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MARINE METEOROLOGY AND ITS RELATION TO ORGANIC PRODUCTION IN SOUTH-EAST ASIAN WATERS

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INTRODUCTION

WEATHER has an obvious bearing on the food produced from land. Sufficient rain is needed to make the crops grow, and adequate sunshine is necessary to warm the air and soil, germinate the seeds, carry on photosynthesis, and ripen food plants. From these plants animals derive their nourishment and in turn supply food for man. All these nutritive processes depend on meteorological conditions.

In South-east Asia, as in other parts of the world, the arable land available for growing food is gradually being reduced. This trend is creating a growing food shortage in already highly populated areas where, to meet its living requirements, cities are being enlarged, settled areas are spreading, buildings are being erected, and roads are under construction across former farm lands. Too often it is the richer land that must be sacrificed, and this reduces what remains of the really fertile area used for agricultural and meat production.

The South-east Asian countries, faced with a growing population must through necessity emphasize the sea as a source of additional food. Since the adjacent waters have a surface far greater than its land area, and a usable, food-producing depth of many times more, the sea represents (1) a source of food the potential of which has scarcely been utilized, and (2) a solution to its incipient food shortage.

Exploration of the sea for the new food sources is still so new a field that the oceanic areas of greatest usable organic production have not yet been clearly defined. Even the life cycle factors involved in the production of organic matter in the sea are not yet completely understood, but some new data on oceanographic conditions and marine biology have been determined by the NAGA Expedition, which conducted oceanographic research directed toward developing the marine resources in the waters off South-east Asia. A full understanding of the food potential in this part of the world, requires consideration of the relationship existing between marine meteorological conditions. These affect plant growth in the sea as well as on land and make possible the growth of larger life forms that can be important source of food.

Marine Meteorology

Rain

In South-east Asia, one meteorological factor, rainfall, averages about 60 inches which is more than twice as great as the world mean of 26 inches. Rain falls not only on the land but also on the oceans. The unusually large drainage of South-east Asian rivers significantly influences the plant-nutrient in the sea.

