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Production, use and fate of Chilean brown seaweeds: re-sources for a sustainable fishery

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Abstract Chile is an important producer of brown seaweeds representing 10% of world supply. Landings of Chilean kelp fluctuated between 40,000 t.year^{-1} in the early ‘80s to 250,000 t.year^{-1} more recently. Commercialized algae come from natural populations and no mass-cultures of involved species have been established. Four species of brown algae are commercially collected in the country: *Lessonia trabeculata*, *L. nigrescens*, *Macrocystis pyrifera* and *M. integrifolia*. Since 2000, the demand of alginate sources and food for cultivated abalones dramatically raised the harvesting of these species. Direct evaluations of *Lessonia* spp. and *Macrocystis* standing-stocks were made along 700 km of coast in northern Chile. *Lessonia* spp. estimated populations exceed 900,000 t, whereas *M. integrifolia* does not exceed 300 t. The insights provided indicate that sustainability of Chilean kelp subjected to intense harvesting would require management programs including the following bio-ecological recommendations: (1) to harvest the entire plant including the holdfast; (2) to harvest plants larger than 20 cm in diameter; (3) to harvest plants sparsely, selecting mayor specimens; (4) rotation of harvesting areas; and (5) for *Macrocystis*, to cut the canopy 1–2 m from the surface. They must be implemented in a National Program of Kelp Management, elaborated by government, scientists, fisherman, and industry.

Keywords Kelp · Chile · *Lessonia* · *Macrocystis* · Abalone

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Introduction

Giant kelps dominate shallow, subtidal rocky-bottom areas in temperate and cold seas to a depth of ca. 40 m (Dayton et al. 1984; Harrold and Pearse 1987; Vásquez 1992; Graham et al. 2007). Many kelp species have economic and social impacts since many local human populations base their economic support on these resources (Shiel and Nelson 1990; Vásquez and Fonck 1993; Stekoll et al. 2006; Rothman et al. 2006; Ugarte et al. 2006). Geographic and local distribution of diverse kelp species in the southeast Pacific is variable: *Lessonia nigrescens* Bory forms intertidal belts along exposed rocky coasts; *Lessonia trabeculata* Villouta & Santelices dominates rocky subtidal environments to a depth of ca. 40 m; *Macrocystis integrifolia* Bory forms shallow kelp beds from the intertidal zone to ca. 15 m in northern latitudes, and is gradually replaced by two species towards southern areas: *Durvillaea antarctica*, which dominates the intertidal zone in wave-exposed areas (Hoffmann and Santelices 1997); and *Macrocystis pyrifera* (Linnaeus) Agardh in both exposed and protected subtidal habitats (Buschmann et al. 2004). While the two mentioned *Lessonia* species have almost continuous distribution along the entire Chilean continental coast, the distribution of *M. integrifolia* is fragmented into patchy populations in northern Chile (Vega et al. 2005), while *M. pyrifera* forms coastal belts from 42°S to Cape Horn, including the fjord zone and the Atlantic coast up to Chubut area, in Argentina. The extension of local populations of *M. pyrifera* from north to south, may vary from 100 m to 100 km. The observed distribution patterns are the result of complex life history strategies and interactions with environmental factors such as spatial and temporal variations in water movement, nutrient availability, and temperature (Muñoz et al. 2004; Vega et al. 2005; Graham et al. 2007).

Lessonia species are dominant organisms in coastal communities, both in cover and biomass, being the foundation species (sensu Dayton 1972) in the intertidal and shallow subtidal rocky bottom. Several invertebrate and fishes, some of which are of economic interest, use *Lessonia* kelps as habitat, food supply, and area for recruitment (Vásquez 1992; Vásquez et al. 2001), so management of these brown seaweeds is also relevant to conservation of many other coastal fisheries.

In Chile, brown algae, especially those collected on the beaches as result of natural mortality, have been used since the 1960s as raw material for alginic acid extraction, with 90% of this productive activity, which occurs exclusively in Northern Chile between 26° and 32°S (Anuario SERNAPESCA 1985–2006), supported by both *Lessonia* species. Plants which have been cast ashore are collected by fishermen, dried, bundled and then sold to intermediaries who sell them to the grinding industry. This fishery is currently not regulated since landings are mainly composed of dead plants. Since 1998, extensive harvesting of intertidal and subtidal populations of *Lessonia* spp. in northern Chile, has put fishery authorities, as well as fishermen, industry and scientists, on alert.

This article presents the most relevant information regarding distribution, abundance, productivity, destination and predicted use of commercially important brown algae from Northern Chile. This information brings together all elements needed for planning their sustainable management.

Materials and methods

Since 2004, bio-ecological studies of production and analyses of the socioeconomic aspects of brown algae fisheries in northern Chile have been developed. Their common goals were to elaborate recommendations for organize, and make more efficient, the administration and management of this activity. This study analyzes the availability of biomass from natural populations (2004–2005), the chain of production (2005–2006), and some socioeconomic aspects of this fishery (2004–2006). The study area includes the entire geographical region of this fishery, between 18° and 32°S. Considering that the majority of collection and harvesting, as well as use and destination, occur between 26°–32°S, most of the information comes from this sub-sector of the Chilean coast (Fig. 1).

