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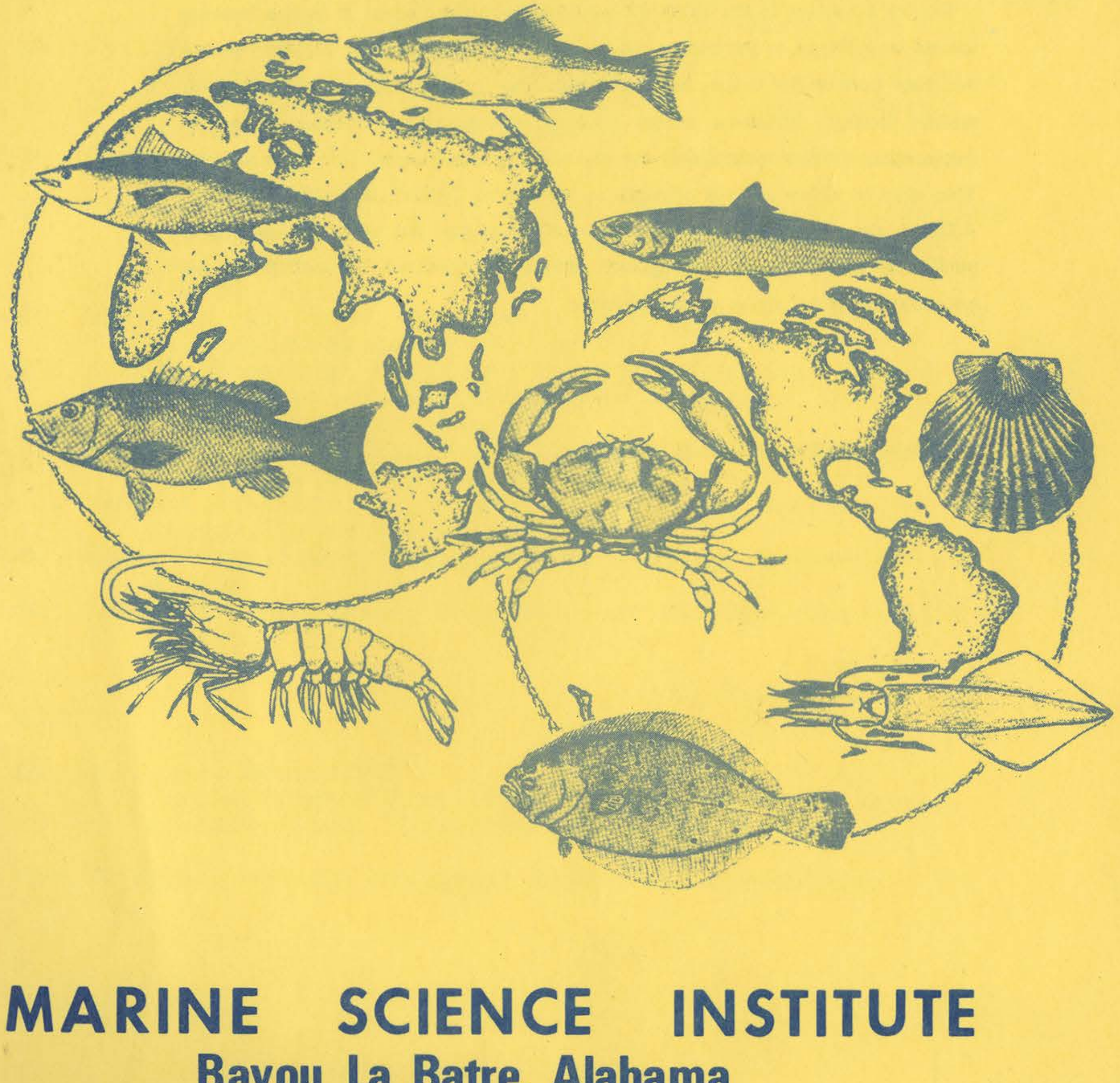

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POTENTIAL FOOD FROM THE SEA

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ABSTRACT

Estimates are made of the maximum sustainable yield of commercial fishery products that reasonably can be expected to be harvested from the world's marine waters.

A theoretical estimate based on primary productivity, trophic levels of the organisms harvested, estimated energy losses between trophic levels, and composition of the biomass at each level, yielded 94 million metric tons per year but many variables lack adequate measurement.

From existing information on yields of typical areas and the extent of each type of habitat an empirical estimate by summation yielded 93 million metric tons. Although close in total, the two estimates differ widely in species composition. The second method is considered to be more reliable.

The third approach attempted extrapolation of historical yields beyond the 58 million metric tons in 1968. This shows that a general rate of increase of 4.3 percent per year has been maintained only by increased fishing pressure and continuous shifts to new species and areas. Most historically fished species are declining in abundance so there is no reason to expect a continued increase in yield. Optimistic estimates of yield, some from two to five times higher, are wholly unwarranted.

INTRODUCTION

What is the maximum sustained yield of fishery products that man can expect realistically to harvest from the Sea? This question needs to be answered as we rapidly approach the limits of a land-based protein food supply amidst a general

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feeling that the ocean is a practically limitless reserve of food for the catching. Thus the Commission on Marine Science, Engineering and Resources (1969b, p.88) states,

> "If man's fishing activities continue to be confined to the species now utilized, to the locations now regarded as exploitable, and to the equipment now available, it is unlikely that production could be expanded much beyond 150 to 200 million metric tons - three to four times present levels. But if man's activities were not so confined, far greater quantities of useful, marketable products could be harvested to meet the increasingly urgent world demand for protein foods.
>
> "It is, therefore, more realistic to expect total annual production of marine food products (exclusive of aquaculture) to grow to 400 to 500 million metric tons before expansion costs become excessive. Even this estimate may be too conservative if significant technological breakthroughs are achieved in the ability to detect, concentrate, and harvest fish on the high seas and in the deep oceans".

This brave and optimistic statement is hardly in accord with what is and has been occurring. There have indeed been great advances in fishing technology, but all these advances, coupled with much greater fishing effort, and the exploitation of deeper areas, have only resulted in a decreasing catch per unit of fishing effort. Optimism therefore, is giving place to genuine concern among fishery scientists as one species after another falls drastically in abundance under the onslaught of ever increasing numbers of modern fishing vessels with ever increasing sophistication in gear and techniques.

The average world catches for a 19-year period from 1950 through 1968 are shown in Table 1 and Figure 1. This includes both freshwater and marine species. In 1968 the total was 64 million metric tons of which 56 million tons

Table 1. Average world catches by continents and by certain countries.[1]
(Thousands of metric tons, live weight)

	1950-53	1954-57	1958-61	1962-65	1966	1967	1968
North America	3,635	4,063	4,165	4,400	4,440	4,360	4,570
Europe	6,843	7,918	8,093	9,542	11,530	11,910	11,820
Africa	1,503	1,903	2,288	2,865	3,210	3,730	4,220
U.S.S.R.	1,869	2,475	2,920	4,262	5,350	5,780	6,080
Asia	9,390	12,260	16,528	19,210	21,420	22,590	24,250
South America	580	895	3,828	9,175	11,070	12,130	12,880
Oceania	95	103	123	145	190	200	210
World	23,915	29,617	37,945	49,599	56,800	60,498	64,000
Peru	150	300	3,030	7,630	8,790	10,134	10,520
Japan	4,140	4,900	6,080	6,730	7,102	7,850	8,670
Norway	1,680	1,950	1,500	1,650	2,865	3,269	2,804
United States	2,530	2,850	2,830	2,780	2,542	2,431	2,442
China[2]	1,450	2,648	5,170	5,800			

[1] Excludes whales but includes freshwater species.
[2] Current statistics unavailable since 1960.

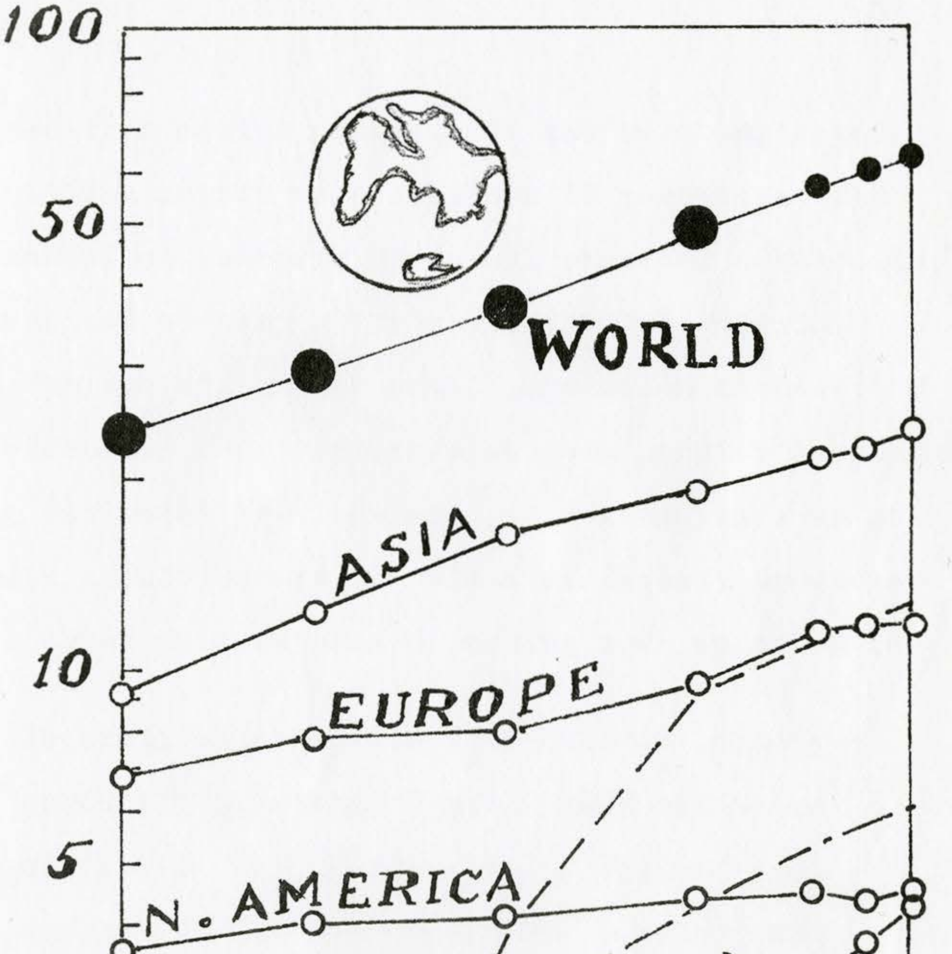

FIGURE 1. World landings of aquatic products by continents (See Table 1) in millions of metric tons.

was derived from marine waters. It has been suggested that 50 million metric tons is about 15 percent of the world's annual consumption of animal protein. Obviously, if the seas are to play a truly significant role in allaying the world's hunger until population control becomes effective they must furnish much greater landings.

Many estimates have appeared in recent years as to the world's total sustainable yield of fishery products. There are three main methods of making such an estimate -

1. Theoretical estimates from data on primary productivity combined with crude estimates of trophic levels of harvest, estimates of energy losses between trophic levels, and composition of the biomass at each trophic level.
2. Estimates from piecing together the estimates of potential yield of exploited and latent fishery resources.
3. Empirical estimates from extrapolation into the future of total landings in the past.

Several of these estimates are given in Table 2. It will be noted (Figure 1) that the annual increase was rather steady, the largest, 6.9 percent, between the 1958-61 and 1962-65 periods, occurred during the meteoric rise in the Peruvian fishery for anchovettas (See Figure 2). This was also aided by the tremendous growth in the Russian and Japanese high seas fishing fleets. Despite these great fleets aided by new high seas fleets from Poland, East Germany, West Germany, Spain and other countries the rate of increase in landings has commenced to decline.

How accurate are these estimates of sustained yield? This is a moot question that we wish to explore further. Five of the reports shown in Table 2 were serious estimates based on available information but with different methodology and interpretation. Thus, Graham and Edwards attempted to extrapolate world catches from known yields of fish per acre on a number of well fished North Atlantic fishing banks, adding a little, with less adequate data, for pelagic fisheries, and estimated a world potential by this method of about 60 million metric tons, with 55 million coming from the continental shelf. Another approach to the solution has been on a largely theoretical basis. We will begin by examining this theoretical approach.

Table 2. Estimates of sustainable yield of world fishery landings.[1]
(millions of metric tons)

Author	Potential Yield	Biomass to Harvest from	Remarks
Thompson (1951)	22	?	
Fisheries Division FAO (1953)	34	?	
Laevastu (1961)	21.5[2]	?	Up from 12.8.
Meseck (1962)	100	?	70 by 1980, 60 for marine only.
Graham and Edwards (1962)	115[3]	230	Give less than 60 million in their closing argument.
Graham and Edwards (1962)	171[4]		
Pike and Spilhaus (1962)	175	180-1400	Five times the current 35 excluding whales.
Schaefer (1965)	200	1045[5] to 2420	
Ryther (1969)	100	240	
Cushing (1969)	40-60[6]	120-130	Does not include non-upwelling portions of continental shelves.
Pike and Spilhaus (1962)	254[7]		
Schaefer (1965)	290[7]		
Ryther (1969)	145[7]		

[1] Some estimates may include a small fraction of freshwater landings and whales.

[2] For Atlantic Ocean only.

[3] Bony fishes only, from areas overlying continental shelves.

[4] Graham and Edwards estimate increased, (Schaefer 1965), by other species.

[5] Schaefer gives 1080 by error in calculation.

[6] Plus 3 to 5 for tuna-like fishes.

[7] Estimates of Pike and Spilhaus, of Schaefer, and of Ryther, adjusted by factor of 1.45 to allow for earlier errors in 14C productivity determinations (Nielsen, 1964; Goldman, 1968).

