Chapter 6

The Brown Seaweeds Fishery in Chile

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Abstract

Chilean fishery of brown algae includes species belonging to the genus *Lessonia*, *Durvillaea*, and *Macrocystis*, which can be found along the coast, ranging latitudes from 18° to 55°S. The exploitation of these seaweeds is done mainly in the Northern coast because the environmental conditions of this region decrease initial production costs. Brown algae are exploited from natural populations and exported to international markets as row material, source of alginates, widely utilized in diverse manufacturing processes and industries. International demand for Chilean kelps has produced sustained increase in harvest during the last decade, reaching more than 390,000 dry tons/year. This chapter approaches the most relevant aspects of the brown seaweed fishery in Chile which covers a wide range of the Southeast Pacific coast, considering the number of commercial species, its abundance and distribution, knowledge achieved on their ecology and biology regarding management, and conservation of these resources, and finally, provides tools for stakeholders and policy makers directed to sustainable management of natural kelp beds occurring in the cold temperate seas.

Keywords: Brown algae, kelp, fishery, coastal environment, management

1. Introduction

Chile, a narrow and long country with over 4500 km of continental coastline, has an ancient tradition in the use of sea resources. Numerous algae, shellfish, and fish species have been incorporated in the diet and every day habits of his inhabitants, since prehistoric times. The astonishing evidence found at the archaeological site Monte Verde, dated 12,500 years BP and located near Puerto Montt (41°S), provides evidence of Pre-Clovis human settlement in South America, and exhibits ancient use of macroalgae, probably as food and for medicinal purposes [1, 2]. The diet of coastal human communities incorporated brown and red algae as significant components along the last 500 years, especially in those coastal populations situated South beyond 30°S [3].

As sources for alginates production, brown algae in Chile are exploited from natural populations and exported to world markets as row and dried commodity for alginates extraction [4, 5]. The local national gel industry, as well as invertebrate aquaculture production, utilizes only a minor fraction of the annual harvest [6]. During the last decade, a sustained increase of harvesting has been taking place, because of the international demand for Chilean kelp; production has reached more than 390,000 dry tons associated with an economic return of more than US$ 90 million [5, 7]. Chilean brown algae of economic importance belong to genus *Lessonia*, *Durvillaea*, and *Macrocystis*, and they occur throughout the coast from 18° to 55°S [8]. Even this wide distribution range, the exploitation of these resources is done mainly in the Northern region of the country between 18° and 32°S, because environmental conditions, such as remarkable air high temperature and dryness of the coastal desert, which decrease production costs of drying process close to zero and, consequently, the total processing cost before their commercialization [6].

In Chile, the harvest of brown algae is also matter of social relevancy since more than 15,000 people depend more or less directly on the exploitation and collection of this marine resource [9]. As established by local law, only authorized and registered artisanal fisherman are allowed to harvest such kelp [6]; however, enforcement measures and control are difficult to put into effect because of the topography of coastal territory where these natural populations of kelp occur, but also due to their extension and accessibility [10]. From the point of view of their ecological role, kelps have been defined as engineer species in the coastal marine ecosystems; they are key species which participate maintaining and preserving foci of high biological and genetic diversity [11, 12]. Also, these species are sensitive to disturbances from both natural and/or anthropogenic origin [13, 12].

2. Species in the fishery

Geographic distribution and occurrence of commercial brown seaweed are associated with high-energy environments in the Southeast Pacific (**Figure 1**). *Lessonia* species can be intertidal and subtidal as well; they form belts along exposed rocky coasts (**Figure 1A, B, D**); *Macrocystis* forms shallow kelp beds ranging from intertidal zone to *ca*. 15 m depth in Northern latitudes (**Figure 1C, G**); it is gradually replaced toward Southern areas by *Durvillaea* (**Figure 1F**), which dominates the intertidal zone in wave-exposed areas [8]. In South direction and beyond 42°S, *Macrocystis* is the most abundant and dominant kelp species [15]; *Lessonia* species have almost continuous distribution along the whole Chilean continental coast; instead, the distribution of *Macrocystis* is fragmented into populations that form patches in Northern Chile [11, 16, 13], contrasting with its continuous coastal belts distribution from 42°S toward Cape Horn (55° 58°S); *Macrocystis* distribution includes the Chilean Southern fjord zone, surrounding Cape Horn, and ascending in North direction by the Argentinian exposed coast until Chubut area in the Atlantic (41°S). Several elements are combined to determine the observed kelp distri-

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bution patterns; they result from multifactorial interaction of complex life-history strategies of the involved species with environmental factors, such as spatial and temporal variations in water movement, nutrient availability, light, and temperature [17, 16, 12].

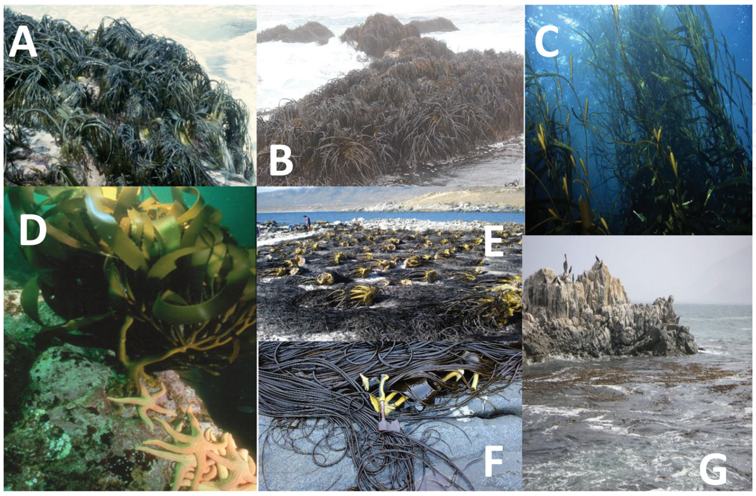

Figure 1. Intertidal beds of *Lessonia nigrescens* (A, B), subtidal beds of *Macrocystis pyrifera* (C), subtidal *Lessonia trabeculata* (D), Harvest on the beach of *Lessonia nigrescens* (E), *Durvillaea antarctica*, intertidal beds of *Macrocystis pyrifera* (G).

Chilean kelp species commercially exploited are as follows: *Lessonia trabeculata*, *Lessonia berteroana, Lessonia spicata* (members of *Lessonia nigrescens* complex, for details see [18–20]); these are all species having two morphotypes during their natural life cycle, which represent very different ecological roles and requirements, in both environmental and physiological aspects. Large and conspicuous (so, harvestable) sporophytes alternate with microscopic few cell and benthic organisms which are the gametophytes.

