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Status of the Georges Bank Haddock Fishery

by

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Introduction

This document presents a brief historical review of the 5Z haddock fishery, and the biological studies conducted since 1932. It also summarizes the current (1969) and probable (1969-70) status of stocks based on information available to date.

The data and information presented herein form the biological basis upon which management decisions with regard to this stock may be based.

Long-term trends in landings and effort

It is convenient to consider three periods within the known span of the fishery. The first is the development stage which extends from early 1900's to the early 1930's. Landings increased from about 15,000 metric tons in 1917 to a peak of about 115,000 tons in 1929, and then declined rapidly to about 26,000 tons in 1934 (Table 1, Figure 1). During this period the beam trawl first developed, and rapidly replaced the line fisheries. The latter years saw introduction of the Vigneron-Dahl trawl and vessels using diesel engines and depth sounders. Essentially, the fleet in existence in the early 1930's was of the same type that has lasted through to current times.

The heavy fishing of the late 1920's apparently caused the stock to decline rapidly, and the low catch per unit effort caused a rapid reduction in fishing effort in early 1930's.

Unfortunately, the data on landings per unit effort are not reliable for this early period because observations were not being made at the time. Also, the effectiveness of a days fishing changed considerably during the period. Corrections have been made for these changes, but the data as presented should be interpreted in a generally descriptive sense only.

The second period is one of relatively stabilized fishing from the early 1930's to the early 1960's. Annual landings varied from 35,000 to 50,000 tons, and effort fluctuated between 5,000 and 8,000 standard days fishing. The war years caused some disruption of fishing, but only of the order of a 20-30 percent reduction in effort. We will later use this period for estimating equilibrium conditions, and a more detailed picture of fluctuations in catch and effort is given in Figure 2.

Biological investigations started in 1932 with the collection of detailed statistics of landings and days fished by area, and of age-length samples from the landings. The same system has continued to date.

In 1953, a 4-1/2 inch mesh regulation was put into effect by ICNAF for S.A. 5 haddock stocks. The effect of this regulation on yields has not been estimated--it is, in fact, inestimable. It was effective in reducing discards,--which in the average pre-regulation year probably were 10-15 percent of landings--to about 1-5 percent of landings in post regulation years.

Table 1. --Statistics of catch and effort for Georges Bank haddock.

Year	Landings MT x 10^{-3} Rnd, Fresh	Land/DF MT Rnd, Fresh	DF x 10^{-3}	DF Ave/3 x 10^{-3}	No's Fish Landed x 10^{-3}	No's Fish Land/DF
1917	14.1	13.3	1.0			
1918	24.8	17.1	1.4			
1919	39.4	18.1	2.2	1.5		
1920	40.6	18.9	2.2	1.9		
1921	29.7	16.8	1.8	2.1		
1922	30.8	12.6	2.4	2.1		
1923	32.9	9.5	3.5	2.6		
1924	36.9	12.0	3.1	3.0		
1925	41.4	16.6	2.5	3.0		
1926	51.3	21.4	2.4	2.7		
1927	73.9	22.6	3.3	2.7		
1928	98.6	17.8	5.5	3.7		
1929	115.5	11.6	10.0	6.3		
1930	95.0	6.0	15.9	10.4		
1931	59.5	4.5	13.0	13.0	39,127	3,020
1932	54.5	6.0	9.1	12.6	39,481	4,334
1933	42.2	5.0	8.4	10.2	30,894	3,673
1934	25.8	5.3	4.8	7.4	19,335	3,996
1935	41.0	6.4	6.4	6.5	32,303	5,007
1936	43.4	7.0	6.2	5.8	35,387	5,686
1937	49.4	6.0	8.2	6.9	36,534	4,459
1938	47.8	6.0	7.9	7.4	37,897	4,813
1939	54.0	6.7	8.0	8.0	43,845	5,470
1940	47.9	6.6	7.2	7.7	34,963	4,844
1941	62.9	8.6	7.3	7.5	51,262	6,997
1942	55.4	9.7	5.7	6.7	45,262	7,896
1943	46.3	9.5	4.9	6.0	37,429	7,667
1944	49.6	8.8	5.6	5.4	33,149	5,861
1945	40.5	8.3	4.9	5.1	26,552	5,428
1946	53.7	7.4	7.3	5.9	37,373	5,132
1947	54.4	6.6	8.2	6.8	41,795	5,083
1948	48.3	6.2	7.7	7.7	41,168	5,337
1949	42.2	5.9	7.1	7.6	33,681	4,717
1950	41.3	7.5	5.5	6.8	42,879	7,816
1951	47.3	7.3	6.5	6.4	43,668	6,728
1952	43.2	7.3	5.9	6.0	45,621	7.689
1953	35.9	5.5	6.5	6.3	32,004	4,915
1954	46.4	8.0	5.8	6.1	48,301	8,318
1955	40.8	8.1	5.0	5.8	33,086	6,540
1956	48.9	7.2	6.8	5.9	39,718	5,924
1957	46.2	5.9	7.8	6.5	35,912	4,619
1958	35.5	4.6	7.8	7.4	27,108	4,298
1959	35.9	3.8	9.4	8.3	26,737	3,358
1960	41.1	5.4	7.7	8.3	34,086	4,493
1961	46.2	6.5	7.2	8.1	36,832	4,898
1962	54.0	6.3	8.6	7.7	40,143	4,713
1963	54.8	4.4	12.4	9.4	36,557	2,922
1964	64.1	5.3	12.1	11.0	44,260	3,654
1965	149.6	5.6	26.7	17.1	125,784	4,761
1966	121.3	4.5	26.8	21.9	111,207	4,104
1967*	51.4	3.7	13.9	22.5	38,358	2,740
1968*	44.1	2.9	15.2	18.6	27,911	1,863

*Preliminary

During the first two periods, the fishery was conducted exclusively by U.S. vessels. The third period, commencing in 1963, covers the entrance of other countries into the fishery, with resulting rapid build-up of fishing effort. Peak landings of 150,000 metric tons were observed in 1965, and 121,000 tons were removed in 1966. A two-fold increase in fishing mortality resulted.

The recruitment of a rather large 1963 year class to the fishable stock on the bank in 1965 was a factor inducing the increased fishing effort. By 1967 the adult spawning stock was reduced to the lowest level on record. Production of fish since 1963 has been extremely low; the brood years of 1964 to 1968 are all 1/10 to 1/100 of previous norms. The age composition of landings for this period compared to the average over the second period are presented in Figure 3.

Estimation of Abundance, effort and mortality from commercial fishery statistics

The index of abundance is derived from the landings per day fished of a selected group of about 21 U.S. otter trawlers of 150-300 gross tons. The selection was based on similarity of characteristics affecting fishing power (size, horsepower, etc.). Although there have been some deletions and additions to this group since 1931 (the actual number varied from 16 to 27), the added vessels had the same characteristics as the original group.

Information on fishing time and area of catch was obtained by dock-side interview when the vessel landed. Trips were generally from one to two weeks duration.

The average landings per day fished was obtained for each quarter. These in turn were averaged over the year. The annual average thus obtained, which represents the index of abundance, was divided into total landings to estimate the total, standardized days fished.

The standard fleet reflected generally the areas and sizes of fish caught by all U.S. vessels fishing for haddock. In recent years, when fleets of other countries have fished for haddock, their landings also have been included in the total from which the total standard effort is obtained. This is no problem with regard to Canadian catches, since their vessels use a regulation mesh and comparison of size composition of landings indicates no significant differences from the U.S. landings. The trend in landings per day of Canadian trawlers closely approximates that of the U.S. (Table 2).

Table 2.--Comparison of relative abundance from U.S. and Canadian fishing fleets

Year	Landings per day relative to 1963 United States	 Canada
1963	1.0	1.0
1964	1.2	1.1
1965	1.3	1.1
1966	1.0	0.9
1967	0.8	0.9
1968	0.6	0.7

Unfortunately, there is no data available on the size composition of the large USSR landings in 1966 and 1965. Analysis of research vessel survey data in a later section indicates the proportion of two-year old fish might have been significantly higher, but the provisional treatment in this document does not adjust for any differences that might exist.

Samples of fish in the landings have been obtained for estimating age and length composition throughout the years since 1932. Numbers of fish landed have been estimated in the usual manner by dividing sample weight per fish into total landings (Table 1). The total numbers have been prorated on a quarterly basis over age groups by utilizing age-length keys. Numbers landed per day was obtained by using the aforementioned estimate of total days fished.

Quarterly averages of $\log_e$ numbers per day over the 1931-61 period are shown in Figure 4. Fish are fully utilized from age 3 onwards. The quarterly fluctuations indicate recruitment aggregations of two and three-year olds in the August-October period (Quarter 3), and spawning aggregations of older fish during February-April (Quarter 1). Age compositions for more recent years (Figure 4) illustrate quite clearly the effect of heavy fishing and lack of recruitment since 1965.

