Analysis of stock size and yield of Southern Gulf herring

by

G.H. Winters, D.S. Miller and J.A. Moores

Introduction

The rapid increase in landings of Southern Gulf herring in the mid 1960's was due to the large-scale introduction of purse-seining which transformed the fishery from one based mainly on fixed gear exploiting spring-spawning herring in the Southern Gulf to a mobile fishery exploiting both spring- and fall-spawning herring at all times of the year and outside the Gulf in Southwest Newfoundland where the stock complex over-wintered. Landings increased from 40,000 m tons in 1965 to 300,000 m tons in 1970 subsequently declining to around 40,000 m tons since 1974. Research studies (Winters and Hodder, 1975 and references therein) revealed that the developing fisheries were based on an accumulation of biomass produced by two very large year-classes (1958 of autumn and 1959 of spring) spawned in the late 1950's shortly after a fungus desease (Tibbo and Grahamn, 1963) had decimated herring stocks in the Southern Gulf. These studies also showed that the precipitous decline in catches during the early 1970's was due to a combination of high fishing mortalities and successively poor recruitment to both spawning components. Winters and Hodder (1975) concluded that the large 1958 and 1959 year-classes having been produced under exceptional circumstances were not a regular feature of the biology of this stock complex; more likely the much smaller year-classes which prevailed in the 1960's represented the normal situation. More recent studies by Winters (1975, 1976) have indicated that the Southern Gulf herring biomass had exerted logistic control of its recruitment, growth and maturation and that competition and predation by an expanding mackerel population in the late 1960's prevented a resurgence of herring production as would have been expected from the rapid attrition in herring biomass during that period. Lett and Kohler (1976) arrive at a similar conclusion regarding the homeostatic effect of the pelagic (herring and mackerel) biomass on herring recruitment but with added logistic control exerted by density-dependent l_1 growth. These documents summarize recent data and present additional hypotheses relating to present and historical production of Southern Gulf herring.

Stock Definition

Since 1972 (Table 1) the fishing pattern on this stock has changed from a predominantly winter fishery along southwest Newfoundland and a summer fishery in the Southern Gulf to a predominant spring purse-seine fishing along the western (so-called "edge" area) and eastern (southwest tip of Newfoundland extending into St. Georges Bay) edges of the Laurentian Channel and a fall fishery in the Southern Gulf. Historical tagging experiments (Winters 1975 and references therein) have confirmed the spring migration across the Laurentian Channel to the "edge" fishery but more recently purse-seiner fisheries have developed at the head of St. Georges Bay. An analysis of spawning group composition (Moores and Winters, MS 1977) indicates these to be comprised mainly of spring-spawners in 1975 and 1976 whereas in previous years (when the fishery was at the southern extreme of St. Georges Bay) the proportion of spring and fall spawners was similar to catches sampled from the "edge" fishery. The high proportion of maturity stages 5 and 6 in the St. Georges Bay samples in 1975 and 1976 together with results of tagging experiments conducted in St. Georges Bay in April 1976 suggest that local stocks rather than Southern Gulf herring were exploited in St. Georges Bay in 1975 and 1976. These catches have therefore been excluded from this assessment of the Gulf herring stock complex; all previous catches on St. Georges Bay are however included as part of the Southern Gulf stock.

Age Composition of 1976 Catches

Total catches in 1976 (Table 2) were 40,000 m tons a decrease of 4000 tons from 1975. Purse-seine catches remained at the 1975 level whereas inshore gears decreased from 13,500 tons in 1975 to 10000 tons in 1976. This decline was most evident in the Gaspé summer fishery which exploits mainly autumn spawners during their spawning season.

Age composition data of purse-seine fisheries along the "edge" and in the Gaspé area for the period 1974-76 are shown in Figure 1. Amongst spring spawners the "edge" fishing continued to exploit mainly the older age-groups whereas there was very little difference between the "edge" and Gaspé fisheries amongst fall spawners, reflecting perhaps the extremely poor production of this component since the 1970 year-class and the apparently high migration ratio (Winters and Hodder 1975) of that year-class in 1976. The 1974 year-class dominated purse-seine catches of spring spawners in the Gaspé fishery in 1976 and appears to be at least as strong as the 1968 year-class.

Spawning Group Composition

Inshore fisheries in the Southern Gulf tend to exploit spawning populations and thus are largely discrete in their spawning group composition (Tabel 3). The Southern Gulf purse-seine fisheries have changed somewhat since spawning grounds were protected from encircling gears in 1975. The fishery is now concentrated in late fall when the schools of herring are mixed and the recent production of good year-classes of spring spawners has resulted in a predominance of that component in the fall fishery.

Commercial samples from catches taken in the "edge" fishery suggest a mixture of spring and fall spawners with a trend towards increasing prepondance of fall spawners with time (Fig. 2). This agrees with observations by Hodder et al (1971) that spring spawners immigrate into the Gulf earlier and at a faster rate than fall spawners. This diminishing contribution of spring spawners to the "edge" fishery in May is also consistent with their inshore spawning migrations at this time both in the Magdalens and in the Chaleur Bay area.

Fig. 3 shows the contribution of fall spawners to the total catches since 1965. The increase from 30% in 1965 to 75% in 1970 was due to developing fisheries on over-wintering concentrations along southwest Newfoundland and on spawning concentrations of fall spawners in the Southern Gulf. The decline in the contribution of fall spawners since 1972 is partially due to the demise of the southwest Newfoundland fishery and the seasonal shift in the Southern

Gulf fisheries but more so as a result of continuing poor recruitment to that component relative to spring spawners.

Catch/Effort Analyses

Log-book records of catch and effort data for the purse-seine fleet operating in the Southern Gulf (Gaspé - Chaleur Bay) and along the "edge" have been analyzed for trends in seasonal and annual abundance changes (Tables 4 and 5). In the Southern Gulf fishery catch-per-unit-effort (CPE) has a seasonal trend, increasing from June to July then decreasing in August followed by a steady increase during the fall apparently as a result of a general concentration pattern of spring and fall spawners prior to their over-wintering emigration from the Gulf. To avoid biases due to seasonal changes in CPE annual CPE indices were calculated as the unweighted mean CPE for the months August - October. 1973 was discarded being based on one boat only and estimates of CPE for August and September 1976 were derived from the ratio of CPE in these months to the average October CPE during the period 1972-72, 1973-74. The data (Table 4) indicates that CPE declined substantially from 1971 to 1974, stabilized in 1975 and showed a significant improvement in 1976. The "edge" fishing , on the other hand, has shown a continuous improvement since 1974 (Table 5).

CPE data are summarized in Table 6 including comparative data from the fishery on over-wintering herring in southwest Newfoundland (Winters and Hodder 1975). Since the southwest Newfoundland data have been shown to be well correlated with changes in biomass (Winters and Hodder 1975) they have been used to obtain prorated estimates of CPE for the southern Gulf. Such estimates have then been used to estimate fishing effort in terms of operating days for the period 969-76. Fishing effort peaked at 4000 days in 1971 but has since declined to a level of 1000-1500 days.

Calculation of Assessment Parameters

(I) Partial recruitment rates. Trial estimates of terminal fishing mortalities (F) were utilized to assess the effect of F on fishing mortality estimates by Cohort Analyses ^{T} for the period 1969-74. No significant changes in fishing mortality estimates for 1969-74 were evident for the range of F employed; hence unweighted mean F_i's were computed by age and plotted as a ratio of F for spring spawners and fall F_{i+1} spawners separately. The results (Fig. 4) indicate that fishing mortality increases with age in both components and at a rate very similar to the migration ratios calculated by Winters and Hodder (1975). These migration ratios indicated that as a year-class grew older an increasing proportion of its numbers emigrated from the Gulf to over-winter. This situation is still evident in the exploitation of older age-groups in the "edge" fishing relative to that in the Southern Gulf.

(II) Terminal fishing mortality (F_T). Using the partial recruitment rates given in Fig. 4 trial values of F_T were used to obtain estimates of fishing mortality rates (spring and fall combined and weighted by population size) for ages 5 and older for the period 1969-74. These are plotted against fishing effort in Fig. 5 and regression analyses indicate a linear relationship described by the following equation:

$$F = .00013E - .022 \quad (r^2 = .98)$$

From the effort data given in Table 6 fishing mortality rates in 1975 and 1976 were computed by the above equation to be 0.17 and 0.10 respectively. F_T = 0.16 was then selected on the basis of the more conservative of the above estimates (F_{5+} (1975) = 0.17). The correspondence between cohort estimates of F(F_C) and regression estimates from effort data (F_E is shown below.

Year	1964	1970	1971	1972	1973	1974	1975	1976
F_C	.28	.39	.51	.25	.21	.15	.17	.16
F_E	.28	.37	.51	.27	.21	.14	.17	.10

Results of Assessment

The 2+ biomass of the Southern Gulf stock complex decreased from 1690 KT in 1969 to 455 KT in 1973 (Table 7) and has stabilized at that level since then. Fall spawners however have shown a continuous decline in abundance whereas the spring-spawning biomass has been increasing since 1973 and is now higher than in any year since 1970. Whereas the fall spawners constituted nearly 75% of the total biomass in 1969 the situation was the reverse in 1976 when spring spawners comprised nearly 70% of the total biomass.

The changes in the relative abundance of spring and fall spawners is mainly due to differing recruitment levels in the two components (Fig. 6). There has been a declining trend in the recruitment levels of fall spawnings and year-classes since 1970 appear to be particularly weak. In spring spawners however, a trend of increasing recruitment levels is evident and the 1972 and 1974 year-classes seem particularly strong although of course much weaker than the 1959 year-classes. If these recruitment trends continue, the Southern Gulf stock complex of herring will have reverted to its status prior to the fungus disease in the mid-1950's i.e. a stock characterized by a predominance of spring spawners.

Calculation of $F_{opt.}$

Winters and Hodder (1975) have indicated there are no significant differences in yield-per-recruit of spring and fall spawners. Consequently yield-per-recruit analyses have been carried out using weighted averages of the various parameters. The results are shown in Fig. 7. The optimum fishing mortality rate ($F_{opt.}$) is calculated to be 0.52, a level which will generate 88% of the maximum yield-per-recruit.

