Table 1. Minerals deposited in the species studied

Species studied	Identified minerals in decreasing abundance
Halimeda discoidea	Aragonite, halite
H. gracilis	Aragonite, illite, feldspar
H. incrassata	Aragonite, feldspar, halite
H. opuntia	Aragonite, quartz
Udotea indica	Aragonite, halite
Acetabularia kilneri	Aragonite, quartz
Padina pavonica	Aragonite-quartz, illite, feldspar
Actinotrichia fragilis	Aragonite, high magnesium calcite, halite
Galaxaura lapidescens	Aragonite, high magnesium calcite, halite
G. lenta	Aragonite, feldspar, high magnesium calcite, halite
G. marginata	Aragonite, feldspar, high magnesium calcite, halite
G. oblongata	Aragonite, feldspar, halite
Amphiroa anastomosans	High magnesium calcite, quartz
A. foliacea	High magnesium calcite
A. fragilissima	– do –
Cheilosporum spectabile	– do –

High magnesium calcite was observed to be the predominant mineral deposit in all members of family Corallinaceae i.e. species *Amphiroa*, *Jania*, *Cheilosporum* and *Arthrocardia* confirming Vinogradov's[1] observation. Borowitzka[8] and Johansen[9] reported that high ambient temperature of the surrounding medium facilitates the incorporation of magnesium in the cell wall. India being a tropical region, water temperature is relatively higher and this probably accounts for the deposition of high magnesium calcite in these forms.

Other minerals like quartz, halite, illite and feldspar were also present in almost all forms which are possibly related to the contamination from detritus, seawater or organisms growing on or in the specimen.

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Chemoheterotrophy in the mangrove environment

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The unique characteristics of the mangrove ecosystem of the tropics are discussed. This ecosystem is endowed with a diversity of habitats within it and is chemoheterotrophic in nature. The production of photosynthetic prokaryotes under chemoheterotrophic conditions is discussed. Nitrogen fixation by planktonic cyanobacteria to augment nitrogen budget of the ecosystem has been worked out. The heterotrophic growth of photoautotrophic prokaryotes as a mechanism of natural evolution to survive in hostile coastal anaerobic and anoxic conditions is emphasized.

THE mangrove or tidal forests are one of the major ecosystems of the biosphere. According to McGill[1], 60–75% of the tropical coasts are covered by mangroves. The unique mangrove forest ecosystem comprises three dominant constituents: forest, water and land. The banks of intricately woven canals, meandering channels and gullies of the mangrove ecosystems are bordered by species belonging to *Avicennia*, *Rhizophora*, *Bruguiera*, *Ceriops* and *Excoecaria*. During low tide the muddy shores get exposed in mangrove ecosystems. The waterways consist of varying degrees of admixed composition of freshwater-brackish water-sea water in its various regions. The muddy shores, mudflats, stilt roots of vegetation like *Rhizophora* within the mangrove ecosystems provide many an ideal habitat and ecological niche for many organisms like photosynthetic prokaryotes, lichens, molluscs, etc. The mangrove ecosystem also induces the production of H_2S in many localized pockets because of the presence of sulphur-reducing bacteria. They find it an ideal environment due to putrefaction of organic matter under the prevailing anoxic conditions of its 'reducing environment' in certain areas.

In short, the mangrove ecosystem with its diversity of habitats and milieu harbours equally diversified microbial flora and biota. The nutritional requirement of microflora also differs widely ranging from photoautotrophic conditions in photosynthetic bacteria and cyanobacteria to chemoheterotrophic conditions in some bacteria.

In this paper we discuss their microbial ecology based on our studies at Pichavaram mangroves (Lat. 11° 29′ N; Long. 79° 46′ E) in Parangipettai, the southeast coast of India. Samples were collected fortnightly at two stations in the Pichavaram mangroves from January to December 1989 (Figure 1). The standing crop of epiphytic and benthic cyanobacteria was estimated by scrapping

