Growth Patterns in a Newfoundland Herring Stock

by

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INTRODUCTION

Traditional fisheries studies have tended to examine fish stocks in isolation as if they were independent from other species and their physical environment; an approach which was often necessitated by the constraints of the available data. As the data base has expanded in recent years, there has been renewed interest in examining the relationship of a species to its biotic and abiotic environment. Of particular interest has been the consideration of growth, maturation and recruitment and whether these are density and/or density-independent fuctions (de Veen 1976, Lett et al 1975, Lett & Kohler 1976, Winters 1976).

Recent studies in the Gulf of St. Lawrence on cod (Lett et al 1975) and herring (Lett and Kohler 1976) have postulated that key environmental factors for both stocks are temperature and mackerel (Scomber scombrus) abundance. In the case of herring, Lett and Kohler (1976) have examined l_1 growth in southern Gulf of St. Lawrence herring and concluded 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. This implies the absence of significant density-independent factors affecting growth such as temperature, density-dependent changes in juvenile and adult growth exerted by total biomass, and growth compensation. Unfortunately, Lett and Kohler (1976) misinterpreted the conventions for conversion of age (given in their data source (Messieh 1973)) to year-class resulting in the assignment of fall spawner year-classes two years too recent and spring spawner year-classes one year too recent. When the data were properly computed and replotted a density-dependent relationship between first-year growth and herring biomass could not be categorically demonstrated (Winters et al MS 1977).

While the evidence for density-dependent growth in herring in the Gulf of St. Lawrence was not strong, it was apparent that Gulf of St. Lawrence herring represented a complex situation. Many factors may have confused the issue including: the many stock admixtures and the large area occupied by the stock (Winters and Beckett 1978), the presence of two large (and perhaps interchangeable) spawning components within the stock, the dominance of two large year-classes which were produced under anomalous conditions, after a major reduction of the stock biomass (Winters and Hodder 1975), by a fungus disease (Sinderman, 1958) and the influence of a seasonal mackerel population. To try and elucidate the question of density-dependent growth in herring, the authors selected a small discrete stock of herring located in Fortune Bay, Newfoundland (Fig. 1). This stock has not only exhibited wide and frequent

fluctuations in year-class success, but in combination with an intensive purse-seine fishery has also shown large changes in overall abundance (Winters and Moores MS 1977). The situation is also simplified by the absence of any large abundance of mackerel in the area and the presence of only one major spawning component of herring, spring spawners, which represent 90-95% of the total stock.

METHODS AND MATERIALS

Otolith samples from each year-class (1958-74 excluding 1973) were selected from commercial samples of the Fortune Bay herring stock. All samples were selected from the months of January to March when growth is minimal. Each otolith was drawn using a Wild M7 binocular microscope, equipped with a camera lucida, at a magnification of 25x. Measurements were made, from the drawings, of radius of first annulus (O_1), radius of second annulus (O_2) and total otolith radius (O_T) along an axis from the otolith centre to the edge of the postrostrum (Fig. 2).

Temperature data used in these analyses are mid-monthly temperatures from Station 27 ($47°32'50"N$, $52°35'10"W$) which is located off St. John's, Newfoundland. Although these temperatures are not from the exact area under examination, they should adequately reflect temperature trends in Fortune Bay since the Labrador current is the major component affecting both areas.

Maturity ogives were constructed from commercial sampling data broken down by length and age into mature and immature specimens. The point of 50% maturity was determined by Probit analysis.

Estimates of year-class strength were derived by cohort analysis with $M = 0.2$ and a starting $F = 0.1$ selected from an analysis of fishing effort and fishing mortality for the period 1967-73 (Winters and Moores MS 1977).

RESULTS

Otolith Radius - Fish Length Relationship:

A plot of otolith radius (O_T) against fish length (L_T) of 1 and 2-year-old herring showed that the otolith radius-fish length relationship was significantly different between the two age-groups both in slope and intercept values (Fig. 3). Thus conversion of otolith radii to fish lengths was accomplished by using age specific regressions given in Fig. 3. This method gave ℓ_1 values without utilizing the proportionality technique (Lea 1919) which is heavily influenced by the observed length.

