CULTURE OF *SARGASSUM* IN KOREA

Techniques and potential for culture in the U.S.

Sarah Redmond
Maine Sea Grant and
University of Maine
Cooperative Extension

Jang K. Kim
University of Connecticut -
Stamford

Charles Yarish
University of Connecticut -
Stamford

Michael Pietrak
University of Maine
Aquaculture Research Institute

Ian Bricknell
University of Maine
Aquaculture Research Institute

In an effort to develop suitable culture techniques for macroalgae in the Northeast, this guide reviews the current knowledge of *Sargassum* biology and reports on culture techniques learned during a research exchange between the United States (NOAA Sea Grant) and South Korea (National Fisheries Research and Development Institute). The authors would like to acknowledge Drs. Miseon Park, Young Dae Kim, and Eun Kyung Hwang from the National Fisheries Research and Development Institute.

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Introduction

Sargassum (Family Sargassaceae, Order Fucales) represents the most common species of brown macroalgae in tropical to warm temperate waters (Guiry and Guiry 2013). It is the most diverse genus of marine macrophytes with more than 130 described species (Xie et al. 2013), with 28 species in Korea (Hwang et al. 2006). *Sargassum* species, collectively referred to in this document as sargassum, include a wide variety of forms and reproductive strategies (Mattio and Payri 2011) that provide important ecological and economical benefits including nutrient cycling (Wanders 1976, Carpenter and Cox 1974). Intertidal and subtidal sargassum beds provide food, habitat, and nursery grounds for a wide array of marine organisms (Tsukidate 1992), while also providing food, alginates, feed, and bioactive compounds for people who harvest or culture sargassum (Belleme and Belleme 2007, Zhao et al. 2008, Xie et al. 2013)(**1**).

Table 1. *Sargassum* classification.

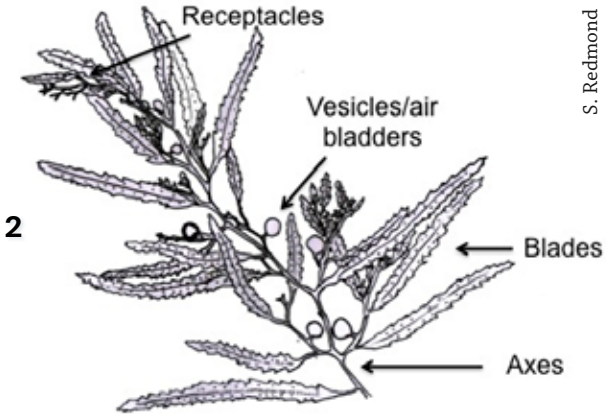
Empire	Eukaryota
Kingdom	Cheromista
Phylum	Heterokontophyta
Class	Phaeophyceae
Order	Fucales
Family	Sargassaceae
Genera	Sargassum

1

J. K. Kim

Sargassum contains higher amounts of protein essential and non-essential amino acids, essential fatty acids, and minerals than kelp (Laminariales). Sargassum also contains phycocolloids and bioactive compounds (e.g., alginic acid and fucoidan) and polyphenols, which may have potential nutraceutical and medical applications (Nisizawa 2002, Gupta and Abu-Ghannam 2011a, Namvar et al. 2013). Sargassum is used in Chinese medicine as an expectorant for bronchitis, and to treat laryngitis, hypertension, infections, fever, and goiter (Hou and Jin 2005).

Sargassum species (**2**) have a high degree of morphological complexity and plasticity, often resembling land plants in their degree of structural intricacy and differentiation. If present, perennial holdfasts give rise to one or more main axes with manifold branches to produce a bushy, branching thallus that can be 20–200 centimeters or more in length. The stipes produce long primary branches with abundant distichously- or spirally-arranged secondary branching. Branches produce serrated leaf-like blades, air bladders, and reproductive receptacles. The long, leafy blades contain midribs and sometimes cryptostomata that appear as minute cavities (Taylor 1957), and are held on branches with a petiole-like base. Small spherical air bladders on short stalks hold attached species upright underwater, or allow unattached plants to float on the surface (Lobban and Harrison 1997). Mature fronds produce reproductive receptacles in the axes of lateral branches, usually with scattered conceptacles and ostioles (Guiry and Guiry 2013).



