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Measures of abundance of Atlantic mackerel off the northeastern coast of the United States[1]

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Abstract

Changes in mackerel abundance in ICNAF Subarea 5 and Statistical Area 6 during 1963-1975 were described by four research vessel survey and commercial fishery indices. These were evaluated in terms of similarity to biomass estimates based on results of virtual population analysis (VPA). The VPA estimates increased from 1968 to 1970 and then declined thereafter. The US spring survey catch per tow index indicated a 96% decline in abundance from 1968 to 1975. The autumn survey index increased from 1963 to 1967-1969 and then showed a 96% decline in abundance from 1969 to 1975. The US commercial standardized catch per day index increased steadily until 1968 before declining 94% to 1974. The distant water fleet (DWF) standardized catch per hour index increased from 1968 to 1970, declined in 1971-1972, and then increased in 1973-1974. Analyses suggested that changes in DWF vessel efficiency occurred during 1968-1974 due to learning or technological improvements, or both. It was concluded that the US commercial index and the spring survey index were better indicators of changes in mackerel abundance than the DWF index.

Introduction

An unproven, but generally-accepted hypothesis has prevailed suggesting that mackerel (*Scomber scombrus*) stock abundance in the Northwest Atlantic has fluctuated widely historically. These fluctuations were assumed (Sette and Needler, 1934; Taylor et al., 1957) to be primarily instrumental in causing the substantial variation in commercial landings recorded since the early 1800's. Bigelow and Schroeder (1953) associated fluctuations in landings in the Gulf of Maine area during 1910-1932 with marked differences in year-class strength. Various environmental factors such as temperature, wind movements, food (plankton) abundance, and epizootics (caused by the fungus, *Ichthyosporidium hoferi*) have been correlated or associated with year-class strength and stock abundance (Sette, 1943; Taylor et al., 1957; Sindermann, 1958; MacKay, 1967). Lett et al. (1975) recently demonstrated from a simulation study of the mackerel fishery that recruitment, stock abundance, and catch vary most under conditions of low fishing mortality such as possibly occurred prior to the late 1960's. Although fluctuations in stock abundance have undoubtedly occurred historically, they remain undocumented except by changes in catch. The present paper attempts to quantify recent changes in mackerel stock abundance other than comparing commercial catches.

1/ Adapted from a paper submitted for publication in the ICNAF Research Bulletin which is an extensive revision of ICNAF Res. Doc. 75/15 including additional data for 1974-1975.

Assessments of mackerel require some measure or index of stock abundance which may be determined from commercial catch per unit effort or research vessel survey catch per tow. The purpose of this paper is to document the changes in mackerel abundance in ICNAF Subarea 5 and Statistical Area 6 (SA 5-6) since the early 1960's from US research vessel survey catch per tow, US commercial fishery catch per day fished, and distant water fleet catch per hour fished, and to evaluate the validity of these various indices. Analyses include the standardization of effort by different fishing gears and vessel classes and a determination of the possible extent of learning and technological improvements in the distant water fleets.

Materials and Methods

US research vessel survey catch per tow

Stratified mean catch (kg) per tow, standard deviation, and coefficient of variation were calculated (Table 1) for US research vessel spring (1967-1975) and autumn (1963-1975) bottom trawl surveys. The survey methods and the strata included in the analysis were described previously by Anderson (1975). A $\log_e (x+1)$ transformation, where x was the individual station catch, was used to normalize the frequency distribution and stabilize the variance of the individual catches. The results were retransformed to the linear scale (Table 1) for comparison with other indices of abundance (Figure 5) using the relation (Finney, 1941)

$$\bar{y} = e^{(\bar{x} + \frac{S^2}{2})} - 1$$

where $\bar{y}$ = stratified mean catch per tow (linear scale), $\bar{x}$ = stratified mean catch per tow ($\log_e$ scale), and S^2 = population variance ($\log_e$ scale).

US commercial fishery catch per day fished

Catch and effort statistics from handlines, otter trawls, floating traps, sink gillnets, drift gillnets, purse seines, pound nets, and mid-water pair trawls fished by US vessels landing in New England ports during 1964-1975 were used to compute catch per day fished. Annual fishing effort of all the different gear-tonnage classes was standardized to that of a single gear-tonnage class as described by Anderson (1975). Catch per standardized US day fished was computed for each year by multiplying the days fished used in the analysis for each gear-tonnage class by the appropriate effort standardization coefficient and dividing the summed products into the total annual US catch used in the analysis. International effort expressed as standardized US days fished was calculated by dividing international catch by catch per standardized US day fished (Table 6).

Distant water fleet catch per hour fished

Otter trawl catch and effort statistics submitted to ICNAF by Bulgaria, GDR, Poland, Romania, and the USSR for 1968-1974 were analyzed to determine mackerel catch per hour fished, as described by Anderson (1975).

Annual observed catch per hour for each country-tonnage class was computed as the mean of the monthly catch per hour values for each vessel class in each ICNAF division or subdivision (Table 3); standard deviations and coefficients of variation were also calculated. These data were analyzed to determine the extent of learning and/or technological improvements as reflected by catch per hour. A model developed by Brown *et al.* (1976) was used which assumed that learning or technological improvements, or both, continued until the ratio (learning index = L) of observed to predicted catch per hour decreased from one year to the next (Table 3). Predicted catch per hour was defined as observed catch per hour in the first year of the fishery and proportional in succeeding years to stock biomass (tons) of age 1 and older mackerel (Table 4) determined from population numbers calculated by virtual population analysis (VPA) (ICNAF, 1975). The first year in the fishery for each country-tonnage class was considered to be the first year having directed mackerel effort.

Annual fishing effort of the various vessel tonnage classes from the five countries was standardized to that of a single country-tonnage class selected as a standard by means of effort standardization coefficients (Table 5) (Anderson, 1975). Catch per standardized distant water fleet (DWF) hour fished was computed for each year by multiplying the hours fished used in the analysis for each country-tonnage class by the appropriate effort standardization coefficient and dividing the summed products into the total catch used in the analysis. International effort expressed as standardized DWF hours fished was determined by dividing international catch by catch per standardized DWF hour fished (Table 6).

Results

US research vessel survey catch per tow

Survey catches of mackerel varied considerably, largely due to the distributional characteristics of the species. Spring station catches ranged from 0 to 4,806 fish and 0 to 1,593 kg while autumn catches were smaller and varied from 0 to 4,495 fish and 0 to 255 kg. Mackerel were caught on the average in 34% of the tows each spring and in 14% of the autumn tows. The mackerel catch from tows producing mackerel averaged 61 and 27 fish per tow from each spring and autumn survey, respectively, whereas the average catch from all tows was 21 and 5 fish per tow, respectively.

