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Assessment of Red Hake in ICNAF Subarea 5 and Statistical Area 6[1]

by

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ABSTRACT

Commercial landings, research vessel survey results, age composition, and mortality, yield per recruit, and stock size estimates were presented and utilized to calculate estimates of the 1974 TAC. Red hake landings from the Georges Bank and Southern New England-Middle Atlantic stocks increased, respectively, from an estimated 900 MT and 11,300 MT in 1970 to 29,200 MT and 43,900 MT in 1972. Fall 1973 survey abundance indices improved for the former stock from 1972 but declined sharply for the latter, with good incoming year-classes indicated for Georges Bank. U.S.S.R. age data were examined indicating serious discrepancies probably resulting from possible ageing errors, insufficient sample sizes, or bias in the sampling designs. Total mortality (Z) estimates for the Southern New England-Middle Atlantic stock averaged 0.90 for 1965-1972, varying from 1.13 in 1965 to 0.68 in 1970. Natural mortality (M) estimates varied from 0.4 to 0.6. Stock size was estimated from survey cruise data and from commercial landings utilizing mortality estimates and the catch equation. Assuming M = 0.4 and fishing mortality not to exceed F_{max} at the current age of recruitment, a 1974 TAC of 22,000 MT and 28,000-38,000 MT was calculated for the Georges Bank and Southern New England-Middle Atlantic stocks, respectively.

INTRODUCTION

An intensive fishery for red hake (Urophycis chuss) was developed in ICNAF Subarea 5 and Statistical Area 6 in the mid-1960's by the U.S.S.R. A. U.S. fishery had existed prior to this time, but was restricted primarily to Southern New England waters. Combined landings peaked at about 113,500 MT in 1966 and then declined sharply to 20,300 MT in 1968. Following an increase to nearly 55,000 MT in 1969, landings dropped to 12,500 MT in 1970 but increased steadily to nearly 76,000 MT in 1972.

A total allowable catch (TAC) for 1973 of 40,000 MT was set for Subdivision 5Zw and Statistical Area 6 by the Commission at the 1972 Annual Meeting. Of this amount, 22,000 MT was allocated to the U.S.S.R., 15,000 MT to the U.S., and 3,000 MT to other nations. Since landings in Subdivision 5Ze were less than 6,000 MT in 1968-1971, a TAC was not set for that area assuming that landings in 1972 would also be low. However, 1972 landings from Subdivision 5Ze increased to 39,000 MT.

Previous assessment studies of red hake by Rikhter (1970a, 1970b, 1972a, 1972b, 1973a, 1973b) pertained primarily to the stock in Southern New England and presented estimates of mortality, stock size, and potential yield. These studies and a Working Paper by Anderson and Au (1972 Annual Meeting) provided the basis for the 1973 TAC of 40,000 MT.

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The present paper considers both the Georges Bank and Southern New England-Middle Atlantic stocks and presents a review of the landings, research vessel survey results, age compositions, mortality and yield per recruit estimates, and estimates of stock size and potential yield.

STOCKS

Rikhter (1968) proposed that three groups of red hake exist in Subarea 5 and Statistical Area 6. The first inhabits the northwest slope of Georges Bank, the second occupies the southwest slope of Georges Bank, and the third extends from Cape Cod to the Middle Atlantic. Later papers by Rikhter (1970a, 1970b, 1972a, 1972b, 1973b) refer only to two stocks (southern and southwestern Georges Bank and Cape Cod-Hudson Canyon area). U.S. landings from the Gulf of Maine suggest the existence of a small stock there.

The existence of three stocks is assumed in this paper: (1) Southern New England-Middle Atlantic; (2) Georges Bank; and (3) Gulf of Maine. These designations are based on the groupings reported by Rikhter as well as distribution of U.S. survey cruise catches. Data are not conclusive regarding precise boundaries between the various stocks and overlap appears to occur during certain seasons. Figures 1 and 2 outline the areas assumed to be inhabited by the stocks. The Southern New England-Middle Atlantic stock occupies Subdivision 5Zw, Statistical Area 6, and U.S. Statistical Area 526 in Subdivision 5Ze. The latter area includes Nantucket Shoals and extends east to the 69° W longitude line. This stock is also delineated by survey sampling strata 1-12, 61-76. The Georges Bank stock occupies the portion of Subdivision 5Ze east of 69° W and includes U.S. Statistical Areas 522-525 and is further defined by survey sampling strata 13-22, 29-30. The Gulf of Maine stock occupies Division 5Y and U.S. Statistical Area 521 in Subdivision 5Ze and survey sampling strata 23-28, 36-40.

COMMERCIAL LANDINGS

Since the areas assigned to the various stocks do not conform with ICNAF divisions and subdivisions, landings were estimated for each stock. U.S. landings are initially reported by the statistical areas indicated in Figure 1 and hence were easily assigned to the respective stocks. However, in order for the landings of other nations to be assigned to stocks, they first were estimated by U.S. statistical areas. NMFS aerial surveillance reports of fishing vessel activity were utilized to estimate the average number of vessels (by country and tonnage class) fishing each month in each statistical area. Monthly landings of red hake by country and tonnage class were obtained from data submitted to the ICNAF Secretariat. Landings by country-tonnage class per month per statistical area were estimated by assuming a direct proportion between the average number of vessels sighted and landings. The procedure is limited by assuming that (1) the same proportion of vessels of a given country-tonnage class sighted in a month were catching red hake in all areas provided that landings were reported and (2) catch/effort for red hake was constant in all areas. In spite of these limitations, it is felt that the procedure provided the only presently-viable method for assigning landings to stocks.

Red hake landings by ICNAF area for 1960-1972 are provided in Table 1 only as a reference base since landings by stock are of greater importance. U. S. landings indicated for 1960-1965 are greater than those given in the ICNAF Statistical Bulletins because they include landings for industrial purposes which were not reported earlier.

Estimated landings from the Southern New England-Middle Atlantic stock increased from 4,300 MT in 1960 to 80,800 MT in 1966, declined to 16,300 MT in 1968, rose to 52,600 MT in 1969, dropped to 11,300 MT in 1970, and then increased rapidly to 43,900 MT in 1972 (Table 2, Figure 3) U S landings averaged 29,100 MT during 1963-1965, peaked at 32,600 MT in 1964, dropped sharply to 4,000 MT in 1966, and then averaged only 4,600 MT from 1966 to 1972. U.S. landings in 1973 were 3,700 MT as compared to 2,000 MT in 1972. The major fishery was conducted by the U.S.S.R. beginning in 1965. Several other nations reported landings varying from 100 MT in 1969 to 2,300 MT in 1971.

Landings from the Georges Bank stock increased from virtually nothing in 1962 to an estimated 31,700 MT in 1966 (Table 2, Figure 3). This increase was followed by a rapid decline to only 900 MT in 1970 and then a rapid climb to 29,200 MT in 1972. The Georges Bank stock had no directed fishery until the U.S.S.R. fishery began in 1963.

Landings from the Gulf of Maine stock (Table 2, Figure 3) have been relatively insignificant, averaging only 2,200 MT during 1960-1972. Landings from Division 5Y averaged about 900 MT (41 percent) while those from Statistical Area 521 averaged about 1,300 MT (59 percent).

RESEARCH VESSEL SURVEYS

Relative Abundance

U.S. Albatross IV groundfish survey (Grosslein, 1969) catch data were used to estimate relative stock abundance. Stratified mean pounds per tow indices for each stock were calculated from fall (1963-1973) and spring (1968-1973) surveys (Table 3, Figure 4). The fall surveys provided a longer series of observations that the spring cruises. Bowman (1972) reported that red hake were uniformly distributed throughout both inshore and offshore areas during the fall surveys whereas they were primarily concentrated only along the deep, offshore water slopes during the spring surveys. Since the spring and fall indices were calculated from the same sampling strata, the fall index would presumably provide a better measure of relative abundance.

Relative abundance of the Southern New England-Middle Atlantic stock decreased from a high of 17.75 pounds/tow in 1963 (fall) to 5.89 in 1967. The fall index remained fairly steady from 1968 to 1971 averaging 9.43 pounds/tow. In 1972 the index rose sharply to 14.61 but then dropped to 6.74 in 1973.

The fall index on Georges Bank dropped from 15.04 pounds/tow in 1963 to 4.73 in 1964 and remained fairly steady through 1973 (2.84 average for 1964-1973). Relative abundance at the time of the 1973 fall cruise was 4.39 pounds/tow, the highest since 1964.

The Gulf of Maine fall index dropped from 11.94 pounds/tow in 1963 to 0.55 in 1968, increased steadily to 4.73 in 1972, and then dropped to 2.53 in 1973.

Young-of-the-Year Abundance

Relative abundance of young-of-the-year red hake was estimated by the stratified mean number/tow measuring 10 cm or less from fall surveys (Table 4). Even though red hake of this size are not normally abundant in survey catches, unusually large numbers caught would perhaps signify the presence of a good year-class. Young-of-the-year indices were exceptionally high in 1966 for the Southern New England-Middle Atlantic stock and in 1969, 1971, and 1971, for the Georges Bank stock. Superficial as these data are, they nevertheless suggest the possibility of improved recruitment to the Georges Bank stock beginning in 1971.

AGE COMPOSITION OF LANDINGS

Age composition of U.S.S.R. red hake landings constitute the only available data. Percentage age compositions were reported for the Georges Bank and Southern New England-Middle Atlantic stocks by Rikhter (1972b, 1973b). Landings were comprised mainly of ages 2-5 with a maximum age of 9.

Table 5 gives the percentage age compositions of landings from the Southern New England-Middle Atlantic stock for 1966-1972. Mean age increased from 3.00 in 1966 to 4.07 in 1968 and then decreased to 2.62 in 1972. Age 2 contributed the highest percentage in 1966, 1971, and 1972, age 3 in 1967, 1969, and 1970, and age 4 in 1968. In 1971 and 1972, 56.5 percent of the landings were age 2 fish,

Percentage age compositions of the Georges Bank landings for 1965-1966, 1968-1970 are given in Table 6. Mean age increased from 3.18 in 1965 to 4.30 in 1968 and then decreased to 3.29 in 1970. Age 3 was predominant in 1965, 1966, and 1970 while age 4 was predominant in 1968 and 1969. In 1970, 70.5 percent were age 3.

