Arana & Soto, 1994), it has been determined that the distribution of the Chilean jagged lobster is concentrated mainly on the edges of the guyots and their outer slopes towards greater depths, and not in the center of the plateaus where abundances proved to be significantly lower.

The Juan Fernández ridge consists of a long, narrow chain of seamounts of volcanic origin that that extending perpendicular to the coast of South America, from about 84°W to the O'Higgins Seamount nears the edge of the Chilean Trench, somewhat north of Valparaíso (Chile) (Vergara &

Morales, 1985). Emerging seamount summits of this ridge are the islands of Robinson Crusoe (33°37'S, 78°50'S), Santa Clara and Alejandro Selkirk (33°45'S, 80°45'W). The average depth of the seabed around this ridge is 4025 m, but some peaks rise up to depths of 225 to 425 m from the sea surface. Some of these seamounts present a reduced summit, with one or two peaks, while others present a mild depression towards their center denoting the presence of ancient craters, followed by abruptly declining slopes which descend to the ocean floor (~4000 m).

The continental slope of South America exhibits characteristics of a subduction zone, with a narrow continental shelf and a steep slope descending to the Peru-Chile trench. The continental shelf and continental slope have a generally flat bottom with muddy sediments. Nevertheless, in certain places, there are irregular structures and slab formations that make it unfeasible to conduct bottom trawling. These places could possibly produce settlements of *P. bahamondei* puerulus, which would allow the development of this species in specific locations along the continental border.

Oceanographic conditions: in the southeastern Pacific Ocean, off the coast of South America, different water masses are present that form part of the complex Humboldt Current System. Thus, in the area of the Nazca submarine ridge, the Subtropical Surface Waters (STW), with an average temperature of 18°C and salinities of 35.0, occur down to a depth of about 120 m. Under this water mass there are remnants of the Subantarctic Water Mass (SAAW), with an average temperature of 12°C and salinity of 34.6. Deeper, down to 400 m, is the minimum oxygen zone (<1.0 mL L<sup>-1</sup>) corresponding to the Equatorial Subsurface Waters (ESSW) and below that, down to 1200 m, the Antarctic Intermediate Water (AAIW), with average temperatures of 5°C, salinity of 34.1 and higher dissolved oxygen contents (2-3 mL L<sup>-1</sup>) (Parin *et al.*, 1997, Silva *et al.*, 2009). From 1200 m to the depth of the seafloor is the Pacific Deep Water (PDW).

The distribution of water masses is similar in the Juan Fernández seamounts, although occasionally, the Subtropical Surface Waters (STW) can be detected in the archipelago of Juan Fernández overlaying the Subantarctic Waters (Sievers & Silva, 1973, 1975; Silva *et al.*, 2009).

Variations in the depth distribution of the ESSW and AAIW and their mixing zone are of great importance, as they appear to determine the depth distribution range of *P. bahamondei* and the bathymetric movements of these lobsters in search of optimal living conditions. According to available

information, the species inhabits well oxygenated waters of the AAIW. It is possible that alterations in climate and oceanographic conditions caused by the El Niño-Southern Oscillation (ENSO) phenomenon have a direct influence on the intensity and depth distribution of different water masses, which in turn may influence the presence/absence of this lobster in certain locations or depth strata.

According to Arancibia (2001), the most appropriate conditions for catching the Chilean jagged lobster off the coast of Chile occur in the depth range of 315-318 m, with a temperature of 8.6-9.8°C, salinity of 34.5-34.6, oxygen 0.5 mL L<sup>-1</sup> and rocky, rock-mud and stone slab bottoms.

### Vertical distribution

The vertical distribution and migratory behavior of the Chilean jagged lobster on the Nazca ridge were investigated by way of visual observation from a Russian submarine. The vertical distribution of lobsters was determined on the basis of water oxygen concentration (Pakhorukov *et al.*, 2000). The authors observed uniform abundances of *P. bahamondei* at the top of the mountains, with the occasional presence of higher density local clusters, while this crustacean was found in more disperse quantities on the continental slope.

As previously indicated, the summits of the guyots are bathed by the Peruvian Countercurrent (STW). When this current is intense, dissolved oxygen concentration may decrease up to 0.14 mL L<sup>-1</sup>, whereas when this current is weak, the mass of Antarctic Intermediate Water is strengthened, increasing oxygen levels. Thus, when oxygen levels drop, Chilean jagged lobsters move down the slope to more oxygenated areas, and when values rise to 0.4-0.6 mL L<sup>-1</sup> they ascend again toward the edge of the guyot (Kudryavtsev, 1981; Golovan *et al.*, 1982; Gevorkyan *et al.*, 1986; Parin *et al.*, 1997).

### Species composition of the benthic community and ecosystem

Despite investigations conducted by U.S., Japanese, Russian (Parin *et al.*, 1997) and Chilean ships the Nazca Ridge is still poorly studied and the composition of its fauna requires further analysis. The catch (in weight) from traps deployed on the summits and slopes of the central seamounts of this ridge tends to be composed exclusively of Chilean jagged lobsters, whereas if the traps are deployed at greater depths (*e.g.*, on the seamount slopes), golden crabs (*Chaceon chilensis*) constitute a higher proportion of the catch, and in areas west of 84°W, the catch consists mainly of the fake crab, *Paromola japonica* (Parin *et al.*, 1997).

