

World seaweed utilisation: An end-of-century summary

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Abstract

The data for worldwide seaweed production for the years 1994/1995 are summarised. At least 221 species of seaweed were used, with145 species for food and 101 species for phycocolloid production. 2,005,459 t dry weight was produced, with 90% coming from China, France, UK, Korea, Japan and Chile. 1,033,650 t dry weight was cultured with 90% coming from China, Korea and Japan. Just four genera made up 93% of the cultured seaweed: *Laminaria* (682,581 t dry wt), *Porphyra* (130,614 t dry wt), *Undaria* (101,708 t dry wt) and *Gracilaria* (50,165 t dry wt). The value of the harvest was in excess of US \$ 6.2 billion. Since 1984 the production of seaweeds worldwide has grown by 119%.

Introduction

Compiling statistics on world utilisation is not an easy task. As Critchley & Ohno (1998) point out, in many cases the data are held by different government departments, personal files, theses or obscure government publications. Fortunately, 'Seaweeds of the World' (Critchley & Ohno, 1998) contains statistics from almost all seaweed-producing nations on the species used, the amounts harvested and or cultured and in many cases the value of the seaweed produced. This review is primarily a synthesis of those data, as this is the most current and complete data set available. These data have been supplemented from other sources, where necessary (see below).

In order to compile an estimate of annual seaweed production, we used the data from either 1994 or 1995, these being the latest years that most authors have reported. In the case of Iceland, the data are from 1980 (the most recent data in the literature). To allow a comparison of the amount of algae produced in each country, it was necessary to standardise the figures to dry weight, as various authors reported production in either dry or wet weight, but rarely both. As the water content of algae is known to fluctuate seasonally, we determined the mean water content (where published) of the species or genus in question and used this to convert wet to dry weight. Calculations were based on a dry weight percentage of: 15% for *Enteromorpha, Codium, Porphyra, Iridaea, Gigartina* and *Gracilaria* and 28% for *Gelidium, Mastocarpus* and *Durvillaea* (Alveal & Ponce, 1997), 27% for *Kappaphycus* and *Eucheuma* (Ohno et al., 1996), 20% for *Pterocladia, Laminaria, Lessonia, Macrocystis, Sargassum* and *Turbinaria* and 30% for *Ascophyllum* (Chapman & Chapman, 1980), 90% for Maerl (King & Schramm, 1982), 20% for *Ecklonia* (Stewart et al., 1961), 20% for *Fucus* (Guiry & Hession, 1998) and 12% for *Chondrus* (Mairh et al., 1991).

Because of their different floras, Alaska and Hawaii are listed separately from the rest of the United States of America. Data from each country in Tables 2 and 3 are from the sources cited in Table 1 .

<i>Table 1.</i> Sources of data used in Tables 1 and
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Country (or region)	Reference	
Alaska	Stekoll, 1998	
Argentina	Boraso de Zaixso et al., 1998	
Australia	McHugh & King, 1998	
Bangladesh	Nurul Islam, 1998	
Brazil	Oliveira, 1998	
Britain	Kain & Holt, 1998	
Canada	Chopin, 1998; Lindstrom, 1998	
Caribbean	Smith, 1998	
Chile	Alveal, 1998	
China	Chaoyuan, 1998	
France	Kaas, 1998	
Iceland	Chapman & Chapman, 1980	
India	Marih, 1998	
Indonesia	Istini et al., 1998	
Ireland	Guiry & Hession, 1998	
Israel and Egypt	Lipkin & Friedlander, 1998	
Italy	Cecere, 1998	
Japan	Ohno & Largo, 1998	
Kenya	Oyieke, 1998	
Korea	Sohn, 1998	
Madagascar	Mollion, 1998	
Malaysia	Moi, 1998	
Mexico	Robledo, 1998	
Morocco	Melo, 1998	
Mozambique	Bandeira, 1998	
Myanmar	Soe-Hun, 1998	
Namibia	Molloy, 1998	
New Zealand	Brown, 1998	
Norway	Jensen, 1998	
Peru	Acleto, 1998	
Philippines	Trono, 1998	
Portugal	Sousa-Pinto, 1998	
South Africa	Critchley et al., 1998	
South Pacific Islands	South, 1998	
Spain	Juanes & Sosa, 1998	
Tanzania	Mshigeni, 1998	
Thailand	Lewmanomont, 1998	
United States of America	Merrill & Waaland, 1998	
Vietnam	Nang & Dinh, 1998	

