Industrial Importance of Marine Algae

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Abstract

The biosphere is now a busy, thriving place due to the microbial occupants of the globe ocean. Additionally, marine microflora may have been the first lifeforms on earth and, therefore, the progenitors of all lifeforms, a distinction that places marine microorganisms in a central spot in the saga of evolution. This is due to the fact that existence on this biosphere most likely apparently started in water. The biosphere's workhorses, marine bacteria, complete many of the processes in these biogeochemical cycles. Marine bacteria, which possess a wide range of potential activities, are responsible for the majority of the planet's metabolic

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processes that maintain the elemental cycle. Additionally, marine microbial populations have high metabolic rates. Even while terrestrial species make up the great bulk of the planet's biomass (3200 gigatons or more, or 1015 kg), marine plankton, which weigh around 0.4 gigatons, are responsible for 45% of the planet's overall oxygen respiration. Microalgae inhabit unique environments that compete for space and nutrients, and have excellent adaptation strategies to live under different physicochemical conditions. Therefore, they evolve with fantastic defense strategies to generate new secondary metabolites (natural bioproducts). In general, the production of these bio-products varies between species and even within the same algae. The production of organic products depends on factors such as environmental conditions, season, geographic location, and life cycle stage. Biologically active compounds (bioproducts) are physiologically active substances that have functionality in the human body.

Keywords

Marine plankton · Biogeochemical cycles · Fisherelin · Cyanobacteria

16.1 Introduction

Microbial life in the waters altered the chemical equilibrium of the oceans and atmosphere over millions of years following the development of the earliest life forms and introduced gradients of oxidizing (electron-scavenging) and reducing agents (electron sources) (Adrian et al. 2009). Molecular oxygen was first introduced to the atmosphere by early bacteria, which paved the way for the emergence of plants, creatures, and eventually humans. A new era of chemistry, based mostly on redox chemistry—the transfer of electrons from one molecule to another—was ushered in by these microbe-induced alterations. The stable biogeochemical and climatological oscillations that support life on this planet are now based on redox chemistry (Bahr et al. 1996).

Salinity, currents, terrestrial inputs, and climate are just a few of the many forces and factors that have an impact on the microbial ecosystems in the seas (World Health Organization (WHO) 2008). In the open ocean, salinity is generally constant, although it is less consistent along the coast. Our knowledge of transport systems in the deep sea has been significantly affected by the discovery that ocean and seafloor currents operate differently than previously believed. Gradients of nutrients, contaminants, and other material are produced by terrestrial inputs, which have an impact on habitats. The highest scale of influence on microbial ecosystems comes from climate effects. Marine communities can be impacted by temperature, precipitation, and wind (especially windborne particulate matter) (Todar 2009; Scheutz and Strockbine 2005).

Importantly, marine microorganisms themselves have an impact on their environments through the consumption, production, and sequestration of various chemicals. As a result, microbe-controlled mechanisms frequently regulate gradients of materials crucial to both micro- and macroorganisms in the ocean (Wilson 2005).

Microbial environments change throughout many time scales—diel (day to day), occasional, decadal, and longer. A significant number of the progressions prompted by human exercises can affect marine microbial networks and, thus, can influence the ways by which those networks tweak the climate and environment (Biavati and Mattarelli 2003). Transient changes in marine microbial natural surroundings can be outlined by portraying three unique living spaces: the focal Pacific gyre, the Chesapeake Bay, and aqueous vents. The focal Pacific gyre is an untamed sea environment that changes on a diel premise, yet it has likewise displayed changes over a long time as movements happen between local area mastery by diatoms and by picoplankton (Ishii et al. 2006; Carpenter et al. 2005). The Chesapeake Bay displays diel changes, checked occasional changes, and significant decadal changes over the recent hundreds of years as human exercises have caused significant damage. Aqueous vents display both short and significant stretches of variance, adjusting over the direction of minutes, hours, and many years. This fluctuation makes a fleeting and erratic living space for microorganisms (Chaffron et al. 2010; Comté et al. 2006; Eiler and Bertilsson 2004).

The issue of either sea microbial variety are either wordlywise, or are limited and restricted to sure terrestrial regions, was produced decades in the past. Current evidence displays that most coastal bacteria are not wordlywise, but, alternatively, are limited to distinguishing resistance types or terrestrial parts (Lindeman 1942; Lindström et al. 2005; Liu et al. 2009). However, skilled are any instances of really worldly-wise structures, containing the open ocean-ocean sea group I archaea. Many sea surface waters claim constant sales of nearly 106 microorganisms and 107 viruses per milliliter, a condition that concede possibility be contingent on mineral disadvantages and predatoriness controls required by protists and viruses. In few cases, microbial society numbers are retained at about an order of size beneath the giving competency of the habitat—presumably by predatoriness (Logares et al. 2009; Newton et al. 2006). Viruses grant permission synchronize accompanying their hosts, serving to makeup societies and variety, but few studies have proves that there placement of viruses from a method has no effect on bacterial affluence and society form. Protists, play a more opposing, less critical part in stable state support of bacterial container abundances by absorbing many various types of bacterial dupe (Nold and Zwart 1998; Rheinheimer 1980).

