The Wet Desert

Oceanic oases depend on more than just water

By Malvern Gilmartin

Can the oceans feed the increased population of the future? Because the oceans cover almost 70 percent of the earth's surface, it is often assumed that vastly increased food supplies can be secured from the oceans simply by more intensive and more extensive exploitation. The validity of this "life and death" assumption and the limits of the oceans as a source of food for expanding world population concern us all.

To estimate the total potential fish catch, biological oceanographers assume a theoretical flow of organic material through the food chain, starting with an estimate of the amount of primary production by marine plants and theorizing certain efficiencies of transfer between known links of the food chain. Almost all marine primary production of signficance can be attributed to the activities of single-celled plants known as phytoplankton. These plants float freely and grow only in a thin surface layer—about 30 to 50 meters in depth—where light can penetrate in sufficient quantities for photosynthesis. This euphotic zone is the growth zone of the phytoplankton.

No technique has been developed that can significantly increase phytoplankton production on a large scale. Furthermore, phytoplankton are distributed so sparsely in the ocean that one cannot conceive of a harvesting scheme that would not utilize more energy in harvesting than it would collect during the harvesting. It is necessary to fall back on indirect harvesting, that is, to crop this primary production at higher steps in the food chain. Only rarely do commercially exploitable fish such as sardine or herring feed directly upon the main primary producers—the phytoplankton. There are usually one to several links in the food chain between these plants and commercially exploitable fish—such as flatfish and tuna. Therefore, since food supplies from the oceans basically depend on phytoplankton production, the key questions to be answered are: What is the production on a world-wide basis, and what ecological factors control this production?

Primary Production from the Sea

Since primary producers are plants, the two major factors that establish the basic pattern of primary production are the availability of light energy and the availability of plant nutrients such as phosphates and nitrates. Light energy is the more important in determining the seasonal patterns of primary production, especially in the higher latitudes, and the availability of nutrients governs the large-scale features of primary production when considered on an annual basis.

A grossly simplified example of the control and interaction that solar radiation and nutrients place on primary production can be illustrated by the annual north temperate zone cycle of phytoplankton growth. During the winter the phytoplankton population is very small; however, each spring brings a dramatic increase. This spring phytoplankton "bloom" tends to coincide with the spring increase in radiation, and is usually considered to be triggered by that increase. This rapid outburst of phytoplankton growth tends to deplete the nutrients that have been introduced into the euphotic zone by vertical winter mixing. By early summer, this reduction, combined with cropping by grazing zooplankton, has produced a marked decrease in population size. However, during mid-summer nutrient regeneration within the euphotic zone again raises the level of nutrients to the point where a secondary outburst of phytoplankton growth occurs, an autumn "bloom" which is subsequently slowed and stopped by the winter decrease in radiation.

In most of the open ocean the low concentrations of available nutrients impose a brake on the rate of primary production, with the consequence that—especially in tropical areas—the rate of supply ultimately determines the rate of primary production. Since these nutrients are supplied primarily by the decomposition of organic material within the euphotic zone, the supply rate is low and primary production is necessarily limited. Therefore, the key factor influencing the production and the distribution of phytoplankton is the mechanism by which the euphotic zone is fertilized with plant nutrients.

By way of contrast, consider the terrestrial habitat. On land a certain amount of "natural fertilization" takes place. That is, dead organisms decay in situ and the nutrients they contain are released to directly serve the next generation of plants. In the sea, however, the decomposition products of plants and animals tend to sink toward the bottom and the organic and inorganic compounds that they contain are constantly being removed from the euphotic zone. Although these remains decompose as they sink and their inorganic nutrients ultimately enter into solution, the process takes place primarily below the euphotic zone. In other words, on land the remineralization process tends to enrich the strata in which the plants grow, but in the sea it tends to deplete the strata in which the phytoplankton live. Since the deeper layers are always relatively rich in nutrients, fertilization can take place by any process which leads to a mixing of underlying with surface waters, a process called upwelling.

