

Dominance of dinoflagellates in microzooplankton community in the oceanic regions of the Bay of Bengal and the Andaman Sea

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Studies on microzooplankton, phytoplankton biomass (chlorophyll *a*) and production were conducted at five oceanic stations in the Bay of Bengal and Andaman sea onboard *FORV Sagar Sampada* during intermonsoon (March 2001). Throughout the study protozoans dominated the microzooplankton community and their contribution ranged between 60 and 100% (avg 88%). Protozoans consisted mainly of ciliates and dinoflagellates. Tintinnids comprised 36 species belonging to 18 genera and 76 species of dinoflagellates belonging to 24 genera were recorded. Most of the genera showed their presence throughout the upper 150 m water column except four genera, two each belonging to dinoflagellates and tintinnids. *Amphisolenia* and *Exuviaella* (Dinoflagellates) were concentrated in the upper 20 m, whereas *Salpingella* and *Salpingacantha* (Tintinnids) were restricted to 75–100 m. Contribution of dinoflagellates to the total density of microzooplankton was as large as 80% (avg 59%). In this paper, the dominance of dinoflagellates is discussed with reference to different modes of nutrition of this group. Combining many nutritional strategies (mixotrophy and heterotrophy with symbiosis) may give dinoflagellates a competitive advantage over strict phototrophs or heterotrophs and may be the possible reason for their dominance in the study area.

MICROZOOPLANKTON are a group of taxonomically diverse, tiny (body dimensions 20–200 μm), phagotrophic organisms, which are often abundant in marine waters. They comprise a significant part in numbers of the marine zooplankton community, even though their biomass is usually less than the biomass of meso- and macro-zooplankton^{1,2}. However, due to their small body size, microzooplankton have higher weight-specific physiological rates such as feeding, respiration, excretion and growth^{3,4} than large metazoans, and hence they are capable of exploiting pico- and nanoplankton, which are underutilized by larger metazoans such as copepods⁵. Available information reveals that microzooplankton graze on most of the primary production in coastal and oceanic environments^{6–9} and hence their importance in the trophodynamics of

pelagic food webs. In the east coast of India, work on microzooplankton is limited to the studies on tintinnids from the estuarine and nearby coastal waters^{10–12}. No studies are available on microzooplankton from the oceanic waters of the Bay of Bengal and the Andaman Sea. The present study attempts to understand the taxonomy and vertical distribution of microzooplankton with special emphasis on dinoflagellates in the open ocean regions of the Bay of Bengal and the Andaman Sea during the intermonsoon period (March 2001). However, the dependency of zooplanktonic organisms on primary food substrates has been examined before in relation to vertical distribution of chlorophyll *a* and that of mesozooplankton^{13,14} and hence attempts have also been made to establish the possible relationship between the microzooplankton and phytoplankton biomass as chlorophyll *a* and production in the upper 150 m water column.

As part of Marine Research-Living Resources (MR-LR) programme, studies were conducted in five open ocean stations in the Bay of Bengal and the Andaman Sea onboard *FORV Sagar Sampada* during the intermonsoon period (March) of 2001 (Figure 1). Water samples for