An estimate of the total annual mortality coefficient, Z, was obtained form age 3 onward each year by utilizing the ratio of catch per day of a given year class from one year to the next. The annual estimates for 1935-63 (Figure 2) range from 0. 4 to 0. 9; the average value being 0. 67. Previous studies have indicated the natural mortality coefficient, M = 0. 2, so that the fishing mortality coefficient, F, is about 0. 5 on the average over this period. The average annual standard effort was 7,000 days.

A preferable technique using virtual populations, i.e. landings and not landings per day, has led to the estimation of Z (and F assuming M=0. 2) for each age group of the 1930-59 year classes. The averages of F and Z values for age 3 onwards were nearly identical to that above. The estimates of F for age 2 range between about 0. 1 and 0. 4, indicating the incomplete recruitment at this age. Fishing mortality on age 1 fish is virutally nil.

Previous studies (see 1958 Res. Doc #92) have shown that the total mortality coefficient increased by a factor of 1. 5 in the years 1965-66, so that if natural mortality had not changed, the fishing mortality coefficient would have doubled, as expected, during this period.

Long-term equilibrium yields

One means of determining the status of fisheries is to estimate the locus of points which represent the equilibrium (steady state) relationship between yield and yield per recruit, and fishing mortality. This is accomplished by fitting an appropriate equation to a set of observed points of abundance and fishing mortality.

These data for the Georges Bank haddock fishery are plotted in Figures 5 and 6. Landings per day and days fished are presumed proportional to abundance and fishing mortality, respectively. A running average of effort over three years was used to reduce the effects of the lag time in reaction of available stock abundance to changes in rate of fishing. This probably does not adequately correct for such effects, particularly when the changes are large. Therefore, the points for periods of rapid change (1927-32, 1964-68) have not been utilized in fitting fuctional relationships.

The curved line in Figure 5 represents a fit of the Beverton-Holt yield-per-recruit function, assuming that 7,000 days produced an F of 0. 5. The straight line was fitted to the points for 1933-63. This purports to represent the Schaefer yield function, which assumes recruitment is a linear function of stock size. The corresponding curves of yield-per-recruit and total yield are drawn in Figure 6.

For both functions, the relations strongly suggest that yield is maximized, for the average recruitment experienced in the period of stabilized fishing (1933-63), at a level of effort of about 7,000 standard days annually. The maximum total yield is, on the average, about 50,000 metric tons. A sustained fishery beyond this level will cause the yield in any terms to decrease, and if recruitment is dependent on stock density, total yield may decrease quite substantially.

We have observed two periods during which removals exceeded substantially the maximum equilibrium value. In both cases, the corresponding decrease in abundance caused a rather rapid adjustment of fishing effort to lower levels. In the most recent years, however, a sustained low recruitment has led to an unprecedented low stock abundance.

Stock-recruitment

Knowledge of the exact processes controlling recruitment is of vital concern. In particular, the effect of spawning stock density (or biomass) is critical since it is a function of the rate of removal which can, to a large extent, be controlled.

We cannot now demonstrate a definite relationship between stock and recruitment. An index of size of year classes produced from 1929 to 1966 when recruited to the fishery as two-year olds is given in Figure 7. Although individual year classes have fluctuated as much as an order of magnitude (10X) from [illegible] to 1965, it is only in the years since 1965 that very poor recruitment has been observed. Thus the bulk of our observations are over a period when the stock size has not changed drastically. In Figure 8, an index of spawning stock (landings per day in season A) has been plotted with the index of year classes resulting therefrom. Stock size in 1931-35 was in every year below the average of 1935-63; about 20 percent below on the average. The year classes produced were not markedly lower, but consistently on the low side. During the next 20 years or so, large deviations in spawning stock and between stock and recruitment were observed. The last series of 10 years, or so, indicates a marked downward trend in spawning stock, and a reduction in magnitude of fluctuations and size of resultant year classes. The points beyond 1965, when available will show an even lower trend.

Some recent studies of stock-recruitment for other gadoid stocks have indicated a tendency for lowered production, particularly at low sotck densities. A specific study of cod in the Barents sea area has shown a possible sharp drop off at rather lower spawning stock levels.

It does seem, therefore, that the currently very low abundance of Georges Bank haddock (with very little prospect for significant recruitment over the next two years at least) does reduce the probability of good year class production, perhaps drastically so.

Research Vessel Surveys

Groundfish trawl surveys have been conducted on a seasonal basis since July 1963. These surveys are quite comprehensive and provide an estimate of stock abundance that is independent of that derived from commercial fishery statistics, and free from the biases related thereto.

It is useful to present some preliminary results of analysis of this data to corroborate the foregoing conclusions. Also, estimates of year class abundance derived from the surveys through 1968 are necessary to predict future recruitment (see also a Research Document by Grosslein submitted this year).

Estimates of abundance at age from the survey data correspond quite well with those from the commercial data (Figure 9). The total mortality coefficients derived from the year class catch curves are also quite similiar. This figure also indicates that haddock are fully available to the trawl gear (with fine mesh liner) during their second year of life. The time series of observations of relative abundance (Figure 10) indicates the reduction caused by the heavy removals between July 1965 and July 1966. The rate of removal was about three times greater than periods before and after. The curve labeled "age 3+" represents roughly the portion of the stock available to the 4-1/2 inch mesh gear. The 1963 year class was rather quickly reduced in abundance in its third year of life. It was not, at this time, available to any extent to the U.S. fishery because they were too small. Thus, the U.S. fishery did not experience any great increase in landings per day from the recruitment of this year class.

This effect is more clearly illustrated in Figure 11, where the index of abundance of year classes in the commercial landings is plotted against an index of year class abundance derived from the survey data. The survey index was obtained by extrapolating backward to age 1, the lines fitted to $\log_e$ numbers per tow at age for the various year classes present from 1963 through 1965.

The linear relationship indicated in Figure 11 will hold only if mortality through age 3 had been constant. The point for the 1963 year class is obviously low and most likely for the reason that mortality on this year class in its third year of life was markedly higher.

Estimation of Quotas

Estimates of the current biomass in terms of weight or numbers, and of recruitment in the next year are required to set quotas which will satisfy the objective of maintaining or increasing the stock of fish.

To obtain estimates of fishable stock, we have employed the relation

$$C_i = N_i (1 - e^{-Z}) \frac{F}{F+M}, \text{ where}$$

C_i = catch in year i, and,

N_i = numbers of fish in population at beginning of year.

Z, F, and M are the standard mortality coefficients.

The relative stability of the fishery during the 1935-63 period provides a reasonably steady state situation. Using F = 0.5 and M = 0.2 in the above equation results in an estimate of average numbers in the available population (essentially age 2+) of 130×10^6. Estimates for the individual years presented in Figure 12. The average numbers landed during this period was 38×10^6. A fishing mortality of $\frac{F}{2}$ was applied to the two year old fish to allow for incomplete recruitment.

The virtual population method as modified by Gulland (1965 ICES report of the Gadoid committee) to provide for varying fishing rates was also employed to obtain estimated stock size. An average population of $133 \times 10_6$ fish was obtained; the yearly estimates are also plotted in Figure 12.

We have also obtained estimates of biomass based on the stratified random sampling of the Albatross IV surveys (Figure 13). Allowing for the fact that the below average 1960 and 1961 year classes (see Figure 7) were recruited to the fishable stock during 1963-64, the estimates of numbers of fish of the order 10^8 indicate reasonable agreement. This data also illustrates the increase in stock from recruitment of the 1963 year class, and the rapid decline of total stock from 1965 to 1968.

Based on landings of two year olds during the 1935-63 period, the average of numbers in the population at this age is estimated at 49×10^6. These data are summarized in the first column of Table 3. Because the maximum harvestable surplus was produced on a sustained basis through this period of years, it seems desirable to set this stock size as the target of management.

Table 3.--Estimates of available population numbers and recruitment for Georges Bank haddock.

		1935-1963	1968	1969	1970
Avail. Pop. No's. x 10^6		132	47	30	18
Removals:					
(No's. x 10^6)	Total	56	33	13	16
	Fish.	38	23	10	13
	Nat.	18	5	3	3
Recruit. No's. x 10^6					
Age 2		43	16	1	16

Estimates of stock size for 1968 indicate we have a long way to go. The U.S. index of abundance for 1968--1,863 kilos per day fished--indicates the population has been reduced to about 1/3 of the 1935-63 average of 5,572 kilos. This would indicate a population of available fish of about 43 x 10^6 at the beginning of 1968. An alternative calculation is provided by estimating that the 15.2 x 10^3 days fished in 1968 caused a mortality of F= 1.0 (this assumes the effort index is proportional to mortality). Again utilizing the equation at the beginning of this section, with M = 0. 2, and the estimated landings of 28 x 10^6 fish, the estimated population is 47 x 10^6 fish.

