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INVITED EDITORIAL

Importance of Seaweeds and Extractive Species in Global Aquaculture Production

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ABSTRACT

The FAO recently published its biennial State of World Fisheries and Aquaculture up to 2018. The FAO continues to treat the seaweed aquaculture sector as a different category, with separate tables and comments in different sections. As this could lead to a distorted view of total world aquaculture, the statistical information provided by FAO was revisited and data regarding the seaweed aquaculture sector were integrated with data of the other sectors of the world aquaculture production, to reach different conclusions: (1) aquaculture represents 54.1% of total world fisheries and aquaculture production; (2) marine and coastal aquaculture represents 55.2% of total world aquaculture production; (3) seaweeds represent 51.3% of total production of marine and coastal aquaculture; (4) 99.5% of seaweed mariculture production is concentrated in Asia; (5) 8 seaweed genera provide 96.8% of world seaweed mariculture production; (6) 2 seaweed genera are the most produced organisms in mariculture in the world; (7) the value of the seaweed aquaculture sector could be much larger, especially if a monetary value was attributed to the ecosystem services provided by seaweeds; and (8) total extractive aquaculture is slightly larger (50.6%) than total fed aquaculture (49.4%).

KEYWORDS
Aquaculture statistics; extractive species; FAO; fed species; seaweeds; seaweed aquaculture

Introduction

The FAO recently published The State of World Fisheries and Aquaculture (FAO 2020a), its biennial document, which contains a wealth of information on both fisheries and aquaculture throughout the world.

While FAO should be commended for giving more and more attention to seaweed aquaculture production, it continues to treat the seaweed aquaculture sector as a different category, with separate tables and separate comments in different sections. This could lead to a distorted view of what really constitutes the total world aquaculture (Chopin 2012). For that reason, the statistical information provided by FAO was revisited and data regarding the seaweed aquaculture sector were integrated with the data of the other sectors of the world aquaculture production (mostly fish, molluscs and crustaceans), to demonstrate how a combined analysis can modify the conclusions reached.

Distribution between world fisheries and aquaculture production

In Table 1 of the latest FAO report (FAO 2020a), total capture fisheries landings are reported as 96.4 million tonnes (expressed on a "live weight" basis, as all other numbers here after) and total aquaculture production as 82.1 million tonnes, in 2018. However, a footnote at the bottom of the table states that this table "excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants." Clearly, this footnote can easily be overlooked by readers, and, consequently, the conclusion that can be reached is that capture fisheries represent 54.0% and aquaculture represents 46.0% of the total world fisheries landings and aquaculture production (178.5 million tonnes; FAO 2020a).

If the worldwide production of aquatic mammals, crocodiles, alligators and caimans is relatively small and poorly documented in data, that of seaweeds is significantly large and should not be ignored (32.4 million tonnes, valued at US$13.3 billion). In marked contrast, the harvesting of wild seaweeds represented only 2.9% of the total global reported seaweed production or 0.9 million tonnes in 2018. Consequently, including these data, capture fisheries (97.3 million tonnes) represent 45.9%, and aquaculture (114.5 million tonnes) now represents 54.1% of the total world

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Table 1. Distribution of worldwide mariculture production between the main types of cultivated organisms from 1996 to 2018 (based on FAO live weight data between 1998 and 2020).[a]

	World mariculture production (%)								
	1996	2000	2004	2008	2010	2012	2014	2016	2018
Molluscs	48.0	46.2	43.0	42.7	37.2	30.7	28.0	28.7	27.4
Seaweeds	44.0	44.0	45.9	46.2	50.9	49.1	47.5	51.2	51.3
Finfish	7.0	8.7	8.9	8.9	9.1	11.4	11.0	11.2	11.6
Crustaceans	1.0	1.0	1.8	1.8	1.8	8.1	12.0	8.2	9.1
Other aquatic animals	–	0.1	0.4	0.4	1.0	0.7	1.5	0.7	0.6

[a]FAO (1998, 2002, 2006, 2010, 2012, 2014, 2016, 2018, 2020a).

fisheries landings and aquaculture production (211.8 million tonnes) in 2018.

Moreover, throughout the FAO document, and on Table 9 (p. 32), the value of 32.4 million tonnes of farmed seaweed production is used; however, on p. 29, it is indicated that "In 2018, farmed seaweeds represented 97.1 percent by volume of the total of 32.4 million tonnes of wild-collected and cultivated aquatic algae combined." In that case, that would mean 0.9 million tonnes of wild-collected seaweeds and 31.5 million tonnes of aquaculture seaweeds. Accordingly, the above numbers could be further adjusted to show that capture fisheries (97.3 million tonnes) represent 46.1% and aquaculture (113.6 million tonnes) represents 53.9% of the total world fisheries landing and aquaculture production (210.9 million tonnes).

