Production of Living Matter in the Sea

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There has always been a general agreement among the scientists that many more living organisms exist in the sea than on land. Scientists have already found about one hundred and fifty thousand different forms of life in the sea and they are adding to the list at the rate of about three new ones per day. Scientists also believe that it is the sea that has been the first home of living things. In other words, the first mysterious spark of life on earth appeared in the sea. How did it happen, is not fully understood. But perhaps about four million years ago, the wonderful substance, probably similar to viruses of today came into existence from the raw materials of the sea. Perhaps it had a form similar to that of a simple chain of atoms which gives rise to molecules. Even today the sea has many living forms just as primitive as the one which originated in the antiquity. Such curious forms of life, are not easily visible under an ordinary microscope; and although their study is extremely fascinating and revealing, they do not have much direct relevance with such living organisms we call *resources of the sea.*

Forms of Life

The forms of life which give rise to ocean harvest can conveniently be divided into three main groups: (*1*) *Plankton*, (*2*) *Nekton* and *(3) Benthos*.

The plankton are countless minute organisms with no or limited capacity of movement. They drift about in the sea and are transported by winds and currents. The myriads of microscopic, unicellular, floating plants are called *phytoplankton* and the drifting swarms of small animals, and the younger stages of larger animals, are termed as *zooplankton*. The *nekton* include actively swimming animals in the sea and the *benthos* belong to the category of creeping and fixed animals of the bottom.