Marine microorganisms seize any of metabolic wherewithal that cannot reside earthly microorganisms. As in added environments, the geochemical residence drives the progress of various metabolic proficiencies in the sea atmosphere. For example, cold surroundings familiar the cool drive various reworking than extreme heat, press residences forthcoming hydrothermal vents. Methane seeps are another model of a particularly sea surroundings that has instigated novel metabolic wherewithal. In poison gas seeps, extreme sulfate concentrations integrate accompanying extreme poison gas concentration to favor the anaerobic corrosion of poison gas, an absorption raise only in the oceans. The light compelled protons send proteorhodopsin, that is established only in sea microorganisms, giving an understanding to play a main act in the strength balance of the residence by way of allure strength to capably produce strength from light. The use of sodium weak transporters is more restricted to sea microorganisms. Marine symbioses, containing the symbioses betwixt macroorganisms and bioluminescent microorganisms and middle from two points shipworms and nitrogen repairing cellulolytic microorganisms, have likely encourage in activity many singular metabolic actions.

16.2 Natural Algal Products and Biological Significance

Microalgae are microscopic organisms commonly found in freshwater, estuarine, and marine environments (Mobin and Alam 2017, 2018). These are usually single-celled microorganisms that exist individually, in chains, or in groups. Sizes vary from a few microns to hundreds of microns depending on the species (Mobin and Alam 2018; Alam et al. 2014; Suganya et al. 2016). They are photoautotrophic organisms that can make complex compounds using simple substances normally available in the environment. It is estimated that there are between 200,000 and 800,000 species of microalgae, of which about 50,000 have been described (Mobin and Alam 2018; Richmond 2004). Because they live under a variety of environmental conditions, they have evolved many defense mechanisms to survive under adverse climatic conditions (varying salinity, temperature, nutrients, ultraviolet radiation, etc.) and eventually new structures. They create a wide range of attractive compounds with a wide range of bioactivity (Herrero et al. 2013). Microalgae therefore provide a commercial source for a variety of high-value bioproducts.

16.3 High-Quality Commercial Bioactive Natural Products

Microalgae have been described as true natural reactors for the production of bioactive natural products and are an excellent alternative to chemical synthesis of certain bioactive natural products of commercial interest (Plaza et al. 2009). We have a great interest in developing and manufacturing various bioactive compounds that may be used as functional ingredients such as carotenoids, phycocyanins, polyphenols, fatty acids, and polyunsaturated compounds. Microalgae-derived bioactive compounds such as proteins, fatty acids, vitamins, and pigments are obtained directly from primary metabolism or synthesized from secondary metabolism (de Morais et al. 2015). In most microalgae, bioactive compounds are rich in biomass. However, in some cases, these metabolites are seccreted into the medium (de Morais et al. 2015).

16.3.1 Antioxidants

Microalgal biomass is a rich natural source of antioxidants with potential applications in human food and aquatic feeds, cosmetics, and pharmaceuticals (de Morais et al. 2015). The use of antioxidants for health has been stimulated by the observation that free radicals and oxidation are involved in many physiological functions that lead to disease states. In the process of evolution, they have adapted uniquely to extreme habitats. A photosynthetic lifestyle leads to high oxygen levels and severe stress. This leads to the development of numerous effective defense systems in the body to prevent the accumulation of free radicals and reactive oxygen species, and this mechanism protects microalgae from cell-damaging effects.

16.3.2 Cosmetics

Cosmetics refers to substances applied to the human body for cleansing, healing, antisun, antibacterial, antiaging, anticellulite, moisturizing, beautifying, perfuming, altering appearance, and other purposes. No more harm to human health than soap (Saraf 2012). Numerous formulas have been developed to smooth, revitalize, and beautify skin, hair, and more (Novak et al. 2014). Microalgae extracts are already used as raw materials in cosmetics containing biologically active ingredients claimed to have medicinal or drug-like benefits (Borowitzka 2013). These extracts are commonly found in cosmetic packaging, especially as ingredients for face, hand and body creams or lotions (Anbuchezhian et al. 2015). The microalgae and cyanobacteria like *Arthrospira, Donaliella, Haematococcus,* and *Chlorella* are mainly used in cosmetics (Borowitzka 2013). Extracts from these microalgae are added to regenerating creams and lotions. It is also used in sunscreens, shampoos, and hair masks. *Chlorella vulgaris* extract has been reported to stimulate collagen synthesis in the skin. It also contributes to fiber regeneration and reduces wrinkles on the skin surface (Codif, France). Protein-rich *Arthrospira* extract slows skin aging (Exsymol, Monaco).