Consequently, the "farming more than catch" milestone was definitely reached by 2018, if the seaweed sector were to be considered in the total statistics. Seaweeds were the first group of organisms to reach the "farming more than catch" milestone in 1971 (Chopin 2018c). Since then, farmed freshwater fish production reached this milestone in 1986, farmed mollusc production in 1994, farmed diadromous fish production in 1997 and farmed crustacean production in 2010. However, according to the FAO, the production of farmed marine fish is not expected to overtake marine capture production in the near future (FAO 2020a).

Distribution of worldwide aquaculture production by major species groups

If seaweed aquaculture production is considered, marine and coastal (ponds and lagoons) aquaculture (63.2 million tonnes) represented 55.2% of the total world aquaculture production (114.5 million tonnes), and inland aquaculture (mostly freshwater; 51.3 million tonnes) represented 44.8% of the total aquaculture production in 2018 (FAO 2020a).

Considering only marine and coastal aquaculture, seaweeds (32.4 million tonnes) represented 51.3%, followed by molluscs (17.3 million tonnes, 27.4%), finfish (7.3 million tonnes, 11.6%), crustaceans (5.7 million tonnes, 9.1%) and other aquatic animals (0.4 million tonnes, 0.6%) in 2018 (FAO 2020a).

Table 2. Seaweed mariculture production by major producers.

	2000	2018
China	8,227.6 (77.7)	18,505.7 (57.1)
Indonesia	205.2 (1.9)	9,320.3 (28.8)
Republic of Korea	374.5 (3.5)	1,710.5 (5.3)
Philippines	707.0 (6.7)	1,478.3 (4.6)
Democratic People's Republic of Korea	401.0 (3.8)	553.0 (1.7)
Japan	528.6 (5.0)	389.8 (1.2)
Malaysia	16.1 (0.2)	174.1 (0.5)
China, Taiwan	…	69.6 (0.2)
Viet Nam	15.0 (0.1)	19.3 (0.1)
Total Asian seaweed mariculture production	10,475.0 (98.9)	32,220.6 (99.5)
Zanzibar, United Republic of Tanzania	49.9 (0.5)	103.2 (0.3)
Chile	33.5 (0.3)	20.7 (0.1)
Other producers in the world	37.1 (0.3)	41.6 (0.1)
Total world seaweed mariculture production	10,595.6 (100)	32,386.2 (100)

Numbers are in thousand tonnes live weight (FAO 2020a); numbers in brackets are percentages.

Moreover, reviewing FAO statistics data between 1996 and 2018 (FAO 1998, 2002, 2006, 2010, 2012, 2014, 2016, 2018), molluscs dominated the world mariculture production until 2000 (46.2%) and thereafter were overtaken by seaweeds (45.9% in 2004). Seaweeds now represent more than half of the marine and coastal aquaculture production (around 51%), while molluscs represent around 28%. Finfish and crustacean productions are way behind, with around 11% and 9% in the last few years (Table 1).

Seaweed mariculture production is concentrated in 9 Asian countries and territories

Over the last two decades, seaweed mariculture has taken place mainly within 9 east and southeast Asian countries and territories (depending on how one considers the status of Taiwan) (Table 2): from 98.9% in 2000 to 99.5% in 2018. Zanzibar (United Republic of Tanzania) and Chile produced very small amounts (0.3 and 0.1%, respectively) of the world seaweed aquaculture production. All other countries in the world, combined, produced only 0.1%.

Global seaweed aquaculture production increased by 40.0% between 2000 (10.6 million tonnes) and 2005 (14.8 million tonnes), then by 36.0% to 2010 (20.2 million tonnes), and 53.4% to 2015 (31.1 million tonnes). Between 2015 and 2018, the world seaweed aquaculture production fluctuated around 32 million tonnes. After a tripling of the seaweed production over 16 years, this stabilization seems to be mostly caused by the slowing growth in the farming of tropical species in southeast

Table 3. The eight genera providing the majority of the world seaweed mariculture production with the other algae combined to make the total world seaweed mariculture production.

	2000	2018
Red seaweeds		
Eucheuma spp.	299.6 (2.9)	9,412.4 (29.0)
Kappaphycus spp.	649.5 (6.1)	1,597.3 (4.9)
Gracilaria spp.	55.5 (0.5)	3,454.8 (10.7)
Porphyra/Pyropia spp. (nori)	954.1 (9.0)	2,872.8 (8.9)
Total red seaweeds	1,958.7 (18.5)	17,337.3 (53.5)
Brown seaweeds		
Saccharina japonica (kombu)	5,380.9 (50.8)	11,448.3 (35.3)
Undaria pinnatifida (wakame)	311.1 (2.9)	2,320.4 (7.2)
Sargassum spp.	12.1 (0.1)	268.7 (0.8)
Other Phaeophyceae	2,852.8 (26.9)	891.5 (2.8)
Total brown seaweeds	8,556.9 (80.7)	14,928.9 (46.1)
Other algae	79.9 (0.8)	119.9 (0.4)
Total world seaweed mariculture production	10,595.6 (100)	32,386.2 (100)

Numbers are in thousand tonnes live weight (FAO 2020a); numbers in brackets are percentages.

Table 4. Major organisms produced in world mariculture in 2018.