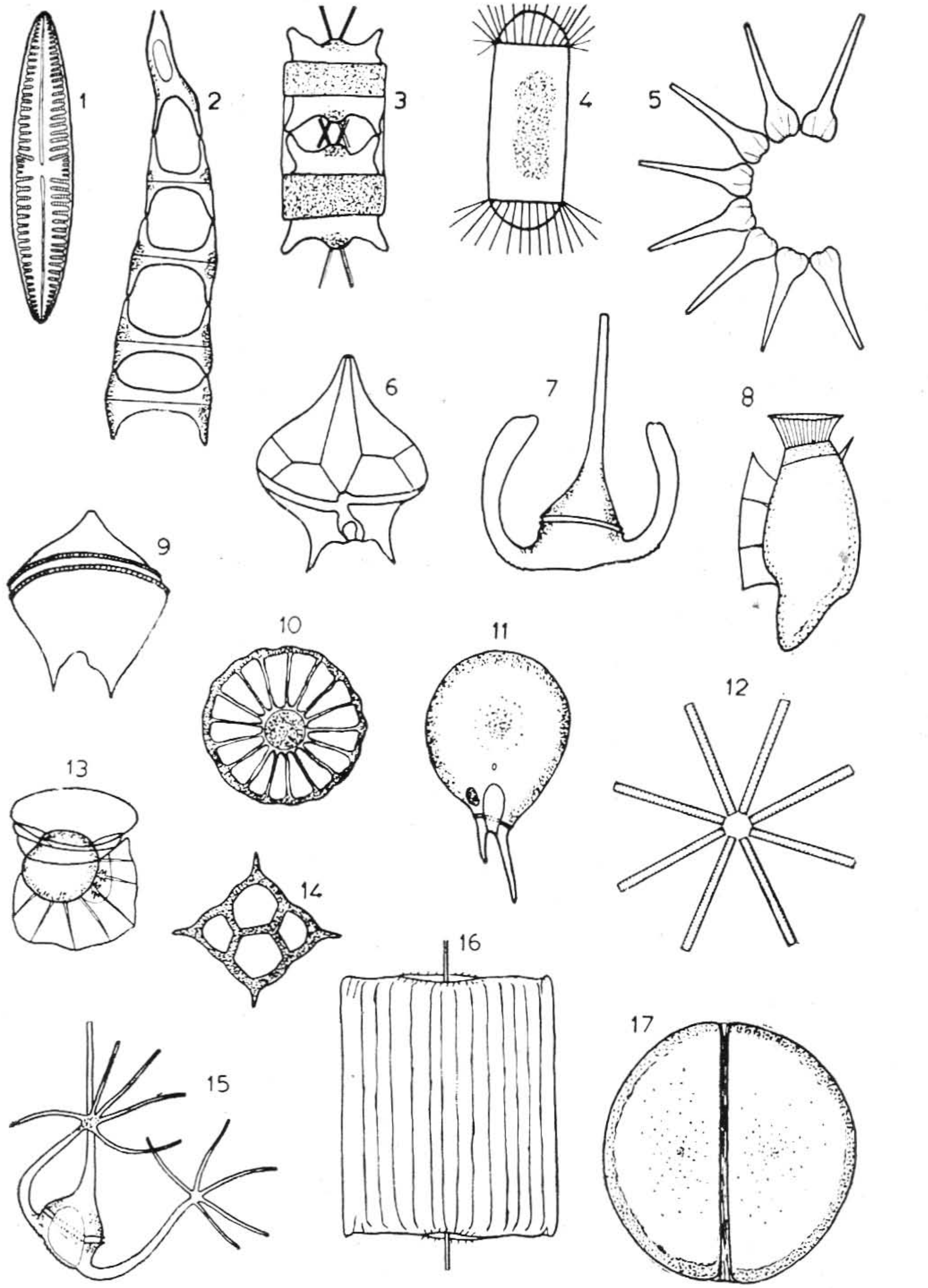

Fig. 1. Common phytoplankton organisms from tropical seas. 1. Navicula, 2. Climacodium, 3. Biddulphia, 4. Corethron, 5. Asterionella, 6. Peridinium, 7. Ceratium sp., 8. Dinophysis, 9. Peridinium, 10. Planktoniella, 11. Ceratium sp., 12. Thalassiothrix, 13. Ornithocercus, 14. Distephanus, 15. Ceratium sp., 16. Ditylum, 17. Hemidiscus.

Production of Living Matter

Among these, the most challenging group and the one which gives us the concept of basic production is the phytoplankton. Basic or primary production would thus mean the *synthesis of organic material* from inorganic substances —an activity entirely of green plants— which gives us the concept of "*production of living matter in the sea*".

Thus primary production on this planet is the result of an activity of plants called *photosynthesis*. During the process water and carbon dioxide are chemically converted to organic carbon as a result of the energy derived from sunlight. A by-product of photosynthesis is oxygen evolution. Primary production occurs both on land and in water by the terrestrial and aquatic plant communities respectively.

The earth's surface has an area of 320 million square kilometres; of which about 220 million square kilometres are occupied by the sea. This would mean that roughly three quarters of the earth's surface is inhabited by microscopic, unicellular flora. The higher (vascular) plants occur on land and in few shallow water-areas of the world. In some coastal waters there are vast beds of seaweeds, but nearly 99% of the oceans are too deep to permit the growth of attached plants and the flora are represented almost entirely by the phytoplankton. The chief members of the phytoplankton community are diatoms, dinoflagellates and other algae. All the members of these groups possess chlorophyll and have great diversity in their shapes and sizes (Fig. 1). These have often been called the "*meadows of the sea*". Scientists began studying phytoplankton well over a century ago. Tubular nets were pulled through the water collecting these microscopic organisms which were identified and ultimately grown under laboratory conditions. Under favourable conditions they divide rapidly during the period of daylight and give rise to several generations. This multiplication and growth of cells has conventionally been referred to in the literature as *production*.

Let us examine some of the characteristics of phytoplankton production in the sea.

Light in the sea

Sea water is a fairly transparent substance, but its transparency is only for the visible portion of the *light*, that is, the non-visible portions of the spectrum—the infra-red and the ultra-violet rays—are quickly absorbed within the first few metres. Sea water is most transparent for the blue region of the spectrum. Longer wavelengths corresponding to red region are also quickly absorbed. In the ocean only the upper 100 metres or so have sufficient light for the phytoplankton to perform photosynthesis (Fig. 2). This is called the *euphotic zone*. As figure 2 will indicate the area in the sea which is capable of plant production is deceptively small as compared with vast depths of the ocean. In the clearest ocean, such as the Sargasso Sea, the euphotic zone may extend upto a depth of 140 metres. The total solar radiation, however, falling on the sea surface varies as a function of the time of the day, season and latitude. The coastal waters and estuaries, because of their proximity to land are far less transparent than that of the open ocean and have the euphotic zone ranging from 5 to 50 metres. The ability of phytoplankton cell to absorb submarine illumination differs from region to region and from one type of organisms to the other. When exposed to very bright light most of the phytoplankton species show an inhibition in their photosynthesis. In tropical forms this inhibition appears at light intensities much higher than in phytoplankton from the temperate and polar regions. (Fig. 3)