Catch Projection

Mean recruitment strengths (and standard deviations) of spring- and fall-spawning herring have been calculated for the year-classes 1961-74 and 1964-74 respectively. Using a random number generator a 20 year projection of stock size and yield (at $F_{opt.}$) has been calculated and the results are shown in Fig. 8. Total catch fluctuates between 55,000 and 90,000 tons with a mean of 70,000 tons. The average yield of fall spawners is 34,000 tons compared to 37,000 tons for spring spawners. The 1977 catch is projected to be 85,000 tons of which 50,000 tons are spring spawners. Total biomass fluctuates between 325,000 and 530,000 tons with an average of 420,000 tons.

The reality of these projections must be considered in relation to the adherence of future recruitment to the predicted pattern. As stated previously spring spawners appear to be oscillating upwards whereas the reverse situation obtains for fall spawners. If this trend continues the projections in Fig. 8 will have underestimated the spring component and overestimated the fall component.

General Biological Aspects

(I) Egg production, recruitment and larval abundance. Age-specific fecundities have been estimated from fecundity-length relationships of spring- and fall-spawning herring given in Hodder (1972) utilizing age-length and age-maturity keys given in Hodder et al. (1972) and Winters (1975) i.e. incorporating changes in growth and maturation rate. From such data total egg production of each spawning group (population fecundity) has been calculated based on population estimates by age from cohort analyses, adjusted to May 1 for spring spawners and August 1 for fall spawners.

Survival rates per unit egg production (recruitment rate) calculated as the ratio of recruitment strength at age-group 2 to egg production 2 years earlier have been plotted against egg production in Fig. 9 (log-transformed). The significant aspect of this plot is that whereas the recruitment rate of spring spawners is following the same trend with population decline as with population increase, the recruitment rate of fall spawners is much lower in recent years for equivalent egg production levels observed in the mid-1960's. This aspect is to some degree consistent with the observation by Winters (1976) that multiple regression analyses indicated that mackerel biomass is having a greater effect on autumn-spawner recruitment than on spring spawners. However both mackerel biomass and recruitment have shown substantial declines during the 1970's and some amelioration of their effect should have been observed in recent year-classes of fall spawners. This suggests that other factors may now be regulating herring production in the Southern Gulf.

Larval abundance estimates (numbers/volume) interpolated from Lett and Kohler (1976) are plotted against egg production estimates (this document) in Fig. 10. If the 1967 data points are considered representative for that year then larval abundance estimates in subsequent years are much lower than would have been expected from the calculated egg productions. This could be explained as a result of intensifying larval predation by mackerel subsequent to 1967 as their population increased. If one further assumes that larval predation is linearly related to mackerel biomass then the larval abundance estimates can be adjusted by multiplying them by the ratio of mackerel biomass in 1968 onwards to the level in 1967. This adjustment is shown by the open circle in Fig. 10. The relationship is linear for both spawning groups thus supporting the predatory role of mackerel. If however the 1967 larval abundance estimates are anomalous (and there is some suggestion of this in Lett & Kohler 1976) the graph suggests that mackerel have not had a significant effect on larval survival. (Lesson: What you gain on the roundabouts you lose on the swings.)

(II) L_1 Studies. Lett and Kohler (1976) have analyzed first-year growth (l_1) Southern Gulf herring, concluding that l_1 values are inversely related to year-class size and act to control population fecundity through effects on subsequent growth and maturation rates. Unfortunately the authors misinterpreted the conventions for conversion of age (given in their data source (Messich 1973)) to year-class resulting in the assignment of fall spawner year-classes two years too recent and spring spawner one year too recent. The data are replotted in Fig. 11. There is little evidence to suggest a density-dependent relationship between year-class size and first-year growth. Rather a general trend of increasing l_1's from the 1957 year-class onwards is suggested. The data points however are based on small sample sizes and have not been adjusted for potential biases due to Lee's phenomenon. We have therefore selected otolith samples from the Southern Gulf stock and have measured l_1 values for year-classes 1958-68 at age 8. The results are plotted against year-class size for spring spawners and fall spawners in Fig. 12. They support the conclusions derived above from Messich's (1973) data. They do not however provide conclusive evidence of the absence of density-dependent l_1 growth since conditions in the Southern Gulf were exceptional during the late 1950's and also there has been only one dominant year-class in each component. We have therefore measured annuli of otoliths from Fortune Bay, Newfoundland which has been heavily exploited since the mid-1960's and which has experienced 3 strong year-classes since the late 1950's. The stock is predominantly spring spawners (90-95%) and estimates of year-class strength have been derived by cohort analyses (data on file).

To obtain an adequate sample size for weak year-classes a range of age-groups (5-8) were measured. This necessitated an evaluation of change in l_1 estimates with age (Lee's phenomenon). The 1968 year-class was selected and measured at age-groups 4-8. The results (Fig. 12) indicate strong Lee's phenomenon from age-groups 8 to 6, then a drop in l_1 followed by an apparent further increase. Other year-classes also demonstrated this drop in l_1 values from age-groups 6 to 5 as did the Southern Gulf samples. No explanation can be given. Fig. 12 was then used to adjust l_1 values of the weak year-classes to age-group 6. L_1 values thus obtained are plotted against year-class strength (1958-71) in Fig. 13. Correlation analyses indicate that l_1 is not significantly correlated with year-class strength.

A corollary of Lett and Kohler's (1976) hypothesis is that l_1 size acts to control egg production through regulating effects on growth and maturation rates. This implies the absence of density-independent effects such as temperature, density-dependent effects exerted by the total biomass, and growth compensation. Fig. 14 illustrates a plot of l_t (age-group 6) against l_1 for Fortune Bay herring. The correlation is not significant suggesting that other factors (named above) may be more important in determining subsequent growth than l_1 size. Fig. 15 shows the instantaneous growth rate during the second year plotted against l_1 size. Growth compensation is evident and undoubtedly acts to stabilize subsequent growth, a growth characteristic also present in capelin (Winters 1974) and a variety of other species.

Surface temperature data are available from Station 27 (off St. John's) for the period under consideration. Fortune Bay hydrography should not be greatly different in terms of temperature trends than Station 27 since both are under the influence of the Labrador Current. Consequently l_1 values of

Fortune Bay herring have been plotted against these summer temperatures in Fig. 16. A significant positive correlation suggests that l_1 growth of Fortune Bay herring is being affected by temperature. Similar conclusions were reached by Day (1957) for Southern Gulf herring. In summary both density-independent and intrinsic factors play an important role in herring growth, and year-class size as an hemeostatic mechanism regulating first-year growth does not appear to be of significant importance.

The critical aspect of stock projection and yield is the causitive factors determining year-class size. Whereas correlation analyses (Winters 1976) suggest that herring biomass in conjunction with mackerel biomass acts in a logistic manner to regulate herring recruitment and growth, it does not explain the recent divergent recruitment trends in the two components nor does it adequately explain the predominance of fall spawner recruitment in the late 1950's and 1960's following a long-standing predominance of spring spawners (Tibbs, 1969). The recent trend suggests that perhaps the stock complex is now normalizing itself in terms of the spawning group composition, a phenomenon which is also evident in the Northern Gulf herring populations (Moores and Winters, MS 1977). Indeed the timing and much larger size of the spring plankton bloom in the Gulf of St. Lawrence would normally favor the greater production and survival of spring-spawned larvae, an advantage somewhat compensated for by the greater fecundity of fall spawners.

In addition to exceptional conditions created by the fungus epidemic in the late 1950's there is other evidence to suggest that conditions were unusual during that period. Olsen (1961) reports that whereas spring spawners dominated all of the major herring fisheries in Newfoundland in the late 1940's, during the late 1950's herring sampled along western Newfoundland tended to exhibit ar extended spawning season from May to September. A similar situation was reported in herring sampled along the south coast area (Tibbo 1957). These populations of herring were substantially depleted in the late 1940's and early 1950's both by heavy fishing and by the fungus epidemic and it may be hypothesized that such an attrition in population size resulted in a substantial increase in growth rate. Olsen's (1961) data support such an hypotheses. This may have resulted in spring-spawned year-classes to mature early enough to spawn (at least partially) in the summer and fall rather than the spring which would result in an extended spawning season. A similar situation may have occurred in the Southern Gulf spring spawners which were also severely depleted by the fungus epidemic. In fact l_1 values of spring- and fall-spawning Gulf herring are very similar in the late 1950's and early 1960's which would not be expected if the spawning seasons were discrete and non-overlapping.

In summary a definitive evaluation of production mechanisms of Southern Gulf herring in the late 1950's which resulted in abnormal recruitment patterns is not possible with present data; the probability exists that such recruitment patterns were abnormal and that the stock is now normalizing both its biomass and its spawning group composition.

(The data and their analyses presented in this report are by the nature of their development preliminary and should not be referenced or used without the written permission of the authors.)

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Table 1 Catch statistics for the various fisheries exploiting the Gulf stock complex, 1969-76.

Year	Catch (KT) by Area			
	SW Nfld.	St. Georges Bay	S. Gulf	Total
1969	128.1	0.3	152.5	280.9
1970	121.2	0.1	175.3	296.6
[illegible]	99.5	3.9	131.9	235.3
1972	[illegible]7.8	6.3	53.9	88.0
1973	2.7	12.5	43.1	58.3
1974	0.5	2.6	34.1	37.2
1975	-	3.6	43.9	43.9*
1976	-	6.5	39.4	39.4*

* S. Gulf only.

Table 2 Catch statistics for 4T herring in 1976

Month	Magdalens - Edge		Southern Gulf		Total
	Inshore	P. Seine	Inshore	P. Seine	
April	418	8052	222		8692
May	694	9637	4766		15097
June			669		669
July			191		191
August			1073		1073
September			1798		1798
October	56		250	3966	4273
November			2	8181	8183
December			-		-
Total	1168	17689	8971	12147	39975

Table 3 Spawning-group composition of commercial samples of herring caught by inshore and purse-seine fisheries in the Southern Gulf 1974-76.