The spring catch (kg) per tow index decreased from a high in 1968 to its lowest level in 1975 (Table 1, Figure 1), corresponding to a linear decline of 96% (Figure 5). The downward trend from 1968 was relatively steady except for an extremely low value in 1969. Virtually all of the mackerel were caught during that spring off Cape Hatteras suggesting that the annual inshore, northerly migration (Sette, 1950) had not yet begun. Water temperatures did not appear to differ from those in adjacent years. Catch per tow for other pelagic species did not exhibit a similar drop in 1969 suggesting that the survey trawl and shipboard operation functioned normally. The high 1968 value resulted primarily from fish of the 1967 year-class at age 1 which comprised 80-90% of the total survey catch. The coefficient of variation ranged from 18 to 32% and averaged 25%.

The autumn catch (kg) per tow index increased from 1964 to a high in 1967 on the $\log_e$ scale and in 1969 on the retransformed (linear) scale (Table 1, Figures 1 and 5). The index then trended downward undergoing slight increases in 1972 and 1974. These data indicated an overall decline of about 96% on the linear scale (Figure 5) from 1969 to 1975. Statistical variability associated with the mean value was higher than that of the spring indices. The coefficient of variation varied from 27 to 72% and averaged 45%.

US commercial fishery catch per day fished

The catch and effort statistics used to calculate catch per day fished represented 6-64% of the annual US mackerel catch and averaged 34% yearly over the 12-year period. The catches, however, comprised only a small proportion of the international catch after 1964 (46% in that year), averaging 10.7% in 1965-1967, 2.3% in 1968-1969, and 0.2% in 1970-1975. The US catches, although taken in all quarters of the year, were limited to coastal waters. Pound nets, floating traps, and purse seines accounted for the majority of the catch.

Effort by the various gear-tonnage classes was standardized to that of the floating trap tended by vessels of 0-50 gross tons (GT). This category was selected because it (1) contained observations in all years, (2) contained a larger number of observations in all years than other categories also meeting criterion (1), and (3) provided greater catches than other gear-tonnage classes satisfying both criteria (1) and (2).

Catch per standardized US day fished increased steadily from 0.43 tons in 1964 to 2.80 tons in 1968, but then dropped each year except in 1970 to a low of 0.17 tons in 1974 (Table 6, Figure 4), an overall decline of 94%. Catch per day increased in 1975 to the 1973 level which was the lowest since 1965. International effort expressed as standardized US days fished increased exponentially from 5,281 days in 1964 to 1,734,847 days in 1974, a 330-fold increase, at an average annual rate of 86%.

Distant water fleet catch per hour fished

Mackerel catches reported by Bulgaria, GDR, Poland, and Romania during 1968-1974 were taken entirely by otter trawl, whereas about 95% of the USSR catches were taken annually by otter trawl. The remaining portion of the USSR catches was caught by purse seine with a small amount by pair trawl in 1970. Catches representing directed fisheries varied from 27% of the international total in 1968 to 91% in 1974 (Table 2) and averaged 70% per year for the period. Observations represented all months of the year, but 90% of the total (1,160) were from January-May and November-December with April providing more than any other month (16%). Observations were taken nearly equally from SA 5 (54%) and SA 6 (46%).

The number of observations per country-tonnage class ranged from 1 to 59 per year (Table 3) and averaged 17. Coefficients of variation of the annual observed catch per hour for the country-tonnage classes ranged from 0 to 148% (Table 3) and averaged 56%. Coefficients of variation by tonnage class averaged 44% for 151-500 GT, 49% for 901-1800 GT, 57% for >1800 GT, and 63% for 501-900 GT, and by country averaged 47% for Poland, 49% for Bulgaria, 54% for USSR, 64% for GDR, and 78% for Romania.

Observed catch per hour for most country-tonnage classes, particularly the larger classes, exhibited patterns divergent from predicted catch per hour (Table 3, Figure 2). Predicted catch per hour, which was proportional to annual VPA biomass estimates (Table 4), increased from 1968 to a peak in 1970 and then declined each year thereafter. Most country-tonnage classes experienced marked increases in catch per hour after 1970 even though stock biomass declined steadily, although several classes did undergo a decrease in 1974. The 151-500 and 501-900 GT classes, particularly the USSR 151-500 GT class, showed the closest agreement between observed and predicted catch per hour, although several of these exhibited increases in catch per hour in 1973 and 1974.

Some country-tonnage classes (USSR 151-500 and >1800 GT, GDR 501-900 and 901-1800 GT, Bulgaria >1800 GT, and Romania >1800 GT) showed increases in the learning index (L) in their second and/or third years followed by a drop in the succeeding year (Table 3, Figure 2). This suggests that a 1-2 year learning period occurred during which the fleets improved their knowledge pertaining to the seasonal and areal distribution of mackerel and their expertise necessary to efficiently locate and catch the fish. A learning period of this duration for new fisheries was proposed previously (Borkowska-Kwinta, 1964; Anthony, 1972; Schumacher and Anthony, 1972; Dunin-Kwinta, 1975) and was demonstrated for the DWF fisheries in SA 5-6 by Brown et al. (1976). Several country-tonnage classes were characterized by learning indices which decreased below 1.0 in the second and sometimes third years. This occurred because observed catch per hour in the first year was higher than expected in relation to that in the ensuing several years. The first-year values may have been in error due to inadequate numbers of observations or insufficient catches from which to calculate a realistic catch per hour value. The Polish 901-1800 and >1800 GT and GDR >1800 GT classes showed continuous increases in L throughout the period with the Polish 901-1800 GT and GDR >1800 GT classes decreasing only in 1974. All of the other country-tonnage classes, except the GDR 501-900 and 901-1800 GT classes, exhibited secondary increases in L during 1972-1974. The continuous increases in L for several of the country-tonnage classes and the secondary increases in L for most of the others suggest that technological improvements (as distinct from learning) occurred following or, perhaps in some cases, during the initial period which resulted in increases in observed catch per hour even though stock biomass decreased. These improvements may have been achieved in various ways such as by the conversion from bottom to midwater trawls, introduction of larger or more efficient vessels and nets, implementation of better electronic fish-locating gear, improvements in shipboard processing, etc. Such changes are poorly documented, although a conversion from bottom to midwater trawls did occur. Only GDR (1968-1974) and USSR (1974) statistics were reported separately for bottom and midwater trawls. These data indicated superior catch rates for midwater trawls. It was concluded, therefore, that observed catch per hour by most country-tonnage classes was invalid as a year-to-year measure of mackerel stock abundance because of the apparent inequivalence in vessel efficiency and, hence, in a unit of fishing effort throughout the 1968-1974 period.

