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APRIL 1984

Coastal Zone Management

MUDBANKS OF KERALA COAST

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
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FOREWORD

The southwest coast, bearing the brunt of the S. W. monsoon, is subject to various dynamic seasonal changes. More than a 100 km of the coastline is affected by serious erosion during monsoon months, while in some areas accretion takes place. The continental shelf waters are highly productive and sustain a large pelagic fishery, consisting mainly of sardines, mackerel and anchovy. The neritic bottom conditions are also subject to major changes, particularly through the process of upwelling, during the monsoon and immediate post-monsoon periods. A considerable amount of river runoff also enters the sea to add to the nutrient load in the inshore waters. In addition to these, a very special phenomena occurs along parts of the southwest coast, particularly along Kerala coast, which is, in simple terms, known as "mudbanks" or *Chakara.* This phenomenon, taking place in the coastal zone, has been known from time immemorial, but, even to-date, we have no convincing evidence as to the origin and nature of dissipation of the mudbanks of Kerala, particularly those found between Ponnani and Quilon. The phenomenon is all the more important as it also enables a thrilling fishery to develop in the coastal area where the mudbank appears during the height of the monsoon period. The waters of the mudbank remain practically an undisturbed sheet, while turbulent conditions prevail along its outer fringes, a situation brought about by the colloidal suspension of fine silt or clay particles in the water column. This calmness facilitates easy operation of fishing canoes, which are transported from fishing villages several kilometres north and south of the mudbank. Often several influxes of prawn or pelagic fishes, such as mackeral and sardine, from the adjacent open sea into the mudbank area occur, when bumper landings take place. When market conditions are good, this fishery is a boon for several thousands of coastal fishermen families, as otherwise operation of canoes in heavy surf-ridden beaches is practically impossible during the monsoon months.

With meagre facilities the late Sir Robert C. Bristow had made a fairly exhaustive study of the mudbank, and his work posed many serious questions which remain unanswered to this day. Besides, we are now aware that mudbanks of different types occur, some, in the estuarine area, as a result of heavy flood waters and silt, which may be transitory, while the type of mudbank seen south of Alleppey sustains itself for weeks. Considering the importance of this coastal phenomena to the fisheries of this region, a baseline and monitoring study was initiated by me in 1971 to study the mudbanks mainly at Ambalapuzha-Purakkad-Thottappally area south of Alleppey, A multi-disciplinary team consisting of fishery biologists, chemists oceanographers, etc., was formed to study the physical and biological characteristics of mudbank south of Alleppey, in order to have an objective idea about their origin, life and nature of dissipation. This report embodies some of the essential aspects of work carried out during these studies. I wish to place on record my appreciation to the team headed by Dr. A. V. S. Murty, Senior Scientist, who have under great strains and sacrifice carried out some very useful observations on the mudbank of Kerala, particularly the one south of Alleppey. In no way could this report be considered an end to the problem of the study of mudbanks; on the other hand, we should consider this as a basis for a national effort for studying this coastal phenomena occurring along Kerala and Karnataka coasts. It is hoped that such a national multi-disciplinary effort would go a long way in our better understanding of this problem. This should also find an important place in the national context of coastal zone management of our country.

The frontispiece to this publication shows the picture of Sir Robert C. Bristow, who made a special study on mudbanks as well as on problems of coastal erosion and accretion, enabling him to propound some views and hypotheses on this. These have been, no doubt, thought provoking and have stimulated a considerable amount of work, and we feel that it is only fitting that this volume be dedicated to the memory of the late Sir Robert C. Bristow as a token of our esteem.

E. G. SILAS
DIRECTOR
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Cochin-682018

ONE

INTRODUCTION

THE MUDBANKS, the formation of which is a curious phenomenon reported hitherto from only the southwest coast of India, appear over restricted areas on the Kerala-south Karnataka coast during the inclement S. W. monsoon as bodies of calm water, where the wave action the coastal waters at this time abounds with is almost absent, largely due to a fine mud in a state of suspension. On a squally, surf-beaten coast, these areas facilitate easy fishing operations of country crafts, which otherwise idle away during this harsh weather. For this reason it gained much popularity, particularly of late, among the coastal people.

Reports on mudbanks date back to the early 18th century. But a serious scientific study on them was not initiated until nineteen-thirties, when Sir Robert Bristow took it up in connection with his port management. His study, however, stimulated further interest, and, because of its contribution often to successful fisheries, with spectacular catches of prawns and fish, particularly the shoaling forms, the mudbank has attracted increasing attention from fishery scientists.

Central Marine Fisheries Research Institute, being the chief body engaged in fisheries research, naturally got itself soon involved in a major programme of investigation, assigning a team of scientists of different disciplines to study the phenomenon in detail. The following report embodies the results of studies on some of the diverse characters of the mudbanks in general, but with particular emphasis to the Alleppey mudbank, which is by far the most important of all. Problems pertaining to physical, chemical and biological aspects have been dealt with in detail as far as possible, in addition to critically reviewing the earlier documented information. In the light of these studies it has been possible to give an explanation of the origin, maintenance and dissolution of the mudbanks. However, it has to be confessed with candour that these studies are by no means conclusive and, needless to say, a lot of multidisciplinary effort still remains to be made, preferably as a part of a national programme of management of coastal zones.

The authors wish to express their thanks to the authorities of the Cochin and the Alleppey ports, especially to Capt. Rajan, the then Port Officer, Alleppey, for furnishing valuable information on the Alleppey mudbank. Their thanks are also due to the Department of Chemistry, Agricultural University, Mannuthy, for permitting them to carry out the chemical and mineral analyses at their laboratory. Shri R. Vasanthakumar, Smt. C. M. Allikunju, Shri P. K. Swamy, Shri P. M. Aboobaker and Shri N. P. Kunhikrishnan deserve special thanks for their helps rendered in the chemical analysis of the samples. Shri K. L. K. Kesavan has helped in the preparation of many of the drawings. Shri P. Narayanan of Cochin Port Trust deserves their special thanks for procuring the photograph of Sir R. C. Bristow, which is reproduced here on the frontispiece. The Cochin Archives has made available some of the early literature relevant to the present work. During the field investigations, a good deal of local cooperation and goodwill was forthcoming which greatly facilitated work, often under adverse conditions. Special mention should be made here of the help rendered by Shri Sivanandan of Ambalapuzha, Shri Devadattan of Purakkad, and the crew of R. V. Cadalmin-I of the Institute.

TWO

MUDBANKS OF KERALA-KARNATAKA—NEED FOR AN INTEGRATED STUDY

E. G. SILAS
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INTRODUCTION

We have documented reports of the mudbanks along the south-west coast between Mangalore and Quilon for well over three hundred years. However, sequential record of their occurrence in time and space is wanting. This phenomenon in Kerala, typically as occurs south of Alleppey (Fig. 1), is known as *Chakara*. or *Santhakara* ("quiet shores"). During the last two decades the presence or absence of the *Chakara* phenomenon has attracted considerable attention of the fisheries sector, resulting in a number of useful studies on mudbanks covering specific aspects. Yet we are far from having precise answers to the problem of the mode of its origin, establishment, stability and dissipation, except propounding some hypotheses and suggestions based on physico-chemical and biological data.

The recent past has also seen large-scale erosion along long stretches of this coast and consequent serious impairment of the life of those living in the coastal zone. Since 1973, the mudbank has not developed to the extent anticipated, to sustain any major fishing activity along the coast. This, combined with extensive erosion, has created serious socio-economic problems in the coastal sector. Of a good mudbank season, the primary beneficiary is the artisanal fisherman, who is able to operate his canoe from the calm waters of the mudbank and often land heavy catches of shoals which enter the area. Owing to heavy surf along other parts of the coast, fishing in the artisanal sector is generally at a standstill during the monsoon season. As such, the formation of mudbank is eagerly awaited as it portends good fishing, and hundreds of canoes are transported by road to the sites of the mudbanks from villages even 50 to 60 km north and south.

These multifarious factors focus attention on an imperative need for developing an integrated multidisciplinary programme to study the mechanisms of mudbank formation, its life and dissipation and its impact on the coastal zone.

HISTORICAL RESUME

In the two volumes entitled "History of Mud Bank" Bristow (1938) refers to the early works on mudbanks, which are mainly narrative in nature. He also opines on the various possibilities of the mode of formation of the mudbanks.

Probably, the first mention of the mudbanks along the southwest coast in recorded history is a mention as early as 1678 in Pinkerton's "Collections of voyages and travels," appearing in the Administration Report of 1860 of Travancore. In his book, "A New History of the East India," Capt. Cope (1755) spoke of the Alleppey mudbank ("mud bay" as he calls), which, he says, is a place that few can parallel in the world. Crawford (1860) may be credited with attempting the first possible explanation of the source of the Alleppey mudbank. Based on personal observations of mud cones on the beach and on roads of Alleppey, Crawford found cause for linking them with the backwaters and rivers. His observations of bursting of mud and water, during the widening of the Alleppey canal, and his attempt to sound the

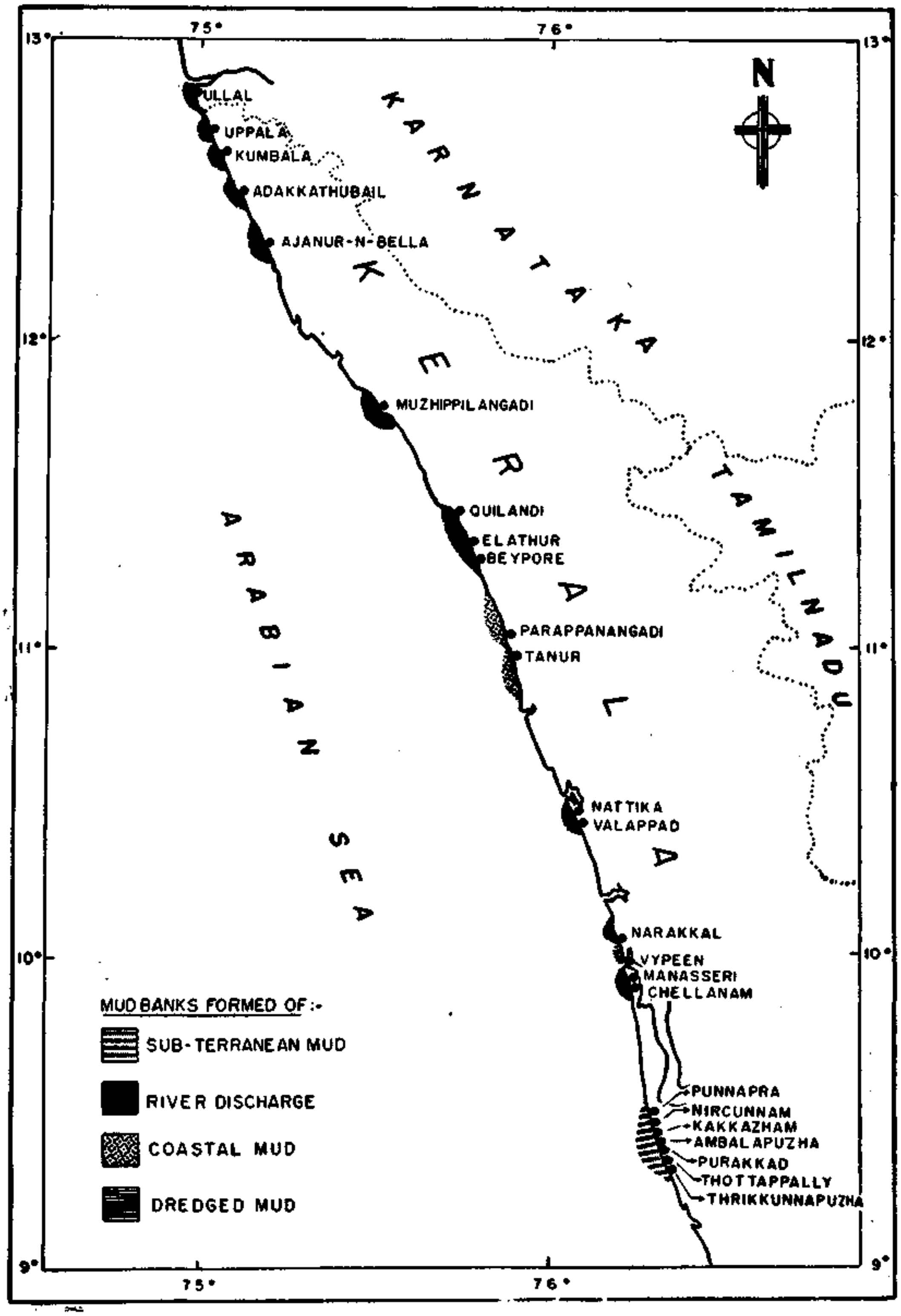


Fig. 1. Areas of mudbank formation and the various types of mudbanks along the Kerala-Karnataka coast

'Linus' of Chengannur River, strengthened his opinion that subterranean mud sustained the Alleppey mudbank. The observations of Logam (1882) further help us to note the importance of subterranean mud deposits. He found "deep pot-holes in the lake east of Alleppey and with a rise of 4' to 6', as occured in the floods of 1882, it can be easily believed that the enormous pressure thus caused would force relief ways for itself below the coastline through soft muds."

King (1881), in a report on "Considerations on the smooth water anchorage of mudbanks of Narakkal and Alleppey on the Travancore coast," discussed the migration and formation of the mudbanks between Alleppey and Purakkad and between Cochin and Narakkal. A siginificant observation was that of Rhode (1886; *in:* Bristow 1938), who spoke of fluid mud existing below Alleppey, and thereby postulating that the mudbank at Alleppey increases and diminishes as the level of the inland water rises and falls, as was observable during the 1882 floods. Opining on the same lines Drury (1906) was of the view that, in the absence of a natural outlet for the vast accumulation of waters which are poured down from the various mountain streams into the basin of the backwater, nearer than 36 miles on either side, it is not improbable that there exists a subterranean channel communication with the sea from the backwater, through which large quantity of mud is carried off and thrown up again by the sea in the from of a bank. According to Lake (1889), "it is to the observation of Mr. Rhode and of his predecessor, Mr Crawford, that we owe most of our knowledge of the Alleppey mudbank, and there is very little to add to what they have already recorded." He also reported on the occurrence of mud cones in his report on the Alleppey mudbank.

For more on these and for other references to the mudbanks, I would direct the reader to the comprehensive treatise of Bristow (1938) on the "History of the Mudbanks", wherein he has also added his exhaustive observations on the formation, maintenance and movements of the mudbanks at Alleppey and Narakkal. The mudbank at Narakkal plays an important role in the silting of the Cochin Harbour channel and was the cause for a Special report by Du Cane et al. (1938). This report also does not favour the view that an increase in the water level in the lake would result in mud being pushed up in the adjacent coastal area, due to the insufficient pressure (2 lbs/sq. inch) that even a 5' rise in water would create. Nor is the consistency of the mud of the mudbank the same as that found in the lake, the latter having a high percentage of carbon and a lot of vegetable debris. However, I feel that a critical study of this is necessary, which will also necessitate borings and soil studies at different depths in the lake, intervening land area and the Purakkad inshore waters.

The post-war period saw a renewed interest in the studies on the coastal ecosystem. This has led to more specialised investigations on the mudbank ecosystem as summarised below: Seshappa (1953) and Seshappa and Jayaraman (1956) have studied the phosphate content of the mudbank at Calicut and noticed higher phosphate concentrations. Ramasastry and Myrland (1959) stated that the formation of the mudbank is associated with upwelling and divergence near the bottom between 20 and 30 m along the coastal line, which produce vertical acceleration, with resultant lifting of the bottom waters; the lifted bottom water carries along with it the fine mud of the bottom. Nair et al (1966) have studied the mud deposited on the sandy beaches of the Vypeen island near Cochin after a storm, for its physical and chemical properties, in order to understand the source and mechanism of mud deposition. A comparative study of these sediments with that obtained from offshore samples has also been made. They came to the conclusion that the mud deposited on the beach was from the nearshore areas, as it was composed of dredged material transported northward from Ernakulam channel. Varadachari (1966) has discussed the part played by the estuaries and mudbanks of Kerala coast on shore-line configuration. Varadachari and Murty (1966) have made some observations on a temporary mud flat that appeared between Cochin harbour entrance channel and Elamkunnapuzha, during a storm in December 1965. Damodaran and Hridayanathan (1966) suggest that lowering of surface salinity and a flocculation effect caused by the same keeps the mud in suspension. Rao (1967) has given an account

FURY OF THE SEA

PLATE II. Heavy monsoon seas and coastal erosion at Chellanam and adjacent areas on the Alleppey-Cochin coast.

MUDBANK AT PURAKKAD

PLATE III. A: Calm waters of the mudbank; B: Boat-seine, Thanguvala, operation; C: Awaiting the catch; D: Ice packing of fish before loading on cycles; E: Catch of Lesser sardines; and F: Heavy catch of *Parapenaeopsis stylifera* at the Purakad mudbank.

HARVEST FROM MUDBANK

PLATE IV. A. Oilsardine; B: a mixed catch; C: prawns spread out for drying; D: Shelling of prawns, after drying; E: a mixed catch of prawns, crabs and fishes; and F: Fishvans at Purakad waiting for transporting prawn and fish catch from mudbank.

of the fishery aspects of the mudbank at Alleppey with some considerations on the physico chemical features. Dora et al (1968) carried out investigations on the texture of Narakkal mudbank sediments.

Varma and Kurup (1969) opined that the formation of the mudbank is the result of the interaction between the inshore and offshore transport of sediments in suspension, the former by waves and the latter by rip-flows. According to Kurup (1972), the converging littoral currents in the inshore waters of the Kerala coast have influence on the shore-line changes along the coast and play an important role on the formation of the mud-bank south of Alleppey. Iyer and Moni (1972) evaluated the effects of mudbanks on the shore-line stability. Gopinathan and Qasim (1974) have investigated the formation and characteristics of the Alleppey mudbank. The organic carbon of the mudbank sediments of Alleppey have been studied by Jacob and Qasim (1974). Two recent fairly exhaustive works are; first, a detailed investigation on the meiobenthos and macrobenthos of the mudbanks on the south-west coast of India by Damodaran (1973) and, second, a study of the physical aspects of the mudbank including the texture of sediments, by Kurup (1977). Mathew et al (1977,) have studied the diurnal variations in the distribution of zooplankton in relation to currents and other ecological parameters of the mudbank of Alleppey. Recently, McPherson and Kurup (1981,) postulated a mathematical model to explain the wave damping at the mudbank.

Information was gathered from several sources, including statements by inhabitants in the fishing village. A fisherman (70 years old) of Punnapra stated that he had never seen mud cones at Punnapra area in his life-time; but he remembered that there was a well-formed mudbank at north Punnapra during 1950. Another person stated that, in the late fifties, the seat of the mudbank was at south Punnapra with its southern end at Nirkunnam, and this was so until 1968. Then it shifted to Valanjavazhi in 1969 and Nirkunnam and Ayyancoil became respectively the northern and southern ends of the mudbank. Local fishermen also stated that mud cones were observed on the land at Nirkunnam in 1969. In 1971 and 1972 the northern periphery of the mudbank was observed at Kakkazham, where the mud cones were observed in 1972 on the beach and in the inter-tidal zone. In 1973, there was no proper mudbank formation at Karoor-Ayyankoil, and the situation has remained so in subsequent years, when only 'incipient' mudbanks or 'evanescent' mudbanks have occurred. Thus Purakkad was the location of mudbank in 1974 and 1975. In 1976 it moved further south to appear between Purakkad and Thottappally. Since 1976, until the mudbank season in 1980, the mudbank appeared at Thottappally, north of the spillway. In 1981 two mudbanks were observed in the Alleppey region, one at Punnapra and the other at Thottappally-Pallana region. However, all the post-1973 mudbanks south of Alleppey have been very evanescent ones of not any great consequence.

TYPES OF MUDBANKS

Studies thus far carried out indicate that the mudbank could result from different factors, such as :

a) erosion, accretion and transport of sediments,

b) transportation of sediments through upwelling or currents in the coastal waters,

c) transport of sediments to the river mouth,

d) formation of mud cones due to pressure in the lake site ; and

e) dredged sludge which is dumped into the inshore sea.

The need of the hour is a critical study of the various types of mudbanks and the mechanisms which are responsible for them under different situations.

Remote sensing and satellite imagery technique for studying mudbanks

It is necessary to obtain synoptic pictures of the river discharges in the inshore waters and the indication of formation or build up of sediments to form mudbank, and the related features between Quilon and Mangalore. The manpower and facilities required for monitoring such a long stretch of coast will be tremendous and, as such, the time has come for techniques such as remote sensing and satellite imagery to be taken advantage of to record the events synoptically. This will also facilitate monitoring the water shed of the rivers to assess the run off and the amount of inflow in the inshore waters. Because of the multifarious uses to which river waters are presently put it is only a short time before major imbalances may develop in the coastal regime, affecting its fertility as well as the other associated natural phenomena. Fortunately, intensive monitoring systems can be developed and today we are aware of the magnitude of the problems and how to approach the same.

Some priorities for consideration in future integrated investigations on mudbank

1. The stabilisation of the coastal track by use of appropriate vegetation is an area which needs investigations. This is necessary on account of the considerable erosion along long stretches of the coast. The importance of rehabilitation of mangrove vegetation as well as other plant community for stabilizing the beaches and the sublittoral should be given priority.

2. The flocculation of cohesive sediments in suspension and the agglomeration of particles added by biological organisms and the subsequent rate of sedimentation, is area which is yet to be understood. Similarly the inter-action between various biological and physical processes involved and accretion and fine-grain sediments in the areas adjacent to the mudbanks is practically unknown.

3. To-date we have no idea of the role of epiphytic microflora and diatoms which produce mucus and thereby accretion of intertidal mud deposition.

4. We know little about action of invertebrates on sediment deposition.

5. Normally, suspended sedimentary material should be a repository of trace metals as well as heavy metals. We have practically no information as to the extent that mudbanks contribute towards this.

6. The role of micro-biota in organic degradation and process of recycling is yet another area where information is lacking.

7. We have no information on sediment oxygen demand and the rate of oxygen transference in the mudbank.

8. The "critical limit" or "critical depth" for defining the boundary based on the suspended or silt disiribution in the mudbank has not been properly defined. This is important as the outer boundary may be oscillating, depending on the load of suspended matter. Our present projections in this are arbitrary.

9. The question may be asked as to whether we have any idea of the mudbank sediments as concentrating mechanisms of organic and inorganic materials. The answer is no! Similarly, we lack in information on entrainment, deposition and transport of fine grain sediments in the mudbank.

10. Is there a way of estimating annual/seasonal total budget of substances of the mudbank, which separate from mud to the water? Particularly suspended materials and trace metals? The answer at present is no.

11. Absolutely no information is available from the mudbank studies on the bio-geochemical cycles taking place there.

12. We have no information on the role of microbial metabolism in the mud sediments and the role it may play in mobilisation of phosphorus.

13. The optimum/maximum of trace metals in this natural ecosystem of mudbank is still unknown. There is hardly any information to assess trace metal uptake in sediments and suspended metals—to understand the modus operandi—whether it is through physico-chemical absorption or through physical accumulation of metal enrichment of particulate matter. Or through biological uptake.

14. There is a lack of information on biological uptake; the role of bacterial population in this process and the mineralisation of


Alleppey - Purakkad
Mud Bank Area

algal matter by bacteria are practically unknown.

15. The earlier works clearly indicate that nematodes constitute numerically the most important component of the meiofauna of the mudbanks. However, we have no information on the nematodes-bacteria interaction. The burying and feeding activity of nematodes may help in improving exchange of metabolites and other essential nutrients for bacteria to maintain the latter at the point of maximum growth. Nematodes also assist in the process of bio-turbination. According to Platt and Warwich (1980), nematodes are primary consumers of food for higher organisms and they play a vital subsidiary role in organic decomposition and in modifying the physical stability of sediments. More work on the nematodes in the mudbank area is necessary.

16. Often large quantities of benthic animals, such as tube-welling polychaetes and bivalves, are found accumulated in the intertidal area when the mudbank exists. The causative factors for their displacement from natural beds in the mudbank area needs study.

17. Examination of core samples from the mudbank and adjacent areas is necessary to understand as to how long this phenomenon in the Alleppey region has been in existence.

In the following reports stress has been made to study some aspects of the physico-chemical and biological aspects of the mudbank. It is hoped that this will stimulate more intensive studies of an integrated nature in future by collaboration and coordination of work with other interested agencies.

Coastal zone management—need for a national policy

The mudbank is a phenomenon of the coastal zone. The management problems connected with it during a year of successful mudbank formation, particularly between Quilon and Cochin, are up to now tackled on an *ad-hoc* or temporary basic. There is an imperative need for a national coastal management strategy to be developed to look constructively at these and other phenomena and shape public policy. A large share of this responsibility will rest with the Department of Environment, Government of India, which should develop a strategy, that would also improve the quality of life of the people involved in various activities along the coastal zone. This would involve also a judicious development of aquaculture practices in the sea and in the adjacent inundated brackish-water areas; the interest of the artisanal fishermen and fisheries; the development of harbour and other infrastructure; the proper management of the mangrove eco-systems; and the protection and safety of the estuarine areas from industrial pollution; besides monitoring of human interference on the rivers and watersheds, which eventually upsets run off into the sea and thereby affects deleteriously the coastal eco-systems, problems of erosion and accretion, and special phenomena such as mudbanks and their importance in influencing the coastal zone management.

It is hoped that priority will be given to evolving a coastal zone management policy for the country taking also into account an integrated approach of demographic and environmental problems of the coastal zone. No doubt, the Department of Environment, Government of India, has to play a nodal function in close liaison with the concerned maritime States and Union Territories. We hope that this Report will create an awareness in this direction and stimulate positive action.

THREE

HYPOTHESES ON MUDBANKS

A. V. S. MURTY, D. S. RAO, A. REGUNATHAN, C. P. GOPINATHAN and K. J. MATHEW

ABSTRACT

The report gives a critical appraisal of the various hypotheses on the formation and the characteristic calmness of the mudbanks, in the ligt of the auther's findings, with special reference to the Alleppey mudbank. A detailed account on various types of mudbanks along the southwest coast of India is also presented.

INTRODUCTION

The mudbanks, though confined to the near-shore waters, is a phenomenon still not fully explained. The formation of mudbanks at the vicinity of river mouths, such as Korapuzha, Bharathapuzha, Chetwai and Azhikode, and Cochin bar mouths, where clay and vegetable debris brought down by the rivers are deposited on the downward side of the littoral currents, is easy to understand. But, the mudbanks at places where there are no river discharges, as at Alleppey, are rather difficult to explain. There are many hypotheses put forward to explain specific aspects, such as the source of the mud and its role in calming down the waves. These hypotheses are briefly discussed here in the light of the present observations.

SOURCE OF MUD

Sir Robert C. Bristow, former Administrator-cum-Chief Engineer of Cochin Harbour, who was also the chief architect of the Willingdon Island, compiled "The History of Mudbanks" from the then available records, which was published in 1938. It details the views held by the earlier authors on the formation and other aspects, mainly of the Alleppey and Narakkal mudbanks, and a hypothesis of Bristow himself. The following is a discussion on the various theories, advanced before and after Bristow, weighing the merits and demerits of each one of them.

1. Subterranean Passage Hypothesis

Crawford (1860; in: Bristow 1938) was the first to advance a hypothesis — the Subterranean Passage Hypothesis — to explain the source of the mud of the Alleppey mudbank. He observed the formation of mud cones on the beaches and in the roads of Alleppey in 1855. This led him to suggest the existence of a subterranean passage, or stream, or a succession of them, that becomes more active during heavy rains, particularly in the commencement of the monsoon, carrying off the accumulating water and with it vast quantities of soft mud from some of the inland rivers and backwater to the sea.

Later Capt. Drury (In: Bristow 1938), observing the deposition of so large a quantity of mud in the open sea, about 2 or 3 miles from the shore and many miles from any bar mouth or outlet from the backwater, suggested that it is not improbable that there exists a subterranean channel through which large quantity of mud is carried off into the sea, where it is thrown up in the form of a bank. He stated that the mud thus formed gradually floated southward with the littoral currents and fresh banks are formed whenever the hydraulic pressure of the inland backwater increases sufficiently to overcome the subterranean resistance of the stratum of fluid mud which is formed at certain places.

According to King (1881), the mudbank may be entirely due to the discharge of mud from under the lands of Alleppey, Purakkad and Narakkal, being effected by the percolation or underground passage of lagoon water into the sea

Philip Lake (1889; in: Bristow 1938) differed from the views held by the previous odservers on the source of mud for the Alleppey mudbank. He opined that the Alleppey mudbank is formed not from the backwater mud, but from an older river deposit found only at particular points along the coast. He further stated that, with regard to the existence of subterranean channels, it might well be doubted whether any could exist in such unstable deposit as found there.

John Rhode (1886; in: Bristow 1938) former Master of Alleppey Port, suggested that a fluid mud strata exists below Alleppey.

The consensus of opinions stated above leads to the conclusion that there is an underground discharge of water, at any rate, into the sea from the lagoon and river system behind the Alleppey-Purakkad coast during flood time, the inland water being at a higher level. This passage of underground water must, more particularly during heavy rains, pour out with it large quantity of the mud.

2. Hypothesis of water bearing stratum

Bristow (1938) ruled out the prossibility of the existence of an underground river at Alleppey. His argument is that it is impossible for the backwater to rise more than a foot without flooding the lower parts of the neck of land separating the backwater from the sea, at many points between Cochin and Alleppey. Besides, a head of 5 ft., the maximum possible, would give a pressure of only about 21 lbs/sq. inch, which is not enough to overcome the frictional resistance set up by solids in suspension, According to him, what is more likely is that a water-bearing stratum exists at a good depth, which brings down water from the hills and crops out under the sea at varying distances from the shore, thereby lifting the bottom mud above it and anything sufficiently buoyant that lies buried in the mud.

3. River deposition hypothesis

According to Ducane et al (1938), the chemical analysis of the backwater mud and the mudbank mud reveals different characteristics. The mud of the mudbank is greenish, very oily, but mixable with water, whereas the mud of the backwater is black and is full of vegetable debris and is immiscible with water. This difference led Ducane's team to conclude that the mud of the mudbank might be from an older source. They held the view that the laterite/alluvial sediments from the land are run down by the rivers and are deposited on the seabed close to the shore in a regular process of river discharge and the sediment deposit thus accumulated near the coast is churned up by monsoon waves, and thus the mudbank is formed.

This explanation is, however, convincing with regard to the mudbanks forming near river mouths and bar mouths. But the mudbank near Alleppey cannot be explained by this hypothesis, because there is no river or backwater emptying in the nearby area.

4. The Upwelling hypothesis

Ramasastry and Myrland (1959) associated the formation of mudbanks with the upwelling along the west coast of India during the southwest monsoon, the upward movement of water lifting the bottom mud.

The presence of upwelling according to them is only at about 20-30 m bathymetric lines of the coastal waters. It is worthwhile to mention here that the presence of upwelling at such depths, however, does not help to explain the formation of mudbank from shore to 10 m depth, unless there is some other mechanism in the region of the bathymetric difference of the locations of the two processes. Secondly, unless upwelling extends down to the bottom, which is unlikely, the mechanism would not be able to lift the bottom mud. Thirdly, why the mud banks are limited to only certain regions when upwelling is there all along the southwest coast (Ramamirtham and Rao 1973) is not explainable.

FORMATION OF MUD SUSPENSION AND THE CALMNESS ASSOCIATED WITH THE MUDBANK.

1. The Deflocculation hypothesis

Flocculalion is the process in which fine particles are brought together and clustered to become heavier masses so that they would be pulled down by gravity. Keen and Russel (Ducane et al 1938) found in their experiment that the mud of the mudbank completely settled (flocculated) when salinity was greater than 20‰ and it remained suspended (deflocculated) at salinity lower than 2.5‰. This hypothesis was adopted by Kurup (1969) and Padmanabhan and Eswaran Pillai (1971) to explain the calmness of mudbank.

As low as 17.04‰ salinity was reported by Damodaran and Hridayanathan (1966) during August 1966 from the surface waters of Cochin mudbank. Nevertheless, the bottom waters always recorded high values and never went below 33‰ (Iyer and Moni, 1972).

Periodical observations at Alleppey mudbank, which extended from Valanjavazhi in the north to Purakkad in the south during the mudbanks of 1971 and 1972 indicated salinity values as shown in Table 1. It would be seen from the table that the mudbank, both at surface and bottom, maintained well above the upper limit for deflocculation.

Table 1. *Salinity values (‰) at surface and bottom at the mudbank during 1971-72.*

(S=Surface, B=Bottom).

	Valanjavazhi east	Valanjavazai west	Ambalapuzha	Purakkad
1971 S	32.22	32.26	30.89	30.74
B	33 70	32.12	31.81	30.89
1972 S	29.28	30.34	29.82	30.02
B	27.76	29.05	29.50	31.47

Even admitting that surface water is diluted by freshwater influx to the optimum level at some places, bottom water at no place recorded the required low salinity for deflocculation, showing that the water immediately in contact with the mud itself is not in favour of deflocculation.