16.3.3 Antifungal Properties

Cyanobacteria (cyanobacteria) are a highly diverse group of Gram-negative prokaryotes and the oldest photosynthetic organisms: 2000 different strains of freshwater and marine cyanobacteria have been found worldwide, demonstrating remarkable ecological diversity. Its ability to grow under adverse conditions and its autotrophic properties make it suitable for cultivation in nutrient-poor lakes, ponds, and seas that pose a serious threat to water and cause eutrophication (Chorus and Bartram 1999; Duy et al. 2000). This can lead to unpleasant tastes and odors in water due to the release of volatile compounds (Jones and Korth 1995). According to Hunter, several genera of cyanobacteria have been reported to produce toxic aquatic flowers and various toxins (Hunter 1995). Known for their diverse antibacterial activity, microalgae are used worldwide to manufacture a variety of value-added products. Pharmaceutical companies, especially drug discovery departments, have continued this 40-year research to extract new compounds and drugs from cyanobacteria. Development without the addition of organic substrates has practical advantages over microorganisms. Lesser availability and high cost of next-generation antibiotics led to the search for new agents with antibacterial activity. The medicinal and nutritional properties of cyanobacteria were first recognized in 1500 BC when *Nostoc* species were used to treat gout, fistula, and some cancers. Cyanobacterias are also antibiotic resistant. Cyanobacteria are a source of antifungal compounds: Flavanoid-type compounds, fisherelin A, phytoalexin, tritoxin, laxaphycin, ambigin, calophycin, scutophytin, and laxaphycin are found in *Oscillatoria, Cytonemapseudohoffmani*, and *Anabaena laxa*. It is isolated from another species of cyanobacteria that is thought to have antifungal properties. It is isolated from another species of cyanobacteria that is thought to have antifungal activity (Chauhan et al. 2020).

16.3.4 Anti-Inflammatory and Analgesic Agents

A significant portion of pharmaceutical waste in 4444 wastewater consists of anti-inflammatory (AI) and analgesic (AN) agents, which are used as analgesics and anti-inflammatory agents, respectively (Fent et al. 2006). Both groups of chemicals are in widespread nonprescription use, with estimated annual consumption in developed countries of several hundred tons (Daughton and Ternes 1999). Because they contribute significantly to the total amount of pharmaceutical contamination in water, this study explores the most common and commercially available AN and AI chemicals, their occurrence and fate in the aquatic environment, and their therapeutic potential. We aim to provide a thorough and critical review of sewage and drinking water treatment plants. Occurrence and Fate of AN and AI in the Aquatic Environment Individual concentrations in surface waters are shown to be within the GLA 1 range, indicating a high proportion of municipal wastewater (Heberer 2002; Mompelat et al. 2009; Boyd et al. 2003; Quintana et al. 2005; Buser et al. 1999). Therefore, most of the AI/AN agents and metabolites used are ultimately discharged into water bodies regardless of the wastewater treatment efficiency of wastewater FAH. The much lower volume of surface water than sewage treatment plant effluent is due to dilution effects and the potential for removal by natural pathways such as hydrolysis, sorption, biodegradation and photolysis. However, some PhAC residues (such as ANs/AIs) can enter aquifers under recharge conditions and have been detected in groundwater samples from water supplies behind urban sewage treatment plants (Heberer 2002). Studies on the fate of anti-inflammatory and analgesic PhACs in received water indicate that many of them and their metabolites are metabolized by a combination of abiotic and biotic processes and direct or indirect phototransformation (Tixier et al. 2003; Miège et al. 2009; Sedlak and Pinkston 2001). Mechanism-determined: In surface waters throughout the food chain, some of the residues may undergo biotransformation, but the extent of transformation by abiotic reactions is much greater (Rahman and Lowe 2006). In the literature we reviewed, we found that hydrolysis is a minor elimination pathway for environmentally relevant human drugs, most of which are transformed by photolytic and biodegradative processes. We also found that human drugs that cannot absorb solar radiation (nonphotolabile) are relatively biodegradable, and poorly biodegradable or partially biodegradable drugs are photoreactive.. IBP was the only human drug (among those examined in this study) characterized by a high sorption coefficient. Therefore, they migrate into sediments as an additional removal pathway (Tixier et al. 2003; Ziylan and Ince 2011).