Upwelling occurs in both the coastal and open oceans. An example of the former is the California coast where the prevailing winds blow from the northwest roughly parallel to the coast for most of the year. The wind-maintained California Current results, and surface waters are transported to the south and also to the west under the influence of the earth's rotation or Corriolus force. The surface waters thus carried away from the coast are replaced by nutrient-rich waters upwelling from depths of 200 to 300 meters. As a consequence, this region, along with similar regions off Peru and West Africa, is one of the most fertile of all the oceans, and very high rates of primary production and enormous fish populations result.

Another area of high production is the upwelling region of equatorial current systems. A band of high primary production, which sweeps across the Pacific Ocean at mid-longitude, is directly linked to the south equatorial current, which flows westward impelled by the trade wind. This surface current, under the influence of the earth's rotation, diverges very slightly to the north and south of the equator, with the consequence that upwelling occurs along the equator. The result is a region of high primary production just north of the equator, and a region of high secondary production farther "downstream" to the north.

It should be noted that the physical forces resulting in the vertical movement of nutrient-rich waters into the euphotic zone are basically and closely linked to the rotation of the earth, and are not amenable to alteration by man. Yet the overall effect of these physical forces and the various ecological factors which control the growth of phytoplankton is to place a finite limit on the total amount of organic material produced by marine primary production.

Marine Versus Terrestrial Primary Production

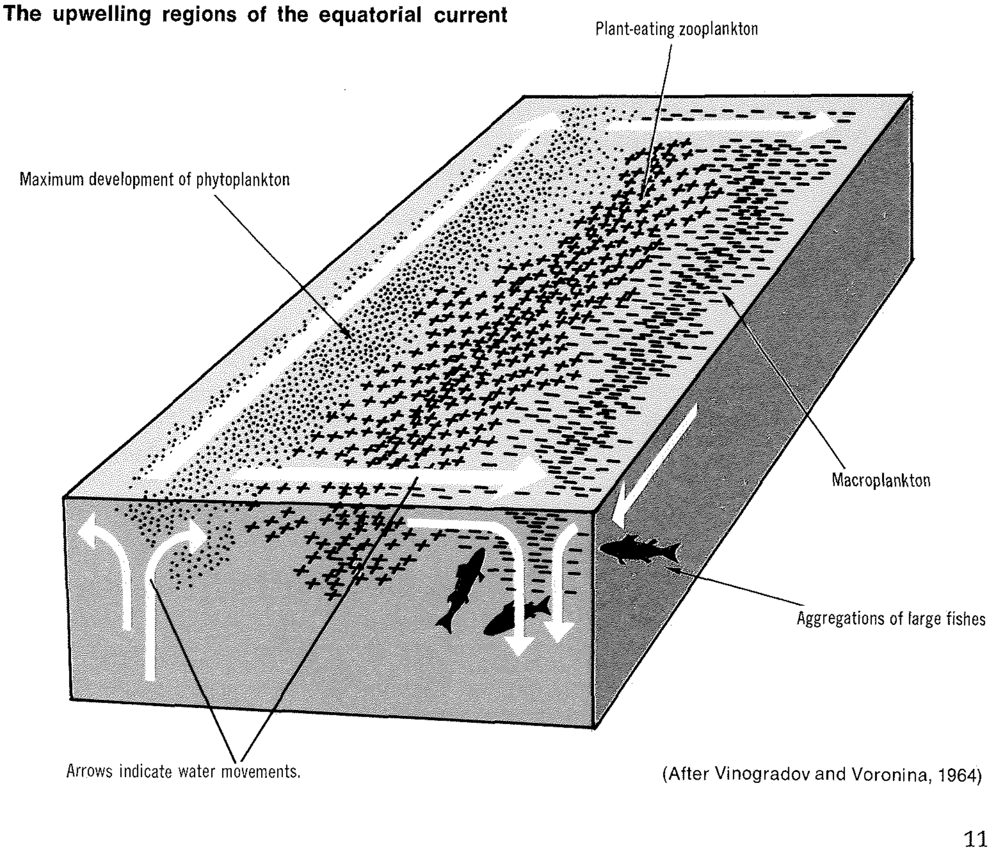
The average gross primary production of the oceans is estimated at about 0.15 grams of carbon per square meter per day ($gC/m^2/day$), ranging from 0.05 $gC/m^2/day$ in the Sargasso Sea to about 3-5 $gC/m^2/day$ off the coast of California, Peru, or West Africa. This represents a total production of 0.14 to 2.5×10^{10} metric tons of organic carbon per year for the world ocean. The best current estimate for that production is about 1.9×10^{10} metric tons per year. Primary production on land, on the other hand, is better known, with a figure of 2.0 to 2.5×10^{10} metric tons per year being generally accepted.