3. Biological and ecological aspects

Studies on the distribution and abundance of Chilean commercial brown seaweed were scarce and locally restricted until the end of 2000 [21–29, 30, 31]. Other than this, the use of non-comparable methodologies in the few studies carried out, which approached biomass stocks information, did not allow extrapolation and inter-annual comparisons of the available total biomass. Similar situation occurred in relation to distribution studies of the involved species, both in temporal and spatial gradients [4]. Harmonization of methods or collection of information, as well as systematization of them, is essential aspects of the population ecology of commercial species, in order to propose adequate regulations and policies that guarantee a sustainable management of these resources.

One of the few extensive and intensive evaluations of biomass distribution of *Lessonia trabeculata, Lessonia nigrescens,* and *Macrocystis pyrifera* was done during 2004–2005, for the geographic extension ranging between 26° and 32°S; its main goal was to determine the distribution and abundance of the mentioned species in more than 700 km of coast. During the study, 140 sampling stations were established separated by 4.5 linear km, excluding *a priori* sandy beaches and soft bottom subtidal areas because they represent inadequate substrates for kelp's spores settlement [6, 5]. *L. trabeculata* was found in rocky subtidal habitats between 0 and 30 m depth in the whole study area. Depending on the extension of the rocky platform into the subtidal zone, local biomass up to 50,000 wet tons was recorded. Estimation of abundance indicated a standing stock of approximately 800,000 wet tons of *L. trabeculata* in the study area. *L. nigrescens* was distributed in a continuous pattern along the rocky intertidal zone of the whole study area, with local biomass (sampling station) registered between 50 and 4000 wet tons. Using GIS abundance polygons were constructed which revealed a standing stock of more than 100,000 wet tons of *L. nigrescens* in the study area [6]. In contrast, *Macrocytsis* evidenced fragmented distribution within the study area. Local populations were small and estimated biomass fluctuated between 2 and 12 wet tons. The sum of local biomass allowed estimation of a standing stock that did not exceed 200 wet tons for the entire study area at the time [6, 5].

In contrast to the lack of ecological information used to determine fishery regulations, several studies arise since the middle 1980s approaching different aspects of kelp knowledge, such as biology and population ecology [12, 13, 17, 32, 33], genetics and taxonomy [18–20, 34], enhancement and cultivation [35–38], new and novel uses for their natural by products, for medical nanotechnology, for example (see [39–41]).

Because of *Lessonia nigrescens* represents more than 70% of total landings of brown Chilean seaweed fishery, several studies have been focused on this species. Studies on genetics, molecular biology, and population ecology show that *L. nigrescens* is a species complex composed by two cryptic species: *Lessonia berteroana* and *Lessonia spicata* [18, 42, 43]; *L. berteroana* is distributed from the South of Perú (*ca.* 15°S) to approximately 30°S, and *L. spicata* occurs form 30°S toward South [20]. In the last decade, the kelp harvest in Chile has been sustained principally by the *Lessonia nigrescens* complex, especially in the area known as latitudinal break for biodiversity distribution which location is considered approximately at 30°S [19].

Exploited and unexploited species belonging to *Lessonia nigrescens* complex form Northern Chile were compared using morphological and demographic parameters such as density, biomass, recruitment, and population structure [5]. These are traits which allow estimation of the effect of harvesting in other natural populations of brown algae [44–47], and the assessment of the impact of natural disturbances [48, 16, 13] and other anthropogenic activities on such species [37]. In this context, the morphological and demographic parameters used for evaluate *L. nigrescens* could be useful as ecological indicators for: (1) to evaluate the consequences of good harvesting practices agreed upon by fisherman, (2) to compare the effect of harvesting in areas with different administration policies, (3) to monitor the sustainability of exploited kelps, and (4) to propose to competent authorities the precautionary and/or recovery adequate measures for sustainable managing of dynamics population of commercially important brown algae.

4. Collection, harvest, and landings

Largely and until year 2000, the whole brown algae fishery in Chile was based on the collection of natural mortality kelp from coastal populations. A sudden and significant increase of its demand, other than as raw material for alginate source, also as food source for cultivated abalones introduced in Chile in the last 16 years, triggered the harvest of kelp species. Since then, the Chilean brown seaweed fishery becomes an extractive fishery in which converge four main factors: (1) still the international market request for alginic acid source; (2) use for feeding the emergent local farming of several kelp-consuming organisms under controlled conditions; (3) the switch of fishers toward the harvest of commercial brown seaweeds as consequence of the collapse of other benthic fisheries, and (4) the strong impact on local economy produced by the international fluctuation of the price of copper. This metal constitutes the Chilean main resource, representing more than 60% of the internal gross product (PIB, as its acronym in Spanish); it provides direct and/or indirect jobs for thousands of people in the country, being Chile the first copper producer around the world. Local economy is extremely sensitive to fluctuations of international cooper price, and the fall (currently crush) of it provokes significant unemployment, particularly of non-specialized workforce; as one of its primary consequences, unemployed people are forced to migrate to coastal areas where they can develop subsistence economy based on precarious jobs represented by the collection and harvesting of brown seaweeds [9, 6].

During the last 35 years in Chile brown algae, landings have fluctuated between 40,000 and 390,000 tons/year, showing sustained increase since 2000 (**Figure 2**); *L. nigrescens* and *L. trabeculata* comprise more than 90% of the total production of them, whereas *Macrocystis* and local consumption of *Durvillaea antarctica,* contribute only marginally to total landings [61].

