Fishery Potential from the Oceanic Regions

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THIS PAPER HAS a scope as vast as the oceanic province itself. Not only is the oceanic province extremely large, but relative to the various other regions of the ocean, very little is known about the resources that occupy its waters. Because so little is known about the oceanic province, inferences on this region tend to be based upon the more complete knowledge of the shallower coastal areas. In addition, the myriad of species and the vastness of the area require that a brief exposition such as this be treated with a rather broad brush. Thus, while my original intent was to treat the North Pacific Ocean, it appeared from the level of knowledge on oceanic resources and the degree of generality and exposition which conform to the style of these Colloquia that the discussion might better be served by a review of the fishery resources of the oceanic province in general. Rather than run through the traditional list of oceanic species or attempt to devise fixed estimators of the potential oceanic fishery production, I shall concentrate upon a few concepts which are used to determine this production, namely extrapolation from trends in present catches and food chain dynamics.

Estimation of the magnitude of resources of the oceanic province involves questions of practical as well as academic importance. Fish are an important element in world commerce, and they are likely to become more important in the future. Fish are also a particularly important commodity to the developing countries, perhaps not so much as a nutritional additive, but as a source of raw material which can be utilized to stimulate economic growth, thus contributing to international stability. This increase in the significance of fishery resources will be accompanied by (1) a reduction in the rate of catch increase for conventionally harvested species and in some instances decreases in the catch; (2) increases in national jurisdiction over fishing stocks that will reduce free access to them; (3) a rise in costs associated with conventional fishing technology; and (4) an increased demand for fishery products.

From the practical point of view we must ask how we can make the best use of our fishery resources, whether they be coastal resources or oceanic resources. There are of course many alternative paths to the development of unused resources and to the "wiser use" of those fishery resources which are already utilized. These alternative paths toward development of fishery resources exist in both developing and developed nations and in coastal waters as well as oceanic regions. The best alternative path for fishery development will depend to a large extent upon the physical capability of the various resources to produce sustained yields. This point is evidenced by noting that the present annual world catch of marine fish is about 60 million metric tons per year. If we anticipate the maximum sustainable catch to be about 80 million metric tons, our developmental strategy would be considerably different than if we anticipate the maximum sustainable catch to be 200 million metric tons. It is, therefore, important that the analysis of the maximum sustainable catch be made with great care and responsibility because appropriate development and utilization of our fishery resources are essential parts of our general resource problems.

In order to guess at the future production from the oceanic region, it is useful to attempt to extrapolate from present trends in world catches in general. These oceanic resources include the tunas, the billfishes, the squids, the flyingfish, the dolphin, and a myriad of various deepwater and surface species. The trends in catches have been reviewed by Gulland (1971). He observed a rather steady increase, at a rate of 7 percent per year, in the world catch. The world catch in 1938 was 21×10^6 tons, in 1956 it was about 30 million tons, and in 1970 it was nearly 70 million tons. The increase of 7 percent per annum has, of course, been compounded by declines and increases in individual fisheries as well as the institution of new fisheries and the elimination of others.

Gulland (1971) points out that in terms of new fisheries we have the following:

Peruvian anchovetta	(1955)	60,000 tons	(1961)	5 million tons
Norwegian mackerel	(1963)	20,000 tons	(1967)	870,000 tons
Thailand otter trawl	(1962)	78,000 tons	(1965)	337,000 tons
Southeast Atlantic hake	(1962)	100,000 tons	(1966)	410,000 tons

Off our own Pacific coast we have had some dramatic increases in catch of hake and other groundfish, and there is considerable potential increase in the catch of some fish such as the anchovy. On the other hand, we have had declines in some fisheries in the North Pacific such as the famous sardine decline, king crab in the Subarctic Pacific, and sauries off Japan. The yellowfin sole peaked at 500,000 metric tons in 1960 (estimated population 500,000 metric tons in 1964). Some fisheries have declined elsewhere, such as the herring in the Atlantic. Because of these rather short-term fluctuations it is rather dangerous to extrapolate from catch trends in individual stocks. Nevertheless we can make some interesting generalizations about the increases in catch:

1. The world catch continues to increase.
2. New fisheries must be found to maintain the increases in total catch.
3. Since relatively few individual fisheries have become extinct (possibly owing to a damping off in fishing effort as the stocks decline in density), we must be fishing an increasing number of species.
4. Fishing changes the productivity of stocks by changing mortality rates, and one can speculate that greater total yields might be obtained from many overfished stocks than from a few moderately fished stocks.

