SEAWEEDS AND THEIR MARICULTURE

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Introduction: What Are Seaweeds and Their Significance in Coastal Systems

Before explaining how they are cultivated, it is essential to try to define this group of organisms commonly referred to as 'seaweeds'. Unfortunately, it is impossible to give a short definition because this heterogeneous group is only a fraction of an even less natural assemblage, the 'algae'. In fact, algae are not a closely related phylogenetic group but a diverse group of photosynthetic organisms (with a few exceptions) that is difficult to define, by either a lay person or a professional botanist, because they share only a few characteristics: their photosynthetic system is based on chlorophyll *a*, they do not form embryos, they do not have roots, stems, leaves, nor vascular tissues, and their reproductive structures consist of cells that are all potentially fertile and lack sterile cells covering or protecting them. Throughout history, algae have been lumped together in an unnatural group, which now, especially with the progress in molecular techniques, is emerging as having no real cohesion with representatives in four of the five kingdoms of organisms. During their evolution, algae have become a very diverse group of photosynthetic organisms, whose varied origins are reflected in the profound diversity of their size, cellular structure, levels of organization and morphology, type of life history, pigments for photosynthesis, reserve and structural polysaccharides, ecology, and habitats they colonize. Blue-green algae (also known as Cyanobacteria) are prokaryotes closely related to bacteria, and are also considered to be the ancestors of the chloroplasts of some eukaryotic algae and plants (endosymbiotic theory of evolution). The heterokont algae are related to oomycete fungi. At the other end of the spectrum (one cannot presently refer to a typical family tree), green algae (Chlorophyta) are closely related to vascular plants (Tracheophyta). Needless to say, the systematics of algae is still the source of constant changes and controversies, especially recently with new information provided by molecular techniques. Moreover, the fact that the roughly 36 000 known species of algae represent only about 17% of the existing algal species is a measure of our still rudimentary knowledge of this group of organisms despite their key role on this planet: indeed, approximately 50% of the global photosynthesis is algal derived. Thus, every second molecule of oxygen we inhale was produced by an alga, and every second molecule of carbon dioxide we exhale will be re-used by an alga.

Despite this fundamental role played by algae, these organisms are routinely paid less attention than the other inhabitants of the oceans. There are, however, multiple reasons why algae should be fully considered in the understanding of oceanic ecosystems: (1) The fossil record, while limited except in a few phyla with calcified or silicified cell walls, indicates that the most ancient organisms containing chlorophyll *a* were probably blue-green algae 3.5 billion years ago, followed later (900 Ma) by several groups of eukaryotic algae, and hence the primacy of algae in the former plant kingdom. (2) The organization of algae is relatively simple, thus helping to understand the more complex groups of plants. (3) The incredible diversity of types of sexual reproduction, life histories, and photosynthetic pigment apparatuses developed by algae, which seem to have experimented with 'everything' during their evolution. (4) The ever-increasing use of algae as 'systems' or 'models' in biological or biotechnological research. (5) The unique position occupied by algae among the primary producers, as they are an important link in the food web and are essential to the economy of marine and freshwater environments as food organisms. (6) The driving role of algae in the Earth's planetary system, as they initiated an irreversible global change leading to the current oxygen-rich atmosphere; by transfer of atmospheric carbon dioxide into organic biomass and sedimentary deposits, algae contribute to slowing down the accumulation of greenhouse gases leading to global warming; through their role in the production of atmospheric dimethyl sulfide (DMS), algae are believed to be connected with acidic precipitation and cloud formation which leads to global cooling; and their production of halocarbons could be related to global ozone depletion. (7) The incidence of algal blooms, some of which are toxic, seems to be on the increase in both freshwater and marine habitats. (8) The ever-increasing use of algae in pollution control, waste treatment, and biomitigation by developing balanced management practices such as integrated multi-trophic aquaculture (IMTA).