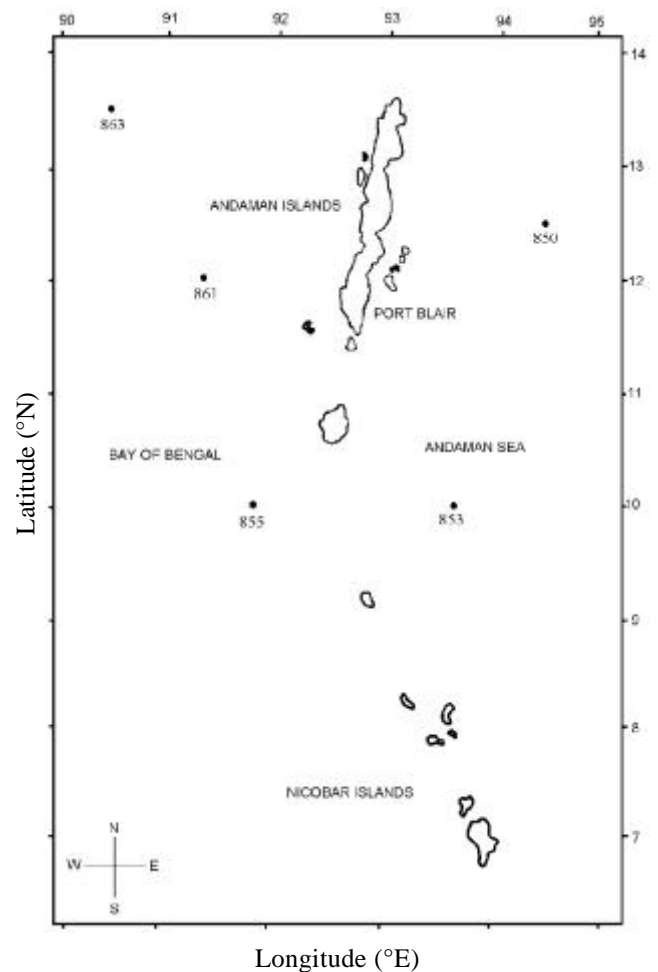


Figure 1. Station locations.

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microzooplankton, chlorophyll *a* and primary production were collected from eight standard depths up to less than 1% light illumination (0, 10, 20, 50, 75, 100, 120 and 150 m respectively) using Niskin samplers. Depth of the euphotic zone was calculated using seecchi disc measurements. Sea bird electronic CTD was used to obtain the temperature and salinity profiles. CTD salinities were calibrated against values obtained with an autosal. Primary production was measured by *in situ* method using ^{14}C technique.

Water samples were collected between 5 and 6 am; incubation experiments were done for 12 h (sunrise to sunset). Prior to *in situ* incubation of ^{14}C series, 1 ml of $\text{NaH}^{14}\text{CO}_3$ was added to each sample (5 μCi per 300-ml seawater). After the 12 h incubation, the samples were filtered through 47 mm GF/F (nominal pore size 0.7 μm) filters with gentle suction. These were exposed to concentrated HCl fumes to remove excess inorganic carbon and kept in scintillation vials for subsequent estimation of ^{14}C uptake. Liquid scintillation cocktail was added to the vials a day before analysis, and activity counted in Wallac scintillation counter. The disintegration per minute (DPMs) values were converted into daily production rates ($\text{mg C m}^{-3} \text{d}^{-1}$) using appropriate formula¹⁵. One litre of water from each depth was filtered through GF/F filters (nominal pore size 0.7 μm) to estimate chlorophyll *a* spectrophotometrically (Perkin-Elmer UV/VIS)¹⁶ using 10 ml 90% acetone for extraction. Column chlorophyll *a* (mg m^{-2}) primary production ($\text{mg C m}^{-2} \text{d}^{-1}$) was calculated by integrating depth values.

Microzooplankton samples were collected by filtering five litres of water from each depth initially through 200 μm bolting net and subsequently filtered through a 20 μm sieve. Concentrated microzooplankton samples were transferred to 100 ml of filtered seawater and preserved in acid Lugol's iodine and kept in dark. Samples were left to settle for > 48 h in a settling chamber (Utermohl 1958). Microzooplankton were enumerated and identified with an Olympus inverted microscope at 100–400 magnifications. Ciliates and dinoflagellates were identified to the species level with available literature^{17–22}. In the recent years, dinoflagellates are considered as an important component of microzooplankton community based on the current understanding of the mode of nutrition of this group where only six species are proved to be strict phototrophs^{23–27}. Micrometazoans (larval stages of metazoans) and other minor taxa of protozoans were identified up to the group level. The dimensions (μm) of different taxonomic groups from microscopic measurements were determined using a calibrated ocular micrometer and the biovolume of the organisms was calculated using appropriate geometrical formulae. Carbon content (pgC) was calculated using appropriate biovolume to carbon conversion ratio²⁸. Microzooplankton standing stock per unit area is calculated by integrating with depth.