Other Factors

While light intensity is of major significance for the production of living

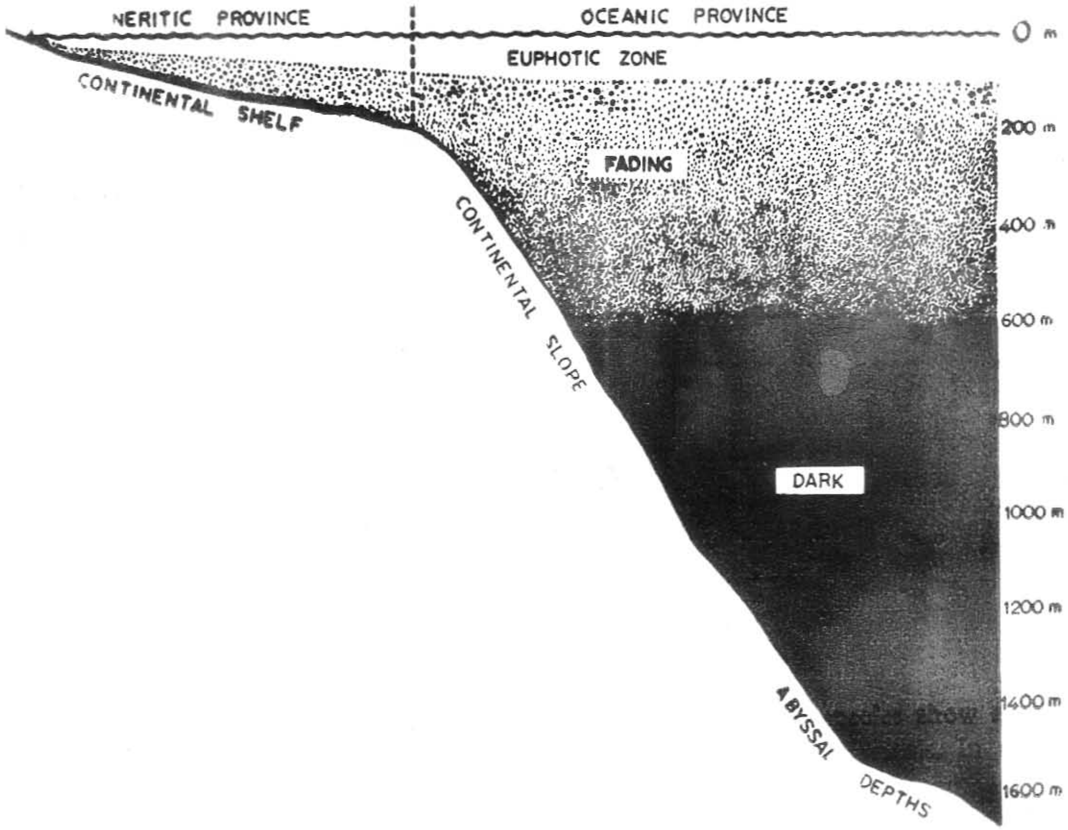

Fig. 2. A simplified diagram showing a small portion of the ocean with its major divisions. Note the shallowness of the euphotic zone and the area of the continental shelf extending upto 200 m depth which demarcates the neritic and oceanic provinces. Where continental shelf ends, continental slope begins leading to abyssal depth where total darkness always prevails.