It was decided to standardize the DWF fishing effort to that of the USSR 151-500 GT class, which exhibited closer agreement between observed and predicted catch per hour than any other country-tonnage class. The learning index (L) deviated little from 1.0 in 1969-1973 (mean = 1.10; range = 0.81-1.31) suggesting minimal learning and technological improvements except in 1974 (L = 2.11). This country-tonnage class contained observations in all years (Table 3) and provided a substantial proportion of the total catch included in the analysis, at least through 1970 (Table 2). The proportions were 67% in 1968, 51% in 1969, 29% in 1970, 10% in 1971-1972, and 2% in 1973-1974. Although catches by the USSR 151-500 GT class decreased in the latter part of the period as those by the larger classes increased, it remained involved in the mackerel fishery throughout the entire period. Mackerel averaged 50% of the annual total otter trawl catch by this tonnage class in 1970-1974 and 70% of the total catch from directed mackerel effort by this class in 1968-1974.

Analysis of variance for the computation of effort standardization coefficients indicated significant (p = 0.05) tonnage class differences in all years and significant country differences in 1971-1974. Significant country-tonnage class interactions also occurred in 1971-1974. Detailed examination of the data indicated that the interactions were caused mainly by classes (GDR 501-900 and 901-1800 GT in 1972 and 1974 and GDR 501-900 GT in 1973) which contributed little to the catch (0.6%) and effort (1.2%) used in the 1972-1974 analyses. The interaction F value in the 1971 analysis, although significant (p = 0.05), was only 10% and 21% of the magnitude of the tonnage class and country F values, respectively. The interactions were not assumed important and were disregarded.

GDR, Poland, and the USSR had vessels in several tonnage classes with GDR and Poland each having vessels in the same three classes, whereas Bulgaria and Romania had vessels only in the >1800 GT class. Effort standardization coefficients exhibited an increase with vessel size and year (Table 5, Figure 3). Mean values for 1968-1974 for GDR and Poland were 1.60 for the 501-900 GT class (based on 1.00 for the standard USSR 151-500 GT class), 4.77 for the 901-1800 GT class, and 5.83 for the >1800 GT class.

There was considerable variation in coefficients among countries within a given tonnage class (Table 5, Figure 3). GDR vessels had the highest average value over years in the 501-900 and >1800 GT classes while Polish vessels averaged slightly higher in the 901-1800 GT class. In the >1800 GT class, represented by vessels from all five countries, Poland had the second highest mean coefficient over years after GDR, followed by Bulgaria, the USSR, and Romania.

The 901-1800 and >1800 GT vessels generally exhibited an increasing trend in coefficients until 1973-1974 when a decrease occurred. The most evident increases were shown for >1800 GT vessels. These results indicate that the fishing ability or efficiency of the vessels harvesting the bulk of the mackerel in recent years underwent a pronounced increase relative to that of the standard class. This further supports the earlier suggestion that significant improvements occurred in the distant water fleets as the result of learning or technological advancements, or both.

Standardization of fishing effort by the various country-tonnage classes utilizing the calculated effort standardization coefficients produced the results shown in Table 6 and Figure 4. Catch per standardization DWF hour fished increased from 0.50 tons in 1968 to 0.99 tons in

1970, declined to 0.53 tons in 1972 and then increased again to 0.88 tons in 1974. International effort expressed as standardized DWF hours fished increased from 120,000 hours in 1968 to 731,000 hours in 1972 and then declined about 55% to 335,000 hours in 1974.

Discussion

According to estimates based on VPA (1968 and on), mackerel abundance increased due to the recruitment of the strong year-classes of 1966 and 1967, reached peak abundance in 1970, and then declined steadily thereafter (Table 4, Figure 5). The US spring and autumn survey catch per tow indices, the US commercial catch per day index, and the DWF catch per hour index were generally similar in indicating the recent downward trend in mackerel abundance until 1973-1974 when the DWF index diverged from the other estimates and increased (Figure 5). The decrease as measured by the various indices was greater than the change in biomass calculated from VPA results. Each index, however, merits some consideration as an acceptable measure of relative mackerel stock abundance. The DWF index was based on selecting the country-tonnage class most closely following the VPA trends and cannot be evaluated in the same manner as the other indices.

The spring survey index was at its highest level in 1968 (the first point) before the stock biomass was greatest according to VPA results (Figure 5). Survey catches in spring 1968 consisted primarily of 1967 year-class mackerel at age 1. The VPA estimate peaked in 1970 when the 1967 year-class at age 3 attained maximum biomass. The spring index did increase substantially from 1969 to 1970-1971 before declining, which corresponded to the time of the maximum VPA biomass estimate. The autumn survey index peaked in 1967 on the $\log_e$ scale and in 1969 on the retransformed (linear) scale. The maximum in autumn 1969 represents the same peak in biomass as indicated by the maximum VPA estimate in 1970 (i.e. January 1, 1970). The decline in abundance after 1970, as shown by VPA results, was demonstrated by both survey indices, albeit they indicated a greater decline than the VPA. Neither survey evidenced a marked increase in abundance as suggested by the DWF index in 1974. The autumn index did undergo a slight increase in 1972 and 1974 but dropped sharply in 1975 and the spring index did increase slightly in 1974 but also fell sharply in 1975.

The US commercial standardized catch per day index might be limited as a measure of overall stock abundance because it was based solely on small, inshore catches. Virtually all of the international catch was taken by the distant water fleets operating farther offshore. The US index would be reasonably valid, however, if the proportion of the total stock subject to the inshore fishery remained constant over time. The index indicated that the decline in abundance after 1970 was greater than that determined from VPA. The abundance of mackerel may have decreased more in coastal waters than offshore because of differential age or stock distribution, except that the US commercial index exhibited virtually an identical decline to that indicated by the US spring survey (Figure 5), which was based on catches taken primarily from the offshore area. It is not known why the US commercial index peaked in 1968 compared to 1970 for the VPA estimate although it did increase slightly from 1969 to 1970. Age data were not available to determine if the US catch that year consisted largely of abundant 1967 year-class fish (age 1) which were responsible for the peaks in the autumn and spring survey indices in 1967-1969 and 1968, respectively.

Catch per hour by the distant water fleets which harvested the bulk of the mackerel catch in recent years might be expected to constitute the most logical measure of stock abundance. Analysis of the DWF statistics revealed, however, that the various country-tonnage classes experienced different patterns of catch per hour during 1968-1974 (Figure 2) most of which were not in agreement with the change in biomass measured by VPA. Furthermore, variability associated with the annual catch per hour indices was shown to be substantial (Table 3) with coefficients of variation averaging 56%, compared to 25 and 45% for the spring and autumn survey indices, respectively. Analysis further suggested that learning or technological improvements, or both, occurred in varying degrees for nearly all country-tonnage classes thus invalidating year-to-year changes in observed catch per hour as a means of accurately monitoring stock abundance changes. The probability, q, that an individual fish would be caught by a given unit of fishing effort, did not remain constant over the period of analysis but instead appeared to increase. From the relationship

$$\text{Stock abundance} = \frac{1}{q} \times \text{catch per unit effort},$$

it is evident that catch per unit effort is not proportional to stock abundance over time if q changes. A time-series of catch per unit effort must be adjusted to incorporate in some way any increased efficiency of a unit of effort (Gulland, 1964).