Collection and harvesting statistics

All data regarding brown algae landings (wet and dry) were obtained from the National Fishery Service, which depends on the Ministry of Economy http://www.sernapesca.cl); data related to exportation of brown algae (US$ and tons) as algae meal, for alginate extraction, were obtained from the Central Bank of Chile http://www.bancocentralchile.cl).

Distribution and abundance of brown algae

From 2004 to 2005, the distribution (latitudinal and bathymetric) and abundance of *Lessonia trabeculata*, *L. nigrescens* and *Macrocystis integrifolia* were determined along approximately 700 km of coast between 26° and 32°S. In this area, 140 sampling stations were established (Fig. 1), separated by 4.5 linear km, excluding a priori sandy beaches and soft bottom (subtidal) areas.

The basal diameters of the plants' holdfasts were measured in situ, since a significant correlation exists between this dimension and the weight and size of the plants in all three species (Cancino and Santelices 1984; Vásquez and Santelices 1984; Villouta and Santelices 1984, 1986; Vásquez 1992, 1993). Density of plants and type of available substrate were also determined. All evaluations were non-destructive.

Lessonia trabeculata: distribution and abundance of this species was evaluated using 160-m transects, perpendicular to the coastline and located between the intertidal zone and 20-m depth, according the methodology described by Vásquez et al. (2006).

Lessonia nigrescens: distribution and abundance of this species was determined using 10 m^2 (10×1 m) quadrants. Morphological attributes of adult sporophytes (holdfast diameter, length, number of stipes and presence of reproductive structures), were evaluated using 1-m^2 quadrants.

Macrocystis integrifolia: since the fragmented distribution of *M. integrifolia*, 0.25 m^2 quadrants were randomly thrown within each algae bed (see Vega et al. 2005). When *Macrocystis* extended into the subtidal zone, sampling was done in layers by positioning four 0.25 m^2 quadrants in different depth ranges (0–2, 2–4, 4–6 >6 m). The limits of each population were georeferenced (GPS-GARMIN 12 Channels) to estimate the total abundance of each bed.

In each sampling area (10 m^2 for *L. trabeculata*, 1 m^2 for *L. nigrescens*, and 0.25 m^2 for *M. integrifolia*) three aspects were evaluated: (1) total number of plants, (2) basal diameter of holdfast, and (3) substrate type. Each sampling area was georeferenced.

Biomass estimation using GIS

The data obtained in the field for each population, and regarding their abundance and distribution, were incorporated into the Geographical Information System (GIS,

