#1 POSITION PAPER – VERSION 2.0 – APRIL 2021

What are Algae?

EUROPEAN ALGAE BIOMASS ASSOCIATION

EXECUTIVE SUMMARY

Algae have become a multi-billion sector in terms of biotechnology development that is expected to grow rapidly, providing valuable goods and services in multiple applications. In spite of centuries of scientific and commercial interest, the term algae has not taxonomic meaning. In the light of rapidly growing business associated with algae, a clear and simple definition of algae is not only required, but essential for developing the necessary standards, and the regulatory and legal issues.

This paper aims to explain 'what are algae' and how to answer the most relevant questions to different players interested in the field, including: academia, industry, trade organizations, consumers, business investors, local and national authorities, international organizations and any other interested party or stakeholder. This position paper represents the position of EABA as the Algae Biomass sector Association from a European perspective and summarizes information from science, technology and business dealing with 'algae' biomass, biotechnology and bioproducts.

Algae is a common name for a group of taxonomically unrelated organisms sharing a number of traits. Algae include cyanobacteria, eukaryotic microalgae and seaweeds. Common traits are: oxygenic photosynthes is (use of visible light to fix CO2 with O2 release); chlorophylls as main photosynthetic pigment; lack of differentiated tissues; primary producers in aquatics ecosystems. There are exceptions because some algae can grow in the dark using simple organic compounds and some algae do not possess photosynthetic organelles so are unable to perform photosynthesis.

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This paper aims to explain 'what are algae' and how to answer the most relevant questions to different players interested in the field, including: academia, industry, trade organizations, consumers, business investors, local and national authorities, international organizations and any other interested party or stakeholder. This position paper represents the position of EABA as the Algae Biomass sector Association from a European perspective and summarizes information from science, technology and business dealing with 'algae' biomass, biotechnology and bioproducts.

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RATIONALE

The European Algae Biomass Association (EABA) was established in Florence in June 2009 as the European association representing both research and industry in the field of algal technologies. EABA represents organizations and individuals interested in both macro and microalgae.

The general objective of EABA is to promote mutual interaction and cooperation in the field of algae biomass production, transformation and use for the whole range of algae applications. EABA aims at creating, developing, promoting and maintaining solidarity, contact, interaction and collaboration among its members and at defending their scientific and commercial interests at the European and international level. Its main target is to act as a catalyst for fostering synergies among scientists, industrialists and decision makers in order to promote the development of research, technology and industrial capacities in the algology field.

The Association is technology neutral and does not aim at favouring a particular kind of production, processing or use of algae biomass or biotechnology. This approach reflects the fact that all production technologies and uses of algae biomass or related services are to be considered as interdependent.
With these aims in mind, the Members of EABA share with each other accurate non-confidential information about the algae biomass sector (adapted from EABA STATUTES).

THE ORIGIN AND EVOLUTION OF THE CONCEPT 'ALGAE'

The origin of the word algae means 'seaweeds' in Latin, and one of the first known reference to 'algae' in Western literature was by the poet Virgil who about 30 BC wrote '*Nihil vilior alga*' ('nothing is as worthless as algae'). However, despite this, since earliest times, algae have been part of the human diet, with records in China and Japan going back for at least 2500 years. In Europe seaweeds were used in soil amendments and for fodder in some cases. Spirulina *(Arthrospira)* biomass was consumed for centuries in Africa and Central America, and macroalgae biomass was used intensively as soil amendment, e.g. in Ireland. In the 17th Century after invention of the microscope, microalgae started to be studied.

The first microalga identified was the diatom *Tabellaria* in 1703 and among the first to be cultured was *Chlorella* in 1890 in Europe. Over the last 100 years, microalgae and seaweed research and commercial applications have evolved in Europe, being at the forefront of algae exploitation for new foods, feeds and chemicals.

Currently, we use algae for many different household and industrial products. Some examples are toothpaste, chocolate milk, candies, cosmetics, ice creams, paint, ink, and pharmaceuticals. Of the more than 70,000 different algae species known, less than 50 are currently used in commercial production (Guiry, 2012), so we can assume that there is a growing number of uses that have yet to be discovered.

