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Spawning stock and other factors related to recruitment of haddock on Georges Bank.

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INTRODUCTION

In 1969, the haddock population on Georges Bank (ICNAF Subarea 5) was about twenty million fish two years of age and greater, compared to an average level in previous years of about one-hundred-forty-five million. Recruitment of two year olds in 1967-69 was very low. Regulations to limit the catch were adopted in 1969, to be effective this year for the purpose of rebuilding the stock to former levels.

This regulation is predicated on the assumption that the probability of good recruitment is decreased when a small stock size exists. It is perhaps not unreasonable to assume this for the very low population now existing; and we must face the fact that because the haddock are seemingly very vulnerable, unrestricted fishing would reduce the population even further. However, outside of very low or very high populations, is the density an effective factor in controlling recruitment?

We have presented herein a summary of existing knowledge, and an analysis of available data which bear on the problem of recruitment for this stock. Some of the information is based on provisional data; we have found some discrepancies which are not yet reconciled. The lack of much critical information has permitted only speculation on mechanisms and causal factors. It was our intention to provide a report on status of knowledge, and to point out thereby, the direction that future studies should take.

HISTORY OF THE FISHERY

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 (Figure 1). During this period the beam trawl first developed, and rapidly replaced the line fishery. 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 fishing effort are not adequate for calculating a reliable index of abundance in 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.

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 the International Commission for the Northwest Atlantic Fisheries. 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.

During the first two periods, the fishery was conducted exclusively by U.S. vessels. The third period, commencing in 1962, 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 1965 to 1969 are all 1/10 to 1/100 of previous norms.

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 (Rounsefell, 1957). 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. The annual average catch per day 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.

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 indicates the proportion of two-year old fish were significantly higher than that in the U.S. landings. Also, in the last two years the vessels in the selected fleet have mostly dropped out of the fishery. A new index of abundance, based on all vessels in the haddock fleet, indicates the 1968 and 1969 abundance was significantly lower than that indicated by the selected fleet.

EARLY LIFE HISTORY

In the southern part of the Northwest Atlantic, the principal spawning concentrations of haddock occur on eastern Georges Bank and on Browns Bank (Figure 2). The peak spawning on Georges Bank usually occurs during March or April, and it is associated with increasing water temperatures in the spring (Figure 3). Spawning peaks occur in March when temperatures are about 4-5°C, and the peak is delayed until April when March temperatures are below 3°C (Marak and Livingstone, 1969). Spawning appears to be more prolonged in years when the peak occurs in March. Spawning on Browns Bank occurs about a month later than on Georges Bank in any given year.

Fertilized haddock eggs rise to the surface and hatch in about 2-3 weeks at average spring temperatures, and larvae are planktonic at least for several months thereafter. Eggs are concentrated in the upper ten meters and larvae are found principally at 10-40 meters, and, therefore, dispersion depends upon the surface circulation (Colton, 1966).

The average net surface drift during the spawning season is believed to be predominantly southwest on Georges Bank, and north on Browns Bank, as indicated by drift-bottle returns (Day, 1958), and tracks of transponding buoys (Colton and Temple, 1961).

The distribution of late stage eggs and larvae collected in surveys with the Hardy recorder in 1953, 1955 and 1956, indicated the dispersion from spawning centers followed this general pattern of drift, which is generalized in Figure 2 (Marak, et al., 1961 and 1962).

There has been much speculation about the possible loss of spawning products to slope waters south of Georges Bank, particularly in the early spring months when the

prevailing northwest winds generate an offshore surface drift on Georges (Colton and Temple, 1961). In fact, Chase (1955) did find a significant negative correlation between haddock brood strength and northwest wind components during early spring months for the period 1928-1951. Also, it should be noted that some of the transponding buoys drifted due south over the slope from eastern Georges Bank. However, haddock eggs and larvae have not been found out over slope waters, and in recent years the predictive accuracy of Chase's index has been low (personal communication). Further clarification of this problem requires more extensive direct measures of surface circulation and egg and larval distributions over a period of years.

By late April the surface circulation generally begins to form in a clock-wise gyre on Georges Bank and a counter-clockwise gyre in the Gulf of Maine, as shown by solid arrows in Figure 2. This pattern obviously would tend to maintain in the region any planktonic eggs and larvae originating from the haddock spawning centers.

Little is known about the distribution of larvae of 2-6 months of age except that in September of 1957 and 1958, substantial numbers were found in midwater within the thermocline about six months after normal peak spawning (Colton, 1966). Juveniles have also been available to bottom trawls in some years as early as July (Colton, 1955; Grosslein, 1969). Their availability to bottom trawls is greater in the fall (October-November), and a series of autumn surveys has shown that O-group haddock tend to be concentrated on northern Georges Bank and along western Nova Scotia (Figure 2). The relative abundance of O-group haddock taken with bottom trawls in both summer and autumn since 1948, is correlated with the abundance of the same year class at later ages as measured by research vessel surveys and landings per unit effort by the commercial fishery (Hennemuth, 1968; Grosslein, 1969). The correlation is high enough to suggest that brood strength is determined within the first six months of life.

Another interesting feature of the autumn catches of O-group haddock is the generally good correlation between areas within years. That is, when O-group haddock are abundant (or scarce) on Georges Bank, they are also abundant (or scarce) off western Nova Scotia and in the Gulf of Maine (Grosslein, 1969). There is also evidence from analysis of commercial landings that relative year class strength tends to be similar throughout the area from Georges Bank to Nova Scotian Banks (Hennemuth et al., 1966). This could arise from the mixing of larvae among the spawning centers, and from factors controlling survival being common to the entire region in a given year. The data at hand are not adequate to clarify the picture.

Observations on the feeding, condition and predators of larval and juvenile haddock on Georges Bank have been very limited. Therefore, we can do little more than speculate about the role such factors may play in controlling year class size. Duration of pelagic life may be of considerable importance and this would interact with food availability and predators as well as factors affecting distribution. It has been noted that haddock postlarvae and juveniles seem to be associated with the red jellyfish (Cyanea) and such association could have an effect on pelagic distribution and level of predation (Colton and Temple, 1961).

FACTORS RELATED TO POPULATION DENSITY

The whole process from spawning to recruitment may be subsumed by intrinsic biological (physiological) factors and extrinsic physical (distributional) factors. Within the former, high levels of stock density might effect the viability or actual production of spawning products. There is enough evidence about the effects of crowding on physiology related to reproduction to make this a reasonable hypothesis. There are a number of specific effects such as poor condition, delayed or incomplete maturation and territorialism which might be involved. At either end of the abundance scale, the stimulus to pair for successful extrusion and fertilization might be dampened. It is questionable whether this state, by and of itself, could affect the ultimate recruitment level, except when very severe. However, it is not implausible to hypothesize that if the initial state of the system is bad (or good) interaction with factors operating at later stages in development would produce bad (or good) recruitment. It is difficult to conceive of physiological requirements at later development stages (hatching, larvae) which might be altered by density of eggs or larvae themselves and affect survival. The eggs and larvae, although strongly aggregated, are free floating, and should not suffer from depletion of oxygen or other vital elements even when very dense, and certainly not when sparse.

Consideration of extrinsic factors offers somewhat more scope for density related effects. High abundance levels may force spawning to occur in areas unsuitable for spawning success or immediate survival, or perhaps lead to over utilization of the suitable areas with similar consequences. Since the eggs are not deposited on the bottom it must be the properties of the water column itself which are important, and in this regard temperature seems most critical, but perhaps other physical properties are also involved.

At the time of hatching and yolk-sac stage, very dense concentrations might tend to quickly reduce available food to the point where very few get amounts adequate for survival. Throughout the egg and larval stages, particularly if heavy spawning concentrations lead to a limited number of dense concentrations of the eggs and larvae, ultimately cannibalism may be severe enough to eliminate the major part of the progeny.

It is at this stage when distributional properties may be most effective in controlling abundance. Low densities may lead to more random distributions which do not promote maximum survival because too few happen to find adequate food concentrations and optimal physical characteristics of the water mass (temperature, drift). This may be limiting also as the densities increase beyond some level, because although the tendency would be for more dense aggregations, there is a limited environmental space suitable for good survival. This probably would not lead to a severe disproportionate reduction in recruitment however.

It is quite probable that the effects of high or low density on recruitment are cumulative. That is, a state of high or low density may have to exist for more than one year to be observably affective. In the following sections, the estimate of spawning stocks in terms of weight is related to recruitment. This does not include the one or two year old populations which could well have a rather severe effect on survival of the years production. This would lead to lag-times of one to two years which might well account in part for the poor direct relationship.

One has to push a bit hard to erect plausible events which lead to reduced recruitment with dense stock. It is easier to concieve of a system that would lead to low recruitment with low stock size - only proportionate production is required - and an asymptotic or nearly constant production at moderate to high densities. Distinguishing between the two alternatives seems to us to be the crux of the matter, and, of course, the most difficult thing to do.

RECRUITMENT

Measures of recruitment have been based on the analysis of numbers and weight of fish landed by the U.S. commercial fishing fleet. This is subject to changes in market demand, mesh size and growth rate. Since 1953, the regulated mesh size (4-1/2 inches, double manila) has provided a catch composition that is very close to that desired for landing, thus discard (primarily two year olds) amounts to only about five percent of landings. Prior to 1953, the smaller mesh sizes may have led to a discard rate of 10-15 percent, on the average, but there is very little data on exact amount.

Haddock are first taken by the U.S. commercial fleet as two-year-olds, i.e. in their third year of life. The predominant season of recruitment is August-October (Figures 4, 8). The distribution of fish and fishing is such that the catch rate decreases in the late autumn and winter, but increases again in July-October, when the fish are three-year-olds. They appear to be fully recruited and available (considering the conduct of the fishery) at this time. As fish become older, the spring spawning season provides the highest catch rate. The earliest reliable index of recruitment is, thus, provided by the catch of two-year-olds in the August-October quarter (Figure 5, solid line).

There have been rather strong deviations in some years, the best exceeding the worst by a factor of about fifty until after 1965 (1963 year class). However, for the period 1933-1962, a number of statistical tests to measure cyclical (including one to five-year lags) or systematic trends have been performed, and none indicate any departures from a hypothesized series of random points. It is rather obvious that the year classes since 1964 do represent a regime of significantly lower recruitment (although not shown, the evidence at hand indicates the 1968 and 1969 year classes will also be very low).