Recruitment of the population in 1968, 1969, and 1970 has been estimated in two ways. First, we can infer from Figure 7 that recruitment from year classes produced since 1963 will be 1/10 (or less) of the average through the 1930-1960 period. The 1969 research document by Grosslein indicates the 1967 and 1968 year classes are about the same order of magnitude. This means that roughly 5 x 10^6 fish of age 2 would be the expected recruitment.

We can be a little more precise by utilizing the index of year class abundance derived from the survey data which was mentioned in a previous section. This data covers the 1956-1966 year classes, but we should note that more recent year classes are based on only two or three observations. The 1958 and 1959 year classes were of similar abundance, and somewhat larger than the long-term average. The virtual population procedure provides an estimate of the population of these two year classes at age 2 of 81 x 10^6 fish. Using this value and applying the year class index computed relative to that of 1958 and 1959, estimates of population numbers at age 2 are obtained. The data are set forth in Table 4. The index given by Grosslein has been used to estimate numbers of recruits for the 1967 and 1968 year classes.

Table 4.--Estimated recruitment for 1956-68 year classes on Georges Bank.

Year Class	Survey Index	Index Rel. to 59 Y. C.	No's. Pop. Age 2 x 10^6
63	5.14	6.2	502
62	3.94	1.9	154
58	3.37)	1.0	81
59	3.26)		
56	3.09	0.8	65
57	2.53	0.5	40
64	2.49	0.4	32
60)	2.34	0.4	32
61)			
66	1.67	0.2	16
65	-0.47	0.02	2
67		0.01	1
68		0.2	16

With known removals of at least 28 million fish in 1968 and an estimated recruitment of 16 x 10^6 two years old (1966 year class), the population of age 2 + fish beginning in 1969 is of the order of 30 x 10^6 fish. We expect landings of about 10 x 10^6 fish in 1969. Providing this is the case, and that recruitment from the 1967 year class is as poor as indicated, the population at beginning 1970 will be about 18 million fish. These estimates are set forth in Table 3.

Finally, in 1970, the expected recruitment from the 1968 year class in 16 x 10^6 fish, and if the population is not to be further reduced, landings will have to be less than 13 x 10^6 fish, or with an average weight per fish of about 1 kilogram, 13,000 metric tons.

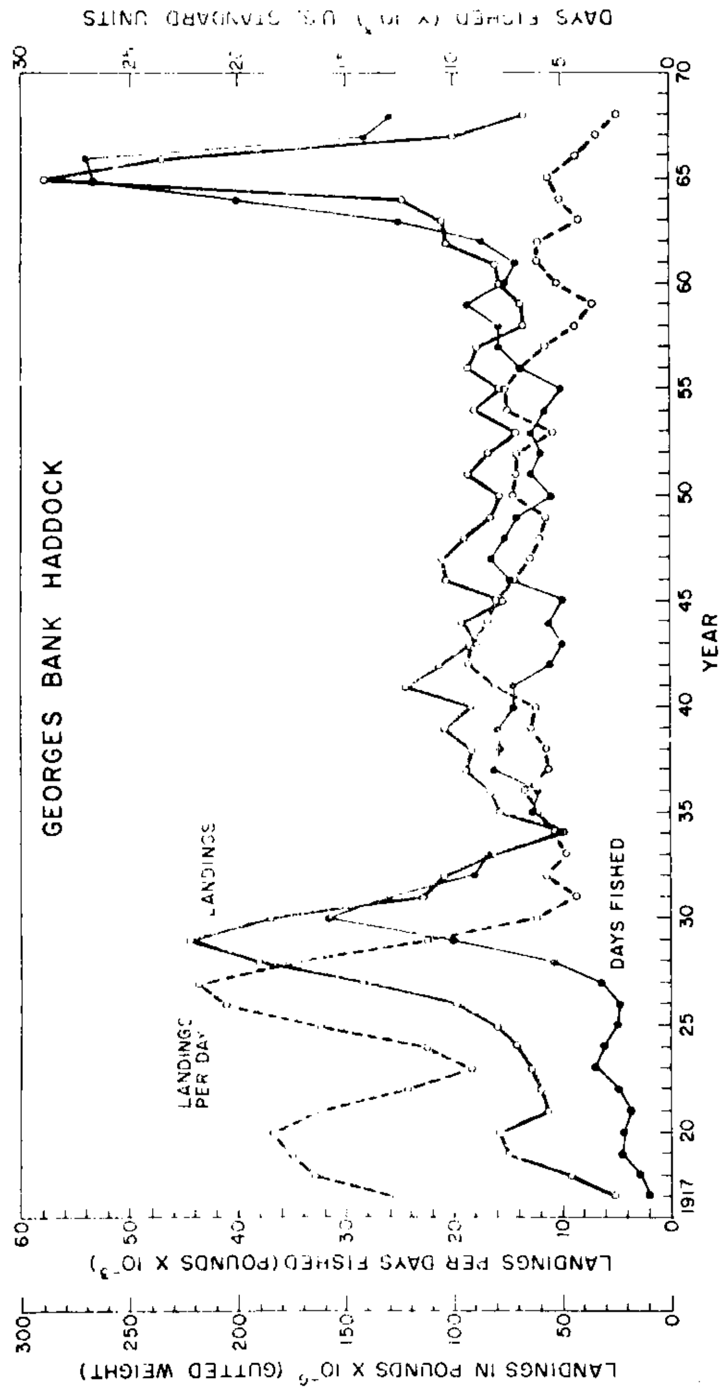

Figure 1.--Total landings and effort, and landings per day fished by U.S. fleet for Georges Bank haddock, 1917-68.

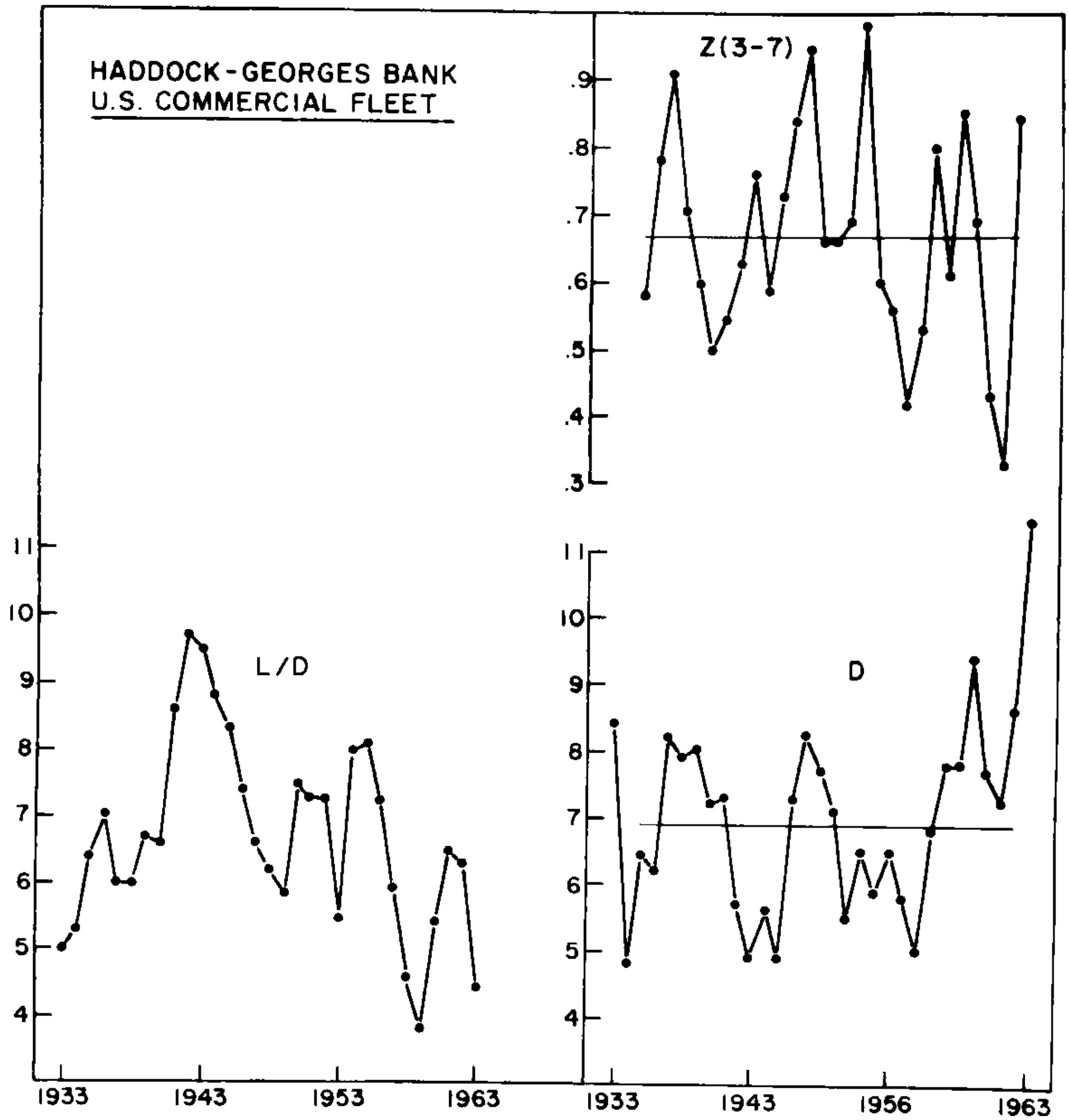

Figure 2.--Landings per day (L/D, Metric tons x 10^3), total days effort (D, days x 10^3), and total mortality coefficient (Z, 3-7 year old fish) for Georges Bank haddock, 1933-1963.