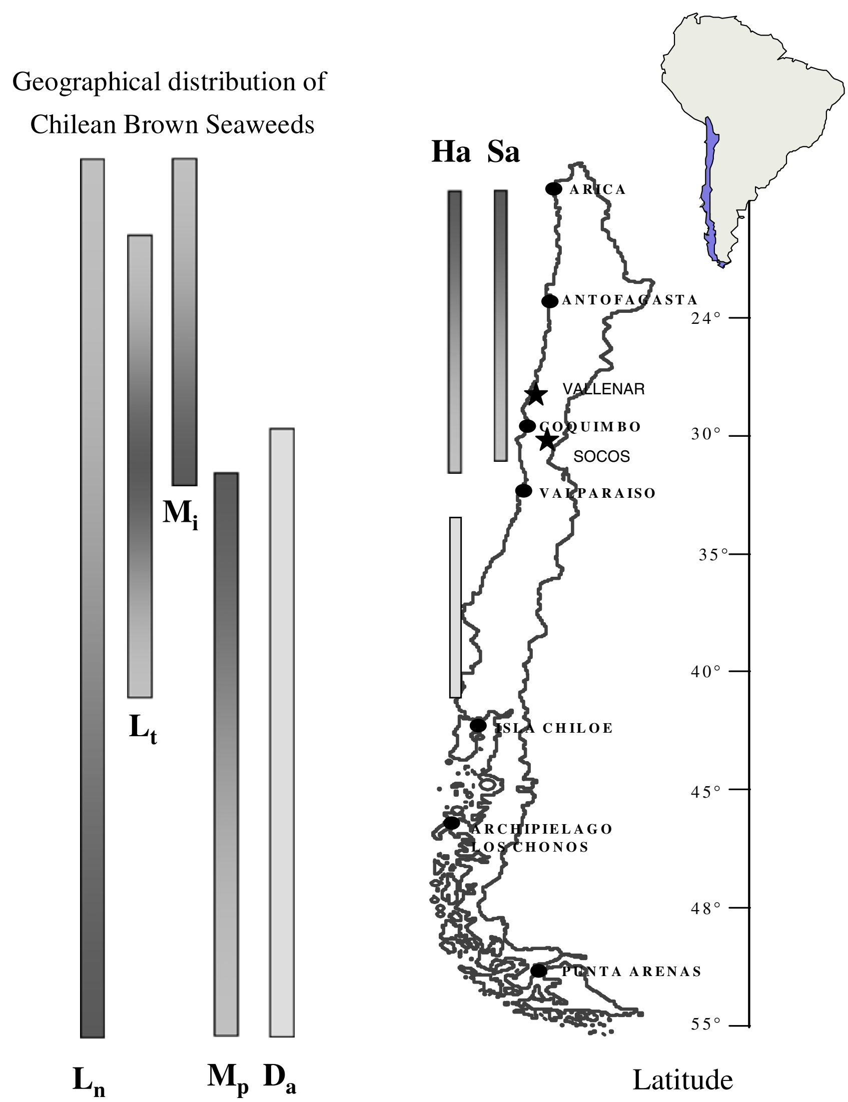


Fig. 1 Geographical distribution of brown seaweed of economic interest in Chile, including the study area of its fishery. L_t *Lessonia trabeculata*, L_n *Lessonia nigrescens*, M_I *Macrocystis integrifolia*, M_p *Macrocystis pyrifera*, D_a *Durvillaea antárctica*, H_a Study area, S_a Sampling area

ArcView and ArcGIS®). The coordinates of each sampling station and transect were acquired in sextadecimal format (degrees, minutes and seconds) from the Provisional South American spatial reference Datum from 1956 (Psad56).

The geostatistical analysis in the ArcGIS program generated variograms within and between sampled transects (Burrough and McDonnell 1998), and allowed construction of abundance polygons between transects (Klopatek and Francis 1999). An average distribution 160-m width was determined for *L. trabeculata* in agreement with Vásquez (1992) and Vásquez et al. (2006). A 2.5-m-wide belt in the intertidal zone was estimated for *L. nigrescens* (Santelices 1989). The abundance of *M. integrifolia* in each section of the coast was obtained by extrapolating the abundance values determined with quadrants along the depth gradient within the kelp forest (Vega et al. 2005). Standing stock of the three brown algae species was calculated as the sum of the abundance polygons from the entire study area.

Use and destination

The destination of extracted and collected brown algae from the study area was determined directly by compiling information from brown seaweed processing factories (milling centers) and abalone cultivation centers between 2005 and 2006. In each of these production activities, surveys were taken to evaluate: (1) species processed, (2) their origin, (3) method of collection/harvesting, (4) landed biomass. These same surveys were taken to the fishermen and commercial intermediaries who supply the processing and abalone cultivation centers.

Socioeconomic aspects

Evaluation of some socio-economic aspects of fishermen involved in the kelp collection and harvesting were made with special attention and care. They included determina-

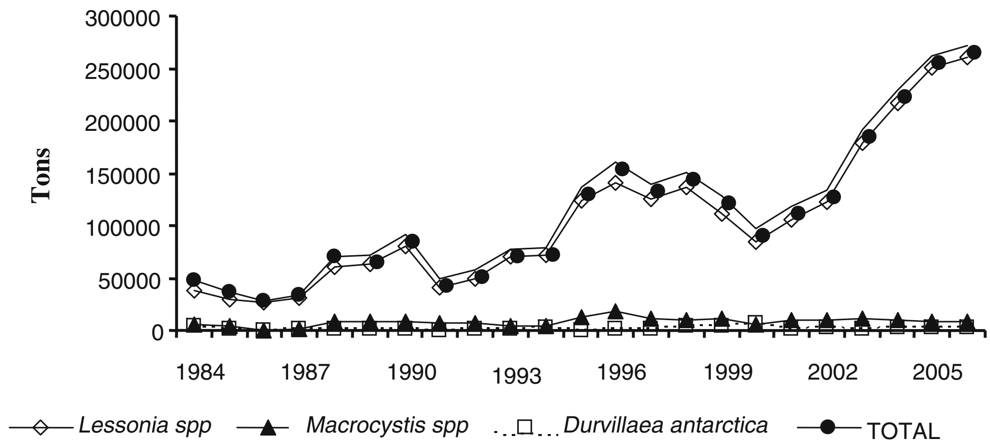


Fig. 2 Annual production (wet biomass) of brown seaweed fishery in Chile (1984–2006)

tion of age, sex, education level, and association to workers unions or consortia.

Results

The brown algae fishery in northern Chile is concentrated between 18° and 32°S. However, the majority of landings are collected or harvested between 26° and 32°S (Fig. 1). In the study area, most of the collection and milling centers are in Vallenar (28°32′S), Ovalle (30°36′) and Socos (30°40′). Abalone cultivation centers are located in Caldera (27°06′S) and Coquimbo (29°58′) (Fig. 1).

Collection, harvesting and destination of brown algae

During the last 25 years, brown algae landings have fluctuated between 40,000 and 280,000 t.year^{-1}, showing a constant increase since 1999 (Fig. 2). In Chile, *L. nigrescens* and *L. trabeculata* comprise more than 90% of the total production of brown algae, whereas *Macrocystis* sp. and local consumption of *Durvillaea antarctica* contribute only marginally to total landings (Fig. 2). Even if brown algae have an extensive distribution along the southeast Pacific coast (see Fig. 1), their fishery is concentrated between 20° and 32°S (Fig. 3). This is due to the arid climate of the wide Atacama Desert located immediately inland of this region, which allows for rapid drying and consequently a reduction in the productive fees.