Southern side of the study area is characterized by

relatively warmer surface waters (> 29°C). Mixed layer depth ranged between 40 and 60 m (avg 50 m) and shallowest at station 853. The sea surface salinity varied from 31.0 to 32.6 with a minimum at station 863. In general, northwest of Andaman Sea is characterized by deeper mixed layer with stable thermocline (Figure 2). Throughout this study, protozoans dominated the microzooplankton community and their contribution ranged between 60 and 100% (avg 88%). Protozoans consisted mainly of ciliates and dinoflagellates. Acantherians, radiolarians and foraminiferans were numerically less (avg 6%) and are considered here as other protozoans. Micrometazoans included nauplii and other copepodide stages of copepods and other metazoan larval forms on an average of 8%. Seventy-six species of dinoflagellates belonging to 24 genera were recorded. Major genera include *Ceratium*, *Peridinium*, *Ornithocercus*, *Phalacroma*, *Dinophysis*, *Oxytoxum*, *Gonyaulax*, *Amphidinium*, *Prorocentrum*, *Amphisolenia*, *Heterolaucus*, *Exuviaella*, *Pyrocystis*, and *Ceratocorys*. Most common species of dinoflagellates were *Ceratium trichoceros*, *C. contortum*, *C. macroceros*, *C. fusus*, *C. furca*, *Peridinium conicum*, *P. tuba*, *P. granii*, *P. nipponicum*, *Ornithocercus thumii*, *O. magnificus*, *Oxytoxum scolopex*, *Prorocentrum compressa*, *Podolamphas elegans*, *P. spinifer*, *P. bipes*, and *Dinophysis uracantha*. Among ciliates, tintinnids were the only order present in the samples. Tintinnids comprised of 36 species belonging to 18 genera and were mainly represented by *Eutintinnus fraknoi*, *Undella claperedei*, *Rhabdonella spiralis*, *Salpingella acuminata*, *Dictyocysta mitra*, *Protorhabdonella simplex*, *Salpingacantha ampla*, *Amphorella pyramidata*, *Steenstrupiella steensrupii*, *Epiplocytilis undella* and *Petalotricha ampulla*. The total absence of five genera of tintinnids, viz., *Favella*, *Helicostomella*, *Metacytilis*, *Steenosemella*, and *Tintinnopsis*, which were reported from coastal waters^{10,29}, ascertained their neritic preference. Presence of *Trichodesmium erythraeum* (avg 125 cells l^{-1}) up to 100 m at all stations may be an indicator for oligotrophic nature of the water^{30,31}.

Microzooplankton density and biomass varied from 6 to $115 \times 10^3 \text{ m}^{-3}$ (avg $45.7 \times 10^3 \text{ m}^{-3}$) and 0.17 to 2.7 mgCm^{-3} (avg 1.1 mgCm^{-3}) respectively. Their maximum column density and biomass were obtained at station 861 and were $875 \times 10^4 \text{ m}^{-2}$ and 226 mgCm^{-2} respectively (Table 1). Contribution of dinoflagellates to the total microzooplankton was maximum and ranged from 39 to 80 (avg 59%) and even more than that of the tintinnid ciliates (5–40%; avg 19%). Other contribution of protozoans and micrometazoans in terms of density and biomass was comparatively low (avg density 15%, avg biomass 19%, Figure 3). Vertical distribution of microzooplankton showed maximum density and biomass in mixed layer (avg 50 m) where chlorophyll *a* showed their maximum and decreased gradually with increasing depth. (Figure 4). The gradual decrease in density and biomass of microzooplankton from 50 m downward may be due to