Changes in efficiency by the individual country-tonnage classes were collectively adjusted by standardizing all effort to that of the USSR 151-500 GT class which appeared to undergo minimal increases in efficiency through learning or technological improvements, at least until 1974. The resulting catch per standardized DWF hour fished agreed closely with the VPA biomass estimate until 1973-1974 (Figure 5). Observed catch per hour by the USSR 151-500 GT class (and accordingly catch per standardized DWF hour) increased sharply in 1974 continuing the upward trend that began in 1973. The slight increase in observed catch per hour by the USSR 151-500 GT class from 0.50 tons in 1972 to 0.58 tons in 1973 (catch per standardized DWF hour increased from 0.53 to 0.55 tons) coincided with a marked drop in otter trawling by that class and a shift to the use of purse seines. It is possible that the trawlers most efficient in catching mackerel were not converted to seiners which could account for the increase in catch per hour. In 1974, however, the observed catch per hour climbed sharply to 0.95 tons (catch per standardized DWF hour was 0.88 tons). Such an improvement would have required a sudden increase in either stock abundance or q as a result of increased efficiency. All other indices presented indicated that stock abundance did not increase 65% from 1972 to 1974 as implied by the DWF index. Even some of the individual DWF country-tonnage classes (i.e. all GDR classes, the Polish 901-1800 GT class, and the Bulgarian >1800 GT class) showed decreases in observed catch per hour in 1974. It would appear, therefore, that factors other than increased abundance caused the increase in catch per hour. It is suggested that technological improvements were made, but it was not possible to document this hypothesis.

The various indices of abundance presented in this paper were evaluated in terms of their similarity to the biomass estimates which were calculated from population numbers determined from VPA. The implication follows that the VPA estimates represented the correct measure of abundance. The VPA estimates for all but the last several years were probably quite good, at least proportionally from year to year. The 1974 and 1973 estimates were, however, quite dependent on the instantaneous fishing mortality (F) selected for the terminal year (1974). Year-class numbers calculated beginning with the terminal year are subject to errors if F is either underestimated or overestimated (greater if the former), but the errors converge rapidly to small values as the cumulative fishing mortalities (from oldest to youngest ages) increase (Pope, 1972). The terminal F used in the VPA (ICNAF, 1975) was determined from several separate analyses and agreed as reasonable for 1974, and was probably sufficiently close to the actual F to eliminate the likelihood of major errors in estimating year-class numbers. If a lower value of F (e.g. 0.5) had been used instead of 0.6, year-class numbers would have been larger, but the overall decrease in biomass from 1970 to 1974 would not have changed much (38% for F = 0.5 and 41% for F = 0.6). The 1974 and 1975 biomass estimates, furthermore, assumed that the 1973 and 1974 year-classes were strong based largely on stock-recruitment curves. Therefore, it was felt that the VPA biomass estimates used in this paper (Table 4) were reasonably accurate on the basis of information available at that time.

In conclusion, none of the measures of abundance presented were completely consistent and accurate over the recent decade as year-to-year indicators of mackerel abundance. The survey indices demonstrated an overall decline in abundance but fluctuated from year to year due perhaps in part to the variability of the catches. The US commercial index showed an uninterrupted decline after 1970 which indicated a sharper decline than the VPA estimates, but was based on a small inshore fishery. The DWF index paralleled the VPA estimate until 1972 after which it indicated a marked increase in abundance. Analyses showed greater variability about the DWF catch per hour indices than for the survey indices, and also indicated that changes in DWF vessel efficiency occurred annually due to learning and/or technological improvements. Changes in vessel efficiency essentially invalidate the DWF index as an accurate measure for monitoring year-to-year changes in mackerel abundance. Bearing in mind the advantages and limitations of the various indices as demonstrated by the data presented in this paper, the US commercial index and the spring survey index were better overall indicators of trends in mackerel abundance than the DWF index.

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Table 1. Stratified mean catch (kg) per tow ($\log_e$ and retransformed) of mackerel from US research vessel bottom trawl surveys in the spring (strata 1-14, 61-76) and autumn (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26) determined from a $\log_e (x+1)$ transformation where x equaled individual catch with standard deviation (SD) and coefficient of variation (CV).

Year	Date	Spring mean ($\log_e$)	SD	CV	Mean retrans-formed	Date	Autumn mean ($\log_e$)	SD	CV	Mean retrans formed
1963	-	-	-	-	-	Nov. 13-Dec. 14	0.013	0.009	69.2	0.016
1964	-	-	-	-	-	Oct. 22-Dec. 4	<0.001	<0.001	-	<0.001
1965	-	-	-	-	-	Oct. 6-Nov. 9	0.046	0.021	45.6	0.073
1966	-	-	-	-	-	Oct. 13-Nov. 13	0.057	0.021	36.8	0.082
1967	-	-	-	-	-	Oct. 25-Dec. 9	0.195	0.053	27.2	0.372
1968	Mar. 2-14	0.567	0.119	21.0	2.770	Oct. 10-Nov. 20	0.117	0.039	33.3	0.214
1969	Mar. 5-22	0.023	0.007	30.4	0.040	Oct. 8-Nov. 22	0.154	0.066	42.9	0.459
1970	Mar. 18-Apr. 29	0.407	0.074	18.2	1.337	Oct. 15-Nov. 20	0.068	0.026	38.2	0.099
1971	Mar. 9-Apr. 12	0.386	0.076	19.7	1.391	Sept. 29-Nov. 19	0.052	0.018	34.6	0.073
1972	Mar. 8-25	0.306	0.074	24.2	0.893	Sept. 28-Nov. 19	0.070	0.024	34.3	0.107
1973	Mar. 16-Apr. 17	0.170	0.051	30.0	0.503	Sept. 26-Nov. 19	0.034	0.014	41.2	0.043
1974	Mar. 13-Apr. 7	0.210	0.067	31.9	0.475	Sept. 23-Oct. 25	0.046	0.033	71.7	0.108
1975	Mar. 4-Apr. 24	0.063	0.017	27.0	0.102	Oct. 7-22	0.010	0.006	60.0	0.018

Table 2. Mackerel catch (tons) from directed mackerel effort by DWF country-tonnage classes in ICNAF SA 5-6 in 1968-1974.

