

# Marine biodiversity and ecosystem functioning: A perspective

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*Biodiversity and community structure are now recognized to be important determinants of ecosystem functioning. In this regard the marine ecosystem has been studied to a much lesser extent compared to the terrestrial. This article discusses the various aspects of biodiversity in marine habitats, as determined by competition, nutrients, heterogeneity, keystone predation and climate and anthropogenic effects, keeping in mind the peculiarities of the mobile and dynamic nature of pelagic waters. Some hypothetical examples from the Arabian Sea are considered. It is an established fact that nutrient availability largely determines the diversity of primary producers. Competitive dominance is rare in pelagic phytoplankton communities and various hypotheses have been put forward to explain this. However, single species algal blooms are not uncommon in coastal waters. Top-down control mechanisms, such as keystone predation can often be a major determinant in maintaining diversity. Heterogeneity is considered an important factor in promoting deep-sea benthic diversity. For the pelagic zone, water column stratification in terms of density, nutrients and light may lead to diverse assemblages. Increasing climate and anthropogenic effects on the marine ecosystem, particularly of the coastal waters have lent a sense of urgency in understanding the role of biodiversity in ecosystem dynamics, so that appropriate predictive models can be developed to facilitate wise management of our waters. Many of these issues have not been sufficiently studied for Indian waters. Some of the important questions that need to be addressed in this context are the effects of biodiversity on the environment and, therefore, successional patterns of communities, the relationship between biodiversity at different trophic levels, and their overall importance in community stability and productivity.*

It is now widely appreciated that ecosystem functioning is dictated to a large degree by biodiversity and the community structure that result from factors such as the richness and evenness of the diversity. Diversity at all levels, including infra-specific or genetic diversity that characterize populations of a species, species diversity that characterize communities, and in turn community diversity that characterize an ecosystem, all play a major role in this. The terrestrial ecosystem has received a great deal of attention from scientists studying biodiversity and several papers have addressed the effects of plant diversity on ecosystem properties such as primary productivity and nutrient retention<sup>1-3</sup>. Worldwide interest in the role of biodiversity in marine ecosystem processes is relatively more recent<sup>4-6</sup>. In the Indian context, studies on the taxonomic diversity of marine organisms have had a long tradition<sup>7</sup>. Increasing concern on destruction of marine

habitats, bioinvasions and alterations to the diversity of various life forms make it necessary now for the management to understand the relation between biodiversity and ecosystem functioning in our coastal and offshore waters.

Tilman<sup>1</sup> has used theory and experiments to argue that high diversity leads to greater community stability and productivity and makes the system less susceptible to invasions. In this article, we examine the effects of a few important determinants of biodiversity, as they apply to the marine environment. These are: competition, heterogeneity and predation. In doing this, we briefly present examples of studies from literature on marine biodiversity and their consequences on the ecosystem. We have further attempted to apply biodiversity concepts on scenarios from our own coastal and oceanic waters with the hope that future in-depth studies on these aspects will help us to understand better the functioning of the ecosystem dynamics in our own waters, leading to its proper management. Figure 1 presents the basic theme, which will be discussed further in this article.

Prior to a further discussion on marine biodiversity, it is important to recognize certain fundamental differences

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between the terrestrial and marine ecosystems. In the former, biodiversity can be related to three-dimensional space to permanent or semi-permanent physical structures. Thus, one may speak of organisms in the soil, below the forest canopy, upon the tree trunks, foliage, etc. In the marine environment, such a semi-permanent mesoscale distribution of organisms may also be discerned to a certain extent in the intertidal regions and the subtidal coral reef communities. Rocky outcrops, the sessile macrophytes and the sedentary or slow moving macrofauna offer such semi-permanent or permanent structures, which are fixed to a given location. Such a concept breaks down in the open water, or the pelagic zone, where waters do not remain stationary, but become part of regional or global circulation. The three-dimensional structure of the pelagos is fluid and mobile. There is yet another important difference. Temporal changes, which affect microscale and macroscale distribution of organisms are much more dynamic in the marine ecosystem. Changes in nutrients of a water body, for example, can occur very frequently and in a matter of days. The life-span of most planktonic marine organisms range from a few days to a few months. Therefore, rapidly changing variables effect short-term alterations to biodiversity at

different trophic levels and these can further lead to long term effects.

The consequences of the constant mobility of structure and frequent alterations in the environment result in dynamic changes in the biodiversity of the water column. Therefore, unlike on land, a study of pelagic marine diversity and its functions will require numerous regular samplings at a given location over a fairly long period of time, to account for inter- and intra-annual changes. Microscale changes leading to larger changes are more difficult to study in the marine ecosystem, owing to their sampling difficulties.

