THE SEAWEED RESOURCES OF SPAIN

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MAIN ENVIRONMENTAL FACTORS

From a marine biogeographic point of view, the Spanish coasts are included in the Warm Temperate Mediterranean-Atlantic Region, Lusitanian and Mediterranean Provinces (Van den Hoek 1975). Considering the geographic distribution and the superficial water temperatures, the Spanish coastline can be divided into four sub-regions (Fig. 1).

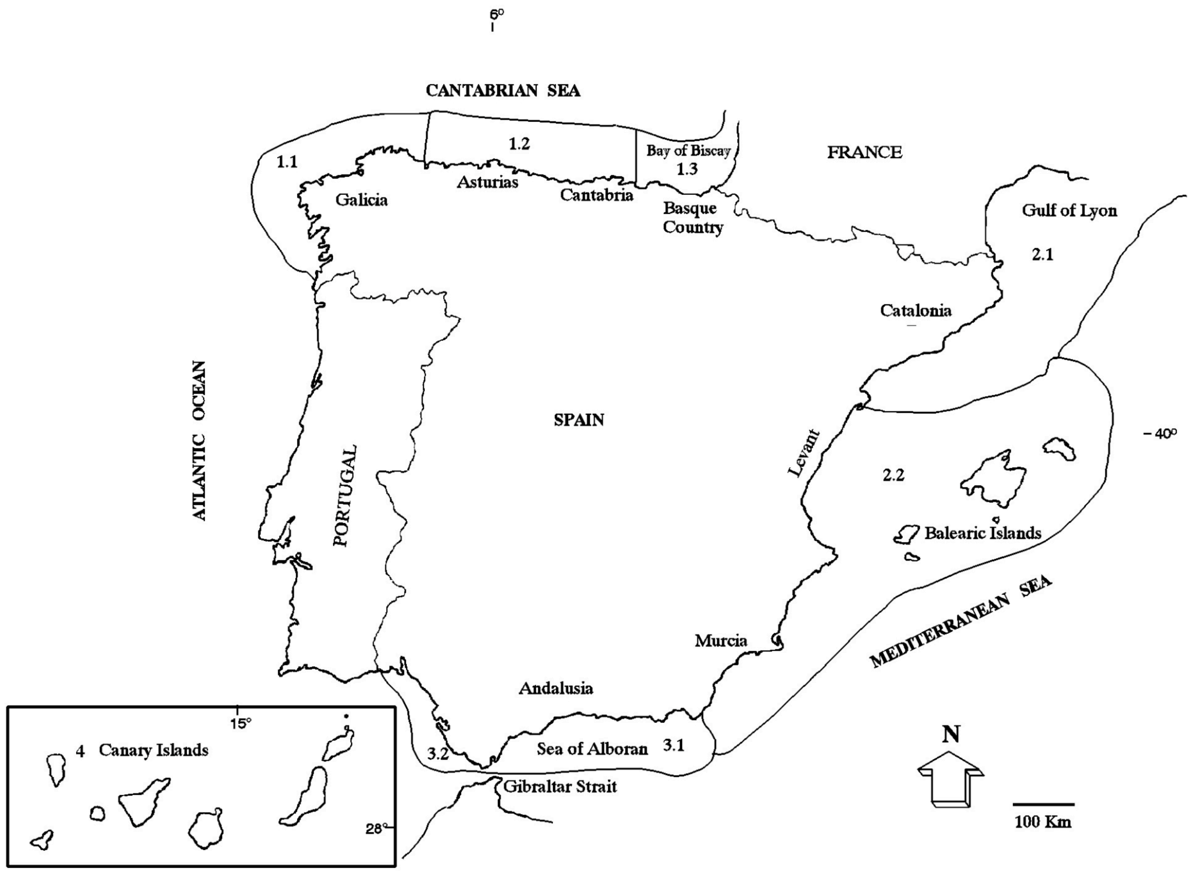

Figure 1. Map of Spain indicating the main coastal sub-regions.

(1)The Northern coast. From the Northwest Atlantic coast (Galicia) to the Bay of Biscay (Basque County); **(2) The Spanish Mediterranean sub-region**, from the Gulf of Lyon (Catalonia) to the Sea of Alborán (Murcia), including the Balearic Islands; **(3) The South-sub-region**, from the Sea of Alborán to the Spanish-Southwest Atlantic coasts (Andalusia) and **(4) The Canarian sub-region** (Fig. 1).

(1). The Northern coast.

This sub-region is characterized by strong water-level fluctuations. It can be subdivided into three sub-sections based on the water temperature gradient: (1.1) The Northwest coast (Galicia) is distinguished by drowned river valleys (in Spanish called Rías). It is one of the coldest parts of the Spanish coast and is where an area of upwelling is localized. The surface water temperature ranges from 12ºC in winter to 17-18ºC in summer. (1.2) The Asturian coast can be considered as a transition zone between the cold water of the Galician coast and the warmer water found on the Basque County coast. (1.3) The inner part of the Bay of Biscay in the Basque County is a subsection where local high water temperatures occur in place of the normal colder temperatures. The temperature can reach as high as 22ºC in summer.

(2). The Mediterranean coast.

Although this wide sub-region is characterized by warm temperatures and is almost tideless (the tidal range in the Mediterranean is from 20-40 cm), two sub-sections can be distinguished: (2.1) The Catalonian coast (Gulf of Lyon), which constitutes the coldest part of the Spanish-Mediterranean coast with a range of surface water temperature from 12-13ºC and 22-23ºC and (2.2) The Levant coast and Balearic Islands which are characterized by warmer temperatures (12ºC-13ºC to 24-25ºC) which together with Sicily constitute the highest temperatures in the West-Mediterranean.

(3). The Southern sub-region.