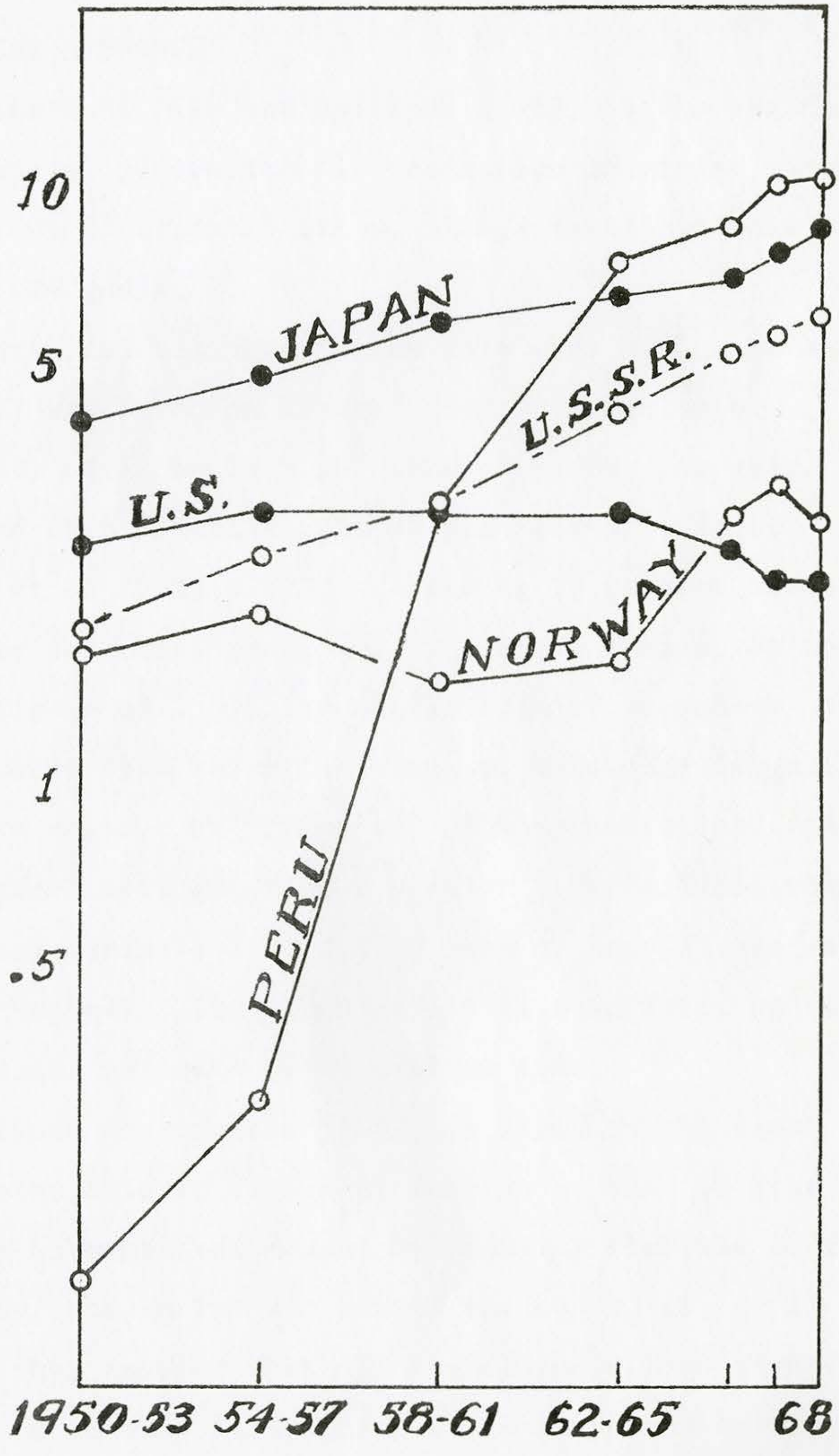

FIGURE 2. Landings of aquatic products by leading countries in millions of metric tons (See Table 1).

THE THEORETICAL APPROACH

The estimate of Pike and Spilhaus (1962) is theoretically based on an annual photosynthetic production in marine waters of 19 x 10^9 tons of organic carbon. Their final estimate of yield is a crude guess.

The theoretical estimate in the same year by Graham and Edwards (1962) was based on Steeman Nielsen's estimate (Nielsen, 1960) of 12 to 15 x 10^9 tons of carbon per year. They converted this to wet weight of plankton by a factor of 37 (Sverdrup et al 1942, p.929). Assuming 20 percent ecological efficiency for herbivores, and 10 percent thereafter they arrive at a figure of 1 billion metric tons of secondary carnivores, which they reject as being unreasonably large. They then make a guess at 70 percent of the theoretical energy transfer at each level winding up with only 343 million tons from which they estimate 230 million tons of bony fishes with a 50 percent harvest. They then reject this in favor of their earlier empirical estimate of 60 million tons.

The estimate of Schaefer (1965) is based on the same amount of photosynthetic carbon production as that of Pike and Spilhaus. He attempts refinement by assuming that the ecological efficiency between trophic levels may be 10, 15, or 20 percent. He then assumes that all the clupeoid type fishes have an average of only 1½ trophic levels (consumer levels). Since about 37 percent of the world harvest is of these herring-like fishes he assumes half of the total world harvest is taken at the second trophic level and half at the third trophic level. I consider these assumptions to be unwarranted.

I take exception to the apparently prevalent idea that just because a fish is capable of straining quantities of water through fine gill rakers that it swims about open-mouthed eating whatever small plankton happen to be available. Herring stomachs, for instance, will be found crammed with such delicacies as large copepods and pteropods, usually with little or no phytoplankton. I have often watched them feeding, darting about in pursuit of 'individual' zooplankters. Furthermore, in the autumn, when zooplankton are less abundant, I have found samples of herring with stomachs crammed with sand launces (Ammodytes). Launces, themselves, would be at about 2½ trophic levels. Furthermore, from Table 14 it is evident that 36 percent of the clupeoid fishes come from non-upwelling areas.

Ryther (1969) also, speaks of the short food chain of the clupeoid fishes, especially in the upwelling areas, and says, "There seems little doubt that many of the fishes indigenous to upwelling areas are direct herbivores for at least most of their lives". He lists as being most abundant in upwelling areas, 'sardines, pilchards, anchovies, menhaden, and so on'. The first statement is directly contrary to the findings of Hand and Berner (1959). In the upwelling area of southern California and Baja California the sardine

(Sardinops caerulea) consumed, by weight of organic matter, 89 percent crustaceans, 4 percent chaetognaths and fish eggs, and only 7 percent phytoplankton. Smaller sizes of sardines ate even less phytoplankton.

The listing by Ryther of menhaden as one of the fishes most abundant in upwelling areas is without foundation. The estuaries and shallows of the Gulf and Atlantic coasts are not "upwelling areas".

The estimate of Ryther (Table 3) is based on about the same total amount of photosynthetic carbon production as that of Schaefer, 20 x 10^9, instead of 19 x 10^9 metric tons. However, he attempts even further refinement by dividing the marine waters into three provinces, Oceanic, Coastal and Upwelling.

He correctly points out that the fish of the open ocean outside of upwelling areas have a very high average trophic level because of the very small size of the nannoplankton, which are consumed by microzooplankton, and in turn by larger zooplankton, so that the smaller fishes are already in at least the third trophic level. Thus his estimate of the biomass of available fishes is very much less than Schaefer's, only 240 million tons. His estimate that 40 percent can be harvested annually seems unrealistically high.

The estimate of Cushing (1969) is for the upwelling areas of the oceans. However, one cannot equate his estimates with those of Ryther by merely adding Ryther's non-upwelling areas, since Cushing shows over 14,958,000 km^2 of upwelling

Table 3. Estimate of fish production (After Ryther 1969).

Province	Percent of Ocean	Area in km^2	Productivity gC/m^2/yr	Carbon (10^9 tons per year)	Trophic Levels	Ecological Efficiency	Fish Production in tons (net wt.)
Oceanic	90	326×10^6	50	16.3	5	10	16×10^5
Coastal	9.9	36×10^6	100	3.6	3	15	12×10^7
Upwelling	0.1	3.6×10^5	300	0.1	1½	20	12×10^7
				20.0			24×10^7

areas compared to Ryther's 360,000 km^2. Cushing also shows vast areas of oceanic upwelling along divergences which, using his figures for gC/m^2/day and his time period, can be calculated as an additional 26,897,000 km^2 in the eastern tropical Pacific.

The large and fundamental differences between their estimates are 1) the large areas that Cushing has defined as upwelling areas 2) absence from Cushing's estimate of the vast productive coastal areas not included in his "upwelling" areas, and 3) Cushing's postulation of very low trophic levels.

Cushing has vastly improved estimates of the carbon production of upwelling zones by careful estimates of the areas involved at each season, the number of days upwelling is occurring, and the number of zooplankton generations.

An example of the difference in areas is Cushing's estimate of 1,004,000 km^2 of upwelling off Peru and Chile, compared to Ryther's estimate of 36,000 km^2. Cushing states that he placed the outer boundaries of his upwelling areas at the points where the quantity of zooplankton or of phosphate phosphorus is half the maximum from the coast.

Because of the difference in approach between Ryther and Cushing their reports are difficult to reconcile. However, if we look carefully at Cushing's upwelling areas one can see that they take in but a minor portion of the continental shelf, since the great majority of the upwelling takes place off relatively steep coasts, and over deep water, often at some distance from land. The areas of coastal upwelling given by Cushing thus extend offshore as far as 290 km (California), 400 km (Peru), 300 km (Canary), 300 km (Benguela), 300 km (Somali), and 175 km (off southwest Arabia). If we eliminate areas with little or no continental shelf (Table 4) there remains about 4,936,000 km^2 that contain any appreciable amount of shelf area. If we allow a full 10 percent of shelf area in this 4,936,000 km^2 remaining, we have only 494,000 km^2 of continental shelf included in Cushing's estimates, leaving about 30,506,000 km^2 of continental shelf not in upwelling zones.

We can now make a rough balance sheet between the areal estimates of Ryther and Cushing as follows (Table 5).

Perhaps the chief difference between earlier estimates of primary productivity, and that of Cushing, for the upwelling areas, is that Cushing did not estimate the primary production by a blanket formula. Instead, for each upwelling area he has used rate of vertical upwelling, speed of surface currents, number of days of upwelling, and actual estimates of seasonal primary productivity in grams of carbon per m^2 per day. He has thus been able to summarize the tons of carbon per year for each of the many upwelling areas in great detail. Using Cushing's estimates for the upwelling areas we have summarized primary productivity in Table 6.

Table 4. Relation of upwelling areas of Cushing to shelf areas.
(km^2 10^3)

Upwelling areas with very little or no shelf		
Costa Rica dome	148	
Marquesas	8,760	
Guinea (dome)	100	
Madagascar Wedge	1,014	
E. Tropical Pacific	26,897	
		36,919
Upwelling areas with small shelf areas		
Peru-Chile	1,004	
Somali-Arabia	226	
Flores and Banda	200	
California	505	
Benguela	629	
Canary	691	
		3,255
Upwelling areas adjacent to large shelf areas		
New Guinea	460	
Orissa	96	
Java	300	
Northwest Australia	300	
East Arafura	250	
Gulf of Thailand	75	
Vietnam	200	
		1,681

Table 5. Comparison of marine areas in $km^2 \times 10^3$.

	Ryther	Cushing	Our estimate
Upwelling Areas			
E. Tropical Pacific[1]	?	26,897[2]	26,897
Around Antarctica	160	0	160
Coastal	200	494[3]	494
Non-shelf	0	14,464	14,464
Shelf Areas[4]	31,000	30,506	30,506
Remaining oceanic areas	330,640	289,639	289,479
Total Area	362,000	362,000	362,000

[1] Ryther includes oceanic divergences in his Coastal Zone which in this table would be in "remaining oceanic areas".

[2] Based on Cushing's tons C/yr and $gC/m^2/d$ with 6 months of upwelling.

[3] See text. Ryther includes some shelf area, Cushing's 494 is estimated as shelf area.

[4] Includes non-shelf in seas with sills under 100 fms, excludes upwelling portions of shelves. Graham and Edwards (1962) estimate the continental shelves at 24.3 x 10^6 km^2, but specify "potentially productive" shelf.

Table 6. Summary of primary productivity.

Upwelling Areas	km^2 10^3	Tons C/yr/10^6	
E. Tropical Pacific	26,897	1,245.55	from Cushing
Coastal (On Shelf)	494	43.29	from Cushing
Non-Coastal	14,464	1,222.40	from Cushing
Antarctic[1]	160	23.52	
Shelf Areas[2]	30,506	4,423.37	
Other oceanic areas[3]	289,479	20,987.24	
	362,000	27,945.37	

[1] Used same rate as for coastal mean, 8.8 percent.

[2] Used 100 gC/m^2/yr (Ryther, 1969) X factor of 1.45 to allow for earlier errors in 14C productivity determinations (Nielsen 1964, Goldman, 1968).

[3] Used 50 gC/m^2/yr (Ryther 1969) X factor of 1.45.

The final estimate for primary productivity of 28 x 10^9 metric tons of carbon appears to be exactly the same as Ryther's estimate of 20 x 10^9 if Ryther's is corrected for earlier errors in 14C data, which would give 29 x 10^9 metric tons. However, Ryther's estimate includes a larger proportion of what he calls "oceanic", in which the ecological efficiency is doubtless low.

In any theoretical approach to the problem there are several obstacles. We need better information on the efficiency of the energy transfer at each trophic level, better information on the composition of the biomass produced at each trophic level, and better information on the possible harvest from each trophic level.

From the estimate of primary productivity in metric tons of carbon one can estimate the production at the first trophic level of consumers. Cushing did not employ the classical approach of making a guess at the ecological efficiency of this transfer but has carefully analyzed zooplankton volumes from net hauls made through the euphotic zone. Those in the Pacific are summarized by Reid (1962), those in the eastern tropical Pacific by Blackburn (1966), those in the Peru current by Flores (1967), Flores and Elias (1967), and Guillen and Flores (1967). Observations in the Indian Ocean were from Wooster, Schaefer and Robinson (1967). Wherever available we have used Cushing's estimate for this first consumer trophic level (Table 7).

Table 7. Estimate of first (consumer) trophic level.