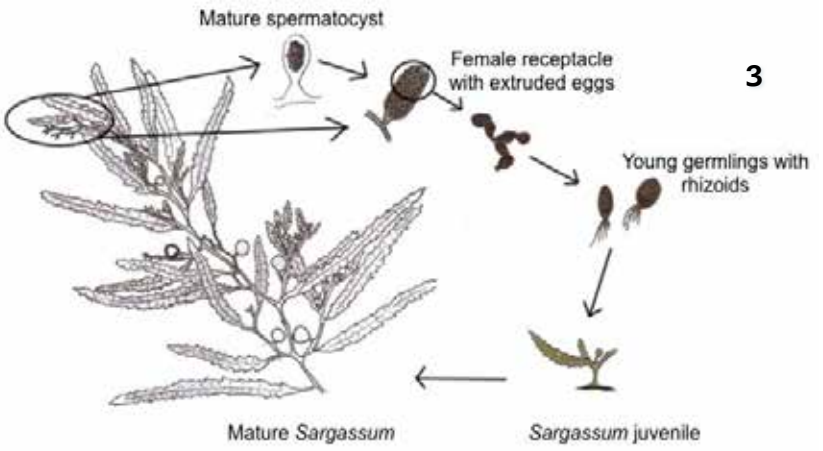
2

S. Redmond

Life history

The *Sargassaceae* family belongs to the Fucales, a brown algal order with a single life history phase.

Motile sperm and relatively larger non-motile eggs are produced inside of reproductive branches called receptacles on the parent plants, then directly fuse to form juvenile sporophytes when released (**3**). The juvenile sporophytes settle on suitable substrate and grow into the mature alga. Some species produce male sex organs, antheridia, and female sex organs, on the same plant. These are referred to as monoecious. The remaining species produce male and female sex organs on separate plants and are referred to as dioecious.



S. Redmond

The reproduction cycle begins with the formation of the female and male sex organs, oogonia and antheridia, respectively. These form in special reproductive cavities called conceptacles, which are found inside of the receptacles. Each antheridium produces 64 sperm that are released into the surrounding seawater to swim to a nearby egg for fertilization (Taylor 1957). Each oogonium extrudes one egg encased in mucilage through an opening, or ostiole, of the conceptacle. This mucus coating allows the egg to remain attached to the receptacle of the parent plant through fertilization, and sometimes germination, of the new zygote.

The free-floating forms have developed a life cycle that occurs entirely within the open ocean with no need to become attached to a substrate. With the exception of one reported case from Cuba (Moreira and Suárez 2002), these species have lost the sexual phase of the life cycle, and do not have holdfasts. Reproduction occurs through vegetative fragmentation, where pieces of existing plants break off to form new branching individuals.

Korean culture techniques

Overview

Several *Sargassum* species are cultured in Asia (**4**), including *S. fusiforme* (syn *Hizikia fusiformis*), *S. thunbergii, S. fulvellum, S. muticum,* and *S. horneri* in China (Xie et al. 2013), and *S. fusiforme* and *S. fulvellum* in Korea, with other species under development (Zhao et al. 2008). These seaweeds are sold dried, salted, or fresh, and consumed in soups, vegetable dishes, salads, or used in various seasonings (often labeled "hijiki" or "hiziki" in the U.S.). "*Hizikia fusiformis*" is currently regarded as a taxonomic synonym of *Sargassum fusiforme* (Harvey) Setchell (Guiry and Guiry 2013), and was recently reclassified as a sargassum based on a phylogenetic analysis (Oak et al. 2002, Stiger et al. 2003). Hijiki has been cultivated in South Korea and China since the 1980s (Sohn 1998, Pang et al. 2008), and techniques developed for hijiki have been adopted for other species of sargassum.

J. K. Kim

Traditional culture methods initially relied on the use of wild seedlings collected from natural beds. Groups of three to four seedlings, 5–10 centimeters in length, were inserted into seeding rope at intervals of 5–10 cm. This smaller

seeding line was then attached to a main longline placed at depths of 2–3 meters, and cultivated from November to May (Sohn 1998). This dependence on wild seedlings resulted in overharvesting of important wild beds, prompting development of new culture methods.

Holdfast-derived seeding was the first step toward developing culture techniques for sargassum in order to reduce pressure on the wild beds. This type of culture takes advantage of the perennial nature of the holdfast, allowing farmers to reuse the holdfasts from the previous year's crops. While plants may still be sourced from wild beds, the attached holdfasts can be reused for the next season's crop by over-summering in the sea after harvest until the next growing season. While this allows for reuse of existing cultured plants, the resulting harvestable biomass tends to diminish after each year of cultivation.

Today, sargassum lines are seeded with juvenile plants obtained from reproductive adults. Obtaining seedlings through sexual reproduction allows for mass production of new plants for seeding, and results in higher biomass yields (Pang et al. 2008). Fertilized eggs are gathered from mature fronds and "seeded" onto string by allowing juveniles to attach to seed lines with newly forming rhizoids. Once attached, seedlings are cultured in a nursery until ready for out-planting at sea, where they are grown on submerged longlines to harvest.