Destination of brown algae

The increase in kelp extraction during the last 7 years is explained principally by the significant rise of their utilization as raw material for extraction of alginic acid, both in Chile and outside the country (Fig. 4). A smaller fraction of this increment can be explained by the yield reduction of kelp used for milling. This was consequence of higher humidity of recently processed plants compared to previous years (Fig. 4). From a different perspective, exports of brown algae during 1997–98, as in other "El Niño" phenomenon, could be related to higher mortalities generated by this large scale oceanographic event. The warming of the ocean surface and decreasing of nutrients concentrations, both associated with "El Niño", cause high mortalities in kelp populations which are then cast ashore by waves and finally collected by fishermen.

The new and impressively growing abalone cultivation industry in Northern Chile, consumed more than 4,800 t of

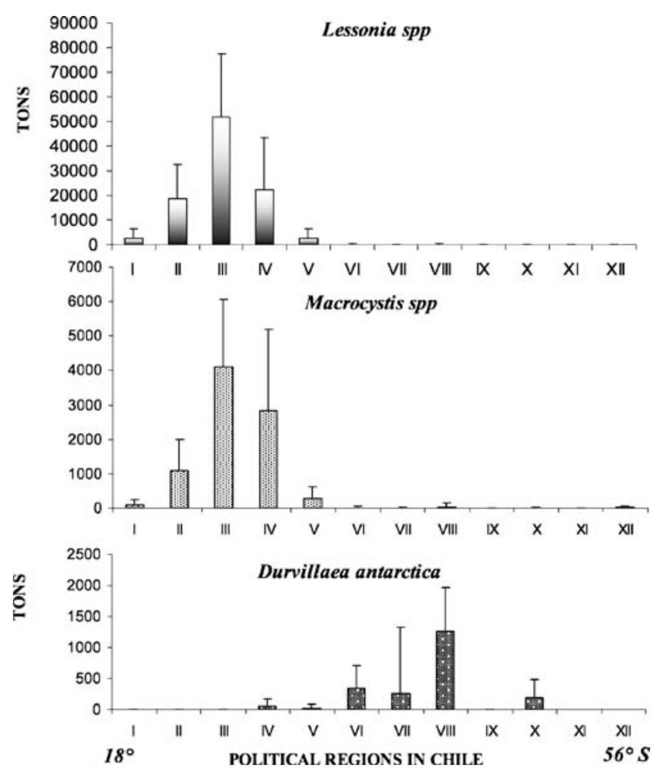


Fig. 3 Average landings (wet biomass) of brown seaweed (1984–2006), along the Chilean coastline: North (Regions *I to IV*), Central (*V to VIII*), and South (*IX to XII*)

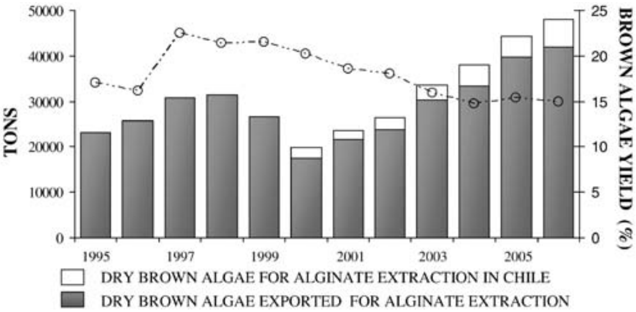


Fig. 4 Annual production (1995–2006) of raw material (dry biomass) for alginate extraction in Chile and overseas. Temporal variability of the percentage of brown seaweed yield (-o-)

fresh algae between 2005 and 2006, principally *Macrocystis* (Fig. 5). However, neither the utilization nor the economic yield of this activity is comparable, until now, to supplying material for alginate extraction (Fig. 6).

Distribution and abundance of brown algae

During 2004–2005, between 26° and 32°S, distribution and abundances of *L. trabeculata, L. nigrescens* and *M. integrifolia* were evaluated along more than 700 km of coast (Fig. 7). 140 sampling stations were established separated by 4.5 linear km, excluding a priori sandy beaches and soft bottom subtidal areas because of their unsuitability as a substratum for kelp spore settlement. *Lessonia trabeculata* is found in rocky subtidal habitats between 0 and 30 m depths in the entire study area (Fig. 7). Depending on the extension of the rocky platform into the subtidal zone, local biomasses up to 50,000 wet t were recorded. Abundance polygons indicate a standing stock of approximately 800,000 wet t of *L. trabeculata* in the study area. *Lessonia nigrescens* is distributed in the rocky intertidal zone of the entire study area with local biomass (sampling station) between 50 and 4,000 wet t (Fig. 7). The sum of the abundance polygons constructed with GIS shows a standing stock of more than 100,000 wet t of *L. nigrescens* in the study area. In contrast, *M. integrifolia* shows fragmented distribution within the study area (Fig. 7). Local populations are small, with biomasses between 2 and 12 wet t. The sum of local biomass determines a standing stock that does not exceed 200 wet t for the entire study area (Fig. 7).