Areas	Primary productivity (Tons C/yr/10^6)	Trophic efficiency[1] (Percent)	Herbivores	
			Carbon (Tons C/yr/10^6)	Wet weight[2] (Tons/yr/10^6)
Upwelling Areas				
Coastal				
California	30.5	15.82	4.7	83.9
Peru	112.9	11.25	10.5	187.4
Chile	43.6	21.81	7.9	141.0
New Guinea	41.0	3.3	2.4	42.8
Canary	15.7	16.48	2.6	46.4
Benguela	274.6	4.46	12.9	230.3
Somali-Arabia	51.3	7.06	3.7	66.0
Orissa	8.7	16.78	1.5	26.8
Indonesia	64.2	9.90	6.4	114.2
N.W. Australia	18.5	10.07	4.5	80.3
Gulf of Thailand	20.8	10.00[3]	2.1	37.5
Vietnam	44.2	10.00[3]	4.4	78.5
Antarctica	23.5	10.00[3]	2.4	42.8
Non-Coastal				
Costa Rica dome	16.7	15.76	5.3	94.6
Marquesas	514.5	4.17	21.4	382.0
Guinea dome			1.6	28.6
Madagascar Wedge	8.7	6.00[3]	0.5	8.9
E. Tropical Pacific	1,245.6	6.46	80.5	1,436.9
Shelf (non-upwelling)	4,423.4	10.00[3]	442.3	7,895.1
Other oceanic areas	20,987.2	6.00[3]	1,259.8	22,476.7
	27,946		1,876.8	33,500.7

[1] Unweighted means when more than one section of coast.
[2] Carbon times factor of 17.85 (Cushing, 1958).
[3] Assumed.

The herbivores at the first trophic level are thus assumed to weigh 33.5 x 10^9 tons wet weight. This biomass will vary in composition by area. In the "other oceanic" areas it will probably consist chiefly of microzooplankton and thus not be directly available to fishes, this will apply to a slightly lesser extent to the eastern tropical Pacific and Marquesas. On the non-upwelling portion of the shelf a fraction will be shelled mollusks, and a small portion will be consumed by fishes, but the great bulk will undoubtedly consist of copepods and other small invertebrates. In the coastal and non-coastal upwelling zones a somewhat larger share of the algae will be consumed directly by fishes, but the bulk will still be grazed by zooplankton.

Let us be optimistic and use a 15 percent ecological efficiency rate which may serve to take care of the recycling of organic substance. For the coastal upwelling zone the catch may be derived largely from the second trophic level. For the non-coastal upwelling zone the third level is more appropriate. Perhaps the bulk of the shelf yield may be as low as the third level. In the eastern tropical Pacific the fourth level may be sufficiently low. For the "other oceanic" the trophic level must be higher, averaging at least five levels. (See Table 8).

This theoretical exercise gives us a total yearly production of fish biomass (including squids, larger crustacea and shelled mollusks) of 277 million metric tons.

Table 8. Estimate of fish production (wet weight).

Area	Biomass of first consumer level (tons/yr/10^6)	Trophic level of harvest	Assumed ecological efficiency	Fish production (tons/yr/10^6			
Upwelling				2	3	4	5
California	83.9	2	15	12.6			
Peru-Chile	328.4	2	15	49.3			
Canary	46.4	2	15	7.0			
Benguela	230.3	2	15	34.5			
Somali-Arabia	66.0	2	10	6.6			
Indonesia	114.2	2	10	11.4			
Thailand-Vietnam	116.0	2	10	11.6			
N.W. Australia	80.3	2	10	8.0			
New Guinea	42.8	2	10	4.3			
Antarctica	42.8	2	10	4.3			
Costa Rica dome	94.6	3	15	(14.2)	2.1		
Guinea dome	28.6	3	15	(4.3)	0.6		
Orissa	26.8	3	15	(4.0)	0.6		
Madagascar Wedge	8.9	3	15	(1.3)	0.2		
E. Tropical Pacific-Marquesas	1,819.9	4	15 then 10	(273)	(27.3)	2.7	
Shelf (non-upwelling)	7,895.1	3	15	(1184.3)	117.6		
Other oceanic areas	22,476.7	5	15 then 10	(3371.5)	(337.2)	(33.7)	3.4
Harvested at each trophic level				149.6	121.1	2.7	3.4
Remainder at each trophic level				(4606.9)	(364.5)	(33.7)	
			Total 276.8				

Having arrived at this calculation of annual production of "fish" biomass the question naturally arises as to the proportion of this biomass that can be harvested if the yield is to be maintained. The previous authors differ widely in their opinions concerning this proportion. (See Table 9).

Differences in opinion between authors in the percent of the total potential biomass that is harvestable stem largely from differences concerning trophic levels at which they believe the harvest can be taken. Thus Schaefer (1965) assumes that half can be taken at the second and half at the third trophic level, whereas Edwards and Graham assumed the whole harvest to be taken at the third trophic level.

It should be obvious that the trophic level of the harvest will vary considerably amongst the different ecological habitats. Thus Schaefer's use of the second trophic level is very probably the best assumption for the pelagic coastal zones of upwelling. If the anchovettas, for instance, are a little below the second trophic level this will be balanced by the larger predators taken in the same zone. I agree with Graham and Edwards that the shelf area harvest will average closer to the third trophic level. This difference between trophic levels for harvesting in different zones was recognized by Ryther in his paper. Cushing went a step further in his excellent detailed analysis of the world's upwelling areas. However, he seemed to fail to recognize that thermal convection, turbulent mixing, intermittent upwelling, and cabelling are widespread over extensive and

Table 9. Estimates of "fish" biomass available and proportion harvestable.

Annual biomass (metric tons 10^6)	Percent harvestable	Possible harvest (metric tons 10^6)	Authors
230[1]	50.0	115	Graham and Edwards (1962)
343[2]	50.0	171	Graham and Edwards (1962)
1045-2420	8.3-19.1	200	Schaefer (1965)
240	41.7	100	Ryther (1969)
120-130[3]	30.8-50.0	40-60	Cushing (1929)

[1] Bony fishes only.
[2] All fishes, including squids, etc.
[3] Upwelling areas only.

highly productive areas. He was apparently preoccupied with tropical and subtropical waters.

The percent of the potential biomass harvested on a sustained yield basis will also vary widely amongst the different zones and amongst the different types and species of organisms. As a very general rule the higher the trophic level the greater the danger of overexploitation. Likewise, species, such as shrimp, with a very short life span and high fecundity, show little or no relationship (within most practical limits) between size of spawning stock and numbers of young shrimp in the next generation. Bearing these limitations in mind I would roughly estimate the potential harvest from our theoretical biomass as shown in Table 10.

Actually my estimate of 94×10^6 metric tons is considerably below the total estimate of Ryther, only 65 percent as large if his estimate is adjusted to 145 metric tons as in Table 2.

If one adds to Cushing's estimate ($40\text{-}60 \times 10^6$) for the upwelling areas, my estimate of 47×10^6 for the shelf areas, making 87 to 107 metric tons $\times 10^6$, we are in very close agreement for the total.

One important source of nutrients neglected in most theoretical estimates is dissolved and particulate matter contained in the runoff from the land. Ketchum (1969) states,

> "The effect of river water carrying nutrients into the sea is important in coastal waters and in semiconfined bodies of water such as the Gulf of Mexico. However, in terms of the total oceanic production,

Table 10. Estimates of potential fish yields.

	Available biomass[1] (tons/yr/10^6)	Percent harvestable	Yield (tons/yr/10^6)
Upwelling areas			
E. Tropical Pacific-Marquesas	2.7	20	0.54
Other upwelling	153.1	30	45.93
Shelf	117.6	40	47.04
Other oceanic	3.4	15	0.51
	276.8		94.02

[1] From Table 8.

> river drainage adds only about 1% of the total nutrient requirement each year. Thus, while river drainage is very important locally, its value to the productivity of the sea has been greatly overemphasized by some."

The importance of land drainage is undoubtedly much greater than the above statement would suggest. For instance, it is estimated (Clarke, 1916) that the Mississippi River annually discharges into the Gulf of Mexico 370 x 10^6 metric tons of sediment and 2,735 x 10^6 metric tons of dissolved salts. My estimate for tons/yr of photosynthesized carbon on the world's continental shelves (Table 6) is only 4,467 x 10^6. From 1964 through 1966 fish yield in the Gulf of Mexico was 68.5 percent as great as the Atlantic coast from Key West to Eastport, yet the bulk was taken from Mobile Bay to Port Arthur, a distance of about 300 miles, around the mouths of the Mississippi.

The effect of the Mississippi River sediments that are carried westward along the Louisiana and Texas coasts on the aggregations of brown shrimp is very striking. Where these sediment-laden waters meet a current flowing northward along the Texas coast they are diverted away from shore onto the continental shelf. Here is where over 50 percent of the Texas catch is made (Lindner and Bailey, 1968).

For the entire world Clarke (1916, p.118) estimates that the runoff from the land carries 2,492 x 10^6 tons per year of dissolved substances which averages 24 tons per km^2 of land surface. Fifty years later, Alekin (1966), estimates

23 tons per km^2. The two estimates are remarkably close. Clarke's estimate gives an average terrigenous contribution of dissolved substances of 6.9 tons per year per km^2 of ocean surface. This is nearly equal to the primary productivity of 7.7 tons C/year/km^2 (27,946 tons C/year/10^6 (Table 7) ÷ 362 $km^2/10^6$).

Since almost all of this dissolved material flows onto the continental shelves it should be noted that this amounts to 44 tons of dissolved material /year/km^2 of shelf area. Thus it appears that the 144 tons C/year/km^2 for the continental shelves, compared to a world average of 7.7 tons C/year/km^2 is not a mere coincidence.

Concerning the usually very productive Sea of Azov, Izhevskii (1961) states, "The productivity of the northeastern part of the Black Sea responded to the decreased productivity of the Azov Sea during the reservoir-filling years on the Don (1952-53). According to A.P. Kusmorskaya this part of the sea proved less productive even as compared to the southeastern portion." Izhevskii (1964) also states, "The diversion of the Don River in 1952-53 resulted in a sharp decrease in the catches, from 800,000 metric centners in 1951 and 600,000 in 1952 to 35,000 in 1955."

The fisheries adjacent to the Nile delta have declined steadily since 1964 because construction of the Aswan Dam has lowered quantities of incoming nutrients. (Anonymous, 1970a).

One point that must be made is the great gap between total primary productivity and even potential yield. Thus it should be noted that the upwelling and shelf areas (exclusive of the tropical Pacific) with a combined total of only about 20 percent of the primary productivity account for 98.9 percent of the potential harvestable fishery organisms. A very low order of primary productivity prevails over most of the deep oceans, excluding only areas of upwelling. This includes 78.5 percent of the oceans, plus an additional 7.5 percent slightly better in the eastern tropical Pacific, in all 86 percent. Partially because of the low productivity, and partly because of the higher trophic levels, this enormous area, comprising 61 percent of the entire surface of this planet, has a theoretical potential of only one percent of our fishery harvest!

How well do the theoretical estimates of potential fish yield seem to fit the known facts? Ryther gives two examples which he apparently regards as authenticating his theoretical approach. In his first example he uses the 110,000 square miles of the New England banks between Hudson Canyon and the channel between Georges Bank and the Nova Scotia banks. According to Graham and Edwards (1962) this area contains only 71,875 square miles of continental shelf. He states,

> "From the information in Tables 2 and 3, it may be calculated that approximately 1 million tons of fish are produced annually in this region. Commercial landings from the same area were slightly in excess of 1 million tons per year for the 3-year period 1963 to 1965 before going into a decline."

Using the information Ryther gives in Tables 2 and 3 (100 g carbon/m^2/yr, a 15 percent ecological efficiency, his 110,000 square miles, and harvest at the third consumer trophic level) the total wet weight biomass of all organisms at the third level is only 960 thousand metric tons. Using his harvesting rate of 41.7 percent results in a yield of only 400 thousand metric tons, far below the 1 million tons actually caught.

For his second example Ryther uses the upwelling area along the Peru-Chile coast. He says the area involved is only 2,400 square miles (6,475 km^2). At his figure of 300 g carbon/m^2/yr, and his 20 percent ecological efficiency the wet weight of the biomass would be 3.9 million tons at the first (herbivore) level and only 0.8 million tons at the second consumer level. Harvested at half at each level as he postulates at a rate of 40 percent harvest we get only 1.9 million tons of yield whereas he says the catch is about 10,000,000 tons and that the guano birds consume an additional 10,000,000 tons. This is an astounding difference between theory and actuality.

For the same Peru-Chile upwelling region Cushing (1969) gives an area of 1,004,000 km^2 and by Cushing's analysis there results a biomass at the second consumer level of 49.3 million metric tons, which he says would be harvested at that level. The 20 million tons that Ryther (1969) has said could be had by fishermen and guano birds, would be produced in an area only 6 percent as large as that used by Cushing.

Probably the greatest discrepancy between theory and fact is caused by a large underestimation of the fertility of inshore areas, especially those receiving substantial freshwater drainage from fertile lands. Thus the area around the mouths of the Mississippi River between Mobile Bay and Port Arthur has produced for several years about one billion pounds of menhaden and industrial fish. Disregarding all other fish production, this is 453,000 metric tons in a shelf area of not over 30,000 square miles (77,700 km^2). To produce this amount of fish at the second consumer level would require 6.6 x 10^6 tons C/yr if the total biomass were harvested. Using Ryther's figure of 100 g C/m^2/yr for this area gives 7.8 x 10^6 tons carbon. Obviously, primary production in the area has to be, at the very least, between two and three times higher than the general coastal average of 100 g C/m^2/yr suggested by Ryther. I contend that one of the difficulties has been the lack of sufficient sampling in inshore areas to truly reflect the average fertility of the continental shelves.

In a recent review (Parsons et al, 1970) the primary productivity in the Gulf of Georgia was placed at 120 g C/m^2 per year, but it was also stated that allochthonous organic carbon from land drainage was at least as great as the total annual primary productivity. Stephens et al (1967, cited by Seki et al, 1968) reported these annual sediments as containing organic carbon and nitrogen in the amounts of 200 and of

27 g/m^2 per year. Seki et al (1968) showed that this organic carbon was utilized by bacteria with an efficiency of about 30 percent. Obviously, then the land drainage in this area is contributing about one-third of the primary food source to the coastal waters.

The importance of these sediments is well illustrated in southeastern Alaska where shrimp are caught on the fine detritus along the face of melting glaciers.