THE IMPORTANCE OF THE 'ALGAE BIOMASS' SECTOR IN EUROPE

The European Algae Biomass sector represented in 2018 an "economic value" of more than 1.7 B€/year (macroalgae 700 M€; microalgae 750 M€; equipment and engineering 180 M€; research & development 60 M€) and provide jobs for more than 14,000 persons. More than 80% of the market is the result of activity by large multinational companies. However, hundreds of SMEs and private producers recently started to develop a highly dynamic business landscape expected to grow rapidly.

Some microalgal strains, particularly belonging to *Arthrospsira* (known as spirulina) and *Chlorella* are consumed worldwide as food supplements. Algae are utilized since many years as feed in aquaculture hatcheries thanks to a nutritionally complete profile of amino acids, vitamins, minerals and essential fatty acids. Among macroalgae the most consumed are nori (*Pyropia tenera*), wakame (*Undaria*), kombu (*Laminaria* and *Saccharina*).

Algae are also utilized as sources of fine chemicals, botanical extracts and active substances in several applications (e.g., for pharmaceuticals and cosmetics). Algae can be used as food or feed according to:

- General food law , Regulation (EC) 178/2002;
- Responsibility quality and safety Regulation (EC) 882/2004;
- Relating to feed: Hygiene, Regulation (EC) 183/2005. Trade / labelling 767/2009.
- Relating to food hygiene: Regulation (EC) 852/2004 (There are no regulations on "food trade" but there are several on labelling of foodstuffs, the general one being Regulation (EU) No 1169/2011);
- Feed Additives, Regulation (EC) 1831/2003
- Regulation on food additives: Regulation (EC) No 1333/2008;
- Undesirable substances in animal feed (Directive 2002/32/EC).

Algae can be used as feed additives according to Regulation (EC) 1831/2003. However, only additives that have been through an authorization procedure may be placed on the market. Algae have been included in the feed catalogue. The Commission has established the European Union Register of Feed Additives, although the Register has only informative purposes and does not replace Community legal acts (ec.europa.eu/food/food/animalnutrition/feedadditives/registeradditives_en.html, http://ec.europa.eu/food/food/animalnutrition/feedadditives/docs/c_50_en.pdf\).

Regulation (EC) No 1831/2003 on "additives for use in animal nutrition, on the placing on the market and use of feed" states in article 24(6)): “the person who, for the first time, places on the market a feed material that is not listed in the catalogue shall immediately notify its use to the representatives of the European feed business sectors referred to in Article 26(1). The representatives of the European feed business sectors shall publish a register of such notifications on the Internet and update the Register on a regular basis. Authorisations are granted for specific animal species, specific conditions of use and for ten years periods.

In order to be sold as food, algae which were not consumed to a significant level within the EU before May 1997 need to be authorised following the procedure set out in the "Novel Foods Regulation". The "EU Novel Foods" catalogue lists species that were widely consumed in the EU before 15 May 1997 and are thus exempted to go through the Novel Food procedure. All foods authorised under the Novel Foods Regulation are listed in the “Union list of Novel Foods”.

For potential uses of Genetically Modified (GM) algae, the regulations on food safety and labelling of GM food and GM feed EC 1829/2003 and 1830/2003 applies.

1. Seaweeds and other algae are covered by Chapter 12 of the Brussels nomenclature, which is listed in Annex I to the Treaty. Seaweeds and other algae are therefore agricultural products falling within point (a) of the first subparagraph of Article 1(2) of Regulation (EC) No 834/2007. Since ‘other algae’ includes ‘microalgae’, microalgae are covered by the scope of Regulation (EC) No 834/2007.

2. As in Commission Regulation (EC) No 889/2008 (Chapter 1.8) no detailed production rules have been laid down until now for microalgae used as food and questions arose as regards which production rules operators have to respect when growing microalgae for use as food, there is a need to clarify the situation and lay down detailed production rules for such products.

3. The production of microalgae resembles that of seaweed in some aspects. Moreover, when they are further used as feed for aquaculture animals, microalgae, like multicellular algae and phytoplankton, are already subject to the detailed production rules for the collection and farming of seaweed on the basis of Article 6a of Regulation (EC) No 889/2008. Therefore, it is appropriate to clarify that the detailed production rules for seaweed should also apply to the production of microalgae for further use as food.

