ABRUPT SET-BACKS IN THE FISHERIES OF THE MALABAR AND KANARA COASTS AND "RED WATER" PHENOMENON AS THEIR PROBABLE CAUSE*

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INTRODUCTION

IN the course of fish population studies along the West Coast in 1948, it was observed that there was an abrupt and a severe set-back in the fishery by about the middle of October within two weeks of the commencement of a bumper season. While we were investigating the probable cause of this dimunition, Mr. T. P. Bharatan, Assistant Director of Fisheries, Madras, drew our attention to the occurrence of the "red water" phenomenon at Hosdurg, one of the important fishing centres in the South Kanara District, where the fishing operations had practically come to a standstill. On further enquiry it was learnt that the phenomenon was widespread over a long stretch of the West Coast of India. The results of a study of the "red water" phenomenon at Hosdurg and of enquiries at other fishing centres along the Kanara and Malabar coasts, and a few general observations on the phenomenon of "red water" are recorded in this paper. A more detailed study of all aspects of the phenomenon could not be undertaken as, shortly after the investigation was started, the phenomenon declined and disappeared; however, the conclusion from the above studies and observations seems inescapable that the sudden diminution in the fisheries is due to the prolific and equally sudden multiplication of *Noctiluca miliaris* (Macartney), and their subsequent death and decomposition.

PREVIOUS WORK

Though large-scale impoverishment of the fisheries such as was observed on the Malabar and Kanara coasts during October 1948 has not been recorded so far from other coasts, there are quite a number of records of localised instances of fish mortality. Hornell (1908) recorded a case of

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severe mortality among sardine shoals in the sea near Mangalore in the middle of November. The area affected was a patch of the sea about fifteen miles long, one or two miles from the shore. The water in the affected area was greenish grey and turbid with unrecognisable organic debris in suspension. He (1917) also recorded numerous instances of mortality among marine animals in general and fish in particular near Calicut, and attributed the mortality to the occurrence of swarms of certain flagellates. This was corroborated by Jacob and Menon (1947). Chacko (1942) and Chidambaram and Unni (1942) recorded cases of mortality in the month of May among fishes and other marine animals near Krusadai Island in the Gulf of Mannar, due to the swarming of the blue-green alga—*Trichodesmium erythreum* and the subsequent fouling of water by their death and decomposition. Aiyar (1935) observed in June 1935 mortality in fish and marine animals near Madras caused by the occurrence of *Noctiluca* in exceptional abundance. He surmised that the mortality was due to the rapid utilisation by the organisms of available oxygen in sea water.

Nishikawa (1901) observed 'red tide' in Japanese waters due to the superabundance of the peridinian—*Gonyaulax polygramma* Stein, causing sometimes considerable destruction of Oysters. Gilchrist (1914) has shown that swarming of *Noctiluca* in South African seas has been responsible for severe mortality among the marine animals. Allen (1933–42) described in a series of papers the phenomenon of discoloured water in the La Jolla Bay, San Diego, California. In May 1933, the "red water" described was due to the preponderance of the Protozoan *Prorocentrum micans* Ehr. In September 1942 the "red water" observed was caused by the conspicuous abundance of *Gonyaulax polygramma* Stein. Allen has not, however, noticed mortality among marine animals as a result of the occurrence of these organisms in such enormous numbers as to discolour the waters. Davis (1948) has recorded a remarkable case of fish mortality in the Gulf of Mexico off the Florida Keys occurring sporadically over a period of nine months from November 1946 to July 1947 due to the superabundance in the sea of a new species of Gymnodinium—*Gymnodinium brevis* Davis, giving the sea surface a yellowish green colour. In a recent paper Brongersma (1947) has expressed the opinion that the fish mortality is caused by noxiousness of the red water of dinoflagellates; the occurrence of the red water in its turn being the result of the presence of upwelling water containing high concentration of nutrients. Marchand (1928) contends that the red water occurrences common in the South African coasts are revealed to be due to masses of *Noctiluca* and attributes the fish mortality to the decay of these masses of *Noctiluca* and diatoms polluting the water.

