Chapter 1
General introduction
Phytoplankton communities comprise several algal groups, such as diatoms, dinoflagellates, phytoflagellates, cocolithophorids, cyanobacteria and others. They are largely governed by light as the first order factor and, nutrients, temperature, community structure life-cycle history, stratification or vertical mixing and tides (Prestidge and Taylor 1995, Keifer and Kremer 1981, Hilmer and Bate 1990, Smith 2006) as second order factors. The interactive effects of these factors play important but different roles in structuring the community.

Among the phytoplankton, diatoms are the most diverse group (Armbrust 2009) consisting of over 250 genera of extant diatoms with perhaps as many as 200,000 species (Mann 1999) ranging across three orders of magnitude in size (5 µm to 2mm). Diatoms belong to Bacillariophyceae within the division Heterokontophyta (or stramenopiles). Their most characteristic feature is the ability to form highly ornamented external wall of amorphous silica, which have also given them their name ‘Jewels of the sea’. They are single celled, sometimes colonial organisms with almost all of them being photoautotrophic. They are extremely variable in form with an amazing array of sizes, shapes and ornamentation and may be symmetrical or asymmetrical. Some are circular or oval, others linear or club-shaped, or wedge shaped; some are triangular, or polygonal, or sigmoid. Many species have spines, horns, setae or other specialized protuberances or structures. Based on the symmetry, diatoms have been classified as centric (round with radial symmetry, Order Centrale) (Plate 1 A-C) and pennate (thin ellipse with
Plate 1. (A-C) Order Centrale, suborder (A) Coscinodiscineae (eg. *Coscinodiscus*, (B) Rhizosoleniineae (eg. *Rhizosolenia*) and (C) Biddulphiineae (eg. *Odontella*). (D-F) Order Pennale, suborder (D) Fragilariineae (*Thalassionema*) and (E) Bacillariineae (eg. *Achnanthes* monoraphid and (F) *Navicula*, biraphid)
bilateral symmetry, Order Pennale) (Plate 1 D-F). These two major taxonomic divisions also reflect a major ecological difference (Round 1971); while pennate diatoms are mostly represented in the benthos, with few representatives in the plankton, centric diatoms are mainly planktonic, with only a few genera that are associated with substrates throughout their life cycles. The centric diatoms have been further classified into suborders, Coscinodiscineae (discoid) (Plate 1 A), Rhizosoleniineae (solenoid) (Plate 1 B) and Biddulphiineae (gonoid) (Plate 1 C) and pennate diatoms have been divided into suborders, Fragilariineae (araphid, pennate diatoms without raphe) (Plate 1 D), and Bacillariineae which could be either monoraphid (pennate diatoms with one raphe on one valve) (Plate 1 E) or biraphid (pennate diatoms with two raphe) (Plate 1 F).

Another interesting feature of the diatom is its reproduction. Normally diatoms reproduce by vegetative division which results in size reduction due to their rigid glass cell wall. Regeneration of the original size mostly occurs via sexual reproduction. This makes sexuality a rather unique feature of the diatom community, since it becomes obligatory rather than a factor in dormancy or dispersal (Edlund and Stoermer 1997). Given this and the known variety of diatoms, information on the reproductive biology of diatoms is still very little. It has been implied by Edlund and Stoermer (1997) that studies on floristics and taxonomy would be difficult to pursue without the understanding of diatom reproduction. Research by Mann and Droop (1996) and Hasle et al. (1983) have been able to shuffle diatoms from being a ‘variety’ of a species to
a separate species by itself and to erect an entire family into centrales based on the sexual strategies adopted by the organism.

Being autotrophs, diatoms are main players in the biogeochemical cycle of carbon (C), as they can account for 40% of the total primary production in the aquatic ecosystem (Nelson et al. 1995, Tréguer et al. 1995, Tréguer and Pondaven 2000). Diatoms are also the main players in the biogeochemical cycles of nitrogen (N), phosphorus (P), and silicon (Si) and iron (Fe) and tend to dominate export production (Tréguer et al. 1995, Buesseler 1998, Sarthou 2005). Some species of the diatom community have the ability of vertical migration and are capable of mining nitrate and phosphate from the deeper waters into the euphotic zone. Furthermore, in warm oligotrophic seas in the tropics, symbiosis between diatoms and nitrogen fixing cyanobacteria (Villareal 1989, Carpenter and Janson 2000) is found. Such associations and the ability of nutrient mining from the deep contribute significantly to the new production of the region (Singler and Villareal 2005, Carpenter and Janson 2000). These seas are also characteristically predominated by free living cyanobacteria such as *Trichodesmium*. In these areas the fixation of nitrogen by the endocellular and/or free living cyanobacteria contributes a significant amount of nitrogen to the ecosystem (Dugdale et al. 1961, Capone et al. 1997).

