THE RATIONAL EXPLOITATION OF THE SEA FISHERIES with Particular Reference to the Fish Stock of the North Sea

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No. 13

THE RATIONAL EXPLOITATION OF THE SEA FISHERIES WITH PARTICULAR REFERENCE TO THE FISH STOCK OF THE NORTH SEA

By

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Explanatory Note

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EDITOR'S PREFACE

This paper is a comprehensive analysis of the vast amount of research work which has been done on the most seriously exploited fishery in the world. This fishery is one which may serve as an example of what to expect in the fisheries on our own coast where similar species are being increasingly sought.

The original language of this paper was Dutch, thus very few workers could read it easily. Therefore, the Fish and Wildlife Service arranged for Mr. Jan Hahn of Woods Hole, Massachusetts to make this translation. Because of the length of the text certain liberties have been taken in order to reduce the bulk. Some seemingly unimportant passages have been omitted and some of the tables have been rearranged.

It has not been possible to submit a translation to Dr. Baerends for approval. He possibly will take exception to some of this translation, due to inherent difficulties in translating Dutch into English equivalents or to actual errors and omissions.

All figures shown are photographs of the original illustrations on which English translations of the more difficult Dutch legends have been added.

The original work which Dr. Baerends has drawn on for his analysis all antedates World War II. Since then there have been marked advances in the methods for mathematical treatment of fishery population data. The Fish and Wildlife Service in distributing this translation does so as an accommodation to fishery biologists, but does not necessarily agree with all of the treatments or the conclusion reached.

August 31, 1949 Howard A. Schuck

INTRODUCTION

The North Sea fishery showed a strong decline during the period 1930-39. It is accepted generally that one of the main reasons for this decline was the diminishing of the fish stocks as the result of too intensive fishing. International conservation measures had been tried several times to stop the diminishing of the stock. However, satisfactory working agreements have not been accomplished.

Although the stock gradually diminished during the last years before World War I, it regained strength during the war. One might have expected, therefore, that during World War II the stock would again reestablish itself. If, soon after the ending of hostilities, an international treaty for the conservation of the fish stock could be made, a new decline of the stock might be prevented.

When during the war years I received the order to investigate the means by which a new decline might be prevented in the North Sea, I meant to look upon the problem from an entirely new point of view, without necessarily continuing those formerly used.

In view of the facts brought to light during the years by fishery investigations, I have tried to see if and how the fish stock can be influenced by fishing, and consequently how fishing should be carried out to get as large returns as possible from the fish stock. These principal questions are dealt with in Part A of this report.

From the definitions propounded in Part A, I have studied in Part B the question as to whether or not the fishing has actually been too extensive in the North Sea and if it has led to a decline of the productive power of the fish stock. As this has proved to be the case, I have, after dealing with the different possibilities for conservation, developed a plan for the regulation of the North Sea fishery.

This paper consists of a study and analysis of available literature rather than a report of an original investigation.

A. THE PRINCIPLE OF A RATIONAL EXPLOITATION OF THE SEA

Before we can start to work out methods for overfishing we have to see what is meant by overfishing, if it is possible, and if danger threatens for the North Sea.

First of all, we will have to answer the question: is man actually capable of influencing the production of a sea; in other words, can he harm the productive power of the sea? Obviously, many will not believe immediately that this is possible. To the casual observer the immense waters, 2-1/2 times as large as all land on earth, appear as a homogenous, continuous water mass.

Some interested people in the fisheries are only too ready to accept the idea that the intense catching of fish from a certain limited area would have no more effect than the taking of many pails of water from the ocean. They think that the fish are spread equally over the sea and therefore those that are caught will be replenished from the immense oceans.

This idea is absolutely wrong. As on the land, there are many obstacles in the sea, generally of a hydrographic nature, which block the free distribution of fish. For instance, in general, the different fish species are related to water masses in which the temperature and salinity remain within specific limits, and many species, especially those which remain near the bottom, cannot occur in those areas where the depths are greater than certain values, or where the character of the bottom has changed. The right living conditions for a species may appear in different places but often these places are divided from each other by uninhabitable areas for that species. If this is the case, then the individuals which inhabit one area will have no contact with their like species in another area. They will form isolated populations which will have to reproduce by their own egg production and will not be reinforced from other populations.

Such isolated populations can be recognized in several ways. Usually, small differences such as the number of vertebrae, the number of fin rays, the shape of the head, etc. are sufficient to designate these populations as different races. A second possibility for differentiation is given by the strength of the year classes, i.e., the number of fish which yearly develop successfully from the roe. The reasons for fluctuations of year-class strength are not yet sufficiently well known. One assumption is that generally they are not brought about by great fluctuations in the egg production, but by fluctuations in the mortality among the hatched-fish larvae. This is probably the result of hydrographic variations, which may form a situation where one year the larvae would, and in another year would not be transported to a section in the living area where sufficient nutrients may be found. Since it is entirely possible that during the same year the hydrographic condition would be good for one living area but bad for another, the picture of the annual fluctuations in the mortality of the year classes often will be different for one population than for another isolated group. Finally, by studying the migrations of tagged fish, one can determine if certain boundaries are not being passed.

The North Sea from Dover Straits to 61° North Latitude and the Skagerak is such a limited area for the plaice, sole, haddock, cod and other economically less-important, bottom-fish species contained in those waters.

The Icelandic Waters and the Northeast Atlantic area of the Norwegian Coast, the Barents Sea, Bear Island and Spitsbergen must also be considered as areas with self-sustaining fish populations.

All additions to the fish stocks must come from roe spawned by the adult females of the populations, and the fish are exclusively dependent on the food present in their living area.

Although we have seen that the size of a fish stock is limited, we still do not have to believe that the fishery can influence the production rate, when it cannot be shown that the percentage of the fish stock which falls into the hands of the fishery is of considerable size compared to the percentage which dies a natural death. Therefore, we have to know which part of a year class dies annually by fishing and which part dies from natural causes. The mortality through fishing starts only after the fish have reached a size whereby it is no longer possible for them to escape through the meshes of the nets. By checking the strength of a year class in the catches from year to year with the aid of age observations, one can find out by what percentage the year class declines annually on the average, as a result of fishing and natural causes together. For the plaice, for instance, this was 56 percent during the period 1925-30 (Thursby-Pelham, 1939).

From the percentage of tagged fish recaught one can establish the mortality caused by fishing. For the plaice this was 45 percent during the period 1929-32 (Hickling, 1937). The natural mortality among this catchable-sized plaice was therefore 56% - 45% = 11% a year. Since many tags were not returned because they are lost by the fish, or because they are not noticed by the fishermen, this percentage will in reality be lower. Indeed, one may say that the mortality through fishing is about 4 times larger than the natural mortality; for the other economically-important fish species one will find ratios of a similar order. The fishing, therefore, must be of very great influence on the fish stock.

The size of a fish stock can be represented by its total weight. The total weight of a fishstock will increase by the addition of the young fish developed annually from the eggs, and by the growth of the various individuals. The fish stock will decrease through mortality caused by natural factors or by fishing. If we represent the annual increase of the number of individuals as a result of egg development as A, the increase by growth as G, the natural mortality as M, and the mortality as a result of fishing as V, then the size of the fish stock at the end of a year (S^1) compared with the size at the beginning of the year (S) can be shown by the formula:

$$S = S^1 + G-M-V$$

The change in the strength of the fish stock is therefore:

$$S - S^1 = A + G-M-V$$ [1]

1/ Editor's note: Seemingly there is a mistake in these formulae, i.e., S and S^1 are switched around. As we see it, the formulae should be:

$$S^1 = S + A + G-M-V$$

and

$$S^1 - S = A + G-M-V$$

If the fish stock is to be maintanined at a constant value, then it is necessary that:

$$V = A + G - M,$$ <u>or in words</u>:

The catch must be equal to the increase: that is, the natural weight increase through egg production and growth, minus the loss through natural mortality.

If more than the amount of the increase is caught, then the strength of the fish stock will decline. Finally, this might lead to emptying of the sea. If less than the increase is caught, than the fish stock will increase in weight. The situation in unfished areas -- for instance in the Barents Sea during the beginning of this century -- shows that the fish stock does not increase in strength indefinitely. Somewhere a constant strength or equilibrium is reached, whereby, if there is no fishing, it is valid that the weight increase through egg production and growth is cancelled by the natural mortality, or $(A + G = M)$.

In such a dense fish stock there are many old fish and insofar as the egg production increases progressively with age, a very large number of eggs are produced. The mortality, however, is very high; partly because the older fish feed more on fish than the younger ones do, and partly because of the higher average age.

If we begin to fish this stock the density decreases. If, after a certain density has been reached, we do not fish away yearly more than the natural increase, a new equilibrium is established that is at a sub-maximum density of the fish stock. We will now find what changes appear in the stock when, for instance, by step-like increasing of the fishing intensity, equilibriums are adjusted by increasingly lower densities. A similar increase of fishing intensity has occurred in several fishing areas. The following changes were thereby observed:

1. By an increase of the fishing intensity the older age groups decrease more in strength than the younger ones. The next table shows us that, theoretically, this must be expected. It is shown here how many fishes are left over from year to year from a group of 1,024 one-year-old fish when the annual decrease is respectively 25 percent, 50 percent, and 75 percent.

Age in years		1	2	3	4	5	6
Yearly decrease	25%	1,024	768	576	432	324	243
" "	50%	1,024	512	256	128	64	32
" "	75%	1,024	256	64	16	4	1

Consequently, the increase of the degree of fishing lowers the average age.

2. With the decrease of density, an increase in growth rate occurs. This is caused by the fact that, as the number of fish declines, more food is available for each remaining fish. A fish uses its food for two purposes: for maintenance (tissue reparation, digestion, muscle labor, etc.) and for weight increase or growth. Therefore, the food which has become available through the catching of a quantity of fish now becomes an extra ration for the survivors. Furthermore, we saw that by increasing the fishing intensity, the average age of the fish lowers and generally the older fish use a larger percentage of their food to remain alive than the middle-aged fish. A sole of 40 centimeters, for instance, increases in one year as much as one of 30 centimeters does, but uses more food during that year. Consequently, by an increase of fishing intensity, more food becomes available per fish and a larger percentage of food will be used for weight increase.

3. The egg production will decrease, as there will be fewer adult fish and the younger ones produce fewer eggs.

4. Because the average age lowers, death from old age decreases and, as the older fish often are formidable cannibals, the death of young fish decreases also.

Summarizing, we may say that when an untouched fish stock is being fished, the result is a decrease in the number of individuals, a decrease in the average age and in egg production, an increase in the rate of growth, and a decrease in natural mortality.

If the stock after fishing is again unfished, it will gradually regain its maximum strength. The quantity with which the stock may increase during a period --for instance one year--that is the rate of increase, is controlled by A + G-M (see above). Also, we have seen that the values of egg production (A), natural mortality (M), and numbers of individuals and rate of growth (product of latter = G) are all dependent on the density of the stock. Therefore, the rate of increase also must vary with the strength of the fish stock.

Regardless of the large number of growing individuals and the high egg production, the yearly increase made by a very large stock is small since the growth rate is small and the mortality is high. In a medium-sized stock, the increased growth rate and decreased mortality outweigh the lower egg production and the smaller number of individuals. In a very small stock, there are too few fish to give G a greater value, even though growth rate is maximum. The egg production is very small and the mortality higher than it is in a moderately fished stock, since smaller fish fall prey easier than larger ones. Consequently, annual increase is low in a fish stock of small strength. The greatest rate of increase is reached by an intermediate stock which is neither too great nor too small.

If we show graphically the changes of the rate of increase, represented as weight-increase-per-year, by increasing fishing intensity and thus lowering density, then it ensues from the foregoing explanation that we must find an optimum curve (fig. 1, curve I). The rate of increase is at first gradual and after reaching a maximum, it declines again. From curve I, we can construct curve II which shows the density of the stock by changed fishing intensity. For instance, if a practically emptied sea (to M in fig. 1) re-populates itself without being fished, after one year this stock will have increased with the amount M M^{1}. This amount is regulated by the speed of increase during the first year of recovery and represented by curve I in the illustration. (It is tabulated in the illustration that the average rate of increase during the first year is equal to the rate of increase at a period 6 months after the start of the protection.) Continuing in the same way, the strength of the fish stock may be tabulated from year to year with the aid of curve I. The result is the S-shaped curve II. This shows, from right to left, how in a sparsely populated sea the fish stock grows if there is no fishing. From left to right, it shows how a fish stock decreases when fished with steadily-increasing intensity. The rate of increase (or increase-per-unit-of-time) is shown for each density value of the fish stock by a point on curve I, vertically below these values.

From the curves, it appears that the rate of increase has a maximum value at density P of the fish stock. If one starts to fish the untouched stock and if, for instance, during one year one catches less than the yearly increase at strength P, then an equilibrium will appear at a density somewhere between P and the limit, whereby the stock remains constant but cannot deliver the largest possible catch annually.

One may speak here of a state of overfishing. If one increases the fishing intensity in such a way that annually more than the increase at strength P is taken from the stock, then, besides this increase, a part of the fish stock is also removed annually. The stock will decrease and as soon as the point of maximum annual increase is passed this decline will go faster because the rate of increase or the productive capacity of the fish stock diminishes at an increasing rate. This is the state of overfishing. Only if the fishing intensity is regulated in such a way that the fish stock remains at strength P will it be possible to harvest a maximum catch from year to year. We shall call this optimum catch and the accessory strength of the stock, the optimum strength. The catch which may be taken at each arbitrary strength of the stock, without changing its strength, we shall call the allowable catch.

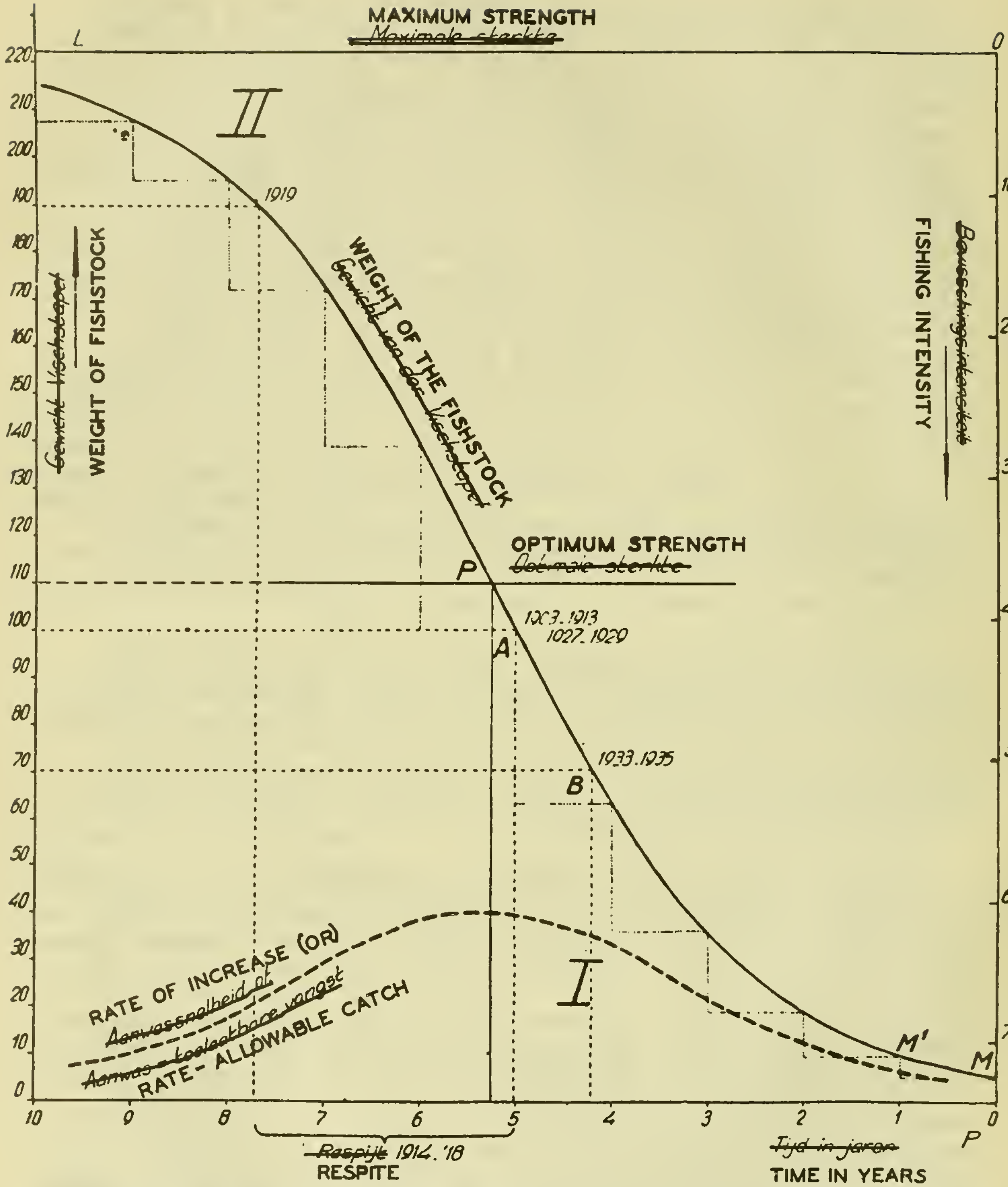

Figure 1.--Relation between the size of the fish stock in the North Sea and the fishing intensity.

Curve I shows with which amount the fish stock increases each year, by the corresponding size of the fish stock on curve II. From right to left, curve II shows how large the fish stock becomes from year to year if an empty North Sea re-populates itself. From left to right, curve II shows the progress of the strength of the fish stock by steadily-increasing fishing intensity.

If the sea is to be exploited as fully as possible, an attempt must be made to retain the stock at optimum strength. A dense, very large stock is very profitable for the individual fisherman because he will be able to take large catches within a short time. However, the total productive power of a very dense stock is rather low. Nevertheless, there seems to be little possibility that any accessible sea will be fished with too low an intensity. The demand for fish and the chance to make a good income will increase the fishing intensity quickly and, if no regulations are made, the strength of the fish stock will soon decline below the values corresponding with the optimum catch. Then, since the fishermen will not be willing to take smaller catches, the fishing intensity will be increased to the point where, in addition to the annual increase of the stock, part of the stock itself will be taken. The stock will then decline with an increasing rate. As soon as the point of optimum (maximum allowable) catch has been reached, a further increase of the fishing intensity will only lead to a decrease of the total catches. The state of overfishing has appeared and that is the state whereby more than the optimum catch is taken from the fish stock.

More than 30 years of intensive international scientific cooperation has been necessary to develop this theory of the ratio between fishing and productive power.

To increase the readability of this paper, several investigators are not mentioned in the text. However, it may be said that Russell (1931) began to analyze the factors which regulated the productive power of the fish stock and that Hjort and associates (1933) were the first to develop the idea of the optimum catch. The theory was further developed by Graham (1935, 1938, 1939, 1944), by Bückmann (1938) and by Russell (1939). In the meantime, Thompson (1934, 1937) showed from a study of the halibut in the northeast Pacific Ocean that decreasing of fishing intensity may lead to an increase of the total catch.

The task is now to find the fishing intensity which, for a given area, corresponds with the optimum productivity of the fish stock. For an area which has been fished for years with changing intensity, the optimum catch and the accessory fishing intensity can be found from the fishing statistics.

B. THE PROGRESS OF FISHING DURING THE PERIOD 1903-1940 AND THE POSSIBILITY OF A FUTURE RATIONAL EXPLOITATION OF THE MOST IMPORTANT FISHING AREAS

I. NORTH SEA

When considering this subject, a distinction must be made between two groups of fish: the bottom fish (haddock, cod and flatfish) and the pelagic fish (herring, mackerel).

1. The Progress of the Bottom-fish Fishery

First, we must determine the history of the fishing intensity for bottom fish.

a. Fishing Intensity

Table 1 shows the average number of steam trawlers engaged annually in the North Sea fishery, during 4-year periods. Table 2 shows the tonnage of these steam trawlers; it may be assumed that the fishing power varies directly as the tonnage. Table 3 gives a survey of the number of days at sea of the steam trawlers in the North Sea. Finally, table 4 shows the number of motor vessels in use in various countries.

From the beginning of this century, until the first World War, the number of steam trawlers and their tonnage increased steadily. The small vessels were chiefly sailing ships. Toward the end of this period most of these were refitted into auxiliary vessels or replaced by motor vessels, increasing the fishing capacity of the fleet. Therefore, from 1904 to 1913, the North Sea was fished with increased intensity.

During the first World War the fishing intensity decreased greatly. Afterward, it is more difficult to get an idea of the progress of the fishing intensity from the existing information.

The total number of steam trawlers decreased rather than increased, but from the increase of the average tonnage, we may assume that their fishing capacity increased considerably. It is shown in table 3 that the number of days at sea of steam trawlers in the North Sea declined very much. When the catches began to decline in the North Sea, many trawlers, especially the larger ones, went in search of more remote fishing grounds.

TABLE 1.--The average annual number of steam trawlers fishing in the North Sea, by 4-year periods.

Period	Country			
	Germany	England	Netherlands	Scotland
1935 - 1938	346	1,181	129	355
1931 - 1934	332	1,308	205	336
1927 - 1930	370	1,237	195	326
1923 - 1926	379	1,279	167	330
1919 - 1922	...	1,413	179	393
1915 - 1918	...	419	196	128
1911 - 1914	263	1,389	142	326
1907 - 1910	210	1,355	87	308
1903 - 1906	145	1,193	73	273

TABLE 2.--The average annual tonnage of steam trawlers fishing in the North Sea, by 4-year periods

Period	Country			
	Germany	England	Netherlands	Scotland
	m^3 gross	m^3 gross	m^3 gross	Net tons
1935 - 1938	845	631	548	86
1931 - 1934	745	568	512	82
1927 - 1930	718	546	501	78
1923 - 1926	646	525	506	75
1919 - 1922	...	499	458	70
1915 - 1918	...	432	445	..
1911 - 1914	...	458	513	54
1907 - 1910	538	433	...	49
1903 - 1906	482	...	...	..

TABLE 3.--Number of days at sea of steam trawlers in the North Sea

Period	Country			
	Germany	England	Netherlands	Scotland
1935 - 1938	9,518	109,115	18,232	69,474
1931 - 1934	10,081	121,850	19,280	64,535
1927 - 1930	13,897	133,179	40,289	58,841
1923 - 1926	31,228	148,375	30,106	53,484
1919 - 1922	. . .	145,088	14,774	. . .
1915 - 1918	. . .	. . .	. . .	. . .
1911 - 1914	. . .	. . .	. . .	. . .

The number of trips made by steam trawlers decreased, especially in the southern part of the North Sea. For instance, in 1910 the German steam trawlers made 1,933 trips to the southern part of the North Sea, but during the years 1935-37, they made an average of only 7 trips a year. During the same period, the trips made by German trawlers to the northern North Sea were respectively 2,901 and 742.

The number of trips made by English trawlers to the southern part of the North Sea declined from 21,650 to 16,830, while their trips in the northern North Sea rose from 984 to 1,252. Moreover, only the less powerful trawlers remained in the southern North Sea.

Offsetting the decreased fishing intensity as a result of the above factors, an increase in fishing intensity resulted from the acceptance of the Vigneron-Dahl trawl. This increase amounted to 25 percent for plaice (Thursby Pelham, 1939) and 50 percent for haddock (Bowman, 1932).

It is not likely, however, that this increase in the fishing technique compensated for the very large decline in the number of trips of the steam trawlers. As is shown in table 4, the number of motor vessels increased very much since World War 1.

These motor vessels fished mostly in the southern North Sea; and although their average individual fishing capacity is probably somewhat less than that of the steam trawlers which used to fish the North Sea, they are numerically so strong that it is our opinion that they have compensated for the decrease in steam trawler activity, and that through their use the fishing intensity must have increased in the southern North Sea during the period 1914-40.

In the northern North Sea, the decline in the steam trawler activity is not so great. Here, haddock is fished chiefly with the Vigneron-Dahl net and the resulting increase in fishing capacity undoubtedly must have erased the influence of the decrease in the number of days at sea, and also must have increased the fishing intensity.