In the Desventuradas islands and Juan Fernández Archipelago the lobster *Jasus frontalis* is exploited by artisanal fisheries by means of traps deployed at depths of 0-200 m. In the former islands lobster extraction is a sporadic activity, whilst in the latter islands it is a permanent activity. The Juan Fernandez crab (*Paromola rathbuni*) is distributed between 100 and 300 m and, below that depth, possibly down to 2000 m, the golden crab (*Chaceon chilensis*) (Retamal & Arana, 2000). Chilean jagged lobsters are occasionally caught while fishing for golden crab or on those occasions when lobster traps are set deeper than usual.

An industrial fishery for benthonic crustaceans by means of bottom trawls exists along the Chilean continental coast, between Huasco and Constitución. This fishery targets yellow squat lobsters (*Cerimunda johni*), red squat lobsters (*Pleuroncodes monodon*) and nylon shrimps (*Heterocarpus reedi*), although at greater depths, red royal shrimps or “gambas” (*Haliporoides diomedae*) and razor shrimps or “camarones navaja” (*Campylonotus semistriatus*) are also caught. However, when trawling are conducted near slab stone or rocky seafloor, *P. bahamondei* specimens occasionally appear in the catch.

In fishing explorations for Chilean jagged lobster conducted off the coast of Valparaíso using Fathom Plus traps, the most abundant crustaceans in the by-catch were king crabs (*Glyptolithodes cristatipes*), nylon shrimps, spider crabs (*Libidoclaea granaria*) and deep-sea hairy crabs (*Trachycarcinus hystricosus*) (Arancibia, 2001).

### Larvae and post-larval phases

Due to the wide distribution of this species in the southeastern Pacific, it is probable that phyllosomas are present in a vast area of this ocean, which is characterized by the existence of numerous eddies and various surface and subsurface currents. This would explain the possibility of settlements in places with appropriate floor depths and oceanographic conditions suitable for the habitation of this lobster.

Báez (1973) analyzed zooplankton samples collected with Isaacs-Kidd mid-water trawl nets (IKMT) between Valparaíso and the Juan Fernández Archipelago. Phyllosomas of *Jasus frontalis* and *Scyllarus delfini* occurred in these samples. Báez (1973) contended that one of the larvae collected in oceanic station N°45 could be the phyllosoma stage X of *P. bahamondei*. Webber & Booth (1988) suggested that such phyllosoma stage X did not belong to *P. bahamondei*, but Báez & Ruiz (2000) insisted on this possibility given that *P. bahamondei* is the only spiny



lobster other than *J. frontalis* occurring in the Chilean coast.

The postlarva (puerulus) and first stage juvenile (postpuerulus) of *P. bahamondei* were described by Báez & Ruiz (2000) from six specimens collected in trawl fishing off the Central Chilean coast. The pueruli measured 19.9 to 20.3 mm in carapace length (CL) and 48.9 to 50.3 mm in total length (TL). The pueruli were orange brown, with a light brown tone in the abdomen and chocolate tones on the carapace; also with spines and seta partially projected out of the body surface (Fig. 5a). The postpueruli measured 21.8 to 23.9 mm CL and 52.9 to 59.3 mm TL and had a chocolate brown color, with a shape generally similar to adults and spines and seta fully projected from the carapace (Fig. 5b).

### Food

The first study on the feeding of *P. bahamondei* was conducted by Andrade & Báez (1980), who reported 13 different components in the stomach contents, including sediment and remains of crustaceans, tanaidaceans (*Apseudes*), and ophiuroids (*Ophiomastus molinae*). According to these authors, *P. bahamondei* is classified as detritivore with an omnivorous diet. Further on, Fedorov & Chistikov (1985) found squid, shrimp, and deep-water bristlemouths (*Gonosto-*

matidae) remains in the stomachs of Chilean jagged lobsters.

More recently, Báez *et al.* (2005) analyzed the stomach contents of 163 specimens captured in the Nazca submarine ridge, between 360 and 400 m in depth. In decreasing order, the relative frequency that occurrence of the different food items was: foraminifera (74.2%), crustacean remains (69.3%), sediment (67.5%), undetermined organic material (24.5%), fish remains (12.9%), crustacean eggs (8.6%), *Thioploca* sp. (7.6%) and a low percentage of undetermined materials. There was no evidence of difference in feeding between males and females. The high percentage of planktonic foraminifera and sediments in the stomachs indicate that these were consumed by lobsters from the ocean floor. The previous items, together with the remains of crustaceans and fish confirm the detritivorous habits of this species.