Situated in the south of Spain, this zone is influenced by both Atlantic and Mediterranean waters. (3.1) The Sea of Alborán (the southern Spanish coast of the Mediterranean) constitutes a relatively cold water zone, for the Mediterranean, due to the Atlantic cold water flow via the Strait of Gibraltar, which comes to the surface in this area. (3.2) The southern Spanish coast has a typical Atlantic character. Temperature ranges from 14ºC - 24ºC with a salinity of 36.5‰ (Seoane-Camba 1965).

(4). The Canarian sub-region.

The Canary Islands, situated between 27-29º N and 13 to 18º W, and just 100 km from the west African coast, consist of seven large islands with a volcanic origin (Fig. 1). They are influenced by the northern Atlantic Current system (Canaries Current) and are characterized by temperate water. August water temperatures rise to 23-24ºC and do not fall below 18ºC during February.

FLORA OF THE MAIN SPECIES OF SPAIN

1. The Northern coast.

(1.1) The Northwest subsection (Galicia). The main flora of this subsection is more related to the flora of the south of Great Britain, French Brittany and Ireland than the rest of the northern Spanish coast line, due to an upwelling zone and associated colder water. Thus, the main species of seaweed localized here have a cold-water character (Niell 1978, Fernández *et al.* 1983, Bárbara and Cremades 1996). The co-dominance of *Bifurcaria bifurcata* and *Himanthalia elongata* are frequent within the exposed locations in the lower eulittoral zone (Fernández *et al.* 1983), accompanied by other important species such as *Chondrus crispus*, *Mastocarpus stellatus*, *Pelvetia canaliculata*, *Fucus spiralis*, *F. vesiculosus* and *F. serratus* (Lüning 1990). In the sublittoral zone, *Laminaria hyperborea*, *L. ochroleuca* and *L. saccharina* are typical. Other species such as *Gigartina acicularis*, *Ulva gigantea* and *U. rigida* have been recorded as having an important biomass (Fernández *et al.* 1983). (1.2) The Asturian coast. This subsection has been widely studied in terms of vertical and latitudinal distribution of seaweeds (Fernández and Niell 1981, Anadón 1983, Anadón and Niell 1981). It has characteristics intermediate between Boreo-Atlantic and Mediterranean systems, constituting a gradient west-east zone which results in a substitution of species typical of cold waters with other Mediterranean species. Thus, some species described above, which are common along the Galician coast are substituted by other more southern species such as *Saccorhiza polyschides*, *Gelidium latifolium* or *G. sesquipedale* (Fernández and Niell 1981, Anadón and Niell 1981). (1.3) The Bay of Biscay. The number of floral studies in the Bay of Biscay undertaken during the last decade are extensive (reviewed by Borja *et al.* 1995). The temperature can rise to 22ºC in summer and therefore the vegetation is not dominated by the cold temperate Laminariales but typical warm water species, for example, the crustose, calcified red alga *Mesophyllum lichenoides* which reaches the Basque coast as its northern geographical limit. Although, this coastline generally exhibits a reduced algal flora (Lüning 1990), the upper sublittoral zones support a greater species diversity than the areas as a whole. One finds warm water species such as *Corallina officinalis*, *Lythophyllum incrustans* and *Cystoseira tamariscifolia*. Communities of *Gelidium sesquipedale* predominate along the Basque County coast in the subtidal zone, increasing their biomass from west to east (Borja 1987). *Halopteris filicina* is predominant at a depth of 25-35 m (Borja *et al.* 1995).

(2). The Mediterranean sub-region.

(2.1) The Catalonian coast (Gulf of Lyon). Almost 520 species of seaweeds have been described for this subsection, of which 61% are Rhodophytes (Ballesteros 1990). Communities of *Rissoella verruculosa*, *Porphyra leucosticta* and *Nemalion helminthoides* are important during certain periods of the year, together with *Cystoseira mediterranea*, an endemic species of the Mediterranean. (2.2) The Levant coasts and Balearic Islands. The algal vegetation of these coasts has been intensively studied by Gomez Garreta and co-workers (Ribera and Gomez Garreta 1984, 1985). In this sub-section one finds warmer water species which are not present or are rare in the Gulf of Lyon, many of which are species with tropical affinities. The species richness is high; more than 435 species have been described for the Balearic Islands alone (Ribera and Gomez Garreta 1984, 1985), of which 288 are Rhodophytes. It is important to emphasize the relatively high number of Mediterranean endemic species in the coast, such as *Acrodistus vidovichii*, *Neurocaulon foliosum* or *Laminaria rodriguezii* (Ballesteros 1993). In sunlit water, and at medium wave exposure in the upper sublittoral zone, several species of *Cystoseira* dominate, such as *Cystoseira compressa*, *C. humilis*, *C. barbata* or *C. crinita* which constitute important communities in this sub-section. In the lower sublittoral zone one finds several species of genera, such as *Laminaria rodriguezii*, *Cystoseira zosteroides* or *Sargassum hornschunchii* which can be found at depths greater than 100 m and Rhodophyte species such as *Mesophyllum lichenoides* or the green alga *Halimeda tuna*. Other predominant species on the coast are *Corallina elongata*, *Phyllophora crispa*, *Osmundaria volubilis* or *Dictyopteris membranacea* (Barceló and Seoane-Camba 1982, Ballesteros 1993).

(3). The South-Southwest sub-region.

