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AND CANADA FOR THE PRESERVATION OF THE
NORTHERN PACIFIC HALIBUT FISHERY

NUMBER 12

THEORY OF THE EFFECT OF FISHING ON THE STOCK OF HALIBUT

BY

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FOREWORD

The present is a twelfth report by the International Fisheries Commission under the terms of the Conventions of 1924, 1930 and 1937 between Canada and the United States for the preservation of the halibut fishery of the Northern Pacific Ocean, including Bering Sea.

It is published in order that the character of the results obtained by regulation of the halibut fishery may be clearly understood. These results show that the stock of halibut is being rebuilt and that it is in much healthier condition than when the Commission was given power to regulate in 1930. The increased abundance which has followed should not now be destroyed by allowing a return to former conditions. Nor should the necessary scientific observation be neglected. The Commission feels strongly that once clearly understood, a reversion will never be permitted.

This report is one of a series of investigations under the direction of Dr. William F. Thompson and carried on by a staff with laboratories and headquarters at the University of Washington, Seattle, U.S.A.

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1. Report of the International Fisheries Commission appointed under the Northern Pacific Halibut Treaty, by John Pease Babcock, Chairman, and William A. Found, Miller Freeman, and Henry O'Malley, Commissioners. Dominion of Canada, Ottawa, 1928.
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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.
9. Life History of the Pacific Halibut (2) Distribution and Early Life History, by William F. Thompson and Richard Van Cleve. Seattle, Washington, 1936.
10. Hydrographic Sections and Calculated Currents in the Gulf of Alaska, 1929, by Thomas G. Thompson, George F. McEwen, and Richard Van Cleve. Seattle, Washington, 1936.
11. Variations in the Meristic Characters of Flounders from the Northeastern Pacific, by Lawrence D. Townsend. Seattle, Washington, 1936.
12. Theory of the Effect of Fishing on the Stock of Halibut, by William F. Thompson. Seattle, Washington, 1937.

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

THEORY OF THE EFFECT OF FISHING ON THE STOCK OF HALIBUT

By WILLIAM F. THOMPSON

I

There are known to be great changes in the supply of fish in the ocean. The changes have been recorded and studied for many years and for many fisheries. From this study there has arisen the theory of fisheries science. This theory has been developed only as accurate records have come to hand on which it could be based. It is, for example, now possible to forecast to some extent the changes in abundance due to successful or unsuccessful spawning, by following the young produced as they grow in size from year to year. But in addition to this type of natural variation in abundance of fish, there have been found changes due to the amount of fishing—in other words, to man's influence. It is these which are described in this report.

Where the natural variations are not large, and where good records are available, the changes caused by man become more easily seen. They are distinct in the halibut fishery of the Pacific, and have been described in Report No. 8, of the International Fisheries Commission. In that fishery and in others of the same kind, the changes due to the fishery are particularly important. But they must be present in all fisheries, even where hidden by changes of other kinds.

There is lacking, however, a simple statement of the theory. It can be traced back through the writings of various fisheries scientists, beginning with C. Joh. Petersen of Denmark. It has developed slowly, mainly because of defective records on which discussion could be based, and because of complicating factors. The writer has discussed it with many men, including especially F. H. Bell, E. S. Russell, Michael Graham, and Johan Hjort. If the following statement is any clearer or simpler than those studies which have gone before, it is due to earnest discussion with these men and many others.

Such a simple statement is necessary because no program of control can be carried out unless as many as possible of the more intelligent and interested men understand it. If it is not possible to secure complete understanding and if it therefore proves necessary to leave much to the decision of technical methods, it is important that the necessity of so doing be accepted. This cannot be unless there is a general appreciation of the place and utility of these technical methods in fisheries science. Some men grant their importance readily, others are more reluctant. For that reason, although the discussion in this report may be carried somewhat farther than some will care to follow, the theory which leads up to the use of technical methods is given as simply and directly as the writer has been able to make it. All technical mathematics and biology are eliminated. In short, the theory has been made available to as many people as possible.

II

In this theory there is of primary importance a mechanical phenomenon which should not be confused with the more complex biology of the various fishes. It is the law of accumulation of capital. Once understood there need be no discussion as to its validity. And there is little difficulty in finding examples of its application not only in fisheries, but in almost every field of human activity.

In fisheries, one of the simplest illustrations which occurs to the writer is that of a fish "farm", where fish are held in ponds.

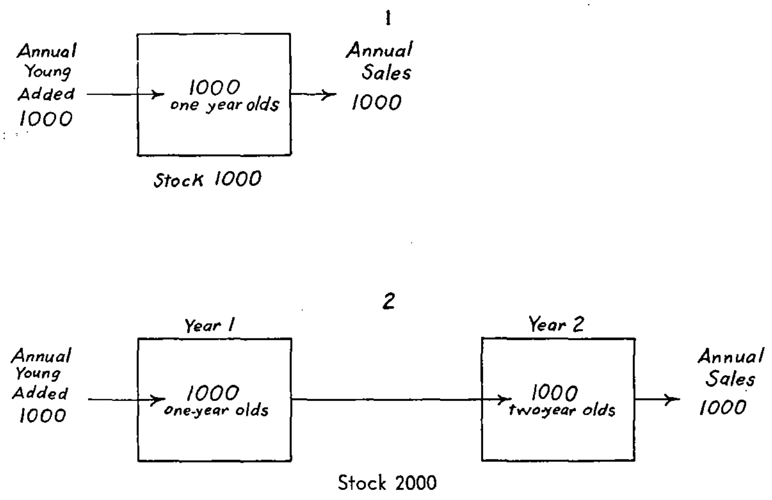

FIGURE 1.—Diagram showing effect upon the total stock and yield of retention of pond fish one and two years.