Nursery culture systems

Culture facilities

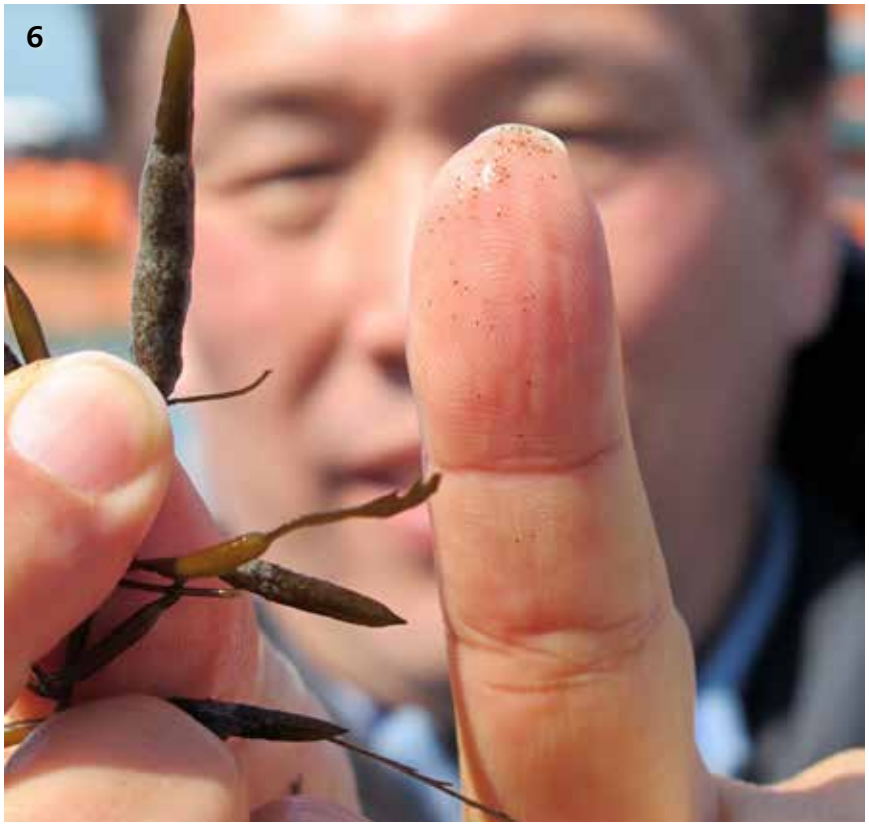
Seaweed nurseries in Korea consist of two parts: controlled indoor laboratories, used for holding seedstock and initiating seeding, and large rectangular concrete tanks filled with running, filtered seawater (**5**). These large tanks are filled with "seed curtains," square or rectangular flat plastic frames that hold specially-made mixed-fiber seed string. Seed frames are placed flat on tank bottoms for seeding, then suspended vertically in the larger concrete tanks for the development of juveniles (Xie et al. 2013). These culture tanks can be indoors or outdoors, but are usually covered by a greenhouse roof with adjustable screening to take advantage of natural lighting. They are high-capacity nurseries, capable of commercial scale production of seedlings for the seaweed industry.

J. K. Kim

Seeding

In order to initiate culture, mature parent plants are collected from farms or the wild in the spring, usually in April or May in Korea (Sohn 1998), before the spring tides (Xie et al. 2013) and transported to a seawater pond or a greenhouse nursery, where they are placed in concrete tanks with filtered seawater and gentle aeration. Optimal water temperatures for sargassum varies according to the species and location, but reproduction for *S. fulvellum* usually occurs with an increase in water temperature in the spring, coupled to a day-length driven formation of receptacles (Pang et al. 2009).

Nurseries can maintain immature thalli in aerated tanks until they are ready to initiate maturation and gamete release. Mature male and female plants are mixed in a 1:1 ratio and exposed to late spring (May–June) ambient water temperature (18–20 °C) and light climates. Seawater is exchanged as necessary, and supplemental fertilizer is added when required ($NaNo_3$ 10 g m^{-3} and $KHPO_4$ 0.1 g m^{-3}, final concentrations; Pang et al. 2008). Simultaneous discharge of gametes usually occurs within one week, under optimal conditions. A synchronized discharge is important to ensure maximal reproductive success. Synchronized release of gametes has been observed to occur in the very early morning, and usually around the same time each year, indicating a seasonal synchronicity (Pang et al. 2008). To achieve this in the hatchery, it is important to understand the phenology of the parent plant population in order to harvest before discharge takes place.



