A GUIDE FOR GOOD HARVESTING PRACTICES OF MACROALGAE IN AZORES (NE ATLANTIC)

The project ASPAZOR and the case study of *Asparagopsis* spp.

Authors: João Faria, Daniel Navas, Afonso Prestes, Eva Cacabelos, Ignacio Moreu, Gustavo M Martins, Leonel Pereira, Ana I Neto

Acknowledgments

This study is a contribution for the research project ACORES-01-1045-FEDER-00060 funded through FEDER (85%) and Regional funds (15%) via Programa Operacional Açores 2020. Funding was also provided from National Funds through FCT - Fundação para a Ciência e a Tecnologia, under the projects UID/BIA/00329/2015-2018, 2019 and UID/BIA/00329/2020-2023. E Cacabelos benefitted from a post-doctoral fellowship awarded by ARDITI Grant Programme Madeira 14-20 (M1420-09-5369-FSE-000001). GMM was supported by post-doctoral grants awarded by FCT (SFRH/BDP/108114/2015). ACL Prestes was supported by PhD grant awarded by FRCT- Fundo Regional da Ciência e Tecnologia (M3.1.a/F/083/2015). Thanks also to Aina del Alcázar Julía, Pablo Muñoz and Celia Serrano for helping in field work.

Figure/Image Credits

All images by João Faria and IAE/GBA-cE3c. Figure 3 is adapted from Álvaro (2019)

A GUIDE FOR GOOD HARVESTING PRACTICES OF MACROALGAE IN AZORES (NE ATLANTIC)

The project ASPAZOR and the case study of *Asparagopsis* spp.

May 2020

Table of Contents

1. Introduction

1.1. Description, distribution and importance of seaweeds

Surely, most of the people at large have said or heard that seaweeds are only “plants of the sea”, which can be smelly when lying at the beach, without being aware of how important they are in the marine ecosystem (Mouritsen, 2013).

Roughly, seaweeds, also known as macroalgae, are eukaryote, multicellular and macroscopic benthic algae, normally attached to firm substrata, mostly on rocky shores (Adams, 1994; Dawes, 1998; Rosas-Alquicira *et al*., 2012; Hurd *et al*., 2014). They are essentially found in the marine environment, although they may occur in brackish or even freshwater environments (Neto *et al*., 2005; Neto & Pinto, 2018). All seaweeds are algae, but not all algae are seaweeds, e.g. the microscopic algae, known as microalgae and/or phytoplankton (Mouritsen, 2013). Nevertheless, all seaweeds, at some point of their life cycle, are microscopic or unicellular, either as spores or zygotes (Amsler & Searles, 1980; Lobban & Harrison, 1994). As with higher plants, they are oxygenic photosynthetic organisms, but here most algae cells contain the green pigment chlorophyll *a* that captures the needed sun’s energy for photosynthesis, the process of building energy-rich compounds (carbohydrates) from CO_2 and the macro and micro nutrients available in the water (Mouritsen, 2013; Barsanti & Gualtieri, 2014; Neto & Pinto, 2018). Yet, they differ from plants in the determinant fact that they do not have true tissues, such as leaves, steams, roots or a transporting network, and neither produce flowers or seeds (Mouritsen, 2013; Neto & Pinto, 2018). Instead, they have an undifferentiated vegetative tissue called thallus, which is the plant body and may be simple or composed by a blade or frond (structure similar to a leaf) and a stipe or axis (similar to a stem). Some of them are attached to the substratum by a holdfast, whereas other use rhizoids or stolon-like structures (Neto *et al*., 2005). Moreover, seaweeds use simple reproductive structures to complete their life cycle by releasing gametes or spores into the environment (Barsanti & Gualtieri, 2014; Neto & Pinto, 2018).

Occurring in all coastal areas throughout the world from the intertidal to the shallow subtidal (Mouritsen, 2013; Netalgae, 2012), and comprising around 12,000 species (Neto *et al*., 2005), seaweeds have their distribution conditioned by several factors such as light, radiation, and photoperiod, temperature, nutrients availability, and herbivory, which can change seasonally (Little & Kitching, 1996). Light is probably the most important factor as it limits these organisms’ growth in depth. Therefore, seaweeds mainly occur from the marginal areas of continents and islands (Ramos *et al.*, 2016) to the subtidal zone until depths where the available light allows photosynthesis (Adams, 1994), the so-called euphotic zone. Even species that have additional pigments (allowing them to capture distinct light intensities, Neto & Pinto, 2018) have their distribution restricted to the first hundred meters of depth. These pigments are the main reason for the different colours exhibited by distinct algal species (Fig. 1) and are an important determinant for seaweed classification in different phyla, namely Rhodophyta (red algae), Ochrophyta (brown algae) and Chlorophyta (green algae) (Guiry & Guiry, 2020). Although phylogenetically distinct, seaweeds from different phyla can exhibit close morphologies that result from convergent adaptations to their habitat. This is very important for adapting to distinct environments, but difficult for species diagnosis and identification (Norton *et al*., 1981; Neto & Pinto, 2018).

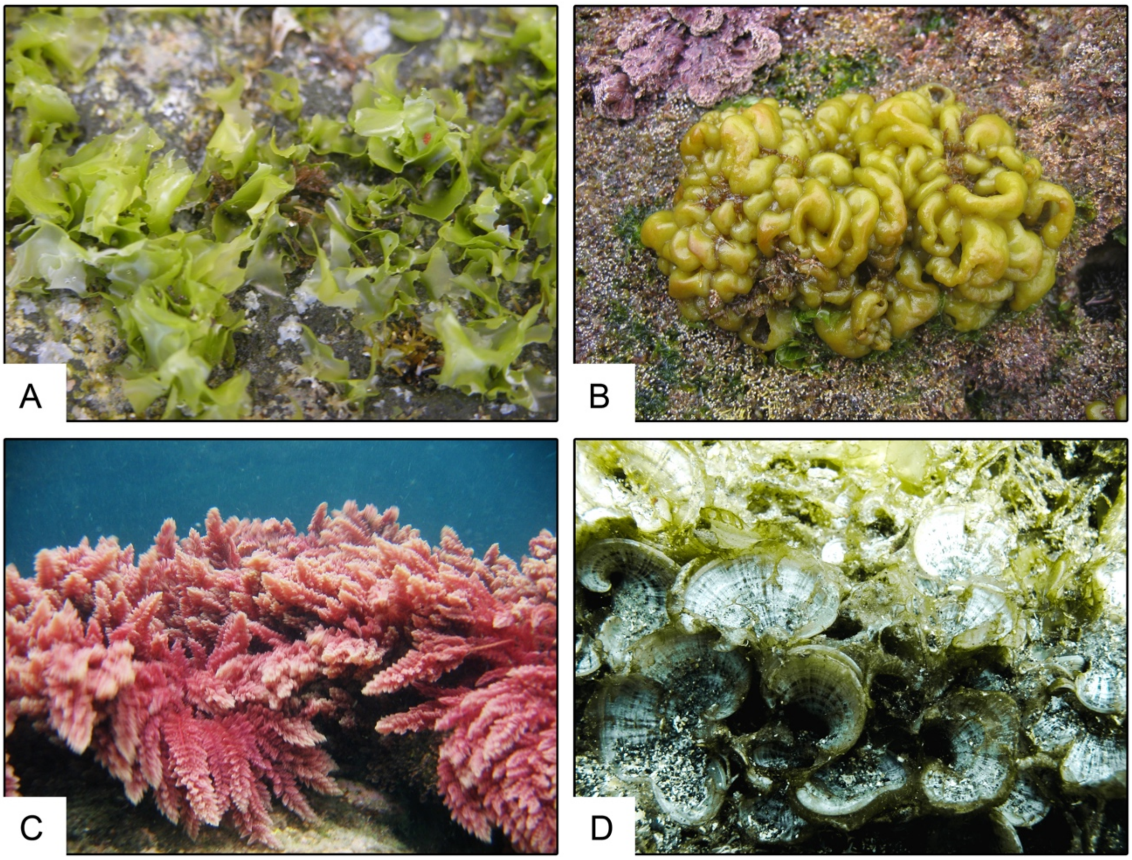


Figure 1. A) *Ulva rigida*, green seaweed, Chlorophyta; B) *Colpomenia sinuosa*, brown seaweed, Ochrophyta; C) *Asparagopsis taxiformis*, red seaweed, Rhodophyta; and D) *Padina pavonica* brown seaweed, which colour is whitened due to a certain level of thallus calcification.

Seaweeds have a major ecological role in the marine environment, essential to the ecosystem's development. They work as oxygen producer (Mouritsen, 2013), and are a CO_2 sink (Chung *et al*., 2011). Moreover, they provide habitat for a diverse array of species (Boaden & Dring, 1980; Christie *et al*., 2003; Kitching, 1987; Nishida *et al*., 2008), a safe place for spawning and nursery (Lenanton *et al*., 1982; Safran & Omori, 1990), and also, a refugee from predators for fish and invertebrates (Lenanton *et al*., 1982; Rangeley & Kramer, 1998). They also provide a direct source of food for many animals (Norderhaug *et al*., 2003; Ugarte *et al*., 2006). Finally, macroalgae are of extreme importance in protecting coastal shores, by dissipating wave energy and capturing sediments and nutrients (Mork, 1996). Some contribute to form siliceous and calcareous deposits (Neto & Pinto, 2018).

According to their origin in a given habitat, seaweeds are considered native or indigenous (e.g. Fig. 2). if they have occurred and dispersed naturally in a region, ecosystem, or habitat, without human influence (IUCN, 2000). Inversely, exotic or non-native seaweeds are those that have been introduced in a location, area or region, in a non-naturally way, mainly via human action (Lonsdale, 1999; D'Antonio & Vitousek, 1992). Non-native species can be invasive, negatively impacting the invaded ecosystem and the native species (e.g. via competition for resources, changes in nutrient cycles or alterations in the trophic chain, Mack & D'Antonio, 1998). Commonly, they are introduced with aquaculture and shipping, and they can cause important socio-economic impacts (ISSG, 2008; Bailey & Owen, 2014).

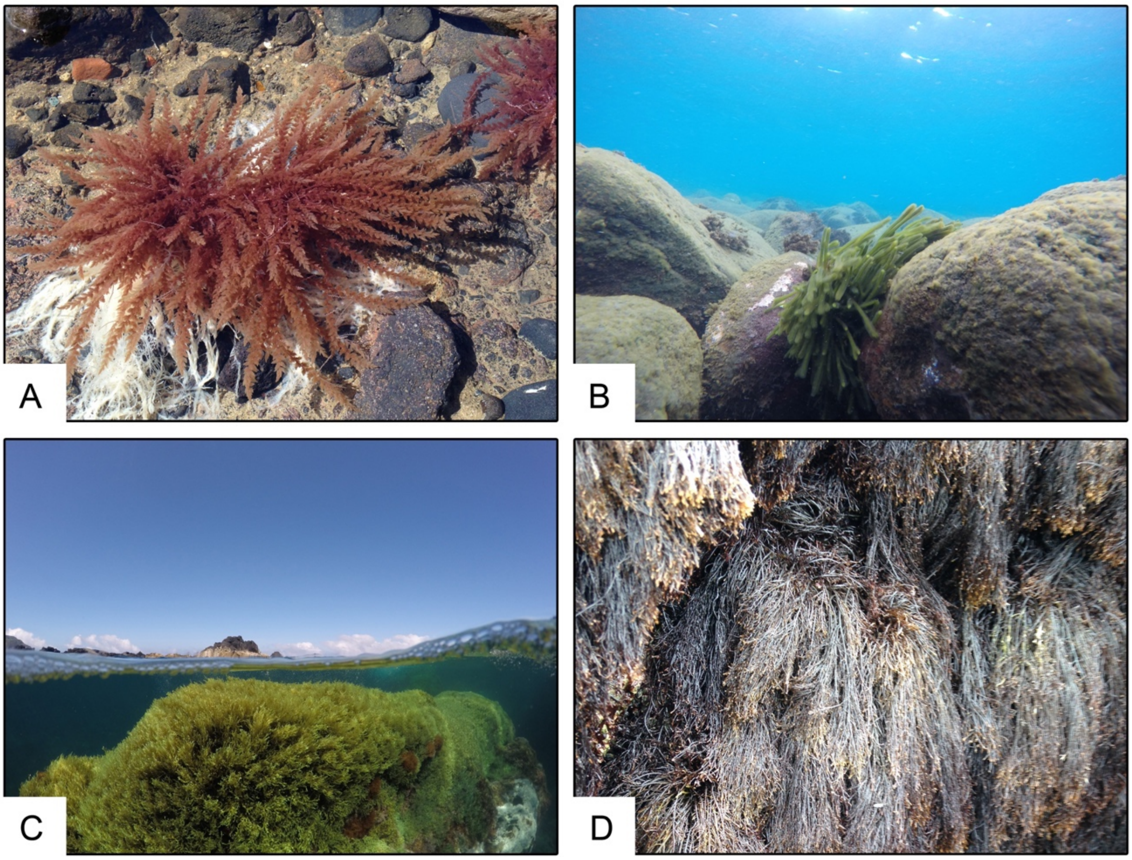


Figure 2. Non-native seaweeds A) *Asparagopsis armata* and B) *Codium fragile* subsp. *fragile*; and the seaweeds C) *Treptacantha abies-marina* and D) *Gelidium microdon* commonly found in the Azores.

1.2. Seaweed applications and uses

Uses and applications of seaweeds are numerous and very diverse. Firstly, and for several centuries, seaweeds were used for domestic purposes, such as human consumption, traditionally in China, Japan and the Republic of Korea (Chapman & Chapman, 1980; Nisizawa *et al*., 1987). More recent uses include biotechnology, animal feed or cosmetics, among other (McHugh, 2003; Bixler & Porse, 2011; Anis *et al*., 2017; FAO, 2018b).

Seaweeds composition is highly variable, depending on species, time of collection and habitat (FAO, 2018b). Around 145 seaweed species are used by the food industry, with 110 species mainly directed for phycocolloids extraction (Nedumaran & Arulbalachandran, 2015). In 2016, seaweed industry provided a wide variety of products for direct or indirect human uses that had an estimated first sale value of USD 11,7 billion per year (FAO, 2018b).

Phycocolloids extraction from the seaweed cell walls has been done since the 17th century (Tseng, 1944; Nisizawa *et al*., 1987; McHugh, 2003), and has been used in the food, pharmaceutical, medicinal, and biotechnological industries as gelling, thickening and stabilizing agents (APROMAR, 2014; Rhein-Knudsen *et al*., 2015; Rhein-Knudsen *et al*., 2017). For instance, agar-agar is obtained from many red algae, such as *Gelidium* spp., *Gracilaria* spp. and *Pterocladiella* spp., and it is used for the food-processing industry, as a culture medium for microbiology or pharmaceutical applications and in the dentistry sector (McHugh, 2003; Callaway, 2015; Porse & Rudolph 2017). Alginates obtained from, e.g. the brown seaweeds *Laminaria, Sargassum* and *Turbinaria*, are used in the pharmaceutical, food-processing and textile industries, among many other applications

(Pérez, 1997). Other seaweeds, such as *Mastocarpus stellatus* and *Chondrus crispus* are a source of carrageenans in Europe, which are used mainly in the food industry as vegetarian alternatives, processed meat or stabilization of flavoured milk (McHugh, 2003). Indeed, hundreds of daily used products (e.g. ice creams, soaps, cosmetics, shampoos and toothpastes) are elaborated with phycocolloids extracted from algae (Sahoo & Yarish, 2005; Yarish & Pereira, 2008).