The accompanying diagram (Figure 1) will illustrate the first case. The owner, buying a thousand fish each year, holds them for one year only, and at its end, removes the thousand (ignoring growth, death, etc.). He would have on hand during the year but 1000 fish at any one time. The fish removed would annually equal the fish brought in.

The second diagram (Figure 1) illustrates what would happen if the owner decided to hold the fish for two years. Buying a thousand fish each year, he would hold each lot an additional year. Although he would have to lose the removals for one year in order to fill the second pond, after that was filled he could resume his removal of 1000 fish annually. Again the fish removed would annually equal the fish brought in, but he would have on hand 2000 fish at any one time, double the former stock. (Figure 2).

Accounts

Purchases	Stock on hand	Sales
Jan.1933 1000	1000	Dec.1933 1000
Jan.1934 1000	1000	Dec.1934 0
Jan.1935 1000	2000	Dec.1935 1000
Jan.1936 1000	2000	Dec.1936 1000

FIGURE 2.

At will he could increase this accumulated stock to 3, 4, or as many thousands as he wished, providing he could save the requisite amount from his removals; and after the accumulation was completed, removals would again annually equal the fish brought in. But the retention of the accumulation would of course depend entirely on the removal of no more fish than were added, and whenever the removals took more than this, the stock would be reduced.

The phenomenon is the simple one of accumulated capital, and can be readily illustrated in many other fields. For instance, if interest on deposited money is ignored, the accumulation of money in a bank is according to the same rule. Deposits annually of $1000, held one year only, then withdrawn, give but $1000 capital in the bank; and annual withdrawals equal annual deposits. Held two years, the equivalent of one year's withdrawals must be foregone, but thereafter withdrawals can each year equal deposits, yet the capital in the bank is $2000 and money remains two years instead of one.

Again, an illustration occurs in the case of reservoirs of water. With a stream of fixed flow, a reservoir of 1000 gallons can be filled, and when full, inflow will equal outflow. If a second reservoir is added, the outflow must be temporarily used to fill this second reservoir, but then inflow and outflow as before are equal. Yet as a result 2000 gallons of water will be on hand in the reservoirs, at any one time, and the water will take twice as long to flow through the system as before.

Further illustration is needless, as it is entirely obvious that a simple mechanical phenomenon is responsible, the accumulation of capital. It occurs regardless of profits, whether of organic growth or interest, or losses as removals by death, etc. With a given income, the amount of capital, of stock, or the reserve of water on hand is determined by the time which the dollar, fish, or gallon takes in passing through the accumulation, to end in use or loss.

Stated in this simple way, the law applies to the case of a marine fish, with the reservation that in such case the accumulation would not be held in a second pond or tank, but in the limited confines of the original bank or area of the sea. The density of population would then be doubled by doubling the stock. The annual removal or catch would be fifty per cent of the total, instead of one hundred per cent. Each set of gear would take twice the catch that it did before, consequently but half the effort would be required for removal of the same amount—nevertheless, as in the preceding examples, the removals could not exceed the amounts brought in (or the incoming young) without reducing and finally destroying the accumulation.

In the simple illustrations used above, no account was taken of deaths due to natural causes. It does not much matter to the stock of fish whether a fish is taken by man or by an enemy of another sort. A fish caught or dead for any reason is a fish removed from the stock, and a change in the amount of fishing increases or decreases the removals. The essential in each illustration is the fact of removal, whatever its cause.

This law of accumulated capital should give a saner outlook on the problem of rationalizing a fishery. Once its results are understood, the use for this purpose of the biological and statistical sciences becomes clear. They alone can show the profit and loss of a capital accumulation, and show what conditions render the creation and maintenance of the accumulation possible. A thorough understanding of this law is therefore necessary to the proper application of further technical methods.

III

On a bank at sea, the accumulation of a stock of fish is made gradually. In the illustrations already given, it has been assumed for the sake of simplicity, that the accumulation was abruptly and immediately accomplished by foregoing the withdrawals, or catch, of a single year in its entirety. But the same amount could be accumulated, although more slowly, by reducing each withdrawal, to a part of the former annual withdrawal. That is, instead of removing all possible each year, a fraction could be left to accumulate, to pile up during the years.

This is what actually happens on a fishing bank, as can be seen when the fish are sorted out according to their ages. The age of a fish can be determined by the marks in the hard part of the skeleton, just as in the trunk of a tree. There are on any fish bank, a number of ages, each a survival of the next younger age. This has been shown clearly and often wherever scientific work has been done. In Figure 3, a typical diagram is given, in idealized form. In this, the height of the bar above any given age indicates the number of fish of that age in the stock.

