Trends in Use and Prospects for the Future Harvest of World Fisheries Resources[1]

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ABSTRACT

Estimates of the potential yield from the marine environment have varied between 20-1000 million metric tons because they were based on poor and incomplete data and differing approaches to trophic level evaluation. The data is improving slightly and the estimates are beginning to agree within half an order of magnitude. We believe that the yield of marine fisheries could ultimately be expanded to ca. 400 million metric tons, by utilizing presently known but underutilized resources, by opening new fisheries in areas like the Indian Ocean and Antarctic and by improving systems of regulating the catch and fishing effort. In order to meet the maximum potential of the marine environment we will have to harvest at a lower trophic level in the food chain because most fish in higher trophic levels are being harvested at their maximum sustainable yield. This increasing harvest of smaller fish, plus the increasing demand for fishmeal for animal feed will cause an increasing proportion of the fish harvested to be used for reduction to fishmeal and oil.

INTRODUCTION

Fish are both a source of needed protein to the world's expanding population and to some countries a prime source of foreign exchange earnings. Fish in themselves will not solve the world's need for protein food, but they are a vital link in the available arsenal of protein foods which must be developed and conserved.

Production of Protein Foods

As shown in Table I, more milk is produced (395 million metric tons in 1968) than any other single protein food commodity for direct human consumption. Fish used for direct human consumption (40.3 million metric tons in 1968) excluding whales, is second to milk with beef and pork following closely at 37.8 and 34.0 million metric tons, respectively. The production of eggs, poultry and lamb were each less than half of the pork production.

The fish production figure stated above does not include the fish used for fishmeal, 23.0 million metric tons in 1968 (see Table II). This production of fish for meal was about half the level of total soybean production (1). Interestingly enough a substantial portion of the poultry production is a result of the increased use of fishmeal for poultry feed.

World Trade in Protein Foods

Table III shows that the quantity and monetary value of fish (export: 3.3 million metric tons, $1749 million) entering world trade has been greater than any other single food for direct human consumption for the past 5 years. A close second in value is beef. However beef has about the same tonnage as fish in world trade. Beef is followed by milk, pork, lamb, poultry and eggs (2).

Fishmeal, as shown in Table IV, has been the most valuable meal (export: 3.5 million metric tons, $381 million) in trade in terms of value for the last 5 years. However the quantity of soybean meal for the last 4 years has been greater. Peanuts, cottonseed, linseed, sunflowerseed and meat meals follow soybean meal in that order.

While the quantity of cereals entering world trade in 1968 is well over 12 times greater than the quantity of direct protein, the monetary value of the direct protein is ca. 705 of the value of the cereals. This means that only the richer countries can afford most of the direct proteins. The meals on the other hand have a greater quantity than the direct proteins, but cost one-fifth as much as the direct proteins. Even if the cost of the meals would double in making them palatable for direct human consumption, the price would still be comparatively low. This lends credence to the idea that in the future the refined meals may be a comparatively inexpensive source of high quality protein for human diets.

In summary, fish are an important source of protein. In fact fish protein makes up ca. 50% of the animal protein consumed in 19 of the 120 countries listed in the "FAO Production Yearbook" and 25% of 45 of the listed countries. Not only is the fishing industry important now, but it has the capability of an expanded production to help meet the increasing protein needs of the world.

Potential

There has been little historical agreement in the estimates of potential marine food production as shown in Table V. Estimates for total yield have ranged from 20-1000 million metric tons (3). This lack of agreement is in part a result of the use of different trophic levels for calculation and estimates based on an incomplete and inaccurate knowledge of the oceans and fish stocks. Since we are very slowly learning more in these areas, the estimates are improving. Now it seems as though most estimates agree within one-half an order of magnitude. Considering present harvesting techniques and expanding into underfished areas and stocks, most researchers seem to agree with Chapman that a doubling (120 million metric tons) of marine food production will occur by 1990 (4). Looking at this projected expansion in terms of the expected growth in food demand of 2.5-3 times by 2000, fish should continue to play an important role in satisfying protein needs.

