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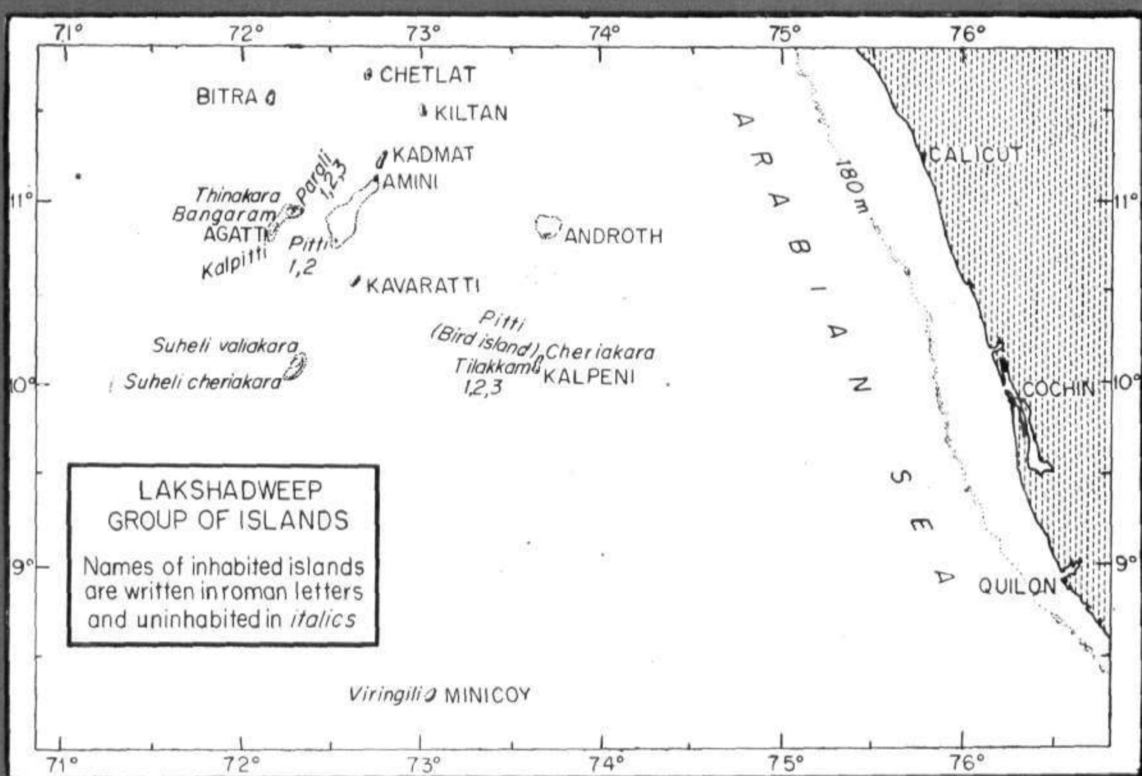

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ENVIRONMENTAL FEATURES OF THE SEA AROUND LAKSHADWEEP

P. V. R. Nair, A. V. S. Murty, C. P. Ramamirtham, D. S. Rao and V. K. Pillai
Central Marine Fisheries Research Institute, Cochin

Introduction

The sea around Lakshadweep forms a part of the southeastern Arabian Sea, also known as the Lakshadweep Sea. The importance of the waters in this region with their special ecological conditions has been shown by Jones (1959c). The submarine Laccadive-Chagos ridge located in this region greatly influences the water masses and Cooper (1957) suggested the importance of the ridge in the enrichment of the upper waters of the mid-ocean in the Arabian Sea. The region also supports a rich pelagic fishery. A knowledge of the environmental conditions of the waters around Lakshadweep, would help in understanding several problems of oceanographic and fishery nature. The Central Marine Fisheries Research Institute was the first to initiate detailed oceanographic investigations on the environmental features in this region as early as 1959 (Jayaraman *et al.*, 1959, 1960) and since then a lot of information have been added by the same and others. The following is an account of the present day information available on the environmental characteristics of the waters around Lakshadweep.

