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Worldwide distribution of commercial resources of seaweeds including *Gelidium*

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Abstract

The commercial exploitation of seaweeds for use as food and for the production of agar, alginate and carrageenan is outlined. The quantities of seaweed harvested for each purpose are tabulated and discussed. Seaweeds for food are derived chiefly from China, Japan and Korea, with almost 94% obtained by cultivation. Alginophytes are collected in 15 countries but six of these account for more than 80% of the total harvest; all are from natural stocks except for a large quantity of *Laminaria* cultivated in China. Natural carrageenophytes, from 12 countries, now account for only 20% of the total harvest; the remainder is cultivated *Eucheuma* species, 99% of which is produced in only two countries, the Philippines and Indonesia. Of the four categories of commercial resources of seaweeds considered, agarophytes are spread more evenly over a greater number of countries; they come from 20 countries and only five of these are minor contributors to the total. *Gelidium* species are particularly important because of the high quality agar they yield; their distribution and location are discussed.

Introduction

In the past 30 years, there have been several surveys of the worldwide resources of a variety of seaweed species. Many of the resulting statistics are approximate, because accurate surveys are difficult, time-consuming and expensive and can usually be justified only when commercial exploitation is being considered; nevertheless, these surveys have been useful in guiding commercial interests to likely locations for harvesting. Even for many of the commercial seaweed beds, estimates for the total available resource are variable, not only because of the limitations of physical measurements, but also because the resource itself varies with changing environmental factors from year to year.

Commercial resources of seaweeds are sometimes only a minor proportion of the total worldwide standing crop. Access and abundance are two of the factors which determine the commercial viability of a resource, and they have been significant determinants of how the industry has developed. Access to some seaweeds has been improved through cultivation; for example, the quantity of *Eucheuma* produced by cultivation now exceeds the accessible natural standing stocks. Other important factors which determine commercial viability include costs of harvesting (for labour and/or equipment), drying, transportation, chemicals, water supply and environmental protection measures.

Illustrative examples can be drawn from the brown seaweeds suitable for alginate extraction.

The Kerguelen Islands in the Indian Ocean are reputed to be the richest resource of *Macrocystis* and *Durvillaea* in the world, yet their distance (4800 km) from both South Africa and Australia makes transportation costs prohibitive. Large quantities of brown seaweeds are found on the Falkland Islands (Malvinas), about 800 km from Argentina, but the climate and lack of fuel make drying difficult. An alginate factory could be established there, although its size would be determined by the minimum size of harvesting vessel that could be operated. Such a vessel would have to be large enough to withstand the rough seas and weather conditions which can prevail in this area. It would need to be used to its full potential to justify the capital cost, so any factory would have to be large enough to cope with the resulting quantity of raw material. The necessary chemicals, solvents and fuels would have to be shipped from Argentina; sufficient water storage would be required. The combination of all these factors would make the factory uneconomical to operate. Large natural resources are, therefore, not necessarily of commercial value.

This survey is confined to seaweeds of commercial interest, and to quantities and locations actually harvested or cultivated. It encompasses seaweeds used in the food, alginate, carrageenan and agar industries. Resources of *Gelidium* species, a valuable source of high-quality agar and agarose, are considered in more detail.

The statistics in all the tables are expressed as 'dry weight', a term used by industry for the mass of the seaweed after it has been dried by natural means. This dried seaweed usually contains about 20% moisture, but this can vary, depending on the post-harvest treatment and the type of seaweed. The main exception is *Eucheuma*, a source of carrageenan, which buyers prefer to contain 35% moisture, for shipping convenience.

Seaweeds for food

Seaweeds used in food are most popular in China, Japan and Korea, although they are used in other Asian countries, and in countries where there are ethnic Asian communities. The main types are *Laminaria* species (kombu), *Undaria pinnatifida* (Harv.) Suringar (wakame), *Hizikia fusiformis* (Harv.) Okamura (hiziki) and *Porphyra* species (nori). The Japanese names are shown in

Table 1. Seaweeds for food – quantity harvested in dry tonnes.