Adjustment for Lee's Phenomenon:

The majority of otoliths examined were from 5-year-old fish. In several weak year-classes, however, insufficient material was available at this age necessitating the inclusion of several ages in the sample. A plot of ℓ_1 against age indicates the presence of Lee's phenomenon (Lee 1920) in the data (Fig. 4). A regression line (r = 0.77) fitted to the ℓ_1-age data, was used to adjust the ℓ_1 values to age 5. An average ℓ_1 value, adjusted to age 5, was calculated for each year-class (Table 1).

Factors Affecting ℓ_1 Growth of Fortune Bay Herring:

A. Temperature: Temperature data summed over the 'first year growth period (May-December), was examined with regard to possible influence on ℓ_1 growth. A plot of the data (Fig. 5) indicated that ℓ_1 size was significantly (r = 0.72) correlated in a positive manner with temperature. Such a relationship has been demonstrated by a variety of authors for a variety of species (Day 1957).

B. Year-class Size and First Year Growth: The effect of temperature on ℓ_1 growth was removed by adjusting all ℓ_1 values to $60^\circ C$ (tempsum) from the regression in Fig. 5. A plot of year-class size on the temperature-transformed ℓ_1 values is shown in Fig. 6. Correlation analysis indicates that ℓ_1 size is not significantly affected by year-class size (r = .1).

Factors Affecting Subsequent Growth of Fortune Bay Herring:

A. Growth Compensation: A highly significant negative correlation (r = .99) resulted when instantaneous growth rate ($G = \ln\ell_2/\ell_1$) was compared to ℓ_1 size indicating the presence of growth compensation (Fig. 7). A plot of observed length of each year-class at age 5 against its ℓ_1 size (Fig. 8) shows no significant correlation (R = 0.26) and further indicating that a compensatory growth mechanism is involved. Thus the effects of the size attained at the end of the first year's growth on such parameters as maturation rate tend to be greatly confounded and modified by growth compensation.

B. Temperature: Mean length-at-age data are available from commercial and research sampling activities for Fortune Bay herring for the period 1966-76. From such data annual growth increments have been computed for age-groups 3 to 6, representing not only the critical growth phase of this stock but also an age range associated with accurate age determination. These growth increments (summed for age-groups 3-6) are plotted against May-December Tempsum (Station 27) in Fig. 9. Correlation analyses indicate a significant positive relationship (r = 0.88) between temperature and growth during the adolescent age-range.

C. Herring Biomass: Utilizing the relationship shown in Fig. 9 annual growth increments (age-groups 3-6) have been adjusted to values corresponding to a temperature of $66^\circ C$. Such transformed values have been plotted against the 2+ biomass of Fortune Bay herring in Fig. 10. Correlation analyses suggest that growth of Fortune Bay herring has not been significantly affected by its population density during the period 1966-76.

Maturity:

Maturity data for Fortune Bay herring were available for the years 1968-1976. The point of 50% maturity for both age and length was calculated using Probit analysis (Table 2). Variation in the point of 50% maturity was small (particularly length) and did not appear to follow a consistent pattern.

Large fluctuations in biomass levels and year-class strength such as those observed in Fortune Bay herring during the period 1966-76 (Winters and Moores 1977) have frequently been associated with logistic changes in maturation rate and hence, population fecundity. Maturation rate data of Fortune Bay herring are plotted against population biomass (one year lag) and year-class size in Fig. 11 A and B, respectively. Correlation analyses suggest that density-dependent changes in maturation rate are not significant factors determining relative changes in population productivity of Fortune Bay herring.

The effect of temperature (mean of the previous two years) as an environmental signal affecting the maturation rate (expressed as % mature at age-group 3) of Fortune Bay herring is shown in Fig. 12. Excluding the 1971 data point results in a highly significant positive correlation suggesting that temperature through its effect on growth is the major factor determining the maturation rate of this herring stock. The 1971 sample was obtained from schools of mature and/or maturing herring near the spawning area and thus would be expected to be biased towards the mature component of that year-class.

DISCUSSIONS AND CONCLUSIONS

Burd (1962) has hypothesized that the length of herring at the end of the first year's growth results in substantial length differences later in life. Lett and Kohler (1976) from analyses of Southern Gulf of St. Lawrence herring further argued that ℓ_1 growth, but not subsequent growth, is density-dependent and acts as the only natural means for regulating a stock through its population fecundity, with the age at maturation being determined by the ℓ_1 size. This implies that density-independent factors such as temperature and intrinsic factors such as growth compensation have minimal and abortive effects on population growth dynamics.