U.S.S.R. commercial age/length tables and length frequencies were obtained from the ICNAF Secretariat for 1968-1972 for Subdivisions 5Ze and 5Zw and Statistical Area 6. Since an

analysis of the Georges Bank stock was of initial concern in this paper, the 5Ze age/length and length frequency data and estimated monthly landings were employed to obtain estimated numbers landed at age. Age/length tables were available for 11 of the 20 quarters in 1968-1972. Prior to their use, the data from the age/length tables were plotted graphically to examine possible variations in year-class growth or to detect possible errors in ageing (Figures 5-8). Figures 5 and 6 show the length frequency at each age of the various year-classes by quarter. Several examples exist where model lengths of different year-classes vary by as much as 10 cm at a given age. In Figure 5, the data from 1968 (e.g. 1966 year-class at age 2, 1965 year-class at age 3, etc.) appear more consistent than other data because of the larger sample they were derived from. A further discrepancy is noted in Figure 6, third quarter, where the modal length of the 1966 year-class at age 5 is 42 cm and at age 6 is 36 cm, and the modal length of the 1965 year-class at age 6 is 42 cm and at age 7 is 38 cm. Figures 7 and 8 illustrate the length frequency of each year-class at succeeding ages. Apparent errors in ageing and/or the limitations of small samples are readily evident from numerous examples of modal lengths decreasing instead of increasing with age. The overall data appear reasonably reliable only for ages 1-3. The discrepancies are possibly explained by one or more of several factors including possible errors in ageing, insufficient sample sizes, bias in sampling design resulting in unrepresentative samples, or the presence of only slow-growing older fish in the samples due to an intensive fishery earlier removing the faster-growing larger fish. Whatever the reason, the data appear to be unreliable for determining an accurate age composition of the landings. Judging from the quality of these data, one must immediately be skeptical of past red hake age data reported and the studies based thereon.

Because of the previously-mentioned irregularities in the age/length data, they were utilized to estimate numbers landed at age by correcting for the discrepancies which existed primarily for ages greater than 3. The data from the various years (quarters) treated separately) were averaged for ages greater than 3. Averages of available tables (all ages) were used for those quarters lacking tables. For months that lacked length frequencies, data from the nearest month were applied. Sexes were combined since U.S.S.R. length frequencies were not available by sex.

The estimated numbers landed at age and percentage composition are given in Table 7. Numbers landed decreased from 15 million in 1968 to 5.3 million in 1970 and then increased to 140 million in 1972. Age 2 was predominant in 1969 and 1970 and age 3 in 1968, 1971, and 1972. Mean age decreased from 3.57 in 1968 to 2.55 in 1970 and then increased to 3.41 in 1972. The percentage compositions for 1968-1970 differed substantially from these reported by Rikhter (1972b)(Table 6).

MORTALITY

Instantaneous total mortality (Z) estimates were obtained for the Southern New England-Middle Atlantic stock for 1967-1972 using mean number per survey haul per age given by Rikhter (1973a)(Table 8). Assuming full recruitment at age 3, total mortality for each year was determined as the slope of the line obtained by plotting $\log_e$ of abundance (mean number per haul) against age for ages 3-5 (Table 10). Estimates varied from 0.68 in 1970 to 0.98 in 1968 and averaged 0.86. The 1972 estimate was 0.90.

This method is reliable only if year-class strength is relatively constant and/or availability changes from year to year. Even though red hake year-class strength quite likely varies, this method was used instead of the method of comparing abundance of a year-class in succeeding years because (1) the catch data indicated a change in availability from 1971 to 1972, (2) a Z for 1968 of 0.43 obtained by the second method seemed too low, and (3) estimates of Z were desired for all years.

Estimates of Z for 1965 (1.13) and 1966 (0.88) (Table 10) obtained from Rikhter (1970a) were determined by the difference of the natural logarithms of the abundance of adjacent age-groups in a given year from commercial catches. All of the Z values for 1965-1972 were used with landings data to estimate stock size (described in a later section).

Rikhter (1970a) estimated an instantaneous natural mortality coefficient (M) of 0.9 by assuming that Z calculated at the beginning of 1965 (0.9) approximated M since fishing prior

to 1965 had been conducted at a low intensity. Rikhter did not indicate for which red hake stock the Z of 0.9 was calculated. However, there was an intensive U.S. fishery in Southern New England prior to 1965 suggesting that if the Z of 0.9 was calculated from that stock, an M of 0.9 was too high. Rikhter reported estimates of Z for the Georges Bank stock of 1.18, 0.89 and 0.65 in 1965, 1966, and 1968, respectively, and for the Southern New England-Middle Atlantic stock of 1.13, 0.88, 0.89, and 0.93 in 1965, 1966, 1967, and 1968, respectively. The assumption of an M of 0.9 would result in an F of 0 even though combined landings were estimated to be 112,500 MT in 1966, 59,500 MT in 1967, and 20,000 MT in 1968 (Table 2) and hence be an overestimate. In the same paper, an estimate for M of 0.62 for the Georges Bank stock was obtained graphically from the relationship between Z and f (fishing effort). By virtue of the validity of the latter technique as compared to the former, the estimate of 0.62 appears more acceptable than 0.9.

The Z values for the Southern New England-Middle Atlantic stock for 1965-1972 in Table 10, which vary from 0.68 to 1.13 and average 0.90, indicate that M could not be as high as 0.9 but instead should be no greater than 0.6.

Beverton and Holt (1959) suggest that for the gadiforms (including red hake) M is generally two to three times K (from von Bertalanffy growth equation). Rikhter (1970b) reported a K of 0.21 and 0.19 for the two red hake stocks. Therefore, M would be expected to be between 0.4 and 0.6.

YIELD PER RECRUIT

Growth parameters of the von Bertalanffy equation were calculated by Rikhter (1970b) for the Georges Bank and Southern New England-Middle Atlantic stocks as follows: K = 0.21 and 0.19, L_∞ = 51 cm and 51 cm, and t_c = -.083 and -1.12. Yield per recruit values were computed for the two stocks using these parameters as well as W_∞ = 1000 gm, t_r = 1, t_λ = 10, t_c = 1-4, and M = 0.4-0.6 in the Beverton and Holt (1957) model. Since the computed values were nearly identical for the two stocks, only those for the Southern New England-Middle Atlantic stock were presented here.

Mean selection age (t_c) was estimated to be approximately 1.5 years for both stocks. This was achieved from the percentage age compositions of the commercial landings (Table 5-7) by assuming 100 percent recruitment at the age with the greatest percentage composition and graphically estimating the age at 50 percent recruitment.

Yield per recruit curves for t_c = 1.5 years are plotted in Figure for M = 0.4-0.6. Values of F_{max} were 0.75, 1.15, and 1.90 for M = 0.4, 0.5, and 0.6, respectively. The values for $F_{0.1}$ varied from 0.35 for M = 0.4 to 0.55 for M = 0.6.

Yield isopleth diagrams were plotted in Figures 10 and 11 assuming M = 0.4 and 0.6. For M = 0.4, yield per recruit beyond F = 0.25 can be increased by increasing the mean selection age (t_c) beyond the current estimated level of 1.5 years. The greatest improvement in yield per recruit possible by raising t_c varies from 2 percent at F = 0.4 to 13 percent at F = 1.0. Beyond F = 0.4, a given level of yield per recruit can be maintained by simultaneously decreasing F and increasing t_c. For example, the yield per recruit obtained with F = 0.85 and t_c = 1.75 can be achieved at t_c = 2.25 with F = 0.55, a 35 percent decrease in F. Maximum yield per recruit is obtained when t_c = 3 years and F exceeds 1.4. For M = 0.6, maximum yield per recruit for F less than 0.8 is achieved when t_c = 1.5 or less and for F greater than 0.8 when t_c = 1.5-2.0 years.

STOCK SIZE AND YIELD ESTIMATES

Minimum estimates of stock size in numbers were calculated from fall survey stratified mean numbers > 10 cm per tow values (Table 9) utilizing the following equation:

$$N' = \frac{\bar{\chi} A}{a}$$

where N' = stock size (numbers)

$\bar{\chi}$ = stratified mean number > 10 cm per tow

A = area of strata sampled (square miles)

a = area swept by the trawl per haul (0.011 square miles)

The area encompassed by the various strata sets is 15,189 square miles for Georges Bank, 15,163 for Southern New England, and 12,692 for the Middle Atlantic. Results from the latter two areas were combined to give an estimate for the Southern New England-Middle Atlantic stock. Values were calculated from the fall surveys for 1964-1973 (Table 10). The estimate from each fall survey was assumed to be the minimum stock size available to the fishery at the beginning of the following calendar year. Estimates for the Middle Atlantic area for 1964-1966 (no surveys there during those years) were calculated using the average ratio of the survey number/tow of the Middle Atlantic to the Southern New England area for 1967-1973.

Stock size estimates were also calculated from annual landings and mortality estimates using the equation:

$$N_i = C_i \frac{Z_i}{F_i} \left(\frac{1}{1-e^{-Z_i}} \right)$$

Where N_i = stock size (numbers) at the beginning of year i

C_i = number landed in year i

Z_i = instantaneous total mortality in year i

F_i = instantaneous fishing mortality in year i.

Numbers landed (C_i) for each stock for 1965-1972 were calculated from the catch in weight (Table 2) and estimated mean weight values. A linear relationship between mean weight and mean age of red hake from the two stocks derived from survey data given by Rikhter (1973b) was calculated by least squares ($Y = 0.9889 + 0.0084X$, $r = 0.91$) and mean weight values (Tables 10-12) were determined from mean ages given in Tables 5-7.

Estimates were calculated for the Southern New England-Middle Atlantic stock (Tables 10-12) using the estimates of Z mentioned earlier and assuming M = 0.4-0.6.

The linear relationship between the survey stock size estimates (N') and the catch equation stock size estimates (N) for 1965-1972 for M = 0.4-0.6 determined by least squares analysis indicated a significant correlation at the 95 percent level in each case. Since landings were unknown for 1973 and 1974, stock size estimates (N) for these years comparable to those calculated for 1965-1972 from the catch equation were determined from the respective linear relationships (see Tables 10-12) using the survey stock size estimates (N') given. Estimates of numbers landed could then be calculated from the catch equation for any level of fishing mortality. Numbers landed were converted into metric tons using the average of the 1971 and 1972 mean weights.

Assuming fishing mortality equalling $F_{0.1}$, the estimated TAC for 1974 for the Southern New England-Middle Atlantic stock varies from 21,000 MT for M = 0.4 (Table 10) to 50,000 MT for M = 0.6 (Table 12). If F is allowed to reach the level of F_{max}, the TAC varies from 38,000 MT for M = 0.4 to 106,000 MT for M = 0.6.

In order to obtain an estimate of the 1974 TAC for the Georges Bank stock, the following procedure was used: the ratio of the survey stock size estimate (N') to the catch equation stock size estimate (N) calculated each year for the Southern New England-Middle Atlantic stock was applied to the survey stock size estimate for Georges Bank to obtain a stock size estimate for the latter stock comparable to that derived from the catch equation for the former stock. The ratio of the numbers landed to the latter stock size estimate, which is equivalent to $F/Z\ (1-e^{-Z})$, allowed F and Z to be obtained from work table values of F, Z, and $F/Z\ (1-e^{-Z})$. The results are given Tables 10-12. They indicate that F was very low in 1969 and 1970 when landings were low (1,887 and 868 MT) and then increased in 1971 and 1972 as landings increased to 8,867 and 29,184 MT. Assuming fishing mortality equalling $F_{0.1}$, the TAC for 1974 varies from 12,000 MT for M = 0.4 (Table 10) to 29,000 MT for M = 0.6 (Table 12). If F is increased to F_{max}, the TAC varies from 22,000 MT at M = 0.4 to 61,000 MT at M = 0.6.