ECONOMIC DEFINITION OF ALGAE OR ALGAE AS GOODS

Custom code tariff number (e.g., TARIC code) comes from Council Regulation (EEC) No 2658/87 of 23 July 1987, which established a nomenclature, known as the ‘Combined Nomenclature’ or abbreviated to the ‘CN’, based on the International Convention on the Harmonised Commodity Description and Coding System, known as ‘the Harmonised System’ or abbreviated to the ‘HS’. Algae have the code 1212 21 00 which is in the heading 1212, e.g., under the chapter 12 “oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruits; industrial or medicinal plants; straw and fodder” therefore are treated legally as “plants”, although such a definition is scientifically inaccurate.

Algae production facilities are regulated in some European countries. In Spain microalgae production facilities are accepted as agriculture activity (Real Decreto 824/2005) as “special crops”. Water supply and disposal of residues regulations applicable for this activity is the same as that for agriculture activities. Agriculture is the cultivation of plants and fungi and breeding of animals, for food, fiber, biofuel, and other products used to sustain and enhance human life.

WHAT ARE ALGAE?

Although algae are widely used in biotechnology and agriculture in Europe and worldwide, and the term algae appears in multiple legal documents, the term as such is poorly defined. Algae are a very diverse group of organisms, found almost everywhere on the planet.

Based on common use the term algae includes representatives from prokaryotes (the cyanobacteria) and from several kingdoms of the eukaryotes, whereby no scientific agreement currently exists on the exact taxonomic classification of those multiple eukaryote kingdoms.

Algae are not one taxonomic group, the term is used similarly to the way in which people refer to “trees”, “bushes”, or “herbs”, albeit at a higher taxonomic level. In the widest sense the term algae includes all photoautotrophic organisms performing photosynthesis to produce sugar from water and CO_2 under release of oxygen lacking complex differentiation, and require high moisture levels for growth, although not for survival. In aquatic ecology microalgae are often called phytoplankton, from the Greek “phyton” (plant) and “planktos” (wanderer or drifter), referring to microscopic photosynthetic organisms that form part of the plankton community.

Algae can be grouped into:

1. macroscopic multicellular species, - free floating, sometimes attached to the bottom of seas, rivers and lakes - called macroalgae or seaweeds;
2. microscopic and mostly unicellular (although they can also be filamentous or colonial) species called microalgae.

However, as we started to understand the aquatic and terrestrial environment in more detail we have found that the macro- and microalgae domains overlap and that algae are complex in terms of taxonomy and biological attributes, and in the ways that industry can utilize them. Although some exclude prokaryotes from the definition of algae, EABA believes that, due to the similar physiology, biotechnology and business applications, cyanobacteria need to be, within the realm of algae biotechnology and business development, included in the term algae and treated likewise in all legal, technological and regulatory matters.

As no definition of algae is generally accepted, we list here just a few options:

- Most algae are photoautotrophic, performing oxygenic photosynthesis and fixing CO_2 using sunlight; lack complex structural differentiation although some primitive specification into organs can be observed; and lack flowers or spores for proliferation but rather multiply by means of single celled gametes or by vegetative cell division;
- One definition is that algae "have chlorophyll as their primary photosynthetic pigment and lack a sterile covering of cells around their reproductive cells";
- A very simple definition would be algae are all oxygenic photosynthesisers other than embryophyte land plants (Cavalier-Smith 2016);
- Another definition adapted from Wikipedia is: Algae is an informal term for a large, diverse group of photosynthetic eukaryotic organisms that are not evolutionary related, and therefore polyphyletic (of different taxonomic backgrounds).
- Cyanobacteria, also known as blue-green algae, are a large heterogeneous group of prokaryotic, principally oxygenic photosynthetic organisms. Cyanobacteria resemble the eukaryotic algae in many ways, including morphological characteristics and ecological niches, and were at one time treated as algae (Encyclopaedia Britannica).
- Thraustochytrids are unicellular heterotrophic marine protists classified within the Stramenopiles. There is an ongoing debate as to whether Thraustochytrids are algae. (Leyland B, Leu S, Boussiba S. 2018). It is ultimately a question of whether the common ancestor of Stramenopiles had plastids and subsequently lost them, or that it was never photosynthetic (Stefansson M. O. et al., 2019). Several companies in Europe and worldwide are producing oil from Thraustochytrids and selling it as algae oil. European authorities as EFSA issued a positive scientific opinion about this product (EFSA Panel on Dietetic Products, Nutrition and Allergies, 2014. Scientific Opinion on the extension of use for DHA and EPA-rich algal oil from Schizochytrium sp. as a Novel Food ingredient. EFSA Journal 2014;12(10):3843, 17 pp.).
- Algae include organisms ranging from the unicellular microalgae to multicellular forms, such as the giant kelp, a large brown alga up to 60 m in length. Most are aquatic and photoautotrophic although numerous prominent species including Chlamydomonas, Haematococcus, Chromochloris zofingiensis are actually soil dwelling species blooming whenever moisture and nutrient conditions are adequate. Algae lack many of the cell and tissue differentiations, such as stomata, xylem, and phloem, which are found in land plants.
- Algae play an essential role in many ecosystems, providing the foundation for all aquatic food chains supporting fisheries and ecosystems in the oceans and inland waters. Despite the fact that algae in the open oceans constitute only a fraction of the biomass of plants on land, algae carry out half of the photosynthesis on the planet, and thus contribute about 50% of the oxygen that we breathe.