Although the amounts of primary production are approximately the same on land and sea, this nearly equal primary production is occurring in two very differently sized areas. The oceans are more than double the land area of the earth's surface. One would therefore expect the marine primary production to be at least 2½ times more sparsely distributed than terrestrial primary production on the basis of area alone. This is compounded by an even more important difference between terrestrial and marine plants. The generation time—time to complete a life cycle—of most land plants is in the order of a year, or an appreciable fraction thereof. In the ocean, to the contrary, the generation time of the most important group of plants, the phytoplankton, is in the order of days. As a consequence, the standing crop of plants in the ocean is even more sparsely distributed; concentrations in even the very richest areas are only in the order of a few grams or so of organic carbon per square meter. By contrast, average north temperature farmland supports crops of plants in the order of 1,000 grams per square meter.

Secondary Production from the Sea

As indicated, most harvestable resources in oceanic regions do not feed directly upon the phytoplankton; there are usually one to several links in the food chain between these and the primary producers. As organic material moves from one nutritional or trophic level to the next, less is available at each new level. This loss is due not only to predation, metabolic activity, and waste products, but because much of the ingested material is not digested, but merely passed through the gut, especially during periods of heavy feeding. As a result, the efficiency of conversion at each level is usually estimated in the 10 percent range. With a food chain of several steps, only some

The upwelling regions of the equatorial current



(After Vinogradov and Voronina, 1964)

1/1000 to 1/10,000 of the original primary productant is available to man.

This can be more clearly illustrated by considering the table below, which shows the potential harvest at various trophic levels, assuming 10-percent, 15-percent, and 20-percent efficiencies of conversion, and starting with a total annual primary production for the world ocean of 1.9×10^{10} metric tons.

From this table it can be seen that if all the secondary production in the ocean were harvested at the secondary carnivore stage, the catch would be in the range of $1.9\text{-}15.2 \times 10^8$ metric tons total weight per year. Obviously, only some fraction of this production can be economically harvested.

There is also another very basic difference between the primary and secondary production of marine systems as compared to the primary and secondary production of terrestrial systems. On land, a very large amount of secondary production is harvested in the forms of herbivores (such as cattle) in a simple one-to-one food chain. In the oceans, to the contrary, the food chains are much more complicated and often include many trophic levels, with the flatfish and tuna being at the second and third carnivore stages.

It is interesting to compare the approach used by biological oceanographers with that usually used by fisheries oceanographers—who base their analyses on actual projections based on known resources and combined with suspected populations which are not currently being harvested but which might be harvested with improved fishing techniques. As shown in the table below, most of the estimates vary by less than an order of magnitude, and fall within a 0.2 to 2.5×10^8 range. If the reasonable assumption is made that due to "harvesting" by other biological elements of the ecosystem, uneven distribution of commercial fish, and technical problems, we can never harvest more than 10 percent of any trophic level, the estimates from the fisheries oceanographers and those from the biological oceanographers agree very well.

