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Contents

Abstract

This report describes the result of literature review about the farming and use of seaweed in Indonesia. It includes results of studies and surveys on seaweed processing, trade, consumption and research. Seaweeds have been used for centuries as food, medicine and fertilizer by many coastal communities. The growing demand of processing factories based in China, Europe, the United States of America as well as locally has driven the expansion of seaweed farming in the past five decades in Indonesia, the Philippines, and a number of other tropical countries. These factories extract carrageenan, agar and alginate from dried seaweed. These products are clear, flavourless and used to thicken and stabilize processed food, cosmetics and have many other applications. In Indonesia farming of seaweed of the genus *Eucheuma* took off in the 1980's. Since then many coastal households have taken up the farming of seaweed. The farming is technically relatively simple and can be started with small capital. Women and youth play a role in the farming and drying of seaweed. Small-scale producers provide the greatest part of the total Indonesian seaweed production which was reported to be 9.78 million metric tons (wet weight) in 2019.

All farming methods applied in open sea start with tying seaweed cuttings to plastic lines that hang just under the water surface. One culture cycle, from hanging lines with cuttings in the sea to harvest, takes on average 40 to 50 days. Fresh seaweed is dried under the sun for several days before it is stored or sold to collectors. Seaweed farming is the main source of income, or generates a supplementary income, for tens of thousands of coastal households in especially Sulawesi, Java, Nusa Tengagara and east Kalimantan. The socio-economic and ecological impacts this activity can have on the coastal environment are described.

The bottlenecks in the various stages of the seaweed value chain that connects farmers via local collectors and regional traders to processing factories and exporters, are identified. Seaweed products are consumed at least once per week by 46% of urban respondents. Jelly, agar powder and dried seaweed (nori) for wrapping around rice and other food are the most popular seaweed products consumed.

Over twenty-five Indonesian research and academic institutes are involved in seaweed research. Their output in the form of publications in international journals as well as in Indonesian language journals shows that publications in the realm of Biological Sciences are by far the highest in number, followed by Engineering and Agricultural & veterinary sciences.

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We would also like to thank our colleagues A.K. van de Werf and S.W.K. van den Burg who reviewed earlier versions of this report and provided useful comments for improvement.

List of abbreviations and acronyms

ASPPERLI	Association of Indonesian Seaweed Farmers and Managers
ATS	Alkali-treated Seaweed
BCE	Before Common Era (similar to BC, Before Christ)
BMP	Best management Practices
CE	Common Era
CEDUS	Center of Excellent and Development Seaweed Utilization
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
GAP	Good Agriculture (or Aquaculture) Practices
IDR	Indonesian Rupiah
I-LMMA	Indonesian Locally Managed Marine Area
IPM	Integrated Pest Management
KKP	Kementerian Kelautan dan Perikanan (Ministry of Marine Affairs and Fisheries
LIPI	Lembaga Ilmu Pengetahuan Indonesia (Indonesian Institute of Sciences)
MoMAF	Ministry of Marine Affairs and Fisheries
Mt	Metric ton
NTT	Nusa Tenggara Timur (East Nusa Tenggara)
SRC	Semi-refined Carrageenan
SNI	Standard National Indonesia (Indonesian National Standard)
TIU	Technical Implementation Unit
TNC	The Nature Conservancy
TSIN	Tropical Seaweed Innovation Network
USD	United States Dollar
WCDI	Wageningen Centre for Development Innovation, Wageningen University & Research
WUR	Wageningen University & Research
WWF	World Wide Fund for Nature

1 Introduction

This report contains the result of a review of literature describing the history and present status of seaweed farming, seaweed use and research on seaweed in Indonesia. Also results of surveys among consumers in Jakarta region, among Indonesian seaweed researchers and outcomes of in-depth interviews with key stakeholders in the Indonesian seaweed value are included, It is one of the outputs of the research team of Wageningen University and Research and Indonesian partners that investigates the possibilities to enhance sustainable food production from the marine environment. The team selected seaweed as one of the crops to focus on due to its potential to contribute to food security on a global level. The Indonesian seaweed sector in particular was selected for more detailed studies because it is well-established and very significant on a global scale; with a harvest of nearly 10 million metric tons of farmed fresh seaweed in 2019 Indonesia ranks second in the world, after China. It is believed that the sector can provide insights and lessons that are relevant for the development and improvement of marine-based food systems on a global scale.

Seaweed has been used as food, fertilizer and as animal feed in many parts of the world and for thousands of years. The history of seaweed as food for people and the role of seaweed as raw material for the production of hydrocolloids such as carrageenan and agar on a global level are sketched in Chapter 2. Carrageen, agar and related hydrocolloids derived from seaweed are widely used in food processing (especially in dairy products and canned food), cosmetics, textiles and in paper manufacturing.

Until the middle of the twentieth century the seaweed that was consumed or used by factories was collected from beaches and harvested from natural ecosystems. But after World War II the growing demand from industry and from growing populations could no longer be met by harvesting of natural stocks. Trials with farming of locally found seaweed species of the genus *Eucheuma* that were undertaken in the Philippines and Indonesia in the 1970’s proved successful. (Later, taxonomists revised some of these species that still play an important role in seaweed farming to the genus *Kappaphycus*). When technical feasibility and economic viability had been shown, seaweed farming was rapidly taken up by coastal households in the two countries but also elsewhere. Chapter 3 outlines the history and present status of seaweed farming in Indonesia, including descriptions of farming techniques, average farm productivity and identification of the factors that influence seaweed growth and productivity. The economic and environmental impacts of seaweed farming are also described in this chapter.

After harvest the fresh seaweed is brought ashore to dry in the sun for several days. Dried seaweed finds its way to the processing factories or to exporters by the actions of a network of many small collectors and traders. In Chapter 4 the stages in the seaweed value chain that take place after the harvest are discussed. The main challenges faced by the various parties in this value chain are listed. In this chapter also the main results of a recent survey of consumer attitude towards seaweed products are highlighted. This survey took place in the region of Indonesia’s capital city Jakarta. It shows that consumers buy seaweed mostly in the form of jelly, agar agar powder, nori (dried seaweed leaves of the genus *Porphyra*) and in fruit ice.

Seaweed research and its results (reports and journal articles) are the subject of Chapter 5. The specific topics and the centers, polytechnical and academic institutions that undertake seaweed research in Indonesia are identified. The respondents of a survey undertaken in October-November 2020 among Indonesian institutes and universities have contributed to the information in Table 8, that shows the *Research centers, Technical Implementation Units, universities and polytechnical institutes involved in seaweed research and development.* The number of scientific publications about seaweed over the years, in both English and Indonesian language, is shown. Biological science This chapter closes with a brief outlook on future developments in the seaweed sector of Indonesia.

2 The use of seaweed on a global level

2.1 Seaweed as food

Seaweeds are found in all coastal areas of the world, from the warm tropics to the cold and icy polar regions. They are grouped into three phyla of red, brown, and green algae, with a total number of species estimated to be between 8,000 and 10,500 (Radulovich et al., 2017). Of the three main phyla the brown and green are usually eaten directly as food while the red and brown are mostly used for the extraction of water-soluble carbohydrates called hydrocolloids of which carrageenan, agar-agar and alginate are the most common. Hydrocolloids are used in many types of processed food, cosmetics and pharmaceuticals. Two-third of the extracted hydrocolloids are also destined for human consumption as an ingredient in processed food (see paragraph 2.2 and chapter 4). The main types of seaweed that are farmed and their main utilization are listed in Table 1.

Table 1 *Main genera and seaweed species farmed, the main producing countries and the utilization (extracted from White, W.L. and P. Wilson, 2015)*

Main Phyla	Main genera / species within this type	Main countries farming this genus / species	Used for
Green Chlorophyta	*Caulerpa spp*	Philippines, Vietnam, Bangladesh	Food
	Enteromorpha	China, Japan, Korea,	Food
	Undaria pinnatifida,	Korea, Japan, China, France, Australia	Food
	Undaria peterseniana	Korea	Food
	Ulva spp	China, Vietnam, Philippines, Portugal, France, Japan, Bangladesh	Food
Brown Phaeophyceae	*Laminaria spp*	China, North Korea, Korea, Japan, Denmark	Alginate, food
	Sacharina japonica	China, North Korea, Korea, Japan, Norway	Food, alginate
	Sacharina pinnatifida	Korea	Food, alginate
	Undaria spp	China, Korea, Japan	Food, alginate
Red Rhodophyta	*Eucheuma denticulatum*	Indonesia, Philippines, Malaysia, Tanzania, Madagascar	Carrageenan
	Gracilaria spp	China, Vietnam, Indonesia	Alginate, food
	Kappaphucus alvarezii	Indonesia, Philippines, China, Tanzania, Vietnam,	Carrageenan, agar, food
	Kappaphycus striatum	Philippines, Indonesia	Carrageenan
	Palmaria palmata	France, Ireland, Canada, USA	Food
	Porphyra spp	Japan, China, Korea, Philippines, Canada, Portugal	Food
	Sargassum spp	China, Vietnam, Philippines, Japan, Korea	Alginate, food

Dozens of seaweed species have been used traditionally as food in different parts of the world. Seaweeds contain important nutrients such as proteins, essential fatty acids, vitamins, and minerals necessary for human growth and development (Mc Hugh, 2003; Mouritsen, 2013; Delany et al., 2016). The concentration of these nutrients however varies, depending on species, season, growing conditions and time of harvesting. Seaweeds are either collected from the wild or cultivated in farms.

The oldest documented use of seaweeds for human consumption dates back to 12,000 BCE from a hearth excavated at Monte Verde in southern Chile (Dillehay et al., 2008; Mouritsen, 2013). The researchers found in the hearth evidence of the presence of about 20 different marine macroalgae, including the genera *Porphyra*, *Gracilaria*, *Sargassum*, *Macrocystis*, and *Durvillaea*.

In Japan and China the use of seaweed as food has been traced back to the fourth century (Japan) and the sixth century (China). Twenty-one different species of edible seaweeds and instructions for their preparation were described in a Japanese–Chinese dictionary dated 934 CE. Seaweeds held a very important place in human history in coastal regions of east Asia since they were seen as hard currency (Mouritsen, 2013).

Seaweed has been an integral part of the diet in Hawaiian and other Polynesian islands for thousands of years. Mouritsen (2013) observes that at least 40 species of seaweeds were eaten in Hawaii. They were eaten raw, baked, pickled, or mixed with other foodstuffs. The custom of eating seaweed was spread to New Zealand by the Polynesians.