16.4 Biotransformation of Arsenic in Algal Cells

Polysaccharides, proteins, chitin, lipids, and vitamins. In the food web, the main producers are edible macroalgae, commonly known as algae. As a medicine and food source, algae are mainly used to produce nutritious products. Algae are also called sea vegetables (Zhao et al. 2018). In the Hawaiian Islands, seaweed is used by humans as a seasoning instead of pepper, oregano, or mustard (McDermid and Stuercke 2003). A myriad of bioactive molecules, including proteins, amino acids, lipids, fatty acids, carbohydrates, sterols, vitamins, and bioactive pigments, is derived from microalgae and is useful in the production of a wide range of nutritious foods and industrial-scale pharmacological applications. (Zhao et al. 2018). Iodine is abundant in freshwater algae. Although food is obtained from terrestrial plants, the iodine content is low and seaweed is a cheaper food option because of the human iodine need (Rajapakse and Kim 2011). The use of freshwater algae is valuable because of its potential applications in industries such as the pharmaceutical, nutraceutical, and cosmetic industries (Gopeechund et al. 2020; Sansone et al. 2020). Many algae antioxidants, such as peptides, polyphenols, polysaccharides, and carotenoids, have been found to be antibacterial, anticancer, antidiabetic, anti-Alzheimer's, Antifibrotic, and neuroprotective (Hosseini et al. 2020). Freshwater organisms and their metabolites produce successive extracts in the form of antioxidants, pure substances, and biomass (El-Shafei et al. 2021). A rich source of natural antioxidants such as sponges, sea squirts, bryophytes, lichens, bacteria, fungi, algae and microalgae. Freshwater algae are the best source of natural antioxidants. The main purpose of antioxidant production in freshwater microalgae and the cleaning ability of such antioxidants is to produce microalgal compounds such as vitamins, sterols and phenolic compounds (Widowati et al. 2017). The potential value and market demand of freshwater microalgae related to carotenoid accumulation is high due to their rapid growth, active metabolism, balanced biochemical precursors and bioproducts (Batista et al. 2013).

16.5 Classification of Algae

Phaeophyte Brown algae (Phaeophytes): There are approximately 1780 species of brown algae and are currently classified in the family Fucoidaceae (or Pheophyta) of the phylum Zooxanthora (De Reviers et al. 2007); this class includes 17 orders Brown algae are notaclose relative of red and green algae, although they are macroscopically similar and intermingled on rocky shores. They belong to another kingdom (Chromista) and their closest relatives are microscopic algae (diatoms, chrysophytes, zooxanthellae) that live in marine and lake plankton. Brown algae are found in all these as of the world, but are more diverse and abundant in coldwaters; especially their largest and most spectacular representatives (Laminariares and Desmareschares species) wholly confined to cold polar and temperate waters. The morphological diversity of brown algae is not inferior to that of green algae and red algae. Filamentous species is composed of finely branched rows, such as *Ectocarpus* and *Pylaiella*, grow on intertidal rocks or larger algae in many parts of the world. However, most brown algae are larger and look like branching ribbons, shrubs, or small trees. Members of Fucales are algae of particular ecological importance, as they form dense areas in the intertidal zone of many rocky coasts of temperate seas. For this reason, they generate habitat that supports enormous biodiversity and are considered keystone species; the Fucus Belt in the North Atlantic and Cystoseira in the Mediterranean are well-known examples. The order also includes the only example of macro algae that float permanently and never clings to the bottom of a rock: the Sargasso Sea in the middle of the North Atlantic Ocean is an area bounded by ocean currents where large amounts of Sargassum are constantly floating around.

TBrown seaweed is largest known seaweed. It belongs to the order of seaweeds represented by the word kombu Ecklonia, Eisenia, Laminaria and Lessonia species produce similar underwater forests in other parts of the world. Anatomically and morphologically, seaweeds are also the most complex algae. Their tissues contain a large number of cells and structures, and their complexity is comparable to that of vascular plants. Based on information about their DNA sequences, their classification has recently changed. Green algae are currently defined as not forming homogeneous, cohesive entities. Instead, they belong to a larger group called Viridiplantae, which also includes terrestrial plants (Lewis and McCourt 2004). Alga is the name of a class that includes all marine green algae. About 920 species inhabit the algae family, which is widely distributed in the world's oceans. The algal bodies of green algae have a wide variety of morphologies, but most of them are very simple. Cladophora and Chaetomorpha are two common taxa, both containing branched or unbranched thin filaments. The sea lettuce species is sometimes called sea lettuce because of its appearance, which is a leaf composed of two layers of cells. These algae grow quickly and are well known for their ability to absorb nutrients from seawater. The growth of sea lettuce is a typical phenomenon in eutrophic waters. If this development is left unchecked, huge masses of sea lettuce accumulate, causing the so-called green tide, which requires mechanical removal of the algal biomass. A specific type of body tissue that exists. Two orders of siphonic green algae—Bryopsidales and Dasycladales—are among the most ecologically effective algae.

These algae consist of a single giant cell with multiple nuclei that serve as its body. *Caulerpa* is the best known genus of siphonal algae. Tropical and warm temperate waters are home to a wide variety of *Caulerpa* species. They are widely used in tropical aquariums and are very popular with aquarium enthusiasts due to their beautiful habits (Stam et al. 2006). Unfortunately, this type of algae tends to grow uncontrollably and rapidly. The spread of *Caulerpa taxfolia* in the Mediterranean Sea after its accidental release from the Maritime Museum of Monaco was one of the most notable instances of land invasion by marine organisms. In the years that followed, *Caulerpa racemosa* var. Cylindracea, introduced from Australia by an unidentified route, has also actively overgrown the Mediterranean Sea (Verlaque et al. 2003; Piazzi et al. 2005).