The above conclusion is supported by the fact that a greater percentage of tagged plaice was caught yearly during the period 1918-40 than during the period 1903-14, and that in the former period the percentage of the category "small" in the catches reached a higher value than it did before the first World War (see table 7).

b. Landings

Table 5 and figures 2a and 2b show the progress of the total catches and of the catches of the major species. The value in guilders is also shown. It is now apparent that the values reached a peak in the first 3 years after the first World War, then showed a small decline and later decreased more rapidly.

TABLE 4.--Number of motor vessels in various countries

Period	Country			
	Denmark	Germany	England	Netherlands
1935 - 1938	340	170	120	474
1931 - 1934	334	143	127	369
1927 - 1930	303	125	123	230
1923 - 1926	234	125	116	183
1919 - 1922	130	...	131	142
1915 - 1918	118	...	50	40
1911 - 1914	100	...	21	5

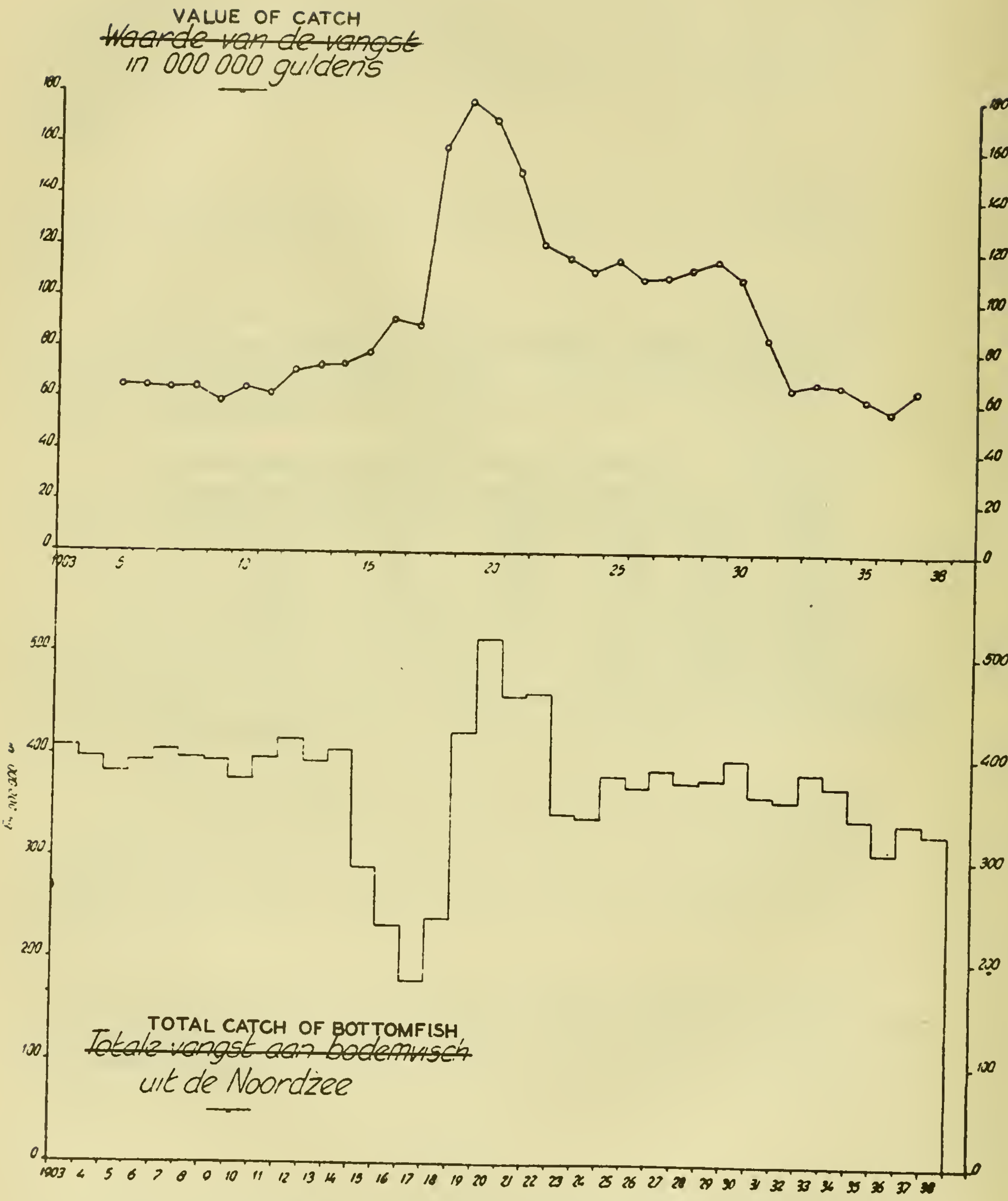

Figure 2[a].--Size and value of the total annual catch of bottom fish in the North Sea. Top: Value of catch in 10^6 guilders. Bottom: Total catch in 10^6 kilograms.

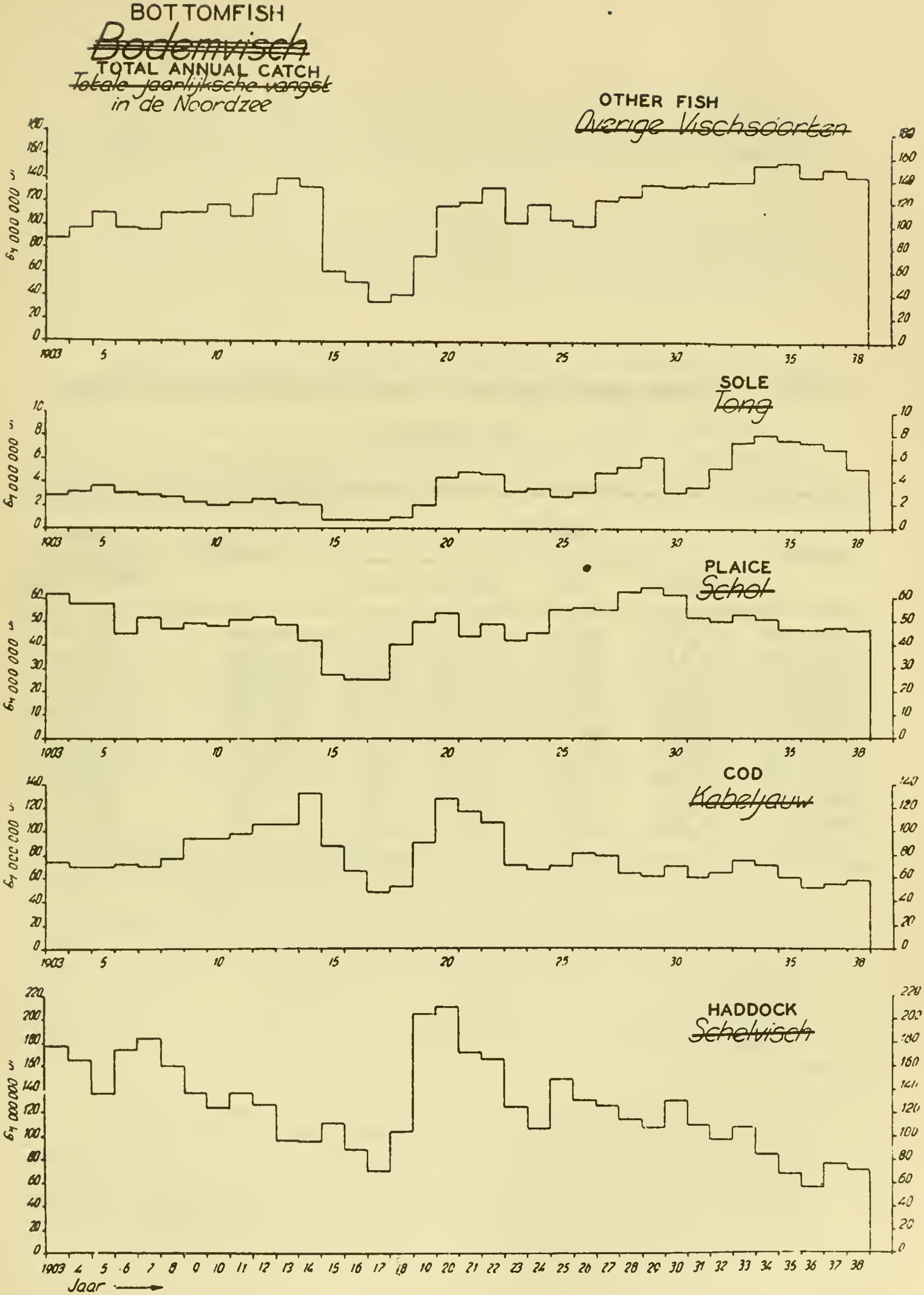

Figure 2b.--Total annual catch of various bottom fish from the North Sea in 10^6 kilograms.

TABLE 5.--Average annual landings of bottom fish from the North Sea

(in 1,000 kg)

Period	Species				All landings	Value landings in 1000 guilders
	Haddock	Cod	Plaice	Sole		
1935-1938	67,880	56,570	46,763	6,723	326,499	61,688
1931-1934	100,458	68,042	52,174	6,081	368,669	71,515
1927-1930	119,262	68,621	61,670	4,794	383,570	111,598
1923-1926	126,989	72,334	50,105	3,105	358,953	113,087
1919-1922	187,803	111,448	49,790	4,031	463,704	154,621
1915-1918	93,481	64,257	29,669	787	235,093	104,670
1911-1914	113,744	110,879	49,083	2,254	402,338	70,558
1907-1910	151,205	83,965	49,148	2,478	392,514	63,163
1903-1906	164,429	71,831	56,209	3,288	394,038	65,215

If we compare the total amounts of haddock, cod, plaice and sole landed in 1903 and in 1938, then these appear to have declined even faster than the total landings. Apparently, this is because the catch of "other fish" increased steadily.

The financial return decreased relatively more than the return in weight. The prices of the most important fish oscillated from year to year, but did not lower constantly, so that the increased landings of fish of lower value must be held responsible for the decline of the returns.

Figure 2B clearly shows that after 1925, the landings of less important fish ("other fish") increased greatly.

It is clearly shown that around 1930, a situation had appeared whereby an increasing fishing intensity brought about a decreasing catch; a clear state of overfishing, and a very serious one considering the financial returns.

It is worthwhile to look at the four most important fish species separately.

aa. Haddock

When we observe the figures showing the total landings of haddock in kilograms, a decline from 1903-14 is apparent. An increase during the post-war years to an amount higher than that of the period 1903-06 occurs, and then a progressive decline, until finally a level has been reached which is lower than the returns of the limited fishery during the war period (see table 5).

Therefore, we notice that an increase of the fishing intensity during the period 1903-14 is accompanied by a decrease of the catches. The haddock stock must have been overfished already during this period. It appears from the high returns of the years 1919-26, the catches had already dropped below the highest value of the pre-war period. Finally, during 1935-38, about one half of the latter value was reached. It has been said that the decrease in the number of steam trawlers is to blame for the lowering of the haddock catches; that is to say, a decreasing of the fishing intensity is blamed. Although we have taken the view that the fishing intensity has increased during the last years, we will consider this point of view.

If the haddock stock were indeed fished with lower intensity, this must have been advantageous for the size of the stock, and the density must have increased. This density must be measured by the catch-per-unit-of-time. We have said already that this is dependent on the fishing capacity. As this capacity has increased in recent years, we must accept that, by equal density of the fish stock, the catch-per-unit-of-time also must have increased. However, the catch-per-day at sea has declined. This is somewhat clearer when (as was done in table 6) a correction is made for the working of the Vigneron-Dahl net (by multiplying the values for the years 1925-27 when the V-D net first came in use by 5/6 for haddock and cod, and by 7/8 for plaice. The values of later years were multiplied respectively by 2/3 and 3/4). The values in table 6 are a combination of German, English, Dutch and Scottish observations.

It is clear that since 1918, the density of the haddock stock has declined steadily. The recession of the total landings can never be blamed on a possibly decreased fishery. We must conclude that after 1918 a state of overfishing of haddock has appeared, probably beginning about 1925.

An increase of fishing intensity is shown always by the gradual disappearance of older individuals. During a state of overfishing, the older fish alone account for a trifling percentage of the catches. Since it is principally these older individuals which spawn, there is danger that the breeding production will become too small. However, since one female lays so many eggs, a fairly small number of older fish is often sufficient to keep the stock up to par. The overfishing first manifests itself because the production capacity of the fish stock diminishes, but if the overfishing continues it can also happen that the egg production becomes too small. The overfishing of plaice in the Baltic has taught us how soon this may have fatal results.

The size of a year class at the end of the first year is especially dependent on (besides the number of eggs laid) a number of environmental factors which may fluctuate greatly from year to year, and thereby bring about the well-known fluctuations in the strength of the various year classes. Consequently, a decline of egg production may not be noticable if it is coupled with a favorable influence of environmental factors. Eventually such a decline becomes clear, however, because the average strength of the year classes diminishes. Although it cannot be said with certainty, it appears that this was the case with haddock; therefore, this would show that the haddock were very seriously threatened.

bb. Cod

The total catches in table 5 show an increase during the period 1903-14 parallel with an increase of the fishing intensity. During the war period the returns decreased, only to increase to the prewar value during the period 1919-22. Thereafter, a decline is shown, but is not as pronounced as the decline of the haddock.

There was no overfishing of the cod stock before 1914, but after 1918, we see a small decline of the total catches from the North Sea, together with an increase of the fishing intensity. Table 6 shows that the density of the cod stock had declined far less than

TABLE 6.--Average annual catch per day at sea, in kilograms

Period	Haddock	Cod	Plaice
1935 - 1938	140	97	86
1931 - 1934	259	118	87
1927 - 1930	275	119	133
1923 - 1926	346	97	156
1919 - 1922	704	221	195
1915 - 1918	1,129	271	237
1911 - 1914	497	206	135
1907 - 1910	...	...	...
1903 - 1906	...	...	...

that of the haddock stock. The percentage of the category "small" has also barely increased for the cod, while that of the haddock has increased (See table 7).

Although the cod stock was fished somewhat too intensely and has declined in productive power, its situation appears much better than that of the haddock stock. Yet, both species are fished in the same way with the same ships. Somehow, then, in some way, the cod must have a natural protection. Probably this protection is due to the fact that the 3-to 5 year-old cod appear much on rocky bottom where they are more difficult to catch; and that such cod do not concentrate in large schools as do haddock of the same age, and that perhaps they leave the bottom from time to time in pursuit of herring schools.

cc. <u>Plaice</u>

The summary of the total catches of plaice (table 5) shows a different picture than that for cod and haddock. We do find some decrease in the landings before 1914 and a great decrease during World War 1. However, the landings do not reach their highest value until the period 1927-30, and especially during 1929. Thereafter, a continuous decline is present. There are several reasons why the greatest returns came so many years after the war.

In the first place, a variation of the influence of the war years on large and small plaice was responsible. The small plaice is distributed along the coasts of Belgium, Holland, and Denmark, chiefly in the Heligoland Bight. This area was fished more intensively during the war years than the far-off fishing grounds in the North Sea. Therefore, the young plaice was caught in great quantities while the older plaice remained untouched in the deeper parts. When the North Sea was opened to the fishery again after the war, it was chiefly large plaice that were landed. This can be seen from the decline in the percentage of "small" in the catches (table 7). The coastal grounds were fished with comparatively little intensity and there was a crowding of growing young fish, produced by the larger plaice. Therefore, the coastal areas were populated densely after 1918 and the rate of growth declined. Before too long, the larger plaice had been caught and the fishing industry again had to depend on the younger year classes. Because of the small rate of growth, only a small percentage of the younger classes were marketable, and these could not give a great increase to the catches. When they began to form a larger percentage of the catches, their density caused a considerable increase in the catches.

A second reason was the enormous increase of the Danish fishery (table 4), which also showed a maximum landing of plaice in 1929. Plaice fishing increased also in other countries. During that period, the Dutch luggers began to trawl for plaice; and with the decline of the cod and haddock, small steam trawlers went back to coastal fishing.

TABLE 7.--Average annual percentage of the "small" category in the catches

Period	Haddock	Cod	Plaice	Sole
1935 - 1938	88	38	88	41
1931 - 1934	86	46	87	44
1927 - 1930	78	54	88	40
1923 - 1926	66	40	79	19
1919 - 1922	49	33	54	16
1915 - 1918	53	47	71	23
1911 - 1914	39	39	74	29
1907 - 1910	41	27	69	22
1903 - 1906	50	34	72	28

Finally, the demand for small plaice increased after 1929 so that a large proportion of the catches could be landed.

The catches declined very much after 1929, and we can safely say that a state of overfishing had appeared. Overfishing was not the result of only the intense fishing for marketable plaice, but was also caused, to a considerable degree, by the increasing trash fishery. This can be shown by some data obtained from Bückmann (1939), considering the plaice landings of German draggers. Bückmann shows that the year classes 1926 and 1927 delivered 13.1 million fish to the German draggers, while the approximately equally-strong classes of 1932 and 1933 delivered only, respectively, 5.8 million and 6.2 million fish. It may be expected that when no fish are being destroyed, equally strong year classes deliver equal amounts of fish. Therefore, we must assume that a very large part of the 1932 and 1933 year classes was destroyed undersized and that this caused the very large decline in productive power of those year classes.

Before 1914, when there was no trash fishing, a state of overfishing had also appeared. This shows that the trash fishery is not the only cause for the overfishing.

dd. Sole

The catches of sole declined during the period 1903-14, apparently since more fishing was done in deeper water as the number of steam trawlers increased. After 1918, the catches increased continuously. This is no doubt due to the increase of the fishery for sole and the growing number of draggers. The smaller ships spend more time looking for sole.

Although the intensive fishing is noticeable by the increase of the percentage of "small" (see table 7), a state of overfishing did not appear. While, in 1934, Bückmann thought that the sole stock had remained constant; Schmidt believed in 1942, that the stock definitely had increased in density. This is extraordinary compared with what happened to cod and haddock. Obviously there is a connection between the increase of sole and descrease of plaice, since both fish use, for an important part, the same kind of food.

The progress of fishing, therefore, varies from species to species. The haddock stock appeared to be the first and most overfished species and the overfishing of plaice appeared somewhat later, about 1930; while for the cod we could discover only a limited amount of overfishing. The stock of sole increased in size, but column 6 of table 5 shows that the increased sole catches did not make good the other losses in fish.

Until now, the decline of the fish stock has been blamed totally on the increased fishing intensity. This is true, provided that other environmental factors do not become unfavorable. The question remains: Did environmental factors in the North Sea change considerably during the past 40 years: Sufficient data of the two most important factors, temperature and salinity, show but little change.

Little is known about changes in the other influential factors. An important one is the amount of phosphate present, which is often the limiting factor for the amount of food a sea may contain and consequently affects the productivity. The phosphate content was determined regularly at the western entrance of the Channel during the past 20 years. It appeared to be fairly high during the period 1924-29, declined considerably until 1935, and increased again between 1935 and 1939. A decline in the number of fish larvae and a general reduction of the fauna in the observation area was parallel with the decline in phosphate content (Harvey, 1946). It is not known if a similar decline appeared in the North Sea, but if that were so, it undoubtedly must have led to a decreased productivity and would be partially responsible for the decline in the catches. However, it is very doubtful that the reduction in phosphate content was the only reason for the decline of the fish stock, since the overfishing became apparent before the appearance of the lower phosphate content. It is more likely that the disappearance of great numbers of fish (containing phosphate) was responsible for the loss of phosphate in the sea. Nevertheless, the phosphate increase after 1935 shows that this content is also controlled by another factor independent of the fishery.

If a decline in the productivity was a responsible factor, together with the increased fishing intensity, it still would not change the conclusion that during the period 1919-39 the fishing intensity became too great for the productive power of the North Sea.

ee. Non-marketable Fish

Only the marketable fish appear in the data given heretofore. The undersized fish, partly landed as trash for meal and partly thrown overboard as dead--but which in any case are removed from the fish stock--do not appear. What we finally need to know is the total amount of fish that died as a consequence of the fishery. Therefore, we have to estimate the amount that is not included in the statistics.

The data necessary for such an estimation are extremely scarce. Reliable data can be obtained only by observations made aboard ship, and these observations have to be made on a large scale since the percentage of undersized fish may vary from place to place and time to time. The English probably have the best data since they have fish measurers serving on board the fishing vessels. Not enough of these data are published to give us an idea of the average relation between landed fish and fish thrown overboard. Russell (1932), referring to Borley in an English report of 1927, shows figures on the amount of fish thrown overboard from English trawlers. They are 4 percent of the total catch of cod, 17 percent of the haddock and 4 percent of plaice, by weight. Russell (1932) shows that during the period 1926-30 the first-class English steam trawlers discarded 10 percent of the haddock and 4 percent of the plaice catches overboard. Converted to numbers these weight figures will be respectively 14 percent and 17 percent. Russell thinks that the 4 percent for plaice is too low. It may be assumed that with the increase of the over-fishing, the percentage increased since 1930. For the last decade we believe that we may assume an average of 6 percent.

Bowman (1932) made an exact study on the amount of haddock thrown overboard during the period 1924-29 in a very intensively-fished part of the North Sea. This area is bounded by latitude 50° N and 57-1/2° N, and longitude 1° W and 2° W (900 square sea miles). Much young haddock is present in this area. 51 percent of the total catches in numbers or 35 percent in weight was thrown overboard in this area.

De Veen (1938) observed the landings of trash in Holland during the period July 1937-June 1938. He found that during this period the "botters", luggers, and small draggers caught about twice as much trash as marketable fish. For the steam trawlers the relation between marketable and trash fish was about 1 : 1. The good market for trash and the decline of the marketable part of the fish stock, stimulated the fishing for trash by the small ships during the past 5 to 10 years before World War II. The high trash landings of these ships during the period 1937-38 may, therefore, not be viewed as representative for the period 1919-30. It appears more correct to assume that, on the average, 50 percent of the total catches of the Dutch fishing fleet on the plaice grounds consisted of trash. This is the figure established for steam trawlers by de Veem. Tesch (1925) reports that plaice-trash formed 35 percent of the total weight of trash. We may assume that about 85% of the catch of marketable fish consisted of plaice. A simple sum shows that about 30 percent of the total catch was plaice trash. The Dutch ships destroyed far more small plaice than the English vessels, since the Dutch fished almost exclusively on grounds where young plaice are abundant. The Germans probably caught somewhat smaller amounts of trash as they used fairly large-meshed nets. Therefore, we assume that the plaice catches of the Dutch, Belgian and German Vessels consisted on the average of 25 percent plaice-trash. It appears to us that this figure is more likely to be too low than too high.

The Danish destroyed very few undersized plaice with their "snurrevaad" (seine). We assume it to be 2 percent.

During the period 1918-38, the Danish took 25 percent of the plaice catches, the English 42 percent and the other countries 33 percent.

On the average, therefore,

$$\frac{25 \times 2 + 42 \times 6 + 33 \times 25}{100} = \pm \quad 11\%$$

of the total catches of plaice will have been destroyed undersized. For the period 1919-30, this percentage perhaps will have to be somewhat lower, for instance 8 percent. For the years 1936-38, it is somewhat higher, for instance 14 percent. For haddock, a percentage of 20 percent does not seem to be too high for the period 1930-40, and 10 to 15 percent for the periods 1918-30. Approximately 5 percent of the catches of other species will have been undersized. Probably this percentage increased during the last years before World War II (up to 8 percent after 1935).

With the aid of these data and the known landings of marketable fish (Bulletin Statistique, 1903-38) it is possible to estimate the total catches from the North Sea. This has been done in table 8 for the average annual catch during the period 1903-13 and for the years 1919-38.

2. Conclusion of the Review of the Progress of Fishing in the North Sea

It is now possible to produce graphically the relation between the fishing intensity and the rate of increase (or productivity) of the fish stock, which has been done by Graham (1935).

First we have to construct the S-shaped curve, which shows what strength the stock would have from year to year in the hypothetical case that an empty North Sea would re-populate itself and inversely shows how the fish stock would decline by a steadily increasing fishing intensity.