The weakness of the relationship between primary, and even secondary, productivity and fishery production is brought out in a statement taken from a report by the SCOR group on monitoring in biological oceanography (Scientific Committee on Oceanic Research, 1970, p.76):

> "Monitoring on an ocean-wide scale of such parameters as chlorophyll-a, C^{14} uptake, and zooplankton biomass have been much overemphasized in their direct application fisheries. A number of examples were discussed to emphasize that application of primary and secondary production data differed very considerably from fishery to fishery.
>
> "During the recent METEOR work in the region of Cabo Blanco, a recently upwelled parcel of water, rich in nutrients, was observed to develop a very strong bloom of a Phaeocystis-like alga. Subsequently, no grazing herbivores developed, probably because few herbivore species are able to utilize these chain-form phytoplankton. In an ocean-wide chlorophyll-a monitoring system such patches would be difficult to assess without additional observations. Similar experiences have been noted off Peru where the Engraulis fishery does not correspond with regions of strongest upwelling, and off South West Africa where the Spanish distant-water trawler fleet has been observed far from upwelling centers, while in the northern Pacific Ocean it has been found that there was no direct relationship between the north Pacific spring bloom and the high seas salmon distribution."

Table 11. Estimate of world marine fishery catch in 1958 and 1968.[1] (thousands of metric tons)

	1958	1968
FAO grand total	33,200.0	64,000.0
Freshwater species	4,420.0	6,660.0
Other freshwater[2]	59.7	48.4
Cultured fishes[3]	52.0	64.4
Miscellaneous non-fish[4]	43.0	63.0
Aquatic algae	520.0	890.0
FAO marine fishes	28,105.3	56,274.2

[1] Exclusive of whales.
[2] Freshwater fishes included in FAO marine fish tables.
[3] Japan, Taiwan, and Denmark.
[4] Porpoises, turtles, frogs, corals, shells, pearls, sponges.

Table 12. Estimate of world marine fishery catch in 1958 and 1968 from FAO tables of catches by countries.[1]

Regions	1958	1968
Upwelling Areas	Metric Tons 10^3	
Chile-Peru-Ecuador	1,218.1	11,943.3
California	312.0	233.4
Angola, Namibia, S. Africa	933.9	2,409.3
Morocco, Ifni, Spanish Sahara, Mauritania, Senegal	291.5	447.7
Guinea dome-Ivory Coast, Ghana, Togo, Dahomey, Sao Tome, Nigeria	164.1	279.4
Somalia, S. Yemen, Saudi Arabia, Muscat, Oman, Trucial Oman	157.6	190.6
India, Ceylon, Maldive Islands	1,117.3	1,693.4
Thailand, Cambodia, S. Vietnam	496.8	1,669.9
	4,691.3	18,867.0
Non-upwelling Areas		
N. of U.S.-Mexico (except Calif.)	3,439.3	3,738.8
Mexico to S. America, Caribbean	240.4	596.7
E. Coast of S. America	412.3	893.4
Mediterranean-Gibraltar to Sea of Aral (Ex. France and Spain)	949.6	1,681.3
Atlantic Europe (incl. Russian Baltic Republics)	7,653.5	12,116.1
N. Temperate Asia-Japan, Taiwan, S. Korea, Ryukyu	6,154.6	10,073.1
China (mainland)	4,060.0	5,800.0 (1960)

Table 12 (continued)

Regions	1958	1968
Non-upwelling Areas	Metric Tons 10^3	
North Vietnam	156.0	290.3 (1962)
North Korea	312.1 (1955)	598.8 (1966)
Philippines, Macao, Hong Kong	522.8	1,056.5
Malaysia-Singapore	152.2	423.8
Pakistan	283.7	424.0
Persian Gulf-Iran, Iraq, Kuwait, Qatar	41.9	53.0
Remainder W. coast of Africa	354.1	346.8
Remainder E. coast of Africa	96.2	161.6
New Zealand	39.3	59.6
U. S. S. R. (Main Federated Republic only)	2,053.0	4,335.6
	22,392.9	35,960.3
Upwelling limited in time or area		
Burma	360.0	396.1
Brunei, Indonesia, Portugese Timor	692.8	1,177.9
Australia	54.3	102.7
	1,107.1	1,676.7
Inland countries (no marine)	236.8	415.9
GRAND TOTAL	32,956.2	63,609.0
Minus exclusions (Table 11)	27,861.5	55,883.2

[1] Exclusive of whales.

Table 13. Estimate of world marine fish catch in 1958 and 1968 by groups of species from FAO Yearbook. (thousands of metric tons).[1]

Species Group	Upwelling		Non-Upwelling		Unclassified	
	1958	1968	1958	1968	1958	1968
Clupeoids	1,863	13,748	5,986	7,911	104	17
Gadoids	160	776	4,370	8,693	5	10
Salmons			500	423		
Mackerels	449	558	1,209	3,370	5	386
Flatfishes			761	1,145	24	19
Redfishes, groupers			800	952	9	18
Sea breams, bluefishes	55	62	213	304	7	67
Tunas, billfishes	264	250	683	847	42	85
Demersal, various			124	261	64	219
Sciaenidae			267	299	10	22
Sharks, rays			247	253	41	75
All other fishes	357	404	1,109	913	249	351
Shrimps, lobsters	128	219	436	639	85	174
Crabs			184	316	5	13
Cephalopods	3	12	571	1,085	2	4
Oysters	3	1	639	818		
Other bivalves	27	43	575	893		
Other molluscs and invertebrates	79	161	166	258	14	36
Unsorted, unidentified[2]	517	1,372	4,152	6,928	670	951
	3,905	17,606	22,992	36,308	1,336	2,447

Table 13 (continued)

Summary	1958	1968
Upwelling	3,905	17,606
Non-upwelling	22,992	36,308
Unclassified	1,336	2,447
	28,233	56,361

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[1] Exclusive of whales.

[2] Corrected for freshwater fishes included for certain countries.

Thus from Tables 11 to 13 we have three estimates of world marine fish catches of 1958 and 1968:

Source	1958	1968
Table 11	28,105	56,274
Table 12	27,862	55,883
Table 13	28,233	56,361
Average	28,000	56,173
Range, -	138	290
Range, +	233	188
Range, Total	371	478

Considering the amounts that had to be estimated for various countries these three approaches give remarkably close estimates for the world catch of marine fishes, which appears to have increased from 28 million to 56 million metric tons over a ten-year period, a rate of 7.15 percent for the whole period.

One of the first facts clearly evident (Table 14) is that the upwelling areas are dependent on a huge catch of clupeoid fishes. This catch of a few schooling species is highly reminiscent of the golden days of the California sardine fishery when the industry rebelled against the few conservation measures imposed by the State of California. The idea that one should place confidence in the annual production of great quantities of animal protein from a single species of fish is gambling with the future. I was in California when the industry used all its influence to allow unlimited exploitation of sardines. Despite the limitations maintained by the State, the sardine fishery collapsed.

Perhaps in thinking of trophic levels one should also consider that the bulk of the great catch of clupeoids, about 78 percent of the 1968 catch in the upwelling areas, is not eaten by humans, but goes through a whole trophic level (into chickens, etc.) and so is much less important than the gross statistics would indicate.

It is interesting to note that 58 percent as many clupeoid fishes were taken from shelf areas as from the "upwelling areas". If we compare the yield per area of the rich "upwelling" areas with the yield of the shelf areas of the world, Table 15, it is indeed surprising to discover that the production per square kilometer is almost identical. What the shelf areas may lack in pelagic species is compensated for by the richness of the demersal fauna.

Table 14. Analysis of 1968 marine catch by types of species (from Table 13, metric tons x 10^3.

	Upwelling Areas	Non-upwelling Areas	Unclassified Areas
Pelagic Species			
Neritic			
Clupeoids	13,748	7,911	17
Sea breams	62	304	67
Mackerels	558	3,370	386
Cephalopods	12	1,085	4
	14,380	12,670	474
Oceanic			
Salmons		423	
Tunas	250	847	85
	250	1,270	85
Demersal Species			
Flatfishes		1,145	19
Gadoids	776[1]	8,693	10
Redfishes		952	18
Demersal, various		261	219
Sciaenidae		299	22
Sharks, rays		253	75
Shrimps, lobsters	219	639	174
Crabs		316	13
Oysters	1	818	
Other bivalves	43	893	
Other molluscs	161	258	36
	1,200	14,527	586
All other fishes and unsorted fishes	1,776	7,841	1,302
	17,606	36,308	2,447

[1] Hakes only

Table 15. Comparison of yields in 1968 from upwelling and shelf areas.[1] (Metric Tons x 10^3)

	Upwelling	Non-upwelling
Demersal species	1,200	14,527
Neritic pelagic species	14,380	12,670
Unsorted fishes	1,776	7,841
	17,356	35,038
Upwelling areas[2], $km^2 \times 10^3$	14,958	
Non-upwelling shelf areas[3], $km^2 \times 10^3$		30,506
Metric tons yield per km^2 all fishes	1.16	1.15

[1] Excludes the oceanic pelagic tunas and the ocean feeding salmons.

[2] See Table 5, excludes Antarctica and oceanic area of eastern tropical Pacific.

[3] Includes total area of seas with entrance sills less than 100 fms, such as the Mediterranean Sea, Red Sea, Baltic Sea, and Persian Gulf.

We know that the catch of the shelf area is coming from only a fraction of the area available. Thus Graham and Edwards obtained an average of 20 pounds per acre of bony fishes for various productive continental shelves. This amounts to 2.24 metric tons per km^2. They excluded all invertebrates and elasmobranchs, which in 1968 were 11 percent of the shelf catch. Adjusting for these omissions would give 2.52 metric tons per km^2.

It will be noted that my theoretical estimate of total sustainable yield (Table 10) estimated exactly 50 percent of the yield coming from non-upwelling shelf areas. However, actual yields (Table 15) show that shelf areas yielded over twice as much as upwelling areas and had the same average yield per km^2. This means that the estimates of productivity for shelf areas are too low. This underestimate of shelf productivity can have two sources, first, the underestimation of primary productivity caused by failure to adequately sample the shallower portions of the shelf, and second, from failure to fully recognize the role of land-derived nutrients.

This underestimation of the fishery potential of the continental shelves versus the deeper areas can be illustrated by a few examples.

Alverson et al (1964) state that the annual catch of demersal fishes from the shelf areas from southern Oregon to the Arctic was 1,549 million pounds, (estimated from several sources for years up to about 1960). This included large

Japanese and Russian catches in the eastern Bering Sea, but excluded the Asiatic side. They state that at 10 pounds per acre this area should produce 1,600 million pounds of demersal fishes. In 1968 the northeast Pacific demersal catch was 2,538,000 metric tons over an area (See Table 16) of 1,058,000 km^2 or 2.399 metric tons per km^2, a great increase in demersal species alone.

Holden (1967) shows total fish landings including invertebrates from the North Sea by 13 countries in 1965 as 2,810 thousand metric tons. For the North Sea with an area of only 575 thousand km^2 this is a catch of nearly 5 metric tons per km^2 an astonishingly high figure, however, it includes all fishes, not just the demersal.

Contrast this with the tuna fishery based in American Samoa (Chapman 1969) in which Japanese, Korean, and Taiwanese vessels fishing an area of 7 million square miles caught 38,000 tons of fish in the peak year of 1967, or only 0.0021 metric tons per km^2.

Without more data any estimate of fishery production is subject to errors that are not necessarily compensating. Furthermore, whether the production reaches or falls far short of an estimate depends largely on whether the fishery resources can be managed by scientific knowledge instead of uncontrolled exploitation. Under the latter regime the fishermen and the consumer are both short changed.

In order to estimate the potential yield of the shelf areas I have made a crude estimate of the areas of shelf involved in each major climatic and geographic region. The modern trawlers fish both the continental shelf proper and the upper slope to a depth of about 600 meters or beyond. In Table 16 we have attempted to estimate both continental shelf and upper slope.

TABLE 16. CONTINENTAL MARGINS (KM^2 10^3).

	SHELF[1]	UPPER SLOPE[2]	TOTAL
ARCTIC SEA[3]	4,990[3]	2,500[3]	7,490
HUDSON AND BAFFIN BAYS, CANADIAN STRAITS	1,010[4]	150[5]	1,160
KARA SEA[5]	883	?	?
LAPTEV AND E. SIBERIAN SEAS[5]	1,000	?	?
CHUKCHI SEA, BEAUFORT SEA,ETC.[5]	2,097	?	?
ATLANTIC, NORTHEAST	2,495	761±	3,256
BARENTS SEA	550[4,7]		550
SPITZBERGEN	240[4,7]		240
NORWEGIAN SEA[6]	130	347	477
ICELAND[6]	96	174	270
FAEROES[6]	26	130	156
EAST GREENLAND SEA[5]	20	110	130
NORTH SEA	575[7]		575
BALTIC SEA[6]	478[7]		478
IRISH SEA	380[7]		380
ATLANTIC, NORTHWEST	1,558	838	2,396
LABRADOR[5]	80	100	180
SOUTHWEST GREENLAND	180[4]	20[5]	200
NEWFOUNDLAND	400[7,4]	40[5]	440
SOUTHERN GULF OF ST. LAWRENCE	100[5]	100[5]	200
NOVA SCOTIAN BANKS	260[5]	10[5]	270
NEW ENGLAND BANKS[8]	267	77	344
MIDDLE AND SOUTH ATLANTIC[8]	271	491	762
SUBTROPICAL ATLANTIC, N.E.	824	645	1,469
BAY OF BISCAY	80[4]	10[5]	90
WEST IBERIAN	50[4]	3[5]	53
MEDITERRANEAN SEA[6]	515	567	1,082
BLACK SEA[6]	141	65	206
SEA OF AZOV	38	0	38
SUBTROPICAL ATLANTIC, N.W.	689	215	904
BAHAMAS[6]	127	17	144
PUERTO RICO AND VIRGIN ISLANDS	5[9]	8[5]	13
N. GULF OF MEXICO	385	155	540
CAMPECHE BANK[6]	172	35	207
TROPICAL ATLANTIC, EAST	580	71	651
N.W. AFRICA[5]	190	16	206
SOUTH TO INCLUDE LIBERIA	190	20	210[4]
GULF OF GUINEA	200	35	235[5]
TROPICAL ATLANTIC, WEST	832	187	1,019
NICARAGUA TO JAMAICA[6]	120	52	172
OFF PANAMA AND COLUMBIA[5]	80	10	90
VENEZUELA[6]	93	34	127
TRINIDAD[6]	24	21	45
AMAZON COAST	515[6]	70[5]	585
SUBTROPICAL ATLANTIC, S.E.	183	229	412
ANGOLA	14[6]	10[5]	24
S. W. AFRICA[6]	69	120	189
S. AFRICA, WEST COAST[6,4]	100	99	199
SUBTROPICAL ATLANTIC, S.W.	400	90	490
SOUTHERN BRAZIL	400[4]	90[6]	490