Year	% Autumn spawners						
	May	June	July	Aug	Sept	Oct	Nov
A. Inshore							
1974	2	0	-	99	100	-	-
1975	1	1	100	94	-	-	-
1976	1	47	78	100	100	-	-
B. P. Seine							
1974	-	-	68	74	79	98	44
1975	-	-	38	-	75	3	3
1976	-	-	-	-	-	48	37

Table 4 Monthly CPE data as evaluated from log records of purse-seiners operating in the Southern Gulf, 1971-76. Bracketed values in 1976 are estimates from regression analyses.

Year	Catch-per-unit effort (CPE)						Unweighted mean (Aug - Oct
	June	July	August	Sept	Oct	Nov	
1971	25.2	70.1	47.0	54.4	77.4	-	56.6
1972	-	55.1	23.8	35.0	58.1	-	39.0
1973	-	-	-	83.3*	-	-	-
1974	-	36.0	25.2	31.2	37.2	66.7	31.2
1975	-	-	25.6	27.6	37.2	38.3	30.1
1976	-	-	(30.9)	(41.5)	55.7	79.6	42.7
Unweighted mean	25.2	53.7	30.3	37.1	53.1	61.5	

* One boat only

Table 5 Monthly CPE of purse-seiners operating along the "Edge" 1973-76.

Year	CPE (m tons/op, day)			Mean	
	April	May	June	Unweighted	Weighted
1973	57.5	54.6	50.5	54.2	55.3
1974	40.7	40.0	-	40.4	40.1
1975	48.7	57.4	-	53.0	55.1
1976	65.6	69.7	-	67.5	67.2

Table 6 CPE for the various fisheries exploiting the Southern Gulf stock complex. See text for explanation.

Year	CPE (M tons/day)			Effort (days)
	SW Nfld.	Edge	S. Gulf	
1969	50.3		(120.0)	2340
1970	41.5		(99.0)	3000
1971	24.6		59.6	3995
1972	13.4		39.0	2270
1973	9.2	55.3	35.0*	1750
1974		40.1	31.2	1220
1975		55.1	30.1	1460
1976		67.2	42.7	940

* Interpolated

Table 7 Biomass levels (age-group 2+) of spring and fall spawning herring in the Southern Gulf as calculated by cohort analyses.

Spawning Group	Biomass (KT) at beginning of year							
	1969	1970	1971	1972	1973	1974	1975	1976
Spring	454	372	272	206	196	239	265	316
Autumn	1237	894	561	324	259	222	191	153
Total	1691	1266	833	530	455	461	456	469

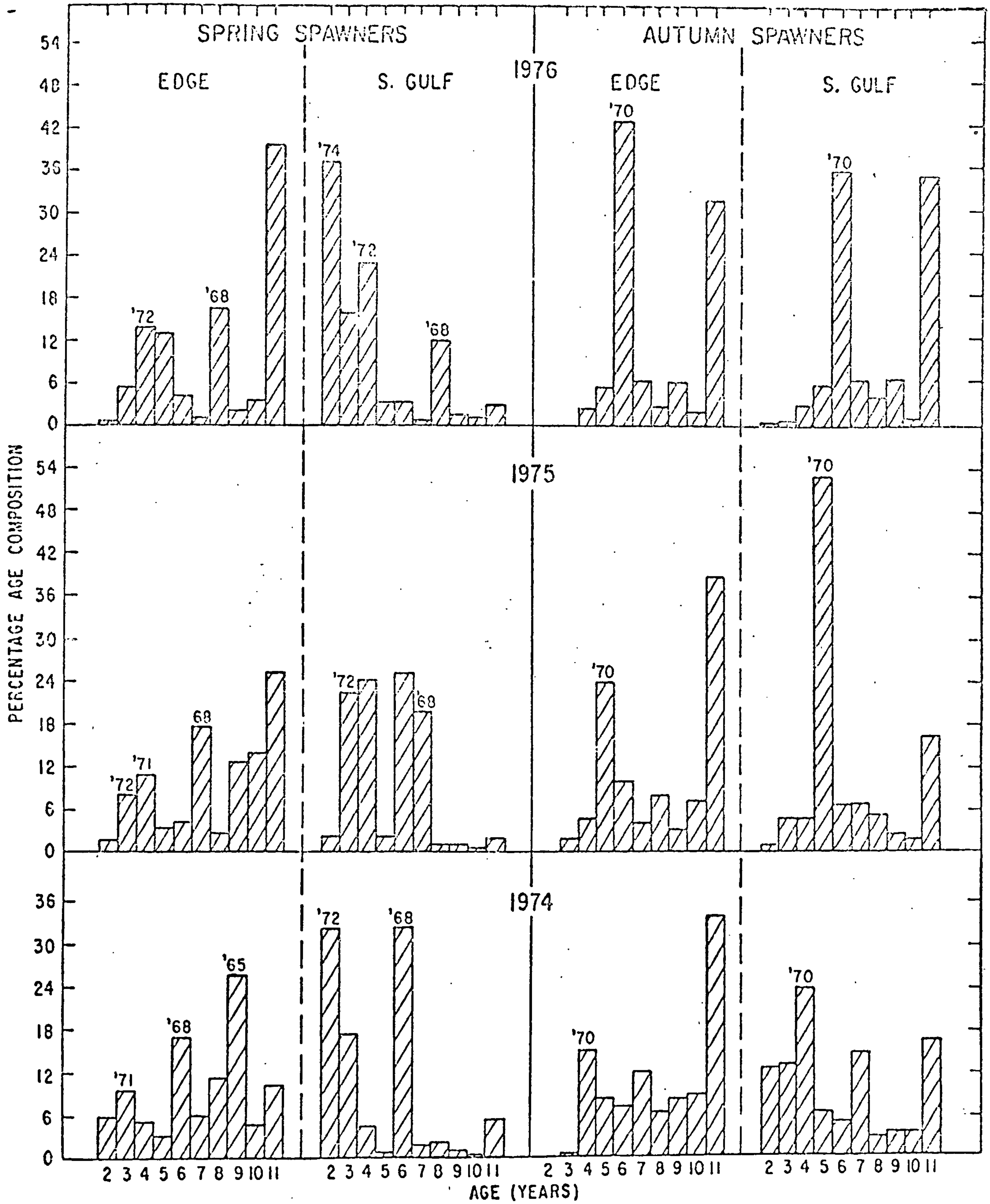

Fig. 1. Age composition data of purse-seine catches along the "Edge" and in the Southern Gulf 1974-76.

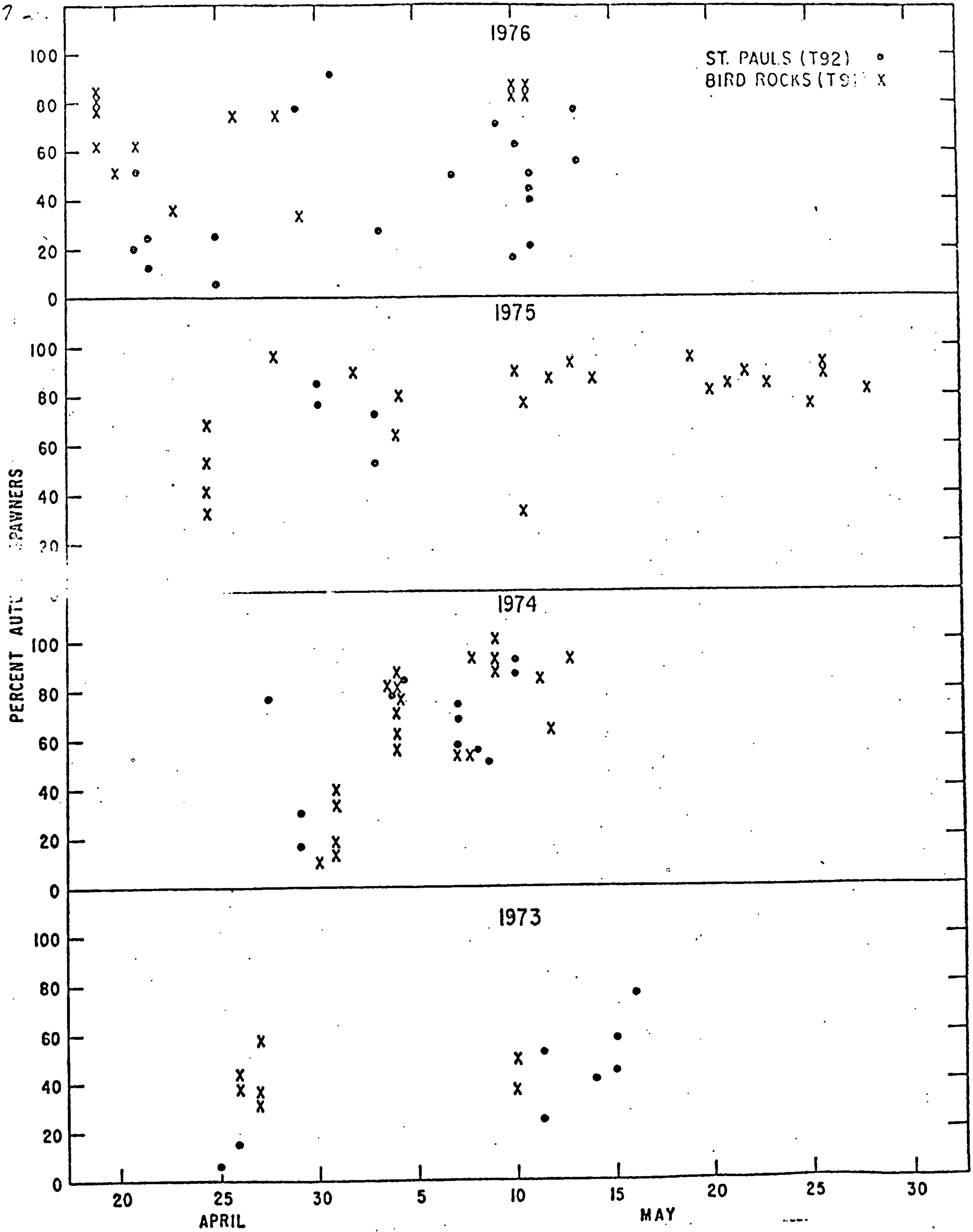

Fig. 2. Percent autumn spawners in individual samples of herring taken along the "Edge" area 1973-76.