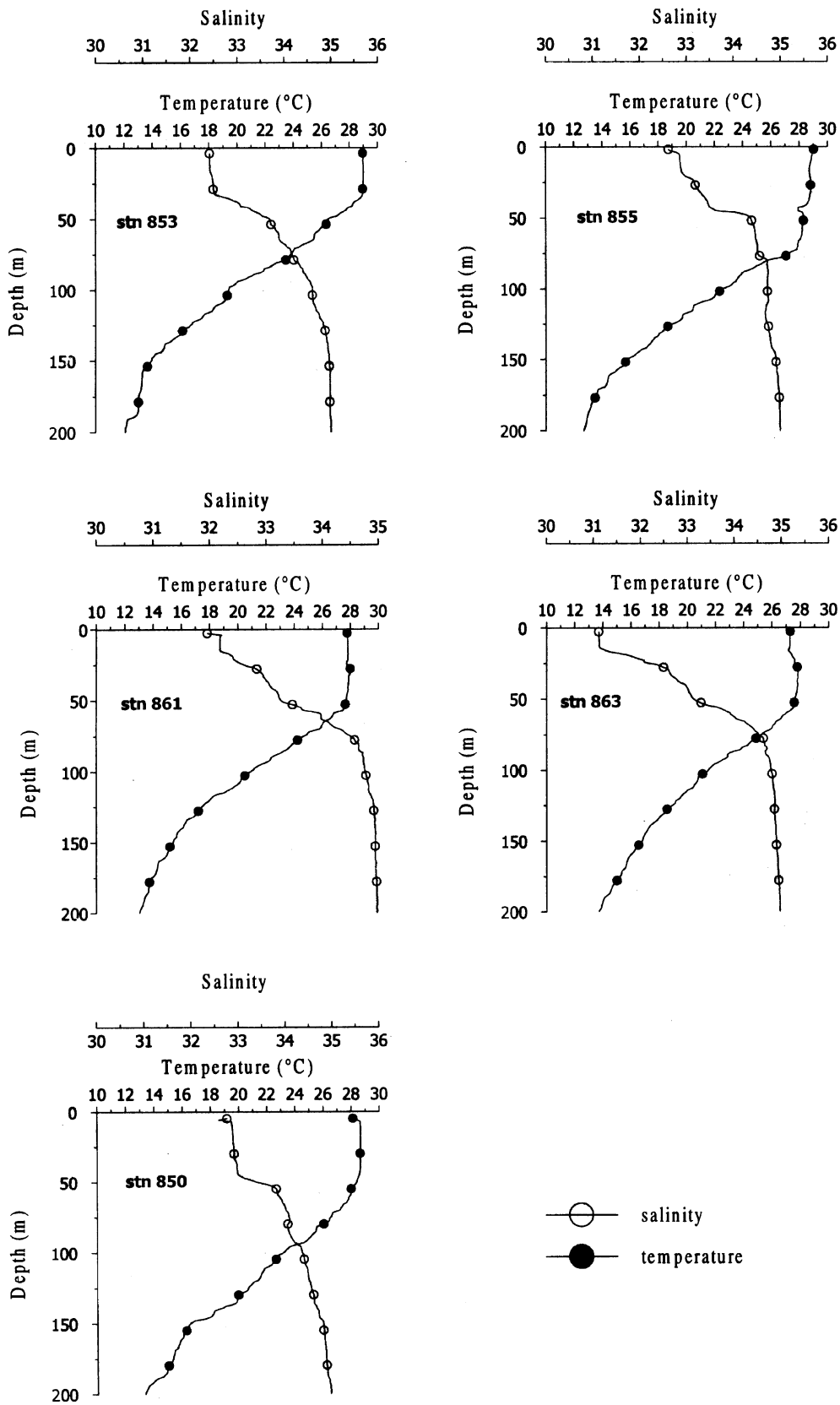


Figure 2. Vertical distribution of temperature and salinity at different stations of the study region.