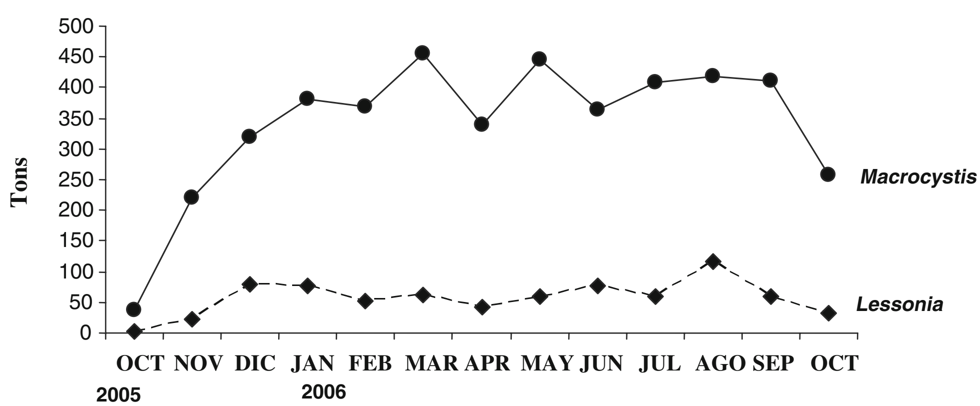
Social indicators

The list of fishermen http://www.sernapesca.cl) shows 7,801 artisanal algae collectors and harvesters in the study area (Table 1). However, only 20% of these individuals showed evidence of permanent collection and harvesting activities during 2005–2006. More than the half of active fishermen (57%) show a preference for working independently, unassociated with consortia or unions; gender analysis shows that 83.4% of active participants are men. The marginality of this activity is reflected in the education of the active fishermen. Almost 70% of participants in this activity have only primary school education, which is generally incomplete. Among the elderly fishermen (>70 years), 4.6% have no formal education, being mostly illiterate. Only 26.2% have secondary education, which in most of cases is incomplete (Table 1).

Discusion and conclusion

Governments have attempted to introduce co-management in coastal waters granting territorial user rights to fishers (TURFs). The rationale behind TURFs is based on a common property approach, which proposes that a well-established rights-based system provides access, withdrawal, and management security for individuals and groups of individuals (Ostrom and Schlager 1996). With such assurances, fishermen would make commitments amonst each other and with the administration, and would develop long-term plans for investing in, and harvesting from, a common-pool resource in a sustainable manner. Accordingly, TURFs change the nature of resource extraction. In this sense, hunting becomes harvesting, a certain degree of predictability is introduced since extraction programs

Fig. 5 Wet biomass of brown seaweeds (*Macrocystis* and *Lessonia*), used as food for abalone culture in northern Chile



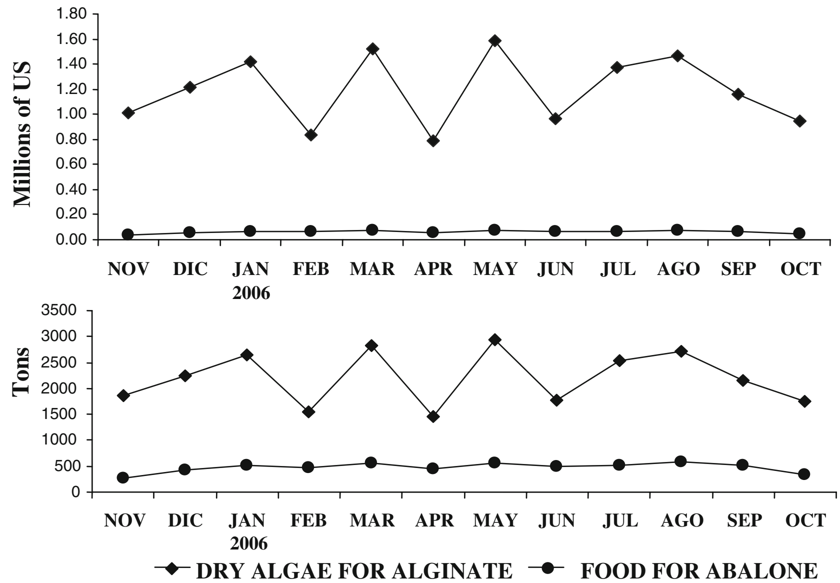


Fig. 6 Monthly variation of brown seaweed biomass used for alginate extraction, as well as fresh food for abalone culture, and respective incomes (US $) of both commercial activities

requires at least previous evaluation of target resources, and the skills of the fishermen (as hunters) become less important (Gelcich et al. 2005a).

Since 1997, Chilean Government has adopted co-management policies for the coastline, granting territorial user rights to fishermen (Bernal et al. 1999). Territorial rights related to users into the Chilean Fishery Law, adopted the legal title of Management and Exploitation Areas for Benthic (bottom dwelling) Resources (MEABR). Through this, the Governmental Entity that regulates fisheries assigns defined rights and norms of utilization to syndicates located in defined geographical coastal areas (Gelcich et al. 2005b). By August 2003, 188 exploitation areas (MEABR) had management plans in progress, and 649 were at diverse stages of application procedures (Gelcich et al. 2005b).