Because of the loss of efficiency of energy conversion in large fishes and species in higher trophic levels, it seems that man should harvest the smaller fishes in lower trophic levels. Of necessity the fishes harvested will tend to become smaller and from lower trophic levels because of increasing world-wide fishing pressure. However we are beginning to realize that with interesting exceptions, like krill which will be discussed later, harvest of plankton is not promising economically. Some sort of concentrator is needed. It is more profitable to fish higher on the food chain even with the attendant loss in energy resulting from conversion of plankton to fish flesh.

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TABLE I

Production of Protein Foods for Direct Human Consumption (Millions of Metric Tons)[a,b]

Food	Average 1948-52	Average 1952-56	1964	1965	1966	1967	1968
Milk	206.4	291.5	357.0	372.1	381.0	388.1	395.3
Fish	18.9	23.3	35.5	37.3	38.6	39.6	40.3
Beef	20.6	24.5	32.7	33.3	34.9	36.5	37.8
Pork	16.4	20.7	30.2	31.8	32.5	33.5	34.0
Eggs	9.4	11.0	14.7	15.0	15.4	16.3	16.7
Poultry	4.2	5.2	9.2	9.8	10.8	11.6	11.9
Mutton and lamb	4.2	4.9	6.1	6.2	6.3	6.5	6.6
Total (1968)							542.6

[a]Beef, pork, poultry, mutton and lamb figures are for dressed carcass weight; fish figures are in live weight.
[b]From "FAO Production Yearbook, 1969," and "FAO Yearbook of Fishery Statistics, 1969."

TABLE II

Production of Foods for Indirect Human Consumption (Millions of Metric Tons)[a]

Food	Average 1948-52	Average 1952-56	1964	1965	1966	1967	1968
Soybean	16.0	20.6	32.3	36.4	39.0	40.7	43.6
Fish for meal[b]	2.0	3.3	15.5	15.4	17.8	20.5	23.0
Cottonseed	13.7	17.1	20.9	21.2	19.9	19.5	21.2
Sesame seed	17.6	16.3	17.1	15.9	15.6	17.0	16.3
Peanut	9.6	11.4	16.1	15.7	16.1	17.1	15.0
Sunflower	3.9	4.6	8.3	8.0	9.1	10.0	9.9
Linseed	3.1	3.2	3.3	3.7	3.1	2.4	3.0
Total (1968)							132.0

[a]From "FAO Production Yearbook, 1969," and "FAO Yearbook of Fishery Statistics, 1969."
[b]Fish used for reduction does not include reduction of parts of fish used for other purposes.

TABLE III

World Trade in Protein Foods for Direct Human Consumption[a]

Commodity	1964 Q/V[b]	1965 Q/V	1966 Q/V	1967 Q/V	1968 Q/V
Fish					
Export	3.0/1361	3.1/1495	3.2/1641	3.2/1650	3.3/1759
Import	2.9/1514	3.0/1646	3.3/1838	3.2/1864	3.4/2027
Beef					
Export	1.5/1035	1.5/1128	1.5/1156	1.6/1240	1.6/1311
Import	1.5/1093	1.4/1128	1.5/1229	1.6/1310	1.6/1383
Milk					
Export	530	629	618	695	676
Import	556	601	657	709	687
Pork					
Export	.32/240	.44/303	.34/284	.34/284	.40/320
Import	.36/260	.42/281	.49/376	.54/400	.53/391
Lamb/mutton					
Export	.52/226	.55/291	.57/284	.57/279	.62/286
Import	.52/284	.53/316	.58/335	.60/334	.64/347
Poultry					
Export	.33/222	.35/246	.35/250	.37/242	.41/266
Import	.32/215	.35/240	.34/244	.36/237	.39/257
Eggs					
Export	.39/225	.38/240	.35/225	.36/224	.41/233
Import	.37/213	.38/237	.36/216	.36/210	.38/225
Total (1968)					
Export					6.74/4851
Import					6.94/5317

[a]From "FAO Trade Yearbook, 1969."
[b]Q = quantity (millions of metric tons); V = value (millions of U.S. dollars).