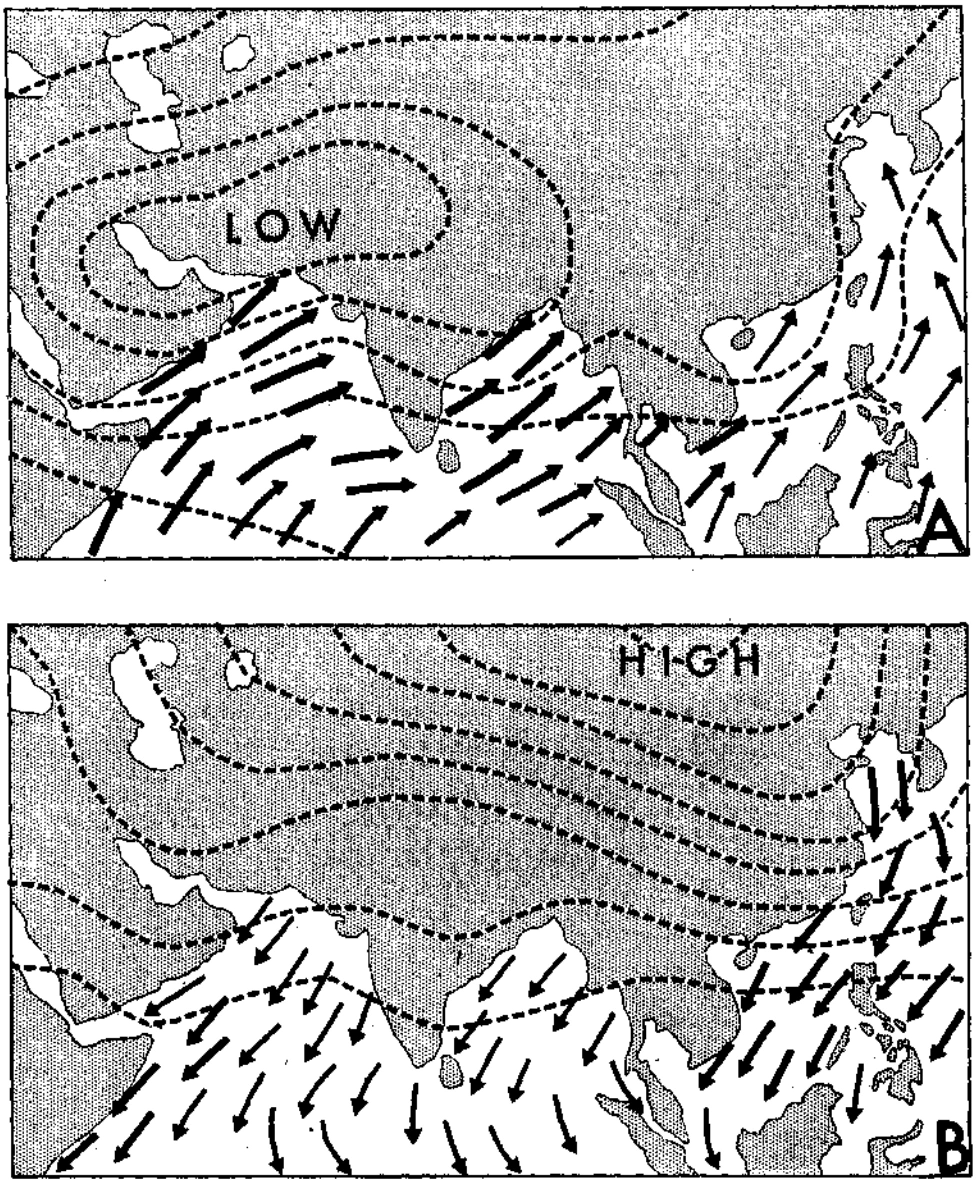

Fig. 1. Major pressure fields and direction of winds over the South-east Asian seas in: A. Summer, and B. Winter.

Wind

South-east Asia is characterized by two dominant wind systems : the north-east and the south-west monsoons (Figure 1).

In summer, the land mass, especially the area north of the Arabian Sea, is heated more than the sea and thus becomes a large, low-pressure area (Figure 1A). This condition creates south-west monsoon winds, which blow generally from over the water toward land, or from the south-west. The stress of these monsoon winds on the water causes horizontal and vertical currents. The currents in turn influence the distribution of nutrients in the sea.

In winter the land, especially the Plateau of Tibet in South China, becomes colder than the sea, and the wind direction is reversed as the air blows seaward. Since the winds are reversed, their effect on water circulation is likewise nearly reversed. These winds are predominantly north-east and north-west, though their direction and speed may vary considerably with time and space. This variability in turn effects the sea currents, and their influence on nutrient distribution.

Organic Cycle

A simplified organic cycle in the sea begins with plant nutrients and solar radiation (Figure 2). Plant nutrient requirements in the sea are similar to those on land and of special importance are phosphates, nitrates, silicates and traces of several other elements, such as iron, manganese, and some organic compounds (such as B-12).

