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The Biological Basis of Fisheries and Global Projections

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Introduction

The vast expanse and unknown nature of the oceans have inspired much speculation about its hidden wealth. The richness and variety of the oceans' living resources have long been a matter of curiosity for scientists, seafarers, writers, and people at large. The mystery of the last of the earthbound frontiers lasted well into this century. Many secrets of the oceans remain to be discovered, but the frontiers have been broached and knowledge has replaced much of the earlier speculation.

The expansion of marine fisheries over the last 50 years, most rapidly since after World War II, has stimulated a great deal of study of the potential of the oceans' living resources. There has been an increasing general concern about meeting the protein needs of a burgeoning world population. The economic returns from fishing are desired by many and needed by a host of countries unable to meet their needs from agriculture or other industry. Much of the interest stemmed from the free access to the resource by all parties outside of rather narrow national jurisdictions that existed until a few years ago.

The many studies of marine fisheries potential provide a wide range of possibilities (Figure 1 and Table 1). The earlier studies were low, based primarily on the limited nature of past experience. It seemed, however, that the vast domain of the oceans had to reflect a vast resource, and the estimates began ranging upwards to the billion-ton mark. The different estimates represented different potentials--some just traditional fish, others the nontraditional fish, and the highest including plankton forms of life. The upper levels, however, provided any justification needed to expand fisheries. As experience and knowledge increased, the unbridled optimism waned. It is still the case, however, that some scientists write of "enormous" resources, particularly where good information is not available. The most recent examples are squid and krill, with possible harvests said to be hundreds of millions of tons.

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Marine aquatic resources are extremely important. It has been estimated that the present yield could, if appropriately distributed, provide for about 30% of the minimum required protein for the four billion people on earth today. To what extent can we expect fisheries to meet the needs of the projected six billion people in the year 2000? To answer this question we must examine rather carefully the basis for estimating renewable resource productivity, and the feasibility of utilizing it.

Global fishery trends

A good place to start the evaluation of resources is an analysis of the fisheries experience to date. Such analysis not only reflects what is demonstrably possible, but much of the knowledge we have gained about fishery biology has been based on the study of fishery statistics.

The trend in world catch as reported by FAO (Figure 2, Table 2) indicates a rapid rise during the 1960's and a leveling off during the 1970's, the latter occurring in spite of a continuing rapid rate of growth of fishing-vessel tonnage. The world aquatic catch in 1978 was reported as 72.4 million metric tons (MMT), of which 64.6 MMT was caught in marine areas. The marine fish catch was 56.2 MMT, and the marine crustacean and mollusk catch was 6.6 MMT; these latter two categories represent 97% of the total marine catch.

Interpretation of these trends in terms of projections for the future is fraught with many pitfalls. Anybody who wants to make a particular case can manipulate the statistics to that purpose. However, the major features of the fisheries in recent years do reveal some portent of the future. They are of some biological and social interest as well.

It should be noted that the FAO statistics do not include recreational catch. In point of fact, these are not very well documented. Some estimates have the US recreational catch equal to the commercial catch. There is no doubt it is significant in the US, but not, perhaps, elsewhere.

Well over half of the total marine catch came from the northern temperate oceans: 33% from the North Pacific, and 23% from the North Atlantic (Figure 3). There has not been much change in this general tendency over the 1970's, and it generally reflects the combination of available resources on wide continental shelves near countries with high industrial development. There have been increases proportionate to the total increase in all areas except the North Atlantic and Southern Pacific. The austral oceans' reported catch has doubled, but remains relatively small (0.4 MMT). This is not an accurate report, which will be discussed later. The 1978 catch by continent is given in Table 3. More detail on geographic distribution of catch is given in Hennemuth (1979).

The 10 leading fishing countries provided nearly 60% of the total aquatic catch in 1978 (Figure 4, Table 4). The leadership has not changed much over the 1970's, except that the Republic of Korea and Denmark have increased relatively more than the others. The recently revised figures for the Republic of China are significantly reduced from former levels. China and India are the only two of the leading countries that have significant freshwater catch, and China now ranks eighth in terms of marine catch.

Japan has developed extensive fisheries throughout the world, and has a very diverse species catch. Even so, two species have predominated in recent years--Alaskan pollock and Spanish mackerel (30% of total). It catches more squids and seaweeds, 1/2 MMT each, than any other country.

The USSR landed 8.9 MMT, has extensive distant-water fisheries, and lands a greater diversity of species than almost any other country. Recent changes in the availability and pattern of fisheries are reflected by the fact that 2 MMT or 23% of its total was Alaskan pollock in 1978. Capelin amounted to 0.8 MMT or 9% of its total.

The US was the third largest fishing country in 1978 and landed 3.5 MMT, almost all from marine areas. Although its diversity of species is great, 34% of the total was menhaden. This amounted to 53% of the finfish landings. Contrary to most other countries, the US catch contains large amounts of shellfish, about 1/3 of the total. Note that shell weight as reported is from 5 to 8 times the edible weight.

China has for the first time reported in depth on the state of its fisheries (De-Shan 1980). The new data indicate that their fisheries have increased from 3.0 in 1970 to 4.6 MMT in 1978. The freshwater catch was 1.1 MMT in 1978, with 72% produced by aquaculture. The marine catch was 3.6 MMT, with 12% reported as aquaculture. Marine seaweed on a dry-weight basis amounted to 0.3 MMT. China's coastline incorporates a wide range of habitats, tropical to frigid-temperate, including the Yellow, East, and South China seas; the South China Sea has over 800 species of fish. This leads to a diverse species catch, and the expected shifting through the years of species dominance in the catch. The acceptability to the Chinese population of a wide variety of species for food encourages more complete utilization of the resource.

Trends in Peruvian landings are almost proportionate to the fluctuations in anchovetta--from a high of 13 MMT in 1970 to 1.2 MMT in 1978. The catch of pilchard is now nearly the same as anchovies (1.1 MMT). These two species still dominate Peru's catches (66%), but 28% of the 1978 catch was of hake and mackerel, compared to very small amounts a few years ago.

For the remainder of the leading countries, Thailand reports a large magnitude of catch of unidentified fishes; and Korea lands a wide variety of species, including Alaskan pollock, tilefish, and seaweeds. The others' catches in 1978 are dependent on a few species: Norway--half capelin, Denmark--half sand launce and sprat (all three primarily for reduction), India--sardines and shellfish.

The consuming countries generally reflect the producing countries (Table 5 and Figure 5). The per-capita consumption includes fish used for reduction. When listed by population, the US is the greatest consumer even though its per-capita rate is lower. The US is unique among all other countries in the high proportion of imported fish consumed--roughly 50%.

Species trends

Nearly three-quarters of the total marine catch was composed of nine species groups (Table 6, Figure 6) in 1978, compared to 85% in 1970. The herrings continue their leading place but have declined by 36% since 1970. The other major change is in the Jacks-mullet group, which has increased by a factor of 3 since 1970, mostly due to the increased capelin fisheries in the North Atlantic. The redfishes have increased by 33% since 1970. It is apparent that over the past decade, the major annual changes in total marine catch have been due to changes in Peruvian anchovy and capelin. This was not the case in 1978 when the Japanese pilchard, Chilean pilchard, and US Gulf of Mexico menhaden increased by 1.1 MMT.

Current status

It is apparent that the total yield over the last decade has been maintained primarily by transferring fishing effort from reduced stocks of the traditional species to other species which are either adequate substitutes (e.g., Alaskan pollock for cod/haddock processed market) or of similar habits and habitat (e.g., capelin and sprat for herring). The latter, since they are not new areas, raise the question of replacement--a question we cannot answer in terms of cause-effect. The trend seems to indicate smaller, short-lived species. The fisheries to date have been largely the product of reaction to changes in availability of stocks. The current status can be classified as poor if one judges that the species-stocks are independent of one another and that the present condition is the result of overfishing causing recruitment failure of the traditional species. On the other hand, one can take a more optimistic view that the changes in availability reflect the natural changes in species composition that occur from time to time and that we are currently more and more able to take advantage of the total biomass productivity. One's perception of which is the more correct status of the marine fishery certainly affects the perception of its prospects for the future.