TABLE IV

World Trade in Meals and Cake

Commodity	1964 Q/V	1965 Q/V	1966 Q/V	1967 Q/V	1968 Q/V
Fish					
Export	2.4 /264	2.4 /303	2.4 /353	2.0 /354	3.5 / 381
Import	2.3 /300	2.3 /345	2.3 /409	2.8/ /396	2.4 / 431
Soybean					
Export	2.3 /204	2.8 /247	3.1 /297	3.4 /324	3.7 / 348
Import	2.0 /194	2.4 /239	3.0 /306	3.1 /318	3.3 / 336
Peanut					
E Export	1.6 /128	1.5 /127	1.6 /131	1.5 /124	1.6 / 134
Import	1.4 /135	1.3 /137	1.4 /144	1.3 /136	1.3 / 131
Cottonseed					
Export	.97/ 65	1.2 / 82	1.1 / 80	1.0 / 73	1.0 / 66
Import	1.1 / 92	1.3 /113	1.4 /118	1.2 /105	1.2 / 94
Linseed					
Export	.68/ 53	.79/ 61	.58/ 50	.54/ 47	.43/ 38
Import	.74/ 67	.78/ 74	.66/ 68	.53/ 54	.46/ 46
Sunflower					
Export	.28/ 19	.35/ 24	.49/ 31	.55/ 36	.49/ 32
Import	.28/ 24	.35/ 30	.63/ 52	.67/ 56	.61/ 48
Meat					
Export	.18/ 15	.18/ 19	.19/ 20	.22/ 18	.22/ 17
Import	.22/ 25	.26/ 33	.26/ 33	.20/ 23	.23/ 24
Total (1968)					
Export					10.94/1016
Import					10.50/1110

[a]From "FAO Trade Yearbook, 1969."

[b]Q = quantity (in millions of metric tons); V = value (in millions of U.S. dollars).

Theoretically, assuming a 10% conversion rate, the yield increases 10-fold for every step down the food chain. Actually, however, the conversion rate may be considerably higher because of the complicated interaction between trophic levels. Several estimates have been made of the yield at various trophic levels. Graham and Edwards estimated that trophic level four, which includes salmon and cod, has a potential yield of 115 million metric tons. Estimates of trophic level 2.5-3 (sardines) are ca. 300 million metric tons. Idyll feels that these estimates are somewhat conservative and believes that the ultimate useful yield of the oceans is 400 million metric tons (5). If Idyll's estimate is accepted, we can expect to expand the production of marine foods about six times their 1965 level. Interestingly enough, this estimate agrees with an estimate based on calculations of the amount of carbon fixed in the ocean (6).

Potential by Ecological Grouping

According to Gulland, world-wide catches of pelagic (open sea) and demersal (bottom-associated) fishes should be capable of doubling, using present methods and expanding into underfished areas (7). Pelagic species whose world-wide production was 28.4 million metric tons in 1968 should ultimately yield 57.8 million metric tons. Demersal species whose world-wide production was 22.4 million metric tons in 1968 should yield 42.5 million metric tons ultimately. The potential of these two ecological groups make up 25% of the 400 million metric ton potential. Of the remaining 300 million metric tons, we believe that 50-100 million metric tons may come from squid and octopi, 50-75 million metric tons may come from krill, and in the next 4-5 decades, possibly 100-150 million metric tons from lanternfish and other underexploited deepsea fishes. In addition to the above amounts, hopefully some contribution will be made by whales and crustaceans and molluscs, depending somewhat on the success of crustacean and mollusc aquaculture. In general the period of rapid geographic expansion and past rates of growth of 6%/year cannot last very much more than a few years,

TABLE V

Estimates of Total Ocean Yields of Aquatic Animals[a]