### Predators

Bahamonde (1987) states that remains of this species have been found in stomachs of Juan Fernandez cod (*Polyprion oxygeneios*). Also, Báez & Ruiz (1985) indicate the presence of a phyllosoma stage X, a molting male and a female of *P. bahamondei* in the stomachs of the same species caught in the Alejandro Selkirk Island (Juan Fernandez Archipelago). Whereas, Labbé & Arana (2001) also found remains of this lobster in the stomachs of orange roughy (*Hoplostethus atlanticus*) from the Juan Fernández seamounts.

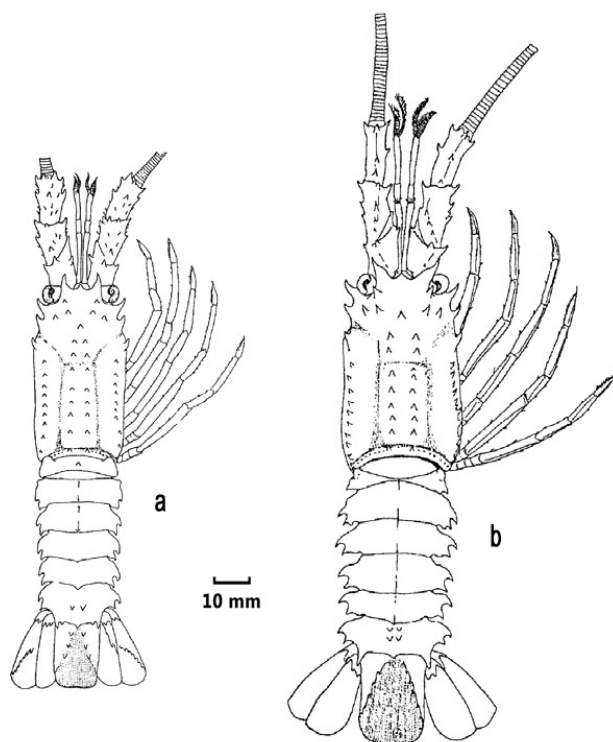
### Parasites

Cirripeds of the family Lepadidae were found in a specimen caught around Desventuradas islands (Báez & Ruiz, 1985).

### Size composition

Rudjakov *et al.* (1990) present length frequency distributions obtained on three seamounts, called by the Russians, Ekliptica (Ecliptic), Professor Mesyatzev and Zveda (Star), in September-October 1980, February 1982 and April 1987. Polymodal curves were observed in both sexes, with two predominating groups that clearly showed distinct lengths and in their weights composition as well.

In November 1991, 3,119 Chilean jagged lobsters caught with traps on the Nazca seamounts were measured (Arana & Venturini, 1991). Their carapace lengths (CL) ranged from 27 to 67 mm CL in males and from 39 to 69 mm CL in females. Ovigerous females ranged in size from 39 to 66 mm CL and non-ovigerous females from 39 to 69 mm CL, respectively. Average lengths were 51 mm CL in males and 50 mm



**Figure 5.** *Projasus bahamondei*. Dorsal view a) puerulus, b) postpuerulus.

CL in females (Fig. 6). The average weight of individual specimens was 80 g. The length frequency distributions of both sexes showed two clearly defined peaks. The maximum relative frequencies of males occurred at 44 and 58 mm CL, and of females at 47 and 58 mm CL (Fig. 6). These modal sizes may correspond to annual classes, possibly of ages 3 and 5 years, respectively (Arana & Venturini, 1991).

A small sample of 163 individuals of *P. bahamondei* also from the Nazca ridge was analyzed by Báez *et al.* (2005). The range in total length (TL) of these lobsters was 111-159 mm TL for males and 111-185 mm TL for females. Males showed two distinctive modes at 120-125 mm TL and 155-160 mm TL, whereas females showed several modes at 125-130 mm, 150-155 mm, 160-165 mm and 180-185 mm TL. Off the coast of Valparaíso, Arancibia (2001) examined 1,630 Chilean jagged lobsters. Males measured 26.7 to 80 mm CL, with three modes at 35, 48 and 64 mm CL, whereas females measured 28 to 65 mm CL, with a distinctive mode at 50 mm CL.

### Length-weight relationships

The specimens from Valparaíso that measured 26.7 to 85 mm CL had a total individual weight (Wt) of 9.9 to 334 g (Arancibia, 2001). The relationship between CL and Wt was determined by the following power equations:

$$\text{Males: } W_t = 7.405 \cdot 10^{-4} \times \text{CL}^{2.919} \quad r^2 = 0.92 \quad n = 836$$

$$\text{Females: } W_t = 9.908 \cdot 10^{-4} \times \text{CL}^{2.848} \quad r^2 = 0.87 \quad n = 794$$

$$\text{Both sexes: } W_t = 7.973 \cdot 10^{-4} \times \text{CL}^{2.901} \quad r^2 = 0.90 \quad n = 1,630$$