Wind system

For a better understanding of the environmental characteristics of the Lakshadweep Sea, a knowledge of the general wind systems and currents prevailing in the northern Indian Ocean and Arabian Sea in particular is essential.

The Arabian Sea and Bay of Bengal which form parts of the northern Indian Ocean are subject to seasonal monsoon winds. During the summer the southwest monsoon and during the winter, the northeast monsoon prevail over this region. In summer, a seasonal low pressure area develops over the Central Asia which causes the winds to blow persistently from southwest forming the southwest monsoon winds. In winter, a high pressure zone develops over the Tibetan plateau and its neighbourhood. The winds from this high pressure region move towards the low pressure belt in the Equatorial Indian Ocean, blowing from northeast to southwest which form the northeast monsoon. The winds are southwesterly during southwest monsoon and northeasterly during northeast monsoon. During March–April and October–November the winds are weak and variable. The atmospheric circulation undergoes a complete reversal in direction during a year. In general, the winds are stronger and steadier during the southwest monsoon than during the northeast monsoon. In the Arabian sea, the southwest monsoon prevails during June–September and northeast monsoon during November – February, the transition being during October.

Sea surface circulation

The sea surface circulation in the Arabian sea, in general, follows the prevailing wind system over the area with stronger and steadier currents during the southwest monsoon compared to those in the northeast monsoon. During the southwest monsoon the surface currents in the open ocean are eastwards and clockwise in direction due to the coastal configuration. It flows northeastwards along the Arabian coast and southwards along the Indian coast as wind driven ocean current. This clockwise circulation strengthens with the progress of southwest monsoon. This coastal current is a continuation of the Somali Current flowing along the East African coast. During the N.E. monsoon the general surface circulation is more or less reversed in the open ocean and is northwestward with a counter-clockwise circulation along the coasts. Along the west coast of India the surface flow is mostly in the north-northwest direction upto 20°N changing to west-northwest direction thereafter, and off the Arabian coast it moves in the southwest direction. As stated earlier these directions of flow are direct effects of the monsoons and the clockwise or the counter clockwise patterns are set up during the transition periods when the winds are variable. The counter clockwise circulation ceases by the end of January and the clockwise coastal current is gradually established by May. This reversal of the coastal current system along the coasts in the Arabian sea is not simultaneous all over the area. During February–April the predominant flow in the open sea is towards west or northwest.

Hydrographic conditions

The oceanographic conditions in the sea around Lakshadweep reveal many interesting environmental features. During summer (Jayaraman *et al.* (1959), which is the period of the year when stable conditions exist in the environment in the Arabian sea, the distribution of temperature indicates the presence of a more or less isothermal layer down to 50 m. The temperature discontinuity layer (also known as the thermocline layer) is found to be between 75 and 150 m. The salinity maximum is observed to occur within a tongue of high saline water at about 100 metres. At deeper depths comparatively low saline waters are found indicating the presence of sub-antarctic drift.

The dissolved oxygen content from surface layers down to 50 m is more or less uniform in the region. From 75 m downward there is a rapid decrease in oxygen content and at 150 metres the oxygen concentration of the waters attains very low minimum values. This layer of sharp sudden decrease in oxygen content corresponds to the layer of the thermocline. This oxygen poor layer continues further below and extends down from 150–500 m. The density (sigma-t) values range between 25.00 and 27.00 within this layer. At deeper depths from 700–1000 m, the values increase and at 1000 m it is nearly double that of the minimum seen above. The oxygen minimum layer is several metres thick and the upper level of this is present at 150 metres as compared to about 300 m in the other open parts of the ocean. These features conclusively point to a rather high level of productivity of the Lakshadweep waters. Below 1000 m there is a remarkable increase in oxygen values up to 3.5 ml/l compared to 0.5 ml/l in the oxygen-deficit layer found above. This has been attributed to the south polar water sinking at the Antarctic and subtropical convergences and spreading in the deep bottom into the basins of the Indian ocean.

Water masses: Three main types of water masses are noticed during the summer in this region (Jayaraman *et al*, 1960). They are:

1) The water mass characterised by rather sharp salinity gradients of very small temperature range and density (sigma-t) values between 21.00 and 23.00 from surface down to 75–100 m, corresponding to the Arabian Sea upper sub-surface waters described by Sastry (1960) as the water mass which participates mostly in the upwelling and sinking phenomena.