Author	Forecast, million metric tons	Year	Method[b]
Thompson	21.6	1949	ext.
FAO	55.4	1955	ext.
Finn	50-60	1960	ext.
Graham and Edwards	55 (Bony fishes)	1962	ext.
Meseck	55 (By 1970)	1962	ext.
Graham and Edwards	60 (Bony fishes)	1962	ext.f.
Schafer	66 (By 1970)	1965	ext.
Meseck	70 (By 1980)	1962	ext.
Alverson	80	1965	ext.
Bogdanov	70-80	1965	ext.f.
Graham and Edwards	115 (Bony fishes)	1962	f.
Schaefer	160	1965	ext.
Schaefer	200	1965	f.
Pike and Spilhaus	200	1965	f.
Chapman	1000	1966	f.
Pike and Spilhaus	180-1400	1962	f.

[a]From Bullis, 1968.

[b]ext. = Extrapolated from catch trends or existing knowledge of world fish resources; f. = flow of material through food chain.

TABLE VI

Disposition of Total World Catch (Million Metric Tons)[a]

Year	Direct human consumption	Reduction[b]
1938	18.3	1.7
1948	17.1	1.5
1949	17.6	1.5
1950	18.1	2.0
1951	20.2	2.4
1952	21.5	2.7
1953	22.0	2.9
1954	23.3	3.3
1955	24.3	3.6
1956	25.4	4.1
1957	26.5	4.0
1958	27.9	4.3
1959	29.1	6.3
1960	30.9	7.6
1961	32.3	9.7
1962	33.4	12.0
1963	34.6	12.0
1964	35.5	15.5
1965	37.3	15.4
1966	38.6	17.8
1967	39.6	20.5
1968	40.3	23.0
1969	40.5	22.6

[a]From "FAO Yearbook of Fishery Statistics," 1965, 1969.

[b]Reduction: Includes only whole fish for reduction, scraps from others.

TABLE VII

Protein Foods—Biological Data[a,b]

Food	NPU[c]	PER[c]	CS[c]
Sorgum	55.8	1.78	31
Meat (meal)	24		40
Sesame seed	53.4	1.77	42
Maize	52.0	1.18	43
Ground meat	42.7	1.65	43
Wheat	40.3	1.43	44
Brewer's yeast	55.6	2.24	45
Cottonseed meal	52.7	2.25	47
Soybean	61.4	2.32	47
Rye	58.3		50
Millet		1.73	53
Barley	60		54
Sunflowerseed	58.1	2.10	56
Rice	57.2	2.18	56
Oats	65.7	2.25	57
Linseed	55.6	2.11	59
Milk	81.6	3.09	60
Fish meal	65.8	3.42	60
Poultry	71.0		64
Pork			69
Beef	66.9	3.2	69
Mutton and lamb			70
Fish	79.5	3.55	70
Eggs	93.5	3.92	100

[a]Listed in order of Chemical Score.

[b]From "FAO Nutritional Studies," No. 24.

[c]NPU = Net protein utilization; PER = protein efficiency ratio; CS = chemical score.

although some new species will be used and new areas developed.

It is beyond the scope of this paper to attempt to dissect the pattern of protein distribution on a country-wide or world-wide basis. Others (8) have pointed out the skewed distribution of protein consumption by the developed nations and by income groups within these countries, and how fish and fishmeal contribute to these problems.

Table Grade Fish

Table VI shows the steady increase in landing of fish used for direct human consumption (table grade fish) and fish used for reduction to fishmeal and fish oil. In the late 1960's the rate of increase of table grade fish landings is notably decreasing. Figure 1 demonstrates this trend more clearly. Since World War II, the percentage of the total landings used for meal and oil has been increasing. This trend increased markedly in the 1960's. In 1969, 64.2% of the total world landings was table grade fishes, and 34.2% was used for fishmeal and oil (9).

This trend is a result of the world-wide fishing pressure on the table grade fishes and the increasing demand for fishmeal. The exploitation of table grade fishes world-wide is about at its maximum sustainable yield. Some increases may come from exploitation of Indian Ocean coastal fisheries and marine invertebrates as stated above. The increasing demand for fishmeal and oil will be described below.