The fishery was subjected to increasingly heavy foreign fishing from 1962 through 1966, and in 1965 and 1966 particularly, the evidence indicates the proportion of small fish was larger than in the traditional U.S. catch. This means that the U.S. catch as a measure of year class strength for this period is biased relative to earlier times.

The groundfish survey which has been conducted on a seasonal basis since 1963, provides another, perhaps better, measure of year class strength. One index has been derived by using the intercept at twelve months of the line fit to the observed $\log_e$ catch per tow at age (See Figure 5a). One disadvantage is that the year classes are represented by different age groups, and different mortalities. Also, the more current year classes have fewer points. However, it is probably a good representation of the relative year class strength. This index for the 1956-66 year classes is presented in Table 1.

This index was converted to one relative to the 1956-57 year classes, and the new index was used as a multiplier to adjust the landings per day index at age two of subsequent year classes. The adjustment is shown in Figure 5 as the dashed line. The adjustment does not have much effect for the 1958-1961 year classes, as would be expected. The 1962, 1963 and 1964 year class indices are increased by factors of 2.1, 4.9 and 7.2, respectively. This was expected for the 1963 and 1964 year classes because of the heavy fishing on them prior to the time the U.S. fleet fished them. The bias was also increased due to slower growth and, hence, later recruitment to the U.S. fishery. The 1962 year class was not fished so heavily as two-year-olds, but there is some evidence that this year class also was recruited to the U.S. fishery at a later date than usual.

The adjustment should reflect more acurately the size of the 1962-64 year classes. It indicates that the 1963 year class was probably the largest ever observed.

Table 1 .--Year class index at age 2 derived from research vessel surveys, and commercial index adjustment factors.

Year Class	Survey Index (log scale)	Relative to 1956-57 for numbers of fish	Landing/Day Fished (Numbers of fish x 10^3)	Adjusted Land/Day
63	5.14	10.27	16.9	83.2
62	3.94	3.09	12.1	25.0
58	3.37	1.75	21.5	14.2
59	3.24	1.57	14.5	12.7
56	3.09	1.0	8.9	8.1
57	2.53		7.3	
64	2.49	0.73	0.9	6.5
60	2.34	0.62	4.9	5.0
61	2.34	0.62	3.1	5.0
66	1.67	0.32	2.0	2.6
65	-0.47	0.04	0.1	0.3

It is also of interest to point out the 800-fold difference between the 1963 and 1965 or 1967 year classes.

There is still, however, some degree of variation due to fishing practices and market demand which lead to concentration of fishing at times and in areas to maximize catches of either large or small fish. For example, it appears that since about 1945 the U.S. fishery has concentrated more heavily on younger fish than it did in the period 1930-1945; this is reflected in the fact that after 1945 the abundance of market category Large haddock (an index of mature stock) dropped to a lower level, whereas the abundance of market category Scrod (an index of recruitment) increased to a level above that of the 1930-1945 period (Figure 9). The same change in the fishery is implied by the relative shifts in age structure of landings of the two periods (Figure 8). A more precise index should be obtained by utilizing all age groups in measuring year class strength. In the subsequent section on the relation between spawning stock and recruitment, the life time landings per day fished (in weight) was used, adjusted for the 1962-67 year classes as above.

This index may be refined somewhat by utilizing the procedure of Gulland (1965) to estimate the population of two-year-olds by adjusting for variable fishing rates (Figure 6). This has the effect of reducing, somewhat, the variations observed in the landings per day index. However, as shown in Figure 7, while there is a reasonable linear relationship between the two indices, the slope is 0.65, not 1.0, which means that the landings per day over estimates year class strength, relative to the virtual population estimate, for large year classes, or conversely. There is also some indication that the 1957-59 year classes particularly, were over estimated by the virtual population method (or conversely under estimated by the landings per day), although they were not particularly large.

STOCK RECRUITMENT

The pre-1930 period

The pre-1930 period is of particular interest from the standpoint of the stock-recruitment relation because: 1) average stock abundance appeared to be considerably higher than the post-1930 stock level, at least by a factor of 2, and 2) there were large apparent oscillations in abundance of both adult stock and recruits which yielded a dome-shaped stock recruitment curve indicating a severe reduction in recruitment at high levels of adult stock (Herrington, 1948). The apparent changes in abundance are shown in Figure 9 for the two market categories, large and scrod[1/] which represent approximate indices of adult stock and recruits respectively. Recall that there were no age-length data collected prior to 1930.

While there is no doubt that the pre-1930 population was larger than in later years the abundance indices for the earlier period probably have a substantial positive bias because apparent reductions in stock during the two rapid declines were larger than could be readily explained by observed removals. Furthermore, abundance indices for the line trawl fishery in the same areas showed far less drastic declines in abundance (Grosslein, 1966). Finally, we may note that market conditions were quite variable in the 1920's, and at times prices were so low that scrod were discarded at sea.

Further study of the pre-1930 records may clarify the situation but so far we have concluded that not only the average abundance, but also the magnitude of fluctuations in the pre-1930 stock may have been exaggerated. Consequently, it is doubtful that the existing stock and recruitment indices for the early period reflect the true changes in the population.

1/ Scrod are the smallest marketable haddock ranging from about 1-1/2 to 2-1/2 pounds gutted weight with a mean fork length of 42-44 cm. Large haddock weigh over 2-1/2 pounds.

The post-1930 period

Turning now to the post-1930 period we can construct a more accurate picture of the relation between spawning stock and resulting recruitment of individual year classes. During the first quarter (February-April) the commercial fleet concentrates on the spawning aggregations and very few haddock less than three years old are landed (Figure 8). Virtually all the three year old males (all sizes) and three year old females (> 40 cm) in the population are mature (Clark, 1959). Average length of three year old fish landed in the first quarter is 45 cm, therefore it is reasonable to assume that all three year olds in the landed catch are mature. Since fecundity is approximately proportional to weight of individual fish the best available index to numbers of eggs spawned is the catch per day in weight of age groups three and older.

Spawning stock indices (catch per day of age groups 3 and older in February-April) were compared with recruitment of resulting year classes measured in terms of cumulative catch per day at all ages, 2 - 9+, i.e. an index of lifetime yield of the year class. This recruitment index is almost identical with an index based on total yield since effort was fairly constant throughout most of the period. In the case of the year classes which had not yet completed their major weight contribution to the fishery prior to the marked increase in effort by 1965, namely year classes 1958-1961, a reasonable approximation to the cumulative recruitment index was constructed by using the average proportional contribution of specific age groups to the lifetime weight index. For example the 1958 year class which was represented in the landings from 1960-1964 as age groups 2 - 6, was adjusted upward according to the contribution made by the average year class at ages 2 - 6 to the cumulative landings per day index. Such a plot for the years (and year classes) 1931-1961, shows no clear relation between spawning stock and recruitment (Figure 10). This is perhaps not surprising since the observed range of stock abundance, only 2-3 fold, is rather limited. The maximum range of recruitment indices

was only about 5 fold. It should be noted that the spawning stock index for 1940 undoubtedly has a negative bias; disputes over prices in the first quarter of 1940 resulted in a major portion of the haddock study boat fleet being tied up, and the abundance index from available first quarter records is not comparable with other years.

In the case of the 1962-1969 year classes, recruitment indices were derived from research survey data as described earlier, and represent estimates of what the cumulative catch per day indices might have been if total fishing effort had remained at the previous level. The points for these year classes are shown as open circles in Figure 10, and with the exception of the strong '62 and '63 year classes which resulted from relatively low spawning stocks, these represent the poorest year classes on record and they came from the lowest spawning stocks on record.

When the stock recruitment indices are plotted as a time series two features are noticeable (Figure 11). First, there is a rather marked downward trend in spawning stocks since the late 1950's, and second, the size and variability of recruitment (except for the '62 and '63 year classes) is definitely smaller for this same period. These data strongly suggest that the probability of good recruitment is reduced at such low stock levels.

YIELD-EFFORT RELATION

The definition of the stock-recruitment relation is of vital importance in relation to management decisions. At the present time, decisions to regulate yields to maintain a given level of stock density are based on the maximization of production, although the economic aspect of maintaining a higher level of catch per unit effort may in fact, be of more concern to the fishing industry. In any case, if we could be reasonably certain of the long-run effect of stock density on recruitment, the process of decision would be more straight forward.

The relation between yield and effort for haddock on Georges Bank is illustrated in Figures 12 and 13. As mentioned previously, the points for the years prior to 1931 are of uncertain accuracy. The curved line in Figure 12 is based on estimation of yield per recruit, which is assumed independent of density, and was adapted from Beverton's analysis (R.J.H. Beverton, 1965). The straight line is fitted by least squares to the 1932-1962 points.

We have attempted, by applying the generalized production model of Pella and Thomlinson (1969), to select the best fitting line from the family which ranges from the severest concave to convex curves. The results of one run, utilizing the entire set of points, is summarized in Table 2. Low m values produce the convex curves, and high m (>2) the concave curves when fitting landings per day against effort; when $m = 2$, the line is straight. The r values are pseudo-correlations which purport to represent goodness of fit of observed and estimated catch.

Maximum r value is obtained for $m = 0.3$, but it is not much reduced for $m = 2.0$. Estimated optimum fishing mortality (F) and catch for $m = 0.3$ are reasonable, but the estimated optimum effort (f) and the population estimate which provides the maximum catch is rather low and the maximum population rather high. More reasonable values of all parameters except F, are obtained when m is nearer 2.0. By reasonable, we mean in comparison to previous estimates

Table 2.--Estimates from fitting the generalized production model to the yield-effort data from Georges Bank, 1917-1962.

	At maximum catch level					
m	f days x 10^{-3}	F	Catch MT x 10^{-3}	Population M.T. x 10^{-3}	Maximum Population	r
0.3	6.6	.47	47	99	551	.68
0.9	5.3	.37	48	131.4	375	.65
1.5	5.4	.35	50	145	327	.60
1.8	5.5	.34	51	153	318	.57
2.0	6.5	.38	51	135	270	.52
2.2	5.6	.31	52	166	323	.54
2.5	6.0	.54	49	191	168	.43
3.0	6.0	.34	53	158	275	.46

based on virtual population estimates.

When the 1917-1931 data are excluded, none of the fits provide reasonable estimates, and all curves provide low, sometimes negative, r values. Thus, conclusions about possible stock-recruit relations cannot be drawn from this type of analysis. It does, however, illustrate that a siginiicant reduction of yield could occur beyond the level of 10,000 days fishing.