Saccharina japonica (kombu)	11,448.3
Eucheuma spp.	9,412.4
Crassostrea spp. (oysters)	5,814.6
Penaeus vannamei (whiteleg shrimp)	4,966.2
Ruditapes philippinarum (Manila clam)	4,139.2
Gracilaria spp.	3,454.8
Porphyra spp.	2,872.8
Salmo salar (Atlantic salmon)	2,435.9
Undaria pinnatifida (wakame)	2,320.4
Sea scallops	1,918.0
Kappaphycus spp.	1,597.3
Mussels	1,570.7
Sinovovacula constricta (Chinese razor clam)	852.9
Penaeus monodon (giant tiger prawn)	750.6
Anadara granosa (blood cockle)	433.4
Sargassum spp.	268.7
Apostichopus japonicus (Japanese sea cucumber)	176.8

Brown seaweeds (brown), red seaweeds (red), molluscs (green), crustaceans (yellow), finfish (grey), and holothurians (blue). Numbers are in thousand tonnes live weight (FAO 2020a).

Asia, while farming of temperate and coldwater species is still rising. There has been significant progress in North America, Europe and South America, mostly through the development of integrated multi-trophic aquaculture (IMTA), promoting the ecosystem services seaweeds can provide and the IMTA multi-crop diversification approach as an economic risk mitigation and management option to address pending climate change and coastal acidification impacts (Carras et al. 2020). However, most often, data are not available because of confidentiality issues due to the small number of producers involved.

China's share has decreased from 77.7% in 2000 to 57.1% in 2018, although seaweed production in that country has more than doubled over this period (Table 2). This is mostly due to the sharp increase in the production of the carrageenophytes *Eucheuma* and *Kappaphycus* in Indonesia, now producing 28.8% of the world seaweed aquaculture production. The production of the Republic of Korea has been multiplied by a factor of 4.6, while its share of the world production has increased modestly by 1.8%. The production of the Philippines has doubled; however, its share of the world production has decreased by 2.1%. The production of Japan has been constantly decreasing and now represents only 1.2% of the world production.

Eight genera provide most of the world seaweed mariculture production

There are approximately 10,500 known species of seaweeds (Chopin 2018c). Around 500 species have been used for centuries for human food and medicinal purposes, either directly as food (primarily within Asian countries; MacArtain et al. 2007; Pereira 2011; Tacon and Metian 2013) or indirectly for the compounds that can be extracted from them (e.g. phycocolloids such as agars and carrageenans extracted from red seaweeds and alginates extracted from brown seaweeds) (Chopin 2018b). Although over 220 species of seaweeds are reportedly cultivated worldwide, only 20 species were listed in the FAO FISHSTAT database for 2018 (FAO 2020b).

Eight genera provided 72.3% (7.7 million tonnes) of the world seaweed aquaculture production in 2000 and provided 96.8% (31.3 million tonnes) in 2018: *Saccharina japonica* (known as kombu and previously described as *Laminaria japonica*; 35.3%), the carrageenophytes *Eucheuma* (29.0%), the agarophytes *Gracilaria* (10.7%), *Porphyra* and *Pyropia* (known as nori; 8.9%), *Undaria pinnatifida* (known as wakame; 7.2%), the carrageenophytes *Kappaphycus* (4.9%) and *Sargassum* (0.8%) (Table 3).

Until 2010, there were always more brown seaweeds produced (11.1 million tonnes) than red seaweeds (8.9 million tonnes). In 2015, this ratio changed, as more red seaweeds were produced (17.8 million tonnes) than brown seaweeds (13.2 million tonnes), mostly due to a major increase in the carrageenan producing species of the genus *Eucheuma* and the agar producing species of the genus *Gracilaria*. Brown seaweeds are mostly used for direct human consumption, the production of other phycocolloids, called alginates, and other applications (Chopin and Sawhney 2009).

Seaweeds the most produced organisms in mariculture

By combining the data of Table 8 (p. 30–31) and Table 9 (p. 32) of the FAO (2020a) document, one