the temperature gradients existing in this layer (thermocline). Maximum microzooplankton density of $115.5 \times 10^3 \text{ m}^{-3}$ was observed at 10 m of station 853. Most of the genera showed their presence throughout the water column except four genera, two each belonging to dinoflagellates and tintinnids. *Amphisolenia* and *Exuviaella* (Dinoflagellates) were found to be concentrated in upper 20 m water column whereas *Salpingella* and *Salpingacantha* (Tintinnids) were restricted to 75–100 m. *Amphisolenia* and *Exuviaella* are well studied for their strict phototrophic mode of nutrition and this may be the reason for their exclusive presence in the surface layers where optimum sunlight is available^{19,32}. The food requirement of *Salpingella* and *Salpingacantha* are still not clear. Preference to particular environmental factors like temperature and salinity might have influenced their vertical distribution³³. Column primary production and chlorophyll value ranged between 170 and 380 $\text{mg Cm}^{-2}\text{d}^{-1}$ and 6–13 mgm^{-2} respectively (Table 1). Maximum pri-

mary production and chlorophyll values were obtained at station 861 where the microzooplankton biomass showed maximum density. Studies have demonstrated that the food supply is the primary factor influencing the spatial distribution of microzooplankton^{10,33}. We examined the relationship among microzooplankton biomass, chlorophyll *a* and primary production for all water samples. A significant positive correlation was obtained between chlorophyll *a* and microzooplankton biomass ($P \leq 0.044$, $n = 39$, Figure 5) supporting the earlier findings^{34–36}. Relation between primary production and chlorophyll *a* also has given a significant positive correlation ($P \leq 0.048$, $n = 39$, Figure 5).

Available literature on nutritional requirements of tintinnids reveals that they mostly feed on pico- and nanoplankton groups^{37–40}. During the present study, contribution of dinoflagellates was as large as 80%. Earlier studies in the Arabian Sea and other tropical waters report flagellates as the major contributors of the microzooplankton community^{26,27}. However, no serious attempts have been made to discuss their mode of nutrition and its ecological advantage. In the present study, the higher number of dinoflagellates in the study area (avg 59%) is discussed with the recent understanding on the different modes of nutrition of this group. That the oceanic regions of the Bay of Bengal and the Andaman Sea are reported to be oligotrophic,^{41–44} is considered in this context. Organisms that are able to withstand or overcome the oligotrophic condition may possibly have a better chance of survival in these regions. Most of the oceanic dinoflagellates are

Table 1. Column values of different biological variables

Station	MZD ($\times 10^4 \text{ indiv. m}^{-2}$)	MZB (mgC m^{-2})	CHL (mg m^{-2})	PP ($\text{mgC m}^{-2}\text{d}^{-1}$)
850	756	184	8.92	252.1
853	599	150	9.56	368.7
855	470	141	6.94	172.1
861	875	226	13.88	378.1
863	501	130	12.91	344.1

MZD, Microzooplankton density; MZB, Microzooplankton biomass; CHL, Chlorophyll; PP, Primary productivity.