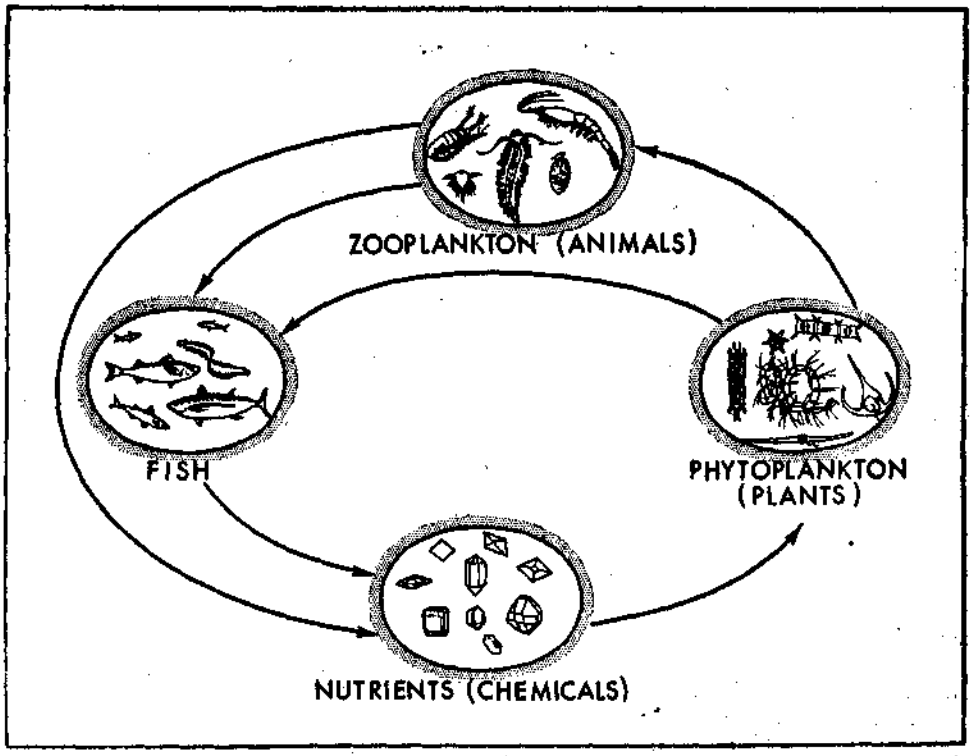

Fig. 2. Organic cycle in the sea.

Photosynthesis

As on land, solar radiation is essential for all sea plant growth. The process called photosynthesis is essentially the combination of carbon dioxide and water, in the presence of chlorophyll and radiant energy, to yield oxygen and carbohydrate. If nutrients are below the depth to which sufficient light penetrates, they are of little value for the growth of plants. But under favourable conditions of light and nutrients, photosynthesis can take place, and small plants may multiply rapidly.

These one-celled plants have the power to combine water, carbon dioxide, and minerals into carbohydrates, proteins, and fats. Nitrogen is necessary for the synthesis of amino-acids and proteins, phosphorus for the synthesis of nucleoproteins, phospholipids, etc. and silicon is required for the formation of skeletal material in diatoms and radiolaria. Thus photosynthesis constitutes an important step in the organic cycle, and plankton serve as the basic foodstuff in this cycle.

Both tiny plants and animals may succumb to unfavourable changes in the chemical, physical, and biological properties of the water. If the rate of utilization of nutrients exceed that of diffusion and advection, the upper layer concentration of phytoplankton will then decrease.

Production of Animals

Small marine animals such as zooplankton and fish larvae depend on phytoplankton as their source of food, as do also some larger fish and even whales. The smaller crustaceans normally live on plankton, both plant and animal.

The next step in the organic cycle involves the sustenance of larger forms of life, such as fish, which live principally on crustacea, smaller fish, and sometimes even plankton.

The life cycle is completed when the nutrient elements are returned to the water either directly as excretion or indirectly during the bacterial decomposition of organic matter. Most plant and animal debris sinks to the ocean floor, there to nourish sea bottom life or to decay. The elements in the fish and plankton tissue are thus redissolved in the sea water, and the organic cycle is completed.

Most nutrients in the sea are concentrated below the euphotic zone at considerable depths. An important task of marine meteorology with reference to the food cycle is to determine the process by which nutrients reach the near surface layers where they can be utilized.

Replenishment of Plant Nutrients

Added to the plant nutrients in the sea are the nutritional reinforcements provided by land drainage. Another more limited factor is dissolution of minerals which compose the shallow sea floor. The main factor however is the vertical motion of water, which raises the nutrients to a near surface level.