	Laminaria	*Undaria*	*Hizikia*	*Porphyra*
Argentina				5 (w)
Chile				10 (w)
China	150000	500		13000
		200 (w)		100 (w)
France				10 (w)
Japan	10000	20000		44300
	22000 (w)	1300 (w)		
Korea R (Sth)	2300	50700	6200	11600
	300 (w)	1200 (w)	3400 (w)	100 (w)
Korea DPR	110000	7500		
New Zealand				5 (w)
Totals	294600	81400	9600	69130
% of Table total	64.8%	17.9%	2.1%	15.2%

(w): harvested from wild resource. Other quantities are from cultivation.

Source: Quantities shown in the Table are the author's estimates, based on published government statistics and/or information received from representatives of industrial, academic and government organisations.

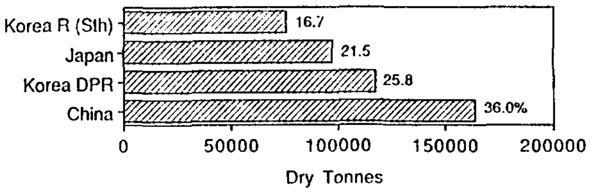

Fig. 1. Seaweeds for food. Total contribution by each country, in dry tonnes and as a percentage of the total for all countries.

brackets; other vernacular names are used in China and Korea. Table 1 shows the quantities of these seaweeds that are produced by cultivation, or harvested from the wild, by the major producing countries. The total production of seaweeds used as food by each country is shown in Fig. 1; each country's contribution by percentage is also shown.

China and Japan are large consumers of *Laminaria*, while South Koreans have a preference for *Undaria*. The Chinese annually cultivate about 200 000 tonnes (dry weight) of *Laminaria japonica* Aerschoug of which about 75% is used in food; Japanese cultivation is on a smaller scale, and the harvest of wild material exceeds the yield from cultivation (Table 1). In South Korea, even less *Laminaria* is cultivated and very little wild material is collected. However, very large quantities of *Laminaria* are cultivated on both the east and west coasts of North Korea, where it is used mostly as food, generally without being dried; some is also sold to the USSR, loaded wet onto ships at sea.

In both Japan and South Korea, most of the *Undaria* comes from cultivation, with South Korea production being about double that of Japan. When relative populations are considered, South Korea produces about six times more than Japan per capita. Most of the South Korean production is in the south-west corner of the south coast, while the northern areas around Hokkaido are the main source in Japan; North Korean cultivation is on a smaller scale. The low *Undaria* production in China is a reflection of the greater interest in *Laminaria* cultivation.

Hizikia is both cultivated and wild in South Korea with about half as much material being collected from the wild as from cultivated beds. There are no separate statistics for *Hizikia* in Japan; it is probably included in the 'Other' category for both cultivated and wild seaweeds in the official Fishery statistics. Appreciable quantities are imported from South Korea – 4 700 tonnes in 1989.

The cultivation of *Porphyra* is well-developed (Mumford & Miura, 1988), especially in Japan, where the production is far greater than in South Korea and China; by comparison, the quantities collected from the wild in all three countries are almost negligible. Small quantities of *Porphyra* (5–10 tonnes) are collected from the wild in France, New Zealand, Argentina and Chile.

There are minor uses of other seaweeds as food but the quantities are not recorded here; for example, for centuries in China and Japan, *Gelidium* has been collected from the shore by local people who boil it in water to make an edible jelly. *Gracilaria* species are collected from the wild and used fresh as a salad vegetable in Hawaii and some Asian countries. *Caulerpa lentillifera* finds a similar use because of its delicate taste and soft, succulent texture. It is commercially cultivated in ponds, particularly on Mactan Island on the outskirts of Cebu, Philippines (Trono, 1986). In Chile, small quantities of wild *Durvillaea*, locally-called cochayuyo, are used in food.