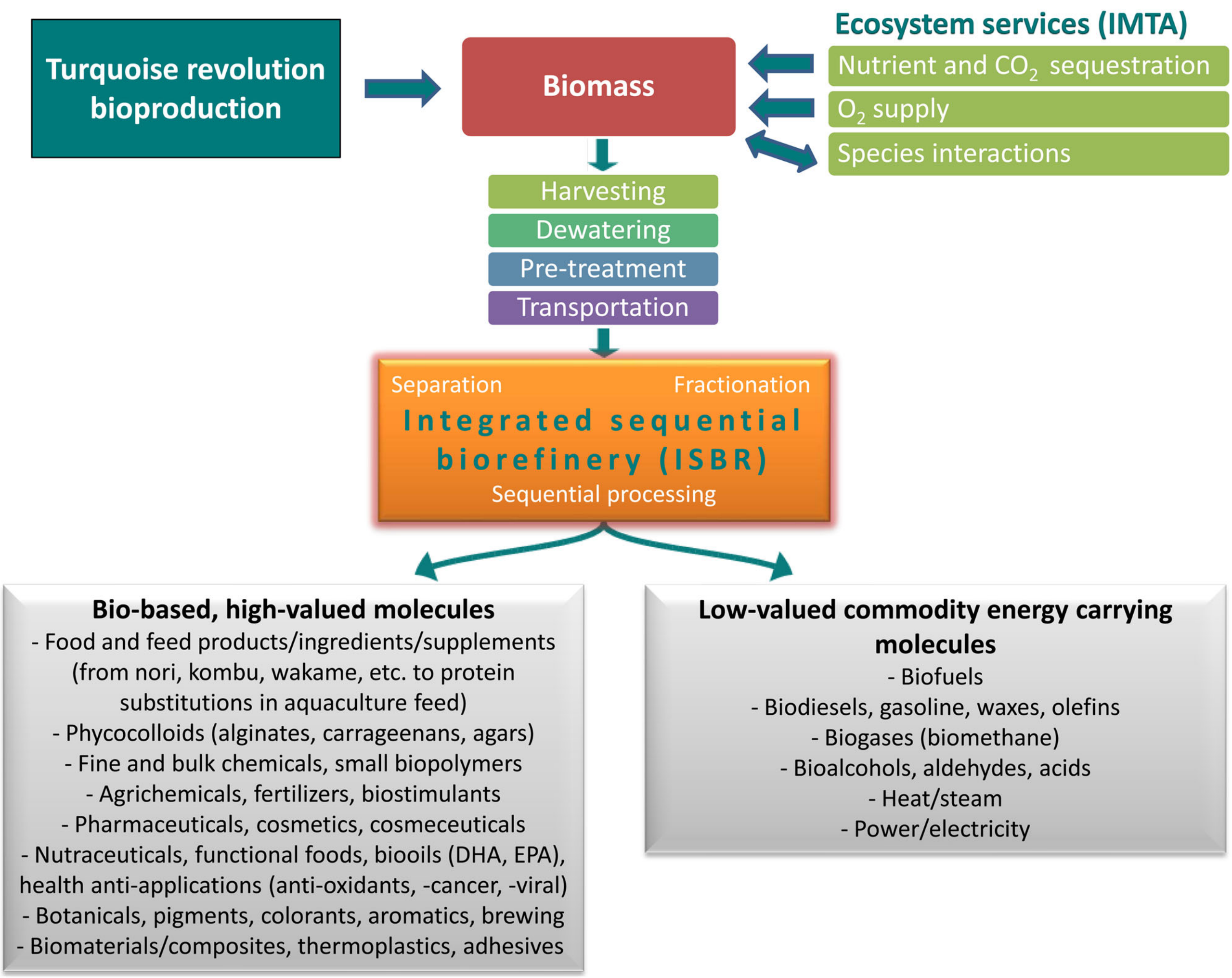

Figure 1. Integrated sequential biorefinery (ISBR) approach to the processing of seaweeds.

realizes that, in 2018, two genera of seaweeds, the brown seaweed *Saccharina* and the red seaweed *Eucheuma*, were the two most produced organisms in mariculture in the world (Table 4).

In fact, when reviewing the top seven most produced mariculture species, there are 4 genera of seaweeds, 2 genera of molluscs and 1 genus of crustaceans. The first finfish (Atlantic salmon, *Salmo salar*) is found in eighth position, followed closely by the brown seaweed *Undaria* in ninth position. Another carrageenophyte, *Kappaphycus*, is in the eleventh position.

Value of the seaweed aquaculture sector

FAO indicates a farm-gate value of US$13.3 billion for the world seaweed aquaculture production (FAO 2020a). Estimating the true value of the different seaweed markets is difficult, as seaweed applications are numerous (Chopin 2018b) and some lucrative emerging markets are presently in full expansion while others need to be further developed.

The phycocolloid sector, predominant in the 1970s–1990s, now represents only a minor part (11.4% of the tonnage and 10.8% of the value) of an industry in full mutation. The use of seaweeds as sea-vegetables for direct human consumption has become much more significant (77.6% of the tonnage and 88.3% of the value). Five genera dominate the edible seaweed market: *Saccharina* and *Laminaria* (kombu), *Undaria* (wakame), and *Porphyra* and *Pyropia* (nori). If the use of seaweeds as edible human food is well-established in Asian countries, a lot of work is still needed to educate westerners regarding cooking with seaweeds and going beyond the superfood fad, to have them understand the benefits of including these crops in their regular diet. The phycosupplement industry is a fast emerging component (11.0% of the tonnage and maybe an underestimated 0.9% of the value). This includes soil additives, agrichemicals (fertilizers and biostimulants), animal feeds (supplements and ingredients; increasingly for aquaculture), fine and bulk chemicals, small biopolymers, pharmaceuticals, cosmetics and cosmeceuticals, nutraceuticals, functional foods, biooils, health bioactive and anti-applications (anti-oxidants, anti-cancer, anti-microbial, anti-viral, anti-inflammatory, anti-diabetic, etc.), botanicals, pigments, colorants, aromatics, brewing components, biomaterials/biocomposites, thermoplastics, adhesives, etc.