Seaweeds have also been used as a food ingredient for many centuries in the western world in places like Iceland, Scotland, Ireland, Maine (USA), Brittany (France), Nova Scotia (Canada), and Wales. Seaweeds like dulse (*Palmaria palmate*) were likely to have been used in the diet of the costal populations of Ireland more than five millennia back. The first written records stem back to fifth-century Ireland, where dulse was used as a condiment with bread, butter, and milk (Rhatigan, 2009, cited in Mahadevan, 2015). Chinese, Japanese, Irish and Scottish immigrants are likely to have carried the tradition of consuming seaweeds to North America (Mahadevan, 2015).

Commercial harvesting of naturally occurring seaweed occurred in about 35 countries in cold, temperate and tropical seas (McHugh, 2003). But after WW II, when demand became larger than could be supplied by harvest of natural resources, the cultivation (farming) of seaweed expanded rapidly, especially in the past five decades. Today seaweed farming takes place in about 50 countries (FAO, 2018). China, Japan and the Republic of Korea are the largest direct consumers of (farmed) seaweed as food (McHugh, 2003). China is the largest producer of farmed edible seaweeds, harvesting about 18.5 million wet metric tons (mt) in 2018 (FAO, 2020) The greater part of this is for *kombu*, produced from the brown seaweed *Sacharina japonica (*called *Laminaria japonica* until taxonomic revision in 2006*)*, that is grown while being tied on submerged parallel ropes in the coastal seas. The Republic of Korea grows about 1.7 million wet mt of three different species (*Saccharina japonica, Undaria spp., Porphyra spp.*). About 50 percent of this is for *wakame*, produced from the brown seaweed *Undaria pinnatifida*, which is cultivated in a similar fashion to *Laminaria* in China. Japanese seaweed production is around 390,000 wet mt and 75 percent of this is for *nori*, the thin dark seaweed wrapped around a ball of rice to make sushi. Nori is produced from *Porphyra,* a red seaweed species (McHugh, 2003).

Of the 291 seaweed species that are worldwide used as food or for production of hydrocolloids, medicines, paper production or for agricultural uses, approximately 100 species are (also) used as food (White and Wilson, 2015). Farmed seaweed now supplies 97% of the global use; the remaining part (being 1.1 million mt in 2013) is harvested from naturally occurring seaweed beds (FAO, 2018). In 2012, 40% of global seaweed production was eaten directly by humans, 40% was consumed indirectly (hydrocolloids added to processed foods) and 20% was used in a range of other industrial applications (FAO Fishstat 2014, cited in Loureiro et al. 2015).

The potential future contribution of seaweed to feed the global population was investigated by van Oort et al. (in prep). Considering parameters such as salinity, temperature, important nutrients and irradiance, the researchers scored coastal areas around the globe for their suitability for farming a cold-water seaweed species, a species for moderate climates and a species often farmed in tropical regions. The results show that the worldwide potential area suitable for seaweed farming is considerable, especially in nutrient-rich coastal waters. Large parts of coastal Africa, the Middle east and Southeast Asia are suitable for farming the warm water species *Kappaphycus alverzii* for 4 to 8 months/year while in the central Pacific Ocean year-round cultivation of this genus should be possible.

2.2 Seaweed for industrial use

Besides for direct human consumption seaweeds are also used in a large number of other applications (FAO, 2018). The industrial use of seaweed biomass has shifted over the years, from exploiting beach-cast seaweeds as fertilizers and a source of potash, via iodine production, to mainly hydrocolloid extraction at present. The use of seaweed as medicines, biofuel, cosmetics and industrial uses (gels, food additives, pet food) emerged after 1945 (Delaney et al., 2016). Overviews of seaweed production and various industrial applications were made by McHugh (2003) and Kaliaperumal (2003); the latter also describes the most common processing techniques.

The main industrial use of seaweeds at present is the extraction of hydrocolloids. Hydrocolloids are water-soluble carbohydrates that act as the skeleton of seaweeds. They are clear, flavorless and can be used to thicken (increase the viscosity of) aqueous solutions, to form gels (jellies) of varying degrees of firmness, to form water-soluble films, and to stabilize some products, such as ice cream (McHugh, 2003). Carrageenan and agar are major industrial ingredients used for gelling, thickening and stabilizing food, pharmaceuticals, cosmetics, hand and body lotions, shampoo, soap, toothpaste, gel fresheners and many other consumer products (Samaraweera et al., 2011, cited in Bjerregaard et al., 2016, p. 4). Alginates, extracted from brown seaweeds, are used by the textile industry as thickeners for the paste containing dye. In the food and beverage industry, alginate is used in ice creams and sauces. It is also used as a separating agent in water-oil emulsions and as a softening agent in baking. In the paper industry, alginate is used to give paper a continuous film surface. It also provides an oil-resistant layer that enhances grease repellency. Other applications of alginate include welding rod coatings and binders for fish feed (Bjerregaard et al., 2016).

After World War II the demand for hydrocolloids rose substantially. The supplies of seaweed were limited by the availability of natural stocks of *Chondrus crispus* (Irish moss) from Canada, Ireland, Portugal, Spain and France and *Gigartina/Iridaea* from South America and Southern Europe (Trono, 1993). In Europe also regulations aimed at protection of coastal and marine habitats and ecosystems imposed limits to the amounts and areas where harvest could take place (Delaney et al., 2016). By the late 1960s, dwindling wild stocks drove producers to scout the world coastlines in order to diversify seaweed supplies. At the same time, seaweed ecology research unveiled the potential of cultivation (farming) as an alternative source of raw material supply (Naylor, 1976). These efforts finally met success in southern Philippines, where native *Eucheuma* seaweeds were found to produce high-quality carrageenan and ecological conditions were favorable for cultivation. The first seaweed farm for production of hydrocolloids was established in the southern Philippines province of Tawi-Tawi in 1969 jointly by U.S.-based Marine Colloids, Inc. (MCI) and Professor Maxwell Doty of the University of Hawaii (Trono, 1990). The two species originally cultivated were named *Eucheuma cottonii* and *Eucheuma spinosum*, commercially referred to as "cottonii" and "spinosum." However, botanists renamed *Eucheuma cottonii* as *Kappaphycus alvarezii* while *Eucheuma spinosum* is now named *Eucheuma denticulatum*. The commercial names 'cottonii' and 'spinosum' are still in use (McHugh, 2003). In the years that followed the number of farms in southern and central Philippines quickly expanded. In 1974, a production of 7000 mt dry weight was reported (Trono, 1990). In 2015 the Philippine seaweed production had increased to 1.56 million mt (FAO, 2018).

Seaweed farming for hydrocolloid extraction expanded also in other countries. Tanzania (especially Zanzibar), Fiji, Kenya, Madagascar, Malaysia and Kiribati have embarked on the farming of *Kappaphycus alvarezi* and *Eucheuma denticulatum* (FAO, 2018). Global farmed seaweed production reached 35.1 million mt (fresh weight) in 2020 (FAO, 2022). Japanese kelp *Saccharina japonica* (formerly called *Laminaria japonica*), *Eucheuma spp* (including species of the genera Eucheuma and Kappaphycus) and Gracilaria spp are the most commonly farmed species, contributing 35.5%, 23.2% and 14.8% respectively (FAO, 2022). Especially the coastal population of Indonesia has embraced the farming of Eucheuma, Kappaphycus and Gracilaria seaweed, making this country the world's second largest producer of seaweeds. In the following chapters the Indonesian seaweed sector will be described in more detail.

3 Seaweed farming in Indonesia

3.1 History

Seaweeds have traditionally been part of the diet of especially coastal communities. Heyne (1926) noted that 22 species have been used traditionally as food in Indonesia, both as vegetables and other ingredients. Zaneveld (1955, cited in Soegiarto and Sulustijo, 1990) noted that 56 species are customary being used as food and some also as medicine by communities in coastal areas (Soegiarto and Sulustijo, 1990). Waryono (2008) cited ethnobotany and ethnopharmacological studies of marine macro algae undertaken by Anggadiredja in 1988–1992 in Riau Province, Lampung Province, the southern coast of Java Island, Madura, Bali, East and West Nusa Tenggara, South and Southeast Sulawesi and the province of Maluku. The studies showed that 61 seaweed species from 27 genera that grow in the waters near the mentioned locations have long been used as food by coastal communities. This number is dominated by 38 species from 17 genera of red algae. A total of 21 species of seaweed from various classes are also used as traditional medicines.

More recently, seaweed is not only consumed directly as salad or as ingredient in a meal. Also the hydrocolloids that are extracted from seaweed are consumed in many other products (Anggadiredja, 2009; see Chapter 4).

Attempts to farm Eucheuma in Indonesia commenced as early as 1967 when Soerjodinoto and Hariadi Adnan undertook planting trials at Thousand Islands as part of a project that was terminated by 1970. In 1975-1977 cultivation projects were launched by Hans Porse and Hariadi Adnan at Pulau Samaringa, under the auspices of the Indonesian Institute of Sciences (LIPI). In 1978, the project moved to Geger Beach at Nusa Dua, Bali. Seaweed cultivars were introduced from the Philippines (Adnan and Porse, 1987) and methods and techniques similar to the ones in the Philippines were tested. From the 1980's onwards the Indonesian government implemented a range of policies and projects aimed at economic development of coastal zones. Among these projects were efforts to develop various kinds of aquaculture including seaweed farming (Zamroni et al., 2011). These efforts contributed to the spread of seaweed culture to many other locations in the Indonesian archipelago (Neish, 2013). Given the positive results achieved, the Indonesian government has embraced the industry as a key focus for economic development. As result of these efforts and the sustained demand for hydrocolloids in the international market, the Indonesian seaweeds sector grew in size and importance. In the Philippines however disease outbreaks, political unrest in especially the southern islands as well as damage by frequently occurring typhoons in the central and northern islands have hampered production in the farming areas. This enabled Indonesia, that suffers less from such natural and anthropogenic setbacks, to surpass the Philippines as the leading producer of carrageenan seaweeds.

3.2 Seaweed species cultivated

Of the four species of seaweed that are at present most commonly cultured in Indonesia (Table 4), two (*Kappaphycus alvarezii* and *Eucheuma denticulatum)* are considered native whereas *Kappaphycus striatus* was introduced to Indonesia, probably from the Philippines (Waters et al., 2019). Four species of *Gracilaria* are farmed in Indonesia: *Gracilaria changii; G. gigas; G. verrucosa and G. lichenoides*. Most commonly farmed is. *G changii* (S. Pawiro, pers. comm, July 21, 2022). *G. changi* is also called *Crassiphycus changi*. Besides from *G. verrucos*a, which is a cosmopolite found in five continents including Asia and Indonesia (Algaebase, www.algaebase.org), information whether the other *Gracilaria* species are endemic or were introduced to Indonesia could not be found. It should be noted that there is considerable controversy over the taxonomy of the genus *Gracilaria* and related genera (Arbit et al., 2019). After detailed study of morphology and molecular DNA analysis the latter authors concluded that *G. verrucosa, G. gigas* and *G. changii* are one species. Morphological differences observed are probably caused by different culture conditions; plants growing freely in shallow ponds develop a different shape than the same plants growing in the open sea while being tied to lines (Arbit et al., 2019).