Prices for seaweeds sold as food are always much greater than for those used for extraction of colloids. The wholesale price in Japan for brown seaweeds of food quality can vary from US$ 7500–10 000 per dry tonne (Nisizawa, 1987) while international prices for brown seaweeds used in alginate extraction range from US$ 150–500 per dry tonne (McHugh, 1987). Red seaweeds may command even higher prices. In Japan, good-quality *Porphyra* (nori) sells wholesale at US$ 24 per kg, while the retail price can be at least double this (Nisizawa, 1987); in Nova Scotia, *Palmaria* (dulse) sells for Can$ 22 per kg (J.L. McLachlan, *in litt.*).

Seaweeds for alginate production

The types of seaweed used for the extraction of alginates are shown in Table 2. Such a wide range

Table 2. Seaweeds for alginate production – quantity harvested in dry tonnes.

	Laminaria	*Ascophyllum*	Other
Argentina			500 – *Macrocystis*
Australia			4000 – *Durvillaea*
Canada		7400	
Chile			16500 – *Lessonia*
			2100 – *Macrocystis*
			1000 – *Durvillaea*
China	50000 – *japonica*		
France	13000 – *digitata*	1000	1000 – *Fucus*
	1000 – *hyperborea*		
Iceland	250 – *digitata*	4000	
Ireland	1000 – *hyperborea*	12000	
Mexico			4000 – *Macrocystis*
Namibia	20 – *schinzii*		25 – *Ecklonia*
Norway	25000 – *hyperborea*	8500	
Scotland	1000 – *hyperborea*	3000	
South Africa	800 – *schinzii*		1600 – *Ecklonia*
Spain	2000 – various species		300 – *Fucus*
USA			10000 – *Macrocystis*
Totals			16600 – *Macrocystis* (9.7%)*
			16500 – *Lessonia* (9.6%)*
			5000 – *Durvillaea* (2.9%)*
			2925 – Other
	94070	35900	41025
* % of Table total	55.0%	21.0%	24.0%

Source: Quantities shown in the Table are the author's estimates, based on published government statistics and/or information received from representatives of industrial, academic and government organisations.

of species is used in alginate production for two principal reasons: there is a strong demand for any good source of alginate which can be harvested economically; secondly, the properties of alginates vary from one species to another and sometimes within the parts of one plant (for example, the fronds and stipes of *Laminaria hyperborea* (Gunn.) Fosile). By having a variety of sources, a manufacturer can blend his products to meet the requirements for any particular use; for example, some applications rely on the formation of gels. The addition of calcium ions to an alginate solution will cause a gel to form; the gel may be soft or firm depending on the alginate used. Alginic acid is a linear polymer based on two different monomers, mannuronic acid and guluronic acid. The properties of alginates extracted from different seaweeds will vary according to the ratio of mannuronic acid to guluronic acid (the M/G ratio) in the polymer. A high proportion of guluronic acid (a low M/G ratio) in the polymer gives an alginate which forms firm gels; the gels are much weaker if mannuronic acid predominates. The stipes of *Laminaria hyperborea* yield an alginate with a low M/G ratio (about 0.4), and this alginate is finding increasing demand for the preparation of immobilised cells and enzymes in biotechnology. Alginates with a range of gel strengths can be made by blending alginate from *L. hyperborea* with others that have higher M/G ratios.