This chapter restricts itself to seaweeds (approximately 10 500 species), which can be defined as marine benthic macroscopic algae. Most of them are members of the phyla Chlorophyta (the green seaweeds of the class Ulvophyceae (893 species)), Ochrophyta (the brown seaweeds of the class Phaeophyceae (1749 species)), and Rhodophyta (the red seaweeds of the classes Bangiophyceae (129 species) and Florideophyceae (5732 species)). To a lot of people, seaweeds are rather unpleasant organisms: these plants are very slimy and slippery and can make swimming or walking along the shore an unpleasant experience to remember! To put it humorously, seaweeds do not have the popular appeal of 'emotional species': only a few have common names, they do not produce flowers, they do not sing like birds, and they are not as cute as furry mammals! One of the key reasons for regularly ignoring seaweeds, even in coastal projects is, in fact, this very problem of identification, as very few people, even among botanists, can identify them correctly. Reasons for this include: a very high morphological plasticity; taxonomic criteria that are not always observable with the naked eye but instead are based on reproductive structures, cross sections, and, increasingly, ultrastructural and molecular arguments; an existing classification of seaweeds that is in a permanent state of revisions; and algal communities with very large numbers of species from different algal taxa that are not always well defined. The production of benthic seaweeds has probably been underestimated, since it may approach 10% of that of all the plankton while only occupying 0.1% of the area used by plankton; this area is, however, crucial, as it is the coastal zone.

The academic, biological, environmental, and economic significance of seaweeds is not always widely appreciated. The following series of arguments emphasizes the importance of seaweeds, and why they should be an unavoidable component of any study that wants to understand coastal biodiversity and processes: (1) Current investigations about the origin of the eukaryotic cell must include features of present-day algae/seaweeds to understand the diversity and the phylogeny of the plant world, and even the animal world. (2) Seaweeds are important primary producers of oxygen and organic matter in coastal environments through their photosynthetic activities. (3) Seaweeds dominate the rocky intertidal zone in most oceans; in temperate and polar regions they also dominate rocky surfaces in the shallow subtidal zone; the deepest seaweeds can be found to depths of 250 m or more, particularly in clear waters. (4) Seaweeds are food for herbivores and, indirectly, carnivores, and hence are part of the foundation of the food web. (5) Seaweeds participate naturally in nutrient recycling and waste treatment (these properties are also used 'artificially' by humans, for example, in IMTA systems). (6) Seaweeds react to changes in water quality and can therefore be used as biomonitors of eutrophication. Seaweeds do not react as rapidly to environmental changes as phytoplankton but can be good indicators over a longer time span (days vs. weeks/months/years) because of the perennial and benthic nature of a lot of them. If seaweeds are 'finally' attracting some media coverage, it is, unfortunately, because of the increasing report of outbreaks of 'green tides' (as well as 'brown and red tides') and fouling species, which are considered a nuisance by tourists and responsible for financial losses by resort operators. (7) Seaweeds can be excellent indicators of natural and/or artificial changes in biodiversity (both in terms of abundance and composition) due to changes in abiotic, biotic, and anthropogenic factors, and hence are excellent monitors of environmental changes. (8) Around 500 species of marine algae (mostly seaweeds) have been used for centuries for human food and medicinal purposes, directly (mostly in Asia) or indirectly, mainly by the phycocolloid industry (agars, carrageenans, and alginates). Seaweeds are the basis of a multibillion-dollar enterprise that is very diversified, including food, brewing, textile, pharmaceutical, nutraceutical, cosmetic, botanical, agrichemical, animal feed, bioactive and antiviral compounds, and biotechnological sectors. Nevertheless, this industry is not very well known to Western consumers, despite the fact that they use seaweed products almost daily (from their orange juice in the morning to their toothpaste in the evening!). This is due partly to the complexity at the biological and chemical level of the raw material, the technical level of the extraction processes, and the commercial level with markets and distribution systems that are difficult to understand and penetrate. (9) The vast majority of seaweed species has yet to be screened for various applications, and their extensive diversity ensures that many new algal products and processes, beneficial to mankind, will be discovered.

