

# Seaweeds

## Ancestors of Land Plants with Rich Diversity

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Seaweeds are taxonomically diverse group of marine plants from which the land plants diverged over fifty crore years ago. Traditionally having been classified based on plant color as green, brown and red, modern molecular systematic evidences suggest that these plants are extraordinarily diverse. A number of seaweeds are edible and have been projected as a future food source. Seaweeds are also important to humanity in a number of ways, including as a source of medicines, food supplements, industrial chemicals, and as a potential candidate for biofuel research and CCS (carbon capture and sequestration). This article introduces the readers to the fascinating world of marine biology in general and seaweeds in particular, with an emphasis on Indian flora.

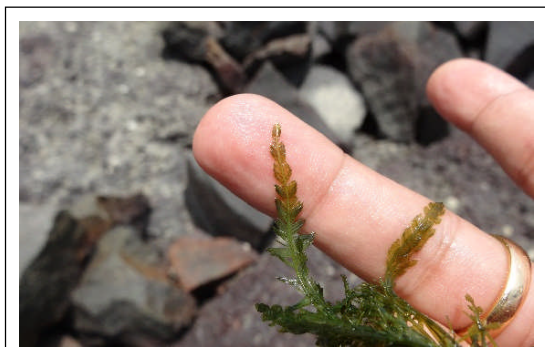
### Introduction

The word 'seaweed' is a misnomer; it is not a weed at all, but a plant with a multitude of uses. Etymology suggests that the word was in use since 1570s, in times when the world had little knowledge of their myriad applications. May be a better alternative is 'sea-plant' or 'sea-vegetable', but these terms are not quite as popular as the former. Seaweeds are indeed marine macroalgae—aquatic non-vascular plants (plants lacking xylem and phloem). Not all algae are seaweeds though; as a rule of thumb, microscopic algae (e.g., *Euglena*, *Chlorella*, blue-green algae) and freshwater algae are excluded from this group. Unfortunately compared to land plants, seaweeds remain largely unexplored and not much data is available on the extent of their diversity or endemism. Reasons for this include scarcity of seaweed taxonomists and comparative difficulty with exploring coastal regions.

### Keywords

Agar, algae, biofuel, carrageenan, CCS, coastal ecology, India, ocean.

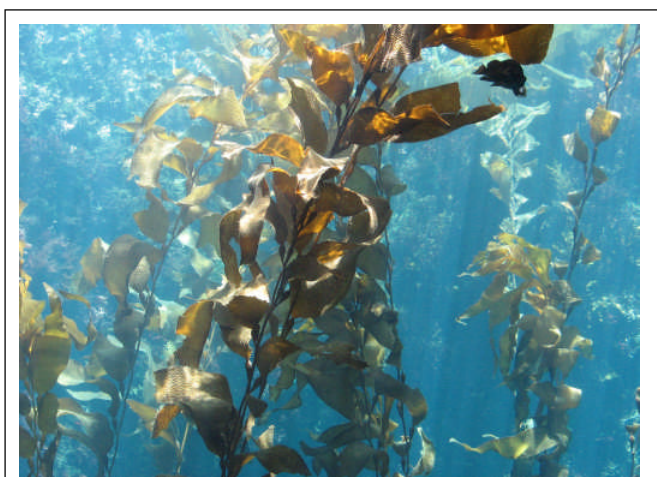




**Figure 1.** *Bryopsis plumosa*, a green seaweed, from Kannur, Kerala, May, 2012.

Seaweeds are very diverse in terms of the body size, from quite minute *Bryopsis* (Figure 1) to giant Kelp (*Macrocystis*, Figure 2). A number of seaweeds are benthic or ‘sub-tidal’ (submerged in water even in the low-tide, e.g., *Macrocystis*) and to collect them you would need to dive; for deeper ones you would need to dive using SCUBA gear. In contrast, intertidal seaweeds (e.g., *Bryopsis*) inhabit the intertidal zone, which gets exposed during low tides and submerged during high tides. To collect them, you would need to refer to the local almanac for ‘tide-tables’ – monthly time table of high and low tide times, similar to the sunrise and sunset times – and plan such that your expeditions happen only during low tide. Tides depend on a number of factors including latitude, local geography and bathymetry, and therefore you need to refer to individual tables for the places you go. The best time falls during the lowest of low tides, known as ‘Spring Tide’, that

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**Figure 2.** Giant Kelp (*Macrocystis pyrifera*), a brown seaweed, from Monterey Bay, California, USA, July, 2007.