Table 2 *Cultivated seaweed types and corresponding carrageenan types extracted (Source: Waters et al., 2019)*

Seaweed species	Trade name	Type	Hydrocolloid type
Kappaphycus striatum	Sacol	Red algae	Kappa carrageenan
Kappaphycus alvarezii	Cottoni	Red algae	Kappa carrageenan
Eucheuma denticulatum	Spinosum	Red algae	Iota carrageenan
Gracilaria spp		Red algae	Agar agar

3.3 Production volume and locations

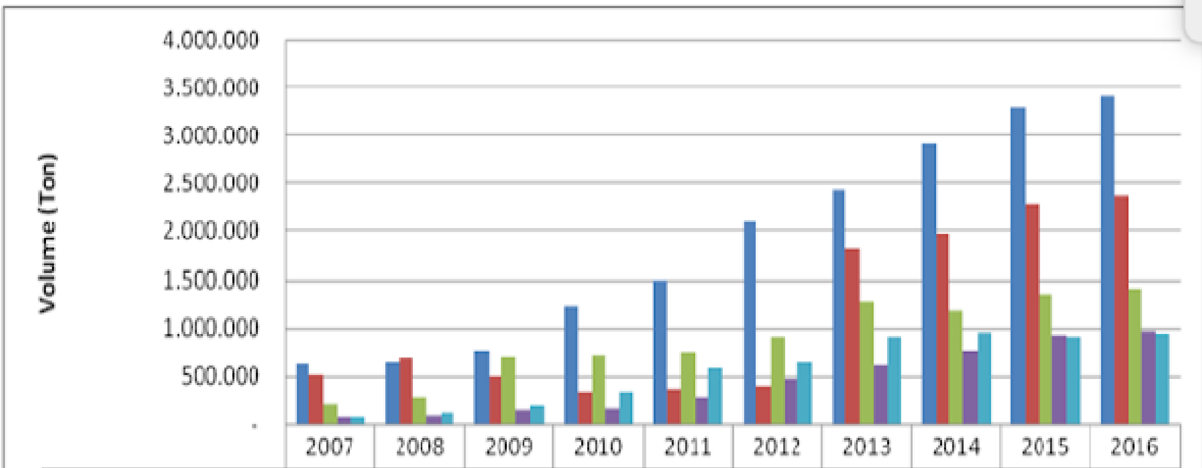
Annual production of wet seaweed in Indonesia increased from 205,000 mt in 2000 via 3.9 million mt in 2010 to 11.27 million mt in 2015 after which it gradually decreased to 9.78 million mt in 2019 (Ministry of Marine Affairs and Fisheries, 2021). Parenrengi et al (2020) attribute the recent decrease of production to slower growth of seaweed due to use of low quality seed (cuttings). Both Anggadiredja (2021) and Neish (2021) noted the difference between official production data on one side and informed industry consensus that estimate the total annual dried seaweed production at 300,000 to 360,000 tons (Neish, 2021) or 365,000 tons (Anggadiredja, 2021) on the other side. A total production of 10 million mt of fresh seaweed would be equivalent to an annual production of approximately 1 to 1.6 million mt of dried seaweed, depending on the moisture content which can range from 42 to 35%, The various sources provide different data and are not always clear about what is measured (semi-dry or dried seaweeds). Besides from inaccuracy in the estimates, the export of unprocessed dried seaweed could explain the discrepancy between potential supply (1 to 1.6 million metric tons dried seaweed) and uptake by local processors and traders (360,000 to 365,000 mt dried seaweed).

Most Indonesian seaweed processors are operating below capacity (see Chapter 4), with limited supply of dried seaweed as one of the reasons mentioned. Soethoudt et al. (2022) point out the competition between domestic and international demand. They state that the prices at the international market are more attractive compared with the domestic market. Also, the payment terms by exporters of dried seaweed are reported to be more attractive than by domestic processors, according to the sources that were interviewed by these authors.

Today seaweed is cultured in 21 provinces (Chapter 5, Fig. 9). The provinces of South and Central Sulawesi, East and West Nusa Tenggara are the main producers. Together these provinces accounted in 2017 for over 50% of the country's total production of fresh seaweed.

Neish (2021) however observed that 50% of the Kappaphycus production of Indonesia occurs in Northwest Kalimantan (Kalimantan Utara), 25% of Kappaphycus and 80 to 90% of Eucheuma is produced in Sulawesi, and most of the Gracilaria is farmed in Java and South Sulawesi. However, Kalimantan was not mentioned among the four main seaweed production areas of seaweed farming in Indonesia mentioned by the Ministry of Marine Affairs and Fisheries in 2018 (Table 3).

Table 3 *Seaweed production on four main provinces in 2007 – 2016 (Source: Ministry of Marine Affairs and Fisheries, Annual report 2018)*



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sulawesi Selatan	630.741	648.528	774.026	1.245.7	1.506.2	2.104.4	2.422.1	2.916.7	3.292.0	3.413.8
Nusa Tenggara Timur	517.699	696.273	498.422	347.726	377.200	398.736	1.846.3	1.966.2	2.283.3	2.367.8
Sulawesi Tengah	200.360	287.268	713.562	728.279	758.910	911.590	1.285.8	1.197.4	1.362.8	1.413.2
Nusa Tenggara Barat	75.509	86.000	147.251	162.411	290.700	477.037	620.116	770.374	937.463	972.148
Sulawesi Tenggara	81.787	123.486	185.229	348.981	586.965	639.192	917.363	956.017	915.895	949.782

Note: Nusa Tenggara Timur = East Nusa Tenggara. Sulawesi Tengah = Central Sulawesi
Nusa Tenggara Barat = West Nusa Tenggara. Sulawesi Tenggara = Southeast Sulawesi

The Ministry of Marine Affairs and Fisheries has estimated that approximately 12.2 million hectares of coastal areas suitable for seaweed farming in Indonesia. Only 1.1 million hectares (9%) are currently used for this purpose (Waters et al., 2019). These authors warn that coastal habitats at present not used for seaweed farming may already have other uses and users, and call for marine spatial planning to avoid conflicts and habitat degradation. Neish (2021) noted that although the East Indonesian region has tremendous potential for seaweed farming, the logistic costs impede the connection of these regions to the existing seaweed value chain (traders, processors in Java and Sulawesi). See also paragraph 4.1.

3.4 Seaweed farming conditions and farm productivity

Seaweeds do not have true roots but are attached through their holdfast, an organ root-like in appearance that serves to anchor them to a substrate but does not supply them with nutrients and water as roots of land plants do. Seaweeds take up nutrients and water as well as dissolved gases directly from seawater through their entire body. Seaweed propagules (cuttings) can become attached to floating structures that provide a substrate (e.g., a drifting log or a buoy and its ropes). This ability of seaweeds to grow attached to floating objects is the basis of seaweed farming. Just about any propagule of any seaweed can be attached to ropes or nets and will grow as long as it receives adequate sunlight and its nutrient and gas requirements are satisfied (Radulovich et al., 2017).

Conditions for seaweed farming can vary spatially and seasonally, depending on the species being farmed. For culture in open sea currents should be below 1 m/s; 20–40 m/min is considered optimal in the sense that water movement is desired to supply seaweeds with nutrients, yet should not be too strong so as not to damage the plants. However, this also depends on the seaweed species being used, for example, in relation to its size at harvest and tensile strength. Seaweeds are sensitive to salinity changes that can occur near river outlets as result of increased freshwater discharge during the wet season. Minimal distance to freshwater discharge has not been well defined (Radulovich et al., 2017).

There are a number of biotic and abiotic stressors ("hazards") that impinge on yields in terms of both quantity and quality. Biotic stressors are mainly

1. pathogenic microorganisms;
2. fouling organisms, ranging from other seaweeds, cyanobacteria and filamentous algae (epiphytes) to a variety of invertebrates that use the cultivated seaweeds as substrate and grow on them (zoophytes);
3. invertebrates that feed on tissue, such as snails, sea urchins, crabs, and copepods; and
4. vertebrates that feed on tissue, such as herbivore fishes and sea turtles (Radulovich et al., 2017).

Abiotic stressors are often considered a more widely occurring limitation than the biotic stressors, perhaps due to their severity. Abiotic stressors are usually the product of adverse or non-optimal environmental conditions, often happening in a short time, such as very low or too high irradiance, high water temperature and salinity changes (Largo, 2021). The effects of such abiotic stressors can be direct, promoting a variety of undesirable responses, including complete disintegration of the crop, or indirect, by triggering or favoring pathogenicity, like with ice–ice. This is a bacterial disease favored by non-optimal environmental conditions. To date, the best procedure to deal with such stressors is prevention by selecting the optimal site, seaweed species, cultivar and propagules, proper timing of the start of the culture cycle in relation to the seasons and farming method for each environment.

Oceanographic conditions in Indonesia are strongly influenced by the monsoon winds and the Indonesian transboundary current. These cause the occurrence of two distinct seasons, namely the west wind season (December-February, also wet season), the east wind season (June-August; also dry season) and the transition seasons in between these periods (Kurnianto and Triandiza, 2013). Yulianto (2004) stated that losses in seaweed cultivation are caused by the emergence of controlling factors (earlier called 'hazards') which occur in the transition seasons from the west wind season to the east wind season or vice versa.

Kurnianto and Triandiza (2013) found that there was a significant difference of *Euchema cottonii* relative growth rate between seasons and locations. The relative growth rate in the period mid-June – early August was lower than the relative growth rate in the period from the end of April– mid of June and the period between early August – early November; Table 4). The low growth rate was possibly due to the start of the planting season, which is at the beginning of the dry season.

Table 4 *Relative growth rate of E. cottonii in four different cultivation seasons (Kurnianto and Triandiza, 2013)*

Cultivation season	Relative growth rate
I (end Apr – mid June)	2.905a
II (mid June – early August)	1.485b
III (early August – end of Sept)	2.263a
IV (end of Sept – Early Nov)	2.565a

Note: the same letter case showed a no significant difference of relative growth rate at P<0.05.

The results showed that the highest seaweed productivity was achieved between the end of September and early November. Yulianto (2003) stated that seaweed cultivation activities should be avoided for 1 to 2 months starting one to two weeks before the dry season. This fallow period should be used to clean the site from disease; after that seaweed planting could be started again. Arfah and Papalia (2008) found that a longer cultivation period (75 – 100 days) and proper timing of seaweed planting (October-November) was the best combination for fast growth.