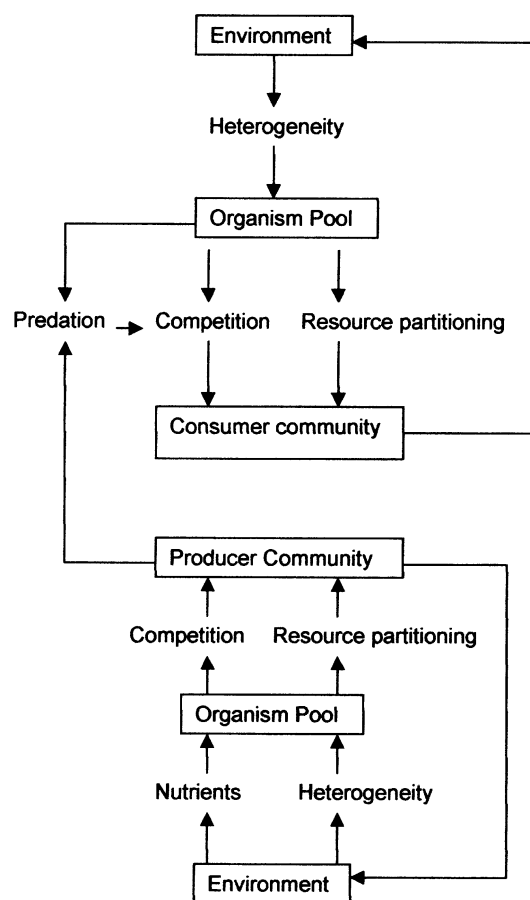
### Competition as a biodiversity determinant

Species that are endowed with better competitive abilities than others in utilizing a given limited resource, such as space or nutrients will ultimately outgrow the less efficient ones, exclude them from the habitat and reduce the diversity. Absence of competitive exclusion will lead to a higher diversity. Underwood<sup>8</sup> cites various examples of competition for space in intertidal rocky shores.

Nutrient levels are an important determinant of marine biodiversity, influencing the processes of competition and community structure in the marine environment (Figure 1). In the pelagic waters, concentration levels of inorganic nutrients, such as nitrate, phosphate and silicate in the water dictate population growth of phytoplanktonic primary producers. Characteristics for the maximum uptake rates for different nutrients ( $V_{max}$ ) and the nutrient concentration at which the uptake rate is half that of  $V_{max}$  (the half saturation constant,  $K_s$ ), vary with individual species. These properties play an important role in deciding which of the species will compete more efficiently at a given level of nutrients<sup>9</sup>.

An example of a nutrient-determined competitive dominance is the presence of 'nuisance algae' under conditions of high nutrient concentrations. According to Margalef, high nutrient, low-turbulent waters are likely to be dominated by dinoflagellates. For example, numerous tributaries pour in high loads of nutrients into the Chesapeake Bay, resulting in high phytoplankton production and eutrophication for most part of the year and are characterized by summer hypoxia/anoxia below the pycnocline in mesohaline areas. Sellner *et al.*<sup>10</sup> reported that the phytoplankton composition in the Patapsco River estuary, a tributary of Chesapeake Bay was dominated by dinoflagellates throughout the summer. Blooms of dinoflagellates, often of toxic species, are a frequent worldwide phenomenon. Such toxic blooms can result in fish kills, while others cause shellfish poisoning in human consumers. Therefore, occurrences of dinoflagellate blooms owing to high nutrient levels in coastal waters could have a direct impact on the human society.

In the Indian context, the National Institute of Oceanography reported blooms of the fish-killing dinoflagellate



**Figure 1.** Schematic figure depicting examples of various determinants of marine biodiversity.

*Cochlodinium polykreikoides* during October 2001 along the coast of Goa. Naqvi *et al.*<sup>11</sup> reported hypoxic conditions below the pycnocline along coastal waters off Goa, presumably following the presence of high nutrient levels. Such a high nutrient situation could have been the cause of the observed dinoflagellate bloom. Toxic blooms have been reported earlier along the west coast of India<sup>12</sup> and the implications of eutrophication of these waters have to be carefully considered.