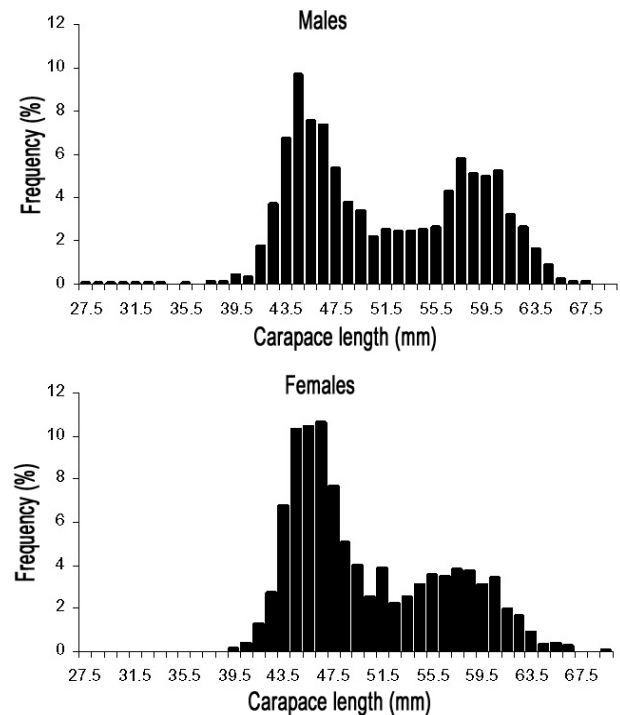
The relationship between TL and Wt was calculated by Báez *et al.* (2005) from the sample obtained from the Nazca ridge and was explained by the following linear equations:

$$\text{Males: } \log W_t = -4.46 + 2.85 \text{ TL} \quad r^2 = 0.74 \quad n = 61$$

$$\text{Females: } \log W_t = -3.99 + 2.64 \text{ TL} \quad r^2 = 0.77 \quad n = 102$$

### Sex ratio

In catches of *P. bahamondei* from the Nazca submarine ridge in November-December 1991 the ratio was 1:1.3 between males and females respectively (Arana & Venturini, 1991). The sex ratio by CL intervals showed a clear predominance of females between 42 and 56 mm CL. Of the total females, 37% were ovigerous, possibly indicating the end of the reproductive period (Arana & Venturini, 1991). In the material examined by Báez *et al.* (2005), also from the Nazca ridge, the male:female ratio was 1:2.



**Figure 6.** *Projasus bahamondei* size frequency distributions in the Nazca Ridge (November 1991).

### Fecundity

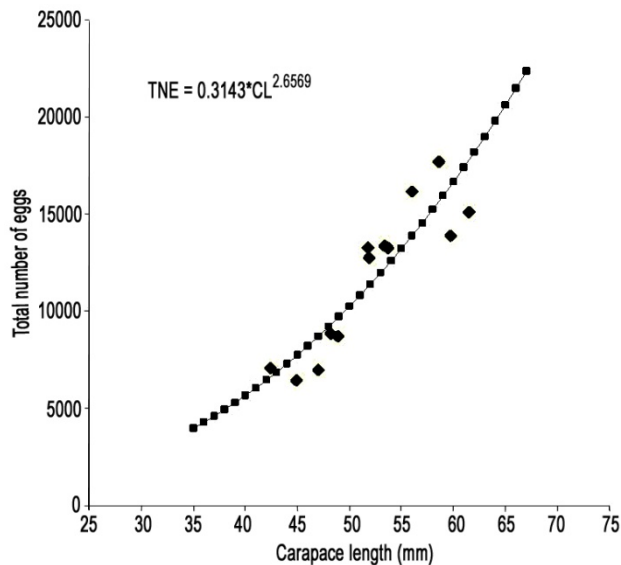
Among the specimens collected in the Nazca ridge in November 1991 (21°30'S, 81°30'W) (Arana & Venturini, 1991), the smallest egg-carrying female was 39 mm CL. The eggs in all ovigerous females were bright orange or brown in color and exhibited grainy homogeneous yolks with no internal structures or differentiated cells. According to the scale proposed for the red squat lobster (*Pleuroncodes monodon*) by Palma & Arana (1990), these eggs were in maturity stage II. Egg diameter (n = 146) ranged from 0.94 to 1.14 mm, with the mode at 1.06 mm.

Fecundity (brood size) was determined in 13 females of *P. bahamondei* between 42 and 61 mm CL. The number of eggs in these females ranged from 6,441 to 17,686 eggs (Arana & Venturini, 1991). The following equation describes the relationship between (CL) and number of eggs (TNE) (Fig. 7):

$$\text{TNE} = 0.314 \times \text{CL}^{2.657} \quad r^2 = 0.913$$

### Biomass

According to Pakhorukov *et al.* (2000) the total biomass of *P. bahamondei* in the Nazca ridge may range between 8,000 and 10,000 ton. In the Desventuradas Islands the mean density was estimated in  $75 \pm 21$  ind  $\text{ha}^{-1}$ , with sizes from 5 to 8 cm CL, and a mean biomass around  $84 \pm 44$  kg  $\text{ha}^{-1}$  (National Geographic-Oceana, 2014).