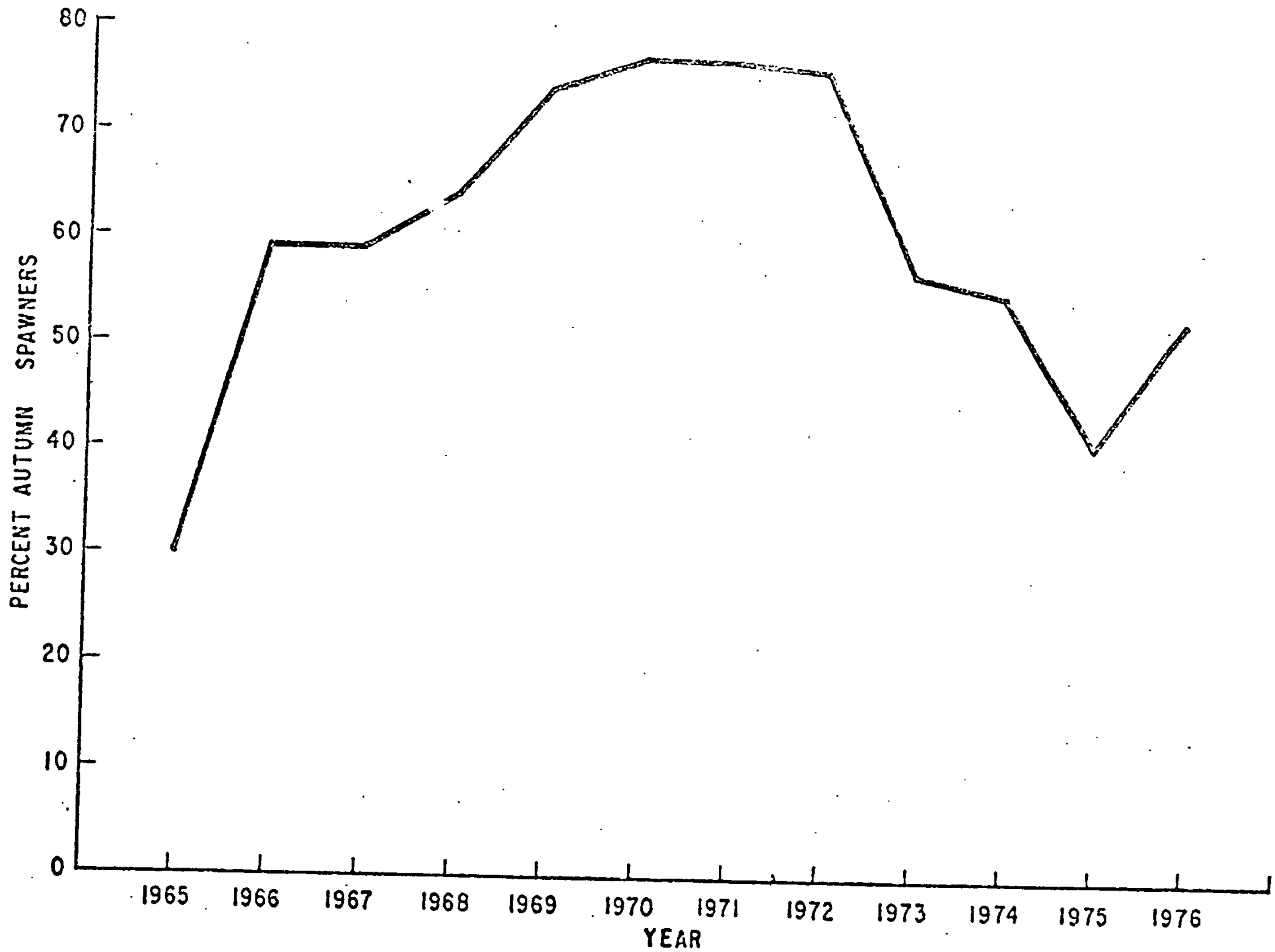

Fig. 3. Percent autumn spawners in total catches of the 4T stock complex 1966-76.

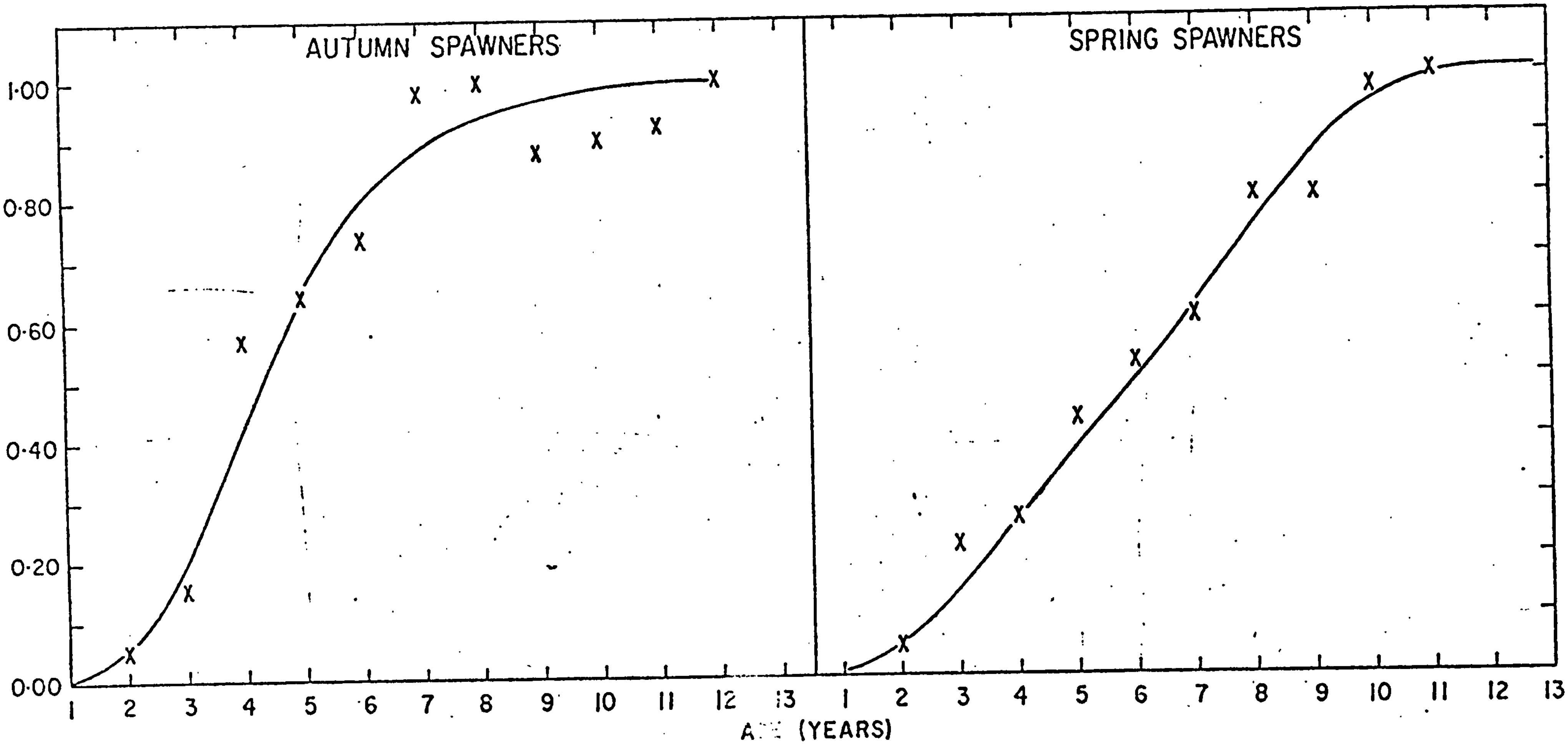

Fig. 4. Change in fishing mortality r... with age, calculated as a ratio of F for age-group 11+. Curves ...ed by eye.