It has been pointed (Anonymous, 1967) out that by assuming both the yield-per-recruit estimates and the yield estimates based on a linear fit to abundance and effort data are correct, the latter divided by the former produces a recruit curve. For the Georges Bank haddock, this curve is shown in Figure 14, and the estimated population of two year olds is also plotted against the population biomass two years earlier. It is obviously somewhat futile to try to establish the correctness of the assumptions based on these data. In particular, many year classes are much too abundant. The results are not unexpected since the system is controlled by several interacting factors, only one of which is population density.

DISCUSSION

It is obvious that one cannot draw firm conclusions about the presence or absence of any effect of stock size on recruitment, let alone induce a generalized stock-recruitment relation from the analysis presented herein. This is not surprising because at least three conditions would have to be met to do so.

i) The variables, stock size and recruitment, must be measured without a large degree of error.

ii) The observations must cover most of the range of the variables.

iii) The system must be rather finely tuned with not too many factors involved, and minimal interactive effects.

None of these conditions seem to be met in the present situation, although the first can be improved upon.

The recent years may offer some clues because both points i) and ii) are more nearly realized. The large 1963 class, which followed a moderately large 1962 class, was produced by a population on the low side. The 1964 year class was somewhat below average, and came from a moderate stock. The small 1965 year class was produced by a very large stock when the two year old fish (1963 year class) are included. Heavy fishing in 1965 and 1966 (178,000 metric tons were removed between July, 1965, and June, 1966) reduced the population density to the point where the 1966 and subsequent year classes, which have all been poor, were produced by low populations. Certainly environmental factors played some part in the process, but it is also possible that the density of stock could well have been a major factor.

M.B. Schaefer, at a recent meeting[1/] pointed out that if there are medium-term secular trends in density independent factors, the juxtaposition of a downward trend with stock-recruitment effects at low populations can rapidly lead to disaster. The imposition of a heavy fishery which caused a rapid reduction in stock size could have been the catalyst in the case at hand.

1/ commemorating the 50th anniversary of the College of Fisheries, and University of Washington

Even if one feels justified in concluding that stock density is an important factor, the year-by-year predictability would be very low unless the effective factors in the system could be identified and the process modeled with a fair degree of accuracy. This will require more investigation of stochastic models. In other words, the deductive approach would lead to better knowledge. Research on this problem will be very frustrating unless some specific hypotheses are available for testing. In the haddock fishery, and perhaps most others, observations at high stock densities will not be available.

It would seem quite likely that if the basic nature of the recruitment process could be clarified for one species, the same principals could be generalized to a whole class of species possessing similar life history patterns. Obviously a realistic general model would be of great value, and this possibility should be kept in mind when considering the cost-benefit ratios as well as organization of future investigations.

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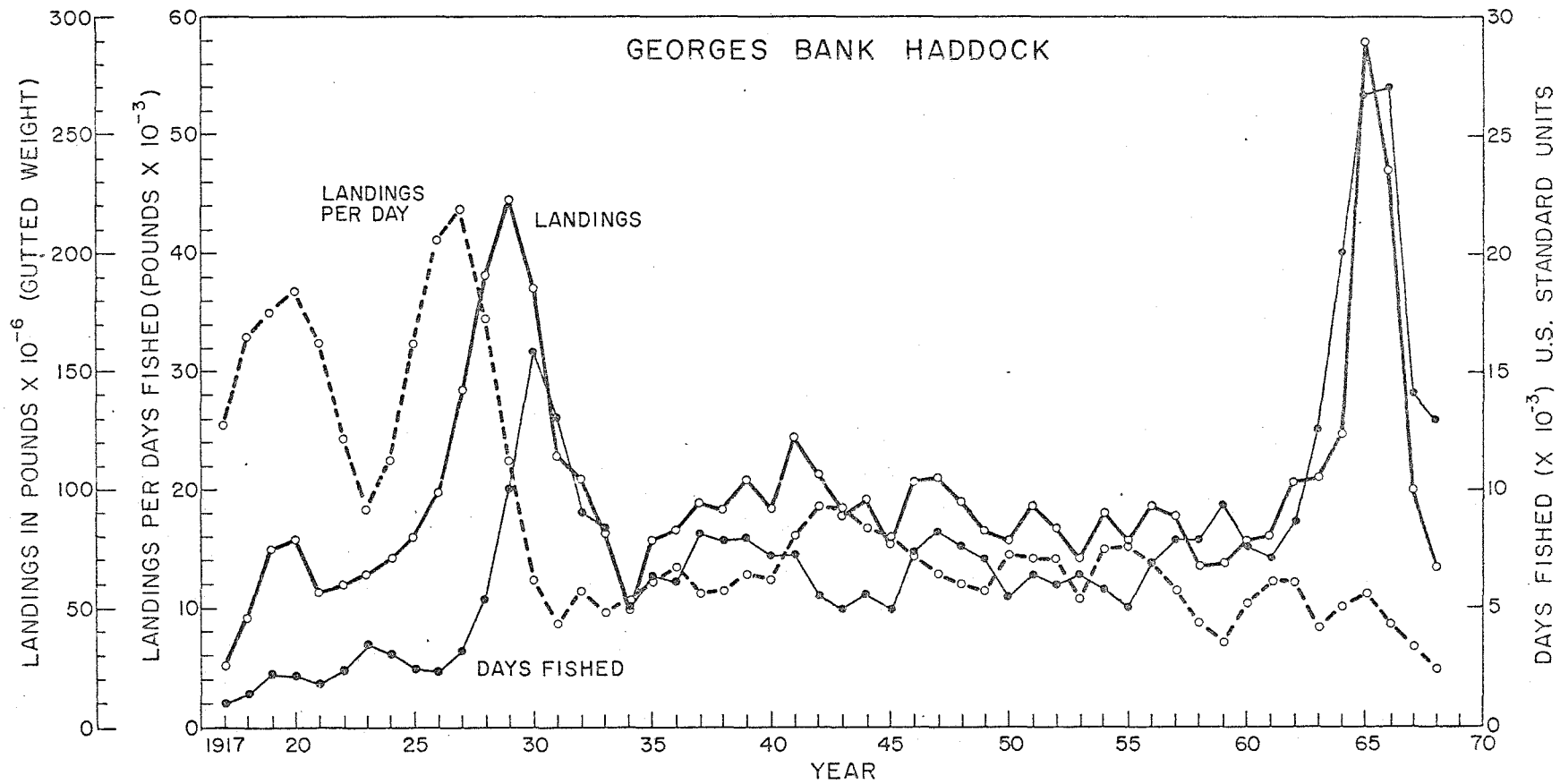


Figure 1.--Total landings and effort, and landings per day fished by U.S. fleet of Georges Bank haddock, 1917-68.

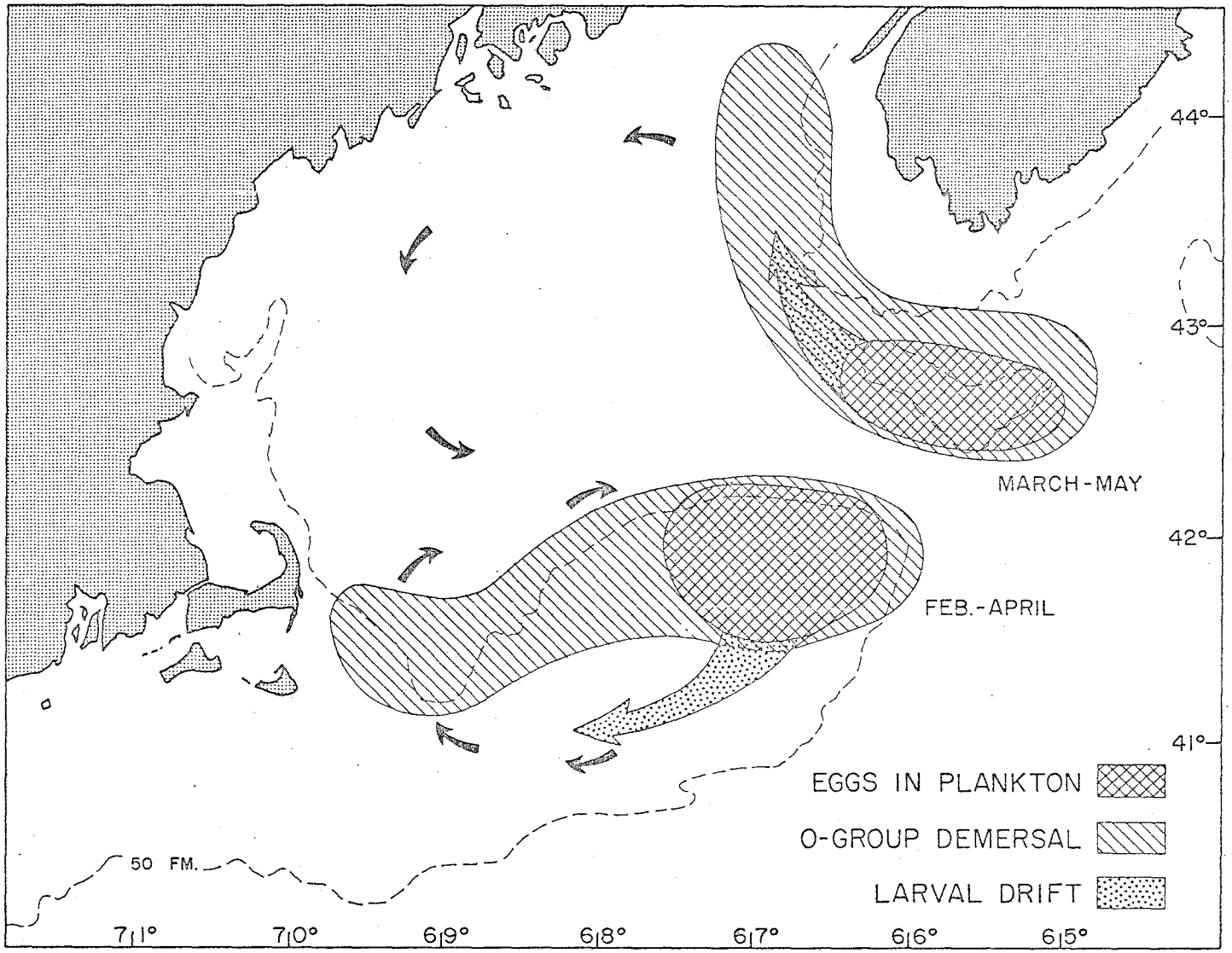
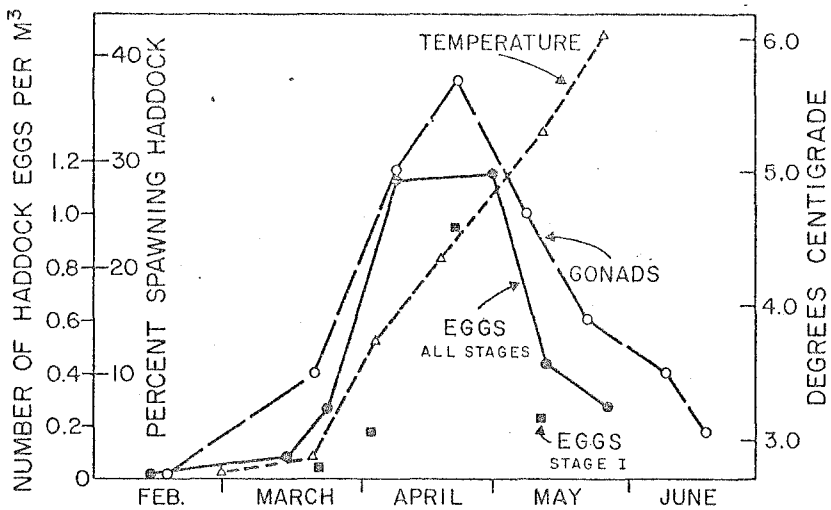