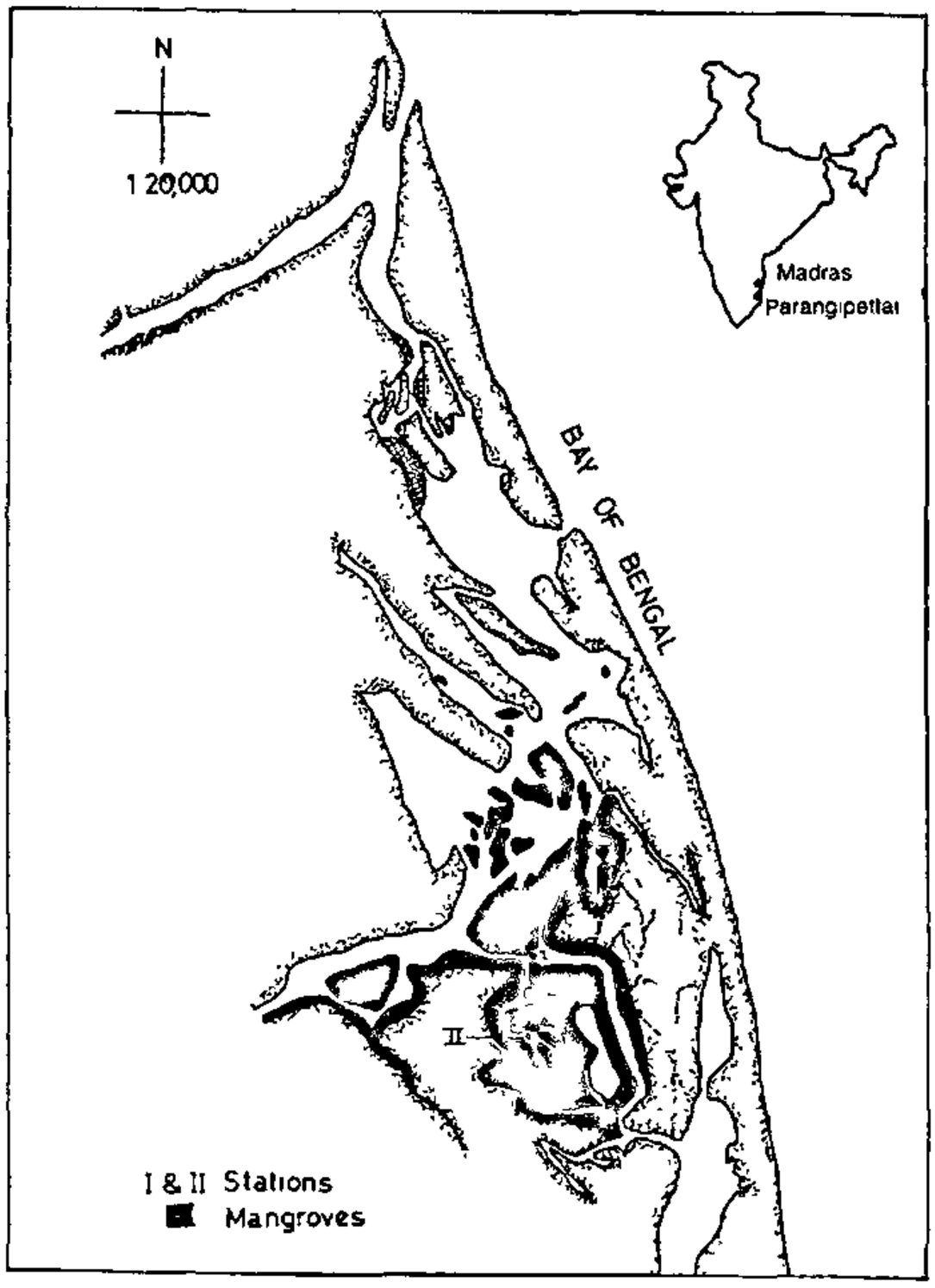

Figure 1. Map showing the Pichavaram mangroves.

an area of 1 cm^2 from the substrate. Photosynthetic bacteria were isolated and cultured from mangrove sediments using the modified Pfenning medium[2].

On the basis of their size, cell structure, presence of murein, 70s ribosomes and other features, cyanobacteria are considered as prokaryotes comprising a large group of morphologically different organisms. They use water as hydrogen donor and perform oxygenic photosynthesis. They occur as unicellular, colonial or filamentous organisms. Cyanobacteria have wide distribution in mangroves as planktonic, epiphytic and benthic organisms. The epiphytic cyanobacteria occur on the stilt roots of *Rhizophora*, pneumatophores of *Avicennia*, submerged wooden poles and stumps. Benthic cyanobacteria form exclusive mats on the organically-rich muddy intertidal areas of the mangroves. The standing crop of both epiphytic and benthic cyanobacteria is much higher when compared to the planktonic cyanobacteria. Also the standing crop of epiphytic and benthic cyanobacteria is seasonally high during summer and premonsoon seasons (Table 1).