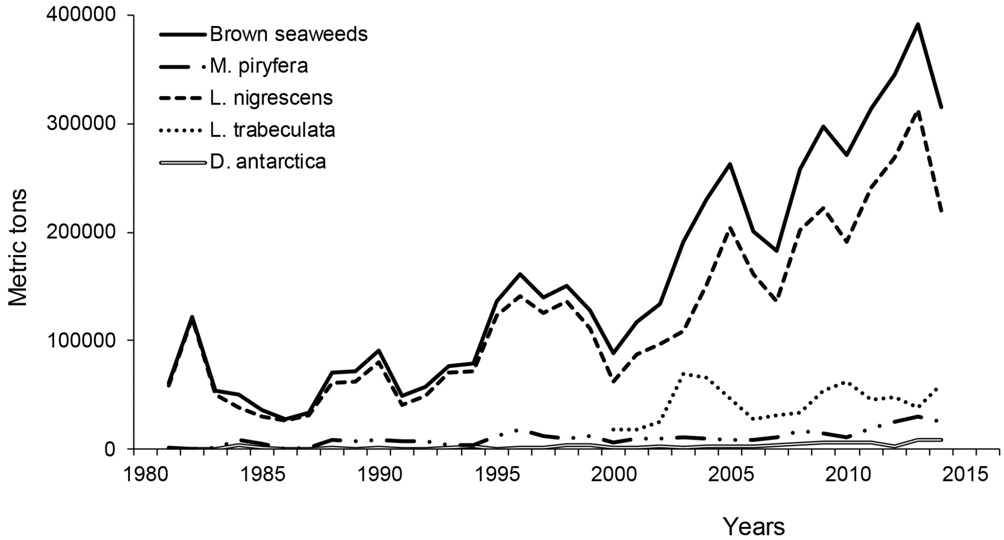

Figure 2. Temporal landing (1980–2014) of brown seaweeds of economic importance in Chile. Source: National Fishery Service (Chile) [61].

The significant rise of kelp demand, as commodity source of alginic acid around the world during the last years, explains the increase of kelp extraction. A smaller fraction of this increment is consequence of the yield reduction of kelp used for milling, because of higher humidity contents of lately processed plants if compared with those from previous years [7, 50]. From a different perspective, during 1997–1998 when a severe ENSO event occurred, Chilean exports of brown algae showed a considerable peak, probably related to significant mortalities generated by this large scale oceanographic event. The warming of the ocean surface, simultaneously to decreasing of nutrients concentrations, both associated with "El Niño," has strong impact over kelp populations and thousands of dead plants are cast ashore by waves which end collected by fishermen [16, 23, 60].

Since 2005, the abalone cultivation industry exhibits a remarkable and sustained growth, especially in Northern Chile; this commercial activity consumes close to 4800 tons of fresh alga/ year, mainly *Macrocystis;* neither the utilization nor the economic yield of this activity is comparable, until date, to demand of Chilean kelp as source for alginate extraction.

5. Management

Chilean authorities have implemented a management and conservation strategy program for economically important brown algae, considering its economic, social, and ecological importance, and also the significant increase of kelp harvest. The expectative of this program is focused on surveillance of available and harvestable biomass, evaluation of strength of harvesting (Capture per Union Effort-CPUE), and characterization of the productive chain based on these primary producers. As a result of this strategy, carried on since 2010, plus several years of kelp knowledge achieved, recommendations have been established for the management of kelp sustainability. The premise is "*how to harvest is more important than how much you harvest*" [5]. This program has been implemented in three Chilean conservation tools performed at the country level and which represent three different conservation strategies: (1) marine protected areas (marine park, marine reserve), (2) open-access areas for artisanal fishermen (OAA), where they collect and harvest marine resources, and (3) management areas for exploitation of benthic resources (MAEBR), where organized fisherman have some territorially rights assigned over a sector of the coast. The conservation strategy involved in MAERB is based on co-management (see [50–55]).

The main practical recommendations of the program for the sustainability of brown seaweeds are focused on selective harvesting of adult sporophytes and maintenance of a permanent stock of individuals able to reproduce, recruitment facilitation, decrease of grazing by benthic invertebrates, and permitting the sustainability of kelps and the conservation of its associated biodiversity [6, 5, 56, 62]. Considering all aspects mentioned, the following bio-ecological recommendations must be applied to kelp beds subjected to significant, frequent, and intense harvesting: (1) to harvest the whole plant, including the holdfast. (2) To harvest plants with a basal diameter larger than 20 cm. (3) To harvest one out of every three plants, with preference for the biggest specimens, thereby thinning the population. (4) For the particular case of *Macrocystis*, to cut the canopy to one meter below the surface.

According to administration regime (Conservation Strategy) assigned by competent authority to natural populations, the density of both adult plants and juvenile recruitment of *Lessonia nigrescens* is subjected to temporal variation (**Figure 3**). In marine protected areas like marine parks or marine reserves (MPA), the annual renewal of kelp populations exhibits a seasonal cycle wherein the natural mortality of adults is compensated by intense juvenile recruitment (**Figure 3A**). In MAEBR, the density of adult plants decreases during the maximum harvest period, which is preferably carried on during spring and summer; in these conditions, the annual cycle of kelp renewal is maintained by recruitment of juvenile plants post-harvest (**Figure 3B**). In OAA, where the kelp harvest occurs all along the year, adult plants density decreased significantly (**Figure 3C**). Thus, constant releasing of substrate by permanent harvesting facilitates sustained juvenile recruitment, which significantly increases the density of recruits throughout the year; this last population renewal process takes places independ-

