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STUDIES OF GEORGES BANK HADDOCK
Part II: Prediction of the Catch

By WILLIAM F. ROYCE and HOWARD A. SCHUCK

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ABSTRACT

A prediction of the catch of the Georges Bank haddock, *Melanogrammus aeglefinus*, is possible because haddock have rather regular habits and because there are statistics on the haddock stocks. Analysis of the relation between catch and amount of fishing provides a statement of a relation that explains 83 percent of the variation in the catch of haddock over a period of 20 years. The catch depends primarily on the number of fish in year classes when they first enter the fishery, and on the amount of fishing. By use of formulas developed, predictions of catch were made for 1951 and 1952 that deviated 2.1 percent and 1.3 percent from actual landings in those years. These predictions are closer than can be expected in the long run. With a coefficient of variation of 8 percent, predictions should be within 8 percent of the actual catch about two-thirds of the time, and within twice that about 19 times out of 20.

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Part II: Prediction of the Catch

By WILLIAM F. ROYCE, and HOWARD A. SCHUCK, *Fishery Research Biologists*

The Georges Bank haddock, *Melanogrammus aeglefinus*, has been the most important stock of fish available to New England fishermen for about 25 years. During this time it has produced annually as much as 223 million pounds (in 1929) and as little as 50 million pounds (in 1934); since its low point it has fluctuated from 78 million pounds to 122 million pounds. In addition to this fluctuation, there was a steady trend from 1942 through 1949 toward smaller catches per day's fishing. In 1950 the catch per unit of effort increased somewhat, but this was due to an especially large run of small scrod haddock and the market category of large haddock was scarcer than in any previously recorded year.

Such fluctuations in production have always been a cause of concern and have contributed to crises in the fishing industry. Some degree of correction of these fluctuations through proper methods of conservation may be possible. Meanwhile, a reliable prediction of the possible catch is of use to all branches of the fishing industry concerned with haddock.

GEORGES BANK HADDOCK POPULATION

A prediction of the catch of the Georges Bank haddock is possible because haddock have rather regular habits and because there are available accurate statistics on the haddock stocks. These statistics, developed as part of an intensive study of the population, include the total catch and the catch per day's fishing, in terms of pounds, numbers, numbers of each size, and pounds and numbers of each age group from each fishing area.[1]

Part of the regularity that makes a prediction possible is to be seen in table 1, which shows the weight of each age group landed in each year from 1931 to 1950. It may be noted that large catches of 2-year-olds in one year are usually followed by large catches of 3-year-olds in the next year and of 4-year-olds in the second year. For example, the 1939 year class appeared as 2-year-olds in the landings of 1941 and continued to rank high in the catches as 3-year-olds in 1942, as 4-year-olds in 1943, and so on. A small year class contributes consistently small catches. The 1942 year class, for instance, which made the smallest recorded contribution of only 1.2 million pounds as 2-year-olds in 1944, continued to contribute relatively little in succeeding years.

This tendency to consistently high or low catches, from year to year, from a given year class, is due to the facts that (1) the haddock on Georges Bank do not mix appreciably with haddock on the Nova Scotian banks (Schuck and Arnold, 1951), and (2) they remain the year round on Georges Bank or in the nearby Gulf of Maine, where they are available to the New England otter-trawl fleet all year (even though there are seasonal movements within this area and a seasonal cycle in the landings).

Some irregularities in the landings from a year class of haddock are due to changes in the amount of fishing from year to year. Such changes have occurred not only as vessels have been added to or removed from the fleet, but also as fishing for other species and on other banks has been more or less attractive than the Georges Bank fishery. We have obtained a measure of this amount of haddock fishing by calculating the catch per day's fishing for haddock on Georges Bank by a selected group of large otter trawlers fishing out of Boston. This measure provides an index of availability of the haddock that we believe to be independent of changes in the size or relative efficiency of vessels in the complete fleet. We then divided the year's landings by the average catch per day during the year. This has produced an estimate (table 2) of the amount of fishing in terms of standard days fished by these selected large trawlers.