Macroalgae that are used for human consumption are known to be particularly rich in minerals and vitamins (Ito & Hori, 1989), as well as proteins, essential amino acids and polyunsaturated fatty acids. Some studies showed that edible seaweeds are also rich in dietary fibres (Nishimune *et al*., 1991; Lahaye & Jegou, 1993). Furthermore, seaweeds contain diverse metabolites with antioxidant (Vo Dinh *et al*., 2017), antibacterial (Shannon & Abu-Ghannam, 2016), antitumoral (Alves *et al*., 2016), antiviral (Hardouin *et al*., 2016), anti-inflammatory (Da Costa *et al*., 2017), photoprotective (Losantos *et al*., 2017) and anti-ageing (Mellouk *et al*., 2017) properties. Seaweeds are also one of the only non-fish sources of natural omega-3 long-chain fatty acids (FAO, 2018b). However, seaweeds cannot be entirely digested by human intestinal enzymes, so many beneficial seaweeds compounds do not contribute as expected to the human diet (Jurković *et al*., 1995; Kishi *et al*., 1982; Lahaye & Kaeffer, 1997; Wells *et al*., 2016). According to Pereira (2016), there are about 345 red algae (Rhodophyta), 195 brown algae (Ochrophyta) and 125 green algae (Chlorophyta) that can be consumed (some of them are showed in the Table 1). For instance, *Porphyra* spp. and *Pyropia* spp. (nori) are traditionally used for wrapping maki-sushi in East-Asia; *Chondrus crispus* is used in Ireland, UK and French Britain to elaborate some handmade desserts, and *Undaria pinnatifitida* (wakame) is used as substitute to or complement vegetables, salads or soups (APROMAR, 2014; FAO, 2018b). Some species of seaweeds, with high content in minerals (e.g. potassium) and trace elements, can also be used in agriculture as fertilizer due to its beneficious properties on poor soils. They can also help on i) soil structuration by retaining water, aerating the land and stabilizing the soil; ii) increasing plants' resistance from frosts or insects and fungi plagues, and/or iii) helping them to increase nutrient absorption and grow healthier. Some examples are *Fucus* spp., *Laminaria ochroleuca* or *Ascophyllum nodosum*, that can be collected while drifting or harvested at the sea (APROMAR, 2014). Moreover, calcareous red seaweeds like *Phymatolithon calcareum* can be used to correct soil acidification (Mesnildrey *et al*., 2012; APROMAR, 2014).

Macroalgae can also be used as animal feed, either directly (grazing at the shore) or as algae flour (dried powder form). However, its energetic input is low due to its high fibre content, so cattle cannot be fed exclusively with seaweeds. They can, however, be an additive to complement animal food with vitamins and minerals, helping the intestinal transit (Mesnildrey *et al*., 2012; APROMAR, 2014; FAO, 2018b).

The use of seaweeds for medical purposes, which has been done for centuries in Asia, is now wide spreading (Holdt & Krann, 2011; APROMAR, 2014). They have many beneficial applications for human health, such as contributing to the reduction or prevention of cholesterol, thrombosis, diabetes and coronary artery diseases (Plaza *et al*., 2008). Seaweeds are also used to treat iodine deficiency, strengthen the immune system, removing toxic substances and as a vermifuge, among many other uses in medicine (Guzmán *et al*., 2003; Mesnildrey *et al*., 2012; APROMAR, 2014; FAO, 2018b).

Table 1. Top seaweed species that are used as human food (CEVA, 2014; APROMAR, 2014; Wang *et al*., 2019).

Red seaweed (Rhodophyta)	**Brown seaweed** (Ochrophyta)	**Green seaweed** (Chlorophyta)
Chondrus crispus	*Alaria esculenta*	*Caulerpa lentillifera*
Erythroglossum laciniatum	*Ascophyllum nodosum*	*Enteromorpha sp*
Phymatolithon calcareum	*Cladosiphon okamuranus*	*Monostroma latissimum*
Palmaria palmata	*Fucus vesiculosus*	*Ulva sp.*
Porphyra umbilicalis	*Fucus serratus*	
Pyropia yezoensis	*Himanthalia elongata*	
Pyropia tenera	*Laminaria digitata*	
Porphyra dioica	*Sargassum fusiforme*	
Porphyra purpurea	*Saccharina latissima*	
Pyropia leucosticta	*Saccharina japonica*	
Pyropia linearis	*Undaria pinnatifida*	

They are also used in the pharmaceutic industry for their antiviral, and anti-inflammatory properties and by using phycocolloids as pill covers. Moreover, the cosmetic industry thrives with seaweed-derived products (e.g. facial masks, skin creams, shampoos) (Mesnildrey *et al*., 2012; APROMAR, 2014).

Seaweeds can also be used as: i) bioindicators for environmental water quality; ii) biofilters in aquaculture; iii) in biorefinery processes (Baghel *et al*., 2015; Trivedi *et al*., 2015); iv) in biofuel production (Mazarrasa *et al*., 2014; FAO, 2018b); v) in biogas production using anaerobic fermentation; vi) in paper and paperboard elaboration; vii) in glass production (Patarra, 2017); viii) in textile industry, and many other applications that are currently under research (Mesnildrey *et al*., 2012; APROMAR, 2014).

1.3. Seaweed harvesting

Coastal populations have harvested seaweeds along, at least, the lasts 14000 years, according to archaeological findings in Chile (Dillehay *et al*., 2008). Since 1945, the demand for seaweed has been constantly increasing and harvesters' organizations and some countries have implemented rules to avoid the destruction of such natural resources (Delaney *et al*., 2016). However, there's still a lot to be done in terms of management and regulation to foster sustainable practices on the exploitation of seaweeds worldwide.

Wild or natural seaweed harvesting has evolved historically, changing according to the target species, its use and the location/country where it is gathered (e.g. on rocks, near-shore areas, etc.). Even though labour-intensive, some species are still harvested manually, due to the impossibility of doing it mechanically. This practice is performed at the shore, by collecting seaweeds that cast ashore after storms (*drift*) or plucking/cutting them from the rocks by hand, using knives, scissors or other tools. Also, it can be made by apnea or scuba diving at shallow water locations. After collection, seaweeds can be dried or kept fresh, depending which use they'll have. Manual gathering of seaweeds is done, for example, in Portugal, including the Azores, Japan, Korea and Ireland (APROMAR, 2014; Delaney *et al*., 2016).

Mechanical harvesting requires specialized boats and specific equipment that guaranty higher capacity of collection. It can be done with dredges, combs, hydraulic hooks or rakes attached to cranes adapted to exploit the bottom of the sea. Countries such as France or Norway commonly use this kind of seaweed gathering (APROMAR, 2014; Mesnildrey *et al*., 2012).

Surely that all kinds of harvesting have an ecological impact on the ecosystem. The extent of the impact depends on how much is being harvested, the intensity and frequency, and the characteristics of the species harvested (e.g. life history, importance and function in the ecosystem, biomass, etc.) (Foster & Barilotti, 1990; Vasquez, 1995). Because natural or wild stocks of seaweeds are not enough for current demands, and to avoid overharvesting effects (Yarish & Pereira, 2008; Bostock *et al*., 2016), macroalgae farming has been increasingly used, and the global production of farmed seaweeds has increased enormously in the last decades (Table 2), with Asia being the main producer (Jansen *et al*., 2019).

Table 2. Marine seaweed (red, brown and green algae) production since 1950 to 2017 for all commercial, industrial, recreational and subsistence purpose (wet weight) (data from FAO, 2018a, b, 2020).

	1950	1960	1970	1980	1990	2000	2010	2017
Farmed	34 636	460 959	1 144 379	3 075 411	3 988 659	7 712 971	17 050 522	31 051 534
Harvested	326 187	678 729	899 371	818 357	1 193 294	1 011 556	792 026	844 558

Macroalgae farming accounts for around 96.5 % of the total seaweed biomass used for economic purposes (FAO, 2018b). Seaweed cultivation started in Asia, specifically in Japan, Korea and China, in the 17th century, with *Pyropia/Porphyra* (Tseng, 1944; Nisizawa *et al*., 1987; McHugh, 2003). In the 1960s seaweed cultivation expanded to about 50 countries (Radulovich *et al*., 2015; FAO, 2018b). Currently, China and Indonesia are the top seaweed producers, and Asia is the main seaweed cultivator worldwide (FAO, 2020).

Despite the global trend for expansion in seaweed farming and aquaculture, cultivation processes and techniques are still in development, and further research is needed to convert such industry in an ecological and sustainable one (Robinson *et al*., 2013; Charrier *et al*., 2015; Loureiro *et al.,* 2015; Kim *et al*., 2017). For instance, the eco-friendly practice of using and farming macroalgae to remove waste materials (e.g. inorganic nutrients, CO_2) in animal aquaculture is now seen as an excellent sustainable practice in food (fish and seaweed) production (FAO, 2018b). As known, macroalgae, have a crucial role in recycling nutrients in marine environments (Gao & McKinley, 1994), so some algal species are used to reduce the nutrient load in the water in animal aquaculture (mainly carnivorous species), in the so-called integrated multitrophic aquaculture system (Buschmann *et al*., 2001; Neori *et al*., 2004; Troell *et al*., 2009).

2. The Azores archipelago

2.1. Brief description and history

The Azores archipelago is located in the middle of the North-eastern Atlantic Ocean, between 37º to 40º N and 25ºto 31ºW, about 1500 km from Lisbon and about 3900 km from the east coast of North America, taking part of the so-called Macaronesia region, together with the Canarias, Madeira, Selvages and Cabo Verde (Neto *et al.,* 2014). These latitudes are characterized by being subtropical/warm temperate areas, considered the southern limit for cold-water species, and the northern limit for warm-water tropical ones (Neto & Pinto, 2018). The Azores, with an area of 2,344 km², has nine volcanic islands and some small islets organized in three groups (Fig. 3): the Eastern Group, with Santa Maria and São Miguel; the Central Group, with Terceira, Graciosa, São Jorge, Pico and Faial; and the Western Group, with Flores and Corvo (Morton *et al.,* 1998; Neto *et al.,* 2005; Calado *et al.,* 2011).

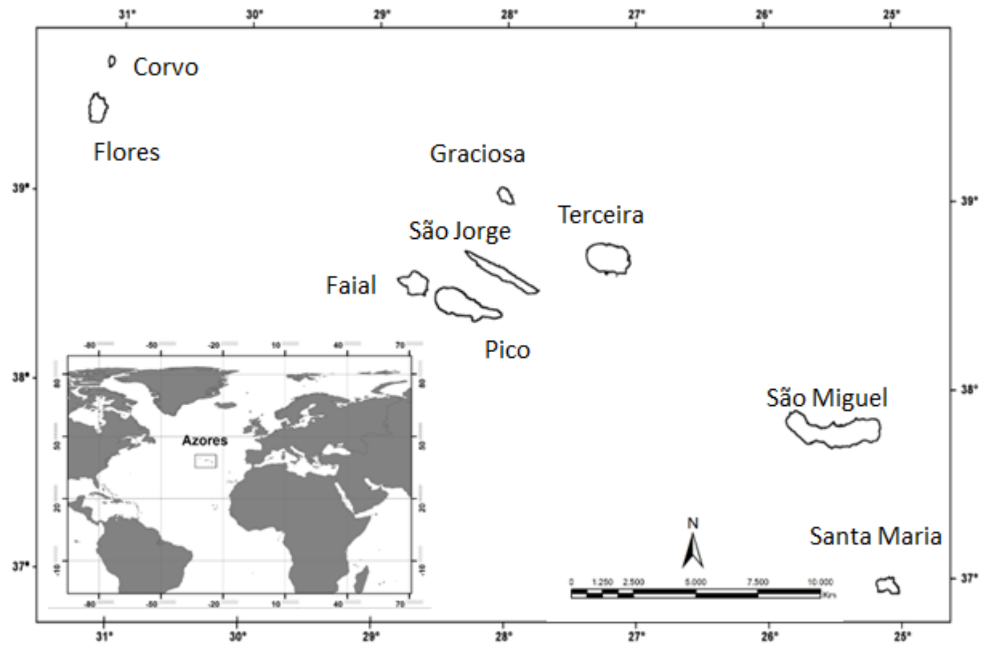


Figure 3. The Azores archipelago and its location in a world map.

Azorean islands, which are geologically young, emerged above the sea level in different moments in time, and are still in a tectonically and volcanically active region, distributed over a 600 km approximately WNW-ESE strip (Neto, 1997; Calado *et al*., 2011). They were never part of a continent, so native plants and animals arrived at the islands by long distance dispersal from continental areas (Whittaker & Fernandez-Palacios, 2007) or adjacent archipelagos (Domingues *et al*., 2008), with a greater influence from Northern Europe (Neto *et al*., 2014). All the islands are in continuous formation since 10-8 million years ago in the Miocene, when the first rock was formed in Santa Maria island due to volcanic activity (Abdel-Monem *et al*., 1975).

2.2. Azorean shores

The coastline in Azores is characterized by being highly rough due to its recent volcanic nature (Morton *et al*., 1998) and it is mainly crafted by black basaltic and pumice stone trachytic deposits. These volcanic rocks can have a vesicular texture, with cavities and crevices where algae can attach, and fauna can hide, or they can be less vesicular, where fauna depends on algal growth to live there (Santos *et al*., 1995; Wallenstein *et al*., 2009).

Only few seashores are sheltered (e.g. bays and harbours). Most of them receive the direct impact of high energy wave due to its long fetch, with its consequent longshore sediment movement (Borges *et al*., 2002). The northern coast of the islands is typically more exposed to swell and surge (Neto *et al*., 2005). Most coasts are composed by bedrock, boulders or cobbles, where coarse sand or gravel is retained, whereas sandy beaches are restricted in number (Neto, 1997; Wallenstein *et al*., 2009). Deep water surrounds the archipelago, reaching 1000 m a mile or two offshore, due to steep submarine slopes and absence of shallow shelves, making the coastal zone rather narrow (Martins, 1986; Neto, 1997; Wallenstein *et al*., 2009).

The intertidal zone of the seashore is divided in three main zones: the higher level, the mid-level and the lower level (Neto *et al*., 2005). In the upper shore there are no seaweeds, only animals (*Littorina* spp., Fig. 4A), lichen (e.g. *Lichina*) and cyanobacteria (e.g. *Rivularia*). Seaweeds appear at the upper mid shore zone (e.g. *Fucus spiralis, Gelidium microdon,* and *Caulacanthus ustulatus*), sharing space with some animals (mainly Chthamalid barnacles, Fig. 4B). Macroalgae dominate the lower mid zone, forming monospecific or multispecific algal turfs with articulated calcareous algae like *Jania* and *Ellisolandia*, or soft algae such as *Ceramium* and *Condracanthus*, among other species (Fig. 4C). This layer is usually 20-30 mm thick, and normally covers large rocky areas. At lower levels, establishing the transition between the intertidal and subtidal areas, patches of frondose algae (Fig. 4D), like *Treptacantha abies-marina, Pterocladiella capillacea* and *Halopteris scoparia* became dominant, although crustose forms and algal turfs are also present. Finally, subtidal levels are often covered by a first strata of crustose corallines, covered by an association of two or more frondose macrophytes, frequently supporting some level of epiphytic species (Neto *et al*., 2005; Neto & Pinto, 2018).

At present, the marine environment of these islands and its surroundings are an Economic Exclusive Zone (EEZ) of more than 1 million square kilometres (Neto, 1997), one of the largest in the European Union. Azoreans depend strongly on the sea for communication and trade, and they have increasingly exploited the littoral, nearshore and offshore living resources (e.g. algae, molluscs, crustaceans, fishes) since the earliest colonization in the XV century, changing from subsistence or artisanal exploitation at the beginning to more commercial operations nowadays (Frutuoso, 1983; Serpa, 1886; Sampaio, 1904). Currently, marine resources exploitation has been calling for more sustainable management and nature conservation actions (Santos *et al*., 1995). Also, the economic and social growth, the associated urbanization and the increase in tourism have incremented the human pressures in coastal regions (Borges *et al*., 2002; Calado *et al*., 2011). This represents an anthropogenic threat to the ecosystem's health (Lotze *et al*., 2006; Worm *et al*., 2006) and, therefore, the urge to protect the marine environment at a regional level has become a priority. That is why Marine Protected Areas (MPAs) have been implemented throughout the Azores archipelago (Santos *et al*., 1995), and set up to protect, conserve and manage ecosystems, as a mean to reduce or mitigate the impact of anthropogenic activities (Lubchenco *et al*., 2003; Gaines *et al*., 2010). Nowadays, there are 38 coastal MPAs across the Azores (ISPA, 2019). However, although MPAs are known by general public as fully protected zones that preserve the whole ecosystem, most of them are not fully enforced (Horta *et al*., 2019), with some industrial fishing, illegal practices and other damaging activities occurring on some (Costello & Ballantine, 2015; Horta e Costa *et al*., 2016; Dureuil *et al*., 2018; Horta e Costa *et al*., 2019).