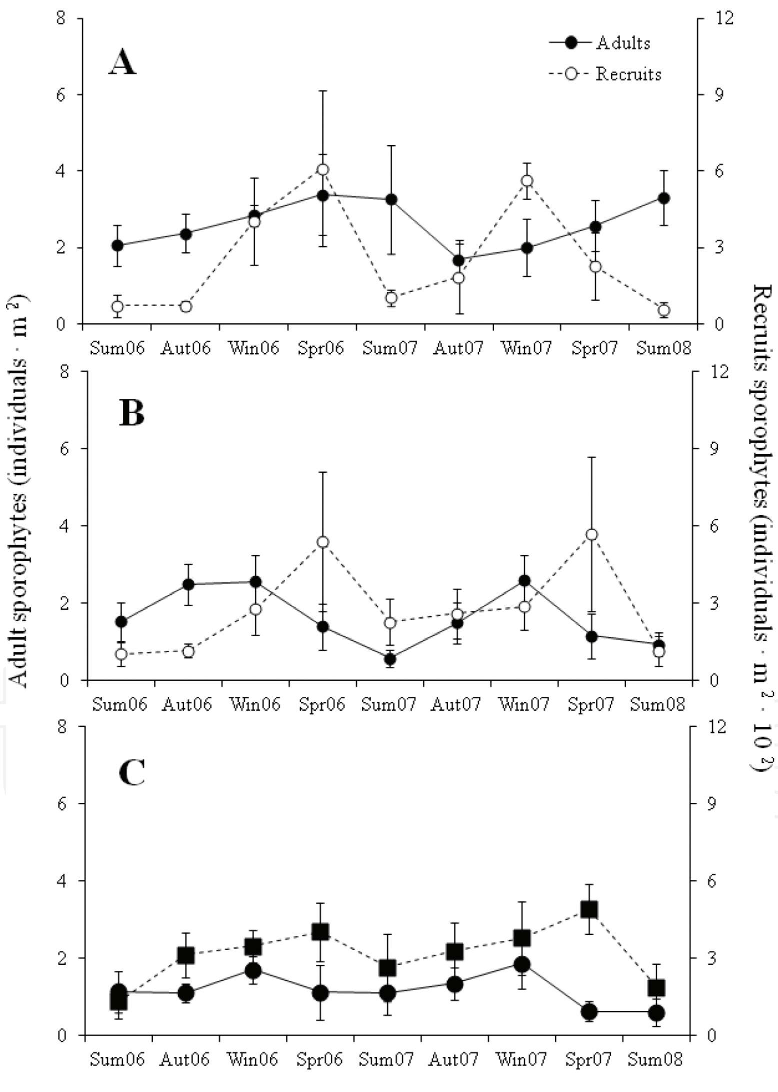

Figure 3. Temporal variation in the density of *Lessonia nigrescens* complex adult plants and recruits in kelp beds located in marine protected areas MPC (A), management areas for exploitation of benthic resources (MAEBR), and open-access area (OAA). Mean + 2SE [49].

ently of seasonal variation in opposition to what was observed in *Lessonia* populations belonging to Conservation Strategies of MAEBR and MPA (**Figure 3**).

The density of adult plants is greatest in populations inside MPA in contrast to those inside OAA (**Figure 3**). As previously exposed in MAEBR, the seasonal harvest of *Lessonia* decreases the density of adults; however, this impact of harvesting is significantly lower than which is observed in OAA (**Figure 3**). In these open-access areas, the density of adult plants is less because of high harvesting pressure produces contraction of the stock of reproductive plants, and thus negatively affects the kelp renewal. There exists an exception to this pattern observed in OAA constituted by those populations where the difficulty of access to the coastline generates a barrier to permanent harvest. In this case, topography constraints to access generate effects that mimic a sort of natural co-management; in this way, the pattern of size distribution of *Lessonia* plants in OAA is quite similar to the pattern observed in MAERB [49].

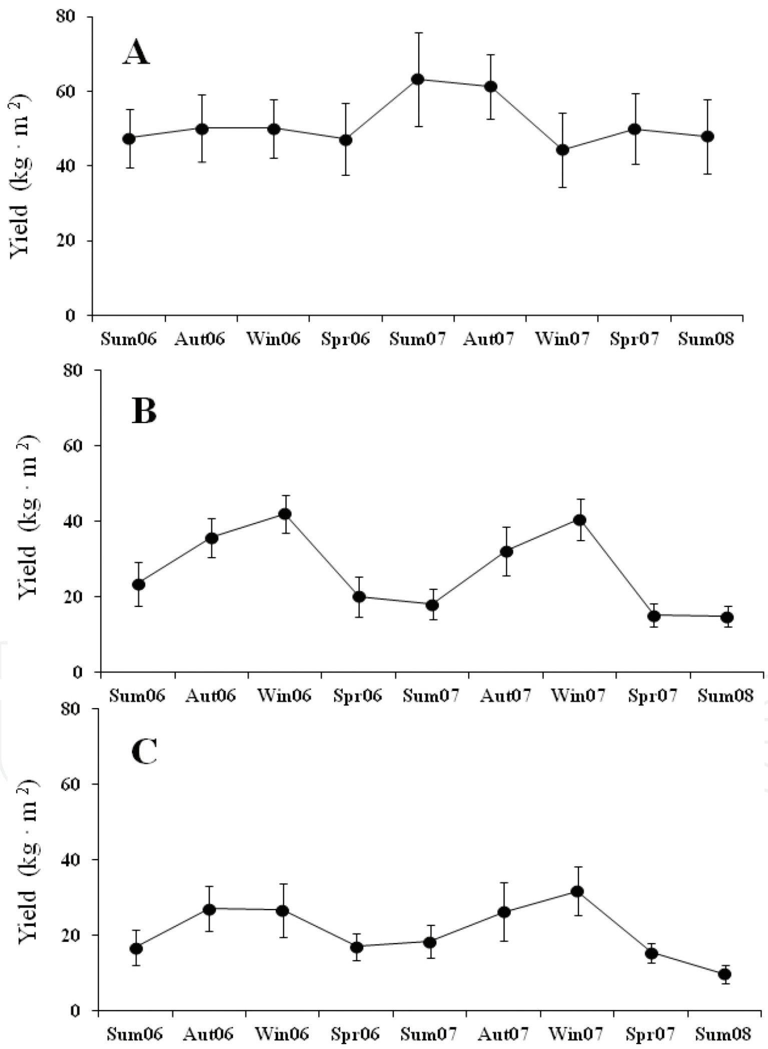

Figure 4. Temporal variation of *Lessonia nigrescens* yield (biomass kg m^2) in kelp beds located in marine protected areas MPC (A), management areas for exploitation of benthic resources (MAEBR), and open-access area (OAA). Mean + 2SE [49].

In MPA, *Lessonia* yield (kg of biomass/m^2) is constant throughout an annual cycle and close to 50 kg/m^2 (**Figure 4A**). By contrast, the available biomass in MAEBR evidences marked seasonality with an annual cycle of renewal of the kelp post-harvest during spring and summer (**Figure 4B**). A similar tendency is observed in OAA, even if with significantly less available biomass which does not surpass 25 kg/ m^2 (**Figure 4C**). Available biomass is biggest in MPA populations and lowest in OAA populations. In MAEBR and OAA, the available biomass is 50 and 65% lower, respectively, than stocks in MPA [50]. The available biomass in MAEBR represents the permissible limit for sustainable exploitation of the kelp forests and is evidence of the adequate application of the management plan. On the other hand, the level of available biomass in OAA is an indicator of highly exploited populations, and its management program would help to establish sustainability parameters dealing with a strong harvest pressure [49].