Here, we will represent the strength of the stock by relative numbers and the average strength during the periods 1903-13 will be set at 100. The fishing standard is the percentage of the fish stock which is caught in the nets each year. This can be estimated from the percentage of tagged fish that is recaught annually. During the above period it was about 40 percent (Graham, 1935). We assume that the annual catch was equal to the natural annual increase during this period which, therefore, is also 40 percent. If the fishing would stop, the stock would increase. With the passage of time, the rate of increase would become smaller. We assume here that the rate of increase changes equally with the decrease of the difference between the existing strength and the maximum strength of the stock. The percentages of increase of the growth of the stock at each period of time can then be calculated, if we know the maximum strength (in respect to the accepted value of 100 for the period 1903-13). To

TABLE 8.--Catches of marketable fish, calculated total catches, and weight of the fish stock

Year	Marketable				Marketable plus undersized							Weight of fish stock	
					Haddock		Plaice		Others		Total		
	Total	Haddock	Plaice	Others	Percent undersized	Millions of kg.	Percent undersized	Millions of kg.	Percent undersized	Millions of kg.		Millions of kg.	Relative units
	Millions of kg.												
1903-13	423	147	50	224	15	173	8	54	5	236	463	970	100a
1919	421	205	50	166	15	241	8	54	5	175	470	1,610	166a
1920	515	210	55	250	15	247	8	60	5	263	570	1,390	143a
1921	459	171	44	244	15	201	8	48	5	257	506	1,205	124a
1922	460	165	50	245	15	194	8	54	5	258	506	1,076	111a
1923	344	124	43	177	15	146	8	47	5	186	379	1,025	105a
1924	341	107	46	188	15	126	8	50	5	198	374	1,039	107a
1925	382	147	56	179	15	173	8	61	5	188	422	1,032	106a
1926	370	130	56	184	15	153	8	61	5	194	418	1,003	103a
1927	386	125	55	206	15	147	8	60	5	217	424	971	100a
1928	374	115	64	195	20	144	11	72	5	205	421	937	97a
1929	376	108	66	202	20	135	11	74	5	213	422	903	93a
1930	398	129	62	201	20	161	11	69	5	212	442	856	88a
1931	362	110	52	200	20	137	11	58	5	210	405	810	83½a
1932	357	98	51	208	20	122	11	57	5	219	398	781	80½a
1933	385	108	54	222	20	135	11	60	5	234	429	733	75½a
1934	371	86	51	234	20	108	11	57	5	246	411	672	69½a
1935	339	67	47	225	20	84	11	53	5	237	374	620	64a
1936	307	56	47	204	20	70	14	55	8	222	347	582	60a
1937	335	76	47	212	20	95	14	55	8	230	380	523	54a
1938	325	71	46	208	20	89	14	54	8	226	369	429	44a

obtain this, we must know one given value for the curve besides the incline of the rate of increase at point 100 and the way in which the rate of increase changes. To get this value, Graham used the change which was found in the fish stock during the heavy decline of the landings during the first World War. From comparison of the numbers showing the catch-per-unit-of-time before and after the first World War (which are, therefore, a measure of the density of the fish stock in both periods), it follows that the stock in the North Sea increased 1.9 times during the years 1914-18. Graham estimates the respite for the fish stock during those 4 years is equal to 2.7 years of complete rest. The curve, therefore, should conform to the condition that after 2.7 years without fishing, the density should have been increased from 100 to 190.

These three conditions are enough to draw the curve and to calculate the maximum strength, the limit. The S-curve for the North Sea is drawn as curve II of figure 1. The limit appears to be 223. The calculated percentages of increase at different values for the strength of the stock are explained in curve I of the same graph.

The fishing intensity during the period 1933-35 was 50 percent (Graham, 1935); this increased later to 60 percent or 70 percent (Russell, 1942). The strength of the fish stock at these values can be read from curve II. It shows that the point of maximum production and, therefore, of optimum catch was passed already in 1903-13. The optimum catch can be obtained with a fishing standard of 37 percent, that is a fishing intensity equal to about three-quarters of that during the period 1933-35. The amount of fish which will be caught by a lesser intensity is shown by curve I (by a state of equilibrium) to be 12 percent larger than the amount the fish stock could bring during the period 1933-35, with a strength of 70.

To estimate the exact size of the optimum catch we must try to replace the relative values of the curves by absolute values. The only absolute values which are given are the total catches from year to year. During the period 1903-13 as well as during the period 1919-40, there was a state of overfishing; thus, more was taken away annually from the stock than was being replaced. The given amounts include the allowable catch, increased with an amount with which the fish stock had declined. The progress of diminishing is expressed in the progress of the density of the stock. The trawler catch-per-unit-of-time shows this. Figure 3 shows the progress of the catch-per-day at sea of English steam and sail trawlers during the period 1919-35. English statistics are used because they have a high degree of accuracy and are thought to be representative of the North Sea. Amounts are given for steam as well as for sail trawlers because it may be assumed that the first have increased in power and the sailing ships have diminished in capacity.

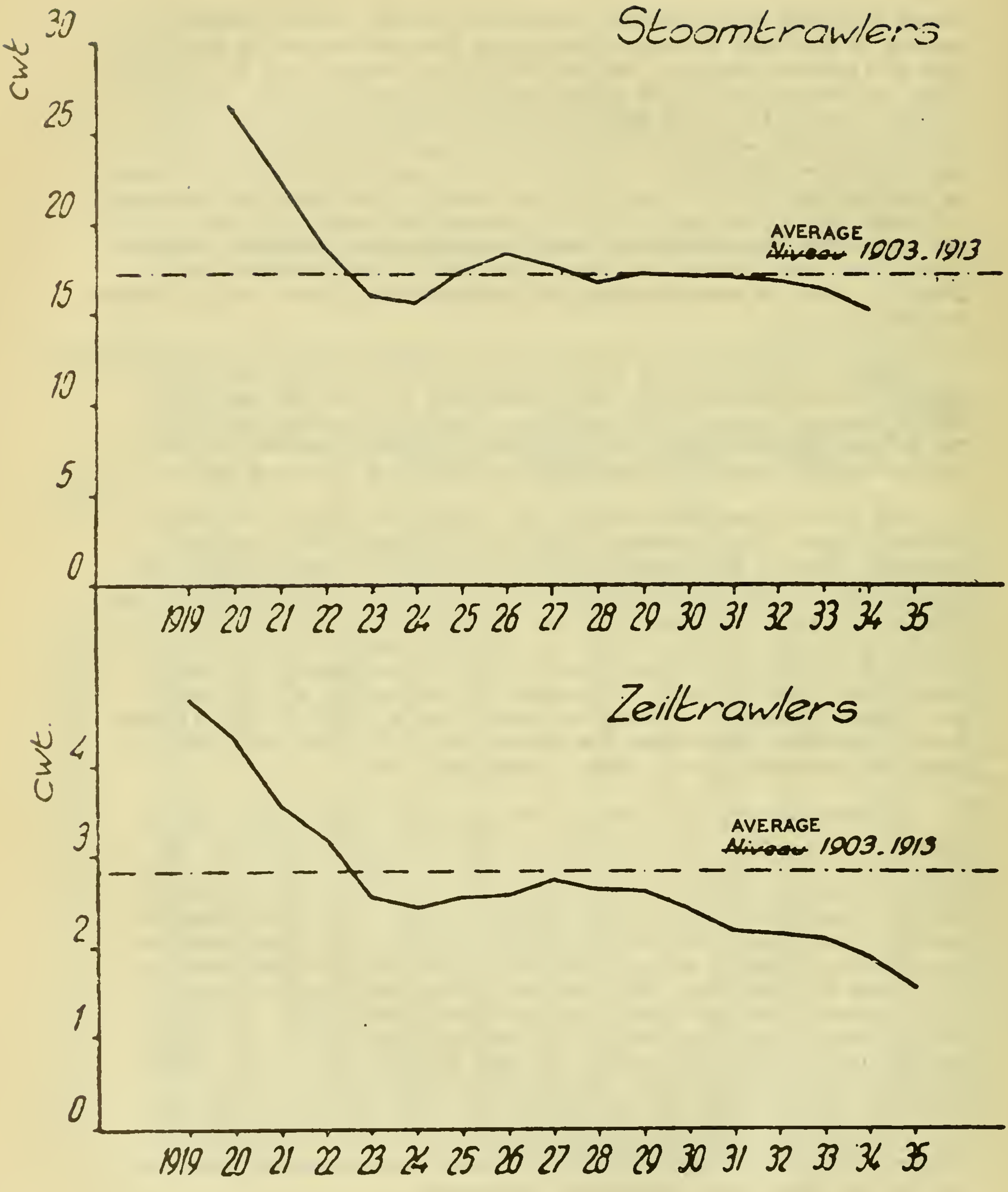

Figure 3.--Catch-per-day's absence of English steam and sail trawlers, shown in hundredweight. (Steam trawlers, top; sail trawlers, bottom). Dotted line: Average 1909-13).

Therefore, in more recent years, the catch-per-day at sea for steam trawlers will make the density appear somewhat higher than it actually is. The catch-per-travel-day of the sailing trawlers will give the appearance that the density had declined more than actually is the case. Both graphs show that during the years 1927-35, the density of the stock sustained a regular yearly decline. Figure 4 shows a part of curve I of Figure 1. ME is the average annual total catch for the period 1927-29 (422 million kilograms) and NF is the same total during the period 1933-35 (404 million kilograms). During the first period, the amount CE is reduced annually, while DF is reduced during the second period. The two periods are 6 years apart and if we assume that the amount of the decline has increased regularly and if we take the curve over the trajectory CD as a straight line, then we can represent the amounts during these 6 years by $C_1 E_1$, $C_2 E_2$, and so forth. The total decrease between both periods is thus:

$$EC + E_1 C_1 + E_2 C_2 + E_3 C_3 + E_4 C_4 + E_5 C_5;$$

or

$$6\ EC + E_1 P_1 + E_2 P_2 + E_3 P_3 + E_4 P_4 + E_5 P_5.$$

$E_1 P_1$, $E_2 P_2$, and so forth are to be represented as PF; together they are 2.5 PF. The amount of the reduction is then:

$$6\ EC + 2.5\ PF.$$

The average density during the period 1933-35 coincides with the point B in curve II of figure 1. If we look at the catch-per-day at sea in figure 3, it is noticeable that the average level of the period 1903-13 was passed for the last time in 1929 1a/ for the steam trawlers and in 1927 for the sailing ships. 2/ It has already been stated that the post-war steam trawler statistics will make the density seem to appear too high and the sail trawler statistics too low. We assume, therefore, that the density level of the period 1903-13 (that is point A in curve I) was reached in 1928. It is also known, however, that the amount of the reduction between the periods 1927-29 and 1933-35 is equal to the difference between the density level in A and in B, thus it is equal to 30 relative units (30a). We have then the equation:

$$6\ EC - 2.5\ PF = 30a \quad (I)$$

1a/ Editor's note: Apparently an error in these dates. Possibly should read "...in 1927 for the steam trawlers and in 1922 for the sailing ship."

2/ That the level 1903-13 was reached temporarily can probably be accounted for by the influence of weak year classes.

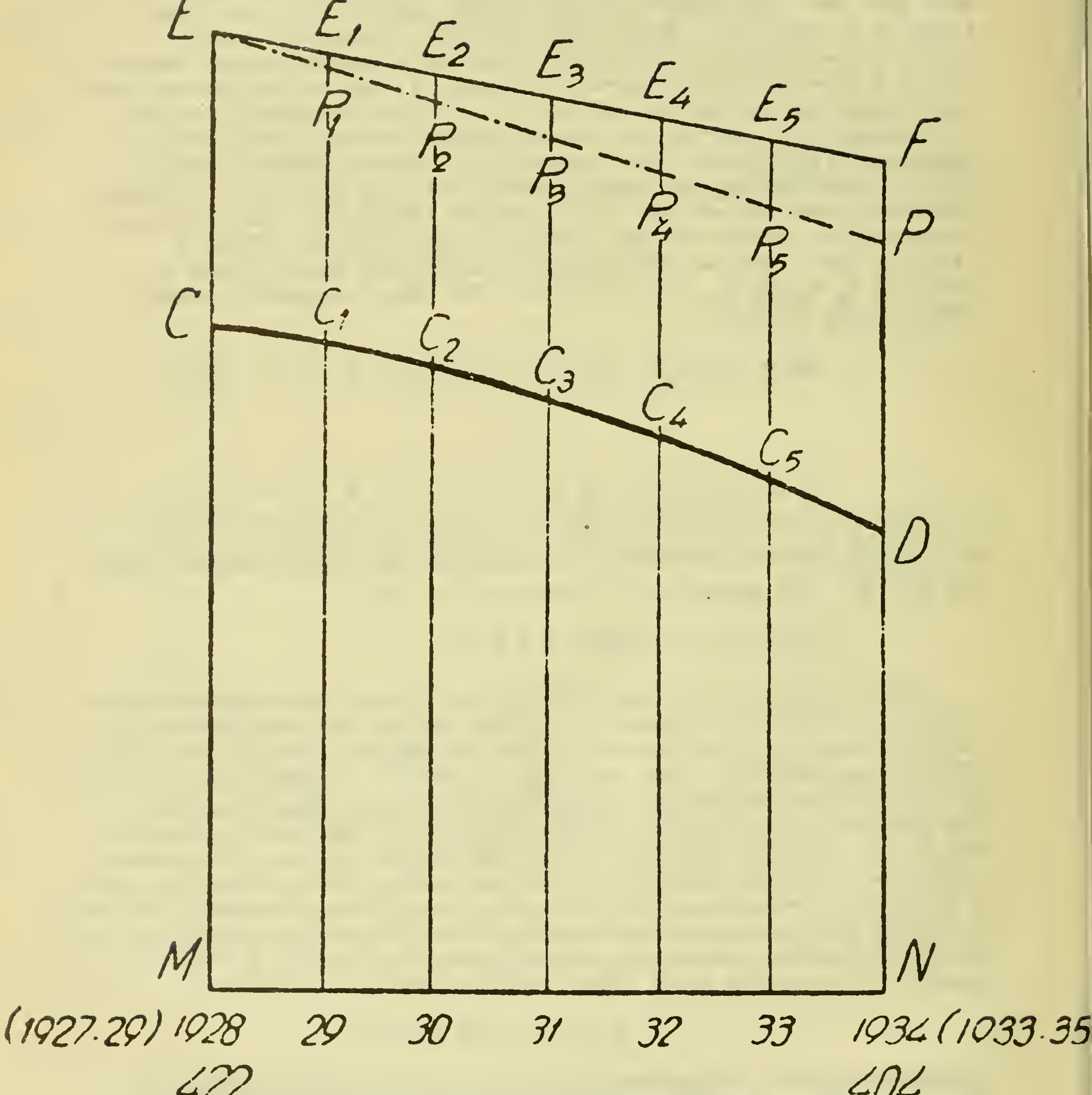

Figure 4.--A section of curve I, figure 1 (see text).

Then EC = ME - MC. ME is 422 million kilograms, MC is, in relative units, 40a (see curve I in figure 1). Thus EC = 422 - 40a. PF = FN-ND-PD. FN is 404 million kilograms, ND is 35a, PD = EC. Thus PF = 404 - 35a - 422 - 40a = 5a - 18. Equation (I) then is:

$$6\ (422 - 40a) - 2.5\ (5a - 18) = 30a$$

$$\text{Or } 2,487 - 257.5a$$

$$a = 9.7 \text{ million kilograms}$$

Therefore, the value of the relative unit used in the construction of figure 1 is known. Each value of those curves can be converted into kilograms. The optimum catch which is 40.4 relative units will be 9.7 x 40.4 = 392 million kilograms.

It is now possible to reconstruct the progress of the fishing in the North Sea between 1919 and 1940, and if the values for a and for the optimum catch are correct, then point A (100a) must have been passed at about 1928 and point B (70a) at about 1935, while the fishing standard shortly before the second World War must be somewhere between 60 percent and 70 percent.

In table 8, column 13 and 14, the density is shown for each of the years between 1919 and 1939. The densities were found in the following manner:

The starting strength of the stock in 1919 was 190a; therefore, the real strength must have been 190 x 9.7 = 1,845 million kilograms. In 1919, 470 million kilograms were caught. However, the stock increased also by a certain amount. The average strength of the fish stock during that year will have been 1,845 - 1/2 x 470 = 1,610 million kilograms or $\frac{1,610}{9.7}$ = 166a.

From figure 1 we can see that 166a on curve II corresponds with 31a on curve I. This last sum shows the quantity by which a stock with a weight of 1,610 million kilograms grows in one year. It is equal to 31 x 9.7 = 301 million kilograms. The starting strength in 1920 is thus 1,845 - 470 + 301 - 1,674 million kilograms. Again the catch of 1920 was subtracted and the increase was calculated and added. The same manipulation was repeated year after year.

It is now apparent that the progress of the density of the fish stock in the North Sea can be presented very well by an S-shaped curve. According to the calculation, the value 100a and the level 1903-19 is reached in 1927. This is thus one year sooner than we concluded from the progress of the catch-per-travel-day. A density of 297a was reached in 1928. The variation between these conclusions, arrived at in two different ways, certainly may be called slight.

The average density during the period 1933-35 ought to be 70a. When calculated we found 69.5, a very minor difference. Finally the value 40a, corresponding with a fishing standard of 60 percent, was almost reached in 1938 and far surpassed in 1939. This, too, is in agreement with the condition as it was actually observed.

Therefore, the North Sea is not able to deliver more than about 390 million kilograms of bottom fish per year. One may catch larger amounts than the optimum catch and will be able to continue to do this for several years, but the stock will decline in such a way that a moment soon will appear where regardless of the increased energy of the fishery the catches will decrease, and the decline will be very fast because of the smaller production capacity of the stock.

When a good stock is present in an accessible sea, and when there is enough demand for fish, a fishery will develop in that sea which will continue to increase in intensity. Not only will more fishermen appear, but the fishermen will try to compensate for the decline of the catch-per-unit-of-time, following the decline in strength of the stock by fishing, by increasing the efficiency of their fishing methods. An abatement of the fishing intensity will occur again only when fishing is no longer profitable. In that case, the largest and most expensive fishing operations will be the first to disappear, but the state of overfishing will have already been exceeded.

If it is desired to prevent the passing of the critical point, then an unlimited increasing of the fishing intensity must be prevented. The most practical way to accomplish this is by limiting the quantity of ships fishing that area and, once this has been accomplished, by forbidding any increase in the catching power of the gear in use. Increasing the efficiency of the industry may then take place only by limiting the quantity of energy used per fish-weight; for instance, by increasing the engine utility or improvement of the methods to locate fish.

The approximate 390 million kilogram bottom fish which the North Sea can deliver each year will be landed by small vessels, which catch chiefly flatfish, and by large trawlers whose catch consists chiefly of haddock and cod. About 15 percent of the catch consists of flatfish, the rest is roundfish.

The average yearly capacity of the different ship types should be calculated (this could be made even easier if types were standardized). Then the total number of steam trawlers which may be allowed can be adjusted to the available quantity of flatfish and roundfish. Finally, since several countries take part in the North Sea fishery, it will have to be established how many ships will be apportioned to each country. Such a quota system is undoubtedly a serious breaking with the traditional freedom of the seas, but it is the only sufficient way to prevent overfishing and to assure a continuous flourishing of the fishing industry.

From the progress of the density it is clear that one would have to continue at the same rate for only a few years to fish the North Sea actually "dead". It is also apparent that the density whereby the stock could deliver the optimum catch (110a or 1,068 million kilograms) was reached already in 1923; that is, only 4 years after the first World War.

Approximate calculations, published elsewhere (Baerends, 1946), show that in 1946 the stock had reached about the same density as it had in 1919. If the fishing intensity is given unlimited opportunity to increase, the threat exists that within 5 years a state of overfishing will have appeared. It is clearly most urgent to introduce a stringent regulation of the fishing intensity in the North Sea.

It is appropriate, if not more than a certain quantity of fish may be taken from the sea, that this fish will bring in as much as possible. That is to say, the quantity of fish which has to be thrown overboard because the fish are too small for human consumption or the quantity which would bring very low prices on the market because of their small size, will have to be kept at a minimum. For economical reasons it is, therefore, desirable, in addition to the quota regulations, to take measures for the protection of the small fish.

We have already given an estimation of the weight of undersized fish which were destroyed. The number also interests us because each fish which was caught small would have been able to bring a better price later. Destroying of an important part of the year class at an early age causes the older year groups to be represented weakly. These are exactly the year groups which bring in the highest returns and consist of sexually mature fish producing the eggs necessary to retain the stock at a steady level.

A fair amount of literature has been published about the quantities of non-marketable fish which are destroyed. We have said already that the quantity of small haddock thrown overboard by English trawlers was about 14 percent of the total haddock catch in 1932 (Russell, 1932), whereas in the areas where much young haddock are present this amount may rise to 51 percent.

Bückmann (1933) shows that during 1930 about 65 million small plaice were landed by shrimp fishers and converted into fish meal. He estimates this to be about 6 percent of the available stock of plaice under 23 centimeters. More than half of these 65 million plaice consist of individuals which have not yet reached the age of two years. The destroying of these is thought to be far less harmful, as will be explained.

According to Gilson (1932) 334,000 plaice, 6,963,000 flounder and 264,000 small sole were destroyed in May 1932 alone by 105 Belgian motor vessels. Finally Tesch (1933) estimates that the quantity of non-marketable plaice landed in Holland in 1932 amounted to 345 million fish which were largely older than 2 years. Tesch calculates that by fishing for such small fish, a year class has only 15 percent of its original strength when the fish reach a marketable size. We also have the idea (see p. 78 and table 16a) that by using narrow-meshed nets, without avoidance of the grounds where the young plaice are, a year class will have been reduced to about 20 percent of its starting strength when the plaice reach a length of 25 centimeters.

During the last 10 years before the second World War, it was a frequent occurrence that our fishermen not only did not avoid the grounds where young plaice were found chiefly, but deliberately searched for them. The reasons here were; 1). the marketable fish had become very scarce, and 2). all sales of small fish reverted entirely to the crew. Therefore, the crew often received more profit from large catches of small fish than from large catches of marketable fish.

The fragmentary observations mentioned will suffice to convince the reader that the limited fish production of the North Sea was handled wastefully. An enormous wastage took place which we shall have to limit to an unavoidable minimum if the annual quota of 390 million kilograms is to bring in as much money as possible.

It has been said that if these small fish were not caught, the rate of growth would decline so sharply that the fisher finally would experience more damage than benefit from the protection regulations. Some say that thinning out of the young age groups would be profitable, since more food would be available for every fish and the speed of growth and also the production capacity of the stock would rise.

It is, therefore, worth while to see what happens when a group of undersized fish is thinned out. Each of these fishes would have needed a certain amount of food to reach a catchable size; this food would have been used in the first place to keep up the metabolic rate. With what is left it would have increased the weight. If the stock is thinned out, the rations of the caught fishes will be available for the remaining fish. This increase of rations will be used for weight increase alone. The thinning thus results in the conversion of food which was used for maintenance into fish-weight. The remaining fish will then increase more in weight during the period between thinning and the time of becoming marketable, than they would have done in the past during the same period of time. If the thinning is to be profitable for the productivity of the fish stock, then the increase in weight must be larger than the loss in fish-weight that came about through the destroying of the undersized fish. The increase in weight corresponds with the ration necessary for maintenance during the period between thinning and becoming marketable. The size of the increase will depend on the length of the period. Whether the increase surpasses the loss is, therefore, a question of time.