[1] Some of these basic statistics have been published by Herrington (1948) and Schuck (1951); the rest are scheduled for publication.

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Method of analysis

Our approach is empirical. We have analyzed what has happened in the Georges Bank haddock population during a period of 20 years, and we assume that this analysis forms a reliable basis for what may be expected to happen. We have determined the relation of the catch of an age group to the previous year's catch from the same year class, and the amount of fishing in the two years. In statistical terms we have made a multiple-regression analysis of the catch in year $n+1$ (Y) as related to the amount of fishing in year n (X_1), the catch in year n (X_2), and the amount of fishing in year $n+1$ (X_3). We have followed Snedecor (1946, ch. 13) in our use of symbols and computational techniques.

TABLE 1.—*Landings of Georges Bank haddock, by age groups, 1931–50*

[In millions of pounds. Bold-face figures denote landings from the "large" 1939 year class, and italic figures denote landings from the "small" 1942 year class, which are mentioned in the text]

Year [1]	Landings in age group—									Total [2]
	1	2	3	4	5	6	7	8	9+	
1931	2.6	13.2	4.6	15.2	29.0	23.4	15.1	8.8	3.3	115.0
1932	.2	3.4	54.4	8.5	13.5	12.3	7.0	3.8	2.4	105.4
1933	.3	12.0	15.8	27.6	7.0	7.3	5.8	2.7	3.2	81.6
1934	.3	6.3	11.9	10.9	10.8	4.3	3.1	1.4	1.0	49.9
1935	1.1	20.3	20.9	11.5	10.3	9.5	2.5	2.4	.7	79.2
1936	.9	19.4	26.4	16.4	7.1	5.6	6.2	1.3	.8	84.0
1937	1.2	18.5	26.1	16.6	15.5	7.9	5.2	2.9	1.5	95.5
1938	1.1	34.2	20.5	12.8	8.8	7.1	4.9	1.7	1.2	92.4
1939	.7	22.1	44.8	16.4	8.2	4.6	4.3	1.9	1.6	104.5
1940	**2.2**	12.5	30.1	25.4	9.1	6.7	4.2	1.3	1.0	92.7
1941	.8	**36.0**	22.7	24.3	20.8	8.0	4.9	1.7	2.6	121.7
1942	.3	22.0	**36.2**	18.5	13.2	9.1	5.3	1.4	1.2	107.1
1943	*.0*	5.9	33.8	**23.1**	10.2	9.9	3.6	1.9	1.2	89.6
1944	.1	*1.2*	17.8	40.1	**20.6**	10.2	2.5	2.8	.8	96.0
1945	.1	13.9	*4.9*	19.4	21.6	**10.6**	4.8	1.7	1.3	78.3
1946	.2	11.3	35.3	*8.6*	20.5	16.5	**9.6**	1.7	.2	103.9
1947	.1	23.6	23.0	22.4	*8.3*	12.5	8.1	**4.4**	2.9	105.3
1948	.1	14.7	38.6	15.3	10.3	*5.3*	4.1	2.8	**2.5**	93.5
1949	.3	9.2	23.6	26.6	8.8	4.9	*3.3*	2.5	2.5	81.7
1950 [3]	.1	38.4	8.6	11.1	11.7	4.9	2.6	*1.4*	1.7	80.5
Total	12.4	337.8	500.0	370.5	265.3	180.7	106.8	50.5	33.7	1,857.8
Average	.6	16.9	25.0	18.5	13.3	9.0	5.3	2.5	1.7	92.9

[1] Because of habits of haddock, the years include 12 months beginning February 1 and ending January 31.
[2] Slight discrepancies in totals are caused by "rounding off."
[3] Partly estimated.