Species of *Laminaria* are the largest resource for alginate production (Table 2). Commercial resources of *L. hyperborea* (16.4% of the total alginophyte resource) are utilised off the coasts of Norway, Ireland, Scotland and France. In Norway, mechanical harvesting, using a drag rake, can yield from a half- to a tonne of wet seaweed per minute; usually the whole plant is used, without drying, for alginate extraction. In Ireland and Scotland, the fronds are removed from cast plants and the stipes ('rods') are air-dried on the stony shore, piled like cordwood. France collects only a small proportion (3.6%) of the estimated available crop of *L. hyperborea* and is looking for suitable harvesting methods. *Laminaria digitata* (L.) Lamouroux is harvested predominantly in France; a 'twisting pole' with hooks on the end is used to pull plants up and off the sea bed. Other species in Table 2 include *L. schinzii* Fosile for South Africa, unspecified species for Spain (Gallardo *et al.*, 1990) and that portion of the Chinese *L. japonica* which is not used for food, although it is not clear whether all of this 50000 tonnes (29% of the total alginophyte resource) goes into alginate manufacture. Some of the *L. japonica* cultivated in North Korea is used for alginate manufacture, but this has not been included in the table; as there is only one alginate factory, the quantity used would be comparatively small. Information on harvests from USSR is not readily available but, after a recent visit, McLachlan and Ragan (1990) estimate an alginate production of about 200 tonnes per annum in the far east and north. This would require a harvest of about 1000 tonnes dry-weight of the *Laminaria* species used (*L. saccharina* (L.) Lamouroux and *L. digitata*); the harvest comes from both natural stocks and material cultivated on a two-year cycle.

Ascophyllum nodosum (L.) Le Jolis, the next largest resource (Table 2), gives darker alkaline extracts than most *Laminaria* species; it contains large amounts of phenolic compounds which are oxidised and polymerised to brown products during extraction. It is an intertidal plant, and the largest single resource, in Ireland (33% of the *Ascophyllum*) is harvested by hand. The two smallest resources, in Scotland (8%) and France (3%), are also hand-harvested, but mechanical methods are used in Norway (24%) and Iceland (11%); in Nova Scotia (21%), both mechanical- and hand-harvesting are done.

Lessonia is cast onto the shores of the northern desert region of Chile; some material is also harvested by hand. It was adversely affected by the warm waters of the El Niño phenomenon in 1982–83, and the current yield is only two-thirds of that obtained before the beds were devastated.

The main resources of *Macrocystis* are found on the west coasts of USA and Baja California. The values in Table 2 represent average annual yields; the standing crop can be seriously affected by storms and the El Niño phenomenon. The harvest fell to 800 dry tonnes in 1983, after the 1982–83 El Niño. The only major commercial resource from South America is in Chile; small and variable annual quantities (100–500 tonnes) are available from Argentina.

Small but important contributions to the variety of available alginates are made by *Ecklonia*, *Fucus* and *Durvillaea*. Dried *Durvillaea* has an unusually high alginate content of 40–45%. Unsuccessful attempts have been made to base an alginate industry on the large resource of *Nereocystis lutekeana* (Mert.) Postels & Ruprecht on the west coast of Canada. Accurate surveys of the best areas show that at least 440000 wet tonnes of seaweed are available. Only about 200 wet tonnes of this (not shown in Table 2) are currently harvested annually.

All weights in Table 2 are in dry tonnes, but some of the resources are processed without drying; in France and Norway, the *Laminaria* species are processed wet. All of the *Ascophyllum* in Scotland and at least 50% of it in Norway and Canada are wet processed, as is all of the *Macrocystis* from USA and Mexico. The total commercial resources available from each country are shown in Figure 2; the only cultivated resource is that from China.

Seaweeds for carrageenan production

The seaweed supply for carrageenan production is now dominated by the *Eucheuma* species, which are cultivated mainly in the Philippines and Indonesia (Table 3). Development of cultivation, beginning in the 1970s, has allowed considerable

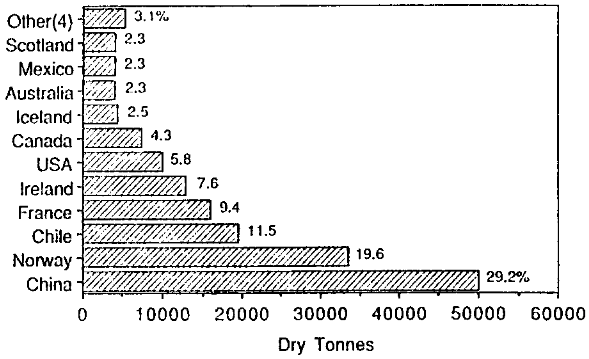

Fig. 2. Seaweeds for alginate production. Total contribution by each country, in dry tonnes and as a percentage of the total for all countries. Other (4) = total contribution by four other countries (listed in Table 2).