The decline is shown in the diagram as a very high percentage, chosen to illustrate an intense fishery, but in fact, it might be different in every case investigated. The removal is, in this assumed case, 80 per cent annually, leaving 20 per cent of each age class to survive as a part of the accumulation for the next year. Of 1000 fish entering the fishery as the youngest age class, 20 per cent, or 200 survive as an accumulation in the second age group. Of these but 40 survive to the third age, 8 to the fourth, etc. As 1000 enter each year, there are at any one time age classes at all stages of transition through the stock of fish. Plainly, each age class in the stock at any given .time represents a stage in the removal, hence as the catch reflects the composition of the stock the numbers in the age classes in the catch decrease

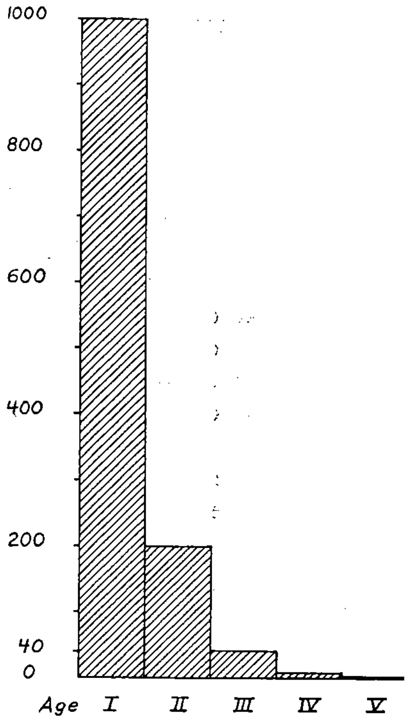

FIGURE 3.—Diagram showing the number of fish of each age in a stock of fish.

just as each class does with age, providing the rate of removal has not been changed. The total of all accumulations is 1000 plus 200, plus 40, plus 8 etc., or 1250.

In this case, as well as in the first illustrations used, there is a simple accumulation of stock, or capital. And in both, the annual withdrawal must not exceed the annual income of young or the accumulation will vanish. The removals, or catch, of a thousand cannot exceed the income of a thousand *unless some part of the accumulation of 250 is taken.* The main difference between the two cases is that in the first, the accumulation was formed in one year and renewed each year, while in the present case, the accumulation was formed of the savings over several years and was renewed as gradually.

In the illustrating diagram, it is assumed that 80 per cent of the available stock is removed annually. But 80 per cent of the accumulation of 1250 is 1000, hence equal to the income, and the stock remains in a state of balance, the same equilibrium between inflow and outflow as in a reservoir.

The result of the percentage rate of removal is therefore a stock of fish composed of different ages, each in number tending to be a certain percentage of those of the preceding age, just as shown in Figure 3. This is the "survival curve" familiar to biologists and actuaries. Its existence wherever studies have been made is evidence that the law of accumulation of capital applies.

IV

In marine fisheries the catch is usually a percentage of the total stock of fish available. A set of a unit of gear will cover a definite fraction of the ground available, and hence, although its catch may be sometimes large, sometimes small, in the long run it will take on the average a definite fraction of the fish on the whole ground unless the second set is used on that part of the ground fished by the first set and before the fish redistribute themselves. But if the efficiency of the gear lessens or increases, the percentage rate of removal is simply less or greater, accordingly. It is still a percentage of the available stock which is removed, and varies with the size of that stock. Moreover, it may be less at one age than at another, without interfering with the law of accumulated capital, or stock, because the total removals will still be a certain percentage of the stock available. It is, however, simpler and more understandable for our purpose to consider the percentage rate of removal as constant from age to age and year to year. We thereby avoid needless complications.

If the removals had been 800, hence a definite fraction of the *income* of 1000, there would have been an annual saving of 200, and the stock would have increased each year, to an indefinite size. The number of removals would not increase, hence could not in any way balance the increase in accumulated stock.

But the 80 per cent in our illustration is of the *total accumulation* of stock of fish, and the number of individuals the 80 per cent represents grows as the accumulation proceeds. It grows until the 80 per cent removed equals the incoming thousand and the accumulation then must cease. This may be illustrated by taking a sheet of paper and setting down a very simple calculation. If 1000 young enter the fishery and 80 per cent are taken, there would be a catch of 800, leaving 200 as an accumulation. But the next year 1000 young enter and make a total of 1200, so that a catch of 80 per cent is 960, and 240 are left. The third year 1000 young, added to 240 make a total of 1240, so that the catch is 992, and 248 are left. So as year follows year, the accumulation approaches 1250, and the removals or catch approach 1000, then both cease to increase because they depend one on the other. The outgo is then equal to the income, with a stock fixed at 1250. In short, the *size of the accumulation is determined by the rate of removal.*

	Stock at first of year	Withdrawals at 80% yearly	Income	Added to Accumulation (Excess of Income)	Income and Accumulated Stock
Year 1	1000	800	1000	200	1200
2	1200	960	1000	40	1240
3	1240	992	1000	8	1248
4	1248	998+	1000	2	1250

This may be stated in the way a fisherman might prefer. Since the catch per set of a unit of gear increases as the abundance or accumulation of fish on the bank increases, the total catch per year by a given number of sets must increase and at last must equal the number of young fish which become of catchable size. Then the abundance can no longer increase, because there is no excess of young over the number caught. The fish increase in number no longer. The fewer the given number of sets of gear, the greater the catch per set must become before this happens, so the amount of fishing, which is the rate of removal, determines the abundance of fish, which is the accumulated stock.

To test this conclusion, a similar calculation of the removals at a rate different than 80 per cent of the available stock each year, will show that a lesser rate simply allows the accumulated stock to increase farther, but does not and cannot change the law of accumulated capital.