Different types of eatables like pasta, vegetable soups breads and snacks (Nunes et al. 2020) have contributed to huge growth in industries. The algal industrial revolution has marked an impressive step toward achieving the Sustainable Development Goals (SDGs) and increasing energy demand. Algae production uses closed, lighted culture vessels to process biomass. It can be defined as a photobioreactor (PBR) that seals a nonenvironmental structure without actively transporting gases or contaminants. PBR allows control of pH, temperature, light intensity, and carbon dioxide rate. Low carbon dioxide content and minimal water evaporation enable high concentration production of complex biopharmaceuticals. Many types of this PBR have been developed to culture algae for bioenergy and bioproducts production (Ugwu et al. 2008). PBR plays a valuable role in algae production, producing large amounts of microalgae for universal cultivation of many species. The PBR architecture ensures uniform illumination of the culture surface and rapid mass distribution of carbon dioxide and oxygen. Microalgae cells are highly adherent and can exchange light on the reactor surface. The reactor architecture aids in algal production, reaching rapid levels of mass transfer by not damaging or inhibiting the cultured cells. Products made from seaweed are available in large quantities in the global market. Microalgae are photosynthetic eukaryotes that grow in both freshwater and seawater. The bioactive components of microalgae consist of lipids (12–48%), proteins (18–46%), carbohydrates (18–46%), and carotenoids (10–14%) (Khoo et al. 2020; Koyande et al. 2019; Tang and Ying 2020; Tibbetts and Injaian 2014). In the biopolymer industry, algae are a potential starting material due to their rapid biomass productivity, five to ten times faster than conventional food crops (Makareviciene et al. 2013). Algae are useful not only as an excellent food source, but also because the biodegradability of algae-based bioplastics is beneficial for a variety of purposes in industries such as packaging of polymers in the food industry, agriculture, and horticultural polymers. (Zeller et al. 2013). In the circular economy, algae-based bioplastics are being investigated as a sustainable solution. This is because it can be converted into a natural material by composting using plastic bags, making it a useful alternative to peat to end the life cycle of bioplastics (Khoo and Tan 2010). From indoor photobioreactors, microalgae cultures can be easily grown and do not require cultivated land (Karan et al. 2019). For microalgae, the culture medium is saved with the help of wastewater resources compared to chemical-based culture medium (Karan et al. 2019; Leong et al. 2019; Gómez-López et al. 2019). Algae-based biopolymers offer key advantages for green production and help improve waste management (Rendon et al. 2016). In algae production, the biorefinery has revealed that early development stages do not cause damage or pollution to the atmosphere. In nature, algae absorb CO_2 and release oxygen into the environment (Khan et al. 2018). To produce algal biopolymers, this process can operate with less maintenance and energy consumption compared to other polymer manufacturing industries (Ortelli et al. 2019). The production of microalgae culture consists of two types: indoor photobioreactor and outdoor open pond cultivation. Davis et al. (2011). Scale-up systems and indoor PBR manufacturing require proper design to support construction and cleaning-in-place (CIP) systems (Zhu et al. 2017). In biopharmaceuticals, algae have valuable properties such as low production costs, absence of toxic compounds in many species, high biosynthetic capacity, and potential use as oral delivery vehicles. They are important hosts. Microalgae are single-celled microorganisms that can be easily grown on very inexpensive media. Photosynthetic algae require minimal nutrients in the system for sunlight to drive biomass production. Photosynthetic algae are very useful in sewage treatment. The primary energy source for this algae is light, and it absorbs carbon dioxide and nutrients for metabolism.

16.6 Conclusion

Thus, the production of algal species is a major source of food ingredients that do not require rigorous purification, and these species do not produce toxic compounds. Algae lack harmful endogenous compounds for this unique property of using algae as hosts to facilitate biopharmaceutical production. In the global market, genetically engineered algae for the production of biopharmaceuticals for the production of algae-based biopharmaceuticals are firstly genetic coding and to generate working vectors that aid in the development of transformed algae clones. Develop cloning. Algae production rates are increasing worldwide as algae are used as biostimulants, increasing crop yields and reducing the need for fossil-based fertilizers (Mona et al. 2021). Therefore, marine algae are a source of great natural products for the human need.

References

Adrian R et al (2009) Lakes as sentinels of climate change. Limnol Oceanogr 54:2283–2297

Alam F, Date A, Rasjidin R, Mobin SMA, Moria H, Baqui A (2014) Biofuel from algae: is it a viable alternative? In: Gikonyo B (ed) Advances in biofuel production—algae and aquatic plants. Apple Academic Press, Boca Raton, FL

Anbuchezhian R, Karuppiah V, Li Z (2015) Prospect of marine algae for production of industrially important chemicals. In: Algal biorefinery: An integrated approach. Springer, pp 195–217

Bahr M, Hobbie JE, Sogin ML (1996) Bacterial diversity in an arctic lake: a freshwater SAR11 cluster. Aquat Microb Ecol 11:271–277