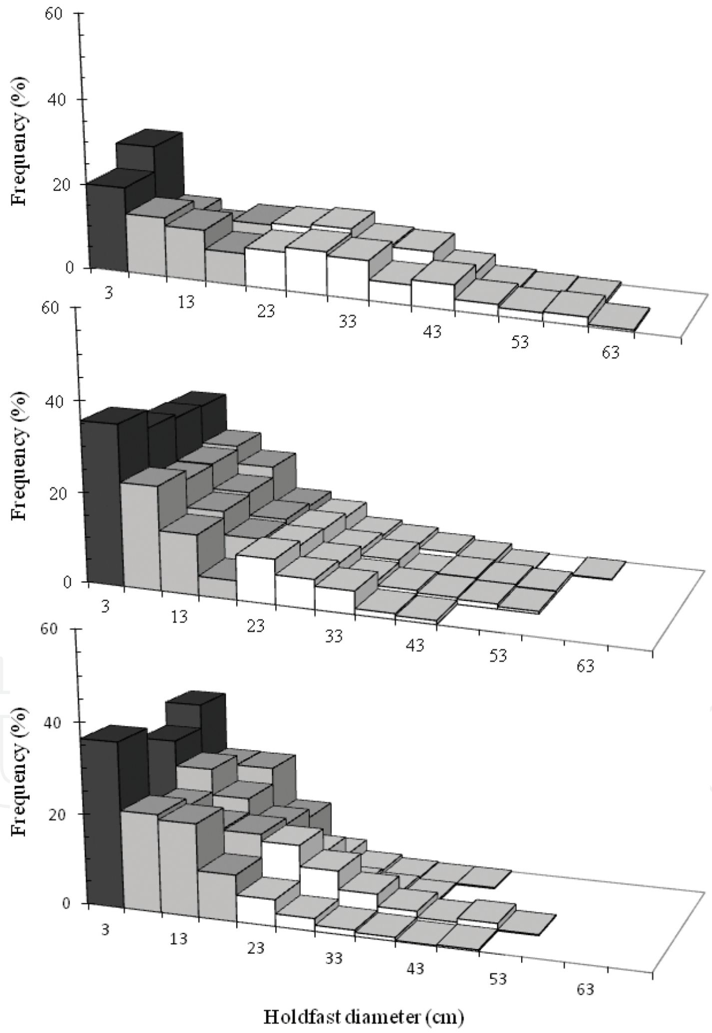

Figure 5. Population structure of *Lessonia nigrescens* in kelp beds located in marine protected areas MPC (A), management areas for exploitation of benthic resources (MAEBR), and open-access area (OAA). The black bars indicate recruits (<5 cm long), the gray bars indicate juvenile plants (without reproductive structures, <20 cm holdfast diameter), and white bars indicate adult plants (with reproductive structures, >20 cm in holdfast diameter) [49].

The size structure of *Lessonia nigrescens* populations, according with the morphological variables suggested [6], varies according to the management and conservation measures applied (**Figure 5**). In MPA, 20% of the populations are recruits and 35% are juveniles, and the rest of the population is adults with large-sized plants (**Figure 4A**). In MAEBR and OAA, recruits represent 35% of the whole population, while juvenile plants represent 45 and 55%, respectively (**Figure 5B, C**). In MAEBR, the fraction of adult plants is renewed by the growth of juvenile plants during the annual cycle, while in OAA, strong harvesting pressure facilitates recruitment and colonization of free primary substrate. In MPA, the portion of adult plants available for harvesting is in general, 45% of the population. In MAEBR, the harvestable portion corresponds to 25% of the total available biomass. By contrast, in OAA, the available biomass for commercial harvesting did not exceed 10% of the total plants in the whole *Lessonia* population studied in Northern Chile [5, 49].

After 25 years of observation and assessment of *Lessonia* populations, after thousands of hours of field monitoring and abundant literature produced, and based on bio-ecological knowledge accomplished, the main concept associated with recommendation for sustainable management of *Lessonia nigrescens* complex is "*how to harvest is more important than how much you harvest*" [6]. This resource management practice has been spread among fisherman during the last 15 years and adopted voluntarily as an alternative to the traditional precautionary method, in which the fishing authority imposes a capture quota, arises from the total available biomass [5, 49]. However, fulfilling the premise previously mentioned requires good practices on the part of artisanal fishermen, who are the only authorized users to harvest brown algae in Chile. The correct application of the management recommendations of MAEBR seems to be strongly related to the social capital that co-management generates [54], a concept that does not make sense in OAA where harvesting activity is individual and difficult to enforce (see [52–54]). The wide latitudinal extension of the littoral zone and several restrictions to it access increase the cost of enforcement and decrease the efficacy of control of the fishing authority [10]. Therefore, as in many other cases if not all of them, the construction of participative awareness is a key factor in the conservation of natural populations of Chilean kelps and the sustainability of this resource [5, 49].

As last recommendations, it will be necessary to make significant progress in areas such as: (a) perfection of the capacities of commercial management by using social capital, (b) optimization of control mechanisms and enforcement considering the idiosyncrasy of Chilean artisanal fishermen, (c) improvement of information flow between and among the different actors in the productive chain and the authorities, and (d) establishment of controlled extraction of brown algae by using management plans from territorial perspective.

A participative, adaptive, and multidisciplinary management plan requires ecological indicators that permanently monitor administrative measures agreed upon by the direct users of *Lessonia* resource. Considering that these ecological indicators need to be validated [55], they can be selected from administrative measures regarding brown algae such as volume harvested, capture per amount of effort, and minimum legal size of capture [50]. Landing of harvested volume is an easy indicator to track and verify but requires an efficient, participative recording system, in real time, allowing the reaching and use of information at the right moment (**Table 1**). Capture per amount of effort and minimum legal size are indicators that are comparatively more complex to monitor and enforce, because they depend on the participation of scientific observers and also on the interest of fishermen to generate such records (**Table 1**). These indicators are useful tools to assign harvest quotas, establish rotation areas, or to establish extractive or biological bans [49].

Resource variable	**Description**	**Time regime**	**Decision policy**	**Verification source**	**Additional requirements**	**Investment items**
Landing (kg)	Fishing/ harvesting area	Permanent (daily)	Once fishing quota is reached, stop the harvest	Artisanal fishing	Implemen tation of an electronic registration system for harvest/ landing	Implemen tation, maintenance of electronic equipment. Training
Capture per unit effort (CPUE)	Capture per unit effort (kg/h/ fisherman) per bed or area. Fishing gear: "barreta"	Permanent (Monthly)	Once CPUE >150 kg/fisherman/h (Fishing ban, extraction area rotation, change fishing gear)	Scientific survey, Landing register, Fishermen statistics	Implemen tation of CPUE registration system by area	Monitors for recording landing information. Training
Minimum legal size of capture (MLS)	Morpholo gical variable: holdfast diameter. MLS 20 cm	Permanent (seasonal)	Once MLS of holdfast diameter ≤ 20 cm. (Change harvesting area, fishing ban)	Scientific survey, landing register, fishermen statistics	Implemen tation of a registration system of MLS by area	Monitors for recording landing information. Training

Table 1. Resource variables proposed to monitor the harvest of Lessonia nigrescens complex.