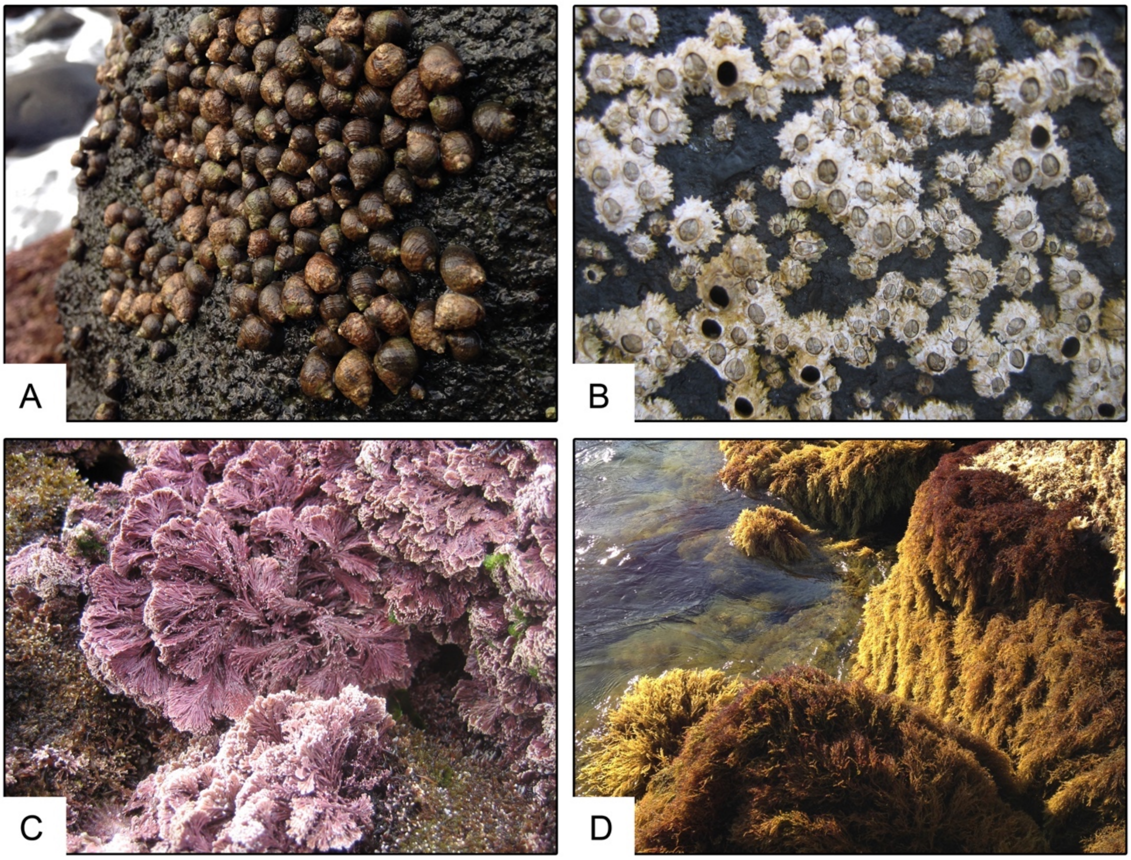


Figure 4. A) *Tectarius striatus* on the upper shore; B) chthamalid barnacles on the intertidal shore; C) the articulated calcareous algae *Ellisolandia*; D) lower zone of the intertidal shore covered with *Treptacantha abies-marina*.

3. Seaweed harvesting in the Azores

Traditionally, the inhabitants of the Archipelago of Azores have gathered seaweeds either for food (which is widespread and accepted as a common practice in the Azores), chemical extraction, or fertilizers in local agriculture and/or horticulture (Neto *et al*., 2005; Paiva *et al*., 2014). For instance, *Fucus spiralis* receptacles (reproductive parts of the frond), commonly known as "fava-do-mar", are usually eaten raw as a snack. As a complement of soups, omelettes or cakes, the red seaweed *Porphyra/Pyropia* ("erva patinha") is also commonly used. *Laurencia* and *Osmundea* ("erva malagueta") are other red seaweeds that are pickled in vinegar with onions and eaten with fried fish throughout the year on some islands (Neto *et al*., 2005). *Osmundea pinnatifida, Fucus spiralis and Porphyra/Pyropia* are rich in proteins, minerals, polyunsaturated fatty acids, vitamins and contain substantial amounts of 9 out of 10 essential amino acids. Their use in food and/or pharmaceutical products can greatly increase the nutritional value of human diet (Paiva *et al*., 2014).

Historically, until the 90s, the red algae *Pterocladiella capillacea* and *Gelidium microdon* (in less quantity) have been harvested manually as a small-scale family business and the algae dried on the streets and then exported for the industrial production of agar (Neto *et al*., 2005). At that time, given the lack of Japanese agar-agar, the Portuguese industry increased and exported worldwide (APEDA, 2016; Patarra, 2017; Patarra *et al*., 2019) with six agar factories operating in Azores. However, national regulation restrictions on harvest seasons and licensing caused a decreased on the Azorean agar-agar industry, and, in 1971, only two factories were operating in the region (Santos & Duarte, 1991), which eventually closed as a consequence of lack of product diversification and also due to unfavourable international circumstances (APEDA, 2016). For more than a decade (CCAH, 2016), seaweed harvesting in Azores was almost absent, but in 2013 the local association "*Associação de Pescadores Graciosenses*" was created and started promoting the commercial harvesting of seaweed across the archipelago. This association increased its seaweed exportations (mainly *P. capillacea*), from 16 tons in 2013 to 133 tons in 2015, either to food, pharmaceutic or cosmetic industries (APEDA, 2016; Patarra, 2017; Patarra *et al*., 2019). Harvesting was initially mostly restricted to Graciosa, Terceira and Flores islands, but in 2014-15 it expanded to São Miguel island, especially in the fishing villages of Rabo de Peixe, Calhetas and Porto Formoso (APEDA, 2016; CCAH, 2016). Most of the harvest is exported to the north of Spain (CCAH, 2016). In 2016, there were 130 registered certified seaweed harvesters in the region and about 450 tons of seaweed were harvested (GaCS, 2017).

Until recently, guidelines and legislation regarding seaweed harvesting were scarce. Seaweed harvesting is indeed an activity with high economic potential in the Azores, but there is the need to ensure its sustainability, as a mean to safeguard the health of marine ecosystems and the future of fishing and algal harvesting. In this regard, the Government of the Azores has promoted the contact between scientists and algae harvesters through a series of workshops and lectures, aimed at stimulating a more competitive and sustainable knowledge-based economy.

More and more, people and companies are working in this sector each year in Azores, and the main objective is to introduce Azorean algae into the world market, highlighting its quality and environmental stamp. Currently, the Regional Government has started supporting private investment in the aquaculture sector, which will contribute to prevent the overexploitation of the Azorean wild algal stock, ensuring the sustainable development of the seaweed industry in the Region (Patarra, 2017; Patarra *et al*., 2019).

3.1. Current legislation and regulations

There are well known mechanisms to legislate and control the exploitation of marine resources, such as time closures, minimum sizes or protected areas for marine species (Diogo & Pereira, 2013a, b). In the Azores, the local government has implemented some legislation for seaweed exploitation (Portaria n.º 69, 2018) to avoid the overexploitation of seaweeds and achieve a sustainable harvesting. This legislation imposes the use of specific tools for the seaweed harvesting activity, such as scissors, chisels, and bags for carrying the seaweed. Other tools can be used but are not specific for seaweeds collection.

The list of seaweed species that can be harvested is restricted and is differentiated between macroalgae that can be harvested for direct human consumption (but also other applications) and macroalgae that can be harvested for processing industries (with no direct use as human food) (Table 3).

Table 3. List of seaweeds than can be harvested in the Azores shores: for A) direct human consumption and other applications and B) processing industries; see *Portaria n.º 69* (2018).

A. Direct human consumption	B. Processing industries
Erva-rabão (*Asparagopsis taxiformis*)	*Asparagopsis* spp.
Erva-malagueta (*Osmundea pinnatifida*)	*Cystoseira humilis*
Erva-patinha (*Porphyra* spp.)	*Halopteris scoparia*
Erva-patinha verde (*Ulva intestinalis*)	*Pterocladiella capillacea*
Alface-do-mar (*Ulva rigida*)	*Sargassum* spp.
	Zonaria tournefortii

Seaweed harvesting must be performed by licensed harvesters or people with governmental authorization for harvesting marine species (e.g. for scientific purposes for instance). This license must be renewed annually. For species of the group A (Table 3), harvesters must do their first sale at the local auction. Also, after every harvest, they must fill the "Diary of Harvesting", and send it to the regional public company LOTAÇOR, S.A. for monitoring and control. For this group of macroalgae, there are no harvesting limits in terms of quantity per harvester per day, nor number of licenses. Harvesting is forbidden in: i) less than 300 m of ports classified as A, B or C (Table 4); ii) less than 100 m of ports classified as D or E (Table 4); iii) less than 100 m of bathing areas; and vi) Marine Protected Areas. Seaweeds that cast up on beaches as drift, which are used as a natural fertilizer for local agriculture, are not subject to any regulation.

Table 4. Port classification in Azores (for details, see *Decreto Legislativo Regional n.º 24/2011/A*).

Classification	Description
A	Ports with commercial warehouse functions, with minimum depths of - 7.00 HZ and accessible piers of at least 400 m;
B	Ports with commercial functions, supporting the economic activity of the island where they are located, with minimum depths of - 4.00 HZ and accessible piers of at least 160 m.
C	Ports with small trade, passenger transport and fisheries support functions
D	Ports exclusively dedicated to fisheries activities.
E	Ports without any of the specific functions defined in the above classes, generally referred to as «*portinhos*».

HZ – Hydrographic zero

The harvesting of algae not intended for direct human consumption, considering all the species listed Table 3B, is limited to a maximum weight of five hundred kilograms (500.00 kg) per harvester per day, fresh or the corresponding weight when dried (after application of a coefficient provided by the government). Number of licenses are limited to 150 (Table 5) and harvesters must fill the "Algae Harvesting Record" and/or the "Transaction Diary" upon collection of seaweed. Governmental authorization is needed to harvest seaweeds by SCUBA and also to use boats for transportation of seaweeds. Considering all cases, fines can reach 250.000 € if rules are infringed.

Table 5. Number of licenses per island to harvest seaweed for processing industries. See *Portaria n.º 69* (2018).

Island	Number of licenses
Corvo	5
Flores	5
Faial	10
Pico	15
São Jorge	15
Graciosa	15
Terceira	40
São Miguel	40
Santa Maria	5

3.3. Seaweeds for exploitation

Almost 400 algal species occur in Azores (Neto *et al*., 2005; Freitas *et al*., 2019), but only a few are abundant enough to be exploited. A short description of species that are allowed to harvest follows:

3.3.1. Seaweed for human food

Asparagopsis taxiformis (Delile) Trevisan

Common name: Erva-rabão

Description: The exploited phase (gametophyte) has a reddish pink colour and may become darker or yellowish with degradation. Fixation to rock or other substrate is done by modified basal branches. Being able to reach 10 to 30 cm in height, the adult plant is very branched and has a triangular outline, with the shorter and denser branches in the terminal zone. The tetrasporophyte (phase not exploited) resembles a cotton ball, of roughly 3 cm of diameter, and its thallus is small, filamentous and highly ramified.

Uses and applications: Considered an edible alga in some countries such as Indonesia, India, China and Korea (Roo *et al*., 2007; Harrison, 2013; Hart *et al*., 2014), it can be eaten fresh, together with meat, added to fruit powder or in many other ways (MacCaughey, 1918; Abbott, 1978; Kaliaperumal *et al*., 1995). It can be also used as anticoagulant (Manilal *et al*., 2012), antifungal (Pereira *et al*., 2015), antimicrobial (Genovese *et al*., 2012) and/or anticyanobacterial (Manilal *et al*., 2010).

Distribution and habitat: Cosmopolitan from warm temperate to tropical waters (Chualain *et al*., 2004). It is found in the Atlantic, Mediterranean, the Indo-Pacific, Caribbean Sea and the North Sea (Lamare & Verlaque, 2018). It occupies a depth stratum similar to *A. armata* and co-occurs with the latter, but its niche seems to extend to more sheltered places (Cardigos *et al*., 2006).

Occurrence in Azores: More abundant and fertile in spring and summer, this species is present throughout the year from the intertidal zone to a depth of 10 m deep.

Species considerations for harvesting: Cut through the base, without plucking to avoid unnecessary damage to associated benthos.

Osmundea pinnatifida (Hudson) Stackhouse

Common name: Erva-malagueta

Description: Dark red (sometimes bleached to yellow-red), cartilaginous, fleshy, erect, markedly compressed and much branched fronds that grow to 2-6 cm tall and arise from a stoloniferous base. The thalli are pseudoparenchymatous, variable in form and size, and may form extensive turfs, or occur as single plants. The main axis grows to 2,5 mm wide and has alternate, distichous, repeatedly pinnate branching; tips have a longitudinal groove (Neto *et al*., 2005).

Uses and applications: It is used for human consumption in many places, such as Scotland, Ireland, and Hawaii (Reed, 1906; Harrison, 2013). In some Azorean islands it is collected, cleaned, and pickled in vinegar and later eaten with fried food (Neto *et al*., 2005). Recently, it has also been used to elaborate gourmet dishes (Matos, 2012).

Distribution and habitat: It occur mainly in the Mediterranean, the North Atlantic, Atlantic islands, the Hawaiian Islands, the North Sea and the English Channel (Pereira, 2016).

Occurrence in Azores: A perennial species common and widespread in the archipelago, being less abundant in summer (Neto *et al*., 2005). Fertile most of the year, it grows at littoral or shallow sublittoral levels on rocks, among the algal turf (Neto *et al*., 2005).

Species-specific considerations for harvesting: Use scissors to cut, leaving the base intact for later regeneration.

Porphyra C. Agardh/ ***Pyropia*** J. Agardh

Common name: Erva-patinha

Description: Blackish-brown (often bleached yellow), membranous, thin fronds that form tufts to 5-17 cm tall. The thallus consists of a single cell layer, is irregularly lobed and split from a central holdfast (Neto *et al*., 2005).

Uses and applications: A good source of vitamin B12, which helps treating anaemia (Watanabe *et al*., 2000), and many other bioactive compounds that prevent and protect against several diseases, this species is used to make sushi (nori) and laver bread, among other dishes, in Wales (Pereira, 2016). In the Azores, is collected on various islands and used in the preparation of various dishes such as soups omelettes and pies (Neto *et al*., 2005).

Distribution and habitat: It is widely spread, being found in Japan, China, Korea, USA, UK, Canada, New Zeland and Azores, among many other places (Levine & Sahoo, 2010). In the Azores, it grows on hard surfaces such as rocks at the upper intertidal levels (Neto *et al*., 2005).

Occurrence in Azores: A seasonal (winter to early spring) species that is widespread in the archipelago, being more abundant in Flores, Faial and São Miguel (Neto *et al*., 2005).

Species considerations for harvesting: There is some evidence that regeneration is quicker if the base of the seaweed remains intact (Nelson & Conroy, 1989). Use scissors to cut, leaving the base intact for later regeneration. If possible, leave also small plants attached.

Ulva intestinalis Linnaeus

Common name: Erva-patinha verde

Description: Bright grass-green seaweed (becoming easily bleached and dying when intensely exposed to sunny and warm days), this species has an unbranched tubular thallus that increase in width from the base to mid-thallus, attached to the substrate by rhizoidal filaments. The thalli can grow to 30 cm tall and 3 cm wide. Cells of the thallus are irregularly arranged (Neto *et al*., 2005; Pereira, 2010).

Uses and applications: It is one of the main components of Japanese green Nori, but also used in soups or as powder (Pereira, 2011). It is also used for food consumption in China, Pakistan, Indonesia, Canada and Hawaii, among many other places (Zaneveld, 1955, 1959; Levring *et al*., 1969; Turner, 1974; Bangmei & Abbott, 1987; Rahman, 2002). Used as medicine for many diseases (Oh *et al*., 1990). In the Azores is used mainly in the preparation of 'tortas', a kind of small omelettes (Neto *et al*., 2005).