TABLE 16 (CONTINUED)

	SHELF[1]	UPPER SLOPE[2]	TOTAL
ATLANTIC, S.W.	1,082	488	1,570
ARGENTINA-FALKLAND IS.[6]	1,030	345	1,375
BURWOOD BANK	35[6]	40[5]	75
SOUTH GEORGIA, SOUTH ORKNEY IS.[6]	17	103	120
PACIFIC, N.E.	915	143	1,058
EASTERN BERING SEA[8]	498	48	546
GULF OF ALASKA[8]	206	52	258
BRITISH COLUMBIA-S.E. ALASKA[10]	71	33	104
OREGON-WASHINGTON[8]	25	10	35
B.C.-ALASKA "INSIDE" WATERS[5]	100	0	100
WASHINGTON "INSIDE" WATERS[5]	15	0	15
PACIFIC, N.W.	1,158	791	1,949
W. BERING SEA-KAMCHATKA[6,8]	553	86	639
SEA OF OKHOTSK[6]	368	550	918
SEA OF JAPAN[6]	237	155	392
SUBTROPICAL PACIFIC, N.W.	979	137	1,116
YELLOW AND EAST CHINA SEAS[6]	979	137	1,116
SUBTROPICAL PACIFIC, N.E.	164	65	229
CALIFORNIA[8]	79	19	98
GULF OF CALIFORNIA[6]	72	31	103
HAWAII[8]	13	15	28
TROPICAL PACIFIC, EAST	95	15	110
COSTA RICA AND PANAMA[5]	25	10	35
COLUMBIA AND ECUADOR[5]	70	5	75
TROPICAL PACIFIC, WEST	2,909	606	3,515
N. PART SOUTH CHINA SEA[5]	500	100	600
SUNDA SHELF[5]	1,000	127	1,127
GULF OF THAILAND[5]	306	0	306
JAVA SEA[5]	300	67	367
SULU SEA[5]	100	8	108
FRENCH PACIFIC ISLANDS[6]	100	137	237
BRITISH PACIFIC ISLANDS[6]	58	58	116
N.E. AUSTRALIA AND NEW GUINEA[5]	545	109	654
PACIFIC, S. E.	100	24	124
S. CHILE[5]	100	24	124
PACIFIC, S. W.	308	1,245	1,553
NEW ZEALAND[6]	206	1,144	1,350
BASS STRAIT[5]	75	15	90
CHESTERFIELD ISLANDS	27	86	113
INDIAN OCEAN, S. TEMPERATE	739	341	1,080
MOZAMBIQUE[6]	137	34	171
AGULHAS BANK	110[4]	22	132
KERGUELEN ISLANDS[6]	52	275	327
S. COAST OF AUSTRALIA[5]	440	10	450
INDIAN OCEAN, TROPICAL EAST	1,840	331	2,171
ARAFURA SHELF AND GULF OF CARPENTARIA[5]	930	0	930
SAHUL AND ROWLEY SHELVES[6]	378	189	567
STRAIT OF MALACCA[5]	155	0	155
ANDAMAN SEA	205[5]	120[6]	325
BAY OF BENGAL	137[6]	17[5]	154

TABLE 16 (CONTINUED)

		SHELF[1]	UPPER SLOPE[2]	TOTAL
CEYLON[5]		35	5	40
INDIAN OCEAN, TROPICAL, WEST		1,006	457	1,463
FRENCH ISLANDS[6]		62	148	210
BRITISH ISLANDS[6]		165	69	234
E. ARABIAN SEA		343[6]	10[5]	353
PERSIAN GULF[6]		237	0	237
RED SEA		189	196	385
TANZANIA		10[5]	34[6]	44
ANTARCTICA[6]		0	3,434	3,434
ARCTIC AND ANTARCTIC		4,990	5,934	10,924
TEMPERATE:	NORTH	6,126	2,533	8,659
	SOUTH	2,229	2,098	4,327
SUBTROPICAL:	NORTH	2,656	1,062	3,718
	SOUTH	583	319	902
TROPICAL		7,262	1,667	8,929
		23,846	13,613	37,459
	PERCENT	63.7	36.3	

[1] USUALLY TO 100 FMS OR 200 METERS.

[2] USUALLY TO 500 FMS OR 1000 M.

[3] EXCLUDING BARENTS SEA, AND SPITZBERGEN, INCLUDING HUDSON AND BAFFIN BAYS, HESELTON (1969).

[4] LAEVASTU (1961).

[5] APPROXIMATION.

[6] HESELTON (1969).

[7] INCLUDES SOME UPPER SLOPE.

[8] COMM. ON MAR. SCI. (1969a).

[9] NAT. COUNCIL ON MARINE RESOURCES (1967).

[10] ALVERSON ET AL (1964).

The totals given in Table 16 are a little less than our summation of Heselton (1969) for km^2 10^6.

	0-200 m	200-1000 m	Total
Heselton (1969)	27.1	16.0	43.1
This report	23.8	10.2	34.0
	3.3	5.8[1]	9.1

[1] Omitting Antarctica

Part of this difference is the absence from our estimate of narrow bands of shoal water along many steep coasts, and the absence of accurate data for Antarctica (Heselton says that much of the area in Antarctica once believed land is actually shelf and that the shelf area may actually be nearly one million square miles).

It is impossible with present data to make a very precise estimate of shelf and slope areas, especially as the depths used by various authors are not the same.

Comparing by oceans (and author's boundaries differ) we seem to be short about the following amounts in km^2 10^3:

	0-200 m	200-1000 m
Indian Ocean	398	1042
Pacific Ocean	2588	3125
Atlantic Ocean	332	2030

The discrepancies in upper slope areas might be in reality of little consequence if we knew how much of Antarctic shelf was estimated to be included in each ocean.

The greatest discrepancy is in the Pacific where we were unable to obtain estimates of bank areas amid the thousands of island archipelagos. Fortunately, the areas underestimated lie chiefly in the tropical reef areas, not in the areas of higher yield.

In Table 17 we have classified the fishing banks of Table 16 according to our estimate of their relative potential yield of demersal fishes.

Table 17. Shelf areas according to relative productivity for demersal fishes. (km^2 10^3)

	Shelf	Upper slope	Total
Highly productive			
Northeast Atlantic (except Baltic)	2,017	761	2,778
Northwest Atlantic south to New England	1,287	347	1,634
Northeast Pacific	915	143	1,058
Northwest Pacific (except W. Bering Sea)	605	705	1,310
Subtropical Atlantic, N.W. (except Bahamas)	557	190	747
Sea of Azov	38	0	38
Subtropical Pacific, N.W. and south to Sunda Shelf	2,785	364	3,149
Bay of Bengal and Ceylon	172	22	194
Southern Chile	100	24	124
Moderately productive			
U.S. Mid and South Atlantic	271	491	762
Bay of Biscay and West Iberian	130	13	143
Black Sea	141	65	206
Tropical Atlantic, east	580	71	651
Tropical Atlantic, west	832	187	1,019
Subtropical Atlantic, S.E. and S.W.	583	319	902
Argentina-Falkland Island	1,030	345	1,375
Pacific, S.W. (except Chesterfield Is.)	281	1,159	1,440
W. Bering Sea-Kamchatka	553	86	639
Subtropical Pacific, N.E.	164	65	229
Tropical Pacific, E.	95	15	110
Mozambique and Agulhas Bank	247	56	303
N. and N.W. Australia and Strait of Malacca	1,463	189	1,652
E. Arabian Sea and Persian Gulf	580	10	590
Java and Sulu Seas	400	75	475
Productivity low			
Baltic Sea	478		478
Mediterranean Sea	515	567	1,082
Bahamas and Puerto Rico	132	25	157
Burwood Bank	35	40	75
N.E. Australia and New Guinea	545	109	654
French, British, Pacific Islands	158	195	353

Table 17 (continued)

	Shelf	Upper slope	Total
Andaman Sea	205	120	325
S. coast of Australia	440	10	450
Red Sea	189	196	385
Tanzania	10	34	44
French, British, Indian Ocean Islands	227	217	444
Productivity very low			
Hudson and Baffin Bays, Canadian Straits	1,010	150	1,160
South Georgia and South Orkneys	17	103	120
Chesterfield Islands	27	86	113
Kerguelen Islands	52	275	327
Productivity extremely low			
Arctic Sea (except Hudson Bay, etc.)	3,980	2,350	6,330
Antarctica	0	3,434	3,434

Summary of Productivity by Areas	Shelf	Upper slope	Total
High	8,476	2,556	11,032
Moderate	7,350	3,146	10,496
Low	2,929	1,505	4,434
Very low	1,106	614	1,720
Extremely low	3,980	5,784	9,764
	23,841	13,605	37,446

Utilizing the compilation of Table 17 we have constructed Table 18 to show the estimated total yields of demersal fishes. Note that the upper slope areas were estimated as 50 percent as productive as the continental shelf. The two depths were approximately equal in yield per km^2 in the northeast Pacific (Alverson et al, 1964) but a sizeable portion of our upper slope extends to as deep as 500 fms or 1000 m, whereas they only considered to 300 fms.

In the following list preceding Table 18 I have shown some estimates of catches in several areas used as a partial basis for estimating yields. In assigning yields I have, if anything, been optimistic.

Some further notion of the accuracy of our assignment of demersal production rates per square kilometer can be gotten by comparing our results for a couple of well fished areas with rather well defined boundaries, with those of other fishery workers.

Thus, for the New England banks our estimate of potential yield of demersal species for the 267 km^2 x 10^3 of shelf and 77 km^2 x 10^3 of slope is 917 x 10^3 metric tons compared to 910 x 10^3 tons by Edwards (1968).

For the northeast Pacific our figure is 2,960 x 10^3 metric tons compared with 1,113-2,269 metric tons (Alverson, 1968).

Catch of fishes in metric tons per km^2 per year.

Area	Period	Demersal	Pelagic	Total
Iceland Banks[1]	1956-58	3.250	0.594	3.844
Eastern Bering Sea[2]	up to 1960	2.018		
Barents Sea[1]	1956-58	1.760	0.089	1.849
Gulf of Maine[1]	1956-58	1.423	0.527	1.950
Grand Banks[1]	1956-58	1.323	0.022	1.345
Nova Scotia Banks[1]	1956-58	1.211	0.314	1.525
North Sea[1]	1956-58	1.121	1.861	2.982
Middle Atlantic Shelf[1]	1956-58	0.863	6.075	6.938
Oregon-Washington[2]	1956-60	0.504		
Baltic[1]	1956-58	0.460	0.392	0.852
British Columbia-S.E. Alaska[2]	1956-60	0.336		
Adriatic[1]	1947-53	0.280	0.235	0.515
Northeast Pacific[3]	1968	2.399		
North Sea[4]	1965			4.887
Samoa[5]	1967		0.002	
Gulf of Mexico, Mobile to Port Arthur			5.830	
Peru-Chile-Ecuador upwelling area 1968[6]				11.895

[1] Graham and Edwards, (1962), bony fishes only.

[2] Alverson et al (1964).

[3] Oregon to Bering Sea, 1,058,000 km^2, includes non-bony fishes and invertebrates.

[4] Holden (1967).

[5] Chapman (1969), tuna fishery.

[6] 1,004,000 km^2, (Cushing, 1969).

Table 18. Estimate of potential demersal fish production.

Metric tons per km^2	Shelf km^2 10^3	Upper slope km^2 10^3	Fish Metric tons 10^3	Productivity
3	8,476		25,428	High
1.5		2,556	3,834	High
2	7,350		14,700	Moderate
1		3,146	3,146	Moderate
1	2,934		2,934	Low
0.5		1,513	756	Low
0.1	1,106		111	Very Low
0.05		614	31	Very Low
0.01	3,980		40	Extremely Low
0.005		5,784	29	Extremely Low

Areas underestimated in Table 17

Metric tons per km^2	Shelf km^2 10^3	Upper slope km^2 10^3	Fish Metric tons 10^3	Productivity
Indian Ocean				
2	398		796	Moderate
1		1,042	1,042	Moderate
Pacific Ocean				
1	2,588		2,588	Low
0.5		3,125	1,562	Low
Atlantic Ocean				
1	332		332	Low
0.5		2,030	1,015	Low
			58,344	

To make a total estimate we must add to the demersal fish catch of 58 million tons, all of the pelagic species, as well as the bivalve mollusks, gastropods, and crabs.

The neritic pelagic species from the upwelling areas in 1968 were 96 percent clupeoids, in fact about 78 percent consisted of Peruvian anchovy, Engraulis ringens. If the 15 percent decrease in the catch of Peruvian anchovy for 1969 reported in preliminary FAO statistics is correct (Beaufort, 1970), the total yield from neritic pelagic species may have reached its zenith. Inasmuch as the 1968 catch in this category was only 14,380 x 10^3 metric tons, we would place the ultimate potential sustainable yield from this source at a maximum of 15,000 x 10^3 metric tons.

The potential neritic pelagic catch from non-upwelling areas is more difficult to estimate. In 1968 it was 12,670 x 10^3 metric tons of which only 62 percent consisted of clupeoid fishes. The Norwegian 1968 catch of 2,804 x 10^3 metric tons was down to 2,200 x 10^3 in 1969 owing to a drop in Atlantic herring which they were unable to replace by herring fishing efforts off New England and Nova Scotia.

There are a few as yet untapped sources of clupeoid fishes, such as the great schools of thread herring, Opisthonema, off the west coast of Florida. However, how these will withstand intensive fishing is pure speculation.