"Red Water" at Hosdurg

Investigations on the red water were carried out at Hosdurg, during the last week of October 1948. During the period of occurrence of the phenomenon, the south-west monsoon had ceased and the north-east monsoon had not yet started, and there was bright sunshine. The sea appeared to be comparatively calm and the water presented the appearance of a thick jelly-like slimy mass and contained decaying organic matter. The colour of the slime was dark grey due to the mixing up of the organic mass with the fine bottom clay. The fishermen of the locality found it extremely difficult to operate the nets. Cast nets would not sink, as they would do normally due to the thick slimy water, if operated, the fishermen could not drag the nets, on account of the weight of slime clogging the meshes; even the boats could not be steered properly through the water. Near Hosdurg, the sea bottom consists of a thick layer of fine brownish black clay. The bottom is often stirred by currents, and the clay particles remain suspended in water for fairly long periods.

A few horizontal plankton hauls were taken with considerable difficulty from the surface and at depths of four and fourteen fathoms. The plankton samples were fixed in five per cent. formalin for further detailed study. The surface plankton was very rich quantitatively and consisted almost exclusively of swarms of *Noctiluca miliaris* with a few other planktonic elements, such as lamellibranch and polychæte larvæ, copepods such as *Oithona* and *Euterpina*, diatoms and protozoans such as *Dinophysis*, *Coscinodiscus* and *Gymnodinium*. It may be stated that the minority elements constituted less than five per cent. of the total volume. When the plankton sample was allowed to stand for a while, the *Noctiluca*, many of them in active stages of fission, formed a thick layer of pink mass at the surface.

The plankton of the horizontal haul at a depth of four fathoms in the sixteen fathom area was dirty grey in colour, and consisted of a mass of mostly dead and putrefying *Noctiluca*, in different stages of disintegration. Most of the *Noctiluca* were shrunk or burst, but the flagellæ and cell walls were discernible in several individuals.

The plankton from fourteen fathoms in the sixteen fathom area was as slimy as that from the four fathom collection except that the slime was more profuse and mixed with black mud, a few fragments of *Noctiluca* and diatoms (*Coscinodiscus* and *Pleurosigma*), and a large number of foraminiferan shells.

An interesting feature of the phenomenon at Hosdurg was the occurrence of a few scattered zones of clear water, each about a furlong square in area,

which could be marked out distinctly from the affected regions. The slime-free parts of the sea, which may be appropriately termed "pockets" of normal plankton, rich and varied, contained a plankton fauna with the copepod element predominating. The following organisms are arranged in their order of abundance:—

Zooplankton	Phytoplankton
Oithona plumifera	*Coscinodiscus gigas* var. *prætexta*
Oithona rigida	*Coscinodiscus concinnus*
Acartia erythræa	*Pleurosigma angulatum* var. *strigosa*
Pseudodiaptomus sp.	*Rhizosolenia alata* f. *indica*
Corycæus furcifer	*Rhizosolenia robusta*
Euterpina acutifrons	*Ceratium massiliense*
Temora turbinata	*Ceratium furca*
Evadne sp.	*Ceratium fusus*
Polychæte larvæ (Spionids)	*Dinophysis miles*
Peneid zoea	*Dinophysis caudata*
Ostrea post larva	*Gymnodinium marinum*
Mytilus post larva	.. ..
Noctiluca miliaris	.. ..
Portunid zoea	.. ..
Carangid eggs	.. ..
Fish larvæ	.. ..

The *Noctiluca* in such areas was, however, conspicuously low in number though in excellent living condition. Under the binocular microscope, copepods could be observed clinging by their anterior extremities round bits of slime. It is difficult to say whether the segregation of zooplanktonic elements, particularly the copepods, in exceptionally large numbers in those "pockets" was due to their avoidance of the "red water" area and the consequent ingression into the clearer waters or to any physico-chemical factor prevailing in that part of the sea at the time.

The salinity and specific gravity of sea water in the affected area at Hosdurg on 23-10-1948 were 35·45‰ and 1·024 respectively. Other hydrological data such as oxygen, ammonia and nutrient salts could not be collected for lack of facilities. The study of the phenomenon could not be spread over a longer period and at other places as the phenomenon was already on the decline at the time of our investigation at Hosdurg.