DISCUSSION

Red hake landings from the two stocks have fluctuated widely since the U.S.S.R. fishery began in 1963. Peak landings in 1966 estimated at 80,800 MT from the Southern New England-Middle Atlantic stock and 31,700 MT from the Georges Bank stock apparently resulted from intensive fishing effort directed at an under-utilized or virgin biomass, the latter particularly being the case for the Georges Bank stock. Following the heavy removals from these accumulated stocks, landings quickly diminished (Figure 3). Landings from the Southern New England-Middle Atlantic stock increased sharply in 1969 due to increased stock size (Table 12) presumably influenced by an apparently strong 1966 year-class as indicated by survey data (Table 4). Even though the stock size was again high in 1970, landings were low due to low fishing mortality. U.S.S.R. vessels concentrated on mackerel, sea herring, and silver hake that year. Landings after 1970 from both stocks showed marked increases each year with 1972 landings estimated at 43,900 MT and 29,200 MT for the Southern New England-Middle Atlantic and Georges Bank stocks, respectively.

Since measures of fishing effort directed towards red hake are unavailable, changes in relative stock abundance can be determined only from research vessel surveys. Data presented earlier in this paper revealed inadequacies and limitations in the available age data and mortality coefficient estimates which accordingly limit the reliability of the results of all analyses reported in this paper.

Survey data indicate increased numbers in the Georges Bank stock at the beginning of 1974 compared with 1973. This improvement is likely due to recruitment from the 1969, 1971, and 1973 year-classes which survey data suggested were better than usual. The estimated stock size (N) is comparable to that in 1965, 1966, and 1972 when landings averaged 28,400 MT. However, the 1965 and 1966 landings (24,500 MT and 31,700 MT) were taken from an accumulated unfished stock and were not maintained in the following years. The estimated 1974 TAC varies from 12,000 MT for M = 0.4 and F = 0.35 ($F_{0.1}$) to 61,000 MT for M = 0.6 and F = 1.9 (F_{max}). If fishing mortality is held at the level of $F_{0.1}$, then the TAC varies from 12,000 MT for M = 0.4 to 29,000 MT for M = 0.6. The latter value appears to be the maximum acceptable level in view of previous landings. If M = 0.4 was assumed, then fishing mortality even as high as F_{max} (0.75) would give a TAC of 22,000 MT, which appears quite reasonable. However, if M = 0.6 was assumed, fishing mortality as high as F_{max} (1.9) would result in a survival rate of only 8 percent. It would then be necessary for 92 percent of the stock to be replenished through recruitment of the 1974 year-class in order to maintain the same stock size in 1975 as in 1974.

The data in Tables 10-12 indicate that the Southern New England-Middle Atlantic stock size (N) at the beginning of 1974 was much less than in all previous years except 1968 and 1970. Landings averaged 54,000 MT in those years having a greater stock size than 1974 and 13,800 MT in 1968 and 1970. In 1967 and 1971, the two years having the closest stock sizes to 1974, landings averaged 38,400 MT. The estimated TAC for 1974 varies from 21,000 MT to 106,000 MT depending on M and F. If F is held at the level of $F_{0.1}$, then the TAC varies from 21,000 MT for M = 0.4 to 50,000 MT for M = 0.6. The latter value equals the 1974 TAC proposed by Rikhter (1973a). In view of the previous comparison between stock size and landings, this value would appear to be too high. Assuming M = 0.4, fishing mortality at the level of F_{max} (0.75) would result in a TAC of 38,000 MT. The F value for 1965-1972 (Table 10) averaged

0.5 A TAC at M = 0.4 and F = 0.5 would be 28,000 MT. A reasonable level for the 1974 TAC appears, therefore, to range from 28,000 MT to 38,000 MT.

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Table 1. Red hake landings (MT) from ICNAF Divisions 5Y, 5Z, Subdivisions 5Ze and 5Zw, and Statistical Area 6.

Area	Year	U.S.	U.S.S.R.	Canada	Spain	Poland	Japan	Bulgaria	Romania	G.D.R.	Other	Total
5Y	1960	3,048	---	---	---	---	---	---	---	---	---	3,048
	1961	3,221	---	---	---	---	---	---	---	---	---	3,221
	1962	2,089	---	---	---	---	---	---	---	---	---	2,089
	1963	622	270	---	---	---	---	---	---	---	---	892
	1964	155	---	---	---	---	---	---	---	---	---	155
	1965	200	---	3	---	---	---	---	---	---	---	203
	1966	634	---	5	---	---	---	---	---	---	---	639
	1967	92	---	13	---	---	---	---	---	---	---	105
	1968	82	---	---	---	---	---	---	---	---	---	82
	1969	140	---	---	---	---	---	---	---	---	---	140
	1970	249	---	---	---	---	---	---	---	---	---	249
	1971	268	---	---	---	---	---	---	---	---	---	268
	1972	373	5	---	---	---	---	---	---	---	---	378
	1973	286										
5Z	1960	4,365	---	---	---	---	---	---	---	---	---	4,365
	1961	8,876	---	---	---	---	---	---	---	---	---	8,876
	1962	12,111	---	---	---	---	---	---	---	---	---	12,111
	1963	22,372	3,205	---	---	---	---	---	---	---	---	25,577
	1964	26,439	3,588	---	---	---	---	---	---	---	---	30,027
	1965	18,973	58,546	26	---	---	---	---	---	---	---	77,545
	1966	3,646	82,889	11	---	---	---	---	---	---	---	86,546
	1967	5,667	37,593	7	61	748	---	---	---	---	13	44,089
5Ze	1968	545	4,509	---	---	---	---	---	---	5	---	5,059
	1969	51	4,237	---	---	---	---	---	---	---	---	4,288
	1970	100	1,815	---	---	---	---	---	---	---	---	1,915
	1971	111	4,398	---	---	---	6	1,366	---	88	---	5,969
	1972	160	37,960	---	---	11	187	1,043	---	5	---	39,366
	1973	77										
5Zw	1968	6,097	6,833	---	---	---	---	---	---	---	---	12,930
	1969	4,732	40,814	---	---	---	---	114	---	---	---	45,660
	1970	3,932	4,700	---	---	---	---	181	---	---	---	8,813
	1971	2,404	11,568	---	---	---	1	---	---	9	---	13,982
	1972	1,178	18,664	---	---	4	15	465	---	---	---	20,326
	1973	2,579										
5NK	1971	---	9,387	---	---	---	---	---	---	---	---	9,387
6	1960	664	---	---	---	---	---	---	---	---	---	664
	1961	689	---	---	---	---	---	---	---	---	---	689
	1962	589	---	---	---	---	---	---	---	---	---	589
	1963	7,986	770	---	---	---	---	---	---	---	---	8,756
	1964	6,188	8,372	---	---	---	---	---	---	---	---	14,560
	1965	6,282	11,745	---	---	---	---	---	---	---	---	18,027
	1966	590	25,722	---	---	---	---	---	---	---	---	26,312
	1967	579	14,884	---	---	---	---	---	---	---	---	15,463
	1968	367	1,865	---	---	---	---	---	---	---	---	2,232
	1969	759	4,099	---	---	---	---	---	---	---	---	4,858
	1970	659	834	---	---	---	---	16	---	---	---	1,509
	1971	821	8,285	---	---	---	7	1,218	---	---	---	10,331
	1972	817	14,704	---	---	1	534	6	43	40	---	16,145
	1973	1,135										

Table 2. Red hake landings (MT) from stocks in ICNAF Subarea 5 and Statistical Area 6.

Year	U.S.	U.S.S.R.	Canada	Spain	Poland	Japan	Bulgaria	Romania	G.D.R.	Other	Total
					Gulf of Maine						
1960	3,725	---	---	---	---	---	---	---	---	---	3,725
1961	4,254	---	---	---	---	---	---	---	---	---	4,254
1962	2,923	---	---	---	---	---	---	---	---	---	2,923
1963	1,038	623	---	---	---	---	---	---	---	---	1,661
1964	160	13	---	---	---	---	---	---	---	---	173
1965	482	1,059	3	---	---	---	---	---	---	---	1,544
1966	868	156	5	---	---	---	---	---	---	---	1,029
1967	169	---	13	---	---	---	---	---	---	---	182
1968	115	195	---	---	---	---	---	---	4	---	314
1969	144	359	---	---	---	---	---	---	---	---	503
1970	320	12	---	---	---	---	---	---	---	---	332
1971	377	553	---	---	---	---	10	---	29	---	969
1972	528	2,332	---	---	---	55	176	---	1	---	3,092
1973	359										
					Georges Bank						
1960	66	---	---	---	---	---	---	---	---	---	66
1961	427	---	---	---	---	---	---	---	---	---	427
1962	1	---	---	---	---	---	---	---	---	---	1
1963	333	2,852	---	---	---	---	---	---	---	---	3,185
1964	---	3,357	---	---	---	---	---	---	---	---	3,357
1965	1	24,438	26	---	---	---	---	---	---	---	24,465
1966	1	31,667	11	---	---	---	---	---	---	---	31,679
1967	1	11,959	7	61	748	---	---	---	---	13	12,789
1968	---	3,722	---	---	---	---	---	---	1	---	3,723
1969	---	1,887	---	---	---	---	---	---	---	---	1,887
1970	1	867	---	---	---	---	---	---	---	---	868
1971	3	8,489	---	---	---	---	328	---	47	---	8,867
1972	4	28,216	---	---	4	90	866	---	4	---	29,184
1973	4										
					Southern New England-Middle Atlantic						
1960	4,286	---	---	---	---	---	---	---	---	---	4,286
1961	8,105	---	---	---	---	---	---	---	---	---	8,105
1962	11,865	---	---	---	---	---	---	---	---	---	11,865
1963	29,609	770	---	---	---	---	---	---	---	---	30,379
1964	32,622	8,590	---	---	---	---	---	---	---	---	41,212
1965	24,972	44,794	---	---	---	---	---	---	---	---	69,766
1966	4,001	76,788	---	---	---	---	---	---	---	---	80,789
1967	6,168	40,518	---	---	---	---	---	---	---	---	46,686
1968	6,976	9,290	---	---	---	---	---	---	---	---	16,266
1969	5,538	46,904	---	---	---	---	114	---	---	---	52,556
1970	4,619	6,470	---	---	---	---	197	---	---	---	11,286
1971	3,224	24,596	---	---	---	14	2,246	---	21	---	30,101
1972	1,997	40,785	---	---	12	591	472	43	40	---	43,940
1973	3,714										

Table 3. Stratified mean pounds of red hake per tow from U.S. Albatross IV groundfish survey cruises.