Figure 2.--Principal haddock spawning times and locations on Georges and Browns Banks (indicated by areas where early stage eggs most abundant), general larval drift and surface circulation patterns, and areas where demersal O-group haddock are most abundant six-eight months later.



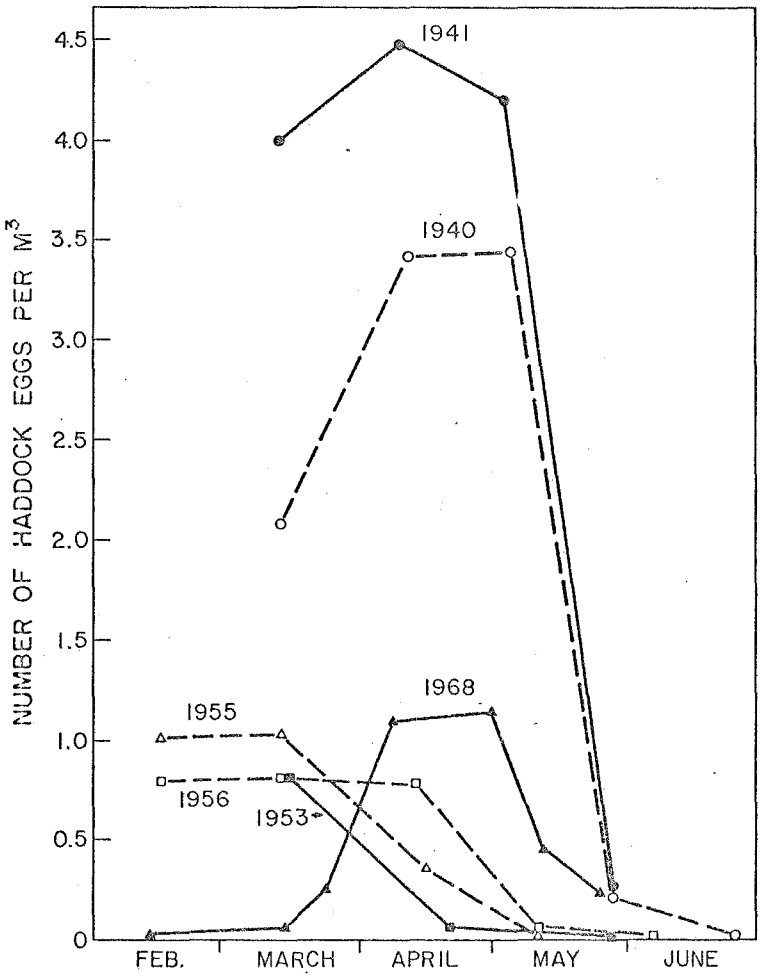


Figure 3.--Upper figure - progression of haddock spawning activity on Georges Bank in 1968 (as indicated by egg surveys and examination of gonads) in relation to water temperature.

Lower figure - comparison of spawning curves in various years.

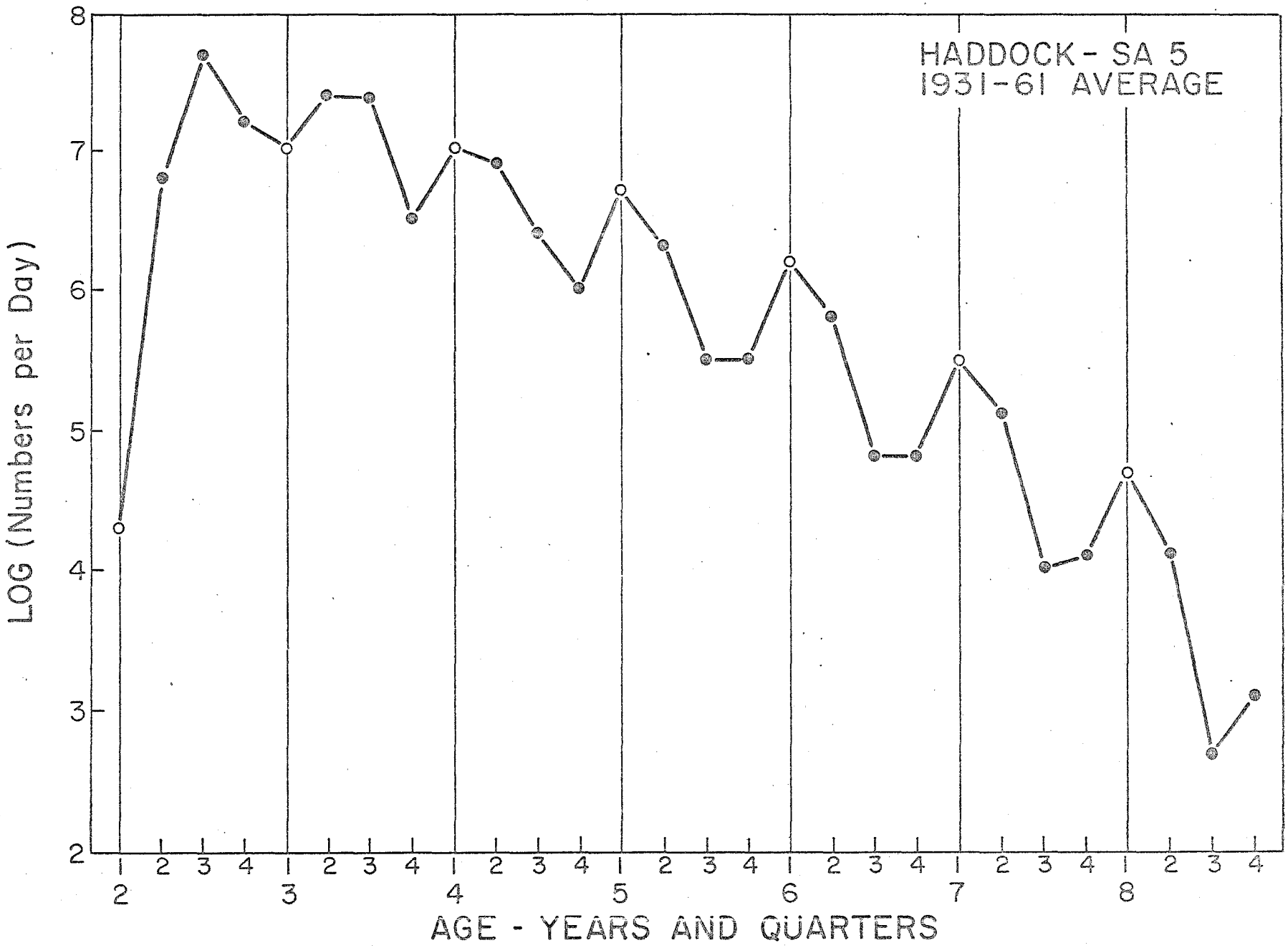


Figure 4.--Landings per day fished of haddock by season and age on Georges Bank, 1931-61.