To date, between 18°–32°S (see Fig. 1), more than 50% of the coastline is under MEABRs regime, and this area represents the main geographical scenario for kelp fishery in Chile. In this context, fishermen syndicates would apply many of the proposed strategies for brown seaweed conservation in MEABRs. Currently, MEABRs that include brown seaweeds as target species have to harvest according biological and ecological recommendations. In addition, the results of harvesting procedure and the recovery of kelp beds after pruning or removal of individuals must be inserted into each management program, which is updated annually.

In open areas of Northern Chile without an MEABR regime, collection of plants cast ashore is the main activity of fisherman along the coast. Harvesting of *L. nigrescens* is the most difficult to control in terms of regulation enforcement along Chile's extensive coast. In contrast, due to the location of *Macrocystis*, harvesting is closely related with the proximity of abalone culture centers; the few and small beds of *Macrocystis* near them have been harvested under a co-management plan developed by fisherman jointly with the direct user, the abalone industry.

During the last 50 years, kelp fisheries have been supported by the natural mortality of coastal populations caused by the drag of bottom currents and wave impact on old and/or debilitated plants. The detached biomass is cast ashore by currents and hand-collected by fishermen. In this case, there was no need for administration and management of *L. trabeculata*, *L. nigrescens* and *M. integrifolia*. This feature of brown seaweed fishery was relevant in the past, not only for the conservation of *Lessonia* and *Macrocystis* populations but also for many other associated species with economic interest, such as keyhole limpets, sea urchins, and several fish and mollusc species (Vásquez and Santelices 1984; Vásquez and Vega 2005). Since 2000, extractive pressures from international markets for alginic acid extraction, as well as the emergent need of fresh food for abalone aquaculture, has dramatically raised the harvesting of brown algae. In this context, and considering the foundation species status (sensu Dayton 1972) of Chilean kelp species, any management program must include the whole coastal marine habitat.

The Kelp fishery is also important in other cold and temperate areas around the world, such as Alaska (Stekoll et al. 2006), Southern California, USA, and Baja California, Mexico (Barilotti and Zertuche-González 1990), Norway (Sjotun et al. 1993), South Africa (Anderson et al. 2006; Rothman et al. 2006), New Zealand (Shiel and Nelson 1990), Canada (Ugarte and Sharp 2001; Ugarte et al. 2006), France (Guillaumont et al. 1993), Japan (Terawaki et al.