Possibly the catch of pelagic cephalopods (squids and cuttlefishes) will increase as they are not consumed extensively in many countries, although highly esteemed in others. Since the 1968 cephalopod catch was but 1,085 x 10^3 metric tons it will take a large increase indeed to make much of a showing.

Weighing all of these factors it would seem that a potential maximum of 15,000 x 10^3 metric tons of neritic pelagic species from the non-upwelling areas is a reasonable estimate.

The oceanic pelagic fishes consist primarily of the tunas and billfishes and the salmons, which, although anadromous, make most of their growth on the oceanic feeding grounds. The 1968 tuna (and billfish) catch was only 847 x 10^3 metric tons despite worldwide fishing by well-equipped fleets. In all oceans the catching rate of tunas is falling. Only the skipjack, Katsuwonus pelamis, holds any promise of more yield. The salmon catch in 1968 of 423 x 10^3 metric tons may perhaps be eventually increased because of very intensive management of the nursery areas although this may be negated by uncontrolled high seas fishing, such as that conducted by Denmark on the small remaining stocks of Atlantic salmon. We would consider 2,000 x 10^3 an optimistic estimate for this category.

The 1968 yield of oysters and other bivalves was 1,711 x 10^3 metric tons. Considering, only the type of bivalve culture employed in the recent past it is difficult to see much increase.

The output of bivalves has increased only 42 percent in the past 10 years despite great efforts. The natural beds are depleted and attempts at cultivation are nullified by increasing estuarine pollution. Extensive use of mussels could help the picture, but in many areas the danger of paralytic shellfish poisoning from ingestion by mussels of toxic plankton organisms, especially dinoflagellates, has militated against their use. We estimate 2,000 x 10^3 metric tons as a reasonable estimate.

Although the 1968 yield of crabs was but 316 x 10^3 metric tons we believe this will continue to rise. The handling and processing of fresh crab meat has been greatly improved so that crab fishing will be expanded to more coastal areas. The deep water crabs, such as the Tanner crab, will augment production. We believe 1 million metric tons to be not unduly optimistic.

Our total estimate of potential world fish production by empirical summation is as follows:

Estimate of potential marine fishery yield
(metric tons 10^3)

Demersal fishes	58,344
Neritic pelagic fishes, upwelling areas	15,000
Neritic pelagic fishes, other areas	15,000
Oceanic feeding (salmons, tunas)	2,000
Bivalves (natural beds)	2,000
Crabs, etc.	1,000
	93,344

It is highly improbable that this suggested potential world yield will be attained for a long time, if ever. The reasons are rather obvious. Species after species has been depleted to scarcely profitable levels, while new species and new areas have been exploited. However, the world is fast shrinking -- new areas and new species are becoming scarce.

A few examples -- the ocean perch, _Sebastes marinus_ (Figure 3) was scarcely used until filleting commenced in the late 1930's. The New England banks' yield fell from over 100 million pounds in 1941 and 1942 to 5 million by 1965. The Nova Scotia banks were next, the ocean perch landings of over 100 million pounds in 1948, 1949, and 1951 fell to 12 million by 1965. Yields in the Gulf of St. Lawrence fell from over 50 million pounds in 1953, 1954, and 1955 to 6 million in 1965. Thus have we managed many of our marine species.

Similar stories can be told for haddock and pollock (Figure 4), and whiting. (Figure 5). In the fertile upwelling area of the California current the story has been more drastic. The sardine, once producing a billion pounds a year (Figure 4) is commercially extinct. The mackerel, likewise, has fallen tremendously in abundance (Figure 5).

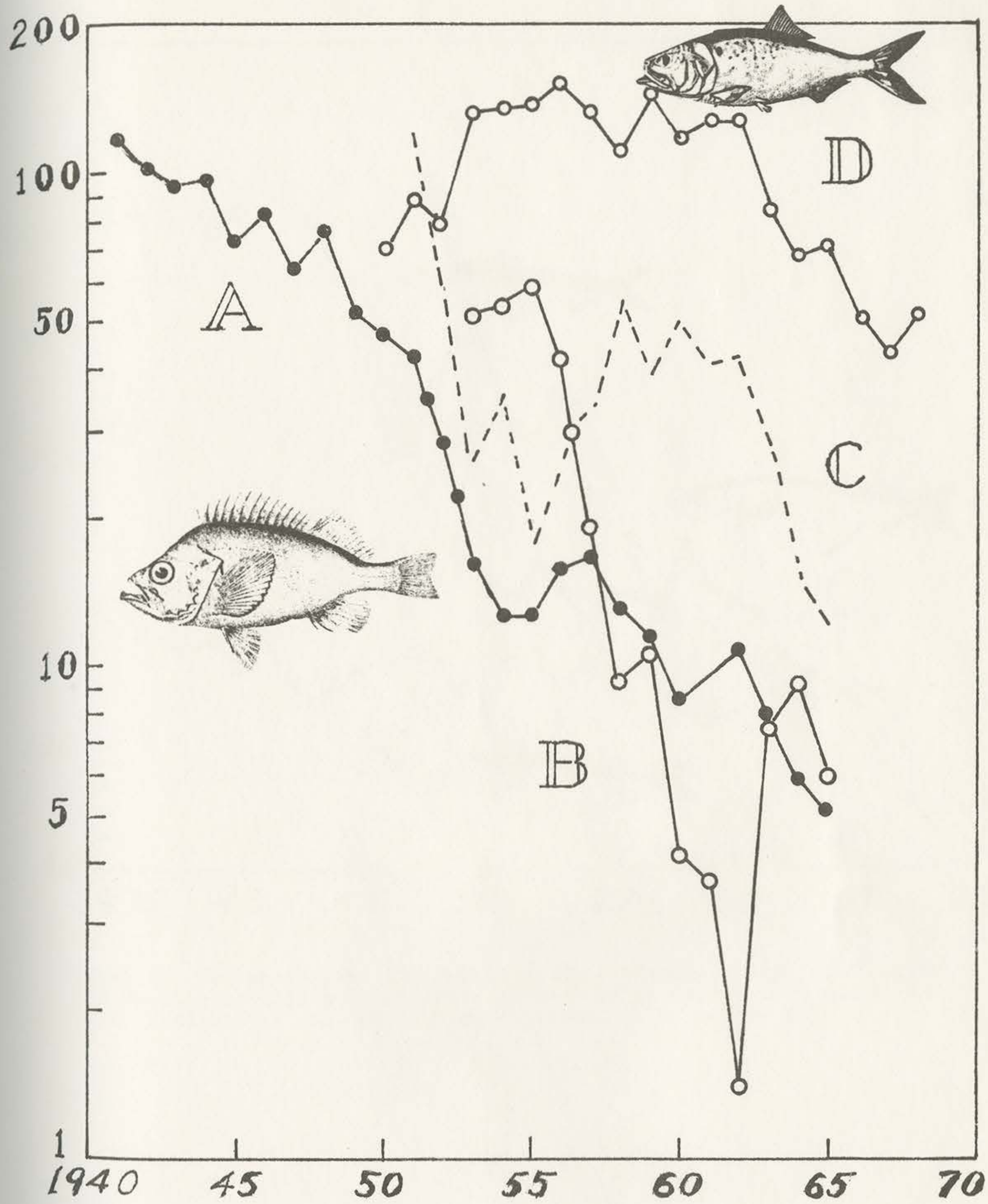

FIGURE 3. U. S. landings in millions of pounds of ocean perch from New England banks (A); from Grand Banks and the Gulf of St. Lawrence (B); from Nova Scotia banks (C); and landings of Atlantic coast menhaden (D).

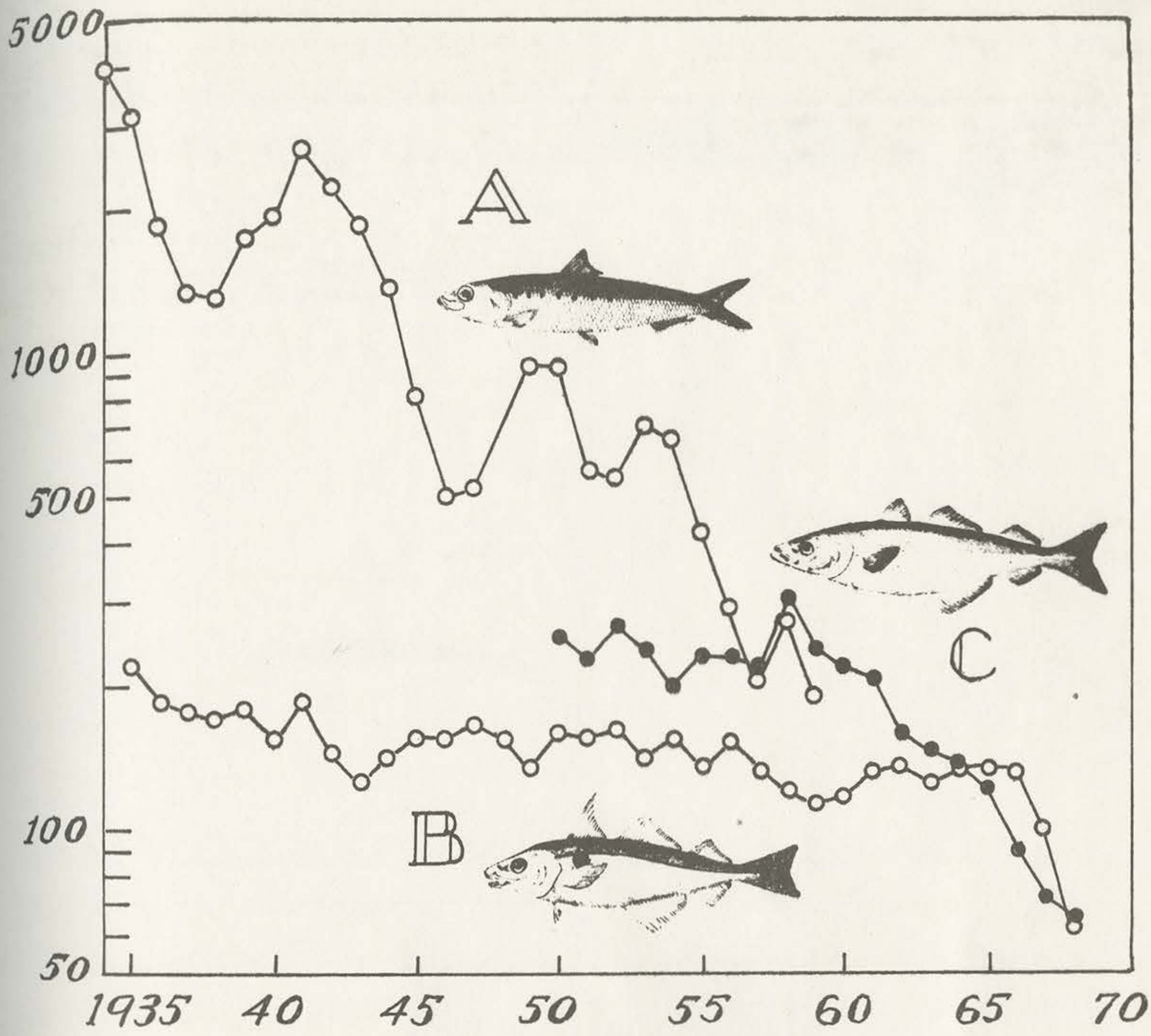

FIGURE 4. Biomass of the California sardine (Murphy, 1966) in thousands of short tons (A); U.S. landings of haddock in millions of pounds (B); U.S. landings of pollock in hundred thousands of pounds (C).

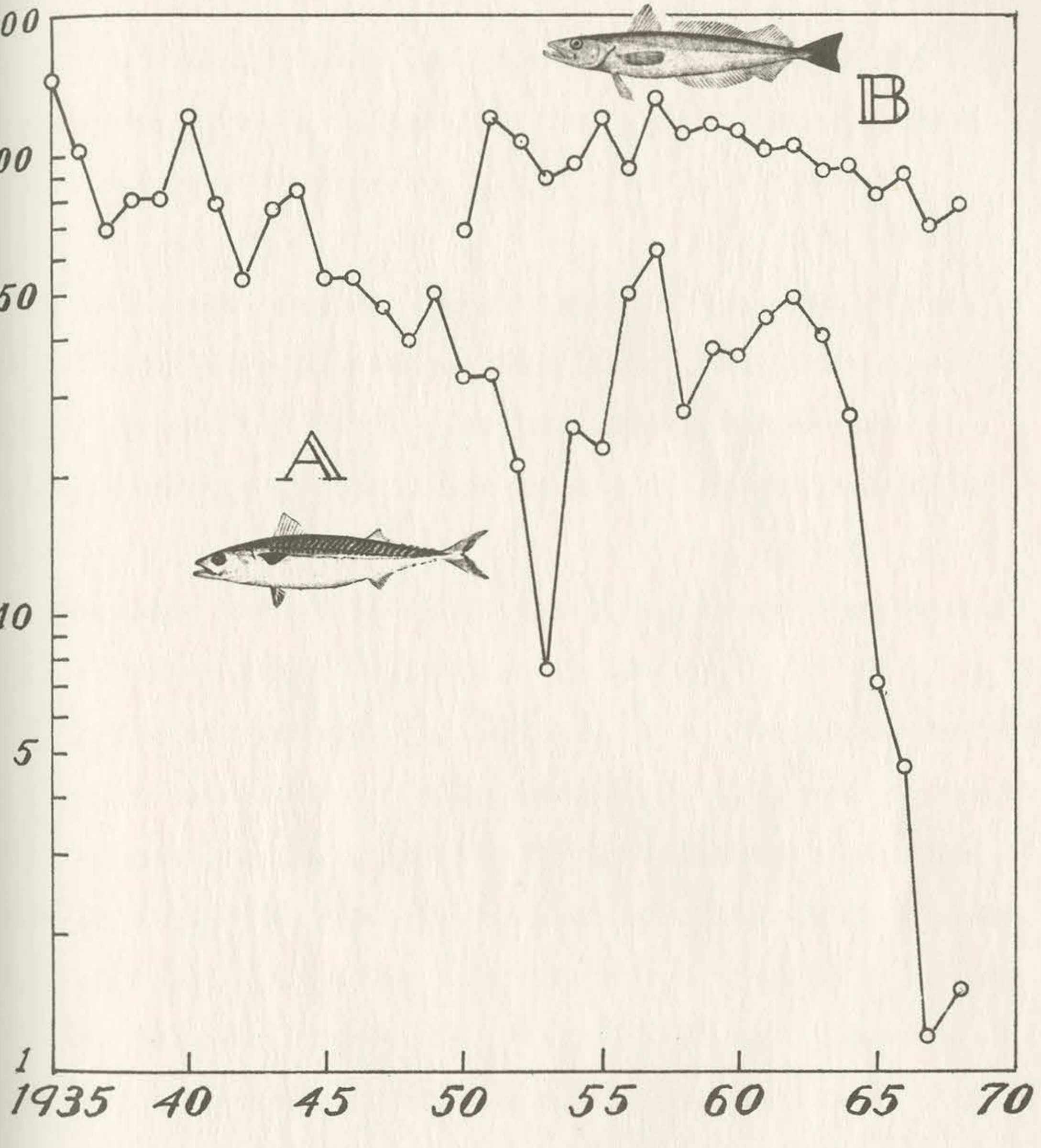

FIGURE 5. U. S. landings in millions of pounds of Pacific mackerel (A) and of whiting (B).