Thus withdrawals by natural death or by capture, etc., of 50 per cent annually will lead to an accumulation of 2000 from an annual income of 1000 young, as compared to one of 1250 when the rate is 80 per cent. If 1000 young enter the fishery and 50 per cent are taken, there would be a catch of 500, leaving 500 to accumulate. But the next year 1000 young enter and make a total of 1500, of which 750 are taken, 750 survive. The third year the total stock would be 1000 plus 750 or 1750, of which 875 would survive. The fourth year the stock would be 1875, the survivals 937, the catch 937. In the fifth year the stock would be 1937, the catch 969, and the survivors 969. And so in successive years the accumulated stock would approach 2000, and the catch 1000.

In Figure 4 the "survival curves" left by 80 per cent and 50 per cent rates of removal are compared and in the following table these survivals and the corresponding catches or withdrawals are shown.

	Stock	Withdrawals of 80% annually	Stock	Withdrawals of 50% annually
Age I	1000		1000	
II	200	800	500	500
III	40	160	250	250
IV	8	32	125	125
V	2	6	61	61
VI		2	31	31
VII			16	16
VIII			8	8
IX			4	4
X			2	2
XI			1	1
Totals	1250	1000	2000	1000

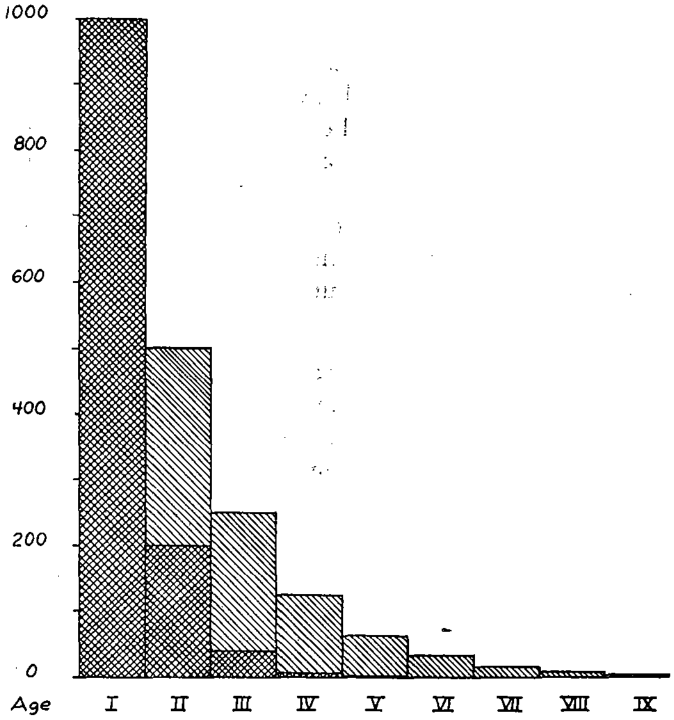

FIGURE 4.—Diagram showing the relative numbers of fish of each age in two stocks, one subject to a removal of 50 per cent yearly, one to a removal of 80 per cent.

Half of 2000 equals 1000. So does 80 per cent of 1250. So outgo must finally equal income, catch or removal must equal added young. The annual withdrawals, by catch or other means, must therefore become equal, 1000 each, regardless of the rate of removal. But the size of the accumulation varies with, and is a characteristic of, this rate of removal.

The varying size of the accumulation, or what is usually known as the abundance of fish, is a direct result of the law of accumulated capital as was shown by reference to fish in a pond. It is of the greatest importance to fisheries, because it shows that the size of the stock on the banks may vary with the amount of fishing, but that the so-called permanent yield does not, unless the accumulation in an indirect way affects the income in a way discussed below.

V

It follows from what has been said that were commercial fisheries constant from year to year, so that each year the percentage taken by fishing was the same, the fishery would remain in an equilibrium, with its stock of a size corresponding to the amount of fishing, as long as the incoming young were also constant. In a line fishery the number of sets of a unit of gear would have to be the same each year; or in a trawl net fishery, the number of hours fishing with a net of a certain efficiency would have to be the same.

But fisheries are not constant from year to year. Fisheries are always varying in their intensity. Under our economic system this variation has almost always been in the direction of a greater intensity. In the halibut fishery this increase in amount of fishing has not been a regular one, but has occurred in three major steps, corresponding to economic conditions which seemed to justify investment and expansion. In other fisheries the changes may be different, in so far as they respond differently to these economic conditions, but are always present.

In such a constant state of change there is an equally constant shift in the size of the accumulated stock. This must follow, because the size of this stock varies in the reverse fashion to the amount of fishing. What happens during the change from one condition to another? In the answer to this question may lie the explanation to much of what we see happening to the catch from year to year.

In our simple first illustration, it was shown that as much stock could be accumulated as desired in a series of successive ponds. Actually nature would limit this, by an increase in natural deaths; but within limits, the stock could be increased as desired. Thus 4000 fish could be held in four ponds, and of those but 25 per cent would be taken to balance the annual income.

If, however, the removals were increased to 50 per cent (doubling the amount of fishing), a change in the accumulated stock would result. The first year 2000 would be taken out. This would leave 2000 to add to the 1000 of the next annual addition. Then 3000, instead of 4000, would be held in the ponds, emptying one. In the second year, the removals would be 1500, the survivals 1500 or 500 less than the year before. In the third year, 1000 plus 1500, or 2500 would be held, and removals would be 1250 or 250 less than in the year before. The fourth year a stock of 2250 would yield 1125, or 125 less than the year before. Finally the stock would have gradually been reduced to 2000, yielding 1000, with a 50 per cent rate of removal, thus reaching equilibrium until the balance would be again upset. This reduction in stock would have been accomplished by each year removing from the accumulation the amount by which the withdrawals or catch exceeded the income.