The nekton of the area was very poor. A few dead fishes were found floating on the surface of water emitting a foul smell. Close to the shore a number of birds were found hovering over the surface of water picking

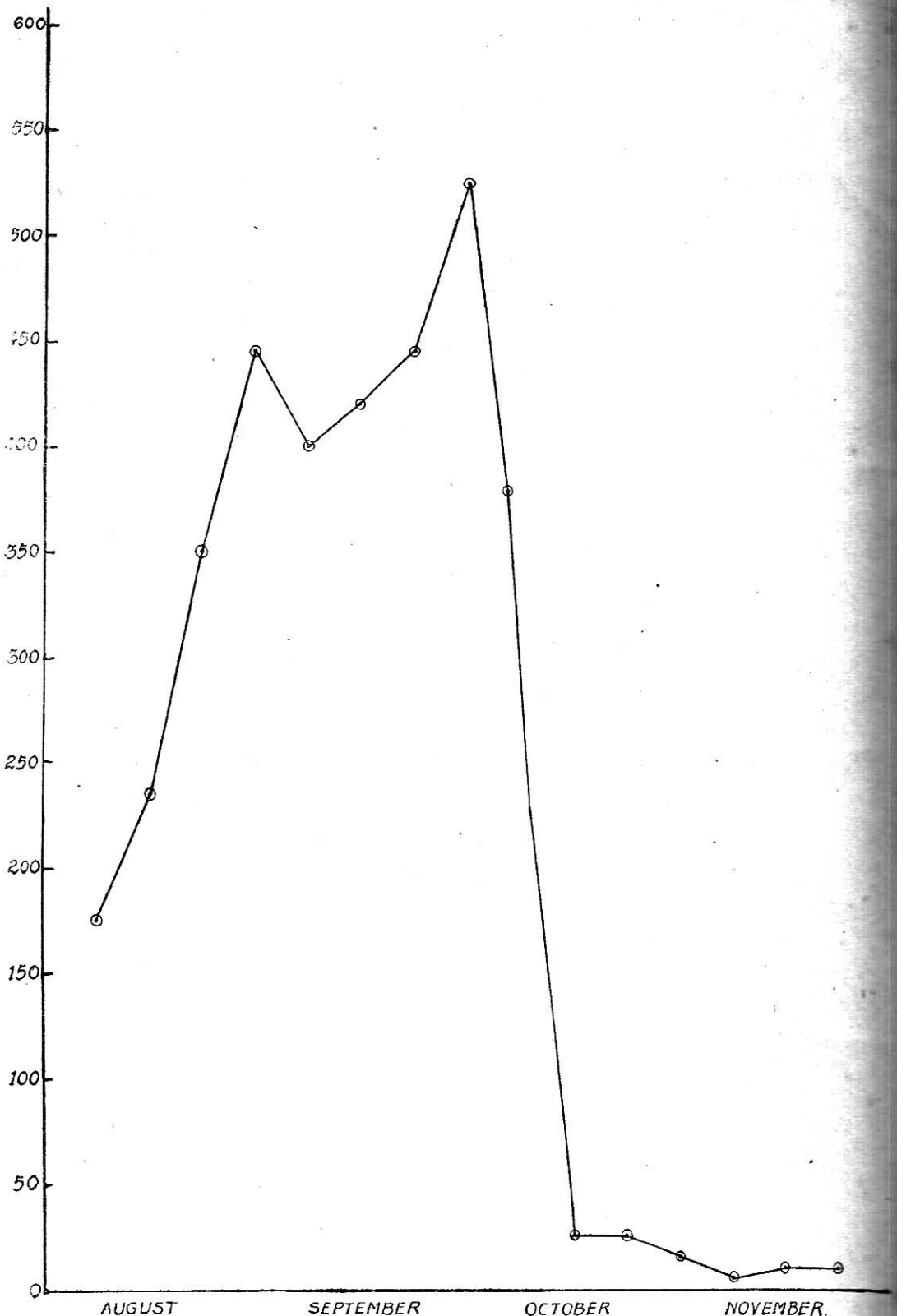
up the dead fish. Repeated netting brought no live fish from the area. The following species of dead fish were, however, entangled in the nets:—

Arius thallasinus	*Synagris japonicus*
Cynoglossus semifaciatus	*Caranx kalla*
Leiognathus bindus	*Carcharias* sp.

Examination of the stomach contents of the dead fish revealed the presence of a small quantity of the slimy debris found in the water. The gills and gill-rakers of all the fish examined were clogged with thick slime present in the sea water.