Seaweed Mariculture

Seaweed mariculture is believed to have started during the Tokugawa (or Edo) Era (AD 1600–1868) in Japan. Mariculture of any species develops when society's demands exceed what natural resources can supply. As demand increases, natural populations frequently become overexploited and the need for the cultivation of the appropriate species emerges. At present, 92% of the world seaweed supply comes from cultivated species. Depending on the selected species, their biology, life history, level of tissue specialization, and the socioeconomic situation of the region where it is developed, cultivation technology (Figures 1–6) can be low-tech (and still extremely successful with highly efficient and simple culture techniques, coupled with intensive labour at low costs) or can become highly advanced and mechanized, requiring on-land cultivation systems for seeding some phases of the life history before growth-out at open-sea aquaculture sites. Cultivation and seed-stock improvement techniques have been refined over centuries, mostly in Asia, and can now be highly sophisticated. High-tech on-land cultivation systems (Figure 7) have been developed in a few rare cases, mostly in the Western World; commercial viability has only been reached when high value-added products have been obtained, their markets secured (not necessarily in response to a local demand, but often for export to Asia), and labor costs reduced to balance the significant technological investments and operational costs.

Because the mariculture of aquatic plants (11.3 million tonnes of seaweeds and 2.6 million tonnes of unspecified 'aquatic plants' reported by the Food and Agriculture Organization of the United Nations) has developed essentially in Asia, it remains mostly unknown in the Western World, and is often neglected or ignored in world statistics … a situation we can only explain as being due to a deeply rooted zoological bias in marine academics, resource managers, bureaucrats, and policy advisors! However, the seaweed aquaculture sector represents 45.9% of the biomass and 24.2% of the value of the world mariculture production, estimated in 2004 at 30.2 million tonnes, and worth US$28.1 billion (Table 1). Mollusk aquaculture comes second at 43.0%, and the finfish aquaculture, the subject of many debates, actually only represents 8.9% of the world mariculture production.

The seaweed aquaculture production, which almost doubled between 1996 and 2004, is estimated at 11.3 million tonnes, with 99.7% of the biomass being

Figure 1 Long-line aquaculture of the brown seaweed, *Laminaria japonica* (kombu), in China. Reproduced by permission of Max Troell.

Figure 2 Long-line aquaculture of the brown seaweed, *Undaria pinnatifida* (wakame), in Japan. Photo by Thierry Chopin.

Figure 3 Net aquaculture of the red seaweed, *Porphyra yezoensis* (nori), in Japan. Photo by Thierry Chopin.

cultivated in Asia (Table 2). Brown seaweeds represent 63.8% of the production, while red seaweeds represent 36.0%, and the green seaweeds 0.2%. The seaweed aquaculture production is valued at US$5.7 billion (again with 99.7% of the value being provided by Asian countries; Table 3). Brown seaweeds dominate with 66.8% of the value, while red seaweeds contribute 33.0%, and the green seaweeds 0.2%. Approximately 220 species of seaweeds are cultivated worldwide; however, six genera (*Laminaria* (kombu; 40.1%), *Undaria* (wakame; 22.3%), *Porphyra* (nori; 12.4%), *Eucheuma/Kappaphycus* (11.6%), and *Gracilaria* (8.4%)) provide 94.8% of the seaweed aquaculture production (Table 4), and four genera (*Laminaria* (47.9%), *Porphyra* (23.3%), *Undaria* (17.7%), and *Gracilaria* (6.7%)) provide 95.6% of its value (Table 5). Published world statistics, which regularly mention 'data exclude aquatic plants' in their tables, indicate that in 2004 the top ten individual species produced by the global aquaculture (50.9% mariculture, 43.4% freshwater aquaculture, and 5.7% brackishwater aquaculture) were Pacific cupped oyster (*Crassostrea gigas* – 4.4 million tonnes), followed by three species of carp – the silver

Figure 4 Off bottom-line aquaculture of the red seaweed, *Eucheuma denticulatum*, in Zanzibar. Photo by Thierry Chopin.

Figure 5 Bottom-stocking aquaculture of the red alga, *Gracilaria chilensis*, in Chile. Photo by Thierry Chopin.

carp (*Hypophthalmichthys molitrix* – 4.0 million tonnes), the grass carp (*Ctenopharyngodon idellus* – 3.9 million tonnes), and the common carp (*Cyprinus carpio* – 3.4 million tonnes). However, in fact, the kelp, *Laminaria japonica*, was the first top species, with a production of 4.5 million tonnes.