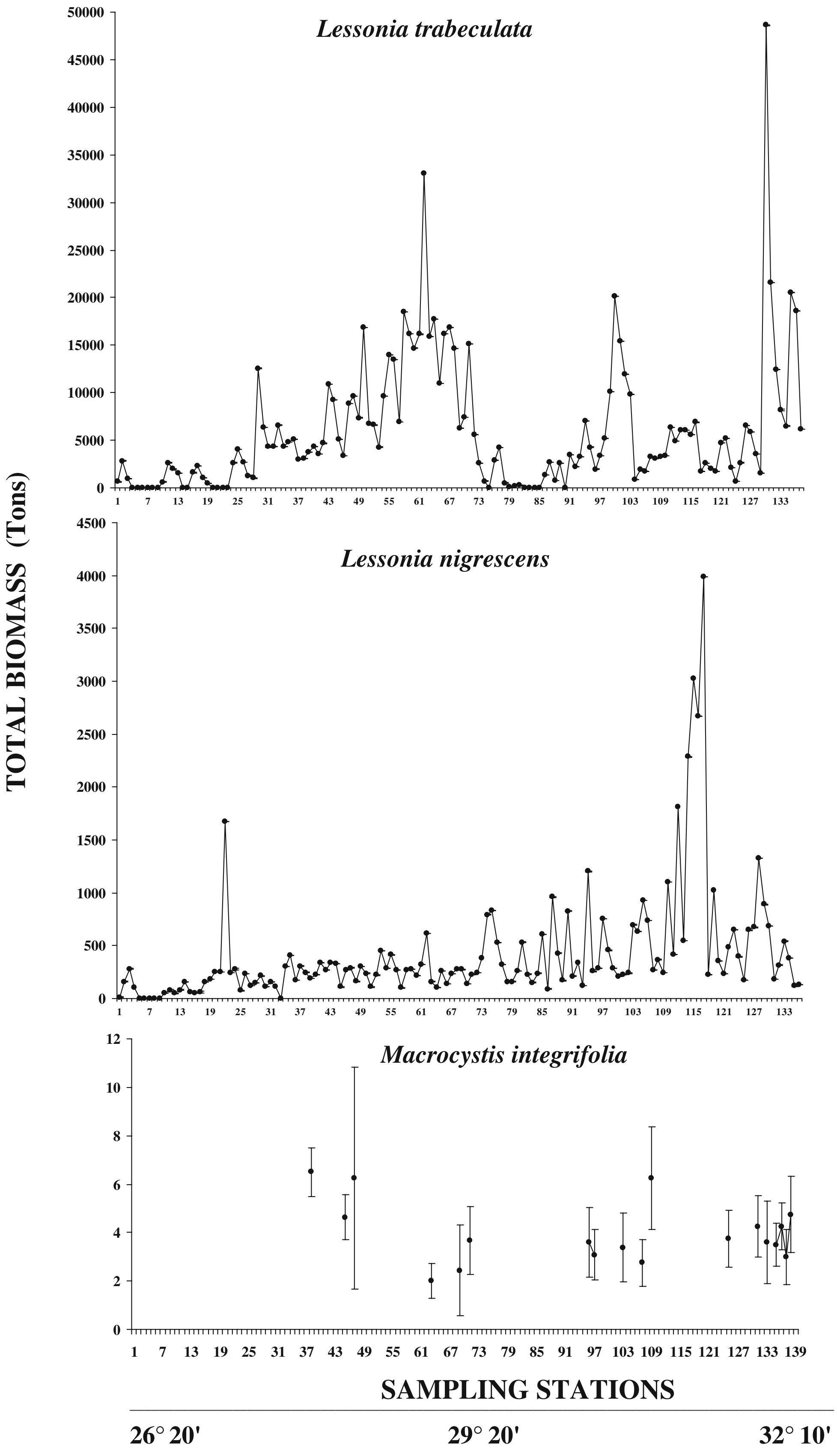


Fig. 7 Distribution and standing stock (wet biomass) of tree species of brown seaweed of economic interest along 700 km of coastline in northern Chile

Table 1 Socio-economic indicators of fisherman of brown seaweeds in Chile

No. of registered fisherman	No. active fisherman	Not-associated fisherman (%)	Female (%)	Male (%)	Education level (%)		
					Uneducated	Elementary	High school
7,801	1,549	57	16.6	83.4	4.6	69.2	26.2

2001), and Ireland (Werner and Kraan 2004). The production and sustainability of involved populations is mostly focused on biological and ecological knowledge, being the management based on a single species resource. In contrast, kelp management based on the ecosystem has been poorly documented.

As in this study, in addition to the bio-ecological features of target species, other management considerations such as maximum exploitation rate, cutting height, gear restriction, effects on associated species, and protected areas have been considered in the sustainability of *Ascophylum nodosum* in Canada (Ugarte and Sharp 2001) and *Laminaria* spp. in France and Norway (Werner and Kraan 2004). Similarly to *Ascophyllum* studies, universities, government authorities, and industry were involved in the production of a research and monitoring program for the sustainability of economically important kelp including also, social impact. In this context, the most important difference between the kelp fishery in Chile and other countries is the relevance we assigned to the social aspect of this fishery, since it provides the main economic resource for several families under high social risk in Northern Chile.

Location of growth meristems and reproductive structures in different kelp species (Edding et al. 1994; Hoffmann and Santelices 1997) determines that the way of harvesting has different consequences for different species: *Lessonia* has sori on apical fronds and along stipes (Edding et al. 1994; Venegas et al. 1992), whereas sporophylls are basally distributed in *Macrocystis*. The meristems of both genera are apically distrubuted, and only *Macrocystis* continually produces new stipes from the holdfast. Pruning *Lessonia* inhibits its growth, and regeneration is nonexistent (Vásquez and Santelices 1990; Vásquez 1992; Mendieta 1997), while harvesting of fronds and stipes eliminates gametangia and thus prevents sexual reproduction. In contrast, the regeneration of biomass after harvesting is a rapid and frequent process in *Macrocystis* (Graham et al. 2007); additionally, pruning only removes the canopy of individuals, and does not affect basal sporophylls involved in sexual reproduction.

Brown algae landings have fluctuated between 40,000 and 280,000 t during the last 25 years, with escalating rates since 1999. At present, approximately 300,000 wet t of brown algae are collected or extracted from the coast of Northern Chile, and *Lessonia* spp. represents more than 90% of this total. This productive activity creates yearly revenues of approximately US$22 million http://www.bancocentralchile.cl), which comes mainly from supplying raw sources for the alginic acid industry. Chile provides 10% of the world wide sources for alginate extraction, which is used primarily by pharmaceutical and food industries (Avila and Seguel 1993; Vásquez and Fonck 1993; Zemcke-White and Ohno 1999), though high quality alginate production within Chile is a growing activity.

In terms of fisheries statistics, the standardization of humidity content and yield of kelp for industrial processes are required at the national level. This would allow more precise predictions for the industry as functions of the requirements and availability of biomass stock from natural beds.

