The sustainability of biosphere is on the small fraction of solar irradiance that is absorbed and subsequently stored within the photosynthetic organisms – including algae, mosses, ferns and seed bearing plants along with some bacteria. Algae are heterogenous photoautotrophic organisms with either prokaryotic or eukaryotic cells having an array of habit, structure, metabolism and reproduction with a strong affinity to water. The cosmopolitan distribution of the algae at different geographic latitudes, on all continents, covering entire biosphere -atmosphere, hydrosphere and lithosphere, is the result of wide adaptive variations. Their occurrence at different degrees of salinity, temperature, trophicity, mineral ions and organic matter along with a size range, from less than 2μm to more than 60m, creates pressure on nature lovers and conservationists to study the diversity among algae. An autotrophic ancestor with an age of 400 billion years, with energy funnelling chlorophyll ‘a’ and other accessory pigments, inhabiting in an upper water column upto a depth of 150-200m gives the outline of a very significant role in phylogeny and ecology of the biosphere. The contribution of these ancestors in the making of the present biosphere, makes the phycological studies more meaningful.
The community structure of the ecosystem is effectively controlled by algae through their critical role as a primary producer in the marine and freshwater food chains. Ecological practices such as adsorption and abatement of pollutants - heavy metals, pesticides and insecticides, leading a way to the purification of polluted waters and sewage; application as an indicator organism for the monitoring of ecosystems and as organisms for biotechnology are the new horizons in algal research. Algae are unique model organisms in evolutionary biology and are also used in various genetic, physiological, biochemical, cytological and biotechnological investigations.

The classification of algae may be based upon size, habit and habitat, motility, pigment composition, reserve food, and reproduction. They belong to monera - prokaryotic unicellular/colonial forms; or protista - eukaryotic unicellular/colonial forms or plantae - eukaryotic multicellular forms (Fritsch, 1935; Whittaker, 1969; Sieburth, 1978; Van den Hoek et al., 1995). Their phylogenetic relationship is given in Figure 1.1.

![Fig. 1.1 Phylogenetic relationship of classes of microalgae (Lee, 2008)](image-url)
These simple aquatic plants are microscopic or macroscopic, unicellular or multicellular, mobile or immobile, attached or free-living. Bold and Wynne (1985) and Stevenson (1996) concluded that there are about 26,000 species of algae all over the world and Norton et al., (1996) reported 37,300 species. Mann and Droop (1996) estimated the number of diatom itself comes to more than 2,00,000 with planktonic, periphytonic and benthic forms. According to UNEP (1995), $10 \times 10^5$ algae are present in the biosphere, out of which only 40,000 are described. There are several studies on macroalgae of the marine environment, the larger ones with a common name ‘seaweeds’, belonging to the algal divisions Chlorophyta, Phaeophyta and Rhodophyta; although they have a lesser diversity in comparison with the microscopic ones, microalgae.

1.1 Microalgae

Microalgae are the microscopic single celled algae, distributed in freshwater, estuarine and marine ecosystems. They comprise a vast group of lower plants which may be photosynthetic, symbiotic, mixotrophic and even parasitic (Lee, 2008). These microflora are unicellular, colonial, or filamentous microalgae having a great range of shape, colour and size; with or without a cellulosic or non cellulosic cell-wall, having mucilage, encrustations, ornamentations and several other modifications which serve as a taxonomic tool for identification of each class, family, genus and species. The size may range from a few micrometers ($\mu$m) to a few hundreds of micrometers. Microalgae, capable of performing photosynthesis, are important for life on earth; they produce approximately half of the atmospheric oxygen and use simultaneously the greenhouse gas carbon dioxide to grow photoautotrophically.

Studies on biodiversity of microalgae in the marine environment are very limited compared to that of terrestrial flora. The biodiversity of microalgae is enormous and they represent an almost untapped resource. The sum total of
species, belonging to any taxonomic class in varied habitats, would naturally be higher than the described number.