Surprisingly, the best-known component of the seaweed-derived industry is that of the phycocolloids, the gelling, thickening, emulsifying, binding, stabilizing, clarifying, and protecting agents known as carrageenans, alginates, and agars. However, this component represents only a minor volume (1.26 million tonnes or 11.2%) and value (US$650 million or 10.8%) of the entire seaweed-derived industry (Table 6). The use of seaweeds as sea vegetable for direct human consumption is much more significant in tonnage (8.59 million tonnes or 76.1%) and value (US$5.29 billion or 88.3%). Three genera – *Laminaria* (or kombu), *Porphyra* (or nori), and *Undaria* (or wakame) – dominate the edible seaweed market. The phycosupplement industry is an emerging component. Most of the tonnage is used for the manufacturing of soil additives; however, the agrichemical and animal feed markets are comparatively much more lucrative if one considers the much smaller volume of seaweeds they require. The use of seaweeds in the development of pharmaceuticals and nutraceuticals, and as a source of pigments and

Figure 6 Net aquaculture of the green alga, *Monostroma nitidum*, in Japan. Photo by Thierry Chopin.

Figure 7 Land-based tank aquaculture of the red alga, *Chondrus crispus* (Irish moss), in Canada for high value-added sea-vegetable (Hana-nori) production. Photo by Acadian Seaplants Limited.

bioactive compounds is in full expansion. Presently, that component is difficult to evaluate accurately; the use of 3000 tonnes of raw material to obtain 600 tonnes of products valued at US$3 million could be an underestimation.

The Role of Seaweeds in the Biomitigation of Other Types of Aquaculture

One may be inclined to think that, on the world scale, the two types of aquaculture, fed and extractive, environmentally balance each other out, as 45.9% of the mariculture production is provided by aquatic plants, 43.0% by mollusks, 8.9% by finfish, 1.8% by crustaceans, and 0.4% by other aquatic animals. However, because of predominantly monoculture practices, economics, and social habits, these different types of aquaculture production are often geographically separate, and, consequently, rarely balance each other out environmentally, on either the local or regional scale (Figure 8). For example, salmon aquaculture in Canada represents 68.2% of the tonnage of the aquaculture industry and 87.2% of its farmgate value. In Norway, Scotland, and Chile,

Table 1 World mariculture production and value from 1996 to 2004 according to the main groups of cultivated organisms

	Production (%)			*% of value in*
	1996	*2000*	*2004*	*2004*
Mollusks	48	46.2	43.0	34.0
Aquatic plants	44	44.0	45.9	24.2
Finfish	7	8.7	8.9	34.0
Crustaceans	1	1.0	1.8	6.8
Other aquatic animals		0.1	0.4	1.0

Source: FAO (1998) *The State of World Fisheries and Aquaculture 1998*. Italy: Food and Agriculture Organization of United Nations. http://www.fao.org/docrep/w9900e/w9900e00.htm; FAO (2002) *The State of World Fisheries and Aquaculture 2002*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/005/y7300e/y7300e00.htm; and FAO (2006) *The State of World Fisheries and Aquaculture 2006*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0699e/A0699E00.htm (accessed Mar. 2008).

Table 2 Seaweed aquaculture production (tonnage) from 1996 to 2004 according to the main groups of seaweeds (the brown, red, and green seaweeds) and contribution from Asian countries

	Production (tonnes)		
	1996	*2000*	*2004*
Brown seaweeds			
World	4 909 269	4 906 280	7 194 316
Asia (%)	4 908 805	4 903 252	7 194 075
	(99.9)	(99.9)	(99.9)
Red seaweeds			
World	1 801 494	1 980 747	4 067 028
Asia (%)	1 678 485	1 924 258	4 035 783
	(93.2)	(97.2)	(99.2)
Green seaweeds			
World	13 418	33 584	19 046
Asia (%)	13 418	33 584	19 046
	(100)	(100)	(100)
Total			
World	6 724 181	6 920 611	11 280 390
Asia (%)	6 600 708	6 861 094	11 248 904
	(98.2)	(99.1)	(99.7)

