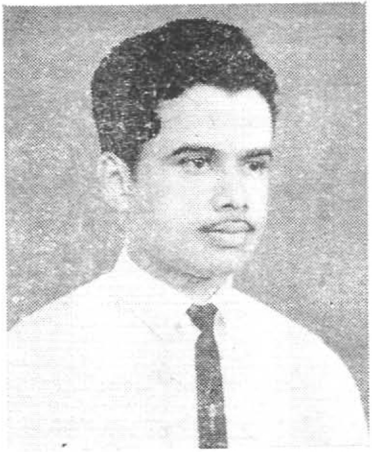

MIXING PROCESSES IN THE SEA IN RELATION TO FISHERIES

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The productivity of a particular area of the sea is dependent on the replenishment of the waters by nutrients either along the vertical or horizontal plane. Within the euphotic zone the availability of nutrients such as phosphates, nitrates, silicates etc. is perhaps one of the most important factors controlling phytoplankton production which in turn affects the zooplankton community and subsequently the entire animal community in the sea including fishes. As most of the commercially important fishes and other marine life are either directly or indirectly dependent on the phytoplankton production, replenishment of the surface layers (euphotic zone) by plant nutrients either along the horizontal or vertical plane is perhaps the most important factor which controls the availability of sea food in a particular region in the sea.

The abovementioned replenishment of the surface waters by nutrients from elsewhere is possible only by the horizontal or vertical transport of the water masses. The same is more or less true of the essential dissolved gases which promote plant and animal life in a particular area of the sea. The various mixing processes within the waterbody which helps in the replenishment of the surface layers by nutrients from elsewhere and transport of other physical and chemical parameters such as temperature, dissolved gases, salinity etc. can make a particular region of the sea highly fertile.

(a) Mixing along the horizontal plane

(i) **Ocean currents:** Currents in the sea contribute to the distribution of water which in turn affects the productivity of a particular region in the sea. In addition, they maintain living conditions required by fishes and other marine life. They may be conveniently divided into three different categories.

(i) Currents that are related to the distribution of density in the sea: The well known large scale permanent currents in the oceans such as gulf-stream, Kuro-shio, Oyashio, Benguela, cromwell and the equatorial currents belong to this category. In the sea, the pressure increases downwards and hence the pressure gradient that is directed against decreasing pressure is directed upwards. It is so nearly vertical that it practically balances the acceleration due to gravity per unit mass. If it exactly balances the acceleration due to gravity, the isobasic surfaces (imaginary surface along which thepressure remains constant) would coincide with level surfaces — (imaginary surface along which no component of gravity acts) and perfect static equilibrium would prevail. If an isobasic surface slopes relative to a level surface, a component of gravity acts along the surface and the water cannot remain at rest and hence it must move down the sloping surface.

(ii) Currents that are caused directly by the stress of wind at the sea surface (wind-generated currents): The effect of wind at the sea surface is two-fold. It leads directly to the development of a shallow wind drift and subsequently the transport of water by the wind drift leads to an altered distribution or density and the development of corresponding currents. The depth of wind current penetration increases with increasing wind velocity and decreasing latitude.

(iii) Tidal currents and currents associated with internal waves: Near land, currents that are caused by tides are most effective in that they cause sufficient mixing within the coastal waters during the periodic "ebb" ann "flood" of the tide. In deep water, tidal currents are weak and are of negligible importance as they only move water forward and backward. Theoretically the tidal currents should run in the same direction and with the same velocity from the surface to the bottom except in the lowest 20–30 metres where they are influenced by bottom friction. Tidal currents contribute greatly to the mixing of the water layers especially in the coastal areas where these currents can attain velocities upto several knots (especially in narrow estuaries and barmouths).

Currents that are related to the internal waves vary in direction and speed with depth. In the open ocean, they can attain higher velocities than the tidal currents. They can be considered as being maintained by rhythmic variations in the distribution of density. In an internal wave one or more isobaric surfaces above or below a level surface are in opposite directions. The corresponding currents are also in opposite directions.