Batista A, Gouveia L, Bandarra NM, Franco JM, Raymundo A (2013) Comparison of microalgal biomass profiles as novel functional ingredient for food products. Algal Res 2:164–173
Biavati B, Mattarelli P (2003) The family Bifidobacteriaceae. In: Dworkin M, Falkow S, Rosenberg E (eds) The prokaryotes: an evolving electronic resource for the microbiological Communityelectronic release 314, 3th edn. Springer-Verlag, New York
Borowitzka MA (2013) High-value products from microalgae-their development and commercialisation. J Appl Phycol 25:743–756
Boyd GR, Reemtsma H, Grimm DA, Mitra S (2003) Pharmaceuticals and personal care products (PPCPs) in surface and treated waters of Louisiana, USA and Ontario, Canada. Sci Total Environ 311:135–149
Buser R, Poiger T, Muller M (1999) Occurrence and environmental behavior of the chiral pharmaceutical drug ibuprofen in surface waters and in wastewater. Environ Sci Technol 33(29):2529–2535
Carpenter SR et al (2005) Ecosystem subsidies: terrestrial support of aquatic food webs from 13C addition to contrasting lakes. Ecology 86:2737–2750
Chaffron S, Rehrauer H, Pernthaler J, von Mering C (2010) A global network of coexisting microbes from environmental and whole-genome sequence data. Genome Res 20:947–959
Chauhan A, Basniwal RK, Narwadia SC (2020) Cyanobacteria: an emerging source for antibacterial, antimycobacterial and antifungal properties. Sci Archiv 1(1):24–31
Chorus I, Bartram J (1999) Toxic cyanobacteria in the water. E & F.N. Spon, London
Comté J et al (2006) Microbial community structure and dynamics in the largest natural French Lake (Lake Bourget). Microb Ecol 52:72–89
Daughton C, Ternes T (1999) Pharmaceuticals and personal care products in the environment: agents of subtle change? Environ Health Perspect 107:907–938
Davis R, Aden A, Pienkos PT (2011) Techno-economic analysis of autotrophic microalgae for fuel production. Appl Energy 88:3524–3531
de Morais MG, da Silva Vaz B, de Morais EG, Costa AV (2015) Biologically active metabolites synthesized by microalgae. Biomed Res Int 2015:835761
De Reviers B, Rousseau F, Draisma SGA (2007) Classification of the Phaeophyceae from past to present and current challenges. In: Brodie J, Lewis J (eds) Unravelling the algae: the past, present and future of algal systematics. CRC Press, Boca Raton, London and New York, pp 267–284
Duy TN, Lam PK, Shaw GR, Connell DW (2000) Toxicological and risk assessment of freshwater cyanobacterial (blue-green algae) toxin in water. Rev Environ Contam Toxicol 163:113–185
Eiler A, Bertilsson S (2004) Composition of freshwater bacterial communities associated with cyanobacterial blooms in four Swedish lakes. Environ Microbiol 6:1228–1243
El-Shafei R, Hegazy H, Acharya B (2021) A review of antiviral and antioxidant activity of bioactive metabolite of macroalgae within an optimized extraction method. Energies 14:3092
Fent K, Weston A, Caminada D (2006) Ecotoxicology of human pharmaceuticals. Aquat Toxicol 76:122–159
Gómez-López M, Viejo C, Ortega-Ruiz R (2019) Psychological Well-Being During Adolescence: Stability and Association With Romantic Relationships. Front. Psychol. 10:1772. https://doi.org/10.3389/fpsyg.2019.01772
Gopeechund A, Bhagooli R, Neergheen VS, Bolton JJ, Bahorun T (2020) Anticancer activities of marine macroalgae: status and future perspectives. In: Biodiversity and biomedicine. Academic Press, Cambridge, MA, pp 257–275
Heberer T (2002) Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data. Toxicol Lett 131:5–17
Herrero M, Mendiola JA, Plaza M, Ibanez E (2013) Screening for bioactive compounds from algae. In: Lee JW (ed) Advanced biofuels and bioproducts. Springer Science + Business Media, New York
Hosseini SF, Rezaei M, McClements DJ (2020) Bioactive functional ingredients from aquatic origin: a review of recent Progress in marine-derived nutraceuticals. Crit Rev Food Sci Nutr 62:1242–1269

Hunter PR (1995) Cyanobacterial toxins and their potential risk to drinking water supplies. Microbiol Eur 3:8–10

Ishii S, Yan T, Shively DA, Byappanahalli MN, Whitman RL, Sadowsky MJ (2006) Cladophora (Chlorophyta) spp. Harbor human bacterial pathogens in nearshore water of Lake Michigan. Appl Environ Microbiol 72:4545–4553

Jones GJ, Korth W (1995) In situ production of volatile odor compounds by river and reservoir phytoplankton population in Australia. Water Sci Technol 31:145–151

Karan H, Funk C, Grabert M, Oey M, Hankamer B (2019) Green bioplastics as part of a circular bioeconomy. Trends Plant Sci 24:237–249