If the increase of 7 percent per year were to continue, we would hit somewhat more than 100 million tons (of conventional forms) by 1980 and about 800 million tons by the year 2000. Most authors feel that the final limit is of a magnitude closer to 100 million tons than to 800 million tons. If we can proceed, however, to several hundred million tons per year, we will almost certainly be exploiting nonconventional fisheries such as squid, larger zooplankton, and small oceanic fish. We would almost certainly need to consider harvesting significant quantities of the oceanic forms if it were possible to do so.

The Pacific Ocean has traditionally supplied somewhat less than half the total world catch, and there is no reason to doubt that it will continue to do this. For the total world catch to exceed 100 million tons and the Pacific to go beyond about 50 million tons, there will need to be considerable reliance on the nontraditional types of fish. Before these fish can be caught, it is almost certain that new technologies will have to be developed. In fact, these technologies are probably a major constraint upon the harvest of oceanic fishes. The potential catches of the various oceanic forms have been summarized by Gulland (1971) from extrapolation and other evidence (Table 1.).

It is interesting to note that the total scombrid catches, primarily the large fish, have remained stable over the last several years at about 1.5×10^6 to 1.6×10^6 tons, so large increases in these forms (with the

Table 1. Summary of potential catches from oceanic resources

Type of fish	Tons
Whales	
Large baleen (1,900 Blue Whale Units)	1,640,000
Sperm whales (25,000 animals)	500,000
Small whales	500,000
Dolphins, porpoises	?
Salmon	
North Pacific	500,000
Atlantic	15,000
Tunas	
Large tunas	
Pacific	350,000 – 450,000
Atlantic	200,000 – 250,000
Indian Ocean	100,000 – 150,000
Skipjack	
Pacific	500,000 – 800,000
Atlantic	250,000 – 300,000
Indian Ocean	160,000 – 300,000
Other small tunas	
Frigate mackerel	(1,000,000)
Bonito	(500,000)
Little tuna	?
Thynnus tonggol	?
Sharks	(500,000)
Coryphaenids	(1,000,000)
Squids	10-100 million
Myctophids, etc.	Hundreds of millions
Red crab	(1,000,000)

Note: Salmon are included here because most of their growth is accomplished in open oceans. (From: *The Fish Resources of the Ocean*. FAO, 1971, J. A. Gulland, ed. Fishing News (Books) Ltd.).

exception of the skipjack tuna) are unlikely. Also, of the important tunas of commerce, roughly 65 percent are caught in the Pacific Ocean, 10 percent in the Indian Ocean, and 25 percent in the Atlantic Ocean. Very roughly, 50 percent of the world ocean is the Pacific, 30 percent the Atlantic, and 20 percent the Indian, which suggests only on the basis of surface area that larger catches may be expected from the Indian Ocean.

If we are to have really large increases in world catch, they are likely to come from the oceanic regions. We have so little experience with the oceanic regions that there is little basis for extrapolation, and this raises the question of using an alternative procedure to guess the potential yield of fish from the oceanic region. The best known alternative procedure is to estimate the potential production of an oceanic region on the basis of primary production and the production at each successive stage in the food chain.