(b) Mixing along the vertical plane

The various mixing processes in the sea which act along the vertical plane are governed by the vertical stability characteristics of the water column. The vertical stability parameter in the sea can be denoted by the expression E=dp/dx (Hesselberg, 1914), where dp/dz is the individual change in density with depth. When "E" is positive, the stratification in the vertical plane is stable and when it is negative, the stratification becomes unstable. Mixing along the vertical plane can take effect only when the startification is unstable.

(i) Mixing caused by evaporation and subsequent cooling: This type of mixing is most effective in the tropics where, in certain regions excess evaporation causes slight cooling of the surface waters. This cooling coupled with the slight increase in salinity causes an increase in density resulting in the slow sinking of the surface waters to subsurface levels and subsequent replacement by subsurface water masses.

(ii) Mixing caused by winter cooling: This type of mixing takes place in those areas where the surface waters are ccoled during the winter season and hence is seasonal. In order to replace the denser surface waters, water from subsurface levels slowly move up and occupy surface levels.

(iii) Convergences and divergences: The former refer to regions where water masses of differing nature meet from opposite directions at the surface layers either in the presence of moderately strong water currents or surface waters rising to the surface layers because of the presence of physical features such as submarine Ridges or rises. In general, shoal areas deflect the movement of water in an upward direction over the shoal. In areas where surface ocean currents branch off, there is every possibility for the sub-surface waters to be induced upwards towards the surface layers. Along the equator, divergences are very common as the wind generated currents are deflected in opposite directions, due to the rotation of the earth, slightly north and south of the equator.

Convergence is the reverse process where an occasional meeting of two surface currents from opposite directions results in the intensive mixing of water masses at the surface levels and probably owing to an altered density (positive) slowly sinks towards subsurface layers. Sub surface waters which are comparatively lighter slowly move up to fill in the gap. In general convergences are found to be good fishing grounds as the resulting physical and chemical characteristics of mixed water massses enable concentration of planktonic organisms in the area which subsequently attracts large shoals of pelagic fishes especially plankton feeders.

Convergences are of common occurrence along ocean current boundaries and also on the leeward side of oceanic islands where the wind removes the surface waters away from the coast thereby enabling the sub-surface waters to slowly penetrate layers.

(iv) **Upwelling:** This is one of the most important mixing processes in the sea which induces the colder, low oxygenated, high saline and nutrient rich subsurface waters to move up towards the surface layers against the force of gravity. The upwelled water makes the stratification of the water column highly unstable.

There is a lot of controversy over the actual mechanism of upwelling. The basic concept is that a wind generated surface current is deflected by about 45° to the right of the wind in the N. hemisphere and 45° to the left in the S. hemisphere. The deflection is caused by the rotation of the earth which is otherwise termed coriolis force. Depending upon the direction of the prevailing wind, especially its orientation with respect to a coast line, in some coastal areas the surface water will be carried away from the coast (if the coast is lying north-south and the prevailing wind northerly — along the western coasts of continents in the N. hemisphere / along the eastern coasts of continents if the prevailing wind is southerly) thereby inducing the sub-surface waters towards surface layers nearer to the coast. Others are of the view that it is not the wind that plays an important role, but the prevailing current system. The basic concept is that in the N. hemisphere the denser water will always occupy the léft hand side of the current and in the S. hemisphere, the reverse is true. In order to fulfil this basic requirement, the comparatively denser sub-surface water would be induced upwards in order to occupy the left hand side of the current, nearer to the coast line. A third group believes on a combined effect of the wind system and the resulting current system.

