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Research Article

Diversification of Chilean aquaculture: the case of the giant barnacle *Austromegabalanus psittacus* (Molina, 1782)

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ABSTRACT. Evidence is presented supporting the technical and economic possibilities of giant barnacle *Austromegabalanus psittacus* (Molina, 1782) culture, one of the main alternatives for diversifying aquaculture in Chile. Spat collection from the wild varied between different sites in the north and south of the country and according to type of artificial collector. Growth also varied between sites (greater in the north), technological systems (greater in tubular systems) and depths (greater at 4 m). Average commercial size in the national market was reached over a period between 18 and 24 months. A long-line can produce between 7 to 10 gross ton during this period, therefore average annual fisheries production can be reached with only 10 to 30 long-lines, in an area of 1 to 3 ha. There is demand for this resource in the external market, particularly in the Japanese market, either as product similar to "fujit subo" (*Balanus rostratus*), or as a new resource; the relationship between production costs and price determines that giant barnacle culture has commercial potential. Economic indicators for cultured giant barnacle were as follows: net present value (*NPV*): US$ 490,000; internal rate of return (*IRR*): 32%; discounted payback period (*DPBP*): 4 years. Results obtained suggest the natural bank repopulation option, and the development of mass cultures. Giant barnacle culture is based on biological characteristics that differentiate it from other crustaceans species**,** as well as simple and economic production technologies and favourable economic projections on external markets.

Keywords: *Austromegabalanus psittacus*, barnacle culture, spat collection, commercial size, aquaculture diversification, Chile.

Diversificación de la acuicultura chilena: el caso del cirripedio gigante *Austromegabalanus psittacus* (Molina, 1782)

RESUMEN. Se presentan evidencias de las posibilidades técnicas y económicas del cultivo del cirripedio gigante o "picoroco", *Austromegabalanus psittacus* (Molina, 1782). Esta especie es una de las principales alternativas para la diversificación de la acuicultura en Chile. La captación de semilla desde el ambiente varió entre distintos sitios del norte y sur del país y según el tipo de colector artificial. El crecimiento también varió entre localidades (mayor en el norte del país), el tipo de sistema (mayor en sistemas tubulares) y profundidad (mayor a 4 m). La talla comercial promedio del mercado nacional se alcanzó entre 18 y 24 meses. Un long-line puede producir entre 7 y 10 ton brutas en ese periodo, por lo que la producción promedio anual por pesquería se puede alcanzar con sólo 10 a 30 long-lines, en un área de 1 a 3 ha. Existe demanda de este recurso en el mercado externo particularmente en el mercado japonés sea como símil del "fujit subo" *(Balanus rostratus*) o como recurso nuevo; las relaciones de costos de producción y precios indican que tienen potencialidades en cultivos comerciales. Los indicadores económicos para el picoroco congelado proveniente de cultivo fueron los siguientes: el valor actualizado neto (*VAN*) es de U$490.000; la tasa interna de retorno (*TIR*) es de 32% y el periodo de recuperación (*PR*) es de cuatro años. Los resultados obtenidos sugieren la opción de repoblamiento de bancos naturales y también para el desarrollo de cultivos masivos. El cultivo del picoroco se basa en características biológicas que lo diferencian de otras especies de crustáceos**,** además de tecnologías de producción sencillas y baratas y sus proyecciones económicas en mercados externos.

Palabras claves: *Austromegabalanus psittacus*, cultivos de cirripedios, captación de semilla, talla comercial, diversificación de la acuicultura, Chile.

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INTRODUCTION

At present, Aquaculture production in Chile exceeds 700,000 ton year^{-1}, most of which corresponds to fish culture (SERNAPESCA, 2009). Around 63% of production concerns introduced species, such as salmonids, abalones, the Japanese oyster and the algae “spirulina”. Twenty-six percent includes various species of native molluscs, such as mytilids, Chilean oysters and the northern scallop. However, they are cultured with technologies developed for similar species in other countries (Navarro & Gutiérrez, 1990). Only around 14% correspond to two species of native algae, cultured with national technologies (Santelices, 1996; Buschmann *et al*., 2001, 2008). Aquaculture diversification is a strategic challenge that must be oriented towards the culture of native species, given that dozens of these commercially interesting species are exploited exclusively by fisheries (López *et al*., 2008a). Apart from the reduced environmental impact associated with native species, as compared to that of introduced species, conservation is an additional benefit, given that several of these resources are overexploited. The principal restrictions to the culture of native species are: insufficient biological knowledge, scarce technological development and erroneous research priorities oriented towards generating commercial cultures (López *et al*., 2006).