2. *The Hypothesis of oil in water as an agent to cause calmness*

King (1881) suggested, based on the analysis made by F. R. Mallet, that some brownish-yellow oily matter was present in the mud collected from the Alleppey bank, which he thought, when released into the water, to be the main agent responsible for bringing about calmness over the Alleppey mudbank. Lake (1880), however, discredited this hypothesis. Later the analysis of Keen and Russel showed that there was no such oily matter in the mud at Alleppey.

3. *Hypothesis of elastic nature of mud and its role in producing calmness*

Another suggestion was that the mud is of springy or elastic nature and hence is able, by alternate contractions and expansions, as the wave passed over it, to absorb the wave energy, so bringing them to rest. Keen and Russel (1983; in: Ducane et al) discarded this view. According to them the primary characteristic of any mud is that it is plastic not elastic, i e., it will alter its shape or configuration under external forces, but will not resume its original shape when the deforming force is withdrawn.

4. *Thixotropic hypothesis*

From the known principles of hydrodynamics and from the results of experiments Keen and Russel (in: Ducane et al 1938) concluded that the calming effect is due to the kinematic viscosity and thixotropic properties of the muddy suspensions produced in the monsoon. They are of the opinion that, when the heavy waves and swells of the monsoon reach the shoal bottom at the seaward fringe of the mudbank, the alternation of stresses associated with ridge and trough of the waves brings mud into suspension. The suspended mud increases the kinematic viscosity of the medium. This factor will tend to dampen the motion of the waves on the surface and in subsurface depths. As the stress thus falls, the properties of the mud suspension resemble those of a jelly which will absorb the wave energy completely. Thus. according to Keen and Russel, the effect of thixotropic suspension on wave motion is a cumulative one. In mud-suspended water, at high stresses, e.g., violent wave motion, the kinematic viscosity of the agitated mud suspension produces a higher rate of damping than in mud-free water and the stresses are reduced. Then the thixotropic effect comes into play, and the remaining stress is rapidly dissipated by the jelly-like behaviour of the suspension.

5. *Rip current hypothesis*

Varma and Kurup (1969) sought to explain the localised formation of the mudbank by attributing it to the rip currents. They said the rip flow, carrying finer offshore sediments, prevents the onshore transport of sediments by waves. Hence localisation of suspended sediments takes place at the rip head.

Although the rip currents are not fully understood (Sverdrup et al 1942), we may believe that these currents are probably associated with the surface transport of water against the beach by the waves (Shepard et al 1941). The rip flow may thus be a concentrated backlash of the waves at the beach and hence its area of action is narrow. On the other hand, the postulated mechanism requires rip flow from behind the mudbank (in between the mudbank and the beach). But backlash of waves from this hind zone is unlikely as the area is calm. The backlash of waves might be possible only if the mudbank is far off from the coast, allowing wave action to take place in the hind zone, which is usually not the case. Therefore, the rip flow cannot be a component of the working mechanism of the mudbank formation.

RESULTS OF THE PRESENT INVESTIGATIONS

The following is an account on the various more probable physico-chemical factors responsible for the formation, maintenance and dissipation of the mudbanks, as revealed by the investigations carried out by the authors from 1971 onwards.

Before dealing with the actual mechanism of the mudbank formation, we may have to consider the geographical features of the areas surrounding the Alleppey mudbank, including the Vembanad lake and also the rivers emptying into it. Vembanad lake is a vast water body lying almost parallel to the coast from Alleppey in the south to Cochin in the north. Its opening to the sea is at Cochin. The lake is separated from the sea by a narrow strip of land of only about 10-13 km width. Five rivers, namely, the Muvattupuzha, the Meenachil, the Pamba, the Manimala and the Achankoil, discharge their waters into the lake. These rivers originate from the Western Ghats in the east and flow towards the west.

There are evidences to believe that, in the past, the area, presently covered by Vembanad lake and the land strip in between the lake and the sea, was under the sea. During that period, the rivers, now flowing into the lake, might have been directly discharging their water into the sea. Later on, owing to some natural causes, such as cyclones, seismic sea waves and earth quakes, huge masses of sand and sediments might have got deposited in between the present lake and the sea to make the Vembanad lake. Boring experiments conducted at various places (Brown; in: Bristow 1938) on the west coast give supporting evidence to this. In one of the borings at Cochin (Brown 1928), the bed rock was found at 395 ft, while in another the hard bottom was felt at 650 ft.

The admirality charts and the recent echo surveys (Silas 1969) indicate that there is rocky substratum at about 75 m depth off the Kerala coast. Thus it seems that the entire vast area between the foot of the hills and at about 75 m depth off the coast was almost a deep basin, got subsequently filled up with mud and sand, over which a sandy crust was formed at some places. The presence of marine shells below 40 m at place like Kaduthuruthy near Vaikom, where the low-lying areas are all under paddy cultivation, gives a positive evidence to this (there is a view that the name Kaduthuruthy is derived from *Kadal thuruthu*; "Sea-island"). The foregoing account suggests that, below the lake and the narrow strip of land, at least between Thottappally and Narakkal, there exists a thick layer of unconsolidated mud, which extends into the sea.

1. Source of mud for Alleppey mudbank

The Subterranean passage hypothesis (Crawford 1860) and the Waterbearing stratum hypothesis (Bristow 1938) owe their leverage respectively to the hydrostatic pressure of the backwater and to the hydraulic pressure in the foot of the hills. The boring experiments have revealed the presence of a clayey substratum of varying thickness. Although no mention is found to have been made of the presence of a waterbearing stratum in the reports on borings of Cochin and Alleppey, the same has been reported to exist at 181' and at 312' in the Wellingdon Island boring. Davey's borings (at Alleppey) have shown the presence of mud, of varying composition, down to 316', while Crawford's borings at Alleppey revealed the presence of sandstone till a depth of 50' and then loose mud to a depth of 80', in which "the shaft sunk of its own from 60 to 80''. Waterbearing stratum has been observed to be associated with sandy substratum, but surfacing of the stratum has not been indicated in any of the boring records. In the absence of this, it cannot be believed that water could permeate the overlying mud layers from great depths (to greater heights) to crop up in the sea and on the shore. Further, it is doubtful whether such a massive hydraulic pressure could be developed at the foot of the hills as to feed the waterbearing stratum and to push the overlying layers of clayey mud. Crawford's experience of violent ejection of water and vegetable debris from 12' below, at a place 200 yards from the beach at Alleppey during the construction of the Alleppey canal, observations of 'Linus' in the Chenganur river by him, the presence of deep pot-holes in the water as reported by Logam (1882, in: Bristow 1938) and other available information, all equally suggest that the pressure-head developed at the bed of rivers as well as at the backwater generates a subterranean passage of mud, which crops out at varying distances through weaker points both on land and in the sea.

The present authors have observed, first time since Crawford, and Davey and Lake, mud cropping up in the form of cones for about 9 to 12 days during the monsoon of 1972, on the beach and at the inter-tidal zone at Kakkazham, near Ambalapuzha. Narrow (a few centimeters wide) cracks, 10 to 15 m long along the shoreline, were observed on the sea side of the beach-mud cones, indicating subsidence, while the mud cones at the intertidal zone feeding loose mud, as well as lumps of it, to the water flowing past the mud cones in its to and fro motion across the shoreline (*See* paper on mud cones). These observations too, support the subterranean passage hypothesis for the Alleppey mudbank.

II. Calmness associated with the mudbank

The most striking character of the mudbank is its calmness. The reasons for the prevailing calmness over a restricted region, when all other places are highly wave-beaten, are to be considered. Several views have been put forward to explain this phenomenon. It is generally accepted that the calmness is brought about by the mud in suspension. But, the view that a purely physical process, say, the churning action of the monsoon waves causes the mud into suspension is not satisfactory. The following hypothesis, evolved by the present authors, is offered to explain the whole processes leading to the calmness associated with the mudbank.

A. Wave Propagation

a) Movement of particles of the medium: The waves at the surface of the sea are caused either by wind force or tidal force. Below the wave crest of a progressive wave, the horizontal motion of the particles is in the opposite direction of that under the trough. The particle attains maximum horizontal velocity (speed) when it is just below the centre of the crest or the trough. During the first half of the wavelength, from mid-trough to mid-crest, the particles experience vertically donward velocities. The vertical velocities reverse in the second half of the wave length. The vertical speed is maximum at a point where the wave passes from trough to crest, or vice versa, and it is zero half-way between the crest or the trough (Sverdrup et al 1942). Thus, as the wave form is propagated in the direction of wave motion, the individual water particles involved in propagation of wave form are subjected to harmonic motions from their mean (undisturbed) position.

Jeffrays (in: Sverdrup et al 1942) pointed out that, within surface waves (deep water waves) the individual water particles near the surface move in circular orbits, the radius of which is equal to the amplitude of the wave (a circular motion can be resolved into a simple harmonic motion). But the radii of these orbits, and therefore the velocities, decrease rapidly with depth. According to the results of the classical hydrodynamics, the orbital paths of water particles in surface waves are elliptical, covering within the same time-interval, during which the wave travels over a distance of a wavelength (Dieitrich et al. 1980). The elliptic orbit changes into a circular orbit, if the water depth exceeds half the wave length, when the amplitude is very small compared to the wavelength (Newman 1978). Theoretically, the diameter of orbits at a depth of one-half the wave length is only one-twenty-third of the corresponding diameter at the surface. Regardless of the actual depth, the character of the wave therefore remains unaltered, if the depth to the bottom is greater than that short distance.

b) Summary of motion at surface : In a surface wave, let us assume, the wave motion is in the 'x' direction and let the distance 'x' and the time 't' be reckoned from a point when the wave passes its equilibrium position from trough to crest. Then the functional representations in terms of x and t of the deflection (y) of the sea surface from its position of rest, the horizontal (V_H) and vertical (V_V) velocities of the particles of the fluid medium at the surface may be written (Dietrich et al 1980 and Starling 1947) as

$$y = a \sin 2\pi \left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

$$V_H = V_{HO} \sin 2\pi \left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

$$V_V = V_{VO} \sin 2\pi \left(\frac{x - \frac{\lambda}{4}}{\lambda} - \frac{t}{T}\right)$$

where λ is wavelength, T is the period of wave, a is the maximum value of y (amplitude of the wave), V_{HO} and V_{VO} are maximum values of V_H and V_V respectively. The magnitudes of V_{HO} and V_{VO} are equal for deep water waves but they differ for shallow water waves.

The behaviour of the parameters of the particle motion at the surface as the wave completes a cycle of wavelength is indicated schematically in fig. 1 by dividing the circle into four quadrants corresponding to the four quarters of the wave length. The length of an arrow in each circle represents the magnitude of the parameter for which the circle stands. Anticlockwise direction is treated as positive. The zero point in each circle represents the starting point of the parameter. The rise of the wave is indicated by y which reaches its maximum at $x = \frac{\lambda}{4}$, thereafter it falls to the zero level at $x = \frac{\lambda}{2}$. Afterwards the height of the wave is negative (below the mean level) and it reaches the negative maximum (trough maximum) at $x = \frac{3}{4}\lambda$ from where

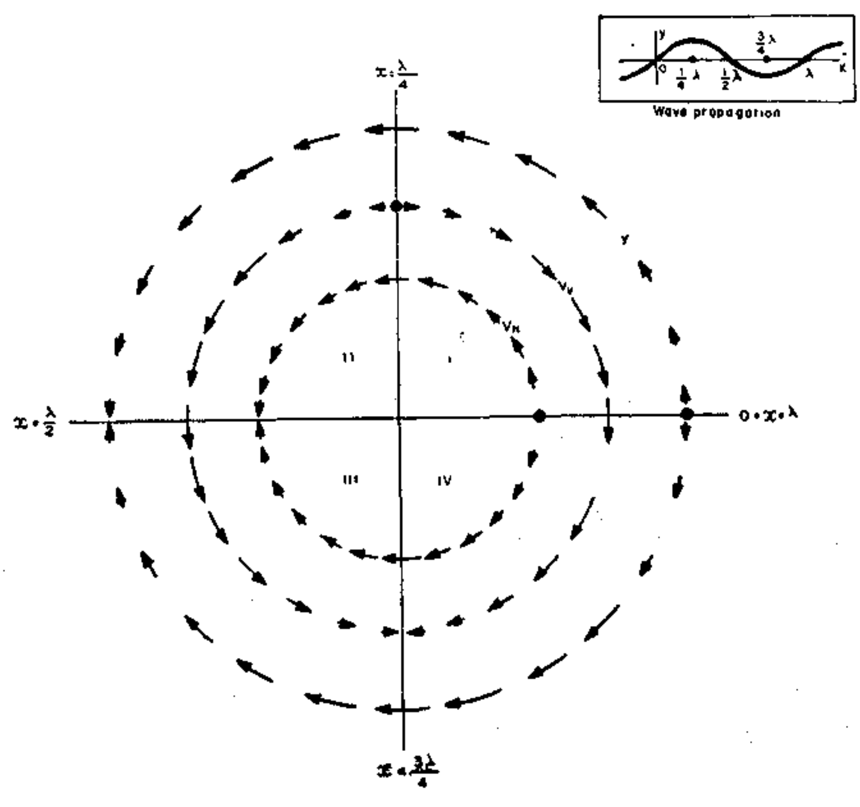


Fig. 1 Schematic representation of motion of a particle at the surface over a wavelegth

its magnitude decreases until it becomes zero at $x = \lambda$.

The horizontal velocity is forward during the crest period and it reverses during the trough period. As it varies in phase with wave height, the magnitude of the horizontal velocity reaches its maximum at $x = \frac{\lambda}{4}$ and at $x = \frac{3}{4}\lambda$.

While the horizontal velocity of the particle varies in phase with the waveheight (particle height), the vertical velocity varies out of phase with it. The vertical velocity leads the wave height by one-fourth of wavelength, therefore it is zero at the peak crest or trough.

Owing to the decrease of velocity with depth, the forward velocity of the particle, when it is above the mean depth, exceeds the backward velocity of it when it is below the mean depth. Therefore over a cycle of one wave-length the particle does not return to its original position but it experiences a net forward motion, resulting in net flow in the direction of progress of the wave. (Sverdrup et al 1942).

In the case of shallow water, the fact that the vertical motion cannot exist at the bottom modifies the character of the waves. At the bottom the motion can be only back and forth, and, if the depth is small compared to the wave length, the motion will remain nearly horizontal at all depths. Actually, the orbits of the individual water particles will be flat ellipses that become more and more narrow when approaching the bottom and at the bottom they degenerate into straight lines. Thus, all the particles involved in wave propogation move in different but systematic ways.

B. Viscosity

As the particles involved in wave propagation experience relative motion, either horizontal or vertical or both, here comes the effect of the internal friction (viscosity) of the medium in which the waves are propagated.

a) Newtonian viscosity : If relative motion occurs, viscosity or internal friction is experienced by the fluid. It was assumed by Sir Isac Newton that, for a fluid moving in parallel layers, the shearing stress at any point—where the velocity gradient is perpendicular to the direction of motion, $\frac{du}{dz}$ — is directly proportional to the value of the gradient, so that the frictional stress, f, per unit area is given by:

$$f = \eta \frac{du}{dz}$$

where η, a characteristic constant for the fluid, is called the coefficient of velocity. Newton's assumption was found true as long as the motion is laminar (non-turbulent), (Newman and Searle 1951). The values of viscosity (in 10^3 times c.g.s. units) of pure water and of seawater of 35‰ salinity at different temperatures are given in the following table (from Sverdrup et al 1942.)

	Temperature °C						
	0	5	10	15	20	25	30
Pure water	17.9	15.2	13.1	11.4	10.1	8.9	8.0
Seawater	18.9	16.1	13.9	12.2	10.9	9.6	8.7

Viscosity decreases with increasing temperature. Viscosity of seawater is correspondingly higher than that of pure water at all temperatures. The effect of pressure on the viscosity in the case of seawater is found to be insignificant.

b) Viscosity of the medium of mudbank : Let us study how the waves are damped once they enter into the region of mudbank. The mud particles present in a vertical column of the mudbank is treated to exist in three different phases.

i. Phase I (Thixotropic phase) : As early as 1923, A. Szegvari and E. Schalek (in Glasstone 195) found that when concentrated pasty mass of ferric oxide is mixed with suitable quantities of electrolyte in aqueous solution, on shaking, formed colloidal solution. This phenomenon has been called 'thixotropy' by Petrifi (1927). Subsequently, this was also observed in other colloidal systems such as alumina, silicic acid, vanadium pentoxide, zirconium dioxide, stannic oxide and even with suspension of fine clays. The analysis of the mud collected from the mud cones showed that it contained ferric oxide in finest clayey form.

The mud particles in this phase are very fine, ultramicroscopic, and they are subject to liquifaction by agitation (thixotropy).

ii Phase II (Sol phase) : The mud particles which are to be treated under this phase are microscopic. However, they do not enter into liquifaction but remain as sols or suspensoids. The viscosity of the medium is tremendously increased by the presence of such suspensoids for which state of solution Albert Einstein derived the formula

$$\eta_c = \eta_o \ (1 + 2.5\ \Phi)$$

where η_o = viscosity of solvent,
η_c = viscosity of solution
Φ = volumetric concentration of soils.

According to Einstein the volumetric concentration of particles (sols), i. e., the aggregate volume of the suspensoids, not their size, come into picture. Thus the presence of sols in the medium increases its viscosity by 2.5 times the volumetric concentration of the sols. For higher concentration a term in Φ^2 has to be added (Encyclopaedia Britannica, 1973).

iii Phase III (Gravity-influenced phase): The mud particles encountered in the third phase are so big in size that they are subjected to gravity where Stokes' theory is applicable. Assuming the mud particle in the third phase be spherical, according to Stoke's law, its rate of fall will be inversely proportional to the viscosity of the liquid and directly proportional to the relative density of the particle with respect to the density of the liquid. According to this law, the terminal velocity v, which is steady, is given by

$$v = \frac{2}{9} g \ \frac{(\rho - \sigma)\ r^2}{\eta}$$

where v is the rate of fall of the particle, η is viscosity of the liquid, σ is the density of the liquid, ρ is the density of the particle and r is its radius, and g is acceleration due to gravity.

Therefore, the fraction of the mud that has entered into the thixotropic phase with seawater increases the viscosity of the latter. Seawater and the thixotropically liquified mud fraction form the medium for the suspensoids which are constituted by the fraction of mud under the second phase (sole phase). Now the sols, thixotropic particles and seawater all together constitute the liquid medium for the suspended mud particles that are accounted under the last fraction which is influenced by gravity. Thus at every stage the viscosity of the medium is stepped up with the result that the particles categorised under the last fraction will experience tremendous amount of resistance to their fall due to the viscosity of the medium. Thus the effective viscosity of the medium depends upon the relative fractions of the mud entering into the first two phases. In case mud is present in seawater only in the gravity-infleuced state, the vis, cosity of the medium in that case remains the same as that of seawater at its corresponding salinity and temperature only.

With the understanding of three-stage (fold) increase of viscosity—seawater, thixotropic solution and sol phase state—of the medium, where large-size mud particles are suspended, let us go back to the propagtion of waves in such a liquid medium.

The wave propagation involved horizontal and vertical oscillations of the particles of the liquid medium as well as the suspended gravity-influenced mud particles. The particles of the liquid medium are equipped with high viscosity, resisting their relative motion, while the movement of the gravity-influenced mud particles is subjected to the influence of gravity and viscosity of the medium together

As a consequence of this, the particles of the medium, as well as the gravity-influenced suspsnded mud particles in it, suffer a loss of vertical and horizontal velocities. Hence it results in reduction in amplitude of the wave. The more the fraction of mud identifying itself with the medium under the first two phases- the more would be the viscosity of the medium, and the greater would be the reduction of amplitude of the waves. Thus, as the wave damping occurs, the mudbank enters into tranquillity, while the neighbouring region is wave-beaten.

The relative fractions of the mud entering into the three stages, namely, the thixotropic phase, the sol phase and the gravity-influenced suspended stage, explain other characters of the mudbank region, such as stability and longevity of a mudbank. In case the first two fractions are sufficiently high, which identify themselves with seawater in constituting the medium, they remain for long in the medium supporting the longevity, intensity of calmness and stability of mud bank. If the entire mud remains solely in the gravity-influenced suspended particle state, as the viscosity of the medium in that case reduces merely to that of seawater at its own temperature and salinity, the system cannot offer any calmness to the mudbank. Such a situation is experienced many times at mudbank regions and elsewhere where the water was apparently muddy, but the waves are found lashing within such areas even under calm wind conditions.

The Alleppey mudbank, where calmness is of higher grade and which remains for months together when compared to other mudbanks, which remain only for a few days, speaks about its richness in the first two fractions of the mud.

One is tempted to solely attribute the wave damping in the mudbank region to the bottom mud. It is interpreted that the mud acts as a semisolid jelly to absorb the wave energy. This concept ignores the physical state of the liquid column standing above the bottom mud. Moreover, as the wind-waves are caused at the sea surface, the origin of wave propagation rests primarily at the surface waters buf not at the bottom mud. McPherson and Kurup (1981) developed an interesting mathematical model for the wave damping at the mudbank region. Their model is in fact based on the mathematical model developed by Gade (1958). In the above mathematical model a two-layer system, the lower layer representing the sediment and the upper layer representing the water above, is considered. In this two-layer model, the bottom layer is assumed to be homogenous and the top layer frictionless. It is the experience of the authors that the mud is more and more concentrated towards the bottom. Setting aside the question of homogeneity of bottom layer, what is more important is the frictional character of the top layer (water column), which offers resistance to the motion set in it. Therefore, the physical conditions assumed in that mathematical model are not identical with the mudbank conditions prevailing here.

DISSIPATION OF MUDBANKS

Towards the end of monsoon, as the rain decreases, the water level in the backwater gets reduced to the normal, leading to reduction in hydraulic pressure in the subterranean strata which finally results in the cessation of supply of fresh mud. As the monsoon gets weakened, the turbulance of the water column also gets reduced and mud in the bank settles down causing dissipation of the banks.

During the mudbank season, the littoral currents are observed to be always southerly and the local tides have no influence on the direction of current. Toward the end of August the currents start reversing, thereby setting in offshore and northerly components (refer Chapter 10). The suspended and loose mud of the bank is gradually taken off by these veering currents.

Thus, towards the end of monsoon, in the absence of fresh supply of mud into the water column, the already available mud fraction which increases viscosity, gradually diminishes and the mudbank dissipatas. This leads to the fading of calmness over the mudbank. Then the rough conditions set in irrespective of the presence or not of gravity-influenced mud particles in the water.

MOVEMENT OF MUDBANKS

It has been observed that the mudbanks exhibit slow movement (in course of time), usually in a southward direction. In the case of the permanent mudbank of Alleppey, the investigations carried out by the authors showed that the mudbank moved from the place of incidence by about 0.5 to 2 km year to year southward. The table given below shows the pattern of movement of this mudbank during 1972 to 1981.

Year	Place of occurrence: Northern limit	Place of occurrence: Southern limit	Distance from Alleppey to the northern limit of mudbank (km)
1971	Kakkazham	Ambalapuzha	13
1972	Kakkazham	Karoor	13
1973	Karoor	Purakkad	15
1974	Purakkad	Chennankara	18
1971-80	Chennankara	Thottappally	20
1981 (1)	Chennankara	Pallana	20
1981 (2)	Paravoor	S. Punnapra	5

The table indicates that the period of rapid shift of mudbank was from 1972-75, during which period it moved a distance of 8 km from Kakkazham to Thottappally. Afterwards the rate of movement was slowed down or became rather nil. However, in 1981 the limit of the mudbank was extended up to Pallana, south of Thottappally spillway. The possibility of fresh discharge of mud in the nearshore areas at Pallana in 1981 or anywhere north of this place during the previous years also cannot be ruled out. In this year a fresh mudbank of approximately 4 km long was formed at Punnapra (Paravoor-south Punnapra), about 14 km north of Chennakara.

The mud from the place of discharge gradually moved southward due to the then southerly flow of the water. This movement was continued till the beginning of the northeast monsoon winds, and the subsequent reversal of the southerly drift, when conditions had already set in for the dissipation of the mudbank.

During the process of the movement, it has been found that the finer particles of mud at the bottom were always deposited at the down-drift side, while coarser particles are left out near the source. A series of mud samples collected from the mudbank and the surrounding places fully support this view.

DIFFERENT TYPES OF MUDBANKS

The mudbanks can be classified into four major categories based on the source of mud:

1. *Mudbanks formed by subterranean mud:* e.g., Alleppey mudbank, described above.

2. *Mudbanks formed by the aggregation of coastal mud :* e.g., Parappanangadi-Tanur mudbank.

In this case, the mudbank is very extensive, stretching over several kilometres along the shore, but is very temporary. There is no calmness as the nongravity-influenced mud particles in the medium do not absorb all the wave energy. By the effect of the southwest monsoon, the mud present in the coastal mud belt is churned up and, at this time, if the prevailing environmental conditions are favourable to the formation of the mudbank, the mud will be brought very near to the shore and thus a mudbank will be formed. Once such favourable conditions cease to exist, these mudbanks disappear suddenly.

3. *Mudbanks formed by the sediments and organic debris discharged from rivers and estuaries :* e. g., Chellanam-Manassery (Cochin bar mouth), Narakkal (The Azhikode bar mouth), Valapad-Nattika (The Chetwai river mouth), Elathur (The Korapuzha river mouth), Quilandy (The Kuttiyadi river mouth), Muzhippilangadi(The Dharmadam river mouth), Kottikulam-Ajanur-N-Bella-Adakathubail (The Chandragiri river mouth), Kumbala (The Kumbala river mouth), Uppala (The Uppala river mouth) and Ullal (The Netravati river mouth).

The flood waters coming down from rivers and lakes during the heay rains of the southwest monsoon bring huge quantities of sediments and other organic matters, which are dumped at the estuary and bar mouths. These sediments are always aggregated on the southern side and are held up there for a while by the southerly flow and the local eddy currents. Once the water force from the lakes and esturies is reduced, and the current reversed, the mud is spread out and the mudbank gradually disappears.

4. *Mudbanks formed by the accumulation of mud resulting from dredging operations :* eg., mudbank at Vypeen, Cochin.

At Vypeen, north of Cochin bar mouth, accumulation of mud is observable right from the shore. This mud is the result of periodical dredging operations done for deepening the navigational channel. Here the water over a wide area is calm due to this mud accumulation.

MUDBANKS AND COASTAL EROSION

It was observed that the silt-clay fraction was more on the southern side of the mudbank, while its northern side is sandy (see Chapter five). The southerly gradient of finer size of grain is due to the effect of littoral currents which are southerly. Occurrence of erosion along the coast during the southwest monsoon period is not uncommon. One may expect that the beach material eroded by the inshore waves and littoral currents may be deposited down stream at a place south of the erosion area. Occasionally erosion is taking place on the down-stream side of the mudbank The mudbanks are ahead of erosion areas with respect to the littoral currents.

Padmanabhan and Eswara Pillai (1971) explained the infleunce of mudbank on erosion process as follows:

"Most of the movement of materials is caused by waves approaching the shore at an angle. As the material so transported reaches the mudbank areas, its further movement is arrested as a result of the absence of waves in this area. This material thus got trapped within the mudbank cannot reach the down-drift side. The shore immediately on the down-drift side suffers from a lack of supply of littoral material, and the coast is eroded to make up the deficiency."

It is difficult to comprehend, unless some eddy currents are thought of, how the coast on the hind side of the mudbank gets eroded, due to the simple reason that the shore immediatley on the down-drift side suffers from the lack of supply of littoral material.

FOUR

SOURCE OF MUD OF ALLEPPEY MUDBANK: MUD CONE AND THE MESSAGE IT CONVEYS

C. P. GOPINATHAN, A. REGUNATHAN, D. S. RAO, K. J. MATHEW and A. V. S. MURTHY

ABSTRACT

The chapter embodies the authors' findings, and the logical conclusions they drew from them, on the mud cones (or 'mud volcanoes') they found in the intertidal zone and on the beach of the Alleppey mudbank region in 1972. Their experiment with regard to these mud cones confirm beyond doubt the viscous nature of the mud that underlies at Allepey, and its being, for all probability, the source of Alleppey mudbank.

Similar mud cones observed earlier by some workers are also discussed briefly.

INTRODUCTION

Crawford (1855) was the first to report on the mud cones, or 'mud volcanoes,' at Alleppey. He has inferred from this phenomenon that there exists a subterranean mud at Alleppey that may be the source of mud for the Alleppey mudbank. Subsequently, Philip Lake (1889) and Davey (1903), too, observed mud cones at Alleppey. However, after 1903 there had been no further records of mud cones in this region and, therefore, their role in the formation of mudbanks was not taken seriously. But, in the course of our intensive investigation on the mudbanks of the Kerala coast we came across active mud cones in the vicinity of the mudbank, that formed at Ambalapuzha, in July 1972. The following account describes in detail these mud cones and the insight they give into the nature of the underlying mud at Alleppey region, which in all probability contributes the mud for the formation of mudbank at Alleppey, as well as into the mechanism by which the mudbank is brought about.

OBSERVATIONS

Six active mud cones, in different stages of formation, were seen at Kakkazham, a place about a kilometer from Ambalapuzha, about the northern limit of the mudbank then in existence (See, Fig. 1), of which three were on the beach, a few meters away from the high-

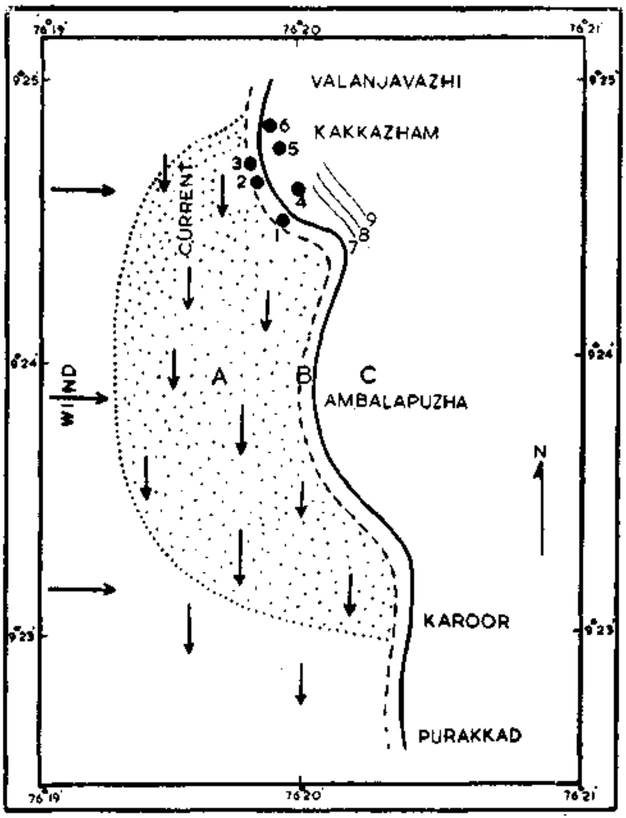


Fig. 1. Diagram showing the places of mud cones at the beach and at the inter-tidal zone, and the cracks observed on the beach.

water mark, and three in the water at the in-tertidal zone (see Table 1). One of the cones that were in the intertidal zone, measuring 7.5 meters across, was found feeding the waves

TABLE 1. *Details of the mud cones at Kakkazham, observed in 1972.*

Mud cone	Mean diametar (cm)	Height of cone from ground level (cm)		Distance between cones (m)
		at centre	at periphery	
In water				
1	425	—	—	2
2	535	—	—	45
3	750	—	—	
On shore				
4	271	40	27	
5	128	17	15	25
6	106	20	15	34

with loose mud as well as lumps of it, while in others fresh mud was oozing out adding to the cones. There were also 'cracks' found to have developed in three places on the surface of the beach more or less parallel to the shore, about 29 m away from the mud cone that was feeding the waves. Each crack was about 2 cm wide, 10 to 15 m long and separated from each other by about 3 to 5 m (Plate I, A & B). During the high tide the sea water covered this area, obliterating the cracks, but they reappeared at the time of low tide.

Attempting to gauge the depth of mud beneath the cones, we found that a half-inch-thick GI pipe failed to touch any hard bottom even when inserted to its full length of 6 meters; but when tilted the hard sides could be felt all round, showing that the cones were mounts, crusted by exposure, of loose mud emerging out of what appeared to be deep wells, full of soft and unconsolidated mud. In the tidal zone ones, on the other hand, this emerging mud, as and when it did, was carried away by the waves, and what remained was only open mud wells, which at times could be like quagmire, very dangerous to fishermen. This is borne out by a sad incident told us by the fishermen when we enquired why a particular spot on the tidal zone was marked out by a partly buried coconut trunk (see: Plate IV, C). A few days earlier to our visit, we were told, a boy, jumping into the water from a home-bound canoe, to haul it ashore, had, instead, jumped unnoticingly into one of these gaping holes and sank down to its depth, in such a way that even his body was not able to be recovered. It was this mud well, which was later covered by sand brought by the oncoming waves, that was thus marked, to ward off any further accidents.

The mud cones, which were active when the S. W. monsoon was intense, became inactive or subsided with the subsidence of the latter, obviously because the forces then responsible for bringing the mud out from beneath had now languished. Within a few days the upper crust of the beach cones became hard and broken down to pellets, due to sun light (Plate II, A-C); but those in the intertidal zone gradually subsided and covered over by sand deposited by the onshore waves (Plate III, A).