Year/Cruise	So. New England-Middle Atlantic (Strata 1-12)	(Strata 61-76)	Georges Bank (Strata 13-22, 29-30)	Gulf of Maine (Strata 23-28, 36-40)
1963				
Fall	17.75	---	15.04	11.94
1964				
Fall	9.60	---	4.73	1.78
1965				
Fall	12.40	---	3.37	2.73
1966				
Fall	6.40	---	2.37	2.06
1967				
Fall	5.89	0.34	1.28	1.01
1968				
Spring	4.26	1.23	0.71	2.28
Fall	9.74	1.76	2.18	0.55
1969				
Spring	3.64	0.37	1.21	0.94
Fall	10.58	0.98	3.31	0.74
1970				
Spring	5.26	0.83	1.40	1.11
Fall	8.60	0.38	1.11	1.02
1971				
Spring	11.86	1.11	2.50	1.40
Fall	8.81	0.76	3.47	2.81
1972				
Spring	12.09	1.59	2.57	2.60
Fall	14.61	0.57	2.15	4.73
1973				
Spring	10.05	3.14	2.26	6.81
Fall	6.74	0.20	4.39	2.53

Table 4. Stratified mean number of red hake per tow measuring 10 cm or less from U.S. Albatross IV fall groundfish survey cruises.

Year	So. New England-Middle Atlantic (Strata 1-12)	(Strata 61-76)	Georges Bank (Strata 13-22, 28-30)	Gulf of Maine (Strata 23-28, 36-40)
1963	2.50	---	0.16	0.11
1964	0.09	---	0.05	0.00
1965	1.06	---	0.16	0.00
1966	13.25	---	0.19	0.22
1967	0.00	0.00	0.04	0.00
1968	0.00	0.04	0.07	0.01
1969	0.04	0.00	6.47	0.02
1970	0.00	0.00	1.97	0.06
1971	0.11	0.56	5.80	0.05
1972	0.06	0.16	0.17	1.22
1973	0.04	0.12	8.58	0.13

Table 5. Percentage age composition of U.S.S.R. commercial red hake catches from the southern New England area, 1966-1972, taken from Rikhter (1972b, 1973b).

Year	Age 1	2	3	4	5	6	7	8	Mean age
1966	4.9	35.5	27.8	19.9	9.9	2.0	---	---	3.00
1967	---	18.6	43.6	25.0	8.6	3.1	1.1	---	3.37
1968	---	15.0	16.9	34.3	23.6	5.3	---	4.9	4.07
1969	6.9	10.3	42.4	31.4	8.8	0.2	---	---	3.26
1970	---	1.5	73.7	23.0	1.6	0.2	---	---	3.25
1971	0.6	56.5	27.0	10.8	4.7	0.4	---	---	2.64
1972	---	56.5	30.9	8.3	2.4	1.9	---	---	2.62

Table 6. Percentage age composition of U.S.S.R. commercial red hake catches from Georges Bank, 1965-1970, taken from Rikhter (1972b).

Year	Age 1	2	3	4	5	6	7	8	9	Mean age
1965	---	28.7	35.7	27.6	5.4	2.6	---	---	---	3.18
1966	---	17.7	41.7	24.5	8.5	6.4	1.2	---	---	3.48
1967	---	---	---	---	---	---	---	---	---	----
1968	---	11.0	22.3	29.4	17.9	10.3	4.2	1.4	3.5	4.30
1969	7.1	3.7	12.9	62.9	13.0	0.4	---	---	---	3.72
1970	---	2.1	70.5	24.0	3.3	0.1	---	---	---	3.29

Table 7. Number ($x10^{-3}$) and percentage age composition of red hake landed from the Georges Bank stock, 1968-1972.

Year	Year class 1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971		Total
							Number								
1968	12	138	229	645	1,572	3,882	6,393	2,086	10						14,967
1969		6	16	52	132	312	1,035	2,390	5,302	156					9,401
1970			2	6	19	55	137	418	1,394	3,146	92				5,269
1971				151	279	605	1,461	3,357	7,433	13,090	12,097	3,985			42,458
1972					350	738	1,775	5,849	14,854	37,625	44,066	29,940	4,753		139,950
							Percentage							Ave.age	
1968	0.1	0.9	1.5	4.3	10.5	25.9	42.7	13.9	0.1					3.57	100.0
1969		0.1	0.2	0.6	1.4	3.3	11.0	25.4	56.4	1.7				2.66	100.0
1970			<0.1	0.1	0.4	1.0	2.6	7.9	26.4	59.7	1.7			2.55	100.0
1971				0.4	0.6	1.4	3.4	7.9	17.5	30.8	28.5	9.4		3.07	100.0
1972					0.2	0.5	1.3	4.2	10.6	26.9	31.5	21.4	3.4	3.41	100.0

Table 8. Mean number per haul (fall survey) per age of red hake from the Southern New England-Middle Atlantic stock, 1967-1972 (data from Rikhter, 1973a).

Year	Age 1	2	3	4	5
1967	3.28	2.80	2.18	0.96	0.36
1968	4.81	4.02	3.01	1.05	0.42
1969	5.33	3.88	4.59	1.86	0.79
1970	4.69	9.11	2.15	1.53	0.56
1971	3.12	12.03	1.42	0.84	0.28
1972	5.78	11.58	12.49	3.97	2.10

Table 9. Stratified mean number of red hake per tow measuring greater than 10 cm from U.S. Albatross IV fall groundfish survey cruises.

Year	Southern New England-Middle Atlantic (Strata 1-12)	(Strata 61-76)	Georges Bank (Strata 13-22, 28-30)
1964	22.16	(2.38)[1]	8.27
1965	29.86	(3.20)[1]	6.73
1966	15.65	(1.68)[1]	3.70
1967	12.09	1.01	2.10
1968	20.74	4.15	3.55
1969	19.94	1.82	4.52
1970	24.42	2.67	2.19
1971	19.10	3.85	5.77
1972	33.77	1.50	4.25
1973	19.51	0.41	8.46

[1]Obtained by dividing the value for strata 1-12 by the mean of the strata 61-76/strata 1-12 ratios for 1967-1973.

Table 10. Landings (Y and C), mortality coefficients (Z and F), and stock size (N) for the Southern New England-Middle Atlantic and Georges Bank red hake stocks using M=0.4[1].

	Southern New England-Middle Atlantic								Georges Bank						
Year	Z_1	F_1	Y_1 (MT)	$\bar{w}_1$ (kg)	C_1 (000's)	N_1 (000's)	N_1' (000's)	N_1'/N_1	N_2' (000's)	N_2 (000's)	C_2 (000's)	$\bar{w}_2$ (kg)	Y_2 (MT)	F_2	Z_2
1965	1.13	0.73	69,766	0.26	268,331	613,563	33,293	0.0543	11,419	210,295	94,096	0.26	24,465	0.75	1.15
1966	0.88	0.48	80,789	0.24	336,621	1,054,546	44,853	0.0425	9,293	218,659	105,597	0.30	31,679	0.84	1.24
1967	0.90	0.50	46,686	0.28	166,736	505,746	23,511	0.0465	5,109	109,871	45,675	0.28	12,789	0.68	1.08
1968	0.98	0.58	16,266	0.37	43,962	118,908	17,831	0.1500	2,900	19,333	9,546	0.39	3,723	0.87	1.27
1969	0.88	0.48	52,556	0.27	194,652	609,794	33,377	0.0547	4,902	89,616	5,897	0.32	1,887	0.08	0.48
1970	0.68	0.28	11,286	0.27	41,800	173,464	29,586	0.1706	6,241	36,583	3,215	0.27	868	0.11	0.51
1971	0.81	0.41	30,101	0.20	150,505	535,609	36,743	0.0686	3,024	44,082	35,468	0.25	8,867	2.40	2.80
1972	0.90	0.50	43,940	0.19	231,263	701,470	30,771	0.0439	7,967	181,481	100,634	0.29	29,184	1.05	1.45
1973	----	----	----	----	----	1,039,840[2]	48,281	0.0464	5,868	126,466	----	----	----	----	----
1974	1.15 0.75	0.75 0.35	37,894 20,936	0.20[3]	189,472 104,681	425,138[2]	27,367	0.0644	11,682	181,398	80,844 44,665	0.27[3]	21,828 12,060	0.75 0.35	1.15 0.75

[1]Definition of terms:
Y = landings (weight).
C = landings (number) = $Y/\bar{w}$.
N_1= stock size (number) calculated from $C_1 = N_1 \frac{F_1}{Z_1}(1-e^{-Z_1})$.
N_1'= stock size (number) calculated from survey mean no. >10 cm/tow (So. New Eng.-Mid-Atl.).
N_2' = stock size (number) calculated from survey mean no. >10 cm/tow (Georges Bank).
N_2 = stock size (number) calculated from $N_2' N_1/N_1'$.
F_2 and Z_2 obtained from $C_2 = \frac{F_2}{Z_2}(1-e^{-Z_2})$ using work table values of F, Z, and $\frac{F}{Z}(1-e^{-Z})$.

[2]Calculated from $N_1 = -379{,}229.9 + 29.3919\ N_1'$ ($r = 0.81$).

[3]Average of 1971-1972 values.

Table 11. Landings (Y and C), mortality coefficients (Z and F), and stock size (N) for the Southern New England-Middle Atlantic and Georges Bank red hake stocks using M=0.5[1].

	Southern New England-Middle Atlantic								Georges Bank						
Year	Z_1	F_1	Y_1 (MT)	$\bar{w}_1$ (kg)	C_1 (000's)	N_1 (000's)	N_1' (000's)	N_1'/N_1	N_2' (000's)	N_2 (000's)	C_2 (000's)	$\bar{w}_2$ (kg)	Y_2 (MT)	F_2	Z_2
1965	1.13	0.63	69,766	0.26	268,331	710,954	33,293	0.0468	11,419	243,996	94,096	0.26	24,465	0.65	1.15
1966	0.88	0.38	80,789	0.24	336,621	1,332,058	44,853	0.0337	9,293	275,986	105,597	0.30	31,679	0.64	1.14
1967	0.90	0.40	46,686	0.28	166,736	632,182	23,511	0.0372	5,109	137,339	45,675	0.28	12,789	0.53	1.03
1968	0.98	0.48	16,266	0.37	43,962	143,681	17,831	0.1241	2,900	23,368	9,546	0.39	3,723	0.70	1.20
1969	0.88	0.38	52,556	0.27	194,652	770,266	33,377	0.0433	4,902	113,210	5,897	0.32	1,887	0.07	0.57
1970	0.68	0.18	11,286	0.27	41,800	320,058	29,586	0.0924	6,241	67,543	3,215	0.27	868	0.06	0.56
1971	0.81	0.31	30,101	0.20	150,505	708,386	36,743	0.0519	3,024	58,266	35,468	0.25	8,867	1.32	1.82
1972	0.90	0.40	43,940	0.19	231,263	876,837	30,771	0.0351	7,967	226,980	100,634	0.29	29,184	0.79	1.29
1973	----	----	----	----	----	1,319,984[2]	48,281	0.0366	5,868	160,328	----	----	----	----	----
1974	1.65 0.95	1.15 0.45	61,114 31,527	0.20[3]	305,571 157,633	542,642[2]	27,367	0.0504	11,682	231,786	130,523 67,332	0.27[3]	35,241 18,180	1.15 0.45	1.65 0.95

[1]See Table 10 for definition of terms.

