REPORT OF THE INTERNATIONAL FISHERIES COMMISSION

APPOINTED UNDER THE TREATY BETWEEN THE UNITED STATES AND GREAT BRITAIN FOR THE PRESERVATION OF THE NORTHERN PACIFIC HALIBUT FISHERY

NUMBER 8

BIOLOGICAL STATISTICS OF THE PACIFIC HALIBUT FISHERY

(2) EFFECT OF CHANGES IN INTENSITY UPON TOTAL YIELD AND YIELD PER UNIT OF GEAR

BY

WILLIAM F. THOMPSON AND F. HEWARD BELL

COMMISSIONERS:

WILLIAM A. FOUND
FRANK T. BELL
EDWARD W. ALLEN
JOHN PEASE BABCOCK
Chairman

SEATTLE, WASHINGTON
1934

FOREWORD

The present is an eighth report by the International Fisheries Commission upon scientific results obtained under the terms of the convention of 1924 and that of 1930 between the United States and Great Britain for the preservation of the halibut fishery of the Northern Pacific Ocean, including Bering Sea.

The Commission, through its scientific staff, has studied where and how the halibut live, the ways in which they are fished and the effect of this fishing upon the supply of fish. By its biological studies it has shown the existence of distinct stocks of halibut, inhabiting different banks, growing at different rates, and having each its own physical characteristics. And by remarkably accurate statistics it has followed from year to year in the case of each stock, the intensity of the fishery and the yield therefrom, showing the dangerous depletion that had gone on unchecked until 1930 and which called into existence the treaty under which the Commission now operates.

So accurate for each stock has been the determination of the amount of gear "run" each year, and so carefully studied the effect of the varying fishery upon the yield and supply, that the Commission is in a position to determine in advance the effect of any given intensity, to a degree not equalled in any other fishery it has knowledge of. The regulations of the Commission, therefore, are not based upon surmise but upon accurate scientific knowledge of what the effects will be. And although the expenditures of the Commission have been small compared to those of similar bodies, nevertheless it is to be doubted whether it is possible anywhere else to proceed with more assurance as to what is necessary and what the result will be.

The conclusions from the investigations of the Commission are most striking and of profound importance to the regulation not only of the halibut fishery but, it hopes, also to many other fisheries. They indicate that in each stock the major changes are due to the fishery itself. They show, as might be expected from the history of many other fisheries, that the more intense the fishery the fewer fish survive to a spawning size. They also show that an intense fishery takes the available fish while they are still small, and that a lessened intensity allows them to grow to a larger size, but takes them just the same. Consequently, the ultimate yield obtained by the less as compared to the more intense fishery, from what young do come into the commercial catch, depends upon whether the growth in bulk exceeds or is less than the loss by natural death during the additional period they are allowed to live. Accordingly, where growth is rapid and the weight of living fish increases with time, the great intensity of the fishery is sheer economic waste in that it does not increase the total catch, but actually decreases it, as well as prevents the growth of fish to spawning size. It does not increase the yield, but lessens it, and destroys the supply of spawners. The application to regulation is obvious.

These scientific results show the basis for the remarkable success of regulation to date, whereby the abundance of the stocks has increased greatly. The Commission has, of course, followed this success closely, because it was determined that however conclusive the scientific results might be, the regulations should justify themselves step by step. On southern grounds the increase has been 50 per cent in 1933 over that of 1930, and there has been a further increase in 1934. The lessened fishery has nevertheless given the fleet as large a yield each year as in 1930, and the Commission has reason to believe that the production of spawn has increased accordingly. These results are in accord with expectation, but the increased spawning must, of course, be proved directly by the observations now under way.

The Commission therefore believes that by regulation not only the yield from what young are available will be greatly increased and require less effort on the part of the fishermen, but that ultimately more young will annually make their appearance. It hopes to determine what is the most favorable intensity of the fishery in order to get the largest permanent yield from each stock. It seeks to continue to provide regulations which will permit the fishermen to make as large catches as can be made without endangering the future supply. In short, the Commission hopes to establish the fishery on such a permanent basis as will benefit both the fishermen and the public at large of both nations.

The International Fisheries Commission, on its organization, created a Scientific Advisory Board with whom the scientific program has been discussed. The Board consists of four members: Dr. C. McLean Fraser, Professor of Zoology, University of British Columbia; Dr. W. A. Clemens, Director of the Pacific Biological Station at Nanaimo, B. C.; N. B. Scofield, Chief of the Bureau of Commercial Fisheries, Division of Fish and Game, California; and Dr. Willis H. Rich, Professor of Zoology, Stanford University.

The International Fisheries Commission also created a Conference Board consisting of members elected by the Deep Sea Fishermen's Unions and the Fishing Vessel Owners' Associations of the United States and Canadian ports on the Pacific. The members of this Board are annually called into conference with the Commission and the Director at the conclusion of each fishing season to discuss conditions. By this method the fishermen and vessel owners are kept constantly informed of the data collected by the staff and its significance.

The investigations have been carried on by a staff under the direction of Dr. William F. Thompson, with headquarters and laboratory in the United States Bureau of Fisheries Building, 2725 Montlake Boulevard, Seattle, Washington, U. S. A.

JOHN PEASE BABCOCK, Chairman.
FRANK T. BELL.
WM. A. FOUND.
EDWARD W. ALLEN, Secretary.

REPORTS BY THE INTERNATIONAL FISHERIES COMMISSION

1. Report of the International Fisheries Commission appointed under the Northern Pacific Halibut Treaty, by John Pease Babcock, Chairman, and Wm. A. Found, Miller Freeman, and Henry O'Malley, Commissioners. Dominion of Canada, Ottawa, 1928.

   Same. Report of the British Columbia Commissioner of Fisheries for 1928, pp. 58-76. Victoria, 1929.

   Same. Report of the United States Commissioner of Fisheries for 1930, Appendix 1. U. S. Bureau of Fisheries Document No. 1073. Washington, 1930.

2. Life History of the Pacific Halibut (1) Marking Experiments, by William F. Thompson and William C. Herrington. Victoria, B. C., 1930.

3. Determination of the Chlorinity of Ocean Waters, by Thomas G. Thompson and Richard Van Cleve. Vancouver, B. C., 1930.

4. Hydrographic Sections and Calculated Currents in the Gulf of Alaska, 1927 and 1928, by George F. McEwen, Thomas G. Thompson, and Richard Van Cleve. Vancouver, B. C., 1930.

5. The History of the Pacific Halibut Fishery, by William F. Thompson and Norman L. Freeman. Vancouver, B. C., 1930.

6. Biological Statistics of the Pacific Halibut Fishery (1) Changes in Yield of a Standardized Unit of Gear, by William F. Thompson, Harry A. Dunlop, and F. Heward Bell. Vancouver, B. C., 1931.

7. Investigations of the International Fisheries Commission to December 1930, and their Bearing on Regulation of the Pacific Halibut Fishery, by John Pease Babcock, Chairman, William A. Found, Miller Freeman, and Henry O'Malley, Commissioners. Seattle, Washington, 1930.

8. Biological Statistics of the Pacific Halibut Fishery (2) Effect of Changes in Intensity upon Total Yield and Yield per Unit of Gear, by William F. Thompson and F. Heward Bell. Seattle, Washington, 1934.

Further reports will bear serial numbers and will be issued separately by the Commission.

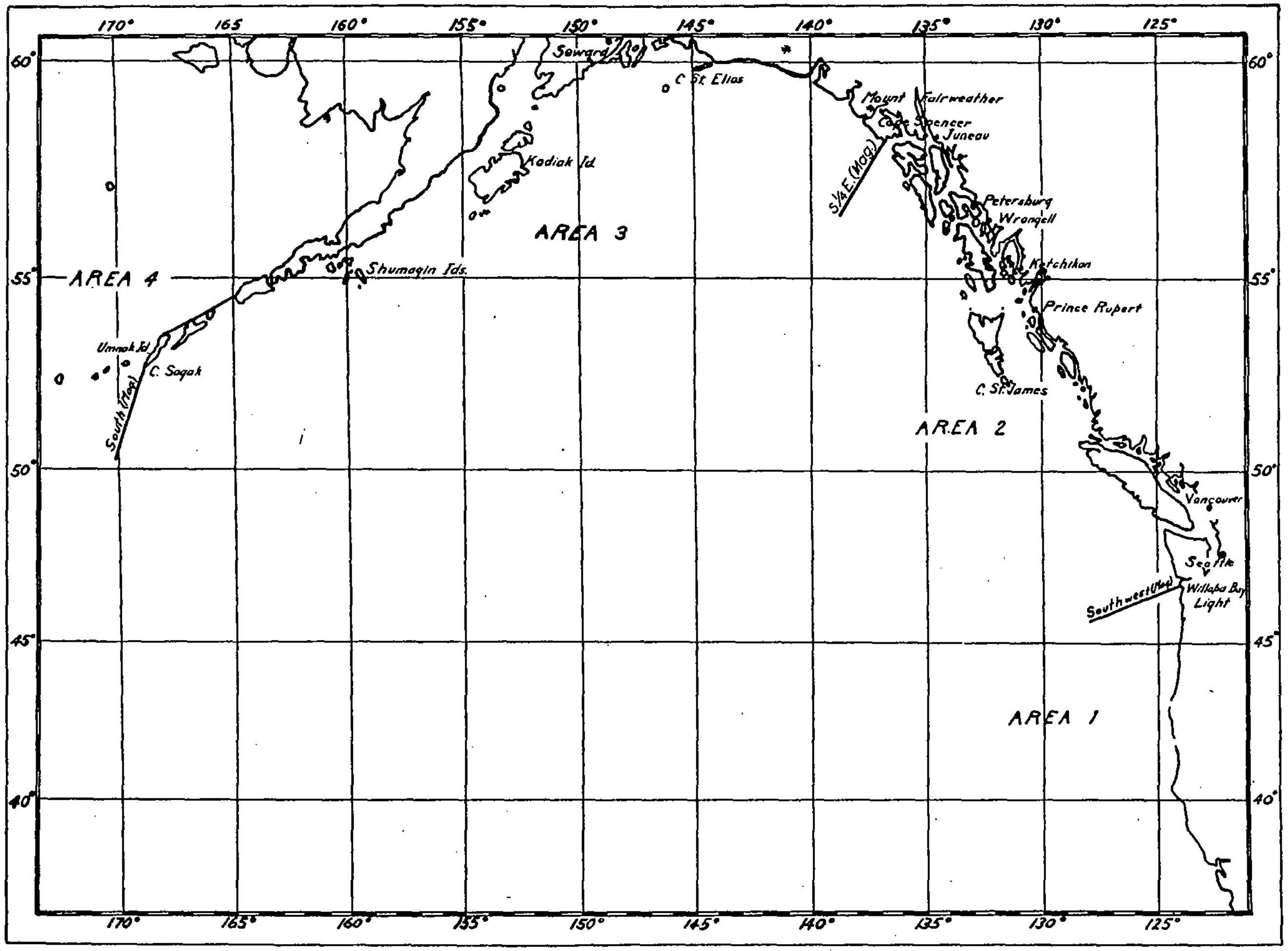

FIGURE 1.—Map of the Pacific coast showing division into areas for regulatory purposes.

BIOLOGICAL STATISTICS OF THE PACIFIC HALIBUT FISHERY

(2) EFFECT OF CHANGES IN INTENSITY UPON TOTAL YIELD AND YIELD PER UNIT OF GEAR

By WILLIAM F. THOMPSON and F. HEWARD BELL

CONTENTS

INTRODUCTION

Regulation of the halibut fishery has for its purpose the maintenance and increase of the yield. This yield has already been shown to have declined greatly, both as to the total from each district and as to the returns to the fisherman. A knowledge of the causes of this decline is necessary to any intelligent action in prevention, and such knowledge can be obtained only through study of what has already happened. One series of records, that of the yield per set of a unit of gear has already been presented. These records, in conjunction with those of total catch from each stock of halibut, and the resultant measure of the intensity of the fishery, are analyzed in the present report.

In preparing the present report the staff of the Commission has had in mind what might be termed the usual business procedure of "keeping books" on the production of halibut. The resultant data have then been subject to analysis, but an attempt has been made to present this analysis in a non-technical way in view of the wide variety of readers interested. The material will, however, well repay a more elaborate mathematical study.

ACKNOWLEDGMENTS

To "keep books" on the production of halibut has been made possible only by the splendid cooperation of the fleet and trade, as well as government officers. The statistical branches of the Canadian Department of Fisheries and of the United States Bureau of Fisheries, and the Customs services of both countries have rendered invaluable assistance in the collection of records. The manager of the Fishing Vessel Owners' Association at Seattle, Harold E. Lokken, has been particularly helpful. Practically all present and former members of the staff of the International Fisheries Commission have had part in the statistical work, especially Messrs. Norman L. Freeman, Olaf E. Eriksen, J. L. Kask, and Misses Dorothy Myers, Sigrid Lokken, and Olivia Froula. Mr. H. A. Dunlop has furnished tables of age determinations from manuscript, and Mr. R. Van Cleve, Figure 7, in addition to their constant help and interest. Dr. A. F. Carpenter and Mr. M. B. Schaefer, now engaged in a study of the mathematics underlying the phenomena described, have assisted and contributed suggestions.

SUMMARY

This report on one phase of the investigations of the Commission to December, 1933, gives a summary of the known changes in productiveness of the halibut banks of the Pacific. Knowledge of these has progressed sufficiently to warrant a presentation of the more general conclusions as to causes and an outline discussion of their bearing on the method of regulation.

The biological evidence justifying the separation of the halibut banks

into two distinct stocks, divided at Cape Spencer, is reviewed. The statistics of yield from these stocks include records of the intensity of the fishery, in addition to those for amount and locality, and provide unparalleled material for a study of the relation of intensity to the changes in the stock.

The major fluctuations in the halibut fishery in each area are shown herein to be dependent upon the changing intensity of the fishery, as measured by the number of sets of a standard unit of gear. This relationship results from the usual well known age composition of any population upon which two influences, other than that of the fishery, have been at work. One, deaths from natural mortality, tends to be balanced by the other, growth in size of the individual. With approximate values for the rate of death and rate of growth, the stock can be theoretically reconstructed, age class by age class, on the assumption that the incoming young are constant from year to year. The total yield can be calculated for each intensity of the fishery.

If the income of young is constant, and as long as the annual increment by growth is equal to the loss by natural mortality, the expectation is that the total annual yield will be approximately equal, whatever the intensity of the fishery, except at the very lowest levels. This conclusion is based on simple and generally accepted principles, the results of which are here shown to correspond to changes in the actual fishery.

It is shown by this reconstruction that each increase in the fishery has resulted in a series of characteristic reactions, independent of any change in the number of incoming young: (1) a temporary increase in total yield, (2) a later gradual fall to a new level, and (3) a continued decline in yield per set of a unit of gear until the fishery finally has reached stability. The actual statistics are compared with theoretical reconstructions and the latter verified, explaining thereby the past changes in the yield of the halibut fishery. The comparisons between the actual and the theoretical are made in Figures 11 to 18, which may be consulted at once by those readers not desirous of following their derivations.

It is also shown that a less intense fishery, because there is a lower total mortality rate, produces many more fish of spawning size and age, hence increases the production of young. And where the increment by growth exceeds the loss by natural causes of death, the less intense fishery produces not merely a higher catch per unit of effort, but a greater annual total catch from what young come into the commercial catch. Hence in fisheries of this type, a less intense fishery should increase both the incoming young and the poundage produced from them, and vice versa, a more intense fishery should decrease both. The statistics for the areas off British Columbia and Southeastern Alaska indicate that its fishery belongs in this class, the successive intensifications of the fishery having reduced the total yield to successively lower levels, confirming the analysis made.

But it is equally obvious that where the growth rate is slow, less than the mortality from natural causes, the greatest total yield from a given number of incoming young is produced by an intense fishery, although the catch per unit of gear is thereby sharply reduced. In such a fishery the intensity should be as great as is consistent with maintenance of the supply of young and as is economically feasible in view of the fall in returns to the individual fisherman. It is suggested that such a fishery may exist in the Gulf of Alaska and west, due to the very slow growth there, but analysis is incomplete.