An area of interest to the commercial aquafeed sector has recently been the use of seaweed-enriched media. Substitution of fishmeal by other protein sources has been investigated in recent years, mostly considering land-plant proteins. There is now an interest in seaweeds as substrate for growth and nutritional enhancement. In a literature review, Chopin (2019) found 107 papers, in which a portion of the feed was replaced with seaweeds: 61 involved the culture of fish (40 of marine fish and 21 of freshwater fish), 24 the culture of crustaceans (shrimp, prawn, lobster), 11 the culture of molluscs (various species of abalone), 10 the culture of echinoderms (sea urchins) and 1 the culture of holothurians (sea cucumbers). These papers demonstrated that substitution of fishmeal by various seaweeds (29 species from 13 genera), generally not in excess of 5–15% (but with exceptions up to 20, 30 and even 50% in some species), has potential in manufacturing new formulations triggering better growth and other benefits in diverse organisms already aquacultured, or whose cultivation is being developed. Further studies are required to determine the best mix of seaweed species and ratios. The wild-harvested brown seaweed *Ascophyllum nodosum* (rockweed) has also been used to modulate the nutrient composition (omega-3 fatty acids and vitamin E) of larvae of *Hermetia illucens* (black soldier fly), then used in fish feed (Liland et al. 2017).

For too long, seaweeds, like other fishery and aquaculture products, have been processed according to a simple scheme: one species—one process—one product. However, seaweeds remain a relatively untapped resource with a huge potential for integrated sequential biorefinery (ISBR) processing (Figure 1). Society will have to change its attitudes and business models to evolve from this linear approach to move toward the ISBR approach (one species—several processes—several products) within a circular economy framework, where there are no longer wastes and by-products, but co-products, which can also be marketed. With careful planning at the time of harvesting, and with sequential processing, more than one product can be manufactured from seaweeds: on one hand, a wide range of bio-based, high-value compounds (cited above); on the other hand, lower-value commodity energy compounds (biofuels, biodiesels, gasoline, waxes, olefins, biogases, bioalcohols, aldehydes, acids, heat/steam and power/electricity generation, etc.).

The price of seaweeds varies greatly, depending on the applications and their added values (Figure 2):

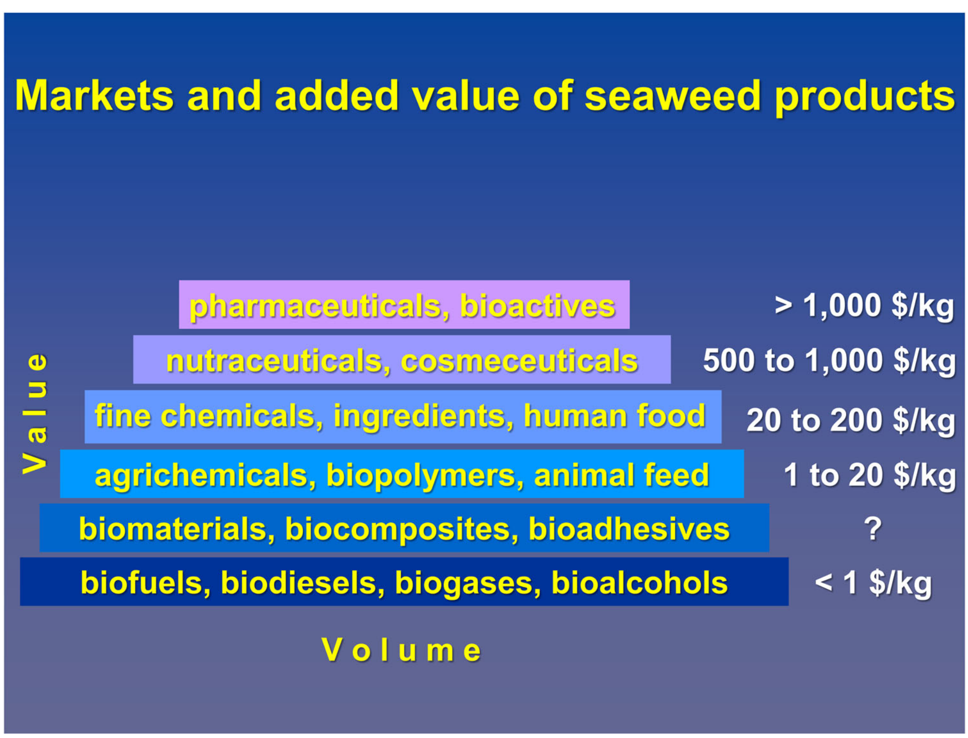

Figure 2. Variability of the price of seaweeds according to their applications, markets and the added value of seaweed products. This is a pyramidal structure as the product volume decreases as the product value increases (values in US$).

from less than US$1/kg (if seaweeds want to be competitive as biofuels compared to the existing fossil biofuel, i.e. petroleum) to more than US$1,000/kg for pharmaceuticals and bioactives.