J. K. Kim

When mature (**6**), eggs are released from the conceptacle, but remain attached to the outside of the receptacle with an envelope of mucilage that acts to protect the eggs and zygotes for several days before dropping off the parent plant.

Once eggs are released, they are very quickly fertilized and begin to divide to form the multicellular zygote, which will develop an ellipsoidal shape with a tuft of rhizoids developing at one end (Xie et al. 2013). After fertilization, female plants with attached zygotes are removed from the tanks and further cultured in aerated containers in filtered seawater, where zygotes are collected for seeding.

There are two methods for seeding zygotes onto seed frames. The first is "broadcast seeding," which spreads zygotes over seed frames placed horizontally on the bottom of tanks, allowing them to attach. This can be done by placing whole reproductive thalli directly over seed curtains to allow embryos to drop naturally onto string (Xie et al. 2013), or by collecting embryos that have been naturally shed from parent plants (10–24 hours for *S. thunbergii*; Zhao et al. 2008), and pouring the embryo solution over seed frames.

J. K. Kim

J. K. Kim

The second method is "paintbrush seeding," which seeds zygotes onto string with a paintbrush dipped in the seed solution (Hwang et al. 2006). The sticky embryos are liberated from parent fronds by briskly rubbing plants together over a fine mesh net (**7**). The embryos are then washed with filtered seawater and painted onto dry seed string (**8**). The mucilage helps zygotes attach to the string until they are secured with their rhizoids and eventual holdfast, within about 24 hours (Zhao et al. 2008). After the attachment period, seeded frames are hung vertically in culture tanks.

Nursery culture

The new seedlings are cultured under ambient light and temperature in greenhouse tanks, with cloth providing shade on days of full sun. This tank-based nursery period can be as long as three to five months, as juveniles develop over the summer (Sohn 1998), or as short as one to two months, when seed lines are moved out to an ocean nursery for further development (Hwang et al. 2006, Xie et al. 2013). The ocean nursery is a protected area consisting of rafts or longlines where seeded frames are hung horizontally. If biofouling is a problem at this stage, seed frames can be sprayed periodically with a water jet to remove sediments and epiphytes. The ocean nursery phase can last from one to five months until plants reach 2–5 cm. Juveniles are then transferred from the nursery stage to the open water farm (Pang et al. 2008).

Farm culture

The seed string is transferred to horizontal longlines with a reel that winds the string along the length of the line in a spiral fashion (Hwang et al. 2006). Long lines are placed at approximately 1–2 meter depths and cultivated through to the following spring (**9–11**).

Multiple harvests can occur through holdfast regeneration of the cut fronds, so a seeded line can produce for two to four years. December–January is the harvest period for the first year's harvest, while the second year's harvest can take place from October to January. Line depth can be adjusted to control irradiation, which was found to be optimal at 26–31% of surface levels for *Sargassum fulvellum*. Receptacle formation may be delayed for *S. fulvellum* when lines are lowered from to three meters depth during the second half of the culture season, allowing for greater harvestable biomass and an extension of the culture season (Hwang et al. 2007). Depth may also be a useful tool for controlling biofouling organisms, which can be a major problem in the warmer months.

Biofouling and predatory organisms can cause problems in all stages of cultivation. Other algae and invertebrates can attach to the sargassum as well as the culture lines, competing for space and resources. Common fouling organisms include green (*Ulva* spp.), brown (*Ectocarpus* spp.), and red (*Gracilaria* spp., *Ceramium* spp.) seaweeds, epiphytic diatoms, amphipods (*Caprellidae* spp.), annelids, mollusks, arthropods, sponges, hydrozoans, and bryozoans. Ideally, the culture period should be optimized to avoid periods of high fouling rates, and the culture depth and seeding density should be adjusted to favor optimal growth (Pang et al. 2008). Biofouling can be controlled through manual removal, pressure washing, or with line treatments. Treatments can include desiccation or water bath dips with altered pH or salinity to reduce the fouling load. Soaking ropes in an acidic seawater bath (pH 4) for two to five minutes can prevent epiphytic growth (Xie et al. 2013), and remove amphipods. A five-minute soak in a basic seawater solution (pH 10) can also be effective for the removal of amphipods (Hwang et al. 2006). Altered salinity dips can also be effective, from freshwater dips (Xie et al. 2013), to five-minute soaks in lowered salinity water (7–10 ppt) or high saline solutions (44 ppt) (Hwang et al. 2006). Treatments will differ with species' tolerances, so should be specifically tailored to the tolerance ranges to help control epiphytic or epizootic fouling organisms.