Tonnage class	Country	1968	1969	1970	1971	1972	1973	1974
151-500	GDR	12	-	-	-	-	-	-
	USSR	10,690	28,240	48,018	31,148	31,544	6,249	5,446
501-900	GDR	624	347	912	1,624	879	1,550	91
	Poland	756	5,108	7,771	7,868	16,317	10,911	6,865
	USSR	-	7,020	25,553	15,761	7,375	8,619	8,947
901-1800	GDR	1,024	-	216	441	1,881	-	792
	Poland	108	-	-	30,868	37,478	45,123	42,569
>1800	Bulgaria	-	1,966	4,007	27,269	23,395	30,702	20,664
	GDR	-	499	3,238	65,269	73,889	74,491	58,949
	Poland	1,272	2,936	49,690	56,826	76,600	49,198	40,477
	Romania	-	-	444	4,043	2,213	5,876	6,555
	USSR	1,569	9,136	26,065	58,593	44,527	68,519	76,128
Total (A)		16,055	55,252	165,914	299,710	316,098	301,238	267,483
International catch(B)		59,973	113,195	209,622	348,744	387,364	381,164	294,924
(A)/(B)		.268	.488	.792	.859	.816	.790	.907

Table 3. Observed catch (tons) per hour of mackerel ($\bar{x}$) including number of observations (n), standard deviation (SD), and coefficient of variation (CV); predicted catch per hour; and learning index (L) for DWF country-tonnage classes in ICNAF SA 5-6, 1968-1974.

Tonnage class	Country	Year	Observed catch (tons) per hour				Predicted catch (tons) per hour	L
			n	$\bar{x}$	SD	CV		
151-500	USSR	1968	4	0.52	0.114	21.9	0.52	1.00
		1969	10	0.84	0.500	59.5	0.67	1.25
		1970	18	1.01	0.415	41.1	0.77	1.31
		1971	22	0.73	0.320	43.8	0.73	1.00
		1972	21	0.50	0.218	43.6	0.62	0.81
		1973	13	0.58	0.245	42.2	0.51	1.14
		1974	8	0.95	0.525	55.3	0.45	2.11
501-900	GDR	1968	2	0.90	0.615	68.3	0.90	1.00
		1969	3	0.63	0.250	39.7	1.16	0.54
		1970	13	2.44	2.823	115.7	1.33	1.83
		1971	10	1.58	1.007	63.7	1.27	1.24
		1972	17	0.68	0.687	101.0	1.08	0.63
		1973	11	1.33	1.633	122.8	0.87	1.53
		1974	4	0.55	0.205	37.3	0.78	0.71
	Poland	1968	2	1.28	0.764	59.7	1.28	1.00
		1969	6	0.96	0.319	33.2	1.65	0.58
		1970	15	1.02	0.467	45.8	1.89	0.54
		1971	13	0.88	0.566	64.3	1.80	0.49
		1972	22	0.82	0.608	74.1	1.53	0.54
		1973	13	1.19	0.578	48.6	1.24	0.96
		1974	5	1.80	0.987	54.8	1.11	1.62
	USSR	1969	14	1.17	0.738	63.1	1.17	1.00
		1970	34	1.18	0.805	68.2	1.34	0.88
		1971	39	0.81	0.349	43.1	1.28	0.63
		1972	25	0.68	0.309	45.4	1.08	0.63
		1973	20	0.74	0.452	61.1	0.88	0.84
		1974	9	1.20	0.537	44.8	0.79	1.52

Table 3. continued.

Tonnage class	Country	Year	Observed catch (tons) per hour				Predicted catch (tons) per hour	L
			n	$\bar{x}$	SD	CV		
901-1800	GDR	1968	2	2.79	1.244	44.6	2.79	1.00
		1970	8	2.39	2.095	87.7	4.13	0.58
		1971	1	5.80	0.000	0.0	3.92	1.48
		1972	7	4.02	3.695	91.9	3.34	1.20
		1974	8	1.89	1.289	68.2	2.42	0.78
	Poland	1968	1	1.86	0.000	0.0	1.86	1.00
		1971	35	3.00	1.481	49.4	2.62	1.15
		1972	46	3.51	2.154	61.4	2.22	1.58
		1973	32	4.15	1.462	35.2	1.81	2.29
		1974	33	2.77	1.504	54.3	1.61	1.72
>1800	Bulgaria	1969	5	1.12	0.299	26.7	1.12	1.00
		1970	5	2.69	2.168	80.6	1.29	2.09
		1971	9	4.02	2.326	57.9	1.22	3.30
		1972	10	2.09	1.337	64.0	1.04	2.01
		1973	21	4.37	1.664	38.1	0.84	5.20
		1974	18	4.10	1.172	28.6	0.75	5.47
	GDR	1969	1	1.59	0.000	0.0	1.59	1.00
		1970	12	2.67	1.925	72.1	1.82	1.47
		1971	29	8.87	5.445	61.4	1.73	5.13
		1972	20	7.90	4.876	61.7	1.47	5.37
		1973	20	8.84	5.239	59.3	1.20	7.37
		1974	20	5.96	3.286	55.1	1.07	5.57
	Poland	1968	3	1.25	0.070	5.6	1.25	1.00
		1969	5	1.12	0.509	45.4	1.61	0.70
		1970	27	3.71	2.051	55.3	1.85	2.01
		1971	31	4.42	2.771	62.7	1.76	2.51
		1972	36	5.02	2.508	50.0	1.49	3.37
		1973	28	5.00	2.324	46.5	1.21	4.13
		1974	21	5.17	2.759	53.4	1.08	4.79
	Romania	1970	3	1.16	1.041	89.7	1.16	1.00
		1971	15	2.08	3.076	147.9	1.10	1.89
		1972	9	1.15	0.538	46.8	0.94	1.22
		1973	10	1.96	0.781	39.8	0.76	2.58
		1974	19	2.27	1.515	66.7	0.68	3.34
	USSR	1968	2	0.84	0.212	25.2	0.84	1.00
		1969	16	1.24	0.433	34.9	1.08	1.15
		1970	30	3.51	4.328	123.3	1.24	2.83
		1971	59	2.44	2.372	97.2	1.18	2.07
		1972	36	2.46	1.736	70.6	1.00	2.46
		1973	39	2.91	1.531	52.6	0.82	3.55
		1974	54	3.61	1.557	43.1	0.73	4.95

Table 4. Biomass (000's tons) of mackerel (age 1 and older) in ICNAF SA 3-6 in 1968-1975 as calculated from virtual population analysis (ICNAF, 1975).

Year	Biomass (000's tons)
1968	1,330.6
1969	1,715.8
1970	1,969.2
1971	1,871.8
1972	1,590.9
1973	1,293.0
1974	1,153.3
1975	1,084.6

Table 5. Effort standardization coefficients calculated for DWF country-tonnage classes in ICNAF SA 5-6, 1968-1974.

