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Current knowledge on biotechnological interesting seaweeds from the Magellan Region, Chile

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Abstract: This paper is a compilation of data from investigations made with marine benthic algae from the Magellan Region that have biotechnological utilization in human consumption or medicine or as a source of phycocolloids or food supplements or animal feed. The most important Rhodophyta species are: *Ahnfeltia plicata* (Hudson) E.M. Fries for agarose production, *Gigartina skottsbergii* Setchell & N.L. Gardner for carrageenan production, and *Callophyllis variegata* (Bory de Saint-Vincent) Kützing for human consumption. The most important Heterokontophyta species are: *Macrocystis pyrifera* (L.) C. Agardh, and *Durvillaea antarctica* (Chamisso) Hariot for human consumption, alginate production, and as biofertilizer for agricultural crops. *M. pyrifera* is also used as a food supplement for salmon, chickens, quails, sheep and bovines and for biofuel production.

Introduction

The Magellan Region, also known as Southern Chile, is located in the southwestern part of the South American continent (48°36' to 56°S; 66°25' to 75°40'W), and has an area of 132,033.5 km² (Pérez, 2000). It is characterized by diverse marine habitats, which are determined by geomorphological factors, depth, orientation and exposure to waves, marine currents and contributions of continental and glacial waters. It is considered to be a representative area of subantarctic environments of great extension (Rozzi et al., 2008). It represents the southernmost territory of the South American continent, which, up to the moment, has been reasonably protected from the impact of human activities. A total of 488 species of benthic marine algae have been reported for the coast of continental Chile, of which 87 belong to Chlorophyta, 103 to Heterokontophyta, and 298 to Rhodophyta.

For the Magellan region, recent systematic studies (Mansilla et al. in preparation) report a total of 395 species collected on the coasts of the Strait of Magellan, the Beagle Channel and Cape Horn, of which 75 species belong to Chlorophyta, 86 to Heterokontophyta, and 230 to Rhodophyta, which are distributed in 58 families and 143 species. According to Ramirez (1995), 50.6% of endemic species have been recorded in the Magellan Region.

The marine macroalgae (red, brown and green algae) are important as primary producers and as raw material for the production of phycocolloids such as agar, carrageenan, agarose and alginate, used in the food, pharmaceutical and cosmetic industries. Nowadays, several species of macroalgae have been cultivated to produce biomass to supply the increasing global demand. As an agricultural crop, seaweed cultivation might regulate the excess of CO₂, nitrogen and phosphorus in the ecosystem. Algal biotechnology has achieved great advances in the last three decades, mainly for microalgae, which are cultivated for the production of carotenoids and glycerol (Stanley, 1987). The capacities of carotenoids to act as antioxidants and immunomodulatory agents have led to active investigations of their potential application in the prevention of carcinogenic disease.

Other uses of macroalgae are orientated toward biofuel production, mainly *Macrocystis pyrifera* (L.) C. Agardh (Heterokontophyta) for bioalcohol production. Chile mandated the replacement of approximately 5% of the consumption of petroleum by the year 2010 (Comisión Nacional de Energía, 2007). For biofuel production, the use of alternative raw materials like macroalgae for bioethanol production presents several advantages: a) it produces less pollution; b) it emits less pollutant gases; c) it does not contribute to the emission of carbon dioxide or sulphur; d) it helps to diminish global warming; e) it

does not use drinkable water; f) it produces neither waste nor garbage; g) CO and CO₂ are captured directly from industrial sources, among others; and h) it does not occupy cultivable terrestrial areas that can be destined to produce food.

Other potential uses of macroalgae, mainly those of the Subantarctic and Antarctic regions, include the accumulation of substances that absorb UV radiation (photoprotectors) and the activation of antioxidant systems. The mycosporine-like amino acids (MAA) are among the best known photoprotectors, with both photoprotector and antioxidant capacities. On the other hand, several references emphasize the other physiological functions of the MAA, including antioxidant activity, osmotic regulation and in breeding.