In Chile at present, the availability of fresh food is the most important constraint for the emerging aquaculture of abalone. In the study area, the estimated requirement of this industry reaches an average of 500 t per month of fresh algae, mainly *Macrocystis*. However, significant consumption of brown algae by cultivated abalone is foreseen. Preliminary studies of conversion rates (Pérez, personal communication) show that the production of 1 t of abalone requires 100 t of fresh algae. In consequence, the projected annual production of cultivated abalone for 2010 is 1,000 t, which would require 100,000 t of brown algae to reach this goal. Considering the low abundance and fragmented distribution of *M. integrifolia* in Northern Chile, this requirement greatly exceeds the production potential of natural populations. Consequently, the sustainability of abalone cultivation depends on the future culture of *Macrocystis*. In this context, successful efforts have been made in Chile to produce *Macrocystis* spp sporophytes using long-line culture systems (Gutierrez et al. 2006; Westermeier et al. 2006). From a different perspective and given the susceptibility of brown algae to interannual oceanographic events like El Niño (Vega et al. 2005; Vásquez et al. 2006), kelp culture would allow independence from unpredictable environmental catastrophic fluctuations and would help the natural recovery of coastal rocky areas after mass mortality events.

In Chile, a second epicenter for the abalone cultivation industry is located at ca. 40° S. At high latitudes, reaching the Pacific coast of Cape Horn and on the Atlantic coast near Chubut Argentina, *M. pyrifera* forms continuous belts that comprise the most important brown algae reservation in the world (Graham et al. 2007). In spite of this, and contrary to the perennial *M. integrifolia*, *M. pyrifera* populations are annual and therefore minimally available in the winter (Buschmann et al. 2006). For this reason, development of cultures should not be centred exclusively in Northern Chile.

Fishers, of whom only 17% are women, carry out collection and harvesting of brown algae in Chile. In the most active areas located between 18° and 32°S, 7,801 collectors are registered, but only 20% of them permanently participate in collection and harvesting activities. The majority of these fishers are independent, not belonging to any workers union or consortium. The level of education attained by active fishermen reflects the marginality of this work. Almost 70% of the workforce has only elementary education and in most cases incomplete.

The estimated standing stock of *Lessonia* (both species analyzed, more than 1 million t) is enough to sustain the actual brown algae landings Considering the morphologic and reproductive attributes of *Lessonia*, "how to harvest" seems to be more important than "how much to harvest". In terms of how to harvest, a few important considerations are relevant: (1) plants should be completely extracted including the holdfast; (2) large plants, with holdfast larger than 20 cm in diameter, should be selected for extraction; (3) harvesting would be sparse leaving a substratum space not larger than 1–2 m between plants. All these recommendations are relatively easy to implement and control in areas with an MEABR regime, even if. in areas with free access, they would be certainly more difficult to carry out. Management Plans would then consider these simple recommendations: (1) to liberate primary substratum for the settlement of juvenile sporophytes, (2) to allow for juvenile recruitment by diminishing competitive interaction between adults and sporelings, (3) to maintain a reproductive stock of adults, while allowing population regeneration, and (4) to prevent overgrazing of plants by benthic herbivores by maintaining a whiplash effect (see Dayton et al. 1984; Vásquez 1992).

In contrast to to the situation with *Lessonia*, where how to manage the stock is the most relevant issue, the sustainable fishery of *Macrocystis* should take into account its distribution and abundance, before authorizing the harvesting of natural populations in Northern Chile. This species has a unique genetic heritage due to its restricted and fragmented distribution. It also plays an important ecological role as an engineering (sensu Jones et al. 1994) and foundation species (Graham et al. 2007), because numerous invertebrates and fish depend on its existence (Vásquez and Vega 2005; Graham et al. 2007). Thus, the small beds of *Macrocystis* in Northern Chile would be under a harvesting program, which must be carried out by local fishermen, funded by the local abalone industry and supervised by fishery authorities.

Currently, some management strategies are being applied in Chile by means of a regionalized system that prohibits the extraction and collection of kelps in open areas (not under MEABR regime) during a certain period of time. Under these restrictions, users are allowed to obtain the resource, as long as they deliver the information required to determine: (1) harvesting and collection effort, (2) locations of collection and harvesting areas, (3) number of fishermen, (4) number intermediate buyers, (5) number and location of milling and abalone cultivation centers, and (6) amount of biomass used by each activity. Using the above information, we collaborated with governmental fishing authorities that organized technical work groups. In these collaborative instances, fishermen, industry representatives, technicians, scientists and administrators work together towards establishing sustainable management strategies that account for the distribution and abundance of brown algae and the requirements of the industries related to these resources.

Biological and ecological knowledge by itself does not guarantee the success of a harvesting program. In practice, social, political and economics aspects (see Vásquez and Westermeier 1993) must be considered for a correct strategy of management of the brown seaweed fishery. Among these, the most relevant are: (1) pressure of national and international markets for raw material, (2) unemployment indexes of coastal workers, which increase seasonal harvesters, (3) control of management recommendation along the extensive coast of northern Chile, and (4) low level of education and incomes of seaweed collectors.

Usually, most management strategies of natural resources start immediately before the imminent collapse or after evident decline of populations subjected to harvesting (e.g., *Gracilaria chilensis*; see Santelices and Doty 1989). This study is an example that illustrates the application of biological and ecological knowledge of target species having regard to the present and future uses of kelp species of economic interest. In this context, concerted actions of government, scientists, fishermen and industry have been taken and should be implemented in time. In the near future, management recommendation will be tested in order to evaluate the stocks of natural populations along Northern Chilean coasts, the production of brown seaweed under culture, and the fate and use of these important benthic marine resources.

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