Analyses of growth data of Fortune Bay herring presented in this paper do not support the above hypotheses. On the contrary, these analyses suggest that density-independent processes mediated through an environmental signal (temperature) act to regulate not only ℓ_1 but also subsequent growth to the extent that maturation rate and length-at-age of a year-class are not measurably affected by density nor the size attained at the end of the first year. Winters et al (1977) reached a similar conclusion regarding the density-dependence of ℓ_1 size from a re-analysis of Southern Gulf data presented by Lett and Kohler (1976). However, Winters (1975) from correlation of trends in size and population biomass concluded that growth of adolescent (age-groups 3-7) herring in the southern Gulf was density-dependent with changes in growth being also affected (to a lesser degree) by fluctuation in mackerel abundance. Temperature effects on growth were not evaluated by Winters (1975) mainly due to lack of complete time-series temperature data for the southern Gulf. Station 27, however, correlate well with those available from the Southern Gulf (Lauzier and Hull 1969) (Fig. 13) and may be taken as representative of hydrographic conditions in that area. Length-at-age data of Southern Gulf herring given in Winters (1975) have been calculated as annual growth increments (summed over age-groups 3-7) and these are plotted against Tempsum (Station 27) in Fig. 14. Correlation analyses suggest that variations in annual growth of Southern Gulf herring are attributable in large part to environmental changes as exemplified by temperature. When the effects of temperature on growth are removed and the data regressed against 2+ herring biomass (Fig. 15), a density-dependent growth response becomes evident. Furthermore, the addition of juvenile

mackerel (age-groups 1 and 2) biomass (which are in the same size range as 3-7 year-old herring) tends to intensify the logistic growth response in herring (Fig. 16). Multiple regression analyses indicate that the amount of explained variation in herring growth increased from 68% when temperature alone was considered, to 73% with the addition of herring biomass and to 77% with the addition of juvenile mackerel biomass. Thus it would appear that logistic growth patterns in this herring stock would only be evident under fairly stable environmental conditions.

The absence of homeostatic growth mechanisms in Fortune Bay herring as opposed to Southern Gulf herring is perhaps related to the more northerly location of Fortune Bay in relation to the distributional range of herring in the Northwest Atlantic (Leim and Scott, 1966). Thus not only would Fortune Bay herring be more susceptable to environmental variations than Southern Gulf herring but also the environmental variations themselves are probably greater in the Fortune Bay area as compared to Southern Gulf. For example the coefficient of variation of summer temperature (June-Sept.) for the period 1955-69 at Station 27 is 7.5% compared with 4.8% for Entry Island (Lauzier 1969). In a broader sense of course, the lower productivity and greater variability in year-class strengths of herring stocks in the Newfoundland area relative to those in the centre of herring distribution in the Nova Scotia area (4X) is a function of environmental control and the same environmental controls with similar variability would apply.

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Table 1. ℓ_1, temperature and year-class size data for Fortune Bay Herring.

Year-class	N	ℓ_1 (regression D_T vs L_T)	ℓ_1 (adj. age 5)	ℓ_1 (adj. age 5 & 60°C)	Temp sum (May–December)	Year-class size 10^{-6}
1958	47	95.1	105.6	115.1	57.1	16.5
1959	50	87.0	94.1	112.0	54.2	21.0
1960	50	122.2	127.7	125.2	60.6	13.7
1961	14	129.4	133.4	118.7	64.5	4.3
1962	15	127.2	132.0	145.2	56.8	3.4
1963	50	114.9	114.9	129.8	55.9	274.9
1964	50	105.9	111.8	133.0	54.3	3.5
1965	36	99.6	105.2	121.0	55.3	5.9
1966	50	93.3	93.3	106.4	55.7	136.8
1967	44	113.6	113.6	97.7	65.9	29.4
1968	49	81.6	81.6	100.4	53.4	149.1
1969	18	109.5	109.5	117.2	57.6	3.0
1970	50	122.1	122.1	105.0	65.8	5.1
1971	50	131.1	131.1	118.0	63.8	9.6
1972	25	98.7	98.7	130.3	51.3	7.6
1974	25	93.3	90.5	119.5	51.4	44.3

Table 2. Age and length of 50% mature for Fortune Bay Herring as determined by Probit analysis.