In the Magellan Region, the macroalgae *M. pyrifera* and *Porphyra columbina* Montagne (Bangiales, Rhodophyta) have been directly consumed as food (in soups, stews and salads) for many years. Among the red algae existing in the Magellan Region and the Chilean Antarctica, only *P. columbina*, known as "luche", is usually consumed by the population. "Luche" grows in the middle and high regions of the intertidal zone of rocky shores.

Nowadays, increasing tourism in the region has opened the possibility of diversifying the use of subantarctic macroalgae for human consumption, through the transfer of scientific knowledge to the local fishermen. The development of a pilot experiment for gastronomic activity that favors the regional identity of Tourism of Special Interests can generate new possibilities for the use of subantarctic macroalgae and also new options for the fishermen and their families who currently focus their efforts almost exclusively on the extraction of sea urchins and king crabs, which are progressively more overexploited every day. At the same time, the use of macroalgae in the human diet might have positive impacts on the health of the population, who currently incorporate relatively few vegetables into their diets.

Materials and Methods

This study is a compilation of data from investigations made with marine benthic algae from the Magellan Region that are utilized for human consumption or medicine or as a source of phycocolloids, food supplements or animal feed. In this work we focus on Rhodophyta species [*Ahnfeltia plicata* (Hudson) E.M. Fries, *Callophyllis variegata* (Bory de Saint-Vincent) Kützing, and *Gigartina skottsbergii* Setchell & N.L.Gardner], and Heterokontophyta species [*Durvillaea antarctica* (Chamisso) Hariot, and *Macrocystis pyrifera* (L.) C. Agardh].

Results and Discussion

Important red algae in the Magellan Region and Chilean Antarctica

In the Magellan Region, some species of red algae of economic importance are collected by fishermen and companies to produce phycocolloids with commercial value.

Gigartina skottsbergii Setchell & N.L.Gardner (Gigartinales, Rhodophyta)

G. skottsbergii is a carrageenan-producing species, endemic to the Southern region of South America (Ramirez & Santelices, 1991; Buschmann et al., 2008). It is known by the common name of "luga roja" or "cuero de chanco". On the coast of Chile, it is distributed from Corral (39° 88' S) (Westermeier & Ramírez, 1978, Ramirez & Santelices, 1991) to the Antarctic Peninsula (63° 23'S) (Bischoff-Bäsmann & Wiencke, 1996). On the coast of Argentina, it is present in Patagonia from Puerto Madryn (42° 08' S), Chubut, to the southern coast of Argentina and subantarctic islands (Piriz, 1996). It occurs in subtidal areas, forming abundant populations in protected environments. The Magellan Region is the main producer of *G. skottsbergii* biomass of the country, with the production of near twenty thousand tons of dry alga. In the region, this alga is harvested exclusively from natural populations. Other carrageenan-producing macroalgae in the region that are not yet commercialized are: *Iridaea cordata* (Turner) Bory de Saint-Vincent, *Mazzaella laminarioides* (Bory de Saint-Vincent) Fredericq, and *Sarcothalia crispata* (Bory de Saint-Vincent) Leister.

G. skottsbergii presents a thick, fleshy, erect red-purple laminar thallus that grows attached to rocks (Figure 1 A-B), pebbles, stones and bivalve shells like *Aulacomya ater*. It is arranged horizontally on the substrate and remains attached by holdfasts and by several haptera that develop in different parts of the frond. This form of growth limits the availability of substrate, reducing the development of other species. The life cycle is isomorphic, of the *Polysiphonia* type. The carposporophytic fronds present protruding cystocarps in papillae distributed over the entire surface of the frond. Male fronds have no papillae. The tetrasporangial sori are located on the edge of the cortex and medulla. The frond is of varying size, wider than long, orbicular in form, and can reach up to 1.5 m in width. They grow at depths ranging from 4 to 30 m or so, depending on the geographical place and location.