[2]Calculated from $N_1 = -474,548.8 + 37.1685\ N_1'$ ($r = 0.85$).

[3]Average of 1971-1972 values.

Table 12. Landings (Y and C), mortality coefficients (Z and F), and stock size (N) for the Southern New England-Middle Atlantic and Georges Bank red hake stocks using M=0.6[1]

	Southern New England-Middle Atlantic								Georges Bank						
Year	Z_1	F_1	Y_1 (MT)	$\bar{w}_1$ (kg)	C_1 (000's)	N_1 (000's)	N'_1 (000's	N'_1/N_1	N'_2 (000's)	N_2 (000's)	C_2 (000's)	$\bar{w}_2$ (kg)	Y_2 (MT)	F_2	Z_2
1965	1.13	0.53	69,766	0.26	268,331	845,096	33,293	0.0394	11,419	289,822	94,096	0.26	24,465	0.55	1.15
1966	0.88	0.28	80,789	0.24	336,621	1,807,794	44,853	0.0248	9,293	374,718	105,597	0.30	31,679	0.46	1.06
1967	0.90	0.30	46,686	0.28	166,736	842,909	23,511	0.0279	5,109	183,118	45,675	0.28	12,789	0.39	0.99
1968	0.98	0.38	16,266	0.37	43,962	181,491	17,831	0.0982	2,900	29,532	9,546	0.39	3,723	0.54	1.14
1969	0.88	0.28	52,556	0.27	194,652	1,045,362	33,377	0.0319	4,902	153,668	5,897	0.32	1,887	0.05	0.65
1970	0.68	0.08	11,286	0.27	41,800	720,130	29,586	0.0411	6,241	151,849	3,215	0.27	868	0.03	0.63
1971	0.81	0.21	30,101	0.20	150,505	1,045,713	36,743	0.0351	3,024	86,154	35,468	0.25	8,867	0.75	1.35
1972	0.90	0.30	43,940	0.19	231,263	1,169,116	30,771	0.0263	7,967	302,928	100,634	0.29	29,184	0.56	1.16
1973	----	----	----	----		1,828,369[2]	48,281	0.0266	5,868	220,602	----	----	----	----	----
1974	2.50 1.15	1.90 0.55	106,194 49,751	0.20[3]	530,969 248,754	761,120[2]	27,367	0.0360	11,682	324,500	226,376 106,055	0.27[3]	61,122 28,635	1.90 0.55	2.50 1.15

[1]See Table 10 for definition of terms.

[2]Calculated from $N_1 = -623{,}341.8 + 50.5522\ N'_1$ ($r = 0.90$).

[3]Average of 1971-1972 values.

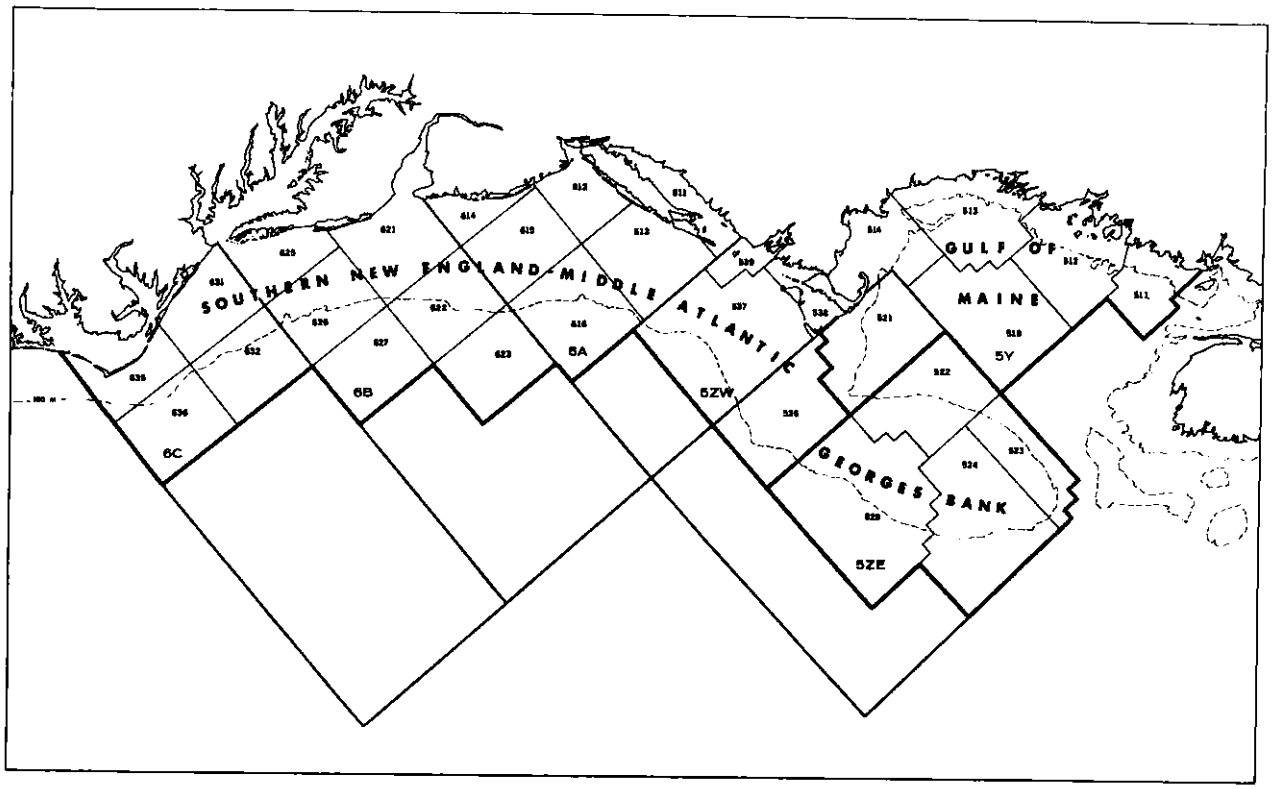

Fig. 1. Map showing the US Statistical Areas delineating the red hake stocks in ICNAF Subarea 5 and Statistical Area 6.

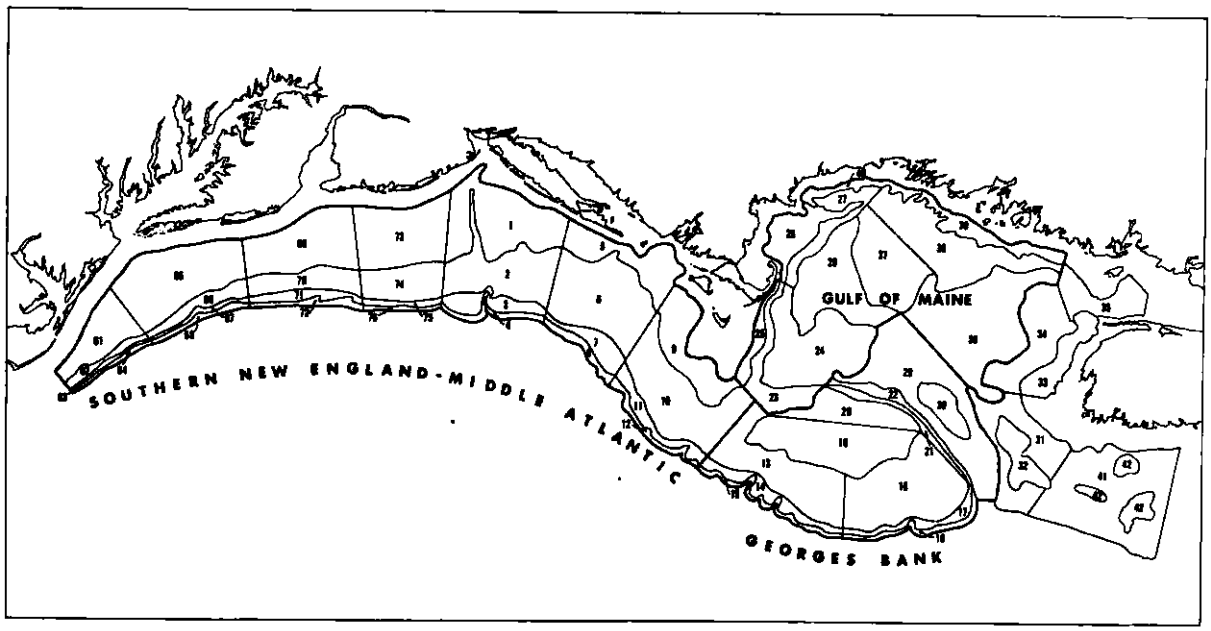

Fig. 2. Map showing the US-USSR groundfish survey sampling strata delineating the red hake stocks in ICNAF Subarea 5 and Statistical Area 6.