Source: FAO (1998) *The State of World Fisheries and Aquaculture 1998*. Italy: Food and Agriculture Organization of United Nations. http://www.fao.org/docrep/w9900e/w9900e00.htm; FAO (2002) *The State of World Fisheries and Aquaculture 2002*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/005/y7300e/y7300e00.htm; and FAO (2006) *The State of World Fisheries and Aquaculture 2006*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0699e/A0699E00.htm (accessed Mar. 2008).

salmon aquaculture represents 88.8%, 93.3%, and 81.9% of the tonnage of the aquaculture industry, and 87.3%, 90.9%, and 95.5% of its farmgate value, respectively. Conversely, while Spain (Galicia) produces only 8% of salmon in tonnage (16% in farmgate value), it produces 81% of its tonnage in mussels (28% in farmgate value). Why should one think that the common old saying “Do not put all your eggs in one basket”, which applies to agriculture and many other businesses, would not also apply to aquaculture? Having too much production in a single species leaves a business vulnerable to issues of sustainability because of low prices due to oversupply, and the possibility of catastrophic destruction of one’s only crop (diseases, damaging weather conditions). Consequently, diversification of the aquaculture industry is imperative to reducing the economic risk and maintaining its sustainability and competitiveness.

Table 3 Seaweed aquaculture production (value) from 1996 to 2004 according to the main groups of seaweeds (the brown, red, and green seaweeds) and contribution from Asian countries

	Value (×US$1000)		
	1996	*2000*	*2004*
Brown seaweeds			
World	3 073 255	2 971 990	3 831 445
Asia (%)	3 072 227	2 965 372	3 831 170
	(99.9)	(99.8)	(99.9)
Red seaweeds			
World	1 420 941	1 303 751	1 891 420
Asia (%)	1 367 625	1 275 090	1 875 759
	(96.3)	(97.8)	(99.2)
Green seaweeds			
World	7263	5216	12 751
Asia (%)	7263	5216	12 751
	(100)	(100)	(100)
Total			
World	4 501 459	4 280 957	5 735 615
Asia (%)	4 447 115	4 245 678	5 719 680
	(98.8)	(99.2)	(99.7)

Source: FAO (1998) *The State of World Fisheries and Aquaculture 1998*. Italy: Food and Agriculture Organization of United Nations. http://www.fao.org/docrep/w9900e/w9900e00.htm; FAO (2002) *The State of World Fisheries and Aquaculture 2002*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/005/y7300e/y7300e00.htm; and FAO (2006) *The State of World Fisheries and Aquaculture 2006*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0699e/A0699E00.htm (accessed Mar. 2008).

Phycomitigation (the treatment of wastes by seaweeds), through the development of IMTA systems, has existed for centuries, especially in Asian countries, through trial and error and experimentation. Other terms have been used to describe similar systems (integrated agriculture-aquaculture systems (IAAS), integrated peri-urban aquaculture systems (IPUAS), integrated fisheries-aquaculture systems (IFAS), fractionated aquaculture, aquaponics); they can, however, be considered to be variations on the IMTA concept. ‘Multi-trophic’ refers to the incorporation of species from different trophic or nutritional levels in

Table 4 Production, from 1996 to 2004, of the eight genera of seaweeds that provide 96.1% of the biomass for the seaweed aquaculture in 2004

Genus	*Production (tonnes)*			*% of production in 2004*
	1996	*2000*	*2004*	
Laminaria (kombu)[a]	4 451 570	4 580 056	4 519 701	40.1
Undaria (wakame)[a]	434 235	311 125	2 519 905	22.3
Porphyra (nori)[b]	856 588	1 010 778	1 397 660	12.4
Kappaphycus/ Eucheuma[b]	665 485	698 706	1 309 344	11.6
Gracilaria[b]	130 413	65 024	948 292	8.4
Sargassum[a]	0	0	131 680	1.2
Monostroma[c]	8277	5288	11 514	0.1

[a]Brown seaweeds.
[b]Red seaweeds.
[c]Green seaweeds.
Source: FAO (1998) *The State of World Fisheries and Aquaculture 1998*. Italy: Food and Agriculture Organization of United Nations. http://www.fao.org/docrep/w9900e/w9900e00.htm; FAO (2002) *The State of World Fisheries and Aquaculture 2002*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/005/y7300e/y7300e00.htm; and FAO (2006) *The State of World Fisheries and Aquaculture 2006*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0699e/A0699E00.htm (accessed Mar. 2008).