The effects of regulation, economic and legal, in reducing the intensity of the fishery since 1930, and increasing the yield per unit 50 per cent on the grounds off Southeastern Alaska and British Columbia, are shown to be in accord with the analysis here made. Although the previous history has shown only a succession of increases in the fishery, with corresponding declines in total yield and in catch per unit, it would be expected that a reversal of the process would reverse the effects. This it is doing.

It is therefore shown that there are two distinct problems: one that of maintaining the incoming young, the other that of making the best use of these after arrival at commercial size. It is apparent that the fishery has been carried on without regard to either, and it can be indicted both for wastefulness of the present supply and disregard of the future.

A. REVIEW OF INVESTIGATIONS AND STATISTICS OF YIELD

The International Fisheries Commission was created in the late fall of 1924 by the first treaty for conservation of the Pacific halibut. In that treaty it was given the function of investigation only, with the duty of making recommendations as its researches might indicate to be necessary. A scientific staff was brought together by June of 1925 and began its collection of necessary statistical and biological facts.

Under this original treaty a closed season of three months was provided. The closure was, however, economically profitable, and since the fishery was at liberty to increase indefinitely during the remaining nine months, it did so, destroying any beneficial biological effect the closure might have had. The lack of any restraining effect on the fishery is shown in Tables 1 and 2 and Figures 2 and 3. For 1925 and subsequent years the annual amount of gear run rose greatly.

Recommendations for regulatory powers were made in the fall of 1928, and these were embodied in a new treaty which became effective in May, 1931. New regulations prepared under this treaty were adopted in February of 1932. These regulations closed two small "nurseries," modified the closed season of three months, and provided a limit to the catch during the open season, thereby making the principle of the closed season, a limitation of intensity, actually effective. The catch was limited according to areas defined in the 1932 regulations, Area 2 between Willapa Harbor and Cape Fairweather to 22,500,000 pounds, and Area 3 between Cape Fairweather and Bering Sea to 23,500,000 pounds. Area 1, south of Area 2, and Area 4 in

TABLE 1.—*Total landings, average catch per 6-line skate, and total number of skates fished on grounds south of Cape Spencer.*[1]

Year	Catch per Skate (Pounds)	Landings (Pounds)	Number of Skates
1895	....	4,251,015	....
1899	....	8,935,640	....
1902	....	22,343,000	....
1904	....	28,077,155	....
1905	....	22,000,000	....
1907	280.0 [2]	50,000,000	178,571
1910	271.0 [2]	51,849,240	191,325
1911	237.0 [2]	56,931,796	240,219
1912	176.0 [2]	60,379,550	343,066
1913	128.9	56,235,578	436,273
1914	124.1	45,276,669	364,840
1915	118.0	45,025,016	381,568
1916	114.6	30,218,908	263,690
1917	81.8	31,602,797	386,342
1918	87.5	27,070,659	309,379
1919	82.3	27,402,631	332,960
1920	84.1	33,158,192	394,271
1921	76.9	37,476,466	487,340
1922	62.6	31,294,067	499,915
1923	57.2	28,844,269	504,270
1924	55.8	27,004,148	483,945
1925	51.8	23,941,311	462,187
1926	52.2	25,790,876	494,078
1927	49.4	24,630,270	498,588
1928	47.8	27,209,093	569,228
1929	40.2	26,253,998	653,085
1930	35.1	22,598,895	643,843
1931	41.0	22,473,326	548,130
1932	50.1	22,881,718	456,721
1933	52.1	23,599,734	452,970

[1] See page 15 for remarks on this division.

[2] From Table 14, Thompson, Dunlop, and Bell, International Fisheries Commission Report Number 6, 1931, taken from Thompson, 1916, Table 17, p. S84.

TABLE 2.—*Total landings, average catch per 6-line skate, and total number of skates fished on grounds west of Cape Spencer.*

Year	Catch per Skate (Pounds)	Landings (Pounds)	Number of Skates
1912	....	55,000	....
1913	....	10,306,733	....
1914	....	22,148,570	....
1915	266.1	23,660,339	88,915
1916	202.8	18,677,214	92,097
1917	157.9	16,995,688	107,636
1918	125.4	10,615,282	84,651
1919	129.9	12,735,424	98,040
1920	147.9	13,456,923	90,987
1921	141.4	14,677,098	103,798
1922	134.8	10,849,830	80,488
1923	150.3	21,468,540	142,838
1924	109.7	25,520,675	232,641
1925	95.2	26,023,413	273,355
1926	94.1	26,059,711	276,936
1927	86.9	30,025,068	345,513
1928	72.8	26,982,962	370,645
1929	72.6	30,191,946	415,867
1930	64.7	26,505,810	409,672
1931	71.7	20,856,830	290,890
1932	82.2	20,740,244	252,314
1933	84.0	22,461,704	267,401

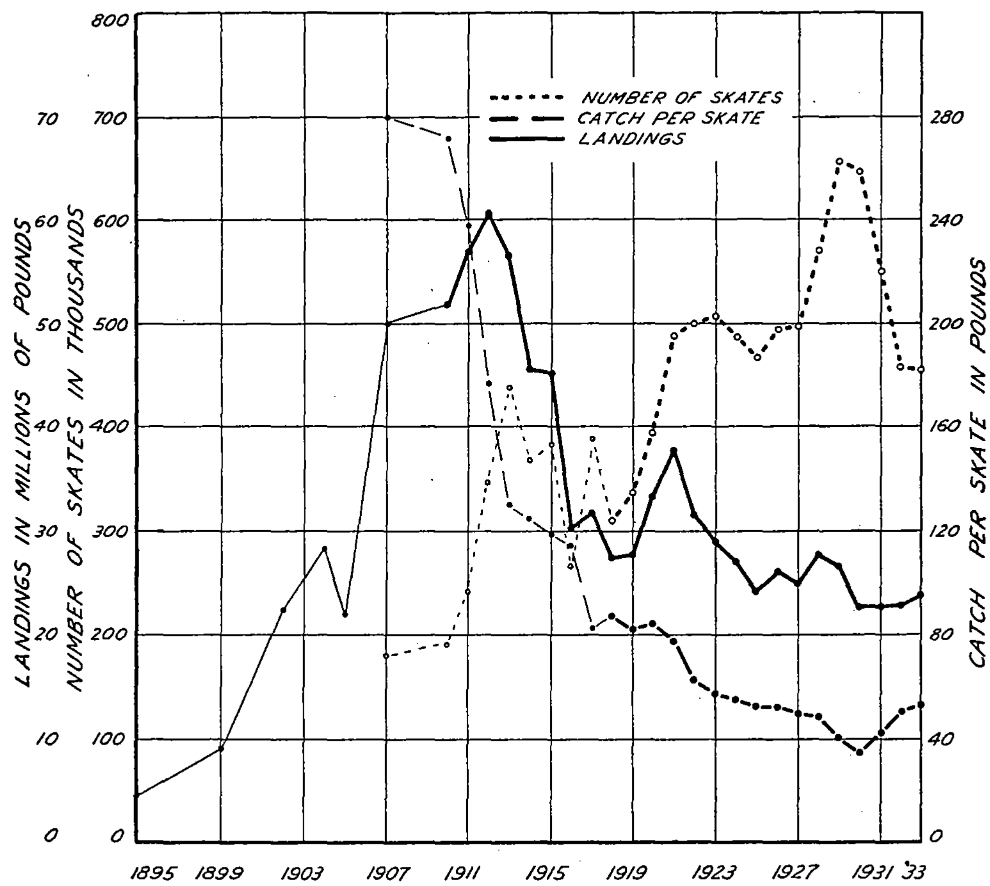

FIGURE 2.—Landings, catch per 6-line skate in pounds, and number of skates fished on grounds south of Cape Spencer.
The lighter lines indicate less complete records

Bering Sea, were not limited, as the fisheries therein were non-existent or not large. The area limits were changed the next year to Cape Spencer instead of Cape Fairweather, with a change in catch limit to compensate. The fishery in each such area was closed on attainment of the specified limit. It closed in Area 2 on October 22 in 1932, and August 25 in 1933, hence shortening the season in 1933 to six months. In Area 3 it was closed November 1, 1932, without attaining the limit, and on October 26 in 1933. This was, in practice, a limitation of the amount of gear run, as the catch per unit was known approximately, and the total fixed accordingly.

Effective regulation had, however, begun during 1931 by virtue of economic conditions, which reduced the amount of fishing.

The resultant limitation of the intensity of the fishery caused the catch per set of a unit of gear[1] to rise sharply, and in consequence the action of

---

[1] Use of the term "catch per skate" in this report refers to the catch in pounds per single set of a 6-line skate carrying a definite number of hooks and set in accordance with the habits of the fishermen.

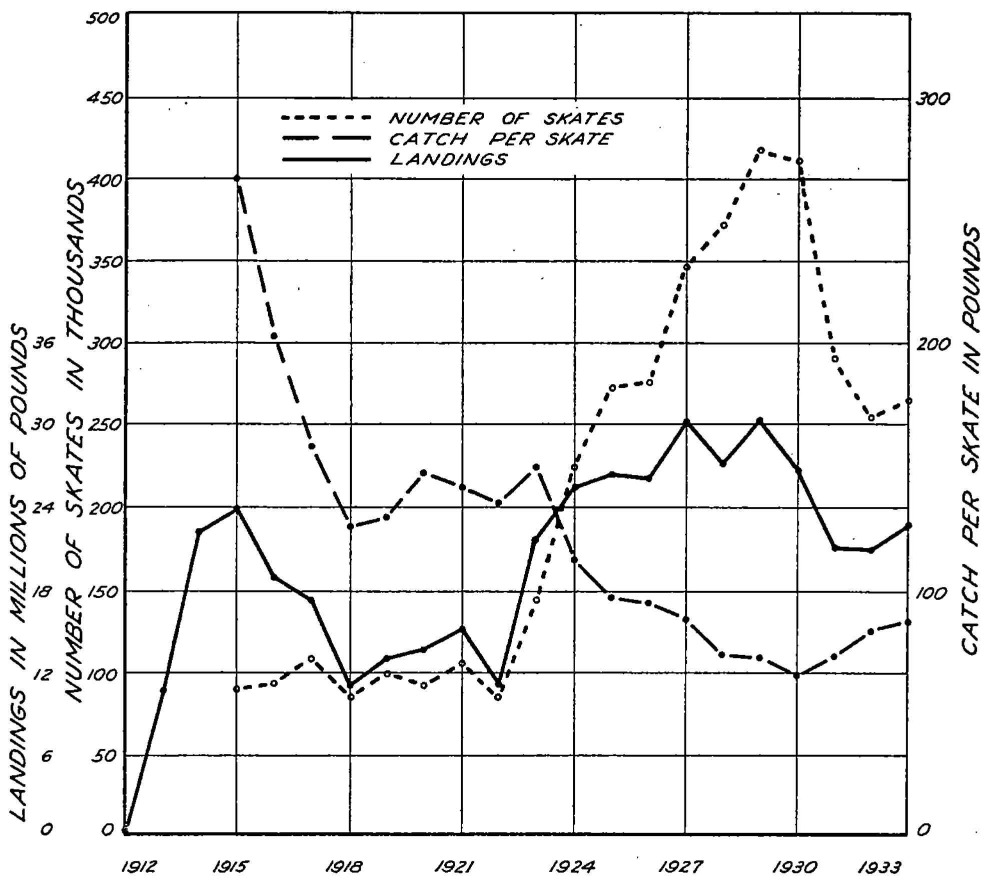

FIGURE 3.—Landings, catch per 6-line skate, and number of skates fished on grounds west of Cape Spencer.

the Commission during 1932 and 1933 in holding the catch to a fixed level still further reduced the amount of gear run as shown in Tables 1 and 2 and Figures 2 and 3.

It is not too much to say that these regulations are successful. There has been in Area 2 an increase of 50 per cent since 1930 in the catch per set of a unit of gear, with the same total catch as in that year. A similar, but somewhat less pronounced effect is present in Area 3. This increase reflects an increase in the stock of fish, but whether it is adequate or not must be tested by biological and statistical researches.

The time since the formation of the Commission may therefore be divided into two periods, that prior to and that subsequent to the beginning of effective regulation, with a total of nine years of continuous observation, made much more adequate in 1932 by regulations regarding statistical return.

This is not a long period for determination of the manner of reaction of the species to the fishery. It has, however, given time for one major fluctuation in the intensity of the fishery and in the yield. The conclusions derived from this period of observation have been supported by the collection of extensive statistics for years previous to 1924, in fact as early as 1906, with the result that an understanding of some of the history of the fishery and some of the principal causes and effects has been arrived at.

Moreover, the biological background has been laid. Experiments such as marking required two years on southern grounds and another two on western, with four and five years for even approximate completion of returns. Age determinations required material collected over a period of four years and intermittently since. And after vessel operations for marking, racial, and age investigations had been completed, those for the study of eggs and larvae could be begun.

In the following pages the results of these investigations will be briefly reviewed and their bearing on the interpretation of the statistics of the fishery indicated.

In this report reference to statistics of Area 2 or Area 3, that is, south or west of Cape Spencer, will mean those for the 60-mile areas 0 to 18 and 19 to 36 respectively. In previous reports of the Commission will be found maps showing the trend of the coast divided into these 60-mile areas. Those

TABLE 3.—*Total Pacific coast halibut landings,*[1] *1888 to 1933.*

Year	Pounds
1888	1,465,000
1889	1,290,000
1890	1,373,000
1891	2,131,000
1892	2,768,000
1895	4,251,000
1899	8,936,000
1902	22,343,000
1904	28,077,000
1905	22,000,000
1907	50,000,000
1910	51,849,000
1911	56,932,000
1912	60,435,000
1913	66,542,000
1914	67,425,000
1915	68,685,000
1916	48,896,000
1917	48,598,000
1918	37,686,000
1919	40,138,000
1920	46,615,000
1921	52,154,000
1922	42,144,000
1923	50,313,000
1924	52,525,000
1925	49,965,000
1926	51,851,000
1927	54,665,000
1928	54,192,000
1929	56,446,000
1930	49,104,000
1931	43,330,000
1932	43,621,000
1933	46,061,000

[1] California and Oregon landings not included.

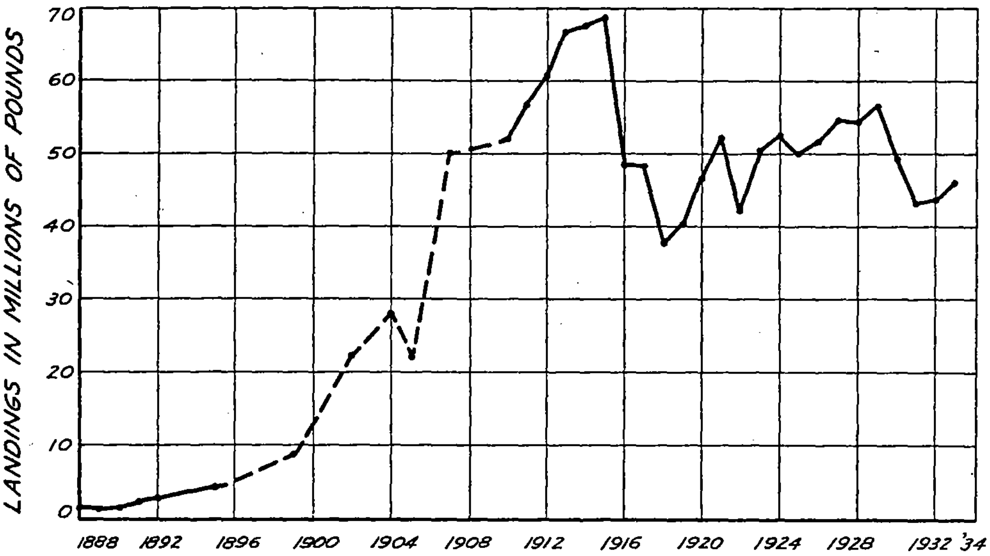

FIGURE 4.—Total Pacific coast halibut landings, 1888 to 1933.

from 4 to 18 approximate very closely the Area 2 limits of the 1932 regulations; namely, from Willapa Harbor to Lituya Bay. The 60-mile areas 19 to 36 are almost exactly the Area 3 of the 1932 regulations. In this report the landings in Seattle, but not those in California and Oregon, from grounds south of Willapa Harbor have been included in the analysis, since in early years it was not possible to separate them. They have been inconsequential in amount since 1917.