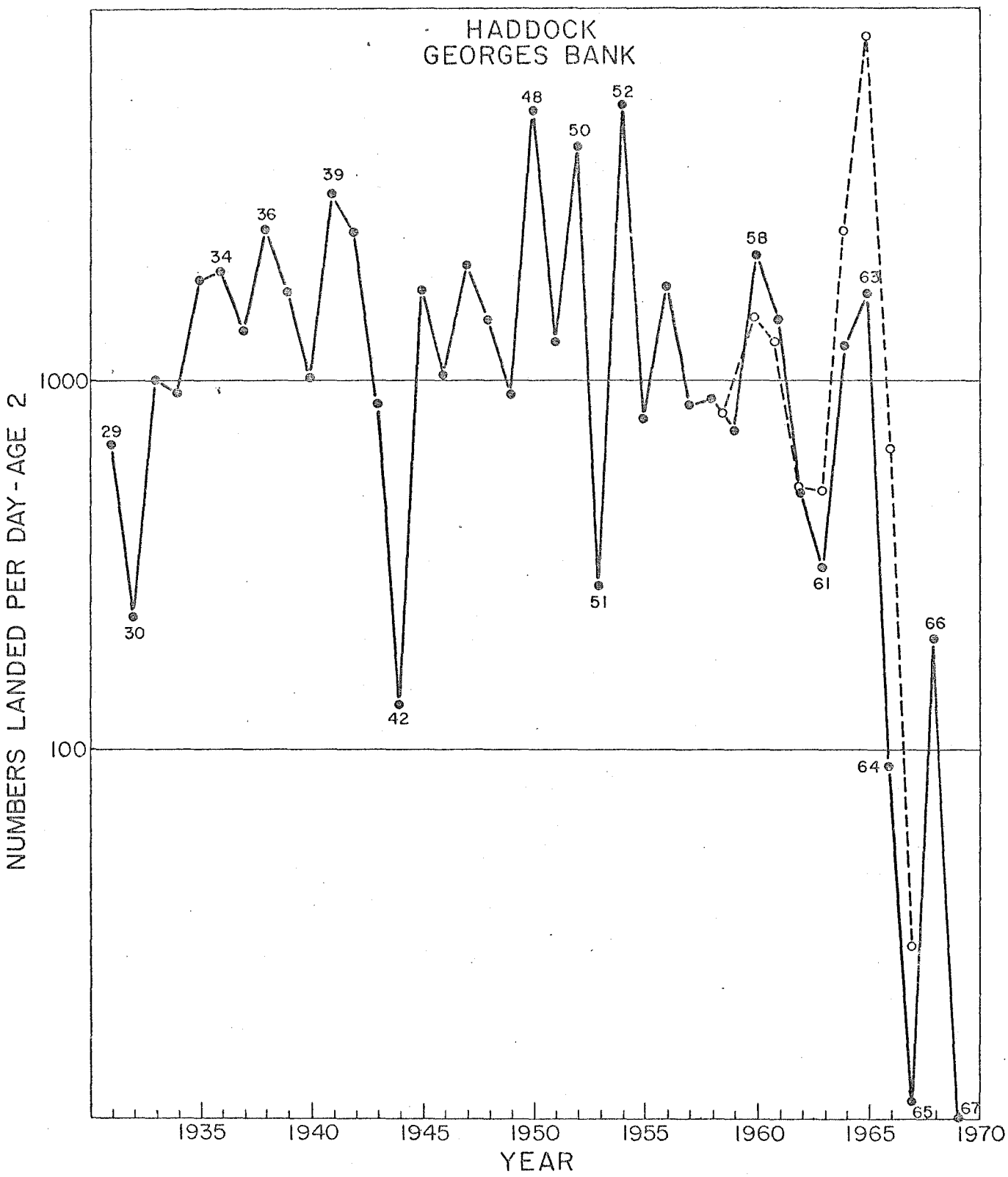


Figure 5.--Annual averages of numbers of two-year-old fish landed per day fished by U.S. fleet, 1931-68 (see text for explanation).

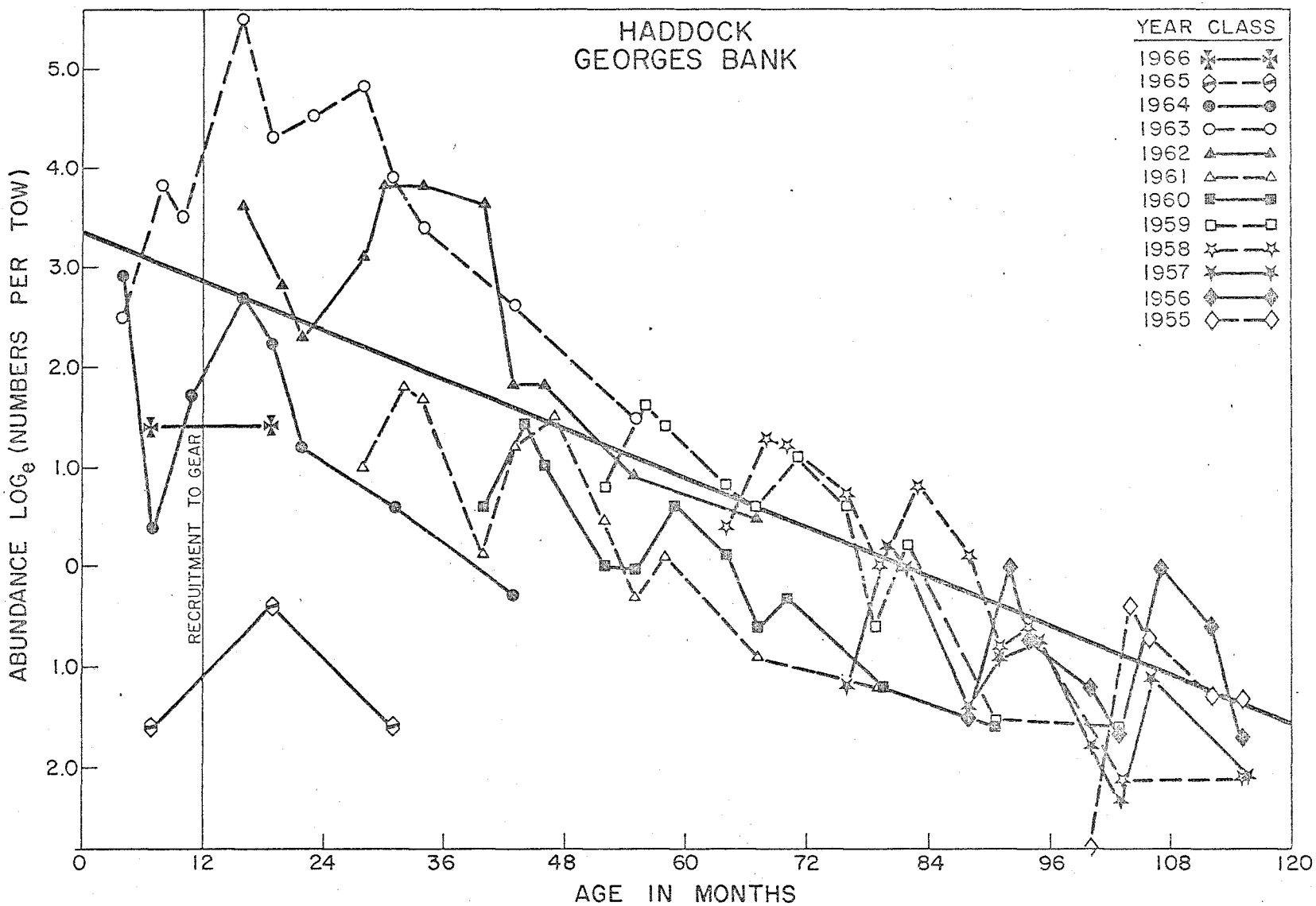


Figure 5a. Log_e numbers of haddock caught per tow on Albatross IV, ground fish surveys by age group and year class.

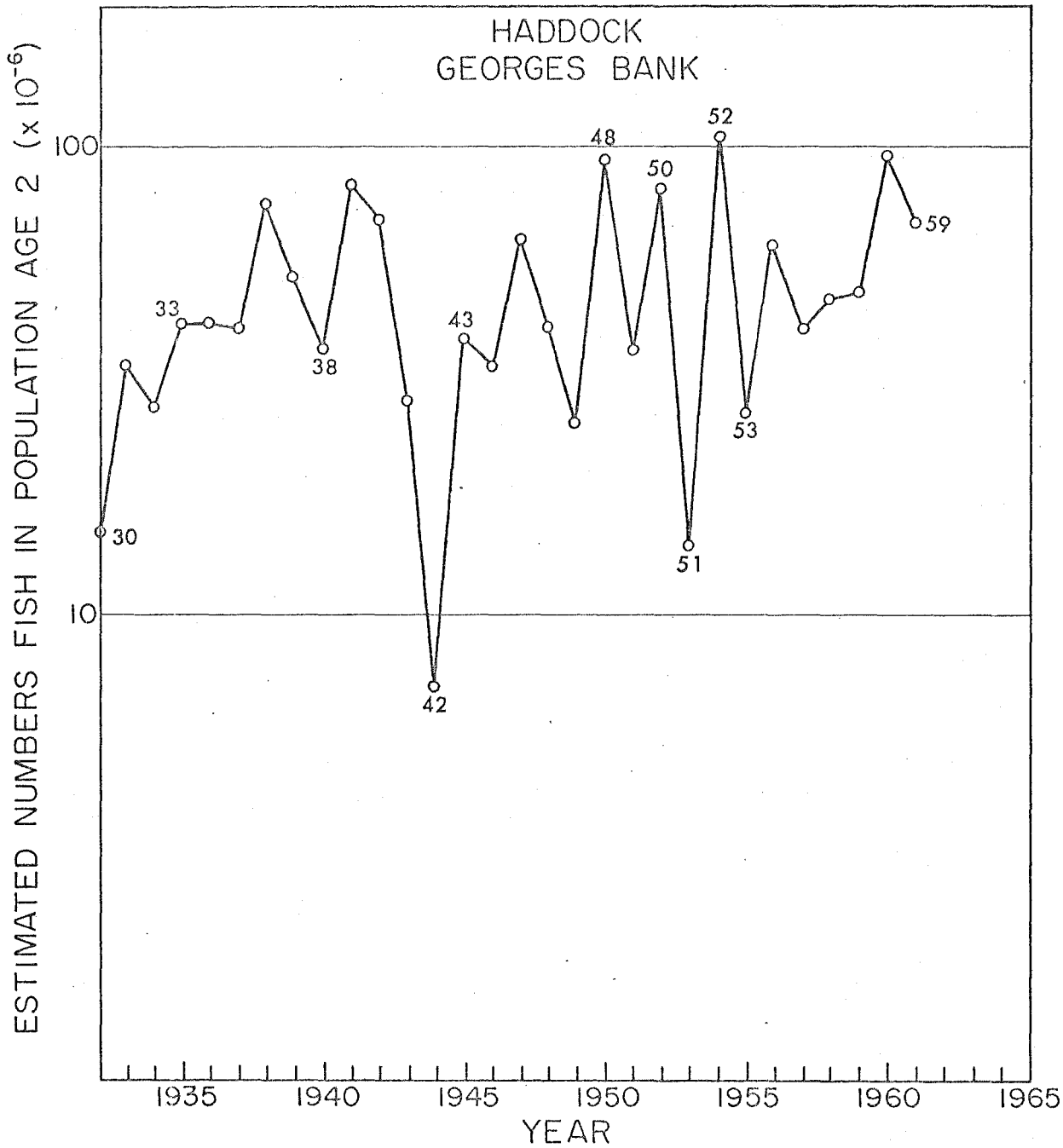


Figure 6.--Numbers of two-year-old haddock in Georges Bank population, 1931-62.