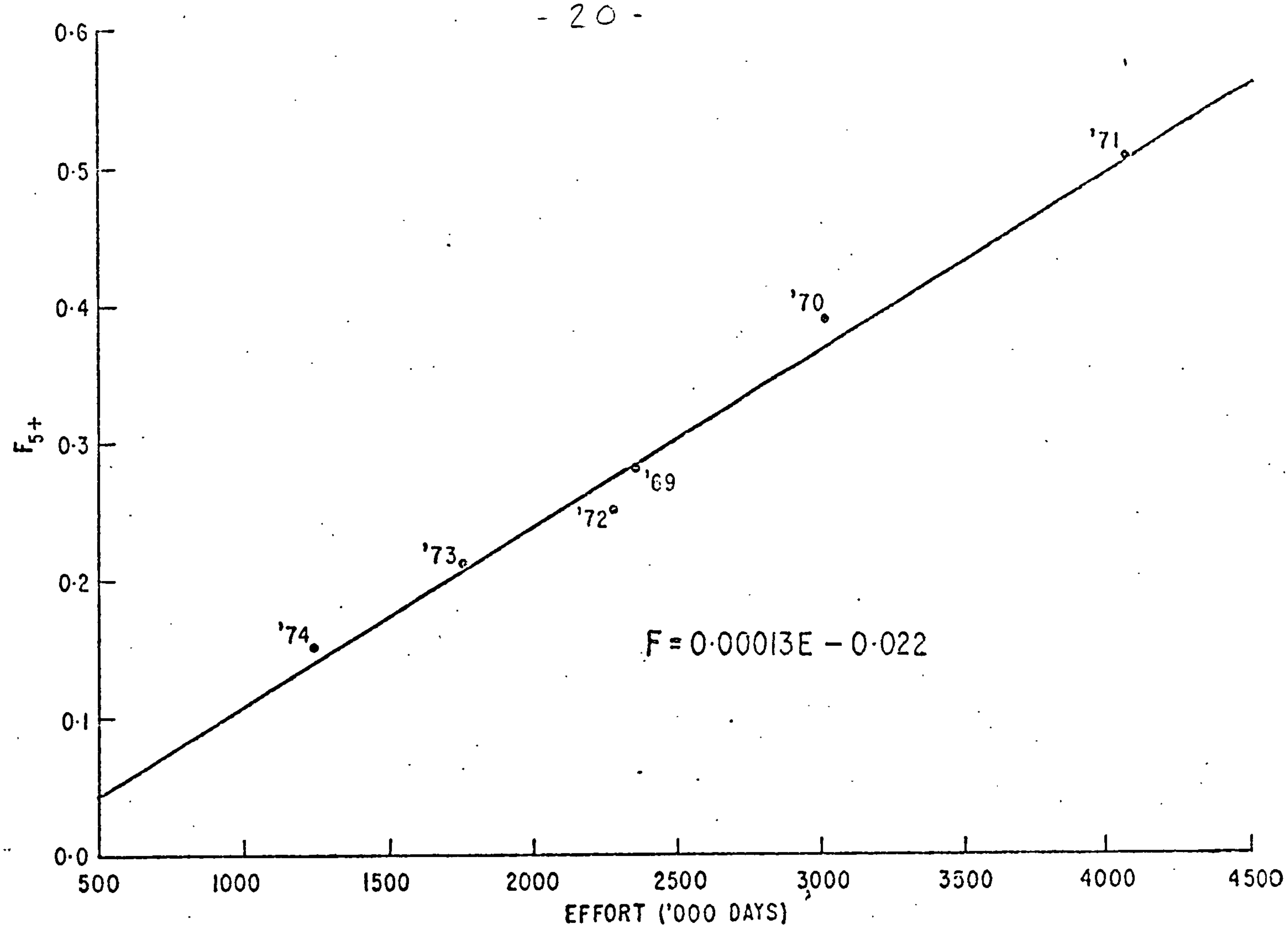

Fig. 5. Regression of fishing mortality rate of 5+ (F_{5+}) herring (autumn and spring combined) and fishing effort (E).

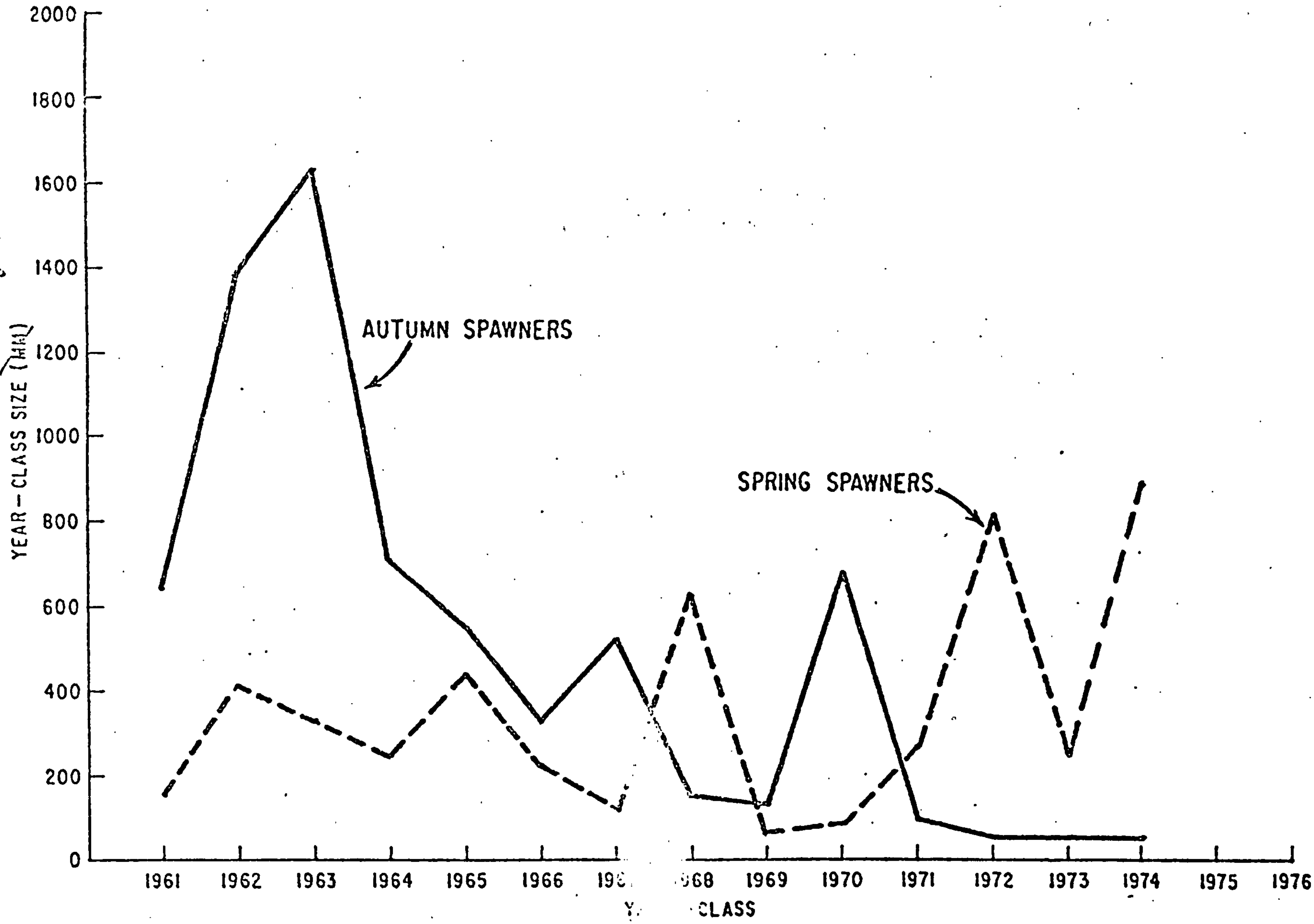

Fig. 6. Trends in recruitment levels (l at age-group 2) of spring- and fall-spawning Gulf herring 19

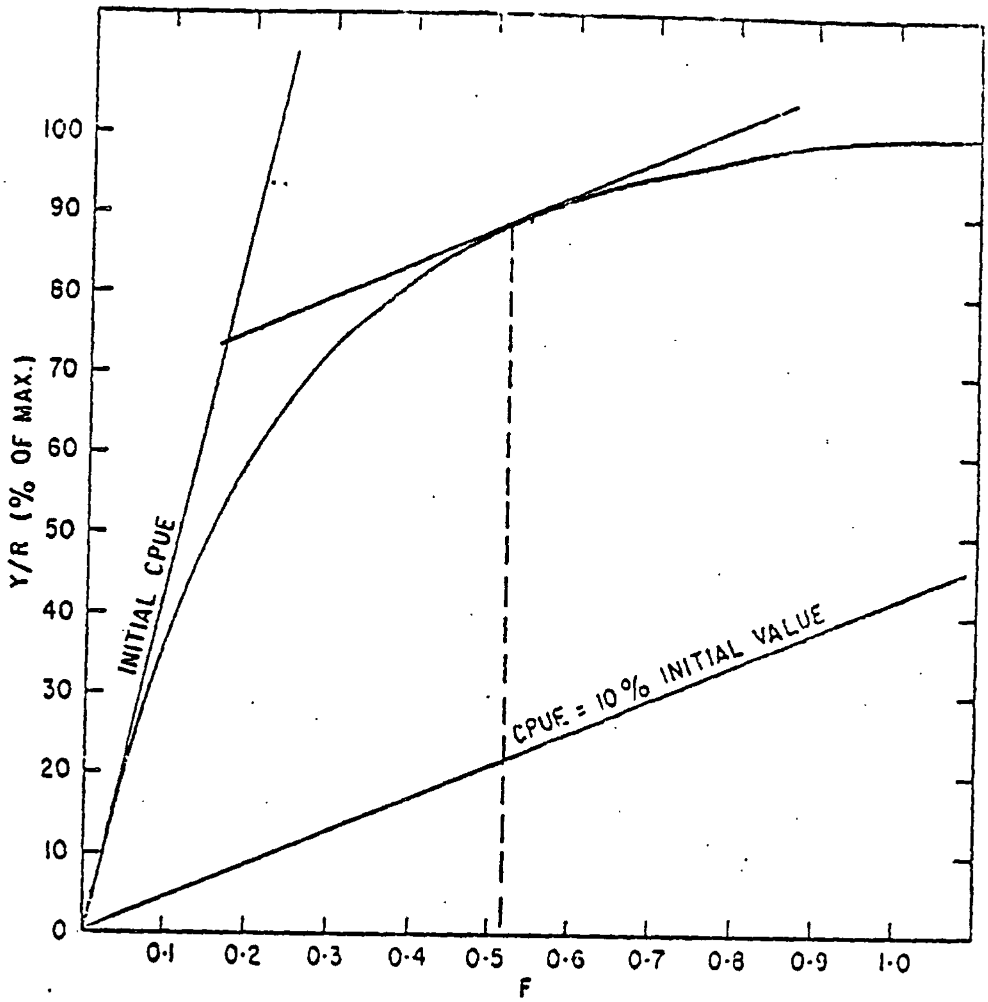

Fig. 7. Calculation of optimum fishing mortality rate.