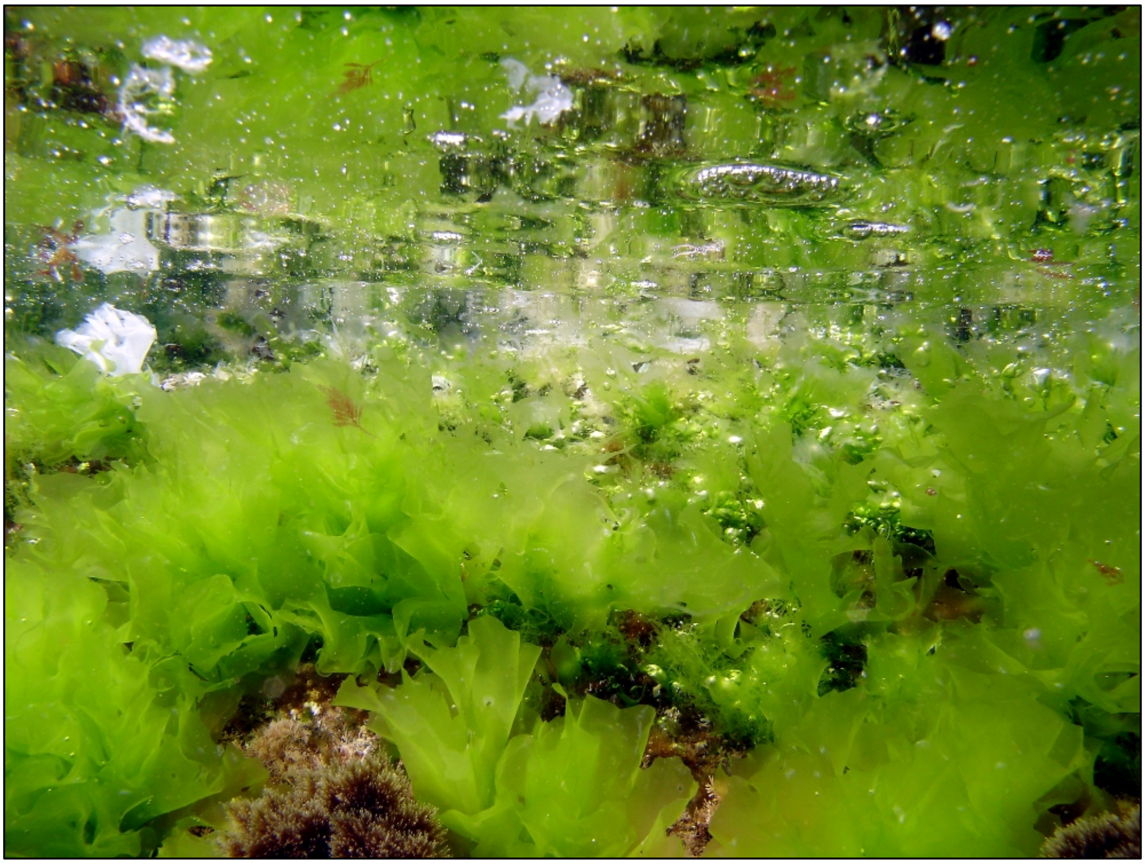
Distribution and habitat: Cosmopolitan, except in polar regions (Pereira, 2016). In the Azores, it grows in areas of freshwater run-off and occasionally in rock pools (Neto *et al*., 2005).

Occurrence in Azores: An annual and opportunistic species that forms patches through rapid reproduction. It is common and widespread in the archipelago, with a peak of abundance in winter and spring, being fertile in late spring and early summer (Neto *et al*., 2005).

Species considerations for harvesting: Harvest during the rapid growth phase. Cut, leaving the base intact for later regeneration.

Ulva rigida C. Agardh

Common name: Alface do mar



Description: Flattened thallus, variable in shape and size, that may form tufts of 2 cm tall although individuals can grow to sheets of 15 cm tall. Firm in texture, the vibrant green thallus (becoming easily bleached and dying when intensely exposed to sunny and warm days) is 2 cell layers thick, and arises from a small stipe and discoid holdfast. The bottom margin of the frond may have small denticulations near the base (Neto *et al*., 2005)

Uses and applications: Due to its high nutrient content and fresh taste, it is consumed by Mediterranean coastal populations (Harrison, 2013) and used in soups, salads and omelettes in the Azores (Neto *et al*., 2005; Matos, 2012). It can also be used as fertilizer, and for cosmetic, pharmaceutics and medical proposes, among many other applications (Milchakova, 2011; Pereira, 2015).

Distribution and habitat: It has a worldwide distribution in temperate and warm seas (Pereira, 2016). In the Azores, this species grows on rocks at the intertidal and subtidal levels, and also on top of other algae.

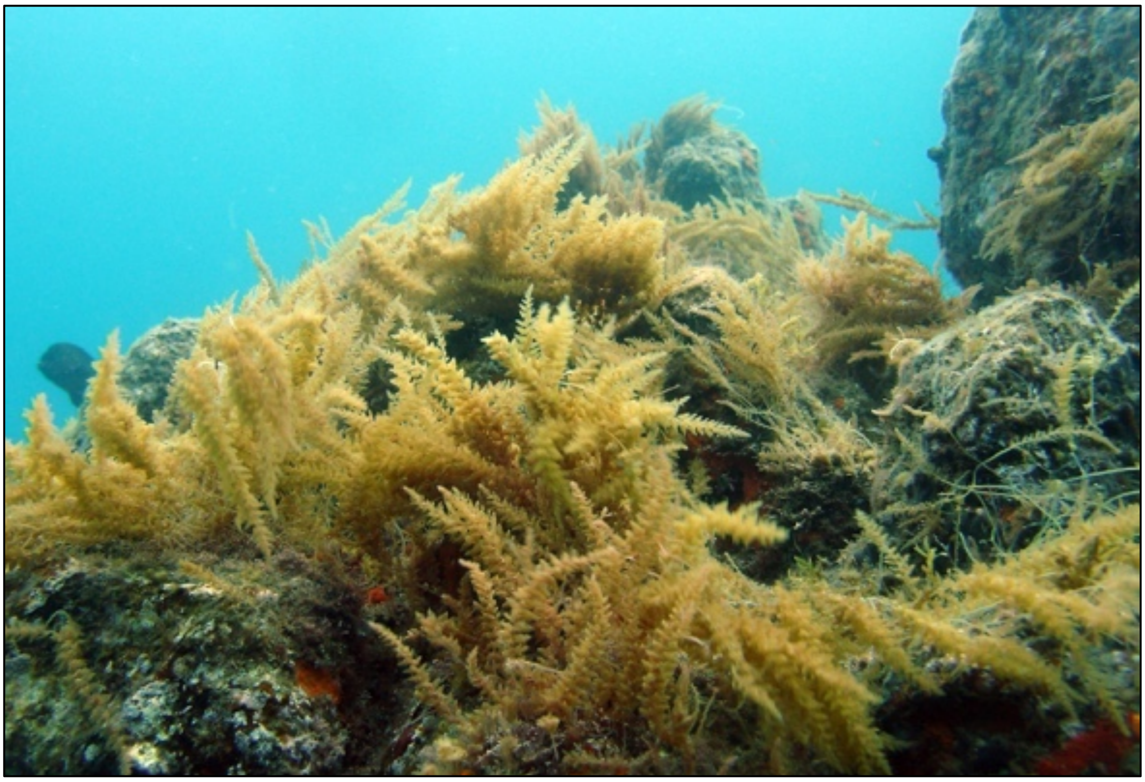
Occurrence in Azores: This annual opportunistic species, fertile throughout the year in the Azores, forms seasonal populations that are common and widespread in the archipelago with a peak of abundance in spring (Neto *et al*., 2005).

Species considerations for harvesting: Harvest during the rapid growth phase. Cut, leaving the base intact for later regeneration.

3.3.2. Seaweed for processing industries

Asparagopsis armata Harvey

Common name: NA



Description: The gametophyte (exploited phase), rose-pink, soft and plumose, forms erect tufts 5-30 cm tall that arise from creeping stolons. The thallus is pseudoparenchymatous comprising several tissue layers. The main axis is prominent with opposite but unequal branches, one short and simple the other long and branched. Paired barbed axes with reverse barbs also arise from the main axis (Neto *el al*., 2005). The tetrasporophyte (phase not exploited) is like a cotton ball of 3 cm of diameter, and its thallus is small, filamentous and highly ramified (Edwards *et al*., 2012).

Uses and applications: Considered edible (Green, 2014), it has antifungal, antimicrobial, antioxidant, antiviral applications (Ballesteros *et al*., 1992; Paul *et al*., 2006; Haslin *et al*., 2001), together with cytotoxicity against human cancer cells (Alves *et al*., 2011). Can also be used for phycolloid extraction (Haslin *et al*., 2000).

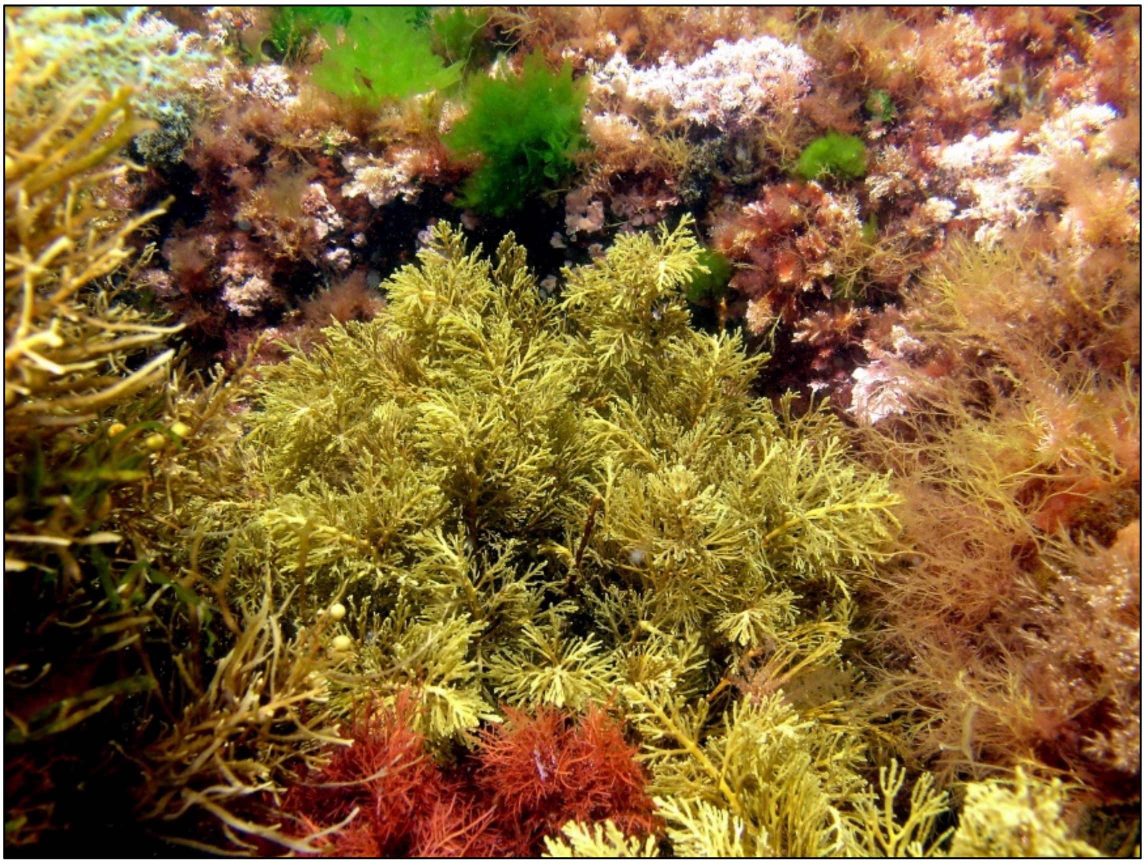
Distribution and habitat: Native from the Southern Hemisphere (Australia and New Zealand), it has been introduced to the Northern Hemisphere, and is now found globally (Horridge, 1951; Pereira, 2016). It's considered a non-indigenous introduced species in the Azores, being well established in all islands (Cardigos *et al*., 2006), where it occurs mainly at low water and shallow subtidal levels (Neto *et al*., 2005).

Occurrence in Azores: It is common in the archipelago (Neto *et al*., 2005), mainly from April to July, with both the tetrasporophyte and the gametophyte being abundant and widely distributed (Tittley & Neto, 1995).

Species considerations for harvesting: Due to its epiphytic nature (it is often found on top of other algae). Cut at the base, without plucking to avoid damage to the associated benthos.

Cystoseira humilis Schousboe ex Kützing

Common name: NA



Description: Bushy branched plants that can grow to 100 cm tall (usually 30 cm), attached by a discoid holdfast. Thalli are narrow with a cylindrical main axis of 2-5 mm wide, smooth, and parenchymatous in structure. Branches are flattened or cylindrical in cross-section and small bladders (aerocysts) may be present. Reproductive organs are formed in special structures, called receptacles, present at the tips of branchlets (Neto *et al.,* 2005).

Uses and applications: It has potential use for antioxidant and antibacterial applications (Belattmania *et al*., 2016).

Distribution and habitat: It has been reported in shores from NE Atlantic (Vaz-Pinto *et al*., 2014), such as Azores, Portugal, Canarias, North of Spain, England, but also in the Mediterranean coast of Spain (GBIF, 2017). Mainly found in intertidal rocky pools and in shallow standing waters in the eulittoral zone, in moderately wave-exposed sites (Garreta, 2001; Engelen & Santos, 2009).

Occurrence in Azores: A perennial species, locally common in rock pools throughout the archipelago (Neto *et al*., 2005), being more abundant and fertile in spring and summer.

Species considerations for harvesting: Although regulated for industrial use, this canopy-forming species is not abundant in the Azores, and therefore it should be collected in moderation. Cut, leaving the base intact for later regeneration.

Halopteris scoparia (Linnaeus) Sauvageau

Common name: NA

Description: Characterized by having alternate plumed and filamentous branches arising from the main axis, this dark brown alga is very ramified and provides habitat to a high abundance of epifauna (Orth & Van Montfrans, 1984). It has a fine appearance, and it can be fan-shaped or resemble an inverted cone of about 15 cm in length, attached to rocks by extensive disks and rhizoids (Pereira, 2008; Pereira, 2010; Pereira, 2014; Campos *et al.*, 2018).

Uses and applications: Containing various antimicrobial and antifungal substances (Munda, 2006; Pereira, 2016), and phytohormones (Pereira, 2008), it is used as food supplement, for pharmaceutical applications and also for cosmetics.

Distribution and habitat: Highly abundant and widely distributed on the Mediterranean (also Black Sea) and Atlantic coasts, such as in Norway, Azores, Cape Verde and Canada, among other places (Pereira, 2016). Found mostly in protected coasts in clear waters, this species forms fluffy balls in shallow waters (Sánchez-Moyano, 1996; Sánchez-Moyano *et al.*, 2000; Pereira, 2008; Pereira 2010; Pereira 2014).

Occurrence in Azores: A perennial species that is abundant and widespread throughout the archipelago, where it grows in rock pools, but mainly at subtidal levels, where it can form dense turfs (Neto *et al.*, 2005). Fertile in late autumn, early winter, this species peaks in abundance in the summer period.

Species considerations for harvesting: Avoid harvesting during the reproductive period. Cut at the base, without plucking to avoid damage to the associated benthos.

Pterocladiella capillacea (S.G. Gmelin) Santelices & Hommersand

Common name: Musgão

Description: Dark-red, cartilaginous, erect and much branched pseudoparenchymatous thalli that grows 4-20 cm tall, 2 mm wide, and arise from a stoloniferous base. Branching is pinnate or bipinnate, opposite or alternate, and much more abundant towards the tip of the main axis (Neto *et al*., 2005).

Uses and applications: Eaten in some countries as Japan, China, Korea and Kawaii (Reed, 1906; Harrison, 2013), this species has pharmacological applications, such as an antitumoral (Ibrahim *et al*., 2005), anticoagulant (Shanmugam & Mody, 2000) and antioxidant (Paiva *et al*., 2012), among others. In the Azores, as in several other places, it is harvested manually for agar extraction (Neto *et al*., 2005).