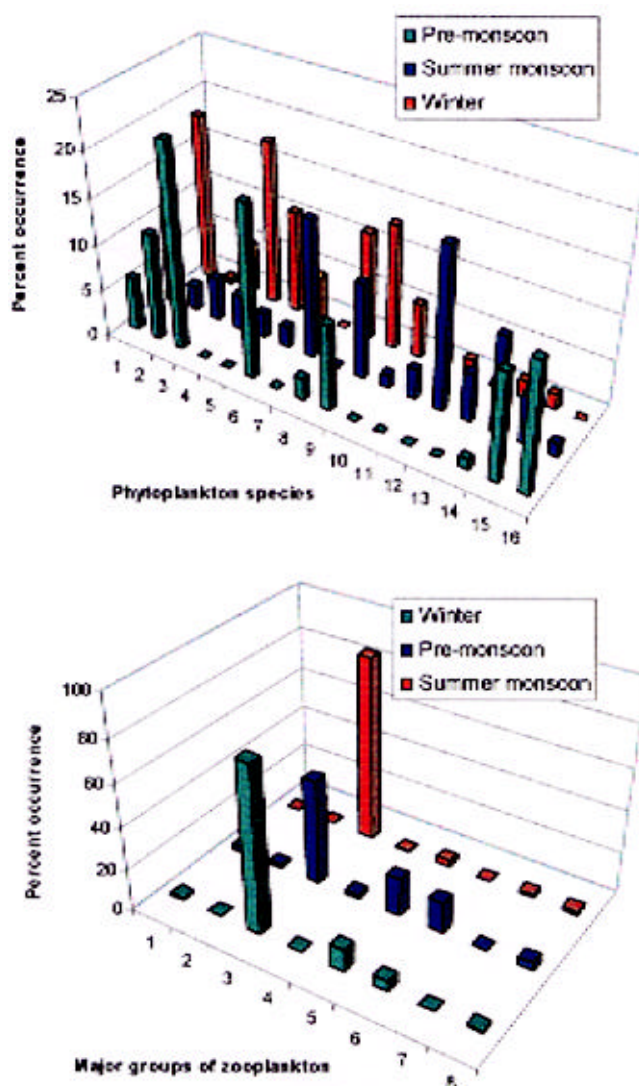
Paradoxically, however, competitive exclusion among phytoplankton species in pelagic waters is rare and their diversity remains generally high. For example, phytoplankton diversity in the neritic and oceanic waters of the Arabian Sea remains fairly high during the pre-monsoon, southwest monsoon and winter<sup>13,14</sup> (Figure 2). Various hypotheses have been put forward to explain the sustenance of phytoplankton diversity in pelagic waters<sup>9</sup>. Thus, the 'temporal succession' hypothesis suggests that the rapid nutrient changes that occur in the water column do not allow competitive dominance for any given species to be achieved within the short time afforded. Microhabitats that develop in low turbulent waters, each supporting different species of phytoplankton has been considered to be another reason for the high diversity, resulting in a patchy distribution of species in the water column (contemporaneous disequilibrium). Strong evidence is available to indicate that a high diversity is maintained as different species in the assemblage of phytoplankton are limited by more than one nutrient, thus not providing a competitive advantage to any single species. More recently, Huisman and Weissing<sup>15</sup> have shown through resource competition models that oscillations and chaotic fluctuations are generated when species compete for three or more resources, allowing the coexistence of many species on just a handful of resources.

The Arabian Sea, where considerable work has been carried out on phytoplankton dynamics, offers a fertile ground to test the various hypotheses on the dynamics of phytoplankton diversity. Devassy and Goes<sup>13</sup>, who studied the phytoplankton community structure and succession in the estuarine complex of Goa, recorded 82 species of phytoplankton, predominantly consisting of diatoms. Although phytoplankton diversity was generally high during most of the period, the centric diatom *Coscinodiscus marginatus* dominated in most stations during February, contributing up to 80% of the total phytoplankton. An unidentified blue-green alga accounted for 65% of the phytoplankton crop during April and May, while the diatom *Nitzschia closterium* dominated at a station during the monsoon, constituting 61%.

Naturally occurring seasonal enrichment in nutrients occurs along many parts of the world, including the waters along the west coast of India, where upwelling during the southwest monsoon period results in high nutrient conditions<sup>16</sup>. This triggers high primary production. Another period of relatively high nutrients and primary production

in the Northern Arabian Sea occurs during the winter cooling, occurring from January to February<sup>16,17</sup>. In the coastal waters of the Arabian Sea, the winter period yielded the highest diversity of phytoplankton, followed by the summer monsoon period. However, the standing stock of phytoplankton, in terms of chlorophyll *a* and their productivity were higher during the summer monsoon<sup>17</sup>. The pre-monsoon period in summer, when nutrient levels were at their lowest, harboured the lowest number of species.