The classic food chain argument is extremely simple. I shall reiterate it here so that I can base my further remarks on certain of its aspects. The food chain can be viewed as a collection of factories. This is diagrammed in Figure 1. An extremely important aspect of this scheme is the number and configuration of the factories. The real "road map" could be quite complicated with such things as multiple tracks, switching yards, and tracks that pass at least once through the factory of origin before reaching the factory of destination. Furthermore, each factory has been treated essentially as a "black box," measuring only the inputs and the outputs without considering the internal working mechanism. (There are, of course, a number of papers that consider internal working mechanisms of the factories, but most of the literature on food chain estimation of production tends to be unconcerned with the details of the phenomena that occur in the "factories." Indeed, the system may, in many respects, be less sensitive to the workings of the factories than to the number of factories.)

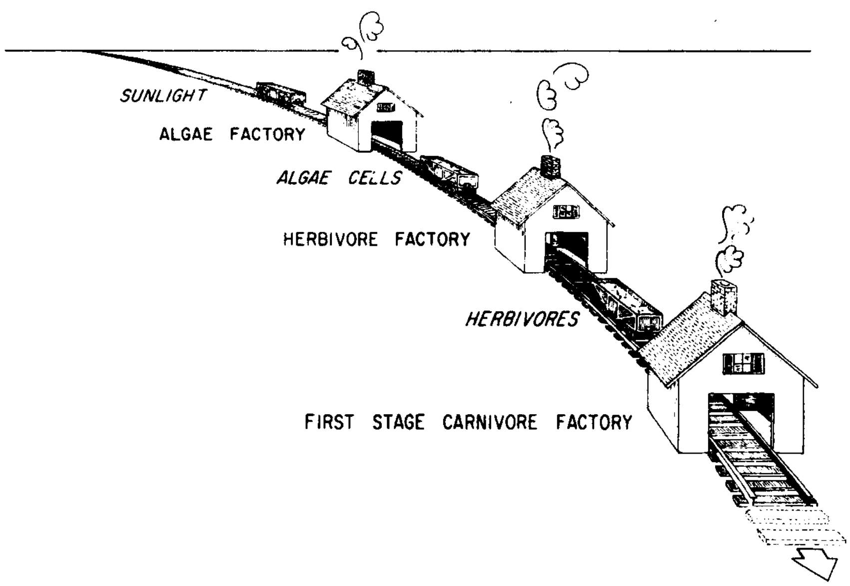

Figure 1. Food chain viewed as a collection of factories.

This food chain approach has actually been used to deduce the total yield of the ocean and portions of the ocean such as the oceanic region. Ryther (1969) discusses the primary productivity of the various ocean regions, the rate of production of the "algae factory." First there is the open ocean or the *oceanic province* which is our major concern today. This province occupies 90 percent of the world ocean. However, its mean primary productivity is rather low (about 50 grams of carbon per square meter per year is fixed in organic matter). Next we have the *coastal zone,* which represents about 10 percent of the total ocean area including offshore areas of high productivity. The productivity is higher here, about 100 grams of carbon per square meter per year. Finally we have the *upwelling areas,* which occupy a fraction of a percent of the total area and have the highest productivity of all—300 grams of carbon per square meter per year. It is significant to note that, even with its low primary production per square meter, the oceanic province represents, according to Ryther's statistics, about 85 percent of the total annual productivity of the sea, yet only 2 or 3 percent of the world fish catch is taken from this area.

Next we need to evaluate the transformation process in each factory. How much material is carried in the boxcars to the next factory and how much is blown out of the smokestacks as metabolites and other material? In discussing the transformation process we will discuss the food chain approach as defined by Ricker (1969). Ricker discusses the two relevant coefficients:

> *E,* the ecotrophic coefficient—the fraction of a prey species' annual production that is consumed by predators (trophic referring to nutritive or food levels);
> *K,* the growth coefficient—the predators' annual increment of weight divided by the quantity of food they have consumed.