**Figure 7.** Fecundity of *Projasus bahamondei*, determined by samples obtained from the Nazca Ridge seamounts.

## FISHING ASPECTS

### Artisanal fishing

Fishing of this species was experimentally performed off the Central Chile from January 1998 to December 1999, between Valparaíso (33°00'S) and Bío-Bío (36°40'S) (Arancibia, 2001). Wooden or fiberglass artisanal boats, 7.5 m long as well as artisanal launches, 17-18 m in length were used for the extraction process. Boats fitted with hydraulic winches can operate two trap lines, each fitted with 100 to 150 traps spaced 22 m apart, in order to perform alternating sequential operations. Fathoms Plus traps were used in these experiments with an average catch of 11 specimens per pot, equivalent to approximately 0.84 kg pot<sup>-1</sup>.

In pilot fishing operations carried out between April and July 2000 off the central coast of Chile, the existence of an appropriate area for the capture of this species is described, located to the southwest of Valparaíso (Laguna Verde-Quintay), between 350 and 450 m deep.

### Industrial fishing

For some years, former USSR ships carried out research in the Nazca ridge seamounts while developing *P. bahamondei* fisheries, without available information about the effort displayed or the amount of catches. Furthermore, in some periods, this species was extracted either as the target species or as incidental catch in operations aimed to obtain fish using trawl nets.

Industrial exploitation of this species has only been performed in the Nazca ridge, in international waters off the coast of Peru, mainly between 20°00'S and 24°00'S and 79°50'W and 84°50'W. Extractive operations have been developed almost exclusively on the Ekliptica (Ecliptic), Professor Mesyatzev, and Zveda (Star) seamounts, with peaks at 240-340 m below the sea surface.

Between December 1990 and February 1991, the joint venture Chilean-Soviet named Latoqui S.A. operated briefly in the oceanic region, using the fishing-research vessel Odyssey, achieving a total catch of 72 ton of Chilean jagged lobster in this period. Traps baited with fish meat were used as fishing gear (Weinborn *et al.*, 1992).

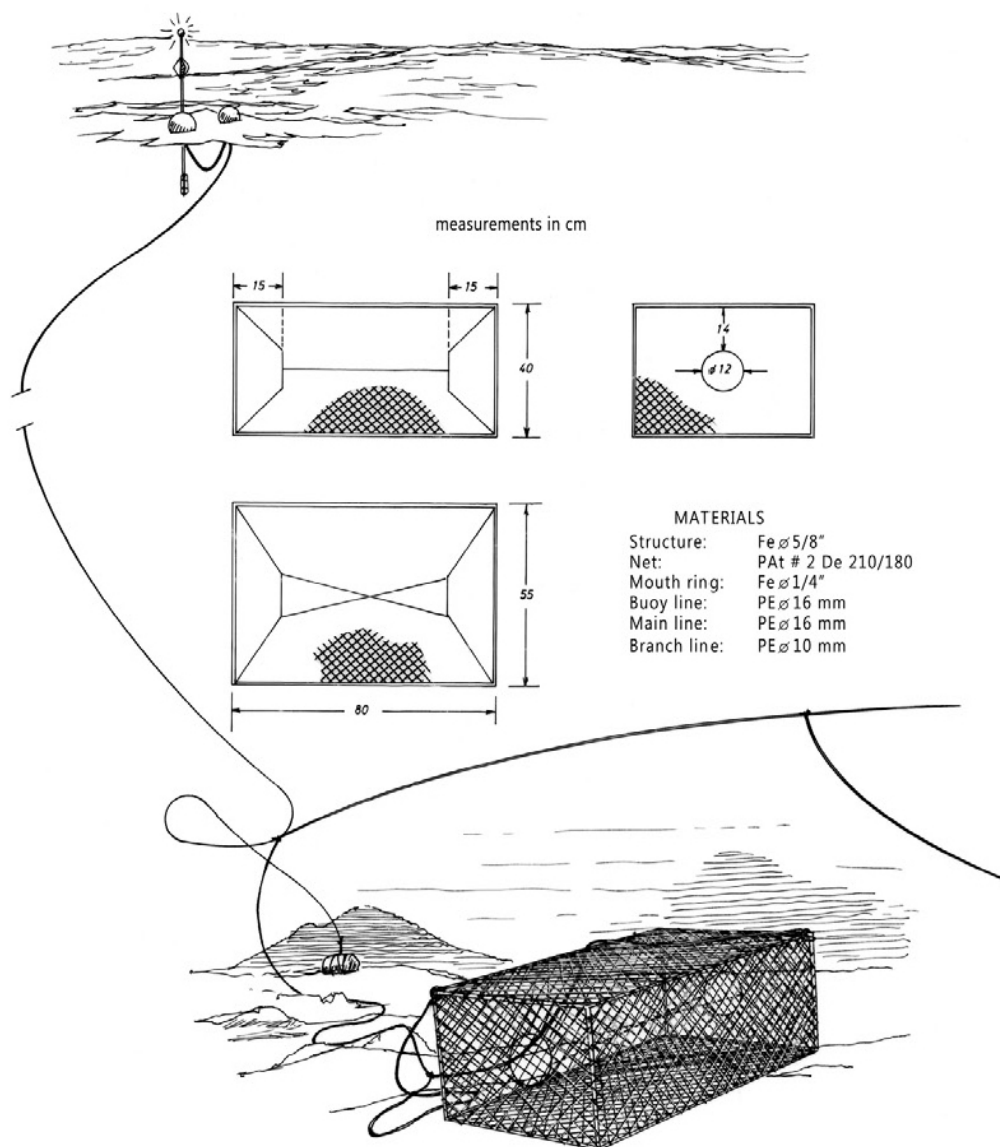
Soon after, between November 1991 and October 1992, Chilean jagged lobster extraction operations were carried out with three ships belonging to Pesca Chile S.A. fishing company (FV Magallanes I, Magallanes III and Magallanes IV, from 42.5 to 48.5 m in length) on seamounts located between 21°00'-22°00'S and 79°50'-82°00'W. These ships operated from Coquimbo, Chile, their base port, and each trip included cycles of approximately 20 days.