An interesting situation of a dominant species bloom occurs in many areas of the west coast of India, during



**Figure 2.** Community structure and biomass of phyto- and zooplankton in the Arabian Sea during 3 different seasons. Phytoplankton species: (1) *Chaetoceros* sp.; (2) *Coscinodiscus* sp.; (3) *Navicula* sp.; (4) *Nitzschia* sp.; (5) *N. seriata*; (6) *N. closterium*; (7) *N. longissima*; (8) *N. pungens*; (9) *Rhizosolenia* sp.; (10) *R. alata*; (11) *R. fragillissima*; (12) *R. stolterfothii*; (13) *R. setigera*; (14) *Thalassiosira* sp.; (15) *T. nitzchioides*; (16) *Trichodesmium* sp. Major groups of zooplankton: (1) Siphonophora; (2) Polychaeta; (3) Copepoda; (4) Pteropoda; (5) Chaetognatha; (6) Copelata; (7) Fish eggs; (8) Decapod larvae. Information taken from Sawant and Madhupratap<sup>14</sup> and Madhupratap *et al.*<sup>40</sup>.

the oligotrophic summer months of April and May. The bloom is formed by the nitrogen-fixing cyanobacterium *Trichodesmium*, which produces vast patches of 'red tide' at this time<sup>18</sup>. Agawin *et al.*<sup>19</sup> have reviewed literature providing evidence that warm, oligotrophic conditions in oceanic waters are dominated by picoplanktonic cyanobacteria such as species of *Synechococcus*, rather than larger phytoplankton, including the diatoms.

Nutrient levels, in addition to their role in dictating competition as discussed earlier, can be a major factor in defining the community structure. Taylor<sup>20</sup>, while discussing the 'nutrient control model', has described community structuring under oligotrophic and eutrophic conditions. In nutrient and phytoplankton-poor waters, such as those that surround oceanic coral atolls, a tight recycling of nutrients is of paramount importance. Coral reefs around the Lakshadweep group of islands in the Arabian Sea is a typical example<sup>21</sup>. Widespread symbiosis in coral reef organisms is one of the mechanisms for maintaining this situation. Benthic crustose coralline and non-coralline algae form an important component of such communities. Since densities of phytoplankton in the water column are low, suspension-feeding organisms, such as barnacles and bivalves are rare at the secondary producer level. Instead, gastropods that feed on benthic algae or detritus are prevalent. At the predator level, organisms in coral reefs feed mainly upon herbivorous gastropods, polychaetes and detritus. Oligotrophic regimes are also characterized by predictable food resources, and the organisms tend to be slow-growing with highly specialized diets. This reduces competition and provides a scope for numerous specialist species to coexist. For example, coral reef environments harbour numerous species of specialist gastropods. Diversity of organisms is typically high.

As nutrients increase and the environment becomes mesotrophic, benthic algae become more important and may overgrow and displace corals and coralline algae for space. Rapidly growing, filamentous algae inhibit the settlement of coral planulae. Phytoplankton productivity becomes higher, resulting in reduced transparency of the water, and where sufficient sediment is available, sea-grasses establish themselves.

At the extreme end of the scale, with the highest levels of nutrient availability, as in the in-shore waters of continental margins during monsoons, most primary production in the water column occurs via the phytoplankton. High densities of phytoplankton and suspended matter reduce the light levels reaching the benthos and also reduce the amount of nutrient supply to benthic algae. Therefore, with eutrophication and the ensuing reduction in benthic algal growth, bottom-feeding gastropods decline and the benthic community becomes dominated by suspension-feeding animals. Organisms, such as the suspension-feeding bivalves typically have high fecundity, early maturity and fast growth rates. They also feed on a vari-

ety of diets and are generalists. The occupation of several niches by a few generalist species reduces the diversity. The number of trophic levels is shortened in eutrophic food webs<sup>9</sup>.

These examples warn us as to how eutrophication may affect the biodiversity of coral reefs in our waters, such as those that surround Lakshadweep and the Andamans. The National Institute of Oceanography carries out a regular monitoring programme in the Lakshadweep islands with a view to issuing timely warnings of impending biodiversity changes, if any.

The above mechanisms, by which nutrients affect community structures at different trophic levels in oligotrophic and eutrophic waters, are termed a 'bottom-up' control, in which primary producers determine the structure of the food web.

### Heterogeneity as a biodiversity determinant

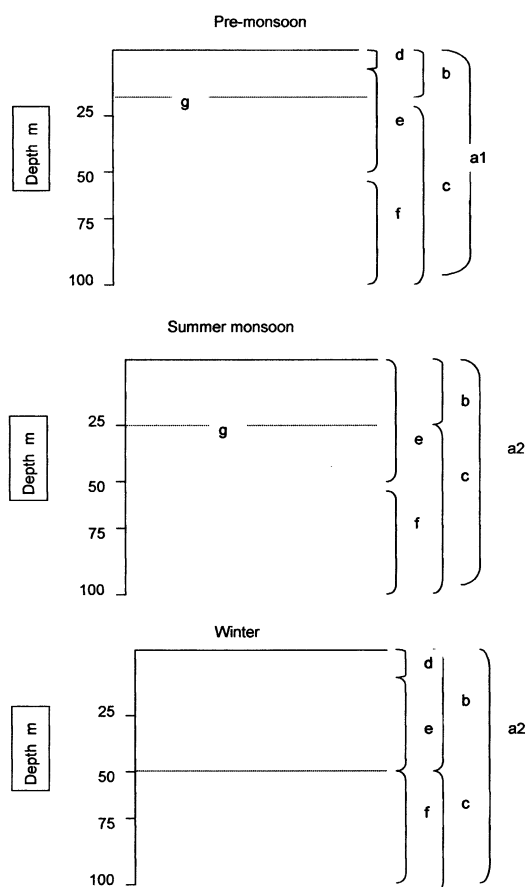
Heterogeneity in terms of the physical structuring of the habitat and the chemical and nutrient environment has a strong role in determining biodiversity, through the process of resource partitioning (Figure 1). Tropical rainforests, for example, provide a highly complex physical structuring. Coral reefs provide a similar three dimensional structural heterogeneity, by virtue of the variety of shapes and sizes of coral species and the nooks and crannies found in them.