The effect of harvesting in OAA has been explained by the absence of precautionary management measures in a scenario of high demand for biomass [9, 14, 44, 46]. Thus, management based on the ecosystem approach requires ecological indicators sensitive to harvesting pressure, which allow establishment of decision criteria that are easy to observe, communicate, and measure by both scientific observers and artisanal fishermen [49]. Demographic attributes, such as density of adult plants, biomass per unit of area, recruitment, and size structure all constitute indicators that satisfy these characteristics, are easy to obtain and can be evaluated along spatial and temporal gradients (**Table 2**) [49].

Demographic variable	**Description**	**Time period**	**Decision policy (criteria)**		**Verification source**	**Additional requirements**	**Investment items**
			Harvest	**No-harvest**			
Density of adult plants >20 cm holdfast diameter	Number of plants per m^2	Permanent (seasonal)	Once adult plant density ≥2.0 plants m^2	Once adult plant density ≥1.5 plants m^2	Landing from fishermen, Scientific survey	Implementation of a registration system by harvesting area, zone or Region	Training for registration system. Scientific survey
Biomass	kg/m^2		Once biomass ≥25 kg m_2	Once biomass <20 kg/m^2			
Recruitment	Number of recruits m^2 ≤1 cm holdfast diameter		Once number of recruits ≤5 plants/m^2	Once number of recruits > 40 plants/m^2			
Size structure of populations in natural beds	Population size structure using holdfast diameter as morphological indicators		Once standing crop ≥30% standing stock	Once standing crop <20% standing stock			

Table 2. Demographic variables proposed to monitor the harvest of Lessonia nigrescens complex.

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Based on demographic indicators, the rule establishes that the harvest in OAA should begin when the abundance and biomass of a population per unit of area is close to biomass or demographic levels detected in an un-intervened population (e.g., MPA): There is a minimal density of recruits, the portion of adult plants must be above 40% of the total population, and the percentage of remaining adult plants in the area should be enough to generate post-harvest recruitment (**Table 2**). Afterward, once the population reaches levels of abundance and biomass per unit of area similar to those found in the population under intense harvesting pressure (e.g., OAA), its sustainability will depend on following elements: (1) stability of recruitment frequency, (2) maintenance of a stock of reproductive individuals, and (3) stability of harvesting frequency. Once these indicators exceed the harvesting period should end and should be followed by a recess period (ban or quotas), until adequate pre-harvest values would be reached (**Table 2**). Thus, the installation of a permanent monitoring program of the populations of *Lessonia nigrescens* complex in OAA and in MAEBR, using demographic indicators, will allow as follows: (a) validation of the application of management plans, (b) detection of the deleterious effects on population dynamics produced by exogenous disturbances in the harvest, (c) respect the necessary period to renew the forest to optimal harvesting levels, and if necessary, (d) determination of extraction quotas by sector, and (e) establishment of extraction bans in a justifiable, participative, and localized way.

6. Concluding remarks

The landings of brown seaweeds in Chile [61] reach 390,000 wet tons/year being the world's largest landings from natural populations. This fishery is managed under the concept of "good practices," based on biological and ecological knowledge of the species [6, 12, 14, 23, 25, 32, 48, 57–59]. Most of the brown macroalgae are known as foundational species of marine ecosystems [12]; they constitute the basis of coastal food webs [14, 26, 60, 62], contribute significantly to the total biomass of the ecosystem [23, 32], and are highly connected with all trophic levels [61]; they provide shelter, food, nursery, and breeding areas [23, 32, 6]. Indiscriminate harvest of a foundational species as *L. nigrescens* can generate a significant negative impact on the ecosystem with unknown effects. In this context, ecological indicators proposed [49] are tools for stakeholders and policy makers, enabling greater sustainability of exposed rocky shores in cold temperate seas of the world where these kelp of economic importance are key dominant organisms in cover, biomass, and ecological role.

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References

[1] Dillehay T (1989) Monte Verde. Late Pleistocene Settlement in Chile. Volume 1. Paleoenvironment and site context. Smithsonian Institution Press, Washington & London.

[2] Dillehay T (1997) Monte Verde. Late Pleistocene Settlement in Chile. Volume 2. The archaeological context and interpretation. Smithsonian Institution Press, Washington & London.

[3] Vásquez JA & Vásquez LA (2016) Algas Marinas Chilenas: aspectos etnográficos y socioculturales. Anales del VI Congreso Internacional de Etnobotánica, Córdoba (Spain), November 17–21, 2014.

[4] Vásquez JA & Fonck E (1994) Algas productoras de ácido algínico en Sudamérica: diagnóstico y proyecciones. In: Documento de Campo N° 13 Situación actual de la industria de macroalgas productoras de ficocoloides en América Latina y el Caribe. FAO-Italia. Programa Cooperativo Gubernamental: 17–26.

[5] Vásquez JA, Piaget N & Vega JMA (2012) Chilean *Lessonia nigrescens* fishery in northern Chile: how do you harvest is more important than how much do you harvest. Journal of Applied Phycology 24:417–426.

[6] Vásquez JA (2008) Production, use and fate of Chilean brown seaweeds: re-sources for a sustainable fishery. Journal of Applied Phycology 20 (5):457–467.

[7] Vásquez JA, Zuñiga S, Tala F, Piaget N, Rodriguez DC & Vega JMA (2014) Economic evaluation of kelp forest in northern Chile: values of good and service of the ecosystem. Journal of Applied Phycology 26:1081–1088.

[8] Hoffmann AJ & Santelices B (1997) Flora Marina de Chile Central. Ediciones Universidad Católica de Chile, Santiago. Chile 356 pp.

[9] Vásquez JA & Westermeier R (1993) Limiting factors in optimizing seaweed yield in Chile. Hydrobiologia 260/261:313–320.

[10] Frangoudes K (2011) Seaweeds Fisheries Management in France, Japan, Chile and Norway. Cahiers Biologie Marine 52:517–525.

[11] Vásquez JA (1992) *Lessonia trabeculata*, a subtidal bottom kelp in northern Chile: a case of study for a structural and geographical comparison. In: U. Seeliger (Ed.), Coastal Plant Communities of Latin America. Academic Press Inc., San Diego: 77–89.

[12] Graham MH, Vásquez JA & Buschmann AH (2007) Global ecology of the giant kelp Macrocystis: from ecotypes to ecosystems. Oceanography and Marine Biology: An Annual Review 45:39–88.