Figure 2 shows the trends in the major fishing nations over the last 10 years. Peru, Japan and the U.S.S.R. have emerged as the leading fishing nations of the world, with the U.S. and Norway in competition at about half the leaders' level.

Fishmeal

Since exploitation of table grade fishes is near its maximum sustainable yield, the large increases must come in the fish used for reduction. Figure 1 shows that percentage of fish used for reduction increased from 16% in 1958 to 34% in 1969. This comparatively rapid growth is largely a result of Peru's contribution as shown in Figure 2. The amount of fish for reduction in Peru jumped from 755,000 metric tons in 1958 to 5,213,000 metric tons in 1961 (10). Since Peru is now harvesting at its maximum sustainable yield of ca. 8.5 million tons, some reduction in the world-wide growth rate may occur until someone else makes a new major effort in meal production (4).

A rather large potential for fishmeal production exists; however the Antarctic krill, for instance, are thought to be capable of producing 5-10 times (50-100 million metric tons) the Peruvian production of fishmeal. Also, as world-wide pressure increases on the fishery stocks, the average size of the fish harvested will tend to become smaller. This factor, coupled with the realization of ecological efficiency from harvest of small species will be additional encouragement to fishmeal production.

One of the best uses of fishmeal has been its inclusion in chicken feeds. Fishmeal has an excellent amino acid pattern. Also it has unique "unidentified growth factors" which encourage more rapid growth in feeding trials over similar proteins from the other sources. In Norway 7% fishmeal in the chicken diet has increased the growth rate by more than 11%. In Denmark experiments have shown the egg production per hen rose from 126 to 153 when 15% fishmeal was added to the strictly vegetable protein diet, and hatching rose from 45% to 74%. The limits of fishmeal additives for broiler production are at present ca. 4-8% because of the comparatively higher cost of fishmeal. In Europe more fishmeal is fed to swine than chickens. In Norway it has been demonstrated that hogs experienced a 5-12% greater weight increase by market size through fishmeal additions over the other protein formulations (5).

The four major consumers (Japan, U.S., West Germany and the United Kingdom) combined used 2.3 million metric tons or 49% of the fishmeal produced in 1969. Though this percentage is down 4% from the previous year, this drop is indicative of the price demand pattern of fishmeal (11). As is somewhat obvious from fishmeal usage, the developed countries have a greater demand for fishmeal than do the developing countries. However, as the developing countries have developed their poultry and hog industries, their demand for fishmeal has increased. Already Mexico, Venezuela, Taiwan and South Korea are beginning to import fishmeal in substantial quantities (4).

As shown in Table II, fish landings used for meal were 23 million metric tons, or half the soybean production of 1968. However these landings yielded only 5 million metric

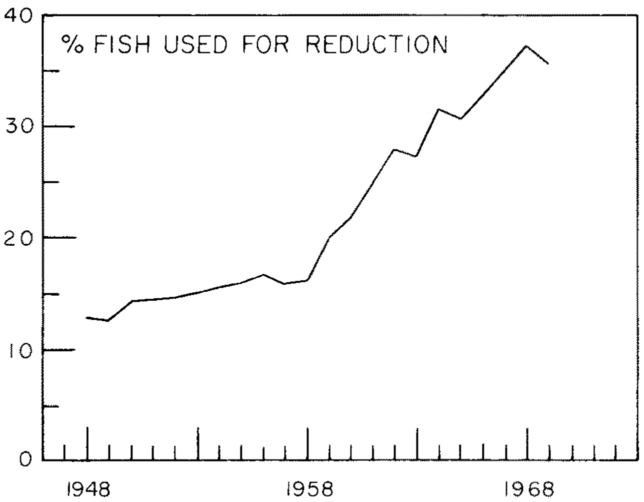

FIG. 1. Percentage of fish used for reduction (from "FAO Yearbook of Fishery Statistics").

tons of fishmeal or 10% of the total meal produced. If all meal is converted to the equivalent amount of soybean meal, fishmeal made up 14% and soybean meal made up 37% of total converted meal production in 1968. In addition, Figure 3 shows that while fishmeal production has increased somewhat over the past 10 years, it has not increased nearly as fast as soybean and other meals. This comparatively lower usage reflects the higher price for fishmeal relative to soybean meal. The price of soybean meal has gone from \$65/metric ton to \$90/metric ton over the last 10 years. During the same period Peruvian anchovetta fishmeal has gone from \$110/metric ton to \$200/metric ton (11).