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happens twice a month around new moon and full moon. That is, the lives of the people studying seaweeds (known as phycologists) are intricately linked with the phases of moon, with them busiest around full moon and new moon.

Like their 'enthusiasts', seaweeds are also interestingly busiest during this period; they reach reproductive maturity and release 'swarmers' (swimming cells; they could be gametes if released by gametophytes, or zoospores, if released by sporophytes). For the readers of *Resonance*, biological rhythms are not a new concept with Vaze and Sharma's excellent series on circadian rhythms [1]. The rhythm of seaweed maturation in contrast is 'semilunar'. This fortnightly rhythm is very common for marine organisms, including zooplankton, crabs and fish, with their spawning (release of aquatic animal gametes) happening around full moon and new moon. A number of studies suggests that synchrony in spawning ensures successful external fertilization and therefore semilunar periodicity that contributes in the synchronous spawning, is a critical factor in the life history of marine organisms. Calibrating the spawning with the lunar cycle acts as a flawless cue for triggering mechanisms involved in the fertilization as well as its dispersal.

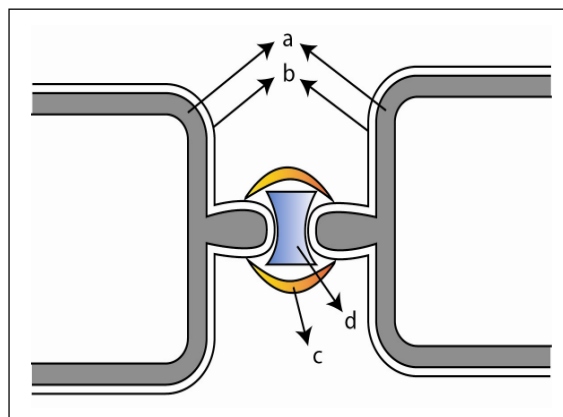
### Classification

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Seaweeds are of three types; green (Chlorophyta), red (Rhodophyta) and brown (Heterokontophyta), based upon the type of pigment they possess. Greens have chlorophylls *a* and *b*, and reds have chlorophylls *a*, and browns have chlorophylls *a* and *c*. Reds have accessory pigment phycoerythrin that gives them distinct red color while browns have accessory pigment fucoxanthin that gives characteristic brown color. These accessory pigments hide chlorophyll in such a way that the green color of the latter is effectively masked. However, if you heat either red algae or brown algae, the accessory pigments get denatured and the color of chlorophyll re-emerges. Dipping either of these seaweeds in a pot of hot water is enough for the instantaneous color change to green, a simple experiment students can perform at home (or for a keen observer at a Japanese restaurant, ordering hot seaweed-soups, like



*mizoshiru*). In my experience, ‘brown’ and ‘red’ tags are very deceptive, with many red seaweeds looking very brown. In such instances, looking at a section under a compound microscope might help. Red seaweeds have secondary ‘pit-connections’ between the cells (*Figure 3*), which neither brown nor green have.



**Figure 3.** Illustration of secondary ‘pit-connection’ between two cells. a. Cell wall. b. Plasmalemma. c. Plug cap. d. Plug. Structure comprising of plug cap and plug is known as pit-connection.

In addition to the color, structure of chloroplasts and flagella also help in the classification, albeit its practical utility at collection location for taxonomical identification remains little. Greens and reds have primary chloroplasts (products of primary endosymbiosis with a cyanobacteria), which are surrounded by two membranes and these two seaweeds are evolutionarily close, being part of the kingdom Plantae, as per Cavalier-Smith’s Six-Kingdom model. At the same time, browns have secondary chloroplasts (products of secondary endosymbiosis with a red algae), which are surrounded by four membranes. Brown seaweeds belong to kingdom Chromista. These three seaweeds are also different in terms of structure of flagella in unicellular phases. Greens have two flagella of equal lengths, reds have no flagella at all, while browns have two flagella of unequal lengths. These distinguishing characteristics are summarized in *Table 1*.

‘kont’= flagella; ‘Heterokont’= different flagella

**Table 1.** Three seaweed classes and their distinguishing characteristics.

Characteristic	Green	Red	Brown
Chlorophyll	<i>a, b</i>	<i>a, c</i> (occasionally) and <i>d</i>	<i>a, c</i>
Accessory pigment	-	Phycoerythrin	Fucoxanthin
Chloroplast membranes	Two	Two	Four
Flagella during unicellular stages	Two equal	None	Two unequal



The lineage most related to the land plants is green seaweed genus *Chara*, with lineage of land plants splitting from Charophyte around 65 crore (650 million) years ago.