Tonnage class	Country	1968	1969	1970	1971	1972	1973	1974	Mean
151-500	GDR	1.48	-	-	-	-	-	-	1.48
	USSR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
501-900	GDR	1.79	1.03	1.13	2.71	1.55	2.22	1.32	1.68
	Poland	1.92	1.25	1.21	1.31	1.63	1.73	1.63	1.53
	USSR	-	1.40	1.03	0.90	0.95	1.02	1.09	1.07
901-1800	GDR	4.48	-	2.01	8.26	5.71	-	2.30	4.55
	Poland	4.79	-	-	4.00	6.01	7.33	2.82	4.99
>1800	Bulgaria	-	1.54	2.21	4.82	3.59	7.55	4.84	4.09
	GDR	-	1.23	2.87	9.63	9.13	11.34	5.12	6.55
	Poland	2.46	1.50	3.07	4.66	9.60	8.84	6.29	5.20
	Romania	-	-	0.92	1.89	2.31	3.42	2.18	2.14
	USSR	1.56	1.68	2.60	3.19	5.61	5.21	4.23	3.44

Table 6. International mackerel catch, US and DWF standardized catch per unit effort, and international standardized effort in ICNAF SA 5-6.

Year	Catch (tons)	Catch per std. US day fished	Catch per std. DWF hour fished	Intl. effort as std. US days fished	Intl. effort as DWF hours fished
1964	2,271	0.43	-	5,281	-
1965	4,538	0.49	-	9,261	-
1966	9,431	0.84	-	11,227	-
1967	22,877	1.75	-	13,073	-
1968	59,973	2.80	0.50	21,419	119,946
1969	113,195	1.92	0.77	58,956	147,006
1970	209,622	2.07	0.99	101,267	211,739
1971	348,744	1.29	0.77	270,344	452,914
1972	387,364	0.84	0.53	461,148	730,875
1973	381,164	0.53	0.55	719,177	693,025
1974	294,924	0.17	0.88	1,734,847	335,141
1975	-	0.53	-	-	-

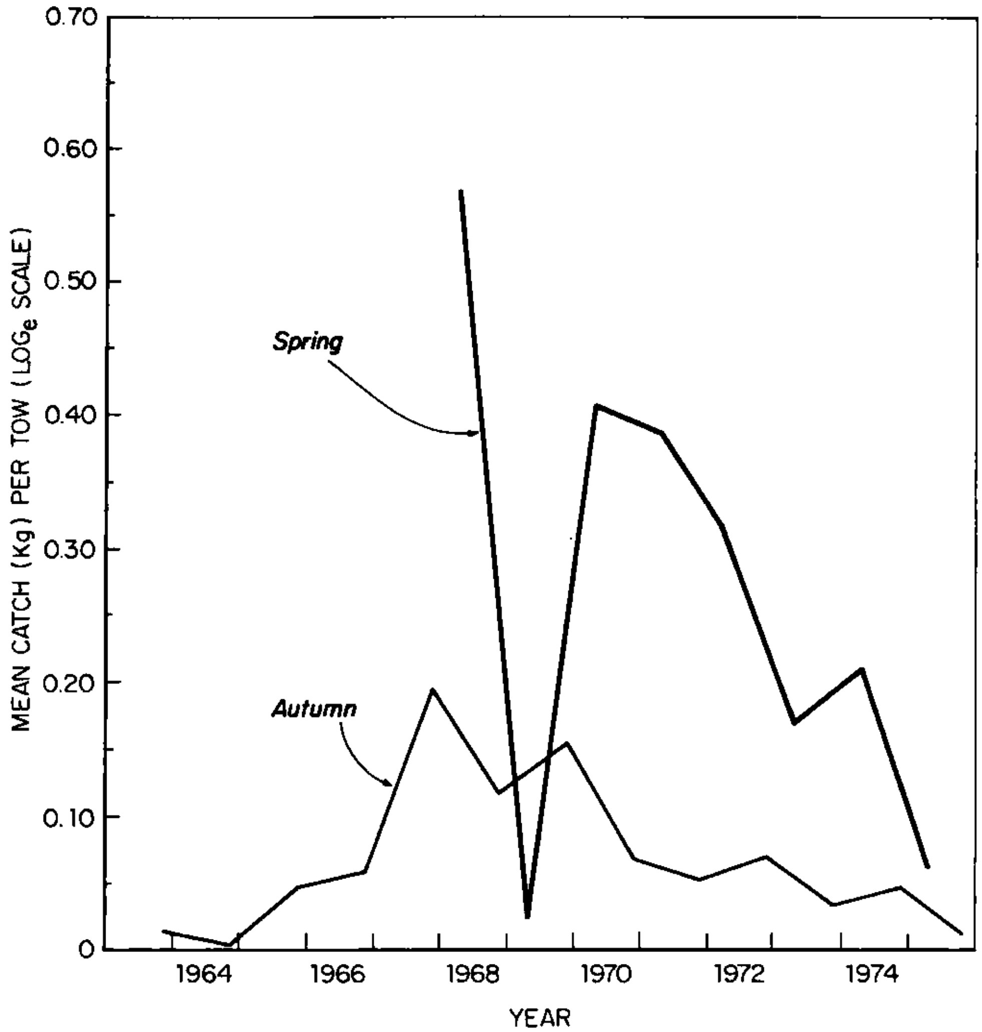

Fig. 1. Stratified mean catch (kg) per tow of mackerel, $\log_e (x+1)$ transformation where x equaled individual catch, from US spring (1968-1975) and autumn (1963-1975) bottom trawl surveys.