Nutritional Value of Fish

Much has been written and said about marine protein concentrate (MPC) which does not have to be repeated here. Generally fish used for reduction could be used for MPC. Two ounces of MPC have as much protein as 12 oz steak. MPC's major problem is consumer acceptability. However children in Santiago have been successfully fed bread made with 7-10% MPC, and in Malaya children were fed cookies made with MPC, causing a growth rate which is three times normal for Malaya. Incidentally, while the children liked the cookies, their parents did not (5).

As shown in Table VII in terms of chemical score and growth encouragement, fish rates higher than any other meat, and fishmeal rates higher than any other meal. Only eggs, with a chemical score (CS) of 100, rate higher than fish (CS, 70). Milk rates about the same as fishmeal (CS, 60) (12).

Fish and the Developing Countries

An interesting side benefit of the fishing industry is that it seems to be an exception to the "rich get richer and the poor get poorer" syndrome in international development. Caplow, on the basis of his development statistics (telephones per capita, etc.) pessimistically concludes that "the rank order of wealth (or development) among the world's countries is relatively fixed, changes hardly at all in the short run, and is surprisingly resistant to the effects of war, revolution, and economic planning" (13). Further, Caplow concludes that "while the LDCs and developed countries are progressing at about the same rate, their starting points are so different that the gap between developed and LDC is actually increasing." Caplow has also shown that this unfortunate trend of events holds for other indicators, i.e., per capita energy consumption, steel production, printing paper, calories, fertilizer, teachers, school enrollment, physician, hospital beds and air travel.

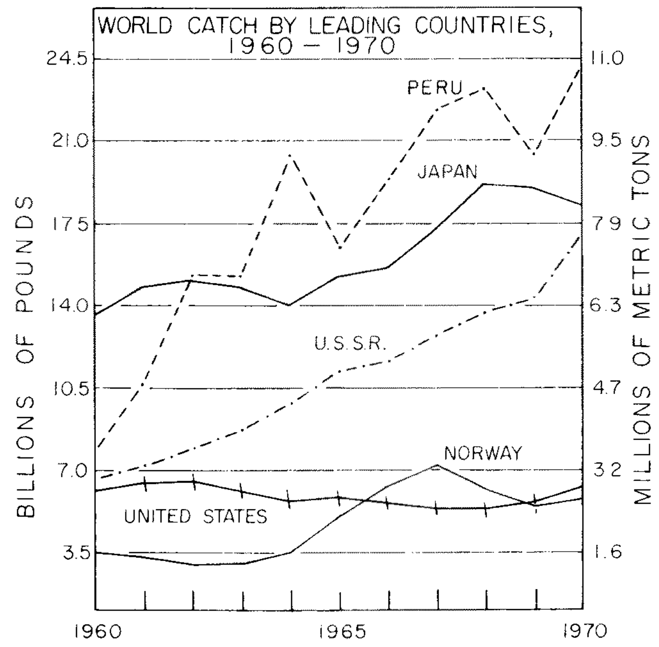

FIG. 2. World catch by leading countries (from "NOAA/NMFS/CFS-5600").