Modern molecular systematic studies have shown that traditional classification is, to a large extent, valid and have revealed extensive diversity in all these lineages. Molecular systematists typically sequence a short stretch of genomes which can be used as a 'barcode' for that species. For example, mitochondrial genome-encoded *cox1* (Cytochrome C Oxidase subunit 1) gene is an example of a universal DNA barcode for both plants and animals. Chloroplast genome-encoded gene for large subunit of RuBisCO (Ribulose 1, 5 Bisphosphate Carboxylase), known as *rbcL*, is a barcode for plants, including algae. Nuclear genome-encoded Internal Transcribed Spacer (ITS) sequence is a barcode for plants and fungi. Scientists have attempted to reconstruct ancestral phylogeny using these barcodes and have concluded that the lineage most related to the land plants is green seaweed genus *Chara*, with lineage of land plants splitting from Charophyte around 65 crore (650 million) years ago [2]. It is very probable that this seaweed or its close relatives had been the ancestor of all terrestrial plants that we see today.

### Seaweed Flora of India

With a coastline of about 7,500 km, the Indian subcontinent has some of the longest uninterrupted coastal ecosystems in the world which support rich seaweed diversity. Most important seaweeds in India in terms of ubiquitous nature are *Ulva* and *Caulerpa* among greens, *Hypnea* and *Kappaphycus* among reds and *Sargassum* and *Turbinaria* among browns. The coasts of Gujarat, Kerala and Tamil Nadu have most of the seaweeds described in India [3].

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In my experience, the region with highest seaweed species diversity in India is Mandapam in Tamil Nadu. a place surrounding Pamban Bridge that connects the island of Rameswaram to the main land, while there are indications that reefs surrounding Andaman and Nicobar islands support higher seaweed diversity. Mandapam is the point where southern Indian Ocean (Palk Strait) mixes with eastern Bay of Bengal; intermixing of these two oceans is thought to cause an upsurge of nutrients for the luxurious growth



of seaweeds. For seaweed enthusiasts, a visit to this place – let us call it as ‘Botanical Beach’ – can be a memorable experience that can easily be combined during a visit to Rameswaram or Dhanushkodi. One can hire a local manual or motorized dinghy and navigate underneath the Pamban Bridge and surrounding areas; one can even snorkel around – the sea is surprisingly calm when the weather is good.

### Uses

Seaweeds have been an integral part of human civilization since time immemorial [4]. A number of references to seaweeds can be found in *waka* – a form of medieval Japanese short poetry, in which the word ‘seaweed’ stood as metaphor to express a number of human emotions, such as love and compassion. In East Asia, especially Japan, Korea, the Philippines, Vietnam, Taiwan and China, seaweeds have traditionally been part of the cuisine. This tradition might have been transplanted during the early nineteenth century when East Asians migrated to South America, when they began seaweed cultivations in countries such as Chile, Peru, Argentina, Brazil, and Mexico. Probably the most famous seaweed dish is *sushi* – a Japanese fish-based dish in which rice, mixed with vinegar and fish, is wrapped with thin sheets of red algae *Porphyra*. Green algae *Monostroma* is also routinely used in place of *Porphyra* due to the characteristic rich taste and aroma. When I was in Japan, I did enjoy seaweeds as food, especially *misoshiru*, a type of seaweed-based soup (consisting of *Undaria* and *Saccharina*). However, in India seaweeds have never been part of the traditional cuisine. With the impending world food crisis, accelerated by shrinking agricultural lands and explosion of world population, new sources of human food are needed for which seaweeds have been proposed as a promising candidate. Major advantages of using seaweeds include availability of cultivable areas (nutrient-rich coastal waters) that are not used by human for purposes other than fishing, and non-requirement of fresh water, fertilizers and pesticides for the agriculture. Cultivation of seaweed is termed ‘Seaweed Mariculture’ or ‘Seaweed Aquaculture’.