Fishery potential

There are three primary concepts that must be examined if anyone is to assess the long-term potential of fisheries. These are the ecosystem productivity, the interspecies interactions, and the population dynamics. Obviously these are really just increasingly specific subsets of the natural universality.

Taking these concepts in reverse order, the first thing to examine is recruitment. This is a process which includes production of viable eggs (spawning), and survival through the egg and larval stage to the time when the animals are suitable for harvest. Since the major segment of fisheries depends on adult forms, primarily fish, we are able to examine this from a time series of observations in active fishing areas.

There do exist estimates of populations of pre-recruits for many of the world's major populations exploited over the last 15-40 years. Recently we

have synthesized these data in a manner which permits an examination of the probability density recruitment function (Hennemuth et al. 1979). The data, estimates of numbers of one- and two-year-old fish based on research-vessel surveys and fishery statistics, have been classed in magnitudes relative to a consistently, but arbitrarily defined smallest year class. We have actually back-stepped five equal intervals from the mean to define the smallest year class. All other year classes then are twice (2X), three (3X), or four (4X) times the smallest. We then combined all the data for 22 stocks, which include groundfish and large and small pelagics from various oceans (Figure 7).

All of these populations exhibit an annual production period so that the frequencies represent the proportion of years that pre-recruits were of the given relative size. There is some evidence of cyclical occurrence, but this is not generally a significant feature; there is a large element of randomness in the observations. The variability defined by this portrayal is what must be expected and coped with when considering potential and management of fisheries. Most of the time, year classes will be within the range of 6X the smallest. This may be perceived as a large or small magnitude of deviation, but the point is that the substance of a fishery is dependent on a large number of relatively small year classes. Another aspect is that the variation in year-class strength is the major factor in variation in possible yields. Growth and mortality after the juvenile stage is relatively less important.

It is also apparent that there are frequently rather large year classes experienced. About 10% are 10X or more. It does seem that the latter are the reason that many fisheries start or expand. It also seems that these large year classes then become a standard against which future occurrences are judged. Thus they may influence the stock-size objective which management might attempt to achieve. A specific example, from many observations, is the Norwegian spring-spawning herring fishery (Figure 8). The expansion of the fishery in the early 50's was the consequence of a very good year class. Another not-so-good year class in the late 50's kept the population high enough to encourage further expansion of effort. Subsequently, the "average" year class would not support the fishing effort, and the stock and landings decreased markedly amidst alarm about overfishing and recruitment failure.

The recruitment function seems more generated by factors other than stock size. The extreme end point of near-zero spawning-stock size has seldom been observed, and the statistical evidence for stock-recruitment relations is very meager. The rather complex recruitment process, depending on many events strongly dependent on environment, would suggest a high degree of randomness. In the expanding fisheries of the past two decades, the combination of applying rapidly increasing effort on previously unfished or lightly exploited stocks, coinciding with the occurrence of good year classes, has been more the case than not.

Most recent assessments of the potential yield have been based on catch-and-effort statistics during the period of expansion. This has led to rather optimistic estimates of sustainable yield. The Peruvian anchovy is a case in point (Figure 9). The MSY models based on 1960's data provided estimates of 9-10 MMT sustainable yield. It does not seem probable that even the average annual catch of 6 MMT taken over the 60's and 70's can be counted on in the long run.

The suggestion of the pilchard replacing the anchovy, based both on the increasing catch and occurrence of pilchard larvae in surveys, is not unexpected. It is rather typical that individual species will vary rather markedly in abundance, but the total biomass will remain rather steady. The Georges Bank biomass illustrates this point rather well (Figure 10). The North Sea and the South China Sea also show this phenomenon; it may be expected in all multispecies ecosystems.

In assessing potential yields on an ecosystem or global scale, very often the estimated individual stock MSY's, which are, as pointed out above, often just a reflection of increasing short-term yields in an expanding fishery, are added up. This sum will likely exceed, sometimes considerably, the long-term average biomass yield which we can really expect. At the very least, the periodic peaks of the individual stocks, which will occur, will not coincide. Therefore the annual expected yields must be viewed more conservatively.

Finally, we get to the flow of energy in the ecosystem. Again, a simple illustration of this aspect may be taken from the available data for Georges Bank (Figure 11). This is taken from the analysis of Cohen et al. (in press). The absolute values are arbitrary, but the relative values are meaningful. Thus the investment of $175,000 worth of sunlight will provide $1.50 worth of fish on the dock. There is, indeed, an enormous amount of energy produced in the system. Many of the high estimates of potential marine yield are based on obtaining more yield from the secondary production levels.

Projections

There are two aspects that one must consider: the ecological potential, and how much of it can be practically harvested. The consideration of past fishery trends and the ecological basis of productivity lead to the conclusion that the current marine yield of 64 MMT of traditional forms cannot be substantially increased over the long run. There will probably be short-run increases. These will not be large, not tens of millions for example, nor will they last very long.

One large potential increase that is currently being touted is the pelagic squids. There are conjectures of "enormous" potential, upwards of hundreds of million tons. The evidence is based on frequent observations of mesopelagic squids. It is true that these appear to be widely distributed. However, they are large specimens, and may therefore reflect a long-lived but slow-producing species. Other evidence comes from observation of squids in the stomachs of seals, whales, etc. Presumably, if we got rid of all its predators, the squid they eat would be available for harvest. I suspect that somewhere someone is counting also as potential the food that the squids eat.

There is no doubt, however, that the biomass of nontraditional forms, the secondary producers, is relatively very large; certainly harvesting even modest proportions of this biomass could provide 10-100 times the yields of the traditional "fish" forms. We do not really know how or if the perturbation of the ecosystem at this level would affect the stability and process of production. The speculation about possible antarctic krill is a case in point.

Estimates of krill harvest potential are based primarily on what the consumption by whales must have been when whales were abundant. This must now be a surplus available to man. The fact is, of course, that there is no surplus of krill production. The assumption must be made that harvest of the krill would increase the productivity. There is some evidence that the present population of krill has a higher proportion of older individuals (2- or 3-year-old krill), and that there is a basis for the concept of increasing productivity by increasing mortality. However, there is also some evidence, and a strong probability, that the variability of production may be very high, and the long-term potential lower than now seems the case.

The realization of the planktonic harvest is strongly limited by technical and societal factors. Rather large investments must be made in vessels and gear to harvest krill and other plankton forms. Although all animals tend to be distributed in concentrations rather than uniformly in space, the concentrations of plankton do not appear dense enough to compensate for the relatively small size of the individual organism. Efficiencies of 10-100 times that presently obtained in fisheries would be necessary. In addition, there are many problems in processing and marketing to overcome. Finally, the preferences of society for maintaining the balance of organisms in the oceans may severely limit the harvest of their food base. Mammals and krill and squid presently create such concerns.

Even the traditional fishery is facing economic problems that might significantly affect the future harvest. Much of the fishery development over the last 20 years was based on developing fleets of large, long-distance trawlers. These require rather high densities of fish to be economic. The increasing costs of fishing, both absolutely, and relative to the lack of more of the previously discovered high-density stocks, is now becoming a significant factor. There has to be a limit to the ratio of the value of a calorie of energy from consumption of fish to the cost of a calorie of fossil-fuel energy.

This problem has been nicely illustrated by Thomson (1980) (Figure 12). The capital-intensive, large-scale fisheries may well be something past its time. The implication of small-scale fisheries is perhaps that they will exert a more gentle force on the ecosystem which will increase stability of the fishery, but at a lower level of output than has recently obtained.

Freshwater potential

The commercial harvest of natural freshwater production is currently low. Assigning all diadromous fish catch to freshwater brings the current total up to something less than 7 MMT. If the natural unit-area productivity in freshwater is the same as marine (more likely it is lower), then the total area of freshwater would give some idea of potential. Certainly the freshwater area is less than 3% of the marine area; therefore the natural freshwater potential yield would be no more than what is currently obtained.

Aquaculture

The limitations to aquaculture are based at present on socioeconomic factors. It is, therefore, rather difficult to make any projections about its potential. The most optimistic current projections indicate an increase from the present 4 MMT or so to 10-20 MMT by the year 2000. This may come about if it does develop that the potential harvest of naturally produced plants and animals is indeed limited by ecological and technical factors, and the demand for protein cannot be otherwise satisfied. There are some opportunities for economy of scale here (labor-intensive but energy-efficient) that don't seem to exist in traditional fisheries.