On the basis of tests of the amount of food used for growth and that used for maintenance, one may calculate the length of this period. Russell (1932) found that the period must be at least 60 growth days for plaice, and we may accept that it will be of the same order for haddock. A year may be calculated at about 200 growth days. Therefore, thinning out to reduce the amount of food used for maintenance is harmful if it takes place within 3 years of the time of market readiness. Since plaice, at the earliest, reach a reasonable length of 25 centimeters at the beginning of the fifth year, one should not be allowed to destroy it after the second year of life. Haddock becomes marketable within 3 years and therefore may not be destroyed undersized at any age. For plaice, the results of Russell are completely in agreement with the observations of Bückmann, who arrived at them in an entirely different way. Bückmann(1932) computed the size and classification of the catches for the hypothetical cases that the whole fish stock is being fished with one of the nets A, B or C (table 9). The chance for escape of undersized fish is smallest with net A, larger with net B, and largest with net C. The loss, originating from the destroying of undersized fish, was included in the calculations. Net A, the steam trawler net used in the North Sea, retains all plaice over 17 centimeters; net B, a net used for the catching of sole, catches all plaice from a length of 20 centimeters; Net C, used for the catching of plaice by draggers, retains all plaice at 29 centimeters.

All plaice below 25 centimeters must be computed as being undersized. Assuming that the strength of this group is a million fish at the end of the first year and further assuming that 50 percent of the stock is caught every year and that the natural mortality is 10 percent until the fourth year but only 5 percent afterwards, we find that the largest catches are made with the largest size meshes; that is, when the smallest number of undersized fishes are destroyed (I). This appears also to be the case if the fishing rate is increased to 75 percent (III).

Bückmann has also observed how much the catch will be if one thins out the 0 and I groups 2/ of the plaice (II). It is shown then that the catches with the nets A and B become somewhat larger than at I, the catches with the net C somewhat smaller. The results with nets A and B show that it may have some advantage not to leave both the youngest groups protected. The results with net C give the impression that no loss will appear through the moderate thinning out of both youngest year groups.

2/ The first year fish is indicated as 0-group, the second year fish as I-group, etc.

TABLE 9.--Hypothetical catches to be expected when fishing a stock with 3 nets of varying selectivity and at varying fishing rates.

Net		Fishing Rate	Catch of marketable fish			Number of under-sized fish
			Strength at end of 2nd year	Weight (Kilogram)	Number of fish	
	A			39,271	166,316	679,532
I	B	50%	1,000,000	44,535	199,227	608,334
	C			87,584	364,237	352,314
	A			41,931	155,397	525,220
II	B	50%	800,000	49,740	213,941	436,354
	C			85,151	337,174	258,354
	A			15,562	74,865	803,435
III	B	75%	1,000,000	30,249	152,553	692,317
	C			73,633	340,927	420,946

The shrimp fishery is the only one which destroys great numbers of plaice of the 0 and I group. From the above it appears that as long as this destroying does not take extraordinary dimensions, it is not necessary for the promotion of the plaice fishery to take measures against the shrimp fishery. The real fishery for trash plaice was after fish of more than two years old, and this cannot be defended with the argument that by increasing density the speed of growth is lowered.

Measures to forbid the landing of undersized fish and to limit their catching have been taken in Great Britain and in Germany since 1933. Denmark has had a minimum size for plaice of 26 centimeters for even a longer period.

3. Summary of Methods for the Protection of Undersized Fish

Theoretically a decrease in the destruction of undersized fish could be accomplished in two different ways:

1. By preventing the catch of small fish.
2. By throwing the small fish back overboard.

a. Regulations Suggested to Prevent the Catching of Undersized Fish

Several methods have been tried to prevent the destruction of undersized fish:

aa. Enlarging the mesh width of the net.
bb. Special devices on the net to promote the escape of undersized fish.
cc. Special fishing methods whereby fewer undersized fish are caught.
dd. The closing of grounds where many undersized fish are present.

A short summary will be given here to show the extent to which these methods have been able to attain the desired goal.

aa. Enlarging the Mesh Width

This is rational only when it appears that more undersized fish escape by using larger meshes. This has been denied often (Beauge, 1934); it was said that during the towing the meshes were pulled together so that nothing could escape. It is, therefore, necessary to show what tests have proven about the possibilities of escape through the meshes of the net.

Davis (1934) showed that the undersized fish escaped during the towing, not, as many others thought, during the hauling on board of the net. Davis fastened a fine-meshed net around the cod end of the trawl. This outer net was closed by a clever device before the trawl was hauled on board. The fish contained in the outer net were in good condition. Therefore, the meshes are open during the towing and it is possible for the small fish to escape undamaged. Iversen (1934) made observations and tests with outer nets in the Barents Sea and came to the same conclusion, i.e., that even the herring were still in excellent condition after passing through the meshes. Herrington (1935) did rather similar work on board American trawlers of the New England coast.

Several tests have been made to decide through which parts of the net the escape takes place chiefly. Todd (1911) found by setting outer nets at various parts around the net that most fish escaped through the rear-end--the so-called cod end--of the net. On the other hand, Borowick (1930) found that a fairly large amount of fish escaped through other parts of the net. It is not impossible that the results of these tests were disturbed by interfering factors. Clark (1934) found with Borowik's method that most undersized fish escape through the cod end of the seine (zeevischzegen). Many other observations support the idea that the fish only begin to try to escape after they have entered the cod end. The cod-end meshes are always the narrowest ones of the net. Therefore, when considering the effect of mesh-width enlarging, it may be sufficient to compare the effect of cod ends of various mesh widths.

The best conception of the effect of a cod end of a certain mesh width is obtained when the numbers of the various length groups of a fish species are determined with the aid of a fine-meshed net. Then, at the same locality, the percentage of the total number of each length group that remains in the net of a certain cod end can be determined. Data are then obtained whereby a selection curve can be drawn, i.e., a curve which shows what percentage of the fish of each length group that come into the net remains there. Figure 5 shows several selection curves made during various tests of foreign researchers. The curves shown in figure 5a for double-twine cod ends of 5 1/2, 6 1/2 and 8 3/4 centimeters for haddock, are part of a series of tests made in the same locality, with the same ship and the same speed of tow (Bowman, 1930). Another series show the selection curves for plaice for double-twine cod ends of 5 1/2 centimeters (Bückmann, 1932) and 10 centimeters (Davis, 1934 c). The curves for single-twine meshes of 7 1/2 centimeters and 8 3/4 centimeters, together with the curves shown in 5c for sole, form part of a series in which sailing trawlers were used instead of steam trawlers (Buchanan-Wollaston, 1935).

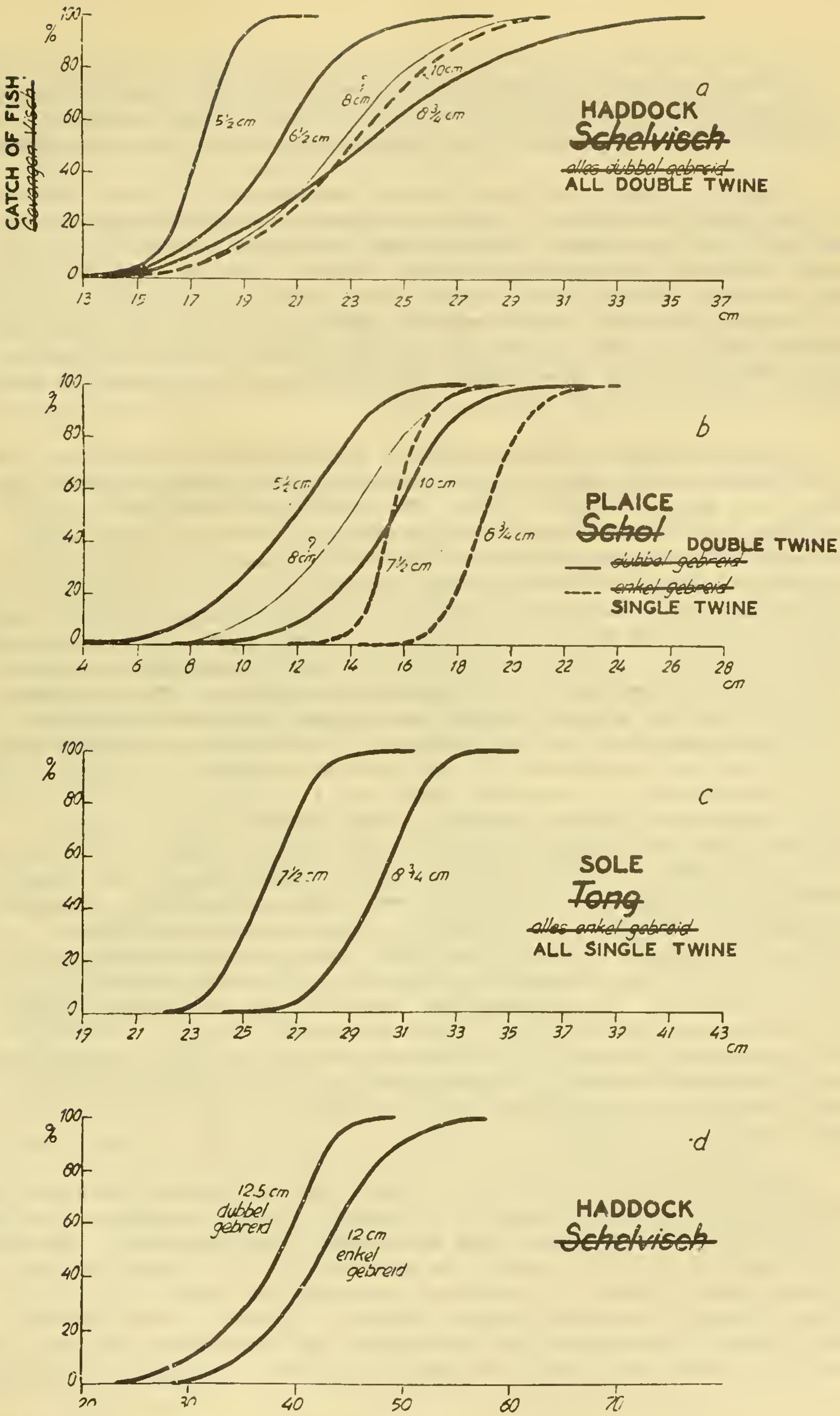

Figure 5.--Selection curves with nets of cod ends of various meshes and species determined under various conditions. The positions of the 9 centimeter curve for haddock and plaice were interpolated from other curves.

If the selected curves of the same series are observed together, it appears that they move to the right by enlarging the meshes; that is to say, more undersized fish escape by enlarging the mesh width.

However, there are other factors responsible for the direction of the selection curves. Figure 5d shows selection curves of cod end of 12 1/2 centimeter double twine and 12 centimeter single twine towed by steam trawlers (Herrington, 1935). The somewhat narrower, single-twine cod end clearly gives more undersized fish an opportunity for escape. This is understandable although single and double knitted nets of the same mesh widths are knitted on the same shuttle, the double knitted ones have smaller openings especially when the knots swell after submerging (Davis, 1929).

Complaints came from many small trawl fishermen about the loss of marketable sole when a minimum mesh width of 70 millimeters for trawl nets was ordered in 1937. The complaints were investigated (de Veen, 1937) and indeed it appeared that a fairly large amount of marketable sole was lost with the 70 millimeter meshes, while by the use of meshes of 55 millimeter practically no very small. marketable plaice were being caught. This pertains chiefly to very small ships, most of which were sailing craft with low towing speeds. The faster towing draggers and cutters caught considerable amounts of small sole, even with the 70 millimeter meshes. The only conclusion that can be made is that the chance of escape diminishes with the increase of the towing speed. Figure 5a for haddock shows, in addition to the series of 3 cod ends with meshes of 5 1/2, 6 1/2 and 8 3/4 centimeters, a selection curve for a cod end with a mesh size of 10 centimeters (Davis, 1934 c). The position of the curve (judged with the length group whereby 50 percent remained in the net) is equal to that of the curve of 8 3/4 centimeters. It is very probable that the 10 centimeter curve moved to the left, compared to the other three, since the first curve was determined on a trawler with greater towing speed than the one used in the other tests. For the tests in which plaice and sole were caught by sailing trawlers, the single-meshed nets and the slow towing speed caused a moving to the right of the selection curves, in relation to the curves prepared for plaice with the aid of double-twine nets towed by steam trawlers. Unfortunately we do not possess curves for sole prepared from tests made with steam trawlers and double-twine nets.

It is clear from the shape of the selection curves that the net does not make a clear selection but always catches a few fish below a certain size and allows a few above that size to escape. Therefore, it is never possible to avoid the catching of all fish below the minimum size. There is a certain non-selective action and as this action lessens the curve becomes steeper. There are two factors which probably encourage the selectivity and therefore make the curves steeper. These are a smaller towing speed and a single-knitted mesh.

Figure 3 gives the impression that the selectivity is lessened by enlarging the mesh width. This does not appear to be true in any of the other curves and it is likely that the flat curve of the 8 3/4 centimeter cod end was caused by faulty testing. The much steeper 10 centimeter curve supports this opinion.

It is very difficult to make regulations to encourage the selectivity of the nets. It is hardly possible to order the fishermen to use single-knitted meshes in the cod end when this would weaken the construction of the net. Nor can a maximum towing speed be set. One can only try to convince the fishermen that it is not necessary to tow as fast as possible, by pointing out that the British and German ships have the habit of turning their engine over at slow speed during the towing.

It is practical, however, to order a larger minimum mesh width. Elaborate English tests have shown the effects of this in practice.

The English fishery biologist, Davis (1934 a,c) had two indentical trawlers fish for two months on a normal commercial basis as near as possible to one another. One had a cod end with 7 1/2 centimeter meshes and the other had meshes of 10 centimeter. The principal catch was haddock. The results of this test, given in weight, appear in figure 6. Fewer small and more large fish were caught with the large-meshed cod end. Moreover, the smaller-meshed cod end brought up more trash. The total returns were approximately alike for both ships. Therefore, undersized fish, labor and material were saved without financial loss.

A similar test was made with two trawlers fishing for "heek" out of Cardiff (Fishery notice, 1934). Cod ends with meshes of about 10 centimeters were compared with cod ends with meshes of about 12 1/2 centimeters. The large-meshed net caught only half as much undersized "heek" as the small-meshed one. The returns per-10-hours fishing for the larger-mesh net averaged 27 guilders, with the small meshes, 25 guilders/7 schillings. It was clearly more economical to fish with the larger-meshed cod end.

The above tests were made by order of the British Government, but similar tests were made by a shipping concern on their own initiative in Grimsby during 1945. Nine trawlers were employed for these tests. They fished in the West and mid-North Sea, chiefly for medium sized cod, plaice and fine fish. The large-meshed net produced about one basket of undersized fish each haul, while the small-meshed net produced 37 baskets each haul. The large-meshed net hauled about 42 baskets of trash against 105 for the small-meshed one.

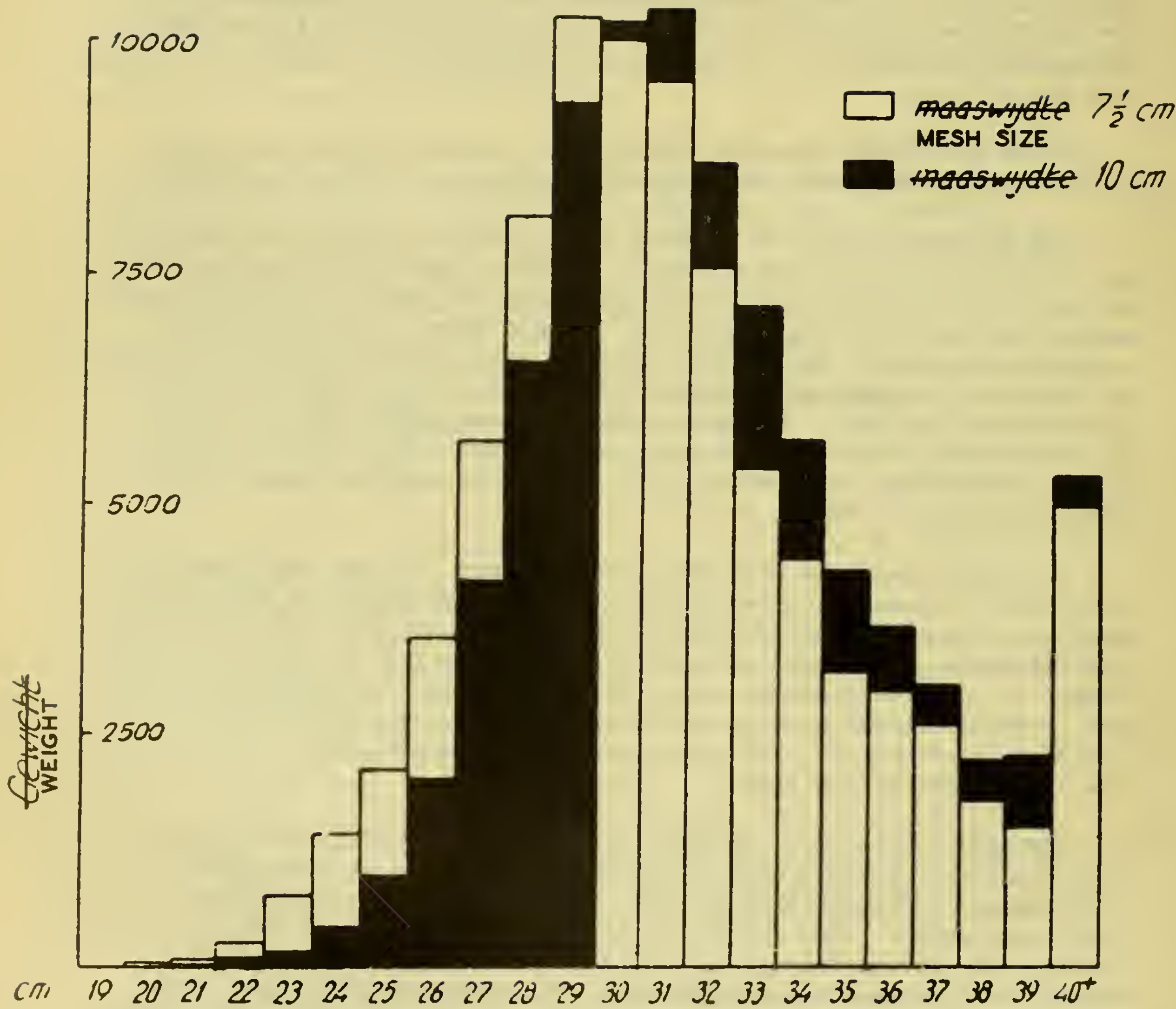

Figure 6.--Graphic picture of the results of tests made by Davis (see text). The amount of haddock remaining in the small-meshed net is shown for each size group in white; those that remained in the large-meshed net are in black.

During conversations with fishermen it appeared often that they were well aware of the advantages of larger meshes. Therefore, we certainly believe that they will begin to use larger meshes when the small fish loses its value. This tendency is clearly shown by the "snurrevaad" fishery. They make such good hauls that they hardly bother with the small plaice and are only too glad to save the labor of picking the nets by the use of increasingly larger cod ends.

The end conclusion undoubtedly must be that enlarging of the mesh size is an effective means of protection for young fish. However, there is one difficulty and that is that this effect is lessened by an increase of the towing speed. If, for instance, the whole fleet were fishing a certain sea and a certain minimum mesh width was ordered, the faster ships would catch more undersized fish than those ships which towed slower. Moreover, by using a very large mesh, the latter would lose small marketable fish which did not get a chance to escape in nets which were towed faster.

bb. Special Devices to Promote the Escape of Undersized fish

Several tests have been made with trawl nets fitted with devices to facilitate the escape of undersized fish.

Insofar as these nets are used exclusively for the catching of roundfish, the device is aimed to make the selection curve steeper. To this end, stiffeners were attached to the nets to decrease the tension on the meshes in a lateral direction. These improvements were effective during tests made on board American trawlers (Herrington, 1935) but we did not receive the impression that they came into general use. Another improvement was tried with the so-called Rowton-Streamline-trawl, which was constructed in such a way that the flow of water would force open the meshes. Neither did this trawl come into general use.

Another savings trawl was designed to let the undersized flatfish (which are far wider than roundfish of the same length) escape without loss of the oversized roundfish. Special panels with irregular meshes (usually elongated meshes) were made in the nets (Ridderstad-trawl, Gelder-trawl) while sometimes devices were fastened onto the trawl to make the meshes stand open (Ridderstad, 1915; Gelder, 1929). Several tests have been made with these trawls (Buchanan-Wollaston, 1929; Davis, 1930; Bückmann, 1931). With this method, greater numbers of undersized flatfish could escape generally. They were, however, very much harder to handle and the chance of damage was considerably greater. The existing forms of "savings trawls" certainly cannot be said to give a solution to the problem.

Protection methods increase the density of the fish stock with a consequent decline in the rate of growth. A decline in the rate of growth will result from protecting the undersized fish by enlarging the chances of escape through the use of larger meshes. Consequently the fish remain undersized longer and the chance that they will be caught increases. Therefore, the chance that they will be taken in the net increases. There are two opposing factors here. When considering the execution of protection regulations it will be necessary to follow exactly the reciprocal working of both factors.

cc. Special Fishing Methods whereby Undersized Fish Received Less Damage

The fishery with seines and line trawls can be considered as such. The first type, that is the "snurrevaad" fishery in general use in Denmark, saves practically 100 percent of the undersized flatfish. With this method the fish are not pushed together in a bag for hours but are gradually driven to the center by a concentric pushing over the bottom of a line towed in a circle. Then they are brought on board alive by a fairly small, wide-meshed, dip net. The undersized fish, which may be still in the net, are then set free alive. This type of fishing is done with the motor-cutters-comparatively small, seaworthy ships--manned by four men.

The great advantages of this fishery are:

1. The good quality of the fish;
2. the protection of undersized fish and the protection of bottom-organism which serve as food, since the bottom is not disturbed by a heavy ground line;
3. the lower fuel consumption and less wear and tear of the gear;
4. the very small likelihood of losing the gear, as compared with the trawl fishery.

The inherent drawbacks are that this method can be used only during the daytime and that during bad weather it has to cease sooner than the trawl fishery. These objections are felt especially during the winter months. Furthermore, very small amounts of sole are caught with this method. Presumably this is due to peculiarities in the behavior of this species. Cod and haddock are occasionally caught, although it is principally a plaice fishery.

The disadvantage of the small catches of sole is made good by the larger hauls of plaice and the smaller costs of exploitation. The final drawback is that the technique is more refined and that more intelligence and persistance is necessary than for the trawl fishery.

The Danish fishery has increased enormously since the perfection of this method. The landings of plaice increased in Denmark during a period when in other countries it was lowered or remained constant. The Danes can keep without difficulty a minimum size of 26 centimeters for their own use and a minimum size of 24.5 centimeters for export.

During the years 1927-37 they caught just under one-third of all plaice landed from the North Sea. This is about as much as England landed and twice that landed by the Netherlands. During and after the last war our fishermen started to understand the advantages of this method and the number of fishermen using the method is steadily increasing.

Line trawling is undoubtedly a technique which saves the under-sized fish. However, since 1935 this method is practically nowhere in use since it is impossible (time-consuming and expensive baiting of the lines) to compete with the inexpensive trawl fish. This also makes it impossible to renew this method for the protection of young fish.

dd. Closing of Grounds where Young Fish are Present for Trawling

This can be done in two ways. First, certain grounds may be set aside, and by a decree and by constant controlling harmful fishing techniques can be prevented. In the second place, the minimum size below which no fish may be landed can be set so high that it would be uneconomical to fish on these grounds. If a fisherman has made a haul on such a spot he will look for other grounds for his next hauls.

The first rule is possible only if the young fish remain in the same grounds. If the young fish appears first in one place and then in the other, it will not be practicable to protect it by closing certain grounds.

Furthermore, the closing of areas for the protection of young fish will be more difficult if considerable quantities of marketable fish are found on the same grounds. The resistance against such a rule would become extraordinarily great if there are marketable species which are less easily caught outside the closed grounds.

In all such cases there is much to be said for protecting the young fish by setting a high minimum size. Generally, the young fish will not be equally distributed over the to-be-closed area, but will be concentrated in certain spots, for instance the shallower areas. The valuable fish will then generally be found in other places such as deep gullies and holes. The minimum size will have to be so high that if a fisherman has accidentally hauled in a concentration of small fish, he will have so much sorting to do and will have so little marketable fish that it will not seem very agreeable to make another haul in the same spot.