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Seaweeds contain unique sulfated polysaccharides (also known as 'phycocolloids') that are highly valued owing to a number of their physical properties. Agar is a polysaccharide made up of agarose and agaropectin that had traditionally been used as a jellifying agent for foods in East Asia, which Angela Hesse, wife of one of the lab attendants of Robert Koch (founder of Bacteriology), is credited for extending its use in microbiology. Legend is that during a picnic trip, Walther Hasse, her husband, noticed that jellies and puddings that Angela brought along did not melt despite the day being hot. Angela made it clear that these contained Agar, a hack that she picked up from her Dutch neighbors, who in turn picked it from their time in Indonesia. Agar does not melt at room temperature; it instead melts at around 85°C, solidifies at around 35–40°C, and is not degraded by microorganisms. To make a typical solid microbial culture medium, we mix agar in its powder form with other nutrients (typically, partially degraded proteins called 'peptone'), add water, boil (to melt the agar as well as to sterilize the media), pour the mix into glass plates and allow it to cool down (to let the agar solidify). Agarose, a constituent of agar, is used in a similar fashion as a jellifying substance, but for Gel Electrophoresis–electrochemical separation of nucleic acids based on the size. Agarose is a standard biochemical used by almost all molecular genetics laboratories and is immensely expensive, 1 kg typically costing around 30,000 rupees. Major seaweeds producing agar, called 'agarophytes', include *Gracillaria* and *Gelidium*. Although our coasts have a rich biomass of agarophytes, we are unfortunately not harnessing this resource at all and almost all of our domestic demand of agar and agarose is met by import from East Asia.

Carrageenan is yet another high-value sulfated polysaccharide from seaweeds, which is used as a jelling substance in food industry. Seaweeds cultivated for carrageenan include *Kappaphycus* (which produces Kappa-Carrageenan), *Euclima* and *Hypnea*. *Kappaphycus alvarezii* is locally known as 'Pepsi Paasi' (Pepsi Seaweed) in neighborhoods around Mandapam, Tamil Nadu where it is being cultivated by PepsiCo Holdings India



Pvt. Ltd. This non-native (also termed ‘exotic’) species was introduced from Japan for research purposes by an institute in Gujarat from where it got introduced elsewhere in the Indian subcontinent either naturally or deliberately for cultivation purposes. Introduced seaweeds like this one have a high potential to be invasive, to invade natural habitats and outgrow native species. Alginic acid (alginate) is also a high value commercial product from algae which is used in a number of products including anti-ischemic drugs, ice creams, diet supplements, waterproof and fireproof fabrics and in cosmetics. Brown algae, especially the genus *Fucus*, is highly valued in the pharmaceutical industry due to Fucoidan – another sulfated polysaccharide that has a number of biological activities, including apoptosis induction of cancer cells. *Box 1* lists and describes some of the most useful seaweeds commercially cultivated in various parts of the world.

#### Box 1. Commercially Important Seaweeds

Seaweed	Importance
Green Seaweeds: <i>Monostroma</i> , <i>Ulva</i> and <i>Caulerpa</i>	Edible seaweeds, commercially cultivated around the world, especially in East Asia and South America.
Red Seaweeds: <i>Porphyra</i> (Nori)	The most valued of all seaweeds in the world, an edible seaweed used extensively in <i>Sushi</i> , a famous Japanese dish.
<i>Kappaphycus</i> , <i>Eucheuma</i> , <i>Hypnea</i> and <i>Chondrus</i>	Carrageenophytes, commercially cultivated for the production of carrageenan – an important sulphated polysaccharide used in food industry.
<i>Gracillaria</i> and <i>Gelidium</i>	Agarophytes, commercially cultivated for the production of agar, a polysaccharide used as a laboratory medium and its further refined form agarose, which is used in gel electrophoresis (separation of nucleic acid molecules based on its size, using electricity).
Brown seaweeds <i>Saccharina</i> (Kombu) and <i>Undaria</i> (Wakame)	Edible brown seaweeds commercially cultivated in East Asia and South America.



Researchers around the world have recently been looking earnestly for ways to harvest biofuel from seaweeds.

Researchers around the world have recently been looking earnestly for ways to harvest biofuel from seaweeds. Drifted seaweeds beached during algal blooms can easily be collected and supplied to biofuel production lines. Algal biomass has been effectively converted into bioethanol for its use in automobiles and even as a jet propulsion fuel. However a major hurdle in this front is the practical difficulties involved with offshore cultivation of seaweeds. Seaweeds are also researched for their potential use in Carbon Capture and Sequestration (CCS) – capturing atmospheric CO<sub>2</sub> and conversion of it to organic carbon – which had been put forth as one way to deal with ever-increasing atmospheric CO<sub>2</sub> concentration, the primary culprit for global warming. However results so far have been quite disappointing with respect to the seaweeds as a potential candidate for CCS.