Most studies in the Indian Ocean, especially the Bay of Bengal, have focused on primary production and coastal ecology (eg. Bhattathiri et al. 1980, Devassy and Bhattathiri 1981, Gomes et al. 2000, Madhupratap et al. 2003,
Prasanna Kumar et al. 2004, 2007). Information about the phytoplankton community (Paul et al. 2007, Madhu et al. 2006, Jyothibabu et al. 2003 and Desikachari and Prema (1987) is scarce, and even fewer have elucidated the spatial and temporal distribution (Paul et al. 2007). Remote-sensing is widely used to determine the biomass of a water body on a large scale. In addition to biomass, remote-sensing imagery also lends itself to the retrieval of information on community structure (Platt 2010). Certain phytoplankton groups such as coccolithophores, cyanobacteria, especially *Trichodesmium*, and large sized diatoms have unique water leaving radiations which can be picked up by sensors (Sathyendranath et al. 2004), thus allowing observations on larger scales.

Unlike other groups that have restricted distribution, diatom communities have an extremely wide distribution and can be found in fresh, salt, brackish water, in ice, hydrothermal vents, and moist soil like that of the inter-tidal zone, thereby constituting the phytoplankton or phytobenthos, either as free floating or sessile communities respectively. The microphytobenthos refers to the microscopic, unicellular eukaryotic algae (Baccilariophyceae, Chlorophyceae and Dinophyceae) and the prokaryotic Cyanobacteria which live on sediment surfaces. They grow in habitats ranging from intertidal sand, mangrove and mud flats, salt marshes, submerged aquatic vegetation beds to subtidal sediments. Although less conspicuous than macroalgae or vascular plants, the microphytobenthos itself can contribute significantly to primary production in littoral zones (Daehnick et al. 1992,
Pinckney and Zingmark 1993, Colijn and De Jonge 1984) and in many shallow aquatic systems the biomass of benthic microalgae exceeds that of the phytoplankton in the overlying waters.

Nutrient concentrations play a key role in regulating diatom growth and thereby in the structuring of a community. Nutrients such as nitrate, phosphate and silicate are extremely important and their levels dictate the diversity in a community. The smaller-sized species tend to be most abundant when nutrients are not limiting such as in the benthos (Kromkamp and Forster 2003).

The benthic diatom community also constitutes a system rich in information for environmental monitoring which can be exploited through analysis of communities’ structural characteristics (Gold et al. 2002). In such communities, where space becomes a limiting resource, close interactions among the species inevitably results in competition. Competition occurs when two species require a resource that is in short supply, so that the availability of that resource to one species is negatively influenced by the presence of the other species (Valiela 1984). Role of each species and their interaction with the other members will decide the fate of the climax community. In a homogenous habitat, species differ in their competitive abilities and are limited by a resource and compete for the same single resource. According to Tilman (1982, 1999) in such a habitat at equilibrium, the best competitor among the species present would win. Therefore, to study the relationship between the distributions of diatoms in the different habitats and the
interactions between them become very interesting and also helps in understanding the community development under changing environmental conditions.

This calls for a holistic approach of an in-depth study of diatom and phytoplankton populations from microscopic identification to large scale mapping of phytoplankton distribution which in turn would combine extensive field studies and laboratory experiments. This thesis presents the work carried out on the distribution of phytoplankton focusing on diatoms in the phytoplankton and the phytobenthos.

The studies carried out are presented in the following chapters:

- Micro-phytoplankton community of the Bay of Bengal
- Diatoms from the benthic environment and their response to nutrients
- Interactions between diatom species
- Life-cycle of a centric diatom (*Odontella regia*)