The influence of heterogeneity on deep-sea biodiversity has been the subject of several papers in recent years. Contrary to the original belief that the deep-sea environment is constant and homogeneous, recent observations indicate that biologically generated heterogeneity is high and that habitat patchiness has contributed to the high biodiversity. These patches include bioturbatory mounds and burrows, phytodetrital pulses from surface blooms, carcass falls, bioturbation, megafaunal predation and benthic storms. Small-scale patchiness presumably permits a large number of functionally similar species to coexist by specializing on different types of patches or different successional stages of a patch. It now appears that the mosaic nature of deep-sea environments might permit high local diversity<sup>22,23</sup>.

Heterogeneity assumes a different dimension in the pelagic zone. Here, heterogeneity at any given geographic location is contributed by water column stratification, which changes seasonally. A schematic representation of the water column stratification in the coastal waters of the Arabian Sea, based on information on physico-chemical gradients, mixed layer depths and nutrient distribution obtained from the Joint Global Ocean Flux studies<sup>16,24,25</sup>, is given in Figure 3. The different layers present in the water column are characterized by sharp gradients in density and nutrients (the pycnocline and the nutricline), as well as in light intensity. The stratifications also change seasonally. The biodiversity of these

waters will be a sum total of all the changes. Theoretically, such spatial heterogeneities generated during different seasons might be expected to support diverse assemblages of bacteria and phytoplankton species and these would affect the community structure and functioning of higher trophic levels.

The role of heterogeneity in dictating zooplankton community structure has been studied in the Arabian Sea<sup>26,27</sup>, where a strong oxygen gradient exists in the northern part, with a pronounced oxygen minimum zone (OMZ) below 200 m. Mesozooplankton biomass is higher above the thermocline in these parts, apparently avoiding the OMZ. However, certain species characterized the oxygen-poor layers of the water column. Calanoid copepods in the water column of the Arabian Sea could be characterized into four categories, comprising those that (1) live above 200 m; (2) predominantly surface-living, tailing-off to deeper waters; (3) sparser, deep-living species below 300 m and (4) those that are distributed throughout the water column.



**Figure 3.** Water column stratification in the Arabian Sea during 3 different seasons. a1: Nutrient-poor layer; a2: nutrient-rich layer; b: low density mixed layer; c: high density layer; d: high light intensity zone for photosynthesis; e: optimal light intensity zone for photosynthesis; f: suboptimal light intensity zone for photosynthesis; g: pycnocline.

### Predation as a biodiversity determinant

Predators may often exert a 'top-down' control (Figure 1). This implies that these organisms which are above the trophic level of the producer or prey, exert an influence on the community structure. A keystone predator crops down the dominant competitor from reaching a competitive equilibrium. By doing this, the predator allows other species competing for the same resource to coexist, thus increasing diversity. Predation constitutes an important factor that disturbs the trend of competition and curbs it, thus counteracting dominance. The best-known example is that of Paine, who showed that mussels, which were strong competitors for space and smothered many, if not all of the other users of the primary space, were kept in check by their predator, the starfish *Pisaster ochraceus*. By predated on the mussels, the starfish indirectly allowed the maintenance of a high species richness<sup>8</sup>. The deep-sea benthic region is now recognized to be a high biodiversity environment. One among the various explanations for this is keystone predation. It is believed that such a predation by megafauna causes patchiness in the deep-sea, crops down densities of species that are strong competitors for resources and allows other, less-strongly competing prey species to coexist<sup>22</sup>. These predators include organisms such as the bathypelagic and megabenthic holothurians.