Algae is a common name for a group of taxonomically unrelated organisms sharing a number of traits. Algae include cyanobacteria, eukaryotic microalgae and seaweeds. Common traits are: oxygenic photosynthes is (use of visible light to fix CO_2 with O_2 release); chlorophylls as main photosynthetic pigment; lack of differentiated tissues; primary producers in aquatics ecosystems. There are exceptions because some algae can grow in the dark using simple organic compounds and some algae do not possess photosynthetic organelles so are unable to perform photosynthesis.

ALGAE CLASSIFICATION AND TAXONOMY

Historically, algal species identification (delimitation) was based on their morphology and their growth behaviour. The science of systematics used the morphological similarities and differences between organisms to determine the evolutionary history and relationships of algal species to other species (Weins 2007).

However, as the shape of many algae can change over their life cycle or depending on the environmental conditions (e.g., nutrient availability), it is hard to classify many species based on morphology alone (Trainor 1998). To address this point, many research groups now classify and recreate lineages using similarities and differences in the DNA sequences of certain regions of their genomes. Typically, these are the 16S and 18S small subunit ribosomal RNA (rRNA) gene and Internal Transcribed Spacer (ITS) of rDNA (Leliaert et al. 2014) from the nuclear genome, with genes from both the chloroplast and the mitochondrion also used. Determining to which group a new organism belongs is still a challenge, and within the taxonomic circles there are species “groupers” and “splitters”, with many debates on how and where individual organisms should be placed in the phylogenetic tree (see John and Maggs (1997) and Leliaert and De Clerck (2017) for excellent reviews).

For simplicity, we group the most prominent algae species in Table 1 based on the ‘Four Eukaryotic Kingdoms’ model elaborated in the Tree of Life Project (www.tolweb.org), although this is a subject in motion and not finally clarified with multiple conflicting and contradictory publications and four to six kingdoms of eukaryotic organisms suggested, complicating the situation. The Kingdom formerly called ‘Protists’ including most algae classes was found, by molecular studies, to have evolved from multiple not related origins and thus became unsatisfactory in light of emerging massive amounts of molecular and high-resolution microscopy information. To date attempts are being made to redefine the Kingdoms of the Eukaryotic domain (Ruggiero et al 2015, Simpson et al 2004 etc.), which has direct implications on the taxonomic position of many algae classes and remains unresolved for the time being. In the classification model adopted algae spread in three out of the four Kingdoms.

One of the best consensus models on how the algae are grouped is presented in “The Freshwater Algal Flora of the British Isles” (John et al. 2011). This flora, alongside other recently curated databases at the UK Natural History Museum (AlgaeVision - www.nhm.ac.uk/our-science/data/algaevision.html) and the Algaebase database (www.algaebase.org/) provide the most up to date consensus on algal species classification and traits. Table 1 provides a summary of the major algal groups, based on the information in John et al. (2011), Algaevision Algaebase and the Tree of Life project. The commonest terms in industrial and academic meetings are “microalgae”, “macroalgae”, “blue-green algae”, “cyanobacteria”, “seaweed”, “diatoms”, and “green algae” and we have indicated in Table 1 where these groups belong within the formal taxonomic classification.