In Figure 5 the change in rate of removal, the number removed and the resultant stock in the ponds are shown as three lines in a diagram.

The resultant record of annual catch is then a peculiarly characteristic one, rising abruptly to a maximum, falling gradually to the former level. The abundance, as shown by the accumulated stock, falls quickly at first, then more and more gradually to a new low level.

The same would follow did the final accumulated stock fill but a fraction of a pond. If the removals were raised to 80 per cent annually, the stock of 2000 left by taking 50 per cent in the above example could be reduced to 1250 by exactly the same process as before, with a diagram as shown in

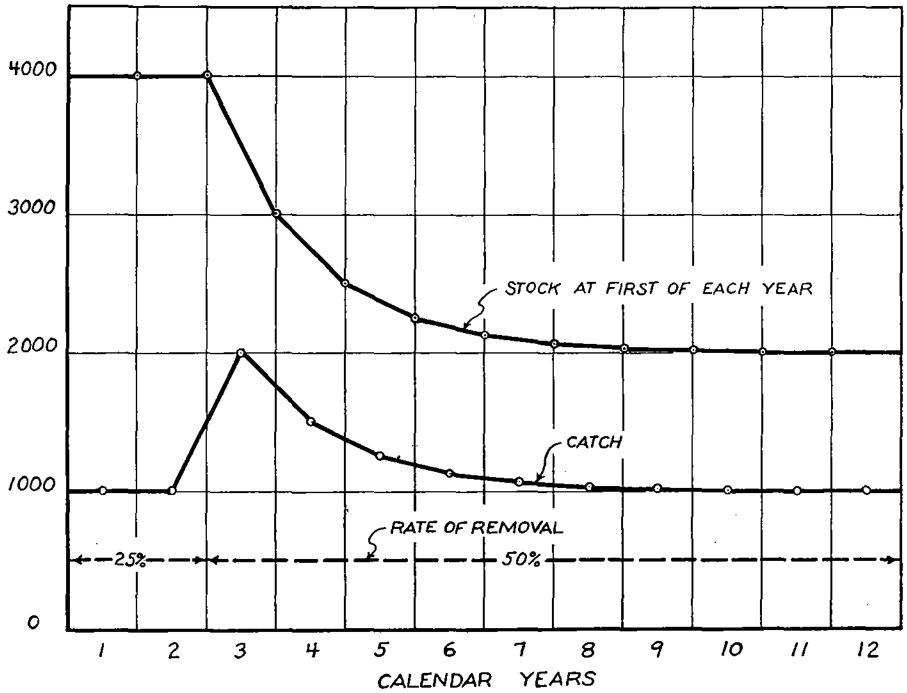

FIGURE 5.—Changes in catch and total stock as a result of a change in the amount of fishing at the end of the second year, from a 25 per cent annual removal to one of 50 per cent.

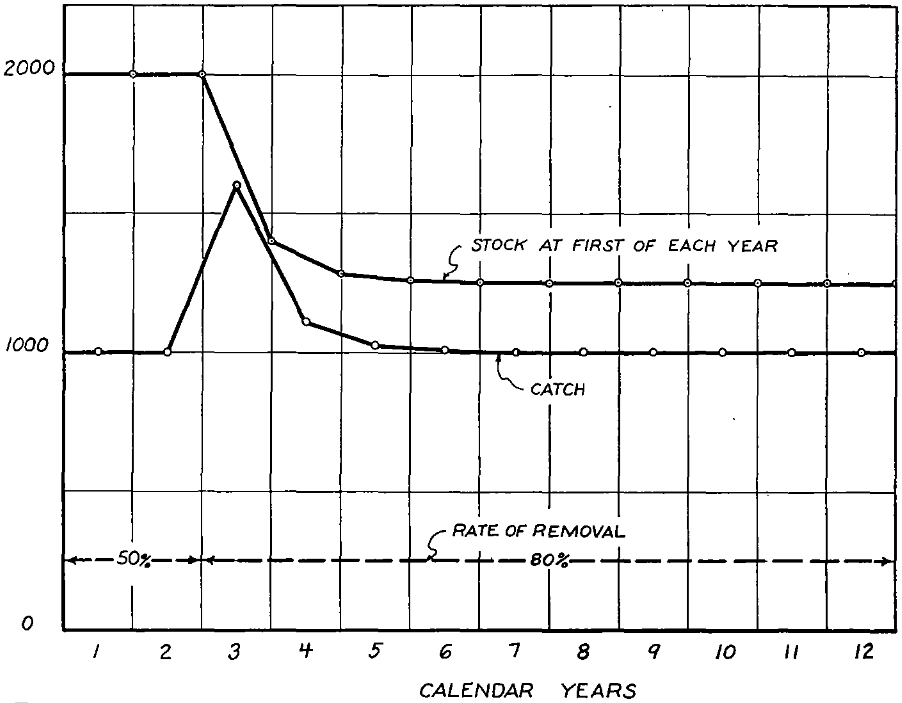

FIGURE 6.—Changes in catch and total stock as a result of a change in the amount of fishing at the end of the second year, from a 50 per cent annual removal to one of 80 per cent.