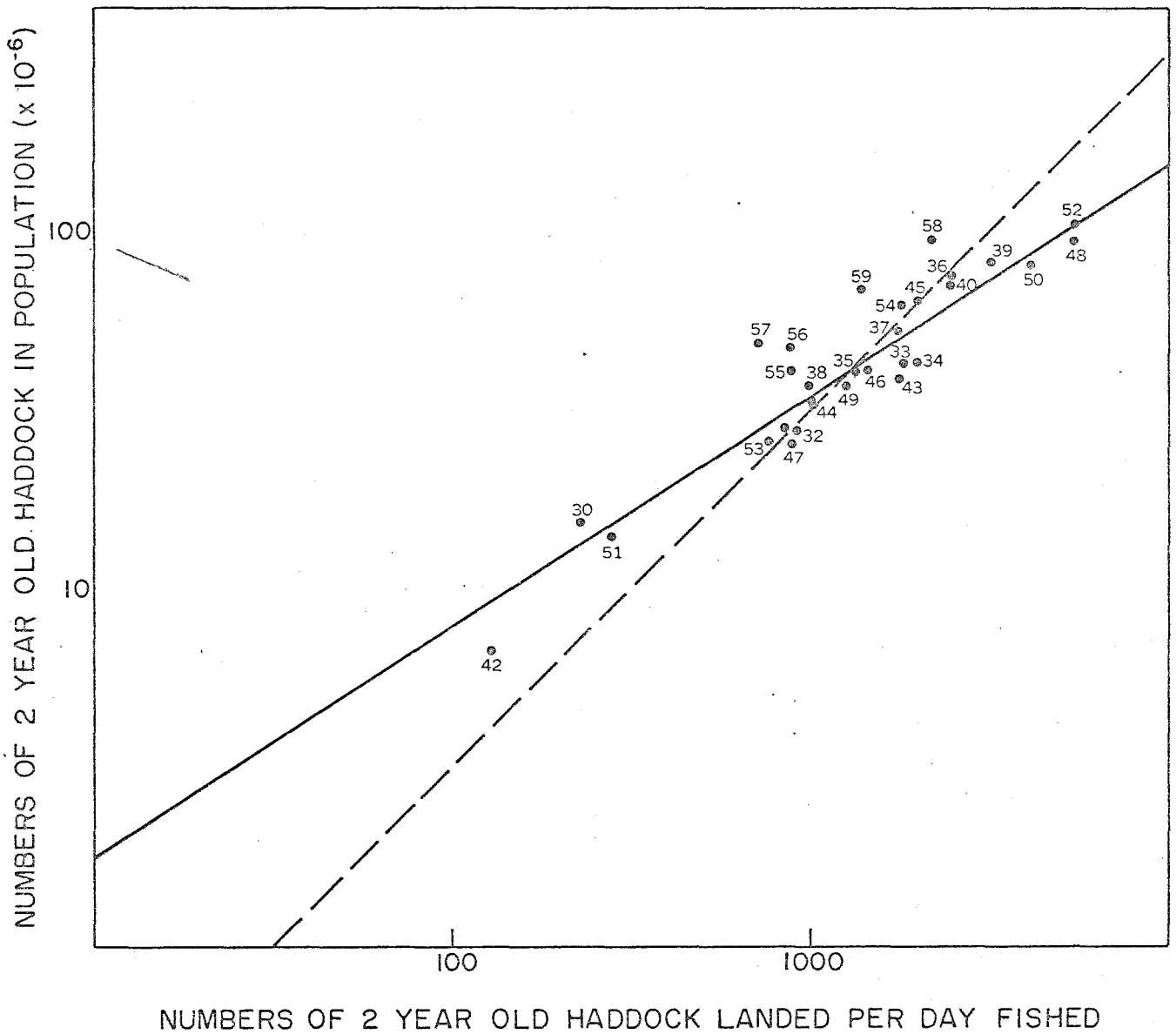


Figure 7.--Relation between catch per day and virtual population indices of two-year-old haddock on Georges Bank.

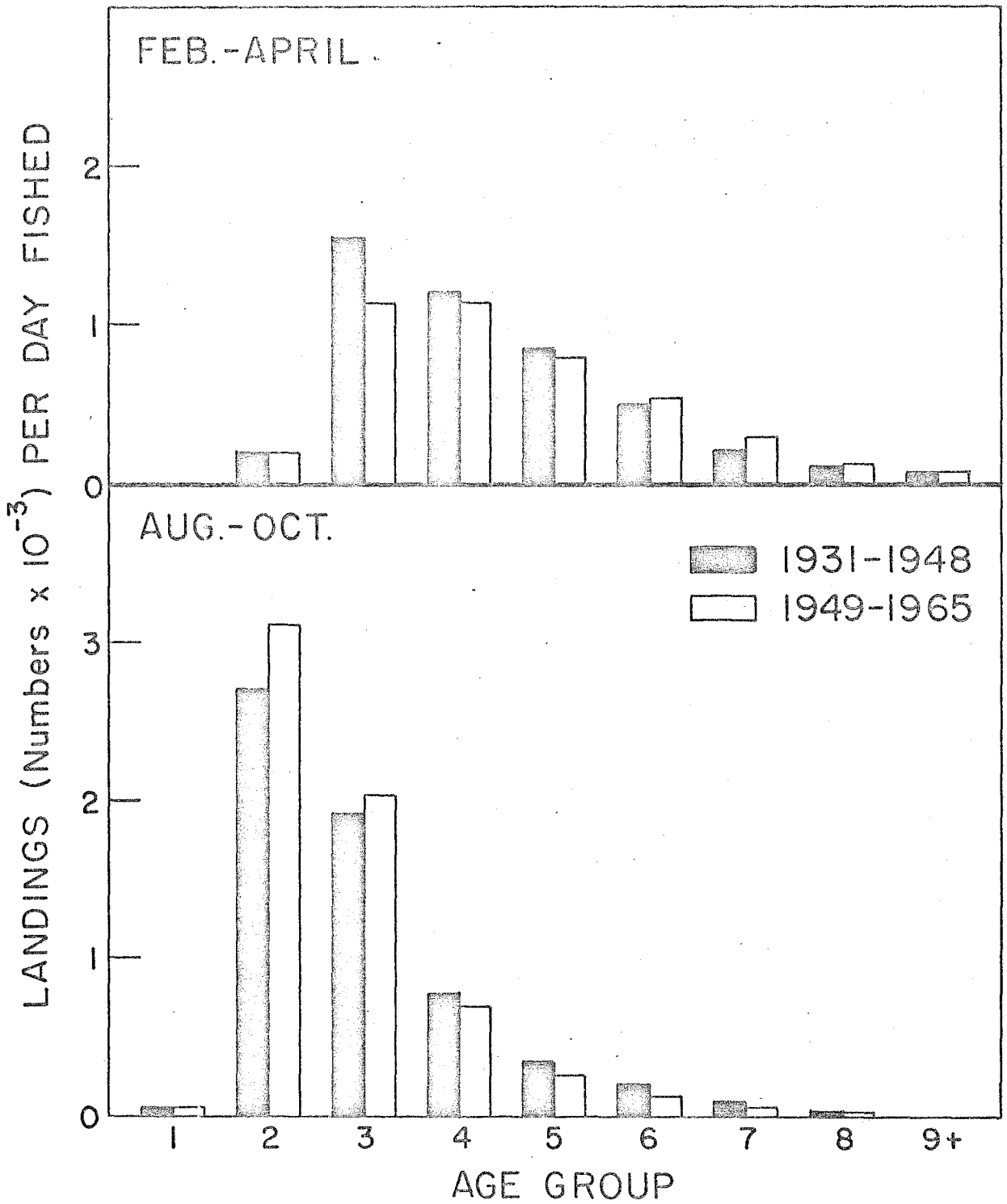


Figure 8.--Haddock landings per day at age for Georges Bank fishery during spawning season (February-April), and in the autumn (August-October) when principal recruitment to fishery occurs at age two.

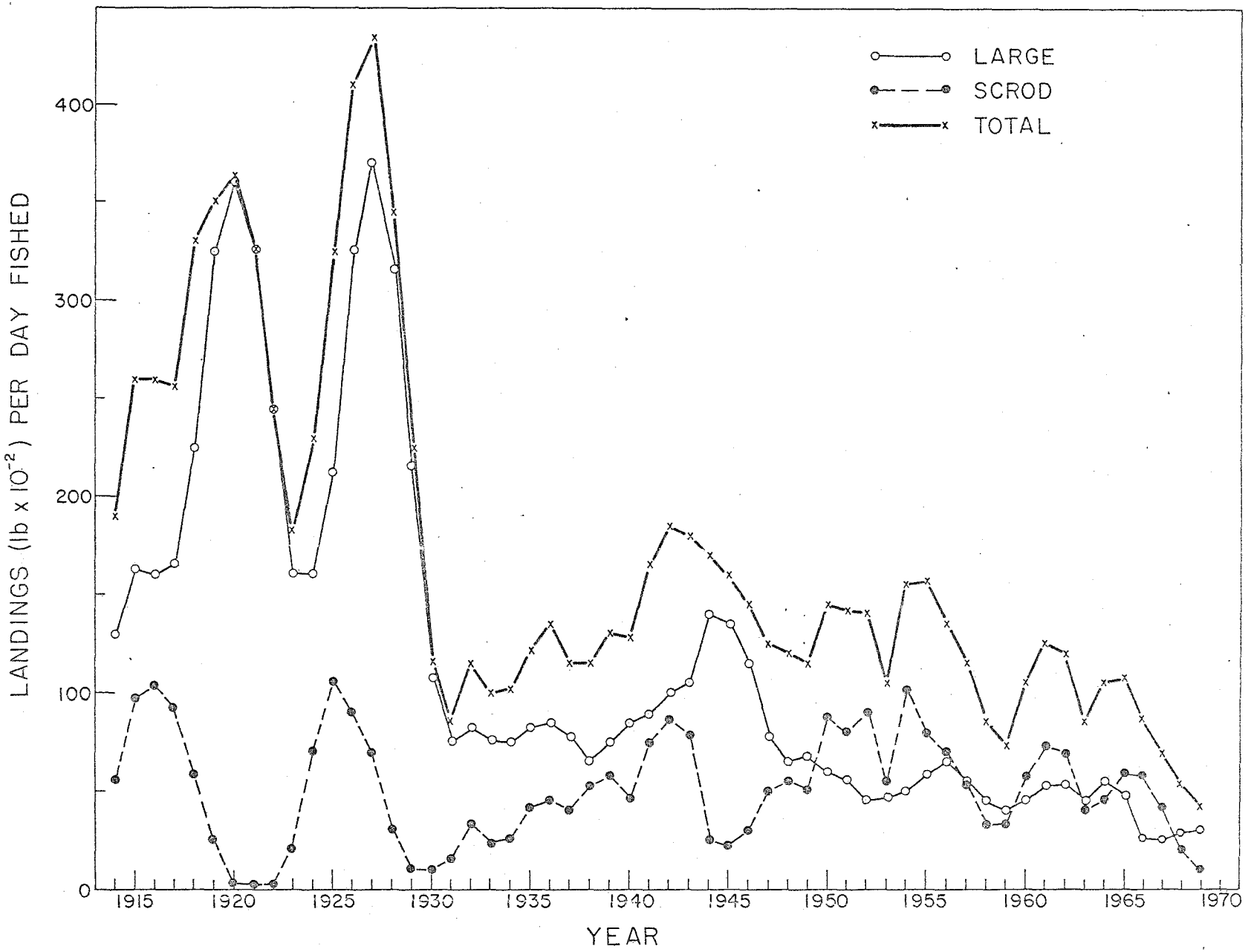


Figure 9.--Georges Bank haddock landings (hundreds of pounds) per standard day fished by principal market categories.