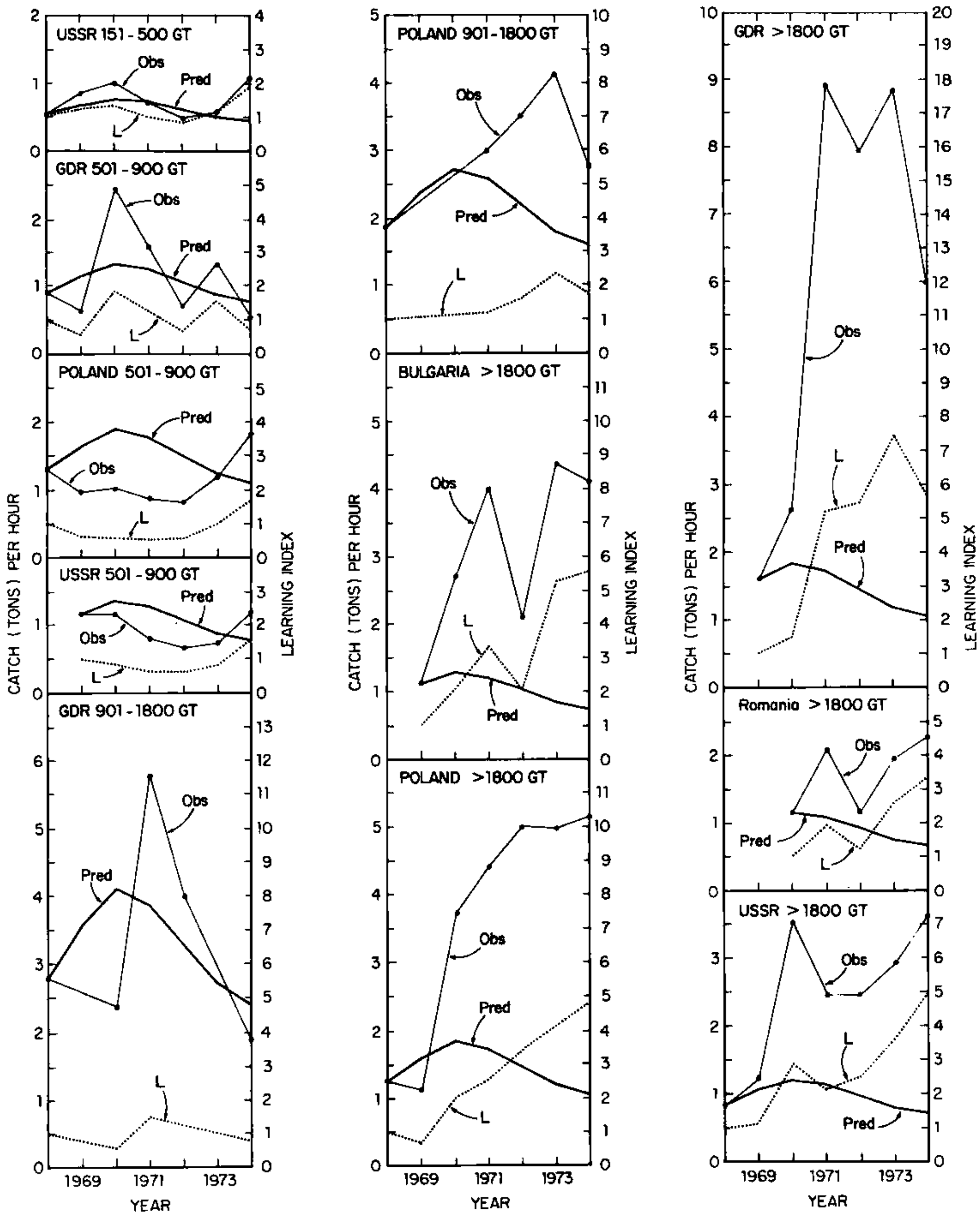

Fig. 2. Observed catch (tons) per hour (Obs) of mackerel, predicted catch per hour (Pred), and learning index (L) for country-tonnage classes in ICNAF SA 5-6, 1968-1974. Years for which observed catch per hour was available are indicated by dots.

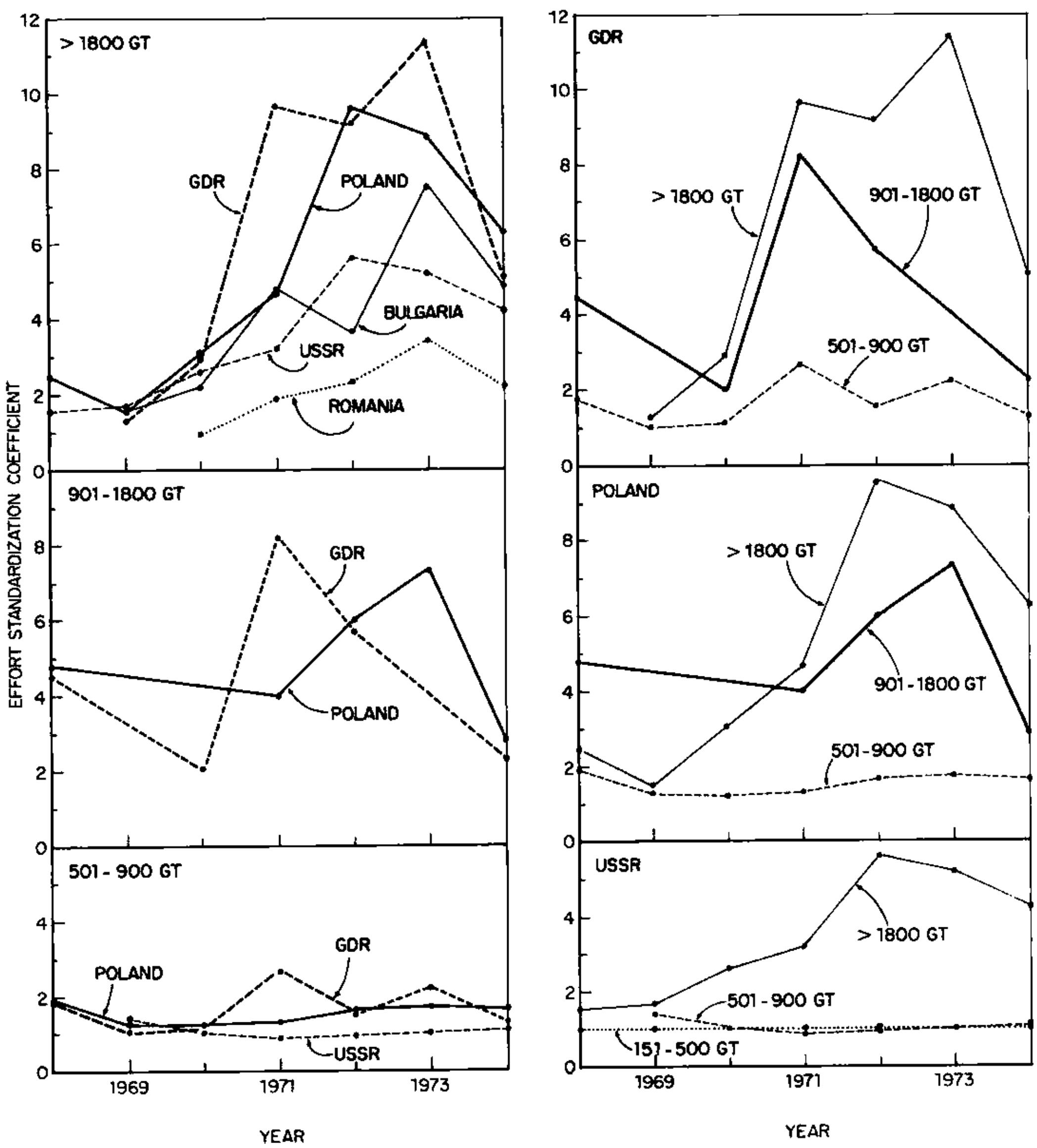

Fig. 3. Effort standardization coefficients by country for the 501-900, 901-1800, and >1800 GT classes (left) and by tonnage class for GDR, Poland, and the USSR (right). Years for which coefficients were calculated are indicated by dots.