expansion of the carrageenan industry. Previously, output of carrageenan was restricted by the natural supplies of *Chondrus crispus* Stackh. from Canada and France and species of *Gigartina*/*Iridaea*, mainly from South America, Mexico and southern Europe; these now constitute only about 20% of the total raw material. New uses for carrageenan have recently placed increased pressure on the seaweed supply and the resulting shortage has caused a rise in price of about 100% from 1987 prices. Carrageenan production for the next year is expected to expand by about 20% and virtually all the necessary seaweed resource must come from cultivation.

There are three main types of carrageenan: *lambda*, *kappa* and *iota*; each has differences in properties and uses. *Chondrus*, as harvested, yields a mixture of *lambda* and *kappa*. The *Gigartina* from southern Europe is a good source of *lambda* (Stanley, 1987) while the product from

Table 3. Seaweeds for carrageenan production – quantity harvested in dry tonnes.

	Eucheuma	*Chondrus*	*Gigartina*	Other
Argentina			80	
Brazil				1100 (*Hypnea*)
Canada		4900		
Chile			2900	4400 (*Iridaea*)
China	300 (gelat)[a]			
Denmark				400 (*Furcellaria*)
Fiji	100 (cot)[b]			
France		800		
Indonesia	8000 (cot)			
	6500 (spin)[c]			
Kiribati	100 (cot)			
Korea R (Sth)		150		
Mexico			300	
Morocco			200	
Peru			20	
Philippines	50000 (cot)			
	1000 (spin)			
Portugal		220	200	
Spain		300	600	
Totals	66000	6370	4300	5900
% of Table total	79.9%	7.7%	5.2%	7.2%

[a] *Eucheuma gelatinae.*
[b] *Eucheuma cottonii.*
[c] *Eucheuma spinosum.*

Source: Quantities shown in the Table are the author's estimates, based on published government statistics and/or information received from representatives of industrial, academic and government organisations.

the South American seaweeds is probably best described as *iota*; the extracted colloids do not necessarily match the exact composition and structures which chemists have assigned to *lambda*, *kappa* and *iota*. *Eucheuma cottonii* Lueben van Bosse yields almost ideal *kappa*-carrageenan, while *Eucheuma spinosum* (L.) J. Agardh. yields almost ideal *iota*-carrageenan (recently some *Eucheuma* species have been transferred to *Kappaphycus*).

The greatest demand is for *kappa*-carrageenan, and *E. cottonii* accounts for about 90% of the cultivated *Eucheuma* species. *E. spinosum* is the more difficult of the two to grow in the Philippines; however when cultivation was introduced to Bali, Indonesia, it was found that both species grow equally well, so the bulk of *E. spinosum* now comes from Bali. The only wild *Eucheuma* in Table 3 is 300 tonnes from China, where the species is *Eucheuma gelatinae* (Esp.) J. Agardh.

In considering the Chilean resources in Table 3, it should be noted that in the past some *Iridaea* species have been listed as *Gigartina*. The values here are derived from recent Chilean government statistics which show three species of *Gigartina* and a single, separate classification of '*Iridaea*'.

Among the minor producers of *Eucheuma*, Fiji had raised production to about 300 tonnes in 1987, but this decreased after the military coup. Efforts are now being made to revive interest among potential farmers and a large company farm is under development. Kiribati has had difficulty in marketing its seaweed because of its isolation, but the increase in price and strong demand will allow it to expand production. China has experimental farms on Hainan Island (latitude 17–18 °N), so production could increase considerably in the future.

The largest suppliers of carrageenophytes are the Philippines and Indonesia (Fig. 3), mainly from cultivated material, followed by Chile and Canada, sources of the more traditional wild seaweeds.