In the past two decades, significant knowledge of the ecology and productivity of natural populations of *G. skottsbergii* has been obtained and basic aspects of the biology and management of this species have also been

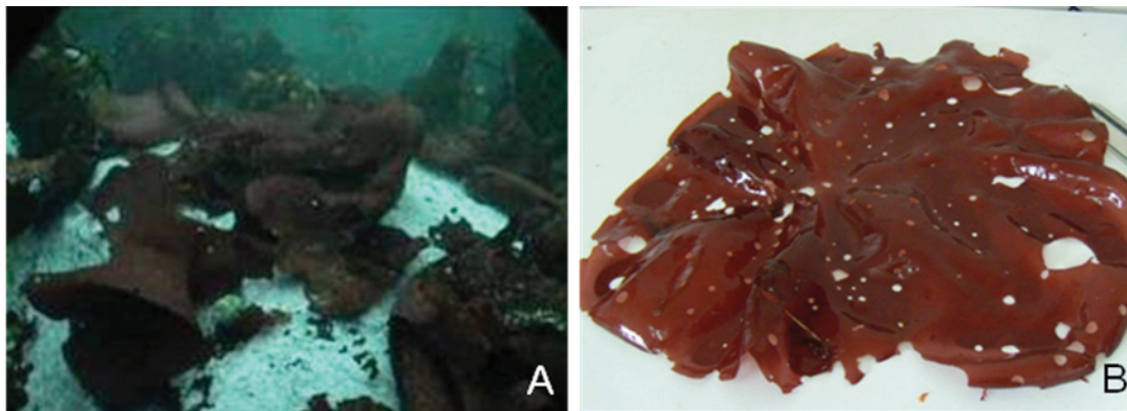


Figure 1. *Gigartina skottsbergii* (Gigartinales, Rhodophyta): habitat (A) and aspect of thallus (B) collected in Magellan Region, Chile.

studied. This basic knowledge includes aspects such as: the ultrastructure of the spores, phenological studies and population dynamics (Avila et al., 1999a), recruitment in natural populations (Westermeier et al., 1999), vegetative propagation in tanks and in the sea (Hernández-González et al., 2007; Romo et al., 2006; Correa et al., 1999; Westermeier et al., 2012), management (Avila et al., 1999b; Westermeier et al., 2012), and methods of cultivation and repopulation (Avila et al., 1999a; Buschmann et al., 2001; Avila et al., 2003; Buschmann et al., 2004; Romo et al., 2006; Mansilla et al., 2008; Westermeier et al., 2012). Reproductive biological records indicate that this species exhibits seasonality in its sexual reproduction (Zamorano & Westermeier, 1996) and alternation in the dominance of reproductive stages, similar to that described for other species of Gigartinales (Kim, 1976).

Recently, pilot programs for repopulation of *G. skottsbergii* have been implemented through research projects with the financial support of the Chilean National Commission for Scientific and Technological Research in the region of Los Lagos and the Magellan Region. An educational program for fishermen and their families (Edukaluga Program) has been initiated as part of the project AQII011 focusing on expanding and strengthening the knowledge that fishermen have about management, repopulation and algal resource sustainability.

***Ahnfeltia plicata* (Hudson) E.M. Fries (Ahnfeltiales, Rhodophyta)**

A. plicata is considered to be one of the most important agarophytes in the world (Maggs & Pueschel, 1989), producing agar of high quality and low sulphate content. It is harvested mainly on the Russian coast of the White Sea (Maggs & Pueschel, 1989). This species is widely distributed, occurring in the North Atlantic Ocean, in the northern North Pacific and southern South Atlantic and South Pacific Oceans (Maggs & Pueschel, 1989).