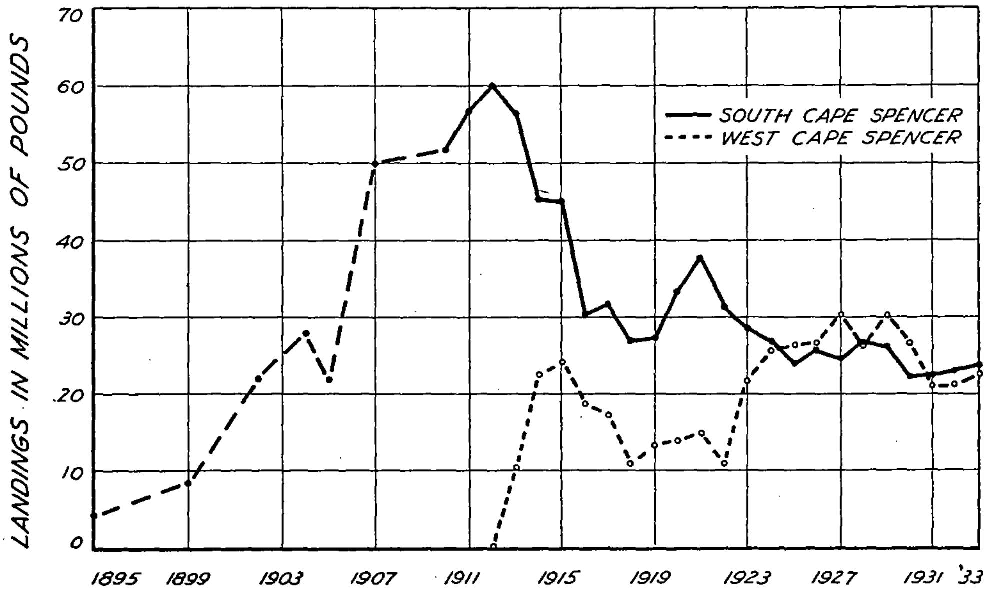

FIGURE 5.—Landings from grounds south of Cape Spencer and from grounds west of Cape Spencer.

The history of the fishery, as gathered from many sources and reported upon by Thompson and Freeman (International Fisheries Commission Report Number 5), shows that the industry has been maintained only by expansion to new banks. Beginning in 1888, the rise of the annual landings was phenomenally rapid until about 1910. Since that time it has varied around 50 millions of pounds annually. (See Table 3 and Figure 4.) Were this to have come from a single stock of fish its consistency might have been regarded as legitimate evidence of a healthy fishery. But we know that in 1911 the fishery spread out of sheltered waters onto deeper banks, and in 1913 the exceedingly heavy winter fishery in the Gulf of Alaska (Area 3) had begun. (See Figure 5.) After the temporary recession of war times, the use of Diesel engines by the fleet enabled them to exploit even the banks along the Aleutians, greatly increasing since 1921 the intensity of the western fishery. This great expansion in area since 1911 has meant the origin of a full half of the yield from a new and separate district.

The condition of the supply on the various banks is closely correlated with their distance from the landing ports. Each is depleted as far as is profitable considering the costs of operating. In Figure 6 it is shown that

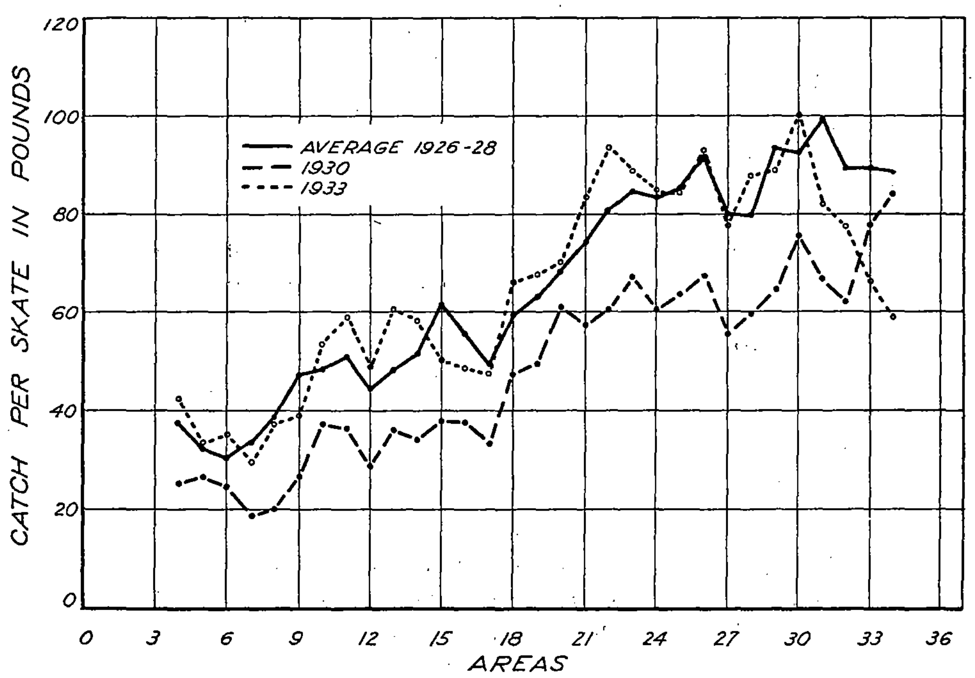

FIGURE 6.—Catch per 6-line skate in pounds by 60-mile sections of the coast from Willapa Harbor (4) to Sanak Island (34). Cape Spencer is in Area 18.

the catch per set of a unit of gear is least on the older southern banks and that it rises to a maximum on the newer western grounds. In this figure the base line from left to right represents the coast from California to Bering Sea, divided into areas, each including sixty miles of trend of the coast. (Compare International Fisheries Commission Report Number 7, Figures 1, 2, and 3.) The level of abundance is in each case an economic one. Hence the older banks, nearer the landing ports, have declined to the greater extent despite their originally far larger population, and must be regulated accordingly. (See Thompson and Freeman, International Fisheries Commission Report Number 5.)

The biological evidence as to the existence of these stocks and the areas they inhabit has been obtained for the adults by marking experiments, by study of the physical peculiarities differentiating them, and by study of rates of growth which differ with the physical conditions. And for the eggs and young, by vessel operations to follow their history and their drift with the ocean currents. This evidence was briefly reviewed in the International Fisheries Commission Report Number 7, dealing with investigations up to December, 1930.

The marking experiments have been carried on by the use of numbered monel metal strap tags, bent over the edge of the operculum, placed on halibut liberated from the research vessels. They are recovered by giving a reward to the fishermen. (See Thompson and Herrington, International Fisheries Commission Report Number 2.) Some 12,969 tags have been used to date of publication, about equally divided between the two regulatory areas. Both mature fish, about 12 years of age on the average, and immature have been tagged.

The results of these marking experiments show that the population, as yet predominantly of mature fish, between Cape Spencer and the Aleutian Islands, hence for the whole of the Gulf of Alaska, forms a unit, with but one in 25 of the adults marked in the Gulf of Alaska reaching Southeastern Alaska, and but one in 100 the coast of northern British Columbia. But within the Gulf, recoveries were spread over the whole coast, regardless of where the marking was done, the results indicating a free migration of mature fish. South of Cape Spencer so reduced in numbers are mature fish that knowledge of the separate stocks there has grown but slowly as opportunity has offered to mark them. In general they are localized around the two main remaining spawning grounds, off the northern and southern parts of the Queen Charlotte Islands. Only two of the fish marked south of Cape Spencer were retaken to the north.

Immature fish, on the other hand, have been shown to be but slightly migratory, and that largely within the confines of their own banks. Pending maturity, the stock on each bank is isolated except for occasional migrants, hardly sufficient in number to disturb the effects of the fishery in each case. The fact that the immature predominate in the catch from southern grounds because the intense fishery prevents their survival to a spawning size, would be reason for treating these grounds as populated by a series of separate stocks. But these have been subject to about the same type and intensity of fishing, since they live on the older grounds, and their condition is sufficiently similar to justify, for our present purposes at least, treatment as one unit in contrast to that on western grounds.

The existence of these stocks has been confirmed by the finding of physical peculiarities characteristic of each stock. Analysis of the various body dimensions of over 20,000 specimens collected from different localities on the coast has shown that the fish on grounds south of Cape Spencer are differentiated morphologically from those on grounds west. An example of such differences is shown in the head length. The stocks on the western grounds, on such widey separated banks as Yakutat, Portlock, and Shumagin, appear to be similar one to the other as belonging to a freely migrating unit characterized by a large head and no differences in number of vertebrae, a conclusion equally well supported by the tagging studies. The southern stock, largely consisting of immature fish, shows that it may be separated into small sub-stocks each of which differs in physical appearance from others in the same general area. For the larger fish in these southern areas it appears that such differentiation is not present. These conclusions regarding the nature of the southern populations are also well borne out by the tagging studies.

A further most significant characteristic of the several stocks is found in the variation of growth rates, which are not only indicative of the difference between the stocks, but are of vital importance in explaining the fluctuations in catch which occur and in the determination of the type of fishery necessary to secure a maximum yield. The growth has therefore been calculated carefully and accurately for all parts of the banks. It is given in Tables 4 and 15 for two localities: one, Goose Island, a southern ground north of Vancouver Island; the other, Yakutat, on the eastern side of the Gulf of Alaska. The latter is slower, as is typical of all stocks in the Gulf of Alaska and west. (H. A. Dunlop, manuscript.)

Conclusions as to the distinctness of these stocks could not be final until the interchange of floating eggs and larvae had been measured. Until the present work was begun the floating eggs and early larval stages of this species had not been discovered even in the much explored European waters. There had been taken near Iceland a small number of later stages.

The researches of the Commission have shown that the eggs are laid between December and March near the edge of the continental shelf. Both eggs and larval stages float in intermediate layers of water and develop for a period approaching six months, during which time many of them are found far at sea over great depths. The later stages are taken near shore and, when settling on the bottom, are frequently found even in tide pools along the coast. Once having identified these and indicated their general distribution, it became evident that the oceanic currents carrying them were of great importance in determining their distribution.

These currents were studied by two methods: one indirect, by measuring the effect produced on the physical characteristics of the water by currents; the other direct, by means of drift bottles. The existence of a great eddy, a northern branch of an onshore stream separating off southern British Columbia and Washington, was proved, and with it the improbability of any

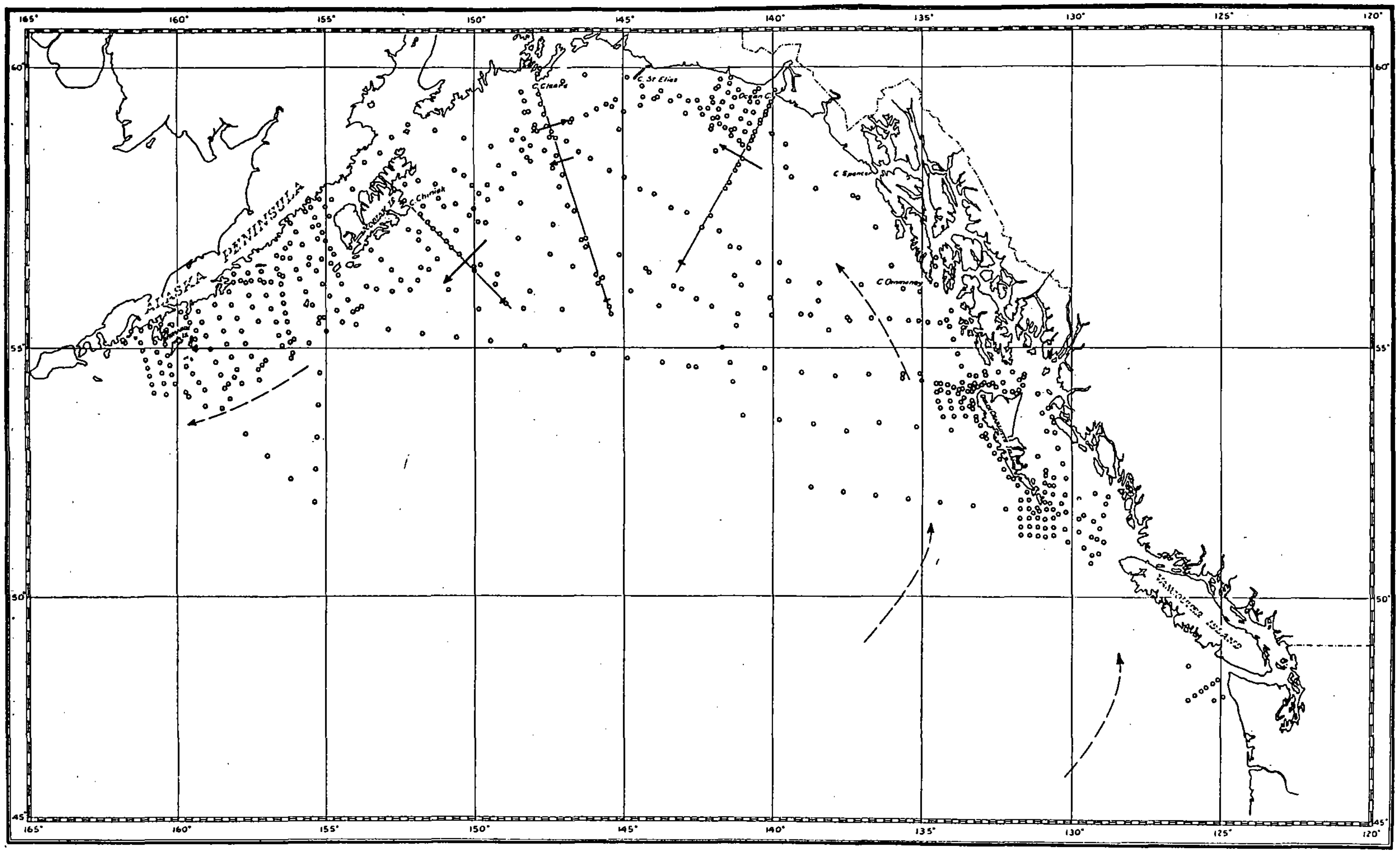

FIGURE 7.—Map of North Pacific Ocean showing net haul stations. Arrows indicate direction of current. Length of solid arrows indicates relative strength of current.

drift of northern larvae to southern banks. The conclusion, from a study of the migration of adults, that Cape Spencer is a natural point of division between the stock inhabiting the eddy of the Gulf of Alaska and the one or several more or less similar stocks found below Cape Spencer, seems justified by these findings regarding the drifting young. (R. Van Cleve, manuscript.)

The separate stocks have therefore been dealt with individually in studying the yield. As long as mature fish dominate in the catch from grounds west and north of Cape Spencer that area will be a natural unit, but if the fishery becomes so intense as to leave immature only, it will cease to be so. That southerly of Cape Spencer is undoubtedly already a combination of units. In consequence all our information has been gathered in such manner and detail as to be capable of separation at any future time when thought necessary.

These stocks vary in history of exploitation, in present condition, and in their biology. They are fished by relatively distinct fleets, and yield a different class of fish. They must be studied separately, and regulation cannot be successful unless it takes into account their different needs and inter-relationships, economic as well as biological.

Having thus decided upon the existence of different stocks and having divided the coast accordingly, it was found that the statistics of yield and effort for the individual areas were varying in a consistent way. Without such separation, this consistency was lacking.

There are three types of such statistics; namely, total catch, amount of gear fished, and catch per set of a unit of gear. The gear used in the halibut fishery is a long ground line carrying a definite number of hooks per unit length, or "skate." The length of this has varied, and for correct comparison it has been necessary to adopt a standard "6-line skate" and express each year's fishing in terms of the number of sets of this unit, a set being hauled after some hours, more or less according to the bank. Naturally, it is impossible to secure accurate returns of the number of sets made by some vessels, and a certain amount of halibut is taken by vessels in other fisheries. But having a sufficient number of accurate records to give a correct average for the catch per unit set and a correct total catch, the number of standard skates which would take this total can be readily calculated by division. It is an expression for the intensity of the fishery, although that number of skate sets may not actually have been made. The need is greatest, therefore, for an accurate total catch and an accurate catch per standard unit.