Results

Seaweed uses

Table 2 shows that world-wide at least 221 species of seaweed were used: 32 chlorophytes, 125 rhodophytes and 64 phaeophytes. These values are certainly underestimates, as some authors state that many species

Table 2. Algal species utilised world-wide, country and uses. F = food, A = agar, C = carrageenan, Al = alginate, M = medicine, RoK = Roe on Kelp, Ag = Agricultural, P = paper. See text for references

Species	Use	Country
Chlorophyta		
Acetabularia major	М	Indonesia Philippines
Capspsiphon fulvescens	F	Korea
Caulerpa spp.	F	Malaysia, Thailand
Caulerpa lentillifera	F, M	Philippines
Caulerpa peltata	F, M	Philippines
Caulerpa racemosa	F	Bangladesh, Japan, Philippines,
		South Pacific Islands, Vietnam
	Μ	Philippines
Caulerpa sertularioides	F, M	Philippines
Caulerpa taxifolia	F, M	Philippines
Codium spp.	F	Argentina
Codium bartletti	F	Philippines
Codium edule	F	Philippines
Codium fragile	F	Korea, Philippines
Codium muelleri	F	Hawaii
Codium taylori	F	Israel
Codium tenue	F	Indonesia
Codium tomentosum	F	Indonesia
Colpomenia sinuosa	F	Philippines
Dictyosphaeria cavernosa	Ag	Kenya
	М	Philippines
Enteromorpha spp.	Ag	Portugal
	F	Bangladesh, France, Hawaii,
		Myanmar
Enteromorpha compressa	F	Korea, Indonesia
	М	Indonesia, Philippines
Enteromorpha clathrata	F	Korea
Enteromorpha grevillei	F	Korea
Enteromorpha intestinalis	F	Indonesia, Japan,
		Korea
	М	Indonesia
Enteromorpha linza	F	Korea
Enteromorpha nitidum	F	Korea
Enteromorpha prolifera	F	Indonesia, Japan, Korea,
		Philippines
	М	Indonesia
Monostroma nitidum	F	Japan
Scytosiphon lomentaria	F	Korea France
Ulva spp.	Ag	Italy, Portugal
	F	Argentina, Canada, Chile,
		Hawaii, Japan, Malaysia
TTI I .	P	Italy
Ulva lactuca	F	Vietnam Indonesia
Ulva pertusa	м	Philippines
Ulva reticulata	F	Vietnam
Knodopnyta	C	Vietnesse
Acantnopnora spicijera	C E	Vietnam Dhilingings Vietnem
Abufaltia plicata	Г	Chilo (Ag)
Amgenia pucaia	ng E	Unic (Ag)
Asparagopsis taxijormis	г М	nawan, muonesia
Patanhuana calati	E C	Viotnom
Calaalossa advata	r, C F	Indonesia
Calaglossa lanaia	r M	Indonesia Vietnem
Catanolla spr	E	Muonesia, viculalli
Chondria crassicaulis	г Е	iviyallillal Korea