In Chile, the occurrence of *A. plicata* was reported in Tierra del Fuego (Wiencke & Clayton, 2002), the Magellan Region and the Diego Ramírez Islands (Mansilla & Navarro, 2003). In the Magellan Region, *A. plicata* grows on rocky substrates from the intertidal zone to 20 m in depth, in sheltered or wave-exposed sites. This species is tolerant to a wide range of salinity variation, from 18 to 40 psu. Along the exposed coast of Riesco Island (Seno Skyring, Magellan Region), *A. plicata* forms extensive beds, producing a biomass of 3 kg.m⁻² (fresh weight), with a yield of 20% in dry weight. The salinity of this area is 22 psu (Ortiz et al., 2011).

Samples of *Ahnfeltia plicata* collected during the spring, summer and autumn from Riesco Island (Magellan Region) showed the presence of agarans (Ortiz et al., 2011). Chemical analysis of agarans obtained in different seasons showed that the content of galactose and 3,6-anhydro-galactose is in a 1:1 ratio and elemental analysis showed that the sulfur content of agarans is less than 0.1%, indicating that the neutral agaran presents the structure of agarose (Ortiz et al., 2011). *A. plicata* is source of agar with high quality, low sulphate content and high gel strength, even in very low concentrations. This agar is used as a gelling and thickening agent by food industries and as a stabilizing agent by cosmetic and pharmaceutical industries.

The morphology of *A. plicata* gametophytes is represented by erect axes, 3 to 21 cm long, which arise in tufts from crustose holdfasts (1 cm diameter). Branching is generally irregular and variable, with some axes forming dichotomies or irregular branches (Figure 2 A-B). Male gametophytes form spermatangial sori on mature axes and are absent in the apical and basal regions of the axes. Similarly, female sori are formed on mature axes, usually along one side of the axis. The life history of *A. plicata* from Canada is heteromorphic, involving the erect thallus of gametophytes and crustose tetrasporophytes, which grow very closely appressed to hard substrata (Maggs &

Pueschel, 1989). However, the life history of *A. plicata* from the South Atlantic and South Pacific Oceans remains to be investigated.

***Callophyllis variegata* (Bory de Saint-Vincent) Kützing (Gigartinales, Rhodophyta)**

C. variegata is a red alga exported as raw material for direct consumption in salads for its bright colors and high content of minerals and vitamins. In Chile, it is known by the common name of "carola". It is distributed in New Zealand, Australia, South Africa, South America, Antarctica and subantarctic regions (Guiry & Guiry, 2012; Arakaki et al., 2011). In Chile, this species has been collected at numerous locations between Antofagasta (23° 38'S) and Cape Horn (55° 43'S). They form subtidal populations, where the fronds grow attached to rocks in semi-exposed or protected habitats, between 0-15 m in depth.

Experimental cultivation of this species has been attempted from carpospores (Hernandez et al., 2010). Phenological studies show that natural populations of *Callophyllis* in Chiloe have a marked seasonal cycle of abundance, with a maximum of 50 g/m² (dry weight) between January and March. (Escalona et al., 1998; Filun et al., 1999; Hernandez et al., 2010) and non-reproductive fronds can be found throughout the year.

C. variegata has flattened fronds branched dichotomously, of intense red color with a small disc of attachment, highly variable in morphology with a smooth texture, up to 30 cm in length (Figure 3 A-D). The life cycle is isomorphic; carposporophytic fronds with many prominent cystocarps are located at the edges of the branches, with 1 to 3 ostioles (Figure 3 D). The tetrasporangia differ in the cortex and are cruciately

divided, distributed over the surface of the frond and hardly distinguishable to the human eye (Hoffmann & Santelices, 1997, Arakaki et al., 2011).

Important brown macroalgae in the Magellan Region and Chilean Antarctica

Among the brown algae, the most representative and the largest is *Macrocystis pyrifera*, known as "huiro". In the Strait of Magellan, some of them are almost 30 m or more in length and can weigh more than 100 kg, with holdfasts more than 80 cm in diameter and 70 cm high (Mansilla & Avila, 2011).