Many primary consumers may also exert a top-down control. Duffy *et al.*<sup>28</sup> have shown that various amphipod species that graze on epiphytic algae of seagrass have significant impacts on ecosystem processes, such as epiphyte grazing and biomass of eelgrass. One of the potential primary consumers in the northern Arabian Sea is the salp *Pegea confoederata*, which appears in swarms at the end of the winter period in February<sup>29,30</sup>. It is an intensive filter feeder and rapidly defecates numerous, square-shaped faecal pellets, approximately 0.25 cm<sup>2</sup> in area. A microscopic examination of the faecal pellets yields a good picture of the enormous diversity the phytoplankton presents in the waters during this time. This animal may be an important 'cropper' of phytoplankton, grazing uniformly on all phytoplankton species, moderating competition and promoting high biodiversity. The importance of such grazers in biodiversity processes is worthy of future studies.

Diseases may constitute another major cause of disturbance, having profound effects on biodiversity. Several recent studies have shown that phytoplankton diversity in the water column may be significantly affected by viral diseases.

### Disturbances and diversity

Predation and diseases may be considered as different mechanisms of disturbance. Underwood<sup>8</sup> has discussed the intermediate disturbance model, originally propoun-

ded by various ecologists. According to this, disturbances that are very frequent, drastic and recent will negatively influence the entire biodiversity, since only hardy species that are capable of withstanding those effects will be able to survive such a situation. At the other end of the spectrum, absence or low levels of disturbances will offer a scope for strong competitors to displace less efficient ones. Intermediate levels of disturbance are most conducive to a high diversity. Huston has enunciated the 'dynamic equilibrium' model along similar lines to explain the relations between competitive displacement and disturbance (see Rex *et al.*)<sup>22</sup>.

Community structure also depends to a great extent on factors affecting recruitment patterns. Spawning and larval recruitment of organisms such as bivalves, barnacles and echinoderms are induced in food-rich environments, as happens during phytoplankton blooms<sup>31</sup>. Such a trigger may induce larval production of a bivalve before that of its predator, such as a starfish. In such a case, the prey might grow to a size that cannot be consumed by the late arriving predator. Therefore, the timing of recruitment would influence the competitive abilities of the prey<sup>8</sup>. Recruitment of organisms in the boreal regions shows distinct seasonal variations. However, this may frequently be non-seasonal in tropical waters, which are subject to intraseasonal vagaries such as cyclones or intermittent rainfall. Thus, non-seasonal spurts of algal blooms occur during breaks in the monsoon rainfall along the west coast of India<sup>32</sup>. These provide cues to barnacles to release larvae on an impulse. With the resumption of rains, the larvae and juveniles are put into stress and this may result in recruitment failure, as observed for the barnacle *Balanus amphitrite* in the Dona Paula Bay located at the mouth of Zuari estuary<sup>33</sup>.

The concept of high biodiversity maintenance in the presence of a dynamic equilibrium is possible if the disturbance affects all species in a random manner. However, all disturbances may not be random. In particular, predation and diseases could affect different species in various ways.

### Effects of climate and anthropogenic changes on marine biodiversity

There is now an increasing evidence to suggest that climate changes affect biodiversity. Phenology, the seasonal timing of organisms, has been shown to be affected in terrestrial organisms by global warming. In addition, community shifts and ecosystem dynamics also appear to be affected by this climate change<sup>34</sup>. Organisms may show range shifts, enabling non-native species to cross frontiers and become elements of the new biota. Many warm water species, such as the green alga *Caulerpa*, phytoplankton species and fishes are increasingly found in the Mediterranean and the North Sea. Community structures

too, have been observed to change. After the massive, worldwide bleaching event that occurred in 1998, thin-tissued, branching acroporid and pocilloporid corals seem to have disappeared in a few cases, leaving the community dominated by hardier species, such as *Porites*. Many further potential effects of climate change, affecting recruitment success and trophic interactions in the marine environment have been described by Walther *et al.*<sup>34</sup>.

Pollution of coastal waters through human activities may drastically alter biodiversity<sup>5</sup>. Industrial effluents, thermal and freshwater discharges, land reclamation and other anthropogenic effects have caused much damage to coastal diversity all over the world. In the context of the Indian scenario, the large-scale destruction of coral reefs in the Gulf of Mannar and the Gulf of Kacchh are well known examples<sup>35,36</sup>. While industrial activities are unavoidable, we are in a situation where we have no clear understanding of the effects that such changes would bring about on the entire ecosystem. Yet another potential threat to coastal biodiversity that looms large is bio-invasion. Release of ballast water carried by ships in foreign ports can pose a major threat. Introduced species may successfully compete and exclude some local species, altering the original biodiversity. This has been recently reviewed by Anil *et al.*<sup>37</sup>. A dramatic example is the introduction of *Salvinia*, originally brought to Kerala as a diet for the fish *Tilapia*, yet another exotic species. Over the last twenty years or so, *Salvinia* has spread so much and become such a menace that it has choked the waterways of Kerala, reducing primary production and leading to high rates of sedimentation. This has led to the virtual disappearance of many common fishes and the freshwater prawn *Macrobrachium* from many areas<sup>38</sup>.