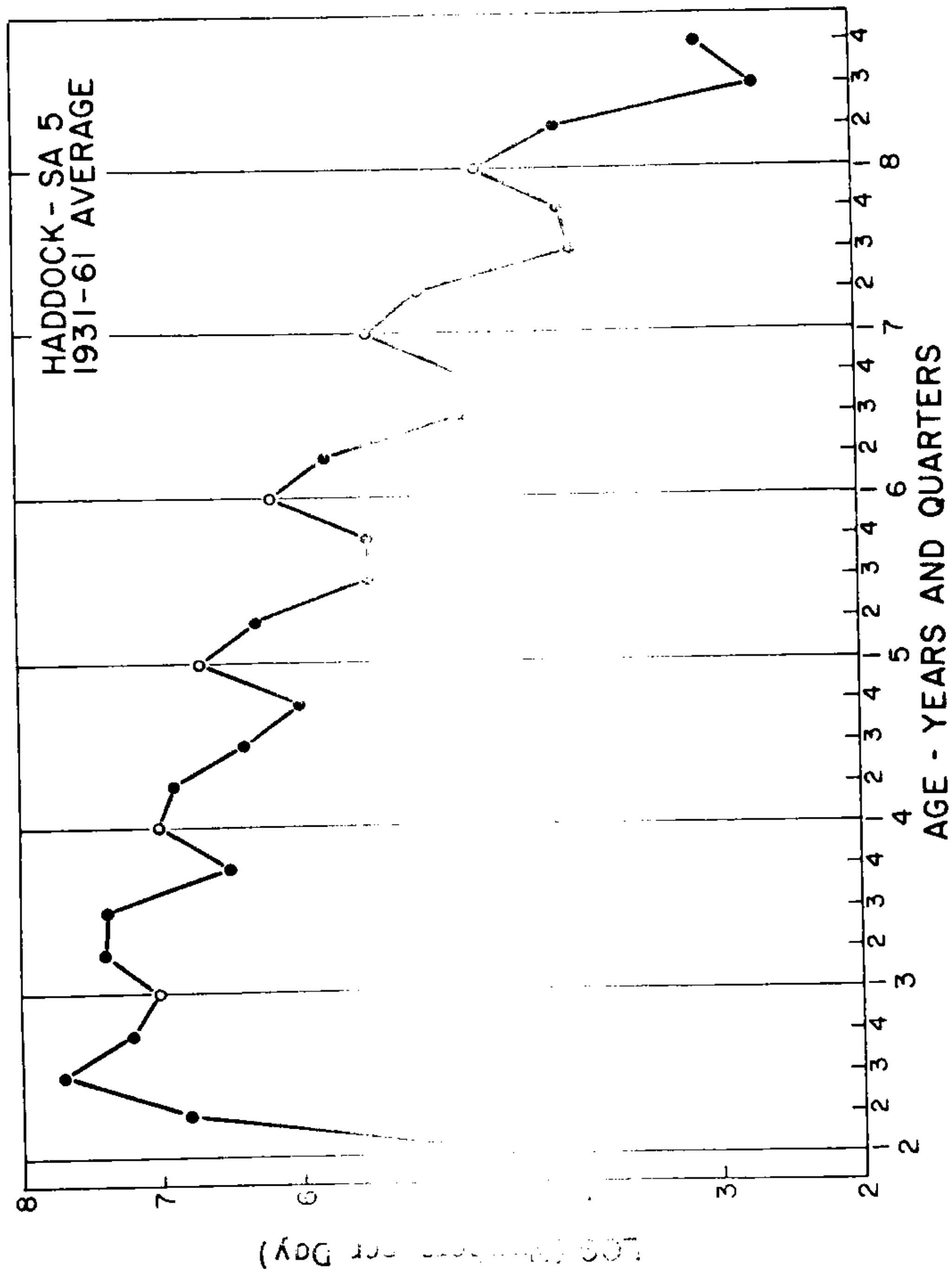

Figure 3.--Average of lo[illegible] landed per day fished by U.S. fleet by age [illegible] quarter of year; Georges Bank, 1931-61.

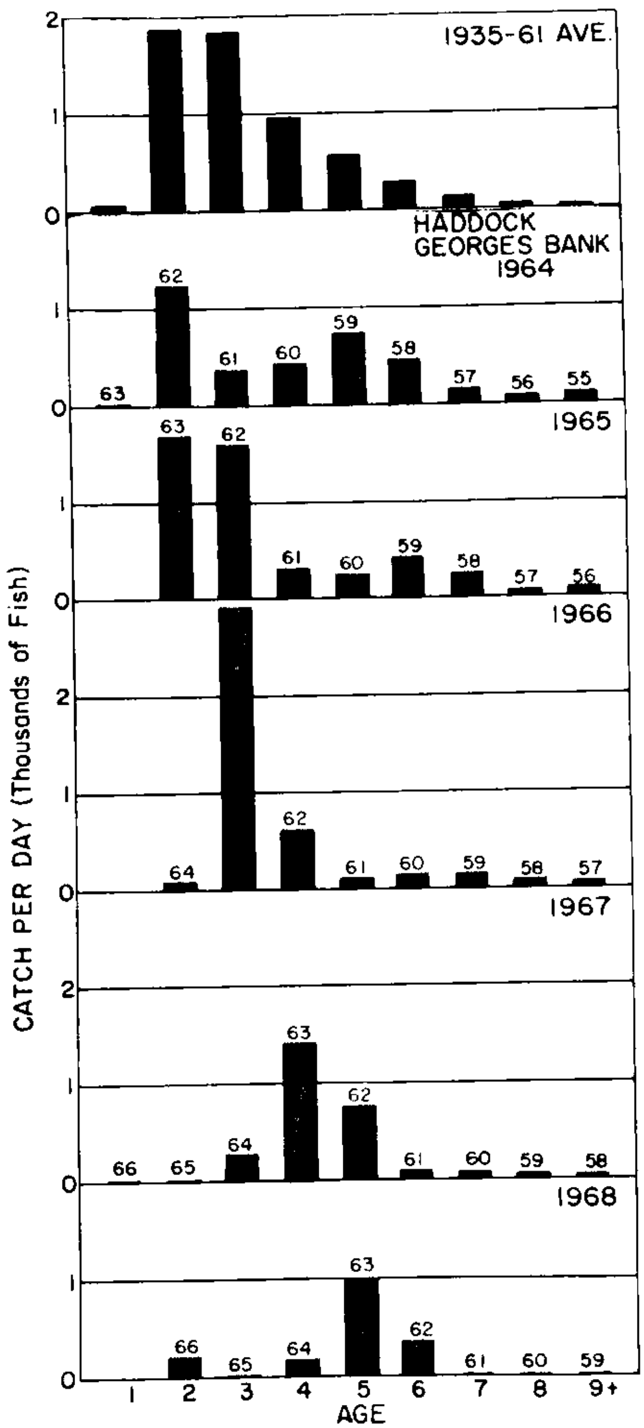

Figure 4.--Age composition of U.S. haddocks landings from Georges Bank, 1964-68.

