

## Chapter 6

### Summary

## SUMMARY

This study illustrates the ecology of diatoms in various habitats. They are abundant in the phytoplankton and phytobenthos of aquatic ecosystems, whatever the latitude. Within the aquatic realm, diatoms further extend their habitats from the pelagic to benthic environment and are also found to colonize various submerged, living and nonliving surfaces. In each of these habitats, diatoms characterize a particular niche.

In the marine environment, coastal regions are considered to be the most productive ecosystems in the world, where the environment is characterized by dramatic temporal fluctuations. Accordingly, the life history of phytoplankton reflects adaptations for survival by forming specialized resting stages in fluctuating environments. Resting stages are a common survival strategy in diatoms and dinoflagellates, which form important components of coastal regions. The fundamental question that remains unresolved is the factors that control their dormancy and rejuvenation. An examination of the planktonic and benthic stages of the diatoms and dinoflagellates, in a tropical estuary (Zuari estuary, Goa (India)) influenced by monsoon was carried out. Diatoms (85-92%) followed by dinoflagellates (7 -11%) dominated the phytoplankton community. Of the 137 phytoplankton species recorded, blooms of *Skeletonema costatum*, *Fragilariopsis oceanica*, *Chaetoceros* spp. and *Thalassiosira* spp. were observed on several instances. There was considerable variation in the bloom and occurrence pattern of these individual species. The typical fate of these blooms is to settle (local or distant places) onto the bottom sediments in the form of live cells or resting stages (Smetacek 1980, 1985, Alldredge and Gotschalk 1989, Kiorboe et al. 1994). Other than this, the phytoplankton cells reaching the sea floor have a variety of fates. In the benthic environment, diatom benthic propagules dominated the dinoflagellates in the same order as observed in the water column, indicating different

seeding strategies between them. Smayda (2002) considered that diatoms and dinoflagellates have contrasting bloom behavior. The former are annually recurrent, predictable, prolonged, of high species diversity and a species succession occurs than the latter (Guillard and Kilham 1977, Smayda 1980). In the Zuari estuary, diatoms are not only dominant in numbers but also exhibit a high species count, richness and diversity than dinoflagellates. Considering such a scenario, the study was further focussed on the pattern of diatom dormancy and rejuvenation. Diatom community structure in the study site was closely linked to various physico-chemical and biological factors. Amongst the 41 benthic propagules of diatoms recorded, *S. costatum* and *F. oceanica* were dominant and persisted throughout the year. During monsoon, stratification develops with a low saline layer because of riverine discharge and precipitation at the surface and an upwelled water (cold, saline and oxygen depleted) at the bottom. This stratification favoured blooms of *S. costatum* and *F. oceanica* in nutrient rich surface and bottom waters respectively. During minimum rains or rainfall break, the resuspended benthic propagules break their dormancy and develop blooms. Ensuing nitrate depletion in the water column, *S. costatum* was induced into dormancy. A 'Bimodal Oscillation Trend' (BOT) in the rainfall during monsoon, shifted the blooms from those adapted to low salinities to high salinities and vice versa, once at the onset and the other after an intermittent monsoon break. These observations indicated that the timing and magnitude of physical events like rainfall and land runoff during monsoon is critical in the occurrence of phytoplankton blooms of different species. It is well known that phytoplankton blooms stimulate zooplankton production and so on up the food chain. The oscillations in rainfall during monsoon can lead to shift in phytoplankton blooms. Such shifts in phytoplankton blooms can in turn influence trophic dynamics and ecosystem functioning.

In addition to the free-floating mode of life, the diatoms are also found to colonize a variety of submerged surfaces in the aquatic environment. The attached communities may be classified according to their substrata; thus epipelagic, epipsammic, epilithic, epibiotic and fouling communities may be distinguished, growing on mud, sand grains, rocks, biological substrates (such as aquatic plants, molluscs, crustaceans, marine reptiles, marine mammals, marine birds) and other objects placed in the sea. Abundant in most benthic habitats, raphid diatoms are the most frequent early algal colonizers of natural and artificial substrata, where they adhere and produce copious quantities of adhesive mucilage during the construction of primary films i.e. microfilm. Microfilms, also referred to as biofilms, are highly variable in time and heterogenous in composition; their formation is an important step in biofouling. Microfilm mainly comprises of adsorbed macromolecules, attached bacteria and diatoms, all of which are enmeshed in a matrix of extracellular polymers. Removal of diatoms from the microfilm is perhaps the most critical step in evaluating the diatom community structure from the biofilm developed on solid substratum immersed in aquatic environment. Different tools such as nylon brush and ceramic scraper were employed in the present study for removal of microfilm diatom community. The differences in diatom abundance through the use of such tools makes evident that the tools employed for the removal of microfilm are critical. Nylon brush was found to be a better tool than ceramic scraper in removing the diatoms from microfilm wherein the percentage loss of diatom cells was comparatively higher in the later. Taking these observations into consideration, nylon brush was employed for the removal of microfilm developed over different substrata (fibreglass, glass, copper and cupronickel) from Dona Paula Bay. Evaluation of diatoms from the microfilm revealed a significant difference in the numbers of diatoms and diversity encountered on the different substrata but the species composition almost remained