The production achieved by farmers depends on the size of the farm but varies also considerably between regions. The average productivity of farms surveyed by Neish (2013) was about 6.3 mt (wet weight) per year and 1.1 mt per kilometer of lines or 10.9 mt per ha. The scale of operation varied across regions from an average of 2.7 km of lines per farm for the surveyed farms in South and Central Sulawesi to 10.8 km per farm in South Sulawesi. Also the productivity varied from average 0.55 mt /km of lines in South Sulawesi to 1.68 mt /km of line in East Nusa Tenggara (Nusa Tenggara Timur). In terms of area, the average farm size varied from about 0.11 ha in Bali to 0.99 ha in South Sulawesi. It should be noted that production per ha is strongly influenced by the average distance between lines, which varied from 0.2 m in Bali to 1.35 m in east Nusa Tenggara.

Significant differences in growth and quality of seaweed cultured in different locations in Indonesia was also discovered by Simatupung et al. (2021). Growth of 50 gr seaweed *Kappaphycus alvarezii* propagules during a 45 days culture cycle was monitored in ten different locations using Best Practices for long-line method as recommended by Pong-Masak (2014). Average growth differed from 0.5 kg/meter line in the region with slowest growth (Banten, West Java) to 2.8 kg/meter line in the region where best growth occurred (Bontang, East Kalimantan). Also the carrageenan content (ranging between 8.6% and 26.4% of dry matter) and quality of the carrageenan in the samples differed significantly between the regions. With the culture methods being standardized and growth taking place concurrently (reducing the seasonal effects), Simatupang et al. ascribe the differences between regions predominantly to the genetic variation in the seaweed cultivars that were grown. This genetic variation was also manifested in the different shapes and color of the cultivars used at the various locations. Average productivity per m line and per farm as reported by Neish (2013) and Simatupang et al (2021) are shown in Table 5.

Table 5. *Productivity of surveyed cottonii farmers in Indonesia (Neish, 2013, p. 74 and Simatupang et al., 2021)*

		Average Productivity		Average scale of operation		Average farm productivity
Province, regency	**Farming system**	**Kg/m of line**	**Mt/ha**	**Km of line**	**ha**	**(mt/year)**
Bali	Off-bottom (short stake)	1.25	59.6	5.3	0.11	6.6
Lampung, South Lampung	Floating long-line	1.55				
Banten, Serang	Floating long-line	0.49				
East Nusa Tenggara	Floating long-line	1.68	11.3	3.4	0.5	5.7
East Nusa Tanggara, Kupang	Floating long-line	2.05				
West Nusa Tenggara, East Lombok	Floating long-line	1.4				
South Sulawesi	Floating long-line	0.55	6	10.8	0.99	5.9
South Sulawesi, Pangkep	Floating long-line	1.65				
South Sulawesi, Bantaeng	Floating long-line	1.55				
South Central Sulawesi	Off-bottom (long stake)	1.15	8.6	2.7	0.36	3.1
West Sulawesi, Mamuju	Floating long-line	0.85				
Gorontalo, North Gorontalo	Floating long-line	0.8				
North Sulawesi, Manado	Floating long-line	0.65				
East Kalimantan, Bontang	Floating long-line	2.8				
Average		**1.32**	10.9	5.8	0.58	6.3

Soethoudt et al. (2022) describe a recent case of seaweed farmers near Timor (Eastern Indonesia) who produce on average 3.7 tons of fresh seaweed in one culture cycle from a farm with 900 m production lines. This would be equivalent to a productivity of 4.1 mt /km production line, several times higher than reported by Neish and Simatupang et al (Table 5). Twenty years ago Ask and Avanza (2002) noted that the increase of global seaweed production was the result of growing numbers of farms and not of increased productivity/farm. At that time commercial eucheumatoid suppliers from the Philippines, Indonesia and Kiribati confirmed that average productivity per farmer was less than 6 mt/year (Ask & Avanza, 2002). If at all average productivity per farm increased between 2002 and 2013, it seems not very significant.

First results of the development of a bio-economic model for seaweed growth were published by van Oort et al. (2022). In this model the consequences of harvesting Gracilaria later than the usual 45 days after planting, and the impact of the average weight of the cuttings used to start the new production cycle are shown. The model also predicts the income from harvest later than the usual 45 days after planting. This income for the farmer seems higher, however more research on both the biological and economic parameters in the model is needed.

3.5 Cultivation systems

The recommended methods to farm seaweed have been described in National Standards (Standar Nasional Indonesia) that are published by the National Standardization Bureau BSNI of the Indonesian Government. The following standards were published:

1. Bibit rumput laut Kotoni (SNI 7672, 2011), discussing Cottonii seaweed seedlings;
2. Produksi bibit rumput laut Kotoni Bagian 1: Metode lepas dasar (SNI 7673, 2011), which describes the production of of Cottonii seaweed seedlings using the off-bottom farming method;
3. Produksi bibit rumput laut Kotoni Bagian 2: Metode longline (SNI 7673, 2011), which describes the production of of Cottonii seaweed seedlings using the floating longline method;
4. Produksi Bibit rumput laut Kotoni Bagian 3: Metode rakit bambu apung (SNI 7673.3, 2011), which describes the production of of Cottonii seaweed seedlings using the floating bamboo raft system. (See 2.3.2 for description of the cultivation systems.)
5. The recommended method to produce Gracilaria seaweed in ponds has been described in 'Produksi Bibit rumput laut grasilaria (*Gracilaria verrucosa*) di tambak' (SNI 7902, 2013).

WWF Indonesia (2014), Pong-Masak (2014), SmartFish Indonesia (2018) and The Nature Conservancy (Waters et al., 2019) have also published Good Aquaculture Practices for seaweed farming in Indonesia. The Aquaculture Stewardship Council ASC and Marine Stewardship Council MSC jointly published a standard for seaweed production that is globally applicable with focus on environmental and socially responsible production, see ASC-MSC Seaweed Standard - ASC International (asc-aqua.org).

Producers of seaweed in Indonesia who grow *Kappaphycus* or *Eucheuma* seaweed use mostly one of the following three systems:

a. Off-bottom culture.
   This method is applied in shallow coastal waters. Plots can be reached and worked on foot during low tide. Seaweed cuttings are tied to plastic lines that are approx. 50 cm above the bottom and tied between wooden pegs that are hammered in the bottom. Lines are 15-25 m long and 50 cm apart. Seedlings are tied 20 cm apart.
b. The floating long-line method
   This method is applied in deeper waters (2 – 8 m). Ropes to which seaweed cuttings are tied are stretched between thicker plastic ropes that are kept 10 – 30 cm below water surface by means of plastic buoys, Styrofoam blocks and plastic bottles. The floaters are anchored to the sea floor by means of sacks filled with sand or stones or by bricks or concrete blocks. Ropes with seaweed seedlings are 50 cm apart.
c. Floating raft system.
   This system can also be applied in deeper waters (2 – 8 m). Plastic ropes with seaweeds cuttings are tied to rectangular or square frames (rafts) made of bamboo. The rafts are anchored to the seafloor with sacks filled with sands or stones or other heavy objects. Plastic bottles that are tied to the ropes with seaweeds with regular intervals of 2 m make sure that the seaweed is kept at 10-50 cm below the water surface.

Species of the genus Gracilaria are also grown in coastal ponds filled with seawater and often stocked with shrimps or milkfish *Chanos chanos* (Neish, 2013). In ponds two different cultivation methods can be applied. The main and most frequently used is the broad casting method where the seaweed is just spread throughout the pond by hand. The other method is the off bottom, long line method; this method is a bit more labor intensive.

In Bali, farmers generally use off-bottom horizontal "short-stake" systems or small bamboo rafts. In South-central Sulawesi horizontal long-stake systems are most common (Neish, 2013).

The investment needed to start seaweed farming is relatively low. WWF (2014) estimated investment costs for a long-line farm at US$ 664 and variable costs for the first production cycle at US$ 432. Limi et al. (2018) estimated investment costs for seaweed farmers in Kendari (Southeast Sulawesi) at IDR 4,152,000 (US$ 311.40), including a boat, engine and tarpaulins for drying the seaweed. Soethoudt et al. (2022) report an investment of US$ 425. These investment costs explain that entry has a low barrier. Of course, with less capital smaller farms can be started. Investment costs for a relatively larger nuclear farm with 6 km of lines in South Sulawesi in 2009 were reported to be US $ 1661, plus US $ 614 costs for inputs for first culture cycle (Neish, 2013).

To start the cultivation cycle, farmers take propagules (cuttings) from existing lines, obtain cuttings from a seed nursery or purchase the cuttings. The weight of propagules that are tied to the lines at the start is recommended to be 50 to 100 gr.

Figure 1 *Ladies tying seaweed cuttings to lines*
Photo: dr. N. Rukminasari

Figure 2 *Line with newly tied cuttings, ready to be placed in the sea*
Photo: dr. N. Rukminasari

While the seaweed is growing, farmers regularly check the plots for damage by predators (sea turtles, rabbit fish, dugongs), detachment of seaweed from the ropes, removal of epiphytes and wild seaweeds that attach to the ropes and plants, damage to the installations, strength of the anchoring systems, proper distance of the seaweed lines below the surface, signs of diseases like ice-ice, etc.

Figure 3 *Seaweed farms with floating longlines.*
Photo: dr. N. Rukminasari

Figure 4 *Seaweed harvest brought to shore.*
Photo: dr. P.A.J. (Pepijn) van Oort

Time between setting out of seedlings and harvest is on average 45 days, according to standardized recommended methods. But harvest may take place earlier, for example when the farmer needs cash urgently.

After harvest, lines with seaweed are taken to shore and dried for 2 to 5 days under the sun, actual duration depending on weather conditions. Four main types of drying apparatus are employed: concrete slabs sloped so they have good drainage; tarpaulins or plastic placed on flat ground; platforms or flakes (“para-para”) made from wood or bamboo and covered with fine netting; and wooden or bamboo racks that are used to hang lines with the cuttings still attached.

Figure 5 *Recently harvested lines with seaweed, laid on the beach for drying.*
Photo: Dr. N. Rukminasari

Figure 6 *Gracilaria drying on a para-para in Brebes, Java.*
Photo: R. Lansbergen

Plants must be turned over frequently. Debris (i.e. stones, sand and dirt, ropes, etc.) and other seaweed then the desired species are removed. (A mix of spinosum plus cottonii may be useless for processing). Wet-to-dry ratios vary between species and locations but generally range from 6:1 to 9:1 (Neish, 2013). The dried seaweed is stored in bags until collected by the buyer or brought by the farmer to the collection points.