### Relation between diversity at different trophic levels

Few studies have considered the relationships between diversity at different levels of the food web. For example, it might be asked as to how the highly transient phytoplankton community diversity in the pelagic ecosystem is translated into that at higher trophic levels. Schnetzer and Steinberg<sup>39</sup> have shown that zooplankton display species-specific preferences for diet. They have further emphasized that in order to understand pelagic food webs and carbon cycling, individual food preferences have to be studied in detail. Madhupratap *et al.*<sup>40</sup> pointed out to the need for such an understanding, while discussing fishery resources in the Arabian Sea. While catches in the northern part of the Arabian Sea are predominated by carnivorous fishes such as the Bombay duck, croakers and ribbon-fish; the planktivorous fish clupeids, perches, carangids and mackerels are more prevalent in the southern part. Among the zooplankton, the ostracods and salps are more common in the northern part.

Lifespans of phytoplankton blooms normally extend to a few days to weeks, that of the primary grazers, the zooplankton, several weeks and that of the primary predators, much longer. Communities of phytoplankton are short-lived and may change continually in weeks. One might expect that both in the Arabian Sea and the Bay of Bengal, a succession of phytoplankton communities takes place even within a season. Information available for the phytoplankton diversity in an estuarine complex in the west coast<sup>13</sup> reveals that changes occur even on a monthly basis. The interactions of each community with the environment may determine the succeeding community at the same trophic level. Thus, red tide blooms of the cyanobacterium *Trichodesmium* during the pre-monsoon occur at a time of nitrogen depletion<sup>41</sup>, which is a likely outcome of events taking place earlier in the season. Likewise, the nitrogen-fixing abilities of this cyanobacterium might play a role in nitrogen flux to the deeper layers. Their influences on subsequent phytoplankton communities that develop during the monsoon are not known.

Some of the available information on seasonal variations in phyto- and zooplankton diversity from the Arabian Sea<sup>14,42</sup> are shown in Figure 2. It has been shown that both the diversity, as well as standing crop values of phytoplankton (chlorophyll *a* concentrations), change drastically during different seasons. On the contrary, zooplankton biomass in the Arabian Sea is almost invariant in all seasons. An attempt has been made to explain this 'Arabian Sea zooplankton paradox' by invoking the microbial loop concept, wherein, microzooplankton, such as ciliates and heterotrophic dinoflagellates that feed on bacteria would provide the larger, mesozooplankton with adequate food during periods of low phytoplankton biomass. Although the biomass of zooplankton changes only insignificantly during the seasons, their community structure displays clear differences, as do the phytoplankton (Figure 2). The immediate question that strikes the mind in this context is the extent of the role that phytoplankton species composition plays in determining the zooplankton community structure.

The seasonal stratifications and associated primary producer communities could profoundly affect zooplankton behaviour. Zooplankton in the water column display diurnal migratory feeding rhythms. It is likely that these migrations are related to layers that harbour the most suitable phytoplankton communities in terms of food. Since adult zooplankton would witness several rapid changes in phytoplankton communities, the composition of a single phytoplankton bloom would be expected to have little effect on them. On the contrary, the effect of a single phytoplankton community structure may be felt more immediately at the larval and naupliar levels, which are the short-lived feeding stages in the life cycles of secondary producers. It is possible that the feeding strategies of zooplankton are adapted to thrive on a succession of phytoplankton communities. How important is the pat-

tern of such a succession? One may envisage that all phytoplankton species are not equally fed upon by the zooplankton, the palatability depending on various factors such as the shape, size and nutritional value. One might have to resort to the concept of functional groups among phytoplankton in order to address this possibility.

Functional groups characterize organisms in terms of their structure and life history strategies. Functional groups would include several unrelated species in terms of certain shared characters related to an ecological function<sup>43</sup>. Several recent examples of such studies are now available. In a study on terrestrial arthropods, Symstad *et al.*<sup>44</sup> noticed that arthropod species richness was affected by plant functional groups with which they were associated, more than the composition of plant species. In an experimental study on motile macrofauna associated with seagrass communities, Parker *et al.*<sup>45</sup> observed that functional properties of seagrass and seaweed more strongly influenced the epifauna than the species diversity per se. Hulot *et al.*<sup>46</sup> carried out a mesocosm study to examine the effect of nutrient enrichment on phytoplankton and higher trophic levels. They concluded that in order to make a successful prediction, it is important to examine functional diversity among phytoplankton species. They further emphasized that such an understanding is essential for effective ecosystem restoration. Banse *et al.*<sup>47</sup> suggested that the enhanced phytoplankton biomass during the southwest monsoon in the Arabian Sea is the result of the fact that the larger phytoplankton species escape grazing by the prevalent zooplankton species, multiply and contribute to the total standing crop. This once again emphasizes the need to study functional groups as an important aspect of biodiversity studies.