2) The Arabian Sea lower sub-surface water mass characterised by a steep temperature gradient with a salinity range hardly exceeding 0.8‰, sigma-t values between 23.00 and 25.00 and much better defined than the first one.

3) The Indian Ocean equatorial water mass below 200 m having small temperature and salinity gradients and appearing like isohaline waters at certain places.

Water movements: The existence of circulatory water movements (eddies) around the islands at practically all levels down to 500 m has been observed from the nature of the density surfaces and geopotential anomalies. Anticyclonic movements (eddies) are present in the upper 100 m and reverse of that below that level. These eddy-like circulatory motion of the waters helps to keep the fish eggs and larvae within the highly productive waters in the vicinity of the islands for a considerable length of time.

It would be worth mentioning here that these circulatory water movements considered typical of island regions are responsible for high levels of productivity observed in the Lakshadweep Sea (Sen Gupta *et al.*, 1979). They have also found that patterns of distribution of nutrients and the nutrients-oxygen relationships were similar to those observed in the other parts of the Arabian Sea. The general upsloping of the water masses around the islands is attributed to the vertical turbulent mixing and wind induced upwelling in the area.

These circulatory water movements are present during winter also, but with lesser intensity and particularly limited to a shallow depth of about 200 m (Patil, *et al.*, 1963). Significant circulatory movements are found in the northern region especially near Bitra Island where it is cyclonic while near Agatti and southeast of Kiltan islands it is anticyclonic. Superimposed upon this general circulatory movements around the islands, the northwesterly drift produced by the prevailing winds is noted in the upper 30 m towards west of Suhelipar, and further towards east due south of Agatti Island. North of Agatti and Androth islands an easterly drift in the upper layers was noticed. An important characteristic of the season is the sinking which was observed in the western region of Bitra-Agatti-Suhelipar along the 23.00 sigma-t surface. High surface salinities were also observed during winter especially in the north-northwestern region, that is the region of the Bitra-Chetlat-Kiltan region, compared to the summer season. This is supposed to be due to the excess of evaporation over precipitation which is characteristic of the winter season. The water masses viz., Arabian sea lower sub surface water and the Indian Ocean Equatorial Water contribute mainly upto 2000 m depth and the presence of Antarctic Intermediate water especially in the eastern part of the Lakshadweep region below 2000 m depth was traced.

Chemical Characteristics of waters: The chemical characteristics of the waters of the lagoon and the sea around Kavaratti atoll such as salinity, pH, total alkalinity, dissolved oxygen, reactive phosphate, total phosphorus, chlorophyll and the particulate organic carbon showed high degree of variability except pH and alkalinity, with location in the lagoon. (Sankaranarayanan, 1973). A marked diurnal variation in the oxygen concentration of the waters of the lagoon was found whereas other chemical factors, mentioned above, did not show significant changes. It was also observed that most of the phosphorus present in the waters was bound organically. Sediment phosphorus showed very low values (0.04–0.06% as P_2O_5) indicating the poor retention of phosphorus with the sediments. It was noted that the benthic macrophytes play a role in the recycling of nutrients in the lagoon (Sankaranarayanan, 1973).

Sea surface temperatures: The sea surface temperatures in the open Arabian Sea were found high during May–June period while a lowering of temperature was observed in the month of July with the advance of the southwest monsoon. The lowered sea surface temperatures ranged from 1°C to as much as 4.5°C (Rao *et al.*, 1976).

Oxygen maxima and minima: The depths of occurrence of oxygen maxima (4.5–5 ml/l and above) during the summer, southwest monsoon, post-monsoon and northeast monsoon have been found to be in the upper surface layers up to 40m, 10m, 10m and 10m respectively whereas those of oxygen minima (0-1.0ml/l) during the same periods were at 300m, 150m, 100m and 300m respectively in this region (Rao *et al.*, 1970). These depths of occurrence of oxygen maxima and minima appear to be governed mainly by water movements, circulation and mixing, in addition to the biological processes.