These algae, which grow abundantly and form large subtidal beds similar to "Submarine Forests", provide environments that shelter fish, crustaceans, and mollusks, besides providing food and areas of reproduction for vertebrates and invertebrates and a substratum for fixation of a varied community of marine benthic algae (Mansilla & Avila, 2011).

The macroscopic species of "huiros" are harvested for the extraction of alginates, used widely not only in the food industry, but also in the pharmaceutical industry. It is also used as food for the mollusk abalone, introduced into Chile and developed for export as a marine cultivated product. In Chile, investigations have been made of the use of this species as a food supplement for salmon (Mansilla et al., 2005).

The largest brown algae in the group is *Durvillaea antarctica*, commonly known in Chile as "cochayuyo". In Chile, "cochayuyo" serves as human food and its commercialization in different riverside cities and its transport by mule to cities in the interior and to Andean settlements play an important social role. A significant quantity of this alga is sold to companies that produce

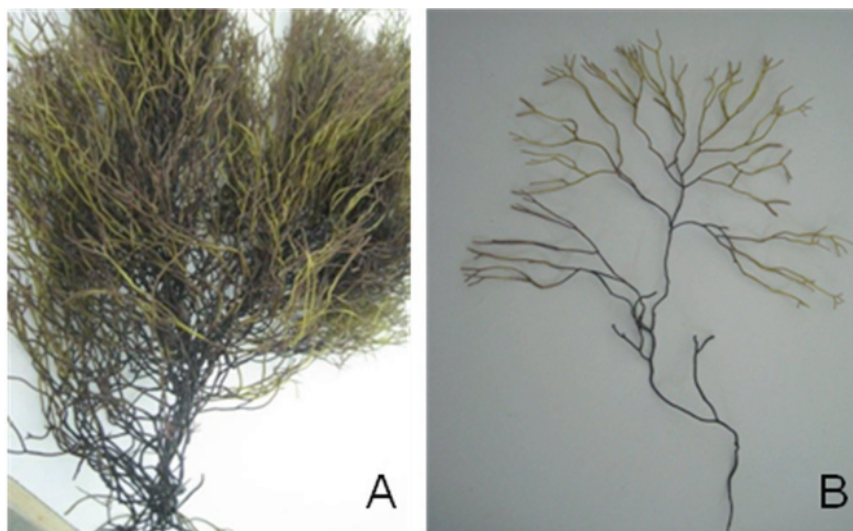


Figure 2. *Ahnfeltia plicata* (Ahnfeltiales, Rhodophyta): habitat (A) and detail of thallus (B) collected in Magellan Region, Chile.