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Table 1. Estimates of marine fishery potential by various authors.

Author	Potential (MMT)	Date of estimate	Type of estimate F = fishery extensions f = flow organic	
Thompson[1]	22	1949	F	
FAO[1]	55	1955	F	
Finn[1]	55	1960	F	
Graham and Edwards[1]	55	1962	F	(bony fishes)
Meseck[1]	55	1962	F	(by 1970)
Graham and Edwards[1]	60	1962	F	(bony fishes)
Schaefer[1]	66	1965	F	(by 1970)
Meseck[1]	70	1962	F	(by 1980)
Alverson[1]	80	1965	F	
Bogdanov[1]	75	1965	F,f	
Graham and Edwards[1]	115	1962	f	(bony fishes)
Schaefer[1]	160	1965	F	
Schaefer[1]	200	1965	f	
Pike and Spilhaus[1]	200	1965	f	
Chapman[1]	2,000	1966	f	
Pike and Spilhaus[1]	180-1,400	1962	f	
Chapman[1]	2,000	1965	f	
Ricker	150	1969	f	
Gulland	262-362	1970	F	(with krill)
Moiseev[2]	82	1973	F	(traditional)
Suda[2]	100	1973	F	(no krill)
Alverson	130	1975	F	(including krill)
FAO	230-445+	1977	F	(including krill)
Hennemuth	60-80	1979	F	

[1]Schaefer and Alverson 1968.

[2]Stevenson 1973.

Table 2. World aquatic catch by categories in millions of metric tons.[1]

Year	Total	Freshwater and Diadromous	Marine fish	Crustaceans and Mollusks	Mollusks
1953	-	-	19.1	2.6	-
1954	-	-	20.3	2.9	-
1955	28.9	-	21.3	2.8	-
1956	30.8	-	22.7	2.9	-
1957	31.7	5.1	22.8	3.0	-
1958	33.3	5.6	24.1	3.0	-
1959	36.9	6.1	26.8	3.3	-
1960	40.2	6.6	29.2	3.6	-
1961	43.6	7.0	32.2	3.5	-
1962	44.8	6.8	35.6	3.8	-
1963	46.6	7.0	36.4	4.1	-
1964	51.9	7.2	40.9	4.0	-
1965	53.3	7.8	39.6	4.1	2.9
1966	57.3	8.1	43.0	4.3	3.0
1967	60.4	8.2	45.9	4.5	3.2
1968	63.9	9.3	48.7	5.0	3.5
1969	62.6	9.8	47.2	4.7	3.2
1970	67.2	9.9	54.2	5.1	3.4
1971	67.8	10.5	54.1	5.1	3.4
1972	63.6	7.2	50.4	5.3	3.6
1973	64.7	7.5	50.6	5.4	3.5
1974	68.9	7.5	54.2	5.5	3.5
1975	68.6	7.9	53.4	5.8	3.8
1976	72.1	7.7	56.7	6.1	4.0
1977	71.2	7.9	55.1	6.5	4.2
1978	72.4	7.8	56.2	6.6	4.3

[1] FAO Yearbook of Fishery Statistics, "Catches and Landings," Vols. 16, 24, 32, 40, 42, 44, 46.

Table 3. 1978 catch by continent (10^6 metric tons).

Continent	1975	1978
Africa	4.5	4.3
N. America	4.9	6.3
S. America	6.0	7.3
Asia	30.7	31.5
Europe	12.6	12.6
USSR*	9.9	8.9
Oceania	0.3	0.3
Total	68.9	71.2

*European and Asian continental catches.

Table 4. Leading fishing countries in 1975-1978 (catches in 10^6 metric tons).

Country	1975	1978
Japan	10.5	10.8
USSR	9.9	8.9
Rep. China	4.4	4.6 (1.3 fresh)
Peru	3.4	3.4
US	2.8	3.5
Norway	2.6	2.7
India	2.3	2.4 (0.9 fresh)
Rep. Korea	2.1	2.4
Denmark	1.8	1.8
Thailand	1.6	2.3
Total	41.4 (60%)	42.8 (59%)

Table 5. Per-capita fish consumption (kg) in 1975 for selected countries.[1]

Japan	74.7
Iceland	66.8
Portugal	50.4
Singapore	50.3
Hong Kong	49.3
Norway	47.2
Malaysia	42.1
Spain	38.5
South Korea	37.0
Denmark	34.6
Canada	16.6
US	15.9

[1]US National Marine Fisheries Service, "Fisheries of the United States, 1978," Current Fishery Statistics No. 7800, April 1979.

Table 6. Leading species groups in world marine catches (in millions of metric tons).

Species	1970	1978
Herring, sardines, anchovies	21.6	13.9
Cod, hake, haddock	10.5	10.5
Jacks, mullet, sauries (capelin)	2.6	8.2
Redfish, bass, congers	3.9	5.2
Mackerel, cutlass fishes	3.1	4.1
Tuna, bonita, billfish	2.0	2.5
Shrimp, prawns	1.0	1.5
Squid, octopus	0.9	1.3
Flounder, halibut, sole	1.3	1.2
Total	49.0	48.4
Total marine	57.3	64.6

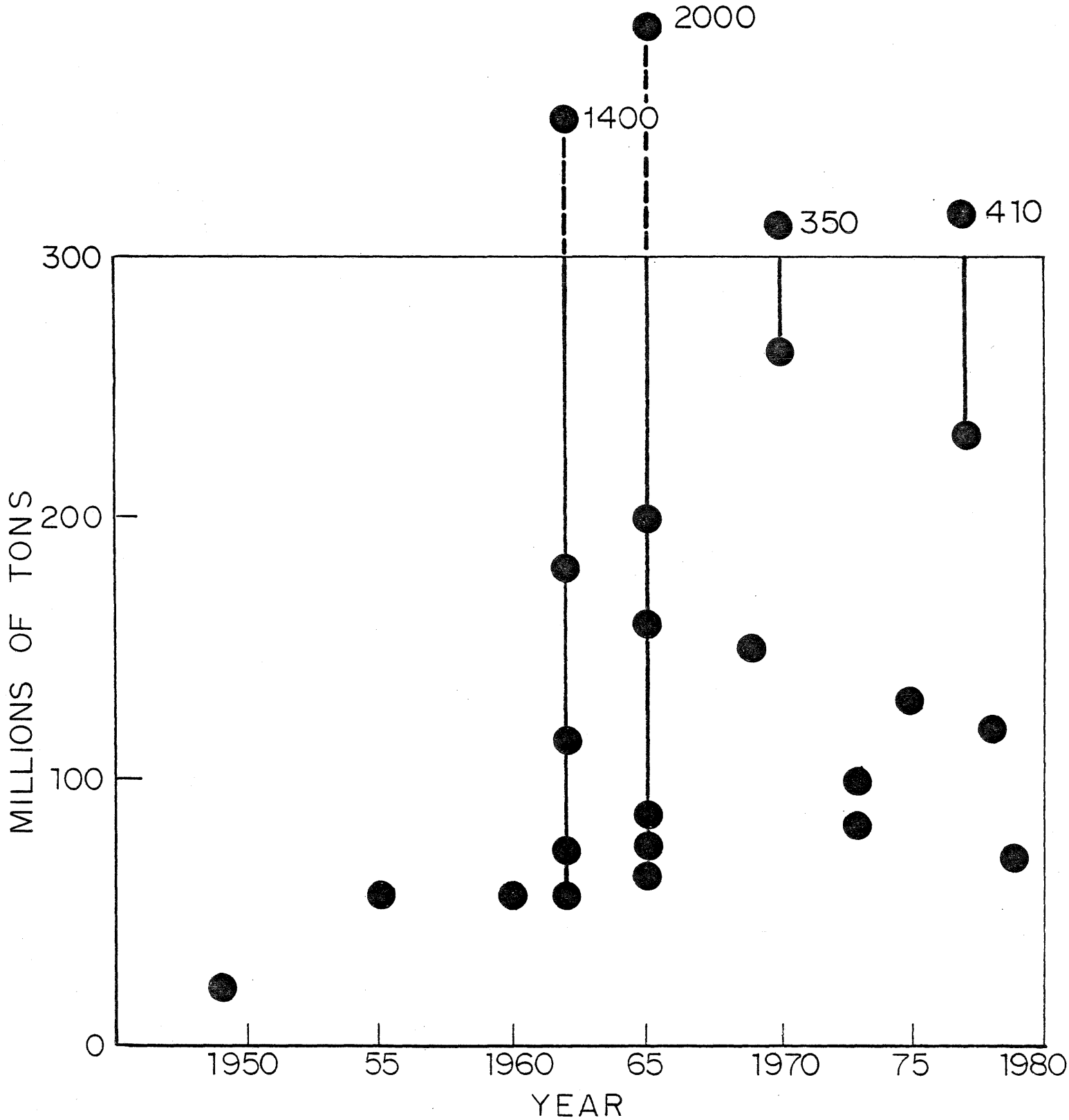

Figure 1. Trend in published estimates of marine fisheries potential harvests.