Rivers

Rivers drain dissolved salts from the continents into the oceans (Figure 3). The fresh, nutrient-laden water then spreads out at the confluences of rivers and moves with the prevailing currents. The effect of river systems on the replenishment of plant nutrients is of considerable importance. The waters between coasts and oceanic regions are a mixture of both fresh and saline composition. In general, coastal water has a lower salinity than ocean water, is more turbid, has lighter colours, and is usually colder in winter and warmer in summer. Off-coast water contains

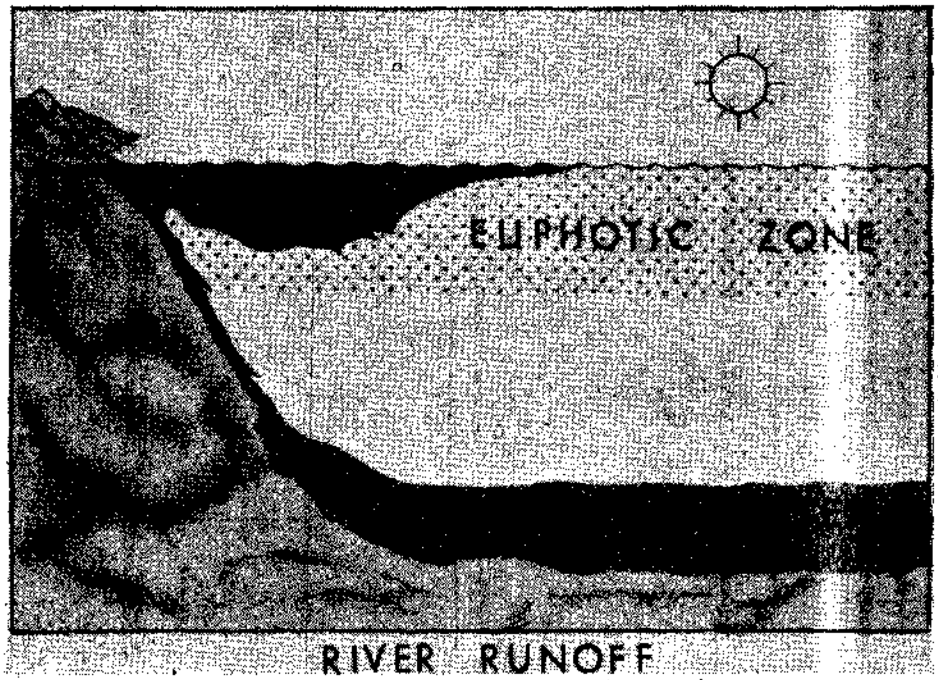

Fig. 3. Method of nutrient replenishment in the sea by river runoff.

more dissolved oxygen, more nutrient phosphate, silicate, nitrate, etc., more organic substances, and usually, has a higher concentration of plankton, benthos, bacteria, and fish. The productivity of near-shore water is greater than ocean water, especially along the boundary of the two masses.

Nutrient Replenishment by Vertical Motion

A main source of nutrients for organic production comes from the deeper layers of the sea (Figure 4). Such strata normally contain large quantities of plant nutrients, and these are commonly brought to the surface or near surface by vertical motion of varying origin :

Convection Currents: Surface density is increased by surface cooling and evaporation, which results in convective overturn (Figure 4A). The meteorological conditions that reduce the surface temperature or increase evaporation will cause water to be denser at the surface than immediately below, and the denser water will sink.

During the overturn, the subsurface water, which is normally richer in nutrients, will rise, as well as mix with the heavier water. This mixing, which continues up to the surface, will bring nutrients into the euphotic zone.

The importance of convection as a stirring mechanism in mid and low latitudes is not yet well understood ; however, it seems likely that seasonal changes will be more important than irregular fluctuations.