Figure 6. The stock of fish would fall from 2000 to 1400, to 1280, 1256, 1251, and finally to 1250, while in the same years, the catch would be 1000, 1600, 1120, 1024, 1004, and 1000.

These illustrations have to do with the simple case of the ponds. But the same would happen in a case more nearly the same as that of a marine fishery. In Section IV, removals at the rate of 80 per cent and 50 per cent of the available accumulated stock were compared as they affected the individual ages on the banks. (Figure 4). The stock was shown to have been much smaller when the rate was 80 per cent than when it was 50 per cent.

The detail of what would happen to this stock in case of a change from 50 per cent to 80 per cent removal may be followed by using the same tabulation according to age as in Section IV. The rates of removal are the same as those used in the simple case of the ponds, illustrated by Figures 5 and 6.

Age	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
I	1000	1000	1000	1000	1000	1000	1000	1000
II	500	500	500	**200**	200	200	200	200
III	250	250	250	100	**40**	40	40	40
IV	125	125	125	50	20	**8**	8	8
V	61	61	61	25	10	4	**2**	2
VI	31	31	31	12	5	2	1	
VII	16	16	16	7	3	1		
VIII	8	8	8	3	1	1		
IX	4	4	4	2	1			
X	2	2	2	1				
XI	1	1	1					
Total Stock	2000	2000	2000	1400	1280	1256	1251	1250
Catch	1000	1000	1000	1600	1120	1024	1004	1000

With a 50 per cent rate of removal, the surviving and accumulating stock in each age is shown in each column of the table on this page. Each column represents a separate year. Thus in each of the first three years the stock consisted of 1000 of the first age, 500 of the second, 250 of the third, and so forth, with a total of 2000 in all, and a catch of 1000. The four year old survivors in Year 3 came from the three year olds in Year 2. But in the fourth year, the removals increased to 80 per cent, leaving survivals of 20 per cent. It should be particularly noted that this rate of survival applied to each age in Year 4. For instance, the survival was 20 per cent in those fish which passed from the II to the III age group, just as it was 20 per cent in those which passed from the VIIIth to the IXth. All ages except the entering age showed the same decreased rate of survival. The accumulated stock was reduced throughout at the same rate, and the catch increased in all ages and sizes except the first, or entering age.

After this first entry, it is plain that the younger ages reached new low numbers first. To show this the number in each age is underlined in the year it reached its low. In the first year of change, Year 4, Age II had reached its permanent level of 20 per cent survivals. The next year, Year 5, Age III reached its lowest level. In Year 6, Age IV had done the same. And it was not until the eighth year that Age VI reached its final level of abundance. Therefore, there was a gradual reduction in the total stock in each year and also in the catch, until the former was 1250, the latter 1000, as shown by the totals at the bottom of the table.

The year by year totals in this illustration are the same as those found in the simpler case shown in Figure 6. It is apparent that the law of accumulated capital applies to identically the same end in the two cases, and also that the transition from one level of abundance to the other is the same. The same diagram suffices for the two cases.

The changes produced are characteristic of a change in the accumulated stock. They are shown in Figures 5 and 6 and may be listed as follows:

1. An abrupt increase in the total yield, that then more gradually falls to a level with the income.

2. A continuous fall in the abundance, or return per unit of fishing, since this reflects the size of the accumulated stock.

3. A first decrease in abundance at the same rate for all ages and consequently all sizes, followed by a larger and more extensive fall in the older ages and larger sizes.

There are other changes which natural conditions may produce, but they are clearly distinct from those produced by a variation in amount of fishing. For instance, the success of spawning may produce a great abundance of incoming young. The percentage of older fish would thereby be reduced. But it would not accompany a decrease in the abundance, as would be the case in Figure 6, but rather an increase. And it would have no relationship whatever to the amount of fishing, except when the latter might increase as a *result* of greater economic profit.

The tabular method of presenting this illustration of the law of accumulated stock is a convenient one for the study of the effect of a variable amount of fishing, growth, natural mortality, variation in numbers of young, selection of size by the fishery, or other factors. Biological and statistical science may ultimately give exact measurement of these factors as they vary from age to age, and year to year. If so, variability of this kind can only be introduced by showing ages and years individually as in the method of tabulation used. For instance, it is commonly supposed that the death rate from natural mortality, not fishing, increases with age, and as our knowledge of this becomes more perfect, so will we be able to reconstruct what happens in the several ages represented in the stock.

But if it is not necessary to introduce the variations by age and year, and if the *average* death rate, the *average* of removal by fishing, or any *average* of a given factor, is known, the simpler and more direct method of following the accumulated stock might be very useful.

By assuming constant rates of survival, mortality, etc., it is possible to develop a more elaborate mathematical treatment than this tabular method affords. But none of these rates are constant and such treatment can only obscure and mislead the application of accurate determinations when such are made.

The more elaborate mathematics possible after assuming constant rates may give the illusion of complicated scientific theory, whereas the principles involved are very simple. That no more can be taken than comes into the fishery as young or as growth, is obvious. That the rapidity with which the stock is taken determines the amount of accumulation, however irregular the rate of removal may be, is as obvious. And that the balance between losses by natural deaths and gains by growth determines the loss or profit in taking fish early or late in life, has been accepted without much discussion for many years—if indeed it is not a truism. Two things have been lacking: first, a plain statement of the whole case; and second, a concrete demonstration as applied to a definite fishery. A complicated, difficult theoretical treatment is not necessary or desirable, and contributes little of value, even in theory.