Table 2 gives the successive changes the mud cones undergo during a period of time.

TABLE 2. *Observations on the behaviour of cones at Kakkazham*

Mud cone No.	Date of formation	Active phase (days)	Dormant phase (days)	Date of complete subsidence
At the inter-tidal zone				
1	19-7-72	12	6	6-8-72
2	19 7-72	9	9	6-8-72
3	27-7-72	10	3	9-8-72
On the beach				
4	18 7-72	9	10	6-8-72
5	14-7-72	10	9	2-8-72
6	15-7-72	12	11	5-8-72

DISCUSSION

Toward the close of the last century and the beginning of the present, the subterranean mud was held to be the source of mud for the Alleppey mudbank by those authors who had chances to observe mud cones. However, the laterinvestigators, who never had any opportunity of seeing the phenomenon in operation, were reluctant to accept this view and they. instead, suggested alternate views about the source of mud for the Alleppey mudbank (see Chapter 3).

Crawford (1855), on seeing the mud cones in operation on the beach and on the roads of Alleppey, wrote that "the beach and roads presented then a singular appearance, nothing to be seen but these miniature volcaneso, some silent, others active". He also noticed subsidence of shore, after or during the rains, causing long fissures, varying from 120 to 360 ft in length.

Philip Lake (1899) also had the experience of seeing mud cones and land subsidence in the vicinity of the Alleppey mudbank. He found subsidence of land to a depth of 2-3 ft; the strip of shore subsided being to 60 ft in breadth and 900 ft in length. Further north of this he found the shore sunk in little steps so that there were a number of "little terraces" each a few inches high, rising one above the other from the sea towards the shore. At the northern end, within the inter-tidal zone, a heap of mud rose to a height of 2 or 3 ft above the level of the sand. All along the seaward edge of the subsided areas there were a number of "basin-shaped holes" in the sand having a diameter of 4 to 5 ft and a depth of 3 to 4 ft. In 1903, Davey had observed mud oozing out, as from little volcanoes, all around the old pier (Alleppey pier) and bringing with it decayed stems of trees.

Our observations well confirm these earlier observations and conclusions. The occurrence of cracks on the beaches, suggesting the sinking of the coastline, and ejection of mud in the form of mud cones (and the continuing oozing of mud through it) show beyond doubt that the source of mud for the Alleppey mudbank is of subterranean origin, the mechanism of bringing it out being the same as indicated by the formation of the mud cones.

MUD CONE

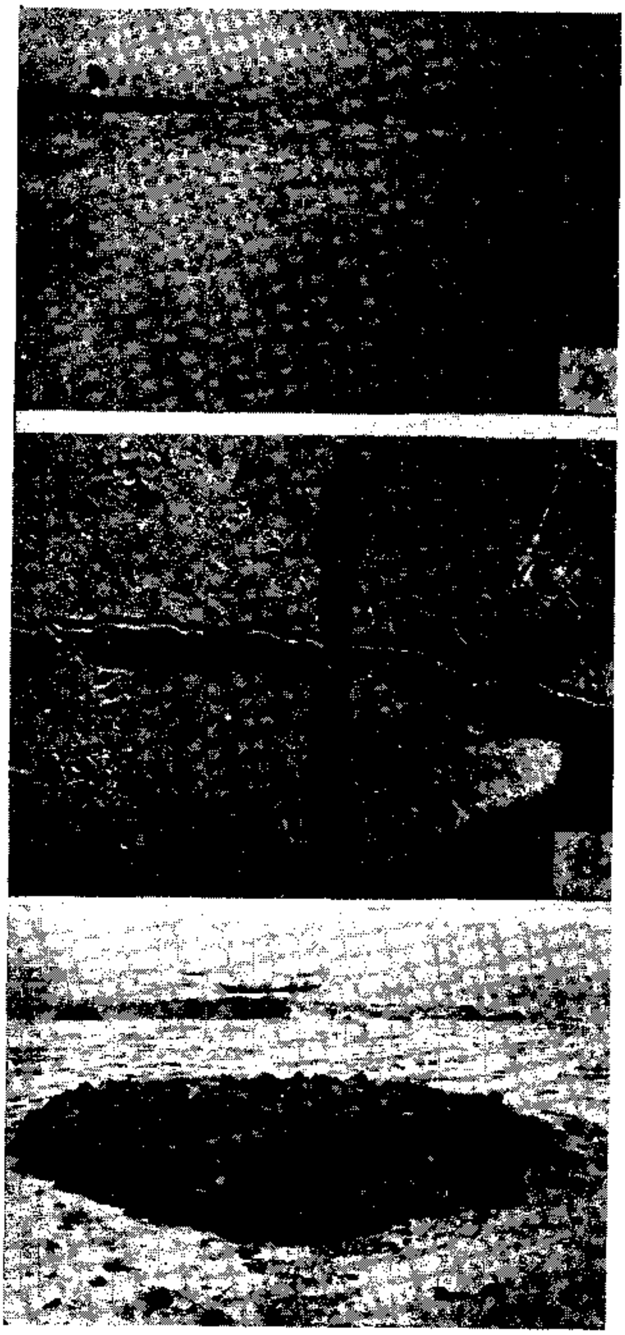


Plate-I. A: The mud, in pellet form, scattered all over the beach. Also seen is a long crack along the beach as a result of subsidence. B: A close-up of the crack showing the subsidence of the seaward portion of the land. C: An active mud cone.

Plate-II. A: The dry crust of a dormant cone; B: The mud cone starts subsiding. C: A fully subsided mud cone.

MUD CONE

Plate-III. A: A subsided intertidal mud cone covered over by sand. B&C: Measuring the depth of the mud cone with a 6-m G. I. pipe.

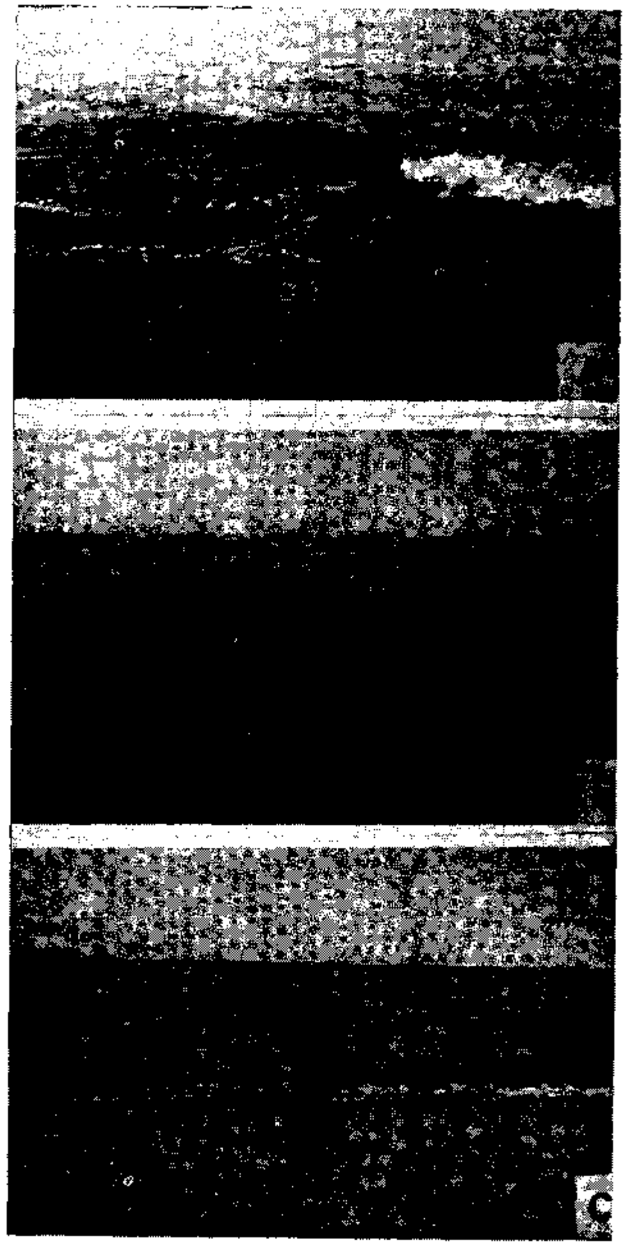


Plate-IV. A: The windward limit of the mudbank marked by the breaking of the waves.
B: An active mud cone seen feeding the waves with subterranean mud. C: The spot, marked by a coconut trunk, where the mud well had been, in which a boy was reported to have sunk'

FIVE

MUD OF THE MUDBANK; ITS DISTRIBUTION AND PHYSICAL AND CHEMICAL CHARACTERISTICS

D. S. RAO, A. REGUNATHAN, K. J. MATHEW, C. P. GOPINATHAN and A. V. S. MURTHY

ABSTRACT

Description of the texture, grain size, thickness and chemical properties, including minerological-studies, of the mud in the mudbanks is given. An echosurvey conducted in the mudbank revealed the pattern of distribution of mud and the extent of the area of the mudbank, which would provide answers to problems connected with the formation of the mudbank and the associated calmness.

INTRODUCTION

The mud being the chief component of the mudbank, a through study on the texture, the thickness of the deposit, the grain size and chemical properties of the mud would provide answers to many problems concerning the mudbanks, which, therefore, formed a major part of study during the present investigations. The earlier authors who attempted to study the physico-chemical aspects of the sediments of the mudbanks are Ducane et al (1938), Dora et al (1968), Gopinathan and Qasim (1974), Jacob and Qasim (1974), Kurup (1977) and McPherson and Kurup (1981).

MATERIAL AND METHODS

Mud samples were collected regularly from June 1971 to September 1972 from 4 stations between Kakkazham and Purakkad. The stations fixed were at Kakkazham (Station 1, near to the coast, and Station 2, away from the coast), Ambalapuzha (Station 3) and Karoor, near Purakkad, (Station 4). The Stations 2-4 were parallel to the cost, about 1 km away and were separated from each other by about 1.0 km each (Fig. 1). A Van veen type grab of 0.03 m^2 was used for sampling the mud. The highly unconsolidated nature of the mud did not permit the grab at times to close. These samples were studied for their texture, grain size and chemical properties.

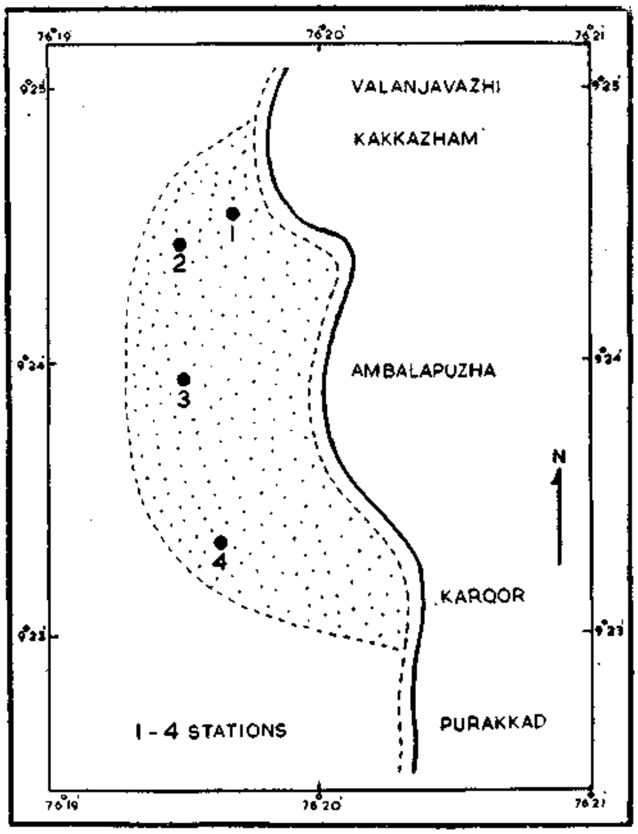


Fig. 1. Station positions, where seasonal observations were made at Alleppey mudbank.

An echo survey at the mudbank area was carried out on 18th May 1975, to study the distribution and thickness of the mud deposit and also to understand the actual extent of the mud deposit in the mudbank. A Simrad Echo sounder of model EX 38 with a transducer 10 x 20 cm of model 65 R was used for this survey. The survey was carried out in two directions, one parallel to the coast along the 3-metre depthline covering a distance of 5 km from Thottappally in the south to Kakkazham in the north and another perpendicular to the coast at Purakkad from 2 m depth to 12.5 m depth off the shore for a distance of 3.5 km. During the survey, mud samples were collected from 8 stations (Plate 1). All the samples were subjected to grain-size analysis by sieving. Measured quantities of the oven-dried sediments were dispersed overnight in 0.025 N solution of sodium-hexa-meta phosphate. The silt and clay fractions were separated by washing the dispersed sediments using a 63μ sieve. The coarse fractions retained in the sieve were dried and examined under the microscope.

The mudbank sediments were compared with samples collected from Elathur (Calicut) mudbank and Vembanad Lake. The mud samples I and II were from the Elathur mudbank (Table 3), sample III from the mouth of the Korapuzha river and sample IV from a station near the railway bridge across Korapuzha. The sediments were analysed according to the methods mentioned by Sankaram (1966).

OBSERVATIONS AND RESULTS

the mud of the mudbank is mostly silty-clay in its nature (Table 1). Relatively a higher percentage of sand was observed at station 1 than at the other stations. The sandy nature of the mud at this station may be attributed to the proximity of the station to the shore and to the wave action at the periphery close to this station. While stations 2 and 3 show less sand in the samples, station 4 showed a high percentage of clay-silt fraction. This may be due to its position in the highest depth contour where the nearshore activities have less impact on the sediments.

The sandy nature of the bottom at station 1 during the non-mudbank season clearly shows the infleuce of anchoring and other activities of the mechanised boats on the otherwise surf-ridden bottom. The present

TABLE 1. *Monthwise sand and silt-clay contents of sediments (%) in the area of Alleppey mudbank.*

	St. 1		St. 2		St. 3		St. 4	
	sand	silt-clay	sand	silt-clay	sand	silt-clay	sand	silt-clay
Jun.	15.71	84.29	2.30	97.70	2.20	97.80	1.00	99.00
Jul.	0.28	99.72	0.80	99.20	0.78	99.22	—	100.00
Aug.	0.82	99.18	0.72	99.28	0.70	99.30	—	100.00
Sept.	3.02	96.98	2.80	97.20	1.70	98.30	0.27	99.73
Oct.	5.04	94.96	3.00	97.00	2.80	97.20	0.30	99.70
Nov.	8.72	94.28	4.25	95.75	4.00	96.00	0.72	99.28
Dec.	13.40	86.60	6.30	93.70	6.00	94.00	1.20	98.80
Jan.	15.28	84.72	8.00	92.00	6.70	93.30	1.72	98.28
Feb.	27.30	72.70	8.20	91.80	6.90	93.10	2.78	97.22
Mar.	32.10	67.90	9.00	91.00	8.92	91.08	2.78	97.22
Apr.	100.00	—	9.50	90.50	8.71	91.29	2.78	97.22
May	100.00	—	8.10	91.90	8.00	92.00	2.00	98.00

investigation showed that the mudbank sediments are predominantly of clay and silt fractions and the sand fraction is negligible.

Extent of mudbank and distribution of mud

The echo survey conducted off Ambalapuzha (remnants of 1974 mudbank) and Purakkad (the active mudbank in 1975) gave some very interesting results with regard to the extent and nature of the mud deposits. Samples collected during the echo survey were analysed for particle size and the details of the analysis are given in the following table:

TABLE 2. *Details of mud analysis.*

St. Nos.	Depth (m)	Silt-Clay fraction	Sand fraction	Grain size (mm)	Average grain(mm)
Thottappally					
1	2.5	99,40	0.56	0.08 -0.220	0.136
2	4.0	96.64	3.36	0.086-0.300	0.143
3	6.0	99.12	0.88	0.066-0.283	0.140
4	8.0	98.72	1.28	0.066-0.250	0.140
5	11.0	95.84	4.16	0.050-0.266	0.133
6	12.5	98.60	1.40	0.050-0.250	0.131
Kakkazham					
7	4.5	90.26	9.84	0.050-0.400	0.150
8	4.0	nil	sand only	–	–

Analysis of the sediments showed a high percentage of silt-clay fraction (99.4%) and only a negligible percentage of sand. The composition of the sediment at Thottappally was in the order of 90% silt-clay and 10% sand, but the sediment at Kakkazham did not show any trace of silt-clay indicating the northern limit of mudbank. Ducane et al (1938) recorded a high percentage of clay content in the mudbank sediments. A high silt-clay fraction ranging from 85.9% to 99.7%, with values clustering around 98.2%, was observed by Dora et al (1968).

The echogram (Fig 2) revealed that the mud of the mudbank was in a heap with a vertical thickness of about 2 m at the centre situated around 2 m bathymetric line off Purakkad. The thickness of the mud gradually decreased from this point until it reached a thin layer on all sides except perhaps towards the shore (draft of the vessel did not permit the vessel to move closer to the shore). The investigations showed that the mudbank extended for about 3 km in the north-south direction along the coast off Purakkad while the remnants of the previous years mudbank off Ambalapuzha occupied a length of about

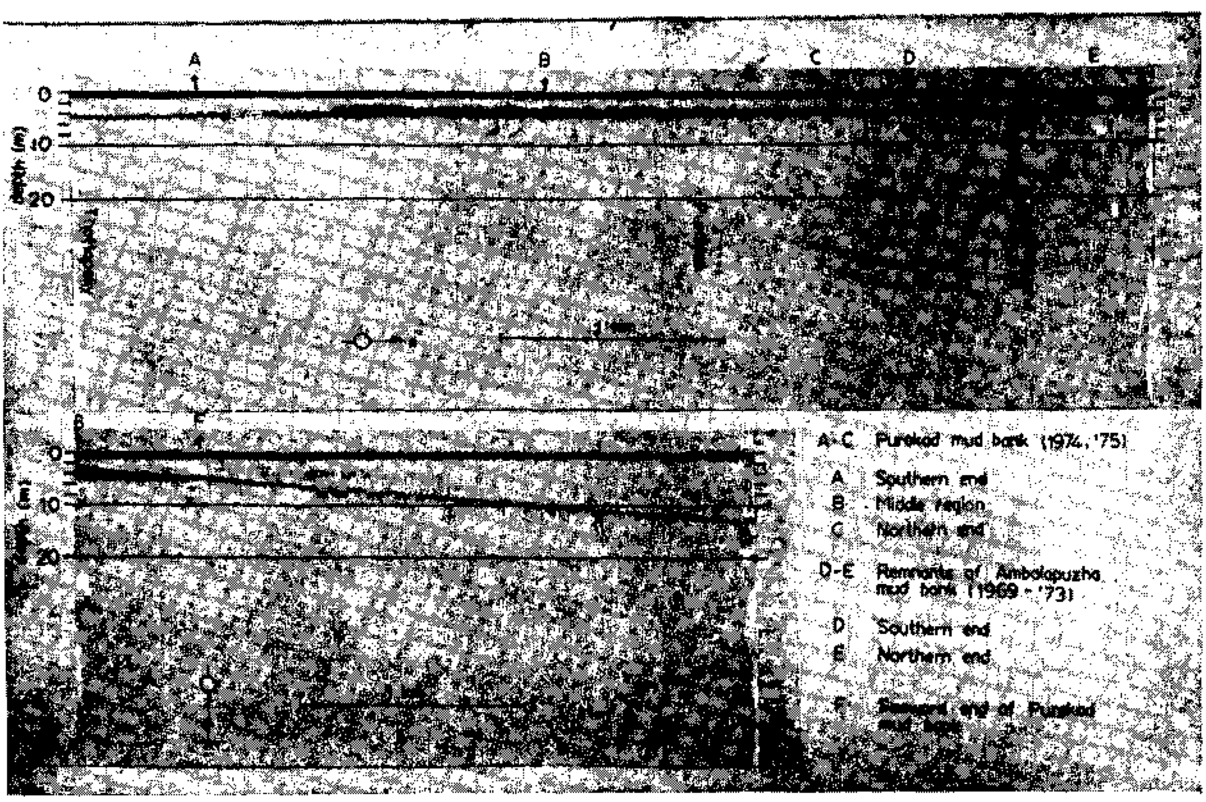


Fig. 2. Echogram showiug the old mud in the mudbank area at Alleppey.

1 km along the coast north of Purakkad. The mudbank extended roughly about 1.5 km out into the sea, but, the thin layer of the spread-out mud extended even beyond 3.5 km. While there was perfect calmness at Purakkad, the sea off Ambalapuzha was somewhat disturbed.

MINEROLOGICAL STUDIES OF THE MUD

The results of the chemical and minerological analysis of the mud are given in table 3. The silica concentration of the mudbank sediments of Purakkad and Elathur and of the sediments of Vembanad lake were in general comparable with each other. The iron contents of the sediments, estimated as ferric oxide, did not show any appreciable variation. The same was the case with the concentrations of calcium, magnesium, alumina, sulphate and phosphate in the sediments.

There were no significant variations during the mudbank season and non-mud bank season.

DISCUSSION

The composition of the mud at Thottappally (10% sand) and Kakkazham (100% sand) suggests these places as the possible southern and northern periphery of the mudbank, respectively, in the year 1975 (Fig. 2 and Table 2) The grain size was observed to be of an average of 0.14 mm but the minimum limit of its range showed gradual reduction in size

TABLE 3. *Minerological analysis of mudbank sediments.*

Sample	Volatile matter %	Acid insoluble SiO_2 %	Iron* %	Calcium as CAO %	Magnesium as MgO %	Alumina %	Sulphate %	Phosphate %	Acid soluble SiO_2 %	Total %
Aug. 71	1.82	42.92	8.91	7.05	5.28	20.35	3.11	9.45	9.68	99.57
Sept.	1.23	42.88	8.91	7.02	5.21	20.92	2.88	0.44	10.11	99.60
Oct.	1.52	42.91	8.80	7.04	5.08	20.81	2.90	0.40	10.20	99.66
Nov.	1.38	43.15	8.77	6.73	5.52	20.63	2.93	0.45	10.31	99.42
Dec.	1.14	42.87	8.92	6.88	5.43	19.98	3.04	0.58	9.82	99.66
Jan. 72	1.61	42.03	8.73	6.92	5.01	20.19	2.97	0.61	10.18	99.24
Feb.	1.30	42.57	8.49	6.98	5.23	21.23	2.93	0.58	10.21	99.52
Mar.	1.12	43.01	8.81	7.81	5.18	20.78	3.01	0.63	9.32	99.67
Apr.	1.82	43.04	8.52	6.63	5.15	20.77	3.41	0.61	9.84	99.69
May	1.43	42.80	8.01	6.81	5.71	20.73	2.88	0.60	10.28	99.25
Jun.	2.05	43.12	8.11	6.77	5.35	20.28	2.95	0.59	10.23	99.45
Jul.	2.21	42.53	8.89	7.12	5.18	20.44	2.98	0.42	9.58	99.35
Aug.	2.13	42.79	8.63	7.17	5.17	21.18	2.89	0.41	9.01	93·38
Vembanad	1.41	43.71	8.12	7.14	5.08	21.08	2.95	0.68	9.13	99.56
Elathur I	1.62	43.42	8.57	7.09	5.27	19.64	3.12	0.43	10.21	99.37
II	1.81	43.38	8.53	7.15	5.19	19.83	3.08	0.41	10.16	99.54
III	1.32	43.41	8.87	7.31	5.31	20.12	2.92	0.48	9.74	99.48
IV	1.92	43.50	8.99	7.04	5.23	19.93	2.99	0.47	9.53	99.60

* Iron as ferrous and ferric oxide (total)

towards west. The sediments at the Kakkazham area did not show any trace of silt-clay fraction. It is interesting to recall here that the active mud supply zone in 1972 was at Kakkazham, where the mud cones were observed to be very active at the inter-tidal zone and on the beach. It may be mentioned that no mud cones were observed to be very active at the inter-tidal zone and on the beach. Further no mud cones were observed in later years and Purakkad became the seat of the mudbank in 1974–75.

From the minerological analysis, it is clear that the mineral composition af the sediments off Purakkad, Elathur and at Vembanad backwater region are almost the same, suggesting that they are all of the same laterite origin as found by Brown et al (1938). The composition of the mineral components compared very well with that observed by Brown.

Further, the presence of ferric oxide, silica and alumina in fine clayey from in the sediments imparts the thixotropic character to it. Thus when the mud cones are in contact with electrolyte lipoids, they form a colloidal solution by thixotropy with the seawater and increases the viscosity of the medium and keeps it in a colloidal form for a longer period.

SIX

ECOLOGY OF MUDBANKS — HYDROGRAPHY

D. S. RAO, K. J. MATHEW, C. P. GOPINATHAN, A. REGUNATHAN and A. V. S. MURTY

ABSTRACT

The variations in physical and chemical parameters of the Alleppey mudbank waters are discussed in this paper. The fluctuations in temperature, salinity, oxygen and the comparatively high nutrient contents of the mudbank waters are highlighted.

INTRODUCTION

Observations on the physical and chemical properties of the mudbank are very meagre. Damodaran and Hridayanathan (1966) and Damodaran (1973) have studied some of the hydrographical properties of the Narakkal mudbank and recently Kurup (1977) reported the temperature and salinity distribution at the mudbank at Purakkad. However, a detailed study on the physico-chemical aspects of the mudbank area is still lacking.

The following account deals with the physical and chemical aspects of Alleppey mudbank, based on observations made during 1971-72, which covered two mudbank seasons. In the year 1971-72, mudbank was formed between Kakkazham in the north and Karoor (near Purakkad) in the south with Ambalapuzha at the centre, and it extended about 3 km along the coast and about 5 km offshore. The average depth was about 4 m.

MATERIAL AND METHODS

A country-craft was used for carrying out investigations in the mudbank. For regular monitoring of the biological and ecological parameters, 4 stations were fixed in the mudbank, (Fig. 1. Chapter 5). The observations were made at surface and bottom for temperature, salinity, dissolved oxygen, reactive phosphate, reactive silicate, nitrite and nitrate. Observations on temperature was made using a bucket thermometer for surface waters and reversing thermometer for bottom. Seawater samples for chemical analysis were collected by Nansen bottle. Salinity was determined by the titration method, dissolved oxygen by Winkler's method and the nutrients by the method of Strickland and Parsons (1968).

RESULTS

Temperature: The variations of the mean temperature at surface and bottom are presented in fig. 1. Before the start of the mudbank season, the temperature was about 28.5°C both at the surface and bottom. During the mudbank season (June–August), the temperature of the waters was between 26 and 27°C at the surface and between 25 and 26°C at the bottom. During November-December 1971 the temperature of the surface was around 29°C and at the bottom it was 28°C. During

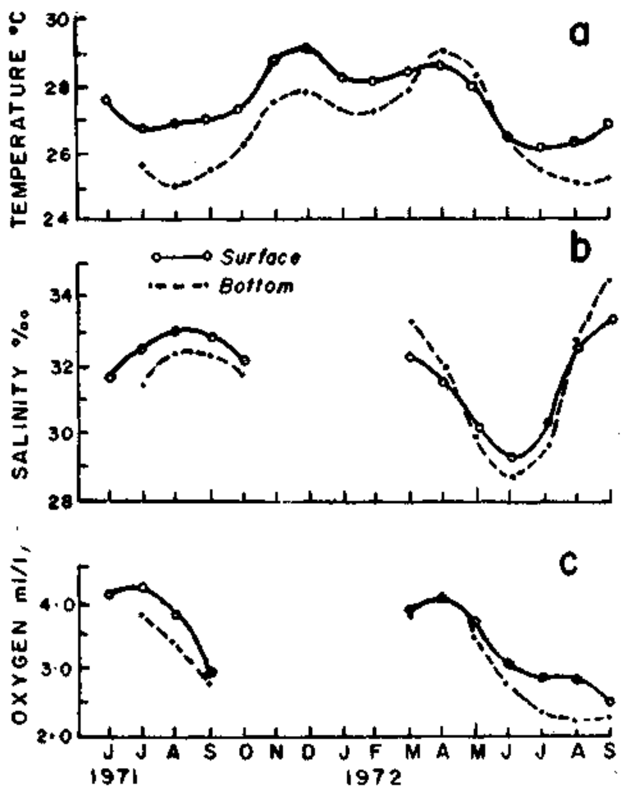


Fig. 1 Monthly mean variations of hydrographic parameters: a. temperature (surface and bottom); b. Salinity (surface and bottom); c. dissolved Oxygen (Surface and bottom).

January-March 1972, the temperature for surface water was 28°C, and at the bottom it was 1°C less.

Salinity: The salinity values at both surface and bottom were relatively high during the pre-mudbank and post-mudbank seasons. During the 1972 mudbank season the average salinity values reached as low as 28.5‰. It is interesting to note that the salinity values at the bottom were slightly lower than at the surface during the mudbank seasons (fig. 1 b).

Dissolved oxygen: The fig. 1 c represent the mean values of dissolved oxygen at the surface and at the bottom. The value rose to around 4 ml/l during the pre-mudbank season. The dissolved-oxygen values in the mudbank season were the same as the pre-monsoon values at surface of 1971. However, during the 1972 mudbank season the dissolved oxygen of both surface and bottom waters was reduced to about 3.2 ml/1.

Reactive phosphate: The variations of the values of reactive phosphate of surface and bottom waters are given in fig. 2 a. The values during winter were generally lower at the two levels and less than 2 µg at P/l. The

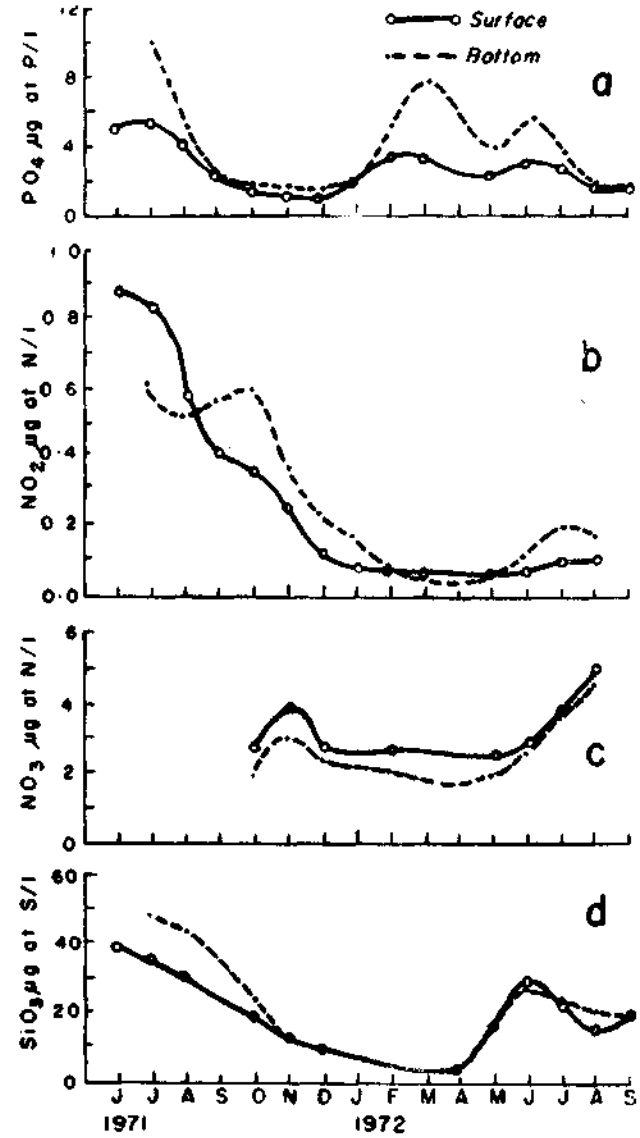


Fig.2 Monthly mean variations of hydrographic parameters: a, phosphate (surface and bottom); b, nitrite (surface and bottom; c, nitrate (surface and bottom); d, silicate (surface and bottom).

seasonal value of phosphate of the surface water, as well as the bottom water, indicated the maximum during the mudbank season of the years 1971 and 1972. However, a sharp rise in the phosphate values was noted in March 1972. As is usually the case, the phosphate values were more at the bottom than at the surface.

Nitrite and nitrate: Fig. 2 b shows the variations in the values of nitrite content. Generally speaking, the values during 1972 mudbank season were much less than those corresponding to the 1971 season. The nitrate nitrogen (fig. 2 c) was low during the pre-mudbank season and appareciably high during the mudbank season. The bottom and surface values did not show much difference in the case of nitrates. The nitrate nitrogen values showed maximum during post-mudbank season at both surface and bottom.

Reactive silicate: The figure 2 d gives the variations in reactive silicate values at surface and bottom. The silicate values at the two levels were at their ebb, being less than 10 µ g at SiO_3/l during the pre-mudbank and post-mudbank seasons. During the mudbank season, the silicate values were high. In general, the bottom silicate values were higher than there at the surface during the post-mudbank season.

DISCUSSION

The reduced temperature observed during the mudbank season could be due to the reduced incoming solar radiation on account of the thick monsoon clouds. The observed reduction in salinity values from the pre-mudbank to the mudbank season may be attributed to precipitation, run off and also due to the freshwater discharge from the nearby spillway The slight decrease of salinity at the bottom of the water column during the mudbank season may be attributed to the seepage of water-borne mud from the subterranean porous stratum of the coastal strip, an observation supporting Crawford's views (see Chapter 3 on mudbank formation).