Seaweeds are also causing a nuisance to a number of human activities, albeit humans themselves are responsible for most of these. The ‘bad’ part of seaweeds as the general public perceives includes marine fouling – colonization of ship hulls to an extent to cause significant drag and reduction in speed (*Figure 4*). Invasive seaweeds is yet another global environmental problem. Many seaweeds including red *Kappaphycus* and green *Caulerpa* have very high invasive potential (*Figure 5*). A major route for the



**Figure 4.** Fouling of the hull of a dinghy by *Ulva paschima* Bast, from Mangalore, Karnataka, May, 2012.



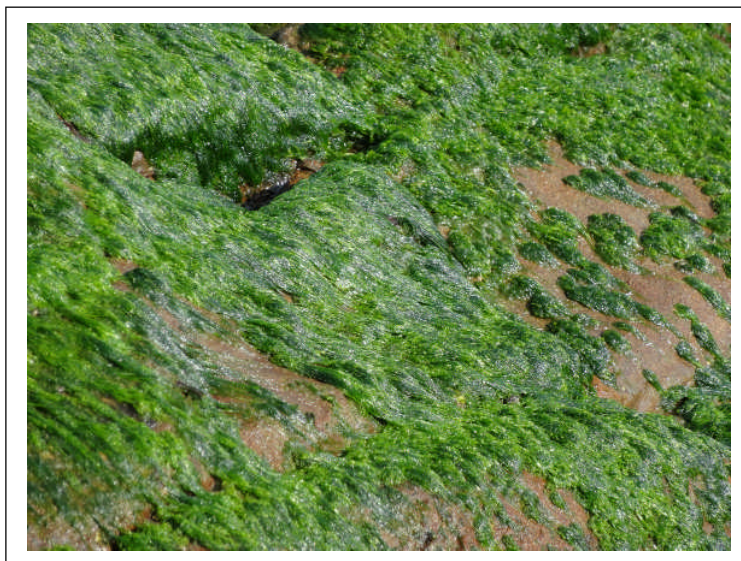


**Figure 5.** Some highly invasive algae in Indian coasts. Mandapam, July, 2012.

dispersal of invasive seaweeds is through ships; either as attached on the hull, or as spores in ballast water, that is being filled in from the destination port and released at the source port to balance cargo load. Invasive seaweeds outgrow many native seaweeds including endemic varieties and the entire coastal ecosystem gets disturbed by their presence. (A related issue is what is known as ‘Canopy effect’ in which a thick canopy of invasive seaweeds forms and prevents entry of light into deeper photic zones. Due to this effect growth of other benthic seaweeds as well as corals are severely hampered.) Explosive growth of algae, known as algal blooms, are a common phenomenon during eutrophication events (nutrient enrichment of water bodies due to a variety of human activities), for example, sewage inflow or deliberate nutrient addition for aquaculture (cultivation of marine organisms in coastal waters, such as shrimp and pearl oyster). Some of these blooms are harmful (‘Harmful Algal Blooms’) if the causative algae produces toxic substances. Harmful algal blooms are caused by



**Figure 6.** Green tide caused by *Ulva paschima* Bast at Anjuna Beach, Goa, May 2012.



microscopic algae – dinoflagellates and diatoms, and are thus not seaweeds. The ‘Green Tide’ (*Figure 6*) refers to a massive growth of green seaweeds, especially *Ulva* and *Cladophora*, due to nutrient enrichment of coastal waters.

### Conclusion

Seaweeds are very important marine plants that constitute flora of our coastal habitats. However information on its diversity is still in a state of infancy when compared with the land plants. A number of civilizations around the world have been using seaweeds as a food since time immemorial and recently these marine plants have been showcased as a food for future. While India harbors a rich diversity of seaweeds, neither the extent of its diversity has been documented nor the resources have been utilized effectively. Apart from culinary uses, seaweeds are also used in a number of industries including cosmetics, nutraceuticals and pharmaceuticals. Negative effects of seaweeds include marine fouling, biological invasion and algae blooms. These include marine fouling, biological invasion and algal blooms. It is hoped that this introductory article on seaweeds will motivate the readers to appreciate the importance of this ancient plant lineage.



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## Suggested Reading

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