VI

Primary evidence that the law of accumulated capital applies in fisheries is the existence of age classes which diminish in number with each year of life. These age classes are discovered by biological methods in fish, but the results are similar in character to those obtained where, as in man, age is otherwise known. All populations in nature reflect this law.

But good evidence is also found in the fact that in every commercial fishery changes occur which are those expected from the building up, or destruction of, the accumulation.

Where a fishery increases in intensity, the proportion of large fish diminishes. This proportion is always large in a virgin, unexploited fishery. It is always less in an intensively fished species. This has been observed so often as to be regarded as inevitable except where temporary successes or failures in spawning upset the sequence of events. As has been shown here, this change in proportion of large and small fish is what can be expected when accumulated stock is reduced. Figure 4 contrasts the numbers of older fish when the accumulated stock varies.

So also the changes (1) in amount of fishing, (2) in abundance or catch for each unit of fishing, and (3) in total yield, *when these are known* with proper accuracy, may be expected to be of the definite character illustrated in Figures 5 and 6. This has been shown clearly for the Pacific halibut fishery in Report number 8 of the International Fisheries Commission. There is no need to repeat this evidence. The results expected from the known changes in the amount of fishing are there compared with those actually observed and found to be so similar as to indicate the operation of the law of accumulated capital as outlined here.

VII

In the preceding sections the law of accumulation of capital, or stock of fish, has been shown as one which would operate regardless of the profit and loss, which in a fishery would be growth and natural death. In actual practice, capital is accumulated in order that interest may be secured from it, and an accumulated stock of fish may also be profitable.

The most obvious gain is the greater economy of effort in obtaining a catch from a larger accumulated stock. This can undoubtedly be of major importance. It not only means less effort, but also less time at sea before the catch is landed. Other gains, equally or more important, require careful observation and adjustment of the fishery in order that they may be fully realized. These are more spawn, greater growth and better quality.

In the first simple illustration of pond fish, the increased accumulation was held in a second pond. The fish in this were older, and may have spawned where those in the first pond did not. So too, on the deep sea fishing banks, the older fish are the spawners, and it is the older fish particularly which are increased by enlarging the accumulated stock. In fact, the abundance of the older fish is increased disproportionately to the younger because the degree of change in survival rate is compounded as often as there are years of exposure to the changed fishery.

The number of spawning adults in any fishery can therefore be controlled by any regulatory body which has power to control the amount of fishing. The amount or intensity of fishing determines the size of the accumulated stock on the grounds, and the increase or decrease is greater in the older fish. Control of this kind does not mean that by increasing the stock the annual yield will be decreased, except temporarily. But it should mean an increase in spawn produced, hence a greater number of incoming young if there is room for them. One of the great problems in fisheries science then becomes the determination of how large an accumulated stock must be maintained to perpetuate the supply.

There is a second problem. The growth in weight of the surviving individual fish may each year exceed the loss by natural means, so that the longer life permitted may mean an actual net increase in the poundage available to the fisherman. This would be particularly important where fisheries are so intense as to reduce the accumulated stock, hence the duration of life, to a minimum. Under such conditions the fish would be younger, and in such a species as halibut, the growth of the replaced stock might be rapid, the loss by natural deaths small, so that the profit in a longer life might be great. So, too, would there be a loss in total annual yield when life was shortened by an intense fishery.

A loss of this kind would mean that the total annual yield would be less after the temporary changes that go with an increase in the amount of fishing. Then, instead of a catch that is shown to be the same at the beginning and the end of the period of change, as in Figures 5 and 6, it would fall to and remain at a new lower level. The reverse would follow a decrease in the amount of fishing.

But under natural conditions, without a fishery, the accumulated stock is known to reach a maximum and to cease increasing. This must logically be true because a balance, even though it be a fluctuating balance, has been reached in all species left undisturbed by man. This balance may perhaps be that characteristic of, or rather resulting from, the rate of removal by natural deaths, the size of the accumulation being determined in the manner already discussed (pp. 10-12). Several possible additional reasons for this may be listed: a decrease in rate of growth with age, an increase in natural deaths as the biological limit in age is approached, an increase in mortality of eggs or young as the maximum in their production is reached, and an over-population of the banks. That this final equilibrium leaves no production for a fishery is apparent, and as the equilibrium is approached, the surplus left for a fishery must decrease.

There is, therefore, an extreme in which the accumulated stock is too large and in which the surplus available for the fishery is too small. And on the other hand, an opposite extreme in which the stock is so rapidly fished that profitable growth is not permitted. Between these, there must be the condition in which the fishery will yield a maximum, and the determination of this maximum must be the second problem of fisheries science.

There is, however, another consequence of the accumulation of stock which gives rise to a third problem. This is to secure sizes most desired for commercial purposes. The greater amount of growth permitted by the longer life within a larger accumulation produces larger sizes. As the stock increases, the proportion of larger sizes available to the fishery increases, and the average size of the fish taken is greater. In the halibut this has led to a larger proportion of first grade fish. If in the future there is an increase in incoming young, the proportion of larger fish may be thereby reduced, but the number of such large fish would still be greater than before. It is, therefore, possible to regulate to some extent the sizes of fish obtained by controlling the size of the accumulated stock, which is in turn controlled by the amount of fishing.