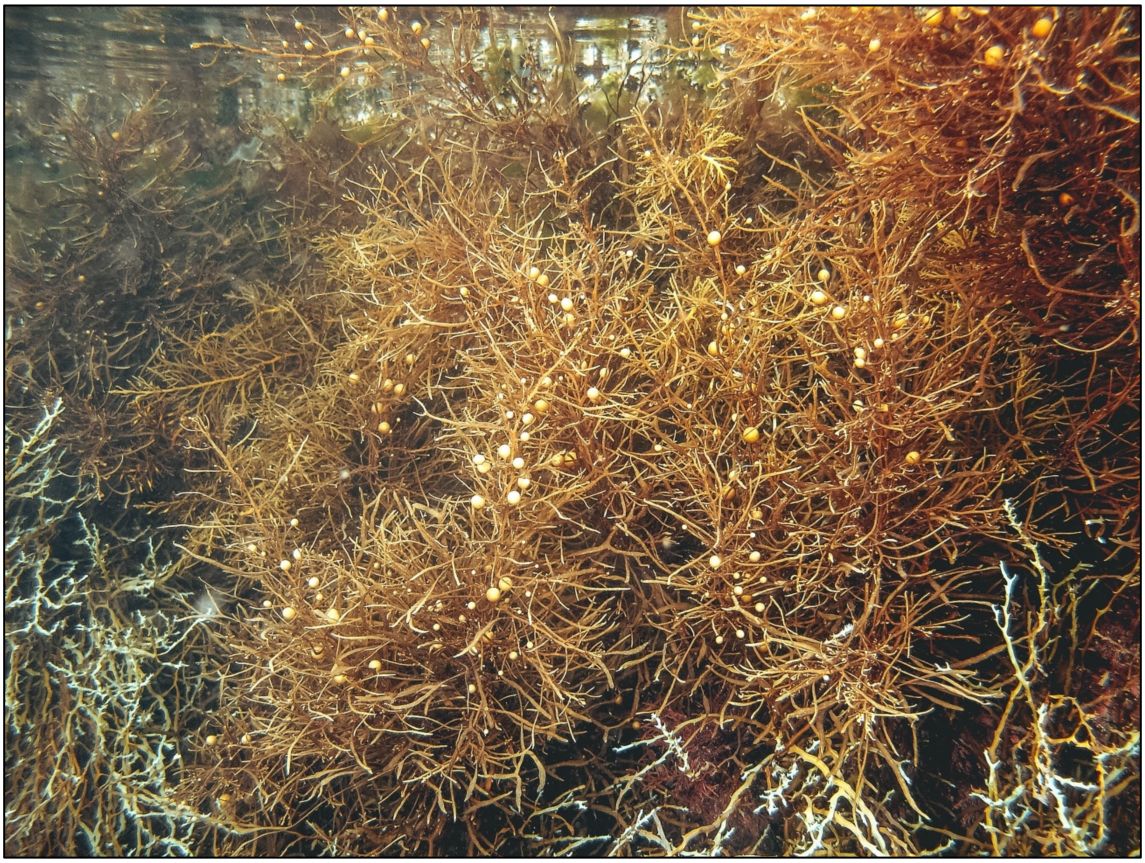
Distribution and habitat: It can be found in Asia, Northeast Atlantic, Atlantic islands (Canary Islands, Azores, Madeira), South-west and Southeast Atlantic, Australia and New Zealand, Hawaiian Islands, among others (Pereira, 2016). In the Azores it grows on rocks from the low intertidal levels into the shallow subtidal down to 15 m depth. It usually occurs as pure stands, but can also grow associated with the coralline alga *Ellisolandia elongata* and be occasionally present in algal turfs (Neto *et al*., 2005).

Occurrence in Azores: A perennial species that reproduces in spring and summer. It occurs abundantly throughout the archipelago all year round (Neto *et al*., 2005), being more abundant from late spring to early autumn, with a peak in the summer period.

Species considerations for harvesting: Cut through the base, without plucking to ensure regeneration and the development of a new stem. Since the species is actually overexploited in the region, harvesting should be moderate and allow that in all collection areas some plants are left intact to ensure population restoration.

Sargassum spp. C. Agardh

Common name: Sargasso



Description: This designation includes several species of the genus *Sargassum*, characterized by having a much branched pseudoparenchymatous bushy thalli that can grow up to 50 cm tall and are attached to the substrate by a discoid holdfast. Primary and secondary branches are cylindrical and usually bear lanceolate foliar branches (4 cm long, 3 mm wide) with serrate or smooth margins. Bladders are formed on short pedicels. Receptacles, often covered with small dots (pits) containing the reproductive organs, are small and often divided and are also formed on pedicels in the axils of the foliar branches (Neto *et al*., 2005).

Uses and applications: Normally consumed fresh (in salads) and cooked like vegetables, but also added to fish or meat, or to some additives like coconut milk or lemon juice (Nisizawa, 2006; Sidik *et al*., 2012; Radulovich *et al*., 2013).

Distribution and Habitat: It is widely distributed in the Mediterranean, the Indian Ocean, the North and South East Atlantic, the Caribbean Sea and in Philippines (Pereira, 2016).

Occurrence in Azores: *Sargassum* species are perennial and common, but not abundant, in the Azores (Tittley & Neto, 1995). They are mainly present in tide pools, the low fringe of the intertidal rocky shores and at shallow subtidal areas.

Species considerations for harvesting: Avoid harvesting during summer when the seaweed is reproductively active. Cut by the base, without plucking to ensure later regeneration.

Zonaria tournefortii (J.V. Lamouroux) Montagne

Common name: NA

Description: Yellowish brown leafy alga of about 20 cm high attached to the substrate by modified ramuli. The thallus lobed and presenting dichotomies, has concentric brawn dark streaks and a central reddish nerve at the base. Growth is apical and ensured by a row of initial marginal cells present on the margin of the thallus (Lamare & Dupré, 2017).

Uses and applications: According to recent studies, it has a considerable potential as antioxidant and antibacterial (Val *et al*., 2001; Nunes *et al*., 2017).

Distribution and habitat: It can be found in the Mediterranean, East Atlantic (Azores, Madeira, Canarias), English Channel and North Sea, North America, Caribbean Sea and Brazil (Lamare & Dupré, 2017). In the Azores, it occurs in the subtidal level, both in exposed and sheltered coasts, on hard substratum (Tittley & Neto, 2000).

Occurrence in Azores: Locally common (Tittley & Neto, 1995), it can form extensive stands throughout the archipelago, often at considerable depths (Tittley & Neto, 2000).

Species considerations for harvesting: Avoid harvesting during winter/ spring when the seaweed is reproductively active. Cut by the base, without plucking to avoid damage to the associated organisms, including the calcareous algae, that commonly work as their hosts.

4. Good harvesting practices

As mentioned before, seaweed harvesting is an increasingly popular activity in Azores for both personal and commercial uses. If not carried out sensitively and sustainably, seaweed harvesting activities can have detrimental impacts on important functions in marine and coastal ecosystems (Stagnol *et al*., 2013). Depending on the frequency, intensity and the amount of removal, unregulated seaweed harvesting can cause vast changes to marine communities (Boaden & Dring, 1980; Hawkins & Harkin, 1985; Jenkins *et al*., 2004), contributing to the loss of habitat, depletion of stocks, and the damaging and disturbance to the shore, seabed, habitats and species. Therefore, it is vitally important that seaweeds are used sustainably and that natural resources are effectively managed. General guidance for good seaweed harvesting practices is needed. This will help mitigate the impact of intensive harvesting and will ensure a more sustainable resource harvesting (Monagail *et al*., 2017).

The following section provides some guidance for good practices, answers some common questions about seaweed harvesting in Azores, and highlights where more detailed information can be found.

4.1. General good practices for seaweed harvesting

- For some species, ensure that the holdfast and part of the blade are left intact for re-growth (e.g. *Osmundea pinnatifida*; *Porphyra* sp.; *Pterocladiella capillacea*).
- Harvesting by hand should be favoured over mechanical harvesting.
- Avoid harvesting during the reproductive season.
- Harvest selectively and avoid by-catch. Associated animals and algae should be left behind, if possible.
- Avoid significant damage to the harvesting area. Harvest sparsely, taking only a small proportion of the total available seaweed and ensure that a substantial proportion of mature individuals remains.
- Harvest from different sites on the shore and rotate harvesting areas to allow ample time for seaweed recovery.
- Avoid harvesting seaweeds which are often habitat for other species such as crustaceans, molluscs etc. (e.g. canopy-forming species such *Cystoseira* spp., *Fucus* sp. and *Sargassum* spp.).
- Avoid damaging habitats and species by trampling when accessing or using the shore.
- If turning rocks over during collection, replace them the correct way up to avoid damaging animals and algae inhabiting on the surface or underside of the rock.
- Provide local authorities information about the harvesting process: species, total harvested amount; date and location of harvesting.

4.2. Harvesting seaweed in Azores – the basics

Do you need a license to harvest seaweed?

No, if you only catch floating, unattached seaweeds and/or seaweeds that are cast up on beaches/shorelines as drift. **Yes**, if catches are directed to seaweeds that are growing on the seabed.

Which species of seaweed can be collected?

According to *Portaria n.º 69/2018*, two groups of seaweed are allowed to be harvested in Azores, namely: the ones for direct human consumption (*Porphyra* spp., *Ulva intestinalis*; *Asparagopsis taxiformis*; *Osmundea pinnatifida* and *Ulva rigida*), and other not directly used for human consumption (*Pterocladiella capillacea, Sargassum* spp., *Halopteris scoparia, Asparagopsis* sp., *Zonaria tournefortii* and *Cystoseira humilis*).

Nevertheless, the competent services of the Regional Government department responsible for fisheries may issue special authorizations for the capture and harvesting of other species. There is no official legislation for the collection of drifted seaweed for the sole purpose of being used as a traditional natural fertilizer for local agriculture.

Where can you collect seaweed?

Seaweed harvesting through snorkelling is prohibited in (a) less than 300 meters and within ports of class A, B and C (Table 4); (b) less than 100 meters and within the ports with classification D and E (Table 4); (c) less than 100 meters from bathing areas or areas commonly used as bathing areas; and (d) Marine Protected Areas.

How do you know if the coast is in a protected area?

Marine Protected Areas are referred in Annex VIII of *Portaria n.º 69/2018*. For more information see *Decreto Legislativo Regional n.º 15/2007/A*.

When can seaweed be collected?

With the exception of the recommendations for specific collecting periods indicated in the *Portaria n.º 69/*2018 for selected species, seaweed harvesting can be performed throughout the year and may take place from sunrise to sunset. Although there are no seasonal harvesting restrictions, attached seaweed should be harvested during the active growth phase to allow a quicker recovery, and after reproduction has occurred, if possible.

Which removal method is the most sustainable and recommended?

Harvesting by hand should be favoured over mechanical harvesting. The cutting method using handhold tools, like scissors or knives, is preferable than plucking. This will have a less detrimental impact. Ensure cutting cleanly to avoid tearing seaweed from the rock and causing unnecessary damage. Mechanical harvesting methods are more likely to have a detrimental impact on the marine environment. As a general rule, fronds should be cut well above the point of growth, and the holdfast (the base of the seaweed) should not be removed.

How much can be collected?

The harvesting of algae not intended for direct human consumption (see Table 3B), is limited to a maximum weight of five hundred kilograms (500.00 kg) per catcher per day, fresh or the corresponding weight when dried (after application of a coefficient provided by the government). There are no limits for species listed in Table 3A.

4.2.1. General advices for stakeholders and policymakers

Regional authorities should support research initiatives dedicated to increase our knowledge about the species of interest. Different seaweeds have distinct growth and death ratios, life history traits, and seasonal variations. Understanding their distribution, abundance, role in the community (structural species or opportunistic), associated fauna, and native or non-native status are important aspects to consider in stock assessment and for conservation/ management initiatives. Research should also focus on understanding the effects and impacts of a given species removal to the ecosystem, and suggest mitigation measures for potential negative impacts. Monitoring programs should be implemented to improve stock assessment and provide valuable management advice and no-take marine protected areas should be monitored for illegal harvesting. Further studies on functions of macroalgae as nursery grounds for a variety of species (i.e. fishes) is needed for integrated conservation and management of coastal fisheries resources.

The definition of spatial and temporal harvesting seasons and closures times, harvesting techniques, minimum sizes and maximum weights harvested per day/ area/ season for a particular seaweed should be supported by validated data on its biology and ecology, and taking into consideration the available stock and not the industry demands.

4.2.2. Relevant legislation

- *Portaria n.º 57/2018, de 30 de maio - Regulamento que estabelece o regime jurídico da apanha de espécies marinhas no mar dos Açores - Alterado pela Portaria n.º 69/2018, de 22 de junho de 2018.* [Regulation establishing the legal regime for the collection of marine species in the Azores]
- *Decreto Legislativo Regional n.º 15/2012/A, de 2 de abril - Aprova o Regime jurídico da conservação da natureza e proteção da biodiversidade.* [Approves the Nature Conservation and Biodiversity legal regime]
- *Decreto Legislativo Regional n.º 9/2007/A, de 19 de abril – Aprova o Regime jurídico da pesca lúdica nas águas dos Açores.* [Legal regime for recreational fishing in Azorean waters]
- *Portaria n.º 67/2014 de 14 de outubro - Revoga a Portaria n.º 68/2013, de 13 de setembro, que proíbe todo e qualquer exercício da pesca marítima, quer comercial quer lúdica, na Lagoa da Caldeira de Santo Cristo, ilha de São Jorge, incluindo a apanha de amêijoa, bem como a apanha de qualquer grupo de algas marinhas.* [prohibits all commercial and recreational fishing activities in the Caldeira de Santo Cristo Lagoon, São Jorge Island, including clam catching, as well as the harvesting of any group of seaweed]

5. The project ASPAZOR and the case study of *Asparagopsis* spp.

The project ASPAZOR, acronym for *Ecosystem impacts and socioeconomic benefits of Asparagopsis armata in the Azores* was developed to investigate how the non-indigenous cryptic species complex *A. armata,* a high-profile invasive red seaweed, impacts Azorean ecosystem services and biodiversity under current and future environmental scenarios. Additionally, the project tested whether the harpoon weed *A. armata* has the potential to turn into a profitable marine resource in Azores, providing important biological and ecological guidance for economical sustainable exploitation. The project was funded by Programa Operacional Açores 2020 and was developed between 2016-2020.

Initial work was aimed at gathering information on the current spatial and temporal distribution of *A. armata* across São Miguel Island, Azores and to identify its effects on coastal native communities. Field-based experiments were performed to investigate the biotic factors responsible for the success of such species on local communities. Also, mesocosms experiments were performed to address the functional and physiological responses of the species to combinations of environmental thresholds simulating future environmental scenarios. The information was then used to develop habitat suitability models to forecast the potential impact of the species under future environmental scenarios (e.g. increased sea surface temperatures). Considering that the attempts to eradicate pests worldwide are usually unsuccessful, the ASPAZOR project was also delineated to investigate the best practices for exploitation of such invasive species biomass (i.e. evaluation of standing stocks and harvesting methodologies). Overall, collected information provided relevant insights for developing conservation and management decisions aimed at preventing and mitigating the invader's impact via its very same use as an alternative resource. This management approach is expected to deliver significant environmental, economic and societal benefits to the Azorean commonwealth.

Overall, the project allowed collecting data to address the following questions:

Where can *A. armata* be found?

Occurring across all Azorean islands at rocky bottoms and/or attached to various substrates (often to other algae by barbed branchlets), *A. armata* has no particular preference for a given habitat. It is more abundant at shallow-water levels (1-10m) but can occur deeper (~25m). The analyses on its spatial distribution and of associated assemblages showed that the abundance of *A. armata* varies significantly among locations and that there is substantial variability in its abundance among islands, locations and sites (Martins *et al.*, 2019).

Under future scenarios of climate change (i.e. increase ocean temperature) it is expected that *A. armata* should contract its current distribution. Experimental *in vitro* procedures showed that at higher temperatures there is a reduction in *A. armata* fitness. Moreover, modelling the species distribution under different scenarios (Casas *et al.*, under revision) predicted that the expansive nature of the colonization of *A. armata* is expected to rapidly decay when temperature of the sea rises, leading us to think that the invasion and establishment of the alga, under future climate change scenarios will not represent a major threat to native communities.

When can *A. armata* be harvested?

The hooked seaweed *A. armata* can be harvested in spring and early summer when adult individuals (gametophytes) are more abundant (Fig. 5). Unpredicted yearly differences in coverage can occur (see differences in coverage in 2017 and 2018; Fig. 5).