Traps with a tetragonal design and dimensions of 80×55×40 cm (Fig. 8) were used to catch this lobster. The traps were designed with these dimensions so that they could be employed using the installations and facilities of these ships, originally built to operate deep-sea longlines. The trap structure was made with wrought iron 5/8" in diameter, covered with PA 210/180 net with 2" mesh. Each trap was fitted with two mouths at the lateral ends (Arana & Venturini, 1991; Arana & Soto, 1994) (Fig. 9). Spanish sardines (*Sardinops sagax*) were used as bait. These traps were deployed with the use of a line, with a distance of 20-30 m between them (Fig. 10).

In the above-mentioned period, 187,669 traps were deployed with an average of 706 pots day<sup>-1</sup>. Of this total, the lowest number of traps used per month was less than 5,000 in April, while more effort was applied in August, with an average of 28,000 traps (Fig. 11).

Within 12 months of operation, the production of Chilean jagged lobster reached 172.2 ton. The production included 111.2 ton of whole lobster (64.6%), 6.6 ton of lobster tails of varying caliber (3.8%), and 52.4 ton of unclassified tails (30.4%) corresponding to a total nominal catch of 354.8 ton.

Upon analyzing the monthly catch per unit of effort (CPUE) it was determined that the highest CPUE was obtained in April, with 2.7 kg pot<sup>-1</sup> on average, and the lowest CPUE was obtained in November, with 0.9 kg pot<sup>-1</sup> on average. According to



**Figure 8.** Tetragonal trap used for the fishing of *Projasus bahamondei* in the Nazca Ridge seamounts.

the results, there is an annual cycle characterized by high yields in summer and autumn and low yields in winter, reversing the process in spring (Fig. 11). The overall average CPUE for the 12-month period was  $1.9 \text{ kg pot}^{-1}$ , with frequent catches of 30-50 lobsters per trap.

Upon analysis of the yield obtained by depth stratum, it was determined that they are relatively uniform between 260 and 318 m deep, with an average CPUE in that range of  $1.8 \text{ kg pot}^{-1}$ . Deeper, yields increase gradually until reaching the highest value of between 348 and 375 m, with a CPUE of  $2.7 \text{ kg pot}^{-1}$ , but the CPUE then decreases to  $2.0 \text{ kg pot}^{-1}$  in the 377-405 m depth range (Fig. 12).

## PROCESSING, CHEMICAL COMPOSITION AND CONSUMPTION

Considering that this species inhabits steep, rocky places, traps are the most appropriate type of fishing gear for exploitation, allowing the captured specimens to reach the deck of the boat alive. Hence, the raw material is of excellent quality, allowing them to be kept in chilled water for onboard processing or subsequently in plants on shore, thereby preventing autolytic oxidation processes and discoloration of the shell (black spots).

If the catch is not processed onboard, storage and transfer of the catch must be carried out by adding ice flakes, over a period not exceeding eight days.