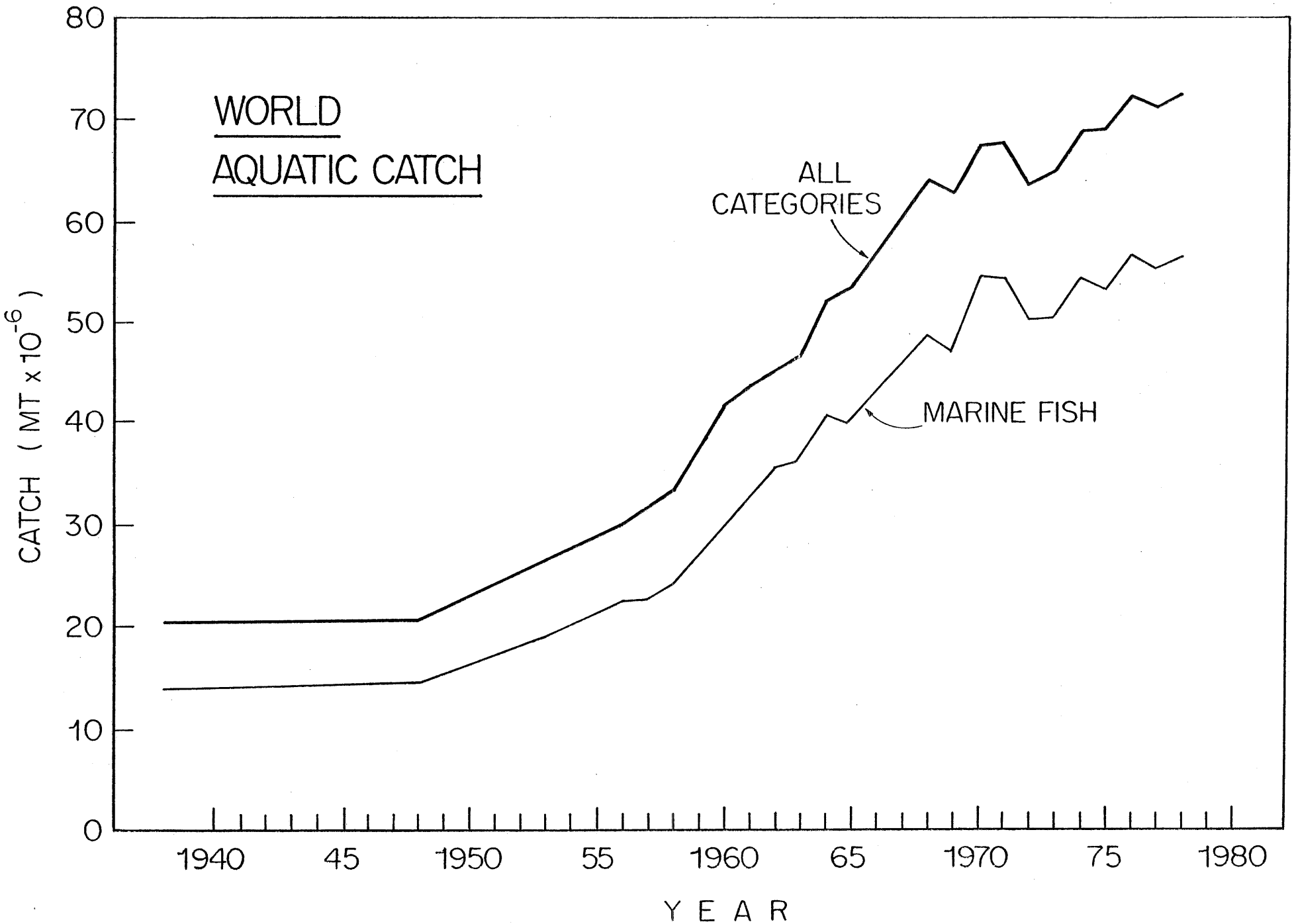

Figure 2. Trends in world nominal catch.

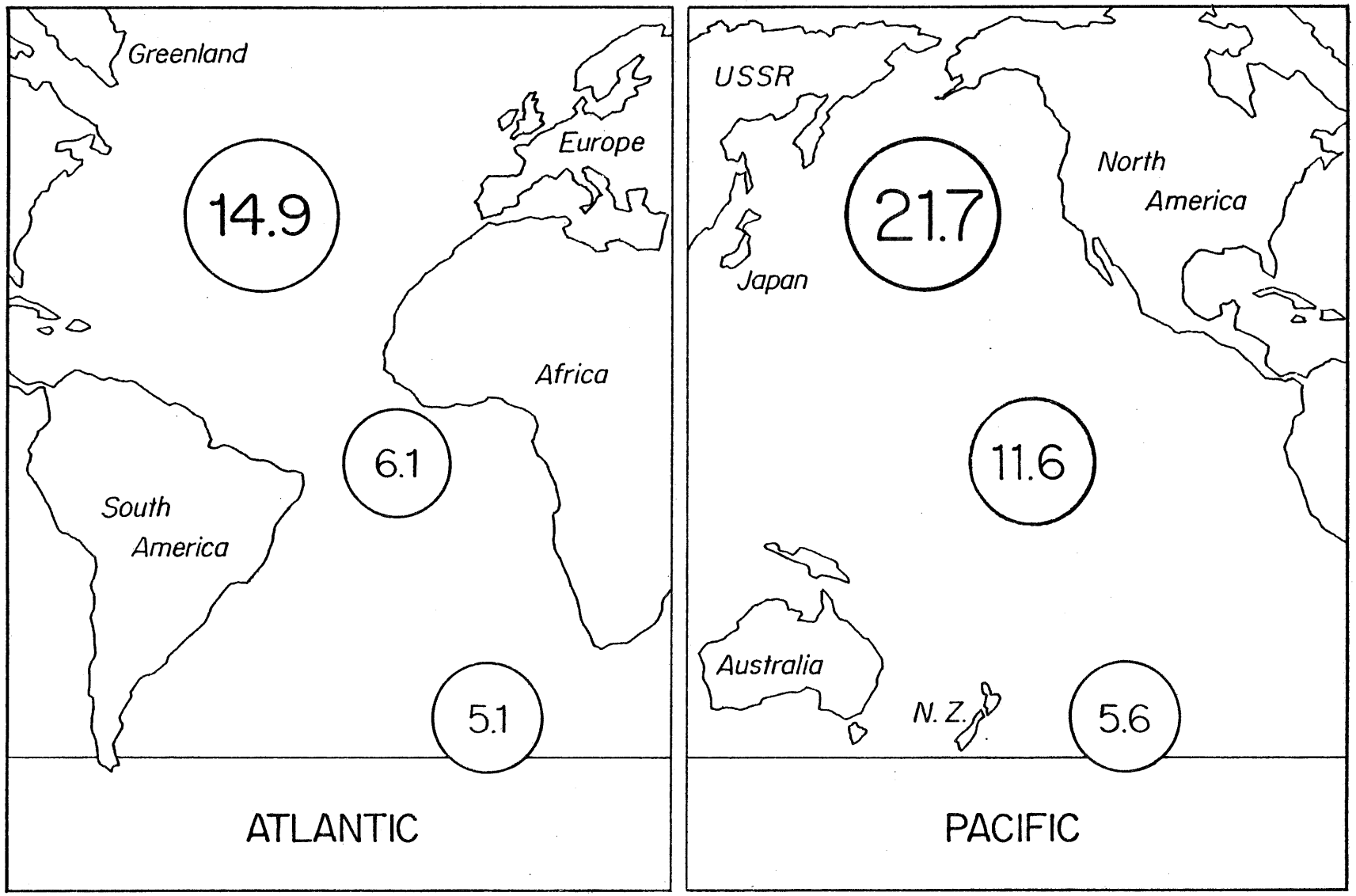

Figure 3. Zonal distribution of marine catch in 1978 (MMT).