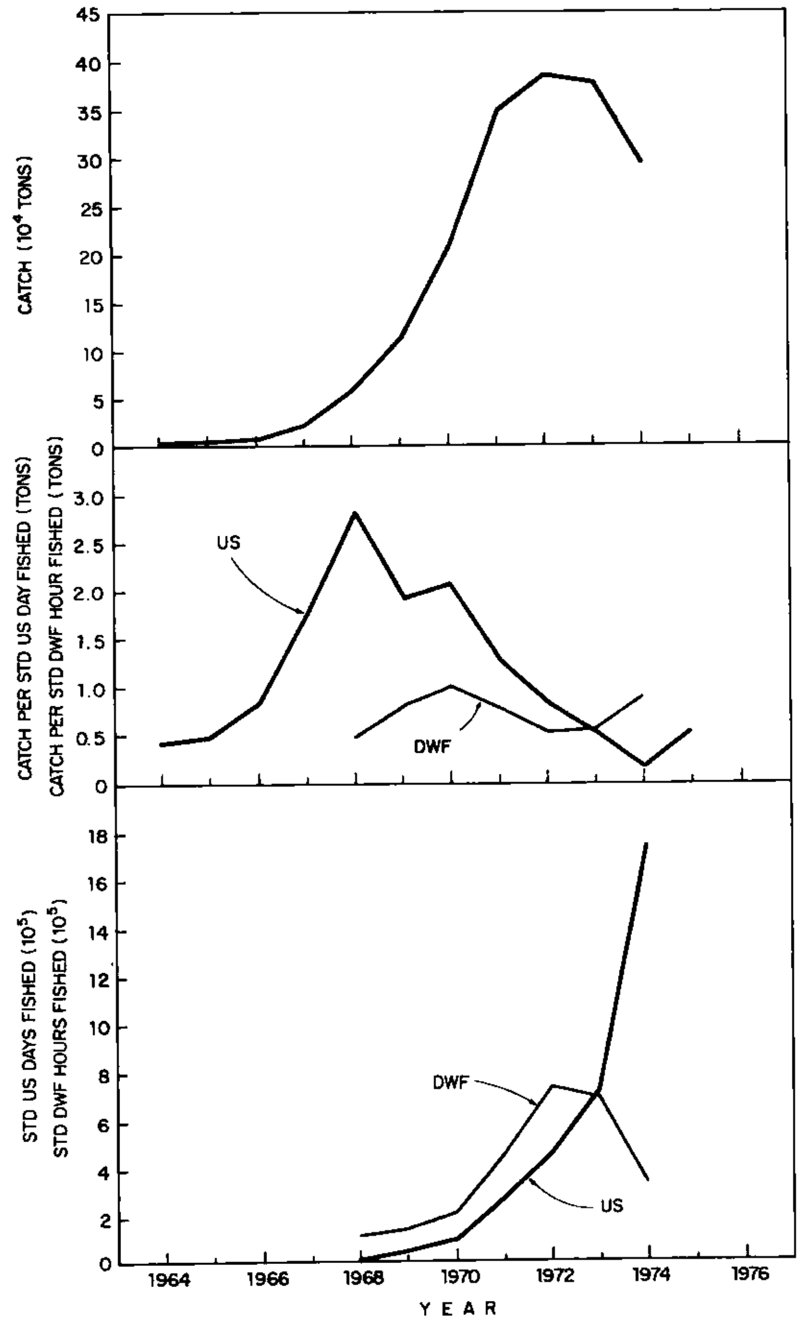

Fig. 4. International mackerel catch (1964-1974), catch per standardized US day fished (1964-1975), catch per standardized DWF hour fished (1968-1974), and international effort expressed as standardized US days fished and as standardized DWF hours fished in ICNAF SA 5-6.

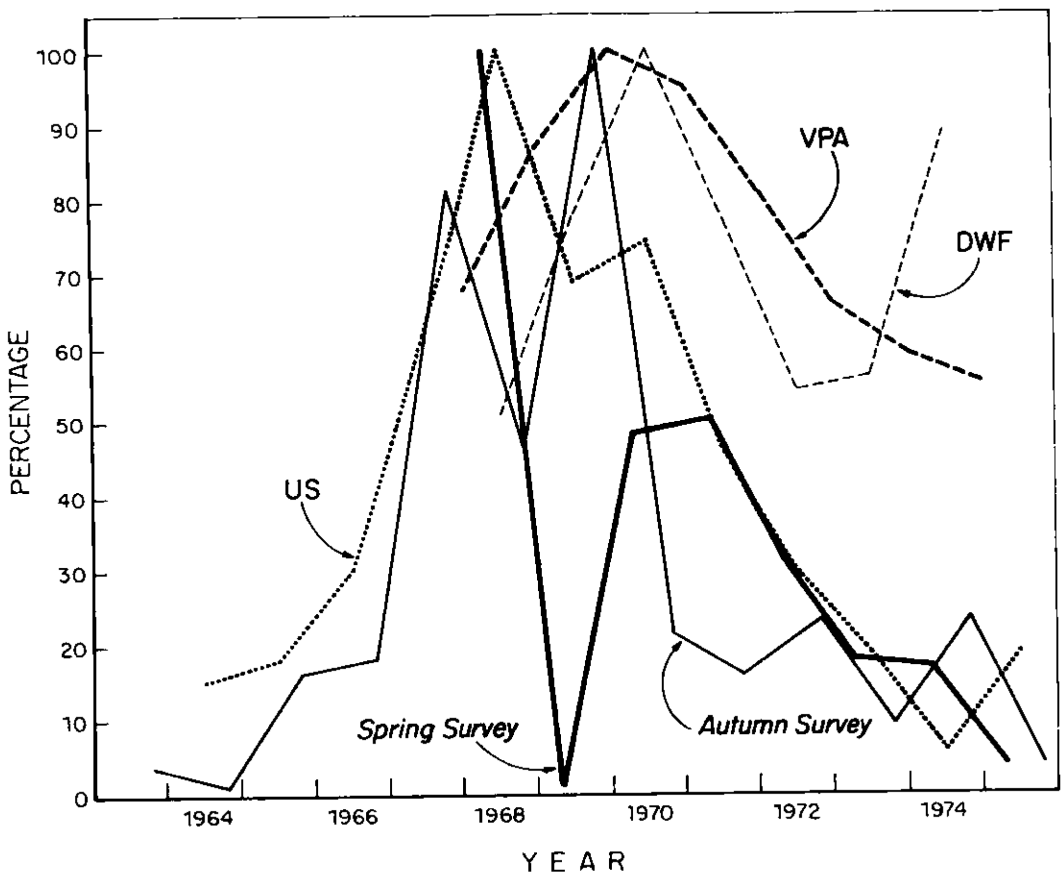

Fig. 5. Changes in mackerel stock abundance as measured by (1) US autumn survey catch per tow (retransformed from $\log_e$ scale) (1963-1975), (2) US spring survey catch per tow (retransformed from $\log_e$ scale) (1968-1975), (3) US commercial catch per std. day fished (1964-1975), (4) DWF catch per std. hour fished (1968-1974), and (5) biomass calcualted from VPA (1968-1975). Each index is plotted as a percentage of its maximum point.