Table 2. Continued

Species	Use	Country	Spee
Chondrus crispus	С	France, Spain, US	Gra
	F	Ireland, France	
Chondrus ocellatus	F	Japan	Gra
Eucheuma alvarezii	С	Malaysia, Kiribati	
Eucheuma cartilagineum	F	Japan	
Eucheuma denticulatum	С	Philippines, Madagascar	Gra
Eucheuma gelatinae	С	China, Indonesia, Philippines	Gra
F I I I	F	Indonesia, Japan, Philippines	Gra
Eucheuma isiforme	F	Caribbean	Gra
Eucheuma muricatum	F, M	Indonesia	C
Eucheuma striatum	0	Madagascar	Gra
Genalena acerosa	A E	Dhilippinos	Gra
Calidialla tanuissima	г F	Philippines Bangladash	Gra
Gelidium spp	Δ	China Japan	Gra
Genaum spp.	F	Hawaii	Gra
Gelidium abbottiorum	A	South Africa	Gra
Gelidium anansii	FM	Korea Indonesia	0/1
Gelidium capense	A .	South Africa	Gra
Gelidium chilense	A	Chile	0/4
Gelidium latifolium	A	Spain	
Senanan rangenan	F	Indonesia	Gra
Gelidium lingulatum	A	Chile	
Gelidium madagascariense	A	Masagascar	
Gelidium pristoides	А	South Africa	Gra
Gelidium pteridifolium	А	South Africa	Gra
Gelidium pusillum	F	Bangladesh	Gra
Gelidium robustum	А	Mexico	Gyn
Gelidium rex	А	Chile	Hal
Gelidium sesquipedale	А	Morocco, Portugal, Spain	Hal
Gelidium vagum	А	Canada	Hal
Gigartina canaliculata	С	Mexico	Hal
Gigartina chamissoi	С	Peru	Нур
	С	Chile	Нур
Gigartina intermedia	С	Vietnam	Нур
Gigartina scottsbergii	С	Argentina, Chile	Нур
Gloiopeltis spp.	F	Vietnam	Нур
Gloiopeltis furcata	F	Korea	Нур
	С	Japan	Irida
Gloiopeltis tenax	С	Japan	Irida
<i>a</i>	F	Korea	Irida
Gloiopeltis complanata	C	Japan	Iride
Gracilaria spp.	Ag	Portugal	Кар
	C E	Malaysia Management Thailand	V
	Г D	Myanmar I nalland	Кар
	r M	Vietnem	Lau
Gracilaria asisatica	Δ	China Vietnam	Lau
Gracuaria asisanca	R E	Viotnom	Lau
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Gracilaria oaudata	Г Л	Japan Prozil	Mas
Gracilaria chanaii	R E	Thailand	Mus
Gracilaria chilansis	Γ. Δ	Chile	Maa
Gracitaria chillensis	Δα	New Zealand	Maz
Gracilaria cornea	Ag A	Brazil	Mar
Graciana comea	F	Caribbean	Ner
Gracilaria coronopifara	F	Hawaii Vietnam	Pale
Gracilaria crassissima	F	Caribbean	Pale
Gracilaria dominoensis	F	Brazil Caribbean Chile	Pale
Gracilaria edulis	А	India	1 411
Graciana callis	11	mana	

Table 2. Continued

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	maria palmata	F	Canada, France, Iceland,