Wind Mixing : Mechanical wind mixing is another natural mechanism for the transfer of nutrients from the upper thermocline to the surface euphotic layer (Figure 4B). It is most effective when strong, gusty winds and a shallow thermocline are involved. At places in the ocean termed ' domes ' or ' ridges ', crests of longer internal waves can occur where the surface layer is thin (less than 10 meters), and in such areas even light winds can bring about mixing by stirring. In certain regions the thickness of the surface layer and the depth of the thermocline are apparently

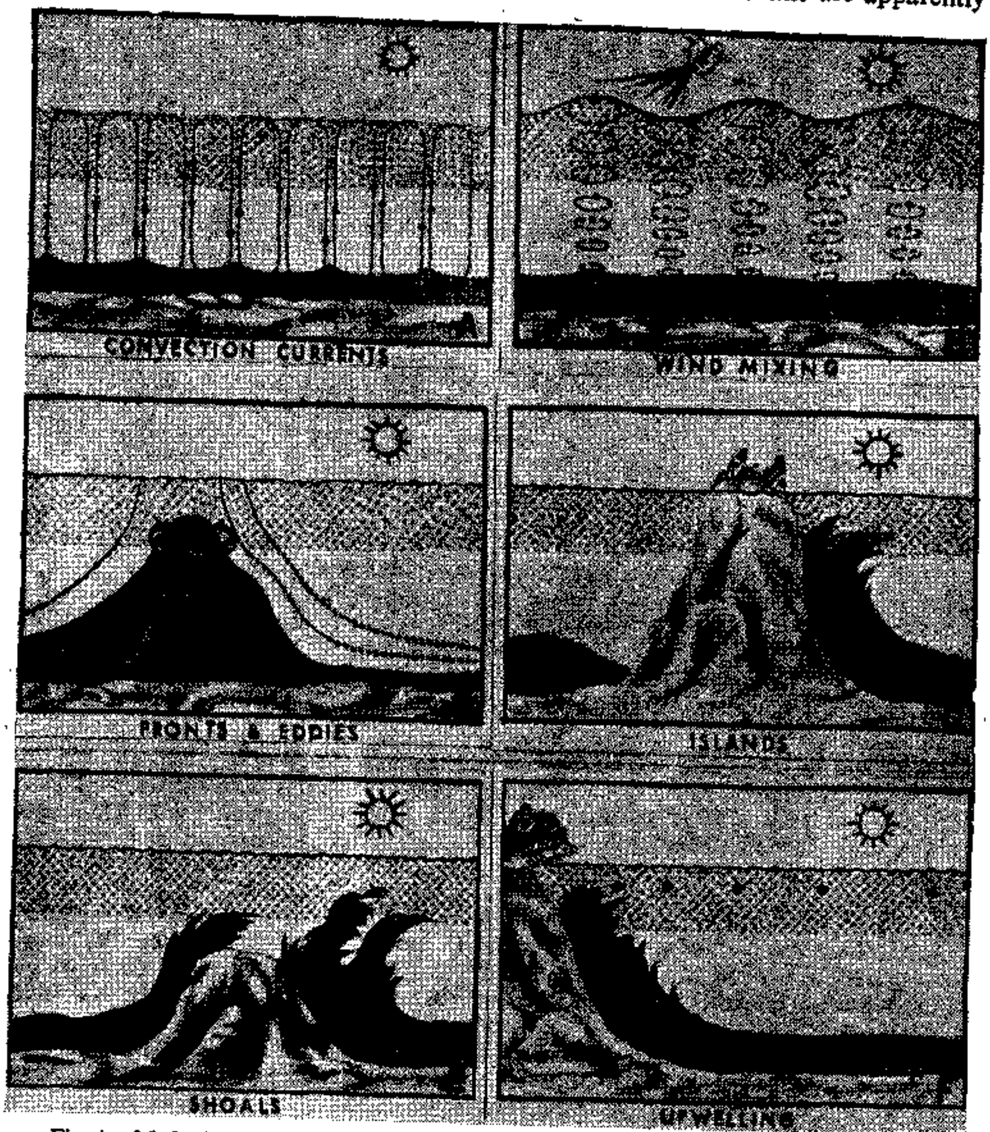

Fig. 4. Methods of nutrient replenishment from deeper layers up to the euphotic zone.