Prominent algal species used in biotechnology such as *Chlorella* and *Chlamydomonas* are grouped under the green algal phylum Chlorophyta. Many other industrially relevant species such as *Phaeodactylum*, *Isochrysis*, *Euglena* and *Nannochloropsis* are taxonomically different phyla in other kingdoms of Eukaryotes (Table 1). For instance, *Phaeodactylum* is specifically a diatom, as are *Chaetoceros* and *Skeletonema,* widely cultivated as feed for aquaculture. The single most prominent and successful object of algae biotechnologists, *Arthrospira* (spirulina) is a cyanobacterium.

Outside the genetic and morphological taxonomy, algal species can also be grouped and defined based on their functionality (i.e., how and where they grow). These include:

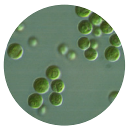
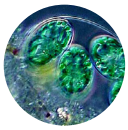
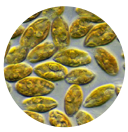
1. The way the algae grow (e.g., suspended in growth media, or attached as biofilms). Most algae grow photoautotrophically by photosynthesis, using sunlight to convert CO_2 and a few nutrients, including nitrogen and phosphorous, into biomass. Some of these algae are also able to grow heterotrophically in the dark using a range of organic substrates, or even combine both growth modes (called “mixotrophic” growth).

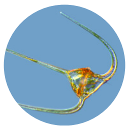
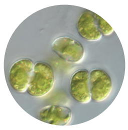
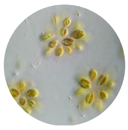
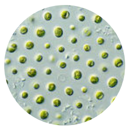
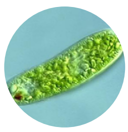
2. The type of habitats in which the algae grow (e.g., salt-loving halophytes, or cold-tolerant psychrophilic species), soil dwelling or aerial microalgae thriving outside of open waters in or on soils and even in deserts exploiting temporary moisture availability.

Table 1: Summary of algal Taxonomic groups, based on John et al. (2011), Algaevision, Algaebase and Tree of Life project;

All contain chlorophyll a, but the presence and relative proportions of the accessory pigments (chlorophyll *b*, chlorophylls *c*, phycobilins, and carotenoids) determine the actual colour of the cells. The cyanobacteria are prokaryotes, whilst all other groups are eukaryotes, with a nucleus enclosing the genetic material, and subcellular organelles (e.g., the chloroplast).

The tentative classification of the different algae phyla into the four different kingdoms of eukaryotes according to the Tree of Life project *(http://tolweb.org/tree/)* are indicated to demonstrate the evolutionary diversity, although the final classification of the eukaryote domain remains a subject of heated discussion.

ALGAE GROUP (COMMON NAME)	GENERAL CHARACTERISTICS	REPRESENTATIVE PHOTOS	COMMONLY REFERRED TO AS:
	Domain Eubacteria		
Cyanobacteria (blue-green algae/ cyanophyta)	» Blue-green, grey-green, violet, brown, purplish or red. » Accessory pigments are bilins: phycocyanobilin (blue), phycourobilin (orange) and phycoerythrobilin (red), present in different proportions depending on the species. » Unicellular, colonial or filamentous; » Internal thylakoid membranes present, but no organelles as such.		Blue-green algae Microalgae
	Domain Eukaryotes		
	Kingdom Archaeplastida (Plantae)		
Chlorophyta (green algae)	» Cells with one to several chloroplasts, clearly green. Major accessory pigment is chlorophyll *b*, direct evolutionary precursors of higher plants; » Unicellular, colonial, filamentous, coenocytic, or macrophytes with robust axes bearing fronds (blade, sometimes with stipe or stem); » Motile or non-motile - if motile then normally have one, two or four usually apical flagella; » Food storage material - principally starch surrounding one to several pyrenoids; » Sexual reproduction oogamous in some orders.		Macroalgae Seaweeds Microalgae Green algae
Glaucophyta	» Cells are bright blue-green due to presence of phycocyanin and other pigments in cyanelles (equivalent to chloroplasts); » Unicellular or colonial; » Food storage material – starch, produced outside the cyanelles.		Microalgae
Rhodophyta (red algae)	» Commonly red due to predominance of accessory pigments phycocyanobilin and phycoerythrobilin; » Unicellular, filamentous or pseudoparenchymatous; » Food storage material - various, including floridean starch.		Macroalgae Seaweeds Microalgae
	Kingdom Chromalveolates		
Bacillariophyta (Diatoms)	» Cells with cell wall made of silica, called frustule. Yellowish-brown chloroplasts typical of heterokonts, surrounded by four membranes. Major accessory pigment is chlorophyll c and the carotenoid fucoxanthin; » Unicellular or colonial, forming colonies in the shape of filaments, ribbons, stars or zigzags. According to their simmetry they are usually classified as centric or pennate; » Non-motile, with only the male gametes of the centric diatoms possessing flagella; » Food storage material – chrysolaminarin and lipids.		Diatoms Microalgae