[13] Vásquez JA, Vega JMA & Buschmann AH (2006) Long term variability in the structure of kelp communities in northern Chile and the 1997–98 ENSO. Journal of Applied Phycology 18:505–519.

[14] Thiel M, Macaya EC, Acuña E, Arntz WE, Bastias H, Brokordt K, Camus PA, Castilla JC, Castro LR, Cortés M, Dumont CP, Escribano R, Fernandez M, Gajardo JA, Gaymer CF, Gomez I, González AE, González HE, Haye PA, Illanes JE, Iriarte JL, Lancellotti DA, Luna-jorquera G, Luxoro C, Manriquez PA, Marín V, Muñoz P, Navarrete SA, Perez E, Poulin E, Sellanes J, Sepúlveda HH, Stotz W, Tala F, Thomas A, Vargas CA, Vásquez JA & Vega A (2007) The Humboldt Current System of northern-central Chile: oceanographic processes, ecological interactions and socioeconomic feedback. Oceanography and Marine Biology: An Annual Review 45:195–344.

[15] Buschmann AH, Moreno C, Vásquez JA & Hernandez-Carmona MC (2006) Reproduction strategies of *Macrocystis pyrifera* (Phaeophyta) in southern Chile: the importance of population dynamics. Journal of Applied Phycology 18:575–582.

[16] Vega JA, Vásquez JA & Buschmann AH (2005) Population biology of the subtidal kelps *Macrocystis integrifolia* and *Lessonia trabeculata* (Laminariales, Phaeophyceae) in an upwelling ecosystem of northern Chile: interannual variability and El Niño 1997–1998. Revista Chile Historia Natural 78:33–50.

[17] Muñoz V, Hernández-González MC, Buschmann AH, Graham MH & Vásquez JA (2004) Variability in per capita oogonia and sporophyte production from giant kelp gametophyte (*Macrocystis pyrifera*, Phaeophyceae). Revista Chile Historia Natural 77:639–647.

[18] Tellier F, Tapia J, Faugeron S, Destombe C & Valero M (2011) The *Lessonia nigrescens* species complex (Laminariales, Phaeophyceae) Shows strict parapatry and complete reproductive isolation in a secondary contact zone. Journal of Phycology 47:894–903.

[19] Tellier F, Vega JMA, Broitman B, Vásquez JA, Valero M & Faugeron S (2011) The importance of having two species instead of one in kelp management: the *Lessonia nigrescens* species complex. Cahiers Biologie Marine 52:455–465.

[20] González A, Beltrán J, Hiriart-Bertrand L, Flores V, de Reviers B, Correa JA & Santelices, B (2012) Identification of cryptic species in the *Lessonia nigrescens* complex (Phaeophyceae, Laminariales). Journal of Phycology 48:1153–1165.

[21] Alveal K, Romo H & Avila M (1982) Estudios del ciclo de vida de Macrocystis pyrifera de Isla Navarino, Chile. Gayana Botanica 39:1–12.

[22] Borazo de Zaixo AL, Piriz ML & Romanello EE (1983) Posibilidades de desarrollo de la industria alguera de la Provincia de Santa Cruz (República Argentina). Informe preparado para el proyecto "Cinco Provincias Argentinas OEA" 187 pp.

[23] Santelices B, Castilla JC, Cancino J & Schmiede P (1980) Comparative ecology of *Lessonia nigrescens* and *Durvillaea antartica* (Phaeophyta) in central Chile. Marine Biology 59:119–32.

[24] Santelices B & Lopehandía J (1981) Chilean seaweeds resources: a quantitative review of potential and present utilization. In: 10th Proc Int Seaweed Symp: 725–730.

[25] Santelices B (1982) Bases Biológicas para el manejo de *Lessonia nigrescens* (Phaeophyta, Laminariales) en Chile Central. Monografías Biológicas 2:135–150.

[26] Santelices B (1989) Algas marinas de Chile: Distribución, Ecología, Utilización, Diversidad. Ediciones Universidad Católica de Chile, Santiago de Chile, 399 pp.

[27] Werlinger C & Alveal K (1988) Evaluación de algas en ambientes restringidos del Golfo de Arauco (Chile): Punta Fuerte Viejo a Río Tubul. Gayana Botánica 45:461–474.

[28] Vásquez JA (1991) Variables morfométricas y relaciones morfológicas de *Lessonia trabeculata* Villouta & Santelices, 1986 en poblaciones submareales del Norte de Chile. Revista Chile Historia Natural 64:271–279.

[29] Vásquez JA (1993) Natural mortality of giant kelp *Macrocystis pyrifera* affecting the fauna associated with its holdfasts. Pacific Science 47:180–184.

[30] Vásquez JA (2015) Evaluación de poblaciones de *Lessonia nigrescens* ("huiro negro") en cuatro localidades del norte de Chile (II y III Región). Informe de Circulación restringida para Exportaciones M2. 76 pp.

[31] Westermeier R, Murúa P, Patiño DJ, Muñoz L, Atero C & Müller DG (2014) Repopulation techniques for *Macrocystis integrifolia* (Phaeophyceae: Laminariales) in Atacama, Chile. Journal of Applied Phycology. 26:511–518.

[32] Santelices B & Ojeda FP (1984) Effects of canopy removal on the understory algal community structure of coastal forests of *Macrocystis pyrifera* from southern South America. Marine Ecology Progress Series 14:165–173.

[33] Vásquez JA & Buschmann AH (1997) Herbivory-kelp interactions in subtidal Chilean communities: a review. Revista Chile Historia Natural 70:41–52.

[34] Macaya EC & Zuccarello GC (2010) Genetic structure of the giant kelp *Macrocystis pyrifera* along the southeastern Pacific. Marine Ecology Progress Series 420:103–102.

[35] Vásquez, JA & Tala F (1995) Experimental repopulation of *Lessonia nigrescens* (Phaeophyta, Laminariales) in intertidal areas of northern Chile. Journal of Applied Phycology 7:347–349.

[36] Gutiérrez A, Correa T, Muñoz V, Santibáñez A, Marcos R, Cáceres C & Buschmann AH (2006) Farming of the giant kelp *Macrocystis pyrifera* in southern Chile for development of novel food products. Journal of Applied Phycology 18:259–267.

[37] Correa JA, Lagos N, Medina M, Castilla JC, Cerda M, Ramírez M, Martínez E, Faugeron S, Andrade S, Pinto R & Contreras L (2006) Experimental transplants of the large kelp *Lessonia nigrescens* (Phaeophyceae) in high-energy wave exposed rocky intertidal habitats of northern Chile: experimental, restoration and management applications. Journal of Experimental Marine Biology and Ecology 335:13–18.