TABLE 2.—*Average daily catch and days fished for haddock on Georges Bank, 1931–50*

[Calculated on basis of fishing by a selected group of large otter trawlers]

Year	Average catch (pounds) per day	Days fished
1931	8,880	12,955
1932	11,572	9,110
1933	9,708	8,410
1934	10,308	4,839
1935	12,275	6,451
1936	13,500	6,224
1937	11,650	8,194
1938	11,733	7,874
1939	13,040	8,016
1940	12,836	7,218
1941	16,615	7,326
1942	18,682	5,732
1943	18,351	4,882
1944	16,973	5,656
1945	16,000	4,892
1946	14,264	7,283
1947	12,801	8,223
1948	12,123	7,714
1949	11,444	7,140
1950 [1]	14,074	5,721

[1] Partly estimated

Because haddock become increasingly available to the fishery until their third year, and then decline in abundance at a fairly constant rate (as indicated in table 1 by the average catch of each age group), it appeared necessary to make separate computations for relations involving the first three age groups. Accordingly we have related the catch of 2-year-olds to the previous year's catch of yearlings, of 3-year-olds to 2-year-olds, of 4-year-olds to 3-year-olds, and of 5-year-olds and older to the previous year's catch of 4-year-olds and older. We assume that the amount of fishing is the same for all groups.

The relations that we have found are expressed in the formulas and parameters listed in table 3. The closeness of the relations is indicated by the standard errors of estimate, the coefficients of variation, and the multiple-correlation coefficients. It is apparent immediately that the fluctuations in the catch of older fish are accounted for more accurately than those of the younger. The formulas derived for the 3-year-olds, 4-year-olds, and 5-year-olds and older may each be judged statistically highly significant according to the value of the multiple-correlation coefficient. The value for 2-year-olds is not statistically significant, and the high value of the standard error of estimate in relation to the mean catch indicates that this formula does not account for much of the variation.

Particularly noteworthy is the close agreement between the actual and estimated total landings (fig. 1). The standard error of estimate is only 8 percent of the mean, and the correlation coefficient (r) is 0.912. The square of this (0.832) indicates that 83 percent of the variation in catch is associated with the previous year's catch and the amount of fishing in the previous and current years. It is noteworthy also that the standard error of estimate for the total (7.34) is far less than the standard error of estimate expected from a sum of the parts (15.03) if we assume that the parts are independent. Clearly, some relation among the catch of the different age groups is indicated and this is supported by general knowledge of the habits of the fish and the fishing fleet. It is well known that the young haddock tend to school more than the older individuals which are found more widely distributed over the Bank. Therefore, when there is a run of small haddock the fleet tends to concentrate on them at the expense of other areas. Thus, even though the regression for 2-year-olds is not a good one, it does not unduly diminish the accuracy of the total.

Some inconsistencies appear in the regression coefficients and in the intercept values in table 3. For example, the coefficients of X_1 vary from -4.2581 to $+1.0629$ and the coefficients of X_3 vary from -0.4715 to $+3.7930$, and in neither case do they change in relation to the age of the fish. This is not explainable with the data at hand, but it is believed that most of the variation arises because, as was indicated in the preceding paragraph, the assumption of equal distribution of the fishing effort is not a fact.