Table 2. Continued

species	Use	Country
Phymatolithon calcareum	Ag	France, Ireland, UK
Porphyra spp.	F	Israel, New Zealand, UK
Porphyra abbottae	F	Alaska, Canada
Porphyra acanthophora	F	Brazil
Porphyra atropurpurae	F, M	Indonesia
Porphyra columbina	F	Argentina, Chile, Peru
Porphyra crispata	F	Thailand, Vietnam
Porphyra fallax	F	Canada
Porphyra haitanensis	F	China
Porphyra kuniedae	F	Korea
Porphyra leucostica	F	Portugal
Porphyra perforata	F	Canada
Porphyra psuedolanceolata	F	Canada
Porphyra seriata	F	Korea
Porphyra spiralis	F	Brazil
Porphyra suborbiculata	F	Korea, Vietnam
Porphyra tenera	F	Japan, Korea
Porphyra torta	F	Alaska, Canada
Porphyra umbilicalis	F	France, US
Porphyra vietnamensis	F	Thailand
Porphyra yezoensis	F	China, Japan, Korea
Pterocladia capillacea	А	Portugal
*	F	Korea
Scinaia moniliformis	F	Philippines
Solieria spp.	F	Myanmar
Pterocladia lucida	А	New Zealand
Phaeophyta		
Alaria crassifolia	F	Japan
Alaria fitulosa	Ag. F	Alaska
Alaria marginata	F	Canada
Alaria esculenta	F	Iceland, Ireland, US
Ascophyllum nodosum	Ag	France, Canada, China,
I J	0	Iceland, US
	Al	Ireland, Norway, UK
Cladosiphon okamuranus	F	Japan
Cystoseira barbata	Al	Egypt
Desmarestia spp.	RoK	Alaska
Durvillaea antarctica	F	Chile
Durvillaea potatorum	Al	Australia
Ecklonia cava	F	Japan
Ecklonia maxima	Ασ	South Africa
Ecklonia stolonifera	F	Korea
Egregia menziesii	F	Canada
Fucus spn	Ασ	France
Fucus gardneri	Ασ	Canada
1 acas guianell	F Rok	Alaska
Fucus serratus	Al	Ireland
I NEWS SETTUINS	F	France
Fucus vasiculosus	Δ1	Ireland
1 acus vesicuiosus	Co	Ireland
	E	France Portugal
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Laminaria angustata	Г Б.Р.И	Japan
Laminaria bongardiana	F, ROK	Alaska
Laminaria diabolica	F Al	Japan
y y y y y		Hrance Ireland
Laminaria digitata	AI	Trance, netanu
Laminaria digitata	AI F	Ireland

Table 2. Continued

Species	Use	Country
Laminaria hyperborea	Al	Ireland Norway Spain UK
Laminaria iaponica	Al	China
Lamma a japonica	F	China, Japan, Korea
Laminaria longicruris	F	US
Laminaria longissima	F	Japan
Laminaria ochroleuca	Al	Spain
Laminaria octotensis	F	Japan
Laminaria religiosa	F	Japan, Korea
Laminaria saccharina	F	Alaska, Canada, Ireland
	RoK	Alaska
Laminaria setchelli	F	Canada
Laminaria schinzii	Ag	South Africa
Lessonia nigrescens	Al	Chile, Peru
Lessonia trabeculata	Al	Chile
Macrocystis integrifolia	Al	Peru
	RoK	Alaska, Canada
Macrocystis pyrifera	Ag	Australia
	Al	Chile, Mexico, Peru, US
	F	Argentina
	RoK	Alaska, US
Nemacystis decipiens	F	Japan
Nereocystis luetkaena	Ag	Alaska, Canada
	F	US
Pelvetia siliquosa	F	Korea
Postelsia spp.	F	US
Sargassum aquifolium	F	Indonesia
Sargassum crassifolium	Al	Vietnam
	F	Thailand
Sargassum spp.	Ag	Brazil, Vietnam
	AI	Vietnam
	F	Bangladesh, Hawaii, Malaysia,
		Theiland Mistager
	м	I hailand, Vietnam
Sanaassum filin on dula	E	Equat
Sargassum juipenaula Sargassum gramminifolium	Г A1	Egypt
Sargassum banslowianum	A1	Vietnam
Sargassum horneri	F	Korea
Sargassum ilicifolium	A1	India
Sargassum mcclurei	Al	Vietnam
Sargassum myriocystum	Al	India
Sargassum oligosystum	F	Thailand
Sargassum polycystum	F	Indonesia, Thailand
0 1 7 7	Al, M	Vietnam
Sargassum siliquosum	Al	Vietnam
0	F, M	Indonesia
Sargassum wightii	Al	India
Sargassum vachelliannum	Al	Vietnam
Turbinaria spp.	Ag	Vietnam
	М	Philippines
Turbinaria conoides	Al	India (Al)
Turbinaria decurrens	Al	India
Turbinaria ornata	Al	India
Undaria pinnitifida	F	Australia, China, France, Japan,
		Korea
Undaria peterseniana	F	Korea