Records of the catch per set of a unit of gear are kept by the greater number of vessels in the fleet for their own purposes. The Commission has encouraged the keeping of these records by distributing log books, by personal requests, by inquiry after each trip, and by explanation of purposes. It has the legal power to require such logs, but it has preferred to obtain them voluntarily, in the interests of accuracy. Those not usable are discarded. In excess of 80 per cent of all the halibut landed on the coast is represented in the usable log records collected by the Commission.

It is not an easy task to have a sufficient number of records from every part of the coast to enable correct average catch calculations to be made. The fishery undergoes shifts both as to area fished in and season. The result is a rather sparse representation of the individual area, or part of a season, despite a seemingly high percentage of the records of the fleets. To one not acquainted with the problem, the proportion of the total represented in our records of the catch per skate seems unnecessarily high, whereas actually it is hardly sufficient. And, of course, the total catch must be complete by area and by season and can only be made so by inquiry as to origin of every trip made by a vessel large enough to travel far.

Total catch statistics have been kept by several organizations whose figures have not always agreed, especially for early years, due to marketing conditions. In view of the vital importance of these statistics to any understanding of the fishery, much effort has been put forth to make them as accurate as possible. Duplications have been removed, careful comparisons have shown errors in even the most reliable series, and in more recent years the records of fishing companies have been carefully compiled. But, of course, these records of landings do not show the area of origin, and for this, inquiry, critical analysis of the history of the fishery, and thorough collection of vessels' logs for early years have been relied upon. What is presented has been critically and carefully compiled.

The statistics of catch per unit are almost unique. In no other great fishery with which the authors are acquainted have as extensive and as readily standardized records been available. Their possession has given a unique opportunity for determining the relationship of the varying intensity of the fishery to the yield, and the results have, the authors believe, fully justified the effort required. The fishery is the means whereby man affects the species used, and it is astonishing that so little effort has in general been exerted to measure the intensity of the fisheries accurately.

The statistics for Area 2 are given in Table 1 and Figure 2. The initially great total yield shown as for the whole coast was, until 1913, entirely from Area 2, as shown in Figure 5. Not until that year did vessels go beyond Cape Spencer. (See Thompson and Freeman, International Fisheries Commission Report Number 5.) A brief rise in total catch in 1921, and a subsequent continuous decline with the exception of 1928, is not reassuring when compared with the great rise in the amount of gear set, and the great and almost continuous fall in the catch per unit until 1930. The amount of gear set by the fishery in Area 2 rose to the high level of 1921 with the introduction of power, but in subsequent years the use of Diesel engines and the resultant more economical transportation shifted whatever expansion was occurring to Area 3. From 1921 to 1927 the fishery was relatively constant in Area 2, with both total catch and catch per unit still falling yet tending toward a level. But in the "boom" years of 1928 and 1929 another great increase in gear occurred, giving a slight temporary increase in total catch but a further depression of the catch per unit set. This increase in intensity was terminated by the coming of the "depression" years and regulation.

In Area 3, as shown in Table 2 and Figure 3, the excessively great increase in the fishery, beginning in 1922 because of the adoption of Diesel engines, is the dominant characteristic of its history. The increase resulted in a great fall in catch per unit of gear, and a rise in total catch to about its present level. There, as in Area 2, 1928 and 1929 saw an increased fishery; 1931 and later a much lessened one.

In both areas it is apparent that each intensification of the fishery resulted in a temporarily increased total but an immediate fall in the catch per unit of gear set. In Area 2, each increase in intensity resulted in a final lower level of the total catch, there being since 1915 three successive downward steps in 1918, 1926, and 1931, separated by two temporary increases in 1921 and 1928. As will be seen below (page 34) this relationship of intensity and total catch obtained has a natural explanation.

In Area 3 the great increase in intensity seems to have raised the level of the total catch, although the latter has not been given as yet opportunity to come to a condition of stability. Referring to Figures 3 and 5, showing the total catch from this area, the level of 1918 to 1922 may be contrasted with that of 1929, but how much of the succeeding fall is due to the deferred effect of the rise in intensity and how much to the decrease of fishing in 1931 is not evident. At all events no precipitous fall occurred in the wake of the increase in the fishery until the intensity itself fell off in 1930 and 1931. As in Area 2, the returns per unit fell greatly during the increase in intensity. In this case, too, evidence will be presented showing that the sequence of events is in general explainable as is that in Area 2.

In both areas, beginning in 1931, it will be observed (Figures 2 and 3) that there is an increase in the catch per set of a unit of gear, despite the fact that the total catch has remained nearly constant. The continuity of this rise in catch per unit, although begun in 1931, is due in 1932 and 1933 to regulation, which has deliberately held the total catch at a level after an initial decline in the amount of fishing, and despite the resultant rise in catch per unit.

The possibility of further successful regulation can, however, only exist if the results to be obtained and the underlying biological problems are clearly understood. As will then be apparent, restriction of the fishery implies not only the production of more young in the course of time, *but a greater yield from existing stock.* An increase or decrease in the fleet will, as the authors now see it, have perfectly definite consequences that can be forecast as far as the immediate total yield is concerned. As a matter of fact, the great short period fluctuations in the catch are assignable to changes not connected with lack of spawn, but rather with the almost equally important problem of rational utilization of the already existing stock. But to understand these possibilities, the underlying theory of the relation of mortality rates and growth to yield must be explored.

B. EFFECT OF THE FISHERY UPON YIELD AND REPRODUCTION

In regard to the yield of halibut in each of the two main districts, that between Willapa Harbor, Washington, and Cape Spencer, and that between Cape Spencer and Bering Sea, it is obvious that there are two well defined problems: first, whether the fishery is obtaining the maximum poundage which can be obtained from the existing supply of young; second, whether the amount of spawn produced is adequate to maintain this supply.

An understanding of the effect of the fishery on the production of spawn cannot, however, be understood without an understanding of the effect of the fishery on the number of mature adults which form a part of the commercial stock. Studies as to the utilization of the available stock by the fishery must therefore precede consideration of the perpetuation of the supply of young, because the proportion of mature is determined by the manner in which the stock is utilized.

It will be first necessary to present certain theoretical considerations, the principles of which are generally recognized in the study of fishes as well as other organisms. In presenting these, two aspects will be emphasized: first, that of the proportion of spawning adults in an intense fishery as compared with a less intense one; second, that of the yield which may be expected from two such fisheries. To prove that these theoretical cases apply to the halibut fishery, it will then be necessary to show that they are recognizable in the actual statistics of yield, and to this end, the manner in which they will show themselves must be developed so that comparison between theoretical and actual can be made.

Considering the stock of halibut from the point of view of age composition, it will be found that whatever the variations in mortality rates, growth, or effectiveness of gear, certain typical reactions to changes in the amount of fishing are to be found. The extent of these reactions and their duration, but not their characteristic form, may be altered within limits by varying the several factors. The authors have made many trial attempts to this end, using values within reason, with the conclusion that the type of reaction is surprisingly constant.

The authors propose to show that the fluctuations which have actually occurred in the halibut fishery are in general peculiarly those to be expected from the reconstructions of the stock which can be made. Although, until work now under way is completed, precise values cannot be given to the factors involved, sufficient is known to indicate the nature of the changes which may be expected as a result of restrictive regulations.

1. EFFECT OF RELATIVE INTENSITY OF THE FISHERY UPON THE NUMBER OF OLDER FISH

The catch of halibut consists of a number of different ages of fish. On any one bank these ages will show, first an increase with age in the number of individuals and then a decrease, until in the very oldest there are very few fish. The first increase with age is due to the gradual way in which any particular age class joins the commercial catch, an increasing percentage of them being from year to year of a size capable of taking the hook. The subsequent decrease is due largely to reduction of the stock through death by natural causes or by fishing.

TABLE 4.[1]—*Calculated frequency, average length, and average weight at each age of Goose Island males and females, separate and combined, according to the samples taken on Goose Island grounds in June, 1926.*

Age	Male			Female			Male and Female		
	Frequency	Average Length (cm.)	Average Weight (Pounds)	Frequency	Average Length (cm.)	Average Weight (Pounds)	Frequency	Average Length (cm.)	Average Weight (Pounds)
IV	24	55.0	4.0	24	56.5	4.2	48	55.7	4.1
V	354	59.0	4.8	222	61.5	5.5	576	60.1	5.1
VI	394	63.5	5.9	224	67.0	7.1	618	64.8	6.2
VII	399	67.5	7.1	217	72.0	8.8	616	67.6	7.6
VIII	392	72.0	8.8	179	77.0	11.0	571	73.2	9.4
IX	452	76.0	10.6	221	82.5	13.4	673	77.6	11.3
X	170	80.5	12.4	104	87.5	15.9	274	83.1	13.7
XI	78	85.0	14.5	29	92.5	18.9	107	87.4	15.9
XII	39	89.0	16.8	8	97.5	22.2	47	90.7	17.9
XIII	17	93.5	19.6	8	103.0	26.2	25	96.1	21.4
XIV	20	97.5	22.2	6	108.0	30.2	26	102.6	26.2
XV	5	102.0	25.3	2	113.0	34.8	7	108.3	30.7
XVI	2	106.0	28.5	....	....	....	....	....	....
XVII	1	110.5	32.5	....	....	....	....	....	....
Total	2347	....	....	1244	....	....	3591	....	....

[1] From H. A. Dunlop, manuscript of unpublished report. Frequency, for all fish measured, the ages calculated on basis of otolith sample read. Average lengths and weights from smoothed curves.

In Table 4 are shown the numbers of each age in a catch from the Goose Island Banks, off the north end of Vancouver Island. Considering the sexes combined, as in the last three columns, the youngest class is No. IV, in its fifth year. It is 55.7 cm. in average length, and weighs 4.1 pounds. This illustrates the age composition and the usual decrease in numbers among the older groups. But the catch analyzed is not typical of the general halibut population of that district, for it was made on banks having a greater number of certain sizes than is true of other nearby banks. With greater age, migration plays a part in diverting the larger fish from banks such as this catch came from to others, and in consequence a true picture of the decline in numbers with age could only be obtained by a system of sampling all existing banks in accord with the numbers of fish on them. Were such ideal sampling possible, we would then have a true picture of the decline in numbers with age, hence a determination of what is termed the mortality rate. Or the latter may be determined by marking experiments, perhaps more accurately. If with age the numbers in the age classes decrease by death through the fishery or natural causes each year 60 per cent, then that percentage is the rate of death or mortality.

Every age class must pass through the successive ages from the first to the age at death, and anything which increases the deaths at one age decreases the numbers surviving to later ages. The number of adult spawning fish is therefore profoundly altered by the varying intensity of the fishery, whether for young or old fish, because it changes the mortality rate. This has been shown not merely in the halibut fishery of the Pacific coast but in the great fisheries of European waters, particularly those for the plaice of the North Sea. The effect is, indeed, a recognized one in all species of animals and plants, having been especially well studied in man because of its importance to life insurance. The general effect of a mortality rate needs no special proof in this particular case.

But it is through the effect of the mortality rate, as increased by the fishery, that the number of spawning adults and hence of the young which they produce, is altered by man's operations. The more intense the fishery, the fewer the spawning adults surviving out of a given number of incoming young.

This is easily illustrated by a comparison of the survivors in two hypothetical stocks in one of which for a number of years a higher intensity of the fishery has prevailed than in the other. A natural mortality of 30 per cent has been assumed. Fishing mortality added to this has in one case

TABLE 5.—*The effect of a decreased fishing mortality upon the stock of mature fish.*

Age	Surviving Number of Fish		Average Weight of Females (Pounds)	Weight of Fish Surviving (Pounds)		Ratio B. to A.
	A. 58% Mortality	B. 44% Mortality		A.	B.	
IV	1,000	1,000	4.2	4,200	4,200	1.0
V	420	560	5.5	2,310	3,080	1.3
VI	176	314	7.1	1,255	2,229	1.8
VII	74	176	8.8	651	1,549	2.4
VIII	31	98	11.0	341	1,078	3.2
IX	13	55	13.4	174	737	4.2
X	5	31	15.9	80	493	6.2
XI	2	17	18.9	38	321	8.4
XII	1	10	22.2	22	222	10.0
XIII	....	5	26.2	....	131	....
XIV	....	3	30.2	....	91	....
XV	....	2	34.8	....	70	....
Total, Ages IX to XIV	21	123	....	314	2,065	6.6
Grand Total	1,722	2,271	....	9,071	14,201	....

(A, in Table 5) given a total mortality of 58 per cent. In the other (B, in Table 5), a much smaller fishing mortality added to the natural mortality of 30 per cent has given a total mortality of 44 per cent. The manner in which two mortalities acting simultaneously must be added will be dealt with later. The rate of growth is that previously presented for the Goose Island Banks, but for females only. (See page 25).

The number of survivors above Age VIII is much greater in the stock with lesser mortality. In fact there is an excess at every age, but it is proportionately greater in the older.

Since it has been shown that the production of eggs increases approximately as the weight of the spawners,[2] the authors have utilized the total weight of each age class and have used females only. The percentage of the total weight above eight years of age, at which spawning first begins, is 3.5 per cent in Case A, and 14.5 per cent in Case B. This percentage is, however, not the most vital consideration, because, as has previously been shown, the total stock itself diminishes with the intensification of the fishery. But the total poundage above eight years is of direct significance and shows for Case A, 314 pounds, and for Case B, 2065 pounds. The fishing mortality, that is, the intensity of the fishery, has in this case been cut in half by the fall from a total mortality of 58 per cent to one of 44 per cent as will be understood from page 29, and this reduction has multiplied the production of spawn over six times. This is a very conservative figure in view of the fact that, although some fish spawn at 8 years of age, the percentage thus spawning increases with age, and the difference between the two cases is greatest in the oldest age classes.

This is a much simplified illustration of the changes which may be expected. The several factors are undoubtedly more complex than what has been assumed. Thus it is known that the mortality due to fishing varies from age class to age class[3] and that it has not been constant from year to year. No precise theoretical calculation of the amount of spawn produced can therefore be hoped for at the present stage of our knowledge. To obtain data upon this there are three alternative methods of investigation: (1) a direct measurement of the number of floating eggs, by net hauls; (2) a direct determination of the number of adults, by examination of the commercial catches, in conjunction with marking experiments to show the fraction these catches form of the existing stock; or (3) similar direct determinations of the number in each entering year class. Research on each of these is under way.

But whatever the accuracy of these researches at present, and however invaluable they may be in the future, they cannot now be extended into the past. For use in understanding the history of the fishery and its present condition there is only a general knowledge of the effect of changes in fishing intensity upon the stock of halibut and the yield therefrom. From these it is to be concluded that changes in the intensity of the fishery must modify greatly the numbers of older fish and hence of eggs these produce.

As early as 1916, the decline in proportion of the larger sizes in the catch of halibut was clearly recognized (Thompson, Report of British Columbia Commissioner of Fisheries, 1915). The continuation of this decline is shown in the statistics collected by the Commission (International Fisheries Commission Report Number 7, 1930, Figure 11). Detailed data as to this are

---

[2] Lawrence Kolloen, manuscript.
[3] Thompson and Herrington, International Fisheries Commission Report Number 2.

available but must await a further report. The sharp contrast in the proportion of older fish on the less intensively fished western grounds and that on the heavily fished southern grounds is what would be expected from the differing mortality rates.

From the practical standpoint, the mistake may easily be made of expecting the increased average size resultant from a decrease in the fishery to show as a diminished number of the smaller sizes. For instance, that the size category "chickens" in the halibut landings should diminish in total poundage. As will be seen from Table 5 this is far from being true. The smaller and younger fish are also increasing, but not to the same extent as the older and larger. The increase or decrease in average size resulting from changes in the fishery is, therefore, a change in the proportion of every age group after the first which can only be affected by factors altering the number of incoming young.