Figure 7 *Bags with dried seaweed stored in barn.*
Photo: dr. P.A.J. (Pepijn) van Oort

Indonesian seaweed producers face a range of challenges and threats that were identified by Soethoudt et al. (2022). The main ones are:

1. reduced productivity and quality of the crop due to poor genetic material. This is caused by repetitive vegetative propagation, leading to reduced plant vigour, which makes the plants vulnerable to diseases like ice-ice and epiphytic infestations;
2. poor drying and contamination of dried seaweed, lack of simple objective methods to determine quality, lack of implementation of quality schemes;

3. unstable production volumes and price fluctuations;
4. often being located far away from final users (processors);
5. changing weather and climate conditions;
6. dependency on buyers who provide credit in exchange of the right to buy the seaweed for a lower price.

In addition, there is the risk of infection resulting from transfer of plant material from one location to another without sufficient biosecurity measures (Kambey et al., 2020).

The majority of the seaweed farmers is not organised and acts independently, selling their produce to the buyer who offers the best price.

3.6 Impacts of seaweed culture on coastal communities

According to the Ministry of Marine Affairs and Fisheries MoMAF, 267,800 persons were engaged in seaweed production in Indonesia in 2017 (R. Rofiq, 2019, Pers. Comm). The statistics website of MoMAF reports 346,320 marine aquaculture producers in 2018. Knowing that seaweed farming is by far the most important mariculture activity in Indonesia, we can conclude that the majority of these producers are seaweed farmers (Statistik KKP, https://statistik.kkp.go.id/ visited on September 15, 2021).

Neish (2013) noted that in 2008 seaweed farming provided an average annual income of the order of US $5 000 to an estimated 20,000 farm families working on a part-time basis. The most diligent farmers have been able to make from two to three times that amount by working full time or by employing the "leader model" approach to farming. The latter entails setting out 30 km of lines with seaweed propagules and relying mostly on hired labor. Neish observed that seaweed farming has in general resulted in higher income and better economic status of the families involved. "Ready cash from seaweed farming has also had a noticeable multiplier effect. Shops, support services for seaweed farming and village infrastructure have all benefited visibly from seaweed cash flowing through local village economies." (Neish, 2013).

The impacts of seaweed farming on fishing communities over a 10 years period were studied by Steenbergen et al. (2017) in the remote and rather isolated Tanimbar Key Island (Key archipelago, Maluku Province, Indonesia). On this island seaweed farming was introduced by a priest in 2005 but with limited results at the start. It was later supported by a local conservation NGO, the Indonesian Locally Managed Marine Area (I-LMMA) network. After seeing the success of the first pioneer seaweed farmers in 2007, the number of farmers and production sharply increased and reached a peak in 2009 – 2011 with over 130 metric tons dried seaweed in 2010. Production declined to approximately 20 metric tons in 2015. The researchers noted that there was " ... noticeable increase in purchasing power amongst villagers, evident in the number of recent housing renovations, considerable boat-building activity, increased ownership of material goods (e.g. TVs, generators and mobile phones), and higher rates of continued education from secondary to tertiary education amongst village youth." As result of increased incomes (reaching an estimated US$ 2000/year in 2012), more youth (aged 14–20 years) were attending school or college away from the island. The researchers also noticed that after the (seaweed) boom many young men opted to stay on the island, since good money was to be made. Increased engagement in seaweed cultivation led to less time spent fishing on the reef and decreased exploitation of nearby coastal fish stocks. This profitable alternative livelihood made it easier for the I-LMMA team to negotiate restrictive measures for fisheries, such as establishing zones where no fishing was allowed, or rules on gear and fishing effort restrictions.

But not all observed changes were positive. Women on Tanimbar Island complained of their youngest children lacking a good diet because of the amount of time older members of the family (including mothers) were away from the house tending to the seaweed lines. Also, people's expectations of a satisfactory financial return from livelihood activities had shifted after the seaweed boom. The dramatic increase in household income from the sale of seaweed could not be matched by the collective income prior to 2006 from activities such as copra production or trochus collection— estimated by some respondents to be as low as half of what they made from seaweed. Villagers were reluctant to return to these activities after the seaweed boom (Steenbergen et al., 2017).

Rahim et al. (2019) studied in 2016 sources and levels of income among 96 respondents in Bungin Permai, a coastal village in South East Sulawesi. They found that of the average annual income of IDR. 29,154,121 (US$ 2,212.84), 36% was earned with seaweed farming, 26% with various forms of capture fisheries and 38% with non-fishery related activities (trade, agricultural laborer, etc.). The average Revenue/Cost ration for seaweed farming was 1.88. La Ode Muhammad Aslan et al. (2018) reported average annual income from seaweed farming by 64 households in Lemo Village (Southeast Sulawesi) to be IDR 10,800,000, (US$ 810), being 63% of total annual household income.

Enhanced income and economic status and improved infrastructure were also observed by Mirera et al. (2020) and Langat (2021) in southern Kenya, and by Msuya (2013; 2021) in Zanzibar and the east coast of Tanzania where 30,000 persons, mostly ladies, were involved in seaweed cultivation.

3.7 Environmental impacts of seaweed farming

Both positive and negative impacts of seaweed cultivation on the environment have been observed. The following positive environmental effects have been reported from seaweed cultivation (Buschmann et al., 2017; Kelly et al., 2020; Theuerkauf et al., 2021):

- Seaweed cultivation areas absorb nutrients and minerals that have entered the coastal waters as part of agricultural run-off, drainage water from coastal ponds and domestic waste water.
- Seaweed cultivation plots offer food, habitat and refuge for marine organisms and can enhance biodiversity in the coastal region.
- Growing seaweed absorbs carbon dioxide, thus reducing the acidification of coastal waters. Acidification of seawater has been recognized as a threat to coral reefs.
- Seaweeds grown in brackish water ponds stocked with fish or crustaceans absorb dissolved waste products excreted by the fish or crustaceans and produce oxygen, thus contributing to improved water quality and health of the animals in the ponds. Seaweeds also provide substrate for periphyton that is a natural feed for shrimp and tilapia. Pantjara et al. (2020) compared polyculture of red tilapia (*Oreochromis niloticus*) and tiger shrimp (*Penaeus monodon*) in brackish water ponds with, and in ponds without seaweed *Gracilaria verrucosa* in South Sulawesi. The results did not show differences in yield of shrimp and tilapia grown in ponds with *Gracilaria* when compared with the harvest from ponds without *Gracilaria*. Survival rate of tilapia was somewhat better in ponds without seaweed (82.1% vs 78.5%).

Negative environmental impacts of seaweed cultivation were observed on Tanimbar Key Island (Steenbergen et al., 2017) and have been described by Kelly et al. (2020) in their review of publications and grey literature about environmental impacts of seaweed farming.

- Mangroves are cut down to obtain wooden stakes needed to tie the long lines in the off-bottom culture systems.
- Seagrass beds are affected in various ways. Sometimes beds are removed to establish farms. In case seaweed farms are located over seagrass beds and the beds are shaded, the result in general is diminished biomass, shoot density, and seagrass bed coverage (Kelly et al., 2020). Seagrass beds are trampled on when operators visit the site (TNC, 2019; Theuerkauf et al., 2021). Seagrass beds are important for coastal protection and as habitat, nursery and food source for many marine species.
- Seaweed farms can affect nearby coral reefs. The most documented impact of seaweed farms on reefs was overgrowth of reef benthos by seaweed fragments that either escaped cultivation due to neglect or physical damage during storms or transported with currents. This overgrowth can smother corals and cause a decline in coral cover over time (Kelly et al., 2020)
- Seaweed farming leads to increased presence of plastic bottles, Styrofoam and plastic ropes (all used in seaweed cultivation) in the coastal zones. Whether these are properly collected and disposed of or end up polluting the coastal area depends on people’s awareness, presence of plastic garbage collection centers, prices offered for plastic waste materials, etc.
- Seaweed plots can cover significant parts of coastal areas. Besides from possible conflicts with others uses (navigation, mudflat and reef gleaning, capture fisheries), too many plots can cause saturation and as result a decline in productivity. This was observed on Tanimbar Key Island. “Increased density of seaweed lines in the bay were said to restrict water flow and lead to stagnation. This in turn prevented fresh

nutrient in-flow, waste out-flow and, given the shallowness of the bay, increased water temperature. These conditions all increased crop stress and associated vulnerability to disease (ice-ice) outbreak." (Steenbergen et al., 2017).

- In regions where the introduced seaweed species is not endemic, the species can become invasive and cover and smother coral reefs. Such impacts have been described from at least 4 countries (Kelly et al., 2020). In Kaneohe Bay (Hawaii, USA) abandoned *Kappaphycus alvarezi* farms resulted in extensive bottom areas covered with this seaweed species. Also near Kurusadai Island, India, *K. alvarezii* invaded and established on live and dead coral reefs (Hayashi et al., 2010). Kelly et al. (2020) note the general lack of monitoring and surveying of areas near seaweed farms for signs of invasion. "The lack of information regarding how frequently cultivated carrageenophytes become invasive and the severity of these invasions is a critical knowledge gap, and carrageenophyte mariculture may not be a sustainable alternative livelihood.", according to these authors (Kelly et al., 2020, p. 332).
- With introduction of propagules or cuttings from elsewhere also new epiphytic organisms (plants, animals, bacteria) attached to the seaweed propagules may be introduced. The invasion of the green alga *Caulerpa taxifolia* into the benthic communities of the Mediterranean Sea and the distribution of *Saccharina japonica* from mariculture farms over the stony bottom areas of the Yellow Sea in China are given as examples by Tilyanov and Tilyanov (2010).

Environmental impacts as mentioned above can be reduced or mitigated by

- Siting of farms over unvegetated areas, away from seagrass beds and coral reefs, or in off-shore areas;
- Use of seaweed species that are native to the area and to take care to maintain the genetic integrity of farmed seaweeds through genetically propagated seaweeds as opposed to solely clonally propagated crops.
- Awareness raising of all members of the households that farm seaweeds to avoid the use of mangrove for wooden stakes and to recover and dispose all synthetic materials used for seaweed farming in a responsible way;
- Ingle et al. (2020) propose to use strategies applied in Integrated Pest Management IPM for terrestrial crops in seaweed farming. Beside from careful assessment and selection of cultivation sites and cultivars, IPM includes crop rotation, fallow, availability of a trap crop and intermediate crops which could all contribute to reduction of pests without harm to the ecosystem. These researchers also point out the lack of pesticides that could be used safely in the marine environment. The most important control step is in the colony forming stage at the nursery, in case propagules are produced on land.