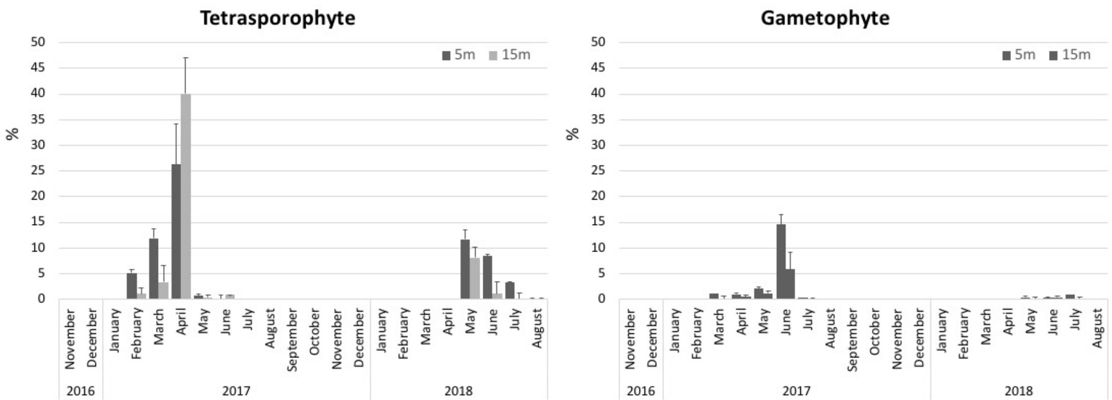


Figure 5. Average coverage (%) of the tetrasporophyte (*Falkenbergia*) and gametophyte stages of *Asparagospsis* spp. (left and right, respectively) in São Miguel, Azores, in 2016-2018.

What is the standing stock of *A. armata*?

The standing stock of *A. armata* (gametophyte) in São Miguel island during 2017 reached a maximum of about 65 tons of dry weight. This is a rough estimate taking into consideration the observed biomass per m^2 (Fig. 6) and extrapolating for the total available area where the species can potentially occur (up to 20m depth).

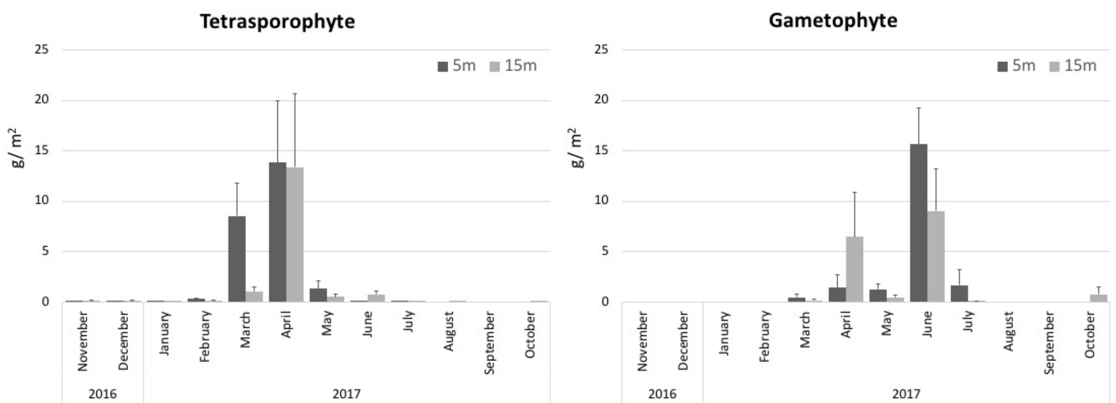


Figure 6. Average biomass (g/m^2 of dry weight) of *Falkenbergia* - tetrasporophyte stage of *Asparagospsis* spp. (left) and *Asparagospis armata* (right) in São Miguel island (Azores), in 2016-2017.

How does temperature and photoperiod contribute to *A. armata* occurrence?

The species shows a clear positive response to a narrow range of photoperiod and temperature values, with a relatively narrow ecological niche, related to an opportunistic behaviour (Fig. 7). An explosive expansion of *A. armata* is expected in relative short periods of time in late spring, when optimal temperature values meet appropriate values of photoperiod.

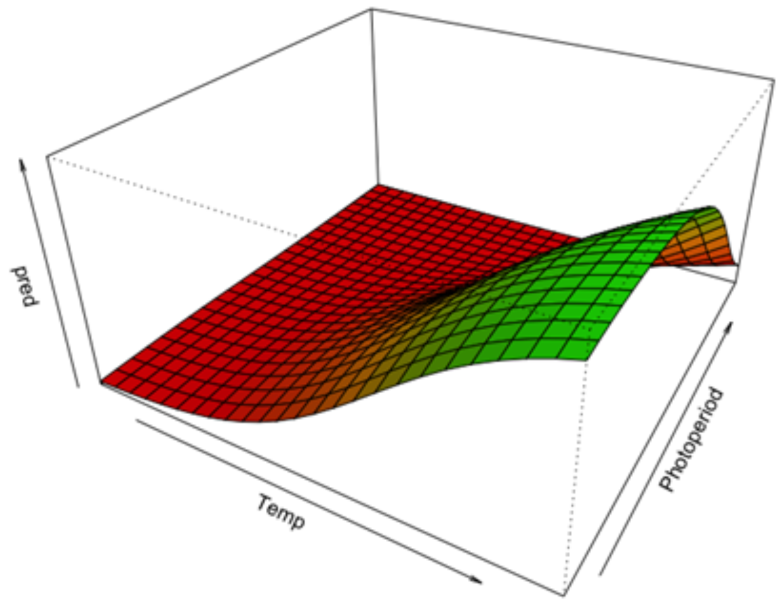


Figure 7. Three-dimensional (3D) prediction surface for *Asparagopsis armata* as a function of temperature and photoperiod

Should an invasive species such as *A. armata* be used for harvesting?

There is a rising interest in combating invaders using commercial markets and other incentives. Indeed, harvesting can be a strategy used to manage and control invasive species. Nevertheless, commercial exploitation of invasive seaweed should be taken with great care and with a full understanding of all aspects of the biology and ecological consequences of such exotic species in the local ecosystems, and of the socioeconomic interests. Harvesting non-native species should be performed in a way to minimize its spread on a region, hence avoiding exacerbating the invasiveness problem. In Azores, *A. armata* is commonly found throughout all islands of the archipelago, and there is no evidence that its removal can augment its spread in the region. If performed correctly (e.g. avoiding by-catch and habitat or ecosystem damage), *A. armata* can be subject to exploitation. Nevertheless, prior to stimulating any harvest activity, a careful evaluation of the functional roles of the targeted invasive species within the ecosystem and trophic interactions with native species should be encouraged. Ongoing research shows that *A. armata* in Azores is unpalatable to most herbivores, due to chemical defences, and it harbours relatively scarce assemblages of organisms. Its major impact seems to be associated with space occupation and its epiphytic nature, negatively impacting marine native species if not properly exploited. In Azores, the overall balance between negative and positive impacts seems to favour the exploitation of *A. armata*.

How can *A. armata* be harvested?

Individuals of *A. armata* should be picked by hand. The use of any mechanical devices should be totally interdict given its negative impact on benthic communities. Moreover, experimental procedures in the field using *A. armata* fronds showed that cutting and plucking add no effect on the species itself. With both methods, the species did not recover and/or regrow. Yet, given that *A. armata* is often an opportunistic species growing on top of other organisms, plucking should be discouraged as it critically damages its hosts, associated fauna and the surrounding habitat.

What is the economic value of *A. armata*?

A. armata exploitation is still uncommon in Azores and its economic potential is thus difficult to estimate. Nevertheless, and similar to other seaweeds collected in Azores, its harvesting may yield catchers and fisherman between 1 to 1,50 € per kg of wet weight and 2,50 to 3,00 € per kg of dry weight. These values may vary depending on algae availability and industry demand. Upon processing, *A. armata* extracts can be sold for between 120-160 € per liter and used by the pharmaceutical, biotechnology and cosmetics industries to generate multiple value-added products.

6. References

Abbott IA, 1978. The uses of seaweed as food in Hawaii. Economic Botany, 32(4): 409–412.

Abdel-Monem AA, Fernandez LA & Boone GM, 1975. K-Ar ages from the eastern Azores group (Santa Maria, São Miguel and the Formigas Islands). *Lithos*, 8(4): 247–254.

Adams NM, 1994. Common seaweeds of New Zealand. 360 pp. ISBN 0-908812-21-3. Canterbury University Press, Christchurch, New Zealand.

Alves C, Pinteus S, Horta A & Pedrosa R, 2016. High cytotoxicity and anti-proliferative activity of algae extracts on an in vitro model of human hepatocellular carcinoma. *SpringerPlus*, 5(1): 1339.

Alves C, Pinteus S, Rodrigues A & Pedrosa R, 2011. *Sphaerococcus coronopifolius* and *Asparagopsis armata* induced cytotoxicity against HEPG2 cell line. *Current Opinion in Biotechnology*, 22: 44-45.

Amsler CD & Searles RB, 1980. Vertical distribution of seaweed spores in a water column off shore of North Carolina. *Journal of Phycology*, 16(4): 617-619.

Anis M, Ahmed S & Hasan M, 2017. Algae as nutrition, medicine and cosmetic: the forgotten history, present status and future trend. *World Journal of Pharmacy and Pharmaceutical Sciences*, 6(6): 1934–1959.

APEDA- Associação de Productores de Espécies Demersais dos Açores, 2016. O renascer da apanha de algas. Azores, Portugal. Retrieved from: https://pescazores.com/o-renascer-da-apanha-de-algas/. Accessed on 22/03/2020.

APROMAR, 2014. Estudio general: Una primera aproximación al sector de las macroalgas. Evaluación Del Estado de Explotación y Propuestas de Gestión Sostenible y Cultivo de Macroalgas En Andalucía, Asturias y Galicia. 92pp.

Baghel RRS, Trivedi N, Gupta V, Neori A, Reddy CRK, Lali A & Jha B, 2015. Biorefining of marine macroalgal biomass for production of biofuel and commodity chemicals. *Green Chemistry*, 17(4): 2436–2443.

Bailey L & Owen K, 2014. Seaweed harvesting: Natural England Advice. Natural England. 24pp.

Ballesteros E, Martin D & Uriz MJ, 1992. Biological activity of extracts from some Mediterranean macrophytes. *Botanica Marina*, 35(6), 481-486.

Bangmei X & Abbott I, 1987. Edible seaweeds of China and their place in the Chinese diet. *Economic Botany*, 41(3): 341–353.

Barsanti L & Gualtieri P, 2014. Algae: anatomy, biochemistry, and biotechnology. 2nd edition. 361pp. ISBN 9781439867334. CRC press, Boca Raton, Florida.

Belattmania Z, Engelen AH, Pereira H, Serrão EA, Barakate M, Elatouani S, Zrid R, Bentiss F, Chahboun N, Reani A & Sabour B, 2016. Potential uses of the brown seaweed *Cystoseira humilis* biomass: 2-Fatty acid composition, antioxidant and antibacterial activities. *Journal of Materials and Environment Science*, 7(6): 2074-2081.

Bixler HJ & Porse H, 2011. A decade of change in the seaweed hydrocolloids industry. *Journal of Applied Phycology*, 23(3): 321–335.

Boaden PJ & Dring MT, 1980. A quantitative evaluation of the effects of *Ascophyllum* harvesting on the littoral ecosystem. *Helgoländer Meeresuntersuchungen*, 33(1): 700-710.

Borges P, Andrade C & Freitas C, 2002. Dune, bluff and beach erosion due to exhaustive sand mining - the case of Santa Barbara, S. Miguel (Azores, Portugal). *Journal of Coastal Research*, 36: 89–95.

Bostock J, Lane A, Hough C & Yamamoto K, 2016. An assessment of the economic contribution of EU aquaculture production and the influence of policies for its sustainable development. *Aquaculture International*, 24(3): 699-733.

Buschmann AH, Troell M & Kautsky N, 2001. Integrated algal farming: a review. *Cahiers de Biologie Marine*, 42(1): 83-90.

Calado H, Borges P, Phillips M, Ng K & Alves F, 2011. The Azores archipelago, Portugal: improved understanding of small island coastal hazards and mitigation measures. *Natural Hazards*, 58(1): 427-444.

Callaway E, 2015. Lab staple agar hit by seaweed shortege. *Nature*, 528 (7581): 171-172.

Campos AM, Matos J, Afonso C, Gomes R, Bandarra NM & Cardoso C, 2018. Azorean macroalgae (*Petalonia binghamiae*, *Halopteris scoparia* and *Osmundea pinnatifida*) bioprospection: a study of fatty acid profiles and bioactivity. *International Journal of Food Science & Technology*, 54(3), 880-890.

Cardigos F, Tempera F, Ávila S, Gonçalves J, Colaço A & Santos RS, 2006. Non-indigenous marine species of the Azores. *Helgoland Marine Research*, 60(2): 160- 169.

Casas E, Gil A, Yesson C, Prestes A, Moreu-Badia I, Neto AI & Fernandez M, (under revision). Ecological niche models of invasive algae: A remote sensing-based occurrence data approach, Journal of Marine Science and Engineering.

CCAH - Camara do Comercio de Angra de Heroísmo, 2016. Apanha de algas rendeu 120 mil euros em 2015. Retrieved from: http://www.ccah.eu/economia/noticias/ver.php?id=11598. Accessed on March 2020.

CEVA - Centre d'Etude et de Valorisation des Algues, 2014. Edible seaweed and French regulation. 15pp.

Chapman VJ & Chapman DJ, 1980. Sea vegetables (Algae as food for man). In: Chapman VJ (Ed.), Seaweeds and their uses. Pp: 62-97. Chapman and Hall, ISBN 978-0412157400.

Charrier B, Rolland E, Gupta V & Reddy CR, 2015. Production of genetically and developmentally modified seaweeds: exploiting the potential of artificial selection techniques. *Frontiers in Plant Science*, 6: 127.

Christie H, Jorgensen N, Norderhaug K & Waage-Nielsen E, 2003. Species distribution and habitat exploitation of fauna associated with kelp (*Laminaria hyperborea*) along the Norwegian coast. *Journal of Marine Biology Association UK*, 83(4): 687-699.

Chualain FN, Maggs CA, Saunders GW & Guiry MD, 2004. The invasive genus *Asparagopsis* (Bonnemaisoniaceae, Rhodophyta): molecular systematics, morphology, and ecophysiology of *Falkenbergia* isolates. *Journal of Phycology*, 40(6): 1112–1126.

Chung I, Beardall J, Mehta S, Sahoo D & Stojkovic S, 2011. Using marine macroalgae for carbon sequestration: a critical appraisal. *Journal of Applied Phycology*, 23(5): 877-886.

Costello MJ & Ballantine B, 2015. Biodiversity conservation should focus on no-take Marine Reserves. 94% of Marine Protected Areas allow fishing. *Trends in Ecology & Evolution*, 30(9): 507–509.

D'Antonio CM & Vitousek PM, 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics*, 23(1): 63-87.

Da Costa E, Melo T, Moreira AS, Bernardo C, Helguero L, Ferreira I, Cruz MT, Rego AM, Domingues P, Calado R, Abreu MH & Domingues MR, 2017. Valorization of lipids from *Gracilaria* sp. through lipidomics and decoding of antiproliferative and anti-Inflammatory activity. *Marine Drugs*, 15 (3): 62.

Dawes CJ, 1998. Marine Botany. 2nd edition. 496pp. ISBN 978-0-471-19208-4. John Wiley & Sons, New York, USA.

Decreto Legislativo Regional n.º 15/2007/A - Rede Regional de Áreas Protegidas da RAA.

Decreto Legislativo Regional n.º 15/2012/A - Aprova o Regime jurídico da conservação da natureza e proteção da biodiversidade.

Decreto Legislativo Regional n.º 24/2011/A – Aprova o sistema portuário dos Açores.

Decreto Legislativo Regional n.º 9/2007/A - Aprova o Regime jurídico da pesca lúdica nas águas dos Açores.

Delaney A, Frangoudes K & Li SA, 2016. Society and seaweed: understanding the past and present. In: Fleurence J & Levine I (Eds.), Seaweed in Health and Disease Prevention. 7–40pp. ISBN 9780128027936. Elsevier Academic Press

Dillehay TD, Ramirez C, Pino M, Collins MB, Rossen J & Pino-Navarro JD, 2008. Monte Verde: seaweed, food, medicine, and the peopling of South America. *Science*, 320(5877): 784-786.