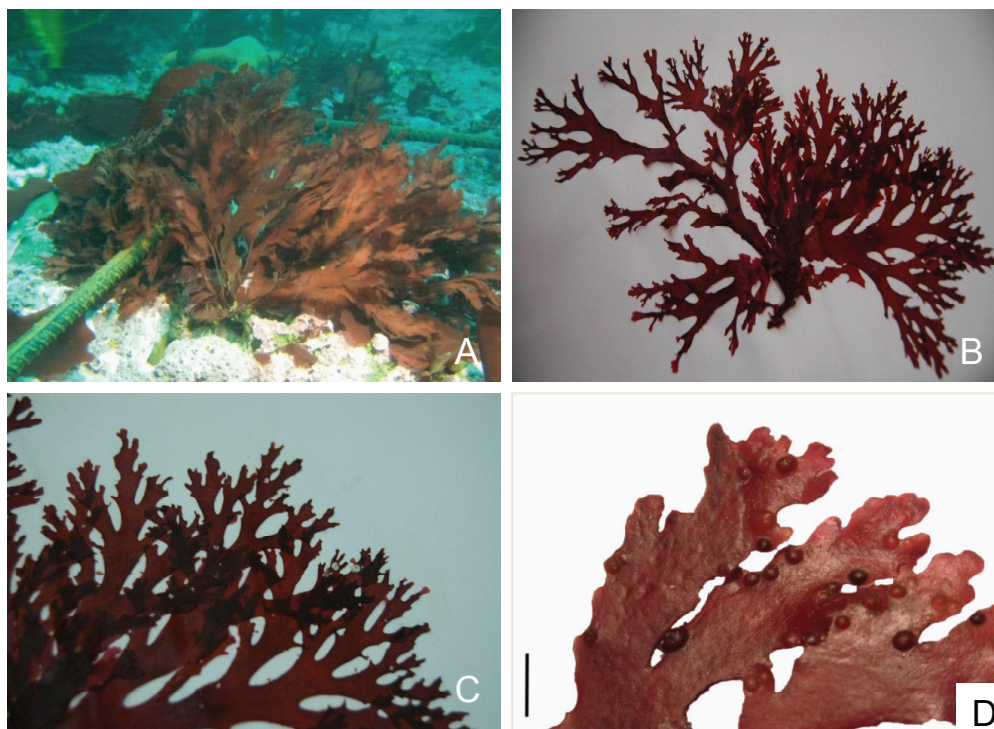


Figure 3. *Callophyllis variegata* (Gigartinales, Rhodophyta): habitat (A), general aspect of thallus (B), detail of thallus (C), and detail of cystocarps in female gametophyte (D) collected in Magellan Region, Chile. Scale = 3 mm.

alginate for export, an industry that has suffered from the decrease in the quantities of existing natural beds.

During the last few years in Chile, important advances have been made in the biological knowledge of *M. pyrifera* and *D. antarctica*. These brown algae live in the intertidal and subtidal coastal zones, on hard substrata, normally in rocky zones, to which they stick and hold by means of a basal disc or holdfast. One of the most notable characteristics is their size (Santelices, 1989), especially the algae mentioned previously, whose fronds can reach several meters of length, and they form real submarine forests and belts that border along the coast. In clear waters, the species of this group can live at great depths.

***Durvillaea antarctica* (Chamisso) Hariot (Fucales, Heterokontophyta)**

This resource is harvested on the shore in the central zone of Chile by collectors. The activity is done during low tide periods, when the stipes are cut from the basal region, the holdfasts remaining on the substrate (Castilla & Bustamante, 1989; Bustamante & Castilla, 1990). Fronds and dry stipes are used for direct human consumption, being commercialized in the local markets as ingredients for salads under the name of "ulte" or "Huilte" and in packages of dry whole or chopped alga under the name of "cochayuyo". Annually, important amounts are harvested (2307 ton), a percentage of this

being exported as dry algae cut into strips under the name of "seaweed noodles" or as raw material for the alginate industry. Nowadays, the most important regions where this resource is collected are, in order of importance, the VIII, VI and X regions of Chile, whereas in the IV and V regions only minor volumes are extracted. In the Magellan Region, fresh and/or dry algae is used for the preparation of domestic recipes.

This species has been widely used in New Zealand; since 1960, it has been collected and used as forage for cattle and as fertilizer. Since the 1970's, it has been harvested for the production of alginate. Recent studies indicate that fronds of *D. antarctica* contain over 50 % of dry weight of alginate with a FM value of 0.7 (Kelly & Brown, 2000).

D. antarctica is a species endemic to the Southern Hemisphere, with a subantarctic distribution. In Chile, it is distributed from Coquimbo down to Cape Horn (Ramirez & Santelices, 1991; Santelices, 1989). It is also found in New Zealand, Argentina (Tierra del Fuego), the Falkland/Malvinas Islands, Heard Island and McDonald Islands (Hoffmann & Santelices, 1997; Vasquez, 2008). It grows on rocky substrates in the low intertidal zone up to approximately 10 or 15 m in depth. It is typical of very exposed zones and shares the substratum with species like *Lessonia*.