4 Distribution, domestic use and export of seaweed

4.1 Distribution

The lion's share of seaweeds produced in Indonesia is used for extraction of agars, carrageenan and alginates. The logistic chains from the production sites on often remote islands and locations to the processors on the main island Java and Sulawesi is long and fragmented, therefore inefficient, costly, and often not transparent. Between the farmer and the processing factory or exporter the dried seaweed needs to be transported first from the farmer to small local collectors, often with bicycles or motor cycles. From the small collectors it is transported by truck to traders at higher (district) levels who transport the seaweed to processing plants or exporters. The logistic connections between the Indonesian islands are not optimal and expensive. As result the transport and collection process takes time: processors receive the dried seaweed 14 to 60 days after harvest with an average of 37 days (Soethoudt et al., 2022).

The main challenges and threats that seaweed collectors and traders are facing were identified by Soethoudt et al. (2022):
1. focus mainly on price and quantity, lack of value addition activities;
2. little incentives to pay for better quality;
3. lack of interest in traceability and supply chain transparency;
4. long scattered supply chains, high logistic costs;
5. price fluctuations.

Many smaller and bigger collectors (middlemen) are said to orchestrating the supply chain (Soethoudt et al., 2022).

One-third of the seaweed produced in Indonesia is processed in-country, mainly for an industrial grade product for (pet) food and/or alkali-treated *cottonii* (Campbell and Hotchkiss, 2017; Waters et al., 2019).

There are twenty-one agar-agar producing factories, 40 factories producing alkali-treated carrageenan, semi-refined carrageenan or refined carrageenan, and two factories producing seaweed-based fertilizer in Indonesia (Anggadiredja, 2021). Of these 63 factories only 39 are active, twenty-five of them are exporting. Eleven factories are based in East Java (Surabaya) and 10 in South and South-east Sulawesi. None of the companies are operating at full capacity and some only at 30 to 40% of their capacity (Hogervorst & Kerver, 2019). In 2015 the Indonesian processors produced 18,780 mt of carrageenan (Neish, 2015).

The seaweed sector offers a range of products (Table 6). Main products are Semi-Refined Carrageenan (SRC; food- and non-food grade), agar-agar and refined carrageenan (FAO, 2018).

Table 6 *Indonesian seaweed products (Source: Anggadiredja, 2021; FAO, 2018)*

Fresh edible seaweed
Dried seaweed
Alkali-treated seaweed (ATS), from *spinosum, cottonii* & *gracilaria*
Semi-refined carrageenan (SRC); food- and non-food grade
Refined Carrageenan (CRG)
Refined agar
Blended products/application products
Seaweed powder and blended products
Bio-stimulator
Various products made from liquid and solid waste
Food jellies, ice-cream, noodles, crackers, drinks, sweets, cookies,

Note: blends are combinations of multiple species and/or strains of carrageenophytes originating from various locations around the world that are mixed for a specific use.

The challenges and threats that domestic seaweed processors face were identified by Southoudt et al. (2022). The main challenges are:

1. inconsistent quantity of raw material, and low quality which affect the quality of the end product;
2. operate below capacity of the factories;
3. high transport costs between islands;
4. long lead times;
5. high competition from Chinese buyers of dried seaweed and from hydrocolloid producers in other countries;
6. little experience with exporting to high-end markets; hence limited compliance to the requirements of such markets.

4.2 Domestic use

The use of seaweed products by domestic consumers in Indonesia is growing. The rising demand is driving the processing of *cottoni* and especially *Graciliaria* for carrageenan and agar-agar respectively for the production of various food products such as jellies, noodles, drinks, crackers, sweets, etc. These items are mainly produced by small-scale family businesses (FAO, 2018) of which there are approximately 50 in the country (Anggadiredja, 2021).

A study of 1139 respondents in Jakarta region showed that the seaweed products that were bought most often are jelly, agar agar powder and Nori. These products are most often used as an ingredient in jelly and pudding dishes, fruit ice and sushi (Puttelaar and Tacken, in preparation). Furthermore it is used in cakes, mixed with rice salads and as a snack.

Figure 8 below shows in which dishes seaweed is consumed. Note that these are the results of a multiple choice with multiple answers question. The figure shows that seaweed is mostly consumed in sweet dishes, as a dessert or in drinks.

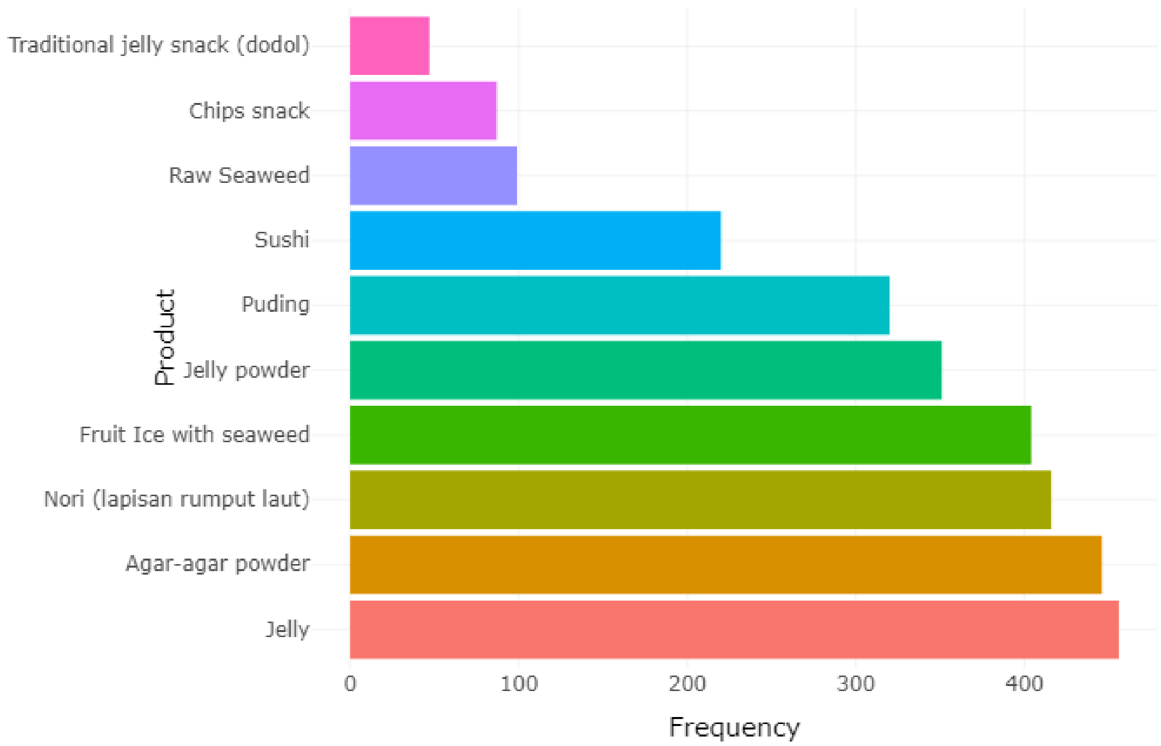


Figure 8 *The most used dishes for seaweed consumption (Source: Puttelaar & Tacken, in preparation)*

The majority of respondents (45,93%) consumed seaweed at least once a week, what indicates that it is part of a habitual consumption behaviour. Forty-four % of the respondents consumed seaweed less than once a week.

4.3 Export

After analysing the national production data of 2013, Anggadiredja (2015) concluded that of the total dried seaweed production of 237,875 mt, 64% was exported and the remaining 36% was used by the domestic industry.

Two-third of the export of *Kappaphycus* (the major species in Indonesia) is as raw dried seaweed (Campbell and Hotchkiss, 2017; Waters et al., 2019). China is the main export market, followed by Philippines and Chile (FAO, 2018). For carrageenan produced in Indonesia, data of UN Comtrade indicate that in 2019 the USA was the second largest importer after China, followed by the Netherlands (Puttelaar et al., in preparation). However, the Indonesian contribution to the import of seaweed products by the EU is small: less than 0,05% of European seaweed imports in 2017 (Hogervorst & Kerver, 2019). Explanation for this small percentage: the EU market requires compliance to food safety and sustainability standards, which again requires standardized and well documented and monitored processes, well equipped and sophisticated facilities, and highly qualified staff. "European players perceive Indonesian suppliers to lack proper food safety and quality management and a lack of knowledge on differences between seaweeds, quality aspects of seaweed extracts and their applications, which result often in inconsistent quality" (Hogervorst & Kerver, 2019, p. 14).

With regard to China, the main export destination, Neish (2021) draws attention to the importance of 'the Chinese connection': many Indonesian processing and exporting companies are owned by Indonesian families of Chinese origin, which made the contacts with processors based in China easier.

As Table 7 shows, the volume and value of seaweed export is fluctuating over the years.

Table 7 *Exports of Seaweed and Other Algae by Major Countries of Destination, 2012-2017.*
FOB = "Free on Board" value. This means that the selling entity is responsible for costs of transportation and loading

Country of destination	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
			Net weight : Ton			
China	103.505,7	130.118,9	136.619,1	147.958,6	139.950,3	148.452,0
Chile	5.955,0	6.043,5	6.650,3	7.975,7	5.043,8	4.742,2
Korea, Republic Of	3.347,2	2.671,8	6.140,5	10.915,2	3.853,8	5.597,6
Hong Kong	4.362,4	4.196,8	5.983,7	3.292,6	3.031,4	1.612,3
Philippines	9.510,6	6.075,9	6.973,8	6.278,2	3.080,3	1.320,4
Japan	815,1	667,2	1.074,8	1.574,0	1.225,3	1.910,7
France	1.200,0	1.720,0	2.538,8	3.655,6	1.537,2	1.845,6
Denmark	818,2	1.455,9	772,4	1.206,0	1.201,3	998,0
Vietnam	6.011,7	1.677,9	5.085,0	6.453,3	1.751,5	4.612,6
Spain	706,0	486,2	1.260,4	1.712,3	762,9	1.052,4
Others	4.029,2	2.954,2	6.750,6	5.339,2	2.216,2	1.480,2
Total	**140.261,1**	**158.068,3**	**179.849,4**	**196.360,7**	**163.654,0**	**173.624,0**
Ave. FOB/ton	785.2	919.7	1279.0	771.9	671.2	873.2

Based on customs declaration documents from Directorate General of Customs and Excise (Exports and Imports Declaration).
Data Cited from Statistical Yearbook of Indonesia.