The Atlantic menhaden, considered by many early biologists to be inexhaustible has fallen in abundance since the very intense fishing of the late fifties (Fig. 3).

In Alaska (Fig. 6) the salmon landings fell from over 500 million pounds to 200 million, but have shown signs of some recovery. The herring fisheries have fallen from over 200 million pounds to about 20 million pounds.

Why has the world catch continued to rise while the Unites States catch is falling slightly?

There are several factors. Some of the underdeveloped countries have only recently commenced using enough modern fishing gear to fully exploit their fisheries. A good example is the meteoric rise of the Peruvian fishery for anchovies (Fig. 8) which is presently the world's largest fishery from the standpoint of sheer volume. Even this fishery is obviously near or at peak production.

Several nations have built large fleets of high seas fishing vessels, some accompanied by floating factory ships. These scour the seas of the world gradually bringing all formerly latent fishery resources into use.

Inevitably, in this process, some of the less resilient species must suffer a severe decline.

The decline in United States fisheries over the past thirty years has resulted in inability to supply the demands of an expanding population. We now import about two-thirds of all our fishery products.

In the face of falling abundance of practically all of the historically fished species we have bolstered our output by fishing new species and by fishing species inhabiting the deeper waters at the edge of the continental shelf and on the upper continental slope. Thus we developed fisheries for king crab in Alaska and surf clams off the Atlantic coast (Fig. 7). These appear to have reached or passed their peak. Other developing U. S. fisheries include calico scallops off eastern Florida, shrimp in Alaska, Pacific hake, and saury. The large populations of thread herring (Opisthonema) off western Florida await exploitation but this is hampered by restrictive local regulations.

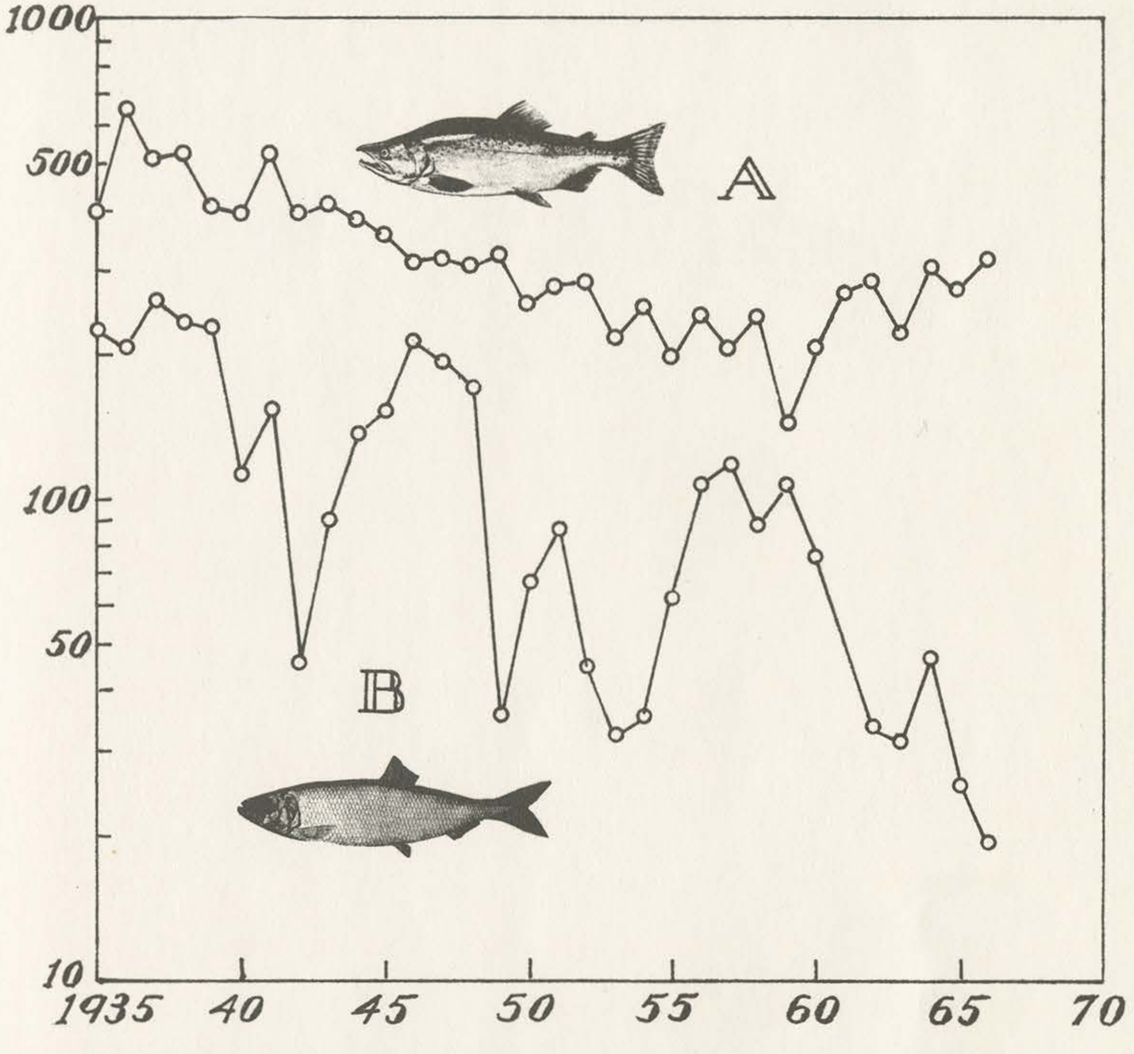

FIGURE 6. U. S. landings in millions of pounds of Alaska salmons (A) and of Alaska herring (B).

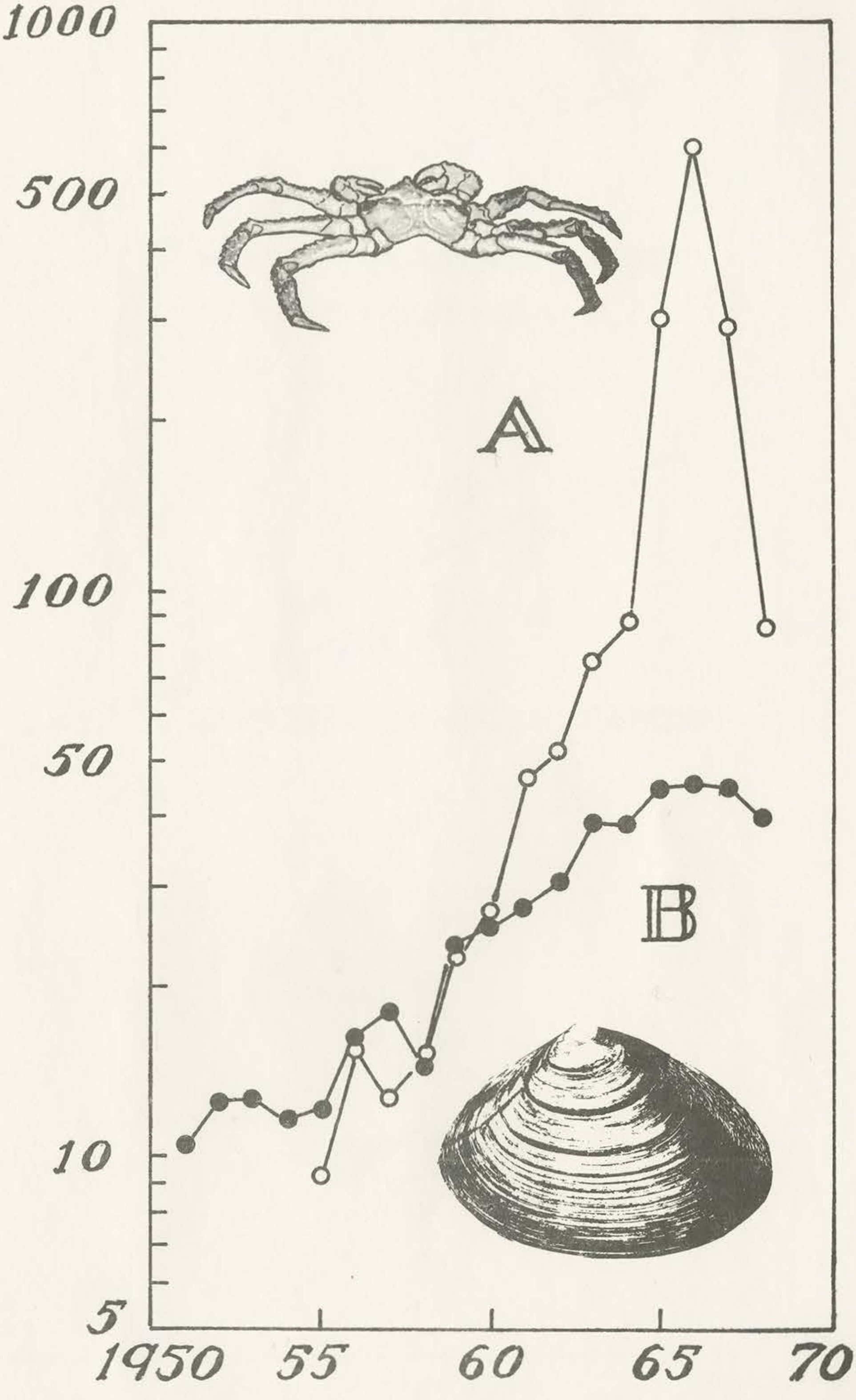

FIGURE 7. U. S. landings in millions of pounds of Alaska king crab (A) and of Atlantic coast surf clams (B).

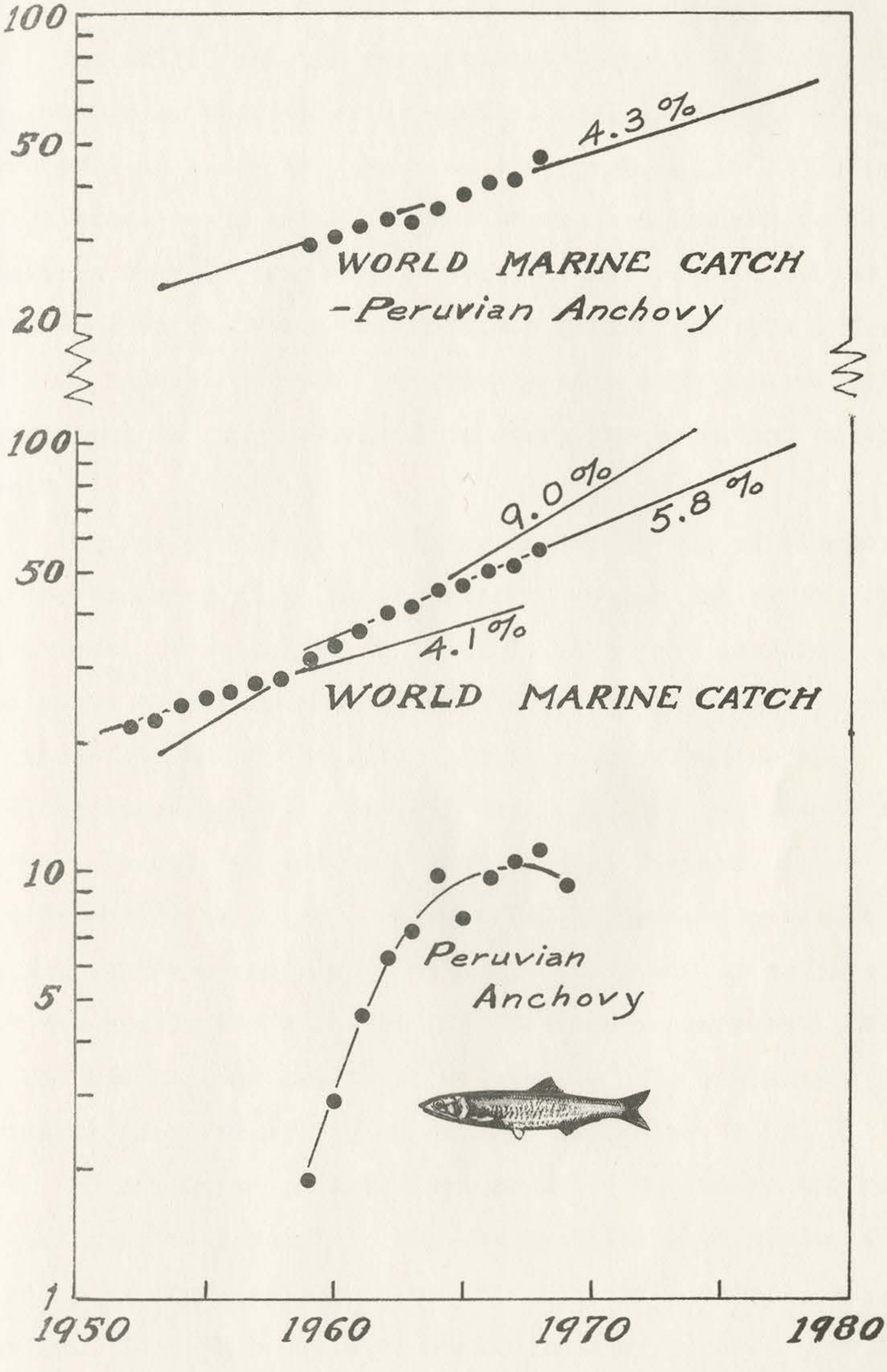

FIGURE 8. World marine fishery catch in millions of metric tons showing rates of increase with and without Peruvian anchovies.