J. K. Kim

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Culture potential for native *Sargassum* in the United States

Native *Sargassum* species can be found in the warmer waters of the United States, from Cape Cod, Massachusetts, to the Florida Keys on the East Coast, and in the Gulf of Mexico, California, and Hawaii (Abbott and Hollenberg 1976, Taylor 1957, Taylor 1960). One invasive species, *Sargassum muticum*, is currently present on the West Coast. All but two native species are benthic, occupying a wide range of marine habitats and depths.

Table 2. Some North American species of *Sargassum*

Species	Distribution
Benthic	
Sargassum filipendula C. Agardh*	East Coast (MA to FL) & Gulf of Mexico
Sargassum cymosum C. Agardh**	East Coast (FL)
Sargassum polyceratium Montagne***	East Coawst (FL)
Sargassum pteropleuron Grunow	East Coast (FL) & Gulf of Mexico
Sargassum agardhianum Farlow	West Coast (Southern California)
Sargassum palmeri Grunow	West Coast (Channel Islands)
Sargassum obtusifolium J. Agardh	Hawaii
Sargassum aquifolium (Turner) C. Agardh	Hawaii (formerly *S. echinocarpum* J. Agardh)
Sargassum oligocystum Montagne	Hawaii
Pelagic	
Sargasuum natans (Linnaeus) Gaillon	Southern Atlantic East Coast & Gulf of Mexico
Sargassum fluitans (Børgesen) Børgesen	Southern Atlantic East Coast & Gulf of Mexico
Invasive	
Sargassum muticum (Yendo) Fensholt	Invasive (US Pacific coast, CA to British Columbia)

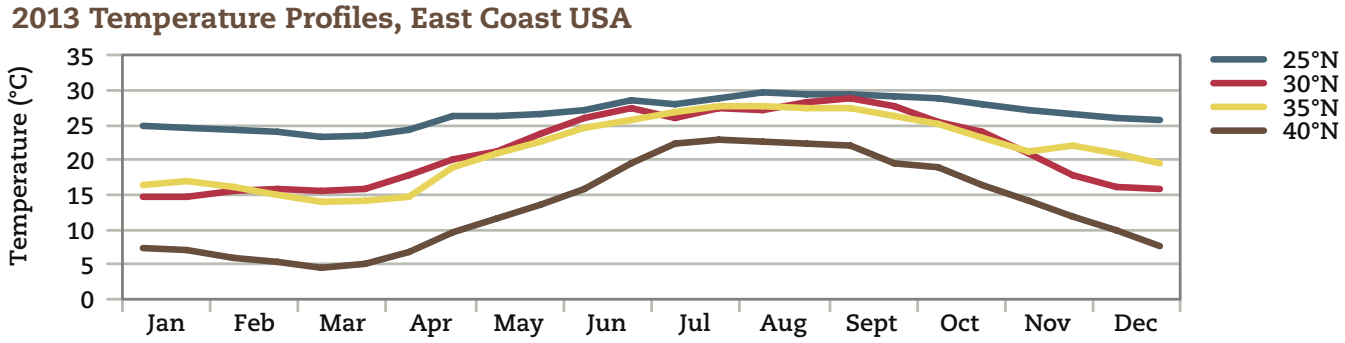
* There are four varieties and two forms of *S. filipendula* listed on Algaebase.org.

** There are nine varieties and one form of *S. cymosum* listed on Algaebase.org.

***One variety of *S. polyceratium* is listed on Algaebase.org.

See algaebase.org and Dawes and Mathieson (2008) for more information and references.

Each species has specific optimal temperature, salinity, and light requirements, as well as different growth and reproductive cycles, depending on local conditions and latitude. In general, for most species, growth rates were found to be maximal between the range of 24–30 °C, with sharp decreases in growth at temperatures above or below this range (Hanisak and Samuel 1987)(**12**). Benthic and pelagic species have different salinity and light requirements, indicating adaptation to their submerged or surface habitats. Benthic species can tolerate a wider salinity range, with an optimal range of 24–42 ppt, than pelagic species, which are more stenohaline, with an optimal range of 36–42 ppt (Hanisak and Samuel 1987). Benthic species are saturated for growth at lower photon flux densities than pelagic species, at ca 150 µmol m^{-2} s^{-1}, compared to 200–300 µmol m^{-2} s^{-1} for pelagic species (Hanisak and Samuel 1987).



12. **2013 Seawater temperature profiles from NOAA coastal buoys at approximately 25, 30, 35 and 40 degree north latitudes. Based on mean bi-monthly data from NOAA buoys SMKF1-FL, 41112-FL, 41036-NC, 44065-NY. Data from ndbc.noaa.gov.**

Out of six species of sargassum tested in Florida, *S. filipendula* and *S. pteropleuron* had the highest growth rates (Hanisak and Samuel 1987). These two benthic species can be found in different types of marine environments, with some physiological differences in optimal growing conditions. Of these two species, *S. filipendula* has the widest distribution, so this species could be a good candidate for culture.