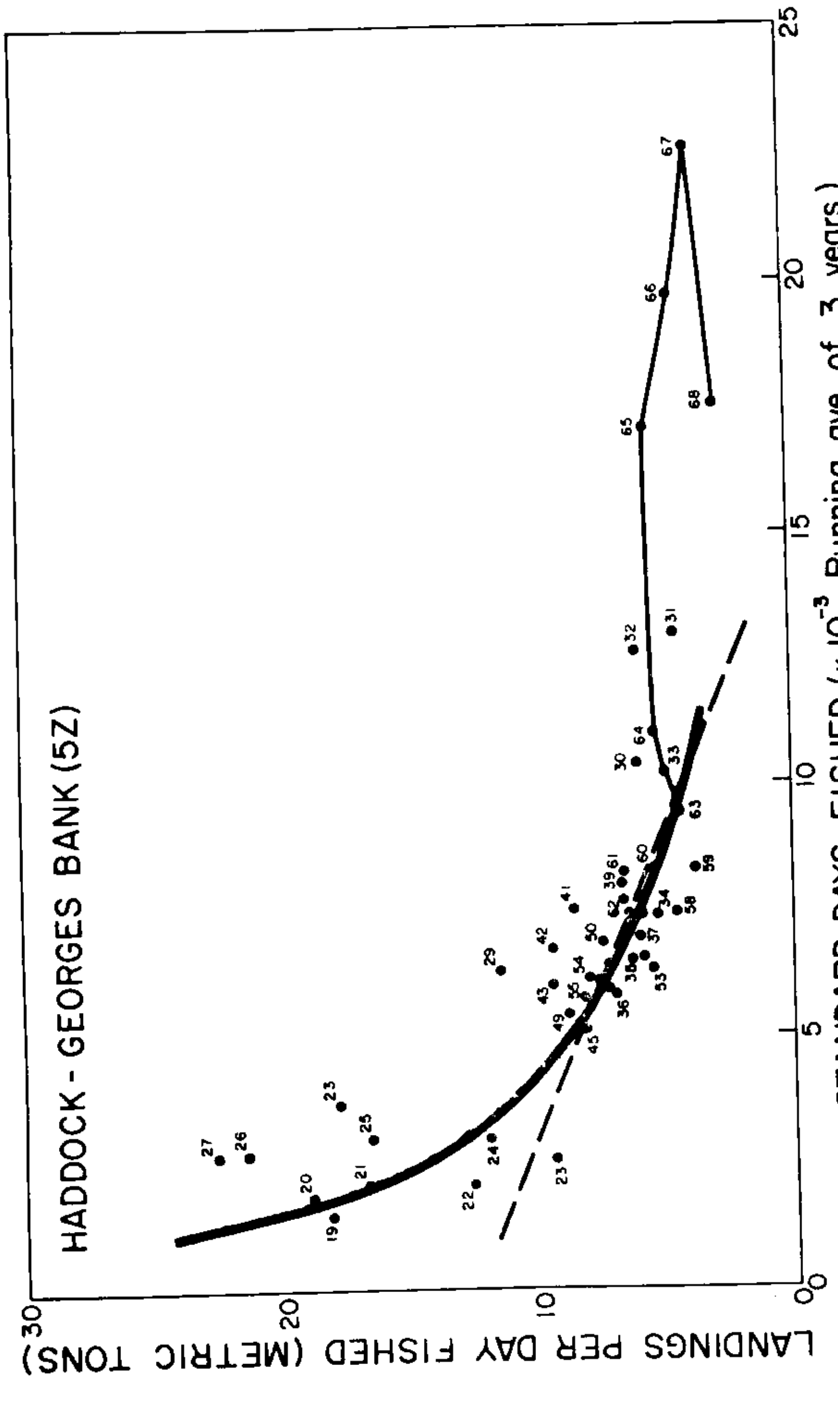

Figure 5.--Relation between landings per day fished by U.S. fleet and 3-year cumulative average effort for Georges Bank haddock, 1919-68.

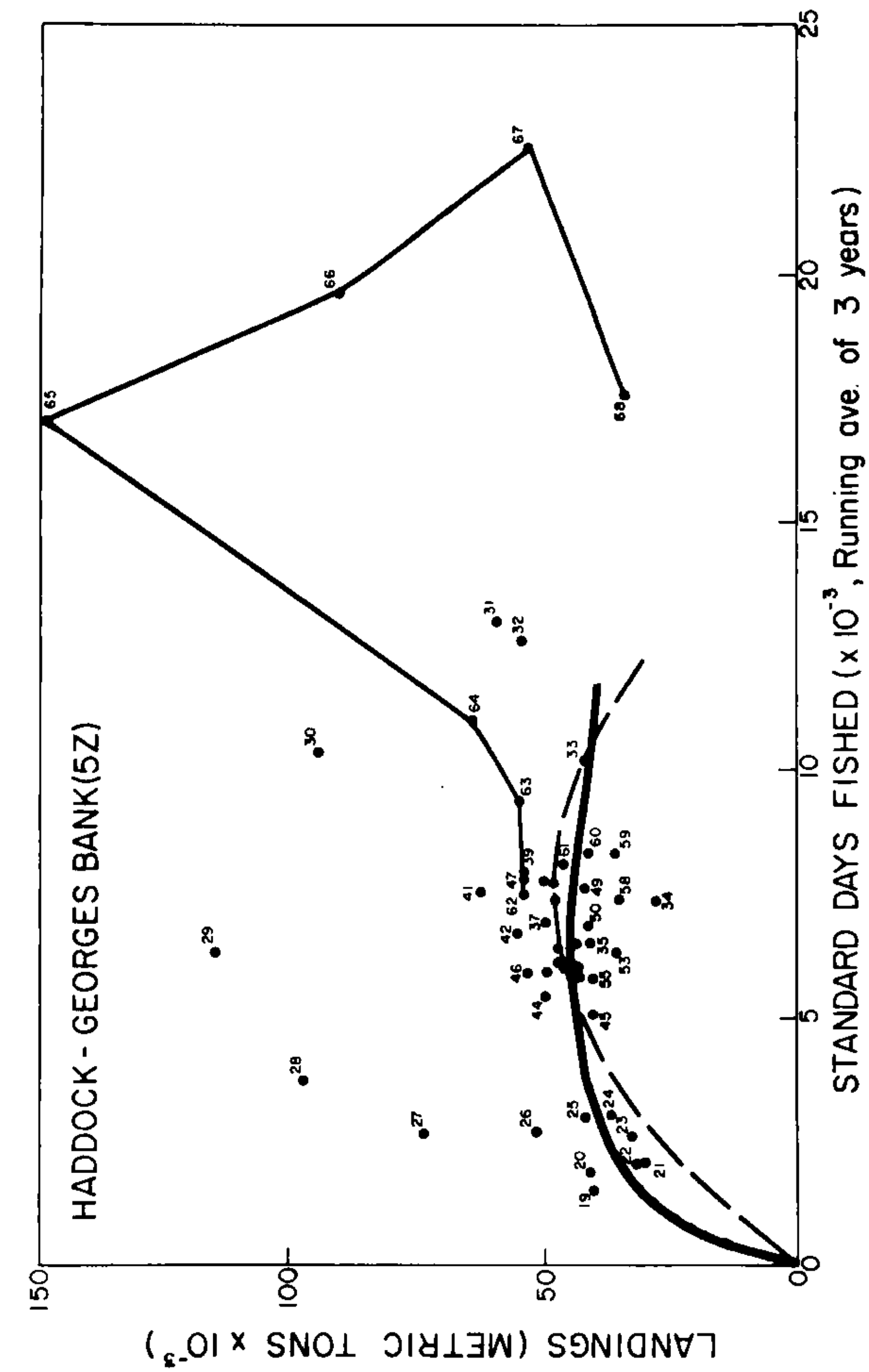

Figure 6.--Relation between total landings and 3-year running average of effort for Georges Bank haddock, 1919-68.