Cryptophyta (cryptomonads)	» Brown, blue, blue-green, red, red-brown, olive green, or yellow-brown due to accessory pigments chlorophyll c, and the bilins phycoerythrobilin or phycocyanobilin; » Unicellular (rarely colonial), often bean-shaped; » Food storage material - starch.		Microalgae
Dinophyta (dinoflagellates)	» Usually brown due to presence of accessory pigments, chlorophyll c and carotenoid peridinin; » Unicellular, rarely coccoid or filamentous; » Walls firm or of regularly arranged polygonal plates, biflagellate, one wrapped round body of cell; » Food storage materials – starch and oil.		Microalgae Sometimes confused with diatoms (see below)
Raphidophyta	» Yellow-green with two or more chloroplasts. Contains chlorophyll c and may or may not have fucoxanthin. Marine species have violathanin, whilst fresh-water species use diatoxanthin and heteroxanthin as accessory pigments » Unicellular with no outer wall, two flagella; » Food storage material - oil.		Microalgae
Haptophyta	» Cells are golden or yellow-brown due to presence of accessory pigments chlorophyll c, fucoxanthin, and diatoxanthin ; » Unicellular, two flagella; » Food storage material - principally chrysolaminarin.		Microalgae
Chrysophyta (golden-brown algae)	» Cells are golden to yellow-brown. Accessory pigments chlorophyll c, fuxoxanthin and violathanin; » Single coccoidal cells or palmelloid, filamentous or parenchymatous, mostly uniflagellate; » Silica scales sometimes present; » Food storage material - oil or leucosin.		Microalgae
Xanthophyta (yellow-green algae)	» Cells are typically yellow-green, contains chlorophyll c and diatoxanthin as accessory pigments; » Unicellular, filamentous, colonial or coenocytic; » Motile forms have two subapical flagella; » Food storage material – oil or leucosin;		Microalgae
Eustigmatophyta	» Cells are yellow-green. Does not contain chlorophyll c, but main accessory pigment usually violathanin in one or more chloroplasts; » Unicellular and coccoidal; » Motile forms have one flagellum or two unequal flagella inserted near apex; » Eyespot unique, independent of chloroplast; » Food storage material unknown.		Microalgae
Phaeophyta (brown algae)	» Cells are brownish due to presence of carotenoids pigments (principally fucoxanthin and violathanin); » Freshwater species of microscopic branched filaments (often closely packed); » Walls frequently contain alginic acid and fucinic acid; » Food storage materials - laminarin and mannitol.		Seaweeds (e.g. Kelp) Macroalgae and Microalgae
	Kingdom Excavates		
Euglenophyta (euglenoids)	» Green, because of accessory pigment of chlorophyll b. Contains red eyespot formed of carotenoids. Chloroplast surrounded by 3 membranes; » Commonly unicellular, exhibiting squirming movements; » Food storage material – paramylon.		Microalgae

Adapted from: Carter CF, John DM, Wilbraham J (2016) AlgaeVision: Virtual Collection of Freshwater Algae from the British Isles. Version II. World Wide Web electronic publication. *www.nhm.ac.uk/algaevision.html*

Questions and Answers about ‘algae’

Some key questions and straightforward answers in the view of EABA experts.

Are algae plants?
Yes and No. Green and red algae can be considered "simple plants" since they are ancestors of higher plants. Some species, including economically important phyla such as brown algae, diatoms, eustigmatophytes, or euglenoids are the result of a second endosymbiosis event of a red - or green alga - with other, eukaryotic host cells derived from different kingdoms of life that are not related to plants.

Are algae a crop?
Yes, algae are a crop with a diverse number of species being cultured or harvested from the wild.

Is algae production agriculture?
Yes, algae cultivation is an agricultural process.

Is algae cultivation in fermentors an industrial process?
No, algae production in fermentors is primary sector. Algae biomass transformation is industry (secondary sector).