Water characteristics around Minicoy Island: From the distribution of temperature, salinity, dissolved oxygen and density, it has been found that upwelling occurs in the very close vicinity of the Minicoy Island during the November – December period (Rao *et al.*, 1966). This phenomenon was found limited to the upper 150m. The presence of diverging current systems has been attributed to the causes of upwelling. During this period the general pattern of the current in the southern part of the Arabian Sea is westerly. Due to the coastal configuration, a north-northwesterly current develops off the west coast of India. These two currents diverge in the vicinity of Minicoy leading to upwelling in this region. The relatively low saline lighter water seen in the surface layers in the nearby regions can be the Bay of Bengal water possibly carried westward by the North Equatorial Current (Rao *et al.*, 1966). It would be worth mentioning here that this upwelling is also presumed to be due to seasonal variations in wind-induced upwelling (Sen Gupta *et al.*, 1979).

Convergence and divergence zones: From dynamical studies of the Indian Ocean Expedition data during winter one large divergence zone around 71°E and 9°30′N has been inferred and a convergence zone with an axis roughly along 74°E around 8°N has also been found. The distribution of oxygen at 75m depth further confirmed the area and extent of the divergence zone during the winter. A region of convergence has also been observed around 8°N and 71°30′E in the upper 200 m during the southwest monsoon period The divergence zone corresponds to the region of upwelling and the convergence relates to sinking. The divergence zone or upwelling area mentioned above is thus in region west of Minicoy and the sinking or convergence zone in the region east of Minicoy in the open ocean during winter. During the summer the sinking or convergence of waters is found in the region west of Minicoy in the open ocean. Boisvert (1966) has observed that in December the surface water mass (up to 100 m) originates in the Bay of Bengal and flows southward along the east coast of India, rounds off Sri Lanka and moves northward along the west coast of India and also enters the Lakshadweep region.

Environmental features in relation to fishery: The information on the environmental characteristics of the sea around Lakshadweep given above are very interesting and useful from the point of view of the local fishery. It is seen that the sea around these islands are highly productive. The circulatory movements (eddies), the vertical turbulent mixing and wind induced upwelling in the region are contributory to this high productivity. The coral island of Minicoy (8°07′N, 73°18′E) is a major tuna fishing centre in the Indian Ocean (Jones and Kumaran, 1959) and the importance of this region from the point of tuna fishery has been well recognised. The presence of divergence and convergence zones in the open ocean near to Minicoy, the presence of upwelling in the close vicinity of the Minicoy Island, the eddy systems present there, and the presence of the relatively low saline waters seen in the surface layers during the November–December period contribute to the high productivity of the area. It has been shown that a stable eddy system present close to Barbados Island causes the littoral animals with long pelagic larval stage to be more abundant than in the exposed areas. Similar eddies are present downstream near the Lakshadweep islands, and it may be worthwhile to investigate whether this feature has any bearing on the tuna fishery. The existence of the anticyclonic eddies around these islands in the upper 100 m support a high productivity. The abundance of decapod larvae, including the red prawns observed in this area in plankton hauls is probably a result of these eddies. (Sen Gupta *et al.*, 1979). According to Jones and Kumaran (1959) in the Minicoy area, the tuna fishery is operative from September–April, the peak season being December–March. It is possible that the features mentioned above were observed during late November–December and these may have a considerable impact on the peak tuna catches of this region.

The importance of the sea around Lakshadweep from the point of tuna fishery is well known. The information on the environmental conditions of the waters here are insufficient for a better understanding and exploitation of the fishery. This is particularly noteworthy, since in many areas, in the world, tuna investigations have always been supported by large scale oceanographic studies. It may be mentioned here that one of the most important discoveries in oceanography, namely the Chromwell Current is also associated with systematic investigations for tunas in the Central and Equatorial Pacific by the Pacific Oceanic Fishery Investigations (POFI) group. It is, therefore, necessary, to follow the exact sequence of events for the ultimate correlation between the environmental processes and the tuna fishery of Lakshadweep. This requires more detailed knowledge on the environmental features and the fishery during different seasons of the year for deriving a better correlation.