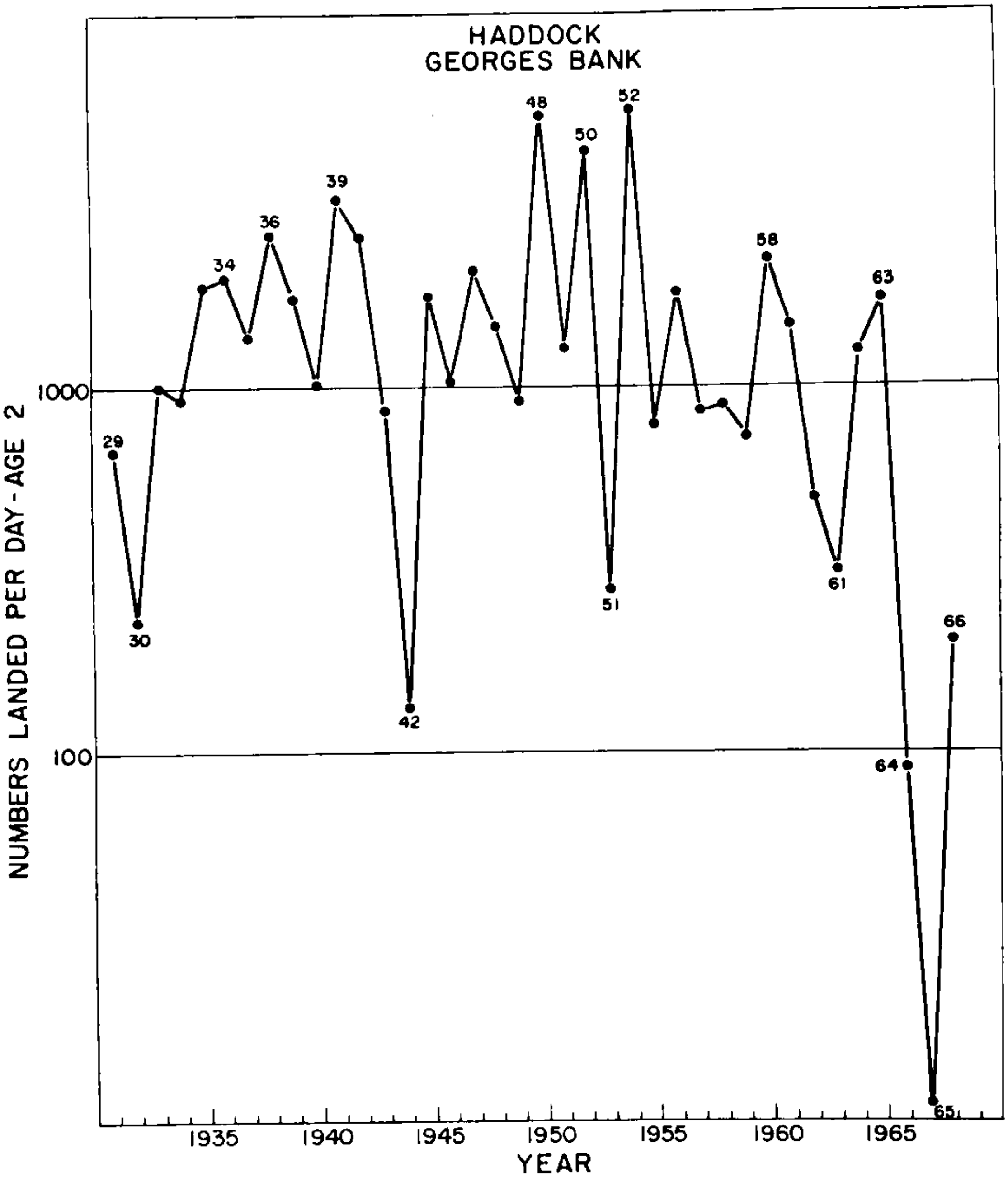

Figure 7.--Annual average number of 2-year old haddock landed per day fished by U.S. fleet from Georges Bank, 1931-68.

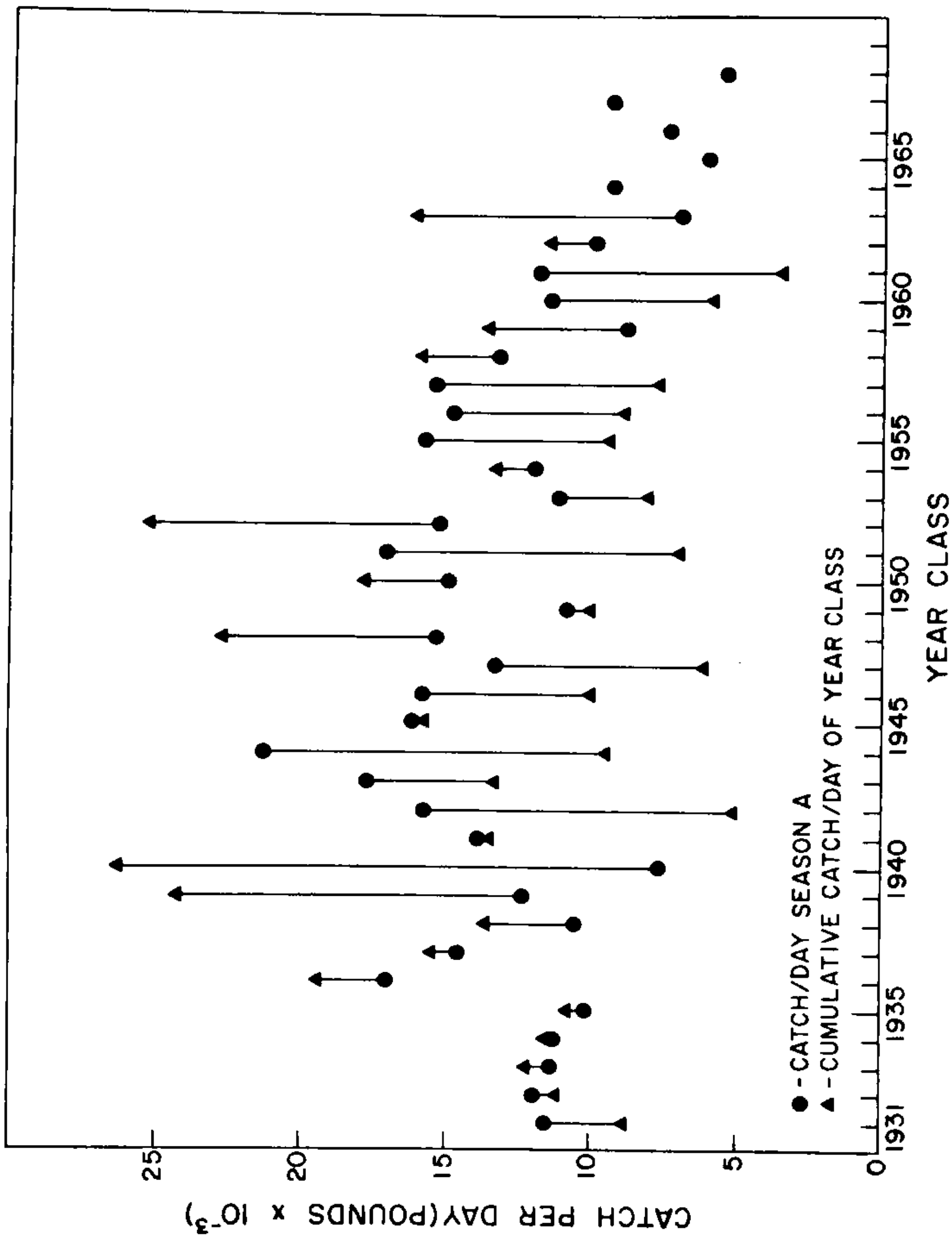

Figure 8.--Stock-recruitment relation for Georges Bank haddock (1931-61 year classes).