Heavy blooming of organism *Noctiluca* can cause a rapid reduction in the dissolved-oxygen content of the water, especially when it is calm. Thus during the post-mudbank season (September–November), the minimum values of dissolved oxygen can be attributed to the observed blooms of *Noctiluca miliaris.*

The nitrogenous compounds and the phosphate contents of the water column showed an approximate inverse relationship (fig. 2), which indicates that the planktonic algae utilises one of the nutrient compounds at a faster rate during a particular season.

The high silicate values during the mudbank season may be due to the fine sediments present in suspension in the water. This increase may also indicate the heterogenous character in space and time of the silica recycling mechanism by the diatoms during its growth and multiplication.

SEVEN

ECOLOGY OF MUDBANKS — PHYTOPLANKTON PRODUCTIVITY IN ALLEPPEY MUDBANK

P. V. R. NAIR, C. P. GOPINATHAN, V. K. BALACHANDRAN, K. J. MATHEW, A. REGUNATHAN, D. S. RAO and A. V. S. MURTHY

ABSTRACT

The standing crop of phytoplankton, in terms of biomass, chlorophyll *a* and total cells, recorded high values during the rise as well as maturity of the mudbank. However, the primary production showed high values only before, and not during or after, the formation of the mudbank. Qualitatively, a total of 58 species of phytoplankters were present. A notable feature seen in association with the mudbank was the blooming of *Noctiluca miliaris*, at the time of dissipation of the mudbank during both the seasons' of 1971 and 1972. The possible relationship of phytoplankton to and the role it plays at the mudbank is briefly discussed.

INTRODUCTION

Observations hitherto made on the organic productivity of our seas and connected backwater systems (Prasad et al 1958; Nair et al 1968; Qasim et al 1969; Nair et al 1975) show that the shallow inshore regions as well as the connected backwaters are highly productive, with an average rate of production of over 1 g C/m^2/day. The season of upwelling, which coincides with the monsoon, is the most productive period, with average rates exceeding 2 g C/m^2/day. There is of course spatial and seasonal variations in the pre- and post-monsoon periods, depending on the light penetration and depth of mixing.

The mudbank, owing to its several peculiarities on account of the mud remaining in suspension, may however be considered as a special type of ecosystem. The high turbidity, owing to both man-made and natural causes, impeding the light penetration decreases thedepth of the euphotic zone. Although the euphotic zone at this time may extend down to between 15 to 50 m in the adjacent waters, in the mudbank it is generally less than 4 m. The study of the phytoplankton production at the mudbank also is confronted with certain problems. The normal *in situ* measurements, which are necessary for the evaluation of potential assimilation in *in vitro* conditions, are not possible in these waters. Therefore, the measurement of potential productivity at best can give a general idea of the productivity of the ambient waters, which nevertheless would lend a clue to the probable causes of fluctuations in the mudbank yield. The two aspects, viz., potential productivity and quantitative variation in phytoplankton, formed an important part of a comprehensive investigation on the ecology of the mudbank.

MATERIAL AND METHODS

With a view to having a general picture of the phytoplankton productivity of the Ambalapuzha coast, fortnightly collections of water samples from the surface and bottom and phytoplankton net samples (surface haul of 10 minutes duration by using a half metre bolting nylon net, No.21, mesh size 0 069 mm) were made from 4 stations (*See* Fig. 1. Chapter 4) during the year 1971-72. (These stations were fixed in June 1971 at the time of the mudbank formation, in such a way that 3 of them were within the mudbank and the 4th at a little distance outside it.) However, during the period of active mudbank, in June-August 71 and May-July 72, study on phytoplankton productivity was greatly intensified by conducting more frequent observations.

The relative abundance of different phytoplankters present in the net samples were noted. The total volume of plankton was determined from an aliquot of 1/5 of the sample, by the displacement method, after removing the zooplankters by means of an organdy cloth. Water samples were analysed both for quantitative and qualitative estimates. The samples, having brought to the laboratory, were transferred to a 50 ml settling chamber and kept for 24 h, adding a few drops of formalin. The phytoplankters present in this 50 ml of water were then identified, counted and the total cells computed per unit volume (1 litre in the present case).

For the estimation of primary production, 2 samples, one from surface and the other from bottom, were collected using a Casella bottle, transfered to 60 ml reagent bottles, and incubated with 5µ c of ^{14}C as $NaH^{14}CO_3$ under natural or artificial constant light (20 k lux) for 2-4 h. Dark uptake also was determined simultaneously. After incubation, the samples were filtered through millipore filters (25 mm; pore size 0.45µ) and the activitiy of the filters were determined using a Geiger counter, the efficiency of which was 3.2%.

For the estimation of chlorophyll *a*, surface water samples, one litre each from the 4 stations, were collected and brought to the laboratory and filtered through GFC filter paper. The filtrate was then dissolved in 90% acetone, centrifuged and, using a Spectrophotometer, different wavelengths were measured and chlorophyll *a* content estimated following the equation given by Strickland and Parsons (1998).

GENERAL TREND OF THE SOUTHWEST COAST

Subrahmanyam (1959) and Nair et al (1968) studied the primary production and standing crop of the westcost of India. Radhakrishnan (1969) studied these parameters of Alleppey coast. Shah (1973) and Qasim and Reddy (1967) studied the chlorphyll *a*. Chennubhotla (1969) and Subrahmanyam et al (1975) studied the biomass and the total cells of phytoplankton. All these studies unanimously reveal that all along the west coast of India phytoplakton production is at its highest during the S.W. monsoon. A secondary peak in the primary production and chlorophyll *a* has been reported varyingly somewhere during the post-monsoon period. According to Chennubhotla (1969) and Subrahmanyam et al (1975) the plankton volume, which increases from May, after reaching a maximum in July declines sleadily up till September, the secondary peak of a lesser magnitude being visible somewhere during December-February.

According to Gopinathan et al (1974) total cells of phytoplankton standing crop in the inshore areas of Cochin are higher in the monsoon months than during the pre- and post-monsoon months.

OBSERVATIONS AT THE MUDBANK

Potential productivity : The study conducted during the two mudbank periods, one during June-August 71 and the other during May-July 72, revealed the following results. Unlike the rest of the west coast, where the maximum rate of production was during the monsoon

TABLE – 1

Potential productivity of the mudbank (surface and bottom)

Period		Production mgC/m³.h St.1	St.2	St.3	St.4
1971					
Jul	S	5.26	13.93	31.05	14.74
	B	—	—	—	—
Aug	S	71.85	28.19	7182	24.49
	B	13.98	10.0	41.40	82.6
Sep	S	1.16	1.95	1.96	0.52
	B	0.69	—	—	—
Oct	S	26.84	26.19	16.35	27.07
	B	17.40	12.61	—	26.26
Nov	S	8.76	8.98	7.68	23.36
	B	1.41	1.31	2 48	7.55
Dec	S	4 75	7.68	2.08	7.55
	B	3 40	3.12	6.85	5.03
1972					
Jan	S	59.64	40.87	29.25	36.64
	B	30.38	43.40	13.83	25.92
Feb	S	41.28	9 69	20.93	22.60
	B	11.71	5 69	14.66	14.08
Mar	S	115.88	39.21	86.52	59.81
	B	84.16	59.96	39.18	43.08
Apr	S	49.67	277.15	93.86	38.93
	B	19.77	37.79	57.50	21.89
May	S	81.53	97.01	58.68	60.20
	B	61.91	—	—	9.91
Jun	S	31.05	116.72	28.63	38.00
	B	—	—	—	—
Jul	S	21.31	5.16	2.25	4.50
	B	8.21	10.48	53.55	33.12

months, the mudbank showed low values during these periods, while during the pre-monsoon months the same area indicated high rate of production. The rate of potential assimilation was uniformly high, averaging 35 mg $C/m^3/h$ with the maximum during February-May, when there was no mudbank prevailing in this area. The monthwise production rate is shown in Table 1. High dark-assimilation rates were noted in the bottom samples and very low values were observed in the bottom at the time of munbank formation.

Chlorophyll a : The standing crop, measured in terms of chlorophll *a*, for the four stations are presented in Table 2. It is believed that the magnitude of chlorophll *a* of a water body gives a true index of the standing crop. The table 2 indicates that, during June–July of both 1971 and 72 periods, when the mudbank was active, chlorophyll *a* values were higher compared to other months. Also it revealed that chlorophyll *a* had an increasing trend during the period of mudbank as was observed at the three stations which were in the mudbank proper, while the 4th station, which was slightly deeper and far away from the mudbank, showed uniformly low values throughout the period. During the period when there was no mudbank, the chlorophyll *a* values at the surface of this area were generally less than 10 mg/m^3. But during the period of the mudbank the values were double or even three fold.

TABLE – 2

Measurement of chlorophyll a at the mudbank area

	Chlorophyll *a* mg/m^3 (surface)			
	St.1	St.2	St.3	St.4
1971 Jun	26.7	18 4	25.1	—
Jul	33 2	16.1	15.5	8.0
Aug	13.7	16.1	16.6	0.7
Sep	14 3	4.9	8.6	—
Oct	14.8	8.5	0.4	9.2
Nov	5.8	2.6	3.1	12.9
Dec	—	0.6	0.9	2.5
1972 Jan	9.7	9.0	3.3	3.2
Feb	4.5	1.8	1.2	3.3
Mar	6.5	1.3	2.2	1.3
Apr	3.0	4.0	3.7	1.7
May	5.7	3.4	2.3	3.1
Jun	16.7	15.8	11.3	16.0
Jul	10.6	6.7	6.2	2 9

Biomass : The plankton volume showed a gradually increasing trend from June onwards, reaching its maximum in August primarily due to the then high abundance of the dinoflagellate, *Noctiluca miliaris.* After August there was a gradual decrease in the volume of plankton, reaching its lowest ebb in December. Again, after December, there was a rise in the volume of plankton through the succeeding months (unimodal) and reached its peak at the period of the next mudbank formation, that is in 1972 (Fig. 1). A notable feature in the biomass distribution at the mudbank was its spatial variability. The values which were highest in the first station declined gradually to the fourth station.

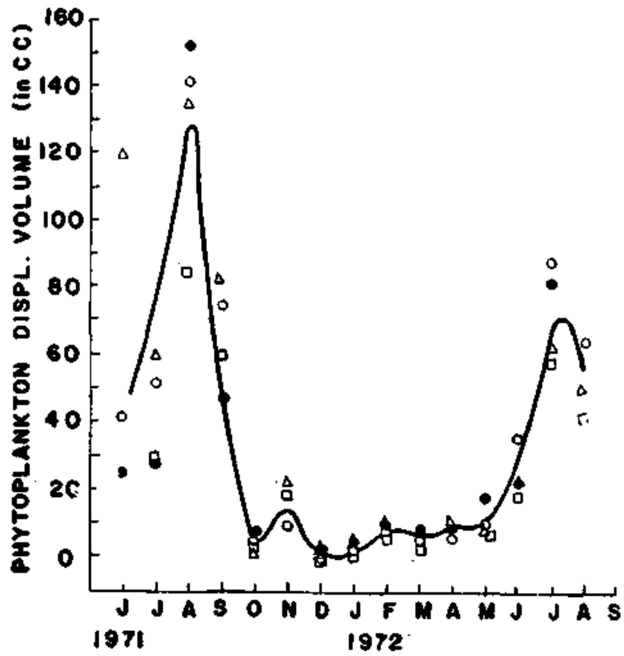


Fig. 1 Phytoplantation displacement volume

Total cells and qualitative studies of phytoplankton : The quantitative distribution of phytoplankton present in one litre of water collected both from the surface and bottom in the mudbank area during the period of investigation is presented in Table 3. The magnitude of production was different in the mudbank for the two years. Diatoms dominated during the formation of the mudbank, while dinoflagellates were most abundant during the period of its dissipation. However, nannoplankters were equally abundant all through the active period of mudbank, which was responsible for the high values of cell counts observed during this period. At the time of dissipation of the mudbank, during August of both 1971

TABLE - 3

Seasonal abundance of phytoplankton of the mudbank at Ambalapuzha. One-litre settling-chamber counts of phytoplankters (average of 4 stations).

Months		Diatoms	Dinoflagellates	Silicoflagellates	Coccoliths.	Cyanophyceae	Nanopl.	Total
1971 Jun	S	183600	650	100	—	670	213200	398280
	B	16170	240	60	—	300	111000	127770
Jul	S	181000	4400	—	—	—	211100	396500
	B	17200	320	—	—	—	112600	129800
Aug	S	35520	12630	—	—	—	116500	164650
	B	24060	17550	—	—	—	118500	160100
Sep	S	2330	16750	—	—	—	111000	130080
	B	14380	1600	—	—	—	123600	139500
Oct	S	15510	690	—	—	—	28000	224200
	B	20970	1200	—	—	—	16000	128170
Nov	S	12140	80	—	—	—	132000	144220
	B	4000	160	—	—	—	121000	125160
Dec	S	17280	1080	—	—	3800	114000	136160
	B	14400	790	—	—	3000	112000	130190
1972 Jan	S	15290	300	—	—	1800	122400	139790
	B	15140	200	—	—	1600	114000	132740
Feb	S	13630	320	—	80	600	116200	130930
	B	13000	340	—	60	250	112600	126250
Mar	S	6360	690	—	—	—	116250	123300
	B	3340	430	—	—	—	114000	117870
Apr	S	34440	970	80	—	—	118500	153990
	B	19820	450	30	—	—	113400	133900
May	S	245800	2110	400	1100	—	26400	275810
	B	44300	690	120	150	—	123600	168880
Jun	S	26280	1950	—	—	—	316800	345030
	B	22090	1050	—	—	—	246400	269540
Jul	S	353600	11050	—	—	—	211200	575850
	B	—	—	—	—	—	—	—

and 1972, blooming of the harmful dinoflagellate, *Noctiluca miliaris*, was a highly noticeable feature· Silicoflagellates and Coccolithophores were found to be very rare and the blue-green alga *(Trichodesmium* spp.) was found to be abundant during June.

From one litre of water sample examined, 58 common species of phytoplankters were identified, among which diatoms constituted 38 species; dinoflagellates 14; Silicoflagellates 2; Coccolithophore 1 and blue-green algae 2. The species-wise distribution of the above mentioned phytoplankters is given in Table 4.

Other observations : In August and in early September of both 1971 and 72, when the mudbank was in the dissipating stage, bright red patches were observed in the surface waters all along the mudbank region. This discolouration was due to extremely high concentration of the dinoflagellate, *Noctiluca miliaris.* A green discolouration was also noticed on 27th August 1971, which was caused by the 'green' *Noctiluca*. *(Noctiluca* with a green euglenoid symbiont, *Protoeuglena noctilucae).* In September 1971 also, a green discoluration of the water was noticed which was however due to high incidence of the diatom, *Fragilaria oceanica.*

DISCUSSION

Although the regional and seasonal variability and magnitude of primary production in the inshore environments of the west coast of India is known and has been correlated with the potential fishery resources (Prasad et al 1970),

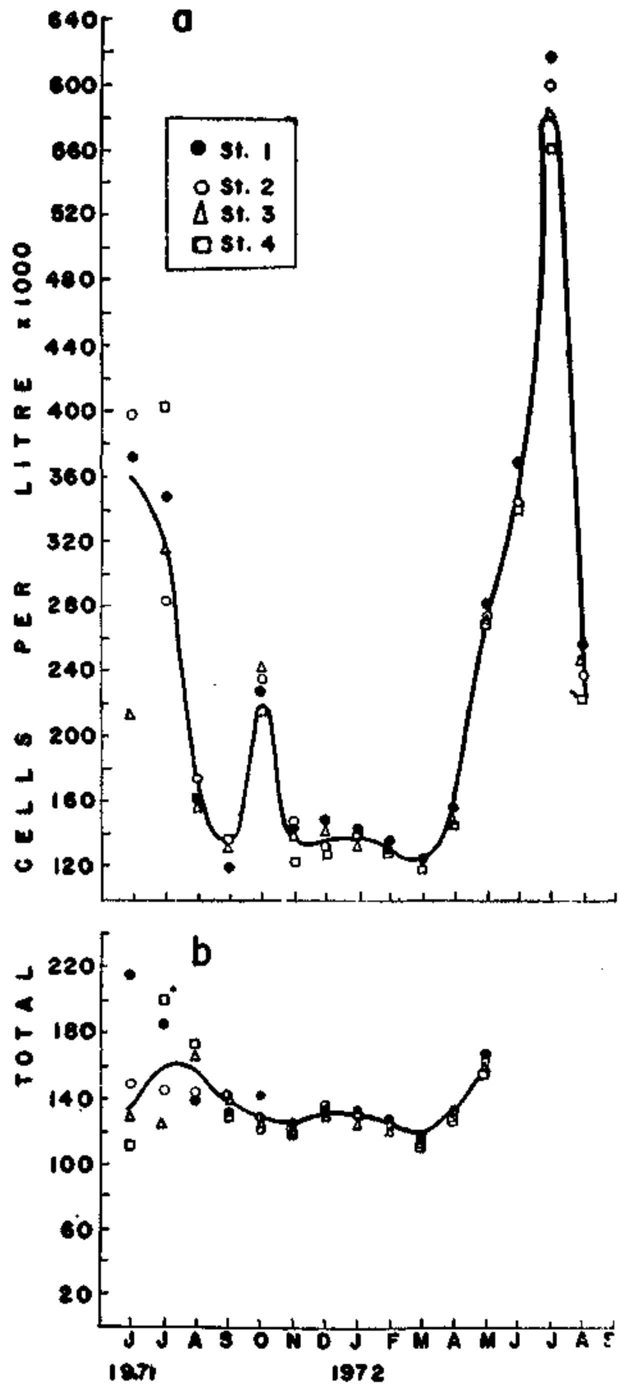


Fig. 2 a-b, Standing crop of phytoplankton in terms of total cell counts (surface and bottom)

these studies are not comparable with those of the mudbank, which, as an ecosystem, is a unique one by itself. Light is never a limiting factor in the tropical waters. But in the mudbank area light penetration is highly restricted due to the suspension of fine particles of mud confining the phytoplankton production to the top few centimetres. The live phytoplankton seen throughout the mixed layer, which in the mudank reaches to the very bottom, may be due to the high rate of primary production observed before the formation of the mudbank.

For the entire west coast and connected backwaters, the monsoon period is the most productive time, with high values exceeding 2 g C/m²/day, followed by fairly high production rates during the post-monsoon period, because of the proportionate availability and replenishment of nutrients (Subrahmanyan 1969; Nair et al 1968; Nair et al 1975; Gopinathan et al 1974; Radhakrishna 1969; and Joseph and Pillai 1975). At Ambalapuzha area, where the mudbank is usually formed, on the other hand, the productivity values are high just before the formation of the mudbank and afterward decrease through the period of mudbank. The reason for the high values of production before the formation of the mudbank may be because there was an abundant population of diatoms during this period (Table 3).

The chlorophyll *a* values in the mudbank are also very high when compared with the values reported from the inshore areas of Cochin by Shah (1973) and Gopinathan et al, (1974). Qasim and Reddy (1967) observed that the values in the Cochin backwater were all less than 10 mg/m³ during the monsoon months. But in the mudbank the chlorophyll *a* values are observed ranging from 10 to 33 mg/m³ during this period.

It is thus seen from the present investigations that the mudbank, in spite of its limited primary production potential due to the shallow euphotic zone, is nevertheless characterised by a high standing crop, as represented by biomass, chlorophyll *a* and total cell counts, especially at its formation as well as its maturity period, presumably favoured by abundant rainfall and enrichment of nutrients from the bottom. Another reason for the high standing crop of phytoplankton at the period of mudbank may be that the nannoplankters contribute to about 70% of the total cells, which is also responsible for the high values of chlorophyll *a* during this period.

TABLE 4

Seasonal variations of different phytoplankters present in one litre of water surface
(average of two years)

	J	F	M	A	M	J	J	A	S	O	N	D
Bacillariophyceae (Diatoms)												
1. *Melosira sulcata*	—	—	—	—	R	R	—	—	—	—	—	—
2. *Hyalodiscus subtilis*	—	—	—	R	R	—	—	—	—	—	—	—
3. *Stephanopyxis palmariana*	R	—	—	R	—	R	R	—	C	—	—	—
4. *Skeletonema costatum*	A	A	A	B	A	A	A	C	R	B	—	R
5. *Thalassiosira decipiens*	—	R	-	R	—	R	R	F	—	C	—	F
6 *T. subtilis*	C	—	F	R	F	C	—	—	—	A	—	R
7. *Coscinodiscus spp.*	C	C	C	A	A	A	F	A	C	A	F	F
8. *Planktoniella sol*	—	—	—	R	A	—	R	R	—	R	--	R
9. *Lauderia annulata*	—	—	—	R	—	F	R	—	—	—	R	—
10. *Schoederella delicatula*	—	R	—	F	A	R	—	—	R	—	—	R
11. *Guinardia flaccida*	—	F	—	F	A	F	R	F	—	—	C	—
12. *Rhizosolenia spp.*	F	—	F	R	F	C	R	A	—	F	R	—
13. *Bacteriastrum varians*	—	-	—	R	—	—	R	—	—	—	—	—
14. *Chaetoceros lorenzianus*	R	R	—	C	R	C	C	—	R	—	A	R
15. *C. decipiens*	—	—	—	R	F	F	—	—	R	—	A	R
16. *C. curvisetus*	—	F	—	R	—	R	R	—	—	—	R	—
17. *C. affinis*	—	—	R	R	R	—	—	—	R	—	—	—
18. *Eucampia zoodiacus*	—	—	—	R	—	R	R	—	—	—	—	—
19. *Climacodium frauenfeldianum*	—	R	—	—	—	—	R	A	—	—	R	—
20. *Streptotheca themesis*	—	—	F	—	—	R	A	—	—	R	—	—
21. *Bellerychea malleus*	—	—	—	—	—	—	—	—	—	R	F	—
22. *Ditylum brightwelli*	R	R	C	F	A	F	R	—	—	—	F	--
23. *Triceratium favus*	F	—	—	F	R	—	R	—	R	—	—	—
24. *Biddulphia sinensis*	—	R	F	F	C	A	R	—	—	R	—	—
25. *Biddulphia mobiliensis*	—	R	C	C	C	—	R	A	R	A	R	C
26. *Cerataulina bergonii*	R	R	R	--	—	—	—	—	—	—	R	--
27. *Hemiaulus sinensis*	—	—	--	—	--	R	C	--	—	R	F	—
28. *Hemidiscus hardmannianus*	R	R	R	—	—	—	—	—	—	—	—	—
29. *Fragilaria oceanica*	A	—	—	A	A	—	A	B	—	—	—	—
30. *Thalassionema nitzschioides*	R	R	—	A	A	F	R	A	—	C	—	—
31. *Thalassiothrix frauenfeldii*	R	—	—	A	—	—	A	F	—	—	F	F
32. *Asterionella japonica*	R	F	C	C	A	R	R	F	—	—	—	C
33. *Pleurosigma elongatum*	—	—	R	—	F	—	—	—	R	—	R	—
34. *P. normanni*	—	R	—	—	F	—	—	F	—	—	—	R
35. *P. directum*	—	—	—	R	F	—	—	F	—	—	—	—
36. *Navicula sp.*	—	—	C	—	—	—	—	F	—	—	—	—
37. *Nitzschia longissima*	C	—	R	A	—	—	—	A	C	R	—	—
38. *N. seriata*	R	R	—	C	—	—	R	—	—	C	R	—

Table 4 (contd.)

	J	F	M	A	M	J	J	A	S	O	N	D
Dinophyceae												
39. *Prorocentrum micans*	—	—	—	—	A	C	—	—	—	C	R	R
40. *Dinophysia caudata*	—	—	—	—	R	—	—	—	—	—	—	R
41. *D. miles*	—	—	—	—	—	—	—	—	—	—	R	R
42. *Ornithocercus magnificus*	—	—	—	—	R	—	—	—	—	—	R	R
43 *Noctiluca miliaris*	—	—	—	—	—	F	A	B	B	F	R	P
44. *Pyrophacus horologicum*	—	—	R	R	—	—	—	—	—	—	—	—
45. *Peridinium depressum*	R	—	R	R	R	—	R	R	—	—	-	R
46. *P. oceanicum*	—	—	—	—	—	—	—	—	—	—	—	R
47. *P. claudicans*	—	—	R	—	R	—	—	—	—	—	—	—
48. *P. pentagonum*	—	—	—	—	R	—	—	—	—	—	—	—
49. *Diplopsalis lenticula*	—	R	—	—	R	—	—	—	—	—	—	—
50. *Goniaulax polyhedra*	—	—	R	—	—	—	—	—	—	—	—	—
51. *Ceratium furca*	—	R	R	R	R	—	F	—	—	—	—	F
52. *C. fusus*	—	R	R	—	—	—	R	—	—	—	—	R
53. *C. breve*	—	R	R	—	—	—	—	—	—	—	R	R
Silicoflagellates												
54. *Dictyota fibula*	—	—	—	R	R	—	—	—	—	—	—	—
55. *Distephanus speculum*	—	—	—	R	R	—	—	—	—	—	—	—
Coccolithophore												
56. *Coccolithus* sp.	—	—	R	R	F	—	—	—	—	—	—	—
Cyanophyceae												
57. *Oscillatoria* sp.	—	—	—	—	—	C	—	—	—	—	—	R
58. *Thricodesmium theibautii*	R	C	—	—	—	—	—	—	—	—	—	C

B=bloom (10,000 cells and above); A=abundant (1000-10000 cells); C=common (500 to 1000 cells); F=few (250 to 500 cells); R=rare (below 250 cells); dash denotes absent.

EIGHT

ECOLOGY OF MUDBANKS — ZOOPLANKTON

K. J. MATHEW, C. P. GOPINATHAN, A. REGUNATHAN, D. S. RAO and A. V. S. MURTY

ABSTRACT

Zooplankton investigations carried out in the region of Alleppey mudbank, commencing with the formation of the mudbank of 1971 and continued through the mudbank of 1972, revealed that the mudbanks are richer in zooplankton in general. The fluctuations of the standing crop as well as of the major individual groups are discussed briefly to show the charateristic of the mudbank.

The stations at which the zooplankton collections were made, the frequency of collection and the duration of study are the same as those described in chapter 5. Plankton samplings were made with a half-meter nylo-bolt ring net of 0.3 mm mesh by making horizontal surface hauls of 10-min. duration. The samples were preserved in 3% formalin and, having brought to the laboratory, the total volume was determined by the displacement method. Numerical counts of individual groups were taken and estimates were made.

OBSERVATIONS AND RESULTS

Standing crop of zooplankton

The monthly mean values of displacement volume of zooplankton estimated for the Alleppey area, during the mudbank and non-mudbank seasons, are presented in fig. 1. In the mudbank of 1971 the biomass reached up to 4·06 ml/10 min, whereas the values never exceeded 2ml/10 min. in the mudbank of 1972. During the pre-mudbank and post-mudbank periods, the zooplankton biomass was extremely low (less than 1/ml/l.)

Altogether 19 groups of zooplankters were present, the important of which, in the order of their abundance, were copepods and copepodites, appendicularians, fish eggs and larvae, prawn larvae, lucifer and crab larvae. Others which were either rarely present or strictly seasonal in their occurrence were

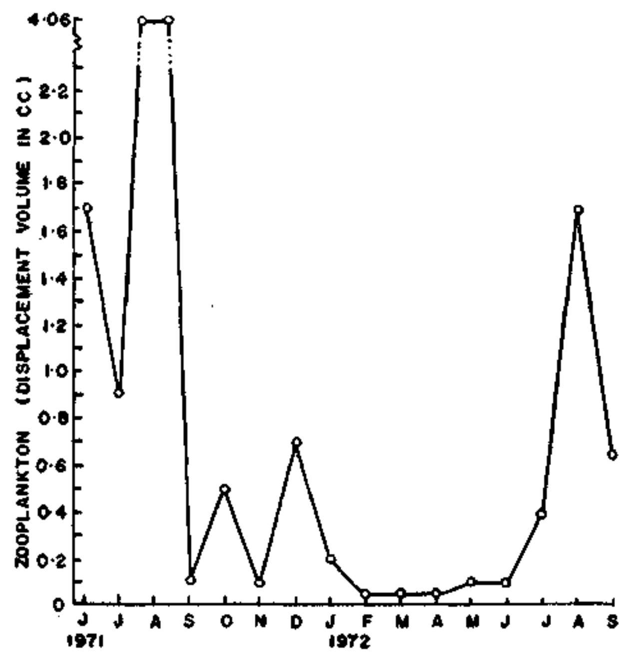


Fig. 1. Monthly mean variations in the displacement volume of zooplankton.

polychaete larvae, juveniles of *Barnea* sp. and tunicates. All these were present in the mudbank also.

Copepods and copepodites were extremely abundant almost throughout the year (Fig. 2a.). The months in which the copepods were less abundant were September 1971 and January, February and September 1972. But the copepods on the whole were comparatively more during the season of mudbank than during other seasons. As observed during both the years, September seems to be the lean month for copepods, and during September 1972 the copepodites were totally absent.

The appendicularians were present in all months and were fairly abundant throughout the mudbank as well as non-mudbauk seasons (Fig. 2h). The two months in which they

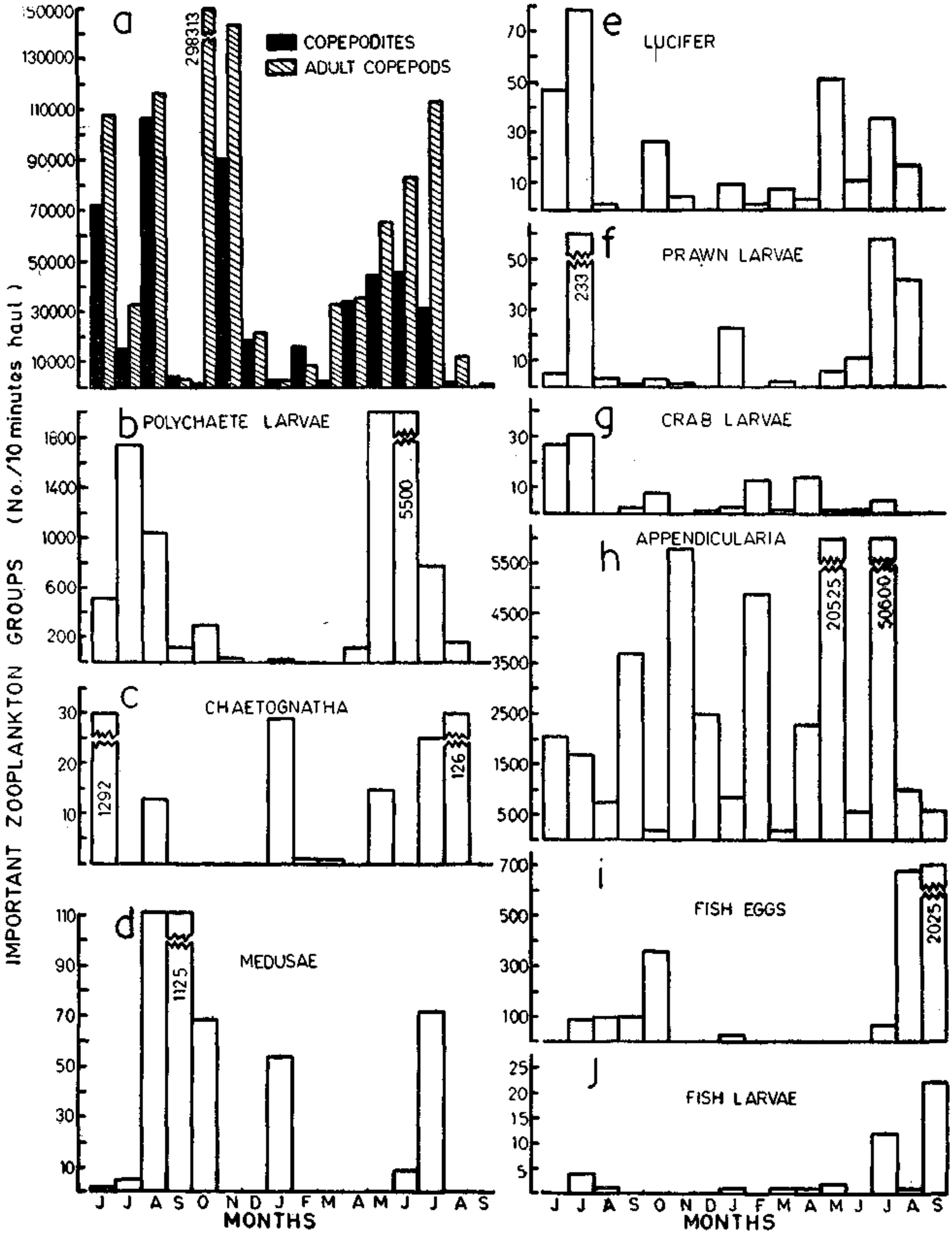


Fig. 2. Seasonal distribution of important zooplankton groups.

occurred in lesser numbers were October 1971 and March 1972. The polychaete larvae were abundant during the mudbank seasons of both the years (Fig. 2b.) During 1971, their maximum number was observed during the months of June, July and August, coinciding with the mudbank. During 1972 their abundance was in May, June and July. November 1971 to March 1972 was the lean period for polychaetes.