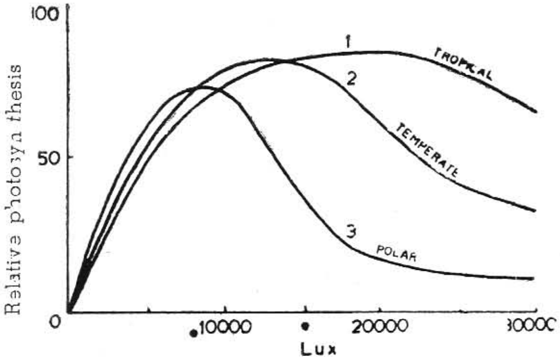

Fig. 3. Rate of photosynthesis in marine phytoplankton in relation to light intensity. Note the difference in the behaviour of tropical, temperate and polar phytoplankton organisms. These differences have been determined by laboratory experiments. Lux is a measure of light intensity.

matter in the sea, several other factors also play an important role. *Temperature* of water is probably of little direct importance to phytoplankton of tropical seas, but in temperate and polar regions maximum phytoplankton production occurs during summer when the temperature is high. *Salinity* variations have been found to have a marked effect on photosynthesis and growth of phytoplankton. Many of the tropical forms have a wide salinity tolerance and their optimum growth occurs when the salinity is lower than normal sea water. In nature significant reduction in salinity occurs during the monsoon months as a result of heavy rainfall and land runoff. Those species which tolerate a wide range of salinity have a remarkably wide range of distribution.

Basic Material

In addition to the environmental factors noted above, for many years, the concentration of two major *nutrients*—nitrate and phosphate—has been recognised as one of the major factors controlling the primary production in the sea. Generally in tropical oceans a limitation is placed by the depletion of nitrate. However, a clear demonstration of the relationship between these two nutrients and primary production is provided by the areas where *upwelling* occurs. During the process of upwelling, the water rich in nutrients, from great depths is brought to the surface and thus enriches the euphotic zone. Such areas are found off West Africa (Somalia), off Chile and Peru, off the coasts of California and south-west India. Besides upwelling, several other well-known phenomena in the sea such as *divergence*, *turbulance*, *convection currents*, *current boundaries* are of significance in renewing the nutrients and thus enhancing primary production. Silicate is another nutrient, the presence of which promotes the growth of diatoms. These organisms have their cell wall made of silica and not of cellulose as is the case with dinoflagellates and other algae. Normally silicate in tropical seas is present in relatively large quantities and it is doubtful whether it can easily become a limiting factor. However, in the Antarctic waters very thin-walled diatoms often reflect the lack of silica.

A number of other elements normally present in very small concentrations in sea water and called *trace elements* or *minor nutrients* are essential for a healthy plant growth in the sea. Iron, manganese, copper, zinc, cobalt and molybdenum are usually considered as the important trace elements.

Recent studies have shown that a variety of *organic substances* in sea water are of considerable importance in promoting the growth of phytoplankton. So far 18 *amino acids* have been determined in sea water. Most of these are found in a dissolved state. In addition to the amino acids, *carbohydrates*, *fatty acids*, *metallo-organic substances* as well as *vitamin compounds* have been discovered in sea water. However, our knowledge of the concentrations of these elements in the sea is so limited that it is difficult to say whether these can ever become a limiting factor. Professor G. E. Fogg of the United Kingdom advances his strong arguments for the view that some excretion of material occurs during the healthy growth of both freshwater and marine phytoplankton. He draws particular attention to the importance of *glycollic acid* which is released by the phytoplankton cells in the water as an *extracellular product.* Some of the glycollates are used by bacteria to synthesize small particles in sea water which contribute to the total productivity. Many American scientists are of the opinion that among the organic compounds which are normally found in a dissolved state, the three *vitamins, cobalamine or vitamin* B_{12}, *thiamin or vitamin* B_1 and *biotin* are of considerable importance as growth promoting substances.