Included among the various species with varying levels of progress relative to their commercial culture (López *et al*., 2006, 2008a), is the giant barnacle *Austromegabalanus psittacus* (Molina, 1782) commonly referred to (vernacular name) as “picoroco”. This barnacle is distributed along the entire Chilean coastline, from southern Peru to southern Argentina (Nillson-Cantell, 1957; Young, 2000, López *et al*., 2007a). It is a traditional resource for small-scale, local fishing activities namely aimed, to the national market. Annual extractions have to decreased progressively fluctuating between 685 and 159 ton year^{-1} over the last 10 years (SERNAPESCA, 2009). Although it has not been proven, this suggests overexploitation of natural populations. The extraction of this resource by artisanal fisheries is not subjected to any type of specific regulation. This giant barnacle is a crustacean with comparative culture advantages over shrimps, prawns or lobsters. The greatest difficulties encountered in crustacean cultures are associated with their mobility, territoriality, high trophic level (carnivores) and low fecundities (Shiau, 1998; Borisov *et al*., 2007). In contrast to these resources, the giant barnacle is a sessile, gregarious, omnivorous species, with high fecundity and early sexual maturity (López *et al*., 2005, 2010). Its gregarious condition does not generate density-dependent effects during growth (López *et al*., 2007b) and it has high resistance to environmental factors (López *et al*., 2003; López & López, 2005). This facilitates its culture options, its manipulation and even live transport. Negative aspects that can be generated by mass culture are associated with processes such as the local accumulation of organic material and egg and larvae filtration, among other factors that can occur in cultures of native species (Camus, 2005). On a world scale, there are around a dozen commercially interesting barnacle species; nevertheless, none of them are cultured on an industrial scale (López *et al.*, 2010). Despite these biological and technical advantages, the development of industrial scale culture of this species also depends on its commercial and financial feasibility. Therefore, it is essential to evaluate the economic attractiveness of giant barnacle aquaculture. Recent research based on empirical data has shown that this species is economically feasible as a product exportable to the Japanese market (Bedecarratz *et al*., 2011).

The main purpose of this study is to provide options for aquaculture diversification in Chile based on the giant barnacle culture. The scientific, technological and economic progress achieved to date in the experimental and semi-industrial cultures is presented. Results include spat collection from the wild based on the settlement of competent larvae on artificial substrates (collectors), as well as information on growth. Similarly, the economic projections of industrial-scale production destined for export are also analyzed in general terms.

MATERIALS AND METHODS

Evaluation of factors that have the potential to influence spat collection from the wild and growth

The effect of culture site, substrate type and depth on spat collection from the wild and on growth was evaluated. Cultures were undertaken between October 2009 and July 2010, in three sites along the Chilean coastline, North Totoralillo (29°29'S, 71°29'W), Tongoy Bay (30°36'S, 71°37'W) and Metri Bay (41°36'S, 72°42'W) the former two are located in the northern zone and the latter in the south of the country (Fig. 1). North Totoralillo is a semi-exposed bay facing SW, it reaches depths of 35 m. Surface water temperature in autumn-winter fluctuates between 13°C and 16°C, while in spring-summer it is between 15°C and 18°C. Tongoy Bay is a protected bay, open to the north. Surface water temperature remains stable in autumn-winter at around 13°C. It increases in spring-summer between 14°C and 17°C. Average depth is 25 m. Tongoy Bay is located approximately 90 km (direct route) to the south of the previous site. Metri Bay is a wave-protected area with high tidal variations, averaging 7 m. Water temperature varies between 8°C and 13°C in autumn-winter and between 12°C to 17°C in spring-summer. The environmental differences between the northern and southern areas of the country are reflected in the period of low temperatures, which is more prolonged in Metri Bay than in Tongoy Bay and North Totoralillo. Surface water temperatures were measured periodically to 0.1°C accuracy.