Table 3. Optimal environmental parameters for culture of native *Sargassum* species.

Species	Type	Temperature (°C)	Salinity (ppt)	Light Saturation (µmol m^{-2} s^{-1})	Source
S. filipendula	Benthic	18–30	24–42	150	Hanisak and Samuel 1987
		25			Prince 1974
S. fluitans	Pelagic	24–30	36–42	200–300	Hanisak and Samuel 1987
S. natans	Pelagic	18–30	36–42	200–300	Hanisak and Samuel 1987

Benthic species

Sargassum filipendula is native to the East Coast of the U.S., with a wide distribution from south of Cape Cod, Massachusetts, to southern Florida and the Gulf of Mexico (Taylor 1957, Taylor 1960). It can also be found in Central and South America and around southern Asia, where it is used in traditional cuisines and in cosmetics. This is a subtidal, attached species, growing from just below the low tide mark down to 40 meter depths (Dawes and Tomasko 1988). Small discoid holdfasts attach onto shells or rocks in relatively quiet waters, with the plant buoyed upright by small round air bladders. Plants are typically 28–60 cm long, with largest individuals reaching up to one meter or more in length (Dawes and Mathieson 2008). Plants have smooth, branching main axes supporting branchlets bearing long, thin, serrated leaf-like blades with clear midribs and scattered cryptostomata. Long, slender receptacles develop in late summer and autumn (Taylor 1957). There are several alternate forms of *S. filipendula*, with four varieties and two forms currently recognized (Guiry and Guiry 2013).

S. filipendula can produce antheridia and oogonia in a single conceptacle, but more often a unisexual tendency produces male and female organs in different conceptacles. The antheridia develop 64 spermatozoids within the conceptacle, while each oogonia produces only one egg. Eggs are discharged within a mucilaginous wall, which allow them to remain attached to the parent plant through development of the multicellular zygote. The fertilized egg develops into a multicellular ellipsoidal structure, forming a tuft of rhizoids at one end, which will develop into the new holdfast structure as the zygotes are released and settle onto the sea floor (Simons 1906).

In the northern range of the distribution, just south of Cape Cod, Massachusetts, and in Connecticut, *S. filipendula* has been observed to have a seasonal cycle of abundance, with the period of maximum standing crop occurring from April to September, and a period of dormancy occurring from November to March (Conover 1958, Schneider et al. 1980)(**13**). Reproduction occurs in the summer months, when both vegetative and reproductive plants are abundant, and sporelings can be found attached with mucilage on parent conceptacles (Simons 1906). Growth in culture of *S. filipendula* from northernmost populations in Massachusetts was found to be optimal at 25 °C, inhibited at 30 °C, and fatal after five days at 35 °C (Prince 1974).

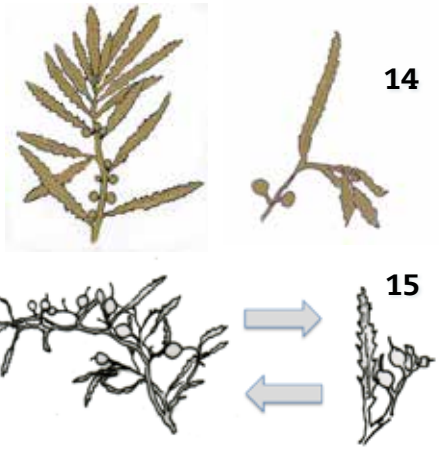
In Florida, *S. filipendula* is common to shallow coastal waters, and can be found in a wide range of marine environments, from very low salinity estuaries to full salinity coastal waters. The seasonal growth and reproductive cycle starts with new shoots developing from perennial bases in spring to early summer (Dawes and Tomasko 1988), rapid growth through spring and early summer (March–June), and maturation occurring in late summer. Reproduction occurs in autumn with the onset of short days and decreasing temperatures, then annual shoots experience die-back in winter, leaving dormant perennial bases (Dawes 1987). *S. filipendula* has a broad tolerance to irradiance, salinity, and temperature.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northern Distribution (MA to NJ)	Dormancy period			Start new growth		Period of maximum standing crop					Dormancy period	
						Reproductive period						
Southern Distribution (FL)	Dieback of annual branches		Start new growth		Rapid growth		Max length & biomass, maturing plants		Reproductive period		Die back of annual branches	

13. Annual growth patterns of *S. filipendula* for two locations on the U.S. East Coast as related to water temperature (Simons 1906, Taylor 1957, Conover 1958, Dawes 1987).