Ricker (1969, p. 94) adjusts the ecotrophic coefficient for recycling and arrives at the following values:

	Growth coefficient (*K*)	Ecotrophic coefficient (with recycling adjustment) (*E*)
Primary consumption (grazing on green plants)....	15%	66%
Higher levels	20%	75%

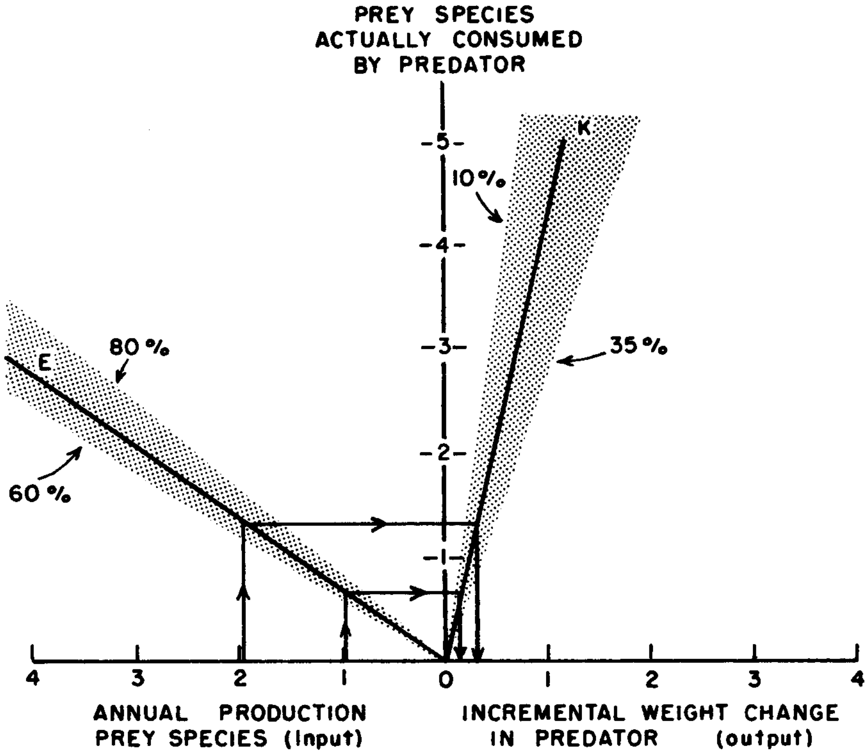

Figure 2. The relation between the annual production of prey species (input), the prey species actually consumed by the predation, and the incremental change in the production of the predator (output). The two lines which trace the transformation of input to output demonstrate the effect of an incremental change of input on output.

giving *KE* values of roughly 10 percent at the herbivore stage and 15 percent at the higher levels. Figure 2 is a diagram of this process, showing that changes in the production of prey species can have proportionately equal effects on the change in incremental weight of the predators.

Note that by the simple way the problem is formulated, the relation between the ordinate values and the abscissa values must be straight lines passing through the origin, a situation which may be quite unlikely in the real world. This is, of course, true of all constant transfer coefficients that are given in the literature.

Ryther used coefficients, *KE,* of 10, 15, and 20 percent for the oceanic, coastal, and upwelling provinces respectively. The exact magnitude of these coefficients is not at all certain. It is also not clear that they differ in a consistent way between the oceanic, coastal, and upwelling provinces. They may, in fact, be more variable depending on the level of the chain rather than the location of the chain. There is, however, general agreement that the coefficients lie between 10 and 20 percent.

Next we need to know how many factories or levels exist in our simple model. Ryther assumed that harvestable fish production would occur at the fifth trophic level in the oceanic province, at the third in the coastal zone, and between the first and second (1 1/2) in the upwelling zone. This assignment along with the efficiencies provided Ryther with a guess at the total potential production of fish in the world ocean of about 240 million metric tons. His figures give equivalent total fish production to the coastal and upwelling provinces, but allocate 1/150 of the total potential fish production to the oceanic province. In other words, only 10 percent of the world ocean accounts for something like 99 percent of the total potential fish production. These particular results of Ryther's have been criticized in the literature (see Alverson et al., 1970). The criticism boils down to the fact that many plausible alternate coefficients could have been used to obtain strikingly different conclusions.