There is, however, a school of thought which holds that the number of eggs is always in excess of what is necessary to maintain the number of incoming young. The reasoning of this school is that exceedingly great numbers of eggs are produced, as shown by Table 6 for the halibut (from

TABLE 6.—*Counts of ova for 12 specimens of halibut between 91 and 144 cm.*[1]

Age	Length (cm.)	Number of Ova
XIII	91	300,656
XII	103	522,268
XV	110	522,773
XVII	121	879,185
XV	121	951,602
XVI	123	1,167,460
XX	133	1,123,210
XVII	135	1,061,307
XXVI	141	1,255,891
XXII	142	1,282,957
XXVII	144	1,282,667
XVII	144	1,592,766

[1] From Thompson, 1917.

Thompson, Report of British Columbia Commissioner of Fisheries, 1917, p. S37), and that even with but few spawning individuals so great are the numbers of young that there is intense competition for food and for survival. So high is the resultant mortality that the effect of the fishery is assumed negligible in comparison, and indeed its effect in thinning the stock is thought beneficial because of the more rapid growth this permits.

The investigations of the Commission show, however, that the eggs and younger floating stages of the halibut are never taken in great abundance anywhere, and that on the more depleted parts of the coast they are to be found with much greater difficulty than on the less depleted, showing clearly that the production of eggs has been greatly curtailed. And in consequence it is difficult to conceive that competition for food or survival exists among the younger age classes of this species when these can be found only with great difficulty.

2. EFFECT OF RELATIVE INTENSITY OF THE FISHERY UPON YIELD

As in other species of animals, it has been shown that in the case of the halibut two major influences are at work; namely, a growth in weight or size, and an annual mortality. The latter is caused by fishing and by natural deaths of all sorts. The mortality due to fishing varies, of course, with the amount of gear run. We have some facts which bear upon both growth and mortality, and on a basis of these facts it is possible to reconstruct in theory the main features of what is happening in such a stock of halibut and thereby to understand its yield. Acceptance of this theoretical reconstruction must of course await proof that it corresponds to what is actually found in our statistical returns.

Assuming that a thousand young fish which have completed their fourth year enter the commercial catch in a given season, weighing during that year an average of 4.1 pounds apiece, there are available 4100 pounds of fish. From this the commercial fishery and natural mortality must year by year take their toll while growth goes on. Marking experiments[4] indicate that the fishery would take upwards of 40 per cent of the total annually. This may be called a "fishing mortality" of 40 per cent. Assuming that natural causes remove 30 per cent, the two mortality rates must be combined. When this is done, it is found that 40 per cent of those fish which would have died naturally are taken instead by the fishery; that is, 40 per cent of 30 per cent, or 12 per cent. Hence, instead of 30 per cent plus 40 per cent, or 70 per cent, the total mortality is 58 per cent; that is, of the thousand, 580 are taken or die, and 420 survive to undergo a second year of fishing.[5] Of the 580, on the average 40 will be taken by the fishery to every 30 taken by natural death, assuming that the two mortality rates act simultaneously. Hence 4 out of 7, or slightly over 57 per cent, some 331, are taken by the catch. The following table results:

Age	IV
Number	1000
Mortality	58 per cent.
Deaths	580
Proportion taken by fishery	$\frac{40}{70}$
Number in catch	331.4
Average weight	4.1
Catch	1359 lbs.
Survivors	420

Before we can go farther it is necessary to know the rate of growth, in addition to the mortality to which the halibut is subjected. In Table 4 and

[4] See Thompson and Herrington, International Fisheries Commission Report Number 2, page 69. As will be seen in later discussion, this determination is a minimum, and the calculation of natural mortality probably too high.

[5] This is equivalent to the following procedure:

$1000e^{-x} = 600$, or the survivals when the fishing mortality is 40 per cent.

$1000e^{-y} = 700$, or the survivals when the natural mortality is 30 per cent.

Then $1000e^{-(x+y)} = 420$, when both fishing and natural mortalities are operative. Hence the total mortality equals 58 per cent.

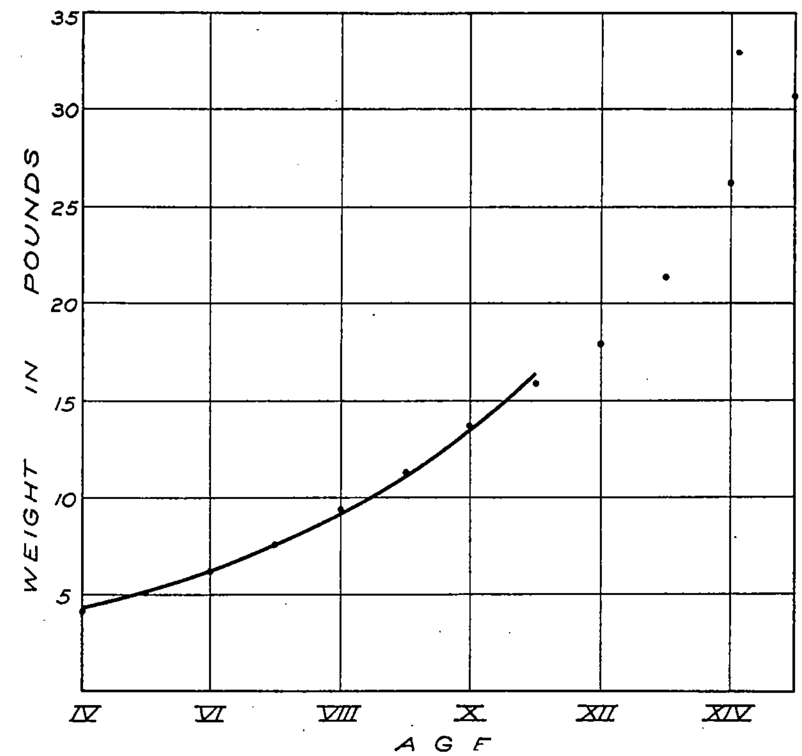

FIGURE 8.—Average weight in pounds at each age of Goose Island fish. Solid line represents about a 21 per cent growth for those ages that are adequately represented.

Figure 8 are given the weight at each age from manuscript, dealing with Goose Island fishes. In the graph the smoothed line indicates a uniform growth of about 21 per cent annually. It is fitted for those age groups which have a good representation of both males and females, since the varying ratio of the sexes obscures the actual rate. This growth rate also reflects selection by the gear for size, but since the yield of the fishery in pounds is the essential point, it is desirable that our determination of weight at each age should reflect this selection. However, the rate, 21 per cent, is arbitrarily chosen as an approximation only, and must be used with caution.

Beginning with the 420 survivors, now in the fifth year, the same procedure as with the original thousand can be repeated, on the assumption that the same mortality rate prevails, and again the catch and survivors can be calculated. On this basis it is possible to reconstruct a simplified picture of what occurs in a stock of halibut subject to uniform mortality rates over a period of years, with a constant supply of incoming young. Table 7 assumes that as stated the fishery takes at the rate of 40 per cent of all age classes and that death from natural causes is at the rate of 30 per cent annually, while the rate of growth is as given in Table 4, using the actual weights, not readings from the smoothed line.

It is found from this that under such conditions the total yield obtained by

TABLE 7.—*Stock and catch in a given year, assuming 40 per cent fishing and 30 per cent natural mortality constant over a period of years preceding.*

Age	Number of Survivors	Number of Deaths	Catch		
			Number	Average Weight (Pounds)	Total Weight (Pounds)
IV	1,000	580	331	4.1	1,357
V	420	244	139	5.1	709
VI	176	102	58	6.2	360
VII	74	43	25	7.6	190
VIII	31	18	10	9.4	94
IX	13	8	4	11.3	45
X	5	3	2	13.7	27
XI	2	1+	1−	15.9	12
XII	1	1−	1−	18.9	6
Total	....	1,000	570	....	2,800

the fishery from an incoming year class (about 2800 pounds in the example given) is far less than would be were the halibut all caught at Age IV, when 4100 pounds would be obtained. This is because the rate of growth in weight (about 21 per cent annually) does not balance the large loss (30 per cent annually) by natural mortality. Of the thousand fish in each year class, 430 are taken by "natural" causes of death, and this loss exceeds the increase in weight of the 570 taken by the fishery. This increase approximated some 465 pounds only; that is, the difference between 2800 pounds when caught and the original 2337 pounds of the 570. In other words, a fishery of the given character would be most productive in poundage if sufficiently intense to raise the mortality rate so high that the individual would be taken while young, before natural causes of death could remove many of them.

This suggests that the theoretical effect of possible variations in the relationship of these mortalities to the growth rate would be exceedingly interesting, as giving an understanding of the possibilities. Thus, if the intensity of the fishery is varied in a series of hypothetical cases similar to the above, it is found that with the natural mortality fixed at 30 per cent and growth at 21 per cent by weight, annually, the total yield would be much less with a less intense fishery and greater with a more intense one. Varying the mortality due to fishing over intervals of 5 per cent, the total yields shown in the third column of Table 8 would be obtained.[6] Each such value is given as for a fishery in which conditions have been stable for a sufficiently

[6] The total yield of each such hypothetical fishery may be calculated by the following formula, taking advantage of the fact that both mortality and growth rates give terms which can be summed:

If S=the total weight of the entering year class, then r_n, r_f, and k can be determined from the following:

$S(1-e^{-r_n})$ = loss by death from natural causes during first year

$S(1-e^{-r_f})$ = loss by death from fishing during first year

Se^{kt} = weight of the year class at end of time, t, without deaths.

Then $S\dfrac{1-e^{-(r_n+r_f)}}{1-e^{kt-(r_n+r_f)}}$ = total poundage removed. when t = one year.

This total poundage may be divided between fishing and natural causes by the procedure discussed on pages 29 and 35.

TABLE 8.—*Supposed yield from fisheries with differing fishing and natural mortality rates allowing a constant growth rate of 21 per cent.*

Fishing Mortality in Per Cent	Natural Mortality in Per Cent					
	40	30	21	18	10	5
10	1088	1004	2762	3585	8468	....
15	1432	1595	2991	3605	5839	....
20	1694	1976	3126	3599	5035	9791
25	1906	2238	3206	3587	4643	7122
30	2074	2427	3257	3574	4410	6026
35	2212	2568	3291	3561	4255	5428
40	2325	2677	3315	3550	4145	5051
45	2419	2763	3333	3539	4062	4791
50	2501	2832	3346	3530	3998	4601
55	2574	2889	3355	3522	3946	4459
60	2635	2936	3363	3514	3905	4343
65	2688	2976	3369	3508	3870	4254
70	2734	3010	3373	3502	3840	4175
75	2776	3040	3377	3496	3814	4113
80	2815	3065	3382	3490	3781	4058
85	2847	3087	3383	3486	3773	4010
90	2907	3107	3385	3481	3768	3970
95	2905	3124	3387	3478	3740	3936
100	2930	3140	3388	3475	3720	3900

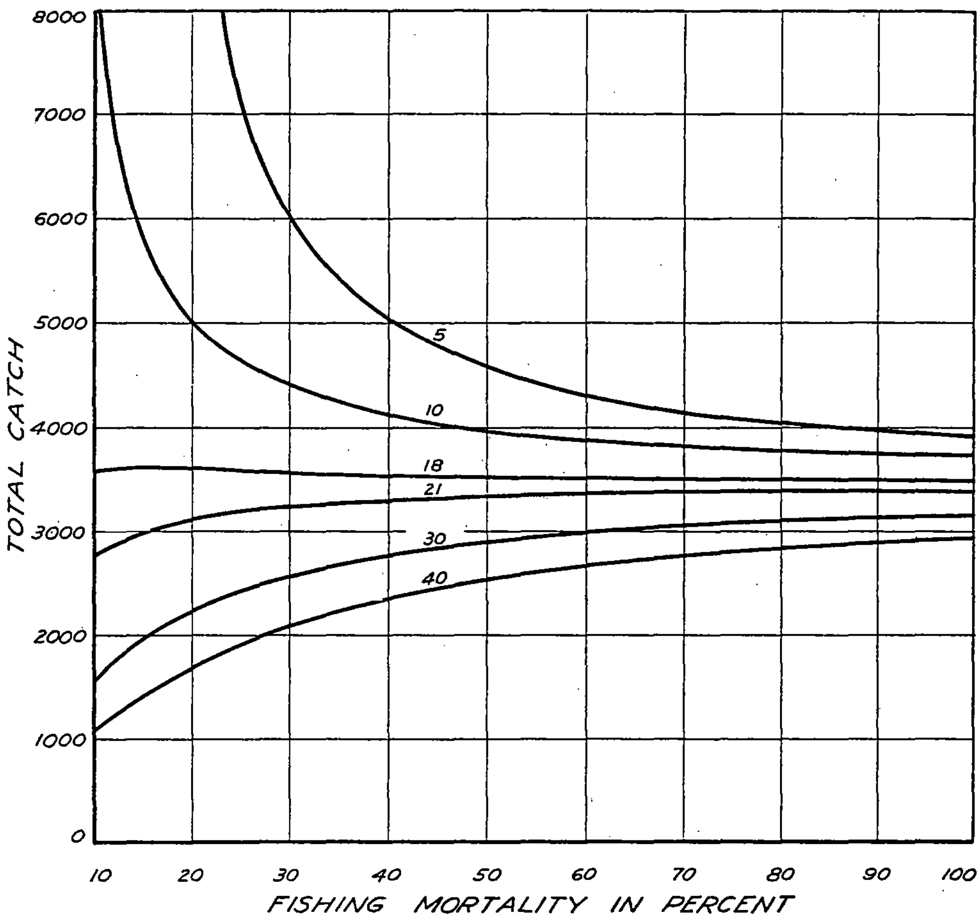

FIGURE 9.—Yield with various fishing and natural mortalities. The numbers shown on each line are the natural mortality percentages.

long period to render the yield constant; that is, for a fishery which in each case has become stabilized.

These values are plotted in Figure 9 along the line marked 30 per cent, as indicating the natural mortality.

A similar calculation has been made for a series of hypothetical fisheries in which the natural mortality was assumed to be 10 per cent. The results are shown in the sixth column of Table 8. In this case the less the intensity, the higher the total annual yield, for the reason that the rate of growth, or annual weight increment, exceeds the loss by natural mortality. Indeed, the theory indicates that a fishery of very low intensity would in this particular case be immensely more profitable, yet there can be no doubt but that at such low intensities many compensating factors enter in, such as a change in natural mortality with the greater age which is reached. Nevertheless, the point is clearly made that in this type of fishery, with a natural mortality lower than the rate of increase by growth, the total yield has a relation to the intensity which is inverse to that of a fishery with a natural mortality higher than the growth rate.

In Figure 9 there are shown not only the total yield values for the two series of hypothetical fisheries with 10 and 30 per cent natural mortalities, but for a variety of such mortalities.

At 21 per cent natural mortality, the yield rises rapidly to a stock in which the fishing mortality or intensity is about 25 per cent, when it remains nearly constant for any intensity up to nearly 100 per cent. In this connection it should be remembered that the rate of growth in weight is approximately 21 per cent annually, or equal to the loss by natural death. When these are balanced, the total yield should be constant whatever the intensity of the fishery. And finally, it is shown that for fisheries with natural mortalities above 21 per cent, the most intense fisheries should yield the most, provided the incoming year class is maintained by sufficient spawning.

In so far as the final level of total yield tends to be alike from one intensity to another, because of the balance between natural deaths and growth, the catch per unit set of gear must tend to vary as the reciprocal of the intensity (as indicated by the number of sets of such units). In other words, the catch per set of gear must be equal to the total yield divided by the number of sets of gear, whatever the competition between this gear, and in so far as the total is constant, the relationship is reciprocal.

This reciprocal relationship is of the greatest practical importance, because it means that after the fishery has approached a constant total yield, the use of more gear can increase that total but slightly if at all at the expense of a great decrease in return per unit of effort or per set of a unit of gear. Such a decrease means a corresponding increase in costs, with an accompanying decrease in number of spawning adults.

This tendency toward a purely reciprocal relationship is, however, obscured in the statistics, as will be shown, not only by the lack of balance between growth and natural deaths, but by the transitory effects of the year by year changes in mortality rate. These are very marked, and take as long to pass and leave the fishery after any given change as it does for a year class to pass through the fishery. Thus a change in 1900, affecting the four year olds, would still be felt in 1910 in the fourteen year old fish in so far as such remained.