Is algae production aquaculture?
Yes, algae cultivation can be considered as an aquaculture activity because it takes place in an aquatic environment.

What is the difference between macro and microalgae?
Microalgae are unicellular or small colonial or filamentous species, and generally microscopic (only visible with a microscope), whereas macroalgae are multicellular and can be up to 60 m in length.

What is the difference between macroalgae and seaweeds?
They are the same thing.

What is the most appropriate way to identify algae?
The fastest way for reliable identification of algae is determination of key DNA sequences, e.g., of the 18S rDNA gene, the rbcL gene or similar.

What are pure algae?
Where a single algal species is present in a culture without contaminant organisms, that is axenic culture.

What is the difference between axenic and unialgal?
The latter is a culture containing just one algal species, but there might be some other organisms – bacteria, fungi – present too. Axenic is a pure culture of a single organism.

What is the difference between autotrophic or photoautotrophic and heterotrophic?
Autotrophic means growing on inorganic carbon (CO_2) as carbon source. Photoautrophic combines growth using light as energy source and inorganic carbon as carbon source. Heterotrophic means growth on organic carbon as carbon source.

What are organic algae?
Organic refers to products that meet certain requirements of cultivation, e.g., absence of synthetic fertilizers and pesticides as defined, e.g., by USDA Organics Food Production Act, USDA NOP (National Organics Program, under the National Organics Law) and in Europe a similar legal and regulatory framework, with both US and EU organic regulations supposed to be mutually acceptable.

What are GMO algae?
The definition is the same as for any other GMO (plant, animal, bacterium etc.).

What are mutant algae?
Mutant algae have one or more characteristics that are different from the original strain. Mutants can arise spontaneously or as a result of treatment to modify DNA. This can sometimes be by genetic manipulation, natural (spontaneous) or induced. Mutants are generally not considered GMOs.

What are toxic algae?
Some species of algae produce toxins to prevent competition with other algae, or to deter predators, often when they bloom in the natural environment. Many of these are so-called harmful algal bloom (HAB) species. However, the vast majority of algae do not have toxic characteristics.

How does the Nagoya protocol apply to algae?
The Nagoya protocol refers to organisms within a national jurisdiction, so any algae collected from a region falls within its remit. The high-seas are not included, nor any species/strains collected before October 2014 (even if utilisation happens after October 2014).

What is the difference between *Arthrospira* and Spirulina?
From a taxonomic point of view spirulina belongs to the genus *Arthrospira*, while *Spirulina* identifies different non-edible cyanobacteria that can even be toxic. These latter have a much lower diameter of the filament, not containing GLA, without gas vesicles. It is important to avoid that people cultivate for food *Spirulina* instead of *Arthrospira*.

NIHIL VILIOR ALGA - OR HOW THE LACK OF KNOWLEDGE OF SEAWEEDS CAUSED THE COLLAPSE OF THE ROMAN EMPIRE...

by Jonas Collén - Station Biologique de Roscoff. France

I have worked with and studied seaweeds for 16 years and this is somewhat of a mystery to my non-biologist friends. What possible change can an increased knowledge of seaweeds bring? Why not work with something more useful, like human health, or something better paid, like business? When I pondered that and read something totally unrelated to seaweeds I found an excellent reason why we should study seaweeds and why it matters- the lack of knowledge of macroalgae caused the collapse of the Roman Empire.

Not much is known about seaweed use and knowledge in classical Europe. However, Bellum Africanum, written in 46 B.C., officially by Julius Caesar, but in reality probably by someone else, states that the Greeks collected seaweed from the shore and gave it to their cattle (Indergaard & Minsaas 1991). This means that useful properties of seaweeds were known even by the mighty Caesar. However, there are indications that seaweeds were held in low esteem by the Romans and this, unknown to them at that time, was a contributing factor to the fall of the Roman Empire; one of the mightiest empires that has ever existed.

This lack of appreciation of seaweeds is exemplified by two quotes, one from Horace, Quintus Horatius Flaccus, an outstanding poet and satirist who lived 65-8 B.C. Maybe he is more known for the quote "carpe diem" than the following from Satires (II, 5, 8): "Et genus et virtus, nisi cum re, vilior alga est." (Noble descent and worth, unless united with wealth, are esteemed no more than seaweed.) If you find this quote strange; note the name of the book.