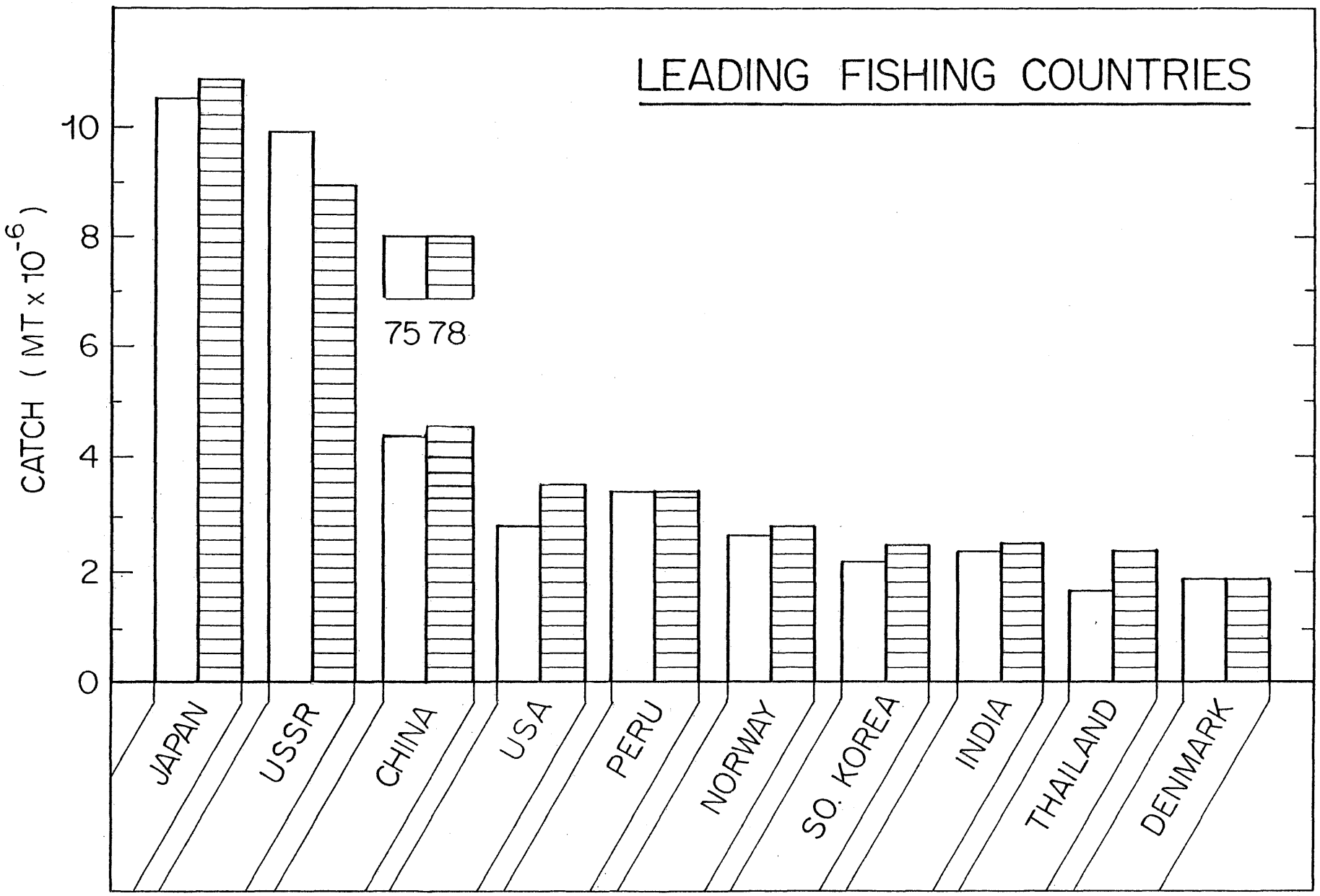

Figure 4. Leading fishing countries ranked according to 1978 total aquatic catch, compared to 1975.

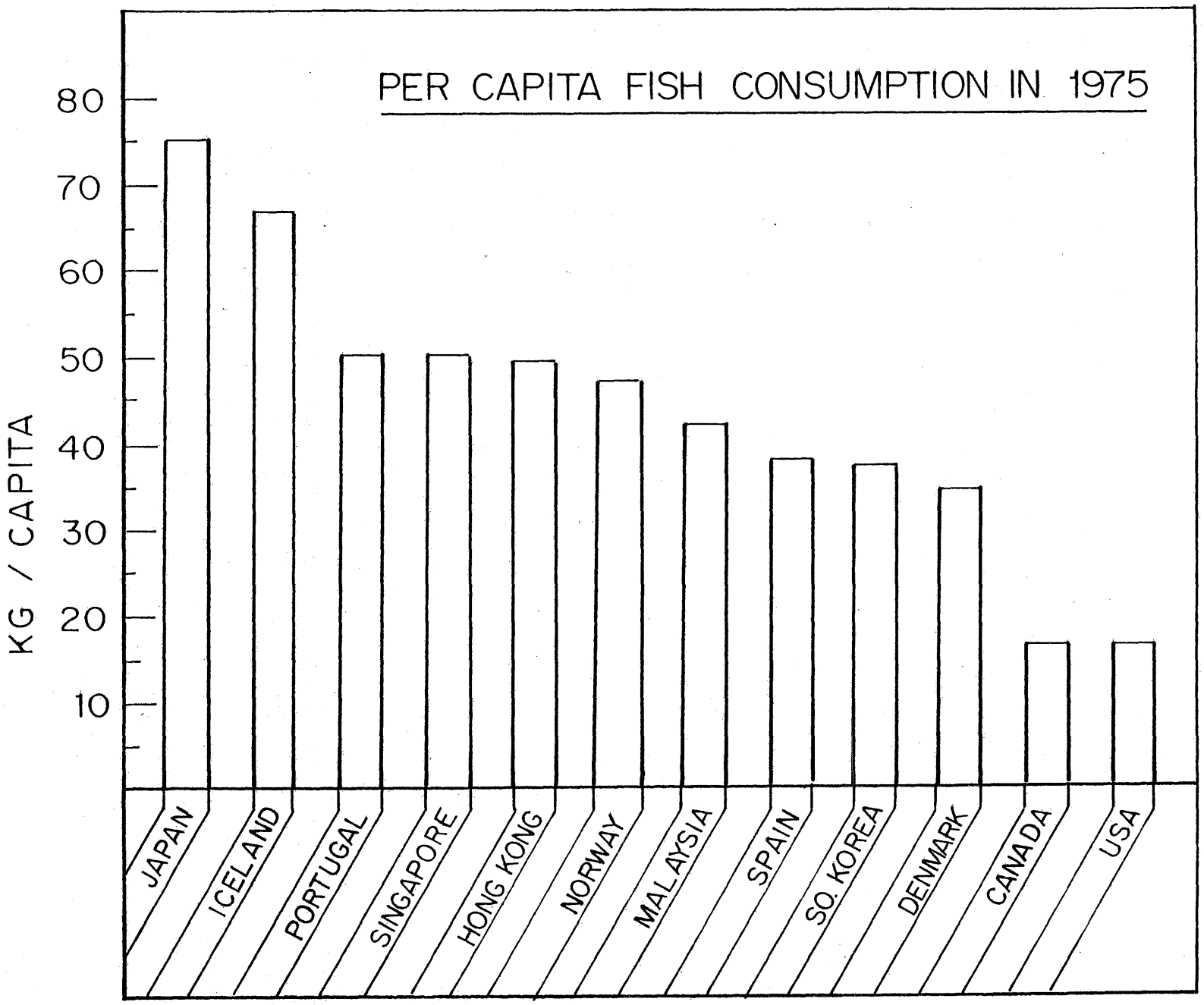

Figure 5. Per capita fish consumption in 1975.