Estimation of Production

Estimates of primary production are made either from the oxygen evolved during photosynthesis or as fixation of carbon from the carbon dioxide present in water. In recent years the *radioactive tracer technique* using radioactive carbon (^{14}C) has become an important and widely accepted method for measuring the rate of photosynthesis. *Radioactive carbon* (^{14}C) is added to water samples which are taken from specific depths throughout the euphotic zone and kept in transparent glass bottles. These are suspended within the euphotic zone or kept in an incubator especially designed for this purpose and fitted with natural density filters to simulate light conditions of the euphotic zone. The samples are recovered and the contents of the bottles are filtered through a membrane filter and the radioactivity in the material deposited on the filter is counted and expressed as the quantity of carbon fixed during a given period of exposure. The vertical profile of carbon fixation at each depth is integrated and expressed as the quantity of carbon fixed under a square metre of ocean surface.

Biomass estimates of phytoplankton are generally made by measuring the *chlorophyll* content of water. Chlorophyll is a major absorbing pigment for light and plays the essential role in photosynthesis. Very often the rate of photosynthesis and chlorophyll are correlated as the amount of photosynthesis per unit chlorophyll. These values show a high degree of variability because the rate of photosynthesis may change as a result of temperature or some other changes in the environment quite independently of the chlorophyll. The presence of dead and degraded chlorophyll in the *particulate matter* (material in the form of suspended particles in contrast to *dissolved matter*) which is not easy to distinguish from living chlorophyll may at times provide errors in measurements.

In coastal waters the values of carbon fixation have been found to be of the order of 3 grams per metre square per day (3 $gC/m^2/day$). In the offshore waters the values range between 0.2 and 1.0 $gC/m^2/day$ and in the open ocean the range is between 0.2 and 0.7 $gC/m^2/day$. By making a large number of measurements in different areas of the oceans and taking a world-wide average it is possible to arrive at a reasonable estimate of primary production of the seas as a whole. Numerous such estimates are available in the literature as *gross* or *net* production. The former indicates instantaneous values without any losses whereas the latter accounts or the losses of carbon during respiration and excretion by the plants. These two processes operate in conjunction with photosynthesis. The rate at which gross production occurs in the sea in relation to light intensity and depth is shown in Figure 4.

Food Chain

Food chains in the sea start with the synthesis of organic material by the phytoplankton. The herbivorous members of the zooplankton community by feeding on phytoplankton assimilate this organic material. The unutilized organic matter on death begins to decompose because of bacterial action. It breaks down into

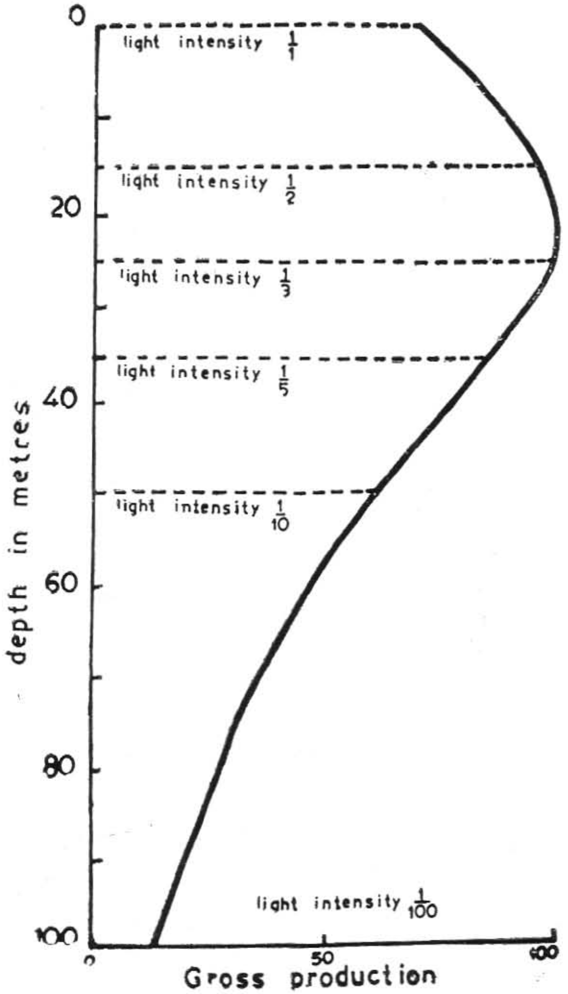

Fig. 4. Gross production as a function of light intensity and depth. Note that the maximum production is at about 20 m depth and not at the surface. The light is too intense at the surface to allow maximum photosynthesis.