The protection afforded by a high minimum size will undoubtedly be less complete than that of closing the grounds. In such places where the danger of destruction of the young is extremely great, for instance by a very limited area of the grounds where the young fish are present, it is possibly better to close the area completely. It is therefore necessary to realize if the advantages of closing are outweighed by:

1. The enormous costs and difficulties connected with the efficient closing of an area in the sea;
2. the possibility of considerable damage to the coastal fishery since most of the area within its reach will be closed.
3. the chance that through over-population the rate of growth in the cloased area will become unfavorably low.

The difficulties of controlling the closed area must not be underestimated. The British found when they closed the Moray Firth to trawlers, that there were many possibilities for surreptitious fishing in the forbidden area. This was true of a comparatively small and easily guarded area; certainly a great deal different than, for instance, a long coastal region. Experiences during the war have undoubtedly produced methods which could be used for the guarding of closed areas, but it may be assumed that it will be a difficult task and especially an expensive one.

The objection that the rate of growth would decline seriously must be considered and may perhaps be solved by experiences found during both World Wars when various areas were practically closed to the fishery. The decline in growth rate may perhaps be limited by allowing seine and line trawl fishing in the closed areas. These techniques are not harmful to the young fish and the older fish would be "culled" so that food again would become available for the young fish.

b. The Possibility of Throwing Undersized Fish Back Alive

Several tests have been made to determine the effect of throwing undersized fish back overboard.

It appeared from older observations (Masterman, 1908; von Reitzenstein, 1908; Borley, 1909) that several factors influence the living vitality of fish thrown on deck. The otter trawl delivers the fish on deck in a worse condition than the beam trawl; longer hauls are worse than short ones; jellyfish or trash in the nets lowers the percentage of living fish. Moreover, the fish deteriorates on deck, especially in warm weather and sunshine.

The British Fishery Biological Service made extensive tests during 1935 and 1936 to determine if it were possible to keep undersized plaice alive after they had been brought on deck by throwing them back. The living vitality was checked in two ways; the fish were kept on board in tanks for several hours and were put back after tagging, then reports on the catching of tagged fish were collected. 71 percent of the plaice set overboard immediately after hauling remained alive during May. 36 percent of the plaice, which had remained on deck for an hour, remained alive. Roundfish are almost always dead or nearly dead when hauled on deck.

Therefore, it appears possible to keep alive a fairly large proportion of the undersized fish by quickly throwing them overboard. Many fishermen think that they cannot do this. In the first place, it is the rule to set the net immediately after the catch has been emptied on deck and it is feared that the trash thrown overboard will immediately get back in the net again. In the second place, it is usual to pick out the marketable fish first and then shovel the rest back. Everyone has a strong desire to take the best fish out of the catch first and it will be very difficult and perhaps even impractical to change this working method. It appears to me undesirable to order the fishermen to throw the trash back immediately, not only because of the enumerated objections but also because the compliance to such an order cannot be controlled. However, it is recommended that the fishermen be encouraged to throw back as much alive undersized fish as possible. I am certain that this will produce some results, especially for the coastal fishery, the more so since I have seen that several fishermen sorted the catch of plaice on their own initiative in such a way that, about half an hour after the catch came on board, the undersized fish had been set back in the sea in excellent condition. They did this by shoveling small quantities of fish on a rail table, picking out the marketable fish and shoving the rest into the sea. These fishermen did not believe that these undersized fish went right back into the net which they had set again. Although we are of the opinion that a great many undersized fish may be saved from destruction by careful handling, we must realize that under present methods, most trash, once caught, is dead when put overboard.

These undersized fish are not lost to the fish stock, however, insofar as they become food for crabs, worms, etc., and thus encourage the growth of food animals for the fish. Therefore, the trash can be of value for the fish stock especially in an area where lack of food keeps the rate of growth below the maximum.

c. Rules for the Determination of the Minimum Size

In the above we have mentioned undersized fish without discussing in which way this size has to be determined.

The utimate lower limit is set by the demand that sufficent eggs have to be produced each year to keep the fish stock at the desired strength. Although the female fish lays thousands of eggs, the very great natural mortality among the young brood may be brought to a point--through fishing--which could result in an insufficient number of female maturing.

Therefore, it is necessary to know how many eggs are absolutely necessary, how many females must mature and how long the growing year classes have to be protected to produce this number of mature females. The males can be ignored in this discussion; they become sexually ripe at a younger age and at a shorter length than the females.

It may be useful to set the size higher if, by allowing the fish to live longer, a greater return can be had from the same number of fish. If a group of fishes is left longer without fishing they will increase individually in weight. A few will die, however, and the weight of these fishes will have to be subtracted from the increase. Moreover, as the fish live longer they will take a larger amount of food from the limited amount of available food stock for metabolism and their rate of growth will decline.

Enlarging the minimum size above the minimum necessary for egg production is only necessary if the increase in weight, regardless of the decline of the growth rate, exceeds the loss by natural mortality and destruction of undersized fish by the fishery.

Finally, it needs to be taken into account if the weight increase also represents an increase in financial returns. This will be true for the majority of fish species as the price per kilogram increases progressively with the length of the fish. In this case protection will already be profitable when the total weight of the fish catch is not necessarily greater but when only the average length increases. Sometimes, however, it happens that the larger fish are somewhat less valuable per kilogram than the smaller ones.

Since the reasons for the determination of the lower limit of the minimum size and those for the determination of the upper limit are different, there is theoretically a possibility that the lower limit advocated for retaining an adequate egg production will be above the upper limit desired for economic reasons. However, this possibility is not very great.

Now we can determine the best size for each species and, in agreement therewith, the best mesh width. Since we may expect various species in the same region, it will be necessary to make one mesh width for all these species. This will have to be a compromise between those which will be best for each species. In many cases it will be desirable to connect the definite minimum sizes,--utilizing the selection curves--with the mesh width; that is, to set them so that as few fish as possible will have to be thrown back, without tempting the fisherman to evade the regulations for mesh widths. We believe, therefore, that the minimum size must be set at the length group whereby 75 percent of the fish caught remains in the net.

Deviations from the size, found by the above rules, may be considered if that size is designed to make fishing unprofitable in certain areas which one does not want to be fished. Also, deviations from the size may be considered if that size is designed to prevent a fishery from becoming unprofitable in certain areas.

It has been stated repeatedly that undersized fish will always remain in the nets and that the possibility is very small that these fish get back in the sea in a good enough condition to remain alive. Therefore, there will always be a vocal protest on the part of the fish-meal industry and the duck farms. They will want these fish, which are lost anyway, to be landed. Therefore, it needs to be emphasized that the minimum size is precisely the only satisfactory control on the compliance with the regulations for mesh widths, as well as for the avoiding of the protected areas.

It is impossible to control the use of cod ends at sea, because the possibilities for avoiding the mesh-width regulations are very simple. (For instance, by setting two cod ends over each other, or by using a cod end authorized for pelagic fishing for herring or mackerel.) Even the catch of some species of less importance for human consumption will have to be limited in order that the value of these fish will not be large enough to constitute a reason for an avoidance of the mesh-width regulations, or that the fishing in the protected areas will be attempted.

Finally I want to remark that undersized fish, even if thrown back dead, will be of some use to the fish stock. Part will be eaten by organisms which in turn will become food for the fish. Part, through bacterial action will free inorganic salts of phosphates, nitrates and other essential nutrients which will build up the productivity of the sea. This is profitable for the fishery, since we have already stated that the productivity of the North Sea is insufficient for the maximum growth of all fishes.

4. Projected Measures to Minimize the Catch of Non-marketable Fish in the North Sea

a. Motivation of the proposed plans.

In the North Sea, the haddock and the plaice were overfished.

aa. Haddock

To begin with we have to establish a minimum catchable size for haddock. This should be established with regard to the fishing intensity which may be expected in the future, to enable the egg production to retain the stock at the proper density level before overfishing occurs. This point can be established fairly accurately. Through the work of Thompson and Raitt (Raitt, 1939) the relative strength of the year classes 1918-36 is known. The strengths change enormously from year to year due to factors still largely unknown, which we have called fluctuation factors (pp.20, 25). The class of 1918, for instance, is 62 times as large as the weak 1922 class.

Figure 7 shows the relative strength of the different year classes (curve A). From this graph it is difficult to see if the average strength has changed during the last decade. However, if we simplify the original fluctuation curve by constructing a new point from the media of 3 successive points we arrive at curve B, showing clearly that after 1930 the strength did not rise above the average of all year classes, while before 1930 only the year classes 1921, 1922 and 1926 were somewhat below the average.

Apparently, therefore, during the second half of the period 1918-36, the egg production was not sufficient to maintain the haddock stock, while during the first period the egg production must have been large enough to do so.

Now we have to establish for both periods how many eggs are produced by a group of haddock which, for instance, at the beginning of their second year had a strength of 1,000 (so-called group I).

We know from Raitt's work (1939) how much each year class has declined on the average from year to year during both periods. With the aid of these numbers we could show in columns 2 and 8 of table 10 how many of the 1,000 one-year-old fishes will be left over at the end of each succeeding year. Exact data on the numerical ratio of both sexes are not known.

It is assumed here that in each year class there would be as many males as females and so we arrived at the numbers in columns 3 and 9. Raitt (1936) has also shown what percentage of females are sexually ripe at different age levels (column 4), thus we can establish how many ripe females were present during the various periods (columns 6 and 10). He has shown also (1933) how many eggs a female delivers on the average at different age levels (column 6) and from that we can establish the number of eggs produced by all females of each age level (columns 7 and 11).

By the addition of these numbers we arrive at the number of eggs which, by various degrees of fishing, were produced by a group of haddock having at the beginning of their second year a numerical strength of 1,000. In other words, we may say that about 17 million eggs are insufficient to product 1,000 one-year-old haddock, but that 34 million eggs very probably will be enough.

Therefore, 34,000 eggs are needed to produce a single one-year-old haddock. Thus, if the fish stock is not to decline and if there were as many males as females, one female has to spawn 68,000 eggs. This is a figure which lies between the number of eggs which a female will produce at 2 years and what she will produce at the age of 3.

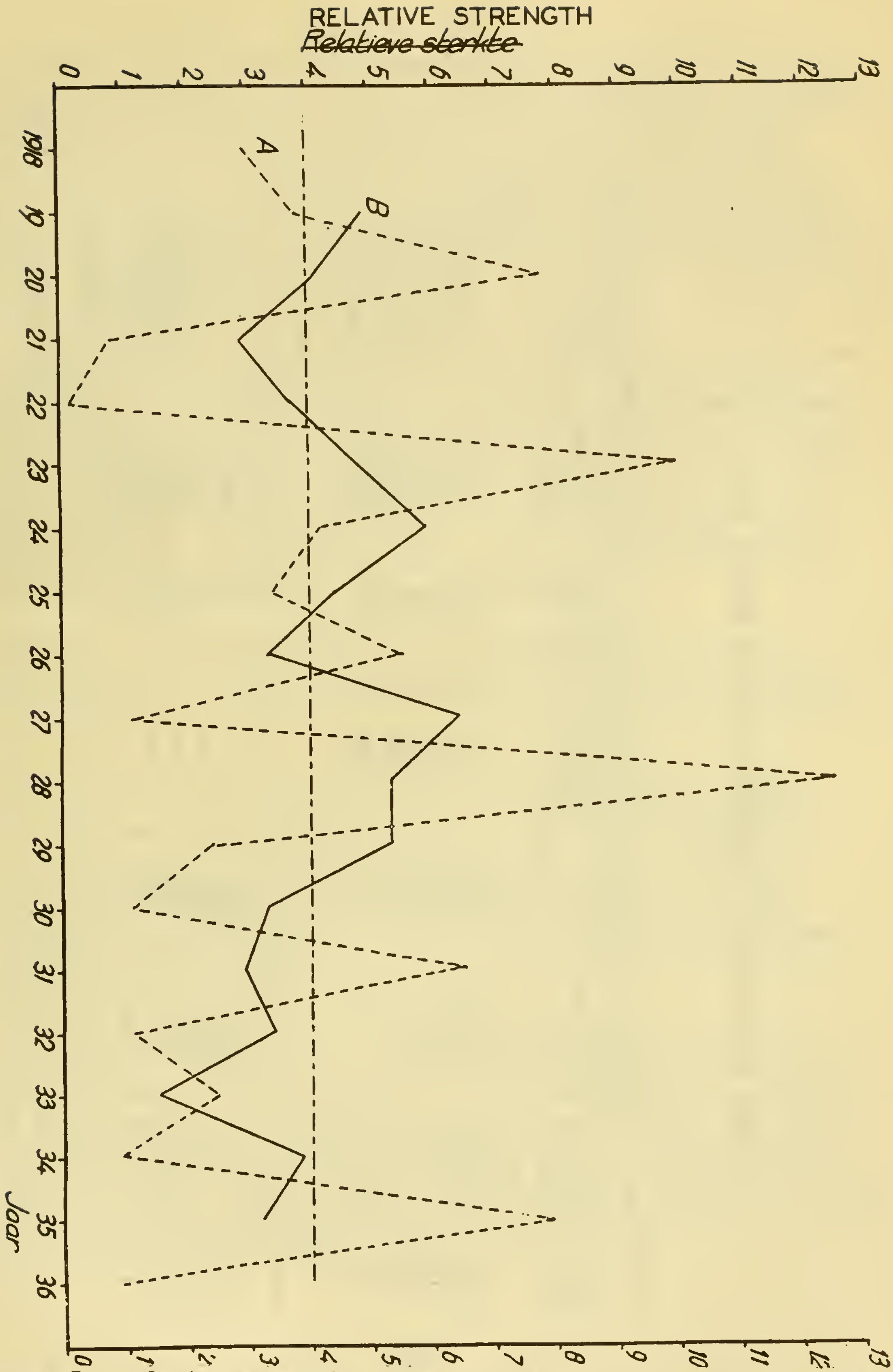

Figure 7.--Relative strength of the different year classes of the haddock in the North Sea. Broken line A shows the actual proportional numbers, line B is constructed from the averages of three continuous series of points of line A.

TABLE 1C.—Estimate of Egg Production of Haddock in Two Periods

Year Group	Period	Number at Beginning of Year	Number of Females	Percentage of Mature Females	Number of Mature Females	Number of Eggs per Mature Fem.	Number of Eggs Produced
I		1,000	500	0	0	0	0
II	1918	830	415	10	42	31,000	1,302,000
III		300	150	75	113	100,000	11,300,000
IV	to	131	66	95	63	159,000	10,017,000
V		66	33	98	32	224,000	7,168,000
VI	1927	33	16	100	16	278,000	4,448,000
							34,235,000
I		1,000	500	—	0	———	0
II		520	260	—	26	———	806,000
III	1927	170	85	—	64	———	6,400,000
IV		76	38	—	36	———	5,724,000
V	to	26	13	—	13	———	2,912,000
VI		5	3	—	3	———	834,000
	1935						
							16,676,000

A small number of females become ripe at the age of 2; the majority, however, do not become ripe before the age of 3. Therefore, the majority of females will (at the age of 3) produce more than 68,000 eggs the first time they spawn and it may be said roughly that the haddock stock retains its strength if, on the average each female spawns once. This is in agreement with a rule accepted by many marine biologists more by feeling than by a collection of facts. In reality it is not necessary that every female spawn, since a number of females spawn several times and the number of eggs increases progressively with their age.

The number of haddock that were caught by the fishery in one year was 40-50 percent during the period 1918-27, whether they remained in the nets or escaped (Bückmann, 1932). We will define this as the fishing standard. If no fish can escape through the meshes in the nets the fishing intensity (that is the measurement of the percentage of the stock killed yearly by the fishery) has the same value. If escape is possible the fishing intensity has a lower value than the fishing standard. It is now possible, for different values of the fishing intensity, to estimate how long the year classes have to be left alone, if egg production is not to decline.

This has been done in table 11 for fishing intensities of 40 percent, 50 percent and 65 percent, which augmented by natural causes would seemingly give a total mortality of, respectively, 50 percent, 60 percent and 75 percent.

Referring to table 11, the number of females which remained after 6 years of fishing, that is at the beginning of the seventh year, was placed at X. If the fishing standard is 40 percent, and the natural mortality is 10 percent, than half of the available fishes will die during each year. At the beginning of the sixth year there would be 2 X females, at the beginning of the fifth year 4 X etc. Therefore, with a total mortality of 60 percent, the number of females in the sixth year would be 2.5 X; and with a total mortality of 75 percent it would be 4 X.

The next step was to show in X the number of eggs produced by each year class. In table 10, column 6 shows the average number of eggs that the mature female spawns at different age levels; column 4 shows the percentage of females that will mature at those age levels. Multiplication of both numbers for each year class shows the number of eggs that the average female, mature and immature together, has at each age level. These numbers, shown in column 2 of table 11, must be multiplied by the number of females, shown as X (column 3), to give the total number of eggs (column 4).

TABLE 11.--Hypothetical decline of a stock of 1,000 haddock under various mortality rates.

Year Group	Average Number of eggs per female.	Total Mortality 50%: No. of females in year group	Total Mortality 50%: No. of eggs produced	Total Mortality 50%: Strength of year group	Total Mortality 60%: No. of females in group	Total Mortality 60%: No. of eggs produced	Total Mortality 60%: Strength of year group	Total Mortality 75%: No. of females in group	Total Mortality 75%: No. of eggs produced	Total Mortality 75%: Strength of year group
I	0	2^5x	---	1,088	2.5^5x	--	2,158	4^5x	--	7,168
II	3,100	2^4x	49,600x	544	2.5^4x	121,100x	863	4^4x	793,600x	1,792
III	75,000	2^3x	600,000x	272	2.5^3x	1,171,875x	345	4^3x	4,800,000x	448
IV	151,000	2^2x	604,000x	136	2.5^2x	943,750x	138	4^2x	2,416,000x	112
V	219,500	2 x	439,000x	68	2.5 x	548,750x	55	4 x	878,000x	28
VI	278,000	x	278,000x	34	x	278,000x	22	x	278,000x	7
			1,970,600x			3,063,475x			9,165,600x	

We now know that 34 million eggs are sufficient to produce 1,000 one-year-old haddock. If the 1,970,600 X eggs, produced by a total mortality of 50 percent, will produce 1,000 one-year-old fishes, then 1,970,600 X must be equal to 34,000,000; consequently, X has a value of 17. If we assume there are as many males as females (probably an incorrect hypothesis insofar as data are still missing), then the total strength of group VI is 34. With the decrease of 50 percent, there must have been 1,088 haddock during the first year. With this degree of mortality the stock can, with some protection for the fishes after their first year, produce enough eggs to maintain itself. Practically, this condition would depend on a minimum size of 19 centimeters.

With a total mortality of 60 percent, $X = 11$. The strength of group VI therefore is 22. To retain 22 fish in the seventh year with a yearly decline of 60 percent, one must start with 2,158 one-year-old fishes. The egg production is only sufficient for 1,000 one-year-old fishes. However, if one protects those 1,000 one-year-olds in such a manner that at least 863 fishes are left at the beginning of the third year, then one can allow the fish stock to decline 60 percent annually without damaging the level of the egg production. This means that during the second year the haddock stock may decline by 14 percent. This is somewhat more than the natural mortality; actually, therefore, the whole I-group must be left unfished.

To find the minimum size, the length of the haddock at the beginning of the third year has to be known. That length will depend on the rate of growth, which again is dependent on the density of fishing. In the future we want to strive to retain the density at about the optimum value. Such a density was reached about 1925. If, for the rate of growth of the haddock, we accept the value reached during the period 1925-30 (Raitt, 1939) then the minimum size will have to be 23 centimeters.

Along the same path of reasoning we arrive at the result that with a total yearly mortality of 75 percent, the 1,000 one-year-old fishes must be protected until halfway into the third year, so that at the beginning of the fourth year not less than 440 will be left. In that case it is necessary that no haddock below 27 centimeters be caught.

The above demonstrates clearly the very important fact that the biologically determined minimum size becomes larger when the fishing intensity is increased. The consequence is that a minimum size does not reach its purpose if the fishing intensity--to which this minimum size has to correspond--does not remain constant at the same time.

Figure I shows that the optimum fishing intensity must be about 75 percent of the fishing intensity that prevailed during 1933-35. From the empirically determined values for the decline of the haddock stock (Raitt, 1939) we can calculate that during the period 1930-35 the total yearly mortality was 70 percent. If we estimate the natural mortality at 10 percent, a fishing intensity of 60 percent remains. Therefore, the optimum fishing intensity would be 45 percent, the total mortality 55 percent. As long as this mortality is not exceeded, it will be necessary to spare all haddock up to 21 centimeters to retain a sufficient production.

Now we still have to see if it is rational to order a larger minimum size for economic reasons. According to Bowman (1932) the ratio between weight increases and intake of food during a given period increases until the sixth year, that is up to 37 or 40 centimeters.

The progress of prices, as it was before the war, shows that the price per kilogram also increases with the age of the fish. It is therefore profitable not to catch too young haddock, although one also may not let them get too old. For instance:

		1946	Average 1933-38
Small haddock III	(21 - 25 cm)	f 0.19	f 0.08
Small haddock II	(25 - 30 cm)	" 0.26	" 0.12
Small haddock I	(30 - 37 cm)	" 0.34	" 0.18
Small medium haddock	(37 - 44 cm)	" 0.41	" 0.30
Large medium haddock	(44 - 50 cm)	" 0.49	" 0.36
Large haddock	(larger than 50 cm)	" 0.49	" 0.38

f = guilder

Economically, therefore, it is desirable to let haddock live until they have reached a length of 21 centimeters.

To be able to see how the protection of young haddock may be brought about, we first have to observe the life history of the haddock.

The haddock stock in the North Sea may be assumed to be practically independent. The most important breeding places are near the Shetlands, the Viking Bank, the Coral Bank, and near the Rockall Bank. The spawning time is around March. The haddock concentrates then in an area, roughly between the Moray Firth, the Hebrides, the Shetlands and a line from the Viking Bank to the fishing grounds and from there to Moray Firth. The largest and oldest fish are near the north and northeast side of this area; the nearer one gets from there to the Moray Firth the younger are the haddock which are caught. After the spawning begins they move to the feeding grounds where the school divides itself. A part goes to the northwest and remains there in the neighborhood of the Rockall Bank, Shetlands and Orkneys and south to the neighborhood of the Moray Firth. The other part goes more or less far into the southern part of the North Sea. The fishes which are not yet mature move little or not at all. Between 55° and 62° n., latitude between the British coast and 4° e., longitude, the haddock may be found everywhere; the older year groups do not go as far as the younger ones do. Eight year-old and older fish are to be found principally on the spawning grounds.

The distribution of the young brood is not the same every year. In general it may be said that the young haddock are found at the British east coast and in the largest concentrations at the Shetlands and near the Scottish and north English coast (see figure 8). In these fairly large areas, where the younger haddock are concentrated, 3-year-old and older-fishes are also fairly numerous.

This phenomenon, although the younger and older fish form separate schools in the same area, makes it undesirable to protect the young haddock by closing certain areas for the fishery. The opportunity to make good catches fairly near home would be taken away from the fisherman and this would be a heavy blow, especially for the smaller British fisherman. Moreover, the area which one would have to close is so large that it is a question whether it is possible to police it efficiently and if the advantage to be had by taking this measure would weigh against the high costs of control. It seems more rational to find a measure which would make the fishing in those areas as unharmful as possible for the young haddock. From our point of view this is possible by enforcing a large minimum mesh width combined with a large minimum size for the fish.

If we observe the selection curves in figure 5 it appears that even with a net with cod-end mesh of 8 3/4 centimeters, a fairly large number of fish of 21 centimeters will still be caught. Therefore, it would be commendable to use an even wider net for haddock. As far as we can see this would not be objectionable for the larger and faster trawlers. The smaller, slower vessels of the coast fisheries would lose fairly large amounts of sole and whiting with cod ends of more than 8 centimeter mesh widths. Much could be said for a regulation that gave the smaller ships a smaller minimum mesh width that the larger ones, if it were not that this would make the control of the regulation appreciably more difficult.