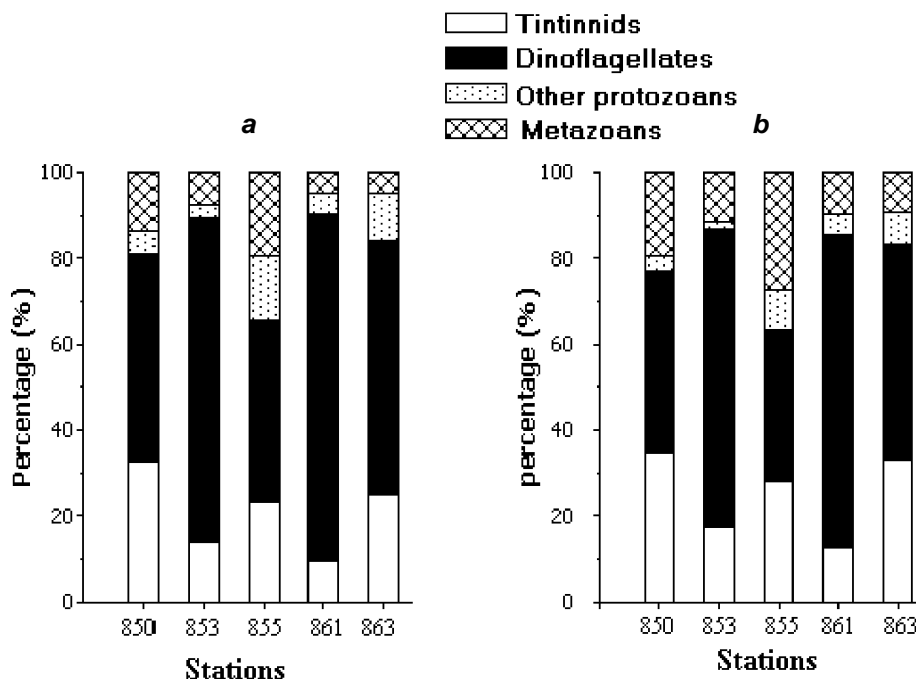


Figure 3. Contribution (%) of different microzooplankton taxa (a) density (b) biomass at different stations.