(3.1) The South-Mediterranean (Sea of Alborán). The Benthic marine algae of this sub-region have been recently studied by Flores-Moya and co-workers (Flores-Moya *et al*. 1995a, 1995b). The region constitutes the limit of penetration for Atlantic floral elements. A number of Atlantic species migrated via the strait of Gibraltar to the southern Spanish coast of the Mediterranean, introducing an Atlantic influence along these coasts (Lüning 1990). Thus, large brown algae such as *Fucus* or *Laminaria* or Atlantic elements such as *Cystoseira tamariscifolia* are mixed with species representative of the Mediterranean such as *Cystoseira compressa* or *Sargassum vulgare*. (3.2) The Spanish southern Atlantic. The flora of this subsection is predominantly Atlantic, with a similarity to the Moroccan coast-line (Seoane-Camba 1965). There is a low representation of *Laminaria*, *Fucus vesiculosus*, *F. serratus* or *Pelvetia*. Species such as *Dictyota dichotoma*, *Padina pavonica* and *Stypocaulon scoparia* dominate. Other important communities are *Plocamium cartilagineum*, *Valonia utricularis*, *Udotea petiolata* or *Sphaeroccocus coronopifolius*.

(4). The Canary sub-region.

The island groups of the Azores, Madeira, Salvage, Canary and Cape Verde Islands are collectively known as the Macaronesian Islands. With the exception of the Cape Verde Islands, this group forms the Canary Province of the Warm Temperate Mediterranean-Atlantic region (Van den Hoek 1975). Various floristic and zonation studies have been carried out by different authors (Gil-Rodriguez and Afonso-Carrillo 1980, Prud'homme van Reine and Van den Hoek 1990, Gil-Rodriguez *et al.* 1992, Haroun *et al*. 2002). More than 627 species of seaweeds have been described for the Canaries, with almost 60% belonging to the Rhodophyta. The origin of the Canarian flora seems complex. Eighty percent of the algal flora are common to those of the Lusitanic and Mediterranean Provinces (Lüning 1990), but, curiously, a high number of species present here (54.5%) are common to the Caribbean region as well. The tropical floral elements are well represented in the Canary Islands. Species such as *Caulerpa* spp., *Valonia utricularis*, *Galauxaura* spp., *Dictyota* spp., *Padina pavonica* and *Zonaria* spp. are easy to find. Other very common species are *Cystoseira abies-marina*, *Jania rubens*, *Halopteris scoparia*, *Fucus spiralis* and *Hypnea cervicornis*. Although the number of endemic species is not high (about 9%, Gil-Rodriguez *et al.* 1992), a number of potentially economically important species occur in the lower eulittoral zone, i.e. *Gelidium canariensis* and *G. arbuscula*.

ECONOMIC SEAWEEDS OF SPAIN

Utilization of seaweed resources in Spain has been developed exclusively along the shores of the four administrative Counties on the Northern coast: The Basque County, Cantabria, Asturias and Galicia (Fig. 1), where the most abundant monospecific stands of red and brown macroalgae occur. According to historical records, this practice dates back several centuries (Fernández 1991, Catoira 1993). Similar to other maritime societies in western Europe, seaweeds have traditionally been used as supplements in animal meals, fertilizers and soil conditioners. Gathering of cast seaweeds on the shoreline, usually after autumn and winter storms, has been the main source of algal biomass for these purposes.

In contrast, during the last 60 years, an increasing and much more effective exploitation of seaweed resources have been recorded in this area in relation to their value as raw materials for the chemical industry. Harvest regulations were first required in 1932, as a consequence of the utilization of brown algae for iodine production, and later, in 1945, when the initial industry for phycocolloids was established in Spain (Juanes and González, in press). From then on, biological, economic, industrial, technical and social factors have contributed in different ways to the development and the management of the seaweed-harvesting industry in Spain (Fernández 1991, Juanes and Borja 1991, Juanes and González, in press).

Since the 1950's, commercial interest in seaweed harvesting has been mainly applied to a few species of red and brown macroalgae used by local manufacturers of agar, carrageenan and alginates. In the following sections some biological and technical aspects regarding the production and current utilization of these resources are summarized.

Agarophytes

The economic importance of agar-producing species from the Spanish coasts exceeds that of the other two sectors of the seaweed industry, i.e. carrageenan and alginate processing (Fig. 2). Resources are based on subtidal populations of *Gelidium sesquipedale*, a Rhodophyte widely distributed along the Northern region while the commercially interesting beds occur on the Cantabrian coast, from Cape Peñas in Asturias (ca. 6ºW) to the French border (Juanes and González, in press). Other species of this genus (*G. latifolium*) from the intertidal of Asturias also contributes, though to a much lesser extent, to the global production of this resource (Fernández and Anadón 1989). Annual harvests from this geographic zone constitute one of the most important in the world (McHugh 1991), being utilized principally by the Spanish manufacturers of agar.

Gelidium resources are exploited by gathering cast seaweeds after autumn and winter storms and also direct harvesting of the beds (Fig. 3). In the former instance, diverse methods are employed, although the most usual and traditional is manual dragging of nets by one or more operators (Fig. 3A). In rocky areas, cranes are used to help hoist the cast seaweeds (in baskets) up the shore. Dragging, using boats (Fig. 3B), is employed in relatively shallow (<20 m) sandy bays, where cast accumulates and can be detected by sonar. A suction-based technology (Fig. 3C) has also been developed in local areas of the Basque County in order to pump out large amounts of detached seaweeds which collect in rocky depressions.