Microalgae play an important role in ocean and coastal ecology by the ability to produce $23.7 \times 10^9$ tonnes C/year, estimated as half of the annual productivity in the biosphere (Falkowski and Raven, 1997), while accounting for almost half of total production, oceanic autotrophs only account for about 0.2% of the total biomass. Microalgae constitute the basic foodstuff for numerous aquatic species, especially filtering bivalves, fishes, larvae or juveniles of almost all aquatic fauna. They provide them with vitamins and polyunsaturated fatty acids, necessary for the growth of the bivalves which are unable to synthesize it by themselves. Most of these microalgal species produce unique products like carotenoids, antioxidants, fatty acids, enzymes, polymers, peptides, toxins and sterols. Certain microalgae are effective in the production of hydrogen and oxygen through the process of biophotolysis. Others naturally manufacture hydrocarbons which are suitable for direct use as high-energy liquid fuels. Approximately fifty percent of the body of the algae is comprised of oil, called “oilage” which in its crude form can become diesel fuel. They are of particular interest in the development of future renewable energy scenarios because of their ability to produce by-products such as fats, oils, sugars and functional bioactive compounds (Dragone et al, 2010). Microalgae are able to produce 15–300 times more oil for biodiesel production than traditional crops on an area basis. Furthermore compared with conventional crop plants which are usually harvested once or twice a year, microalgae have a very short harvesting cycle ($\approx 1–10$ days depending on the process), allowing multiple or continuous harvests with significantly increased yields (Schenk et al, 2008). The advantages of microalgae in greenhouse gas mitigation are that they can utilize CO$_2$ from power plant and other flue gases directly, that they can produce high value liquid and gaseous fuels (biodiesel, hydrocarbons, ethanol, methane, hydrogen), that they could potentially exhibit very high biomass
productivities approaching the theoretical limits of photosynthesis (about 10% solar conversion efficiency), and that they are able to use waste water and nutrients, allowing for integration of such processes with waste treatment (Huesemann et al, 2003). Over 15,000 novel compounds originating from algal biomass have been chemically determined.

The microscopic species are distributed as planktonic, which remain suspended in the water column and as benthic, which live in association with some substrata, seen in pelagic and benthic environments of the aquatic ecosystem. Any individual alga may be benthic or planktonic at one time or another, but many species are characteristically adapted for either benthic or pelagic environments. Some are mobile, swimming by means of flagella or gliding over the substrata. Others are non-motile-drifting in the plankton, fixing to a substratum or lying free. Several microalgae, in spite of their characteristic adaptations to the specific habitat, have been found both in benthic and pelagic environments.

1.2 Planktonic Microalgae

Most of the planktonic microalgae are distributed throughout the euphotic zone, which is defined by its optical properties and extends to a depth where the incident radiation is attenuated to 1%. Many planktonic microalgae in the oceans are motile, and can undergo substantial vertical migrations in the water column to optimize their position with respect to the incident irradiance (Burns and Rosa, 1980, Tyler and Seliger, 1981). Since light intensity changes during the day and is modulated by a vetting cloud cover, aquatic organisms need to readjust constantly their positions in the water column to achieve optimal rates of photosynthesis. Microalgae suspended in the pelagic environments are of various taxonomic groups such as diatoms, dinoflagellates, green algae, blue green algae, silicoflagellates and coccolithophorids. Depending on the size, microalgae can be grouped into macroplankton
General Introduction

(>1mm), microplankton (<1mm), nanoplankton (5-50µm), ultraplankton (5µm) and picoplankton (>1µm) (Gopinathan, 2004).