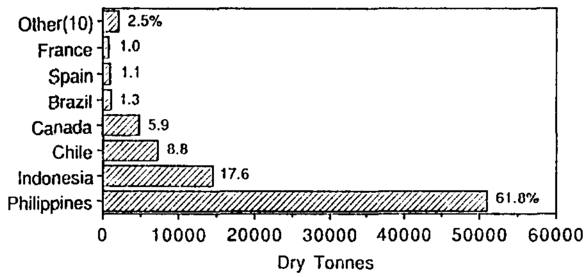

Fig. 3. Seaweeds for carrageenan production. Total contribution by each country, in dry tonnes and as a percentage of the total for all countries. Other (10) = total contribution by ten other countries (listed in Table 3).

Seaweeds for agar production – *Gelidium* species

The principal sources of agar are species of *Gelidium* and *Gracilaria*, with minor contributions from *Pterocladia* and *Gelidiella* (Table 4). *Gelidium* and *Pterocladia* are usually regarded as giving the best quality agar, and they command a higher price. Species of *Gelidium* on the coast of Japan were the original source of agar, but these became depleted by industrial expansion and pollution.

Three main grades of agar are recognised: bacteriological agar, sugar-reactive agar and food-grade agar. *Gelidium* and *Pterocladia* are the sources of bacteriological agar because their extracts best meet the requirements of gel strength (about 600 g cm^{-2}) and temperature hysteresis (the difference between melting temperature and gelling temperature); the desirable characteristics are, gelling temperature of 32–36 °C, melting temperature of 85–86 °C (Armisen & Galatas, 1987). Sugar-reactive agar is obtained largely from some *Gracilaria* species found in the eastern Pacific (Santelices & Doty, 1989). This type of agar retains its gel strength with the addition of sugar (at least up to 75 g per 100 mL of 1% agar gel) and the gel becomes elastic. This is in contrast to agar from *Gelidium*, which loses gel strength with the addition of even small amounts of sugar while the gel remains brittle (Moss & Doty, 1987). Agar which cannot meet the specifications for the above two grades is sold as food grade, this being the least expensive of the three grades.

Each country's harvest and its contribution to

Table 4. Seaweeds for agar production – quantity harvested in dry tonnes.

	Gelidium	approx. % of total *Gelidium* harvest	*Gracilaria*	Other
Argentina			2500	
Australia	10			
Brazil			1000	
Chile	430	2	6800 6020 – cult.	
China	200	1	2000 – cult.	50 (G)[a]
France	300	1.5		
India			600	300 (G)
Indonesia	1400	6.5	3450	
Japan	3100	14.5		
Korea R (Sth)	2900	13.5	50	
Korea DPR	270	1		
Madagascar	200	1		
Mexico	2200	10		
Morocco	4000	18.5	200	
Namibia			1200	
New Zealand				250 (P)[b]
Portugal	2000	9.5	120	700 (P)
South Africa	190	1		
Spain	4300[c]	20		
Taiwan			1600 – cult.	
Totals	21500	100	25540	1300
% of Table total	44%		53%	3%

[a] Gelidiella.
[b] Pterocladia.
[c] Based on 60% of actual harvest of 7100 t; estimate approx. 40% of harvest is not *Gelidium*.

Source: Quantities shown in the Table are the author's estimates, based on published government statistics and/or information received from representatives of industrial, academic and government organisations.