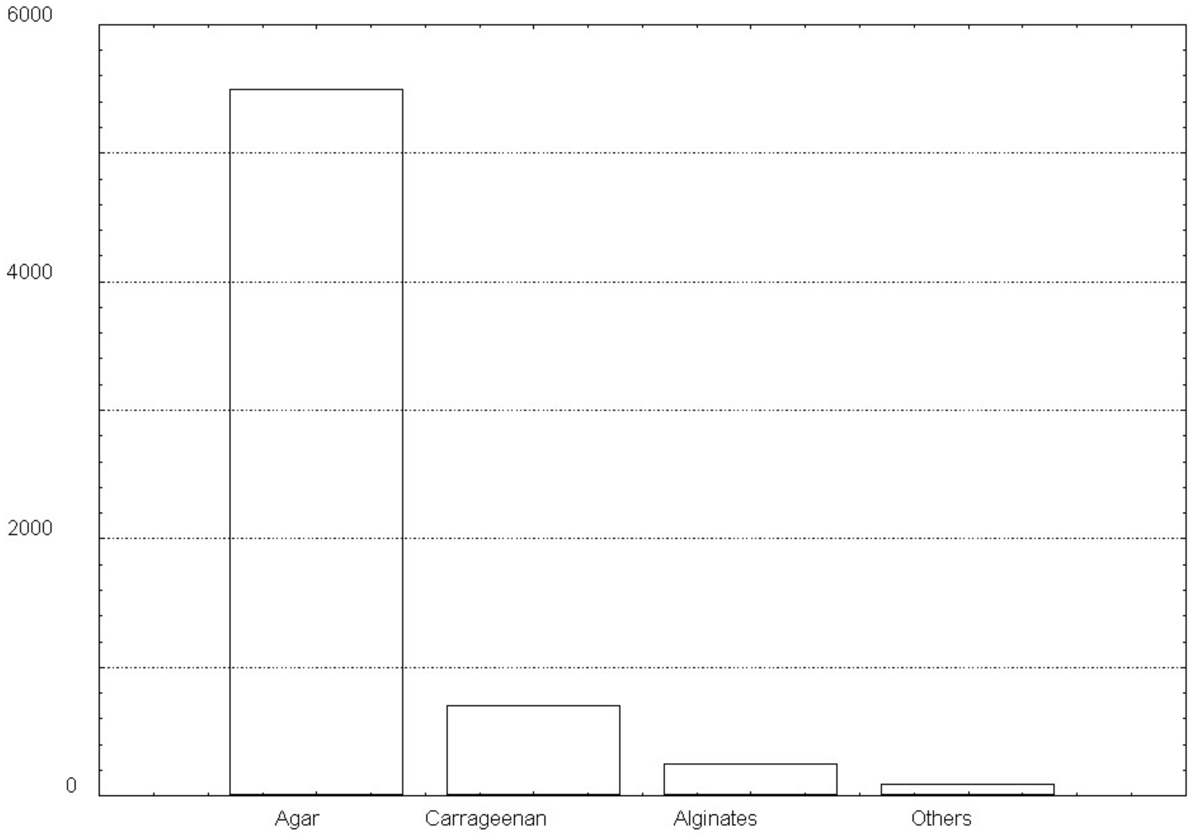

Figure 2. Comparison of average annual harvests of seaweeds for different sectors of the extraction industry (agar, carrageenan and alginates) and for other traditional uses (food, fertilizers).

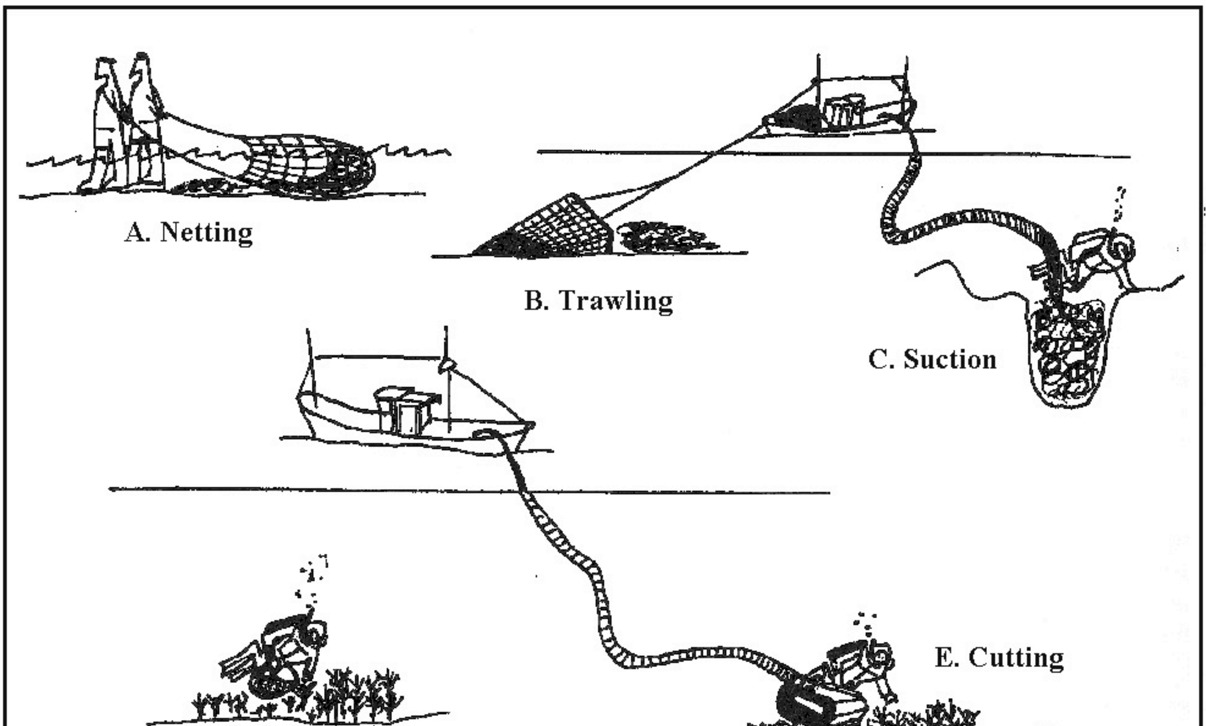

Figure 3. Harvesting methods used along the Spanish coasts for the exploitation of *Gelidium* (Source: Juanes and Borja 1991).

On the other hand, two different types of direct harvesting are used: Plucking of seaweed fronds by divers (or from boats on the shallower harvesting spots), the traditional method of harvest which was used since the start of exploitation until 1986 (Fig. 3D), and cutting (Fig. 3E). Cutting is a more complex and expensive technique that was first suggested, in the last decade, as an alternative to reduce the possible impact of plucking on certain commercial beds (Juanes and Borja 1991, Juanes and González, in press).