Widespread Occurrence of the "Red Water" Phenomenon

Enquiry showed that the phenomenon was widespread over an extensive stretch of coastal waters in the Malabar and South Kanara Districts. Pink patches at the surface of the sea first, and later thick slime in water were the initial indications of the set-back in the fishery during the period of its occurrence. At our request, the Assistant Director of Fisheries (Coast) furnished from forty-two Fish Curing Yards in the two districts, detailed information relating to the period and extent of the occurrence of the phenomenon, to the manner in which fishing was affected and to the occurrence of such a phenomenon in the previous years. This information and the results of our personal enquiries at a number of fishing centres, revealed to us that the phenomenon observed at Hosdurg, occurred on a stretch of coast about one-hundred and seventy miles long from about three miles north of Calicut in Malabar to a few miles north of Gangoli in South Kanara District, that it has not been known to occur at any time in the past, that difficulty in fishing operations was uniformly felt throughout the area of its occurrence, that fishes had practically avoided the affected areas and that it occurred for about ten to twenty days during the later half of October over a distance of about four to twenty miles from the shore. A consolidated report received from the Assistant Director of Fisheries (Coast) states: "Such a phenomenon was not observed anywhere on this coast within the memory of the oldest of the present generation. Even the very old fishermen say that they never saw such a phenomenon in the sea and that they have never heard their elders saying about it. Wherever it was seen the fishing became impossible and there were no catches during the period of its occurrence and some days after. The different kinds of nets used in the coast could not be cast as they would not sink in the sea with the use of ordinary weights and even if they sank, the fishermen found it difficult to pull them up as the slimy substance was sticking to the nets and the water would not pass out through the meshes. There are instances when the nets which



GRAPH I. *Noctiluca* Peak on the Calicut Coast, 1948
(Numbers denote *Noctiluca* in 1 c.c. of standardised plankton)

were cast in this water got torn when they were pulled up. Even hooks and lines could not be operated successfully as they did not go sufficiently deep in the sea and the sharks were not able to see the bait and swallow it. The lines got thick by the slimy substance sticking on to them. Fishing was comparatively a failure throughout the period of the appearance of the substance in the sea. The substance was reported to be visible with a thick layer of muddy water with purple colour and a peculiar smell."

ABUNDANCE OF *Noctiluca* IN THE SEA NEAR WEST HILL

It is significant that just prior to and during the occurrence of the phenomenon elsewhere on the coast, there was a marked abundance of the *Noctiluca* population in the sea near West Hill. From the records of the quantitative estimation of the triweekly plankton collections maintained at this laboratory, it is seen that *Noctiluca* made its first appearance in the year in the last week of May and continued to be present in normal numbers in the plankton during June and July. In August and September, its incidence gradually increased until in the latter half of September it attained a peak constituting the main bulk of the plankton. It was still dominant upto about the middle of October when there was an abrupt decline in its numbers. They practically disappeared from the plankton by the middle of November. The accompanying graph shows the relative abundance and scarcity of *Noctiluca* in the plankton during the period from August to November 1948.

During the peak period pink patches of *Noctiluca* were very commonly seen at the surface of sea water and were even washed ashore in large quantities due to tidal action. Examination of samples of sea water brought to the laboratory showed that considerable numbers of *Noctiluca* were dead and settling down to the bottom of the glass trough while the live ones formed a thick layer at the surface; and after two days it was observed that decomposition of the dead *Noctiluca* had set in and a large number of marine ciliates and flagellates had developed.

On the morning of 30th September an interesting case of shoaling of the Malabar sole—*Cynoglossus semifasciatus*—was observed. As there was bright sunlight and the sea was very calm we were able to see shoaling of large masses of the sole very clearly just below the surface of water. In spite of their active movements the fish could be netted easily. A single haul of a cast net brought in about 9,000 fish weighing 162 pounds. The fishermen were able to draw the net with the fish to the boat with very great difficulty. Further, a signal was given to a boat seine (Paithu vala) party who caught in a single operation of the net two complete boat loads of the fish. It is possible that the fouling of the bottom layers of water by the

dead *Noctiluca* was responsible for the occurrence of the habitually bottom fish at the surface. It was stated that at Hosdurg also the pink patches preceded the increase of *Noctiluca* population which formed thick slimy masses in suspension.