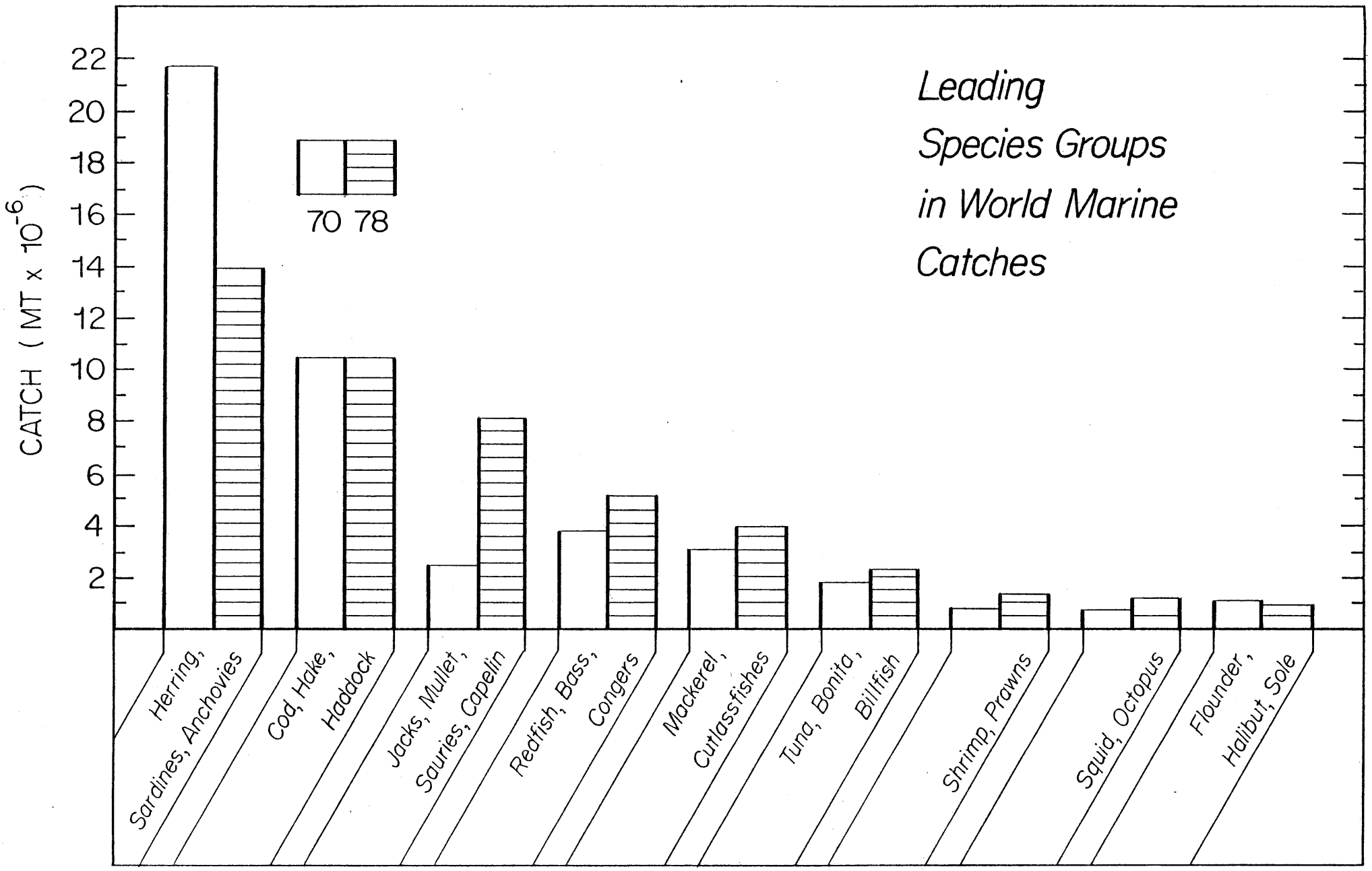

Figure 6. Nominal landings of species groups from marine areas in 1970, 1978.

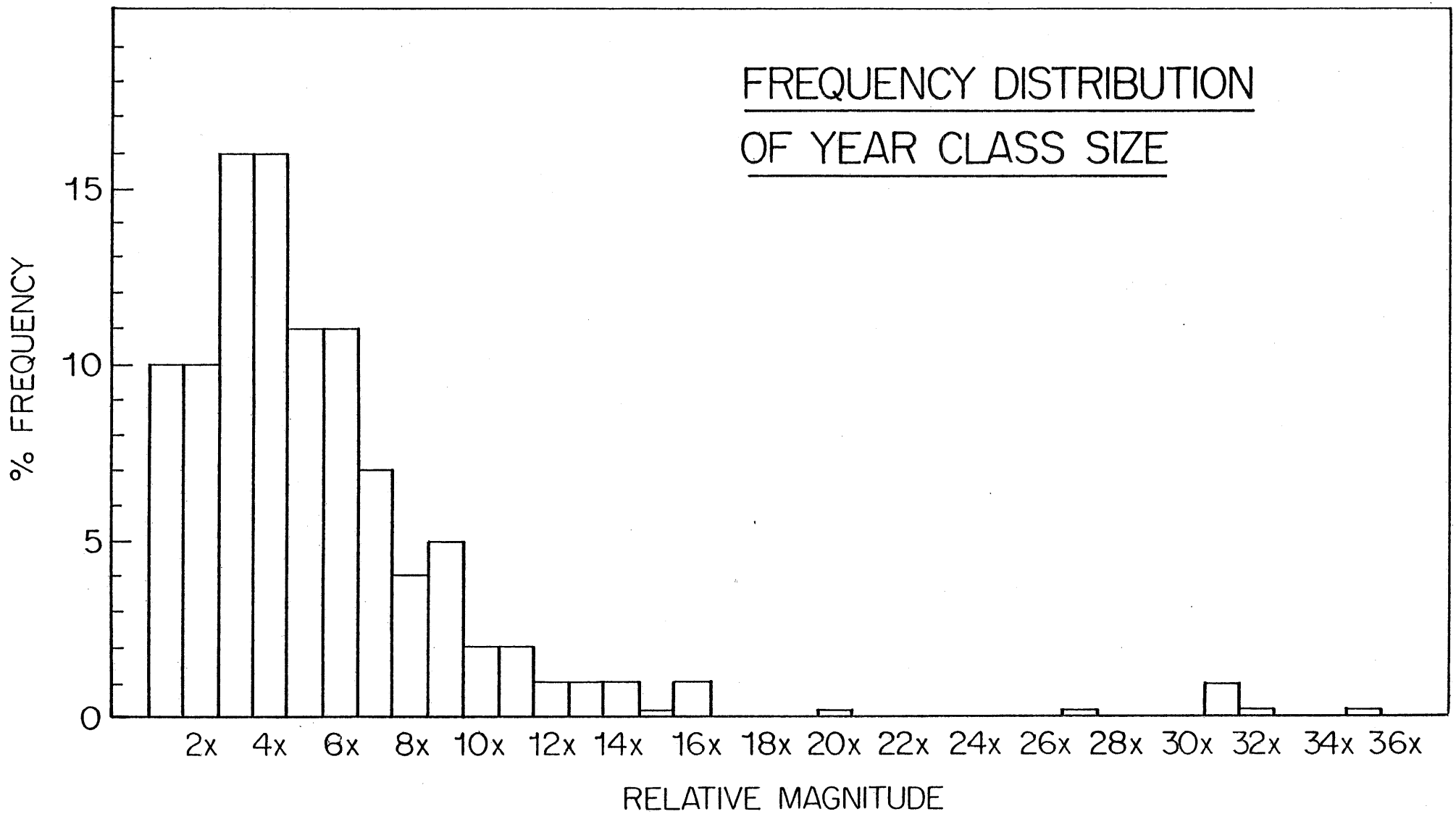

Figure 7. Composite frequency of year class size for 22 different fish stocks for time periods of 15-40 years.