It is, naturally, the existence and distinctive character of these transitory effects which will give strongest proof that the reasoning in this section is correct. The trend of the total annual yield is not in itself distinctive evidence of what is happening within the stock, because if there is a downward trend it is possible to explain this by lack of incoming young as well as by the effects of mortality and growth rates upon the poundage produced by these young.

C. EXPLANATION OF OBSERVED CHANGES IN YIELD AND ABUNDANCE

There can be no doubt but that the theory outlined in the preceding section is based upon principles so general in application and on facts so universal in occurrence as to be deserving of acceptance. But in the case of the halibut it can also be shown that the sequence of events according to this theory produces immediate and transitory effects which are characteristic and recognizable. These effects are paralleled in the actual statistics, and there can be no doubt but that the theory corresponds to the processes occurring in the stocks of halibut.

1. AREA 2, PERIOD 1918 TO 1926

The simplest case is one in which the fishery changes from one level of intensity to another, continuing in each a sufficient period to allow the stock to approach a condition of stability. Such a case is approximated in Area 2 between the years 1918 to 1926. In Table 1 and Figure 2 are given the annual total catches landed in these years and the total number of sets of a standardized unit of gear made by the fleet to catch these totals. It will be observed that the intensity of the fishery, as indicated by the number of sets of units, rose during 1920 and 1921 from a level of 300,000 sets to that of 500,000, a 67 per cent increase, and maintained itself for some time in the neighborhood of the latter. The total catch rose with the intensity during 1920 and 1921, from 27,500,000 to 37,500,000 pounds, a 36 per cent increase, but promptly fell again, reaching in 1926 a lower level than ever before.

The case is essentially similar to a theoretical one in which there is postulated a single change in intensity of the fishery. This will illustrate the method of calculation and the results obtained. In Table 7, page 31, there is shown in the second column, the stock which would result in any given year were a fishing mortality rate of 40 per cent and a natural mortality of 30 per cent to have prevailed for a series of years. Were the natural mortality rate of 10 per cent to be nearer the truth, the total annual mortality would necessarily be recalculated, as follows: $40 + 10 - \frac{40 \times 10}{100} = 46$. Column 2 of Table 7 then becomes Column 2 (Year 1) of Table 9. This represents a stock of halibut in which the take by the fishery had been at a constant rate of 40 per cent annually during the preceding years.

In the second year the mortality due to the fishery is changed to 60 per cent, which, with 10 per cent natural mortality, gives a total mortality rate of 64 per cent and a survival of 36 per cent (Column 3, Table 9). These rates apply to the survivors of the previous year. There are assumed to be a thousand young fish appearing each year for the first time. But of the 1000 four year olds in the previous year, only 360 survive to become five year olds. Of the 540 five year olds, 194 become six year olds. The results in Column 3, Table 9, show the number of survivors after a change for one year to a fishing mortality of 60 per cent. Application of the same procedure in successive years to the previous year's survivals produces the successive columns of the table.

TABLE 9.—*Number of survivors at end of year with a fishing mortality of 40 per cent in Year 1 and 60 per cent thereafter as combined with 10 per cent natural mortality in each year.*

Age	Year								
	1	2	3	4	5	6	7	8	9
IV	1000	1000	1000	1000	1000	1000	1000	1000	1000
V	540	360	360	360	360	360	360	360	360
VI	292	194	130	130	130	130	130	130	130
VII	158	105	70	47	47	47	47	47	47
VIII	85	57	38	25	17	17	17	17	17
IX	46	31	21	14	9	6	6	6	6
X	25	17	11	8	5	3	2	2	2
XI	13	9	6	4	3	2	1	1	1
XII	7	5	3	2	1	1	1	....	....
XIII	4	3	2	1	1	....	....	....	....
XIV	2	1	1	1	....	....	....	....	....

Each of these columns, representing the age composition of the survivors in a stock of halibut, can be treated as in Table 7, page 31, to give the total poundage taken by the fishery year by year from this stock of halibut as it changes under an intensified fishery. First, the number of deaths from all causes in each year and age group is tabulated in Table 10. Their weights are calculated according to age groups by use of the average weights of males and females combined as given in Table 4 and totalled for each year. Of the total weight for each year, a fraction is allotted to the fishery in the proportion of the fishing mortality rate to the summed mortalities, which in the first year would give $\frac{40}{40+10} = \frac{4}{5}$. In the second and following, this would be $\frac{60}{60+10} = \frac{6}{7}$. The weight taken annually by the fishery is given in Table 11.

TABLE 10.—*Number of deaths from all causes in each year class with a fishing mortality of 40 per cent in Year 1 and 60 per cent thereafter as combined with 10 per cent natural mortality in each year.*

Age	Year 1	2	3	4	5	6	7	8	9
IV	460	640	640	640	640	640	640	640	640
V	248	346	230	230	230	230	230	230	230
VI	134	187	124	83	83	83	83	83	83
VII	73	101	67	45	30	30	30	30	30
VIII	39	54	36	24	16	11	11	11	11
IX	21	29	20	13	9	6	4	4	4
X	11	16	11	7	5	3	2	1	1
XI	7	8	6	4	3	2	1	1	1
XII	3	4	3	2	1	1	1	1	....
XIII	2	3	2	1	1	1	....	....	....
XIV	....	....	....	....	....	....	....	....	....

The number of sets of units of gear which this change in intensity represents can be calculated on either of two assumptions: one that the gear is competitive, the other that it is non-competitive. If the latter, for each 100 sets of a skate made in the less intense fishery, 150 would be set in the more intense one, since the intensity would have increased 50 per cent. If the gear is competitive, the efficiency of each set decreasing as the numbers of such sets increase, the following calculation is necessary.

TABLE 11.—*Weight of fish dying from all causes in each age class with a fishing mortality of 40 per cent in Year 1 and 60 per cent thereafter as combined with 10 per cent natural mortality in each year.*

Age	Average Weight Pounds	Year 1	2	3	4	5	6	7	8	9
IV	4.1	1886	2624	2624	2624	2624	2624	2624	2624	2624
V	5.1	1265	1765	1173	1173	1173	1173	1173	1173	1173
VI	6.2	831	1159	769	515	515	515	515	515	515
VII	7.6	555	768	509	342	228	228	228	228	228
VIII	9.4	367	508	338	226	150	103	103	103	103
IX	11.3	237	328	226	147	102	68	45	45	45
X	13.7	157	219	151	96	68	41	27	14	14
XI	15.9	103	135	95	64	48	32	16	16	16
XII	17.9	54	72	54	36	18	18	18	18	18
XIII	21.4	43	64	43	21	21	21	......	......	......
XIV	......	......	......	......	......	......	......	......	......	......
Total	....	5498	7642	5982	5244	4947	4823	4749	4736	4736
Fraction taken by fishery	....	$\frac{4}{5}$	$\frac{6}{7}$	$\frac{6}{7}$	$\frac{6}{7}$	$\frac{6}{7}$	$\frac{6}{7}$	$\frac{6}{7}$	$\frac{6}{7}$	$\frac{6}{7}$
Total catch	....	4398	6550	5128	4495	4240	4134	4070	4060	4060
No. of skates	....	100	179	179	179	179	179	179	179	179
Catch per skate	....	44.0	36.6	28.7	25.1	23.7	23.1	22.7	22.7	22.7

Let x and y equal the number of skates set in the two years; then, if the intensity in the first year is 40 per cent, and $x = 494{,}000$

$100\,e^{-kx} = 60$, whence
$k = .001034$. Then
$100\,e^{-ky} = 40$, whence
$y = 886{,}000$.

Or, if y is known, and the resultant intensity unknown, it can be calculated. In the particular case considered, it is of little moment whether the gear is considered competitive or not, since it is the character of the change produced, rather than its magnitude, which is of interest, for the time being.

Knowing thus the annual total catch and the relative number of sets of gear, the catch per set may be calculated. The values for all three of these are shown in Table 11 and in Figure 10, assuming the gear to be competitive.

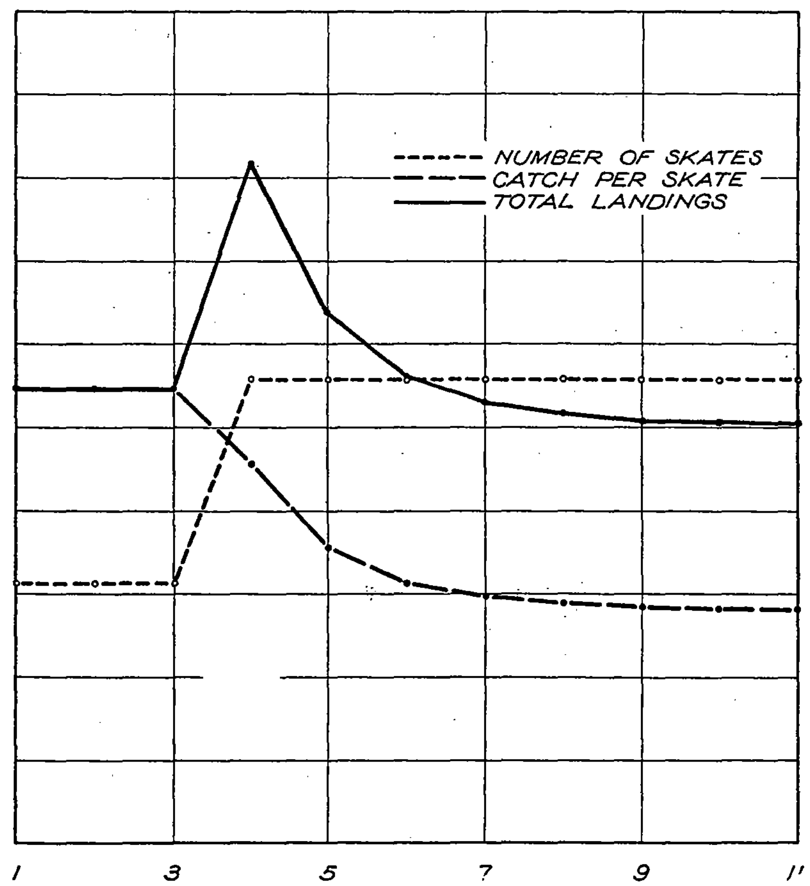

FIGURE 10.—Effect of change of intensity or fishing mortality from 40 per cent to 60 per cent with a 10 per cent natural mortality in each case upon landings and catch per skate.

The calculated total catch rises sharply the first year and falls the next year and during a series of years to a new level, characteristic of the mortality rates applied; in this particular case to a lower level, because growth exceeds loss by natural deaths. The catch per unit of gear falls each year, more rapidly at first, less so as time elapses. It will be observed that the complete change requires as many years as there are ages in the catch. Consequently, since the higher the total mortality, the fewer the significant year classes present, the complete change is much more quickly attained under a more intense fishery, as can be ascertained by trial.

The whole sequence of changes is strikingly similar to those shown for the years 1918 to 1926 in Area 2. The assumed conditions are obviously very much more simple, but repeated trials with various combinations of mortality and growth rates, and various relationships of gear to intensity, have been carried through by the authors, with but very little modification of the essential character of the relationship between intensity, total yield, and yield per unit. It is plain that a strongly characteristic series of changes is initiated by each change in the intensity of the fishery.

But a more striking and closer comparison can be made between actual and theoretical by using the actual number of sets of skates fished in the years 1918 to 1926. In doing so, it is necessary to establish for some individual year the proper relationship between the number of skates and the intensity of the fishery. Since the marking experiments reported upon by Thompson and Herrington (International Fisheries Commission Report Number 2) were initiated in 1925 and 1926, their tentative determination of the total annual mortality, about 60 per cent, was used as applying to 1926. Their estimate of fishing mortality, 40 per cent annually, might also have been used, but in view of the very rough nature of the corrections made in the tagging returns, there is little need of holding strictly to this. Indeed, it will be justifiable to adopt a higher rate of return on the assumption that tags are lost. The theoretical case has been calculated accordingly with three different combinations. In view of the total mortality of about 60 per cent, a fishing mortality of 47 per cent has been combined with a natural mortality of 21 per cent to make a total of 58.1 per cent. It will be noted that this 21 per cent rate of natural mortality approximates the growth rate in weight of the combined male and female stock on southern grounds (Goose Island samples), and should balance it, leaving the total yield unchanged when the temporary effect of altered intensity has vanished. Again, to illustrate the effect of the natural death rate the authors have combined the death rate of 47 per cent from fishing with a natural mortality rate of but 10 per cent, to make a total of 52.3 per cent. Finally, to contrast with the fishing mortality in the latter case, a higher rate of capture, 56 per cent, has been assumed, combined with the rate of natural death, 10 per cent. In each case these rates were assumed to be true of the year 1926.

On these assumptions, the equations on page 37 were used to determine the fishing mortality from the number of sets made in each year other than 1926. As previously mentioned, it was of relatively little consequence for the present purposes whether these were calculated as competitive or non-competitive. The constant, k, having been determined from the values $100\,e^{-kx} = 60$, where $x =$ the number of sets of skates in 1926, was substituted in an equation for each year, $100\,e^{ky} = z$, where z is the desired intensity and y the number of sets of skates made in the given year. Then the procedure outlined for Tables 9 to 11 was repeated, but with the intensity changed each year in turn instead of in but one year.

The results for the combination of 47 per cent fishing mortality (in 1926) and 21 per cent natural mortality are presented in Table 12 and

TABLE 12.—*Comparison of the actual catch per skate and total landings with the theoretical, as reconstructed from the growth rate and mortality rates and as based upon the actual number of skates fished on grounds south of Cape Spencer for years 1918 to 1926 for various combinations of fishing and natural mortality.*

Year	Actual Number of Skates Fished (1000's)	Total Landings to 4 Significant Figures				Catch per skate (Pounds)			
		Actual (10,000's)	47/21 [1]	47/10	56/10	Actual	47/21	47/10	56/10
1918	309	2707	3328	4706	4416	87	108	152	143
1919	333	2740	3520	4985	4657	82	106	150	140
1920	394	3316	3911	5555	5131	84	99	141	130
1921	487	3748	4269	6049	5461	77	88	124	112
1922	500	3129	3900	5382	4844	63	78	108	97
1923	504	2884	3666	4920	4460	57	73	98	88
1924	484	2700	3424	4515	4152	56	71	93	86
1925	462	2394	3295	4255	4005	52	71	92	87
1926	494	2579	3492	4527	4251	52	71	92	86

[1] Columns 47/21, etc., represent the theoretical results of the combined mortality rate of 21 per cent natural and 47 per cent fishing as equated to the actual number of skates fished in 1926.

Figure 11, contrasting in the latter the actual statistics (see Table 1 and also Table 12) with those derived from the theoretical case. In this figure, the actual scale of values is not given, since in the theoretical case an arbitrary number of individuals, one thousand, was chosen as the initial stock. There is at present no way of determining the number of such arbitrary units in the actual stock, other than by choosing a multiple which will bring the derived values to an equality with the actual. Care was taken, however, to see that in each graph a common base line was chosen, from which all ordinates were measured, and this base line can be determined if necessary from Tables 1 or 12.

The similarity is striking, and it is plain that an explanation has been arrived at for some of the major changes in the fishery. There can remain but little doubt that the action of the fishing intensity, through the usual laws of mortality rates as applied to successive age classes, already affected by natural mortality and growth, is the dominating factor in the halibut fishery for the years in question.