Table 5 Value, from 1996 to 2004, of the eight genera of seaweeds that provide 99.0% of the value of the seaweed aquaculture in 2004

Genus	*Value (× US$1000)*			*% of value in 2004*
	1996	*2000*	*2004*	
Laminaria (kombu)[a]	2 875 497	2 811 440	2 749 837	47.9
Porphyra (nori)[b]	1 276 823	1 183 148	1 338 995	23.3
Undaria (wakame)[a]	178 290	148 860	1 015 040	17.7
Gracilaria[b]	60 983	45 801	385 794	6.7
Kappaphycus/ Eucheuma[b]	67 883	51 725	133 324	2.3
Sargassum[a]	0	0	52 672	0.9
Monostroma[c]	6622	1849	9937	0.2

[a]Brown seaweeds.
[b]Red seaweeds.
[c]Green seaweeds.
Source: FAO (1998) *The State of World Fisheries and Aquaculture 1998*. Italy: Food and Agriculture Organization of United Nations. http://www.fao.org/docrep/w9900e/w9900e00.htm; FAO (2002) *The State of World Fisheries and Aquaculture 2002*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/005/y7300e/y7300e00.htm; and FAO (2006) *The State of World Fisheries and Aquaculture 2006*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0699e/A0699E00.htm (accessed Mar. 2008).

the same system. This is one potential distinction from the age-old practice of aquatic polyculture, which could simply be the co-culture of different fish species from the same trophic level. In this case, these organisms may all share the same biological and chemical processes, with few synergistic benefits, which could potentially lead to significant shifts in the ecosystem. Some traditional polyculture systems may, in fact, incorporate a greater diversity of species, occupying several niches, as extensive cultures (low intensity, low management) within the same pond. The 'integrated' in IMTA refers to the more intensive cultivation of the different species in proximity to each other (but not necessarily right at the same location), connected by nutrient and energy transfer through water.

The IMTA concept is very flexible. IMTA can be land-based or open-water systems, marine or freshwater systems, and may comprise several species combinations. Ideally, the biological and chemical processes in an IMTA system should balance. This is achieved through the appropriate selection and proportioning of different species providing different ecosystem functions. The co-cultured species should be more than just biofilters; they should also be organisms which, while converting solid and soluble nutrients from the fed organisms and their feed into biomass, become harvestable crops of commercial value and acceptable to consumers. A working IMTA system should result in greater production for the overall system, based on mutual benefits to the co-cultured species and improved ecosystem health, even if the individual production of some of the species is lower compared to what could be reached in monoculture practices over a short-term period.

While IMTA likely occurs due to traditional or incidental, adjacent culture of dissimilar species in some coastal areas (mostly in Asia), deliberately designed IMTA sites are, at present, less common. There has been a renewed interest in IMTA in Western countries over the last 30 years, based on the age-old, common sense, recycling and farming practice in which the by-products from one species become inputs for another: fed aquaculture (fish or shrimp) is combined with inorganic extractive (seaweed) and organic extractive (shellfish) aquaculture to create balanced systems for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction), and social acceptability (better management practices). They are presently simplified systems, like fish/seaweed/shellfish. Efforts to develop such IMTA systems are currently taking place in Canada, Chile, China, Israel, South Africa, the USA, and several European countries. In the future, more advanced

Table 6 Biomass, products, and value of the main components of the world's seaweed-derived industry in 2006