In order to determine and evaluate spat collection from the wild, giant barnacle spat collectors were installed in the month of October 2009, initially using existing competent larvae (cyprid) in each site. The giant barnacle cyprid measures approximately 0.9 mm. *A. psittacus* colonization has been recorded over different submerged substrates in the three sites. Three types of artificial substrates were used: high density polyethylene tubes, arranged vertically: height, 100 cm diameter, 10 cm and thickness 0.5 cm; rectangular plates arranged lengthwise: 70x10x0.3 cm thick; "bidín" plates coated in tar and fixed to a rigid 70x60 cm frame. Each collector system consisted of three units, joined by polypropylene ropes suspended from a double long-line of 100 m length, at depths of 4, 5 and 6 m (Fig. 2). A total of 100 collector systems with 300 units were suspended from each long-line. The materials selected to construct the collectors are innocuous. High density polypropylene is a very versatile polymer, given that it can be used as a collector during various seasons; it is black and was texturized to take advantage of the rugophilic behaviour of the competent larvae. The "bidin" is a polyester textile, 1.7 mm thick, with 0.4 cm s^{-1} permeability. To increase its water resistance, it was treated with tar, a petrol-derived asphitic impermeabilizer. The "bidin" has a tar retention capacity of 1.5 L m^{-2}. The polyethylene collectors does not allow

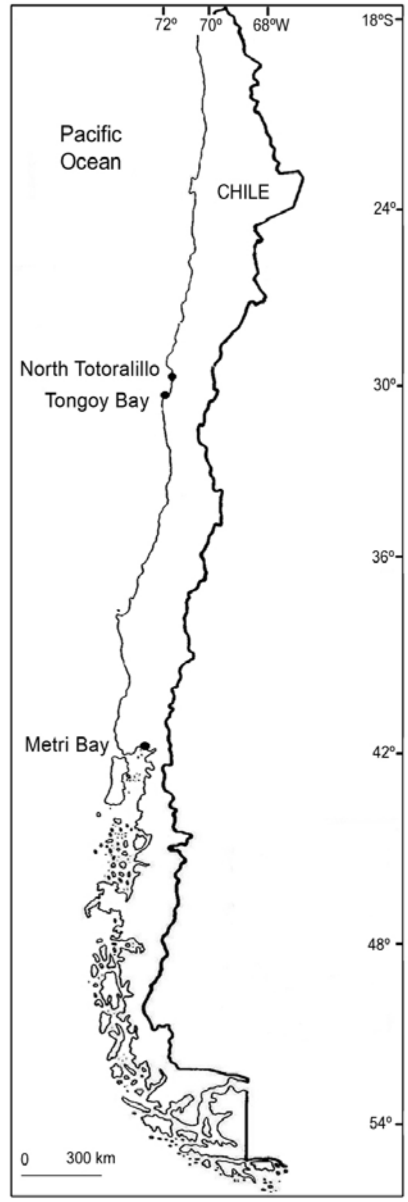

Figure 1. Geographic location of the study sites.

Figura 1. Localización geográfica de los lugares estudiados.

the detachment of spat without damaging them, as a result of which specimens must grow in the same substrate where they settle. On the other hand, in the "bidin" collectors, spat can be detached and transferred to a growth system. The tubular and plate collectors differ with regard to the surface/volume relationship.

After a period of 9 months, in July 2010, density of specimens recruited in the collectors was evaluated; a random sampling of 8 systems of each type of collector was carried out, taken from those located

Figure 2. Technological systems used in giant barnacle cultures. Tubular system.

Figura 2. Sistemas tecnológicos empleados para el cultivo de "picoroco". Sistema tubular.

at a depth of between 4 and 6 m. Number of specimens per collector was measured and expressed as density (number of individuals cm^{-2}). To calculate density in the tubular systems, the external area of each tube (3,142 cm^2) was considered, while in the plates, the area of each face was evaluated (4,200 cm^2).

Random samples of 100 specimens were taken from each type of artificial substrate to evaluate growth during this period and the carino-rostral length (mm) of specimens was measured; this corresponds to the maximum distance between the carino-rostral plate and it is a density-independent measurement of age (López *et al*., 2007b). The measurements were taken using a vernier to 0.001 cm accuracy. Similarly, mortality was measured based on a sample of collectors, where number of loose or dead specimens that remained attached to the substrate was recorded.

Statistical analysis

Data on spat collection density and specimen size were transformed through log10 and subsequently subjected to three-way variance analysis, considering: a) site, b) substrate type, and c) depth, as fixed factors. Normality and homoscedasticity of data was analyzed using the Kolmogorov-Smirnov and Levene tests, respectively. If significant differences were found, an *a posteriori* Tukey test (Zar, 2009) was performed. All analyses were carried out using the 8.0 STATISTICA statistical package (Statsoft, 2007).