The fishing industry is already pushing the upper limit of total production as they move toward lower trophic levels. There are all sizes of animals in the ocean, from zooplankton to whales, but only those longer than about 5 centimeters, i.e., 1½ inches, occur in sufficient densities to support

Estimates of total ocean yields of aquatic animals

Author	Forecast (metric tons)	Year
Thompson	$.2 \times 10^8$	1949
FAO	$.6 \times 10^8$	1955
Finn	$.5\text{-}.6 \times 10^8$	1960
Graham and Edwards	$.6 \times 10^8$ (bony fishes)	1962
Meseck	$.6 \times 10^8$ (by 1970)	1962
Graham and Edwards	$.6 \times 10^8$ (bony fishes)	1962
Schaefer	$.7 \times 10^8$ (by 1970)	1965
Meseck	$.7 \times 10^8$ (by 1980)	1962
Alverson	$.8 \times 10^8$	1965
Bogdanov	$.7\text{-}.8 \times 10^8$	1965
Schmitt	10×10^8	1965
Schaefer	1.6×10^8	1965
Kasahara	$2\text{-}2.5 \times 10^8$	1967
Chapman	20×10^8	1970

Extrapolated from catch trends or existing knowledge of world fish resources.

Estimates of potential yields* (per year) at various trophic levels, in metric tons

Trophic level	Ecological efficiency factor 10% Organic Carbon	10% Total wt.	15% Organic Carbon	15% Total wt.	20% Organic Carbon	20% Total wt.
(0) Phytoplankton (net particulate production)	1.9×10^{10}		1.9×10^{10}		1.9×10^{10}	
(1) Herbivores	1.9×10^9	1.9×10^{10}	2.8×10^9	2.8×10^{10}	3.8×10^9	3.8×10^{10}
(2) 1st stage carnivores	1.9×10^8	1.9×10^9	4.2×10^8	4.2×10^9	7.6×10^8	7.6×10^9
(3) 2nd stage carnivores	1.9×10^7	1.9×10^8	6.4×10^7	6.4×10^8	15.2×10^7	15.2×10^8
(4) 3rd stage carnivores	1.9×10^6	1.9×10^7	9.6×10^6	9.6×10^7	30.4×10^6	30.4×10^7

* Output to predation at each trophic level.

(after Schaefer, 1965)

"With a food chain of several steps, only some 1/1,000 to 1/10,000 of the original primary productant is available to man."

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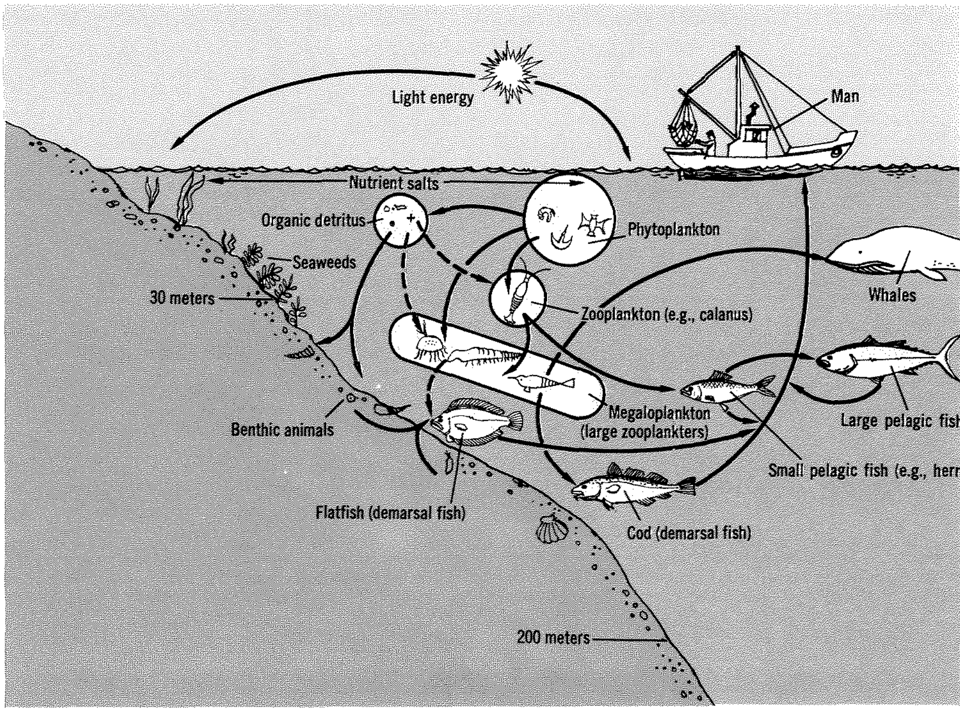
commercial fisheries. Furthermore, the greatest volume of fish used for direct human consumption are animals longer than about 25 centimeters, i.e., 10 inches. This is due simply to the economics of collecting and processing the catch. It's cheaper to work with larger animals.