As microalgae are exposed to ever-fluctuating physico-chemical parameters, they exhibit wide diversity in species and abundance. Similar to terrestrial vegetation, marine phytoplankton diversity is a unimodal function of phytoplankton biomass with maximum diversity at intermediate levels of phytoplankton biomass and minimum diversity during massive blooms (Irigoien et al., 2004). Large biomass standing stocks are generally associated with higher diversity in terrestrial ecosystems, the opposite seems to be the rule in pelagic marine ecosystems, where it is generally reported that increased production is associated with decreased diversity (Krebs, 1994). Changes in species composition and diversity may produce changes in community level parameters, like phytoplankton growth rate and those variables regulating the photosynthetic response to irradiance or other limiting factors. It is important to understand how these changes are reflected in ecosystem functioning and ecosystem services (Duarte et al., 2006). Nutrient levels are important determinants of marine biodiversity, influencing the processes of competition and community structure in the marine environment. In the pelagic waters, concentration levels of inorganic nutrients, such as nitrate, phosphate and silicate in the water dictate population growth of planktonic primary producers. Seasonal variations of nutrient concentrations have been correlated with the abundance of microalgae.

They have several modifications or adaptations; gas vacuoles for cyanophytes; flagellation for the movement from unfavourable chemical, physical and biological conditions; extracellular products to increase the viscosity of surrounding water and wind induced rotation for surface dwelling non flagellates. Several types of cell structure modifications also occur which may be floating life-bladder/needle shape, branching frustules, colony formation, mucilage production, etc. Sometime cell density increases for sinking (Tomaselli, 2004).
1.3 Benthic Microalgae

Benthos (Greek- ‘Bevoo’ = bottom) is an assemblage of organisms living in the benthic habitat of various aquatic ecosystems. The primary producers of the benthic habitat, phytobenthos, may be macroscopic seaweeds or microscopic benthic microalgae, the microphytobenthos. Microalgae found attached to any inert material such as rock, coral, sand particles and those attached to detritus or living organisms come under benthic microalgae. The benthic microalgae are very small with an average size of about 62µ (Underwood and Kromkamp, 1999).

Benthic microalgae are always found associated with some kind of substrata in different coastal habitats or within the sediment of intertidal areas. These habitats include estuaries, sand flats, muddy shores, salt marshes and deep soft substrate areas. Based on the substratum affinity, phytobenthos can be classified as epilithon, attached to stones and rocks; epipelon, attached to silt or clay; epipsammon, attached to sand; endopelon, inside the sediment; endolithon, inside rock; epiphyton, attached to macrophytes; epizoan, attached to animals and psychropelon, attached to ice (Round, 1966, 1971, 1991). Epilithic algae grow on hard, relatively inert substrata such as gravel, pebble, cobble and boulder that are bigger than most algae. Epiphytic algae grow on plants and larger algae, which provide relatively firm substrata those, are bigger than the epiphytic algae, but can be highly active metabolically and can be a great source of nutrients (Hynes, 1970).

Benthic microalgae or microphytobenthos are, in fact, the dominant flora in the littoral zone and estuaries. Benthic microalgae are recognized as important primary producers in shallow aquatic ecosystems (MacIntyre et al., 1996). Benthic microalgal species serve as the food of prawns and other crustaceans and oysters and they have a significant role in the bio productivity of benthic environment. In fact, the contribution of benthic algae is more than
that of any other type of algae in shallow water. On tidal flats benthic macro-organisms receive their nutritional needs by feeding on benthic microalgae and labile organic matter settling out of the overlying water. Surface-algal covers are food sources for surface deposit feeders and act as interceptors for nutrients that are regenerated in sediments.

While extensive studies have been carried out on planktonic species, very little has been done on the taxonomy, distribution, abundance and productivity of benthic microalgae which contribute about one sixth of the total primary production in the world Oceans (Cahoon, 1999). In the absence of comprehensive studies on the microalgae in benthic habitats, a realistic estimate of the biodiversity, biotic interactions, potential fishery resources, etc., becomes difficult.