Industry component	*Raw material (wet tonnes)*	*Product (tonnes)*	*Value (US$)*
Sea vegetables	8.59 million	1.42 million	5.29 billion
Kombu (*Laminaria*)[a]	4.52 million	1.08 million	2.75 billion
Nori (*Porphyra*)[b]	1.40 million	141 556	1.34 billion
Wakame (*Undaria*)[a]	2.52 million	166 320	1.02 billion
Phycocolloids	1.26 million	70 630	650 million
Carrageenans[b]	528 000	33 000	300 million
Alginates[a]	600 000	30 000	213 million
Agars[b]	127 167	7630	137 million
Phycosupplements	1.22 million	242 600	53 million
Soil additives	1.10 million	220 000	30 million
Agrichemicals (fertilizers, biostimulants)	20 000	2000	10 million
Animal feeds (supplements, ingredients)	100 000	20 000	10 million
Pharmaceuticals nutraceuticals, botanicals, cosmeceuticals, pigments, bioactive compounds, antiviral agents, brewing, etc.	3000	600	3 million

[a]Brown seaweeds.
[b]Red seaweeds.
Source: McHugh (2003); Chopin and Bastarache (2004); and FAO (2004) *The State of World Fisheries and Aquaculture 2004*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/007/y5600e/y5600e00.htm (accessed Mar. 2008); FAO (2006) *The State of World Fisheries and Aquaculture 2006*. Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0699e/A0699E00.htm (accessed Mar. 2008).

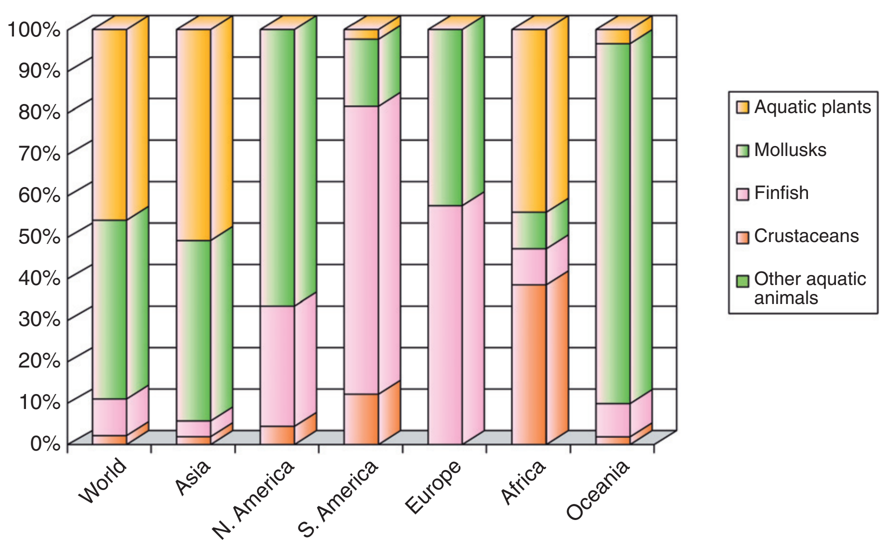

Figure 8 Distribution (%) of mariculture production among the main farmed groups of organisms, worldwide and on the different continents. The world distribution is governed by the distribution in Asia; however, large imbalances between fed and extractive aquacultures exist on the other continents. Source: FAO (2006) *FAO Fisheries Technical Paper 500: State of World Aquaculture 2006*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0874e/a0874e00.htm (accessed Mar. 2008).

systems with several other components for different functions, or similar functions but different size brackets of particles, will have to be designed.

Recently, there has been a significant opportunity for repositioning the value and roles seaweeds have in coastal ecosystems through the development of IMTA systems. Scientists working on seaweeds, and industrial companies producing and processing them, have an important role to play in educating the animal-dominated aquaculture world, especially in the Western World, about how to understand and take advantage of the benefits of such extractive organisms, which will help bring a balanced ecosystem approach to aquaculture development.

It is difficult to place a value on the phycomitigation industry, inasmuch as no country has yet implemented guidelines and regulations regarding nutrient discharge into coastal waters. Because the 'user pays' concept is expected to gain momentum as a tool in integrated coastal management, one should soon be able to put a value on the phycomitigation services of IMTA systems for improving water quality and coastal health. Moreover, the conversion of fed aquaculture by-products into the production of salable biomass and biochemicals used in the seavegetable, phycocolloid, and phycosupplement sectors should increase the revenues generated by the phycomitigation component.

See also

Mariculture Overview.

Further Reading

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