Sub-surface waters, rich in plant nutrients, once brought to the eupholic zone give rise to a favourable environment for a phytoplankton bloom which in turn leads to concentration of zooplankton and ultimately results in a good fishery. The dissolved oxygen content of the upwelled water increases as soon as it reaches the surface layers by contact with the atmosphere. Upwelled water can contribute towards productivity of a particular region in the sea only when the same is brought up from sufficiently deeper layers where the nutrients were not at all utilised due to want of sufficient amount of sunlight. Addition of freshwater at the surface levels, either through rainfall or land drainage which results in a stable stratification at the surface levels, will put an end to the process of upwelling. Moreover, in the presence of a strong thermocline the possibilities of deeper waters upwelling towards the surface layers, are quite remote.

Relation to fisheries : Among the different processes which promote the productivity of a particular region in the sea, the most important are upwelling, divergences and convergences as they result in the concentration of phyto/zoo plankton which form the food of some of the commercially important pelagic fishes like sardine, mackerel, anchovy etc. Along the coast of peru, the upwelling areas of the peru current support one of the richest fisheries in the whole of the world. Other areas viz. california coast, gulf of Aden, off the coast of somalia and S. Arabia, zones of equatorial divergences, current boundaries along the kuroshio and oyashio current systems along the Japanese coast (Hela and Laevastu, 1970) parts of the western and eastern coast of the Indian sub-continent also belong to this category.

Along the Indian coast the process of upwelling has been studied by various workers viz. Lafond (1954), Banse (1959. 1968), Ramamirtham and Jayaraman (1960), Varadachari (1961), L. V. G. Rao and Jayaraman (1966), Darbyshire (1967) and Sharma (1968). According to Banse, the prevailing current system and not the wind is to be regarded as the main reason for the upwelling off the S. W. coast of India. Even if a uniform current velocity is considered all along the coast, the rise of denser deep water will be stronger in the north further away from the equator. He is of the opinion that off the S. W. coast of India upwelling starts with the onset of the S.W. monsoon and reaches the maximum intensity during the months July-August. L. V. G. Rao and Jayaraman reported upwelling around Minicoy waters during the last week of November and attributed the same to the divergence of current systems in the visinity of Minicoy. They have also indicated the possible relationship between upwlling observed during late November and the peak seasons for tuna fishing (December to March) in this region. Ramamirthan and Jayaraman have stated that off Cochin upwelling starts by mid August, establishes by late September and ends by mid October. Darbyshire indicated that along the west coast of India the dense bottom waters approach the surface because of the immediate interplay of the current with the tilting of the sea surface and the thermocline. According to Sharma, upwelling along the west coast of India starts earlier in the south and slowly extends towards North. He is of the opinion that the process commences at deeper depths earlier in the month of February and reaches the surface by May. The process comes to an and by July-August when the thermocline in this area reaches the surface layers. Moreover the influx of run off and rain water stratify the surface layers from July onwards thereby opposing the process. Varadachari (1961), Stommel (1966) and Byther and Menzel (1966) stressed the need for considering coastal currents as a factor in inducing upwelling. Theoretical and physical studies by Varadachari (1958, 1961) show that a northerly current along the east coast of India is favourable for upwelling. During the south west monsoon period both the wind and currents are favourable for upwelling along the Waltair and Madras coasts (June-July). Studies conducted by Lafond on the process of upwlling along the Waltair coast showed that the process is a very slow one. Vertical upwlling velocity observed off Andhra coast ranges between 10 and 40 metres per month when compared to a rate of 20 metres/month recorded off the California coast. According to him the postulation of upwelling on the eastern and northern sides of the Bay of Bengal were confirmed by maasurements made by the Research vessel "Anton Bruun", which revealed a high rate of organic production in this region.

Thus the relationship between mixing processes like upwelling and the resulting high organic production rates clearly indicate the importance of similar processes in the organic cycle, especially from a fisheries point of view. It is needless to emphasise the importance of oceanographical studies relating to these phenomena as in the long run the results will enable us to predict, sufficiently in advance, the probable areas of good fisheries.

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