Pleurobrachia and cladocerans were found having an interesting trend. There was a swarming of pleurobrachia in August 1971,and afterwards they disappeared. Simultaneously with this was a swarming of cladocerans. However, unlike the pleurobrachians, the cladocerans did not make a sudden appearance but were presenf in moderate numbers during the previous 2 months. But from September 1971 to June 1972 the cladocerans were absent in the mudbank area. Again in July 1972, they swarmed the mudbank and disappeared afterwards.

The appearance of medusae was strictly seasonal (Fig. 2d.) They started appearing in June, during the first mudbank, but the peak was in September, when 1125 specimens were caught in a 10-mini. haul. By November, they totally disappeared and in January they again reappeared, but withdrew during the same month. Afterwards they were totally absent for the next 4 months until June-July 1972, when they were again present in the plankton.

The chaetognaths were quite sgnificant in that they were abundant in the mudbank (Fig. 2c.). While they were caught in good numbers in June and August 1971, the next year they showed their abundance in July and August. In January 1972 also a few of them were caught from the mudbank region. *Sagitta inflata* was the dominant species. During the period of observations the siphonophores were present during three months only, *viz.*, June and August 1971 and July 1972. Altogether five species of siphonophores were identified, which in the order of abundance were *Lensia subtiloides, Diphyes chamissonis, Bassia basseusis, Enneagonum hyalinum* and *Abylopsis tetragona.*

Post larvae of penaeid prawns of species *Penaeus indicus, Metapenaeus dobsoni* and *M. monoceros* were present in the plankton in varying numbers. Their maximum abundance was observed during the mudbank periods, especially during the month of July (Fig. 2f.). A second peak, of low intensity, was observed in the month of January. The two peak periods of occurrence of prawn larvae agree with the two peak breeding seasons of penaeid prawns on the southwest coast of India.

Good number of specimens of lucifer were present in almost all the months. But they were absent in September 1971 and September 1972, as well as in December 1971. As in the case of other zooplankton organisms, their peak period of occurrence was during the mudbank seasons (Fig. 2e.). The crab larvae constituted only a small portion of the total plankton. They occurred in varying proportions in all but four months, namely, August and November 1971 and August and September 1972. Two peak periods in their occurrence were noticed; one during the mudbank season and the other during the February-April pre-mudbank season, (Fig. 2g). Fish eggs though were encountered in the plankton in varying numbers in all except four months, they showed more abundance during and after the mudbank (Fig. 2 i.). In 1971, their maximum number was in October, while it was in August and September during the next year. Generally speaking, the lean months for the fish eggs were from November 1971 to June 1972.

The fish larvae did not contribute much to the plankton, probably because most of them escaped the net which was towed from the country craft with varying speeds, (Fig. 2j). The juveniles of *Barnea* sp. were extremely abundant in the plankton during July 1971 and July 1972. The occurrence of these juveniles is associated with the reproductive cycle of this species. Stray specimens of amphipods were collected during the monsoon period of both the years. The tunicates were also found in the samples collected in the monsoon months. A few stomatopod larvae were present during October 1971, January 1972 and April to August 1972. The adult ostracods never occurred in the plankton, but the larvae of one species, *Cyrrpidina dentata,* were numerically abundant in the plankton during June and July 1972, when 28125 and 130 specimens, respectively, per 10 minutes haul, were collected.

TABLE-1. *Relative Abundance of Zooplankton Groups*

Zooplankton Groups	June '71	July	Aug	Sept.	Oct.	Nov.	Dec.	Jan. '72	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.
Meduse	0.001	0.010	0.042	9.053	0.023			1.048					0.006	0.036		
Siphonophores	0 009		0.040											0 007		
Pleurobrachia			0 115													
Chaetognaths	0.700	0.002	0.005					0.562	0.003	0.003		0.011	0.001	0.013	0.859	
Polychaete larvae	0.286	3.357	0.397	1.014	0.083	0.013		0.039			0.178	1.523	3.401	0.394	1.148	
Copepodites	39.179	27.812	40 236	33.298	0.478	37.335	43.425	40.043	45.515	5 719	47 431	33.258	27.670	15 561	2.658	
Copepodites	58.588	63.212	44.147	26.153	99.212	60 226	50.668	40.043	52.556	93.644	49.027	40.530	51.161	56.810	83 536	19.101
Cladocerans	0 100	0.604	14.690													
Amphipoda		0.002	0.001										0.001	0.001	0 007	
Lucifer	0.025	0.152	0.001		0.009		0.002	0.195	0.007	0.023	0.006	0.040	0.007	0.008	0.116	
Prawn larvae	0.003	0.449	0.001	0.008	0,001	0.001		0.449		0 006		0.005	0.007	0.026	0.286	
Crab larvae	0.015	0.060		0.026	0.003		0.002	0 039	0.045	0.003	0.020	0 001	0.001	0.003		
Stomatopod larvae						0.001		0.020			0.010	0.006	0.005	0.003	0.048	
Barnea sp.*		0.912					0.005							0.816		
Ostracod larvae													17.390	0.066		
Appendicularians	1.093	3.246	0.284	29 677	0.071	2.423	5.887	17.089	16.873	0.600	3.325	15.625	0.348	25 532	6 820	18.337
Tunicates	0.001		0.003											0.005		
Fish eggs		0.175	0.037	0.781	0.119	0 001	0.012	0.566			0 003		0.005	0.033	5.604	61.889
Fish larvae	0.007	0.001						0.020		0.007	0 001	0.002		0.006	0.007	0 672

*Juveniles only

Relative abundance of zooplankters

The relative frequency of among various groups of zooplankters is given in the form of percentages in Table 1. It is observed that in all the months copepods dominated the plank. ton, forming more than 80% of the total biomass. The month of September in both 1971 and 1972 appeared to be the lean period for copepods when they formed about 60% and 19% respectively of the total plankton. The number of copepods was so enormus that the other groups were rarely represented by more than 1% numerically in the standing crop of zooplankton.

The abundance of fish eggs and appendicularians and the reduction in the number of copepods in September 1972 gave an unusual picture of relative occurrence of plankton, compared to other months. During this month, copepods, appendicularians, fish eggs and larvae alone were present as zooplankters.

DISCUSSION

The general picture which emerged from the study of zooplankton of the area, both quantitative and qualitative, is that zooplankton was more abundant during the mudbank. Incidentally, a correlation between the abundance of zooplankers and the ecological features has been observed. The environmental factors, such as nitrate, phosphates and silicates showed definite increase in the mudbank (ref: Chapter 6.) The standing crop of phytoplankton, which is directly linked up with these chemical properties, also showed a general increase during this period (Fig. 1.). The same trend was reflected in the case of zooplankton also. Mukundan (1967), based on material collected on the inshore plankton of Calicut from 1957 to 1965, found that August-November period was the peak period for the zooplankton, while February-July period registered moderate values, and in the months December and January, the zooplankton biomass was poor. The observed difference with regard to the seasonal variations in zooplankton abundance between Calicut and themudbank region may be attributed to the peculiar ecosystem that prevails in the mudbank area. However, the swarming of cladocerans during the monsoon period, when the water salinity was comparatively lower, was observed both at Calicut and in the area under present study.

NINE

ECOLOGY OF MUDBANKS — BENTHOS

A. REGHUNATHAN, C. P. GOPINATHAN, K. J. MATHEW, D. S. RAO and A. V. S. MURTHY

ABSTRACT

Occurrence, abundance and seasonal distribution of the benthic fauna of the mudbank area at Alleppey were investigated. The substratum at the mudbank area being of an unconsolidated and unstable nature due to the fresh supply of sediments and their periodic movement, it was thougt that tbe fauna therein may be of a recent colonisation and a study on the animal-sediment relationship would be of interest. This was well established during the present studies with regard to the occurence and numerical abundance of species and the benthic population in general.

INTRODUCTION

It is generally recognised that the benthic fauna and flora play an important role in the marine food chain and a knowledge of benthos is one of the important pre-requisite to have a comprehensive picture of the fishery potential of an area. Mudbanks, known for their fishery potentials, therefore, prompted the authors to investigate the role of benthos in these areas. A perusal of the literature (Seshappa 1953; Kurien, 1953;1967; Damodaran 1973) on the bottom fauna reveals that our knowledge on the sub-tidal bottom fauna of the Indian seas in general is very little.

Mudbanks have been classified into four categories (Chapter 3) based on the nature of sediments that come into suspension. It may be expected that, the source of these sediments being different, the faunal assemblage may be different too. Hence a study on the bottom fauna of the different mudbanks is necessary to have an understanding on the qualitative and quantitative picture of the level-bottom communities and their role in the mudbank fishery.

MATERIAL AND METHODS

Since the observations had to be carried out from an indegenous country craft, heavy gear had no place in the choice of instruments. A Van-veen type grab of $0.03 m^2$ was used for sampling the bottom fauna. The highly unconsolidated nature of the mud, particularly during the mudbank, did not permit the operation of the dredge, which would easily get buried in the mud.

Materials for the presnt study were regularly collected continuously from June 1971 to August 1972; from the same 4 stations described earlier (see Chapter 5). Samples were sieved using a 0.5 mm sieve to seperate the macro-fauna and the meio-fauna. All those animals retained by a 63µ sieve were treated as meio-benthos. All the meio-benthos were treated together due to poor individual abundance. The bottom fauna was expressed in No./0.1 m of the substratum.

All the organisms were treated in phylogenetic sequence and, wherever possible, identifications were carried out up to genus and species levels. When such identifications were not possible they were treated groupwise.

DISTRIBUTION OF BENTHOS IN THE AMBALAPUZHA - PURAKKAD AREA

Foraminifera

Although a number of species belonging to different genera are recorded from many regicns of southwest coast of India, only a few species of the genera *Discorbis, Spirolocolina, Potalina* and *Textulyria* were present in the samples from the Ambalapuzha area. They were distributed in all the stations and round the year, except in April, May and June. They were found to be abundant in stations 1 and 2 (Table 1 and 2). Monthwise occurrence of different groups showed wide fluctuations; however, foraminifera showed the first peak in November-January followed by another peak in June-August. The highest number of

Table 1

Monthly variations in the mean number of various groups of organisms expressed in 100s per 0.1 m² of bottom sample.

STATION 1

Organisms	Mudbank season 1971			Post-mudbank season				Pre-mudbank season					Mudbank season 1972		
	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug
Foraminifera	367	210	—	1572	1008	5896	40596	37064	7316	21772	—	—	—	96	—
Nematoda	—	74	210	1512	1452	5464	27996	22808	3716	60	—	3696	—	22	—
Polychaeta	—	1	—	12	—	—	—	12	—	—	—	—	—	22	—
Ostracoda	—	3	70	120	264	310	648	—	336	24	—	—	—	—	—
Copepoda	7	8	2	9	24	—	24	—	—	24	—	24	—	1	—
Amphipoda	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
Crustacean nauplii	—	—	48	24	12	—	—	—	—	—	—	—	—	—	—
Arachnida	—	—	—	12	12	—	—	—	—	—	—	—	—	—	—
Pelecypoda	—	10	2498	267	318	354	517	36	72	—	—	24	—	—	—

Table 2

Monthly variation in the mean number of various organisms expressed per 0.1 m².

STATION 2

Organisms	Mudbank season 1971			Post-mudbank season 1971				Pre-mudbank season 1972					Mudbank season 1972		
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.
Foraminifera	2191	19	234	48	522	180	420	50	288	312	—	—	—	960	71760
Nematoda	—	265	58	216	432	3264	984	2793	727	6600	99	288	2510	480	—
Polychaeta	—	—	2	—	—	12	—	24	—	—	—	—	—	—	—
Ostracoda	13	3	16	—	12	24	48	—	—	—	—	—	—	—	—
Copepoda	—	7	2	12	—	120	24	—	4	—	—	—	—	—	—
Amphipoda	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Crustacean nauplii	—	—	1	36	—	—	—	—	—	—	—	—	—	—	—
Arachnida	—	3	1	12	—	—	—	—	—	—	—	—	—	—	—
Pelecypoda	9	3	180	27	46	480	—	—	—	—	—	—	—	—	—

Table 3

Monthly variations in the mean number of various groups of organisms expressed/ 0.1 m^2

STATION 3

Organisms	Mudbank season 1971			Post-mudbank season 1972				Pre-mudbank season 1972					Mudbank season 1972		
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
Foramifara	127	14	180	2	62	373	484	2052	9	12	—	—	—	—	1488
Nematoda	—	—	21	517	67	355	949	1068	24	12	—	73	—	14	115
Polychaete	—	—	—	4	—	—	—	7	—	—	—	—	—	—	—
Ostracoda	16	3	6	7	4	3	19	—	—	—	—	—	—	—	—
Copepoda	4	1	1	14	—	1	2	—	2	—	—	—	—	—	—
Amphipoda	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Crustacean nauplii	—	—	7	45	62	—	—	—	—	—	—	—	—	—	—
Arachnida	—	2	2	—	2	—	—	—	—	—	—	—	—	—	—
Pelecypoda	—	3	131	160	74	2	33	29	—	—	—	—	—	—	—

Table-4

Monthly variations in the mean number of various groups of organisms expressed/0.1 m²

STATION 4

Organisms	Mudbank season 1971			Post-mudbank season 1971				Pre-mudbank season 1972					Mudbank season 1972		
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.
Foraminifera	—	42	698	—	148	669	—	160	42	24	—	—	—	7812	242
Nematoda	—	106	37	7	4	48	26	33	2	24	—	1204	88	3372	19
Polychaeta	—	—	1	7	7	10	40	—	—	—	—	4	—	—	—
Ostracoda	—	16	51	4	19	54	24	2	—	—	—	—	—	—	—
Copepoda	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—
Amphipoda	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Crustacean nauplii	—	—	4	40	—	—	9	—	—	—	—	—	—	—	—
Arachnida	—	1	2	2	2	—	—	—	—	—	—	38	—	—	4
Pelecypoda	—	39	230	48	110	8	48	—	—	—	—	—	—	—	—

71,76,000/0.1m² was observed in st. 2 in August 1972 (Table 2).

Nematoda

Nematodes were present in almost all stations. They were second only to foraminifers in the faunal abundance and the peak period of occurrence of this group was observed in November-January. The maximum number of 2,79,900/0.1 m² was recorded from st. 1 in December 1971 (Table. 1).

Polychaeta

The polychaetes in general were one of the poorly represented group in the area throughout the year. *Aramandia lanceolata* and *Glycera alba* were encountered along with *Prionospio pinnata* in the samples. They were found to be abundant in st. 4 in the months November and December.

Ostracoda

Considerable number of ostracods were recorded from all the stations. They were observed in the samples in all the stations up to January, and, in station 1, their occurrence continued up to March. The maximum of 64,800/0.1 m² was observed in st. 1 in December (Table 1).

Copepoda

Copepod fauna was represented by species of *Pseudonthessium, Harpacticus, Scotecilathricella* and *Hetenohabdes*. Most dominant of the copepods was *Harpacticus* sp. Copepods were present in all the stations and throughout the year. The maximum of 12,000/0.1 m² was observed in st. 2 in November (Table 3).

Amphipoda

Amphipoda were the most poorly represented group among the benthos. Amphipods were observed in July in st. 1 (Table 1). Their occurrence was not observed in any station afterwards. Arachnids were represented by the *Targigrades* and they were numerically less in the samples.

Pelecypoda

This group was represented mostly by *Barnea* sp. and they were observed from June to December in the samples. Mortality of molluscan fauna was observed in January.

DISCUSSION

Fluctuations of different groups through months did not show any relation to the hydrographical features. Of the benthos, foraminifers were found to be the most dominant group. Nematodes and bivalves were observed to follow in the order of numerical abundance. The peaks of foraminifers and nematodes were found to coincide with each other. The peak of benthic production in general was observed within the period November-January. Majority of the benthic components were observed to show a declining trend from January. The oil spill and churning up of the bottom, caused by anchoring and movement of the mechanised vessels, apart from providing an unstable substratum, may pollute the overlying waters and bring in the observed faunal reduction in this area. The animal diversity and abundance in stations 1 and 2 may be attributed to their preference to a sand-clay bottom rather than a silt-clay bottom. The abundance of polychaete fauna in st. 4. may be attributed to the depth which provides a stable substratum by buffering the activities of the overlying waters and the preference of silt-clay nature of the substratum.

The bottom fauna in general showed a low intensity in the mudbank. This may be due to the unconsolidated nature of the sediments which does not give a stable substratum for the animals to settle. The fishery components were mostly of pelagic and column feeders except the soles and prawns. Since they have been identified as migrant populations (see Chapter. on fisheries) and the soles come into the fishery at the fag end of the season, the low intensities of the bottom fauna does not favour any special significance on their role in the mudbank fishery.

TEN

ECOLOGY MUDBANKS — THE CURRENT SYSTEM OF ALLEPPEY MUDBANK

K. J. MATHEW, A. REGUNATHAN, C. P. GOPINATHAN, D. S. RAO and A. V. S. MURTHY

ABSTRACT

The knowledge of the water currents in the locality being essential for understanding the causes of formation, maintenance, movement and dissipation of mudbanks, the current system over two tidal cycles, one in May, before the formation, and the other in August, toward the end of the mudbank period, in 1975, at Alleppey mudbank was studied. Marked difference in the direction and velocity of the current was noticed between the two occasions. In May the effect of the tides was not noticeable on the direction of the current, which was southerly, whereas in August, though the major current continued to be southerly, the speed was considerably reduced due to tidal influence, introducing thereby a northerly component. Along with the current observations, the diurnal changes in the hydrological and biological aspects observed in the mudbank are reported.

INTRODUCTION

As the pattern of currents, with its possible influence on the physical, chemical and biological characters of the region, is bound to have a direct bearing on the formation, retention,upkeep, movement and dissipation of the mudbank, a study on the current system was made at Alleppey mudbank. Since the current velocity and other parameters would in all probability exhibit diurnal variation in relation to tide, the current system was studied at fixed intervals over two tidal cycles, one in May, prior to the formation of the mudbank, and the other in August, toward the end of its formation; after assessing the tidal influence it would then be possible to obtain the mean values of the characteristics, after eliminating the tidal influence.

MATERIALS AND METHODS

The observations were at first carried out on board the research vessel *Cadalmin-I*, anchoring in the mudbank off Purakkad at 4 m depth, about 1 km away from the coast, from 0900 hrs on 16th to 0400 hrs on 18th May 1975. For the 2nd set of observations in August, as mechanised vessels were not permitted then to operate within the mudbank area, a platform was made, tying two canoes together and anchoring it in the middle of the mudbank at 4m depth. From this platform the observations were conducted from 20.00 hrs on 16th to 19.00 hrs on 17th August 1975. On both the occasions the direction and velocity of the currents were measured by using an Ekman's Current meter, which was lowered to 2m depth, at one-hour intervals. The seawater samples for salinity, dissolved oxygen, nutrients and phytoplankton productivity were collected at 3-h intervals from surface and bottom. The quantitative and qualitative aspects of the phytoplankton were estimated by the settling method. The estimation of the chlorophyll content of the surface and bottom waters was made by filtering the samples through G. F. C. filters, dissolving in 90% acetone, centrifuging and transmission measuring using Spectronic-20. *In situ* experiments were conducted using ^{14}C for measuring the rate of primary production. Zooplankton sampling was done once in every 3 h by vertical tows from bottom to surface using a half-metre nylon net having mesh size of 0 4 mm. The volume of the plankton was determined by the displacement method. The zooplankton samples were analysed up to the group levels.

OBSERVATIONS AND RESULTS

Weather conditions

In May, at the time of starting the first set of observations, the sky was clear, the weather fair and sea calm. However, from 0200 hrs to

0900 hrs on 17th, it drizzled. The wind was calm during the midnight hours and in the early morning, but rose to a strength of 10–13 km per hour in the evening (Fig.2i). It rained heavily on the 18th morning. During the 2nd set of observations, it rained during the early hours of the night. The weather was fair during the following day. Maximum wind speed (fig.4 a) recorded was about 18 km/h, during noon on 17th August. The direction of the wind was north-easterly during night and north-westerly during the day.

Currents

The direction of the currents observed during the first observations is presented in fig-1. The figure indicates the percentage of lead balls fallen in each chamber. The distribution of total number of balls is indicated at the right extreme column of the figure. It is interesting to note that, throughout the period of observations, the directions of the current was between 150° and 180°, except at times when the flow was nearing zero and the water thrust was too feeble to keep the current meter in a fixed direction. The major direction was at 160°, indicating the coast-parallel southerly flow (longshore current), during the entire period of observations. The results obtained during the 2nd set of diurnal observations were totally differenf in that the water movement was in all the directions (Fig.3). A northerly flow was set in at about 0400 hrs, eventhough its duration was short during the tidal period. The differences in the pattern of direction of incurrents at the two phases of the mudbank is considered significant.

Fig. 2a represents hourly variations of the strength of the flow during May. The values of

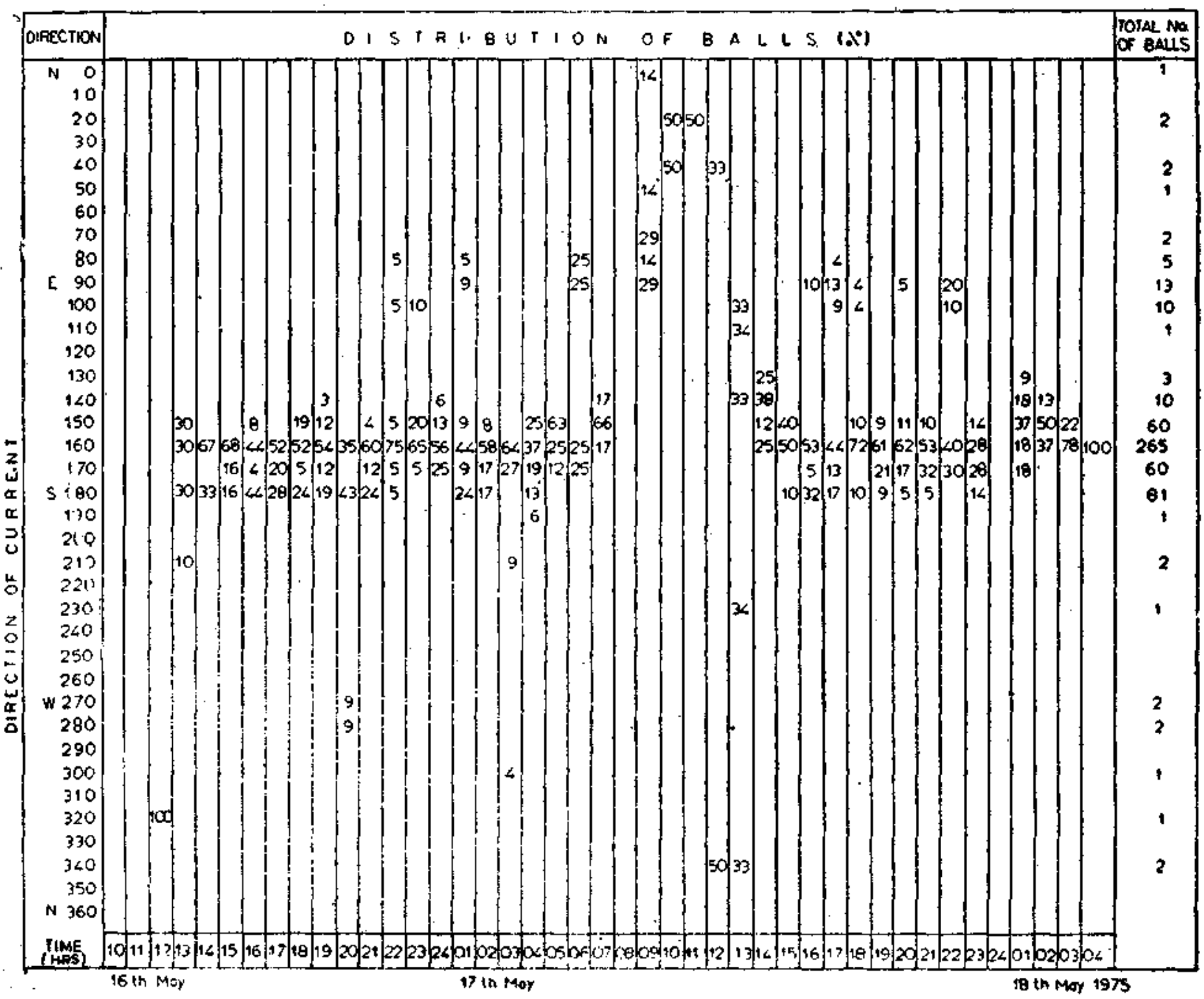


Fig. 1. The hourly distribution of balls in the current meter to show the direction of current, during 16-18 May 1975.

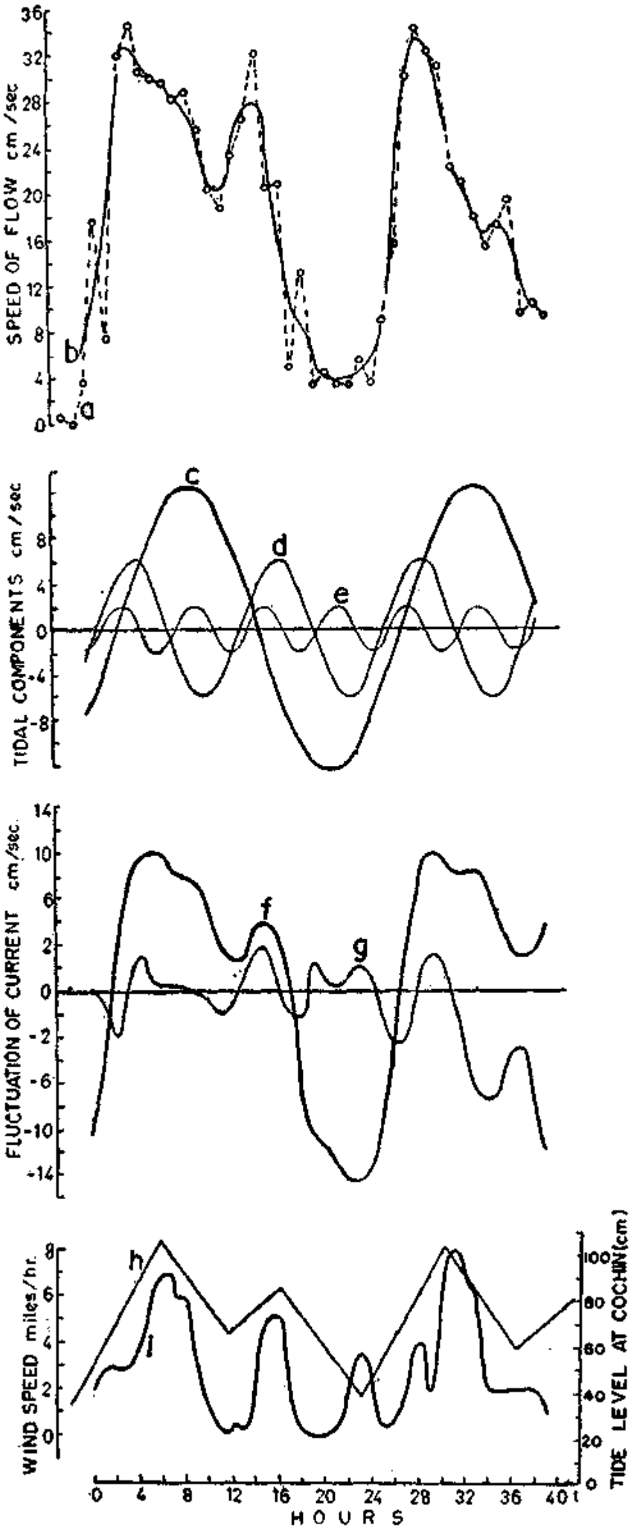


Fig. 2. Speed of current flow, tidal components, current fluctuation and wind speed during 42 hours, starting from 1200 hrs on 16th May. a: absolute values of currents observed; b: observed currents after smoothening of overlapping values; c: diurnal component of tidal flow; d: semi-diurnal component of tidal flow; e: quarter-diurnal component of tidal flow; f: effective tidal flow; g: residual flow; h: tide level at Cochin; i: wind force.

observed flow were smoothened out in order to eliminate the observational errors if any This smoothening effect was brought out by overlapping means, taking three consecutive values at a time. The smoothened data (Fig. 2 b) were considered for further analysis.

As the observed flow was practically confined to the coastline direction with nocoast-normal component (as revealed from Fig. 1), the influence of tidal forces on the currents of the location is only oscillatory, not rotatory. In order to nullify the effect of tides on currents, mean values for 25 h were considered. Thus, there is a set of 16 moving averages obtainable from the middle portion of observations, barring the extreme 12 h on either side of the observational period from 1200 hrs on the 16th to 0300 hrs on the 18th.

It is well known that the tides and tidal currents are caused by the gravitational forces of the sun and moon exerted on the earth. The times of occurrence of high and low tides at Cochin corresponding to the period of current observations are noted from the Tide table and presented in fig. 2. The lowest low tide on 16-5-75 was 33 cm at 10.09 hrs and the highest high tide (105 cm) occured at 1722 hrs on the same day. The next day the lowest low tide of 38cm occurred at 1046 hrs, while the highest high tide of 103 cm occurred at 1759 hrs.

The tidal currents are less readily observed than the tides and even more difficult to examine theoretically (Sverdrup et al 1942). Owing to the proximity of the moon to the earth, the lunar influence are predominant on tides, and tidal currents therefore exhibit an average length of diurnal tidal period equal to a lunar day (24 h 50 min., which is approximately 25 h).

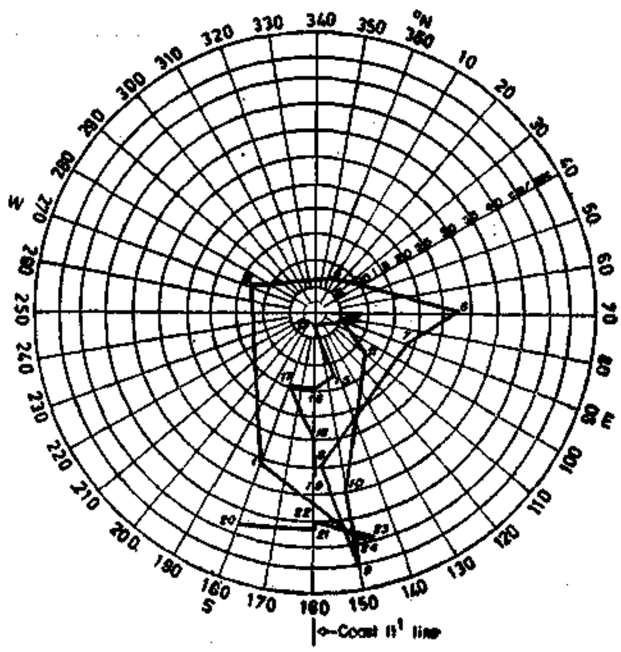
Assuming that the lunar diurnal, semi-diurnal and quarter-diurnal cyclic variations are present in the total fluctuations of currents, and considering twenty-five hourly observations from 1200 hrson16.5.75 to 1300hrs. on17.5.75, the harmonic coefficients are determined by framing linear equations (Joseph Lipka, 1918 & Selvadori, 1948). The results are:

$$V_t = 18.5 - 7.57 \text{ Cos } 2\pi \frac{t}{\tau_1} - 2.95 \text{ Cos } 2\pi \frac{t}{\tau_2} - 1.85 \text{ Cos } 2\pi \frac{t}{\tau_3} + 9.73 \text{ Sin } 2\pi \frac{t}{\tau_1} + 5.25 \text{ Sin } 2\pi \frac{t}{\tau_2} - 0.117 \text{ Sin } 2\pi \frac{t}{\tau_3}$$

where t refers to time in hours, starting from noon of 16th May 1975, τ_1 is the diurnal tidal period (24.8 h), τ_2 is the semidiurnal period (12.4 h) and τ_3 is the quarter-diurnal period (6.2 h). The mean steady current is 18.5 cm/sec. The amplitude of the three tidal components are 12.3 cm/sec., 6.0 cm/sec. and 1.9 cm/sec., respectively (Fig. 2c, d, e). The proportionality of the respective amplitudes is 6:3:1. The resultant of the three tidal components is presented in fig. 2f. From the figures it is clear that the high tides coincided with the maximum and the low tides with the minimum of the tidal component of the tidal flow. The highest high tides of both the days correspond to the peaks of southerly tidal components of the currents and the lowest low tides to the northerly components of the tidal oscillations.

The residual currents obtained on subtracting the tidal components and as expressed over the mean current (18.5 cm/sec.) is presented in fig. 2g. Therefore the zero line in figs. 2c-g refers to the steady southerly current. The positive values along the vertical axis refer to southerly fluctuations and the negative values to the northerly components of fluctuations. The estimated wind force is presented in fig. 2i for comparison of current fluctuations. Observations on wind-speed variations showed almost calm conditions during the midnight on 16/17th and also during early morning hours on 17th. The wind rose to about 10-13 km/h by the evening hours on both the days as the sea breeze gained strength. On the 17th May the wind rose to about 7 km/h between 0300 and 0400 hrs from the midnight calm conditions. Throughout the period of observations, the wind consistantly blew from northwest. There is a general agreement between the peaks of wind force and strong southerly components of the residual currents, indicating the influence of weather (wind) on such current fluctuations.