S. filipendula exhibited the greatest salinity tolerance out of several species tested from Florida, growing at salinities as low as 6 ppt (Hanisak and Samuel 1987), though some studies have observed mortality of annual branches at salinities of 5 and 15 ppt, with perennial bases able to tolerate a wider range (15–35 ppt) of salinity treatments (Dawes and Tomasko 1988). The optimal salinity range has been found to be within 24–42 ppt (Hanisak and Samuel 1987). Maximal growth rate occurred between 18–30 °C, with a decrease above 30 °C. Growth rates were saturated at a photon flux density of 150 µmol m^{-2} s^{-1}, with compensation levels at 10– 20 µmol m^{-2} s^{-1} (Hanisak and Samuel 1987).

Pelagic species



The two strictly pelagic or planktonic species, *S. natans* and *S. fluitans*, are unique holo-pelagic species, reproducing exclusively by vegetative means, where blade fragments develop directly into new individuals. They are found in open coastal environments as vegetative floating individuals and mats along the eastern coast of Florida (Dawes and Mathieson 2008). Generally known as "gulf-weed," *S. natans* and *S. fluitans* can form large floating mats offshore, especially in the North Atlantic central gyre, an area known as the "Sargasso Sea." Large masses are also common off the southern U.S. Atlantic coast, often found cast up on beaches and shorelines, especially after storms. Floating sargassum can provide important refuge for fish, invertebrates, and birds by providing protection, food, and substrate (Lüning 1990). Both species have long, serrated, lanceolate leaves, but *S. fluitans* (**14**) has wider leaves (3–4 mm) compared to *S. natans* (1–2 mm). Air bladders on *S. natans* (**15**) have a spine-like apical projection, while air bladders on *S. fluitans* lack projections (Edwards, 1970).

These strictly pelagic species have potential to be cultivated in open water or in a land-based system. Land or tank-based systems have the advantage of added control over environmental parameters for production of food or specialty extracts. In a study comparing growth rates in Florida, both species showed a range of maximal growth at temperatures between 24–30 °C, while *Sargassum natans* had a broader optimal temperature range of 18–30 °C. There was no detectable growth of either species at 12 °C, and growth decreased at temperatures above 30 °C. Optimal salinity ranges were found to be stenohaline, at 36–42 ppt, with no growth occurring at 18 ppt or below. Growth rates of both species were saturated at light levels of 200–300 μmol m^{-2} s^{-1}, with compensation levels of 25–50 μmol m^{-2} s^{-1} (Table 3). *S. fluitans* exhibited a higher growth rate than *S. natans* under optimal growth conditions (Hanisak and Samuel 1987).

Invasive species

Sargassum muticum, also known as Japanese wire weed, was introduced to Europe and the U.S. West Coast from Japan (Critchley et al. 1990, Lüning 1990). This is a species of concern to the East Coast as well, because of its high growth rates and invasive nature in warmer waters. *S. muticum* is capable of reproducing both sexually and asexually through fragmentation. Individuals are monoecious, producing male and female organs within the same receptacles on the same plant, and are probably capable of self-fertilization (Lobban and Harrison 1997). Invasive seaweed species can pose a threat to native habitat by proliferating and outcompeting native species, effectively reconstructing underwater architecture and associated food webs. Besides altering the underwater landscape, invasive seaweeds can impact recreational, industrial, and commercial use of coastal waters. Invasive species are spread around the globe by ballast water, hull fouling on ships, transport of live shellfish or other seafood, and by ocean currents. Only species native to local waters should be farmed, and any observations of the highly invasive *S. muticum* should be reported immediately to the local Sea Grant program or to the Federal Aquatic Nuisance Species Task Force (anstaskforce.gov/state_guidance.htm).

Uses for cultured native species of Sargassum

Food and extracts

With development of culture techniques for native species in the U.S. comes great potential for new products and ecosystem services. Marine macroalgal species contain a variety of minerals, vitamins, fiber, and bioactive compounds that could be used as functional ingredients for human, animal, and plant health (Stengel et al. 2011). Sargassum species, like other large brown algae, contain unique bioactive compounds that could be used as extracts or as components of whole foods (Nisizawa 2002, Namvar et al. 2013).