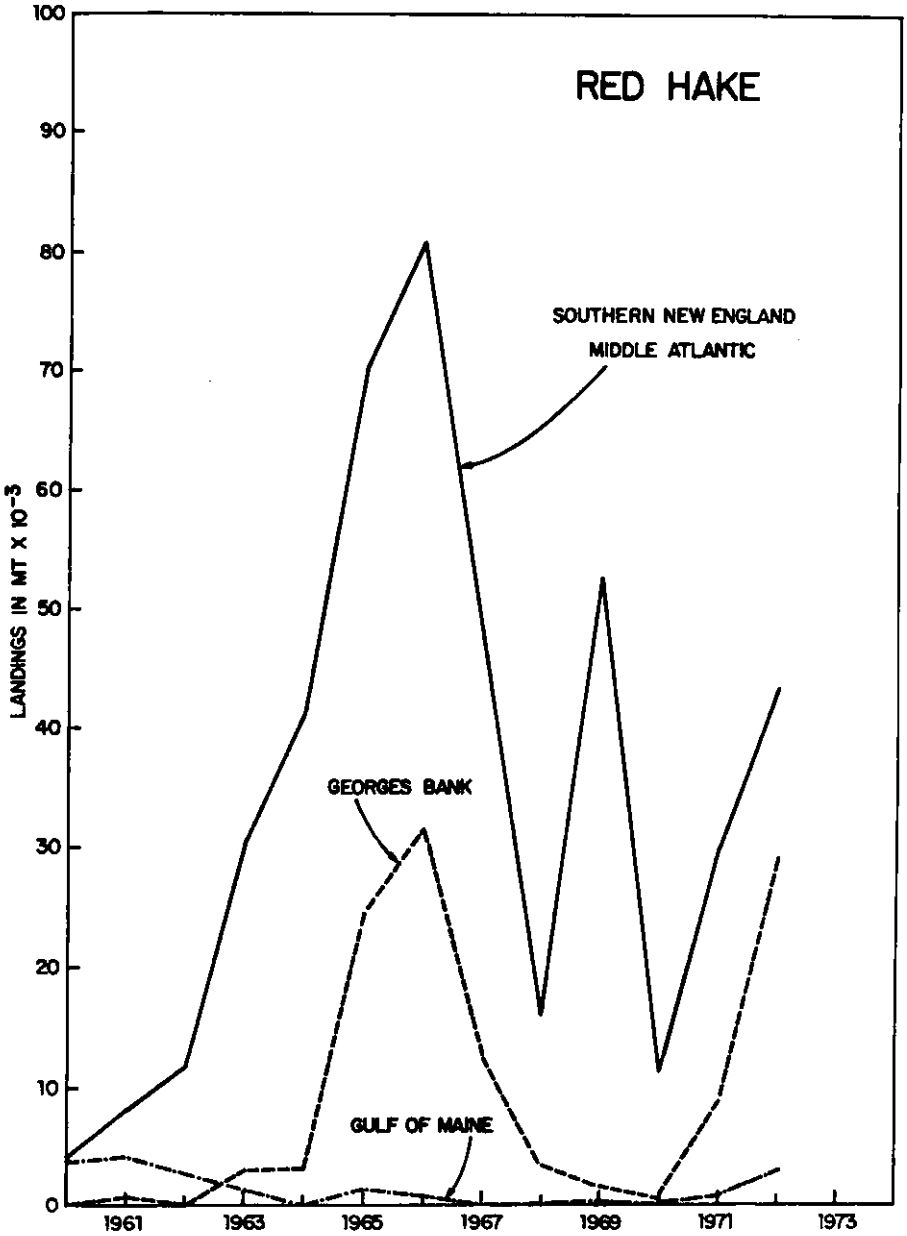

Fig. 3. Red hake landings from the stocks in ICNAF Subarea 5 and Statistical Area 6.

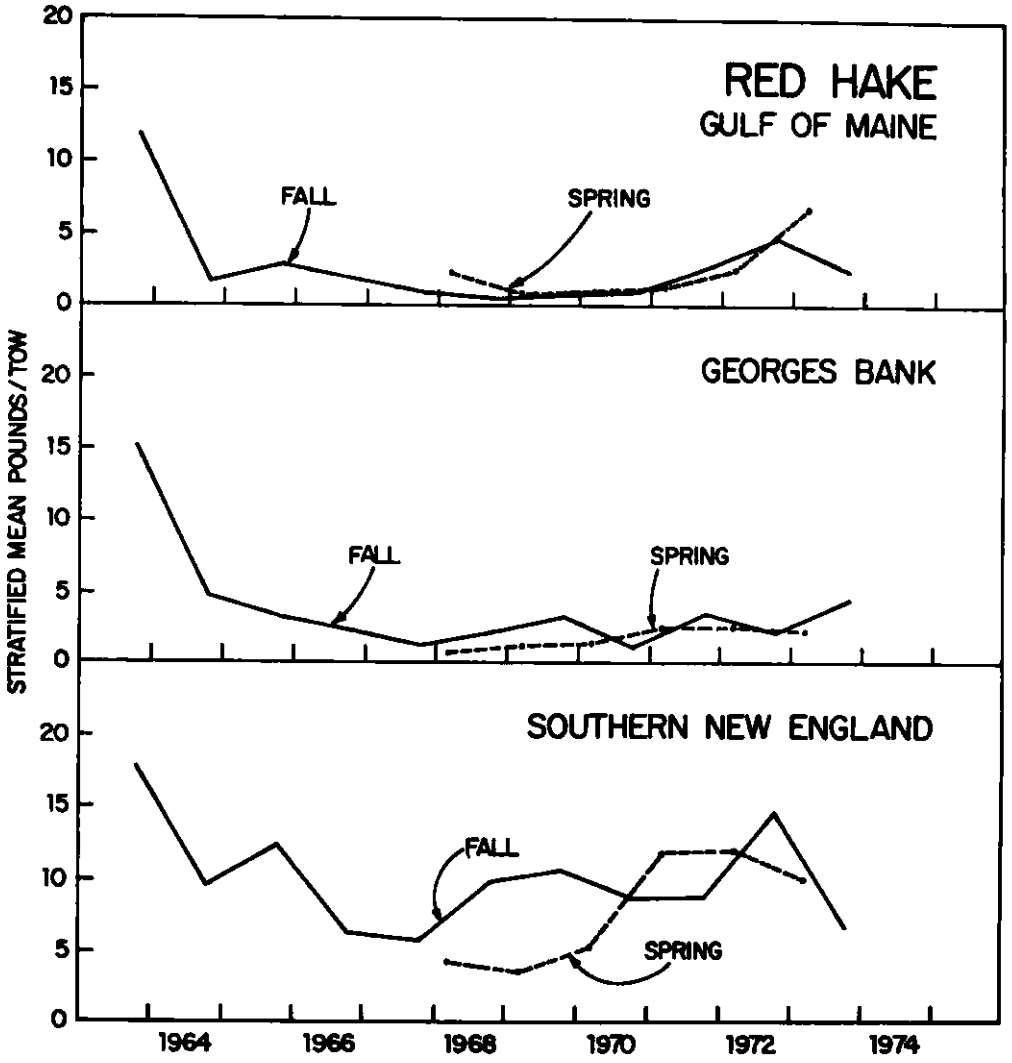

Fig. 4. Stratified mean pounds per tow of red hake (by stock) from US spring and fall groundfish survey cruises in ICNAF Subarea 5 and Statistical Area 6.

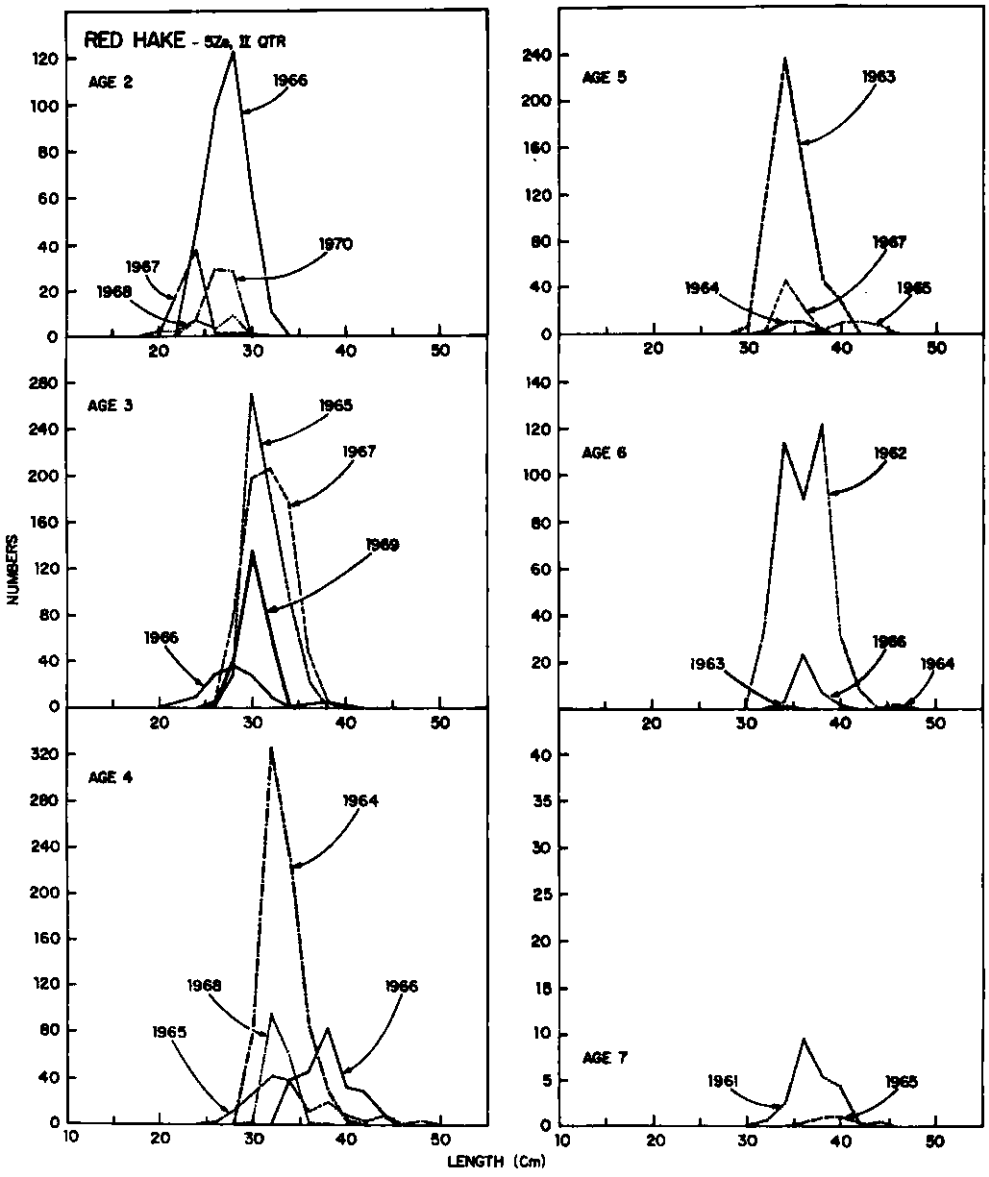

Fig. 5. Length frequency of different red hake year-classes at given ages from USSR ICNAF Subdivision 5Ze quarter II age/length tables.