Hourly observations of currents were made over a total period of 24 h in August. Unlike the previous occasion, the water movement during the present investigation was in all the directions during the course of the tidal period (fig. 3). Nevertheless, the major currents were southerly. A northerly flow was set in, even though its duration (about 4 h) was short during the tidal period.



DIURNAL FLOW

Fig. 3. Hourly observation of currents.

The mean southerly component (fig.4 b) of the current during the tidal period was 24 cm/sec, while the mean northerly component was only 5cm/sec. The net flow (southerly) was 18 cm/sec. The coast-normal components of current are indicated in Fig. 4 c.

Hydrography

The diurnal variations in the hydrographic properties showed a high correlation with the current and tidal influence. In May the surface temperature (fig. 5 a) showed a maximum at 1500 hrs on both the days. During the second diurnal cycle (August), the temperature at both surface and bottom was more or less steady

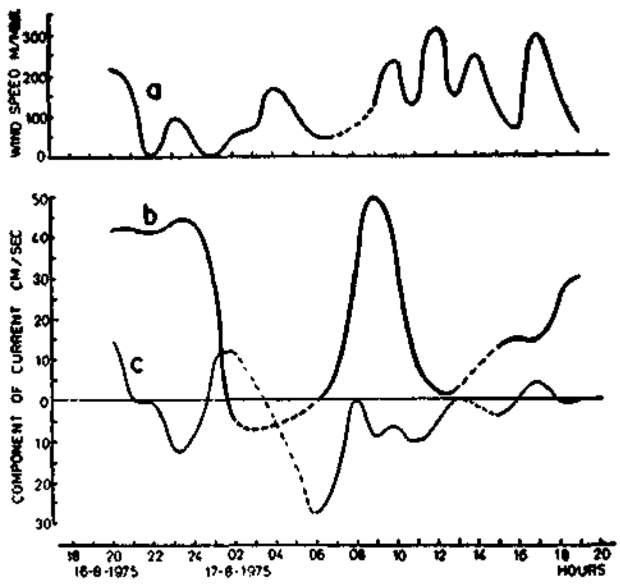


Fig. 4. Wind speed (a), coast parallel component of current (b) (positive Southerly) and coast normal component of current (c) (positive northerly).

(fig.7a). The mean of the diurnal cycle was about 26.0°C at the surface and 23.0°C at the bottom.

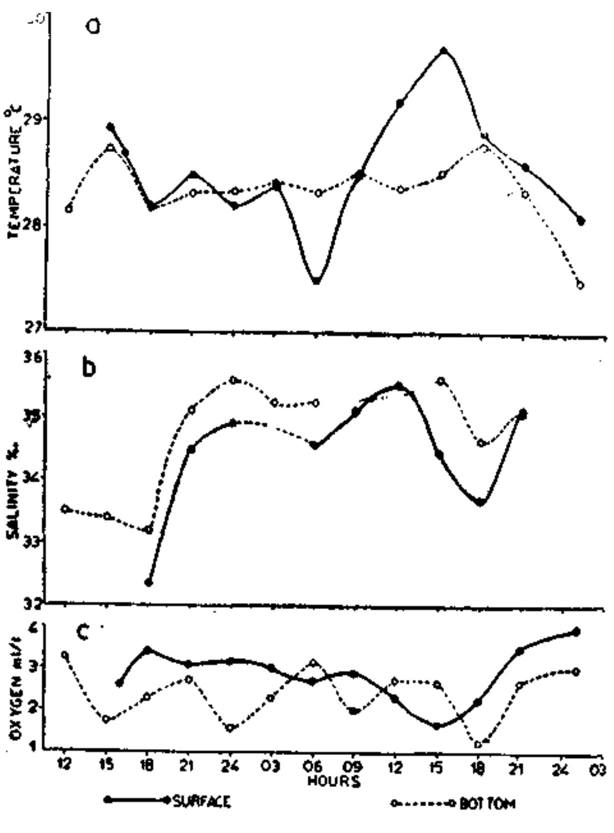


Fig. 5. Diurnal variations in the physical properties of water. a: temperature; b: salinity; c: dissolved oxygen.

Salinity

The salinity variations during the first diurnal cycle at surface and bottom are given in fig. 5 b. The surface salinity values were generally lower than the bottom. They were maximum at 1200 hrs on 17th. The bottom values showed a maximum at 2400 hrs and 1500 hrs (35.50‰). The mean values of salinity at the surface was 34.57‰, whereas at the bottom it was 34.62‰. On the other hand, the salinity values fluctuated over a wide range during August (fig. 9 a). The wide fluctuations were due to the varied degree of mixing of seawater with fresh water, which was being discharged in August from the Thottappally spillway, about 2 km south of the place of observation.

Oxygen

Fig.5 c shows the variations in the dissolved-oxygen content at surface and bottom during May. The values were more or less steady throughout the period of investigation. At the surface the values were around 3 ml/l while at bottom it was around 2.4 ml/l. During August the dissolved oxygen (fig. 7 b) of the mudbank waters fluctuated from about 0.5 ml/l to 3.0 ml/l, with a mean value of about 2 ml/l. The hour-to-hour variations were maximum, both at surface and bottom, which was indicative of the mixing process in the mudbank of waters of different qualities, which was characteristic during August.

Nutrients

The reactive-phosphate content of the water at surface and bottom in May is shown in fig. 6 a. The surface values showed that the maximum was at 2100 hrs (1.75 µg at P/l) on the 17th. Minimum was found at 1800 hrs and 2400 hrs on 16th and 1500 hrs on 17th. The bottom values showed that it was less at 1800 hrs on both the days and in the early morning hours. In August there was little difference between the surface and bottom values (fig.9 b). The values varied from 1 to 2 µg at P/l.

The Nitrite-N values of the water for May is shown in fig 6 b. NO_2-N maximum was found in the surface at midnight on 16th and at 1500 hrs and 2100 hrs on 17th. The bottom values showed peaks at 1800 hrs on 16th and

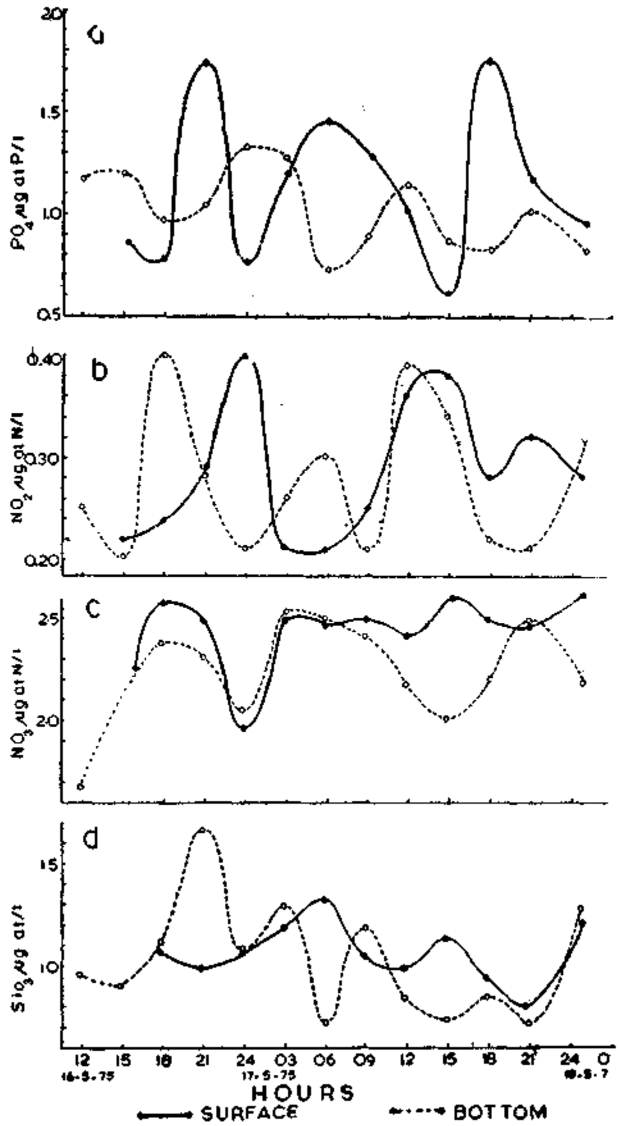


Fig. 6. Diurnal variations in the nutrient contents.. a: phosphate; b: nitrite; c: nitrate; and d: silicate.

0600 hrs, 1200 hrs and 2400 hrs on 17th. In August the Nitrite-N values (fig.7 c) varied between 0.15 and 0.85 µg at N/l.

The variations of NO_3-N at surface and bottom for May are shown in fig.6 c. Both surface and bottom values showed peaks at 1800 hrs on 16th and early morning hours on 17th. In general, the NO_3-N values showed the same trend at surface and bottom except at 1500 hrs and 1800 hrs on 17th. In August the nitrate values showed variations between 1.1 and 1.5 µg at N/l (fig.9 c). The values were generally more at the bottom.

The values obtained during May for the silicate content at surface and bottom are represented in fig. 6 d. In general, the silicate values were higher at the surface (10.62µg at SiO_3-S/l) than at the bottom (10.18µg at SiO_3-S/l). At the surface the peaks were at 0600 hrs and 1500 hrs on 17th and 0100 hrs on 18th, whereas at bottom the peaks were found at 2100 hrs on 16th and 0300 hrs and 0900 on 17th and 0100 hrs on 18th. During August the silicate values were comparatively more at the bottom (Fig. 9 d). An almost steady increase, both at surface and bottom, was noticed from the beginning to the end of the observation. The values ranged between 5µg at S/l to 15 µg at S/l.

Phytoplankton productivity and chlorophyll

The productivity values obtained by the ^{14}C technique indicated that on 16th May the rate of production was 35 mgC/m³/h at 0900 hrs. The production rate increased towards the noon reaching a value of 106 mgC/m³/h at 1200 hrs. Since then the rate of production showed a decline and at 1500 hrs it was only 4 mgC/m³/h. The midday maximum in the rate of production appears to be related to the sunlight conditions. In August a slight difference was noticed with regard to the time of peak production. The production rate increased from 0600 hrs and reached its maximum at 10.00

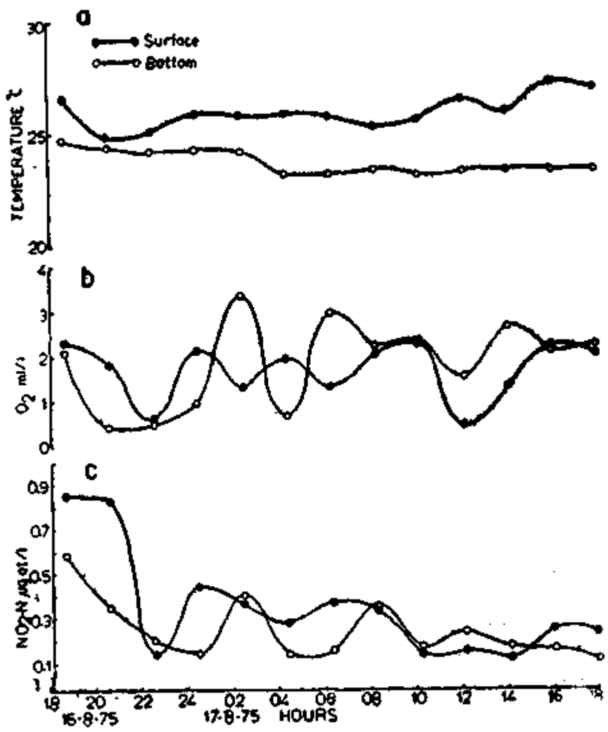


Fig. 7. Diurnal variations of temperature (a), dissolved oxygen (b) and nitrite (c).

hrs (200 mgC/m³/h) and decreased from noon to evening (Fig.9f). The low rate of production was recorded towards the evening at 1600 hrs (10.1 mgC/m³ h).

The diurnal variations of chlorophyll in May and August, for both surface and bottom, are shown in fig 8 and 9 e. In May the values showed two peaks at surface at 0900 hrs on 16th (23.5 mg/m³) and at 0300 hrs on the next day (29.37 mg/m³). The minimum value

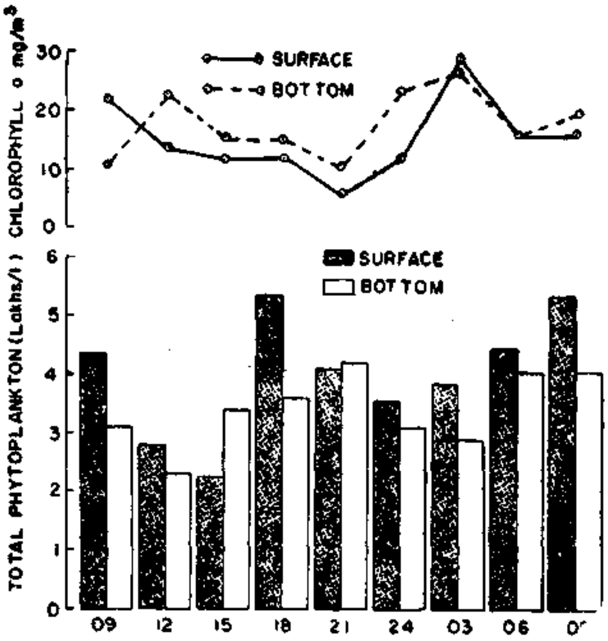


Fig. 8. Diurnal variations in the standing crop of phytoplankton in terms of total cell counts and chlorophyll *a*.

of 6.41 mg/m³ was noticed at 2100 hrs. The bottom values also showed 2 peaks; one at 1200 hrs on 16th (22.43 mg/m³) and the other at 0300 hrs on 17th (16.7mg/m³). In August the chlorophyll values showed wide fluctuations and the maximum value of 100 mg/m³ was noticed at 1000 hrs on the surface During this hour the bottom value was 80.00 mg/m³, which was the maximum for the bottom waters. The minimum values (5-6 mg/m³) were noticed during the midnight on 16th and 17th.

Qualitative studies on phytoplankton

The diurnal variations in the total cell counts of phytoplankton estimated per litre of water for both surface and bottom are given in fig.8 for May and in fig.9 f for August. In May there were two peaks at the surface, one at 0900 hrs and the other at 1800 hrs. In the case of the total cell count at the bottom, the peaks were at 0900 hrs, and at 2100 hrs. In general, the variations in the cell counts were

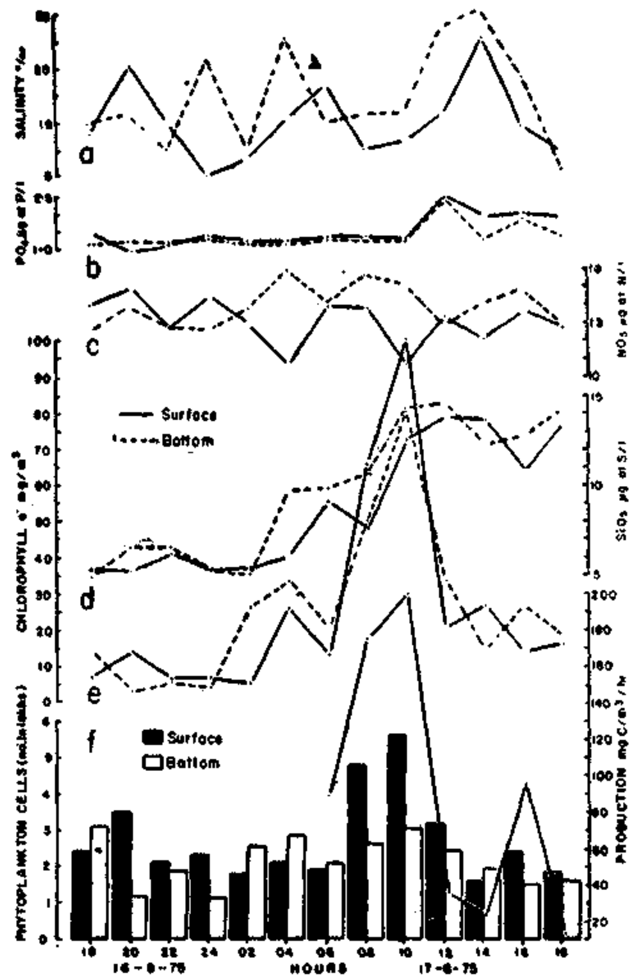


Fig. 9. Diurnal variations of salinity (a); phosphate (b); nitrate (c); silicate (d); chlorophyll *a* (e); and standing crop of phytoplankton in terms of total cell counts and primary production.

observed to be proportionate to thev ariations in the chlorophyll *a* values. In August also a positive correlation between diurnal values of chlorophyll *a* and total cell counts was observed. The night samples showed less number of cells and the minimum was found at 0200 hrs. The cell counts showed a gradual increase from 0600 hrs and reached the peak at 10.00 hrs whence it declined.

In May, all the samples considered together, 38 species of phyotoplankters (excluding the nannoplankton), 18 species of diatoms, 7 dinoflagellates and the other 3 species, represented by the blue-green algae, were noticed in the water. Silicoflagellates and coccolithophores were totally absent It was found that 5 species of diatoms, such as *Coscinodiscus* sp. *Biddulphia sinensis, Chaetoceros curvisetus, Thalassionema nitzschioides* and *Asterionella japonica,* were represented throughout the period of observations. In August, even though Diatomaceae were abundant in general, one member of the Cyanophyceae,*Microcystis* sp, caused a bloom, which was responsible for a high rate of production, high chlorophyll content and total cell counts. Silicoflagellates and coccolithophores were found to be totally absent in the samples. It was observed that, during this month, four species of diatoms, namely, *Coscinodiscus, Nitzschia, Navicula* and *Pleurosigma,* were represented throughout the period of investigation.

Zooplankton biomass

Owing to the comparatively large mesh size of the net (0.4 mm), relatively large zooplankters only were obtained. The zooplankton biomass was comparatively more during May.

In May the displacement volume (fig.10) varied between 0.1 ml and 2.5 ml per sample (1.27 to 3.17 ml/m³ of water). In August the displacement volume was not estimated on account of the poor quantity of zooplankton obtained. In both the months the zooplankton was more during the night. In May the biomass showed maximum at 2100 hrs and 2400 hrs on 16th and 0300 hrs and 2100 hrs on 17th. The minimum biomass was found from 0900 hrs to 1800 hrs on the first day and at 1200 hrs on the second day. On the whole, the first-night samples were richer than the second-night samples.

The relative abundance of various zooplankton groups obtained during May and August is given in Table. 1

Table 1

The relative abundance (in %)zooplankton groups

Zooplankton groups	May	August
Copepoda	87.97	10.87
Chaetognatha	7.77	—
Decapod larvae	2.20	3.09
Appendicularians	1.34	—
Pleurobrachia	0.67	—
Lucifer	0.56	—
Polychaeta	0.14	5.49
Medusa	0.13	0.10
Acetes sp.	0.13	—
Fish larvae	0.06	0.30
Amphipoda	0.02	0.83
Juveniles of *Barnea* sp.	—	72.73
Zoea larvae	—	4.30
Cladocera	—	0.41
Fish eggs	—	1.86
Cumacea	—	0.11

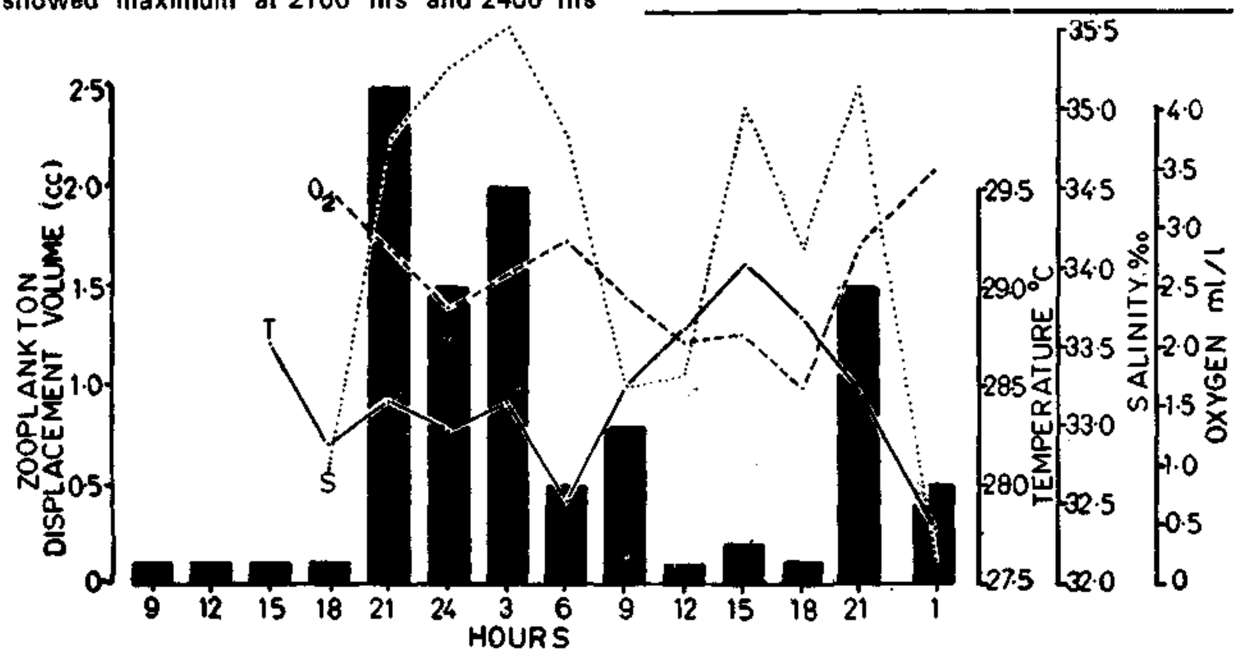


Fig: 10. Biomass of zooplankton in relation to diurnal variation in the physical properties of water.

There was a remarkable difference in the composition and relative abundance of various groups of zooplankters in the two months. While copepods formed the major group in May, the juveniles of *Barnea* sp. dominated over all the others in August. Some groups, like chaetognaths, appendicularians, lucifer, pleurobrachia, and medusa, were absent in August, which was mainly because of the low salinity of the mudbank waters during this month.

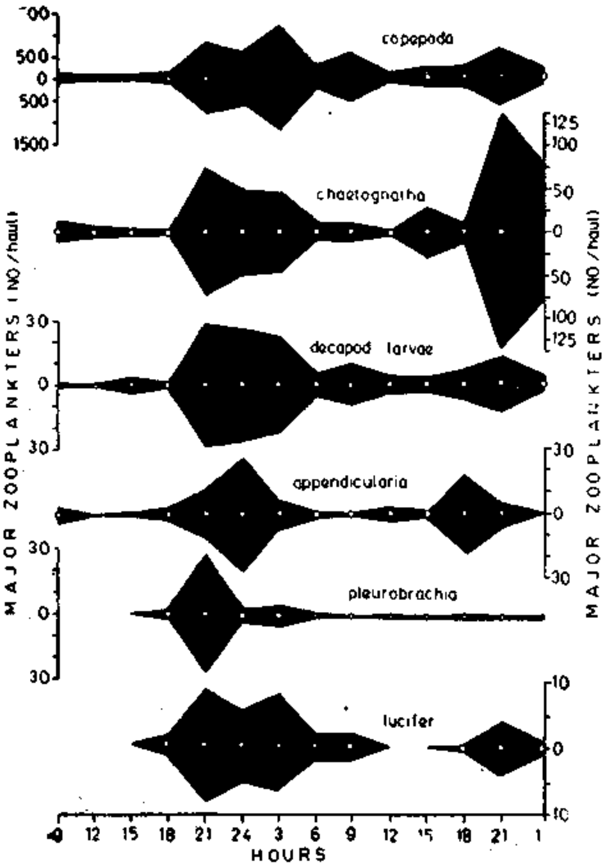


Fig: 11. Diurnal variations of the major zooplanktonic groups on 16-18 May 75.

The diurnal variations in the numerical abundance of zooplankton groups are presented in figs. 11 and 12. In May the percentage composition of copepods in the different samples in relation to other zooplankters ranged between 71.6 and 95.3 (Fig·13), while in August it varied between 0.2 and 36.7 only (Fig. 14b). Their number during the first observation showed pronounced diurnal variations, being in the range respectively of 82 to 1083 during day and 532 to 2442 during night (Fig.11) Numerically the copepods were much less during August. But as in May, they were relatively more during the night (Fig, 12). While 624 specimens were caught in 7 night collection only 94 specimen were present in the 6 day samples.

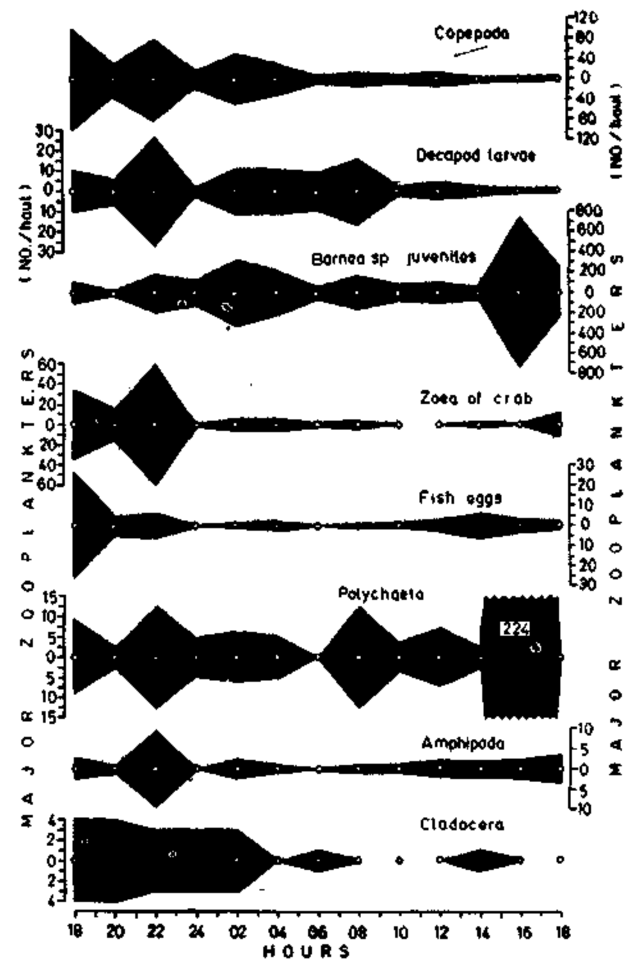


Fig: 12. Diurnal variations of the major zooplankton groups on 16-17 August 75.

The relative abundance of chaetognaths, which were present during May only, varied from 1.3 to 26 3% (Fig. 13). The maximum abundance was noticed at 2500 hrs on both the nights and minimum at 1800 hrs on 16th and 1200 hrs on 17th (Fig.11).

The decapods were mainly composed of prawn larvae. The percentage distributions in the different samples in May ranged between 1 and 7.5 (Fig. 13). The maximum number of 60 was obtained at 2100 hrs on 16th. The minimum number was found during the day hours. (Fig. 11). in August the prawn larvae occurred in all the samples, though in varying numbers. While a total of 134 specimens were present in the 7 samples collected in the night, only 70 specimens were present in the 6 days samples. Their percentage contribution in the

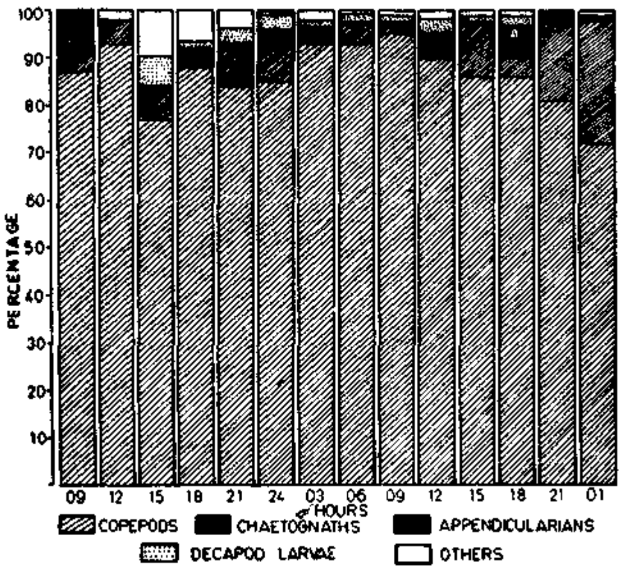


Fig: 13. Relative abundance of important zooplankton groups in the total samples.

different samples varied from 0.1 to 8.2. The maximum number of 54 was obtained around 2200 hrs (Fig. 12).

The percentage contribution of appendicularians in the different samples in May was low, ranging from 0.3 to 6.7 (Fig. 13). Their maximum abundance was noticed at 2400 hrs on the 16th and at 1800 hrs on 17 th (Fig. 11). The minimum was found during day, between 1200 and 1500 hrs on the first day and between 0600 hrs and 0900 hrs on the 2nd day. This group was absent during August.

The pleurobrachia was also present during May only. Their abundance was found only from 1800 to 0600 hrs on the first night with the peak at 2100 hrs (Fig. 11). Their percentage of abundance among other groups in the different samples ranged from 0.06 to 2.9.

Lucifer was another group which was absent in August. In May also they constituted only a small percentage in the plankton, ranging from 0.2 to 1.3. They were especially noted for their presence in the collections during the night hours (Fig.11). The maximum abundance was noticed at 2100 hrs and again at 0300 hrs on the first night. The second night collections contained less number of specimens.

Eventhough the plychaetes were present in May as well as in August, they occurred in very few numbers during the former month. Out of the 14 samples only 5 contained a single specimen each. It was interesting to note that they were present in the day samples only. However, in August, except at 0300 hrs, they were present in the samples collected in the other hours (Fig. 12). There was no indication of any difference in their diurnal abundance. In this month the percentage composition of polychaetes larvae to other zooplankton was between 1.8 and 12 9 (Fig 14 b).

The medusae were poorly represented in May and were found in only 5 samples, mostly collected during the night. In August 6 specimens were present in a single night collection. *Acetes* sp. was also rare occurring only in 4 samples collected in the night in May. A total of 7 fish larvae were found in 3 samples collected in May. In August they occurred in 4 samples of which 3 were collected

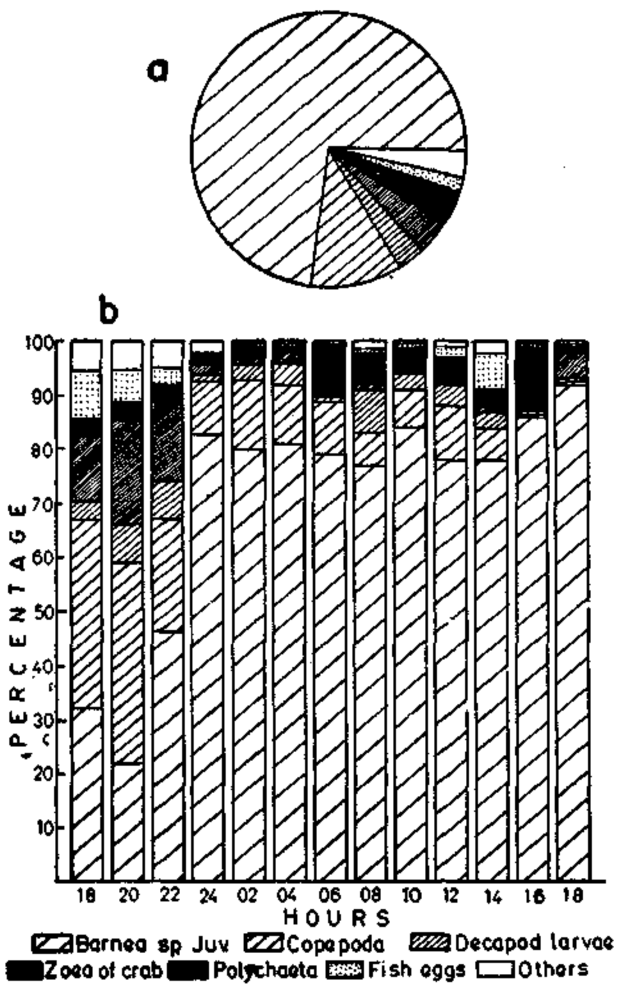


Fig: 14. Percentage composition of important zooplankton groups in the total samples (a); and their percent composition in various samples (b).

during the night. One specimen of amphipoda was present in each of the 2 samples in May.

The percentage abundance of juveniles of *Barnea* sp.,a bivalve present in the zooplankton, varied between 22.2 and 91.6. They were present in August and was them the most abundant form. The number in the different samples ranged from 40 to 1500. However, diurnal variation was not noticed. The zoea larvae, which constituted 4.3% in the total plankton, was the 3rd abundant group in August. They showed marked diurnal variations The cladocerans, though were present in a limited number of samples (only in August), were remarkable for their diurnal variations. Among the night samples they were present in all but one. One specimen each was present in 2 of the day samples also.

The fish eggs were present in all but 2 samples in August and their percentage in the different samples ranged between 0.2 and 2.4. A good number of them were present in the beginning of the observations and at 1800 hrs, 53 numbers of eggs were present, Eventhough the fish eggs were more in 3 of the night samples, a diurnal difference in their presence was not noticed. Six number of benthic cumaceans were also present in 4 of the night samples of August.