For several decades, the considerable absence of scientific knowledge on the potential and dynamics of the *Gelidium* populations (standing stocks, regenerative capacity) resulted in the application of a very simple and conservative management approach in order to preserve the commercial beds from possible over-exploitation. Traditional actions in this field have been mainly concerned with controlling direct exploitation, through issuing licenses, establishing quotas and setting seasons and areas to be harvested. Although regulations implemented since 1945 (Juanes and González, in press) and the importance of cast seaweed harvesting as the main source of algal biomass (at least 80% of the annual yield) have been taken into account, the actual control of those activities poses difficulties and consequently has not been at all rigorous. With this in mind it should be opportune to consider official statistics on total landings merely as rough approaches to the amounts harvested.

McHugh (1991) estimated an average yield of 5500 to 6000 tons dry weight (DW) per year of agarophyte seaweeds, from which he established that only 60% (3300 to 3600 tons) seemed to be pure *Gelidium*. Distribution of amounts harvested by region is shown in Figure 4. From these average harvests, only a maximum of 20% of the total landings resulted from the utilization of direct harvesting techniques (Juanes and Borja 1991), but incomes generated by these high-quality, high-purity resources are greater on a weight basis (ca. by a factor of 2-3).

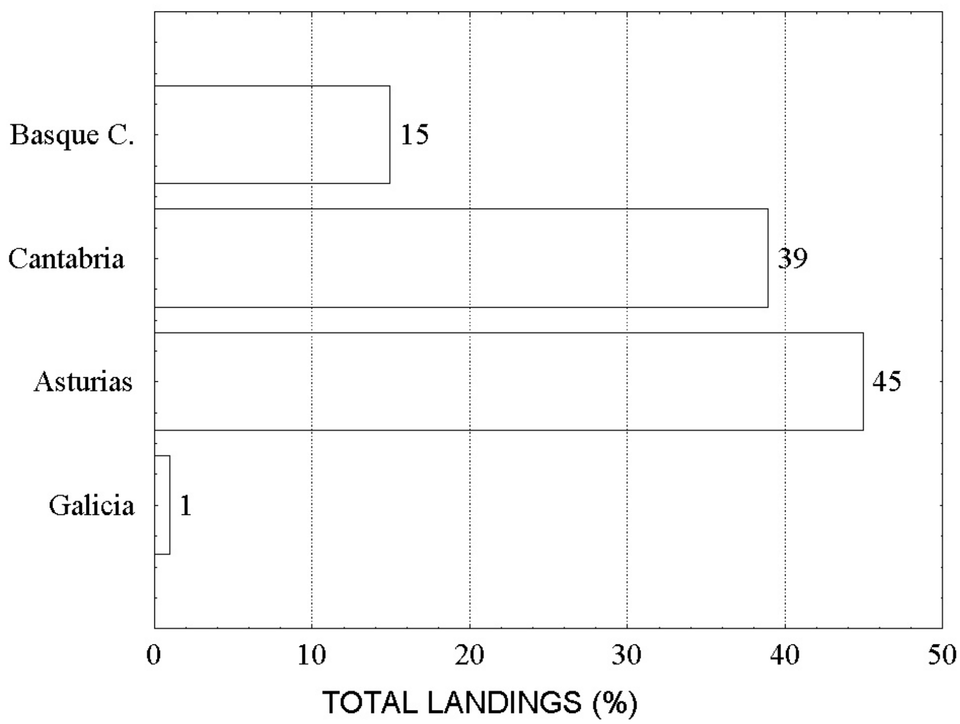

Figure 4. Distribution by counties of mean annual percentages of *Gelidium*.

Since the assumption of administrative responsibilities for fisheries affairs by County Governments in 1986, there has been a stronger compromise with the social agents to ensure the rational management of the renewable resources. Recent works by Gorostiaga (1990), Fernández (1991), Juanes and Borja (1991) and Juanes and González (in press) synthesized the changing views and the current interests in establishing a scientific-based management program.

Some of the most urgent questions proposed in those papers at the beginning of the 1990's (Fernández 1991, Juanes and Borja 1991) have already been answered. On one hand, evaluation of standing stocks in the whole harvesting area is now completed. Main features of these seaweed beds are summarized in Table 1. Total standing stocks for this resource have been quantified as 57371 tons fresh weight (FW). This value excludes those beds from the Asturias County with less than 40% cover. Additional information derived from these studies, concerning, for example, vertical distribution of resources (Fig. 5), presence and distribution of epiphytes with depth, community composition and diversity or cover variations in relation to abiotic gradients, have been valuable for improving the previous biological (seasonal patterns) and ecological knowledge (biotic and abiotic interactions) on these species (cf. Gorostiaga 1990, Fernández 1991, Juanes and Borja 1991).

Table 1. Values of: average summer maximun biomass (g FW m^{-2}), after correction by cover, and bed Widths (m); main depth range of species distribution (m); shore length colonized by agarophyte resources; and standing stocks of *Gelidium sesquipedale* (tons FW) for each county and for the harvesting area (NA = Not Available).