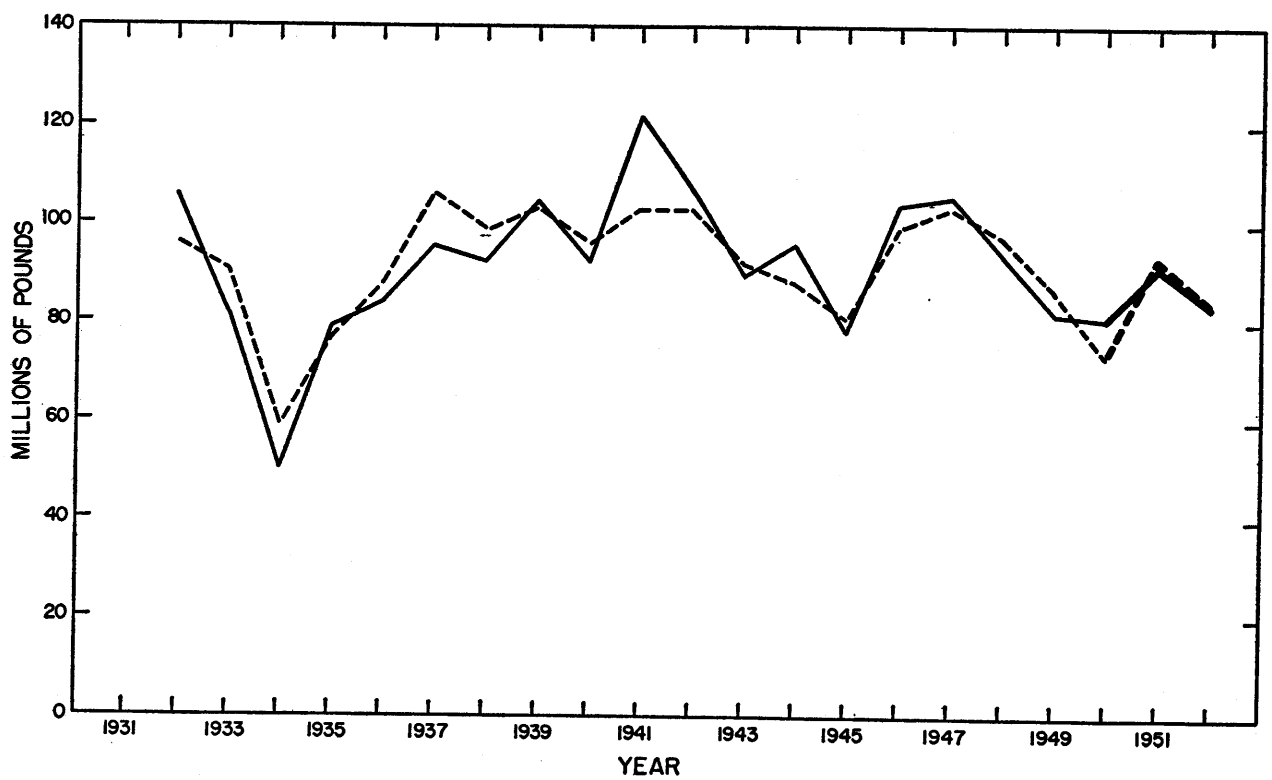

FIGURE 1.—Comparison of actual and estimated landings from Georges Bank.

TABLE 3.—*Multiple-regression equations and other statistics*

$\hat{Y}$=estimated catch in year $n+1$ (in hundreds of thousands of pounds).
X_1=amount of fishing in year n (in hundreds of days by standard trawlers).
X_2=catch in year n (in hundreds of thousands of pounds).
X_3=amount of fishing in year $n+1$ (in hundreds of days by standard trawlers).

Age group	Regression equation	Mean catch [1]	Standard error of estimate	Coefficient of variation (percent)	Multiple-correlation coefficient
2-year-olds	$\hat{Y}_2=209.8764-2.3987X_1+6.5582X_2+1.3446X_3$	17.09	10.84	63.4	0.375
3-year-olds	$\hat{Y}_3=-169.6105+1.0629X_1+0.7924X_2+3.3146X_3$	26.07	8.19	31.4	**.799
4-year-olds	$\hat{Y}_4=154.1039-0.8123X_1+0.4810X_2-0.4715X_3$	18.70	5.21	27.9	**.803
5-year-olds and older	$\hat{Y}_5=62.9507-4.2581X_1+0.5440X_2+3.7930X_3$	29.34	3.77	12.8	**.909
All ages	$\hat{Y}_T=0.5+\hat{Y}_2+\hat{Y}_3+\hat{Y}_4+\hat{Y}_5$	91.72	†7.34	8.0	**†.912

1 Mean values (in millions of pounds) do not include the year 1931 and hence differ slightly from table 1.
**Statistically highly significant, that is, expected less than once in 100 times owing to chance.
† Standard error of estimate and simple correlation coefficient (r) have been computed from actual total catches and derived estimates.