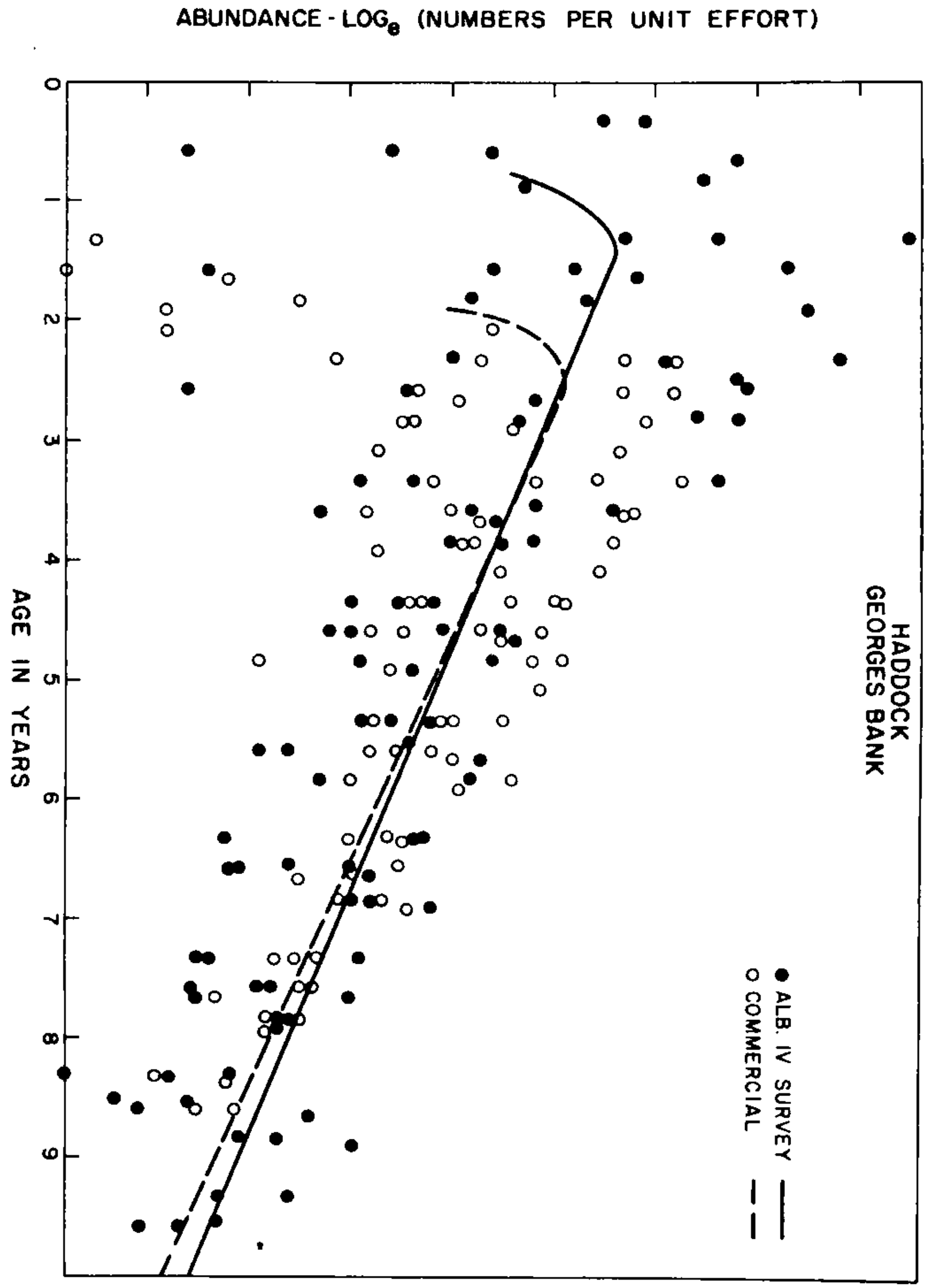

Figure 9.--Log numbers of haddock caught per unit of effort by U.S. commercial fleet and Albatross IV surveys. The points represent seasonal observations of age group abundance.

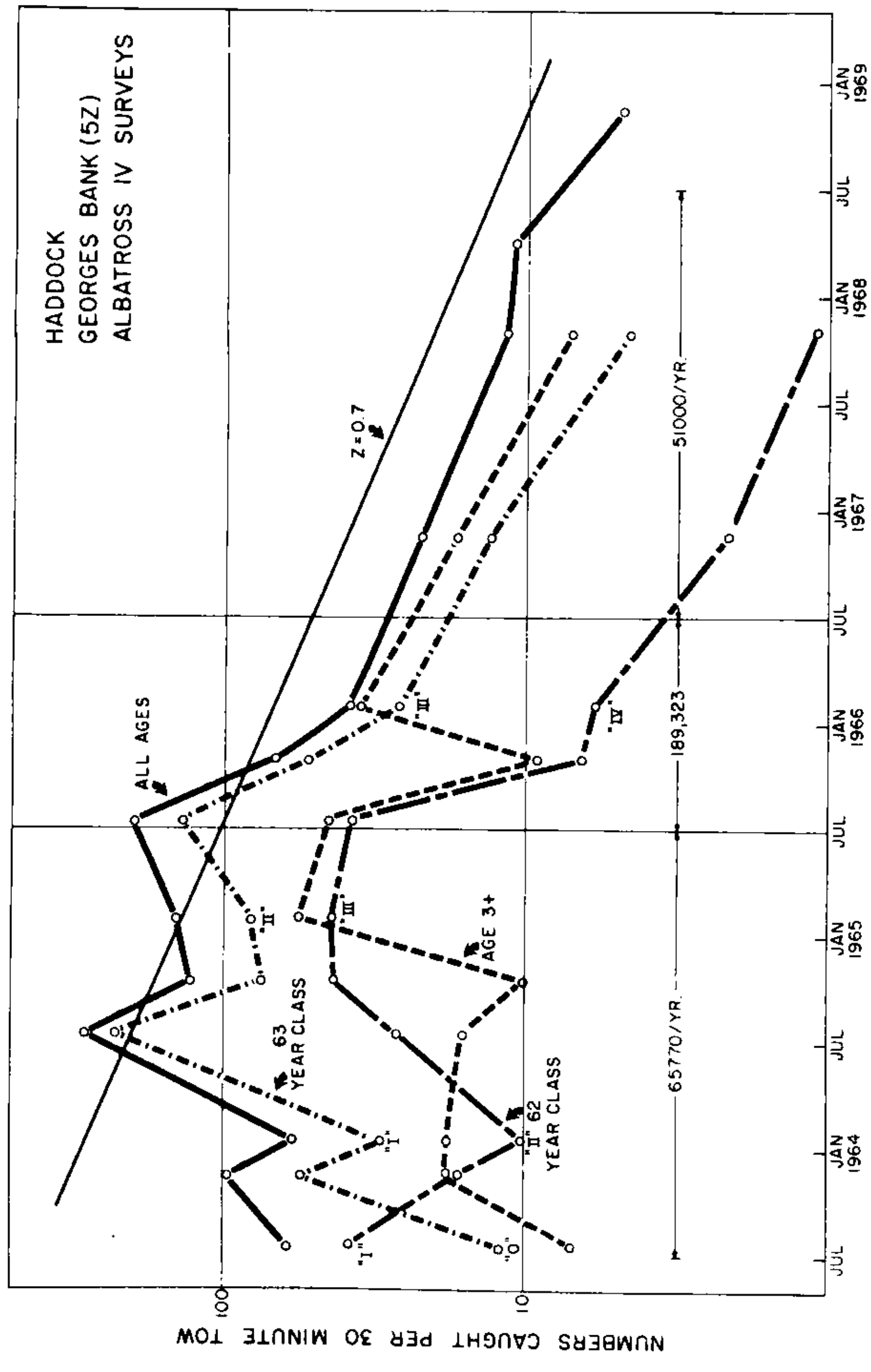

Figure 10. --Abundance of haddock on Georges Bank as measured by Albatross IV groundfish surveys.

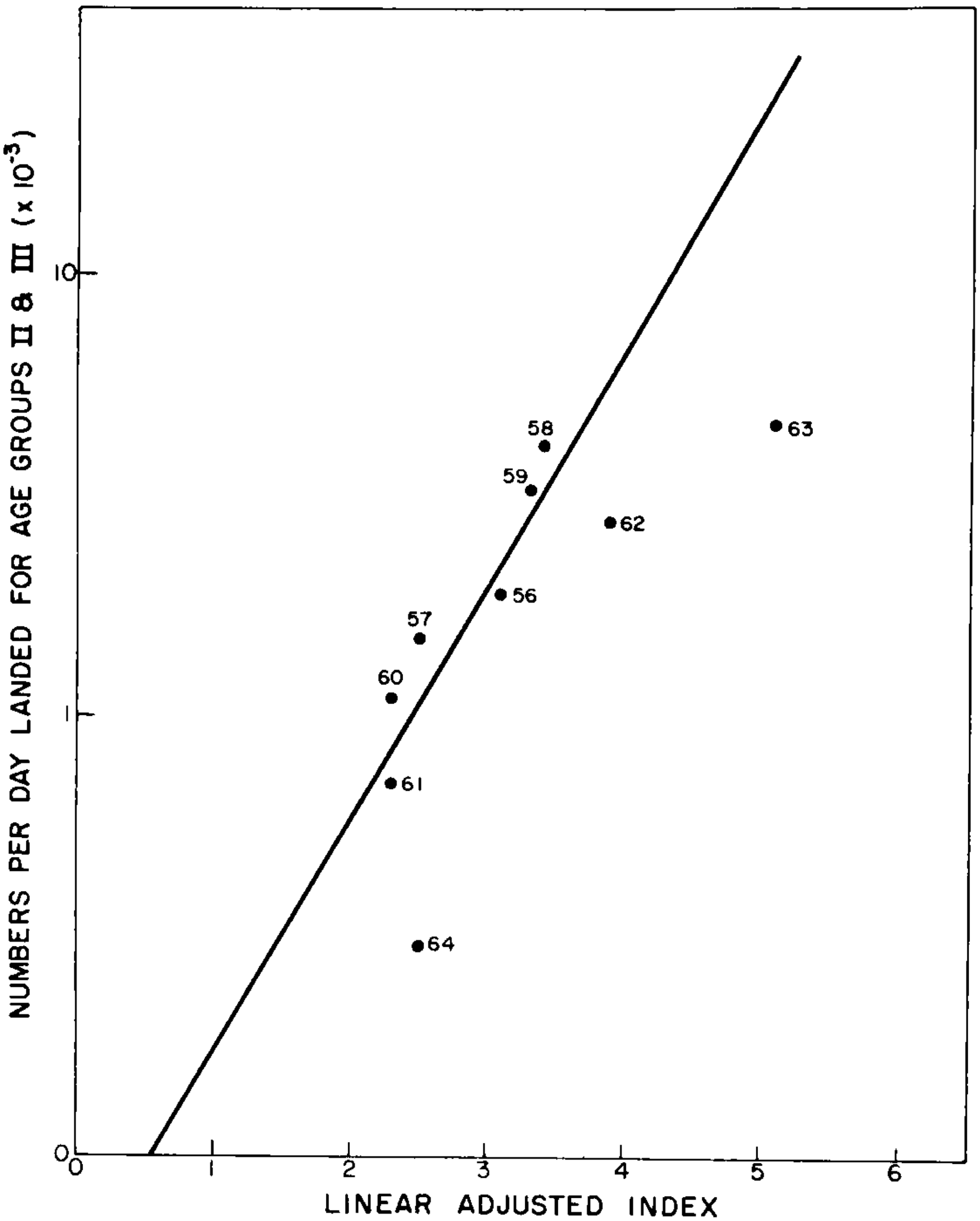

Figure 11.--Relation of year class abundance index of haddock on Georges Bank derived from catch curves based on Albatross IV data to numbers landed per day fished by U.S. fleet.