Therefore, we would advise the adoption of one uniform, minimum mesh width of 80 millimeters for the entire North Sea. Efforts should be made by publication and eventually by enlarging the experiments so that the owners of haddock boats will fit their ships out with wide-meshed nets without being forced to do so. This will turn out to be in their own interest. It is not improbable that it will also be to the interest of the coastal fishermen to use a wider mesh.

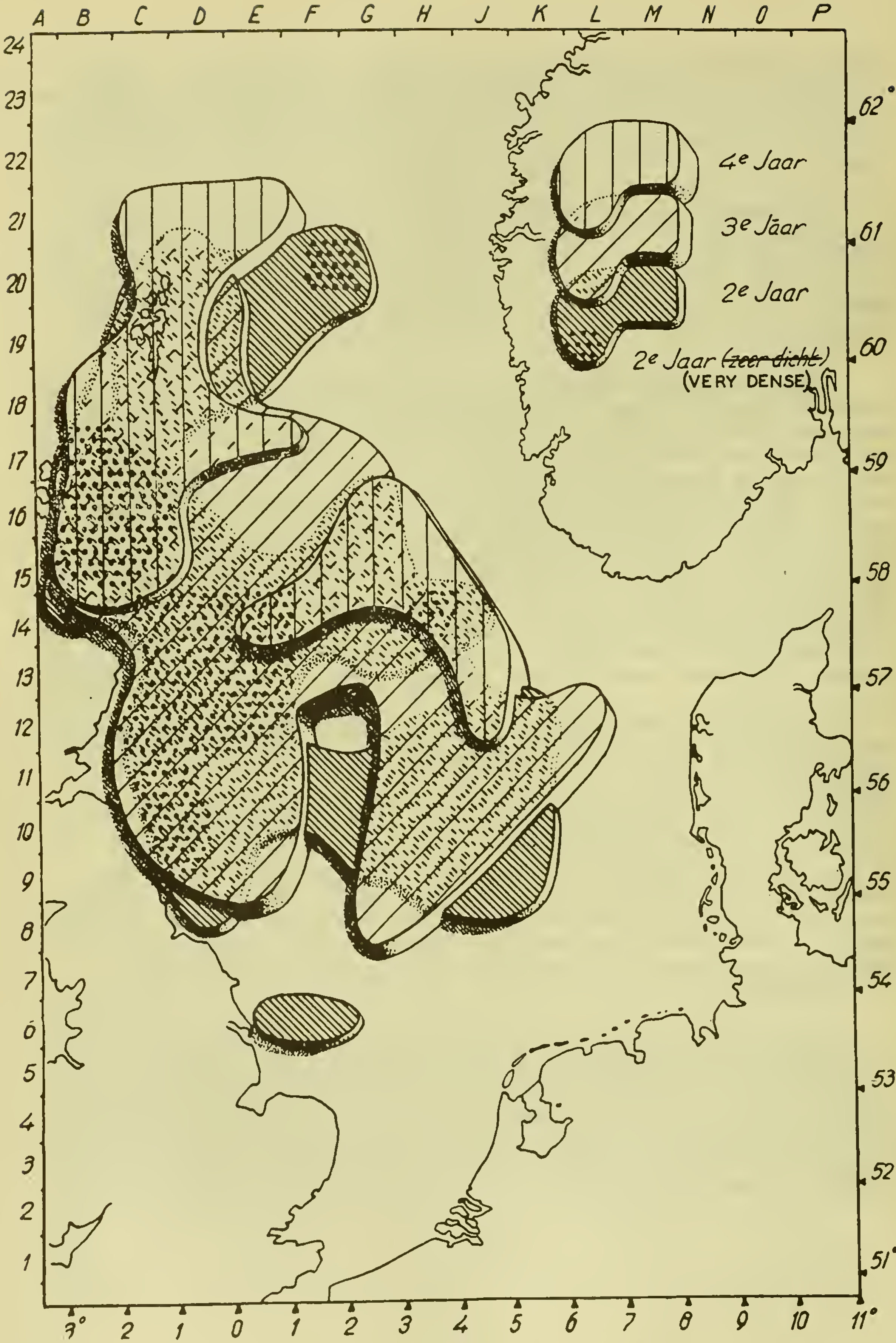

Figure 8.--Distribution of the 1, 2, and 3-year-old haddock in the North Sea. There may be haddock outside the indicated areas, but in much smaller quantity.

However, in the absence of experiments with this type of ship, it cannot be said with certainty. An important part of their income comes from the sole catches, and it is not unlikely that with cod ends of more than 8 centimeter mesh width, they would lose sole of 16-30 centimeter. Generally sole of such size bring good prices, often not much less than larger sole. There is no doubt that, with wider cod ends, they would lose more whiting. This would be of little importance to the total amount of their returns since whiting brings a very low price. It is to be expected that the loss of whiting will be very well compensated by better catches, as a result of the increase of density of the stock by the preservation of young fish with the wide-meshed nets. A serious objection against the reduced catch of whiting, however, is the fact that the whiting in normal times is so little in demand that it actually may be looked upon as a sort of weed. The food consumed by the whiting could be eaten by more valuable fish and, therefore, it is objectionable to give the whiting an unlimited opportunity to increase itself.

If one wants to be certain that the regulation (to use nets of not less than 80 millimeters) will not be by-passed, then one has to set the minimum size for haddock at a length whereby three-quarters of those which enter the net are caught. This means a minimum size of 27 centimeters (see fig. 5A).

The size of 27 centimeters is absolutely necessary to prevent the by-passing of the mesh-width regulations. As with every minimum size, it has the disadvantage that some fish will have to be thrown back into the sea. Included therein are fish which in the past had a fairly good value. Therefore, we have to ask ourselves if this waste is balanced by the advantages of the regulations.

A series of tabulations has been made in table 12 to estimate the price of 1,000 haddock while fishing with 1) nets with cod-end meshes of 5 1/2 centimeter and 2) nets with a minimum mesh width of 8 centimeters. In the first case, a minimum size of 21 centimeters would be in effect. Before the war practically no haddock were brought in below this size. In the second case, all haddock below 27 centimeters were taken to be valueless.

In table 12a, the rate of growth has been taken as it was during the period 1926-33, when cod-end meshes of 55 millimeters were principally used (Raitt, 1939). It is calculated that 40 percent-per-year of the haddock present were caught and with the aid of the selection curve in figure 3a, it was tabulated how many fish of each age group remained in the net (column 5). The natural mortality everywhere is taken at 10%. The prices are the average prices during the period 1933-38

TABLE 12.

TABLE 12a

5-1/2 centimeter purse with minimum size of 21 centimeters

Year Group	Average length at beginning of year in centimeters	Av. length over whole year in centimeters	Natural mortality in percentage	Mortality through fishing	Strength of year group at end of year	Catch in numbers of fish	Av. weight by length sizes of column 3 in grams	Catch in kilograms	Price per kilogram in cents	Returns in guilders
0			10	0	1,000					
I	17	20	10	35*	900	162	80	13	8	1.04
II	24.5	26.5	10	40	500	200	160	32	12	3.84
III	29.5	31	10	40	250	100	260	26	18	4.69
IV	33.5	34.5	10	40	125	50	370	18.5	18	3.33
V	37	38	10	40	62	25	500	12.5	30	3.75
VI	40	41	10	40	31	12	650	7.8	30	2.34
VII	43	44	10	40	15	6	870	5.2	30	1.56
					2,883			115.0		20.55

*18% of this above 21 centimeter

TABLE 12b

8 centimeter purse with minimum size of 27 centimeters

Year Group	Average length at beginning of year in centimeters	Av. length over whole year in centimeters	Natural mortality in percentage	Mortality through fishing	Strength of year group at end of year	Catch in numbers of fish	Av. weight by length sizes of column 3 in grams	Catch in kilograms	Price per kilogram in cents	Returns in guilders
0			10	0	1,000	--				
I	15	18	10	5	900	45	64		non-	
II	22	24.5	10	27	765	207	128		Marketable	
III	27	29	10	39	482	188	208	39.1	15	5.86
IV	30.5	32.5	10	40	246	98	296	29.0	18	5.22
V	33.5	35.5	10	40	123	49	400	19.6	18	3.53
VI	37	38.5	10	40	62	25	520	13.0	30	3.90
VII	40	42	10	40	31	12	696	8.4	30	2.52
VIII	42.5	44.5	10	40	16	6	900	5.4	30	1.62
					3,625			114.5		22.65

To find the average length of the various age groups, under the changed circumstances of table 12b, it was assumed that the rate of growth (measured as weight-increase-per-year) decreases in reverse proportion to the density-increase of the stock. This is a simplified illustration which, however, seems to be reasonable (Bückmann, 1932). The densities of both stocks are equal to the sums of columns 6 of each table, that is as 2,883 + 3,625. With this number the intervals between the average weights of the various age groups (column 8, table 12a) must be multiplied to arrive at the intervals, and consequently the weights, under the new conditions (column 9, table 12b). The average sizes and the starting lengths of each age group can be found again from these weights.

Our tabulations show that by fishing with the wide-meshed net, about 115 kilograms of haddock bring in 2.10 guilders more than when the small-meshed purse is used (see table 12a). This means a profit of 294,000 guilders on the approximately 14,000,000 kilograms which could be landed in Holland (1930).

This is not the only advantage. The most important result is that because of the protection, the haddock stock becomes 1.3 times as dense. That is to say, the same catches can be made in only 78 percent of the time formerly necessary. In the above tabulations it was assumed that after the start of the conservation regulations, as many young haddock would get into the nets as in the past. However, this will not be the case, because, as we have said already, the fishermen will avoid the schools of worthless young haddock. The loss resulting from the imperfect selectivity of the nets, therefore, will be less than was assumed in the tabulations; consequently, the profit will be greater. This review leads us to the conclusion that the facts presently available show that a minimum mesh size of 8 centimeters and a minimum fish size of 27 centimeters are necessary to protect the haddock sufficiently. This will only be valid as long as the total mortality of 50 percent is not exceeded.

bb. Plaice

As for the haddock, we first have to determine the lower limit of the minimum size. This is determined by the condition that the egg production must remain on one level.

Bückmann (1939) gives a summary of the strength of the year classes during the period 1925-36. From this picture shown in figure 9, it does not appear that the average annual strength declined after 1930. Therefore, we may assume that the egg production of the plaice was sufficiently large to maintain the supply of young. Statistics can be taken from Bückmann's work (1932) about the average decline of a year class. With the aid of these numbers, table 13 shows how a group of plaice, with a strength of 1,000 at the end of the second year, declines from year to year. Franz (1908) has given

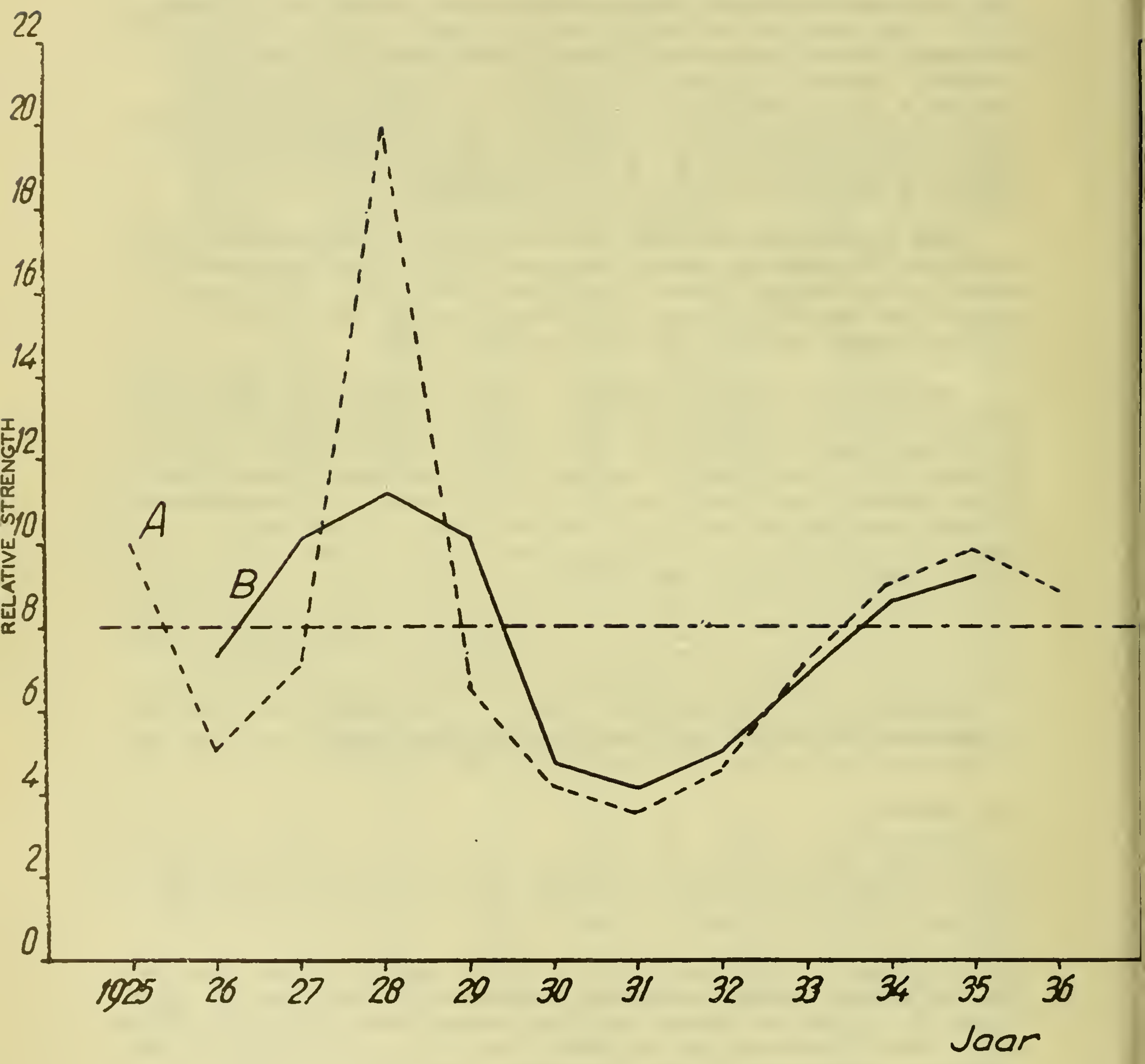

Figure 9.--Relative strength of the various year classes of plaice. Broken line A shows the actual relative numbers. Line B is constructed by averaging three successive points of line A.

TABLE 13.--Percentage of female plaice required to reach spawning stage to maintain fish stock at constant level.

Year Group	Strength at spawning time.	Percentage of females	Number of females in group	Percentage of sexually mature females	Number of mature females	Number of eggs per mature female	Number of eggs produced
I	1,000						
II	830	45	373	0			
III	506	48	243	0			
IV	237	49	116	0			
V	107	50	54	5	3	15,000	45,000
VI	48	59	28	20	6	30,000	180,000
VII	21	65	14	50	7	40,000	280,000
VIII	9	75	7	75	5	50,000	250,000
IX	5	100	5	100	5	60,000	300,000
X	2	100	2	100	2	70,000	140,000
XI	1	100	1	100	1	80,000	80,000
							1,275,000

the relation in numbers between males and females in the various age groups; it is, therefore, possible to determine for each of these groups how many females there were. With the aid of Redeke's observations (1909) the number of sexually mature females could be determined (column 6). Franz (1908) determined the average number of eggs contained in females of different ages. Therefore, we could ascertain the total number of eggs produced by 1,000 two-year-old plaice.

Table 13 shows that about 1.3 million eggs are sufficient to produce 1,000 two-year-old plaice. Therefore, 1,300 eggs are necessary to produce one plaice; each female, therefore, has to produce at least 2,600 eggs if the stock is to remain constant. According to Franz (1908) a sexually mature female has at least 9,000 eggs. Thus, only a third of the total number of females has to reach the spawning stage to keep the plaice stock at the same strength. This is considerably less than that necessary for the haddock and probably explains why interference of the breeding production, through intensive fishing, always appeared sooner for the haddock than for the plaice.

In table 14 it has been determined to which age the young plaice has to be protected by various stages of fishing intensity, if the breeding production is not to decline. Due to Franz's observations, we could account here for the changes in the numerical relation between the sexes, which we could not do for haddock.

The table shows that if the total annual mortality is 40 percent, 397 one-year-old plaice are sufficient to give an egg production during the course of the years which will deliver 1,000 plaice. With a total mortality of 50 percent, 1,344 one-year-old or 672 two-year-old plaice are therefore necessary. We have only 1,000 one-year-old plaice and can only obtain 672 two-year-old plaice by protection of the fish during their second year. If we wish to retain 672 two-year-old plaice from the 1,000 one-year-olds then the mortality may not rise above 30 percent. With a natural mortality of 10 percent, the mortality through fishing may not be larger than 20 percent. That is half of the value assumed in these series for the following years. Roughly, we may say that the plaice must be protected during the first year and during half of the second year. A minimum size of 10 to 15 centimeters would, therefore, be necessary depending on the rate of growth.

If the total mortality has reached 60 percent, then there will be an egg production for 1,000 one-year-old plaice only if, at the beginning of the fourth year, 935 plaice are present. In other words, the 1,000 one-year-old plaice have to be protected in their second and third years, and--since the natural mortality will have reduced the 1,000 fish to 729--also during a part of the fourth year. This would make a minimum size of 25 centimeters necessary.

TABLE 14.--Age to which young plaice must be protected through controlled fishing intensity to prevent a decline in breeding production.

Year Group	Aver. No. of eggs per female	No. of females in group discussed	No. of eggs produced	Strength of discussed group	No. of females in group discussed	No. of eggs produced	Strength of discussed group	No. of females in group discussed	No. of eggs produced	Strength of discussed group
I				397			1344			5,850
II				238			672			2,340
III				143			336			935
IV	0			85			168			375
V	750	1.67^6x 0.50	8,140x	51.5	2^6x 0.50	23,400x	84	2.5^6x 0.50	91,400x	150
VI	6,000	1.67^5x 0.59	46,100x	31	2^5x 0.59	113,300x	42	2.5^5x 0.59	343,000x	60
VII	20,000	1.67^4x 0.65	101,100x	18.5	2^4x 0.65	208,000x	21	2.5^4x 0.65	507,000x	25
VIII	37,500	1.67^3x 0.75	130,900x	11.1	2^3x 0.75	225,000x	10.4	2.5^3x 0.75	439,000x	10
IX	60,000	1.67^2x 1.00	167,500x	6.7	2^2x 1.00	240,000x	5.2	2.5^2x 1.00	375,000x	4
X	70,000	1.67 x 1.00	116,800x	4	2 x 1.00	140,000x	2.6	2.5 x 1.00	175,000x	1.6
XI	80,000	x 1.00	80,000x	2.4	x 1.00	80,000x	1.3	x 1.00	80,000x	0.7
			650,540x			1,029,700x			2,010,400x	
		Total mortality 40%			Total mortality 50%			Total mortality 60%		

As with the haddock it is clear that the biological lower limit of the minimum size increases when the fishing intensity increases.

If, in the future, we maintain the density of the stock at a value corresponding with the optimum catch, then the total mortality will be 50 percent. The biological lower limit of the minimum size is then at most 15 centimeters. Now, we have to see if it is desirable to increase the size for other reasons.

The prices of the various market divisions of plaice are:

			1946	Average 1933-38
Small plaice	IV	(15-21 cm)	F 0.15	-
Small plaice	III	(21-27 cm)	0.22	F 0.07 1/2
Small plaice	II	(27-35 cm)	0.41	0.15
Small plaice	I	(27-35 cm)	0.41	0.28
Medium small		(35-40 cm)	0.56	0.38
Medium large		(40-50 cm)	0.56	0.34
Large plaice	(50 cm and more)		0.56	0.28

f = guilders

Undoubtedly one recieves considerably higher prices for plaice if the smaller ones are left in the sea longer, but in general they have to be caught before they reach a length of 40 centimeters and lower in price again.

We have seen on page 61 that it is difficult to set a minimum mesh width larger than 8 centimeters when considering the losses of roundfish and sole. Figure 5a shows that with a cod end of 8 centimeter mesh width, no plaice more than 16 centimeters in length escape. About half of the plaice of 15 centimeters escape. The width of the plaice makes it necessary that a net, from which most of the non-marketable plaice can escape, has to have meshes of at least 12 centimeters. Although fishing is usually done for one particular species, considerable quantities of other fish usually are taken incidentally. A mesh width of 12 centimeters would be suitable for the plaice fishery but would lose most of the marketable roundfish and sole (the sole can roll itself up, so that it can escape through much narrower meshes than the other flatfish). Therefore, we have to find another method to protect the non-marketable plaice. It is, therefore, necessary to observe the life history of the plaice.

The plaice spawns from January to March in the whole southern part of the North Sea. The eggs are most numerous in the Flemish Bight, particularly where there is warm water with high salinity content (Redeke, 1909). The developing eggs are transported by the Rest stream to the North Sea, along the continental coast. First, the larvae are symmetrical fishes contained in the upper water layers with the other plankton. Soon thereafter they undergo a metamorphosis whereby they obtain the typical flatfish form. This lasts about 6 to 7 weeks, after which there is a change in their mode of life. The larvae move to the bottom, especially on shallow areas near the coast. There, they find enough food and in the autumn have reached a length of about 6.5 to 7.5 centimeters. As they grow, they seek deeper water and it may be said in general, that the length in centimeters is equal to the depths in meters where they are found. Figure 10 shows a chart from the plaice report compiled by Heincke (1913 a, b) for the International Council for the Exploration of the Sea. The chart shows how plaice of various length groups are distributed over the North Sea. It is based on English observations compiled by Masterman. It appears that along the Belgian, Dutch, German and Danish coasts there is a broad zone in which more than 50 percent of the plaice are smaller than 25 centimeters, and only 1 percent are larger than 35 centimeters. There are also very many small plaice in the regions B3 and B4. Bückmann (1933) estimates the number of plaice below 22.5 centimeters in the German Bight (except the Wadden Sea) to be 1,000 million to 1,600 million and thinks that half of this number appear off the Dutch and Belgian coasts. The percentage of plaice of more than 26 centimeters in length increases with the distance from the coast and northern latitudes.

The plaice in the coastal zones do not remain in the same places during the whole year but migrate periodically. The progress of this migration was checked by Heincke and Mielck (1925) and Bückmann (1927). It is shown in figure 11. This chart is a combination of several, prepared by the authors, and shows the distribution of the plaice-stock during various periods of the year along lines perpendicular to the coast. It is clearly shown that the fish, which are concentrated along the coast in spring, move further out to sea during the summer months. There are few plaice in the coastal zones during the winter, most of the young plaice having gone to deeper, warmer water. Many others, especially the smallest, seem to bury themselves in the coastal zone where the fishery cannot touch them.

Besides this periodic migration and return, there is a gradual movement of the larger plaice to deeper, more distant grounds. After sexual maturity (usually for the first time after the fifth year) they move to the Flemish Bight to spawn.

Based on these facts, a commission of the Permanent International Council for the Exploration of the Sea decided in 1921 to propose the closing of the coastal zone for trawl fishing for the protection of the non-marketable plaice. This decree would be valid for all steam and motor trawlers with a capacity of more than 50 horsepower. These ships would not be allowed to fish during the whole year in a zone between the coast and the 12 fathom curve from 52° N (Hook of Holland) to 56° N (the so-called inner zone). During the first, third and fourth quarter of the year fishing would be forbidden in the area between the inner zone and the 15 fathom curve. That is, from Heligoland to 56° N. Both zones are shown on the chart.