Because of the great amount of labor required to determine the catch by age groups, it is worth while to consider the direct relation of total catch to the current findings of fishing and to the previous year's total catch and amount of fishing. This is readily computed, using the total figures from table 1 and the same data on the amount of fishing. The regression formula is

$$\hat{Y}=16.043-0.55200X_1+0.58078X_2+0.89318X_3$$

However, the standard of error of estimate becomes 11.24 or 12.25 percent of the mean, and the multiple-correlation coefficient (R) becomes 0.754. This value is statistically highly significant, but R^2 is 0.568, indicating that only about 57 percent of the variation in catch is accounted for by this shortcut method as contrasted with 83 percent when using the catch by age groups. We have therefore not further considered this method.

THE PREDICTION

The preceding formulas relate the catch to the amount of fishing in the same year, and to the catch and the amount of fishing in the preceding year. If the formulas are practicable, they can be used to predict the catch of a forthcoming year. But the proposed amount of fishing is best known by the people interested in haddock—the fishermen themselves, the vessel owners, and the primary dealers.

These men are in the best position to know about boats entering or leaving the fishery, whether the price of cod will be higher than the price of haddock (inducing some boats to fish cod instead of haddock), or whether there is an expanding market for haddock fillets (which will increase the demand and the price). From our observations the number of boats is usually the most important factor in determining the amount of fishing, and their number is fairly well known at the beginning of the year. Though in the absence of data on price trends, retirement of old vessels, and other factors pertaining to the fishery, any estimate of the amount of fishing one year hence is problematical.

A multiple prediction is needed that may be based on the best guess of the probable amount of fishing as well as greater and lesser amounts. For instance, in 1951 on the basis of some new vessels joining the fleet we guess that about 10 percent more fishing is expected than was done in 1950, and make an estimate accordingly. At the same time, we estimate the catch with 10 percent less fishing, with the same amount, with 20 percent more, and with 30 percent more. These amounts of catch are readily computed from the formulas by substituting the values for landings and amount of fishing in 1950 and the various amounts of fishing in 1951 (table 4). The result is a prediction of 93.4 million pounds with an increase of 10 percent in fishing, 88.8 million pounds with the same amount of fishing, 97.9 million pounds with an increase of 20 percent, and so on.

With 10 percent more fishing expected, the average catch per day will be slightly more (15,481 pounds) than in 1950 (14,074 pounds). Comparison of any column in table 4 with the average year-class catch in table 1 indicates also that there will be a much larger than usual proportion of 3-year-old haddock. These will average about 2 pounds each at the beginning of the year and increase in weight about three-quarters of a pound during the year. Since scrod haddock are defined as those weighing from 1½ to 2½ pounds, this means a high proportion of fish in this market category.

TABLE 4.—*Predicted catch for 1951*

[In millions of pounds]

Age group	Predicted catch, assuming a change in fishing from 1950 of—				
	−10 percent	No change	+10 percent	+20 percent	+30 percent
1-year-olds	0.5	0.5	0.5	0.5	0.5
2-year-olds	14.9	15.6	16.4	17.2	18.0
3-year-olds	36.6	38.5	40.4	42.3	44.2
4-year-olds	12.5	12.2	12.0	11.7	11.4
5-year-olds and older	19.8	22.8	24.1	26.3	28.4
Total [1]	84.3	88.8	93.4	97.9	102.5
Average catch per day in thousands of pounds	16.4	15.5	15.9	14.3	13.8

[1] Slight discrepancies occur because of rounding off.