How important are individual species to the ecosystem? The functional group approach can be interpreted as one which emphasizes that a diversity comprising several species of the same functional group contribute less to the overall diversity, than a diversity of a fewer number of species with different functional groups. While this might be broadly true, it is possible that every individual species is a functional group at a level too fine for us to discern their role, given our present understanding of the ecosystem. Therefore, it is possible that every individual species plays a role in ecosystem functioning. Thus, the model of Ray *et al.*<sup>48</sup> predicts that removal of a species or a group of species will affect not only the biodiversity of the ecosystem, but also environmental feedbacks, thus altering environmental conditions.

An understanding of the relations between diversity at different trophic levels has important implications in conservation management. Thus, for example, if a system is driven by 'bottom-up' control mechanisms, care needs to be exercised in such a way that the environment is not overloaded by nutrients, resulting in eutrophication and loss of diversity, including species that are of utility to mankind. On the other hand, if the system is top-down

controlled, excess removal or overexploitation of the predator or the primary consumer needs to be avoided, if the diversity and ecosystem functioning are to be in a healthy state<sup>49</sup>. Along the Californian coast, sea otters and invertebrates are predators of sea-urchins, which, in turn, feed on kelps. The overexploitation of the sea otters for their skin, resulted in an increase in sea-urchin population and an eventual destruction of vast areas of the kelp and its associated communities. Likewise, the removal of large sharks to protect swimmers off the South African coast affected the fish community<sup>49</sup>.

## Conclusions

For any given ecosystem, a biodiversity inventory per se is important. Equally, if not more important, is to understand their role in ecosystem processes. Much information is now available on the taxonomic diversity in our waters. Biological oceanographic process studies in these waters have so far emphasized the overall microbial, primary and secondary productivities and biomass of organisms at various trophic levels. Much stress has been laid on the physical and chemical parameters that affect these processes. These include the monsoonal upwelling, nutrient levels, irradiance and current circulation patterns. That the biological processes and to a great degree, the environment, are ultimately dictated by the community structure at various trophic levels is yet to be appreciated, or verified. In view of our present knowledge of taxonomic diversity and biological processes in the Arabian Sea and the Bay of Bengal, one may ask the following questions.

- How is seasonal productivity related to biodiversity?
- What are the mutual relationships between the environment and biodiversity?
- How does a given community structure affect the processes and structure in subsequent communities at the same trophic level?
- How does the community structure at any given trophic level affect productivity and diversity of higher levels?
- What are the effects of intra-seasonal, non-cyclic climate oscillations on biodiversity and productivity?
- What are the effects of anthropogenic influences on biodiversity and ecosystem processes in coastal waters?

It is now accepted that the sea is not a permanent buffer, absorbing any amount of climatic or anthropogenic influences. The biodiversity and ensuing ecosystem processes can be severely affected for various reasons. Several concepts and hypotheses that pertain to marine biodiversity and ecosystem functioning have now been formulated. However, the validity of these, and their application to different habitats now have to be examined with care. A variety of monitoring and experimental tools

such as mesocosm manipulations are available to study these effects. Such studies are extremely important if we are to understand the biodiversity dynamics of our waters, prepare predictive models and formulate policies that will enable the sustainable use of the marine ecosystem.

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## MEETINGS/SYMPOSIA/SEMINARS

### The Second Asian Particle Technology Symposium (APT 2003)

Date: 17–19 December 2003  
Place: Penang, Malaysia

Topics include: i. Particle and bulk powder characterization: Particle characterization, Online and inline measurements, Particle mechanics and tribology, Particle–particle interaction, Bulk powder mechanics, Slurry rheology, Soft solids characterization. ii. Particle design, new technologies and industrial applications: Crystallization and precipitation, Flocculation, Agglomeration and granulation, Comminution, attrition and erosion, Aerosol process, Nanoparticle technology, New products and technologies, Biological aspect of particle technology. iii. Powder handling and multiphase flow: Fluidization and CFB, Modeling of fluid-particle systems, Bulk solids, Multiphase flow, Fluid–particle reaction, Dynamics of granular flows. iv. Solid–fluid separation process: Membrane separation, Filtration, Centrifugal separation, Flotation, Gravity settling.

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### National Symposium on Molecular Modulation by Oxidative Stress and Cell Function

Date: 20–22 November 2003  
Place: Chandigarh

Topics include: Gene expression and repression in oxidative stress, Oxidative stress and heat shock protein expression, Redox regulation pathways, ROS production and signal transduction, Oxidative stress as a mediator of apoptosis, Nutritional status, ROS production and immunity, Antioxidant enzyme systems.

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