the total *Gelidium* harvest are shown in Table 4. The most prolific geographical area is the Iberian Peninsula and Morocco. The largest harvest appears to come from Spain (7100 tonnes in 1989, although a more average year would yield 5500–6000 tonnes); however, much of the Spanish *Gelidium* is badly contaminated (up to 50%) with other seaweeds so that in an average year's harvest, the actual amount of *Gelidium* would be closer to 3000 tonnes. This can be compared to the harvest from neighbouring Portugal, where the 2000 tonnes collected is 'clean' *Gelidium*. The Spanish harvest area (yielding 20% of the world *Gelidium* harvest) runs along the entire north coast and the adjoining part of the west coast to the border with Portugal; from the border to Porto in Portugal, *Chondrus crispus* is collected rather than *Gelidium*. In Portugal (9.5%), the main areas for *Gelidium* collection commence almost halfway down the west coast, about 70 km of coast extending north from Peniche; other areas are south of Lisbon, near Cabo Espichel, around Vila Nova, and on the southern coast near Lagos. In Morocco, the main harvest areas (18.5%) lie between Larache in the north and the 30° parallel of latitude, south of Agadir. Also used are three other areas on the former Western Sahara coast; a little south of Cap Juby near the former border, around Cap Boujdour, and about 50 km of coastline just south of the 25° parallel of latitude.

Japan remains a major producer of *Gelidium* (14.5%). The Izu Islands, part of Tokyo Prefecture, and the Izu Peninsula have long been major sources. Significant amounts also come from the east and west ends of the island of Shikoku, from the prefectures of Hyogo and Wakayama which border the Seto Inland Sea on each side of Osaka, and from Nagasaki prefecture on Kyushu (Japan, 1990). The Japanese agar industry has the capacity to use all the local *Gelidium* and for some years also imported *Gelidium* and large quantities of *Gracilaria*; however, the increasing costs of processing seaweeds in Japan, coupled with the rising price of *Gracilaria*, has led some companies to establish extraction plants in other countries, such as Chile, where costs are lower and seaweed supplies are closer. In South Korea (13.5%), *Gelidium* is reputed to be present around most of the coastline but commercial harvests are concentrated in the area between Pusan and Pohang, with the agar processors based in Pusan. The only data available for North Korea is the importation of 270 tonnes (~1%) by Japan from that country.

Commercial *Gelidium* harvests for Mexico (10% of the world *Gelidium* harvest) are made on the west coast of Baja California in selected areas from Punta Descanso, B.C., which is north of Ensenada, to Bahía Tortugas, B.C.S., south of the 28° parallel of latitude. The quantity of *Gelidium* from Indonesia has fluctuated widely in the past, but with the increased demand and price, substantial quantities are now being regularly harvested (6.5%). Collection is spread over a wide area; the southern coast of Java yields about 30% of the total, the islands between Java and Timor about 25%, Sumatra about 15%, and the remainder comes from several areas to the north and east of Timor. In Chile, *Gelidium* accounts for only 3% of the total agarophyte output of the country, all of which is exported; it is harvested near Cabo Tablas, north of Valparaiso, and at two locations about midway between Valparaiso and Concepcion.

Seaweeds for agar production – Other species

Gracilaria species had been known to give good yields of agar with poor gel strength; treatment of the seaweed with alkali was found to lower the yield but increase the gel strength (Funaki & Kojima, 1951). With the industrialization of this discovery, *Gracilaria* became a useful source of agar; the conditions for the alkaline treatment can vary according to the origin of the *Gracilaria* (Okazaki. 1971), but they range between 60–90 °C for 1 to 3 h using 4–7% sodium hydroxide.

The polymer molecules in agar usually form themselves into helices; the interaction of these helices causes gel formation. The agar from untreated *Gracilaria* has been found to contain units of L-galactose 6-sulfate in its polymer molecules; its presence causes kinks (irregularities) in the helices. Treatment with alkali converts the L-galactose 6-sulfate into 3,6-anhydro-L-galactose and the shape of this new molecule removes the kinks from the helices. This allows the helices to align more closely with each other as the gel forms, giving a higher gel strength.

Gracilaria production is dominated by Chile, with about 50% of the world total; almost half of this comes from recently-introduced cultivation. The Chinese production (8%) is all from cultivation, in the southern provinces of Guangdong and Hainan Island. Taiwan produces 1600 tonnes, cultivated in ponds, but 85% of this is used for abalone farms so the Taiwanese agar industry imports raw material. There are other significant producers: Indonesia (13%), Argentina (10%), Namibia (5%), Brazil (4%). Other minor producers are shown in Table 4.