Moreover, to calculate the full value of seaweeds, these extractive species need to be valued for not only their biomass and food trading values, but also for the ecosystem services they provide, along with the increase in consumer trust and societal/political license to operate that they give to the aquaculture industry in general (circular economy approach) (Barrington et al. 2010; Martínez-Espiñeira et al. 2015, 2016).

One of the key ecosystem services provided by seaweeds is nutrient biomitigation and a monetary value can be calculated for this service. If 1) the composition of seaweeds can be averaged at around 0.35% nitrogen (N), 0.04% phosphorus (P) and 3% carbon (C), 2) the recovery costs, calculated from wastewater treatment facilities, are US$10–30/kg N and US$4/kg P, and 3) a value of US$30/tonne C for carbon tax schemes is used, then, the ecosystem services for nutrient biomitigation provided by worldwide seaweed aquaculture (32.4 million tonnes) can be valued at between US$1.214 billion and US$3.482 billion, i.e. as much as 26.2% of their present commercial value (US$13.3 billion). The value of this important service to the environment and, consequently, society has, however, never been accounted for in any budget sheets or business plans of seaweed farms and companies. Moreover, the other ecosystem services provided by seaweeds should also be analyzed in a similar manner to establish their own monetary values.

Much has been said about carbon sequestration and the development of carbon trading taxes. In coastal environments, mechanisms for the recovery of nitrogen and phosphorus should also be highlighted and accounted for in the form of nutrient trading credits (NTCs, a much more positive approach than taxing, for those implementing sustainable practices). It is interesting to note that the value for C is per tonne, whereas those for N and P are per kilogram. Nobody seems to have picked up on that when looking at the sequestration of elements other than C. There is more money to be made with NTC (between US$1.134 and 3.401 billion for N and US$51.82 million for P) than with carbon trading credits (CTC; only US$29.15 million for C).

The recognition and implementation of NTCs would give a fair price to seaweeds (and other extractive aquaculture species). They could be used as financial and regulatory incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable aquanomic option to their current practices to develop the nutritious and sustainable food production systems of the future.

Seaweeds can participate in the dietary shift toward the consumption of sustainable, safe, equitable, resilient and low-carbon sources of food from the ocean that will reduce gas emissions and carbon footprints from animal land-based food production systems, and contribute significantly to climate change mitigation to keep global temperature rises below 1.5 °C, by 2050, to reach the targets of the Paris Agreement (Hoegh-Guldberg et al. 2019; Chopin 2020). Moreover, seaweeds welcome vegetarians and vegans into the seafood world by offering access to highly nutritious ocean-based, plant-equivalent food sources from pristine waters (Pereira 2011; Tacon and Metian 2013). By eating more seaweeds, people will participate in the decarbonization of this world and contribute, at their level, in helping to mature the Blue Economy into the greener Turquoise Revolution.

Seaweeds for biofuel has been touted several times over the last 10–15 years. However, some reality-check is necessary at several levels. It is doubtful that the surface area needed to secure the raw material for significant biofuel production will be societally acceptable, especially in the western world. Seaweed biomass production is highly seasonal, while people refill at gas stations 52 weeks of the year. Scaling up from laboratory experiments to commercial markets needs reality testing. Moreover, to be economically competitive, seaweed biofuel would have to be at least as cheap as the fossil biofuel presently used, i.e. petroleum. Why try to sell seaweeds at several cents/tonne fresh weight when they cannot be produced that inexpensively? On the contrary, seaweed farmers are interested in a spectrum of products commending much higher prices (Figure 2).

More recently, some projects have developed the idea of using seaweeds to sequester carbon and then to bury them in the seabed to store carbon. However, significant investment in additional research and development would be required to ensure associated risks to the marine environment are minimized prior to implementation at scale. Moreover, the value of the proposed carbon tax schemes would have to be very significantly increased to incite seaweed growers to sell their biomass for burying when they can get much more money selling it for much more lucrative applications.

Distribution of fed and extractive species around the world

Aquaculture production can be divided into two major groupings based on how they source their

Table 5. Distribution of the total world aquaculture and mariculture production between extractive and fed organisms, in 2018.

	Total world aquaculture production, including seaweed production		Total world mariculture production, including seaweed production
	Inland aquaculture	Marine and coastal aquaculture	Marine and coastal aquaculture
Extractive aquaculture			
Seaweeds + aquatic plants	—	32,386.2	32,386.2
Molluscs	207	17,304	17,304
Non-fed finfish	8,000	—	—
Total extractive aquaculture	57,897.2 (50.6)		49,690.2 (78.7)
Fed aquaculture			
Fed finfish	38,951	7,328	7,328
Crustaceans	3,653	5,734	5,734
Other aquatic animals	528	390	390
Total fed aquaculture	56,584 (49.4)		13,452 (21.3)
Total aquaculture	114,481.2 (100)		63,142.2 (100)

Numbers are in thousand tonnes live weight (FAO 2020a); numbers in brackets are percentages.

nutrient inputs, namely the exogenously fed species and the endogenously fed extractive species. Exogenously fed species need to be externally fed with feeds added to the culture system, while endogenously fed extractive species either filter or graze on organic small and large particulate matter (invertebrates), or absorb dissolved inorganic nutrients (seaweeds), already endogenously present in the aquatic environment. It is interesting to compare their level of production and worldwide distribution to see if they strive toward a balance.