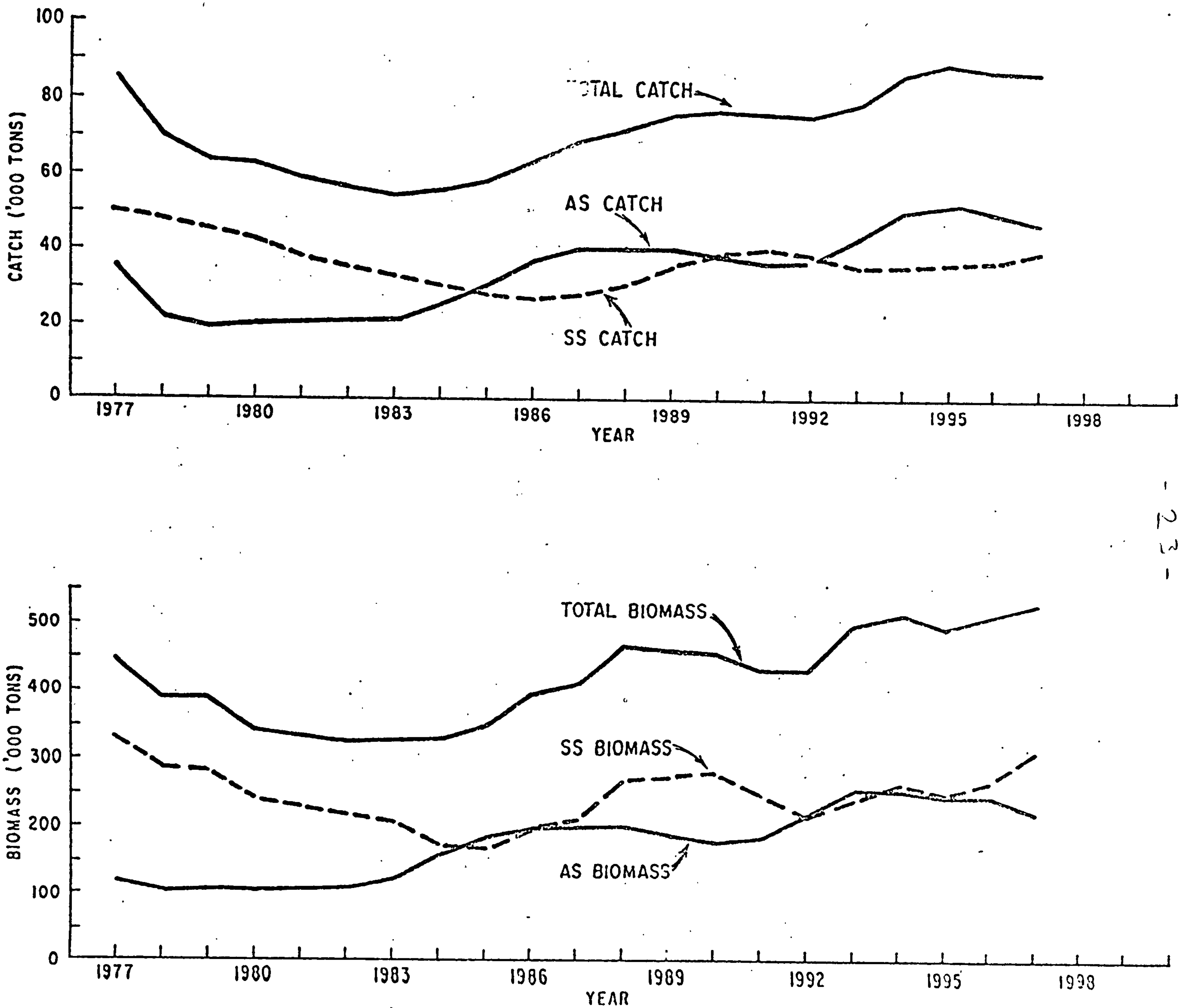

Fig. 8. Projection of stock and hield of Southern Gulf herring 1977-1997. See text for explanation.

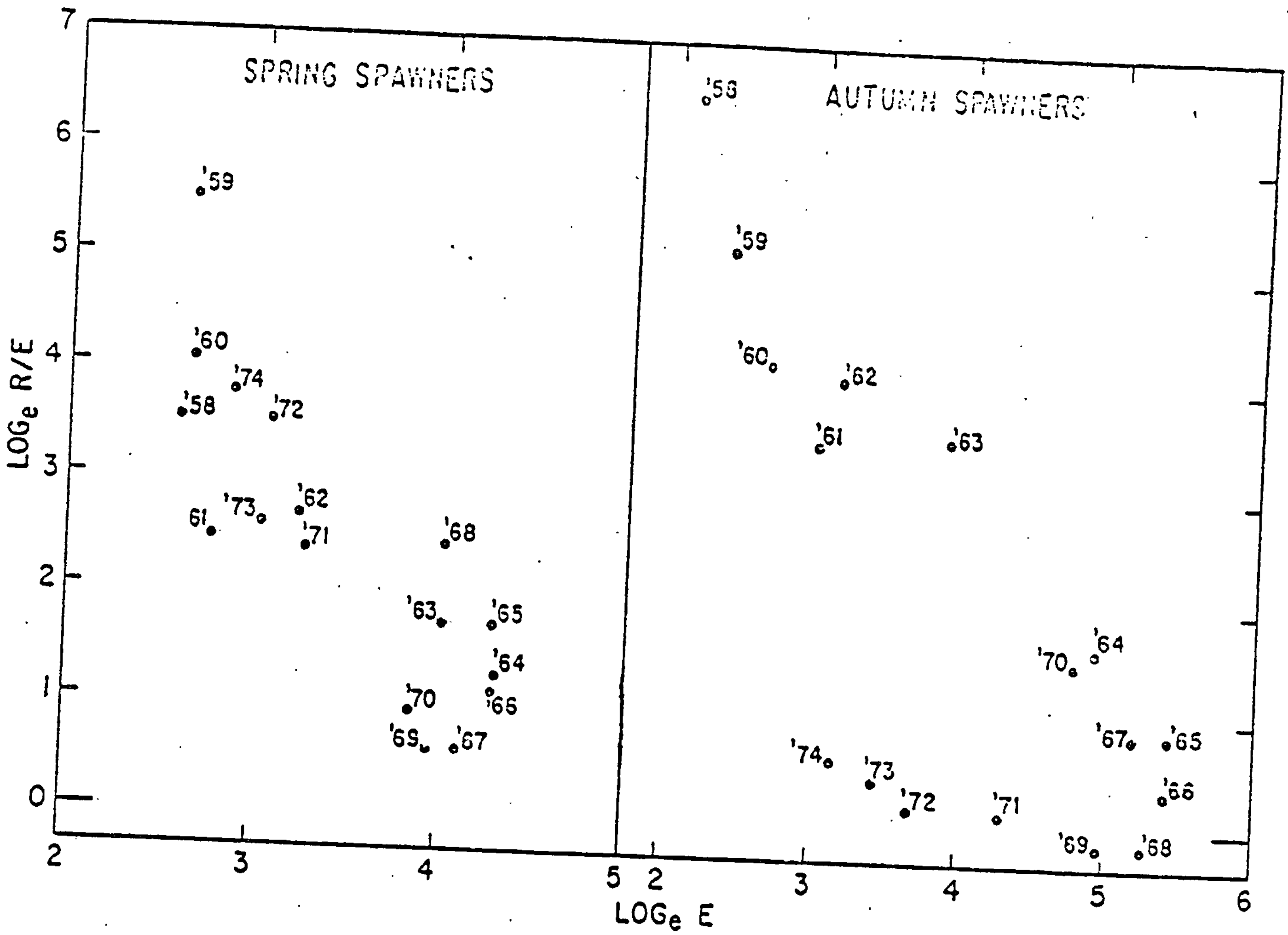

Fig. 9. Relationship between the rate of recruitment (survival rate per unit egg production) and egg production (E) of spring- and fall-spawning Southern Gulf herring.

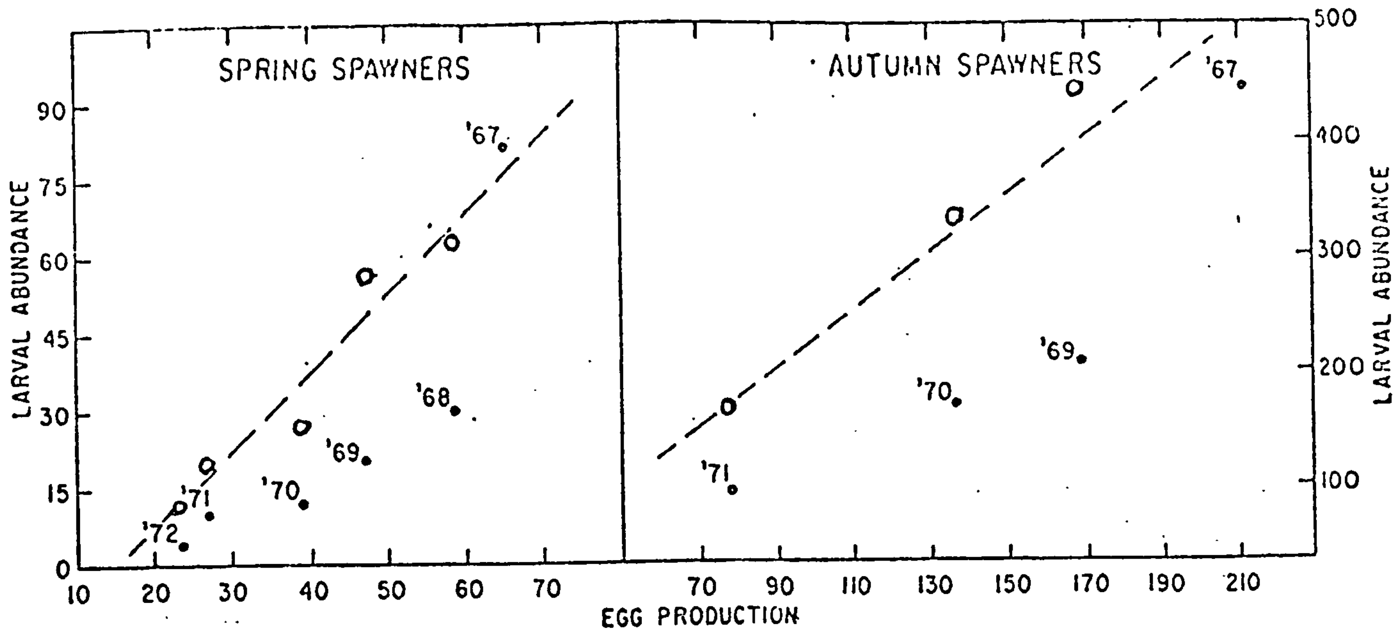

Fig. 10. Effect of egg production on the abundance of larvae (larval abundance data from Lett & Kohler (1976)). See text for explanation.