[38] Westermeier R, Patiño DJ & Müller DG (2007) Sexual compatibility and hybrid formation between the giant kelp species *Macrocystis pyrifera* and *Macrocystis integrifolia* (Phaeophyceae: Laminariales) in Chile. Journal of Applied Phycology 19:215–221.

[39] Wolff R, Zimmermann D, Weber M, Feilen P, Ehrhart F, Salinas-jungjohann RM, Katsen A, Behringer M, Geßner P, Plieb L, Steinbach A, Spitz J, Vásquez JA, Schneider S, Bamberg E, Weber MM, Zimmermann U & Zimmermann H (2005) Real-time 3-D darkfield microscopy for the validation of the cross-linking process of alginate microcapsules. Biomaterials 26:6386–6393.

[40] Zimmermann H, Zimmermann D, Reuss R, Feilen PJ, Manz B, Katsen A, Weber M, Ihmig FR, Ehrhart F, Geßner P, BehringerM, SteinbachA, Wegner LH, Sukhorukov VL, Vásquez JA, SchneiderS, Weber MM, Volke F, Wolff R & Zimmermann U (2005) Towards a medically approved technology for alginate-based microcapsules allowing long-term immunoisolated transplantation. Journal of Material Science: Materials in Medicine 16:491–501.

[41] Zimmermann H, Wahlisch F, Baier C, Westhoff M, Reuss R, Zimmermann D, Behringer M, Ehrhart F, Katsen-Globa A, Giese C, Marx U, Sukhorukov VL, Vásquez JA, Jakob P, Shirley SG & U Zimmermann (2007) Physical and biological properties of barium crosslinked alginate membranes. Biomaterials 28:1327–1345.

[42] Oppliger LV, Correa JA, Faugeron S, Beltrán J, Tellier F, Valero M & Destombe C (2011) Sex ration variation in the *Lessonia nigrescens* complex (Laminariales, Phaeophyceae): effect of latitude, temperature and marginality. Journal of Phycology 47:5–12.

[43] Oppliger LV, Correa JA, Engelen AH, Tellier F, Vieira V, Faugeron S & Destombe C (2012) Temperature effects on gametophyte life-history traits and geographic distribution of two cryptic kelp species. Plos one 7 (6):e39289.

[44] Thompson SA, Knoll H, Blanchette CA & Nielsen KJ (2010) Population consequences of biomass loss due to commercial collection of the wild seaweed *Postelsia palmaeformis*. Marine Ecology Progress Series 413:17–31.

[45] Omoregie E, Tjipute M & Murangi J (2010) Effects of harvesting of the Namibian kelp (*Laminaria pallida*) on the re-growth rate and recruitment. African Journal of Food, Agriculture, Nutrition and Development 10:2542–2555.

[46] Ugarte R (2011) An evaluation of the mortality of the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. produced by cutter rake harvests in southern New Brunswick, Canada. Journal of Applied Phycology 23:401–407.

[47] Ugarte R & Sharp G (2012) Management and production of the brown algae *Ascophyllum nodosum* in the Canadian maritimes. Journal of Applied Phycology 24:409–416.

[48] Martínez EA, Cárdenas L & Pinto R (2003) Recovery and genetic diversity of the intertidal kelp *Lessonia nigrescens* (Phaeophyceae) 20 years after El Niño 1982/83. Journal of Phycology 39:504–508.

[49] Vega JMA, Broitman B & Vásquez JA (2014) Monitoring the sustainability of *Lessonia nigrescens* complex (Laminariales, Phaeophyta) in northern Chile under strong harvest pressure. Journal of Applied Phycology 26:791–801.

[50] Gelcich S, Edwards-Jones G, Kaiser MJ & Watson E (2005a) Using discourses for policy evaluation: the case of marine common property rights in Chile. Society and Natural Resources 18:377–391.

[51] Gelcich S, Edwards-Jones G & Kaiser MJ (2005b) Importance of attitudinal differences among artisanal fishers towards co-management and conservation of marine resources. Conservation Biology 19:865–875.

[52] Gelcich S, Godoy N & Castilla JC (2009). Artisanal fishers' perceptions regarding coastal co-management policies in Chile and their potentials to scale-up marine biodiversity conservation. Ocean Coastal Management 52:424–432.

[53] Marín A, Gelcich S, Castilla JC & Berkes F (2012) Exploring social capital in Chile's coastal benthic co-management system using a network approach. Ecology and Society 17:13.

[54] Garcia SM & Cochrane KL (2005) Ecosystem approach to fisheries: a review of implementation guidelines. ICES Journal of Marine Science 62:311–318.

[55] Vásquez JA (2013) Implementación de un sistema piloto de auto-atención electrónica, para la acreditación de origen de recursos pesqueros. Informe Final Proyecto 11BPC 10060. INNOVA-CORFO Chile. 125 pp.

[56] Vásquez JA & Santelices B (1990) Ecological effects of harvesting *Lessonia* (Laminarials, Phaeophyta) in central Chile. Hydrobiologia 204/205:41–47.

[57] Camus P, Vásquez E, González E & Galaz L (1994) Fenología espacial de la diversidad intermareal en el norte de Chile: patrones comunitarios de variación geográfica e

impacto de los procesos de extinción-recolonización post El Niño 82–83. Medio Ambiente 12 (1):57–68.

[58] Vásquez JA (1995) Ecological effects of brown seaweed harvesting. Botanica Marina 38:251–257.

[59] Seeley RH & Schlesinger WH (2012) Sustainable seaweed cutting? The rockweed (*Ascophyllum nodosum*) industry of Maine and the Martitime Provinces. Annals New York Academy of Science 1249:84–103.

[60] Vásquez JA & Vega JMA (2004) El Niño 1997–1998 en el norte de Chile: efectos en la estructura y en la organización de comunidades submareales dominadas por algas pardas. In: Avaria S, Carrasco J, Rutland J and Yañez E (Eds.). El Niño-La Niña 1997–2000 sus efectos en Chile. CONA. Valparaíso. Chile. 119–135.

[61] Anuario Estadística de Pesca. Subsecretaría de Pesca y Acuicultura, Ministerio de Economía Fomento y Reconstrucción. Gobierno de Chile. www.sernapesca.cl.

[62] Vásquez JA & Santelices B (1984) Comunidades de macroinvertebrados en discos de adhesión de *Lessonia nigrescens* en Chile central. Revista Chile Historia Natural 57:131–154.

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