County	**Biomass (g FWm^{-2})**	**Width (m)**	**Depth Range (m)**	**Shore Length (km)**	**Standing Stock (tons FW)**
Basque County East[(1)]	2.371	147	0 to -17	48	15.943[(6)]
Basque County West[(2)]	1.600	91	0 to -17	36	5.068[(6)]
Cantabria East[(3)]	1.300	143	0 to -14	42	6.290[(6)]
Cantabria West[(4)]	1.518	367	0 to -17	35	18.142[(6)]
Asturias East[(5)]	2.287	248	-5 to -15	NA	11.928[(7, 8)]
TOTAL					57.371[(9)]

(1) Borja (1987).
(2) Borja (1988).
(3) Juanes and Gutiérrez (1992).
(4) Juanes *et al.* (1991).
(5) Llera *et al*. (1988): with reference only to beds with percent covers of resource higher than 40 %, in the maritime district of Llanes.
(6) Estimated by the transect-based method of Mann (1972).
(7) Estimated by extrapolations of biomass of individual samples to the corresponding commercial harvesting bed.
(8) Total standing stocks for this county. (A. Vizcaíno, pers. comm.).
(9) Total standing stocks on the Cantabrian Coast.

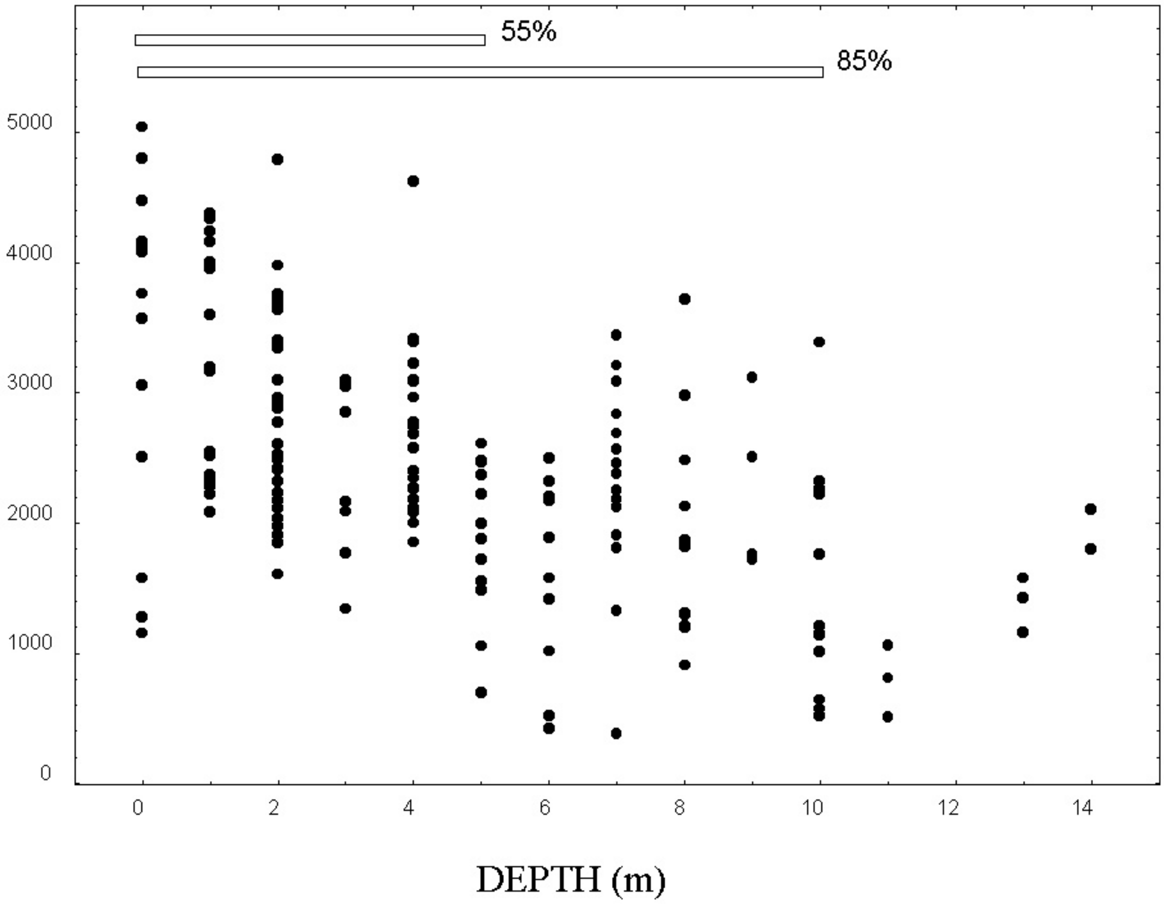

Figure 5. Fresh weight biomass of *Gelidium sesquipedale* in East Cantabria (kg m^{-2}, previous correction by cover) at different depths (m, referred to the 0 level), including percentages of standing stocks within the various bathymetric ranges (Modified from Juanes and Gutiérrez 1992).

On the other hand, experiments on commercial exploitation of *Gelidium* beds, carried out by Borja (1994), have supported the hypothesis that both the plucking and the cutting techniques allow the recovery of the exploited populations in less than one year when harvesting takes place at the beginning of the summer.

Based on such complete information, management of the resource has been undertaken independently in every one of the three main counties involved in the harvesting of the resource, with two major similarities:

- Improvement of the recovery efficiency of naturally-detached seaweeds by the application of new methodologies of locating (e.g. side scan sonar) and exploiting (e.g. suction pumps) the resources. Current estimates of efficiency range between 18 and 35% (Borja 1987).

- After a period of prohibition, hand-picking of subtidal beds of *Gelidium* is now licensed in the whole area (in recent months, Cantabria has been the last county to regulate this activity). Establishment of quotas, harvesting seasons and areas are authorized following a previous control of the commercial beds (A. Borja, pers. comm.). Rigorous checking of landings (weights, percentage of rhizoidal structures, etc.) are combined with post-harvest evaluations of ecological impacts on seaweed beds. Increasing amounts of *Gelidium* have been collected using this approach during the last 5 summer seasons, reaching a maximum of 2170 tons FW in the Asturian County in 1996 (E.M. Llera, pers. comm.).

Nevertheless, in order to complete a rational schedule for management, scientific and technical criteria must be linked to the social organization of this sector (control of licenses, promotion of co-operatives), providing professional training to the local harvesters (alternative methods for active gathering, quality selection of material harvested) and making the different interests of the most representative sectors (e.g. farmers and fishermen; Fernández 1991, Juanes and González, in press) more compatible.