In the calculation of the total extractive aquaculture (Table 5), inland aquaculture needs to be considered in order to account for the significant production of 8 million tonnes of filter-feeding and herbivorous fish (mainly silver carp, *Hypophthalmichthys molitrix*, and bighead carp, *Hypophthalmichthys nobilis*) produced in Asia. Molluscs (mostly marine) add 17.5 million tonnes and seaweeds add 32.4 million tonnes for a total extractive aquaculture of 57.9 million tonnes. This means that total extractive aquaculture is slightly higher (50.6%) than total fed aquaculture (56.6 million tonnes or 49.4%). Calculations for 2016, using FAO data (Chopin 2018c) showed a similar distribution of 50.8% total extractive aquaculture and 49.2% total fed aquaculture.

If considering only the total world mariculture production (Table 5), then total extractive mariculture is even higher (49.7 million tonnes or 78.7%) than total fed mariculture (13.5 million tonnes or 21.3%).

At first glance, one could rejoice at such a high percentage of extractive species; however, it is important to remember that 99.5% of seaweed aquaculture is still concentrated within Asia. So, we have not yet balanced the different production types of aquaculture at a worldwide scale. Extractive aquaculture needs to be more evenly distributed worldwide in an attempt at balancing fed aquaculture. Moreover, what should be calculated is the weight ratio of harvested extractive species required to sequester an equivalent weight of nutrients loaded per unit growth of fed species (Reid et al. 2013).

One solution to reach such a goal would be the increased development of IMTA systems, especially in the western world (Chopin et al. 2008). In these systems, the waste materials from fed species become co-products to grow extractive species, considered as additional crops reducing the nutrient load, hence benefitting the environment though bioremediation, while providing economic diversification with more efficient practices within a circular economic approach (Diana et al. 2013). FAO (2020a) recommends, on p. 25, 27, 29 and 125, integrated aquaculture, aquaponics and polyculture and appears to encourage their development for enhanced overall productivity, improved resource-use efficiency, reduced impacts on the environment, and improved water quality by removing waste materials and lowering the nutrient load.

It has recently been suggested (Dunbar et al. 2020) that the use of fed species and extractive species should be replaced by excretive species and extractive species. We question the basis for such a proposition. After all, seaweed and invertebrate extractive species also excrete. What would be the fate of an organism if it was not excreting? Sooner or later, it would become internally toxified and/or explode. In recognizing the existence of exogenously fed species, one acknowledges the fact that these organisms have to be given feed (by humans), which represents an additional input into the ecosystem, while endogenously fed extractive species rely on feed already present in the ecosystem (even if partially originating from the co-products of the co-cultivated exogenously fed species in IMTA systems) that they will filter, graze upon or absorb.

Conclusions

Seaweeds are at the intersection of many topical trends. They provide many inter-sectorial benefits: 1) they are a source of food and many other applications; 2) they provide several key ecosystem services;

3) they allow local diversification of a more balanced aquaculture industry; and 4) they participate in the dietary shift toward more decarbonized ocean-based sources of proteins. Seeing FAO dedicating more time and space to seaweeds in its 2020 version of its biennial document The State of World Fisheries and Aquaculture is, therefore, very much appreciated.

In several tables and figures, the FAO has a footnote indicating "excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants." Unfortunately, these footnotes can easily be overlooked by readers who do not realize the consequences for data interpretations, which can lead to incorrect conclusions.

By including the total seaweed aquaculture production (32.4 million tonnes), as just another component of the total world aquaculture production, it can be concluded that, in 2018:

1. Aquaculture accounted for 54.1% of the total world fisheries and aquaculture production; whereas the FAO (not including the seaweed production) mentioned that aquaculture accounted for 46% of the total production.
2. Marine and coastal aquaculture produced 63.2 million tonnes, accounting for 55.2% of the total world aquaculture production (114.5 million tonnes); whereas the FAO mentioned that with a production of 51.3 million tonnes of aquatic animals, inland aquaculture accounted for 62.5% of the world's farmed food fish production (82.1 million tonnes), while marine and coastal aquaculture (30.8 million tonnes) represented 37.5%.
3. Seaweeds (32.4 million tonnes) represent 51.3% of the total production of marine and coastal aquaculture, molluscs (17.3 million tonnes) represent 27.4%, finfish (7.3 million tonnes) represent 11.6%, crustaceans (5.7 million tonnes) represent 9.1% and other aquatic animals (0.4 million tonnes) represent 0.6%; whereas the FAO indicated that molluscs represent 56.3%, finfish represent 23.8%, crustaceans represent 18.6% and other aquatic animals represent 1.3%.
4. Total extractive aquaculture is slightly larger (57.9 million tonnes or 50.6%) than total fed aquaculture (56.6 million tonnes or 49.4%); whereas the FAO mentioned that fed aquaculture (56.6 million tonnes) has outpaced (68.9%) non-fed aquaculture (25.5 million tonnes) accounting for 31.1%.