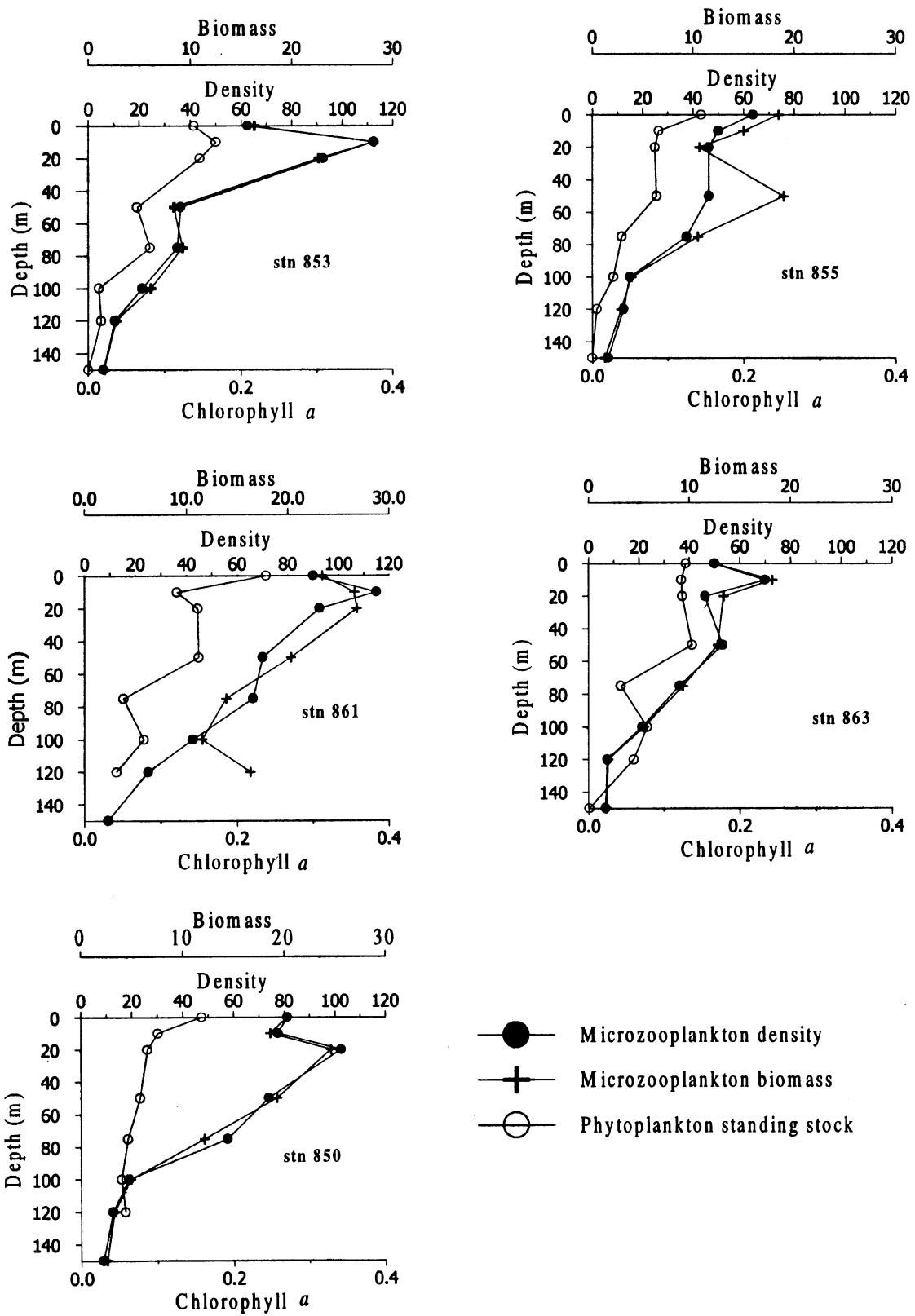


Figure 4. Vertical profiles of biological variables; microzooplankton density ($\times 10^3$ indiv. m^{-3}), microzooplankton biomass ($\times 10^2 \mu g C m^{-3}$) and phytoplankton standing stock-chlorophyll *a* ($mg m^{-3}$) in the study area.

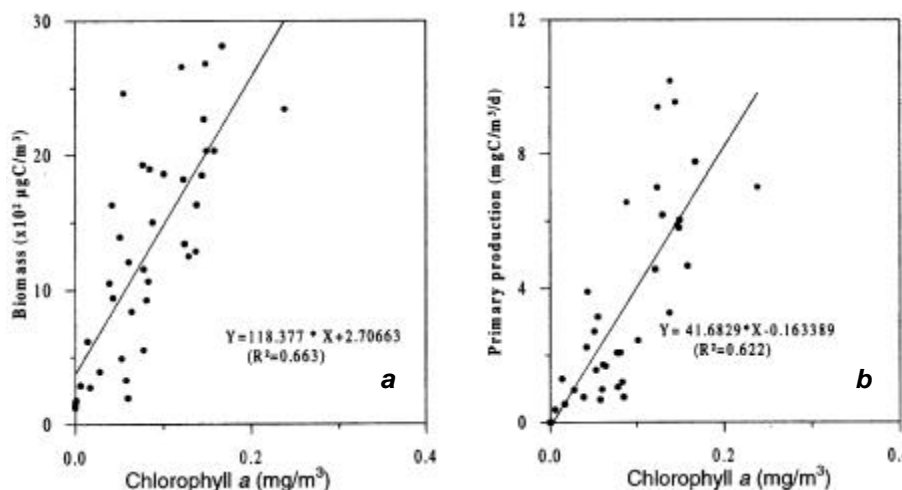


Figure 5. Relationship between (a) microzooplankton biomass and chlorophyll *a* concentration and (b) phytoplankton standing stock and production in the oceanic regions.