	50% Mature	
Year	Age	Length
1968	3.5	26.8
1969	3.3	27.0
1970	3.2	26.9
1971	3.1	27.7
1972	2.9	26.9
1973	3.1	27.3
1974	2.6	26.5
1975	3.2	28.1
1976	3.3	26.6
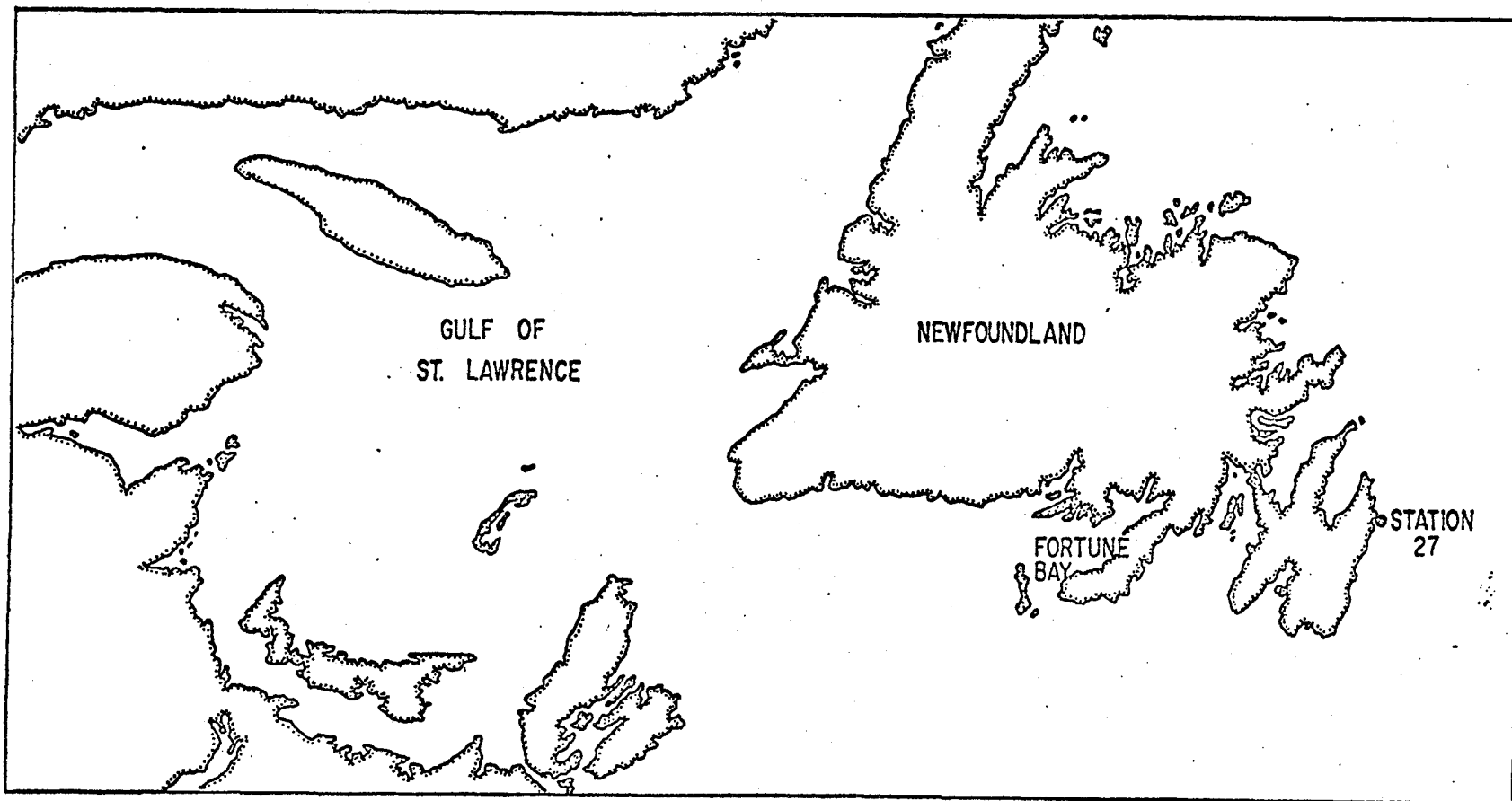