Khan MI, Shin JH, Kim JD (2018) The promising future of microalgae: current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed, and other products. Microb Cell Fact 17:36–36

Khoo HH, Tan RBH (2010) Environmental impacts of conventional plastic and biobased carrier bags. Int J Life Cycle Assess 15:338–345

Khoo KS, Chew KW, Yew GY, Leong WH, Chai YH, Show PL, Chen W-H (2020) Recent advances in downstream processing of microalgae lipid recovery for biofuel production. Bioresour Technol 304:122996

Koyande AK, Chew KW, Rambabu K, Tao Y, Chu D-T, Show P-L (2019) Microalgae: a potential alternative to health supplementation for humans. Food Sci Human Wellness 8:16–24

Leong YK, Show P-L, Lan JC-W, Krishnamoorthy R, Chu D-T, Nagarajan D, Yen H-W, Chang J-S (2019) Application of thermo-separating aqueous twophase system in extractive bioconversion of polyhydroxyalkanoates by Cupriavidus necator H16. Bioresour Technol 287:121474

Lewis LA, McCourt RM (2004) Green algae and the origin of land plants. Am J Bot 91:1535–1556

Lindeman RL (1942) The trophic-dynamic aspect of ecology. Ecology 23:399–418

Lindström ES, Kamst-Van Agterveld MP, Zwart G (2005) Distribution of typical freshwater bacterial groups is associated with pH, temperature, and lake water retention time. Appl Environ Microbiol 71:8201–8206

Liu YQ et al (2009) Bacterial diversity of freshwater alpine Lake puma Yumco on the Tibetan plateau. Geomicrobiol J 26:131–145

Logares R et al (2009) Infrequent marine-freshwater transitions in the microbial world. Trends Microbiol 17:414–422

Makareviciene V, Skorupskaite V, Andruleviciute V (2013) Biodiesel fuel from microalgae-promising alternative fuel for the future: a review. Rev Environ Sci Biotechnol 12:119

McDermid KJ, Stuercke B (2003) Nutritional composition of edible Hawaiian seaweeds. J Appl Phycol 15(6):513–524

Miège C, Choubert JM, Ribeiro L, Eusèbe M, Coquery M (2009) Fate of pharmaceuticals and personal care products in wastewater treatment plants—conception of a database and first results. Environ Pollut 157:1721–1726

Mobin SMA, Alam F (2017) Some promising microalgal species for commercial applications: a review. Energy Procedia 110:510–517

Mobin SMA, Alam F (2018) A review of microalgal biofuels, challenges and future directions. In: Khan MMK, Chowdhury AA, Hassan NMS (eds) Application of thermo-fluid processes in energy systems: key issues and recent developments for a sustainable future. Springer Nature Singapore, Singapore

Mompelat S, Le Bot B, Thomas O (2009) Occurrence and fate of pharmaceutical products and by-products, from resource to drinking water. Environ Int 35:803–814

Mona S, Malyan SK, Saini N, Deepak B, Pugazhendhi A, Kumar SS (2021) Towards sustainable agriculture with carbon sequestration, and greenhouse gas mitigation using algal biochar. Chemosphere 275:129

Newton RJ, Kent AD, Triplett EW, McMahon KD (2006) Microbial community dynamics in a humic lake: differential persistence of common freshwater phylotypes. Environ Microbiol 8:956–970

Nold SC, Zwart G (1998) Patterns and governing forces in aquatic microbial communities. Aquat Ecol 32:17–35

Novak AC, Sydney EB, Soccol CR (2014) Biocosmetics. In: Brar SK, Dhillon GS, Fernandes M (eds) Biotransformation of waste biomass into high value biochemicals. Springer Science+Business Media, New York

Nunes MC, Graça C, Vlaisavljevic S, Tenreiro A, Sousa I, Raymundo A (2020) Microalgal cell disruption: effect on the bioactivity and rheology of wheat bread. Algal Res 45:101749

Ortelli S, Costa A, Torri C, Samorì C, Quintavalla A, Vineis C, Varesano A, Bonura L, Bianchi G (2019) Innovative and sustainable production of biopolymers: the Italian flagship initiative. In: Factories of the future, pp 131–148

Piazzi L, Meinesz A, Verlaque M, Açali B, Antolic B, Argyrou M, Balata D, Ballesteros E, Calvo S, Cinelli F, Cirik S, Cossu A, d'Archino R, Djellouli AS, Javel F, Lanfranco E, Mifsud C, Pala D, Panayotidis P, Peirano A, Pergent G, Petrocelli A, Ruitton S, Zuljevic A, Ceccherelli G (2005) Invasion of Caulerpa racemosa var. cylindracea (Caulerpales, Chlorophyta) in the Mediterranean Sea: an assessment of the spread. Cryptogam Algol 26:189–202

Plaza M, Herrero M, Cifuentes A, Ibañez E (2009) Innovative natural functional ingredients from microalgae. J Agric Food Chem 57:7159–7170