The total catch and catch per unit in the two graphs of actual and theoretical do not exactly correspond when superimposed, even if the trends, and relationships one to the other, are alike. This dissimilarity is what must

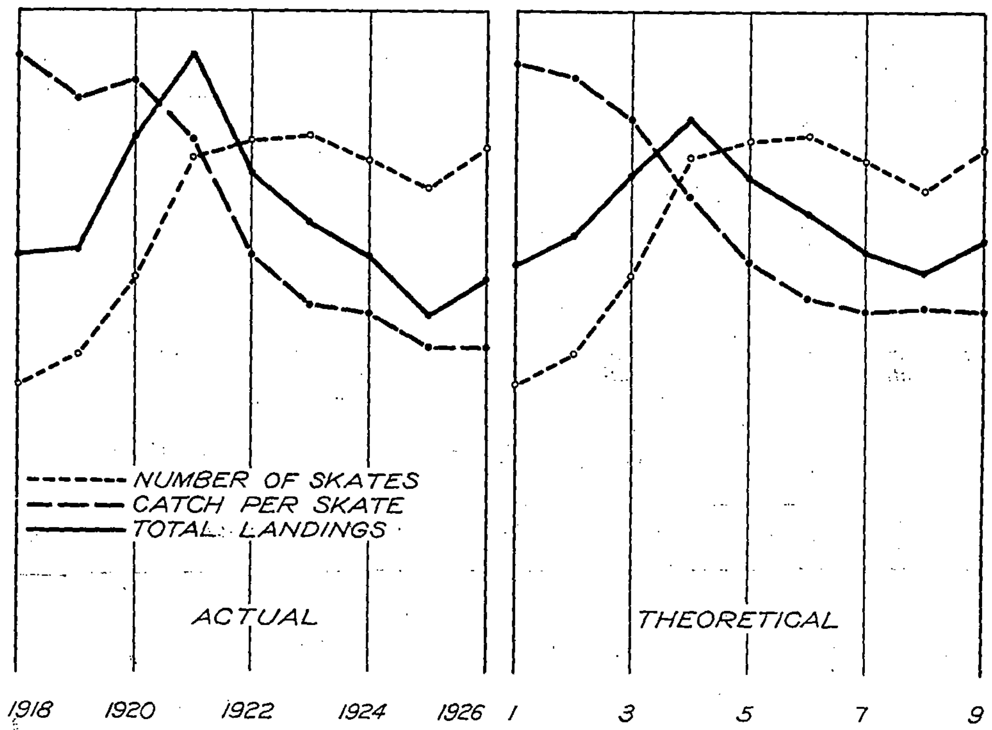

FIGURE 11.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds south of Cape Spencer using 47 per cent fishing mortality and 21 per cent natural mortality as of the year 1926, period 1918 to 1926.

be expected, inasmuch as the factors in nature are unlikely to be nearly as simple as those in the reconstruction, nor have either of the mortality rates been measured with the exactness necessary. These rates doubtless vary from age to age and from year to year, as well as react on each other in other ways than those here postulated. The incoming young, if those of other species are any criterion, must vary from year to year. And even food supply and migrations must play a part in producing variations. The remarkable fact is, not the presence of such deviations of actual from theoretical, but that they are minor in importance.

One of the most significant differences between the actual and theoretical is in the relative levels of the total catch at the beginning and end of the period. In the actual case it is lower at the end, in the theoretical it is the same at the end as at the beginning of the period. This difference is eliminated in the next trial, using 47 per cent fishing (for 1926), and 10 per cent natural mortality, as presented in Table 12 and Figure 12. This result is in accord with the expectation, as shown in Figure 9, page 32, where the annual weight increment by growth exceeds the annual loss by natural death, the more intense fishery yielding finally a smaller total catch.

That this result is due to the rate of natural death and not the changed total death rate, 52.3 per cent instead of 58.6 per cent, is shown by a third

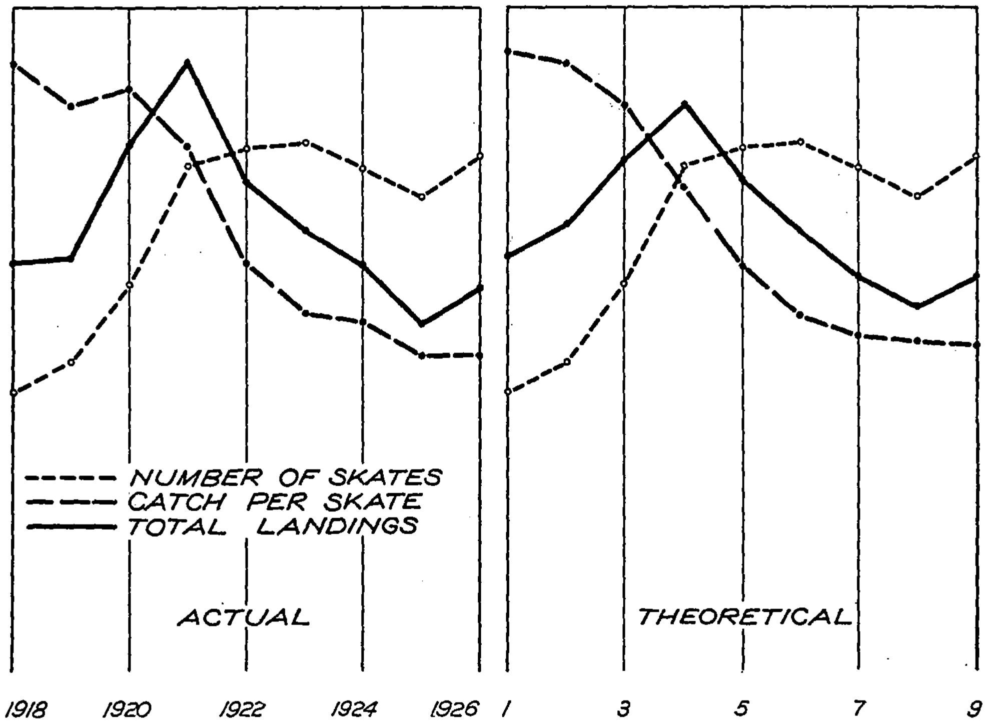

FIGURE 12.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds south of Cape Spencer using 47 per cent fishing mortality (as of 1926) and 10 per cent natural mortality, 1918 to 1926.

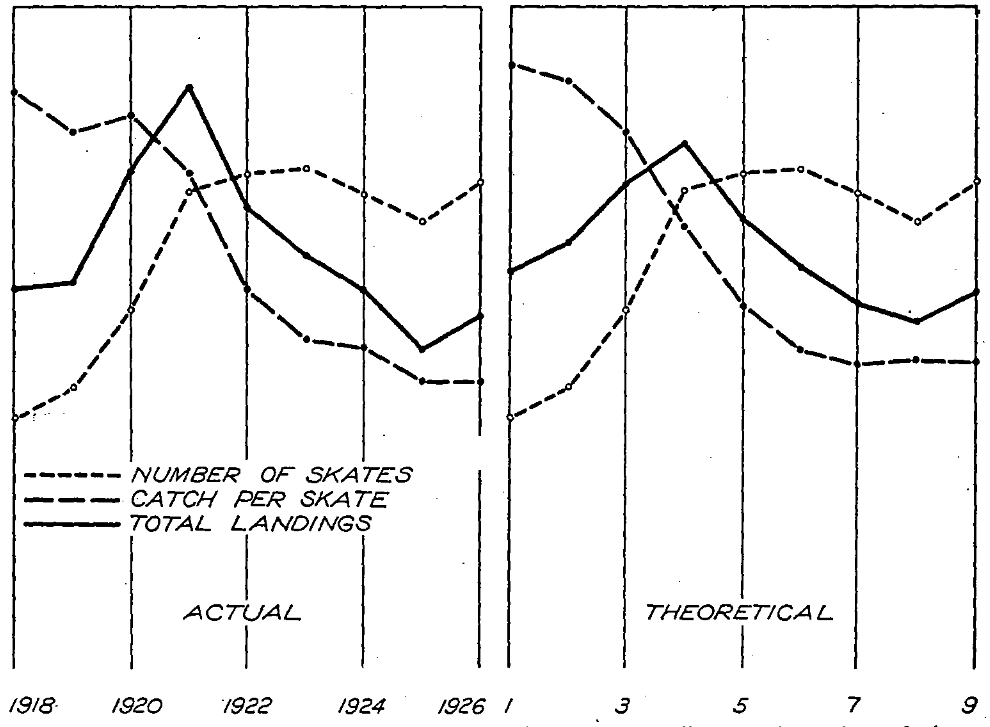

FIGURE 13.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds south of Cape Spencer using 56 per cent fishing mortality (as of 1926) and 10 per cent natural mortality, 1918 to 1926.

trial, Table 12, Figure 13, where 56 per cent fishing mortality (for 1926) is combined with a natural death rate of 10 per cent, making a total of 60.4 per cent. The only difference between the theoretical in this case and that preceding as shown in Figure 11, is the somewhat lesser range of the total catch between the maximum in the fourth year and the minimum in the eighth year.

In Figures 12 and 13, it should be noted that in the theoretical case, as in the actual, the total yield fell to a level below that initially obtained. This is, as explained in a preceding section, characteristic of a fishery in which the annual loss by natural mortality is less than the gain by growth. The theoretical cases here assume this condition to exist, and the correspondence with the actual yield indicates strongly that on the banks in Area 2 the assumption is correct that the rate of growth is the greater. If so, each successive increase in the fishery should be reflected in a lower level of total yield. By referring to Figure 2, in which the statistics for this area are shown, it will be found that there are three successive downward steps in the level of the total catch in 1918, 1926, and 1931, and that the downward steps are inaugurated by temporary increases in total yield; namely, the initial maximum of the fishery and two less marked in 1921 and 1928. In each case an increased intensity of the fishery occurred at the time of the temporary increase, and was obviously the cause.

2. AREA 2, PERIOD 1925 TO 1933

By referring to Table 1 and Figure 2, where the statistics for Area 2 are given for 1895 to 1933, it will be seen that in the three instances where the total catch has risen in response to increased intensity, this transitory effect was each time less in magnitude. In the period 1918 to 1926, the intensity of the fishery, as indicated by the number of sets of "skates," rose 67 per cent of its initial magnitude, and in the period 1925 to 1930, about 33 per cent. The catch rose but slightly in the latter period, 10 per cent as compared to 36 per cent in the previous period. As before, the total catch failed to maintain the initial increase, breaking in 1929 and 1930 to a new low level, despite the maintenance of the intensity up to the latter year. The changes as far as the latter year are plainly assignable to the same cause as in the period 1918 to 1926.

The case is, however, complicated by the sharp fall in the fishery in 1931 and 1932. In the present case the total catch was held nearly constant by legal means, and as a consequence the tendency toward an increase in this total was felt rather as an accentuation of the return per set of a unit of gear. The latter rose sharply, indicative of an increase in the stock of fish on the banks. This effect, the reverse of that occurring during the years 1927 to 1929, is, of course, in harmony with the theoretical explanation given for the changes as initiated by variations in the fishery.

For comparison of the actual course of events and the theoretical, during this period, the same combinations of mortality rates were used as for the period 1918 to 1926 in Area 2. These are presented in Table 13 and Figures 14, 15, and 16.

TABLE 13.—*Comparison of the actual catch per skate and total landings with the theoretical, as reconstructed from the growth rate and mortality rates and as based upon the actual number of skates fished on grounds south of Cape Spencer for years 1925 to 1933 for various combinations of fishing and natural mortality.*

Year	Actual Number of Skates Fished (1000's)	Total Landings to 4 Significant Figures				Catch per Skate (Pounds)			
		Actual (10,000's)	47/21 [1]	47/10	56/10	Actual	47/21	47/10	56/10
1925	462	2394	3296	4232	4000	52	71	92	87
1926	494	2579	3491	4516	4249	52	71	91	86
1927	499	2463	3471	4408	4196	49	69	88	84
1928	569	2721	3727	4742	4490	48	65	83	79
1929	653	2625	3873	4894	4565	40	59	75	70
1930	644	2260	3568	4399	4156	35	55	68	65
1931	548	2247	3130	3807	3685	41	57	69	67
1932	457	2288	2887	3508	3466	50	63	77	76
1933	453	2360	3085	3785	3766	52	68	84	83

[1] Columns 47/21, etc., represent the theoretical results of the combined mortality rate of 21 per cent natural and 47 per cent fishing as equated to the actual number of skates fished in 1926.

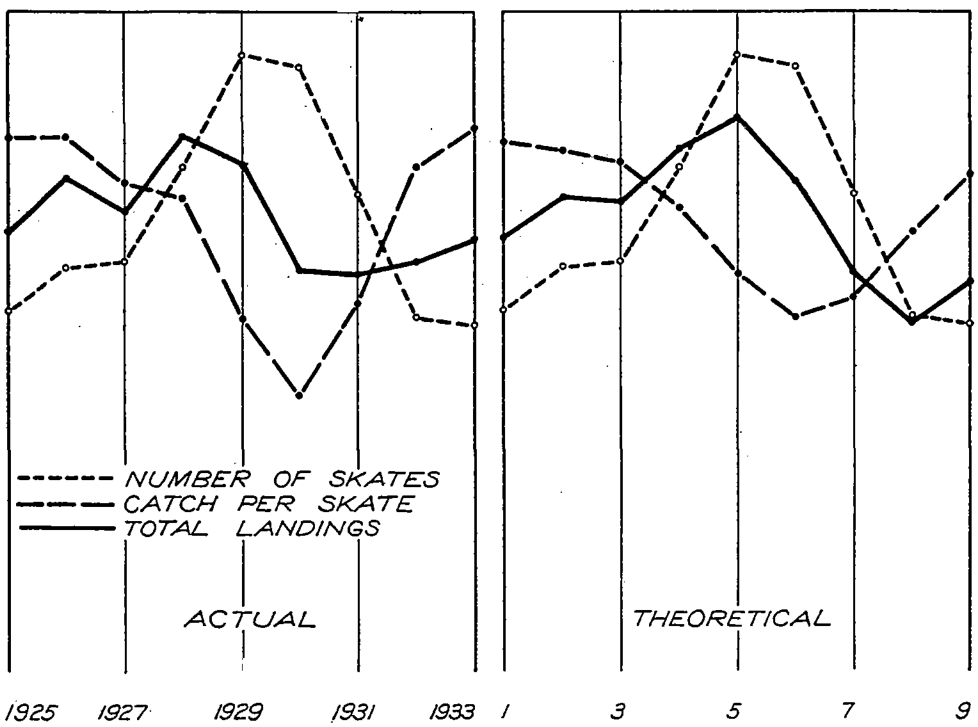

FIGURE 14.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds south of Cape Spencer, using 47 per cent fishing mortality (as of 1926) and 21 per cent natural mortality (as of 1926).

Again it is apparent that the changes in the returns from the fishery are explained in their major features, although, as might be expected, the graphs

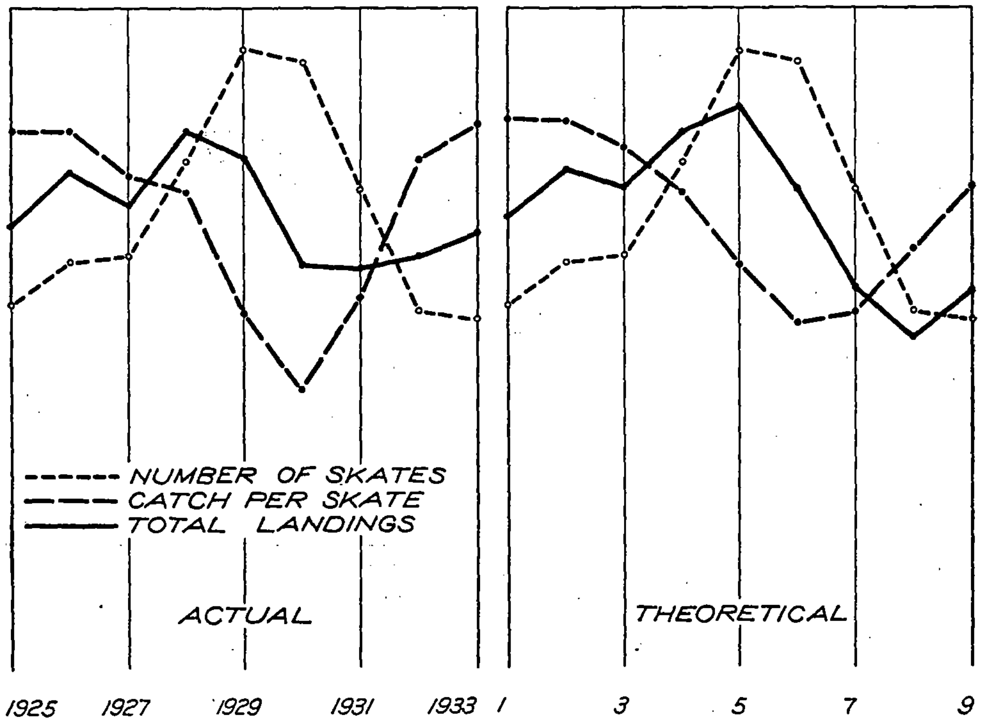

FIGURE 15.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds south of Cape Spencer, using 47 per cent fishing mortality (as of 1926) and 10 per cent natural mortality, 1925 to 1933.

of actual and theoretical do not compare in detail. The three combinations of mortality rates do not, any one of them, affect the comparison to any great degree, as was also true of the previous cases considered.