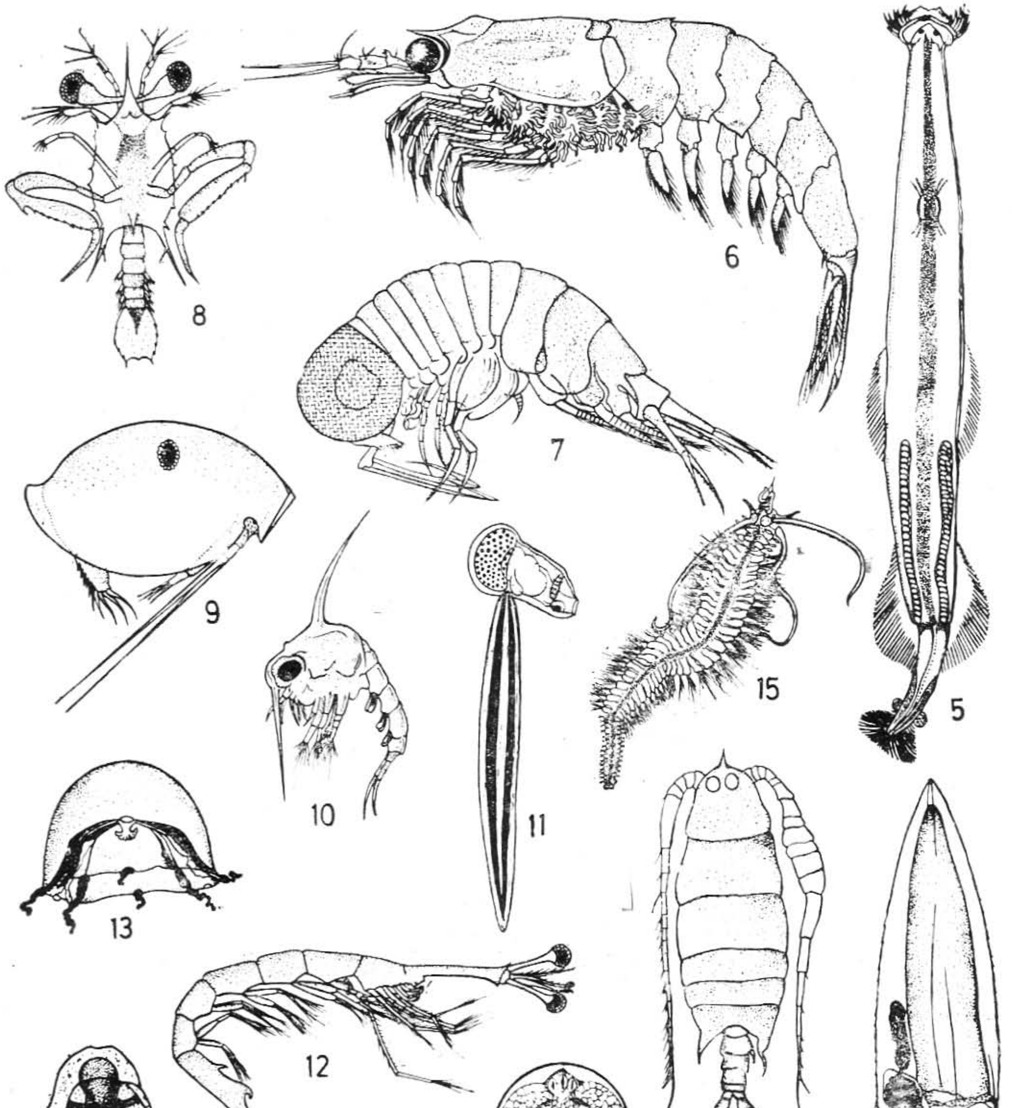

Fig. 5. Common zooplankton organisms from tropical seas. 1. Fish egg, 2. Fish larva, 3. Copepod, 4. Siphonophore, 5. Chaetognath, 6. Euphausiid, 7 Amphipod, 8. Alima larva (Stomatopoda). 9. Ostracod, 10. Decapod brachyura larva, 11 Appendicularian, 12. Serqestid, 13. Medusa, 14. Tunicate and 15. Polychaete.