Determination of the period required to reach commercial size and production levels

Average commercial size of the giant barnacle on the national market was determined, using samplings taken from local fish markets in southern Chile during 2007. The descriptive values (average, standard deviation and range) of the carino-rostral length and carinal height were established in a sample of 100 specimens.

In order to determine the period required by recently settled specimens to reach a commercial size, growth was evaluated up to reaching the average value. To this end, 20 tubular collector systems, consisting of three units of polyethylene tubes, height 100 cm, diameter 10 cm, were placed at depths of between 4 m and 6 m, suspended from a 100 m double long-line in Metri Bay (41°36'S, 72°42'W), from September 2006. Five collector systems were sampled bimonthly, at random, over a period of 20 months. On each occasion, the carino-rostral length of 100 individuals was measured, and the total period over which 50% of the individuals reached the reference commercial size was established. The weight of the specimens of approximately 35 mm carino-rostral length was determined, using a 0.01 g precision balance. Total wet weight and weight of the soft parts was determined in each specimen.

In order to evaluate biomass production of cultures in suspended systems, projections based on empirical information were obtained from semi-intensive cultures in the locality of Metri Bay (41°36'S, 72°42'W), between 2006 and 2008. Density values of spat collection and mortality correspond to the most frequent values observed in the collector systems, which consisted of three units of tubular collectors, 100 cm height and 10 cm diameter, suspended between 4 and 6 m. Weight corresponds to the average total biomass value of a commercial-sized specimen on the national market (35 mm carino-rostral length); yield is equivalent to the percentage of weight of soft parts in relation to total specimen weight. Quantity of long-line collector systems corresponds to the maximum number of collectors on a 100 m, double floating line, each line being separated by 2 m.

Economic analysis

In order to support the potential development of a giant barnacle industry in Chile, an economic evaluation of aquaculture of this resource was undertaken in an hypothetical culture system in southern Chile. A maximum annual production capacity of around 420 gross ton (including the shell) was considered, which represents an industrial-scale culture for the export market. Although this species could be commercialized in different formats and markets, this economic evaluation considers that total production is destined to the Asian market, in a frozen meat format, including opercular plates. The market price of this product was based on an evaluation of the Japanese market, undertaken during a business trip to Japan in April 2008. In this occasion, meetings were held with companies from the Aomori Prefecture that currently commercially produce “mine fujit subo”, *Balanus rostratus*, a similar species to the giant barnacle (López *et al*., 2010).

Based on technical and economic findings, annual cash flows were budgeted (Sapag & Sapag, 2000) in US$ for a 7-year planning horizon and economic profitability measures -net present value (*NPV*), internal rate of return (*IRR*) and discounted payback period (*DPBP*)- were estimated. Detailed information on each can be found in Barry *et al*. (1995) and the Asian Development Bank (1997, 2002). The principal baseline assumptions for the present economic evaluation are described on Table 1. They correspond to empirical data obtained from the three culture sites. The relative costs of supplies and processes are calculated on the basis of empirical data, according to Bedecarratz *et al*. (2011).

RESULTS

Statistically significant differences between sites were shown in the densities of *A. psittacus* spat collected from the wild, with greater densities observed in North Totoralillo than in Tongoy Bay and Metri Bay (F = 56.2; df = 2; n = 102; P < 0.001). In Metri Bay spat densities were greater in tubular and “bidin” collectors than in plates (F = 13.2; df = 2; n = 102; P < 0.001); in the other sites there were no differences between substrates. No variations in spat collection between depths were reported (F = 0.007; df = 1; n = 102; P = 0.932) (Tables 2 and 3).

The carino-rostral length of specimens differed between sites, being greater in North Totoralillo (22.9 ± 3.9 mm) and smaller in Metri Bay (15.5 ± 3.7 mm) (F = 902.4; df = 2; n = 1782; P < 0.001). Similarly, differences were observed between sizes according to substrate type. Thus, specimen sizes were largest in tubular collectors, followed by plate collectors, while the smallest individuals were found in the “bidín” collectors (F = 97.2; df = 2; n = 1782; P < 0.001). Furthermore, variations in size were also observed according to depth, with larger sizes at 4 m than at 6 m (F = 9.7; df = 1; n = 1782; P < 0.001) (Tables 2 and 3).