More optimistically, the fishing industry could be the happy exception to Caplow's generally pessimistic conclusions. The "FAO 1969 Yearbook for Fisheries Statistics" shows that, although the developed countries have a slightly greater catch than the developing countries, the last 6 years indicate that the gap between developed and developing countries is at least remaining constant and is

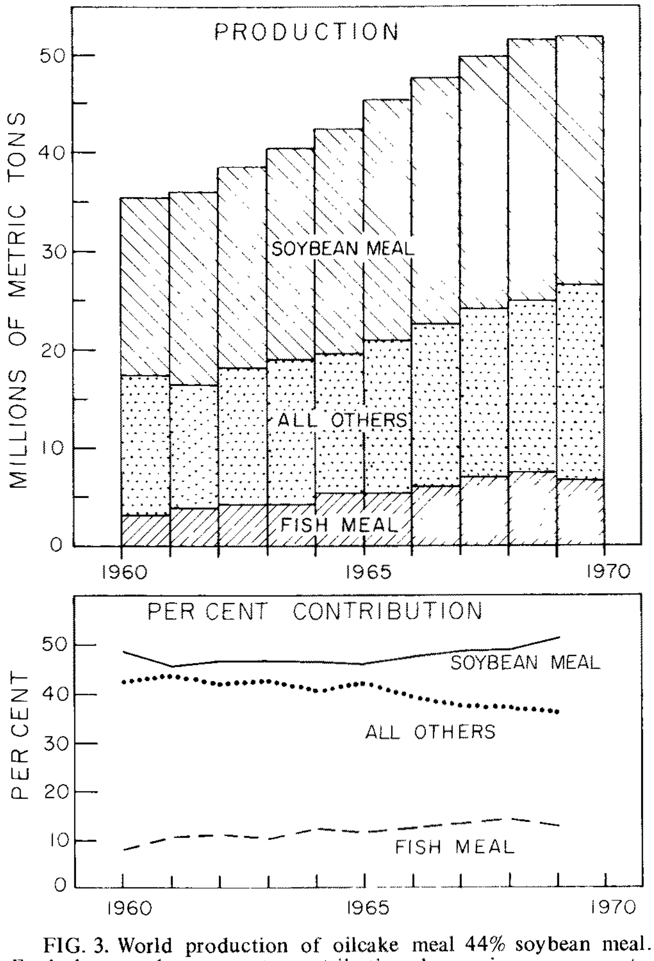

FIG. 3. World production of oilcake meal 44% soybean meal. Equivalent and per cent contribution by major components, 1960-69 (from Alverson, 1971).

probably closing. Chapman predicted that "for natural economic reasons, this trend is likely to continue if not interfered with by new Law of the Sea rules" (14).

Unfortunately this trend does not carry over into fishery products entering foreign trade. The developed countries are importing and exporting much more fish and fish products than the developing countries, and this gap appears to be widening. However the above foreign trade trends may change particularly with regard to fishmeal, which is being used more and more by LDCs for their developing chicken industries.

Aquaculture

The subject of aquaculture has been much publicized, but not enough is known about possibilities of aquaculture to make meaningful projections. However, by the year 2000, fresh and brackish water fish culture production should be 10 times the present level or ca. 50 million metric tons (15). Aquaculture of limited species in circumstances where lower-priced and more acceptable alternatives are not available holds some promise. Japan and the People's Republic of China have had some success in brackish and fresh water aquaculture. The technical, legal, political and economic complications of mariculture or sea-farming push this form of fish culture beyond the foreseeable future.

International Problems

Unless solutions to international management problems and conflicts with other uses of the marine environment, i.e., pollution, are developed, the world will not realize the full benefit of marine production from the living resources, or worse, the world will effectively lose these resources. The sad history of whaling demonstrates that valuable stocks will be exploited to extinction if unregulated. Technological developments in harvesting techniques, competition among fishermen and inadequate regulations caused the reduction of Atlantic haddock stocks in 1965. Some means of coordination of resource utilization is needed to prevent what the economists call "externalities" or the passing on of some costs of exploitation to nonexploiters. Pollution of the oceans is becoming increasingly more evident.

In handling the above problems, some effective international authority for resource allocation, including enforcement, coordination of resource utilization must eventually be established over the ocean areas. Such a mechanism could also include the ability to give preferential rights to the developing countries. While we should not look to the oceans for the institutional framework for the solution to man's international problems, we certainly can use the oceans as a tool to promote more equitable sharing of the world's resources and encourage development in the developing countries.

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