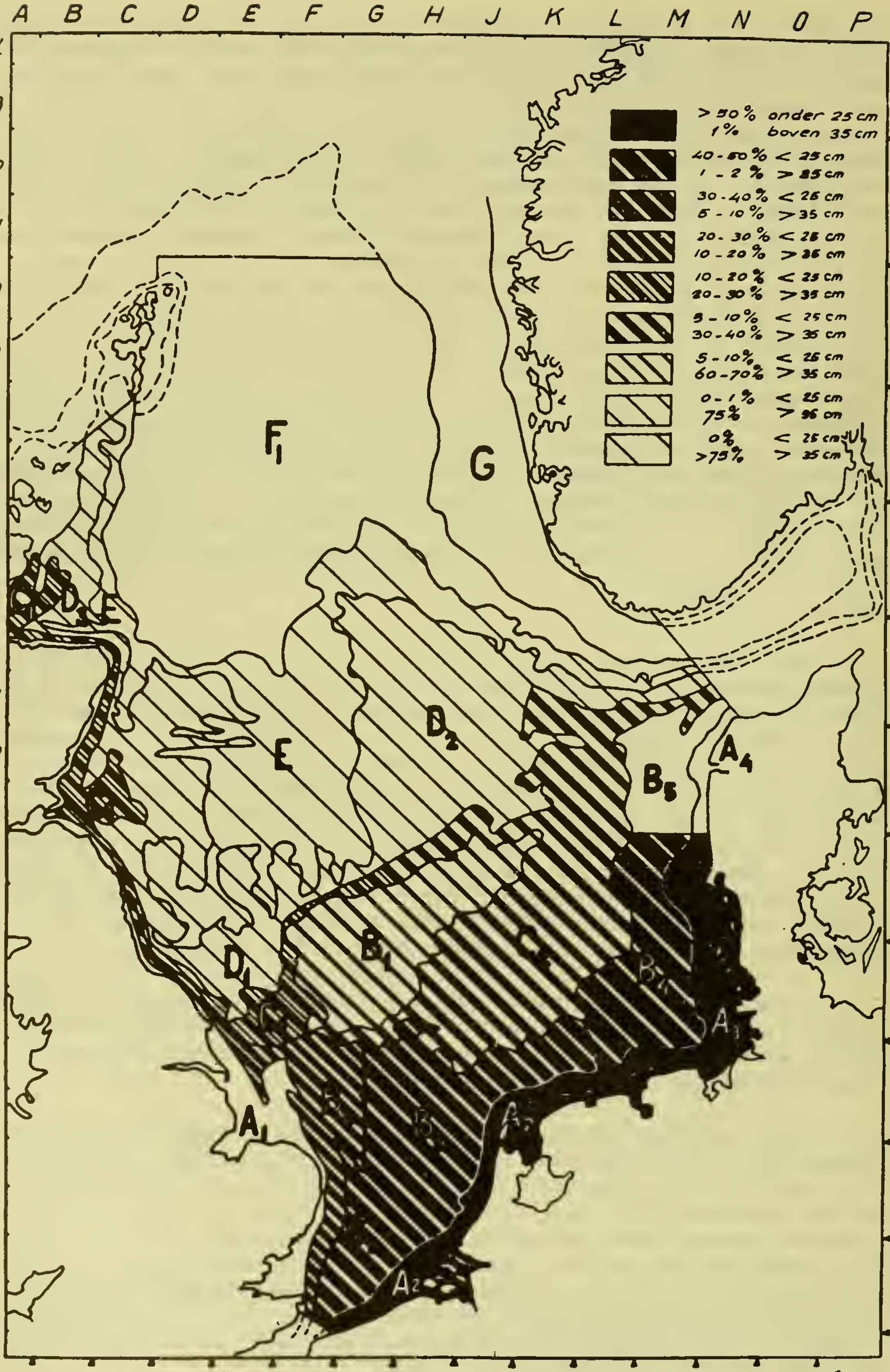

Figure 10.--Distribution of plaice of various sizes in the North Sea.

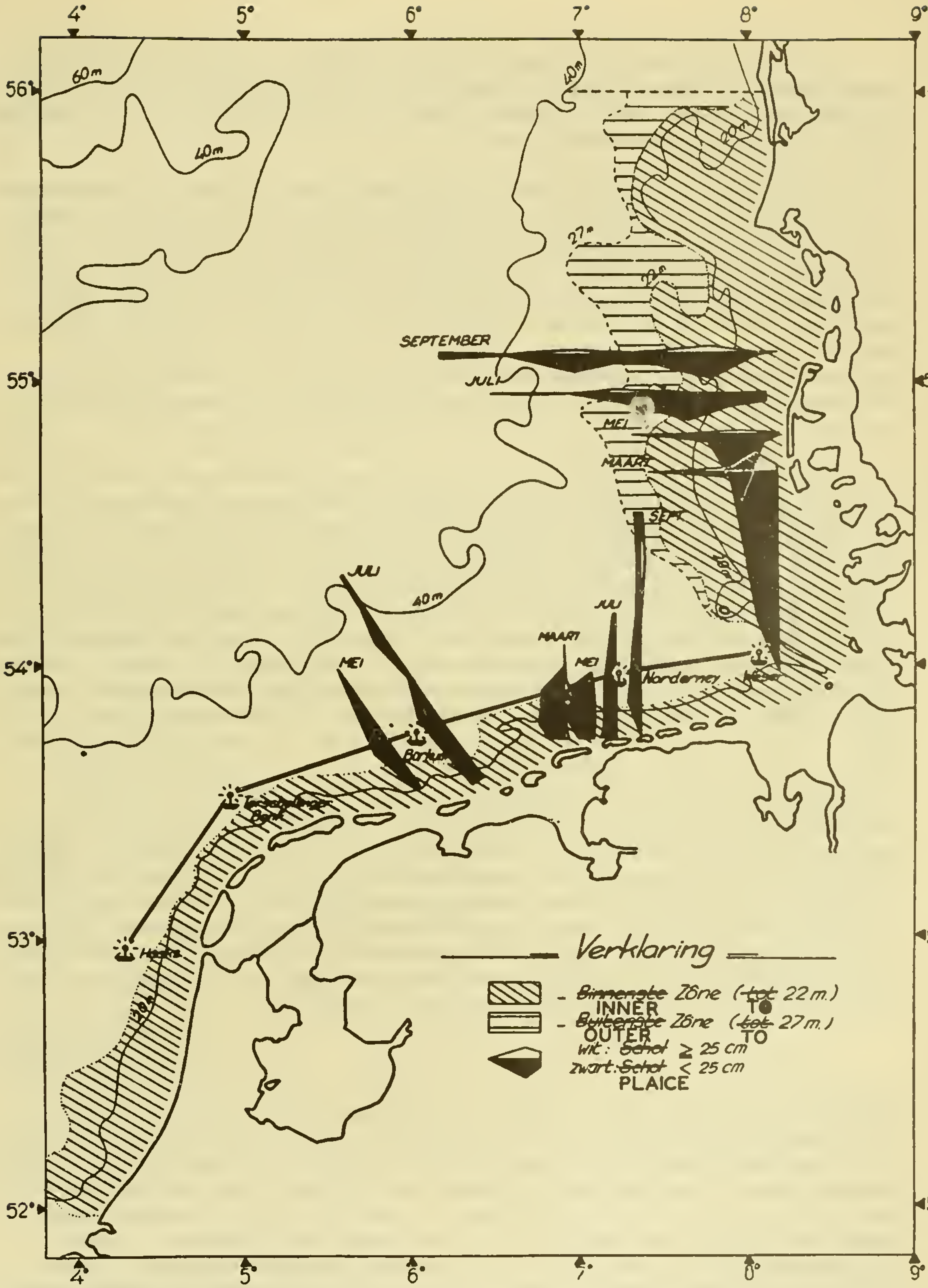

Figure 11.--Distribution of plaice of various sizes during various seasons in the Heligoland Bight. The distribution is shown for three areas. For each month, one of the vertical cuts is made in each area. For some areas the density of plaice (divided in plaice larger and smaller than 25 centimeters) is shown on axis vertical to the cuts. For each of these areas one cut is shown for each month. For technical reasons the cuts are placed side by side. Actually they fall on each other.

It was believed that the outer zone could be left open during April, May and June since the majority of the younger fish are still in the inner zone. During those months, great quantities of fine fish can be caught in the outer zone.

Based on the German observations, mentioned above, an amendment was added later. The German scientist proposed to open both zones during the months of January, February, November and December. In this period good catches of roundfish can be made in the areas while few plaice will be caught. They also believe that the outer zone would not need to be closed during March, since at that time there are no young plaice (see fig. 11). On the basis of observations made between the lightships of Borkum and Norderney they also found it desirable to have the outer zone extended to the east Frisian coast.

The regulation that ships of less than 50 horsepower could not be forbidden to fish the zones was added to prevent the coastal fishery from being discontinued. Most of the coastal ships are not seaworthy enough to fish regularly outside the zones. However, this regulation caused the British Trawl Federation to refuse its cooperation. They would not agree to the idea that some ships could fish in the zones. We, too, believe that it would be very undesirable to allow the small ships to fish at will in the protected areas. The gear of these small ships has become increasingly destructive since 1925. Some of the small ships even use the Vigneron-Dahl net. Many of the "botters" were the worst offenders in fishing for trash fish to be used for fishmeal before the last war. We think that the plan can only become effective if all trawl fishing were forbidden inside the zones. Seine fishing could be allowed, as practically no undersized fish are damaged by this method. However, many coastal fishermen would not be able to convert their ships for seining. The ships are too small for this purpose and the fishermen lack the knowledge necessary to use this difficult fishing technique. Closing of the coastal zones would be a hard fate for them. It needs to be considered if it is necessary for the retaining of the plaice stock to impair the small coastal fishermen so badly.

We have seen that it is not practical to save the non-marketable plaice with the aid of a minimum mesh width. The protection has to be made by preventing the fishing on grounds where the young plaice is concentrated. In addition to closing of a certain area, this can also be done by making it unprofitable to fish on such grounds. This can be done by setting the minimum size so high that the catches will consist of a very high percentage of undersized fish and the time spent on culling the nets will not be worth the profits. Such a regulation has a great advantage since it is more elastic. Figure 11 shows that a not inconsiderable part of the undersized plaice appears outside the zones during July and September. These plaice would not be protected by the closing of areas, as proposed in 1925, but would be protected by a high minimum size. On the other hand there are many places inside the zones where large plaice may be caught without destroying many younger ones. Those places, often the deeper gullies and holes, can be fished by the coastal ships with only the protection of a high minimum size. This would help the coastal fishermen. It is reasonable to expect that they will preserve the young fish. If they cannot do this with a minimum size, then the argument that their interests have to be protected loses its value and one of the most important arguments against closing would be lost. However, the technical difficulties of control and the high expenses will remain a serious argument.

It has been recognized that, for plaice especially, the protection in coastal zones will cause a decline in the rate of growth. This has been stated already and it was noted that the destruction of 26-year-old or-older plaice cannot be of advantage to the fishery. The thinning of the 0- and I- groups would be of advantage. However, we have stated that for the retention of a sufficient egg production it will be necessary to save the 0- and I- groups entirely by a total mortality of 50 percent. These statements are seemingly contradictory. However, if the older groups are fished less intensively, a sufficient egg production may be had with the thinning out of the 0- and I- groups. Table 15 illustrates this; it shows that it is equally possible to retain the same number of 4-year-old and-older fish by thinning of the 0- and I- groups and partial protection of the II- and III- groups as it is to afford complete protection for the 0- and I- groups.

The shrimp fishery is chiefly responsible for the catch of the 0- and I- groups. It would be very difficult to prevent the destruction of a quantity of plaice by the shrimp fishery and it will, therefore, be a good thing if there is no objection against a not too large reduction of these year groups, when it is possible to give the older year groups a partial protection by a higher minimum size. This destruction of the young plaice by the shrimp fishermen should not become too large, however. It is, therefore, necessary to forbid the landing of these plaice so that the shrimpers will not be stimulated to catch more small plaice than is unavoidable in normal operation.

Heincke (1913a) estimates in his report that a minimum size of 26 centimeters is necessary to make the fishing on young plaice grounds uneconomical. We believe that it will be sufficient to set a size of 25 centimeters. This size will also be acceptable to the coastal fishermen.

This size does not correspond at all with the selection curves of a net with cod-end meshes of 8 centimeters; such a net will retain all plaice above 18 centimeters. Undersized plaice will thus be caught which may not be landed and with the usual methods will

TABLE 15.--Thinning of the 0 and I- groups with partial protection for the II and III groups.

Without thinning			With thinning of groups 0 and I	
Year Group	Strength	Percentage of decline	Strength	Percentage of decline
0	1,000	10%	1,000	40%
I	900	10%	600	40%
II	810	50%	360	25%
III	405	50%	270	25%
IV	202	50%	200	50%
V	101	50%	100	50%
VI	50	50%	50	50%
VII	25		25	

be largely dead when thrown overboard. This is damaging and we have to decide whether the advantages of the protection overweigh this damage. Therefore, table 16 shows the returns of a group of plaice which as 1-year-olds had a strength of 1,000 when this group was fished either with nets with a minimum mesh width of 55 millimeters without a set minimum size (table 16a) or by nets with a mesh width of 88 millimeters and with a minimum size for plaice of 25 centimeters (table 16b). It appears that in the second case the returns are somewhat smaller. However, we have assumed that the plaice between 18 and 25 centimeters were not at all protected. We expect that this will happen through the forcing of unprofitable operations on the young fish grounds. If we assume that through the avoiding of the young fish grounds only two-thirds of those undersized fish are caught, which would be destroyed by an unlimited fishery with the 8 centimeter net, then it appears that the returns from the protected fish stock are greater than the return from the unprotected stock (table 16c). It is most likely that considerably more undersized fish will be saved and that the financial returns will be even greater.

The decline of returns, caused by a minimum size of 25 centimeters, will not be great enough to prevent profitable fishing on the young plaice grounds. The fishing will be less profitable, the labor of culling will certainly increase and fishermen with seaworthy ships will prefer to avoid the grounds of undersized fish. However, fishermen with smaller ships will have to stay in the coastal zone and be satisfied with lower returns, undoubtedly damaging the younger fish. It is, therefore, necessary to encourage the eventual disappearance of these less seaworthy ships and let them be replaced by more seaworthy ships, preferably those of the "cutter" type.

Although it is possible to give a reasonable protection with a minimum size of 25 centimeters, considerable quantities of young plaice will always be caught on most grounds in the North Sea as long as the trawl is being used. The trawl actually is undesirable for the plaice fishery. The ideal gear for plaice is the seine or Danish "snurrevaad". The results of the Danish fishery show how profitable this type of fishing is. A healthy exploitation of the plaice stock would occur by fishing with the seine from "cutters". Insofar as seining has to be done during the day and ceases during bad weather, it will be best suited for the southern part of the North Sea. For that reason most of our seine fishermen prefer trawl fishing during the winter months. For the protection of the young, however, this is not too damaging since fewer undersized fish are caught during the winter. Some trawl fishing will remain since the "snurrevaad" cannot be used for the catching of sole.

cc. Sole.

The available information does not show that the sole stock was in danger. On the contrary, the catches increased. This was probably not entirely due to more intensive fishing but could be attributed also to an increase in the density. It is possible that the decline of the plaice influenced the increase of sole,

TABLE 16a.--Groups of plaice fished with a minimum mesh width of 55 millimeters without a set minimum size.

Year Group	Aver. Length beginning of year in cm.	Aver. length whole year in centimeters.	Natural Mortality	Percentage of mortality by fishing.	Strength discussed group at beginning of year.	Catch in Numbers	Aver. weight by lengths of column 3 in grams	Catch in Kilograms	Price per kilogram in cents	Returns in Guilders
I	7	10	10	10	1,000	100	112	1.2	7.5	0.09
II	13	16	10	40	800	320	40	12.8	7.5	0.97
III	19	21.5	5	45	400	180	100	18.0	7.	1.26
IV	24	26	5	45	200	90	170	15.3	15	2.27
V	28	30	5	45	100	45	255	11.5	21	2.42
VI	32	34	5	45	50	23	375	8.6	28	2.41
VII	36	37.5	5	45	25	11	500	5.5	38	2.09
VIII	38.5	40	5	45	13	6	600	3.6	38	1.37
IX	41	42	5	45	7	3	690	2.1	34	0.71
X	43	44	5	45	4	1.5	795	1.2	34	0.41
XI	45	46	5	45	2	1	900	0.9	34	0.30
								80.7		14.30

TABLE 16b.—Groups of plaice fished with a mesh width of 88 millimeters and with a minimum size of 25 centimeters.

Year Group	Aver. Length beginning of year in cm.	Aver. length whole year in centimeters.	Natural Mortality	Percentage of mortality by fishing	Strength discussed group at beginning of year	Catch in Numbers	Aver. weight by lengths of column 3 in grams	Catch in kilograms	Price per kilogram in cents	Return in Guilders
I	7	9.5	10	3	1,000	30	11			
II	12.5	15.5	10	26	870	226	35			
III	18	20.5	5	45	557	250	86			
IV	23	25	5	45	278	125	146	9.1	15	1.36
V	27	28.5	5	45	134	62	218	13.5	21	2.84
VI	30.5	32	5	45	67	31	320	9.9	28	2.77
VII	34	35.5	5	45	34	16	425	6.8	33	2.24
VIII	37	38	5	45	17	8	510	4.1	38	1.56
IX	39	40	5	45	9	4	586	2.3	38	0.88
X	41	42	5	45	5	2	675	1.4	34	0.48
XI	44	43.5	5	45	2	1	764	0.8	34	0.27
								47.9		12.40

TABLE 16c.—Percentage of returns from protected fish stock.

Year Group	Percentage of mortality by fishing	Strength of discussed group at beginning of year	Catch per number	Catch in kilograms	Returns in guilders
I	2	1,000	20		
II	17	880	150		
III	30	642	196		
IV	38	418	159	11.7	1.75
V	45	238	107	23.3	4.90
VI	45	119	54	17.3	4.81
VII	45	60	27	11.5	3.80
VIII	45	30	13	6.6	2.51
IX	45	15	7	4.1	1.56
X	45	8	3.5	2.4	0.82
XI	45	4	2	1.5	0.51
				78.4	20.66

since both species are largely competitors for the same food. In that case it is possible that a satisfactory protection of the plaices will decrease the density of the sole. This would be an argument to include the sole in the protection scheme. A stronger argument is raised, if an infraction of the 8 centimeter minimum mesh-width regulation is to be prevented, a size will have to be set for the sole to correspond with this mesh width. This is probably 25 centimeters; although exact data of the selectivity of the 8 centimeter net for sole are not available. There can be very few objections against this size. Shortly before the last war large quantities of small sole were landed. During 1938 the smallest group varied between 15 to 27 centimeters with an average of 21 centimeters. However, it is very uneconomical to land such small sole. More than any other species the sole brings in a considerably higher return if left to grow for a few years.

The sole has a high rate of growth, higher than that for plaice. It appears that up to now this rate of growth is not inversely proportional to the density of the stock.

Probably due to a very efficient method of finding food, the sole still manages to get a sufficient amount of food for a maximum growth speed, even at the density it has now reached. The natural mortality is low and is fully compensated for by the growth. While the plaice suffers a disadvantage by the migration of older fish from the coast, thereby getting outside the reach of the fishermen who have protected it at a younger age, the older sole return in great quantities to the coast to spawn. Moreover, although the small sole has a comparatively high value, the older ones bring a considerably higher price per kilogram. The prices were:

	1946	1932-1938
Small sole IV to 15 cm	f 0.22	
Small sole III 15 to 23 cm	0.56	
" " II 23 to 26 cm	0.82	f 0.696
" " I 26 to 29 cm	0.12	
Small medium 29 to 32 cm	1.42	0.77
Large medium 32 to 37 cm	1.69	0.77
Large sole above 37 cm	1.69	0.94

f = guilders

Finally, about 50 percent of the female sole are sexually mature at a length of 27 centimeters (about the fourth year). A high upper limit of the size will therefore encourage the egg production and increase the stock. There is no objection to the increase in density since the rate of growth is so high.

dd. Turbot and Thornback.

Little is known of the stock-strength of these fine species. It seems that the turbot and thornback have not increased during the respite provided by the war years. It does not appear improbable that an increase of the egg production will have a favorable influence on the stock of these fishes. The females of both species become sexually mature only at a length of about 40 centimeters. It will, therefore, not be good for the egg production if considerable quantities are landed between 20 and 30 centimeters which was the case during the period 1930 to 1940. Fish of these lengths have a low value; they ought to get an opportunity to grow more. The large width of these fishes unfortunately makes it impossible to protect them by the use of a minimum mesh width. A high minimum size, even if it does not correspond with the mesh width, will be of value. The fishermen have a great desire to take the best fish first; therefore, the undersized turbot and thornback have a much better chance to be thrown overboard alive and in good condition than the undersized plaice. We should like to set the minimum size for turbot and thornback at 30 centimeters.

ee. Flounder.

The flounder has always had too low a value to protect it for its own sake. At least half of the trash-fishing catches for meal consisted of flounder and since the small flounder appears on the young plaice grounds, the fishery could still be economical on these grounds, if there were no size limit for flounder. The size does not need to be too high since it is only necessary to make the trash fishery impossible. A minimum size of 20 centimeters seems sufficient. More protection is not desirable since this cheap fish might become a harmful competitor of the better species. The flounder becomes sexually mature earlier than the plaice (at a length of about 20 centimeters).

ff. Cod.

Our conclusion was that the cod stock was not in danger but that some protection would have a good effect.

This effect might amount to an increase of the catches near the coast. It is an interesting phenomenon that after the second as well as after the first World War, the cod catches increased greatly in areas near the coast; after 1930 there were no cod far to the south in such great density. There is a possibility that in the North Sea two cod populations appear. One to the south, of which the females become ripe at 24 centimeters, and one in the north where the females become ripe only when they have reached a length of 60 centimeters; the southern group having been heavily overfished and the northern group very little or not at all. There is no certainty regarding this question since very little has been done to investigate the cod in the southern part of the North Sea.

However, to aid the conservation regulations for the haddock it is necessary to set the same minimum size for cod, since both species can be expected on the same grounds. Commercially there are no objections against this, since before the war very little cod below 29 centimeters was looked upon as marketable.

gg. Whiting.

This species has a low value, except during the war years, and protection is therefore not necessary for its own sake. Nor is it necessary for the protection of the haddock since the whiting usually is found on more southerly grounds. However, whiting appear also on the young plaice grounds and in this respect everything that may lead to more intensive fishing has to be avoided.

Large quantities of whiting begin to appear along the coast in autumn. Catches of whiting might make the fishing on coastal grounds profitable again, but the catches are too irregular to cause many ships to fish for this species only in the coastal areas. The younger plaice, moreover, have started their migration to deeper water and the few ships which fish for whiting will not do very much damage. Therefore, we do not consider it necessary to prevent fishing for whiting between 20 and 29 centimeters.

Smaller whiting appear on the coastal grounds in the early summer and during the summer when most of the young plaice are still there. During this period the fishing for whiting must be made uneconomical and it is therefore desirable to place the minimum size for whiting at 20 centimeters.

hh. Tongshar, Scharretong and Witje.

These species are not important enough for a separate discussion. The size set by the London Conference of 1937 can be accepted without objection. For the three species the proposed minimum size was 23 centimeters.

ii. Heek.

The minimum size for heek will have to be set at 29 centimeters to help in the protection of the young haddock. The size proposed in London was 30 centimeters. We can accept this size without objection.

There has to be an exception observed in the regulation of minimum mesh width in the trawl fishing for herring, mackerel, sprat and shrimp. It has to be shown by the catches that only these species are being fished. No fishery must be left outside the regulation for minimum sizes since it is a control on the use of the right net for a certain species. It has been brought out, especially by German sources, that it is impossible for the shrimp fishers to pick the trash. One source has pleaded that shrimp fishermen should be allowed to land their trash, which consists of the very youngest year classes. This plea was defended with the argument that it is not unwise to thin the O- and I- groups of the plaice. This is only true for plaice and certainly not for the young sole which is also caught and perhaps also not for the young turbot which appears near the coast. Insofar as these fish come in with the shrimp, they cannot be avoided. Many shrimp fishermen, however, took part in the deliberate fishing for trash and it must be assured that this will not happen again. All landings of fish below the minimum size <u>must</u> be forbidden.

b. The Probable Effect of the Protection

We now have to estimate the decrease in the catch of undersized fish after these regulations have become effective.