The average commercial size of specimens from local fish markets was 35.9 ± 6.3 mm carino-rostral length, commercialized from a minimum size of 21 mm carino-rostral length; the maximum size recorded in a sample was 50 mm. Average carinal height of specimens was 100 ± 16.5 mm. The minimum was 67 mm and the maximum 140 mm.

In suspended systems, specimens that settled in spring 2006, from October onwards, reached the average commercial size after a period of 20 months. If the minimum commercialization size of individuals is considered (21 mm carino-rostral length), the period is reduced to 7 months following larval settlement. The reference values of biological and technological variables obtained empirically are indicated in Table 4.

Harvest can be undertaken between 18-24 months, depending on the season the collectors were placed in the water. Each tubular collector can produce on the average 15 ± 8 kg of *A. psittacus* biomass, equivalent, on the average, to 100 individuals of a commercial size, with a yield of 20-30 g per individual, depending on the maturity of the female gonad. Considering the dimensions of a floating line, each line can produce between 7 and 10 gross ton of total biomass that can signify approximately 2 ton wet weight of soft parts.

Evidence indicates that giant barnacle production in a frozen meat format destined to the Japanese market is economically attractive. The costs are indicated in Table 1. Capital investments, which include principally maritime concessions, marine culture systems, buildings and equipment, total US$886 thousand. The relative costs of each variable are outlined in Table 5. The cost in Chile per individual is US$0.24 at maximum size (150 g) and US$0.10 for average commercial size. Projected income would be perceived from the second year, remaining constant at US$924 thousand for this production scale and generating a net utility of US$360 thousand. Considering all the relevant inflows and outflows, projected cash flows should be negative during the first two years, but it would reach US$479 thousand from the beginning of the commercialization cycle to the end of the productive horizon. These economic results generate a positive net present value

Table 1. Reference values for economic evaluation and their sources.
Tabla 1. Valores referenciales para la evaluación económica y sus fuentes.

Variable	Value	Source
Number of collectors/long-line	140	Empirical results extrapolated
Average spat density (Nº/collector)	79,178	Empirical results extrapolated
Months to harvest	20	Empirical results
Number of long-lines harvested/year	45	Productive scale evaluated
Mortality to harvest (%)	20	Empirical results
Gross annual production (number of individuals)	2,850,422	Empirical results extrapolated
Gross production volume/year (ton)	428	Empirical results extrapolated
Processing loss (%)	10	Empirical results
Yield of processed product (%)	14	Empirical results
Net production volume/year (ton)	77	Empirical results extrapolated
Sale price (USD FOB/kg)	12	Analysis of Japanese market
Exchange rate CLP/USD	547.19	01.07.2010 Central Bank of Chile
Corporate tax rate (% of earnings)	17	Chilean legislation
Annual discount rate (%)	19.6	Zúñiga & Soria (2009)

(*NPV)* at a 19.6% discount rate of US$416,000 and an internal return rate (*IRR*) of 32%; thus, the project is economically attractive. Despite this, important capital requirement must be considered when entering this business, because analysis of cumulative discounted cash flow indicates that the discounted payback period (*DPBP)* for this product is 4 years.

DISCUSSION

Giant barnacle culture in Chile not only presents options for diversification of the national Aquaculture in Chile. In the world, only two similar species have a commercial value: in the case of *Megabalanus azoricus* ("craca"), spat collection trials from the wild have been carried out with limited success (Pham *et al*., 2008); in the case of *Balanus rostratus* ("fujit subo"), a species commercialized in the internal Japanese market, there are no culture experiences and demand is satisfied entirely through fisheries extraction (López *et al*., 2010).