The thallus of *D. antarctica* is dark greenish-brown in color and can measure up to 15 m in length (Figure 4 A-D). They are fixed to the substratum by means



Figure 4. *Durvillaea antarctica* (Fucales, Heterokontophyta): habitat (A-B), general and detail aspects of holdfasts and stipes (C-D) of specimens from Magellan Region, Chile.

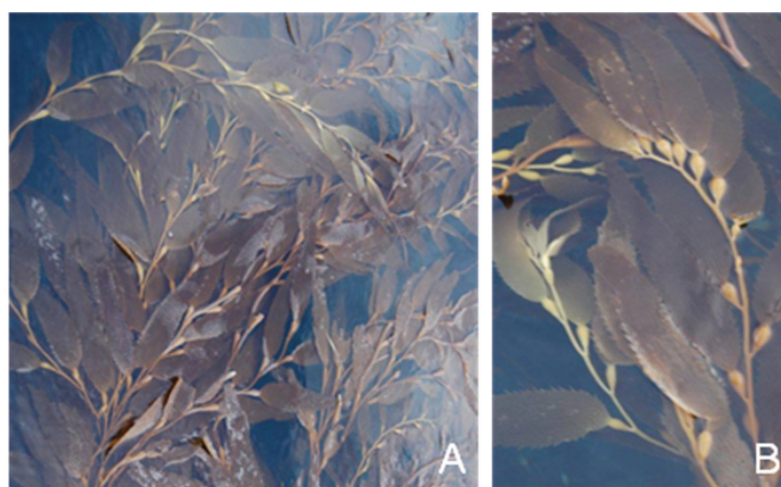


Figure 5. *Macrocystis pyrifera* (Laminariales, Heterokontophyta): habitat (A) and detail of thallus (B) of specimens from Magellan Region, Chile.

of a conical, compact disk of circular contour and smooth surface (Figure 4 C-D). From the disc, a distally flattened thick cylindrical stipe is developed, forming thick fronds of coriacea consistency divided into many thin segments in the shape of thick tapes of different lengths that float on the surface of the sea. The life cycle is diplobiontic, with an independent diploid phase. The meiosis occurs in the gametogenesis and corresponds to a dioecious species with small gametophytes of short duration (Buschmann et al., 1984).

***Macrocystis pyrifera* (L.) C. Agardh (Laminariales, Heterokontophyta)**

This species is distributed from Tocopilla to Cape Horn and is used for the extraction of alginates and food. In the Magellan Region, the forests of *M. pyrifera* are distributed parallel to the coast, forming constant and irregular belts approximately 30 to 45 m in width.

M. pyrifera, commonly known like “huiro” or “Sargaso”, corresponds to plants of large size that can

measure up to 90 m of length (Figure 5 A-B). They stick fast to the substratum through a basal disc or holdfast formed by branched unfused haptera up to 1 cm in thickness (Hoffmann & Santelices, 1997). Several cylindrical stipes arise from the disc, can be divided into two, and finish in elongated sheets provided with elongated basal air bladders. Between the terminal portion of the stipes and the base of the sheets, fissures are produced in the distal direction moving towards the edge of the sheet, producing the growth of stipes and sheets (Santelices, 1989; Hoffmann & Santelices, 1997). The life cycle of *Macrocystis pyrifera* is heteromorphic and is characterized by the alternation of generations between an individual macroscopic diploid, corresponding to the sporophyte, and individual microscopic haploids, corresponding to female and male gametophytes.

Its utilization is mainly as a raw material for the production of alginates. Nevertheless, other important uses are: i) flour for supplementing the food of salmon, chickens, quails, sheep and bovines; ii) as a source of biofuels; iii) utilization of the carbohydrates to promote the growth of marine organisms of commercial interest; iv) as a biofertilizer for agricultural crops, and v) for human consumption through culinary recipes.

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