constant. The only indication of differences in community structures are between the time (months/seasons) and substrata, which can be attributed to physico-chemical and biological changes of the ambient waters and the substratum. Temporal variations in the tycho-pelagic diatom community structure (temporarily dislodged benthic diatom community) of the surrounding water column were observed to exert its influence on the microfilm community. Such differences in the diatom community structure in the microfilm might offer differing signals to the settling larvae of the sedentary organisms, which is critical in determining the functional ecosystem of the benthic environment. Majority of diatoms that inhabit the submerged surfaces are able to secrete copious amounts of extrapolymeric substances (EPS) that are primarily comprised of carbohydrates (Hoagland et al 1993). These polymers play an important role in the ecology of intertidal mudflats and epibenthic communities. Benthic diatoms themselves probably benefit from the secretion of EPS in various ways, such as motility, attachment to surfaces, the ability to sequester toxic compounds, to capture nutrients and to protect against desiccation (Decho 1990). For the ecosystem as a whole, secretion of EPS by benthic diatoms is important because it provides a food source for other organisms (van Duyl et al 1999; Middelburg et al 2000) and stabilizes the sediment surface (Paterson 1997). However, till date very little information is available on the cues offered by the biofilms dominated by benthic diatoms and its EPS for the settling invertebrate larvae. An investigation was carried out to evaluate whether the films of monospecific benthic diatoms and its EPS generated a similar range of cues for the cyprid larvae of *Balanus amphitrite* (dominant fouling organism) as shown with bacteria and its components. Experiments to evaluate the influence of epibiotic/fouling diatoms (dominant in microfilm) on cyprid settlement of *B. amphitrite* indicated that the benthic diatom films and their components induced the metamorphosis in the following order: diatom films >

biofilm EPS > free EPS for axenic diatoms suggesting that the cues offered by benthic diatoms can also mediate invertebrate larval metamorphosis. In the case of non-axenic diatoms, films and its biofilm components also promoted larval metamorphosis. However, the cues varied from weak to strong depending upon the species and their density in the films as well as the composition of extracellular polymeric substances. This investigation indicates that the bacteria associated with diatoms plays an important role in providing cues to invertebrate larvae.

Diatoms are also found growing attached to surfaces of living organisms i.e. plants and animals and are termed as epibiotic diatoms. A variety of organisms form hard substrata in the benthic marine environment. When free space is not available, one organism (epibiont) grows on the other (basibiont). This process is defined as epibiosis. Adaptation to epibiosis by basibionts arises from three ways: tolerance, avoidance and defence (Wahl 1989). Many sessile marine organisms such as sponges, corals, bryozoans, holothurians and ascidians and mobile organisms such as most of the crustaceans, sea weeds and turtles keep an essentially clean body surface in the face of competition for space by epibionts (Davis *et al.* 1989; Wahl 1989; Caine 1986, Clare *et al.* 1992). Diatoms as a component of epibiotic population on horseshoe crab carapaces indicated that the basibiont characteristics could influence the community. Horseshoe crabs act as moving substrata for simple to complex communities of small marine organisms. Amplexed adult pairs migrate for breeding once every 2 weeks from deep waters towards nearshore waters during highest high tide. Female horseshoe crabs bury themselves to the level of the lateral eyes to lay eggs after the male crabs fertilize them. *Tachypleus gigas* (Müller) is the most abundant horseshoe crab species available along the Orissa coast (India). Adults reach terminal anecdysis once sexually mature and live with their carapace for 4 to 9 years. In spite of this, epibiosis is limited. In the current

investigation, differences in the epibiotic community (diatoms and macro-epibionts) present on horseshoe crabs according to gender were evaluated, and the macro-epibiont population from different regions of the carapace was mapped. In general, female horseshoe crabs harbored fewer epibionts than the males. Among the diatoms, *Navicula* spp., *Nitzschia* spp. and *Skeletonema* sp. were dominant in both sexes. However, the abundance and diversity of diatoms was greater on the carapaces of male crabs. Among the macro-epibionts, the acorn barnacle (*Balanus amphitrite*, Darwin) and encrusting bryozoan (*Membranipora* sp.) were the most dominant forms. Barnacles and bryozoans were greater in abundance in the 'rough' zone (cardiothoracic region and anterior region of the opisthosoma). Mapping of the macro-epibionts from different regions of the carapace revealed differential distribution in males and females. Such differentiated distribution of the macro-epibionts can be related to factors such as changing habitat by the horseshoe crabs during breeding, mechanical abrasion and surface availability during mating and nesting periods, requirements of epizootic larvae and surface properties of the carapace (wettability and roughness). In case of females, mechanical abrasion and surface availability played an important role in the epibiotic community structure and distribution patterns. The surface wettability measurements indicated male carapace to be slightly more hydrophobic than the female carapace. Scanning electron microscopy (SEM) revealed that the male carapace was comparatively rough compared to the smooth carapace of the female. A comparison of surface properties of the carapace indicated that the male carapace is more conducive for epibiosis. These observations indicate that the female horseshoe crabs exhibited potential defence mechanisms against epibiosis. Experiments to evaluate chemical defence mechanism of the horseshoe crab indicated that the secretion of female horseshoe crabs showed species-specific control of diatom

epibiosis. This study on diatom ecology reveals that the nature of habitat determines the diatom community structure, which in turn decides their functional role in an ecosystem.



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