Consequently, the FAO is urged to consider seaweed aquaculture as another aquaculture component and to include the data of this sector directly in tables, figures and sections, among the data of the other sectors in the animal, and marine and coastal aquaculture categories. That way, one also comes to realize that, in 2018, two genera of seaweeds were the two most produced organisms in mariculture in the world. Treating seaweed aquaculture separately can lead to a distorted view of what really constitutes the total world aquaculture (Chopin 2012).

It is not uncommon to see the words "algae," "aquatic algae," "seaweeds," "marine plants" and "aquatic plants" used interchangeably, and without consistency, in many papers and reports published in non-phycological journals. The FAO could play a major role in clarifying the situation. For example, expressions such as "farmed aquatic algae, dominated by seaweeds" are confusing. As micro-algal production is not covered in the State of World Fisheries and Aquaculture series, one can only wonder what the remaining "aquatic algae" could be. If it were the remaining "marine plants," it would be seagrasses; however, these true marine plants are not cultivated, to our knowledge.

Seagrasses, which most probably came from the sea, colonized land, acquired the capability of differentiating roots (capable of attachment and nutrient absorption, whereas seaweeds only have holdfasts capable of attachment but not of absorbing nutrients) and differentiated visible reproductive organs (i.e. flowers; that is why they belong to the Phanerogams, whereas seaweeds have hidden reproductive organs, recognized mostly by specialists, and belong to the Cryptogams). Seagrasses, then, recolonized the marine environment about 75 to 100 million years ago (Papenbrock 2012).

In fact, the seaweeds closest to plants are the green seaweeds, which evolutionarily and molecularly speaking are the ancestors of organisms that colonized the land to become terrestrial plants (Graham et al. 2009). However, these are not the most produced in aquaculture and even aonori [species of the genera *Ulva* (some previously described as *Enteromorpha*) and *Monostroma*], cultivated in Japan, Korea and Taiwan, is not produced in large enough quantities to be recognized in FAO statistics. The same applies to sea grapes (different species of *Caulerpa*). The relationship between plants and red seaweeds is not as direct if one pays attention to the features of the chloroplasts (also acquired through primary endosymbiosis), ultrastructural arguments, and reproduction and cell division specificities. As for brown seaweeds, they do not have anything to do with plants and are, in fact, closer to the fungus-like, heterotrophic Oomycetes and diatoms [again based on the features of the chloroplast (acquired through secondary endosymbiosis), ultrastructural arguments and differences in the flagellar system]. As the confusion around the words "algae," "seaweeds," "kelps" and "marine aquatic plants" is recurrent, Chopin (2018a) dedicated his second column in *International Aquafeed* to the clarification of these terms.

It is hoped that this paper contributes to clarifying the rightful place of seaweeds in the total world mariculture and total world aquaculture productions, and in the worldwide distribution of fed and extractive species. Including them in comprehensive tables, figures, sections and chapters, with the other aquaculture crops, would help simplify and improve the understanding of fisheries and aquaculture statistics to avoid recurrent misconceptions about the aquaculture world and enable it to be approached with a more holistic perspective.

Paradoxically, seaweed production in global aquaculture suffers the same mistreatment as animal livestock production in global agriculture, in which it is not given similar importance as the production of plant food crops, including cereals, fruits, nuts, roots, tubers, oilseeds, pulses and vegetables. The FAO (2020b) lists 330 cultivated species in aquaculture, of which 244 are fed species and 86 are extractive species (66 species of molluscs and 20 species of seaweeds); in agriculture, 158 species are recognized as cultivated, with 140 species being plant crops and 18 species being animal fed species.

Moreover, it is important to include seaweed aquaculture not only for its biological and environmental aspects, but also for its economic and societal aspects. According to FAO (2018), fisheries and aquaculture are critical for the livelihoods of 59.5 million people worldwide, 39 million people in capture fisheries and 20.5 million people in aquaculture. We are not sure if these statistics reflect accurately the number of people involved in seaweed aquaculture, in which women represent a significant component, in variable proportions along the value chain: early stages of cultivation in "hatcheries," cultivation, harvest, post-harvest artisanal or industrial processing, value addition, trade, marketing, sales, nutritious/low-carbon/diverse food security and securing livelihoods. Different cultivation techniques for different species of seaweeds are also responsible for different levels of involvement and empowerment of women, especially the need to use motorized boats to access/harvest the crops versus the ability to harvest them using non-motorized boats or by foot at low tide (cultural preconceptions and perceptions about gender roles, responsibilities and control over production, resources, assets, credits, training and technological transfers, decision-making and leadership).

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