from a given genus are utilised, without listing the individual species (e.g. Ulva spp.). 145 species (66%) were used for food: 79 rhodophytes, 28 chlorophytes and 38 phaeophytes. Just over half of the rhodophyte and phaeophytes were used for phycocolloid production; 41 species for alginates, 33 for agar and 27 for carrageenan. 24 species were used in traditional medicines. This is probably also an underestimate, as many authors did not list medicinal seaweeds. 25 species were used in agriculture, including animal feed and fertiliser, while at least 2 species (Ulva laetevirens and Gracilaria verrucosa) were used in the production of paper in Italy. Several seaweeds (mainly Macrocystis, but also Laminaria and Fucus) were utilised in the 'Roe on Kelp' industry in Canada, Alaska and the north-western United States. Pacific Herring eggs spawn on the kelps which are collected as a gourmet food item.

Production figures

Table 3 shows that, worldwide, in 1994/1995 over 2 million t dry weight of seaweed was produced annually. 90% came from just six countries (China, France, UK, Korea, Japan, Chile) and just five genera (*Laminaria*, maerl (*Lithothamnion*), *Porphyra*, *Undaria* and *Gracilaria*).

52% of seaweed produced was cultured; 74% of chlorophytes, 22% of rhodophytes and 82% of phaeophytes. 90% of the cultured seaweed was produced in China, Korea and Japan. Of the genera cultured, *Laminaria* was produced in the largest amount (682,581 t d. wt) followed by *Porphyra* (130,614 t d. wt), *Undaria* (101,708 t d. wt) and *Gracilaria* (50,165 t d. wt). These four genera made up 93% of seaweed cultured worldwide.

Economic value

If data on production of seaweeds are difficult to gather, then data on their value are even more so. Because of competition. farmers and harvesters are loath to give accurate figures on the price paid for their products, so little is published. With the exception of the highly organised industry in Asia, much of the seaweed gathered for food is done by cottage industry or local families, and is generally not regulated or the amounts recorded. Where there are records, the economic value can be inferred from the market prices of the finished product.

In terms of price paid by weight, the seaweed used for food, particularly in Japan, is the most valuable. *Table 3.* Annual world seaweed production 1994 or 1995 (t dry weight). See Table 1 for references

Genera	Country	Total	Cultured
Chlorophyta			
Codium	Korea	0.15	0.15
Caulerpa	Philippines	810	810
Enteromorpha	Japan	1,400	1,400
	Korea	1,038	1,038
Monostroma	Japan	1,250	1,250
Ulva	Japan	1,500	
Rhodophyta	•		
Chondrus	Canada	10,000	
	France	1,260	
	Ireland	3	
	Japan	500	
	Portugal	30	
	Spain	300	
	US	120	
Euchuema	China	300	300
	Indonesia	13,447	13,447
	Kiribati	396	396
	Madagascar	500	
	Malaysia	800	800
	Philippines	10,102	10,102
Gelidiella	India	232	
Gelidium	Chile	1,144	
	China	300	
	France	1,800	
	Japan	5,714	
	Madagascar	300	
	Mexico	1,200	
	Morocco	6950	
	Portugal	900	
	South Africa	139	
	Spain	326	
Gigartina	Argentina	22	
-	Chile	6,389	
	Mexico	200	
Gloiopeltis	Japan	900	900
Gracilaria	Argentina	2,276	
	Chile	68,436	34218
	China	300	300
	India	215	
	Indonesia	13,447	13,447
	Mexico	205	
	Namibia	835	
	Peru	194	
	South Africa	439	
	Thailand	200	200
	US	2	
	Vietnam	2,000	2,000
Iridaea	Chile	5,606	