The phototrophic bacteria (purple and green bacteria) do not use H_2O as H donor to perform photosynthesis

Table 1. Standing crop epiphytic, benthic and planktonic cyanobacteria in the Pichavaram mangroves (filaments/cm^2) (Year: 1989)

Month	Epiphytic cyanobacteria	Benthic cyanobacteria	Planktonic cyanobacteria (cells or filaments/l)
January	–	–	–
February	669	179	23
March	761	700	35
April	1068	994	70
May	2060	1168	40
June	2552	1618	45
July	1276	193	19
August	1876	370	41
September	2062	425	77
October	1919	381	40
November	–	–	39
December	–	–	20

During January, November and December the epiphytic and benthic cyanobacteria were not much in evidence owing to preponderant freshwater influence

like cyanobacteria and green plants, but perform photosynthesis using other electron donors such as H_2S, H_2 or organic compounds. Therefore, they do not produce O_2 during photosynthesis. On the other hand, the phototrophic bacteria do not possess chlorophyll a but possess bacteriochlorophylls. These anoxic photoautotrophs are divided into purple and green bacteria. Differences between these two groups rest mainly on their ultrastructure, physiological characteristics and nature of pigments.

The exposed mudflats and availability of localized pockets of reducing environment in the mangroves (i.e., where there is H_2S production) provide the ideal microhabitat for photosynthetic bacteria. The photosynthetic bacteria recorded from the Pichavaram mangroves were *Chromatium* sp., *Rhodopseudomonas* sp. and *Chloroflexus* sp.[3,4].

In the Pichavaram mangrove forests, the organic matter production in waterways is high owing to abundant litter fall. The runoff of water *en route* the terrain brings in a considerable amount of terrigenous material. It augments the quantum of organic matter and enhances nutrient salt cycling and contents in mangroves. The organic matter and continuous recycling of nutrients due to seasonal flood, diurnal ebb and flow of tides provide ideal conditions for the growth of heterotrophic bacteria. The heterotrophic bacterial counts in the silt and finemud in Pichavaram mangroves are high compared to the adjoining neritic region of the Bay of Bengal, the Vellar estuary and the backwater[5] (Table 2). Besides heterotrophic bacteria, pathogenic bacteria have also been recorded from Pichavaram mangroves belonging to the genera *Bacillus*, *Micrococcus*, *Aeromonas*, *Alcaligenes*, *Flavobacterium*, *Corynebacterium*, *Vibrio*, *Pseudomonas* and *Salmonella*.

Table 2. Heterotrophic bacterial counts in the sediment and water samples from the Parangipettai environments[5]

	Sediment (10^6/CFU)	Water (10^4/CFU)
Neritic environment	108 46	302.21
Vellar estuary mouth	92.56	61.54
Backwater	40 24	60 28
Pichavaram mangroves	358 61	120.77

The degree of penetration of sunlight in the water column is an important ecological criterion for production of organic matter. As on land, solar irradiance plays a key role. Light attenuates with depth as quickly as it penetrates into water column. Considering the mangrove ecosystem, the water in mangrove channel is usually murky due to turbidity. The microbial biodegradation of organic matter releases dissolved organic matter, leptopel, trace elements, humic acids, etc., in the waterways. Thus, the fertility of the mangrove waterways is further promoted, despite their murky and turbid nature.

The shadows cast by the canopy of mangrove forests upon waterspread areas diminish the availability of natural sunlight to the phototrophs living on the intertidal muddy shores and on the submerged substrata. The light available for these phototrophic organisms is below the level of sustenance for their photoautotrophic mode of living. Under these conditions, these photoautotrophs must adapt themselves to enforced and imposed physiological condition to ensure their very survival in this ecosystem.