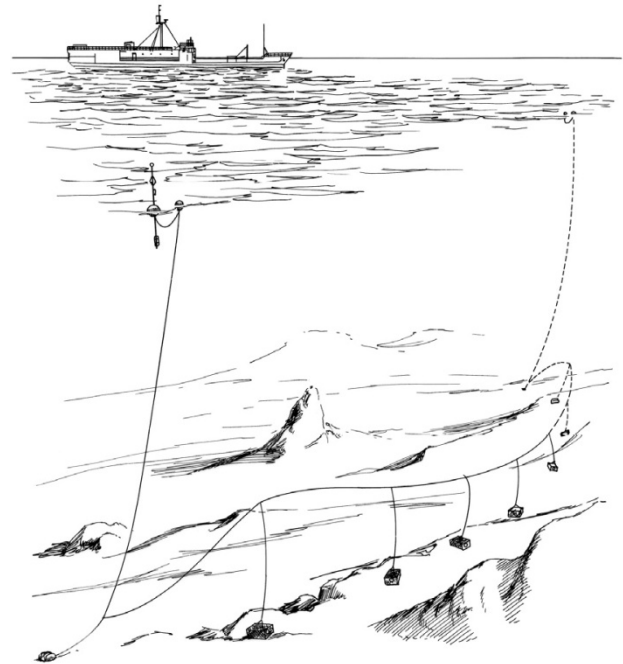


**Figure 9.** Tetragonal trap designed for catching *Projasus bahamondei* in the Nazca Ridge seamounts.

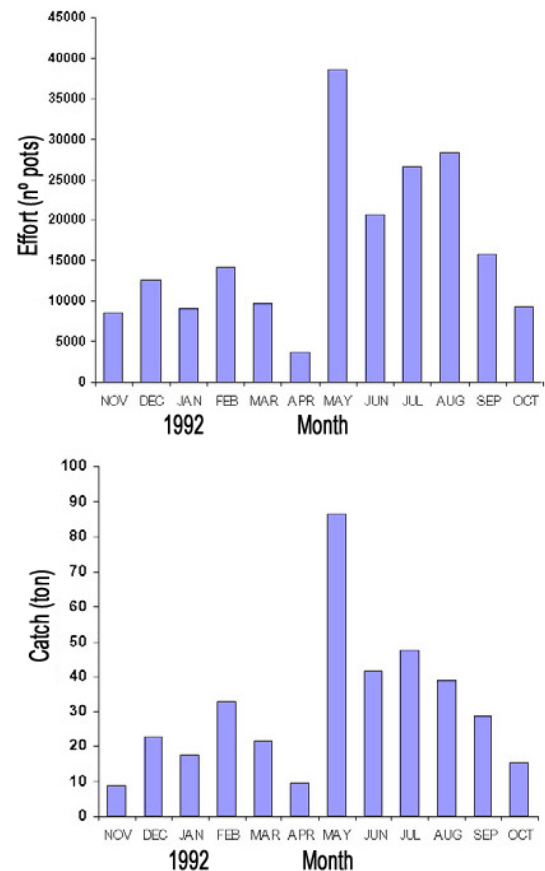
However, in order to preserve the color of the specimens, the application of cryo-preserved and antioxidants is recommended (Arancibia, 2001). In small vessels, the most appropriate option is to keep the specimens in reservoirs or tanks with circulating water, with salted ice to maintain the salinity and a low temperature (5-8°C), and if possible in complete darkness to avoid discoloration of the exoskeleton. Low mortality is achieved through this procedure, and at the same time, the raw materials reach the plants with optimum freshness.

The industrial processing of this resource may follow different options according to market requirements. Historically, Russian factory ships operating in the Ridge undertook block freezing of the lobsters. Later, Chilean vessels carried out onboard freezing of whole lobsters and tails with shell (Arana & Venturini, 1991). Once ashore, the raw material was reprocessed into more elaborate products.

In onshore plants, this kind of processing is carried out using the following main steps: a) reception of raw material at the plant: the lobsters are weighed and washed and the shell is then scrubbed by hand, dead or

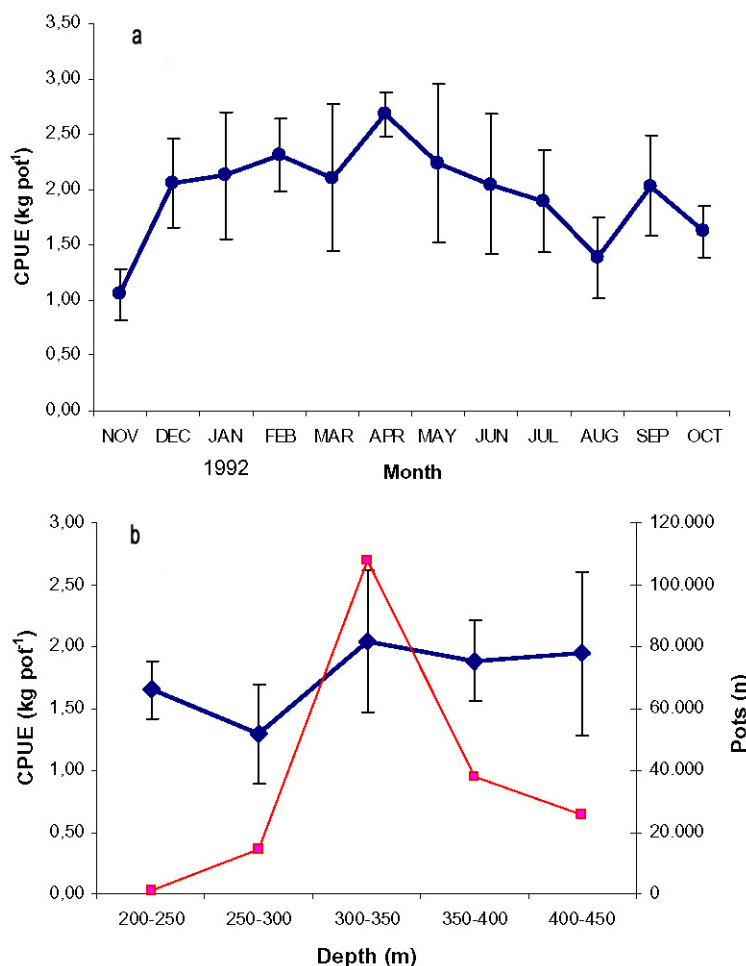


**Figure 10.** Fishing line with traps using a tetragonal design for catching *Projasus bahamondei* in the Nazca Ridge seamounts (southeastern Pacific Ocean).