Table 3. Continued

Genera	Country	Total	Cultured
Kappaphycus	Philippines	30,306	30,306
Mastocarpus	Spain	600	
	Ireland	5	
	Portugal	70	
Palmaria	Canada	100	
	Ireland	3	
Porphyra	Argentina	3	
	Chile	5	
	China	30,165	30,165
	Japan	60,000	60,000
	Korea	40,449	40,449
Pterocladia	New Zealand	50	
	Portugal	300	
Maerl (t ww)	France	600,000	
	Ireland	1,000	
	UK	200,000	
Phaeophyta			
Ascophyllum	Canada	2,500	
	China	3,000	
	France	1,700	
	Iceland	4,400	
	Ireland	8,999	
	Norway	6,632	
	UK	3,500	
	US	280	
Cladosiphon	Japan	1,500	1,500
Durvillaea	Australia	4,000	
	Chile	464	
Ecklonia	South Africa	350	
Fucus	France	2	
	Ireland	80	
	Portugal	0.04	
Hizakia	Korea	7,497	6,297
Laminaria	Canada	0.48	
	China	644,464	644,464
	France	12,000	
	Ireland	523	
	Japan	32,000	24,000
	Korea	6,117	4,588
	Norway	34,000	
	Scotland	1,000	
	South Africa	350	
	Spain	40	
	UK	1,000	
Lessonia	Chile	24,754	
Macrocystis	Argentina	20	
	Australia	14	
	Chile	2,510	
	Mexico	8,800	
	US	14,721	

Table 3. Continued

Genera	Country	Total	Cultured
Nereocystis	Alaska	20	
	Canada	2	
Sargassum	India	2,249	
	Philippines	5,000	
	Vietnam	400	
Turbinaria	India	307	
Undaria	Australia	6	
	China	20,000	
	Japan	18,310	18,310
	Korea	83,398	83,398
Roe on Kelp	Alaska	175	
	Canada	35	
	US	11	
Totals			
Chlorophytes		5,998	4,498
Rhodophytes		1,042,507	237,029
Phaeaophytes		956,954	792,122
Grand total		2,005,459	1,033,650

Monostroma has been worth US $20-30 \text{ kg}^{-1}$ in Japan for the last ten years (Ohno & Largo, 1998), while *Porphyra* in Japan is a US 1.5 billion per year business (Ohno & Largo, 1998), equating to US 25 kg^{-1} . Not all food seaweed is so expensive. In 1994 *Hizikia* in Japan was worth approximately US 9 kg^{-1} , while *Undaria* was worth approximately US 2.25 kg^{-1} . Extrapolating these prices to the total amount of these four algal genera produced worldwide gave an annual value of aproximately US 3.6 billion.

Turning from food to phycocolloids, there was an annual total of 108,229 t (d. wt) of agarophytes, 81,858 t (d. wt) carrageenophytes and 826,178 t (d. wt) of alginophytes produced in 1994/1995. Using figures in the literature for phycocolloid extraction, we can extrapolate to the amount of each phycocolloid which could be produced from this harvest. This is not a precise estimate, as phycocolloid content varies between different species (Black et al., 1951), seasonally (Bird & Hinson, 1992), and among species at different locations (Ohno et al., 1996; Rebello et al., 1997; Freile-Pelegrin et al., 1996). An estimated 25% yield from agarophytes (Mouradi-Givernaud et al., 1992; Freile-Pelegrin et al., 1996; Rebello et al., 1997), 35% from carrageenophytes (Chopin et al., 1995; Ohno et al., 1996) and 20% from alginophytes (Black et al., 1951), would give a total possible worldwide yield of: 27,057 t agar, 28,650 t carrageenan and 165,235 t alginate. A further extrapolation gives the approximate value of this resource. Using US \$ 10 kg⁻¹ for agar and alginate and US \$ 25 kg⁻¹ for carrageenan, this phycolloid production would have an approximate annual value of US \$ 2.6 billion.

Growth in production

Since 1984 there has been a large increase in seaweed production. Guiry & Blunden (1991) report a wet weight harvest in 1984 of: 8,402 t chlorophytes, 1,035,760 t rhodophytes and 2,392,958 t phaeophytes, making a total of 3,437,120 t. The corresponding annual wet weight production for 1994/1995 was 39,986 t chlorophytes, 2,770,249 t rhodophytes and 4,736,519 t phaeohytes, giving an overall total of 7,546,754 t. This represents an increase of: 376% for chlorophytes, 167% for rhodophytes and 97% for phaeophytes, with 119% overall.

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