Some four species of mangrove cyanobacteria were isolated from the mangrove environment and nurtured to test their ability for growth under chemoheterotrophic conditions. Two of the experimental species of cyanobacteria namely, *Anacystis dimidiata* and *Schizothrix* sp. occur as planktonic while the other two species *Phormidium fragile* and *Microcoleus vaginatus* occur as benthic and epiphytic forms respectively.

These species were able to grow in the dark (chemoheterotrophic growth) on the organic compounds supplied, but showed wide variation in the degree of relative utilization of organic compounds (Table 3). Similarly, one species of photosynthetic bacteria (*Rhodopseudomonas*) sp was also able to grow on organic compounds (Table 4). Thus it is evident that the obligate heterotrophic mode of life is plausible under stress conditions.

This ability to grow heterotrophically on organic compounds confers a distinct advantage to these photoautotrophic organisms to survive and proliferate in mangrove ecosystem. The phototrophic organisms living in these waters need the capability to utilize the suspended organic material under low light or partially dark conditions. The variation in the growth pattern of

Table 3. Specific growth rate (μ) of cyanobacteria growing in different organic compounds under chemoheterotrophic conditions

Organic compound	*A. dimidiata*	*Schizothrix* sp	*P. fragile*	*M. vaginatus*
Mannitol	5 49	5.19	6 59	–
Sucrose	5.75	5.75	6.77	4.86
Galactose	4 86	–	–	–
Lactose	4 02	4 47	–	–
Dextrose	6.21	–	–	–
Fructose	5.19	–	6 59	–
Glycerin	4 02	–	5.75	–

Table 4. Growth of *Rhodopseudomonas* sp. isolated from Pichavaram mangroves, in different organic compounds (from Vethanayagam[4])

Organic compound	Protein (μg/ml)
Lactic acid	75
Acetic acid	70
Succinic acid	52
Valeric acid	48
Butyric acid	44
Malic acid	42

phototrophic organisms when grown on different organic compounds could be due to their nature and degree of permeability of cell membrane.

The organic carbon estimated in mangrove sediment showed higher values during summer and premonsoon seasons, and lower values during monsoon (Table 5). This higher organic carbon content in mangrove sediments during summer together with the high standing crop of benthic cyanobacteria indicate that these organic compounds would be utilized by cyanobacteria.

The degree of success of planktonic cyanobacteria to lead heterotrophic life would rest on their innate ability to utilize the available organic compounds. When these compounds are plenty in the milieu, they tend to live heterotrophically rather than autotrophically.

When the cyanobacteria live heterotrophically in reducing environments they prefer to fix nitrogen. Though the organisms do not possess any specialized mechanisms to protect their cellular nitrogenase enzyme, the external milieu with anoxic conditions keep the enzyme nitrogenase active in cells and help fix nitrogen. This could be seen in the *in situ* nitrogen fixation rates of

Table 5. Organic content in the sediments of Pichavaram mangroves

Season	Organic carbon (mg C/g)
Postmonsoon	6.5
Summer	7 6
Premonsoon	7 0
Monsoon	4 1

planktonic and benthic cyanobacterial mats consisting only of non-heterocystous forms. The nitrogen fixation rate by planktonic cyanobateria was 41.1 nmol/l/day and that by the benthic cyanobacteria 3.54 μ mol/cm^2/day.

The ability of these organisms to switch over to other plausible mode of existence depending upon exigencies of natural circumstances as in a reducing environment has enabled improvement of their physiological mechanism by successful evolution over the millennia.

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Importance of immigrant alatae on the population development of mustard aphid *Lipaphis erysimi* (Kaltenbach)

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Aphids are pests of major agricultural crops. Since aphids move from plant to plant mainly by flight, the alate or winged morph is important in initiation of new colonies in their distribution between plants[2]. Temperature and host quality have been shown to influence the production of alatae[3]. A knowledge of the factors responsible for and the time of immigration of aphids to crops is important in deciding when the crop should be sampled or control should begin. This was examined in the context of the mustard aphid *Lipaphis erysimi* (Keltenbach) which is a proven menace in different mustard growing states of India[4].