**Figure 11.** Effort and catch of Chilean jagged lobster (*Projasus bahamondei*) in the Nazca Ridge (1991-1992).





**Figure 12.** *Projasus bahamondei*. a) Monthly CPUE, b) CPUE and number of traps (red) by depth stratum in the Nazca Ridge seamounts (1991-1992).

damaged specimens are removed and the antennae are cut, b) cooking: the specimens are introduced into an industrial steam or water cooker at 94-96°C, c) cooling: the specimens are then passed through a chilled water system (8-10°C) to rapidly reduce their temperature, d) sanitization: the lobsters are bathed in chlorinated water with citric acid, e) freezing: performed in freezing chambers or tunnels at about -30°C, f) Calibration of parts by determining their individual weight, g) glaze: the specimens are immersed in cooled water (1-3°C), h) package: individually or in bags with a determined weight and, i) storage.

Another option is the preparation of frozen tails with or without shell, for which, once the lobsters are cooked they tails are removed, leaving the abdomens with carapace (shell on) or proceeding to remove the shell, after which the general process described above for calibration and packaging is followed.

The yield of *P. bahamondei* in processing plants reaches different values, depending on the catches destination. Thus, when preparing frozen cooked whole lobsters (IQF) the yield is equivalent to approximately 90%; in frozen cooked tails with shell 30% and in frozen cooked tails without shell 20%.

The chemical composition of the abdominal muscle of the Chilean jagged lobster was determined as: 79.4% moisture, 13.7% protein, 4.4% fat and 2.1% ash (Arancibia, 2001).

It should be noted that this lobster is an excellent resource and has a delicate flavor, similar to the Juan Fernandez lobster (*Jasus frontalis*) and other crustaceans such as shrimps and crabs. This lobster has been exported to Europe as an alternative for the "Norway lobster" (FAO, United Kingdom), "scampo" (Italy) or "cigala" (*Nephrops norvegicus*) (Spain), with good reception in this demanding market. This species is listed as a delicacy for the discerning palate.



## ECONOMICAL APPROACH

The economic and financial evaluation associated with the fishing yield, based on the research results conducted with traps in the central region of Chile, indicates that this activity would be a good business opportunity and an alternative work source for the artisanal fishing fleet that uses deep-sea longlines, in those months when traditional target resources such as Patagonian toothfish, seabass or “bacalao de profundidad” (*Dissostichus eleginoides*) and kingclip or “congrío dorado” (*Genypterus blacodes*) are not fished (Arancibia, 2001). The acquisition cost of traps represents between 77% and 88% of total investment, it is possible to decrease this cost by way of large volume purchases by suppliers (Arancibia *et al.*, 2000).

The ex-vessel price of the jagged lobster, reaches ~US \$4-5 kg<sup>-1</sup>. The price of frozen lobster tails with shell (shell-on) can reach a price of around US \$20 kg<sup>-1</sup> in the international market.

## PERSPECTIVE AND MANAGEMENT

This resource has generated interest in exploitation development, whether in industrial type operations in the Nazca ridge, as well as an alternative option or supplementary to the extractive work performed by artisanal fishermen off the Central Chile. These actions are motivated by the fact that this species constitutes one of the few lobsters with exploitation perspectives in the southeastern Pacific.

Nevertheless, the long distance between the continent and the Nazca Ridge or the Desventuradas islands and surrounding areas (400 nm), implies the need for large expensive vessels, that would allow the catch to be frozen on board or processed at the catch site. In the case of artisanal fisheries, high investment costs, the possibly limited abundance of this species off the mainland coast, the great depth at which the resource is located, as well as the small areas where this lobster is distributed on the continental slope has limited the consolidation of a fishery. It should be noted that official statistical records indicate that only a few tons of *P. bahamondei* have been landed in Chile: 1999 (38 ton), 2000 (7 ton), 2001 (1 ton) and 2007 (2 ton) (SERNAPESCA, 1999, 2000, 2001, 2007). For this reason, currently there are no specific conservation measures imposed by the Chilean fisheries administration, and there are no species-specific conservation measures for this species imposed by the International Union for Conservation of Nature and Natural Resources (IUCN) (MacDiarmid, 2011).

While this species is not currently being fished off the coast of Chile, a large number of seamounts have been detected (Yañez *et al.*, 2009), some of which could present summits at depths suitable for the existence of this crustacean. However, so far none have been investigated, with the exception of the O'Higgins seamount where it has been positively confirmed that this species is present.

Although the Chilean jagged lobster is a potential resource, its presence in relatively cold, deep water would imply a slow growth rate and a low population turnover rate, which is why any attempt to exploit this resource requires the adoption of extreme caution in order to not decrease the stock below a critical size. Hence, biological and fishery research of this resource should be a priority, in order to adopt management measures appropriate for its conservation.

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