A. Convection Currents. B. Wind Mixing. C. Fronts and Eddies. D. Islands. E. Shoals. F. Upwelling.

dynamically controlled, so that a direct link between the circulation and the supply of nutrients seems possible.

Fronts and Eddies : Water masses are usually characterized by the presence of particular oceanographic properties such as temperature, salinity, phosphate, dissolved oxygen, etc. At boundaries between two water masses, commonly called 'fronts', the properties may change abruptly (Figure 4C). These boundaries can be associated with a differential in current speed, or direction, and may contain eddies. In the Asian area which is north of the equator cyclonic (anti-clockwise, positive) eddies are cold because they bring up colder, higher nutrient water, which creates a favourable area for organic production. In the anti-cyclonic (clockwise, negative) eddies, surface water accumulates and sinks. In so doing, it accumulates and traps surface debris, including plankton, which may be lighter than the surrounding water. Both types of circulation engender favourable areas for organic production and the accumulation of fish.

Islands : If an island is in the path of a current, its surface water tends to accumulate on the up current side and localized upwelling will occur on the down current side of the island (Figure 4D). Such an upwelling brings nutrients as well as colder water from subsurface levels. Consequently, the lee sides of island are important areas for organic production.

Shoals : A shoal area deflects the movement of water in an upward direction over the shaol (Figure 4E). If subsurface, nutrient-laden water is brought near enough to the surface, photosynthesis can take place. The interposition of shoals thus causes the vertical motion, turbulence, and horizontal eddies that help in nutrient enrichment and create a favourable environment for organic production.

Upwelling : A common phenomenon in vertical motion is upwelling, which can occur either near a coast or in the open sea and is the result of divergence brought about by wind-drift currents (Figure 4F).

In a counter-clockwise circulation in the northern hemisphere, the heavier subsurface water rises toward the surface in the central part of the eddy. On the equator, the upwelling is caused by a divergence related to a reversal of Coriolis Force.

The most common upwelling areas are associated with wind-drift currents and land configuration. When the wind blows nearly parallel with the coast, with the water on the right side in the northern hemisphere, the surface water will be displaced offshore. Subsurface water will upwell toward the surface to take its place. The high-density water levels will tilt upward toward shore. They may or may not reach the surface, but the process is still defined as upwelling. The degree of upwelling will depend on the angle of the wind with reference to shore, its strength and duration, and the stratification of the water.

Monsoon Winds

During the winter when the monsoon winds blow from the north east, the zigzag features of the South-east Asian coast provide several locations where the direction of the wind is such that surface water should be displaced offshore and upwelling occur, i.e., the eastern part of the Gulf of Thailand, the eastern part of the Bay of Bengal, and the eastern part of the Arabian Sea. These areas should be regions of coastal upwelling where organic production is high.

The summer monsoon winds blow from the south-west about half the year. Therefore the areas where the coastal water will be displaced offshore are the western side of the Arabian Sea, the western side of the Bay of Bengal, the western side of the Gulf of Thailand, and the coasts off South Viet Nam in the South China Sea (Figure 5). An example of the temperature structure taken by the NAGA Expedition in May demonstrated this upwelling off the Viet Nam coast. A second example in July showed that the upwelling had moved a little south and offshore. The