Recent advances in the management of the resource have resulted in the promotion of new expectations for the *Gelidium* harvesting industry along the north coast of Spain, an economic sector that has suffered during the last decade the consequences of the establishment of a more rational management of that renewable resource.

Carrageenophytes

In the Northern region there are commercially-interesting populations of two carrageenan-producing species, *Chondrus crispus* and *Mastocarpus stellatus* which have a complimentary distribution with the agarophytes. Dense stands of these species occur on the western half of the area, from Cape Peñas in the Asturias County to the border with Portugal and have been exploited for more than 20 years for the supply of raw material to the local carrageenan. As is the case of *Gelidium*, gathering of cast seaweeds on the shoreline (autumn and winter) and direct hand-plucking from intertidal and shallow subtidal beds (spring - summer) are the usual harvesting techniques for exploitation of this resource. Cutting devices have also been used in subtidal populations of the Asturias County (A. Vizcaíno, pers. comm.), with lower economic returns.

Management actions for the exploitation of these seaweeds have suffered similar problems to those mentioned previously. Quantification and control of harvests are more efficient and total landings obtained from seaweed beds on Asturias and Galicia are processed by one company. Estimates of average yields for the whole area are between 600 to 900 tons DW per year, from which two thirds may correspond to *M. stellatus* stands (McHugh 1991), mainly from the intertidal and the other third to *C. crispus* landings, mostly from the subtidal level (ca. -4 m). Average proportions of production by the two counties is 4:1, i.e. 80% of the harvests are registered in the coast of Galicia and the other 20% comes the Asturian beds.

Different studies related to important biological (seasonal patterns, life cycles) and ecological aspects of these populations (distribution, standing stocks, regeneration capacity) have been carried out during the last decade (Anadón and Fernández 1988, Gutiérrez and Alvarez 1989, Catoira 1990, 1991, 1992, 1993, Fernández and Menéndez 1991a, 1991b). Most of the results presented in these works can be applied to the management of the resource. In Table 2 a summary of the main features of the commercial beds is shown. Total standing is estimated as 12015 tons FW for both species, although values from Galicia seem to be, as for other species evaluated in this area, overestimated. Extrapolation methods of single biomass samples to large areas may be the reason for that problem.

Table 2. Values of: average summer maximum biomass (g FW m^{-2}, without correction by cover) and bed widths (m); main depth range of species distributions (m); shore length colonized by carrageenophyte resources; and standing stocks of *Chondrus crispus* and *Mastocarpus stellatus* (tons FW) for each county and for the harvesting area.

County	Level	Biomass (g FW m^{-2})	Width (m)	Depth range (m)	Shore Length (km)	Standing Stock (tons FW)
Asturias West[(1)]	Intertidal[(7)]	2.328	8	+ 0.8 to + 0.4	140	2.588[(9)]
Asturias West[(2)]	Subtidal[(7)]	4.520	83	0 to -10	8	1.869[(9)]
Galicia[(3,4,5,6)]	Intertidal[(8)]	2.470	3	+ 0.8 to -2	NA [(7)]	1.227[(10)]
Galicia[(3,4,5,6)]	Subtidal[(7)]	1.060	NA	0 to -7	NA [(8)]	6.531[(10)]
TOTAL						12.015

(1) Anadón and Fernández (1988).
(2) Gutiérrez and Álvarez (1989).
(3) Catoira (1990).
(4) Catoira (1991).
(5) Catoira (1992).
(6) Catoira (1993).
(7) Mainly resources of *Chondrus crispus*.
(8) Mainly resources of *Mastocarpus stellatus*
(9) Estimated by the transect-based method of Mann (1972).
(10) Estimated by extrapolations of biomass of one sample to the whole surface of each seaweed bed.

Increasing profits from these stocks will depend on the international carrageenophyte market that, at this moment, appear to be saturated with highly competitive *Eucheuma*-based resources.

Alginophytes

Alginate-producing species constitute the largest seaweed resource registered in the Northern area, showing a geographical distribution close to that of the carrageenophytes (Catoira 1993). Standing stocks of two species of *Laminaria*, *L. hyperborea* and *L. ochroleuca*, on the coast of Galicia, have been estimated (possibly overestimated due to the same problem as above) at more than 800 000 tons FW (Catoira 1993). Unfortunately, exploitation of those seaweeds has been a minor activity compared to the potential productivity of the area. According to estimated data, annual harvests of *Laminaria* spp. have varied around a mean value of 200 tons DW. The seaweeds are obtained for the most part by cast seaweed gathering techniques along the western shores of Asturias and the northern shores of the Galicia area, where a small factory for alginate production was operating until 1993. Since then, exploitation of this resource has been reduced, except for certain quantities of these species that are used for other purposes, (*e.g.* health-related applications, together with *Fucus* species).

Future increases in the exploitation of this resource appear to be very unlikely, because of the current production in other regions of the world.

CULTIVATION OF SEAWEEDS IN SPAIN

To date, there is no industrial production from seaweed cultivation in Spain. However, research carried out in this field over the last ten years has resulted in three possible commercial applications in the Northern region. The first for the agarophyte *Gelidium* spp., the second for the brown macroalgae *Undaria pinnatifida*, an introduced species to the northern region of Spain since 1988 (J.M. Salinas, pers. comm.) and recently a third one for the red macroalgae *Palmaria palmata* (J.M. Rico, pers. comm.).

A cultivation system for *Gelidium* species, based on the regenerative propagation of apical fragments on artificial substrata, has been described by Salinas (1991). Because of the current status of natural stocks of this resource on the coast, future applications for this type of culture appear to be related to the restoration of damaged seaweed beds rather than to attempts at commercial cultivation.