mineral substances (nitrate, phosphate, trace elements etc.) which return to the system and thus complete the biological cycle. Any approach, therefore, towards analysing the production of living matter in the sea must include the chain of events associated with the *food cycle* or *trophic relationship*, of the major marine communities. Even in plankton group (phyto-and zooplankton) there is a complexity of feeding pattern. Most of the herbivores feed on phytoplankton in a way which has been referred to in the literature as *grazing*. Perhaps the best known groups of animals studied for grazing are the *copepods*. However, beside grazing on flora of the sea, zooplankton feed quite actively on inert substances (organic aggregates), dead material of plant and animal origins called *detritus*. Recent studies on the suspended matter obtained from the sea have shown that the particulate material is largely composed of detritus. In coastal areas and estuaries, attached plants may also contribute substantially to the detritus formation. Benthic and sedentary animals largely depend on this detrital material as food which they obtain by filtering large quantities of water or by swallowing larger aggregates and mud.

Most fish larvae feed on zooplankton, although they may also eat phytoplankton in early stages. Some of the common zooplankton organisms have been given in Figure 5. The most important food items of fish larvae are small organisms called copepods. Phytoplankton can also serve as food of adult fish such as the oil sardine and anchovies. Pelagic fish (which swim about in the upper layers of waters) largely depend upon zooplankton while demersal fish (which live close to the bottom) may feed on benthic organisms, although not all benthic animals are acceptable as food. Bigger and carnivorous fishes such as tuna feed largely on fish and larger invertebrates.

The broad pattern of feeding relationship in the sea has been illustrated in Figure 6. The real intricacies of the food web, however, can only be revealed by considering the food habits of individual species at different steps of the food chain. These steps are called *trophic levels*. The food eaten by the fish or by other animals is converted partly into energy and partly into growth. The rate at which food supply is utilized by a predator is called *efficiency* or *transfer coefficient*, which is expressed as

$$\frac{\textit{calories of prey consumed by the predator}}{\textit{calories of food consumed by prey}} \times \frac{100.}{1}$$

This ratio is also called *gross ecological efficiency*.

From laboratory experiments it has been deduced that the ecological efficiency for some animal populations is of the order of 10%. If this efficiency is assumed to be constant at various trophic levels then 100 kg of microscopic plants (phytoplankton) will produce 10 kg of herbivores (zooplankton) and 1 kg of fish such as mackerel which feeds on zooplankton and 0.1 kg of larger fish which feed on other smaller fish.