The results indicate that commercial culture of the giant barnacle is technically feasible. Collection levels of spat from the wild allows a production of between 7 and 10 ton on a 100 m long-line. Based on this data, it would be possible to equal the average gross production obtained from small-scale, local fishing activities, with only 10 to 30 long-lines. When collection and growth are at a maximum, it is possible that the weight of the systems may make it necessary to transfer a fraction of the growth systems to a new long-line, in order to avoid overloading and the subsequent loss of buoyancy. Even if the number of systems had to be argumented as growth progresses and weight increases, this would only require an area of 1 to 3 ha, which would not imply spatial restrictions for the mass production of this species in suspended cultures. Furthermore, the results show that spat collection from the wild is feasible in different sites; although the quantity of spat can vary in each site, all levels of spat obtained are compatible with those required by commercial cultures. Similarly, growth is rapid and the commercial size required in the domestic market can be reached in 18 to 20 months from larval settlement. This is possible because market demand is for smaller sizes, as occurs in the Japanese market, where the commercial size of the "fujit subo" (5 cm height) can be reached over a period of 6-10 months from larval settlement; or, alternatively, because the product is commercialized as a frozen or tinned product, and, as such, does not require a defined harvest size. Giant barnacle culture is also economically feasible. Projected cash flows and economic indicators *(NPV* and *IRR)* for an industrial culture system in southern Chile destined to produce giant barnacle in a frozen meat format for the Asian market, are attractive.

The options for achieving successful commercial giant barnacle cultures are based on favourable biological characteristics, such as: sessile adult state; availability of competent larvae in the environment;

Table 2. Average values ± SD collection density and size of giant barnacle specimens according to culture site, production system and depth. Comparisons between culture sites with *P* values according to ANOVA analysis and *a posteriori* Tukey test.

Tabla 2. Valores promedio ± 1DE de densidad de captación y talla de los ejemplares de "picorocos" según sitio de cultivo, sistema de producción y profundidad. Comparaciones entre sitios de cultivo con valores de *P* según análisis de ANOVA y prueba *a posteriori* de Tukey.

	Site			Culture system			Depth	
Variable	Metri Bay	North Totoralillo	Tongoy Bay	Tubular	"Bidin"	Plates	4 m	6 m
Density (individuals cm^{-2})	0.032 ± 0.023	0.085 ± 0.028	0.043 ± 0.028	0.063 ± 0.037	0.054 ± 0.029	0.039 ± 0.032	0.052 ± 0.053	0.035 ± 0.033
Size of the specimens (carino-rostral length in mm)	15.54 ± 3.67	22.93 ± 3.99	22.23 ± 3.35	21.52 ± 4.32	19.33 ± 4.96	19.85 ± 5.29	20.48 ± 4.29	19.99 ± 4.99

Comparisons	$P < 0.001$			$P < 0.001$			$P = 0.932$	
Density (individuals cm^{-2})	a	b	a	a	a	b	a	a
	$P < 0.001$			$P < 0.001$			$P < 0.001$	
Size of the specimens (carino-rostral length in mm)	a	b	c	a	b	c	a	b

Table 3. Average values ± 1SD collection density and size of giant barnacle specimens according to culture site, production system and depth during the three culture periods (month 3, 7 and 9).

Tabla 3. Valores promedio ± 1DE de densidad de captación y talla de los ejemplares de "picoroco" por sitio de cultivo, según sistema de producción y profundidad durante tres periodos de cultivo (mes 3, 7 y 9).

A. North Totoralillo

Factor		Variable					
		Density (individuals cm^{-2})			Size (carino-rostral length in mm)		
Substrate	Depth (m)	Month 3	Month 7	Month 9	Month 3	Month 7	Month 9
Tubular	4	0.311 ± 0.120	0.100 ± 0.030	0.116 ± 0.009	11.70 ± 2.75	20.30 ± 1.80	21.58 ± 3.78
	6	0.387 ± 0.153	0.090 ± 0.050	0.090 ± 0.042	11.40 ± 2.70	20.20 ± 3.40	23.23 ± 3.87
Plate	4	0.457 ± 0.240	0.180 ± 0.030	0.075 ± 0.012	11.80 ± 2.30	23.10 ± 2.70	24.47 ± 4.17
	6	0.430 ± 0.250	0.160 ± 0.088	0.078 ± 0.022	11.90 ± 1.70	23.60 ± 2.80	24.85 ± 3.70
"Bidin"	4	0.682 ± 0.310	0.170 ± 0.050	0.076 ± 0.017	11.80 ± 3.20	21.60 ± 1.70	22.78 ± 3.00
	6	0.340 ± 0.154	0.110 ± 0.096	0.075 ± 0.033	9.00 ± 2.40	19.10 ± 1.70	20.70 ± 3.73