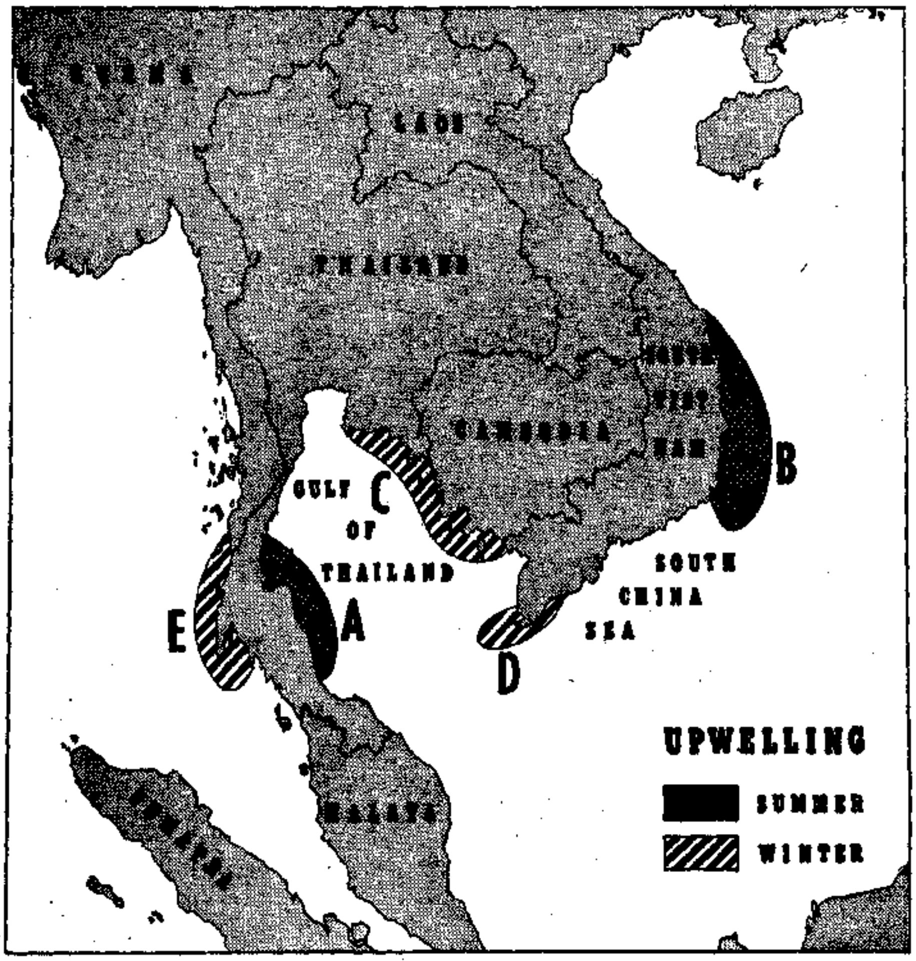

Fig. 5. Areas of upwelling and high organic production in South-east Asian waters.

A. Summer, Gulf of Thailand area. B. Summer, South China Sea area. C. Winter, Gulf of Thailand area. D. Paulo Obi front area. E. Probable winter, Andaman Sea area.

extent of upwelling in these areas depends on the duration and the strength of the wind and its persistence in a given direction. Monsoon winds, which do not blow consistently from the southwest, vary a great deal and come only from a generally south-west direction.

Winds and marine conditions thus bring up the nutrient rich subsurface water, which is richer in nutrients and create a favourable environment for primary food production. Supplementing this process in the life cycle of the organisms must be favourable temperature and adequate food supplies. Probably water motion also plays an important part. If some of these factors are not present at the proper time and sequence in the life cycle, the organisms may die.

CONCLUSIONS

From the foregoing it is obvious that thorough exploration of marine meteorological conditions is necessary before full utilization of the oceanic food-producing potential can be achieved. Present knowledge is still far from adequate, but a start has been made. It has been found that, in addition to rainfall and radiation, other marine meteorological conditions such as creation of vertical water movement in order to bring nutrients up to the euphotic zone from the deeper layers are also important to enrichment of the sea. As shown, this may come about through wind mixing, convective overturn, and upwelling, but marine meteorological conditions of favourable light and radiation must also exist in order to cause the organic cycle to progress.

It is certain that marine meteorological conditions trigger off the organic cycle that results in the production of food. In future study programmes it will be necessary to include, a marine meteorologist, a physical oceanographer, a marine chemist, and a fisheries biologist in the scientific teams. The services of these specialized scientists will be needed for analysis of different phases of the processes that will ultimately produce more food from the sea. The campaign to solve the food problem looming in South-east Asia has therefore begun with a preparatory study of the particularized marine meteorology peculiar to the area. A significant contribution has already been made by the NAGA Expedition.