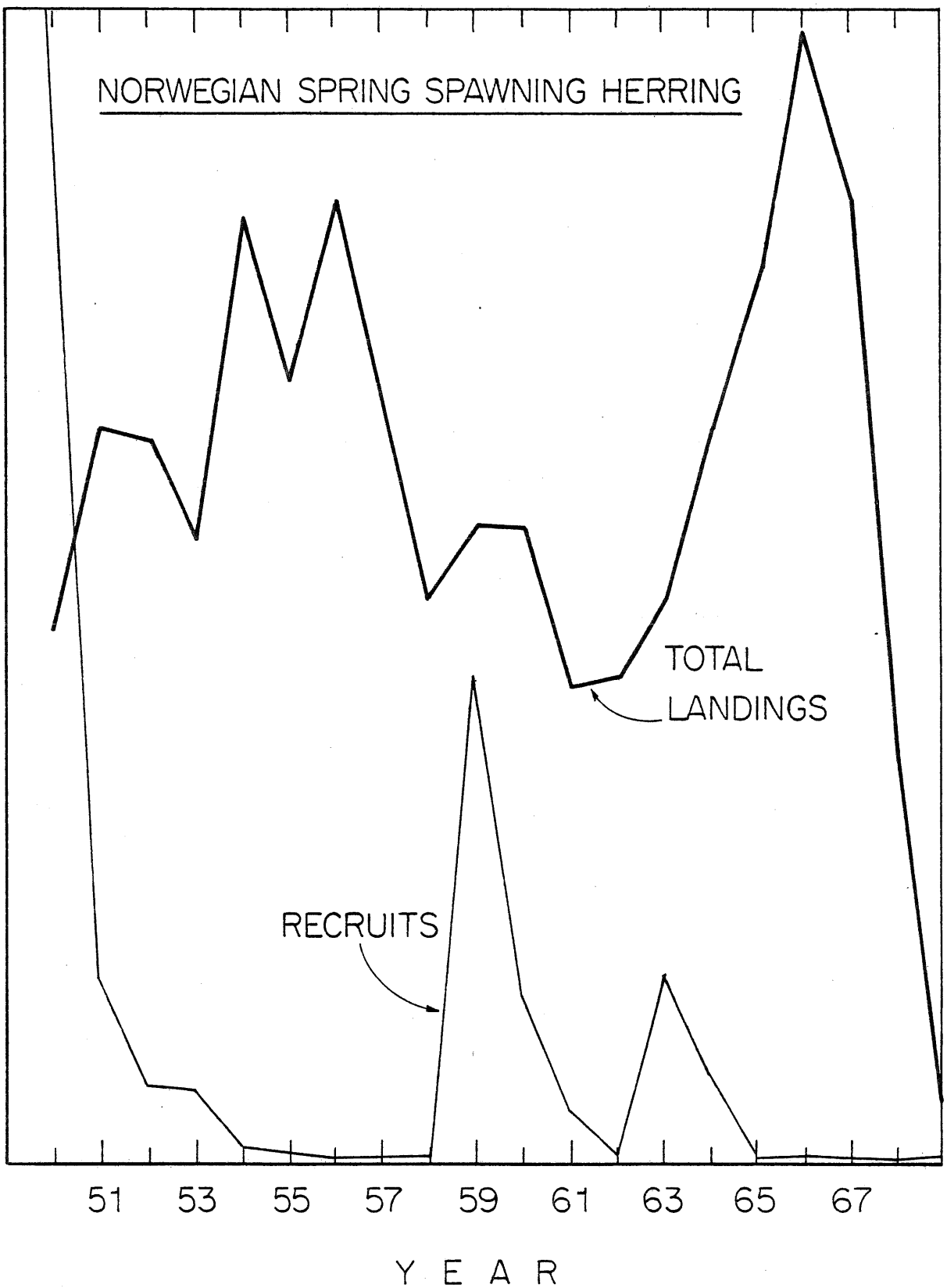

Figure 8. History of recruitment and landings of Norwegian herring stock.

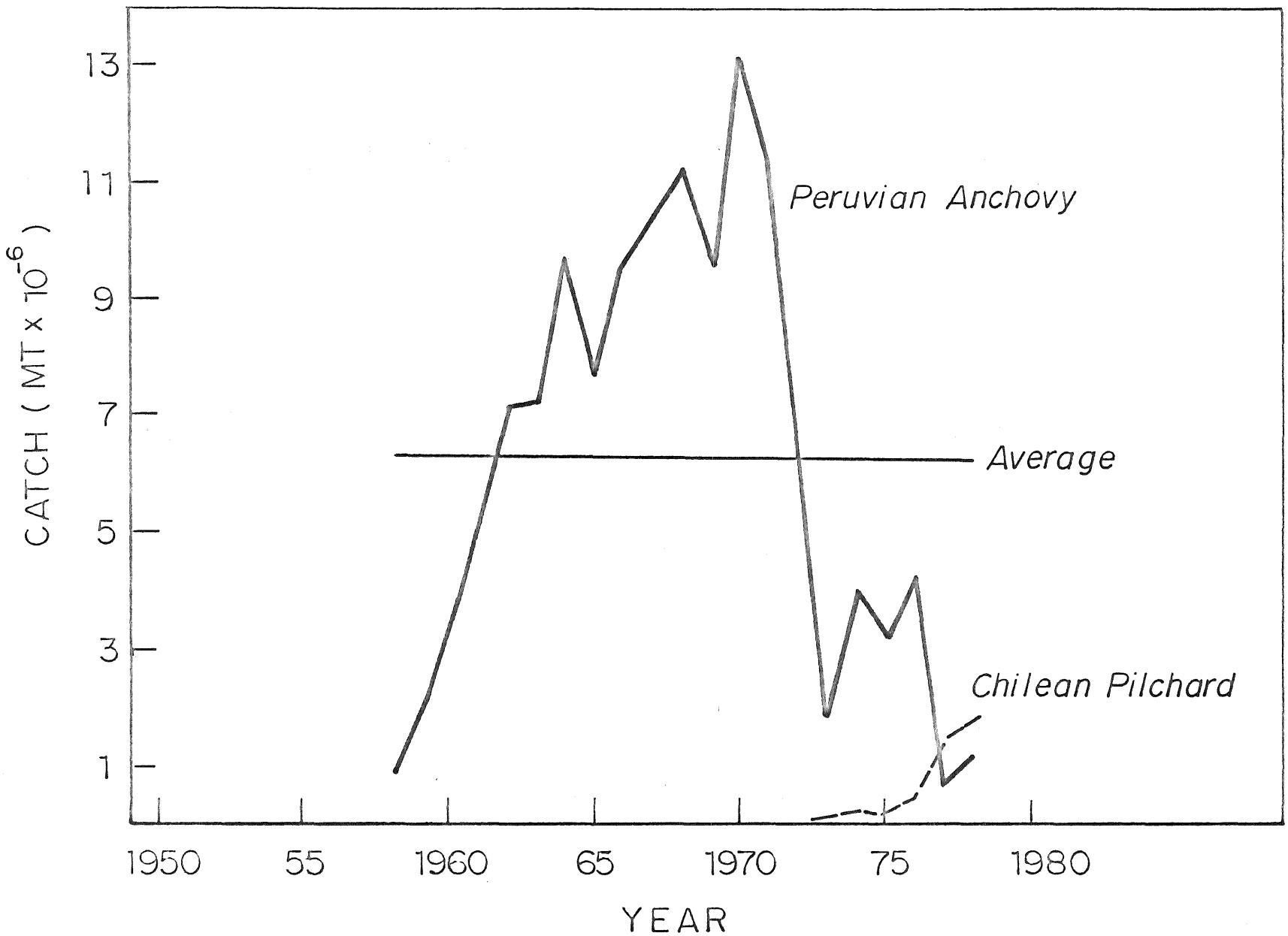

Figure 9. Landings history of the Peruvian anchovy fishery.