B. Tongoy Bay

Factor		Variable					
		Density (individuals cm^{-2})			Size (carino-rostral length in mm)		
Substrate	Depth (m)	Month 3	Month 7	Month 9	Month 3	Month 7	Month 9
Tubular	4	0.020 ± 0.030	0.010 ± 0.005	0.022 ± 0.015	11.70 ± 3.11	23.20 ± 4.73	24.20 ± 2.94
	6	0.097 ± 0.036	0.072 ± 0.030	0.060 ± 0.021	12.10 ± 2.50	20.50 ± 2.70	23.87 ± 3.00
Plate	4	0.056 ± 0.036	0.100 ± 0.030	0.026 ± 0.032	10.50 ± 2.40	19.00 ± 2.30	20.87 ± 3.29
	6	0.150 ± 0.034	0.100 ± 0.030	0.036 ± 0.016	11.30 ± 2.30	19.70 ± 2.40	20.48 ± 2.24
“Bidin”	4	0.359 ± 0.081	0.180 ± 0.033	0.068 ± 0.021	11.70 ± 2.70	20.60 ± 15.20	22.60 ± 3.73
	6	0.400 ± 0.171	0.050 ± 0.035	0.044 ± 0.032	10.90 ± 4.40	17.10 ± 2.40	21.37 ± 2.83

C. Metri Bay

Factor		Variable					
		Density (individuals cm^{-2})			Size (carino-rostral length in mm)		
Substrate	Depth (m)	Month 3	Month 7	Month 9	Month 3	Month 7	Month 9
Tubular	4	0.008 ± 0.003	0.099 ± 0.017	0.048 ± 0.012	4.50 ± 2.10	13.90 ± 3.70	18.56 ± 3.21
	6	0.011 ± 0.005	0.202 ± 0.016	0.061 ± 0.025	4.00 ± 1.70	13.10 ± 3.30	17.71 ± 4.03
Plate	4	0.012 ± 0.006	0.080 ± 0.030	0.013 ± 0.007	3.70 ± 1.80	11.80 ± 7.60	14.29 ± 2.41
	6	0.011 ± 0.007	0.098 ± 0.042	0.011 ± 0.007	3.60 ± 1.20	10,80 ± 2.30	14.18 ± 2.22
“Bidin”	4	0.015 ± 0.006	0.289 ± 0.162	0.034 ± 0.020	3.80 ± 1.90	12.40 ± 3.30	14.99 ± 3.91
	6	0.011 ± 0.007	0.240 ± 0.047	0.028 ± 0.012	3.30 ± 1.20	8.30 ± 2.00	13.54 ± 2.69

Table 4. Reference values for the biological and technological variables of *A. psittacus* culture.
Tabla 4. Valores referenciales de variables biológicas y tecnológicas del cultivo de *A. psittacus.*

Variable	Reference value
Spat collection density (Nº of individuals cm^{-2})	0.06
Tubular collector area (cm^2)	3,142
Average size at harvest (mm carino-rostral length)	35
Specimen weight at harvest (g)	150
Yield (%)	14-20
Mortality (%)	20
Number of collector systems per long-line (100 m)	100

Table 5. Estimated cost in US$ for a giant barnacle cultures (420 gross ton).
Tabla 5. Costos estimados en US$ para cultivos de "picoroco" (420 ton brutas).

Main cost sources	US$	%	Component
Capital investment	462,000	42.47	Production technologies = 66.9% Others (land, maritime concession; building, light truck, equipment, other supplies, setup cost) = 33.1%
Operation cost	626,000	57.53	Labor = 40.9% Others (maintenance productive systems, harvest, post-harvest, transport, other operational cost, processing and packing) = 59.1%
Total	1,088,000	100.00	-------------

wide range of substrates colonized; omnivorous characteristics; gregarious larval settlement behaviour, without density-dependent effects on growth and reproduction and finally, rapid growth (López *et al*., 2007b, 2010). These characteristics allow the development of simple, low cost production technologies, both for obtaining spat and for growth, where personnel and packing are the principal outflows.

Giant barnacle culture strategy is similar to that successfully developed for the culture of the mussel, *Mytilus chilensis* (Hupé) "chorito", in Chile (Buschmann *et al*., 1996; López *et al*., 2008a). The spat supply is obtained using competent larvae from metapopulations present in the water column and offering them suitable artificial substrates. Knowledge gathered on the behaviour of the pediveliger during settlement (Toro *et al*., 2004, 2008) is taken into consideration for spat collection technologies. The collection period is seasonal, similar to the case of the mussel, and occurs from the end of spring through to early summer; a second period where quantity of competent larvae in the water increases, occurs in autumn. Subsequently, specimens are transferred to a growth system suspended from long-lines or rafts; due to their filtering condition, feeding of this species also originates from the seston available in the environment. In the case of the giant barnacle, either the same strategy can be used, or spat can be maintained in the same substrate up to harvest. This will depend on the type of final product required. Different systems for larval settlement and growth must be used when it is necessary to obtain individuals that do not form groups.