The natural mortality rate should affect the levels of total catch prior to and subsequent to the change in intensity. But in this case the intensity rises and falls again, so that the effect on the total is obscured, and will remain so until the intensity is allowed to stay constant for several years. It is also true of any changes in trend due to decline of incoming young, that as long as constant changes in the intensity of the fishery are permitted, the transient effects of such changes must obscure the more permanent underlying trend.

The relatively small range through which both actual and theoretical cases vary in this period as compared to that between 1918 and 1926 is probably due to two factors. One, the competitive nature of the gear, if present, renders it less effective per unit the more intense the fishery. The other, the small size of the existing stock, requires a larger change to produce an effect on the total poundage caught equivalent to that of the fishery at lower levels.

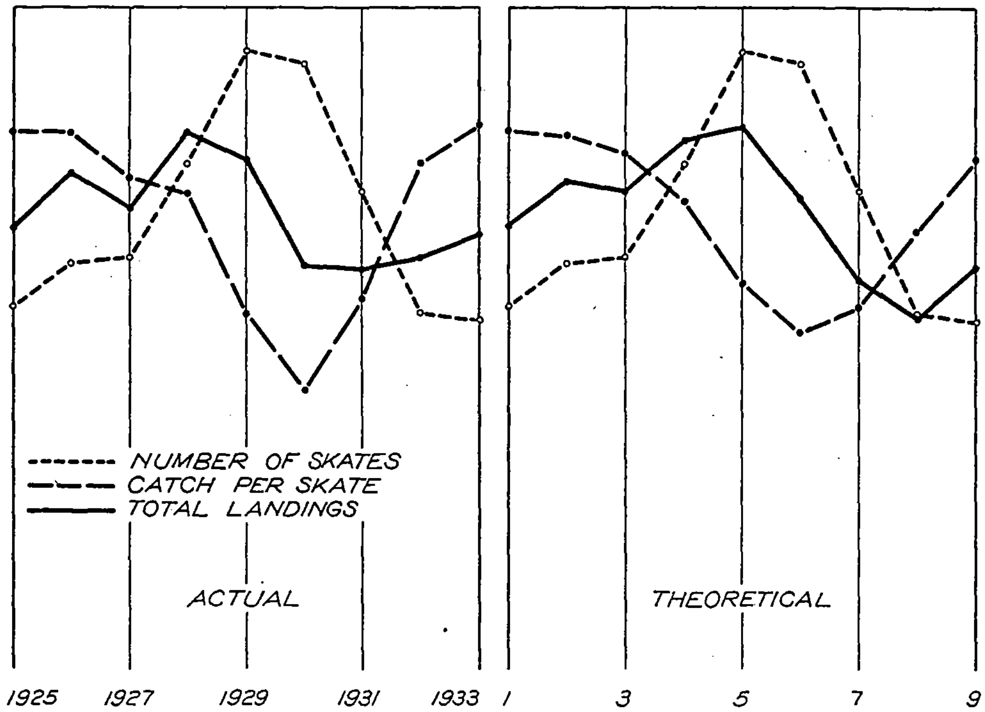

FIGURE 16.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds south of Cape Spencer, using 56 per cent fishing mortality (as of 1926) and 10 per cent natural mortality, 1925 to 1933.

3. AREA 3, PERIOD 1920 TO 1929

The dominating feature of the period from 1912 to 1933 in the more distant banks of the Gulf of Alaska and along the Alaska Peninsula that form Area 3, is the great rise in the intensity of the fishery from 1922 to 1929

TABLE 14.—*Comparison of the actual total landings and catch per skate with the theoretical as reconstructed from the growth rate and mortality rates, and as based upon the actual number of skates fished on grounds west of Cape Spencer, for years 1920 to 1929, for various combinations of fishing and natural mortality.*

Year	Actual Number of Skates Fished (1000's)	Total Landings to 4 Significant Figures			Catch per Skate (Pounds)		
		Actual (10,000's)	12/20 [1]	40/20	Actual	12/20	40/20
1920	91	1346	1976	3854	148	217	424
1921	104	1468	2295	4290	141	221	413
1922	80	1085	1722	3390	135	215	423
1923	143	2147	3031	5655	150	212	396
1924	233	2552	4640	7735	110	199	332
1925	273	2602	5100	7252	95	187	266
1926	277	2606	4810	6140	94	174	222
1927	346	3003	5525	6360	87	160	185
1928	371	2698	5460	5750	73	147	155
1929	416	3019	5593	5560	73	134	134

[1] Columns 12/20, etc., represent the theoretical results of the combined mortality rate of 20 per cent natural and 12 per cent fishing as equated to the actual number of skates fished in 1926.

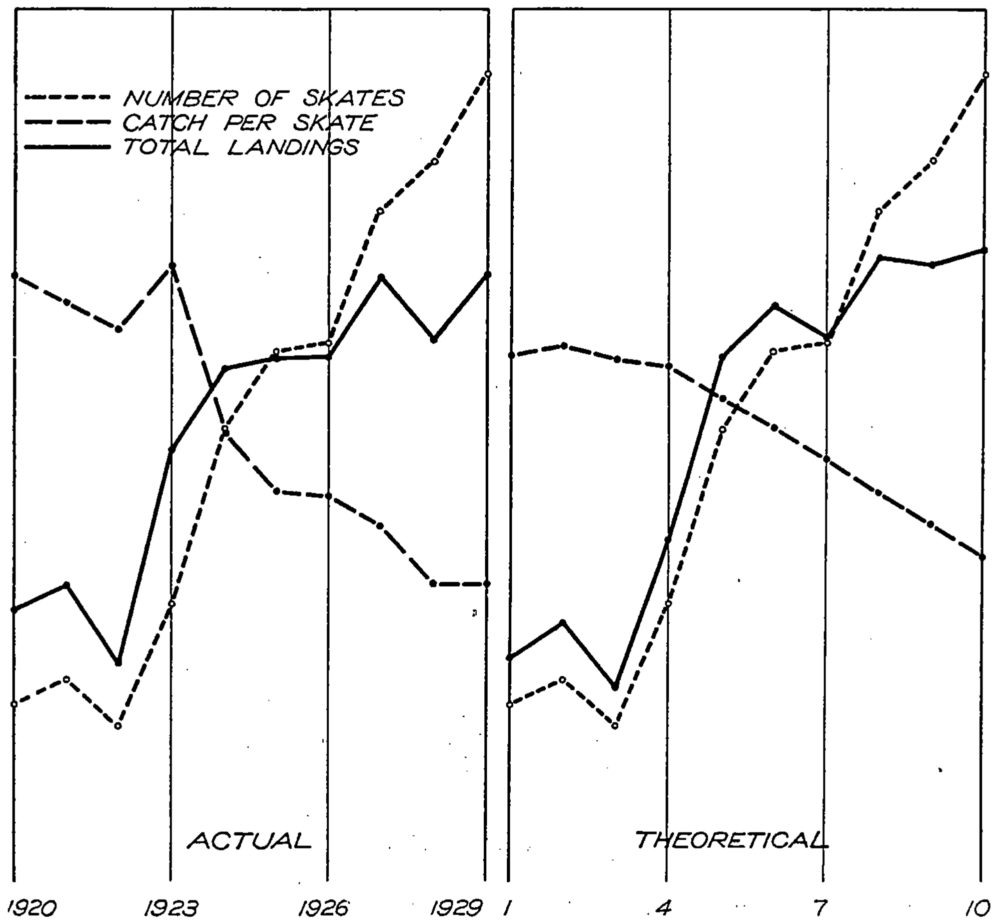

FIGURE 17.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds west of Cape Spencer, using 12 per cent fishing mortality (as of 1926) and 20 per cent natural mortality, 1920 to 1929.

(Figure 3). The fishery within three years after its beginning (1913) was nearly equal to what it was in 1922, since the increased number of boats repairing to those grounds was of a smaller type than the original fleet of steamers and large schooners, so that the time from 1913 to 1922 may be regarded as one during which the stock was readjusting itself to the fishery. This leaves the period 1920 to 1929 and its great increase in the fishery for comparison with a theoretical case, to illustrate the results of continued change.

In Table 14 and Figure 17 the same comparison between actual and theoretical is made as in the two periods for Area 2 which have already been dealt with. In this case, however, the rate of growth used is less (given in Table 15), and it has been necessary to use a much lower level of intensity than can be used in Area 2. The marking experiments which indicated a fishing mortality in excess of 40 per cent in Area 2, indicate one of approximately 10 per cent in Area 3. It has been assumed that a rate of 12 per cent prevailed in 1926, and the rates in other years have been determined accordingly, as though competitive. The natural mortality has been assumed to be 20 per cent annually. The result is a theoretical case remarkably similar to the actual (Figure 17).

It is worthy of note that when the same natural mortality and growth rates are used, but the fishing mortality made more comparable to that in Area 2, the results are not comparable as far as the total catch from 1924 on is concerned, since it falls rapidly (Table 14, Figure 18). It is evident that

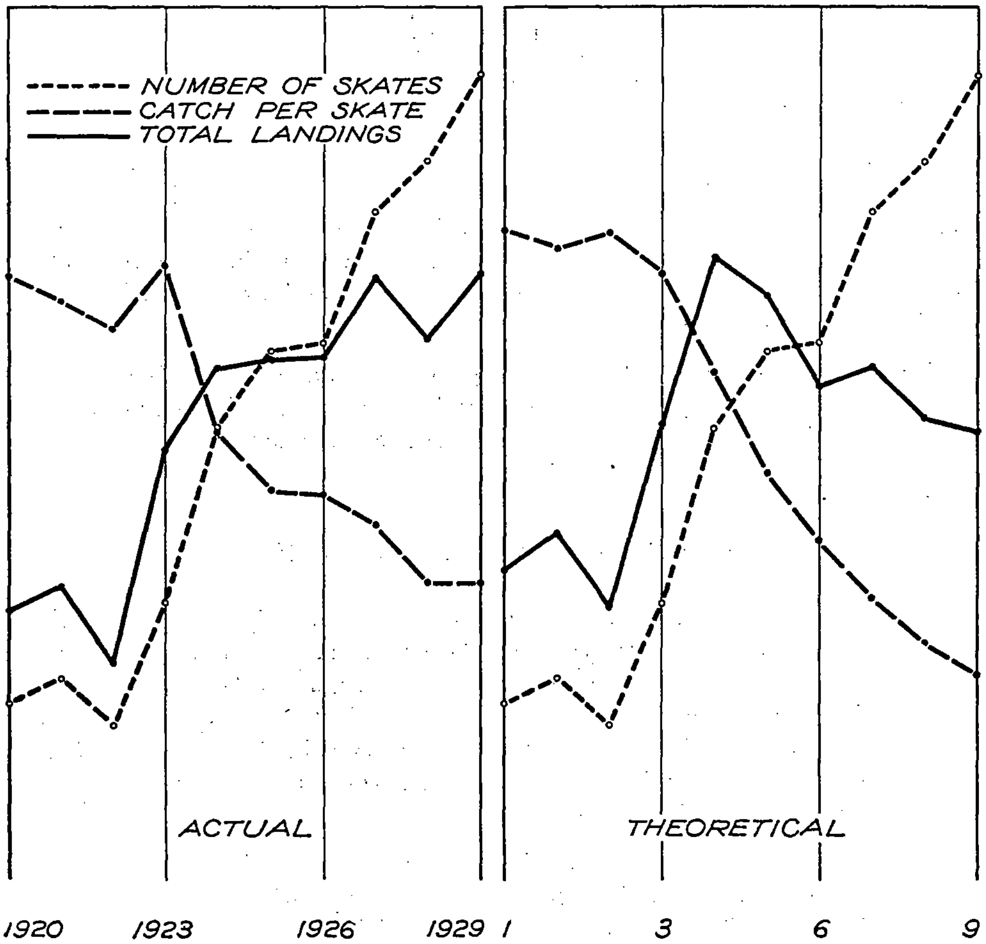

FIGURE 18.—Actual and theoretical catch per skate, total landings, and number of skates fished on grounds west of Cape Spencer, using 40 per cent fishing mortality (as of 1926) and 20 per cent natural mortality, 1920 to 1929.

in the actual case the slow growth rate gives an annual increment less than the decrease from natural deaths, so that the more intense the fishery the greater the yield, providing the incoming young are not diminished in number. It is perhaps fair to compare the conditions in Area 3 with those which would prevail in Area 2 were the natural mortality above 21 per cent,

TABLE 15.[1]—*Average weight in pounds, heads on, of males and females from Yakutat Bank.*

Age	Average Weight (Pounds)
VII	6.2
VIII	7.6
IX	8.0
X	8.8
XI	11.0
XII	12.5
XIII	15.7
XIV	18.8
XV	21.7
XVI	24.9
XVII	28.8
XVIII	33.0

[1] From H. A. Dunlop, manuscript of unpublished report.

perhaps 30 per cent, hence considerably in excess of the growth rate there. If Figure 9 is referred to, it will be seen that the graph marked "30" shows a very rapidly increased total yield as the fishing mortality increases, due to the excess of natural mortality over growth, and that this increase is greater the less intense the initial fishery. We have tried various alternative combinations of rates without success.

The remaining period 1930 to 1933 is so short that it will suffice to note that the inverse correlation of intensity and catch per set of gear, as well as the initial fall in total catch, is in accord with expectancy.

CONCLUSION AND DISCUSSION

The outstanding feature of this report is undoubtedly the presentation of acceptable statistics of total yield, catch per standardized unit of gear, and consequently of the intensity of the fishery. These, analyzed in accord with the biological work indicating the existence of distinct stocks of halibut, have shown themselves capable of explanation in a remarkably clear cut way, a way nevertheless which might be expected wherever man's influence on the fishery dominates.

The explanation is of much significance to the economics of the industry as well as to conservation. The consequences of growth in the fishing fleet are well defined. The tendency of the total yield from a given income of young, to remain unchanged at the higher levels of fishing intensity, whatever that intensity, renders increase in amount of gear and vessels at best an economic waste, to be paid for by greatly increased costs of production.

In so far as this total does change, it may increase or decrease, according to the balance between biological conditions determining growth and natural death. But more important still, the intensified fishery decreases the number of mature, and must affect the annual influx of young into the commercial catch.

There are therefore two causes of decline in yield of the banks, one the existence of biological conditions whereby overfishing produces a smaller poundage from the incoming young, the other the decrease in these young by intensification of the fishery. This seems to be true of the banks south of Cape Spencer where the growth rate is high. Either would indicate the necessity and profit of decreasing the intensity of the fishery.

It would be fair to conclude that if decreasing the effort put forth by the fisherman can thus actually increase the total catch per year from what young are produced, it is a small price to pay for the decided contribution thus made to increased production of spawn and hence, possibly, of young.

Increases in the fishery also have a temporary effect upon the total yield. It rises sharply at first, but falls steadily thereafter to a level near the old. The returns per vessel, or per set of a unit of gear, fall continuously from the start. The temporary effects on total catch are in themselves disadvantageous to the individual fisherman, because a greater total landing lowers prices obtained, while his own return diminishes. Rational and profitable exploitation means, very apparently, restraint.

The conclusions here arrived at give great importance to biological facts such as growth, death rates, and migration. Rational treatment must vary according to what they indicate. It is entirely possible, for instance, that on certain parts of the halibut banks, as on the western banks in Area 3, due to the slow rate of growth, the yield from the given income of young is greatest under the most intense fishery, even though the catch per unit does fall. If so the limit to the fishery is either the legal one which allows production of young or that economic one at which profitable operation by the individual ceases.

In general, after the fishery has passed well beyond the initial stages of exploitation, and even though a small increase in total yield is obtained by further intensification, it is unlikely that the increase will repay the greater costs of operation or justify the threat to the future supply.

Printed by
Wrigley Printing Co. Ltd.
Vancouver, B. C.
1934