The results of setting a minimum size for fish will be two-fold, 1) the deliberate catching of small fish will be discontinued; and 2) the fishermen will try to stay away from those areas where undersized fish chiefly appear. Before 1930, about 15 percent of the haddock catches (in weight) consisted of non-marketable fish. We will assume that the same amounts of undersized fish would be caught now, if minimum sizes only were established. However, if a minimum mesh width were established also, the catch of undersized fish would be reduced. The effect of this large-mesh width can be estimated.

The quantity of undersized fish caught with the 8 centimeter net in proportion to the quantity of undersized fish caught with the 5 1/2 centimeter net is estimated in table 17. In both cases a fishing standard of 50 percent is assumed. It is also assumed that the chance to be caught is the same for each length group of a certain year group. From the "selection curve" it then can be estimated what percentage of each length group remains in the nets.

For instance, by fishing with the 5 1/2 centimeter cod end the haddock reaches a length of 16 centimeter in its first year. Of 1,000 haddock existing at the beginning of the year, 500 (50 percent) get into the nets during the year. That is, of each length (centimeter) group 500 ÷ 16 haddock. According to the selection curve in figure 5b, none below 14 centimeters remain; at 14 centimeters, 1; at 15 centimeters, 2; and at 16 centimeters,

TABLE 17.--The expected catch of undersized haddock and plaice in nets of 2 mesh sizes with a fishing standard of 50 percent with 1,000 fish existing at the beginning of a year.

	5-1/2 cm. Net		8 cm. Net	
Species	Number	Weight	Number	Weight
(below 23 cm.) Haddock	271	22,191 g	87	7,540 g
(below 19 cm.) Plaice	418	13,369 g	301	10,746 g

4. After 1 year, the year class is then diminished by 10 percent of 1,000 (natural mortality) and by 7 fish through fishing; therefore, at the beginning of the second year 893 fish remain. One-half of this group is caught; that is, of each centimeter group an eighth part of 50 percent of 893 haddock, since the third year is reached at 25 centimeters, etc.

The category of undersized fish taken in both types of nets were below the size thought to be just useful for human consumption about 1938. We accepted this limit because we want to know how much of the fish thrown overboard caught in a mesh-width net of 55 millimeters will still be caught by a mesh-width net of 80 millimeters.

Only a third of the undersized haddock which is destroyed with the narrow net will be caught with the wider net. Undersized plaice will be caught only 1 1/4 times as much in the 55 millimeter cod end as in the 80 millimeter one. The question remains why the effect of the different cod ends is considerably less for the plaice than for the haddock.

The explanation of this is as follows: The rate of growth declines because the small fish are spared. This increases the chance that the undersized fish will be caught. The decline of the rate of growth reduces the effect of the protection. The effect of the protection will be even more reduced as the rate of growth of the affected species is smaller. The rate of growth of the plaice is appreciably smaller than that of the haddock and this is one of the reasons why, by using an enlarged mesh width, relatively more non-marketable haddock will be saved. The second reason is that the 80 millimeter meshes are more suited for the escape of non-marketable haddock than for the escape of undersized plaice.

While we have concluded that by introduction of minimum sizes alone, the quantity of undersized plaice would be 8 percent of the total plaice catch, we may now conclude that by introduction of a minimum mesh width of 80 millimeters this quantity will decline to 100 ÷ 125 x 8 = 6.4 percent. The quantity of undersized haddock caught will decrease to one-third. We had assumed that by shunning the areas where much young haddock is present, the quantity of undersized haddock would lower to 15 percent. After introduction to the measure, 5 percent would be an acceptable amount of the quantity of undersized haddock. Few undersized fish of cod and other species were caught. We estimate that quantity at 5 percent and expect that this would be halved when the protection regulations are introduced.

According to the estimation on page 33, the optimum catch in the North Sea would be approximately 390,000,000 kilograms of bottom fish. This includes the non-marketable fish.

During the period 1903-40, the average catch consisted of 32 percent haddock, 12 percent plaice, and 56 percent of other species. After the introduction of the proposed protection, 95 percent of the catch of haddock, 93.4 percent of plaice, and 97.5 percent of other species will consist of marketable fish. If we place the total quantity of marketable fish at X then:

$$\frac{100}{95} \times \frac{32}{100} X + \frac{100}{936} \times \frac{12}{100} X + \frac{100}{97.5} \times \frac{56}{100} X = 392,000,000 \text{ kilograms}$$

or X is 377,000,000 kilograms. This then would be the amount of the optimum catch of marketable fish. If the fishing would have been carried on in the same way as had been done during the period 1933-35, then the optimum catch would have amounted to only 350,000,000 kilograms. To arrive at this figure, it is necessary only to take the amounts corresponding with that period for the percentage of undersized fish, from table 8 in the above formula, to replace the percentages now used. We get then:

$$\frac{100}{80} \times \frac{32}{100} X + \frac{100}{89} \times \frac{12}{100} X + \frac{100}{95} \times \frac{56}{100} X = 392,000,000 \text{ kilograms}$$

There appears to be an optimum catch at a fishing intensity of not quite 40 percent. The size of the catch is 390,000,000 kilograms and 370,000,000 kilograms of that amount can be caught as marketable fish, if the protection here proposed is introduced. If the younger fish are less protected, then a higher percentage of undersized fish and smaller returns will result.

5. Conclusions and Summary of the Proposed Regulations for the North Sea

We enumerated in detail the amount of the optimum catch for the North Sea and how great the benefits or disadvantages would be by changing the mesh widths or by the introduction of a minimum size fish. The danger inherent to an enumeration is that the reader may be impressed that these statistics cannot be assailed and that it is certain that the optimum catch from the North Sea is exactly 392 and not 380 or 400 million kilograms. Unfortunately this is not the case, the numbers have only an approximate value; they have the value of an extensively supported estimation. The calculation could become more exact if the basic information becomes better known, as for instance better values for the natural mortality, the fishing intensity, and the relation between density and speed of growth.

The studies on overfishing in the North Sea and the fight against this overfishing are generally not characterized by a large amount of quantitative information. I have found this a difficulty because the questions connected with growth and productive power of the population can be solved satisfactorily only by a quantitative analysis. It is understandable that only a very few quantitative treatments have been given, since the statistics to be used as a basis often were not reliable. I have persuaded myself into a quantitative treatment because, in the first place, the basis of the necessary information now is not too unreliable, and in the second place, I hoped to show what information is necessary to arrive at a workable plan for future research. In the third place, I was of the opinion that I could best give the reader an illustration of the relation between the various factors by the use of statistics. Although the statistics may not be accepted as final, I believe that their doubtfulness is not of sufficient magnitude to change the predicted effect of the proposed measurements to an essential degree. By execution of the plans the results will have to be controlled, of course, so that possible mistakes may be amended.

In the above study it has not been taken into account that changes in the hydrographic conditions may change the fertility and thereby the productive power in the North Sea. We have worked with a constant fertility--an average over several decades--and we have determined how, with this constant quantity of food, the productive power was changed by variations in the fishing intensity. I think this is a responsible working method because it does not appear that important changes have taken place in the environment during this century. However, in the future this possibility will have to be considered.

To increase a rational fishing in the North Sea our conclusions have led us to propose:

1. That the fishing intensity must be regulated in such a way that each year not more than 390 million kilograms of bottom fish be taken from the North Sea.

2. That the minimum sizes and the width of the meshes be regulated in order to insure that these 390 million kilograms will bring as high a price as possible.

The first proposal is sweeping. It is a serious encroachment upon the traditional freedom of the sea and there will be many difficulties involved in the practical application of such a "quota system". It will be asked if it is not possible to prevent overfishing exclusively by the protection of the small fish. We will, therefore, re-examine this possibility.

Looking at the progress of the fishing during this century it is clear that the state of overfishing did not occur because too many small fish were caught. On the contrary, it was impossible to sell small fish at the beginning of this century because no one wished to accept them. The sailing vessels fished as a rule farther out to sea than they do now because they could find a market only for the larger plaice, which were to be found in deeper water. Only when the larger fish were reduced by over-fishing and when insufficient plaice were brought to market was it profitable to bring in smaller plaice. The same thing happened with haddock. After the landing of small fish had started, it increased as soon as new uses were found for them in fish fry shops and the fish-meal industry.

Since an increase of fishing intensity means that the larger fish are caught before the smaller fish are seriously pursued, it is impossible to retain the production of marketable fish solely by protecting the non-marketable fish. Suppose that in fishing a stock of large density the only limitation imposed is that fish below a certain minimum size are not to be caught. At first, more and more ships will be attracted by the large catches. The density of the stock will decrease, the catch-per-unit-of-time also will decrease, and attempts will be made to keep landings high by increasing the fishing intensity. Eventually the stock will reach such a low density that it will be impossible to keep the catches at the original levels unless one catches undersized fish, which is forbidden. Finally, the fishing becomes unprofitable and new areas will have to be sought or ships will have to be laid up. Only a few ships will be able to find employment by catching the fish which barely pass the minimum size. It is clear, therefore, that the fishing of this stock was not organized in a rational way. The returns could be higher if there were not a state of overfishing. Money and energy were wasted by increasing the fleet, which led only to a reduction of the income.

A second reason for a necessary rationing is that a minimum size reaches its full use only by a constant fishing intensity. We have postulated on page 49 that the minimum size must be set so that enough females mature to produce an amount of eggs large enough to retain the fish stock at its optimum strength. It appeared that this biological lower limit increases with increasing fishing intensity. We saw, for instance, that with a total mortality of 50 percent, no haddock below 19 centimeters may be caught if egg production is to be maintained. When the total mortality is 60 percent, none below 23 centimeters, and at 75 percent mortality, none below 27 centimeters may be caught. If the fishing intensity is steadily increased, the minimum size does not answer the biological demands any more. The egg production will decrease and the younger brood will be reduced. This will happen although no undersized fish are destroyed by the nets. A minimum size must therefore be combined with a limiting of the fishing intensity.

Theoretically the possibility of limiting the fishing intensity exists by adopting a minimum size alone. The minimum size must then be placed so high that fishing is not profitable when the optimum fishing intensity has been passed because insufficient marketable fish are present. There is no doubt that the minimum sizes then would have to be considerably higher than previously had been suggested, i. e., higher than 30 to 35 centimeters. This means that much fish which ordinarily would be considered as marketable, must be thrown back. While destroying of roundfish could be limited somewhat by a very large mesh width--for plaice that is not practically possible. We consider such large minimum sizes unnecessary and economically undesirable.

The London Conventions of 1937 and 1946 observed a limit by regulating only the sizes for fish and mesh widths of nets. It is questionable that such limitations are completely satisfactory if they do not include a limitation of the fishing intensity. We think that minimum sizes alone have some value although they are certainly not sufficient to prevent overfishing; nor do they lead to a satisfactory rational fishing.

Minimum sizes are valuable in that more fish have the opportunity to become marketable and bring a higher price; the fishery remains profitable longer and overfishing appears at a later period than when fish of all sizes are taken by the fishery. Moreover, there will still be a reserve of young fish present when, by intensive fishing of the marketable part of the fish stock, overfishing has appeared and the fishery thereby becomes unprofitable. The fish stock will be able to rebuild itself from this reserve, as soon as a diminishing of the fishing intensity gives it an opportunity to do so.

If the minimum size does not exist then the largest part of this reserve will disappear in the fish-meal factories and in the stomachs of ducks, making the recovery of the fish stock much more difficult. If there are no minimum sizes, then fishing will continue until the sea practically has been emptied and the chance of recovery has become minimal.

The fact that overfishing of plaice along the Danish coast was delayed--causing a less serious problem than in other parts of the North Sea--undoubtedly is due to the higher minimum size which the Danes had set for themselves.

Therefore, minimum sizes alone are a small step in the direction of intelligent fishing. The greatest need, however, is to obtain as soon as possible a limitation of the fishing intensity.

On the other hand one may ask if it is still necessary, with a limitation of the fishing intensity, to protect the non-marketable fish. As long as adequate fish become sexually mature, the setting of minimum sizes does not appear essential from a biological point of view. From an economical point of view, it is certainly not satisfactory if we can catch 377 million kilograms of marketable fish with minimum sizes, to be satisfied with the smaller returns from 350 million kilograms which we may obtain without regulations on the size of the fish.

CONCLUSION

The optimum annual return from the North Sea in marketable and undersized bottom fish is 390 million kilograms. If it is desired to obtain as high a price as possible for this 390 million kilograms, then as few undersized fish as possible must be caught. To reach that goal it is proposed:

a) A minimum size of 8 centimeters for the meshes of all nets used to catch bottom fish,
b) forbid the landing or the handling on land or at sea of: haddock below 27 centimeters, cod below 29 centimeters, plaice and sole below 25 centimeters,
c) promote the fishery with the seine (dragnet),
d) aid coastal fishermen--especially for Holland--to buy larger ships and forbid the further increase of the fleet of smallest ships.

By application of these regulations it is to be expected that one may take 377 million kilograms of marketable bottom fish from the North Sea annually.

To prevent the fishing intensity from increasing beyond the allowable value, it is necessary to calculate how many ships of different types are necessary to make this catch, that this number of ships be partitioned over the different countries interested in the North Sea fisheries, and that measures be taken to restrict an increase in the fishing power of these ships.

Only by applying such an international regulation can it be expected that one may get the optimum harvest from the North Sea regularly and that overfishing will not appear in the future.

6. The Progress of Fishing the Herring Stock

Table 18 shows the annual landings of herring from the North Sea during various periods.

It appears that the landing of herring generally increased and that during the last few years more than twice as much herring was caught in comparison to the amount of the optimum catch of bottom fish. There is, therefore, no question of overfishing--whether it is to obtain material for the production of artificial

TABLE 18.—Average total annual catch of herring in the North Sea

Period	Catch in 1,000 kilograms
1935-38	975,870
1931-34	691,166
1927-30	616,151
1923-26	366,459
1919-22	541,804
1915-18	273,793
1911-14	698,514
1904-10	662,423
1903-06	285,771

pearls or for human consumption (whitebait)--regardless of the fact that enormous amounts of young herring are destroyed annually by the beam fishery. There has been a very intensive herring fishery along the Norwegian coast for several decades, where very great amounts of one-year-old herring are also caught. Here, too, there is no indication of a state of overfishing.

It is shown by the enormous catches made since the capitulation of Germany that the density of the herring stock increased considerably. The decrease of this density by increasing fishing intensity is a normal manifestation and if not accompanied by other criteria of overfishing is not an indication of a state of overfishing.

Most of the herring are caught with driftnets and, for technical reasons, only the ships which fish this way could be used to determine the fishing intensity. The Germans, however, have started to fish for herring on a large scale with trawlnets since 1925. In England and Holland, fishing by this method has increased also, but on a very much smaller scale. There is a possibility that the continental countries especially will make more intensive use of the herring-trawl fishery. This will increase the possibility of overfishing. To make interference possible, it is desirable to keep the herring stock under scientific control, although there does not appear to be much danger.

To find a bigger market for the herring seems to be a greater problem than how to catch them.

There are several possible reasons for the great difference between the effect of fishing on bottom fish and the herring. First, the North Sea can possibly absorb more herring than it can bottom fish because there is more food present for the herring. The herring's food consists chiefly of small shrimp-like creatures belonging to the plankton, which in turn live on the phytoplankton. The food of the bottom fishes consists of lower forms of bottom organisms, which depend for their food chiefly on the dead and sinking plankton organisms, principally those which have been left by the herring. While the herring is only one step removed from the phytoplankton, the bottom fishes receive the nutrients from the phytoplankton only after it has passed through numerous other organisms. As we have seen, the food is used partly for growth and for metabolism. Only the first amount of food can, after the organism has been eaten, benefit another organism again. The food used for maintenance is lost to the food chain. Therefore, only a part of the food left by the herring benefits the bottom fishes (Baerends, 1946).

In the second place there is a difference in the fishing methods for herring and bottom fish. The latter groups are continuously chased by the trawlnets, while the herring fishery is limited to certain seasons. The herring, therefore, has a period of rest.

II DISTANT FISHING GROUNDS

1. Iceland

a. Progress of the Fishing.

Data on the fishing intensity, that is to say the number of fishing trips made, are available only from England and Germany. It increased considerably during the period 1920 to 1930 and has remained about constant since then. Nevertheless, the fishing intensity will have been increased after 1930 through the enlarged fishing capacity of the ships. We believe that the intensity of fishing in Icelandic waters increased during the period 1920-39.

If we observe the column which shows the total average annual catches, it appears that the increased fishing intensity did not lead to a constant addition to the catches. The catches show a maximum annual catch during the period 1929-33; thereafter, the average annual catch declined again. If we observe the various fish species in the table we find a decrease in the catches of cod, haddock, halibut and plaice. The decline of the latter three species seems especially disturbing since the average annual amounts during the period 1934-38 are below the quantities which were brought in during the postwar years (World War I) when the fishing intensity was lower. The fact that the catch-per-hour fishing of English trawlers have not increased, regardless of the added fishing intensity, shows that the density of the fish stock must have declined. Against the decline in the landings of the discussed species stands an increase in the landing of "koolvisch" and red sea perch. This does not mean that the catches of these species have increased; formerly this fish was accepted as practically worthless and either thrown back or not completely included in the statistics.

Although the data are not sufficient to make a definite conclusion, we believe that a more intensive fishing of these waters will be harmful to the productivity. From the values given here, we estimate the total optimum productivity of Icelandic waters to be 500 million kilogrmas of marketable bottom fish.

TABLE 19.—Average annual landings of fish from the Icelandic waters. (in 1,000 kg.)

Period	Cod	Haddock	Coal Fish	Ling & Lom	Red Sea Perch	Wolf Fish	Hali-but	Plaice	Total
1934-38	346,635	25,432	48,723	8,141	40,750	10,456	2,796	4,974	508,023
1923-33	476,842	40,251	37,669	5,308	13,539	11,233	2,888	6,875	612,253
1924-28	266,449	40,826	36,268	7,114	10,863	10,626	5,316	6,405	394,798
1919-23	196,436	39,469	10,278	6,173	5,467	6,334	3,471	6,695	282,515
1914-18	105,053	14,619	6,678	2,818	270	2,630	2,097	1,451	157,193
1909-13	146,387	29,265	9,156	4,703	2,245	3,506	5,429	5,661	210,162
1906-08	114,324	32,549	6,781	5,391	842	1,540	7,730	8,552	205,691

The herring fishery near Iceland is now just growing and there is no question of overfishing here.

b. Regulations

The Netherlands fishery biologist, until now, have not taken part in the research of distant fishing grounds. It is, therefore, impossible to give an independent opinion on necessary protection measurements. As for the North Sea, mesh-width determinations supported by minimum sizes for fish will have a good effect for this area. It is especially important to protect the young plaice and halibut and in this area it can probably be done best by the closing of the Faxa Bay to the trawl fishery.

Faxa Bay is in an area southwest of Iceland where much young haddock, plaice and halibut grow up and there are not so many objections to the closing of this area as there were for most of the grounds in the North Sea. The Icelandic coastal fishery is not a trawl fishery and would not be hindered by such a closing. The organization of Icelandic fishermen is strongly in favor of the closing. Moreover, the bay is comparatively small and has much traffic so that the control would be easier than that of a long coastal region. Finally, the bottom fauna is abundant, thus insuring sufficient available food for the growth of a large fish stock. The nearness of the fishery in Icelandic waters also contributes greatly to the enforcement of protective measures.

2. Northeast Atlantic Area

a. Progress of the Fishing.

The fish stocks of the Barents Sea, the Spitsbergen area, Bear Island, and the area before the Norwegian coast, are closely connected and probably must be taken as one fish stock.

Table 20 shows the quantity of fish, for five year periods, landed annually from the areas of the Barents Sea, Spitsbergen, Bear Island and from the Norwegian coast. Since we do not possess Russian data, the statistics are incomplete, particularly those from the Barents Sea. Considering the Russian catches, they probably will have to be increased by 25 percent. Changes made in the partition of fishery areas during the period 1906-39 in the statistics tables of the International Council are responsible for the fact that the numbers will not be altogether comparable. We believe, however, that they give a fairly good overall picture and that is sufficient here.

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TABLE 20.—Average annual landing from the Northeast Atlantic waters

(in 1,000 kg.)

Period	Barents Sea	Spitsbergen and Bear Island	Norwegian Coast	Total
1934-38	208,975	133,245	372,750	714,970
1929-33	100,923	123,575	309,063	533,561
1924-28	36,766	148,732	279,048	464,546
1919-23	5,440	78,785	153,884	238,109
1914-18	758	107,637	342,195	450,590
1909-13	25,797	161,465	209,681	396,943
1906-08	10,137	82,938	192,601	285,676

It can be seen that with the increase of the fishing intensity, the catches in the three areas increased also. Generally, therefore, there can be no reason for apprehension. That the fish stock of the Barents Sea has not declined appears from the fact that the English catch-per-hour fishing increased from 405 kilograms in 1924 to 820 kilograms in 1938. The increase must be due to the enlarged fishing capacity and a better knowledge of the fishing grounds. The great difference between the two amounts makes it probable that the density declined little or not at all.

It appears to us that these areas and certainly the Barents Sea are capable of delivering much more fish. The statistics show that there is a state of underfishing. The area of the Barents Sea, Spitsbergen and Bear Island are more than twice as large as the North Sea, have very good feeding grounds and until now have not yet delivered as much as the maximum production of bottom fish from the North Sea.

Not all species may be included in the conclusion that the Barents Sea can deliver greater quantities of fish. The plaice stock here may be overfished very easily and even faster than in the North Sea, probably since the best places for the growing of young are scarce. When the English began to fish in the Barents Sea, in the beginning of this century, they were tempted chiefly by the excellent catches of plaice. The catches increased rapidly from about 2 million kilograms in 1906 to 15 million kilograms in 1909. Then they declined from 5.5 million kilograms in 1912 to 3 million kilograms in 1913. The plaice was protected after the first World War, when Russia forbade foreign ships from fishing within 12 miles off the Murmansk coast. The spawning areas for the plaice were in this area. Nowadays, the quantity of plaice brought by non-Russian trawlers from outside this zone varies from 2 to 4 million kilograms per year.

b. Regulations

Although there is no danger for these stocks, it is to the interest of the future industry to limit the catching of undersized fish. Sometimes considerable quantities of undersized fish are caught in these areas, frequently up to 50 percent. Since it is harder to keep the small fish in good condition, those trawlers which do not have fish meal installations on board will avoid these grounds. A large minimum mesh width for the cod end will be of influence in the protection of the young fish. The International Conference of minimum fish sizes and mesh widths held in London in 1937 set a minimum mesh width of 10.5 centimeters for the areas North of 66°N., and East of Greenwich Meridian. Later, in 1946, the Icelandic waters were included.

Controlling the non-usage of undersized fish will be extremely difficult in these areas. Many trawlers fishing there have fish meal installations on board. However, it is not expected that they will deliberately fish for trash fish, since that will not be profitable on these expensive voyages.

It seems impossible, at the moment, to determine how intensive the fishing may be in the northeast Atlantic area. The best means to prevent overfishing in the future will be to have a continuous control of the changes in the fish stock, whereby the passing of the point of overfishing most probably can be established in time, so that restrictions can be effected.

III. SUMMARY

In the first chapter it was explained that the quantity of fish which a sea can deliver is limited. The productive power of the fish stock of an area changes with the magnitude of the stock. For a certain numerical strength corresponding to a certain fishing intensity, it will be possible to harvest a constant optimum catch of this fish stock.

Next it was shown that the intensity, with which the bottom fish in the North Sea was fished during the years 1930-40, was much higher than the fishing intensity which corresponds to the optimum catch. Hence there was a state of overfishing.

On the basis of statistics on the North Sea fishery gathered during the last 40 years, one may estimate the catch of bottom fish from the North Sea at 390 million kilograms each year.

It is necessary that in the future the North Sea fishery be fixed by international quotas so that no more than 390 million kilograms of bottom fish will be caught each year.

To receive as high a return as possible and to see to it that sufficient fish become fully developed (sexually), it is desirable to minimize the catch of non-marketable and very cheap-consumption fish.

A documented survey was given of the measures with which the above could be obtained and it was explained which measures would give the most protection for the young fish in the North Sea. A summary of the advisable regulations is given on page .

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