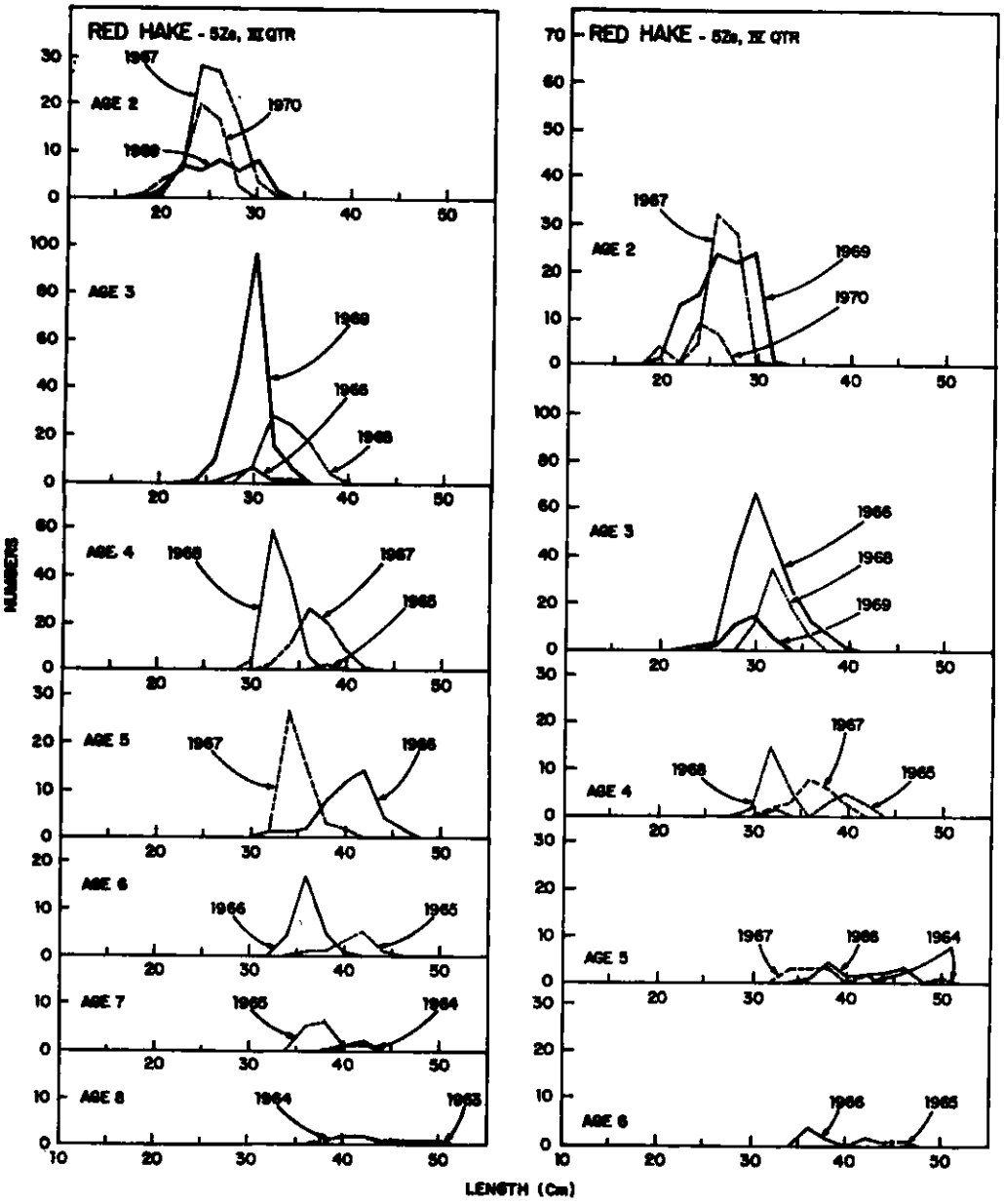

Fig. 6. Length frequency of different red hake year-classes at given ages from USSR ICNAF Subdivision 5Ze quarter III and IV age/length tables.

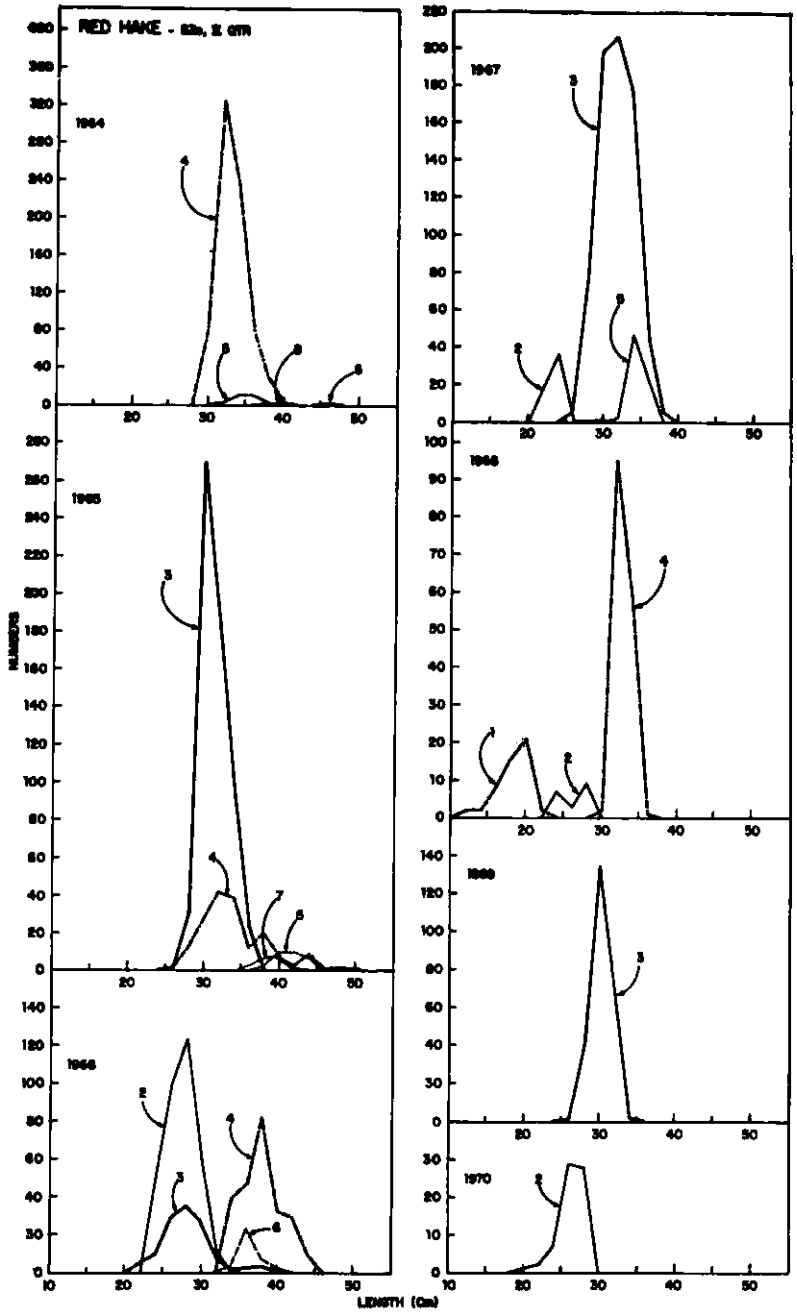

Fig. 7. Length frequency of given red hake year-classes at succeeding ages from USSR ICNAF Subdivision 5Ze quarter II age/length tables.

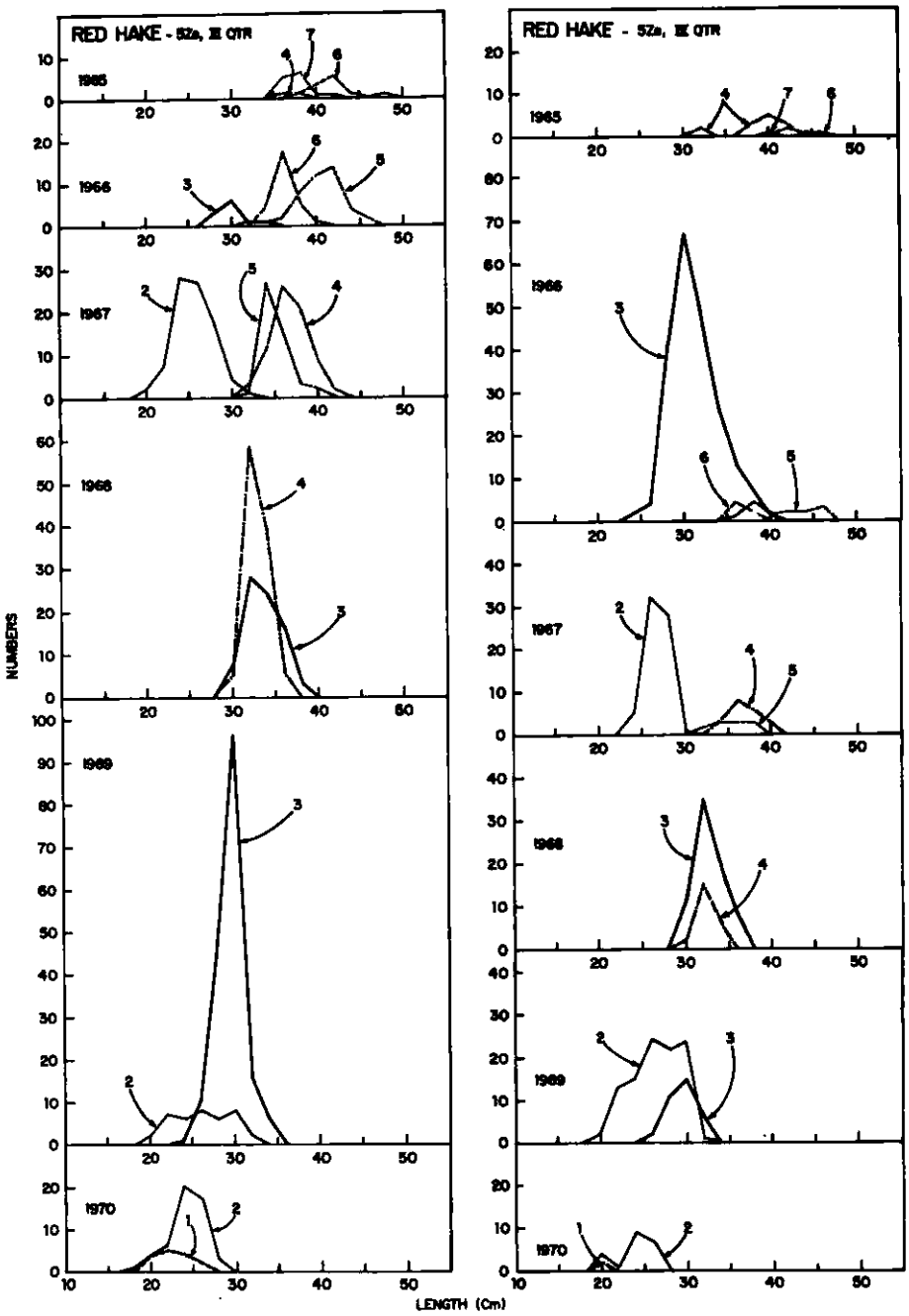

Fig. 8. Length frequency of given red hake year-classes at succeeding ages from USSR ICNAF Subdivision 5Ze quarter III and IV age/length tables.