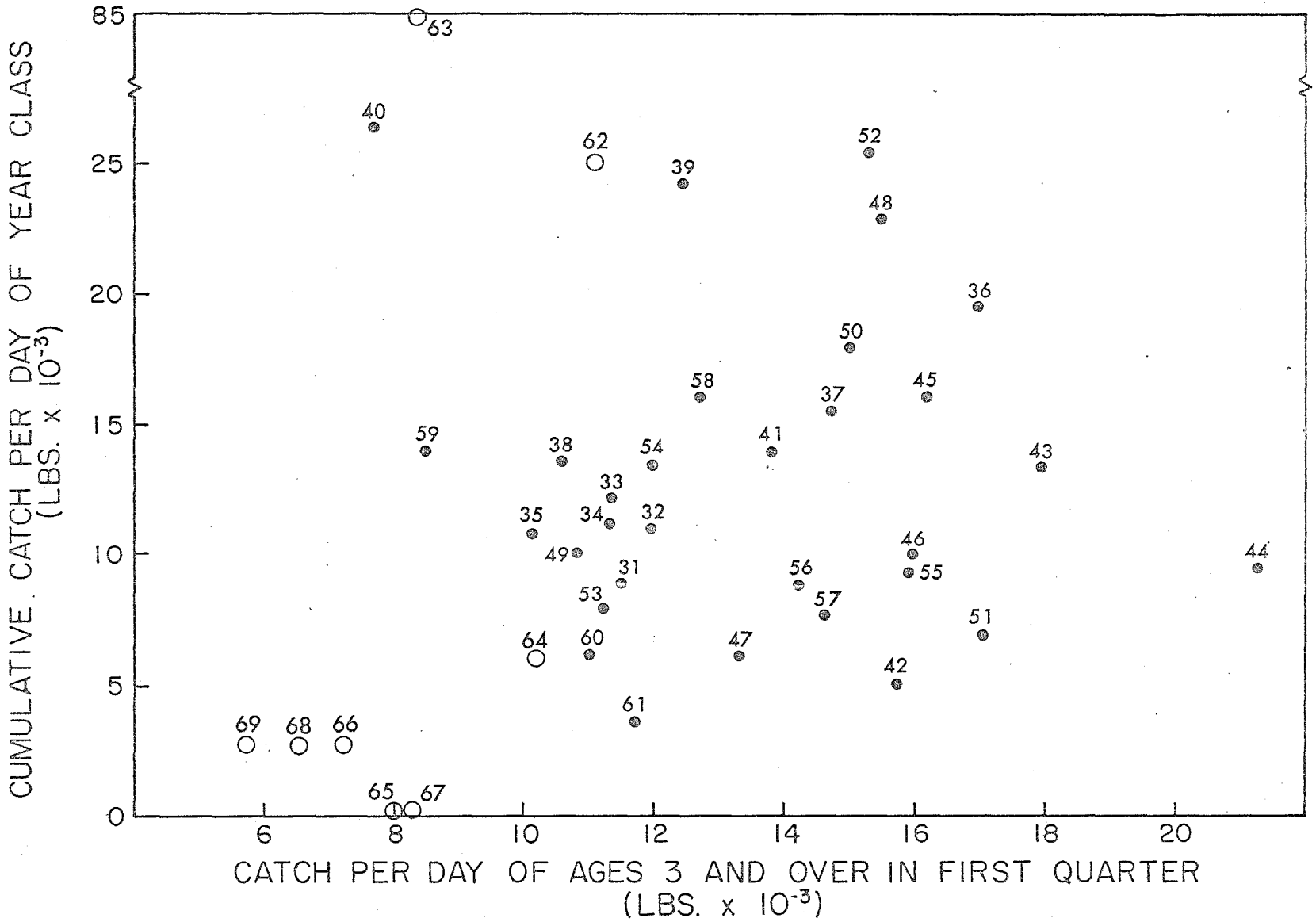


Figure 10.--Georges Bank haddock spawning stock (February-April landings per day of mature fish) vs. lifetime abundance index (cumulative landings per day at all ages) for resulting year class in years 1931-1969. Number beside each point represents year class. Open circles represent estimates of expected lifetime yield given fishing effort at average 1931-60 level.

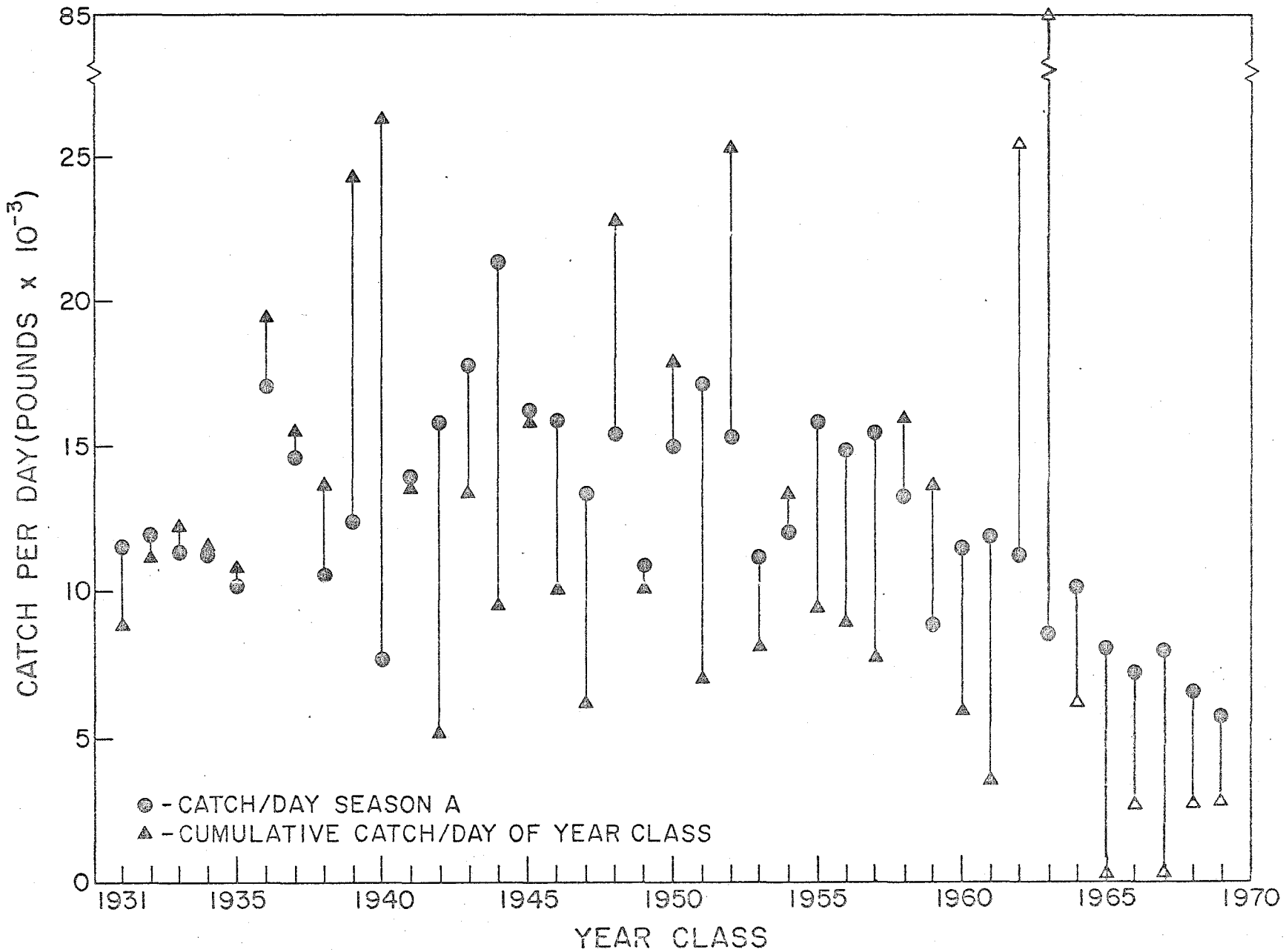


Figure 11.--Georges Bank haddock stock-recruitment relation, 1931-1969. Data same as plotted in figure 10.