5 Seaweed research

5.1 Institutes involved in seaweed research

In Indonesia research on seaweed biology, culture, value addition and biochemistry is carried out in a number of research institutes that are under the Ministry of Marine Affairs and Fisheries (MoMAF) and in several universities that operate under the Ministry of Higher Education. Also a number of private companies are involved in seaweed research and development. The research institutes that are part of the MoMAF can be divided in research institutes *sec* and so-called Technical Implementation Units TIU's. The task of the research centres and TIU's is "... to develop and implement technologies for hatchery, nursery and grow-out production systems, environmental monitoring and management, and fish health management" (Rimmer et al., 2013). The TIUs are tasked to develop new or improve existing technologies that can be applied by producers and to provide demonstration and training about the new technologies. The TIU's also serve as an important source of quality fingerlings and seedlings/cuttings to support aquaculture development and play a role in the distribution of new and improved varieties developed in the research centres. The main research centres, TIU's, universities and polytechnical institutes with departments or faculties that are involved in seaweed research are listed in Table 8. Information in this table was collected from the institutes' websites and from the responses obtained from a survey held in October-November 2020 among Indonesian seaweed researchers. It should be noted that when the data for this table were collected, a reorganization of Indonesian research institutes had been started which may have led to mergers and changes in names and of research focus.

Table 8 *Research centres, Technical Implementation Units, universities and polytechnical institutes involved in seaweed research and development*

Name institute (Eng)	Name institute (Ind)	Location	Main seaweed research topics
Dedicated research centers			
Centre for Aquaculture Research and Development	Pusat Penelitian dan Pengembangan Perikanan Budidaya (PPPPB)	Jakarta	
Research Institute for Mariculture	Balai Riset Budidaya Lau (BRBL)	Gondol (Bali)	
Research Institute for Coastal Aquaculture	BRPBAP3 Maros	Maros (South Sulawesi)	
Research Institute for Seaweed Culture	Loka Budidaya Rumput Laut (LRBRL)	Gorontalo (N. Sulawesi)	Improving seaweed production and processing opportunities in Indonesia
Research and Development Division for Marine Bio Industry, Indonesian Institute of Sciences	BBIL-LIPI (part of LIPI)	South Lombok (West Nusa Tenggara)	Integration of Gracilaria culture with milkfish and sea cucumbers; seaweed as feed for abalone and turban snail; Biotechnology; post-harvest, product development; (seaweed) culture technology
Deep Sea Research Center	Pusat Penelitian Laut Dalam (part of LIPI)	Ambon (Molukkas)	
Research Center for Marine and Fisheries Socio-economics RCMFSE	Balai Besr Riset Sosial Ekonomi Kelautan dan Perikanan (BBRSE)	Jakarta	Socio-economic aspects of fisheries and aquaculture
Centre for Oceanography Research COR	Pusat Penelitian Oseanografi (part of LIPI).	Jakarta	Socio-economic aspects of fisheries and aquaculture

Name institute (Eng)	Name institute (Ind)	Location	Main seaweed research topics
Technical Implementation Units			
Main Centre for Brackish water Aquaculture Development	Balai Besar Perikakan Budidaya Air Payau (BBPBAP)	Jepara (Central Java)	
Brackish water Aquaculture Development Centres	Balai Perikanan Budidaya Air Payau (BPBAP/UPT)	Ujung Batee (Aceh) Takalar (South Sulawesi) Situbondo (East Java) Maros (South Sulawesi)	Seeds propagation from tissue culture (Kappaphycus, i.c.w. SEAMEO-BIOTROP) and spores (Eucheuma); effect of light & temperature on production
Main Centre for Mariculture Development	Balai Besar Perikanan Budidaya Laut (BBPBL)	Lampung (South Sumatra)	
Mariculture Development Centres	Balai Perikanan Budidaya Laut (BPBL)	- Batam (Riau Islands) - Lombok (W. Nusa Tenggara) - Ambon (E. Nusa Tenggara	
Centre for Marine and Fisheries Product Processing and Biotechnology	Balai Besar Riset Pengolahan Produk dan Bioteknologi Kelautan dan Perikanan (BBRP2B)	Jakarta	
National Center for Examination of Marine and Fisheries Products Implementation	Balai Besar Pengujian Penerapan Produk Kelautan dan Perikanan (BBP3KP)	Jakarta	Analysis of Marine products
Agency for the Assessment and Application of Technology	Badan Pengkajian Dan Penerapan teknologi Laboratorium Pengembangan Teknik Industri Agro & Biomedika (LAPTIAB) BPPT	Banten (W. Java)	Use of seaweeds in end products
Universities			
University of Indonesia	Universitas Indonesia (UI)	Depok (W. Java) and Jakarta	
University Diponegoro, Department of Marine Sciences	Universitas Diponegoro, Fakultas Perikanan dan Ilmu Kelautan (UNDIP- FPIK)	Semarang (C. Java)	Community structure of seaweed in Java sea; Biology of seaweed from various divisions; Nutritional aspects of seaweed in relation to processing method; Gracilaria seaweed culture methods in ponds; seaweed as phyto-remediator (biofilter)
Center of Excellent and Development Seaweed Utilization, Hasanuddin University	CEDUS (UNHAS),	Makassar (S. Sulawesi)	Seed production with spores; seaweed cultivation technique, bioactive ingredients from seaweed, seaweed processing, high protein content of seaweed, and nori production development.
Airlangga University	Universitas Airlangga (UNAIR)	Surabaya (E. Java)	
Bogor Agricultural University, Department of Marine Science	Institut Pertanian, Bogor, Fakultas Perikanan dan Ilmu Kelautan (IPB - FPIK)	Bogor (W. Java)	
Pajajaran University	University Pajajaran Bandung	Bandung (W. Java)	
Sam Ratulangi University	Universitas Sam Ratulangi, Fakultas Perikanan dan Ilmu Kelautan (UNSRAT-FPIK)	Manado, (Sulawesi)	
Halu Oleo University	Universitas Halu Oleo - Fakultas Perikanan dan Ilmu Kelautan (UHO -FPIK)	Kendari (Sulawesi)	
Gadjah Mada University	Universitas Gadjah Madah	Yogyakarta (Java)	
Jenderal Soedman University	Universitas Jenderal Soedirman	Purwokerto, (Central Java)	
Sriwijaya University	Universitas Sriwijaya	Palembang (South Sumatra)	

Name institute (Eng)	Name institute (Ind)	Location	Main seaweed research topics
Polytechnical institutes			
Bosowa Polytechnic	Universitas Bosowa	Makassar (S. Sulawesi)	
Jakarta Fisheries Polyterchnic	Sekolah Tinggi Perikanan (STP)	Jakarta	Alginate content of *Sargassum polycystum*
Pangkajene Island Agricultural Polytechnical	Politeknik Pertanian Negeri Pangkajene Kepulauan	Pankajene, S. Sulawesi	

To enhance collaboration and synergy, many Indonesian seaweed experts from both private companies and public institutes have united themselves within the Tropical Seaweed Innovation Network (TSIN). Formation of TSIN was facilitated by the SmartFish Indonesia project. The network counts 161 experts in various disciplines regarding seaweed, such as aquaculture, genetics, processing technology and socioeconomics. TSIN connects the seaweed industry with researchers to bring innovation in the whole seaweed value chain with the aim to improve its productivity as well as the competitiveness of the Indonesian seaweed industry. TSIN has reached 28 districts in 8 provinces (Figure 9; (https://seaweednetwork.id/, accessed July 14, 2021).

Figure 9 *Map of Indonesia, indicating with numbers the 21 provinces where seaweed farming takes place (Hurtado et al, 2017). In dark green the 8 provinces with universities and industry partners that are connected in the Tropical Seaweed Innovation Network (TSIN). Red dots show the location of the public research entities listed in Table 8*

A Centre of Excellence for Utilisation and Development of Seaweed CEDUS was established in 2018 at the University of Hasanuddin (UNHAS, Makassar, South Sulawesi; Kasmiati, 2021). Members of the Centre of Excellence are three Faculties or Centres of UNHAS (Marine Science and Fisheries; Pharmacy; Research and Development Centre of Marine, Coast and Small Islands) as well as Pangkajene Island Agricultural Polytechnical, Ujungpandang State Polytechnic, South Sulawesi Provincial Board of Research and Development, Association of Indonesian Seaweed Farmers and Managers ASPPERLI, Main Centre for Brackish Water Aquaculture Development and the Brackish Water Aquaculture Development Centres of Takalar and of Maros, Research topics covered by the CEDUS members are Seed & cultivation, Food, Pharmacy & health, Post-harvest, Socio-economic aspects and Renewable products from seaweed (bio-ethanol, fertilizer).

5.2 Research topics and publications

Between 2000 and 2020 approximately 3000 articles were published internationally with the keywords *Seaweed cultivation* AND *Indonesia* (Figure 10).

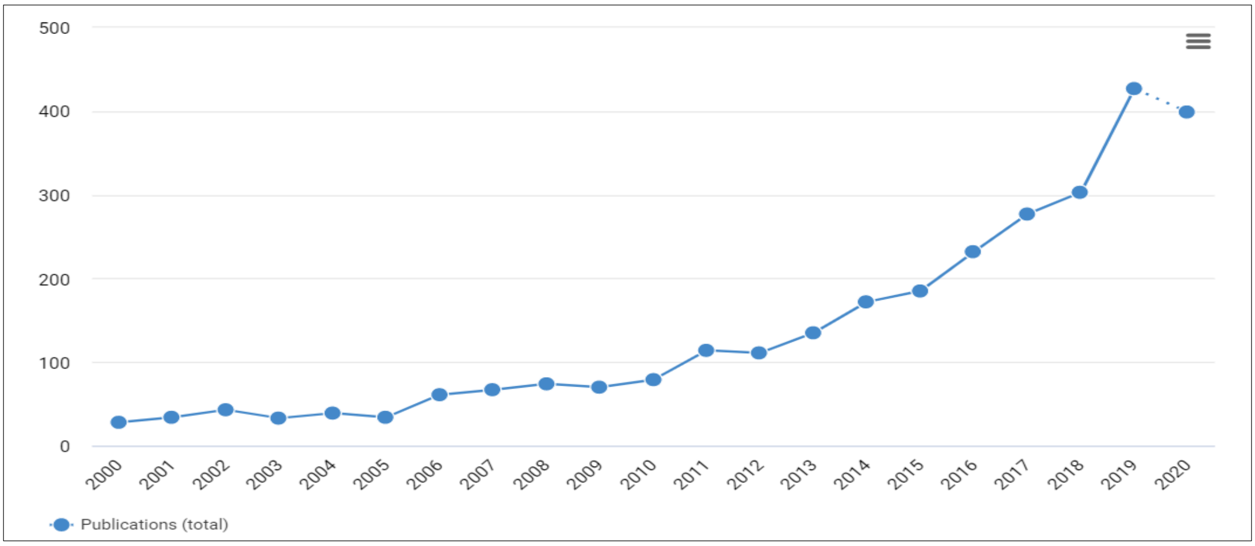


Figure 10 *The number of international publications per year between 2000 and 2020 with keywords 'Seaweed cultivation' and 'Indonesia' (Digital Science & Research Solutions 2020)*

In the same period approximately 250 publications written by Indonesian authors appeared in peer reviewed scientific articles in English language with the keywords: *Seaweed cultivation* and *Indonesia* in the abstracts of Indonesian universities, see Figure 11. This means that Indonesian researchers contributed about 6.7% of the articles about seaweed cultivation in Indonesia published in international (English language) journals. However, when looking at the number of publications with the keywords: *budidaya rumput laut* (meaning 'seaweed cultivation' in Bahasa Indonesia), there are about 1000 articles published between 2000 and 2020. Apparently, most of the results of seaweed research done in Indonesia is published only in the national language.