By contrast, *Undaria* cultivation trials have been directed at the adaptation of the basic aspects of the "European technique" to the ecological conditions on the northern coast of Spain, especially in the "Rias" of Galicia (Perez-Cirera *et al.* 1997), a geographic region where the most important commercial cultivation of marine species takes place. The 4-year project, sponsored by the Regional Government of Galicia County and carried out in close collaboration with French researchers (J.M. Salinas, pers. comm.) has resulted in a scientific-based technology available for anyone interested in its application at a further commercial level.

Cultivation from vegetative thalli of the edible red macroalgae *Palmaria palmata* (dulse) in open sea ropes has been successfully developed, at a commercial scale, in Asturias. Biomass obtained from a 2,400 m^2 farm is canned and sold for human consumption in a still growing market (J.M. Rico, pers. comm.). The company is also processing other seaweed species, mainly *Himanthalia elongata* and *Mastocarpus stellatus*, harvested from natural populations and canned with the same purpose.

Since 1990 at the Center of Applied Algology (east coast of Gran Canaria, Canary Islands) the development of an intensive culture pilot plant for the production of economically interesting seaweed species has been achieved. At present, a 180 m^2 cultivation surface occupied by vertical photobioreactors, tanks (Fig. 6) and raceways (Fig. 7) is producing a yearly mean value closed to 30 g dry weigh m^{-2} d^{-1} (1,9 Tm dry weight $year^{-1}$) of red and green macroalgae such as *Gracilaria cornea* (Fig. 8), *Hypnea spinella*, *Halopytis incurva* and *Ulva rigida* (Fig. 9) with an interesting commercial quality (Lahaye *et al.* 1995, Gómez Pinchetti *et al.* 1998). In the last years the cultivation methodology is based on an integrated poly-aquaculture system for the biofiltration of fish ponds nitrogen-enriched wastewaters (Jiménez del Rio *et al.* 1996). Funded by the European Commission's "Quality of Life" programme a recent project "SEAPURA" has permitted to increase the diversity of seaweed species not previously used in such poly-aquaculture systems, in which the growth of macroalgae is combined with fish aquaculture. Biomass obtained from the system is processed and manufactured as agricultural biostimulants for the local market.

The potential of the red agarophyte *Gracilariopsis longissima* as biofilter in effluents from intensive marine fish cultures has been also studied in Cadiz (Andalucía). Vegetative cuttings on suspended nylon ropes of algae growing in earthen ponds reach yield values up to 1 kg fresh weight m^{-2} (growth rates up to 6% d^{-1}) (I. Hernández and

J.J. Vergara, pers. comm.), encouraging the development of large scale cultivation of this species in local fish farms which result in both environmental and economic advantages for the region.

Figure 6. Semicircular glass-fiber and circular polyethylene tanks for the culture of macroalgae at the Center of Applied Algology (Gran Canaria, Canary Islands).

Figure 8. Harvesting *Gracilaria cornea* red and green morphological variants grown in tanks. This original caribbean species has been cultivated longer than 10 years at Gran Canaria (Canary Islands) showing a high level of intraclonal variation under such intensive culture conditions.

Figure 7. Harvesting *Ulva rigida* grown in a 60 m^2 raceway with open flow wastewaters from fish ponds.

Figure 9. *Ulva rigida* grown in tanks at the intensive poly-aquaculture system in Gran Canaria. Deep green pigmented algae are nitrogen enriched and green-yellow ones are nitrogen depleted (Gómez Pinchetti *et al.* 1998).

PROCESSING AND INDUSTRY IN SPAIN

Processing of phycocolloids in Spain dates back to 1940, when the first commercial production of agar was initiated. Since then, the great expansion and diversification of this sector has created a highly competitive industry. After the recent closing of the alginate processing factory that was operating on the north coast (Ribadeo, Galicia), the phycocolloid industry in Spain is now only related to agar and carrageenan processing.

Agar

The agar industry in Spain has traditionally been based on the abundant resources of *Gelidium* on the Cantabrian coasts; but depending on prices of local seaweeds, variable amounts of other agarophytes of this genus from different countries (Chile, South Africa, etc.) have also been processed.

Since the introduction in the 1940's of the first artesanal industry, up to 20 different agar factories have operated in various geographical locations in the northern half of the Iberian Peninsula (from the Madrid area to the Cantabrian coast), from which only four are currently functioning, and only two operating continuously (Juanes and González, in press). Shortages of raw materials during the 1960's, over-growth of processing, lack of diversified production (different agar grades and high-tech products) and loss of prospective markets have been some of the main causes of closed factories.

Total production of agar from Spanish companies at present is estimated to be about 600 to 650 tons, including bacteriological (ca*.* 90 tons) and food grade agars. Ninety to 95% of produced agar is exported to Europe, the United States and Japan. In addition, production of different types of agaroses for biochemical applications has reached 10 tons, accounting for a high proportion (40%) of the total amount of this high-tech valuable agar-derivative manufactured globally.

Carrageenan

Production of this phycocolloid in Spain begun at the end of 1960's, based on the *Chondrus-Mastocarpus* resources from the coast, combined with carrageenophytes, first imported from Canada and the USA, (*Chondrus* resources) and later from the Philippines and Indonesia (*Eucheuma* resources). At present there are two factories involved in carrageenan processing. The first, located in Galicia, uses the discussed sources of raw material in a approximated proportion of 1:3 (local to imported seaweeds). The second factory, being one of the most important for world agar production, processes only imported material.

Processing capacity of the two factories exceeds the current estimates of carrageenan production, which averages 1600 tons per year, from which 60 - 80% are exported to various industrialized countries. Due to the world-wide trend in utilization of new carrageenophyte-derived products, it is unlikely that improvements to the harvesting of local resources may facilitate a further expansion of this industry.

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