DISCUSSION

The investigation shows that, during May, the seasonal currents in the mudbank was southerly. The peaks correspond to the high tides and the troughs to the low tides. Therefore the high tide corresponds to the southerly component of the tidal current. The lowest low tide (1100 hrs), which reversed the tidal current to the northerly direction (14 cm/sec.) was sufficient to nullify the steady southerly flow (18.1 cm/sec.) completely. Thus the current direction was always maintained at 160° (southerly). In August change in the direction of current was observed. The weaker coast-normal currents indicated the transitions of the change over from the southerly currents during monsoon to the northerly current system during the winter. It may be noticed that, in August, the offshore components, though feeble, was present almost throughout the day. Such a development in the current systems towards the end of the mudbank season has a definite bearing upon the dissipation of the mudbank. The stronger the development of the offshore currents, the quicker the dissipation by mixing with the offshore waters.

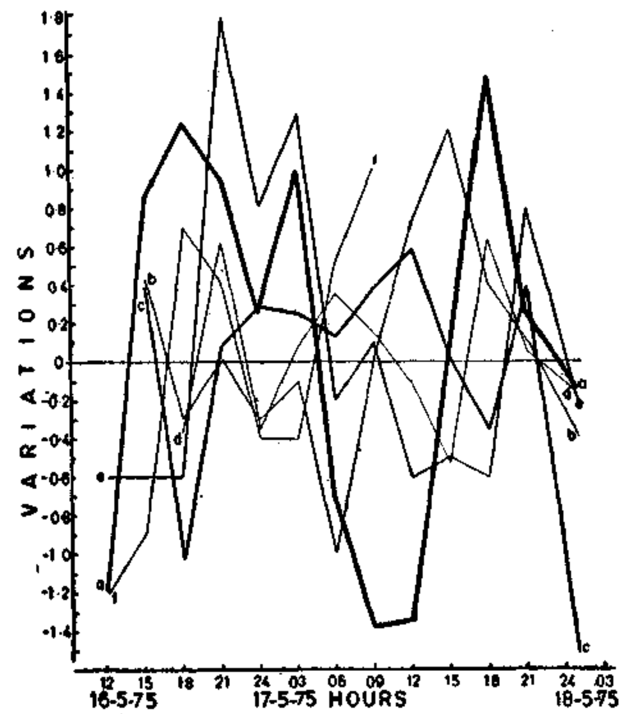


Fig. 15. Anomaly of various parameters studied: a-current (from 18 cm/sec: Scale X10 = velocity in cm/sec); b. surface temperature (from 28.5° C); c. surface salinity (from 34.35 ‰); d. surface phosphate from 1.13/g at P 1); e. mean values of zooplankton displacement volume (from 0.1 cc); f. mean cell counts of phytoplankton (in lakhs).

When the anomaly of various parameters, such as temperature, salinity, reactive phosphate, phytoplankton cell counts and zooplankton biomass, was compared with the changes in the pattern of the currents in May, a high degree of correlation was noticed and the same is presented in fig. 15. However, in August, the centre of observation being closer to Thottappally spillway, through which there was a constant outflow of fresh water, and being further influenced by the tides, and currents, the hydrographic properties, such as temperature, salinity and dissolved oxygen, showed great fluctuations from hour to hour. The complexity of variations was such that a definite correlation of any of the hydrographic parameters with the pattern of the currents was not possible. With regard to the phytoplankton productivity, no significant changes

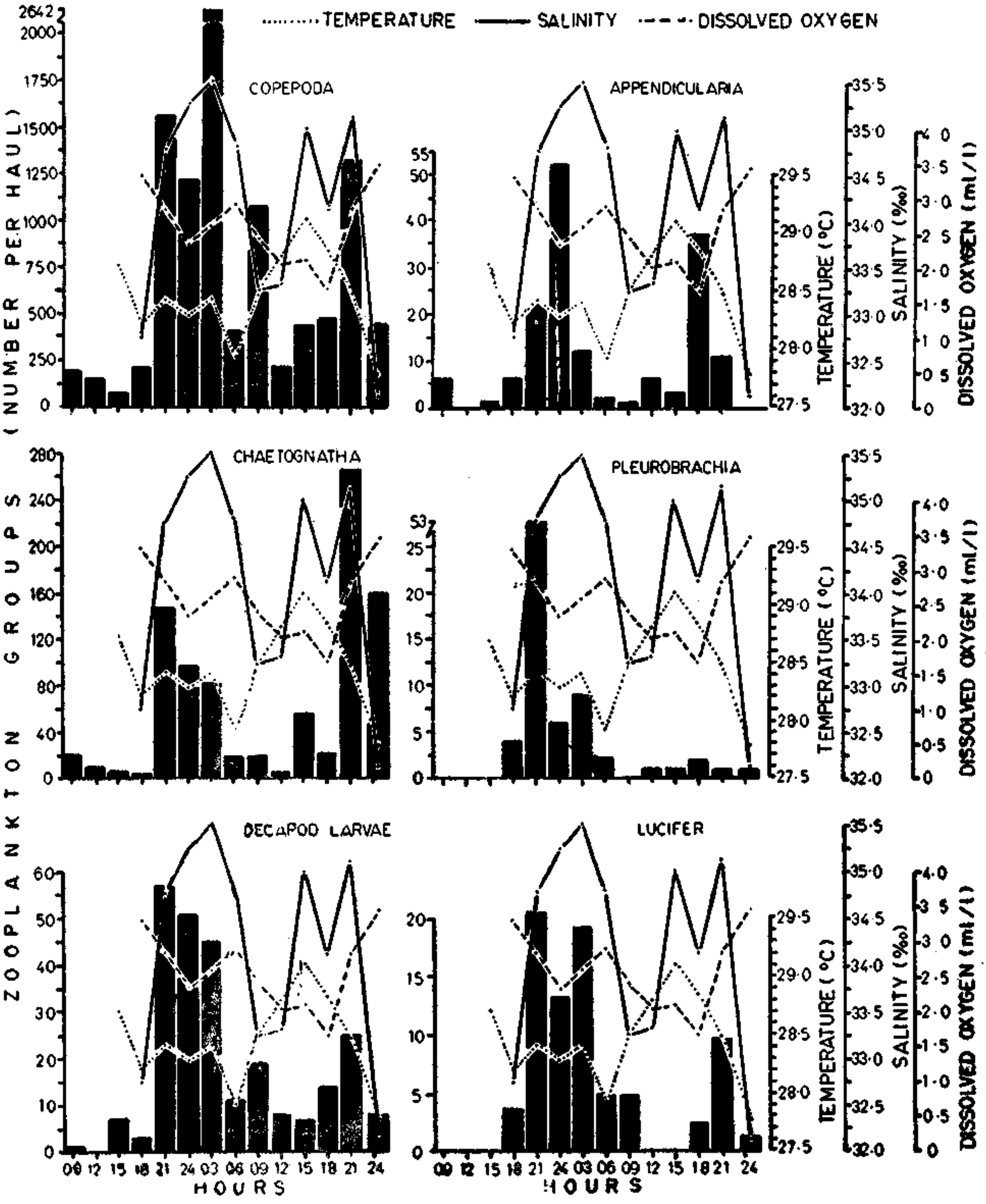


Fig. 16. Diurnal abundance of the important zooplankton groups in relation to environmental parameters on 16-18 May 1976.

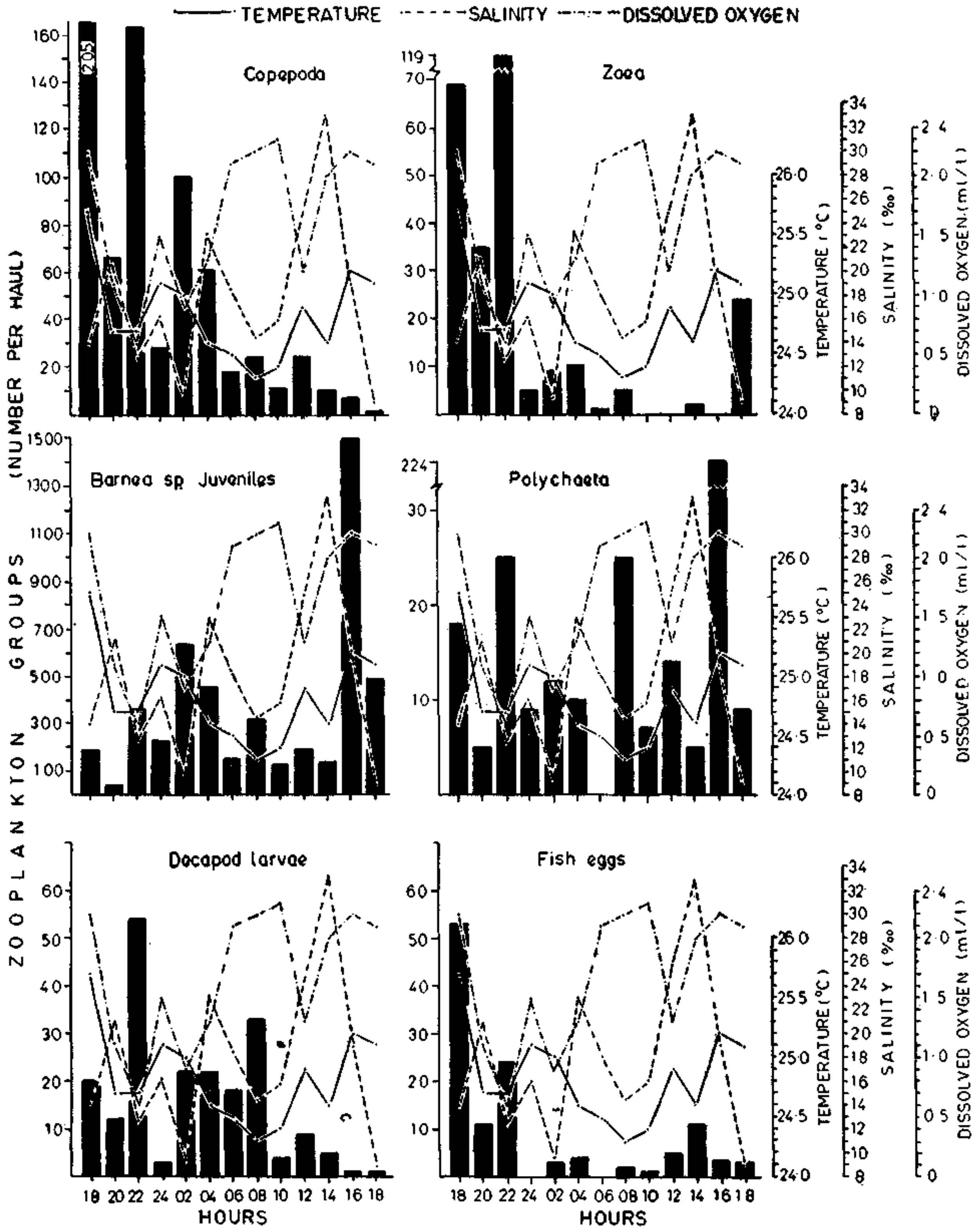


Fig. 17. Diurnal abundace of the important zooplankton groups in relation to environmental parameters on 16-17 August 1975

were noticed during the diurnal observations in May other than what usually happens in the inshore areas.

The production at the primary level during the 24-h period in August was generally high. However, this high rate of production was mainly due to the presence of *Microcystis* sp., a freshwater alga which was brought down through the spillway. Its population was especially more between 0800 hrs and 1200 hrs. during which period the marine diatoms and dinoflagellates, such as *Nitzschia, Pleurosigma. Ceratium* and *Peridinium*, were totally absent,

During both these periods of diurnal observations the zooplankton was more during the night. This cannot be attributed to the vertical migration. as the plankton samples were collected from the bottom to the surface straining the complete water column. The avoidance reaction of zooplankton to the sampling net could be one reason for their reduced frequency in the day samples. However, light being the most important factor in the vertical distribution of the zooplankton, their day time aggregation in the deeper strata may reflect in a low catch by the net. During the night the diffused condition of the zooplankton distribution in the complete water column enhances the chances of capturing the zooplankters. In spite of the rather turbid nature of the subsurface water at the mudbank, this general principle of the zooplankton distribution was found operating in the mudbank.

Eventhough light plays an important role in the diurnal variations of the plankton in general, the effect of temperature and salinity are also significant. In May the plankton showed maximum abundance when these two environmental parameters were almost steady (fig:16). For example the salinity was at its maximum during the whole period of the first night and the temperature was moderate. This was followed by the maximum abundance of plankton in general and different groups in particular. But during the second night the salinity showed greater fluctuations and declined to the minimum at 0100 hrs. The temperature also showed a steady decrease during the period and dropped to the minimum by 0100 hrs and the plankton was less in quantity. During August also the hydrological parameters influenced the occurrence and abundance of the zooplankton. The relationship of the major zooplankters with the hydrographic properties is given in fig. 16–17. A significant result of the extreme dilution of the mudbank waters during August was the absence of chaetognaths and appendicularians, which frequent the coastal waters in all the seasons. Similarly the copepods, which usually form the most dominant groups, were present in less numbers.

ELEVEN

FISH AND FISHERIES OF THE MUDBANKS

A. REGUNATHAN, K. J. MATHEW, D. S. RAO, C. P. GOPINATHAN,
N. SURENDRANATHA KURUP and A. V. S. MURTY.

ABSTRACT

The mudbanks attracted the affention of fishery scientists as they play a vital role in coastal fishing during the S. W. monsoon. Studies on the fishery associated with mudbanks were carried out from Quilon to Mangalore, particularly in the mudbanks of Purakkad and Nattika, where the fishery is more intense. The total catch and catch per unit effort for mudbank and non-mudbank areas were estimated and compared. Changing pattern of fishery, species composition and their relative abudance were studied. The present paper thus embodies a detailed account on the much publicised 'mudbank fishery'—or *Chakara* fishery—and its magnitude and limitations. An attempt has also been made to project the socio-economics of the fishing community of these areas, along with the infra-structure and the impact of legislation in regard to mudbank fishery.

INTRODUCTION

Mudbanks have been a navigational problem since olden times for port authorities, Although mudbank is mentioned in literature since 1678 (*Adm. Rep. Travancore*, 1860), there is very little recorded information on the fishery associated with mudbanks. What little is known in regard to it is restricted to the infrastructure rather than the fishery. Paucity of details on the fishery associated with the mudbanks necessitated the present study.

Many years have elapsed since Bristow (1938) gave his first evaluation of the mudbanks of Kerala coast and it is not known whether any notable changes have taken place in the environment or in our fishing activities all these years. The country, after independence, made a big leap in mechanising the fishing industry and in extending our fishing activitiea farther out into the offshore waters. Nevertheless, the requirements of the necessary infrastructure to meet the increase in production by the improved fishing activities are not yet adequately met with. It may be recalled in this connection that the Purakkad mudbank experienced a bumper landing in 1969, and the prawns and fishes that were landed in large quantities had to be buried along the beaches due to the processing and storage facilities then inadequate.

The S. W. monsoon period is generally an offseason for the fisherfolk on the west coast of India, who still use non-mechanised fishing crafts. In this period of general idling, the calm areas created by the mudbanks naturally attract fishermen in large numbers, from far and wide. These calm areas, varying in extent from about 10 km² to 25 km², provide safe harbourage to the country crafts. Launching and landing of canoes are very easy in the mudbank areas. Most of the canoes from the fishing villagesof Cochin-Quilon and Cochin-Ponnani congregate (plate 1,A&B) respectively at the mudbanks of Alleppy and Nattika, and these places then become centres of intense fishing activity.

Fishery at the mudbanks of Kerala coast in general, and of Purakkad in particular, had, however, a severe set back in the year 1971, when the presses in Kerala came out with headlines on the failure of mudbank formation and the fishery associated with it. This mudbank failure prompted the Central Marine Fisheries Research Institute to make the all-out effort to investigate the nature of the mudbanks and the fishery associated with them.

MATERIAL AND METHODS

Ambalapuzha, Purakkad and Thottappally (Alleppey), Valapad (Nattika), Tanur (Calicut) and the fishing villages in and around these places were visited and fish samples and catch data were collected. Tanur could not be visited frequently, but Valapad, Ambala-

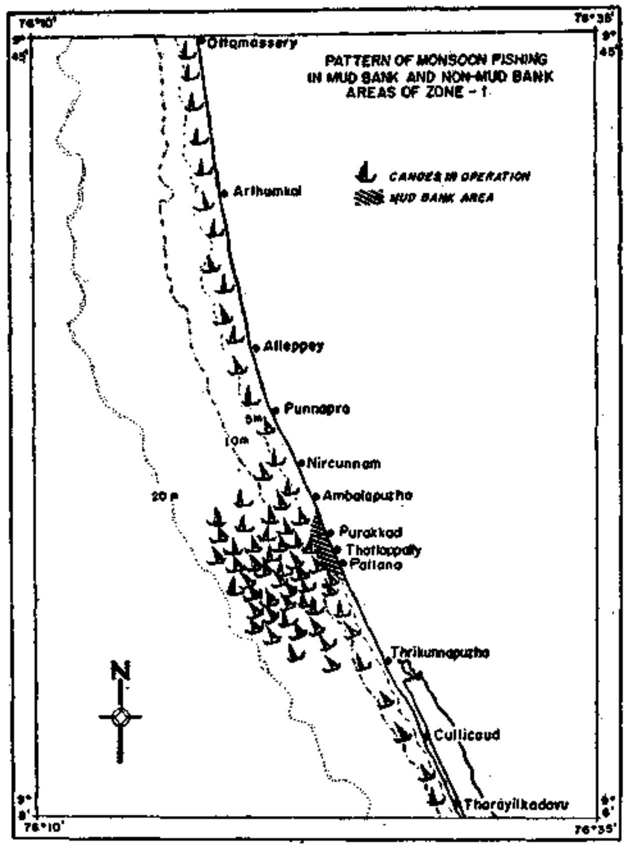


Fig. 1. Pattern of monsoon fishing in the mudbank and non-mudbank areas of Zone-1.

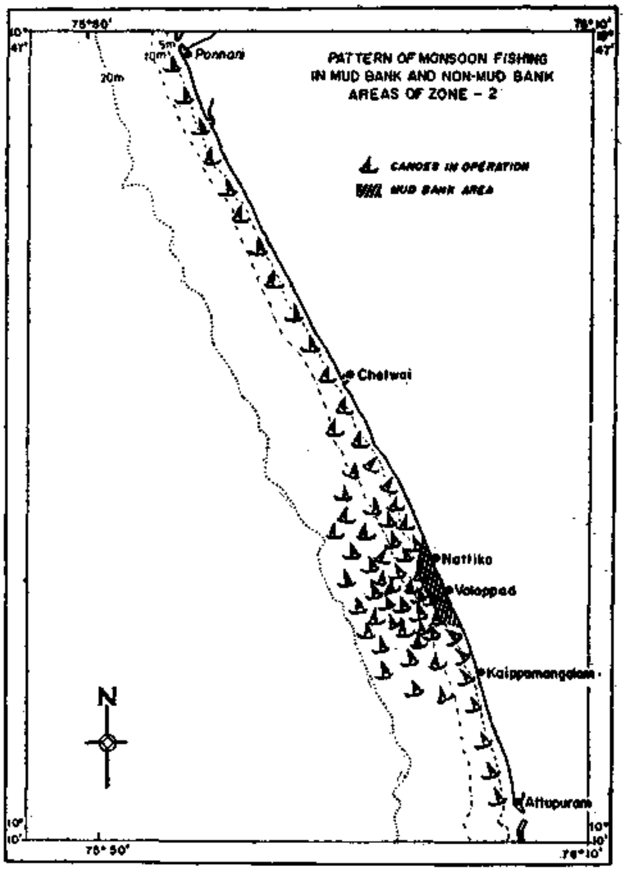


Fig. 2. Pattern of monsoon fishing in the mudbank and non-mudbank areas of Zone-2.

puzha, Purakkad and Thottappally were under regular observation. The present account deals with the craft and gear, species composition and total landings of the mudbank and non-mudbank areas of Alleppey and Nattika. For the purpose of this study the fishing villages of Alleppey (Ottamassery-Tharayilkadavu) is treated as Zone 1 (Fig. 1) and Nattika (Ponnani-Attupuram) as Zone 2 (Fig.2). The catch statistics of Zone 1, in regard to both mudbank and non-mudbank areas, is dealt with in detail. The Zones 1 and 2 are compared in respect of both total landing and the catch per unit effort (CPUE) worked out for a five-year period. The changing pattern of the fishery and the relative abundance of the species are discussed in detail.

FISH AND FISHERY

Craft and gear

Dug-out and rigged canoes (*vallam* or *vanchi*, in Malayalam) were the main crafts used in the fishing operations. Catamarans of Tamil Nadu with hooks and lines were also seen. The canoes were mainly of two sizes, a larger one of 9.5 m, manned by 15 persons, and a smaller one of 6 m, manned by 9 persons. Canoes fitted with outboard motors, which had been introduced in 1980, were also in operation. The canoes of Calicut area were of flat bottom, while that of Valapad-Nattika and Ambalapuzha-Thottappally were of keel bottom. The main gears of operation were drag nets *(Thangu vala)* and gill nets *(Mathi-chala vala)*. Cast nets were also used effectively near the shore in the mudbank area (plate: 1B)'

Thangu vala: This is a rectangular net made of cotton or nylon and is about 50-60 m in length and 15-20 m in width, with a narrow end measuring about 6-9 m. The mesh size is about 20 mm. On sighting a shoal, one person jumps into the water holding one end of the net and remains stationary, while the canoe moves paying out the net to encircle the shoal. The canoe, on reaching the person, collects the other end also from him, and the net is hauled. Hauling the ends, a bag-like belly in the centre is formed, where the fishes are collected and removed.

Mathi chala vala: This is a gill net made of cotton or nylon pieces, each piece, measuring about 2.5-3 m long and 4-6 m broad, with a mesh of 9-25 mm. One or two canoes are operated to lay the net and these canoes carry 7-8 pieces of net laced together. When a shoal is sighted the net is rapidly paid out in a semicircular fashion, the fishermen making loud noise. Thus driving the shoals toward the net they are gilled on the nets and removed.

Fish

The monsoon fishery was composed of 50 species of fish and six species of prawns. Fishes of the families Carcharinidae, Clupeidae, Dussumieridae, Dorosomidae, Engraulidae, Tachysuridae, Ambassidae, Theraponiidae, Chirocentridae, Sillaginidae, Sciaenidae, Siganidae, Trichiuridae, Scomberomoridae, Stromateidae, Cyanoglossidae and Drepanidae were enountered in the landings. Of the prawns, *Penaeus indicus, P.monodon, P. semisulcatus, Metapenaeus dobsoni, M monoceros* and *M. affinis* represented in the catch. While the monsoon fishery of tha Alleppey mudbank region was dominated by *M.dobsoni, Stolephorus* sp. *Sardinella* sp. and *Leiognathus* sp., the major bulk of the catch of the northern sector (Valapad and Tanur) was contributed by *Sardinella* sp., *P.indicus* and *M.dobsoni.*

The monsoon fishery in Kerala has a legal protection from the state government, providing exclusive operational rights during monsoon to canoes and catamarans, especially so in the vicinity of the mudbank region. Fishing by mechanised vessels is strictly prohibited at the mudbank and nearby areas. However, indigenous crafts fitted with outboard motors, introduced in 1980, are allowed to operate in the mudbank regions.

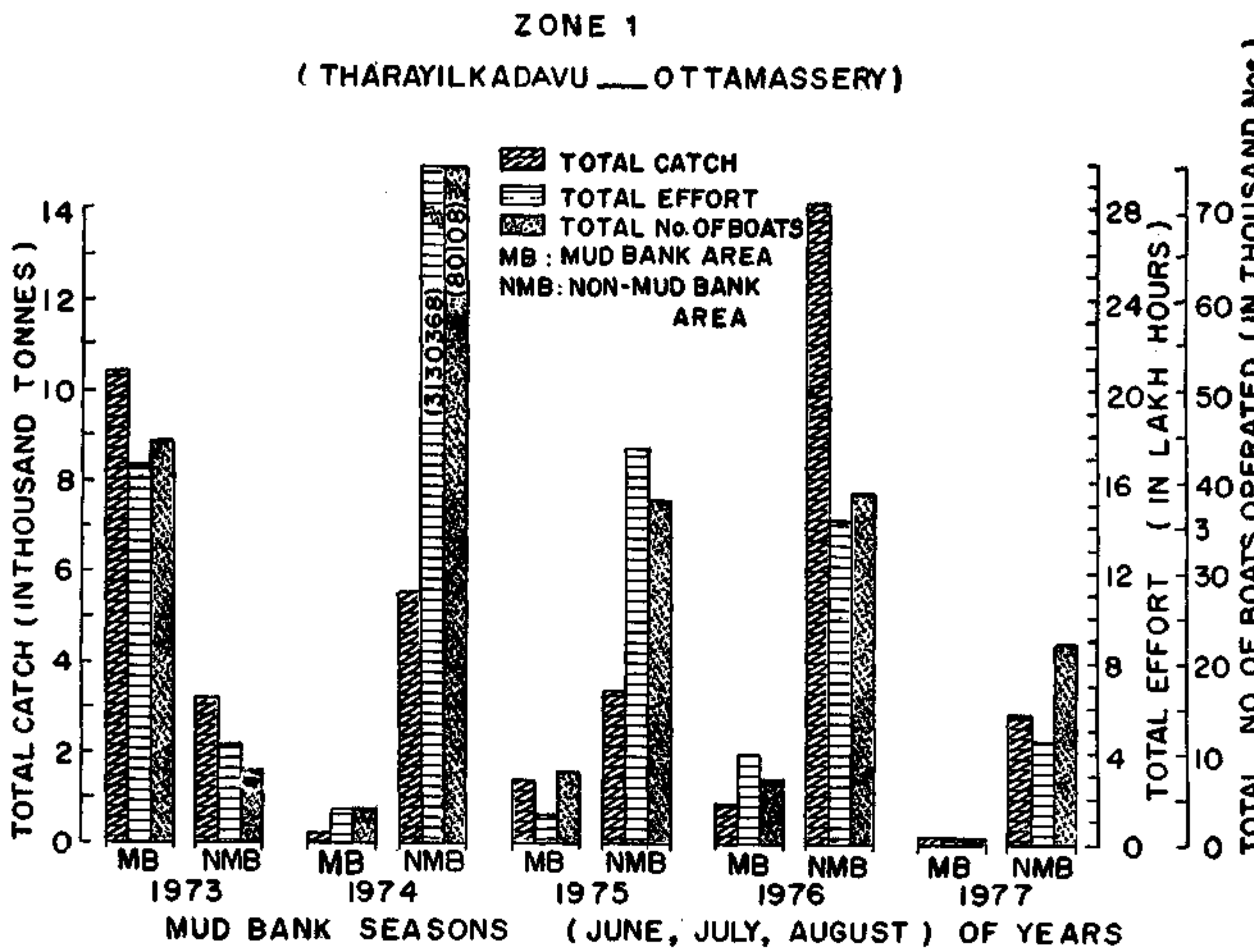


Fig. 3. Total fish landed, total effort and number of canoes operated in the mudbank and non-mudbank areas of Zone-1 during the mudbank seasons of years 1973-1977.

TABLE 1. *Camparative study of fish landed in mudbank (M) and non-mudbank (N) areas during the mudbank seasons of the years 1967 to 1970 (in tonnes).*

	1967						1968						1969						1970					
	June		July		August		June		July		August		June		July		August		June		July		August	
	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N
Scoliodon sp.			179.1						6.0		6.4				3.2			8.4	1.0		2.0			
A dussumieri	246.5																53.4							
S. longiceps	27.2					87.3			434.7				1042.7		0.84		0.80	809.9	528.3					
Engraulis sp.	17.3		25.5		5.5		0.2		0.8		20.0	13.0	13.8						9.4		27.9		3.1	
Opisthopterus sp.	10.0		4.1				0.4				0.8		5.7						4.7					
Otolithus sp.							0.6		4.3				3.3		17.1				0.3		3.9		1.3	
Caranx sp.			8.4		2.3	0.4	1.7				5.7	30.1	9.3	2.7	0.5		3.4		18.4					
Leiognathus sp.	9.3		8.1		4.1		31.6		55.7		197.3		37.7	11.5	386.1		71·7	314.9			106.0	71.3	9.1	17.8
L· lactarius			22.8		1.2	1.0			3 9		155.4	1.5	19.4				3.0	8.7						
P. indicus							0.3		0.2		123.7		0.8	4.8	4.8		4.6	6.3	0.3			3.6	0.2	9.5
M. dobsoni	562.7		3618.7		9·6	271.6	549.4		1488.7	406.0	20.1		1665.9	168.7	29.0		3.7	14.0	18 9		110.3	408.1	1044.2	160.4
P. stylifera	20.8		44.8				9.2						2.2										65.3	
Rhynchobates sp.										55.1		2.5											0.1	
Dusumieria acuta									23.4		17.8	45.0			0.5		2.1	479.4			6.7		4.2	
S. fimbriata									45.7		53.0	10.0									12.8		0.3	
Anchoviella sp.					17.6	1.7			8.7		5.2	6.0	1.0				89.1	194.9			2816	10.7	31.9	
Ambassis sp.						3.6	1.9		9.6		38.4		4.7				6.4	467.5			35.2	50.6	2.8	29.7
Sciaena sp.	6.9		75.6		10.8								9.3		20.3		8.1	22.8			16.6		3.9	
Cynoglossus sp.													3.6		1.0			9.0			1.1			
Trichiurus sp.	2.7												5.6					1.0						
R. kanagurta					1.2																			
Zygaena sp.																	5.9							
Cybium Commcrsoni													0.5		17.6									
M. affinis											4.9													
Sphyraena sp.											13.2	1.5	13.7	0.6	10.8		3.9	2.4						
A. thalassinus									13.9															
Miscellaneous	4.5		73.0		2.1	4.0	9.2		12.1	9.2	38.0	2.0	29.7	2.7	8.0		7.9	41.7	6.7		28.8	40.6	14.9	9.5

TABLE 2 *Annual landings in metric tonnes for the mudbank and non-mudbank areas of Alleppey coast.*

Year	mudbank area				non-mudbank area				Total for mudbank and non-mudbank
	June	July	August	Total	June	July	August	Total	
1966	18.22	3800.49	—	3818.71	932.48	534.27	—	1466.75	2399.23
1967	906.52	4005.40	54.95	4966.87	—	—	369.98	369.98	5336.85
1968	607.44	2090.18	748.74	3446.36	—	415.25	68.80	484.05	4930.41
1969	2871.51	524.59	224.14	3620.24	186.43	—	2490.47	2676.90	6297.14
1970	1755.62	632.97	1182.38	3570.97	—	581.45	226.97	808.42	4379.39
1971	177.22	698.65	106.70	982.57	4680.00	860.24	892.39	6432.63	7415.20
1972	436.13	1652.62	1148.08	3236.83	863.11	2500.27	152.34	3515.72	6752.55
1973	46.19	2538.83	7840.19	10425.21	—	3207.33	—	3207.33	13632.54
1974	23.24	23.93	—	47.17	1222.84	106.53	4338.40	5667.77	5714.94
1975	—	938.59	472.97	1411.56	133.32	1566.06	1709.52	3408.90	4820.46
	6823.87	18105.76	11778.15	31767.78	7085.70	9237.13	10248.87	26571.70	

THE FLURRY AT THE MUDBANK

Plate-I A Canoes all set for operation; B. Transportation of a canoe to the mudbank area by road; C. Cast nets in operation in the mudbank.

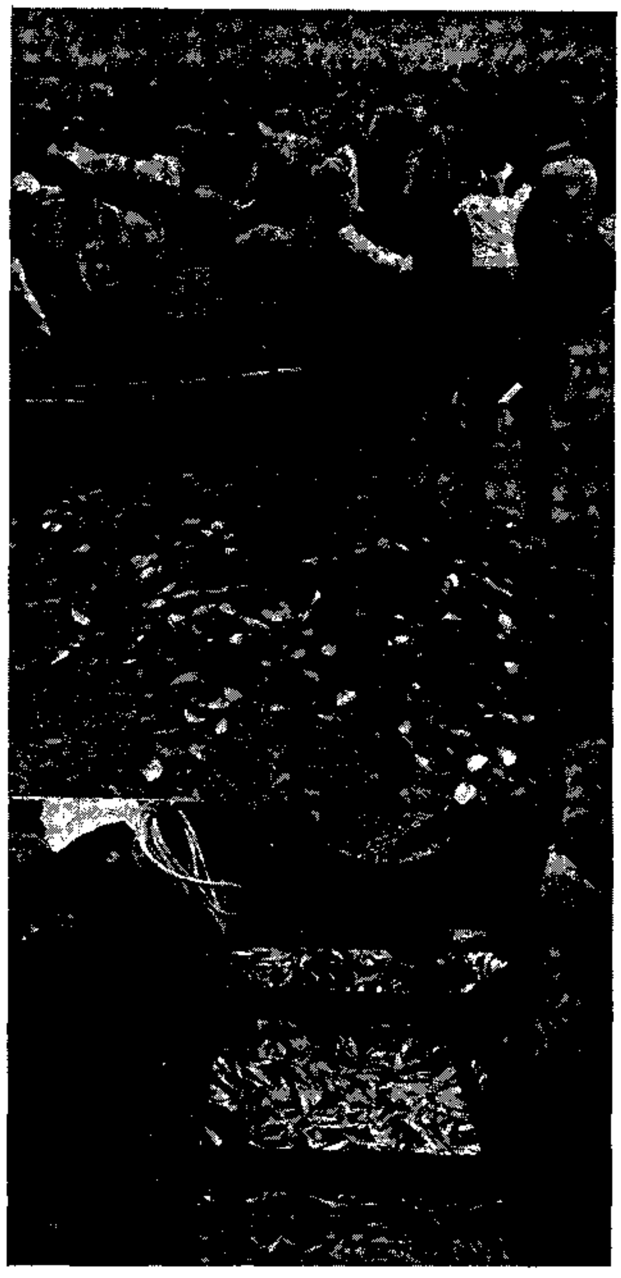


Plate-II A. Throng of fishermen and fish vendors at the mudbank of Alleppey; B & C. Bumper catch of prawns and fishes.