Polysaccharides isolated from brown algae species, in particular fucoidans and alginate, are of interest for a range of bioactive properties (Morales et al. 2006, Peng et al. 2013) and as a source of health-promoting dietary fiber and potential prebiotics (Gutpa and Abu-Ghannam 2011a). Fucoidans are sulphated polysaccharides unique to brown algae that have

been found to have anti-tumor (Nisizawa 2002, Khotimchenko 2010), anti-metastatic, anti-proliferative, antiviral, anti-coagulant, antibacterial, and anti-inflammatory properties in laboratory trials (Nisizawa 2002, Gutpa and Abu-Ghannam 2011a, Li et al. 2008). Sulphated polysaccharides extracted from *Sargassum filipendula* exhibited strong antioxidant properties, with stronger reducing power than vitamin C, and were effective in inhibiting cell proliferation (Costa et al. 2010). *S. filipendula* was reported to contain up to 26% dry weight of fucoidan in tropical populations (Garcia-Rios et al. 2012).

Alginate, the salt of alginic acid and a polysaccharide, is currently extracted and used in food, medical, and industrial processing for gelling, thickening, and stabilizing properties. Alginic acid and alginate occur in the cell wall matrix and in the intercellular mucilage, and abundance depends on depth, life stage, species, and season. Alginates are believed to have immunomodulary properties, and have been effective inhibitors of tumors in mice (Gutpa and Abu-Ghannam 2011a). Alginate in *S. fluitans* can consist of up to 45% of its dry weight (Fourest and Volesky 1996), though studies in Florida found values that ranged from 13% (*S. filipendula*), to 9% (*S. natans*), to 6.8% (*S. fluitans*) (Davis 1950), and 17.4% in the tropics (García-Ríos et al. 2012).

Sargassum contains multiple photosynthetic pigments including fucoxanthin. Fucoxanthin has been found to have inhibitory effects on several different types of cancer cells, when supplied as an extract in the diet of laboratory rats. It also has been shown to reduce white adipose tissue in rats, suppressing weight gain when ingested. It has been suggested that fucoxanthin, either through diet supplementation or as part of a whole food, can have an anti-obesity effect and increase metabolism (Holdt and Kraan 2011). Other bioactive compounds found in brown algae include diterpenes and phenolic phlorotannins that have exhibited antitumor, antiviral, antioxidant, anti-allergic, anti-diabetic, antibacterial, and algicidal properties (see Gutpa and Abu-Ghannam 2011a, Stengel et al. 2011 for review).

Seaweeds can also be added as components of other food products, or used for nutritional supplementation in animal feeding regimes. When blended with meat, they can improve texture and quality through their water retention and bulking properties and increase nutritional value, reduce sodium content, and increase antioxidant capacity of the product (Gutpa and Abu-Ghannam 2011b). They may also replace synthetic preservatives in processed or packaged food due to their high antioxidant and antimicrobial activity, and can naturally enhance nutritional quality of food by adding vitamins, riboflavin, niacin, pantothenic acid, folic acid, and a range of minerals (Gupta and Abu-Ghannam 2011b). When used as a dietary supplement in livestock feed, brown seaweed has been found to reduce harmful gut bacteria, increase weight gain, increase and improve gain to feed ratio, and improve gut health of young pigs (O'Doherty et al. 2010).

Environmental applications

Besides being cultivated for food or supplements, marine macroalgae can be used to improve water quality. Seaweeds take up dissolved inorganic nitrogen and phosphorous from seawater, so can be cultivated for nutrient remediation and bioextraction benefits. This is a natural benefit of the algal farming process, and can be used as a nutrient mitigation tool for nutrient bioextraction in areas of excess nitrogen and phosphorus loading (Kim et al. 2014), or as part of an integrated multi-trophic aquaculture model (Neori et al. 2004, Neori et al. 2007). For example, in integrated seaweed-prawn culture systems, excess nutrients could be built into algal biomass, reducing environmental impacts (Mai et al. 2010, Zonghe et al. 2013).

Like many of the brown algae, sargassum have strong chelating properties, with potential for bio-monitoring coastal waters for the presence of heavy metals (Filho et al. 1997). They could also be cultured for metal sequestration in seawater via bioaccumulation (Davis et al. 2003), or biosorption, the extraction of metallic species from waste liquids using non-living material (i.e. dried tissue). There are models for using sargassum in packed bed columns for the removal of ions from a solution, and even a U.S. patent for the use of *Sargassum natans* for sequestering gold from water (Volesky and Kuyucak 1988). Any seaweed grown for bioremediation of polluted waters is not suitable for human consumption, and should be used or disposed of in the most appropriate manner (e.g., biofuel).

Sargassum beds trap nutrients and make a significant contribution to the high rates of primary production found in shallow subtidal areas (Wanders 1976), and therefore play an ecologically important role in the maintenance of a healthy coastal ecosystem. By developing effective culture techniques for native species, it is possible to develop a new tool for environmental enhancement, restoration, and biomass production.

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