The other quote is from Virgil, Publius Vergilius Maro, (70-19 BC) often called the greatest Roman poet, who wrote in Bucolics: "Immo ego Sardoniis videar tibi amarior herbis, horridior rusco, proiecta vilior alga." (Nay, but may I seem to thee bitterer than herbage of Sardinia, rougher than the spiky broom, more worthless than stranded seaweed.)

Although taken out of contexts, these quotes clearly show that seaweeds were not very fashionable in the Roman society; in fact they were used as metaphors for the utterly worthless by two of the giants of early Western civilization. But how did this cause the fall of the mighty Roman Empire?

It has been suggested that lead poisoning contributed to the decline of Rome (Nriagu 1983), through the use of lead pipes, to transport water, and lead cauldrons, especially when used for the production of a concentrated grape juice called sapa or defrutum. Lead leaked from the pipes and cauldrons slowly poisoning the once so proud Romans. It is well known that seaweed polysaccharides, especially alginates, have the capacity to bind heavy metals, such as lead. In fact, seaweeds products have been used to diminish problems caused by toxic heavy metals. Alginate containing species that can be found around the Italian peninsula includes for example: Laminaria ochroleuca, L. rodriguezii, and Fucus virsoides. In addition, the Roman Empire included large parts of the Atlantic coastline in Europe and an effective (by the standards of the time) transport system which could easily have been used to import seaweeds such as Laminaria to Rome.

Had the Romans held seaweeds in higher esteem and eaten more seaweed products, cleaning their bodily systems of lead, then maybe this text would have been entirely in Latin, the year would not be 2005, but 2755 (number of years since the founding of the city of Rome), or possibly MMDCCLV and the author be named Jonasus Collenius. I therefore urge the present imperial, national and local funding agencies to support seaweed research in order to avoid a collapse of civilization as we know it. Remember, the Roman Empire fought "terrorism" successfully for centuries, but succumbed to limited resources for seaweed research.

SELECTED REFERENCES

Indergaard M & Minsaas J 1991. Animal and Human Nutrition. In: Seaweed Resources in Europe: Uses and Potential, (Ed. M.D. Guiry & G. Blunden).

Nriagu JO 1983. Saturnine gout among Roman aristocrats: Did lead poisoning contribute to the fall of the Empire? New England Journal of Medicine 308, 660-663
in: https://listserv.heanet.ie/cgi-bin/wa?A2=ALGAE-L;994c2f19.051013 [acessed in Oct 2005]

Archibald JM. (2015) Endosymbiosis and Eukaryotic Cell Evolution. Curr Biol. Oct 5;25(19):R911-21. doi: 10.1016/j.cub.2015.07.055.

John and Maggs (1997) Chapter 5, pp. 83-107. In: Species problems in eukaryotic algae: a modern perspective Species in: The Units of Biodiversity. Ed. Claridge, M.F., Dawah, H.A. & Wilson, M.R. 1997. Chapman & Hall. London. DAVID M. JOHN* and CHRISTINE A. MAGGS*

John et al. (2011) The Freshwater Algal Flora of the British Isles"

Frederik Leliaert, Olivier De Clerck (2017) Refining species boundaries in algae First published: 13 March https://doi.org/10.1111/jpy.12477

Leyland B, Leu S, Boussiba S. 2017, Are Thraustochytrids algae? Fungal Biol. 2017 Oct;121(10):835-840.

Simpson, Alastair G.B.; Roger, Andrew J. .(2004) "The real 'kingdoms' of eukaryotes". Current Biology. 14 (17): R693–R696. doi:10.1016/j.cub.08.038. PMID 15341755

Cavalier-Smith, T. (1998). "A revised six-kingdom system of life". Biological Reviews. 73 (3): 203–66. doi:10.1111/j.1469-185X.1998.tb00030.x. PMID 9809012

Cavalier-Smith (2016) Higher classification and phylogeny of Euglenozoa. European Journal of Protistology 56: 255,

Ruggiero, Michael A.; Gordon, Dennis P.; Orrell, Thomas M.; Bailly, Nicolas; Bourgoin, Thierry; Brusca, Richard C.; Cavalier-Smith, Thomas; Guiry, Michael D.; Kirk, Paul M.; Thuesen, Erik V. (2015). "A higher level classification of all living organisms". PLOS ONE. 10 (4): e0119248. Bibcode:2015PLoSO..1019248R.

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