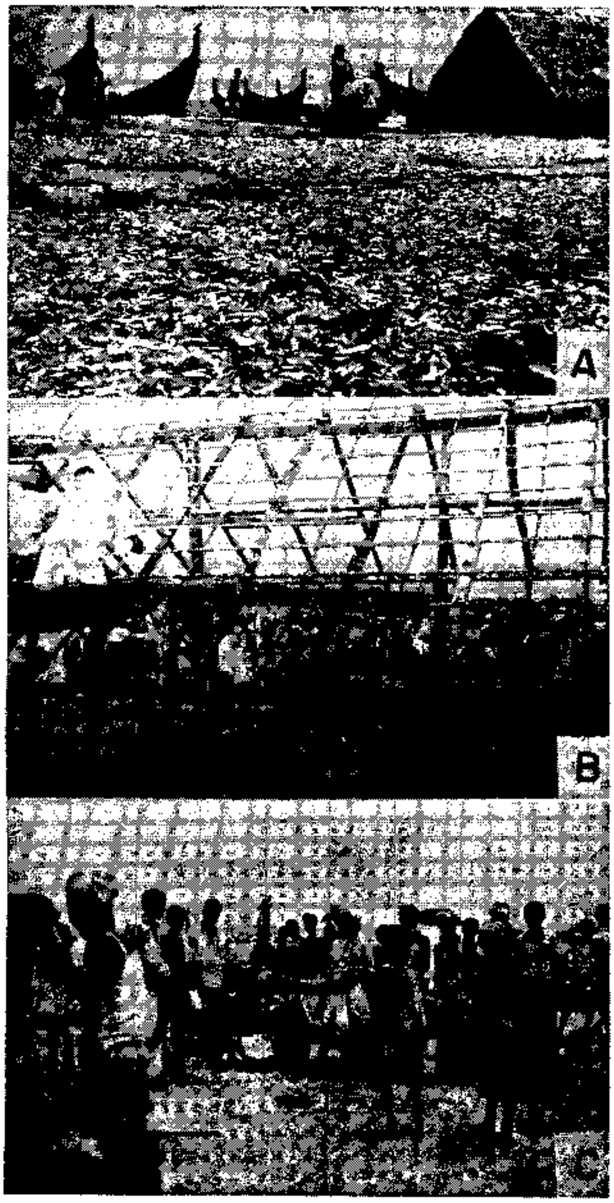


Plate-III A. Drying of excess catch on the beach; B. Preparation for the mudbank fishery—fish storage shed under construction; C. A section of the commercial setup at the mudbank.'

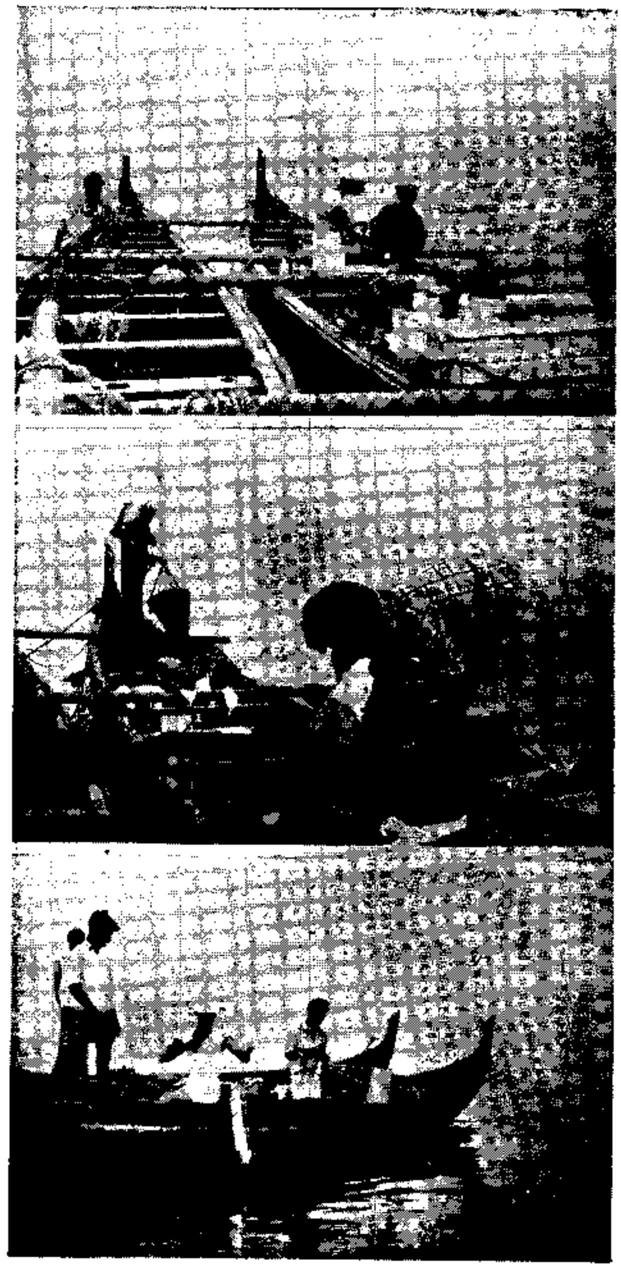


Plate-IV A-C. Diurnal studies being conducted at Alleppy mudbank (Thottappally). (See Chapter 7)

ZONE 2
ATTUPURAM — PONNANI

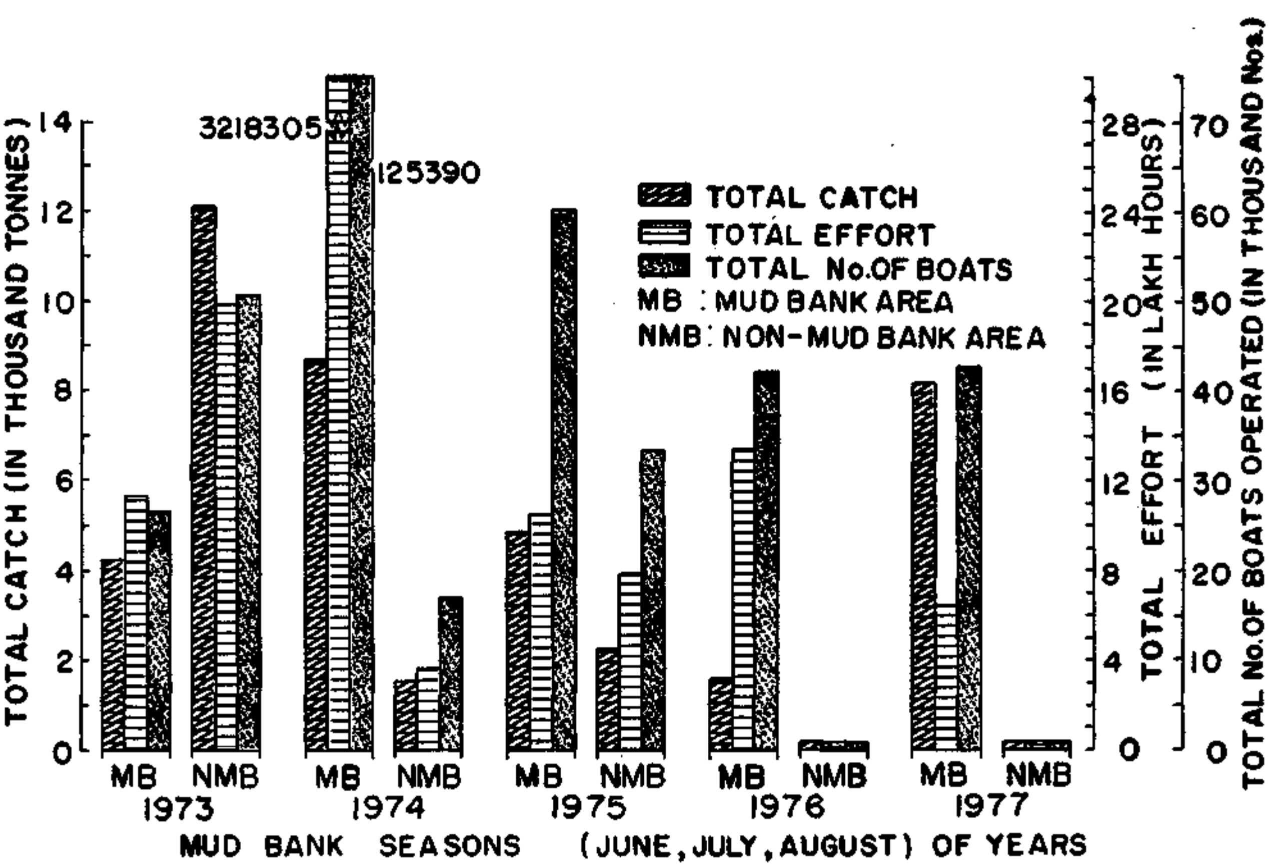


Fig. 4. Total fish landed, total effort and number of canoes operated in the mudbank and non-mudbank areas of Zone-2 during the mudbank seasons of years 1973-1977.

Normally, fishing in the mudbank is done from the early hours of day till noon. But, on heavy fishing days fishing continues through out the day. The authors themselves have witnessed the fishing operations on many occasions and collected information on the fishing pattern prevailing in the mudbank regions. The fishing is generally confined to the peripheral region of the mudbank. When catches are heavy, the boats have been observed to come to the shore to unload their catches and return to the same area to resume the fishing operations. Because of the legal prohibition on mechanised vessels, the authors could not conduct any exploratory fishing operation in the mudbank. But it has been observed that the fishery, though intense at times, is in no way a permanent feature of the mudbanks, because there are many a days when the boats return ,after hours of scouting, without even a single fish. However, on such days, weather permitting, fishermen go farther from the mudbank and bring sometimes heavy catches from places north and south of the mudbank (Plate: 2&3A). Catamarans from Tamil Nadu have been observed to move far off to places outside the mudbank area for hook-and-line fishing. On days of rough weather, fishing operations are at times carried out very close to the shore, inside the mudbank proper.

Specieswise composition of the fish landings from the mudbank and non-mudbank areas of Alleppey during the years 1967-70, presented in Table 1, shows that *Metapenaeus dobsoni, Sardinella longiceps, Leiognathus* sp.' *Stolephorus* spp. *(Anchoviella)* and *Ambassis* sp. form the bulk of the landings in the mudbank as well as in the non-mudbank areas during this period.

Table 2 shows the total annual landings at the Alleppey coast covering both the mudbank and non-mudbank regions for a period of ten years (1966-75). The total landings of the mudbank area, as can be seen from these data, has dwindled steadily from 1971, except for a reversal in 1973, and that of the non-mudbank area increased substantially from the earlier years.

Catch, effort and units in operation

The total fish landed, effort expended and the number of canoes operated during the S. W. monsoon both at the mudbank and non mudbank areas of Zones 1 and 2 in the years 1973-77 are shown in the figures 3 and 4.

The highest rate of catch (catch per unit effort) for the mudbank area in Zone 1 was in 1975, while that for the non-mudbank area was in 1976 (fig. 5). In Zone 2, the highest catch per unit effort was recorded in 1977 for the mudbank area, and for non-mudbank area it was in 1973. In Zone 1 the catch per unit effort was more for the mudbank area than for non-mudbank area in 1973 and 1975; but in 1974, 1976 and 1977 it was the reverse. In Zone 2, the non-mudbank area had a higher catch rate than the mudbank area in 1973 and 1974, while, in all the other years under consideration, the catch per unit effort was higher in the mudbank area. However, the overall catch per unit effort was on tne higher for the non-mudbank area in Zone 1 (Purakkad) and for the mudbank area in Zone 2 (Nattika).

Changing pattern of fish distribution

The pattern of fish distribution in the coastal areas during the monsoon season has been observed to change very frequently, even from day to day. This phenomenon was then not only confined to the mudbank area but also to other areas outside it, obviously because of the shoaling behaviour of the fishes. The daily changing pattern of the fish landed at the mudbank area of Alleppey was studied for 13 days in July 1971, and the results are given in fig. 6. Of the major constituent species at this time. *M.dobsoni* dominated the catch for 6 days, During these six days, *P.indicus* ranked second for one day, and *Leiognathus* spp.

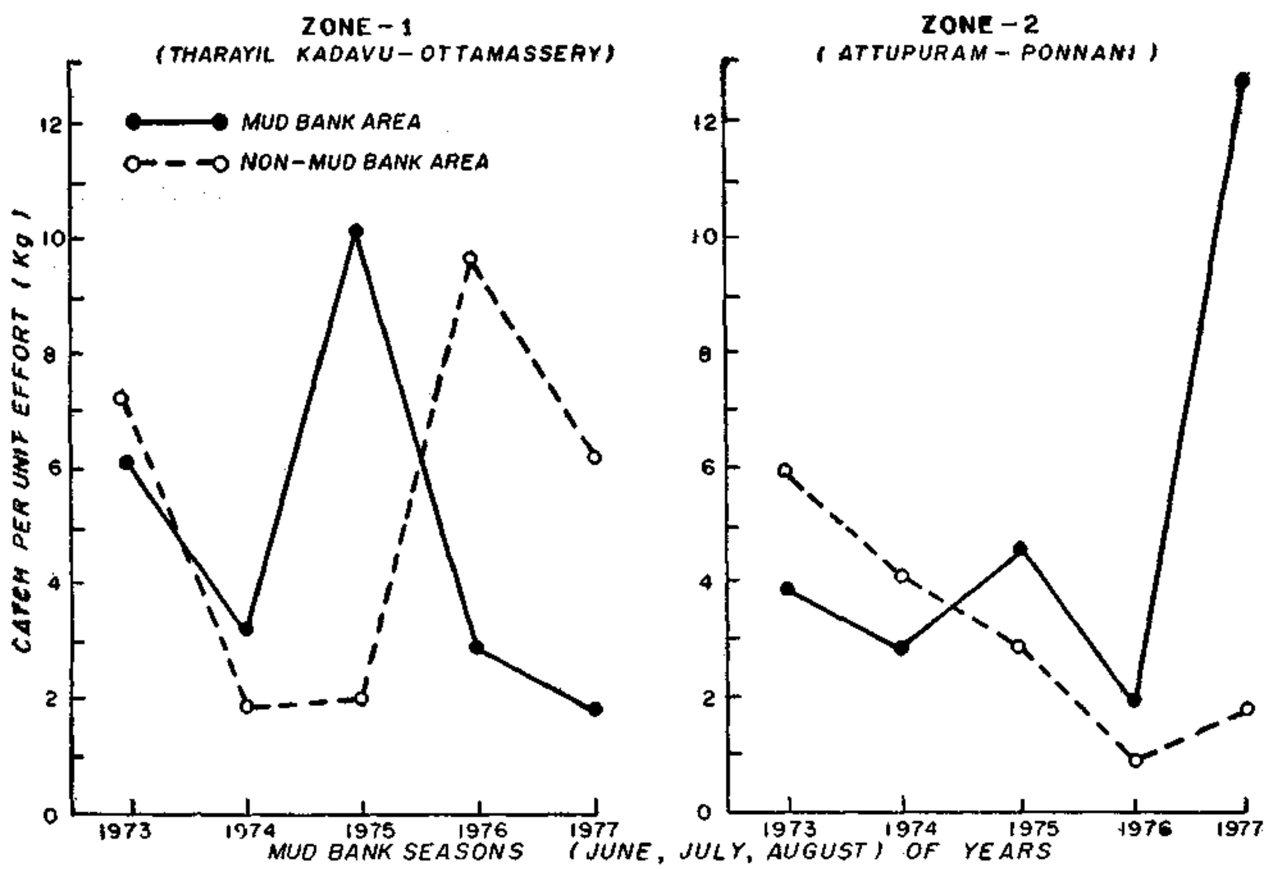


Fig. 5. Catch-per-unit-effort of mudbank and non-mudbank areas of Zones 1 and 2 for the period 1973-1977

and *Stolephorus* spp. for two days each. On the remaining day, the catch was of a mixed type, without having any species predominance. Eventhough there were some gaps in the observations, the overall figure emerged out was sufficient to show the daily changing pattern of the fishery.

SPECIES / DATE *	JULY - 1971												
	1	5	13	14	16	17	18	23	25	26	28	29	30
METAPENAEUS DOBSONI	●	+	●	●						●		●	●
PENAEUS INDICUS	+												
SARDINELLA LONGICEPS		●											
LEIOGNATHUS SPP			+	+	●	●			●				
STOLEPHORUS SPP							●	●		+		+	
MISCELLANEOUS					+	+	+	+	+		●		+

● MOST ABUNDANT SPECIES + SECOND ABUNDANT SPECIES
* NO DATA AVAILABLE FOR MISSING DATES

Fig. 6: The changing pattern of fishery at the Alleppey mudbank in July 1971.

Relative abundance of fishes in mudbank area and in non-mudbank area

An attempt was made to compare the distribution patterns of fishes at the mudbank and non-mudbank areas of the two zones, based on the landing figures, eventhough the mudbank areas were fished almost every day while the non-mudbank areas were fished only when calm weather prevailed. The catch distribution, species composition and their percentage abundance for the mudbank and non-mudbank areas did not differ much (fig. 7&8). It is obvious from the figures, that except in July (1975) and August (1977) for Zone 1 and in June (1975) and August (1977) for Zone 2, the pattern did not show much variations.

Infrastructure

With the onset of a mudbank the fishing village, all on a sudden, turns into a place of hectic activity (plate: 3). Thousands of fishermen and people associated with fish marketing and processing industry assemble here. Fortune seekers, too, other than fishermen, encamp at the mudbank area. New hotels and tea stalls come up. Pedlars find their job thriving. The law-and-order department becomes more vigilant. To meet the fishing requirements, an elaborate infra-structure is then naturally needed. Sufficient number of crafts, gears, pre servation and marketing facilities, and mean of quick transportation are essential. Above all, every fisherman has to have a reasonable price for his commodity. It will be worthwhile to examine how far these needs are met with during the mudbank fishery.

The ice plants estabilished in the vicinity of mudbank areas of course ensures steady supply of ice. At times, when there are heavy landings, quantities of ice are brought also from distant places. As there are very good transportation facilities all along the Kerala coast quick movement of the catches by insulated and ordinary trucks is not ordinarily a major problem. In spite of all these, the price of fishes falls very low on days of heavy landings.

Socio-economics

Majority of the fishermen who engage in fishing at the mudbank come from far-off places. They come with their own or hired crafts and gears. At the mudbank region, they usually stay with their relatives or friends, or in rented tenements on the open beach. These people are not a homogenous group; they belong to various castes and religions and speak different languages, but, they nevertheless work in perfect harmony.

The income of the fishermen at the mudbank area is never steady, like any where else. On days of good fishing it is not uncommon for a fisherman to get Rs. 300/-or even more per day. On the other hand, on many days they get nothing since they return without any catch at all. However, of late, several canoes fitted with out-board engines are under operation in the Alleppey region enabling them to fish further out with better results.

Majority of the fishermen hire boats and nets for operation in the mudbank regions' and, therefore, a major portion of their income has to be disbursed as rent for the boat and net. Besides, fishermen borrow good amounts of money from money lenders or fish agents (at usurious rates) anticipating good income from mudbank. This takes a heavy toll, too, apart from the sad fact that the money lenders usually decide the price of catches. Thus it is not unusual that the fishermen who come to the mudbank with the hope of getting a good harvest at times go back with empty hands. Of course, there are rare exceptions. A few diligent fishermen earn enough from mudbanks even to purchase boats and nets for themselves.

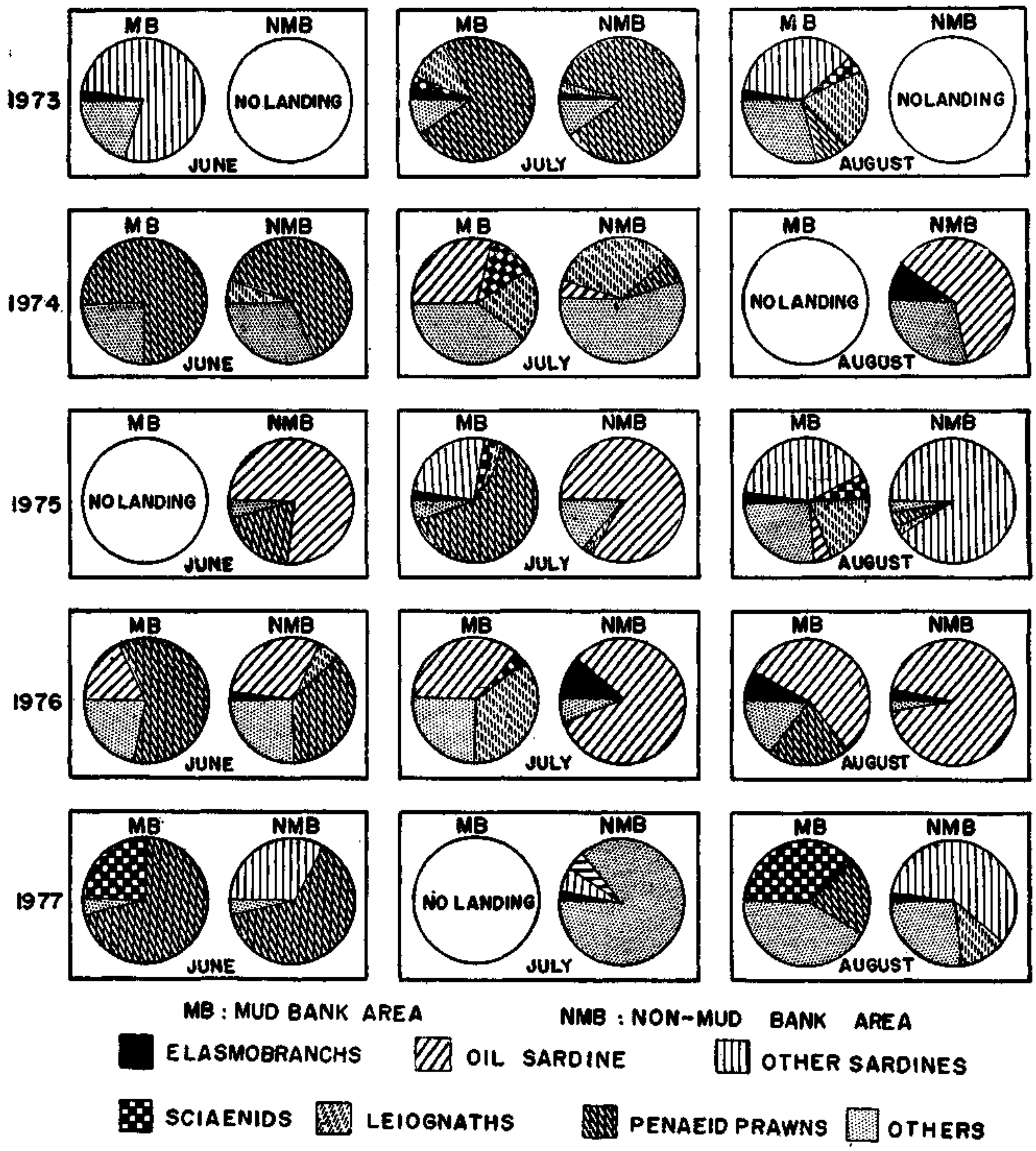


Fig. 7: Relative abundance of important fishes landed at the mudbank and non-mudbank areas of Zone 1 during the years 1973-1977.

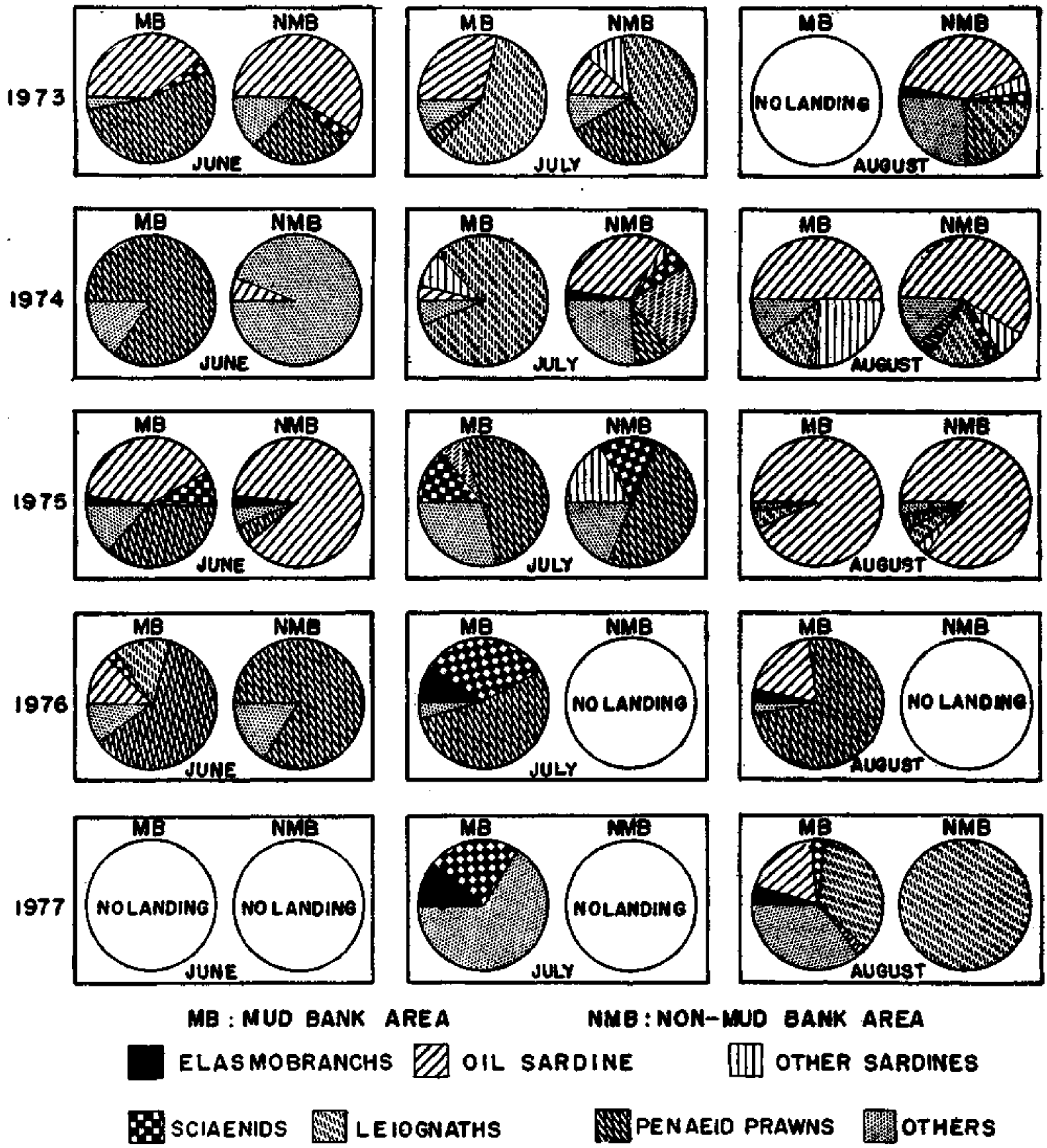


Fig. 8: Relative abundance of important fishes landed at the mudbank and non-mudbank areas of Zone 2 during the years 1973-1977.

DISCUSSION

It can be seen from the ten years' data (Table2) that the popular belief that mudbanks are, as it were great fish bowls, abounding in fish which can be caught easily needs rethinking. The abundance of species, like *M. dobsoni* (1967, 69 and 70), *S longiceps* (1967, 69 and 70), *Leiognathus* spp. (1969, 70), *Stolephorus* spp. (1969, 70), Ambassis sp. (1969, 70) and *P. indicus* (1970), that is seen in the mudbanks many a days in the months of July-August (Table 1) is in no way an exclusive feature of the mudbank, but is found all along the coast during the monsoon months. It has been found by many authors that the inshore fishes, especially prawns, move from deeper waters to closer to shore during the S.W. monsoon, probably due to the process of upwelling (Banse 1959). During the monsoon, the current has been observed to be southerly. The general tendency of fish being to swim against the prevailing current, it is possible that a good part of these fishes are then moving in shoals northward and a portion, on passing through the mudbank area, are easily caught by the numerous canoes operating in and outside the mudbanks. If so, it is also possible that a shoal of a particular composition, after its passing, is followed by another of entirely different composition, which might account for the abrupt changes in the composition of fish landed. The overall picture obtained thus seems to support the hypothesis that the catches landed at the mudbank area are from shoals which are on the move, and they are caught only at this area because at this time fishing is possible only at this region. While the data in general show (Table 2 and fig. 4) a higher landing for mudbank areas, fig. 6 shows the day-to-day variation in the catches of the mudbanks indicating the probability of the existence of a fishery resource along the west coast during the monsoon months. This is furthermore indicated by the fact that, whenever weather permits fishing, the fishermen land sizable quantities of the same species from the non-mudbank areas as well; only that the fishermen operating at the mudbank area have an added advantage in fishing at the periphery and occasionally inside the mudbank even when fishing is not generally possible. It may also be mentioned that fishes caught elsewhere in non-mudbank areas on calm days are often landed at the mudbank area due to the good marketing facility then available only in the mudbank area, thus raising the catch figures wrongly attributed to mudbank. For example, on calm days, fishermen stationed at the mudbank have been observed to move out to places like Thrikkunnapuzha, Kalikadu (Kayamkulam), etc., and bring heavy catches of prawns and fishes. These are also landed at the mudbank area. Thus the higher landing figures generally available for the mudbank area includes the catches not only of the mudbank, but also of far-away areas which have no mudbank condition what so ever (Fig. 1 and 2).

A low overall total marine landing figure of 1970 monsoon fishery (table 2) as well as a very poor catch in the mudbank areas in 1971 made the press to come out with headlines. In fact, there was a perfect mudbank formed in 1971, though the fishery associated with it suffered a set back. But it is interesting to note that the non-mudbank area had at this time a very good fishery. All through from 1971, except 1972 and 1973, the fishery of the mudbank area was of a low magnitude. in the year 1974 it amounted only to a very meagre amount of 47.17 tonnes. It may thus be seen from this data that the popular opinion about the mudbank fishery is baseless; and to think that an area of 10-25 km² within a period of three months to produce a fishery of its own or even to 'attract' fishes in such large mumbers is beyond all scientific reasons. 1971, a year of good mudbank formation, had a landing figure of 7415.20 tonnes for mudbank and non-mudbank, whereas the year 1973, when the mudbank was poorly formed, had an all-high figure of 13632.54 tonnes for both mudbank and non-mudbank. It may be pointed out that of the 7415.20 tonnes in 1971, the mudbank contribution was only 982.57 tonnes. During the years 1973-77 the highest figures for mudbank (10425.21 tonnes) and non-mudbank (14231.55 tonnes) were recorded in 1973 and 1976, respectively. The lowest was in 1977 for both mudbank (47.81 tonnes) and non-mudbank (2884.70 tonnes) in Zone 1 (Fig. 3). In Zone 2, the highest figure recorded for mudbank was in 1974 (8776.84 tonnes) and for the non-mudbank areas it was in 1973 (12100.61 tonnes). The lowest figure recorded for the regions were respectively in 1976 (2638.19 tonnes) and 1977 (0.25 tonnes) (Fig. 4).

In zone 1, the catch per unit effort (CPUE) for the mudbank (Fig. 5) was 4.6 kg and that for the non-mudbank was 5.4 kg, showing a higher CPUE for non-mudbank areas, but in zone 2, the CPUE was 5.2 for mudbank and 3.0 for non-mudbank, showing the reverse. The variation in CPUE clearly shows that the catch is determined by the fishing facility, man power and gear and craft rather than the mudbanks. (Fig. 3 & 4). It is also seen that, as the monsoon of 1973-77 was such as to favour fishing all along the coast, the non-mudbank, covering a large area and having more canoes and man-power in operation, was able to dominate with the catch; the overall landing figures show a higher catch for the non-mudbank areas (45301.53 tonnes) and lower for the mudbank areas (41605.11 tonnes). The occurrence of the stock remaining the same, the yield would have most probably shown a considerable reversal had the monsoon been more active so as to prevent fishing in the non-mudbank regions.

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