The contributions to agar production of *Gelidium* and *Gracilaria* species were about equal five years ago, but successful cultivation has led to an increased availability of *Gracilaria*; its use now exceeds that of *Gelidium* (Table 4). Commercial sources of *Pterocladia* are limited to natural stocks in the Azores and New Zealand. The contribution of *Gelidiella*, from India and China, to world agar production is very small.

McLachlan and Ragan (1990) report that, in the USSR, production of galactans from red seaweeds has been as high as 1000 tonnes per year. The largest factory is at Odessa, and it is dependent on *Phyllophora nervosa* (DC) Greville from the Black Sea, a resource which has been considerably depleted in recent years by industrialisation and pollution; some aquaculture of this species is being undertaken in the Black Sea. In the north and far east, agar is produced from *Ahnfeltia* species. Only small quantities of agar are produced in the north (Archangel), using *A. plicata* (Huds) Fries. In the far east (Vladivostok), *A. tobuchiensis* (Kanno + Martsub.) Makami is used, with a production of about 400 dry tonnes per year from Stark Field and the Kuril Islands (J. L. McLachlan, *in litt.*); also being evaluated is *Gracilaria* from Vietnam, where farming in ponds has been expanding since 1987.

Each country's total contribution of agarophytes is shown in Fig. 4: Chile leads with its combination of wild and cultivated *Gracilaria*: then follows a group of five countries each producing 3000–5000 tonnes, all predominantly *Gelidium* except for Indonesia, where *Gracilaria* production is higher, probably because of the introduction of cultivation in some areas. From Fig. 4, it can be seen that the supply of agarophytes is spread more evenly over a much wider range of countries than that of the other types of seaweed considered here (Figs. 1–3).

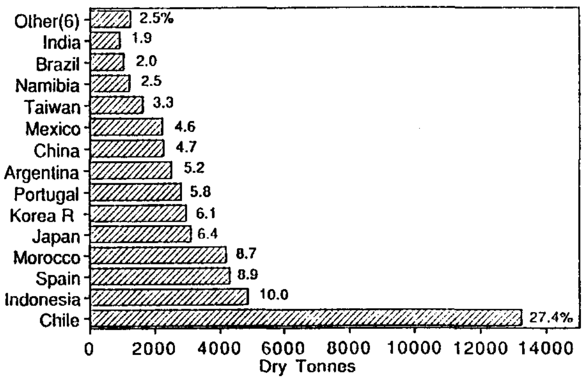

Fig. 4. Seaweeds for agar production. Total contribution by each country, in dry tonnes and as a percentage of the total for all countries. Other (6) = total contribution by six other countries (listed in Table 4).

The current world demand for seaweed foods is matched by the supply and any future increase in demand could be adequately met by extending cultivation. The natural stocks of alginophytes are meeting world demand but there is little surplus; natural disasters such as the El Niño, or strong storms on the southers Californian coast, have lead to difficulties in meeting demand. Larger quantities of *Ascophyllum* could be harvested from natural stands in Nova Scotia and New Brunswick, Canada; present methods of cultivating brown seaweeds give a product which is affordable for food but normally too expensive to use for alginate extraction. New uses for carrageenan have led to increased demand for carrageenophytes in the past two years, and the consequent shortage has increased prices, particularly for *Eucheuma*. Natural stocks of traditional species are limited, and the industry is dependent on increased cultivation of *Eucheuma*, which is now being undertaken. The applications of agarose in biotechnology are increasing, and the demand for bacteriological agar continues to grow. There has been difficulty in meeting the resultant demand for high quality agarophytes, with most natural *Gelidium* beds being well exploited and the quality of the available natural *Gracilaria* declining. Mixed results have been obtained from the cultivation of *Gracilaria*, careful choice of species, strain and growth conditions being necessary to obtain a good quality agar. The commercial cultivation of *Gelidium* has proved to be difficult, but current research and development is promising and offers the best prospects for those hoping to meet future demands for a high-quality agar.

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