Quintana JB, Weiss S, Reemtsma T (2005) Pathways and metabolites of microbial degradation of selected acidic pharmaceutical and their occurrence in municipal wastewater treated by a membrane bioreactor. Water Res 39:2654–2664

Rajapakse N, Kim S-K (2011) Nutritional and digestive health benefits of seaweed. In: Advances in food and nutrition research. Elsevier, Amsterdam, pp 17–28

Rahman K, Lowe GM (2006) Garlic and cardiovascular disease: a critical review. J Nutr 136:736S–740S

Rendon N, Bailey A, O'Malley K, Demas G (2016) Food as a supplementary cue triggers seasonal changes in aggression, but not reproduction, in Siberian hamsters. Physiology & Behavior 167:298–308

Rheinheimer G (1980) Aquatic microbiology. Wiley, New York, NY

Richmond A (2004) Handbook of microalgal culture: biotechnology and applied phycology. Blackwell Science, Oxford

Sansone C, Brunet C, Noonan DM, Albini A (2020) Marine algal antioxidants as potential vectors for controlling viral diseases. Antioxidants 9:392

Saraf S (2012) Formulating moisturizers using natural raw materials. In: Lodén M, Maibach HI (eds) Treatment of dry skin syndrome. Springer, Berlin

Scheutz F, Strockbine NA (2005) Genus Escherichia. In: Brenner DJ, Krieg NR, Staley JT (eds) Bergey's manual of systematic bacteriology, vol 2, Part B, 2nd edn. Springer, New York, NY, pp 607–623

Sedlak D, Pinkston KE (2001) Factors affecting the concentrations of pharmaceuticals released to the aquatic environment. Water Resour 120:56–64

Stam W, Olsen JL, Zaleski SF, Murray SN, Brown KR, Walters LJ (2006) A forensic and phylogenetic survey of Caulerpa species (Caulerpales, Chlorophyta) from the Florida coast, local aquarium shops and e-commerce: establishing a proactive baseline for early detection. J Phycol 42:1113–1124

Suganya T, Varman M, Masjuki MH, Renganathan S (2016) Macroalgae and microalgae as a potential source for commercial applications along with biofuels production: a biorefinery approach. Renew Sustain Energy Rev 55:909–941

Tang L, Ying B (2020) Mental Health Education in Primary and Secondary School. Investigation on mental health status and its influencing factors among secondary school students during the COVID-19 epidemic:57–61

Tibbetts EA, Injaian A (2014) Cognition across castes: individual recognition in worker Polistes fuscatus wasps. Animal Behaviour 87:91–96

Tixier C, Singer HP, Oellers S, Müller S (2003) Occurrence and fate of carbamazepine, clofibric acid, diclofenac, ibuprofen, ketoprofen, and naproxen in surface waters. Environ Sci Technol 37(6):1061–1068

Todar K (2009) Shigella and shigellosis. Todar's online textbook of bacteriology. http://www.textbookofbacteriology.net/Shigella.html. Assessed 1 Sept 2010

Ugwu CU, Aoyagi H, Uchiyama H (2008) Photobioreactors for mass cultivation of algae. Bioresour Technol 99(10):4021–4028
Verlaque M, Durand C, Huisman JM, Boudouresque CF, Parco Y (2003) On the identity and origin of the Mediterranean invasive Caulerpa racemosa (Caulerpales, Chlorophyta). Eur J Phycol 38:325–339
Widowati I, Zainuri M, Kusumaningrum HP, Susilowati R, Hardivillier Y, Leignel V, Bourgougnon N, Mouget JL (2017) Antioxidant activity of three microalgae Dunaliella Salina, Tetraselmis Chuii and Isochrysis Galbana clone Tahiti. In: IOP conference series: earth and environmental science, vol 55. IOP Publishing, Bali, p 012067
Wilson M (2005) Microbial inhabitants of humans their ecology and role in health and disease. Cambridge University Press, Cambridge
World Health Organization (WHO) (2008) Guidelines for drinking-water quality, incorporating 1st and 2nd Addenda. Recommendations, vol 1, 3rd edn. WHO, Geneva
Zeller MA, Hunt R, Jones A, Sharma S (2013) Bioplastics and their thermoplastic blends from spirulina and chlorella microalgae. J Appl Polym Sci 130:3263–3275
Zhao C, Yang C, Liu B, Lin L, Sarker SD, Nahar L, Yu H, Cao H, Xiao J (2018) Bioactive compounds from marine macroalgae and their hypoglycemic benefits. Trends Food Sci Technol 72:1–12
Zhu N, Ye M, Shi D, Chen M (2017) Reactive compatibilization of biodegradable poly(butylene succinate)/spirulina microalgae composites. Macromol Res 25:165–171
Ziylan A, Ince NH (2011) The occurrence and fate of anti-inflammatory and analgesic pharmaceuticals in sewage and fresh water: treatability by conventional and non-conventional processes. J Hazard Mater 187:24–36