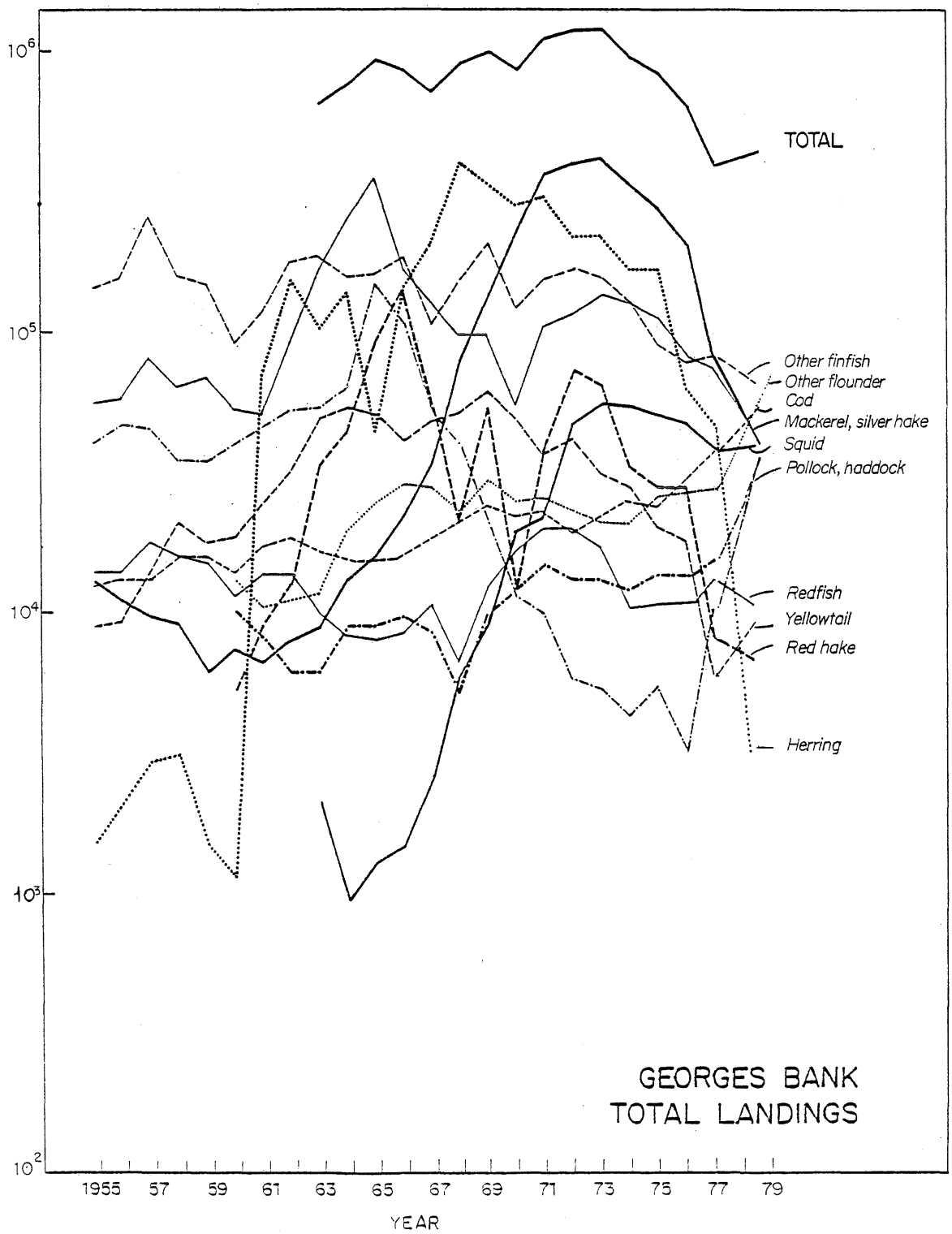

Figure 10. Trends in total and stock-components biomass on Georges Bank.

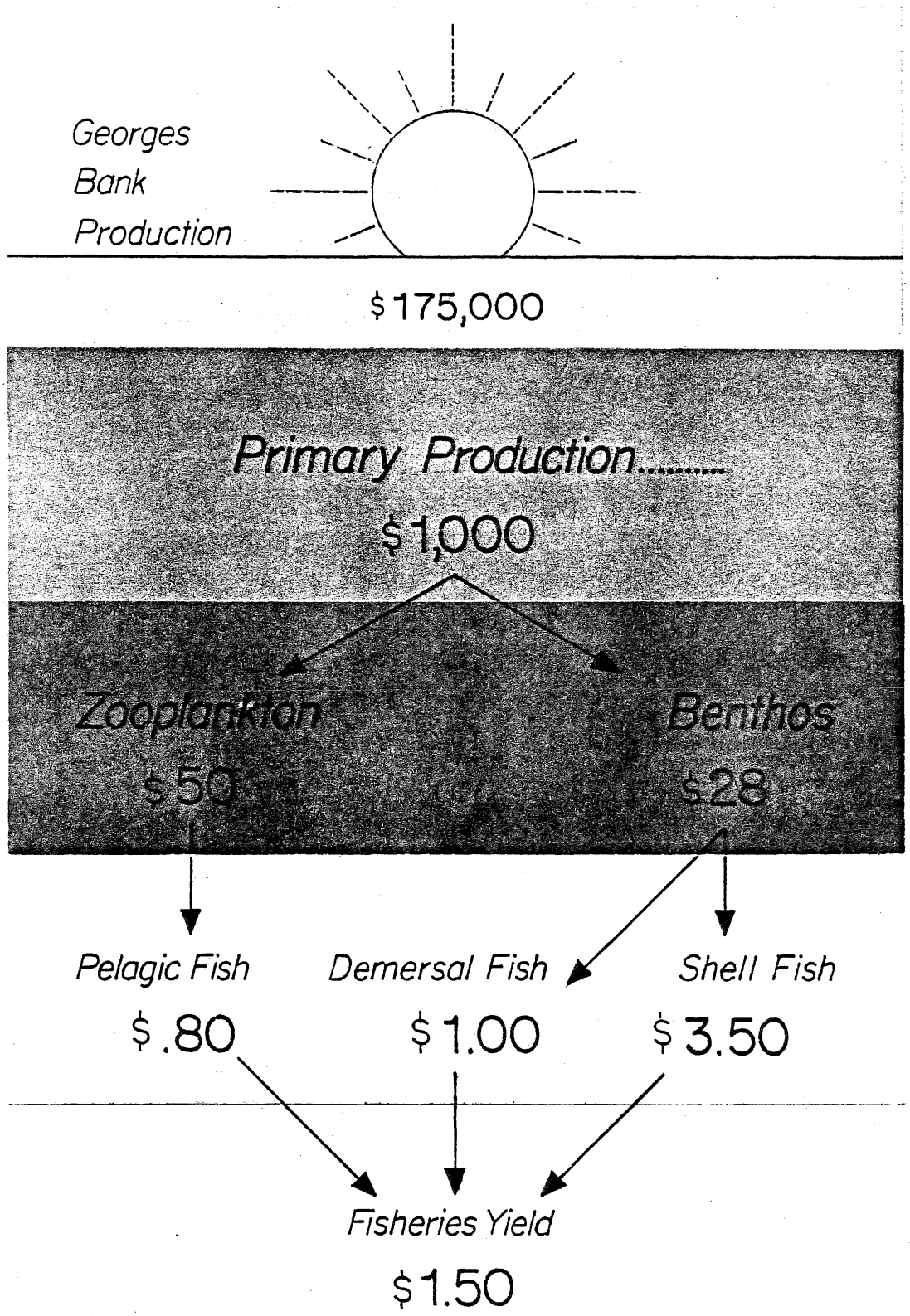

Figure 11. Flow of energy per unit area on Georges Bank.

THE WORLD'S TWO MARINE FISHING INDUSTRIES — *how they compare*

	LARGE SCALE *Company-owned*	SMALL SCALE *Artisanal*
Number of fishermen employed	*Around* 450,000	*Over* 8,000,000
Marine fish caught for human consumption	*Around* 24 *million tons annually*	*Around* 20 *million tons annually*
Capital cost of each job on fishing vessel	$ 10,000 *to* $ 100,000	$ 100 *to* $ 1,000
Marine fish caught for industrial reduction to meal and oil, etc.	*Around* 19 *million tons annually*	*Almost none*
Fuel oil consumption	10 *to* 14 *million tons annually* TTTT TTT	1 *to* 2 *million tons annually* TT
Fish caught per ton of fuel consumed	2 *to* 5 *tons* 1T =	10 *to* 20 *tons* 1T =
Fishermen employed for each $ 1 m invested in fishing vessels	10 *to* 100	1,000 *to* 10,000

Figure 12. Comparison of costs of large-scale and small-scale fisheries.