Diogo HMC & Pereira JG, 2013a. Recreational boat fishing pressure on fish communities of the shelf and shelf break of Faial and Pico Islands (Azores Archipelago): implications for coastal resource management. *Acta Ichthyologica et Piscatoria*, 43 (4): 267–276.

Diogo HMC & Pereira JG, 2013b. Impact evaluation of spear fishing on fish communities in an urban area of São Miguel Island (Azores Archipelago). *Fisheries Management and Ecology*, 20 (6): 473–483.

Domingues VDS, Stefanni S, Brito A, Santos RS & Almada VC, 2008. Phylogeography and demography of the blenniid *Parablennius parvicornis* and its sister species *P. sanguinolentus* from the northeastern Atlantic Ocean and the western Mediterranean Sea. *Molecular Phylogenetics and Evolution*, 397-402.

Dureuil M, Boerder K, Burnett KA, Froese R & Worm B, 2018. Elevated trawling inside protected areas undermines conservation outcomes in a global fishing hot spot. *Science*, 362(6421): 1403–1407.

Edwards M, Hanniffy D, Heesch S, Hernández-Kantún J, Moniz M, Queguineur B, Ratcliff J, Soler-Vila A & Wan A, 2012. In: Soler-Vila A & Moniz M (Eds.), Macroalgae Fact-sheets. Pp: 7-8. Irish Seaweed Research Group, Ryan Institute, NUI Galway.

Engelen A & Santos R, 2009. Which demographic traits determine population growth in the invasive brown seaweed *Sargassum muticum*? *Journal of Ecology*, 97(4): 675–684.

FAO, 2018a. FAO yearbook. Fishery and Aquaculture Statistics 2016/ FAO annuaire. Statistiques des pêches et de l'aquaculture 2016/ FAO anuario. Estadísticas de pesca y acuicultura 2016. Rome/ Roma. 104pp., ISBN 978-92-5-130636-9.

FAO, 2018b. The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO, 227pp., ISBN 978-92-5-130562-1.

FAO, 2020. Global Aquaculture Production - Fishery Statistical Collections, http://www.fao.org/fishery/statistics/global-aquaculture-production/en, accessed on 20/03/2020.

Foster MS & Barilotti DC, 1990. An approach to determining the ecological effects of seaweed harvesting: a summary. *Hydrobiologia*, 204–205: 15–16.

Freitas R, Romeiras M, Silva L, Cordeiro R, Madeira P, González JA, Wirtz P, Falcón JM, Brito A, Floeter SR, Afonso P, Porteiro F, Viera-Rodríguez MA, Neto AI, Haroun R, Farminhão JNM, Rebelo AC, Baptista L, Melo CS, Martínez A, Núñez J, Berning B, Johnson ME Ávila SP, 2019. Restructuring of the 'Macaronesia' biogeographic unit: A marine multi-taxon biogeographical approach. *Scientific Reports*, 9: 15792.

Frutuoso G, 1983. Livro Terceiro das Saudades da Terra. 300pp. Instituto Cultural de Ponta Delgada, Ponta Delgada, Açores.

GaCS - Gabinete de Apoio à Comunicação Social, 2017. Governo Regional estimula atividades que geram rendimentos complementares aos pescadores açorianos. Portal do Governo dos Açores. Retrieved from: http://www.azores.gov.pt/Portal/pt/novidades/Governo+Regional+estimula+atividades+que+geram+rendimentos+complementares+aos+pescadores+a%C3%A7orianos.htm. Accessed on 09/03/2020.

Gaines SD, White C, Carr MH & Palumbi SR, 2010. Designing marine reserve networks for both conservation and fisheries management. *Proceedings of the National Academy of Sciences*, 107(43): 18286–18293.

Gao K & McKinley KR, 1994. Use of macroalgae for marine biomass production and CO2 remediation: a review. *Journal of Applied Phycology*, 6(1): 45-60.

Garreta AG, 2001. Flora Phycologica Iberica: 1 Fucales. 192pp. ISBN 84-8371-208-3. Universidad de Murcia, Servicio de Publicaciones, Murcia, Spain.

GBIF - Global Biodiversity Information Facility, 2017. *Cystoseira humilis* Schousboe ex Kützing, 1860. Retrieved from: https://www.gbif.org/en/species/3197616. Accessed on 16/02/2020.

Genovese G, Faggio C, Gugliandolo C, Torre A, Spanò A, Morabito, M & Maugeri TL, 2012. In vitro evaluation of antibacterial activity of *Asparagopsis taxiformis* from the Straits of Messina against pathogens relevant in aquaculture. *Marine Environmental Research*, 73: 1–6.

Green S, 2014. Paleo Diet for Beginners: Top 30 Paleo Bread Recipes Revealed! 116 pp. ISBN 978-1505512854. CreateSpace Independent Publishing Platform, US.

Guiry MD & Guiry GM, 2020. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. Retrieved from: http://www.algaebase.org. Accessed on 03/04/2020.

Guzmán S, Gato A, Lamela M, Freire-Garabal M & Calleja JM ,2003. Anti-inflammatory and immunomodulatory activities of polysaccharide from *Chlorella stigmatophora* and *Phaeodactylum tricornutum*. *Phytotherapy Research*, 17(6): 665-670.

Hardouin K, Bedoux G, Burlot A-S, Donnay-Moreno C, Bergé J-P, Nyvall-Collén P & Bourgougno N, 2016. Enzyme-assisted extraction (EAE) for the production of antiviral and antioxidant extracts from the green seaweed *Ulva armoricana* (Ulvales, Ulvophyceae). *Algal Research*, 16: 233–239.

Harrison M, 2013. Armageddon Cookbook and Doomsday Kitchen. Pp: 127–133. ISBN 978 0 9544158 8 4. Wild Food School— Marcus Harrison, Lostwithiel, Cornwall, UK.

Hart G, Ticktin T, Kelman D, Wright A & Tabandera N, 2014. Contemporary gathering practice and antioxidant benefit of wild seaweeds in Hawai'i. *Economic Botany*, 68(1): 30–43.

Haslin C, Lahaye M & Pellegrini M, 2000. Chemical composition and structure of sulphated water-soluble cell-wall polysaccharides from the gametic, carposporic and tetrasporic stages of *Asparagopsis armata* Harvey (Rhodophyta, Bonnemaisoniaceae). *Botanica marina*, 43(5): 475-482.

Haslin C, Lahaye M, Pellegrini M & Chermann JC, 2001. In vitro anti-HIV activity of sulfated cell-wall polysaccharides from gametic, carposporic and tetrasporic stages of the Mediterranean red alga *Asparagopsis armata*. *Planta Medica*, 67(04): 301-305.

Hawkins SJ & Harkin E, 1985. Preliminary canopy removal experiments in algal dominated communities low on the shore and in the shallow subtidal on the Isle of Man. *Botanica Marina*, 28 (6): 223-230.

Holdt SL & Kraan S, 2011. Bioactive compounds in seaweed: Functional food applications and legislation. *Journal of Applied Phycology*, 23(3): 543–597.

Horridge GA, 1951. Occurrence of *Asparagopsis armata* Harvey on the Scilly Isles. *Nature*, 167(4253): 732 – 733.

Horta e Costa B, Claudet J, Franco G, Erzini K, Caro A & Gonçalves EJ, 2016. A regulation-based classification system for Marine Protected Areas (MPAs). *Marine Policy*, 72: 192–198.

Horta e Costa B, Gonçalves JM dos S, Franco G, Erzini K, Furtado R, Mateus C, Cadeireiro E & Gonçalves EJ, 2019. Categorizing ocean conservation targets to avoid a potential false sense of protection to society: Portugal as a case-study. *Marine Policy*, 103553.

Hurd CL, Harrison PJ, Bischof K & Lobban CS, 2014. Seaweed ecology and physiology. 2nd edition. 565pp. ISBN 9781139192637. Cambridge University Press, Cambridge, UK.

Ibrahim AMM, Mostafa MH, el Masry MH & El-Naggar MMA, 2005. Active biological materials inhibiting tumor initiation extracted from marine algae. *Egyptian Journal of Aquatic Research*, 31:1.

ISPA- Instituto Universitario, Ciencias Psicologicas, Sociais e da Vida, 2019. MPAs Portugal. Portugal. Retrieved from: http://mpas- portugal.org/azores/islandsandcoastal/. Accessed on 15/02/2020.

ISSG - Invasive Species Specialist Group, 2008. El manejo de especies invasoras en ambientes marinos y costeros: introducción a las especies invasoras marinas y costeras. Módulo I. 44pp.

Ito K & Hori K, 1989. Seaweed: Chemical composition and potential food uses. *Food Reviews International*, 5(1): 101–144.

IUCN- International Union for Conservation of Nature, 2000. Definicion de especie exótica invasora y cirterios para su identificación. Retrieved from: https://www.miteco.gob.es/es/parques-nacionales-oapn/publicaciones/edit_libro_04_01_tcm30-100254.pdf. Accessed on 24/03/2020.

Jansen HM, Tonk L, van der Werf A, van der Meer I, van Tuinen S, van der Burg S & Brouwers E, 2019. Development of Offshore Seaweed Cultivation: food safety, cultivation, ecology and economy: synthesis report 2018. Wageningen Marine Research, Wageningen University and research. 18pp.

Jenkins SR, Norton TA & Hawkins SJ, 2004. Long term effects of *Ascophyllum nodosum* canopy removal on mid shore community structure. *Journal of the Marine Biological Association of the UK*, 84 (2): 327- 329.

Jurković N, Kolb N & Colić I, 1995. Nutritive value of marine algae *Laminaria japonica* and *Undaria pinnatifida*. *Die Nahrung*, 39(1): 63–66.

Kaliaperumal N, Kalimuthu S & Ramalingam JR, 1995. Economically important seaweeds. CMFRI Special Publication, 62: 1-35.

Kim JK, Yarish C, Hwang EK, Park M & Kim Y, 2017. Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services. *Algae*, 32(1): 1-13.

Kishi K, Inone G, Yoshida A, Fuwa H, Koishi H, Koide G, Miyoshi T, Inone T, Yoshida M & Omori A, 1982. Digestibility and energy availability of sea vegetables and fungi in man. *Nutrition Reports International*, 26: 183–192.

Kitching JA, 1987. The flora and fauna associated with *Himanthalia elongata* (L.) S.F.Gray in relation to water current and wave action in Lough Hyne Marine Nature Reserve. *Estuarine, Coastal and Shelf Science*, 25(6): 663–676.

Lahaye M & Jegou D, 1993. Chemical and physical-chemical characteristics of dietary fibres from *Ulva lactuca* (L.) Thuret and *Enteromorpha compressa* (L.) Grev. *Journal of Applied Phycology*, 5(2): 195.

Lahaye M & Kaeffer B, 1997. Seaweed dietary fibres: Structure, physico-chemical and biological properties relevant to intestinal physiology. *Science des Aliments*, 17: 563-584.

Lamare V & Dupré C, 2017. *Zonaria tournefortii* (J.V. Lamouroux) Montagne. Retrieved from: http://doris.ffessm.fr/ref/specie/1591. Accessed on 6/02/2020.

Lamare V & Verlaque M, 2018. *Asparagopsis taxiformis* (Delile) Trevisan de Saint-Léon. Retrieved form: http://doris.ffessm.fr/ref/specie/2074. Accessed on 6/03/2020.

Lenanton R, Robertson A & Hansen J, 1982. Nearshore accumulations of detached macrophytes as nursery areas for fish. *Marine Ecology Progress Series*, 9: 51-57.

Levine IA & Sahoo D, 2010. Porphyra: Harvesting Gold from the Sea. 104pp. ISBN 978-9380026947. IK International Publishing House, Bangalore, India.

Levring T, Hoppe HA & Schmid OJ, 1969. Marine algae. A survey of research and utilization. 421 pp. Cram, De Gruyter & Co., Hamburg.

Little C & Kitching JA, 1996. The Biology of Rocky Shores. 240pp. ISBN 0198549350. Oxford University Press, New York.

Lobban CS & Harrison PJ, 1994. Seaweed ecology and physiology. 366 pp. ISBN 9780511626210. Cambridge University Press, Cambridge, UK.

Lonsdale WM, 1999. Global patterns of plant invasions and the concept on invisibility. *Ecology*, 80(5): 1522–1536.

Losantos R, Funes-Ardoiz I, Aguilera J, Herrera-Ceballos E, Garcia-Iriepa C, Campos PJ & Sampedro D, 2017. Rational design and synthesis of efficient sunscreens to boost the solar protection factor. *Angewandte Chemie*, 129 (10): 2676-2679.

Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH & Jackson JB, 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science*, 312 (5781): 1806-1809.

Loureiro R, Gachon CMM & Rebours C, 2015. Seaweed cultivation: potential and challenges of crop domestication at an unprecedented pace. *New Phytologist*, 206(2): 489-492.

Lubchenco J, Palumbi SR, Gaines SD & Andelman S, 2003. Plugging a hole in the ocean: the emerging science of marine reserves. *Ecological Applications*, 13(1): 3-7.

MacCaughey V, 1918. Algae of the Hawaiian archipelago, II. The Botanical Gazette, 65(2): 121–149.

Mack MC & D'Antonio CM, 1998. Impacts of biological invasions on disturbance regimes. *Trends in Ecology & Evolution*, 13(5):195–198.

Manilal A, Sujith S, Sabarathnam B, Kiran GS, Selvin J, Shakir C & Lipton AP, 2010. Bioactivity of the red algae *Asparagopsis taxiformis* collected from the southwestern coast of India. *Brazilian Journal of Oceanography*, 58(2): 93-100.

Manilal A, Sujith S, Selvin J, Panikkar MVN & George S, 2012. Anticoagulant potential of polysaccharide isolated from Indian red alga, *Asparagopsis taxiformis* (Delile) Trevisan. *Thalassas, an International Journal of Marine Science*, 28: 9-15.

Martins GM, Cacabelos E, Faria J, Álvaro N, Prestes ACL & Neto AI, 2019. Patterns of distribution of the invasive alga *Asparagopsis armata* Harvey: a multi-scaled approach. *Aquatic Invasions* 14(4): 582–593.

Martins JA, 1986. Potencialidades da ZEE Açoriana. Relatório da VI Semana das Pescas dos Açores, 6: 125-132.

Matos S, 2012. Designing food cultures: propagating the consumption of seaweed in the Azores Islands through recipes. *Iridescent*, 2(3): 24-33.

Mazarrasa I, Olsen YS, Mayol E, Marba N & Duarte CM, 2014. Global unbalance in seaweed production, research effort and biotechnology markets. *Biotechnology Advances*, 32: 1028-1036.

McHugh DJ, 2003. A Guide to the Seaweed Industry. FAO Fisheries Technical Paper 441. 118 pp. Rome. ISBN 92-5-104958-0.

Mellouk Z, Benammar I, Krouf D, Goudjil M, Okbi M & Malaisse W, 2017. Antioxidant properties of the red alga *Asparagopsis taxiformis* collected on the North West Algerian coast. *Experimental and Therapeutic Medicine*, 13: 3281-3290.

Mesnildrey L, Jacob C, Frangoudes K, Reunavot M & Leseur M, 2012. Seaweed industry in France. Report Interreg program NETALGAE. 42pp. HAL id: hal-00840572.

Milchakova N, 2011. Marine Plants of the Black Sea. An illustrated Field Guide. 144pp. ISBN 978-966-02-5801-3. Digit Print Press, Sevastopol, Ukraine.

Monagail M, Cornish L, Morrison L, Araújo R & Critchley AT, 2017 Sustainable harvesting of wild seaweed resources. *European Journal of Phycology*, 52(4): 371-390.

Mork M, 1996. The effect of kelp in wave damping. *Sarsia*, 80(4): 323–327.

Morton B, Britton JC & Martins ADF, 1998. Ecologia costeira dos Açores. 249pp. ISBN 9729777411. Sociedade Afonso Chaves, Ponta Delgada, São Miguel, Açores, Portugal.

Mouritsen OG, 2013. Seaweeds: edible, available, and sustainable. 304pp. ISBN 9780226044538. University of Chicago Press, Chicago and London.

Munda IM, 2006. The seaweed resources of the Adriatic Sea. In: Critchley AT, Ohno M & Largo DB (Eds.), World Seaweed Resources—An Authoritative Reference System. Pp: 185–199. *ETI Bioinformatics*. ISBN: 90-75000-80-4.