Why is there a considerable difference in fish production deduced from impressions of the populations (Table 1) and the food chain analysis? For example, the food chain method gives a fish production in the oceanic province of only 1.6 million metric tons. The actual catch (not the production) is actually approaching this quantity, and yet there are rather large stocks as judged by the number of larvae of unexploited scombrids in the oceanic regions, not to mention the squids, deepwater fishes, and others.

Since it is difficult to pinpoint the difficulties, we might examine the model itself. The most sensitive spot in our food chain model is the length of the food chain. To take an example we note that

$$P_n = P_o k^n$$

where P_n is the production at the nth stage, P_o is the primary production, k is the transfer coefficient, and n is the number of stages. Table 2 gives values of P_n for several P_o at various k and n. Clearly, the number of trophic levels, n, affects P_n very strongly. Changes in k appear to be relatively unimportant for most reasonable values of k. Using the above equation for particular areas may give us some idea about the adequacy of the classic food chain model in the regions of interest. As we explore the details of the simple model, we are aware that the divergence between the food chain approach and the extrapolated estimate of oceanic productivity could very well be produced by the model

Table 2. Expected levels of fish production in the oceanic province (derived from food chain model)

Level of primary production	Transfer coefficients (k) 20%			15%			10%		
	Trophic levels (n) 2	3	5	2	3	5	2	3	5
$gCm^{-2}yr^{-1}$									
50	10	2	0.08	7.5	1.13	0.025	5	0.5	0.005
100	20	4	0.16	15	2.25	0.051	10	1	0.01
300	60	12	1.48	45	6.75	0.153	30	3	0.03

diverging from the real world, a difference in the number of trophic steps which was used for the food chain model, or extrapolations that are too high. It is less likely that the values of the transfer coefficients or the estimates of primary productivity produce these divergences. With respect to realism it is well known that it is extremely difficult to evaluate at which trophic level an animal actually resides. While it is relatively easy to determine what an animal eats, it is not easy to determine what its food ate; in any case, no organism is going to fit into neat integral trophic levels, especially during the course of its life.

Given that the factory model is a very simplified abstraction, we must ask whether it is a satisfactory approximation. It is, in the sense that we can come up with almost any answers by modifying the various coefficients. But this may not be a good criterion. The main utility of such a model will almost certainly lie in enabling us to understand how the fundamental processes in the ocean *differ* from the simple model. Most critical are the pathways and feedback mechanisms that channel the flow of energy among the factories and the inner workings of the factories themselves. Short circuiting of the chain can produce substantial differences in production of animals of harvestable size.

Some of the problems of generalizing about the biology of oceanic fishes with respect to trophic dynamics could be considered in terms of "average" coefficients and trophic levels. It may be that certain species which inhabit particular water masses (see Ebeling, 1967) are characterized by particular sets of coefficients and trophic levels and that the differences in these features among water masses would induce more variability in these characteristics than that which would obtain, for example, for demersal fishes. In addition the "two-layered" tropical ocean produces some intriguing problems in food chain dynamics with respect to introducing nutrient-rich water into the photic zone by eddies downstream of islands (see Barkley, 1972) and by the diurnal migration of some fish between the surface and deep layers.

Another intriguing problem in oceanic food chains, which again involves the question of how we interpret trophic levels, is the role of organic substances and the equilibrium between dissolved and particulate organic material. Exactly how this material is incorporated into the food chain and if it is incorporated in significant amounts remains elusive. Provasoli (1963) has compiled a considerable amount of information on this subject. He emphasizes the difficulties of dealing with organic substances in sea-water which are caused by their minute concentrations: "Characterization of organic compounds in sea-water is complex because the dissolved organic C averages 2 mg/s (maxima up to 20 mg/s). These minimal quantities have to be separated from 35,000 mg of inorganic salts in a liter of sea-water. . . ." These tiny quantities of organic material evidently contribute to the existence of the phenomenon that Provasoli calls "good" and "bad" waters; for example, the ". . . productivity along the coast of California is far less than around the British Isles, yet the phosphate content of California waters is many times higher."