In considering these three problems, it is obvious that the first must take precedence, but that the others may be very important. To deal with them requires first of all adequate statistical and biological records. From these can be secured a degree of guidance in regulation which depends upon the thoroughness and extent of the scientific work done. Rational regulation in the present state of our knowledge, will require careful observation of the results of each step, before another is taken. This means research at sea to measure the abundance of spawn, and research at the landing ports to measure the changing proportion of old and young.

Thus far the theory has been dealt with as though the amount of fishing applied to all ages alike. It is plain, however, that if the rate of capture can be varied according to size, as is done by change of mesh in nets, or a legal size limit for fish landed, the survivals of smaller sizes can be increased. Perhaps the number of spawning adults can thereby be increased, the profit in larger growth be realized to some extent, and better sizes be secured. But it will remain true that the laws governing the accumulation of stock will still apply above this limit. Greater profit will increase the fishing for larger sizes and will accordingly decrease the accumulated stock above the size limit. This should be particularly true among the sizes so valuable for spawning, as the older sizes vary disproportionately to the young, the change in rate of survival being compounded with each year of age. The importance of the law and the need of careful observation of results is not lessened by limiting the size of mesh.

It should be realized that the accumulated stock is much easier to preserve than to rebuild. Once lost by an intensified fishery, stock cannot be regained except by restriction of that fishery, which is naturally difficult. At present in the halibut fishery, stock has been rebuilt to a very small extent compared to what it once was. Yet, the demand for relaxation of the restrictions has been heard since the increased abundance was first felt because the nature of the increase as accumulated capital, is not commonly realized.

In response to such demands it must be pointed out that if there had been a continuing decline in production of young prior to regulation, the decline would be merely temporarily masked by the increase in accumulated stock. If this stock has not now been increased to the point where the lack of young is remedied, the decline in annual yield and in yield per unit of gear will be resumed as soon as the effect of the present restriction is complete. In other words, the first increase in accumulated stock and the profit thus gained does not prevent a later decline in harmony with the decreasing income. Not until it is ascertained whether a new decline or an increased yield is to follow the present regulations, can the sufficiency of the present regulations be certain.

Experience has already shown that the yield of halibut decreases under an intensified fishery. In fact, it was this decrease which gave rise to the present regulation. If a greater yield is desired, the only possible way to obtain it is not by increasing the amount of gear fished but by decreasing it.

APPENDIX

It is not the purpose of the writer to review in this report the literature of the theory. The essentials of this are simple, in fact almost truisms. They can be found in many papers which have dealt with the supply of fish in the North Sea and elsewhere. One may refer, for example, to Petersen (1903, pp. 11, 12, 16 and 17). It is fitting, however, that one more closely associated with the European work review the literature, and the writer is delighted to have seen a manuscript report by M. Graham on this subject, which it is to be hoped, will be published soon.

The urgent need is, as has been said in the present report, for a simple statement of the accepted theory. The latter has been applied successfully to the statistics of the halibut fishery by Thompson and Bell (1934). The securing of the necessary statistics, the demonstration that the theory applies, and the analysis of the changes produced by the period of transition from one intensity to another, are the major contributions of these authors. But there has been lacking an adequate and clear, non-mathematical statement which will enable the general reader to understand the results. It is hoped that this report will fill the need, and that it will show the essentials of the theory to be extremely simple.

It is the belief of the writer that these essentials do not need clarification by those assumptions that are necessary for a generalized mathematical treatment. It is not necessary to assume a constant growth rate or a constant mortality rate in order to state or to understand the simple laws of accumulation of stock, or of the necessary equality of income and outgo, or of the economic importance of the difference between growth and loss. These have been repeatedly stated and have been long accepted. It is the difficulty of measuring and applying the known factors which has delayed progress in general understanding of these effects. The papers by Russell (1931) and Graham (1935) show this clearly and these authors wisely focus attention on the need for accurate knowledge of the variable factors. (See also Thompson, 1919.)

Nevertheless, F. H. Bell and the writer after their publication (1934) were interested to receive a paper by F. I. Baranov (1918) which gives a mathematical treatment on a basis of assumed constant rates. The text is unfortunately for us, in Russian and an adequate and complete translation has not as yet been obtained. The similarity between Baranov's Diagram 10 and Figure 9 of Thompson and Bell is striking, however, and there can be little doubt but that his treatment should be carefully considered.

Graham (1935 a) has called attention to the need for "some treatment of the variation in the postulate as to the ratio of growth rate and natural mortality". He referred to a statement made by Thompson and Bell (1934) as to the desirability or otherwise of an intense fishery when one or the other rate was the greater. He has criticized Thompson and Bell for not recognizing the variation in these rates. The author believes this criticism mistaken, as the variability in rates of growth and death is recognized in the cited report (l.c. pp. 27, 33). Wherever those rates are there referred to, they are obviously the average rates of growth or of death prevailing *under the conditions discussed and at the given time,* and it is those rates which determine the profit or loss in intensifying the fishery under those conditions. It is true that if a rate or rates change, the conclusion reached as to the desirable intensity of fishing must be correspondingly altered; and the study of the variation in those rates must be important. But reference to this change is not an essential part of the statement as made by Thompson and Bell.

Attention might well be called to the text of pages 22 and 23 of this report and to the work of Hjort, Jahn and Ottestad (1933), as bearing on the theory of the maximum productivity of the fishery.

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