Nedumaran T & Arulbalachandran D, 2015. Seaweeds: a promising source for sustainable development. In: Thangavel P & Sridevi G (Eds.), Environmental Sustainability. Pp: 65-88. Springer, ISBN 978-81-322-2055-8.

Nelson WA & Conroy AM, 1989. Effect of harvesting method and timing on yield and regeneration of karengo (Porphyra spp.) (Bangiales, Rhodophyta) in New Zealand. *Journal of Applied Phycology*, 1(3): 277-283.

Neori A, Chopin T, Troell M, Buschmann AH, Kraemer GP, Halling C, Shpigel M & Yarish C, 2004. Integrated aquaculture: Rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. *Aquaculture*, 231(1-4): 361-391.

Netalgae 2012. Netalgae- Inter-regional network to promote sustainable development in the marine algal industr. Seaweed Industry in Europe: A Guide to Better Practice. An output of the NETALGAE project. 8pp.

Neto AI & Pinto IS, 2018. Introduction to Marine Algae: Overview. In: Malcata FX, Pinto IS & Guedes AC (Eds.), Marine Macro- and Microalgae: An Overview. Pp: 1-19. CRC Press, ISBN 9781498705332.

Neto AI, 1997. Studies on algal communities of São Miguel, Azores. Tese Doutoramento. Universidade dos Açores, Ponta Delgada. 309pp.

Neto AI, Tittley I & Raposeiro P, 2005. Flora Marinha do Litoral dos Açores [Rocky Shore Marine Flora of the Azores]. 156pp. ISBN 972 99884 0 4. Secretaria Regional do Ambiente e do Mar, Açores, 1500 exemplares, http://hdl.handle.net/10400.3/1677.

Neto AI, Viera MA & Haroun R, 2014. A synthetic overview of marine phycological studies in the Macaronesian Archipelagos. *Silva Lusitana*, 22: 217-244.

Nishida T, Matsunaga A, Onikura N, Oikawa S, & Nakazono A, 2008. Fish fauna associated with drifting sea weeds in the Chikuzen Sea, Northern Kyushu, Japan. *Fisheries Science*, 74(2): 285–292.

Nishimune T, Sumimoto T, Yakusiji T, Kunita N, Ichikawa T, Doguchi M & Nakahara S, 1991. Determination of total dietary fiber in Japanese foods. *Journal-Association of Official Analytical Chemists*, 74(2): 350-359.

Nisizawa K, 2006. Seaweeds kaiso—bountiful harvest from the seas. In: Critchley AT, Ohno M & Largo DB (Eds.), World Seaweed Resources—An Authoritative Reference System. ETI Bioinformatics, ISBN: 90-75000-80-4.

Nisizawa K, Noda H, Kikuchi R & Watanabe T. 1987. The main seaweed foods in Japan. In: Ragan MA & Bird CJ (Eds). 12th International Seaweed Symposium: Proceedings of the 12th International Seaweed Symposium. Sao Paulo, Brazil. Springer Netherlands, Dordrecht, 5-29pp.

Norderhaug KM, Fredriksen S & Nygaard K, 2003. Trophic importance of Laminaria hyperborea to kelp forest consumers and the importance of bacterial degradation to food quality. *Marine Ecology Progress Series*, 255: 135–144.

Norton TA, Mathieson AC & Neushul M, 1981. Morphology and environment. In: Lobban CS & Wynne MJ (Eds.), Biology of Seaweeds. Pp: 421-452. Blackwell Scientific Publications, ISBN 0-520-04585-8.

Nunes N, Ferraz S, Valente S, Barreto MC & De Carvalho MP, 2017. Biochemical composition, nutritional value, and antioxidant properties of seven seaweed species from the Madeira Archipelago. *Journal of Applied Phycology*, 29(5): 2427-2437.

Oh YS, Lee IK & Boo SM, 1990. An annotated account of Korean economic seaweeds for food, medical and industrial uses. *The Korean Journal of Phycology*, 5(1): 57–71.

Orth RJ & Van Montfrans J, 1984. Epiphyte-seagrass relationships with an emphasis on the role of micrograzing: a review. *Aquatic Botany*, 18(1-2): 43-69.

Paiva L, Lima E, Patarra RF, Neto AI & Baptista J, 2014. Edible Azorean macroalgae as source of rich nutrients with impact on human health. *Food Chemistry*, 164: 128–135.

Paiva LS, Patarra RF, Neto AI, Lima E & Baptista JA, 2012. Antioxidant activity of macroalgae from the Azores. *Arquipélago. Life and Marine Sciences*, 29: 1-6.

Patarra RF, 2017. Culture studies of economically important seaweeds. Doctoral thesis in Biology. Faculdade de Ciências e Tecnologia, Departamento de Biologia, Universidade dos Açores. viii+157 pp.+Appendix.

Patarra RF, Iha C, Pereira L & Neto AIN, 2019. Concise review of biological data on *Pterocladiella capillacea* (S.G. Gmelin) Santelices & Hommersand. *Journal of Applied Phycology*.

Paul NA, de Nys R & Steinberg PD, 2006. Chemical defence against bacteria in the red alga *Asparagopsis armata*: linking structure with function. *Marine Ecology Progress Series*, 306: 87-101.

Pereira L, 2008. As algas marinhas e respectivas utilidades. Monografias. Available online at: http://br.monografias.com/trabalhos913/algas-marinhas-utilidades/algas-marinhasutilidades.pdf

Pereira L, 2010. Littoral of Viana do Castelo—ALGAE (Bilingual). Câmara Municipal de Viana do Castelo, Portugal, 68pp.

Pereira L, 2011. A review of the nutrient composition of selected edible seaweeds. Chapter 2. In: Pomin VH (Ed.). Seaweed: Ecology, Nutrient Composition and Medicinal Uses. Pp: 15–47. Nova Science Publishers Inc., ISBN 978-1614708780.

Pereira L, 2014. *Halopteris scoparia*—MACOI, Portuguese Seaweeds Website. World-wide Electronic Publication. IMAR, Department of Life Sciences, University of Coimbra.

Retrieved from: http:// macoi.ci.uc.pt/spec_list_detail.php?spec_id=164. Accessed on 28/02/2020.

Pereira L, 2015. Seaweed flora of the European north Atlantic and Mediterranean. In: Kim SK (Ed.), Springer Handbook of Marine Biotechnology, Part A. Pp: 65-178. Springer-Verlag Berlin Heidelberg, ISBN 978-3-642-53971-8.

Pereira L, 2016. Edible seaweeds of the world. 463 pp. ISBN 978-1-4987-3050-1. CRC Press, Boca Raton, FL, USA.

Pérez R, 1997. Ces algues qui nous entourent: Concepcion actuelle, rôle dans la biosphère, utilisations, culture. 272pp. ISBN 2905434759. Édition Ifremer, Plouzané, France.

Plaza M, Cifuentes A & Ibáñez E, 2008. In the search of new functional food ingredients from algae. *Trends in Food Science & Technology*, 19(1): 31–39.

Porse H & Rudolph B, 2017. The seaweed hydrocolloid industry: 2016 updates, requirements, and outlook. *Journal of Applied Phycology*, 29 (5): 2187–2200.

Portaria n.º 57/2018 - Regulamento que estabelece o regime jurídico da apanha de espécies marinhas no mar dos Açores.

Portaria n.º 67/2014 – Revoga a Portaria n.º 68/2013.

Portaria n.º 69/2018 - Primeira alteração ao Regulamento da apanha aprovado pela Portaria n.º 57/2018.

Radulovich R, Neori A, Valderrama D, Reddy CRK, Cronin H & Forster J, 2015. Chapter 3 - Farming of seaweeds. In: Tiwari NK & Troy DJ (Eds.), Seaweed Sustainability. Pp: 27-59. Academic Press, ISBN 978-0-12-418697-2.

Radulovich R, Umanzor S & Cabrera R, 2013. Algas marinas: cultivo y uso como alimento humano. 52 pp. ISBN 978-9977-15-261-5. University of Costa Rica, San Jose.

Rahman S, 2002. Molluscan fauna of intertidal rocky ledges of Karachi - a comparative ecological study. Doctoral Thesis, Department of Zoology, University of Karachi, Pakistan. 636pp.

Ramos M, Bertocci I, Tempera F, Calado G, Albuquerque M & Duarte P, 2016. Patterns in megabenthic assemblages on a seamount summit (Ormonde Peak, Gorringe Bank, Northeast Atlantic). *Marine Ecology*, 37 (5): 1057-1072.

Rangeley R & Kramer D, 1998. Density-dependent antipredator tactics and habitat selection in juvenile pollock. *The Ecological Society of America*, 79(3): 943-952.

Reed M, 1906. The Economic Seaweeds of Hawaii and their Food Value. 88 pp. ISBN 978-1333872885. Hawaii Agricultural Experiment Station, Honolulu, Hawaii.

Rhein-Knudsen N, Ale MT, Ajalloueian F, Yu L & Meyer AS, 2017. Rheological properties of agar and carrageenan from Ghanaian red seaweeds. *Food Hydrocolloids*, 63: 50–58.

Rhein-Knudsen N, Ale MT & Meyer AS, 2015. Seaweed hydrocolloid production: an update on enzyme assisted extraction and modification technologies. *Marine Drugs*, 13 (6): 3340-3359.

Robinson N, Winberg P & Kirkendale L, 2013. Genetic improvement of macroalgae: Status to date and needs for the future. *Journal of Applied Phycology*, 25(3): 703-716.

Roo PVS, Mantri VA, Ganesan K & Kumar KS, 2007. Seaweeds as a human diet: an emerging trend in the new millennium. In: Gupta RK & Pandey VD (Eds.). Advances in Applied Phycology. Pp: 85–96. Daya Publishing House, ISBN 978-8170354765.

Rosas-Alquicira EF, Pacheco-Ramírez C, Chávez EJR & García AC, 2012. Ecosistemas conformados por macroalgas, pastos marinos y mangle en México: *su curriculum vitae*. *Ciencia y Mar*, 16(48): 31-36.

Safran P & Omori M, 1990. Some ecological observations on fishes associated with drifting seaweed off Tohoku coast, Japan. *Marine Biology*, 105(3): 395–402.

Sahoo D & Yarish C, 2005. Mariculture of Seaweeds. In: Andersen RA (Ed.), Algal Culturing Techniques. Pp: 219-237. Elsevier Academic Press, ISBN 9780080456508.

Sampaio AS, 1904. Memoria sobre a Ilha Terceira. Imprensa Municipal, Angra do Heroismo, Açores.

Sánchez-Moyano JE, 1996. Variación espacio-temporal en la composición de las comunidades animales asociadas a macroalgas como respuestas a cambios en el medio. Implicaciones en la caracterización ambiental de las áreas costeras. Doctoral Thesis. Universidad de Sevilla, España. 407 pp.

Sánchez-Moyano JE, García-Adiego EM, Estacio FJ & García-Gómez JC, 2000. Effect of environmental factors on the spatial distribution of the epifauna of the alga *Halopteris scoparia* in Algeciras bay, Southern Spain. *Aquatic Ecology*, 34(4): 355–367

Santos R & Duarte P, 1991. Marine plant harvest in Portugal. *Journal of Applied Phycology*, 3(1): 11-18.

Santos RS, Hawkins S, Monteiro LR, Alves M & Isidro EJ, 1995. Marine research, resources and conservation in the Azores. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 5(4): 311–354.

Serpa J, 1886. A Industria Piscatoria nas Ilhas Fayal e Pico. 1-18pp. Opusculos Agorianos, I. Imprensa Academica, Coimbra.

Shanmugam M & Mody KH, 2000. Heparinoid-active sulphated polysaccharides from marine algae as potential blood anticoagulant agents. *Current Science*, 79: 1672-1683.

Shannon E & Abu-Ghannam N, 2016. Antibacterial derivatives of marine algae: An overview of pharmacological mechanisms and applications. *Marine Drugs*, 14(4): 81.

Sidik BJ, Harah ZM & Kawaguchi S, 2012. Historical review of seaweed research in Malaysia before 2001. *Coastal Marine Science*, 35(1): 169–177.

Stagnol D, Renaud M, & Davoult D, 2013. Effects of commercial harvesting of intertidal macroalgae on ecosystem biodiversity and functioning. *Estuarine, Coastal and Shelf Science*, 130: 99-110.

Tittley I & Neto AI, 1995. The marine algal flora of the Azores and its biogeographical affinities. Boletim do Museu Municipal do Funchal, 4: 747-766.

Tittley I & Neto AI, 2000. A provisional classification of algal-characterised rocky shore biotopes in the Azores. *Hydrobiologia*, 440 (1-3): 19-25.

Trivedi J, Aila M, Bangwal DDP, Kaul S & Garg MO, 2015. Algae based biorefinery – how to make sense?. *Renewable and Sustainable Energy Reviews*, 47: 295–307.

Troell M, Joyce A, Chopin T, Neori A, Buschmann AH & Fang JG, 2009. Ecological engineering in aquaculture - Potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. *Aquaculture*, 297(1-4): 1-9.

Tseng, CK, 1944. Utilization of Seaweeds. *Scientific Monthly*, 59(1): 37-46.

Turner NJ, 1974. Plant taxonomic systems and ethnobotany of three contemporary Indian groups of the Pacific North-west (Haida, Bella Costa, and Lillooet). Doctoral thesis, 7: 1–104.

Ugarte RA, Sharp G & Moore B, 2006. Changes in the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. plant morphology and biomass produced by cutter rake harvests in southern New Brunswick, Canada. *Journal of Applied Phycology*, 18: 352–359.

Val A, Platas G, Basilio A, Cabello A, Gorrochategui J, Suay I, Vicente F, Portillo E, Río M, Reina G & Peláez F, 2001. Screening of antimicrobial activities in red, green and brown macroalgae from Gran Canaria (Canary Islands, Spain). *International Microbiology*, 4(1): 35-40.

Vasquez J, 1995. Ecological Effects of Brown Seaweed Harvesting. *Botanica Marina*, 38(1–6): 251-257.

Vaz-Pinto F, Martínez B, Olabarria C & Arenas F, 2014. Neighbourhood competition in coexisting species: The native *Cystoseira humilis* vs. the invasive *Sargassum muticum*. *Journal of Experimental Marine Biology and Ecology*, 454: 32-41.

Vo Dinh T, Saravana PS, Woo HC & Chun BS, 2017. Ionic liquid-assisted subcritical water enhances the extraction of phenolics from brown seaweed and its antioxidant activity. *Separation and Purification Technology*, 196: 287-299.

Wallenstein FM, Neto AI, Álvaro NV, Tittley I & Azevedo JMN, 2009. Guia para Definição de Biótopos Costeiros em Ilhas Oceânicas [Coastal Biotope Definition Manual for Oceanic Islands]. Secretaria Regional do Ambiente e do Mar, Açores. ISBN 978-972-99884-9-3.

Wang J, Zhang M & Fang Z, 2019. Recent development in efficient processing technology for edible algae: A review. *Trends in Food Science & Technology*, 88: 251–259.

Watanabe F, Takenaka S, Katsura H, Miyamoto E, Abe K, Tamura Y, Nakatsuka T & Nakano Y, 2000. Characterization of a vitamin B12 compound in the edible purple laver, Porphyra yezoensis. *Bioscience, Biotechnology, and Biochemistry*, 64(12): 2712–2715.

Wells MML, Potin P, Craigie JS, Raven JA, Merchant SS, Helliwell KE, Smith AG, Camire ME & Brawley SH, 2016. Algae as nutritional and functional food sources: revisiting our understanding. *Journal of Applied Phycology*, 29 (2): 949–982.

Whittaker RJ & Fernandez-Palacios JM, 2007. Island Biogeography: Ecology, Evolution and Conservation. 414pp. ISBN 978-0198566120. Oxford University Press, London, UK.

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, John JS & Watson R, 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science*, 314(5800): 787-790.

Yarish C & Pereira R, 2008. Mass production of marine macroalgae. In: Jørgensen SE & Fath BD (Ed.), Encyclopedia of Ecology. Pp: 2236-2247. Elsevier Science, ISBN 9780080454054.

Zaneveld JS, 1955. Economic Marine Algae of Tropical South and East Asia and their Utilization. Indo-pacific Publications, 3.

Zaneveld JS, 1959. The utilization of marine algae in tropical South and East Asia. *Economic Botany*, 13(2): 89–131.