1.4 Microalgal Blooms

A rapid temporary increase in the population of microalgae may result in the formation of discoloured water, generally known as ‘algal blooms’ or ‘red tides’ or even simply ‘tides’. Algal blooms are easily identified by the rapid change in water colour - green, white, olive, brown, red, yellow, golden, or even black colour in the water and may produce unpleasant odour and taste. On the surface of the viscous water, there will be thick slicks, scums or mats and may leave behind coloured deposits on rocks and substrates around the edges of aquatic ecosystem. When a bloom happen, naturally the diversity would decrease and the abundance of a particular species or two would increase. At the end of the bloom event or bloom crash, the species diversity may further go up and abundance will fall.

Planktonic blooms in the marine system can be broadly classified into two types, 'spring blooms' and 'red tides'. Seasonal blooms occur annually, mainly as a result of changes in temperature and nutrient availability whereas
red tides are localized outbreaks and occur due to a variety of reasons which are characteristic of each species and locality (Richardson, 1997).

Most of the blooming algae are vitally important to marine and freshwater ecosystems, and serve as the energy producers at the base of the food web; but some are harmful by toxin-production, or gill clogging; and it is termed as harmful algal bloom (HAB), which may harm the health of the environment, plants, or animals. Of the 5000+ species of marine phytoplankton that exist worldwide, about 2% are known to be harmful or toxic (Landsberg, 2002). HABs occur in many regions of the world. Most harmful algal blooms are caused by plants that form the "base" of the food chain that referred to as phytoplankton. Other HABs are caused by accumulation of non-chlorophyll containing cells that are similar in form to microscopic algae. HABs can deplete oxygen and block sunlight that are required for the survival of other organism, and some HAB-causing algae release toxins that are dangerous to animals and humans. HABs can occur in marine, estuarine, and fresh waters, and HABs appear to be increasing along the coastlines and in the surface waters of the oceanic biome.

1.5 Significance of Microalgae

The marine environment provides many different niches for microalgae. The presence of microalgae, both phytoplankton and autotrophic microphytobenthos, have significant role as primary producers. Millions of years of effort of prokaryotic oxygenic autotrophs, blue green algae, was the force behind the shift of atmosphere from primitive anoxygenic condition to an oxygenic environment.

The microalgal species within each niche has specific combination of requirements to the external environment, as any other species in any ecosystem. Microalgae exhibit seasonal fluctuations, many species are found at certain periods of the year, others are present for much of the time but their
numbers may fluctuate, with massive abundance interspersed by periods of relative scarcity. Planktonic species are more seasonal and their seasons may last only a week or two in each year, with a succession of species waxing and waning throughout the year. The relative composition, distribution pattern, and community dynamics of microalgae becomes the index card of ecosystem health in both pelagic and benthic environment.

The marine pelagic ecosystem has the greatest size of all ecosystems on earth. The Oceans comprise 71% and contain more than 97% of all water on the planet (Riley and Chester 1971). There are 5 major – Pacific, Atlantic, Indian, Arctic and Southern Oceans and 20 minor ocean basins (Dawes, 1998). The marine pelagic environment comprises all ocean waters from the surface to the sediments with an average depth of 3.8 km, approximate volume coming to 14 billion km$^3$, or 99% of the earth’s biosphere volume (Norse, 1994). The extreme heterogeneity, a characteristic of the coastal zone, which harbours more than 50% of the human population, influences the carbon cycling and carbon storage at global scale (Dileepkumar, 2006). India is the largest country having a wider EEZ, with coastal line of 8000 km that occupy 400 million human beings in the coastal area (Venkataraman, 2003). Increasing population along with the expansion of human activities build the potential to diminish the ocean’s productivity in various ways. The Ocean’s living resources and the benefits derived from them are threatened by fisheries operation, chemical pollution and eutrophication, alteration of physical habitat and invasion of exotic species (Choudhury et al., 2002). Both natural and anthropogenic activities that affect the coastal area in turn may influence these microscopic photosynthetic organisms. The microalgae of the oceanic environment, both pelagic and benthic, have a direct or indirect influence over the dynamicity of coastal as well as Open Ocean.
References


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