The Effect of "Red Water" on the Fisheries

The immediate effect of the occurrence of the "red water" or slimy water phenomenon was a steep fall in the fish catches over a long stretch of the coastal waters. It is clear from our own observations and enquiries that the bulk of commercial fishes—particularly the shoaling species, the chief among them being the mackerels and allied forms, sardines and anchovies—did not appear in such waters. There was, however, no severe mortality of fishes. It would appear that the physicochemical conditions of the waters thus affected were in some way unfavourable for live fish that they completely avoided such areas. Though the fishing season was favourable in the first half of October it deteriorated during the latter half of the month when the phenomenon occurred. Table I, which gives the total quantities of fish landed in October from 1944 to 1948 for the area covered by thirty-one Fish Curing Yards from Calicut to Gangoli, shows the extent of decline of fish-landings in October 1948 as a result of the widespread occurrence of the "red water" phenomenon. It may be added that the quantity of fish landed in October 1948 pertains only to the first half of the month, there being practically no fishing during the second half.

Table I

Total fish landings from Calicut to Gangoli

October 1944	..	5,14,860 maunds*
October 1945	..	7,87,980 ,,
October 1946	..	4,55,084 ,,
October 1947	..	5,59,828 ,,
October 1948	..	2,42,970 ,,

* 1 Maund = 80 lbs.

Plankton records show clearly that during the occurrence of the "red water" phenomenon there has been considerable destruction, not only of fish eggs and larvæ but also of plankton in general (diatoms, copepods and cladocerans) which forms the food of fishes. The repopulation of the area by these forms which would attract fishes to the coastal waters was observed to be slow. That the avoidance by fish of the "red water" zone was not merely due to the physical obstruction caused by the slimy masses of *Noctiluca* but also to the high toxicity of the water, was demonstrated by

the following simple experiment. A few live fish were kept in the filtered " red water " in glass troughs with separate controls containing sea water taken from an unaffected area. While the fish in the controls were perfectly normal throughout, those in the filtered water from the affected area, though normal at the beginning, showed signs of the toxic effects of the filtrant in two hours and died thereafter.

Discussion

It appears clear from the foregoing observations that the severe set-back in the fishery over a long stretch of coastal waters in the Malabar and South Kanara Districts during October 1948 was mainly due to the putrefaction of a superabundant *Noctiluca* population, giving rise to thick masses of slimy substance occurring in a state of suspension in the coastal waters. The most characteristic feature of the phenomenon was the extensive slimy masses of dead and decaying *Noctiluca* mixed partly with the fine clay of the mud banks characteristic of the area. It was therefore, considered appropriate to use the term " slimy water " for this phenomenon. But we have, however, preferred to retain the term " red water " since it has already been used by previous workers (Gilchrist, 1914; Marchand, 1928; Nishikawa, 1901) to indicate the abundance of *Noctiluca* in other seas. It must, however, be admitted that even in the present instance, to begin with, large pink patches of *Noctiluca* were noticed on the surface waters at several places in the coast, which soon gave place to the slimy masses.

It may be pointed out that the term " red water " has been used vaguely in the past. As has been observed under the chapter "Previous Work" this term has been applied to denote the superabundance of several forms such as dinoflagellates, euglenoids and peridinians. The hue presented by these forms varies with the individual organism concerned, and further with the intensity of their populations. In an instance such as the one during the euglenoid domination, the colour imparted to the sea water is definitely not red, as has been noticed by us on certain occasions. Hornell (1923) admits that the colour of this water is " amber brown " though he uses the term " red water ". We agree with Jacob and Menon (1948) that the colour of the water during euglenoid abundance is brownish resembling hay decoction. Further the colour of the dense patches of *Noctiluca* is also not red in the strict sense but only pink. It is therefore necessary to define precisely the term " red water " and use it appropriately.

The researches of Gilchrist (1914) and Marchand (1928) have shown clearly that in African seas, thick masses of decaying *Noctiluca* bring about pollution of water resulting sometimes in mass mortality of fish and other