The effect of this preferential use of larger animals has been to limit the total catch. As can be appreciated, these larger animals are also usually higher in the food chain, with the usual loss of 80 to 90 percent at each subsequent trophic level. Yet there has been a gradual increase in total yield predictions over the years as more and more smaller fish are taken. And at least one expert, Chapman, felt that the total catch may eventually reach 20×10^8 metric tons. It should be noted that Chapman, and perhaps Schmidt, are talking about a different mix of animals than the others. Those who contend that the upper production limit may be in the neighborhood of 2×10^8 metric tons are talking about the kinds of animals the industry is currently catching, primarily animals 25 centimeters or longer for direct human consumption, with some mix of smaller fish. Those who hold that the upper production limit may be in the order of 20×10^8 metric tons are talking about the whole range of animals 5 centimeters or longer that could be caught. These would include such animals as the krill of the Antarctic which the Russians are now experimentally fishing, the red crabs off Baja California and the west coast of Mexico, and the lantern fishes.

This is more than just an academic point. The way in which the total potential fish yield is expressed has rather significant political implications. It is difficult enough to get sovereign countries to force their fishermen to follow conservation regulations, and overfishing on "conventional" fish is already a major problem in many areas. Some fisheries biologists feel that if politicians "knew" that the upper limit of sustainable production for the sea was actually 20×10^8 rather than 2×10^8 metric tons per year, they would never enforce conservation regulations, and there would be even greater damage and loss of productivity in stocks of the "conventional" fish that now produce most of the fish used for direct human consumption.

What does this actually mean in terms of food for humans? As we've seen, the total primary production of the ocean has a finite limit due to the amount of available light energy and plant nutrients. These place an upper limit on the total secondary production and total catch, even with vastly improved fishing techniques and/or the discovery of unexploited fish stocks. The current annual fish production of



Animals in the ocean range from zooplankton to whales, but only those longer than 1½ inches occur in sufficient densities for commercial fisheries, and most fish that we eat are longer than 10 inches.

0.65×10^8 metric tons equals 6×10^{12} gram calories of food energy, sufficient to satisfy about 18 percent of the food energy requirements of the current world population. It is generally accepted that current production will be increased to at least 1×10^8 metric tons, and possibly $1.6\text{-}1.9 \times 10^8$ metric tons by the year 2000. If a production of 1.6×10^8 metric tons is achieved it would suffice to supply about 3 percent of the minimal food energy requirements, and perhaps 30 percent of the minimal protein requirements of the world population in the year 2000—*if rationed and equally distributed.*

Therefore, while this increased production may not be able to make a major contribution to providing the quantity of food mankind will require in the future, it can make a very significant contribution to the quality of food essential to a healthy diet. These potential nutritional benefits are so significant, particularly in protein-deficient developing countries, that accelerated efforts are urgently required to establish the scientific and technological base essential for an expanded harvest of the ocean's food resources, and to establish the socioeconomic base essential to the harvesting, processing, and distributing of an incredibly valuable world resource. ■

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