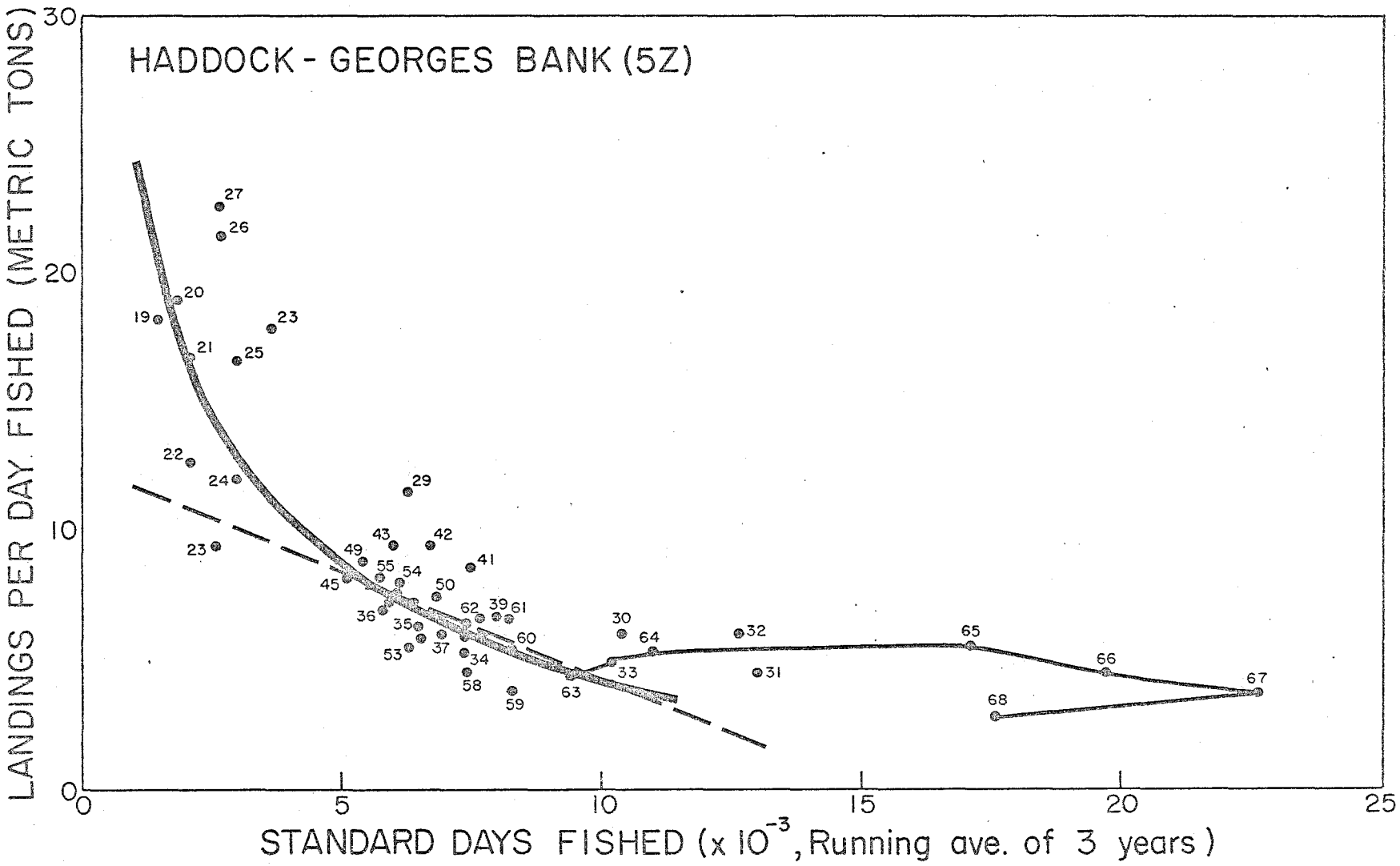


Figure 12.--Relation between abundance of haddock and total effort for Georges Bank.

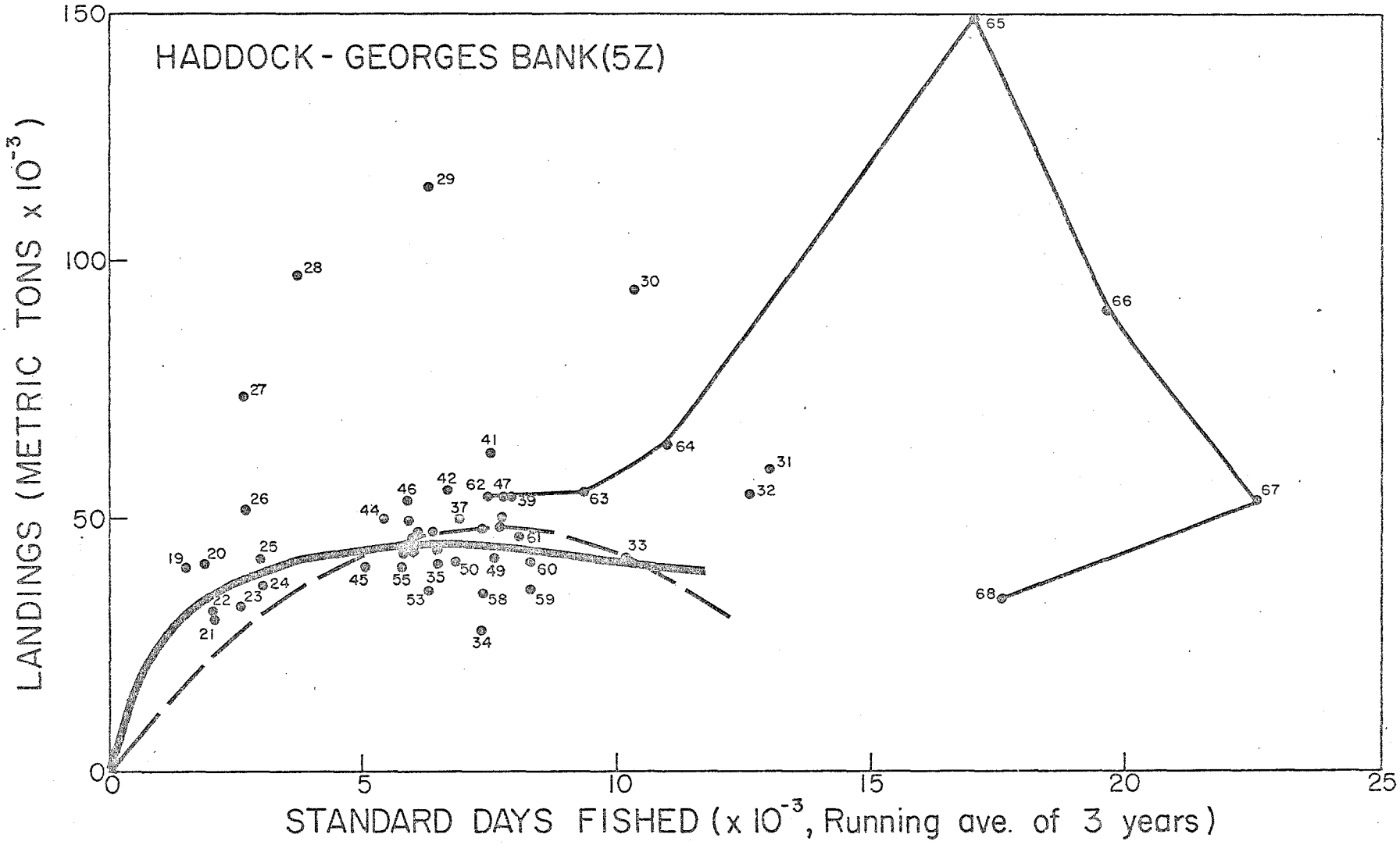


Figure 13.--Relation between total landings of haddock and effort for Georges Bank.

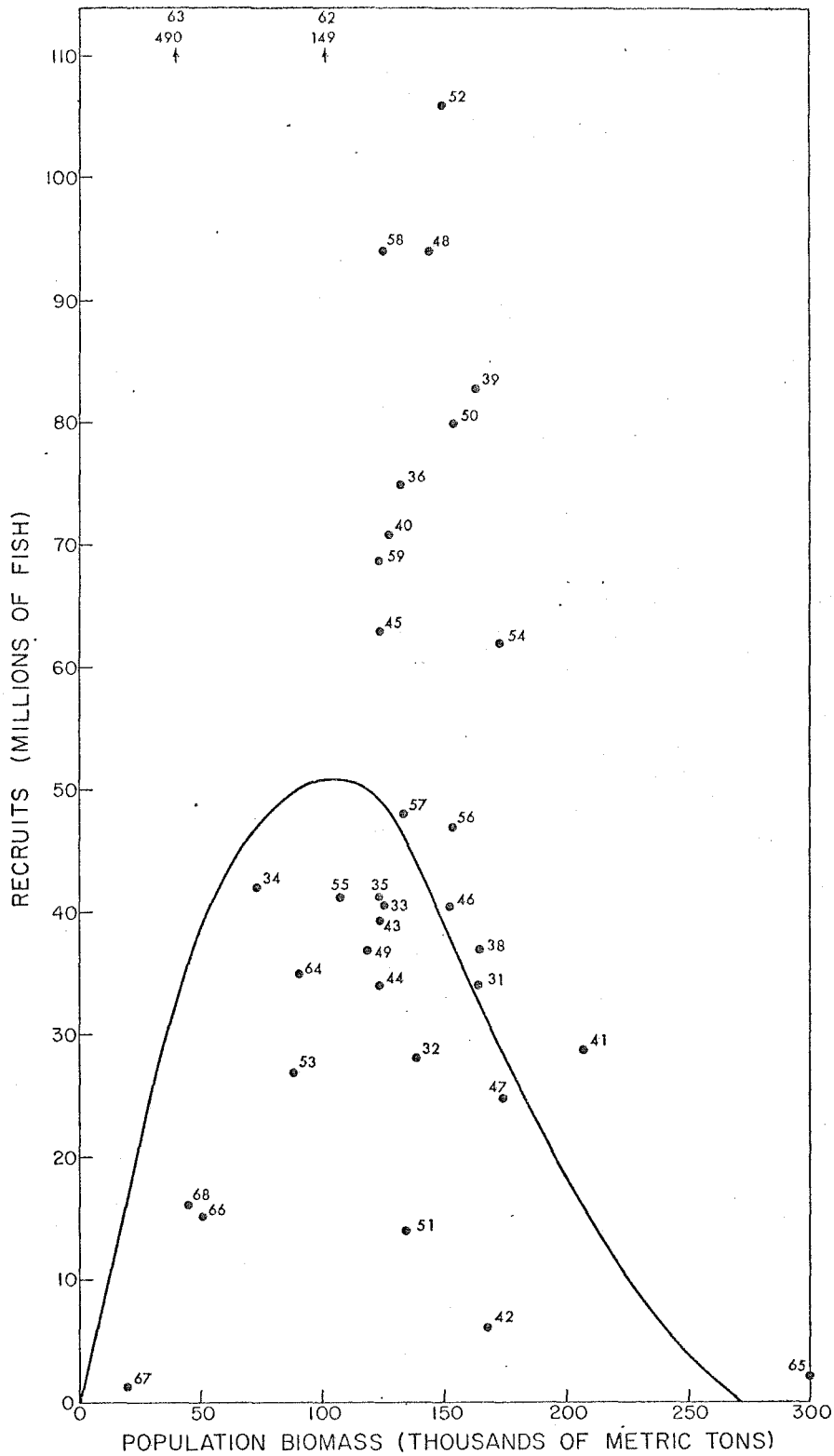


Figure 14. Stock recruitment curve derived from yield curves and observed points.