DISCUSSION AND SUMMARY

In our analysis we have considered only the matters having to do with the relation between catch and amount of fishing, or with the prediction of the catch. We have avoided many complications that go beyond the scope of this paper: these include an explanation of why a 10-percent change in the amount of fishing changes the total catch only about 5 percent, and why the catch of 4-years-olds decreases with an increase in the amount of fishing. Furthermore, our empirical approach omits any separate consideration of the interacting factors of growth, recruitment, and mortality. Better knowledge of these matters is desirable and will be sought in our continuing analysis of the haddock population.

Despite these qualifications we have a statement of a relation that explains 83 percent of the variation in the catch of haddock over a period of 20 years. It shows that the catch depends primarily on the number of fish in the year classes when they first enter the fishery, and on the amount of fishing. Even so, there is room for improvement in the prediction. The largest unexplained variation is associated with the estimates of the catch of the young year classes while they are entering the fishery. This estimate could be improved with special gear from research vessels to obtain an adequate estimate of the abundance of a year class before it is fully available to the fishery.

Any prediction based on an average, such as this, may be invalidated by long-term trends or unusual conditions not encountered during the study period. The effect of trends can be negligible if the latest data are included each year in the computation of the regression formulas. But nothing can be done about the unexpected. Catastrophic changes in environment, like the one that caused the mass mortality of the tilefish in 1882, have been known to occur in the vicinity of the New England banks. Such changes might cause unusual mortality among haddock, or change the migratory pattern and induce haddock to migrate between the Nova Scotian banks and Georges Bank in greater numbers; haddock might be subject to an epidemic of disease; there might be a recurrence of predators on the large haddock. Since things of this nature have not occurred in 20 years, the odds are against their occurrence.

ACCURACY OF PREDICTIONS FOR 1951 AND 1952

Because of delay in the appearance of this paper, it is possible to compare the results of predictions for 1951 and 1952 with the actual catches. It was predicted that in 1951, if a 10 percent increase in the amount of fishing occurred, the total catch of Georges Bank haddock would be 93.4 million pounds.

There was actually a 9.7 percent increase in the amount of fishing (Schuck 1952a), and a total catch of 91.3 million pounds, caught at a rate of 14,500 pounds per day. Approximately 43 percent of the landings were 2- to 2½-pound fish. With this amount of fishing the expected catch had been 93.2 million pounds,[2] caught at a rate of 14,800 pounds per day. And with any amount of fishing the 3-year-old fish (averaging 2 to 3¾ pounds each) were expected to predominate.

The prediction for 1952 was for less fishing on Georges Bank, owing to more abundant fish on the Nova Scotian Banks and fewer haddock on Georges (Schuck 1952b). The predicted catch was 79 million pounds with 20-percent less fishing, 84 million pounds with 10-percent less fishing, and 89 million pounds with the same amount of fishing. The prediction also stated that in 1952 a larger-than-usual proportion would be in the 2½- to 3½-pound size, and the ratio of market categories, "large" and "scrod" would return to near normal

[2] Recomputation has slightly changed Schuck's figures.

after the predominance of "scrod" in 1950 and 1951.

The exact prediction for 1952 was 84.5 pounds, allowing for a 9-percent decrease in effort. Pounds landed in 1952 were actually 83.4 million. Thus actual landings deviated from predicted landings by about 1.3 percent. The expected large proportion of 2½- to 3½-pound fish did not appear. A large run of 2-year-old scrod (many less than 1½ pounds) occurred, and the proportion of scrod haddock is perhaps larger than in any previous year of the fishery. This run of small haddock did not increase the total catch over the predicted catch because the fleet apparently fished for the small haddock in locations where the larger haddock are not found, and the catch of the larger haddock was less than expected.

These two predictions, off 2.1 percent from the actual landings in 1951 and off 1.3 percent in 1952, are gratifyingly close. They are closer than can be expected in the long run. With a coefficient of variation of 8.0 percent, predictions should be within 8.0 percent of the actual catch about two-thirds of the time, and within twice this about 19 times out of 20.

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