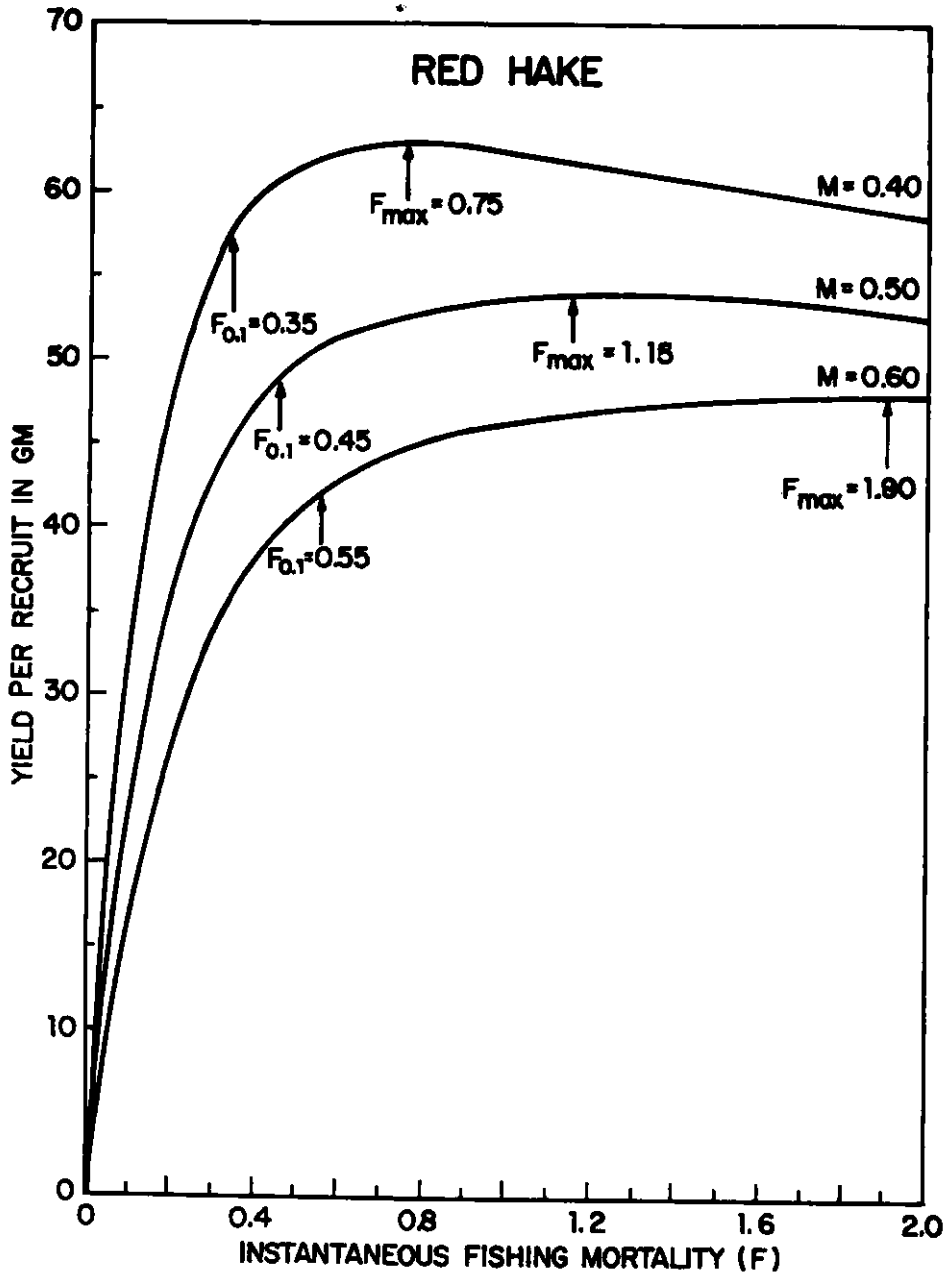

Fig. 9. Red hake yield per recruit with mean selection age (t_c) of 1.5 years and different values of M given W_∞ = 1000 gm, K = 0.19, t_o = -1.12, t_r = 1, and t_λ = 10.

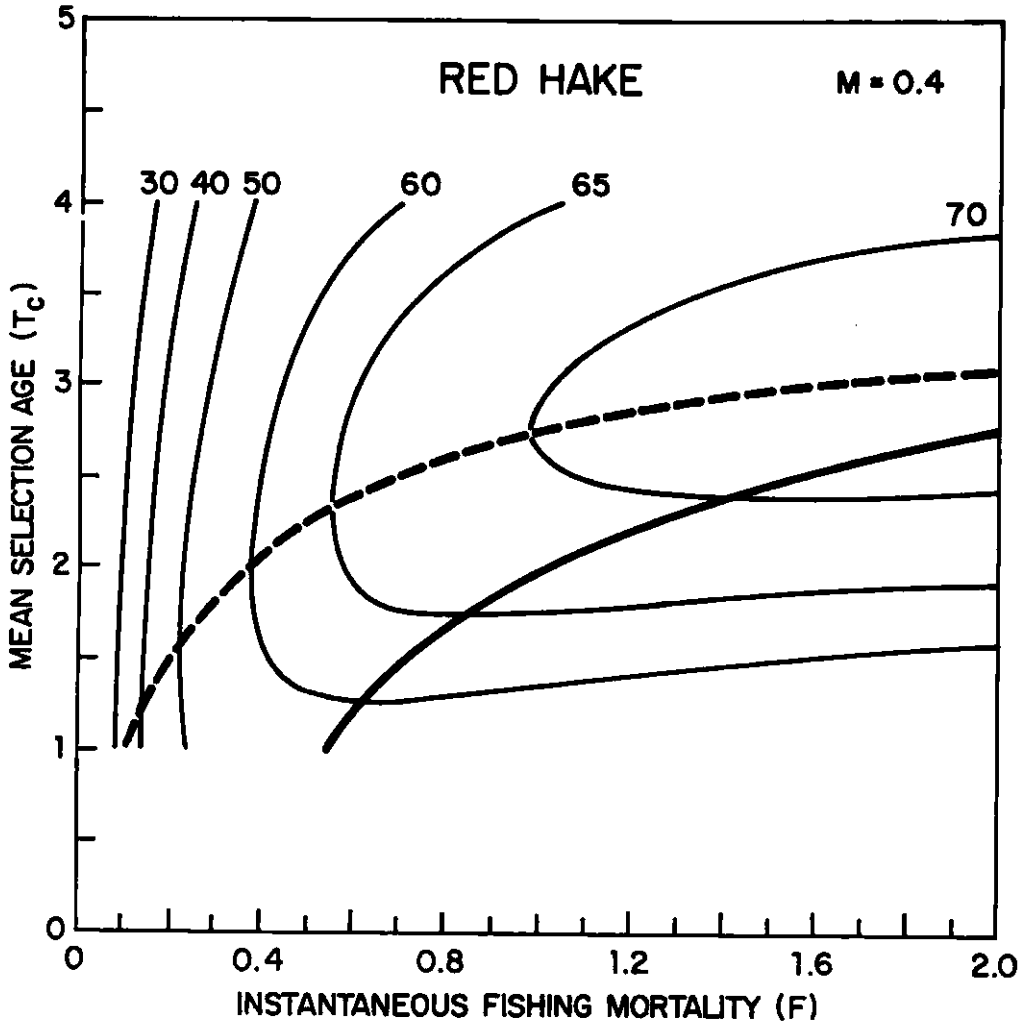

Fig. 10. Yield isopleth diagram for red hake given W_∞ = 1000 gm, K = 0.19, t_o = -1.12, t_r = 1, t_λ = 10, t_c = 1.5, and M = 0.4. The heavy solid line indicates F_{max} at t_c and the dashed line indicated t_c giving the maximum yield per recruit at a given F.

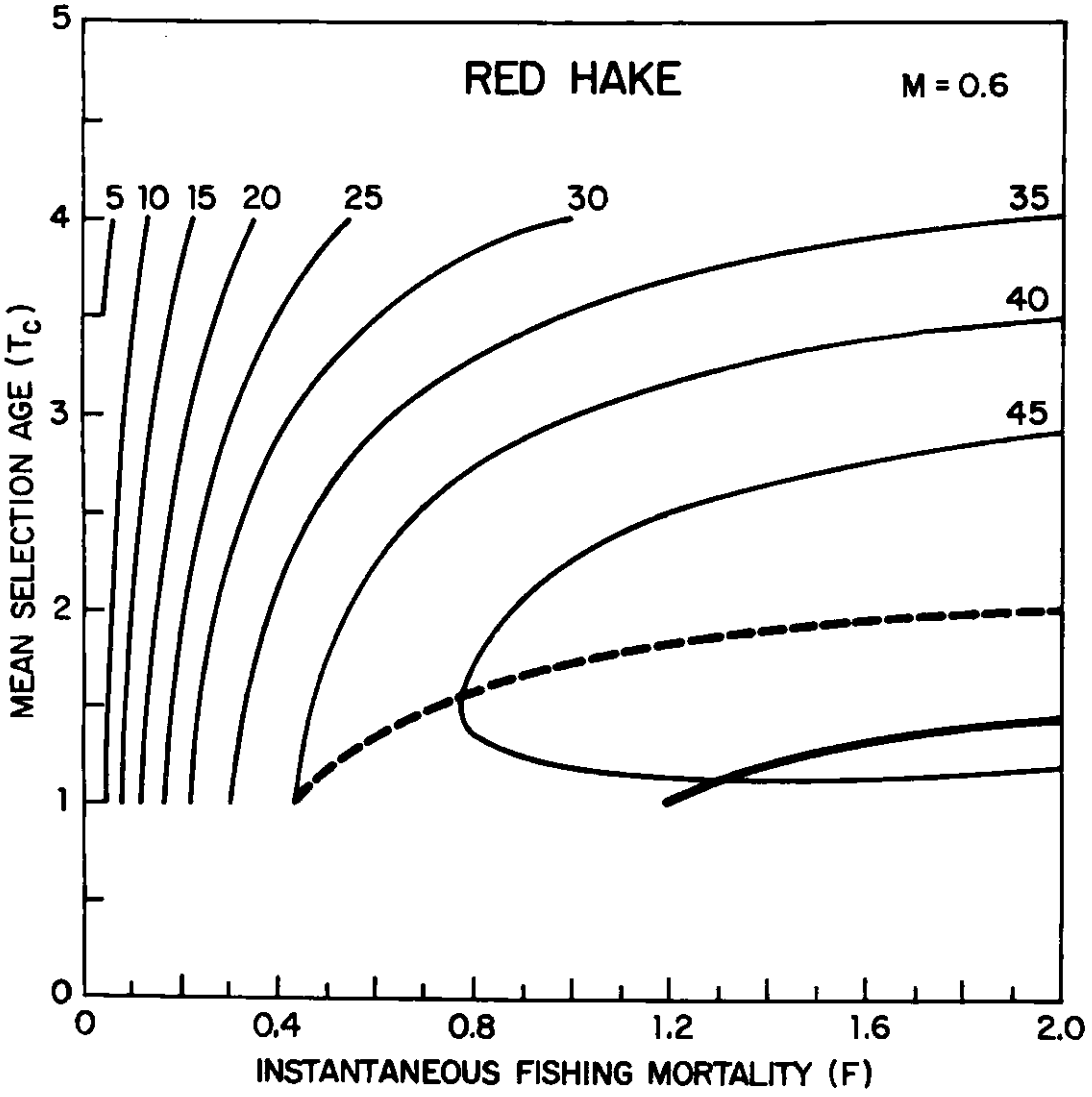

Fig. 11. Yield isopleth diagram for red hake given W_∞ = 1000 gm, K = 0.19, t_o = -1.12, t_r = 1, t_c = 1.5, and M = 0.6. The heavy solid line indicates F_{max} at t_c and the dashed line indicates t_c giving the maximum yield per recruit at a given F.