It is important to notice that, as opposed to the mussel *Mytilus chilensis*, having similar culture conditions, the giant barnacle "picoroco" could enter the international market as a substitute for other premium aquaculture products such as lobsters and shrimps, given its meat characteristics. Due to its quality, the value of giant barnacle meat on the external market, like that of other crustaceans, is high, even exceeding other luxury products (PROCHILE, 2006, 2007; Bedecarratz *et al*., 2011). This would mean higher sale prices and improved economic results. Even other product formats, such as canned meat or fresh "picoroco", which have been experimentally elaborated and exported, could achieve better sale prices and profitability levels. (Bedecarratz *et al*., 2011). The unitary cost is compatible with commercial cultures.

Giant barnacle culture also incorporates existing biological knowledge on this species, applied to culture development. Information is available with regard to reproduction (López & Toledo, 1979); physiological capacities (López *et al*., 2003, Simpfendörfer *et al*., 2005, 2006); effects of environmental factors on growth and survival (López & López, 2005; López *et al*., 2008b) and on growth (López *et al*., 2007b).

Results obtained indicate that appropriate technology is available, with simple and economical designs. The polypropylene tubular systems were more efficient for collection and growth than the plates, which can be associated with the collector surface – water column relationship. Both spat collection and growth were greater in the north, particularly in one site, North Totoralillo. This indicates that a complex group of environmental factors may influence spat collection (Andrade *et al*., 2011). Further growth could be interpreted as the result of the higher water temperature. Nevertheless, previous information reveals greater growth at a temperature of 10°C than at 16°C (López *et al*., 2008), although these determinations were taken under controlled conditions. Increased water temperature tends to increase the growth of marine invertebrates; however, this depends on the energetic costs of metabolism (Newell, 1979). The study of López *et al*. (2008), showed greater growth at 4-6 m depth than at 1-2 m, associated with illumination and lower temperature.

Giant barnacle culture on a commercial scale is an important alternative for diversifying national Aquaculture. Empirical culture results and economic projections currently available should encourage the development of a new aquaculture activity based on "picoroco" culture and exportation. The next step is to analyze the principal risks or restrictions on the regulatory uncertainty and to develop hatchery technologies as an alternative to spat storage. Parallel to this, alternative product formats are being tested on different markets, to minimize potential fluctuations in sale price and economic projections. Production records in Chilean Aquaculture establish that exotic species correspond to 58.9% of the total species and to 62.3% of the harvest. Environmental effects provoked by the culture of exotic species have been documented in the case of salmonids, in different areas (Soto *et al*., 2001, 2006; Gajardo & Laikre, 2003; Arismendi *et al*., 2009; Buschmann *et al*., 2009). Although cultures of native species are not environmentally innocuous (Camus, 2005), the effects are less harmful than those associated with exotic species, especially, when, as in the case of the giant barnacle, neither exogenous feeding, antibiotics or other chemical substances are used. Alternatively, giant barnacle culture can also contribute to repopulating natural populations. Although at present there is no information about overexploitation of giant barnacle populations, periodic changes in the extraction zone due to small-scale fishing activities along the Chilean coastline, suggest limitations for the exploitation of natural stocks. From 1979 to 1983, the southern zone produced around 80% of the national giant barnacle extraction. From 1985, it was replaced by the central zone; however, since 1987 extraction in this zone decreased, and was replaced, in turn, by landings in the northern zone. From 1991 until 1999, participation in extraction activities was higher in the central zone, with a participation of less than 10% in the southern zone; however, the southern zone subsequently again reached between 80% and 90% of the national production, falling once again from 2003 onwards. At present, no bans or extraction restrictions have been imposed. As a result of progress made with cultures, it has been established that the most important breeding period occurs during spring-summer. This is when the greatest potential risks to natural populations occur, given that environmental conditions facilitate the extraction of specimens incubating the entire embryonic development up to the first larval stage.

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