marine animals. The only record of mortality of fish in Indian waters due to the abundance of *Noctiluca* is by Aiyar (1935). Hornell (1917), however, asserts that *Noctiluca* is not an active agent in causing fish mortality. He states " I have seen it in great profusion colouring considerable areas bright pinkish red both off Cannanore and Palk Bay and in neither locality did I find any associated with fish mortality nor would any of the fishermen accuse it of evil influence; they agreed in declaring it to be innocuous ". On the other hand we are inclined to think that the only case of severe mortality of fish recorded by Hornell (1910) off Mangalore was due to the abundance and subsequent death and decay of *Noctiluca* as his statement " a haul of plankton where dead sardines were plentiful almost entirely consisted of obscure organic unrecognisable debris, so fine that the meshes of the townets became clogged almost immediately, rendering it difficult to collect a satisfactory sample " agrees very well with what has been observed by us during the occurrence of " red water " in October 1948. It is true that mere abundance of *Noctiluca* unaccompanied by their death and decomposition is harmless to the fishery. The contention of Hornell that abundance of *Noctiluca* is innocuous to fish life while the dominance of euglenoids is the prime cause of mortality of marine animals, especially fishes, along this coast, appears to us to be untenable. Our laboratory observations show that marine euglenoids and ciliates develop in large numbers in glass troughs in which decaying *Noctiluca* are kept, indicating that the latter constitutes a good culture medium for these organisms. The same sequence seems to occur in nature as observed by us on the 29th August 1949 when dense populations of euglenoids mixed with a small number of ciliates made their appearance in the shore waters near West Hill. A bottom haul of plankton taken at 15 meter depth revealed the presence of a thick layer of putrefying *Noctiluca*. From the plankton records at our laboratory it was seen that for a week prior to this date, there was an abundance of *Noctiluca* in this part of the sea. At the same time it was observed that the fish catches for this date was very poor. There was, however, no fish mortality. In our opinion the avoidance of this part of the sea by the fishes is to be attributed to the toxicity and the physical obstruction caused by the putrefying *Noctiluca* rather than to the abundance of the euglenoids. Euglenoids constitute only a link in this chain of succession and cannot be regarded as the primary cause of the set-back in the fishery or the fish mortality.

As stated above the occurrence of *Noctiluca* " red water " affects fish life in every way. The water rendered slimy by the decaying *Noctiluca*, causes mechanical obstruction to the movement of fish while its foulness is toxic to fish life. The fishes either die or pass out of such waters. There

is also considerable destruction of fish food, fish eggs and larvæ. It appears to us that, the avoidance of such waters by the majority of the fish population is of greater consequence to the fishery production rather than the mortality of a few fishes. It has been observed on occasions that fish, which cannot immediately retreat from the "red water" zone, especially when the increase of *Noctiluca* is sudden, actually die. Detailed enquiries made at different fishing centres along Malabar and South Kanara coasts during the occurrence of red water in 1948, have shown that there was not a single instance of mass mortality of fishes anywhere; but on the other hand, the impoverishment of the fishery was noticed throughout the area. Generally, the shoaling species, which form the bulk of commercial fishes, shift from foul water areas to more favourable grounds in the neighbourhood. In the West Hill sea, the shifting of the fishery has been observed not only during periods of excessive production of *Noctiluca*, but also on days when dense populations of euglenoids, *Nitzchia* and *Oscillatoria* make their appearance. On such days the sea near West Hill which is normally a productive area presents a deserted appearance as the fishermen do not find it profitable to fish there. Beyond the affected area, however, the fishery appears to be good, as has been observed by us in the course of fish population studies. The local fishermen seem to know the shifting nature of the fishery when the "red water" is on, and the places where they can get a good haul.

It is suggested that the frequent occurrence of foul water, whether due to *Noctiluca* or other forms of Protozoa, diatoms, etc., with its attendant toxicity and destruction of fish food may possibly be one of the factors responsible for the scarcity of the oil sardines, which once contributed to the bulk of the commercial fisheries along this coast.

From previous records as well as the present investigation, it is evident that there is a definite periodicity (September to November) in the occurrence of foul water, along this coast in varying intensities, causing adverse effects on fishery in general. There are many gaps in our knowledge of this phenomenon. The causes of the sudden outburst and multiplication of organisms which result in foul water are at present obscure. The severe turbulence of the sea during the south-west monsoon period on the Malabar and South Kanara coasts possibly combined with upwelling in the offshore region having impact on inshore waters, the stirring up of the fine bottom sediments characteristic of this part of the coast and the sea currents may be severally responsible for the phenomenon. Sewell (1932) has adduced evidence to show that "the last part of the Antarctic Bottom Drift, after passing across the South of Ceylon is deflected by the Maldive ridge to the north and flows

northwards into the Laccadive sea especially along its east margin". The physicochemical factors responsible for the immense production of *Noctiluca* and other forms, the different organisms which cause foul water, the causes of their death and decay, the maximum density in their population for bringing about the adverse effect and the precise effect on fish and other marine animals are some of the problems which require detailed elucidation and investigation.

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