The shift from the more accessible species to the less accessible as species after species fell in abundance is portrayed in Table 19. Forty-one percent of the 147 principal species taken in the United States had maximum 3-year landings over 30 years ago. Seventy-five percent of the species from the first four habitat categories fell after the two initial periods. Obviously with such poor management practices, we can never hope to reach the potential sustainable yield.

Another problem in reaching higher levels of production is the waste of fish due to pampered eating habits in some countries. To illustrate, Table 20 shows the landings in the northwest Atlantic (New England to Greenland) and in the northeast Atlantic (Spain to Russia, except Baltic and Mediterranean Seas). You will note that 3.7 percent of the European landings consisted of fishes we largely waste. During World War II when food was at a premium we smoked anglerfish from the Boston trawlers and found it excellent, yet the public won't accept it. Delicious sea mussels abound on the New England coast but go unused. The few sharks actually used are apt to be sold as swordfish.

The intensive advertising campaigns to induce the public to eat more fish usually tout the excellence of products already in short supply -- haddock, halibut, salmon, whitefish, shrimp. This is a waste of public funds.

Table 19. Number of the principal species of fish and invertebrates according to periods in which their maximum United States landings occurred, listed by their habitat.[1]

Habitat	Three-year periods[2]							Total
Category	1929-31	1938-40	1952-54	1955-57	1958-60	1961-63	1964-66	Species
Catadromous	1	0	0	0	0	0	0	1
Anadromous	9	4	1	0	2	1	0	17
Estuarine benthic	4	1	0	2	0	1	0	8
Shore and estuarine	5	0	0	0	0	1	0	6
Quasi-catadromous[3]	3	2½	5	3	0	2	2½	18
Benthic	11	7	8	7	6	4	18	61
Coastal pelagic	5	4	1	1	2	1	6	20
Oceanic pelagic	2	2	2	1	1	5	3	16
	40	20½	17	14	11	15	29½	147

---

[1] In a few cases two or more species have not been separated in the statistics and have had to be grouped as one, e.g. the alewife, <u>Alosa pseudoharengus</u>, and the blueback, <u>A. aestivalis</u>.

[2] The two earlier periods had to be chosen to include years in which complete canvasses of the fisheries were made.

[3] Species spawning in high salinity offshore waters whose young are nurtured in the estuaries.

Table 20. Utilization of less desirable species, 1968 catch.[1]

(Metric tons 10^3)

Less desirable species	N.W. Atlantic	N.E. Atlantic
Anglerfishes	0.0	40.0
Gurnards, sea robins	0.0	12.4
Picked dogfish	0.0	27.0
Sharks	0.9	30.7
Rays and skates	0.9	52.6
Winkles	0.1	4.2
Conchs	1.0	2.4
Mussels	2.7	243.3
Squids	1.7	20.8
Octopus	0.0	5.2
	7.3	438.6
All species	3231	11866
Percent of less desirable species	0.2	3.7

---

[1] Species common to both sides of Atlantic, Mediterranean excluded, except the capelin and sand eels which are taken wholly for reduction.

THE EMPIRICAL APPROACH BY EXTRAPOLATION

A third approach is through extrapolation of existing catch statistics. In Figure 8 the world marine catch is plotted from 1952 through 1968. There are three distinct rates of increase; from 1952 through 1958 at slightly over 4 percent per year, from 1959 through 1962 at about 9 percent per year, and from 1963 through 1968 at about 5.8 percent per year.

These changes in rate were engendered chiefly by the rise of the great fishery for the Peruvian anchovy. At the top of Figure 8 is shown the world marine yield over the 10-year period from 1959 through 1968 excluding the Peruvian anchovy. This 10-year rate is 4.3 percent. Since the Peruvian anchovy fishery is at its zenith it would appear that the 4.3 rate of increase for the remainder of the marine catch is a reasonable assumption.

Schaefer (1965) gives the rate of increase in the total world marine catch from 1957 through 1962 as 8 percent. Actually 1958 is the year in which the abrupt change occurred from 4.1 percent to 9 percent coinciding with the rise of the Peruvian fishery.

If we assume that the catch (excluding the Peruvian anchovy) will increase by 4.3 percent per year we should reach the theoretical total limit of 94 x 10^6 metric tons by 1982. Is this a valid assumption? Any extrapolation of the world catch must include one or more of three ASSUMPTIONS:

1. The seas have a certain productivity level that can be attained and this will be attained regardless of man's effect on the abundance of particular species. This logically means that the decimation of one species merely results in its replacement by another.

2. Any decline in particular species can always be more than offset by searching out and exploiting hitherto underfished species.

3. New fishing grounds exist that are practically untouched by fishing so that expansion can continue for a very long time.

Apparently there are those who must believe in the validity of these assumptions. Thus Pariser (1969) cites 2 authors who place the worlds sustainable fishery harvest at 500 x 10^3 (sic) metric tons and 2 who place it at 2,000 x 10^3 (sic) metric tons. Obviously, he means 10^6 not 10^3 as he makes the same error for several authors with lesser totals. It may be worthy of note that at the rate of 4.3 percent increase per year the 500 x 10^6 metric tons could be achieved in 56 years and the 2,000 x 10^6 in 912 years!

Pariser (1969) assumes that U. S. continental shelves can produce 5,490,000 metric tons per year of fish from stocks now unutilized or underutilized. If this is true it would triple the present U. S. catch which has declined over a 30-year period. In making my optimistic suggestion for a sustainable world catch by empirical summation I already allowed 3 metric tons of demersal fishes per km^2 for the continental shelf he has mentioned and 1.5 metric tons of demersal fishes for the upper slope of the selfsame areas. Despite these very optimistic yields I failed to obtain a world figure higher than 93 x 10^6 metric tons, far short of the wild estimates that Pariser has cited.

Let us examine closely the three assumptions we mentioned above.

Assumption 1: In certain instances other species do tend to fill the vacuum created by the decimation of a formerly abundant species. Thus Murphy (1966) shows that the anchovy is increasing in abundance in the California upwelling areas once dominated by the Pacific sardine. On southwestern Georges Bank the haddock, abundant in the late 1920's, declined drastically but was replaced by the yellow-tail flounder. When the flounder was fished out it was replaced by red hake. In both cases the resulting product was inferior. Whether or not these changes are reversible is yet to be demonstrated.

In many other instances there is no ready replacement. The anadromous species and those dependent on the estuaries are not readily replaceable. Each species is the product of long periods of evolution. When a species is gone how do you replace it? Perhaps the practical demise of the great Antarctic whale herds is convincing enough.

Assumption 2: This assumption, the continuous availability of new species to exploit, is fast running out. During the years of expansion of the Pacific halibut fishery the vessels first overfished the Washington and Oregon Banks, then moved in succession to Hecate Strait, Dixon Entrance, Cape Spencer, Yakutat, Cook Inlet, Portlock Bank, Trinity Bank, the Shumagin Islands, and finally the Bering Sea. When they were finished the stocks were depleted over the whole range of the fishery. The ability to shift ever farther westward sprang from the building of larger vessels, the change from dory to longline fishing, the change from gasoline to diesel engines, and the development of efficient hauling gurdies. Now with more efficient navigational instruments, the development of better winches, fish searching equipment and so forth, we are fishing deeper waters on the upper slope below the edge of the continental shelf, but these areas are smaller, less productive, and more expensive to fish.

Assumption 3: This assumption that expansion can continue indefinitely through exploitation of new fishing grounds has several facets. First, we must ask why these hypothetical rich fishing grounds remain unexploited. Are they too distant from ports of landing? Are they too difficult to fish because of ice, stormy weather, or rough bottom? If such grounds exist, can their exploitation cause the world catch to rise while the already exploited banks are yielding smaller and smaller returns in the face of heavier fishing pressure? Will not the exploitation of new grounds, if many exist, merely end in final decimation of the fish stocks on all banks -- a repetition of the history of the halibut fishery?

In the case of one of the world's great fisheries, the cod fishery, for instance, Idler and Jangaard (1969) state,

> "In Table 6 the world catch of Atlantic cod is listed by countries; it is evident that the quantity caught increased dramatically from 1948-1956, which was the peak year. Since then the quantity has fluctuated from 2,560 to 3,010 thousand metric tons per year in spite of greatly increased fishing effort. Several fishing areas are now producing only a fraction of the quantity caught only 10-15 years ago; it is estimated, for instance, that the cod population of the Barents Sea is only about 10% of what it used to be. The other chief fishing areas have as yet not reached this point, but increased fishing pressure on the stocks are showing in smaller average size of the fish and the increased effort needed to catch the same amount of fish."

There is thus no obvious reason why fishery landings should continue to increase at any particular rate. The landings have not kept pace with the great increase in fishing effort. Furthermore, the FAO statistics are singularily unconvincing. Figures for many countries, e.g. mainland China, North Korea, and North Vietnam, are not current and we do not know by how much their last available figures were wishful thinking. The statistics for many other countries are merely rough estimates which FAO admits were at least ten percent estimates. Furthermore, there is little doubt in the mind of anyone well acquainted with the difficulties of acquiring accurate fishery statistics that a good fraction of the increase in total landings over the past decade is an artifact.

As the collection of statistics has improved the percentage of the landings actually recorded has risen.

The desperate need for more animal protein from the sea in countries with extremely limited arable land is well exemplified by Japan. Despite their huge worldflung fishing fleets they are unable to increase their catches except by increasing their fishing effort to unprofitable levels. They have recently been experimenting with trying to catch in quantity the small shrimplike euphausids, which formed the staple food, the "krill", of the once mighty Antarctic baleen whale herds (Anonymous, 1970b). The problems are tremendous, including a month each way for vessels. So far, experiments to strain these small organisms from the water with fine-meshed nets, necessarily towed at slow speeds, have not been successful.

SUMMARY

The serious estimates of marine fish harvest can be classified as theoretical or empirical. Some of these estimates have stressed the bank areas of the oceans with little regard for upwelling zones while others have done the opposite. A comparison between the 1968 catch and the various estimates is contained in Table 21.

Table 21. Comparison of certain estimates of potential marine landings.

(Metric Tons 10^6)

	Shelf and non-upwelling			Upwelling	Oceanic	Total
	Demersal	Pelagic	Both	Pelagic	Pelagic	
Theoretical estimates						
Graham and Edwards (1962)						115 bony fishes
Graham and Edwards (1962)						171 all forms
Schaefer (1965)						200
Ryther (1969)			50.0	50.0	0.1	100
Cushing (1969)			?	40-60	3.5	43-65
This report			47.0	46.5	0.5	94
Empirical estimates						
Graham and Edwards (1962)			55.0		5.0	60
This report	(61.3)	(15.0)	76.3	15.0	2.0	93.3
1968 World landings						
FAO (1969)	(27.2)	(13.1)	40.3	14.4	1.5	56.2
Percentage of total						
1968 World landings	(48.4)	(23.3)	71.7	25.6	2.7	100.0
This report (empirical)	(58.3)	(15.0)	81.8	16.1	2.1	100.0

Examination of the table shows at once that the theoretical estimates based on primary productivity give undue weight to the yield of upwelling areas. It appears that any long continued increase in landings will have to depend on increased catches on the continental shelf and upper slope.

Whether the future marine catch rises, remains static, or falls, depends chiefly upon both national and international observance of sound conservation measures. At the present moment there is little reason for optimism.

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FISH AND INVERTEBRATE CULTURE. *By Stephen H. Spotte.*
Wiley-Interscience, xiv + 145. 1970. $8.95.

This book is of value to those desiring to maintain closed aquarium systems for fresh, brackish, or marine organisms. Such closed systems lend themselves to experiments in which the investigator wishes to maintain fairly rigid control of the environment. Closed systems are also of value where limited quantities of water are needed for rearing critical stages of marine forms.

The discussion of biological, mechanical, and chemical filtration, including resin filters, foam fractionation, and use of ozone and ultraviolet radiation is well written but hardly encouraging to anyone needing large quantities of water. It should be noted here that these difficulties are all magnified in dealing with salt water.

The author does not explain how he achieves controlled temperatures and there is no description of pumps. It seems strange that his references include neither the 590-page compendium "Culture methods for invertebrate animals" by over 180 authors nor the reports of Victor Loosanoff on tidal aquaria, and on facilities for out-of-season spawning.

Only once does he mention adding new water to the system by the bold statement "... the standard 10 per cent change routinely provided for each culture system biweekly." This statement (p.112) seems oddly at variance with the great precautions he elaborates on for maintaining the quality of the water. Thus, a 60,000-gallon system at the Galveston Laboratory of the National Marine Fisheries Service has been in constant use for over 10 years, with much lower additions of new water.

On p. 98 he states "Brass meters are preferable, since they are corrosion resistant. The minute amount of copper that may leach from a brass meter is insignificant from a toxicity standpoint. Besides, the tap water used to hydrate the mix will have passed through many feet of copper pipe before it reaches the vat. All-brass, plastic, or stainless steel pumps are recommended for pumping brine or sea water." As long ago as 1937, it was stated by Paul S. Galtsoff (In Culture methods for invertebrate animals, Comstock Publ. Co.) that "... ordinary cast iron pumps are preferable to bronze ones. There is but little oxidation of iron when the pump is in operation and consequently water delivered to the laboratory is not toxic. Furthermore, water supplied under similar conditions by bronze pumps proves to be much more harmful to a number of marine forms, such as lamellibranch larvae, that are very sensitive to minute amounts of copper."

In summary, the book should be very useful to anyone desiring to maintain fresh water aquaria or sea water aquaria of small size where either natural sea water is unavailable, or it is desired to use water of known original composition for experimental purposes. For large marine aquaria, or for large mariculture projects the book is not too helpful.

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