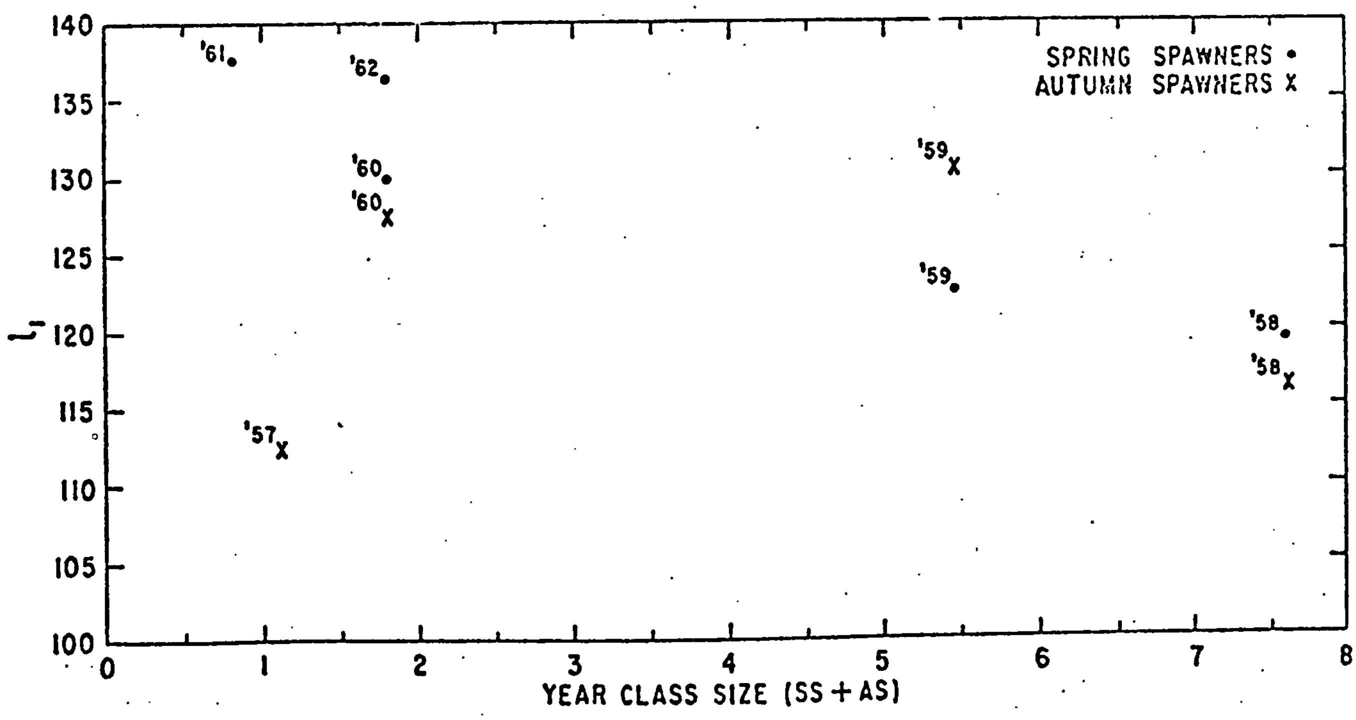

Fig. 11. Relationship between year-class size and length at the end of the first year (l_1). Replotted from Lett and Kohler (1976) with correction interpretation of year-class of Messich's (1973) data.

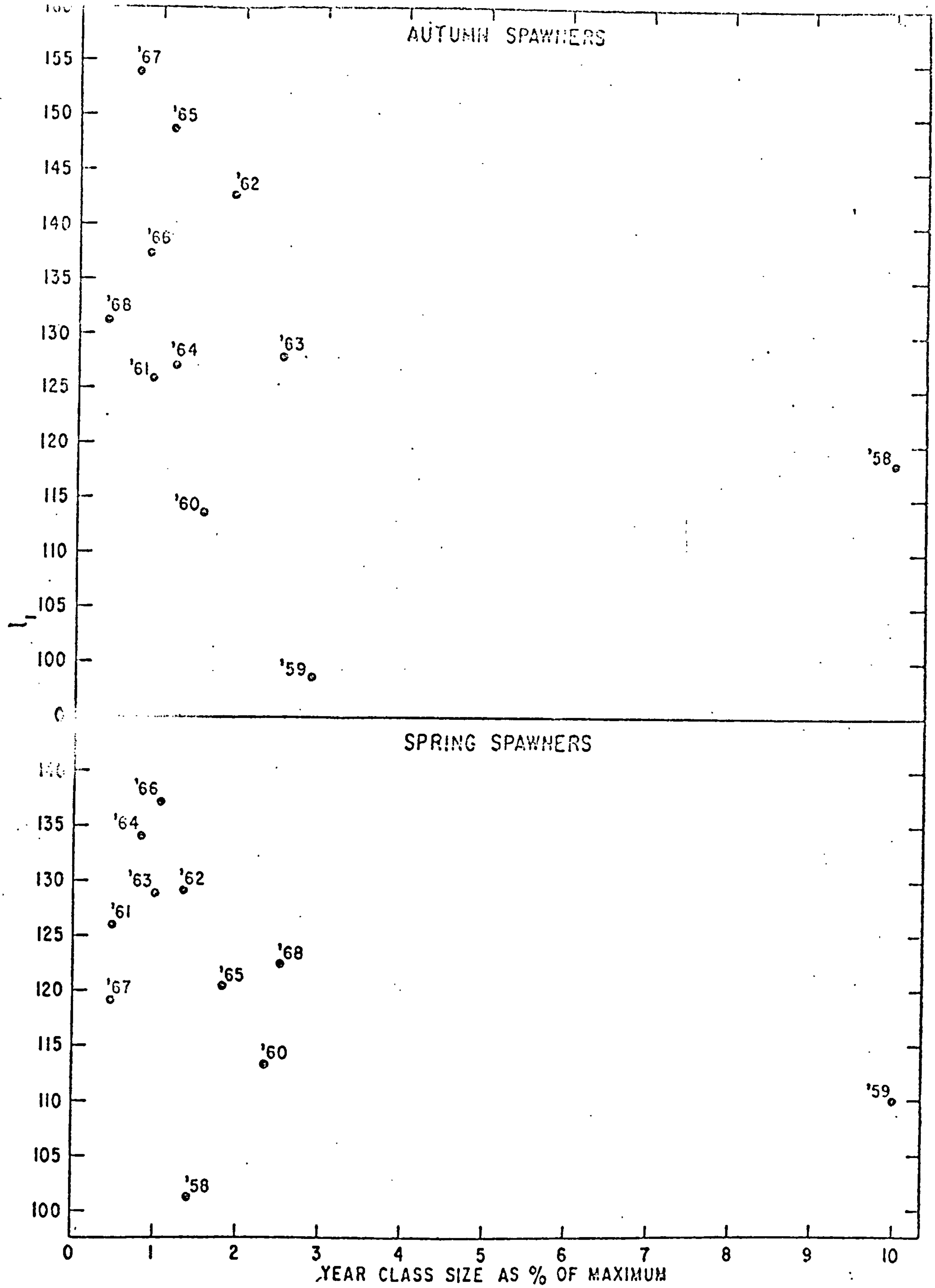

Fig. 12. Relationship between year-class size and l_1 growth as measured from otolith annuli of Southern Gulf herring.

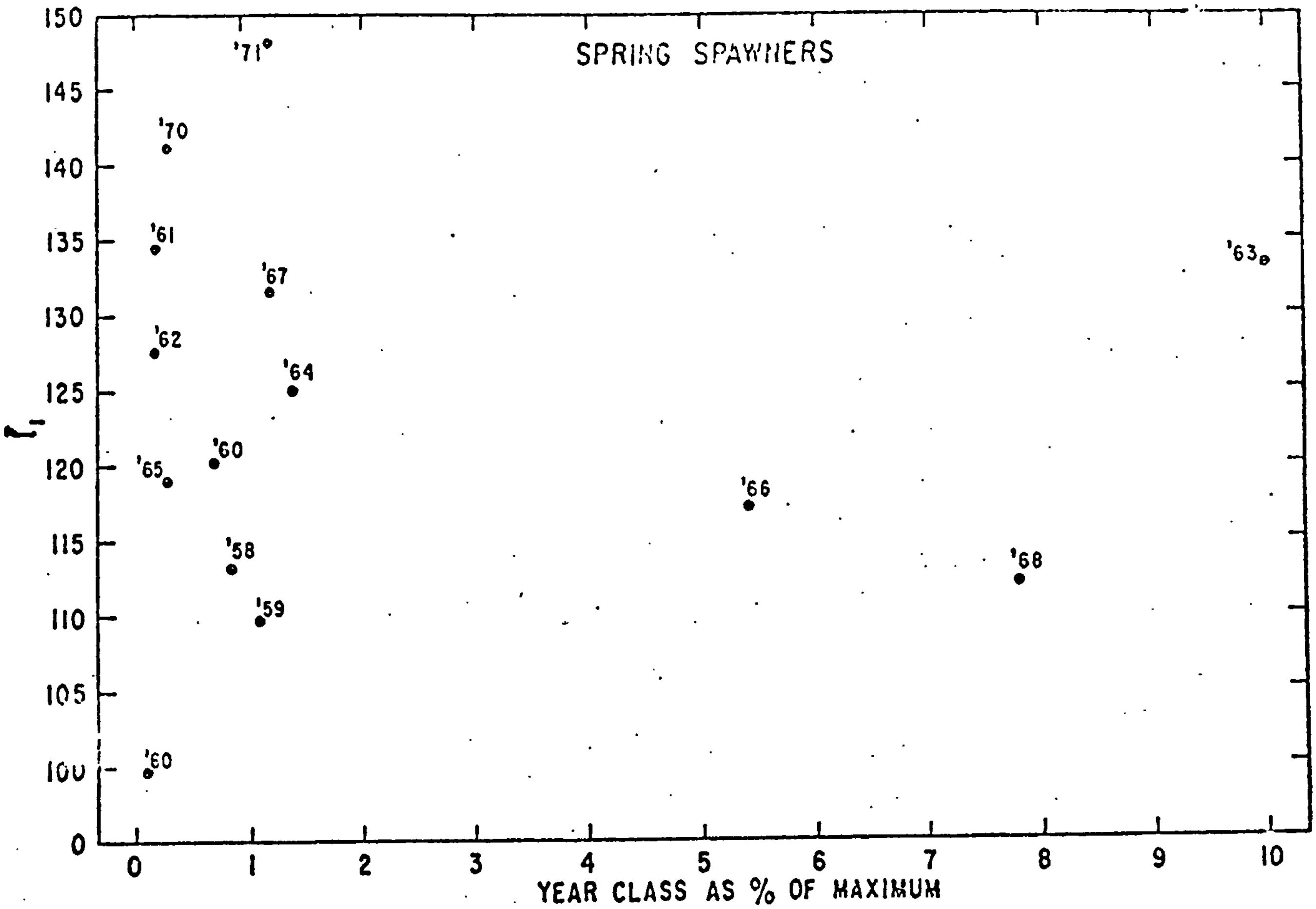

Fig. 13. Relationship between year-class size and l_1 growth as measured from otolith annuli of Fortune Bay spring spawners.