mixotrophic or heterotrophic^{23,32}. Mixotrophic organisms gain their nutrition through a combination of photosynthesis and uptake of dissolved or particulate organic material. The benefits and costs of these nutritional strategies to individual species assemblages are not fully understood. Combining the two nutritional strategies may give mixotrophs a competitive advantage over strict phototrophs or heterotrophs by enabling them to acquire organic carbon and nutrients when photosynthesis is limited, and/or to fix inorganic carbon to survive periods of reduced particulate food availability. Dinoflagellate phagotrophy on ciliates has also been reported⁴⁵. Many species of mixotrophic dinoflagellates are primarily phototrophic and can assimilate dissolved inorganic nutrients, but use phagotrophy to supplement limited inorganic nutrient regimes to increase their growth rates and thus mixotrophy may make a stronger link between the microbial and classic planktonic food webs by increasing trophic efficiency⁴⁶. Reports are available on the symbiotic association of cyanobacteria with many of the heterotrophic dinoflagellates from regions of nitrogen limitation⁴⁷⁻⁴⁹. Mixotrophic and heterotrophic dinoflagellates, by adopting the different modes of feeding may compete with other predators for prey and re-package smaller prey into larger plankton cells (the mixotrophs) and this may possibly be the reason for their dominance in the study area. The extent of mixotrophy among dinoflagellates taxa is still largely unknown. For some dinoflagellates it is not yet clear whether their photosynthetic machinery is their own or derived from prey, nor whether the plastids or endosymbionts need to be periodically replenished through ingestion⁵⁰. For most mixotrophic dinoflagellates, information on functional responses to light, dissolved inorganic and organic nutrients, as well as quality and quantity of prey are yet to be understood. It is felt that the role of advantageous modes of nutrition

(mixotrophy and heterotrophy with symbiotic associations) proposed in the present study for the abundance of dinoflagellates in the oligotrophic systems merit more detailed studies targeting its ecological significance.

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Discovery of a cave as the day roost of a rarest fruit bat *Latidens salimalii*

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Salim Ali's fruit bat *Latidens salimalii* is one of the three rarest bats in the world. It is endemic to Tamil Nadu in the southern part of India. Even though it was repeatedly mist-netted in the High Wavy Mountains, whether it roosts in foliage or trees or buildings during daytime, similar to sympatric fruit bats, was previously unknown. We report here for the first time that this species roosts in a cave in the High Wavy Mountains. Most of the individuals roosted in clusters in the darkest areas of the cave. We mist-netted 24 individuals during their evening outflights and confirmed their identity. The distance between the day roost and the only known night roost of *L. salimalii* was less than 1 km.

AMONG the 120 species of bats known from the Indian subcontinent, 14 are frugivorous and the remainder are insectivorous¹. Among fruit bats, the Indian flying fox *Pteropus giganteus*, the fulvous fruit bat *Rousettus leschenaulti* and the short-nosed fruit bat *Cynopterus sphinx* are relatively abundant species found in many parts of India. Salim Ali's fruit bat, *Latidens salimalii*, alone among the remaining 11 species, is endemic to the Tamil Nadu State in the southern part of India. Although Hutton² collected this enigmatic species 53 years ago, Thonglongya³ identified it correctly only 30 years ago. During April 1993 a team from Bombay Natural History Society and Harrison Zoological Museum rediscovered *L. salimalii* at the Kardana Coffee Estate situated in the High Wavy Mountains (9°42'N, 77°24'E). They mist-netted a few individuals of *L. salimalii* especially when the latter visited a shallow rocky chamber during the night. The team suggested that the High Wavy Mountains may be the only habitat harbouring this endemic bat⁴. Later it was entered into the *Guinness Book of World Records* as one of the rarest bats of the world⁵. The International Union for Conservation of Nature and Natural Resources (IUCN) listed *L. salimalii* as 'critically endangered' and it was noted as threatened based on its small distributional range, decline of habitat, and small population size⁶. Recently, Ghosh *et al.*⁷ mist-netted a few individuals of *L. salimalii* along with *C. sphinx* and *R. leschenaulti* at the Kalakkad–Mundanthurai Tiger Reserve forest (8°25'N, 77°35'E).

Recently, we mist-netted a few individuals of *L. salimalii* during pre-midnight hours as they visited the same rocky chamber in the High Wavy Mountains⁸. Based on

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