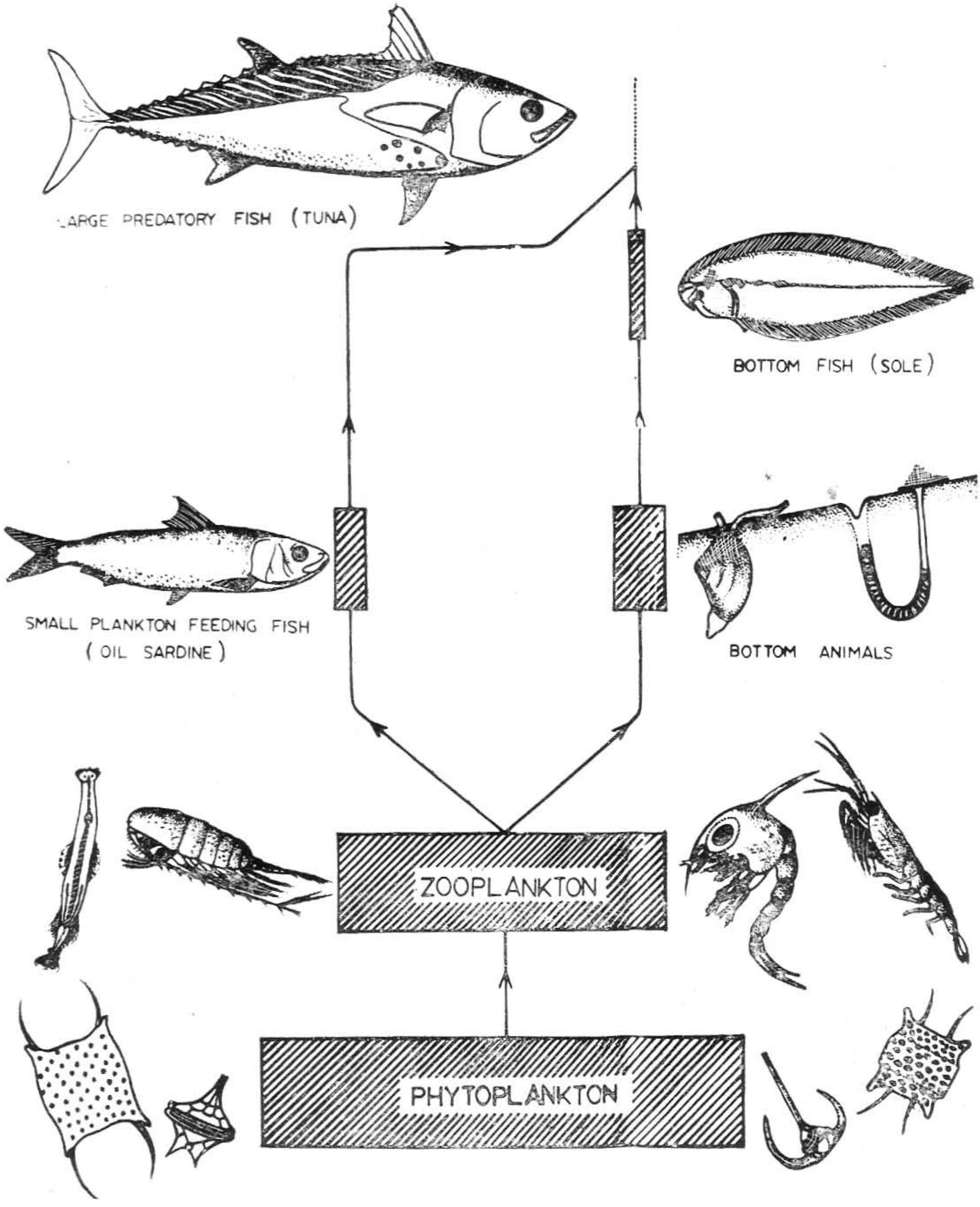

Fig. 6. Food cycle in the sea. The diagram shows feeding relationships between major marine communities.

Assuming that all the net primary production is eaten up by the herbivores and that at each trophic level the carbon is transferred at an efficiency of 10%, the theoretical yield per year from the seas of the world at various trophic levels would be as follows:

		(million tons)
Phytoplankton	—	200,000
Zooplankton	—	20,000
Zooplankton eaters (mackerel)	—	2,000
Predatory fish (seer fish)	—	200

Conclusion

Today the seafood production of the world is approximately 60 million metric tons. This means that only 3% of the world's food production is derived from the sea. If the future growth of all the conventional fisheries is going increase at the same rate as in the past, that is about 7% every year and doubling every 10 years, the overall impact of the total food supply to the world population would not be impressive. Nearly 60% of the population in developing countries, which comprises nearly two-thirds of the world's population, suffer from undernutrition, malnutrition, or both. It seems that technical competence in some of these countries is not developing fast enough to avoid famine. If the ocean harvest is to be realized fairly rapidly to meet the increasing demand for protein food, some radical changes are necessary in developing a complex technology by which the cost of marine protein to the consumer is substantially reduced. This can possibly be achieved through *aquaculture* or *sea farming*—a programme in which biologists, oceanographers, marine engineers, technologists and economists could work together to increase the seafood production at a lower cost.