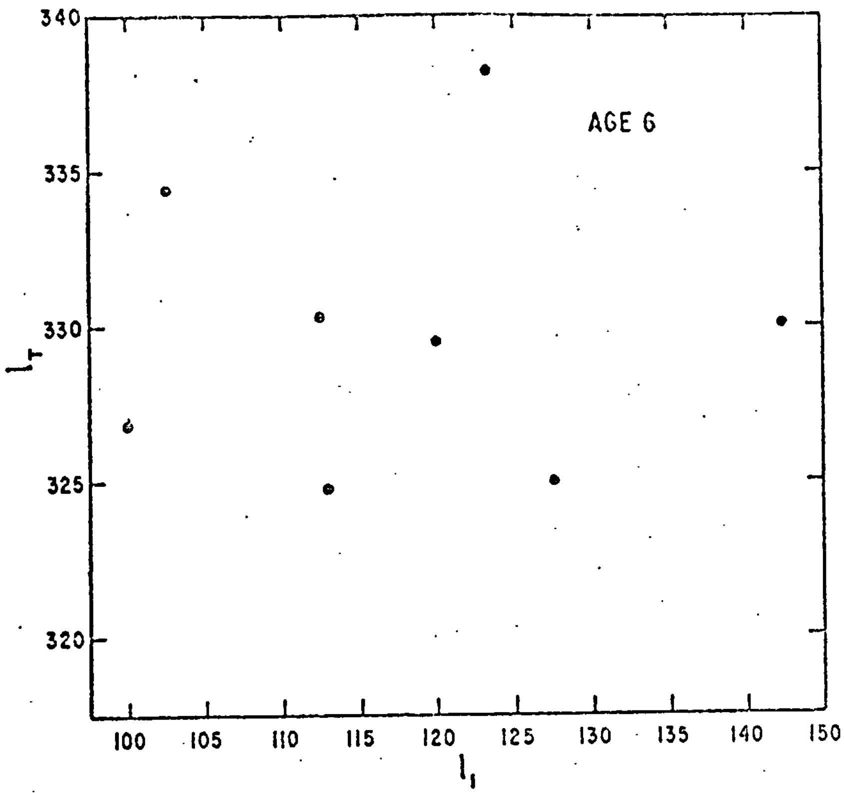

Fig. 14. Relationship between length at age-group 6 and l_1 growth of Fortune Bay herring.

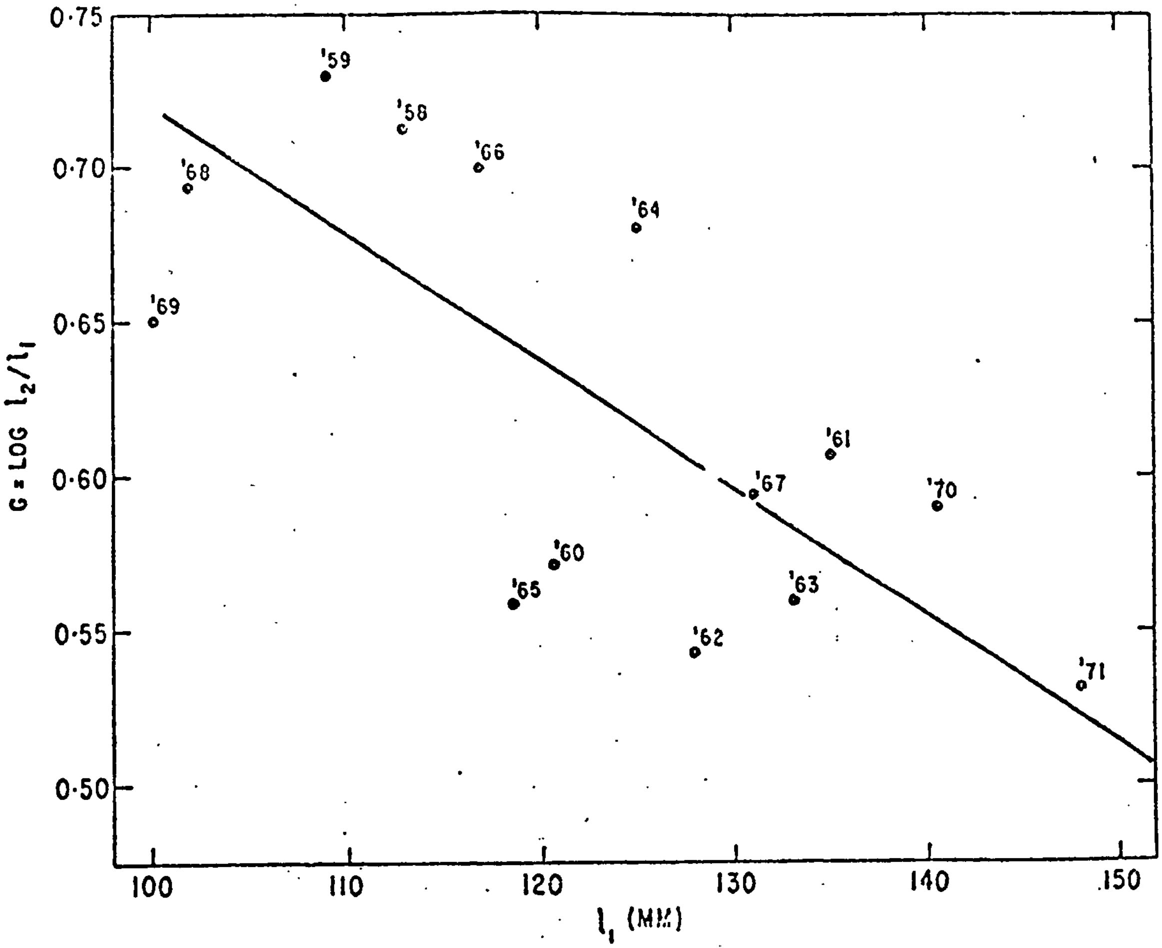

Fig. 15. Relationship between instantaneous growth rate during the second year of growth and first year size of Fortune Bay herring.

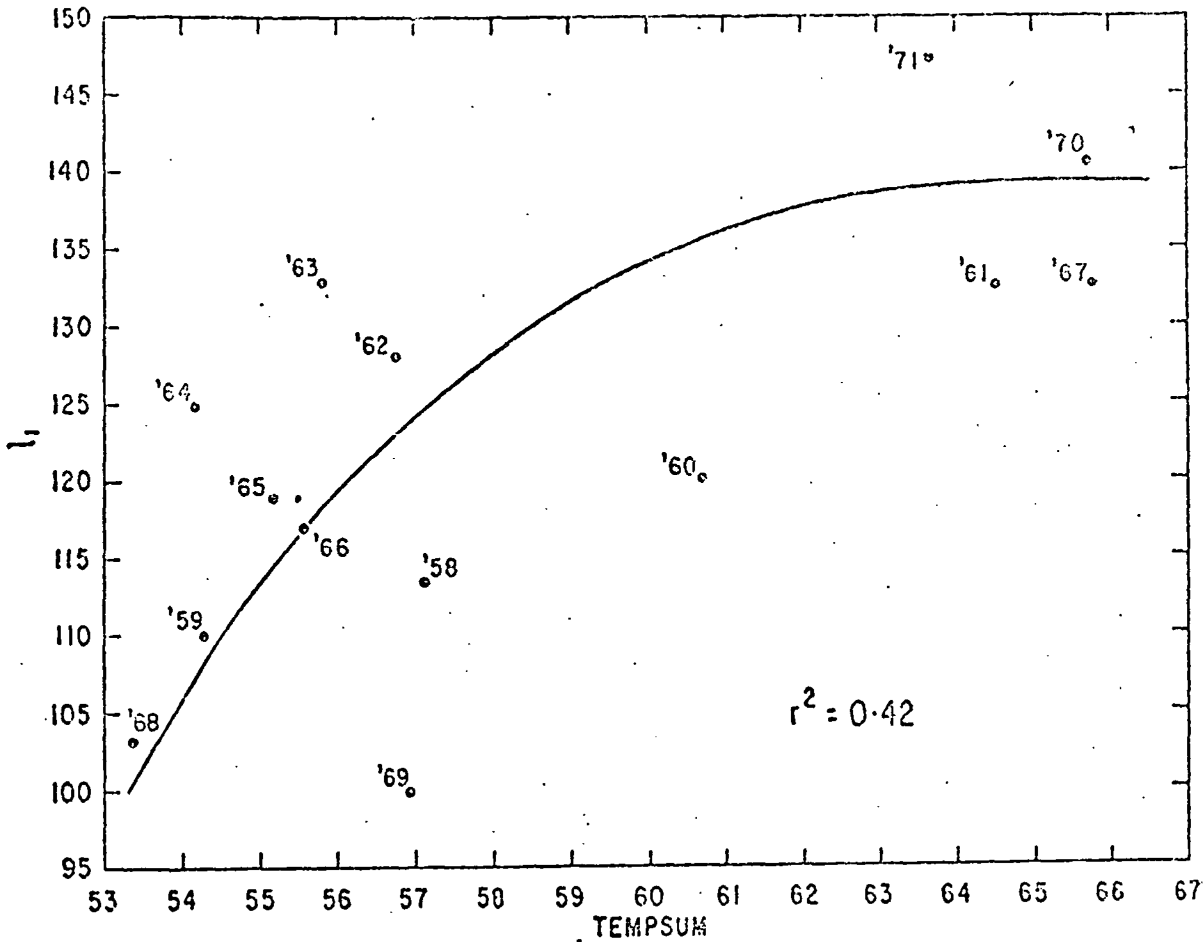

Fig. 16. Relationship between first year growth and surface temperatures summed from May - December, Station 27.