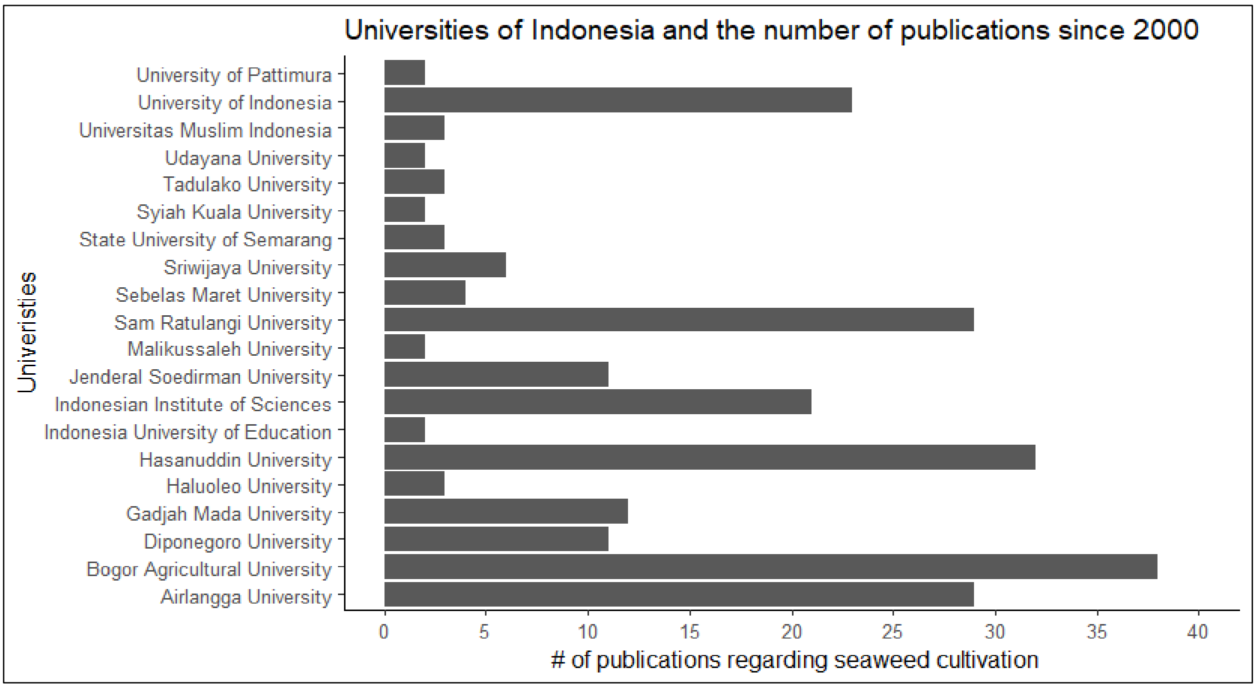


Figure 11 *Number of international publications on seaweed cultivation by Indonesian universities (Search with Keywords: 'seaweed cultivation' AND 'Indonesia', in either the abstract or title (Digital Science & Research Solutions 2020)*

Figure 12 shows the main research topics of the publications in English language about seaweed cultivation in Indonesia. Biological sciences dominate the research focus, followed, with a wide margin by engineering, agricultural and veterinary sciences and medical and health sciences.

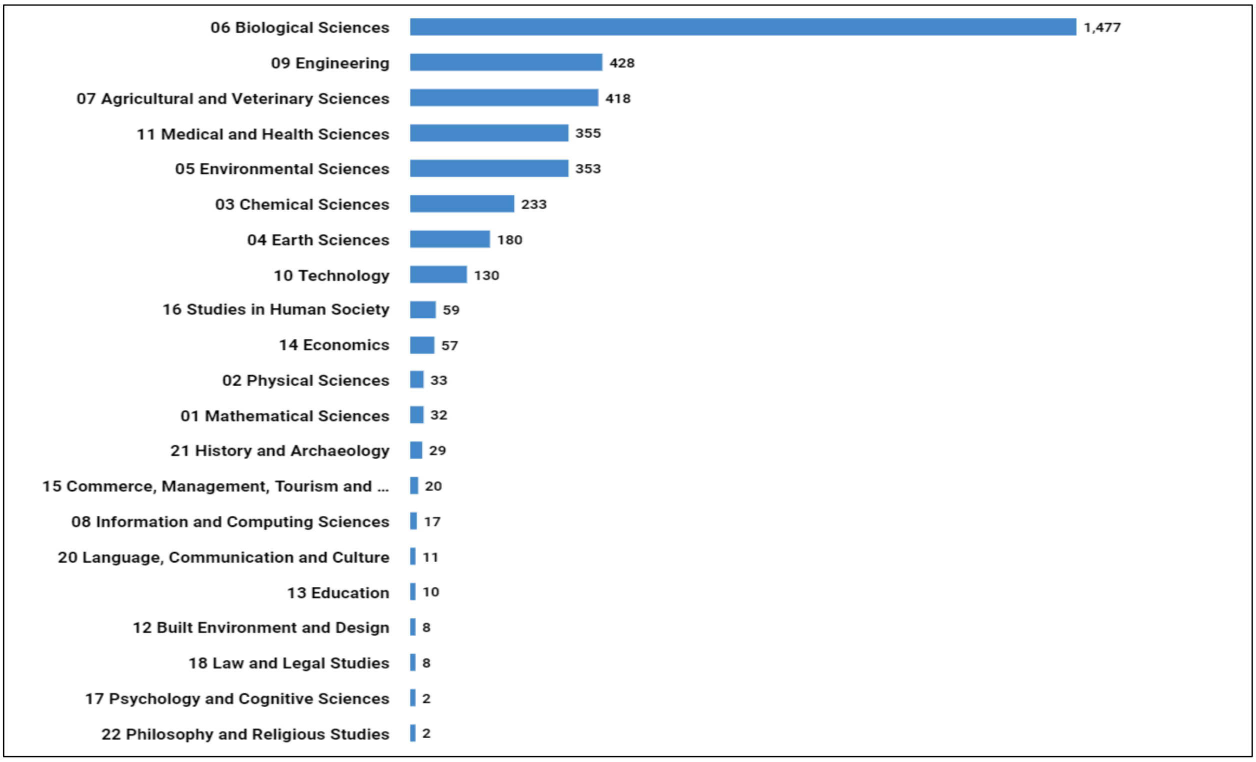


Figure 12 *Research categories that published internationally about seaweed cultivation in Indonesia. The number of publications within each category is indicated by bar length*

To give insight into the seaweed research development in Indonesia a search with keywords was performed. The keywords were chosen based on both Indonesian and globally relevant research topics. In Table 9 below the keywords which were found in the abstracts of published articles are given with the amount of publications in the years 2010 and 2020. The number of publications about seaweed has increased faster in the decade 2010-2020 than in the decades before. The number of publications with keywords 'genetics', 'protein extraction', 'processing', 'ice-ice' and 'aquaculture' have increased remarkably. Also research on 'ecosystem services' and 'socio-economics' in relation to seaweed in Indonesia increased with a factor 5 when compared to the decade before (2000 – 2010).

Table 9 *Keyword search for scientific publications about seaweed research in Indonesia by researchers worldwide. Keywords were found in an abstract search for the years 2010 and 2020 (Digital Science & Research Solutions 2020)*

Keywords	# of publications in 2010	# of publications in 2020
Seaweed AND Genetics AND Indonesia	79	430
Seaweed AND polyculture AND Indonesia	11	82
Seaweed AND "carbon sequestration" AND Indonesia	52	167
Seaweed AND "protein extraction" AND Indonesia	48	293
Seaweed AND "Ecosystem services" AND Indonesia	42	234
Seaweed AND processing AND Indonesia	81	448
Seaweed AND socio-economics AND Indonesia	48	238
Seaweed AND carrageenan AND Indonesia	62	272
Seaweed AND aquaculture AND Indonesia	86	402
Seaweed AND "Ice-Ice" AND Indonesia	129	490
Seaweed AND protoplast AND Indonesia	52	219

Indonesian research studies conducted in support of the seaweed industry were listed by Parenrengi et al. (2020). These studies include site suitability for seaweed culture, genetic characterization, seed production by conventional and tissue culture technique, effects of temperature and light on photosynthesis, pests and diseases, development strategies for seaweed cultivation and growth rate enhancement through strain selection techniques.

Indonesia is home to over 550 seaweed species (Banyuriatiga et al., 2017) and this rich biodiversity has stimulated the exploration into the possibilities and opportunities offered by farming of new species. Farming of new species or new varieties is one of the two foci of the National Seaweed Research Programs 2018-2021 as described in the Presidential Decree of 2019 (Perpres No. 33/2019). The other is innovations in seaweed down-streaming (Saleh et al., 2020). Research in production of seaweed seedlings focus on selection, tissue culture and seedling production based on spores (Anggadiredja, 2021)**.**

5.3 Future developments

Seaweed farming has become an important source of income and employment in many coastal regions of Indonesia (Chapter 3). Producers face a range of challenges, both in the farming process as in the sales process and price. Seaweed also provides jobs and income for laborers, input suppliers as well as to stakeholders further down the value chain (collectors, traders, processors). Food products derived from carrageenan and agar-agar, especially jellies and pudding, are becoming a regular part of the diet of the population, which can drive further growth (Paragraph 4. 2). A range of institutes is investigating the challenges related to seaweed farming as well as value addition; networks that combine seaweed researchers and seaweed companies have been established (Chapter 5).

The office of the President of the Republic of Indonesia has published a strategy (Perpres Nomor 33, 2019) that identifies a series of actions aimed at increase of productivity and efficiency of the seaweed business (Anggadiredja, 2021). The strategy includes improvement of quality standards to meet export requirements and development and promotion of seaweed products for the Indonesian market. The implementation of the strategy will require concerted actions by the business community, the government, researchers, the general public / coastal communities and the news media in a so-called 'penta helix collaboration'.

With an expanding global market for hydrocolloids and the demands of a growing local population as drivers and being blessed with large coastal areas that are suitable for seaweed aquaculture, supportive government policies and legislation and hundreds of researchers and practitioners investigating many aspects of seaweed cultivation and processing, the seaweed value chain in Indonesia seems to be in a favourable position for further development.

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