IMMIGRATION of *L. erysimi* was monitored by collecting air-borne aphids at 8 a.m. on alternate days from yellow pan water traps (YPT). Four YPTs, each 51 × 30 × 13 cm in size and painted bright yellow inside and bottle green outside, were placed 3 feet from ground level, one in each direction of the periphery of a plot measuring 20 × 15 m^2. The study plot was located in a mixed agricultural habitat. Adjacent crops included potato (Solanaceae), cabbage and radish (Cruciferae), and cowpea and groundnut [Fabaceae (= Leguminosae)]. YPTs were placed on the edge of the study plot. The YPTs were made operational three weeks in advance of sowing of the mustard crop till harvest.

The plot was prepared for a commonly grown mustard variety of *Brassica juncea* M27 adopting the recommended agronomic practices. No insecticide was applied to the crop. The study was conducted in the cropping seasons of 1990–91 and 1991–92. Crop infestation of *L. erysimi* was monitored by recording the total number of nymphs and adults, both non-winged and winged, from terminal 10 cm shoot portion of each of the 100 plants selected at random at weekly intervals between 8 a.m. and 12 noon on the day of counting. The aphid population was monitored throughout the crop period commencing on the 7th day after sowing.

The first aphids in the mustard crop were noticed in the seedling stage which is three weeks from the date of sowing. However, the first migrate alatae of *L. erysimi* was collected in YPT in the third week of its operation, i.e. in the week of crop sowing and 20 days in advance of actual settling of aphids in the crop (Figure 1). Total YPT-catch in the first two weeks (before setting on crop) was higher than the succeeding two weeks (after settling on crop) in both years (Fisher Exact test, 1990–91: $P < 0.02$; 1991–92: $P < 0.06$).

First crop infestation, as evident by the collection of the first adult aphid, was noticed in the third week in both the years. The YPT catch in the first four weeks of crop age (seedling phase) was positively and significantly correlated with the crop samples by a two week lag (1990–91 : $r = 0.89$, $P < 0.007$; 1991–92 : $r = 0.75$, $P < 0.02$) (Figure 2). As the crop entered the vegetative phase of growth in the fifth week, the propor-

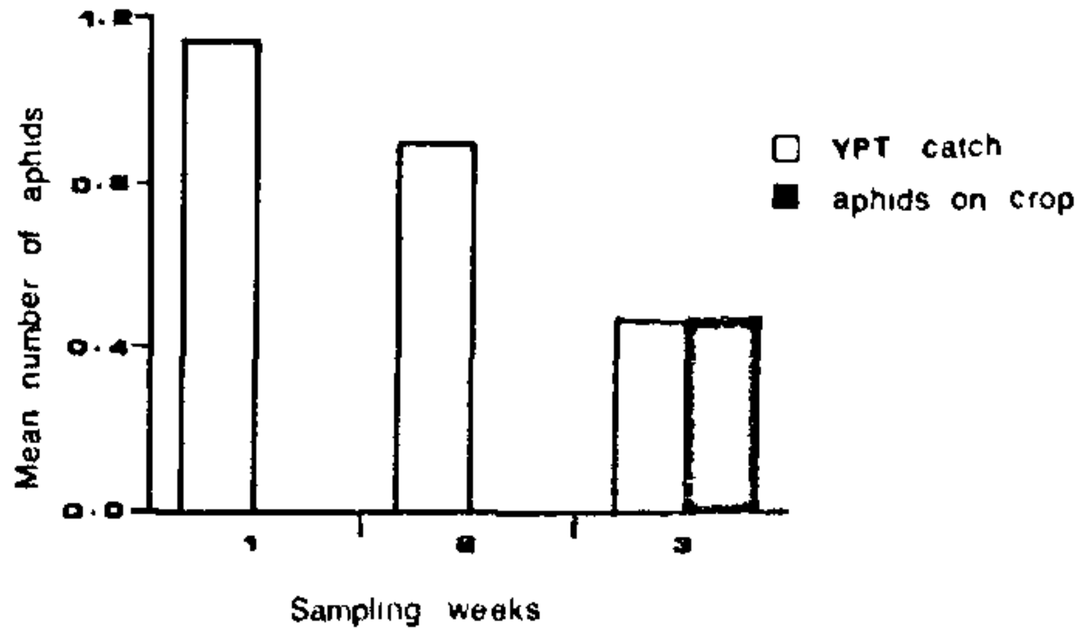

Figure 1. Mean number (of 1990–91 and 1991–92) of the mustard aphid collected in YPT ($n = 4$) and on 100 plants of mustard crop in the first three weeks of sowing