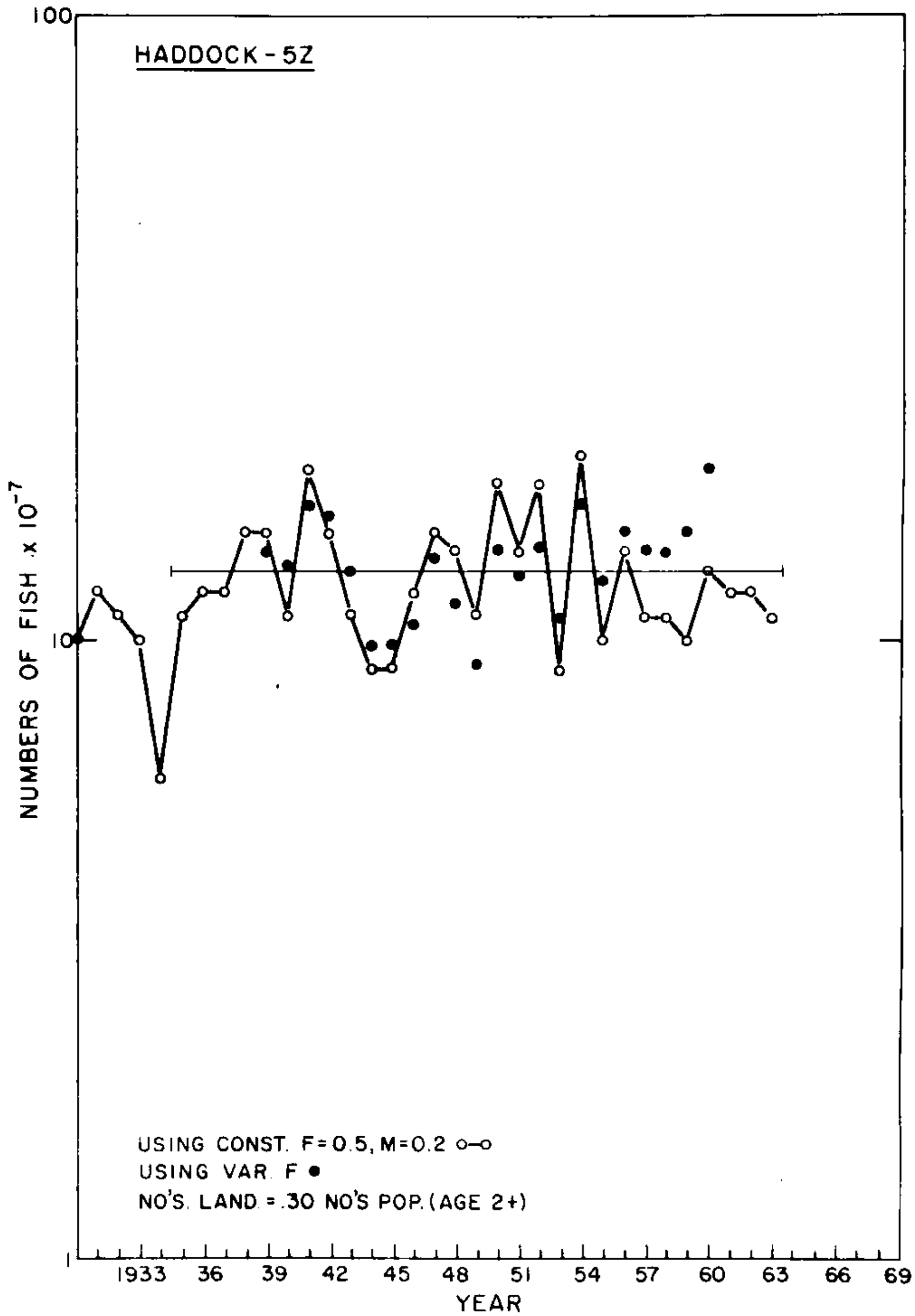

Figure 12. --Estimates of commercially available population of haddock on Georges Bank.

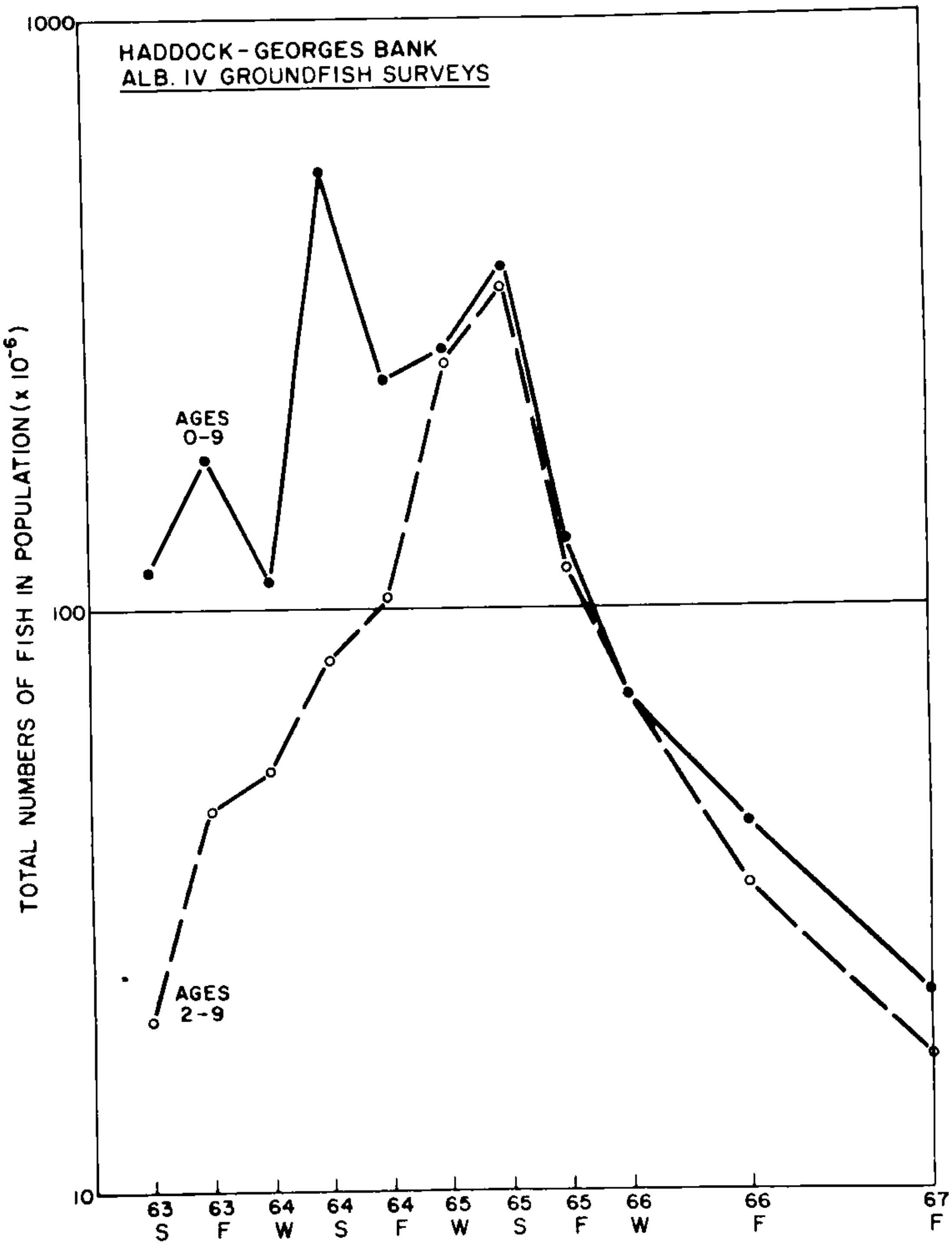

Figure 13. --Estimated population size of haddock on Georges Bank based on research vessel surveys by year and season (S = summer, F = fall, W = winter).