Even though modifications in the transfer function may not be relatively important, it is worth emphasizing the simplicity of the model by pointing out that it does not consider time lags. This is easily demonstrated by examining simple control system equations. The transfer function that is typically used in food chain dynamics is the zero order function:

$$I = k\Omega$$

where I is the output, Ω is the output, and k is a constant. There are quite plausible, more complex functions which can represent the process, viz., the first-order and second-order differential equations:

$$I = k\Omega + L\frac{d\Omega}{dt}$$

and

$$I = k\Omega + L\frac{d\Omega}{dt} + M\frac{d^2\Omega}{dt^2}.$$

A simple unit-forcing function can, depending upon the value of the constants, L and M, generate quite different results for the time-behavior of the output of the system. This is shown in Figure 3.

Thus, with the zero order equation the quantity of material produced at a factory is a constant fraction of the material that enters the factory. With more complex, more realistic equations, there are time

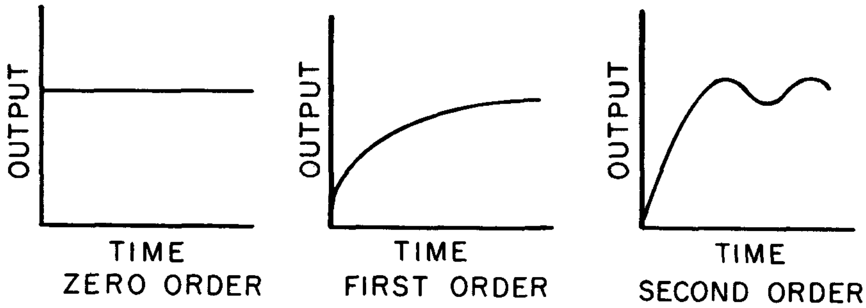

Figure 3. Typical outputs resulting from constant input as a function of time showing different kinds of lag effects possible for zero-order, first-order, and second-order differential equations.

lags which could cause considerable oscillations in the system. (Are these oscillations reflected in varying year-classes of fish?) Another time-related effect is the age effect. Most population theory relates to $dN/dt = zN$, and it can be shown that the average age of the organisms in the population is $1/z$. However, the average age of the population can be modified by changes in the predator population or by fishing. If we assume that size is a function of age, and that diet is a function of size, then the transfer coefficient must be continually changing. The point of this is that the zero order equation is conventionally used, but the higher order equations are much more likely to operate. If, for example, the damping ratio is small, the fluctuations can have yearly or quarterly periods, and the trophic position of organisms must be changing constantly with mortality and other vital rates.

Other factors that affect the nature of the transfer coefficient are various changes in the environment that can be temporary but occur at important stages during the organism's life, and changes of a longer term. Take, for example, the whole question of nutrition (see Phillips, 1969). It is conceivable that there are long-term and short-term changes in the amounts of proteins, fats, and carbohydrates present in a trophic level. The essential amino acids and fats, the sparing action of certain amino acids and fats, and mineral and vitamin requirements may also vary. As another example, consider the fluctuations in temperature that can operate upon an animal's temperature tolerance, preference, "appetite," and digestion. When do these variations of nutrition, temperature, and a host of other factors create significant perturbations in the system? We do not know.

Thus, it is clear that there are many unanswered questions concerning the use of the factory model to forecast the productivity of the oceanic region. Perhaps we need to ask what additional knowledge the food chain model will produce. Perhaps we need to look at some newer configurations of the problem involving the fate and residence time of packets of energy in groups of animals. We could in this context consider a variety of queuing questions for each group of animals: what is the arrival time of packets of energy at different densities and nutritional quality, what are the lengths of the queues, what are the holding times, and what is the effect of queue impatience?

All of this has simply served to point out that the oceanic province is about as little known, with respect to the kinds of information required to make resource decisions, as it was at the time of the *Challenger* expedition. If economic pressures accelerate the harvesting of the oceanic regions, then we need to concentrate upon obtaining information that will promote correct decisions with respect to the exploitation of these resources.

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