Fig. 1. Map of Newfoundland and the Gulf of St. Lawrence showing location
of Fortune Bay and Station 27.
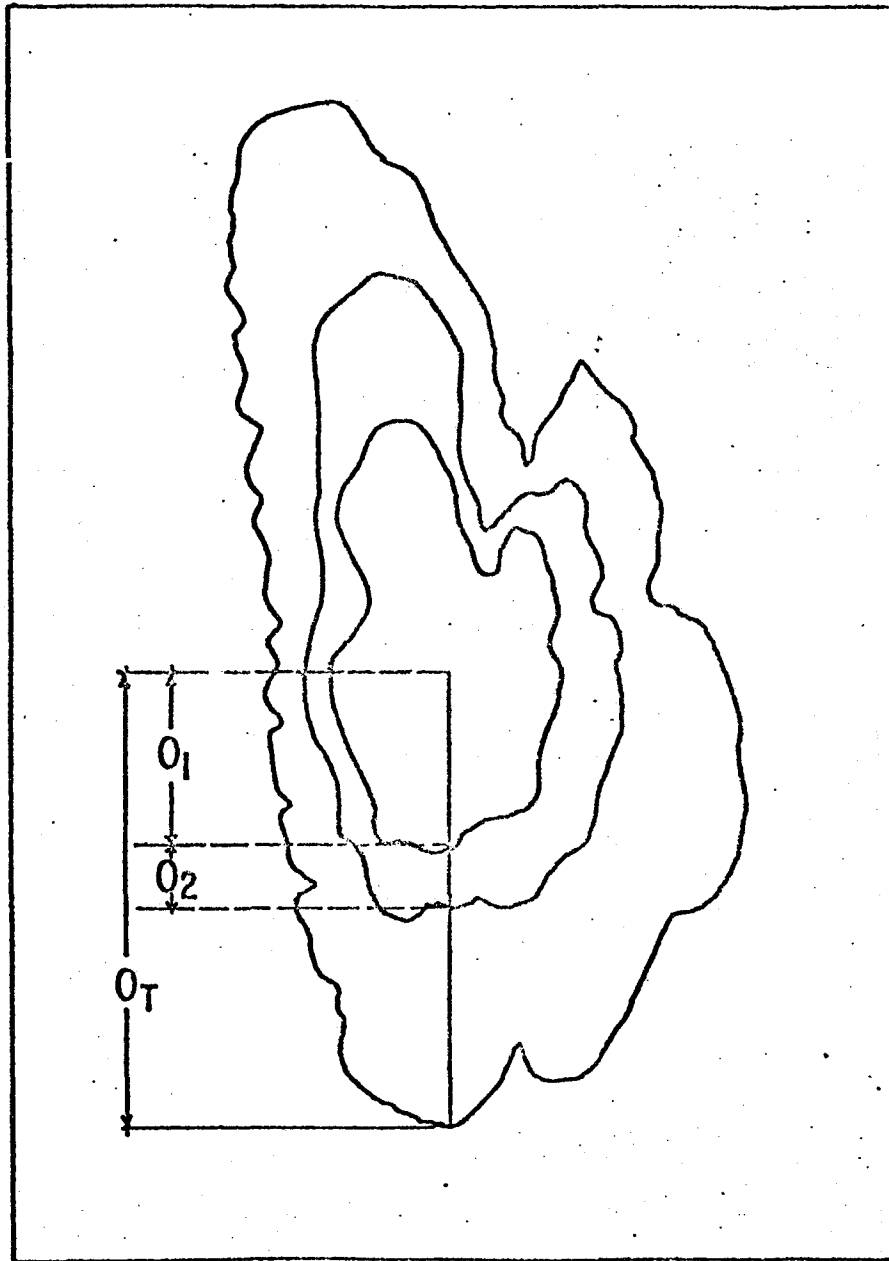
Fig. 2. Otolith measurements taken for back calculation.
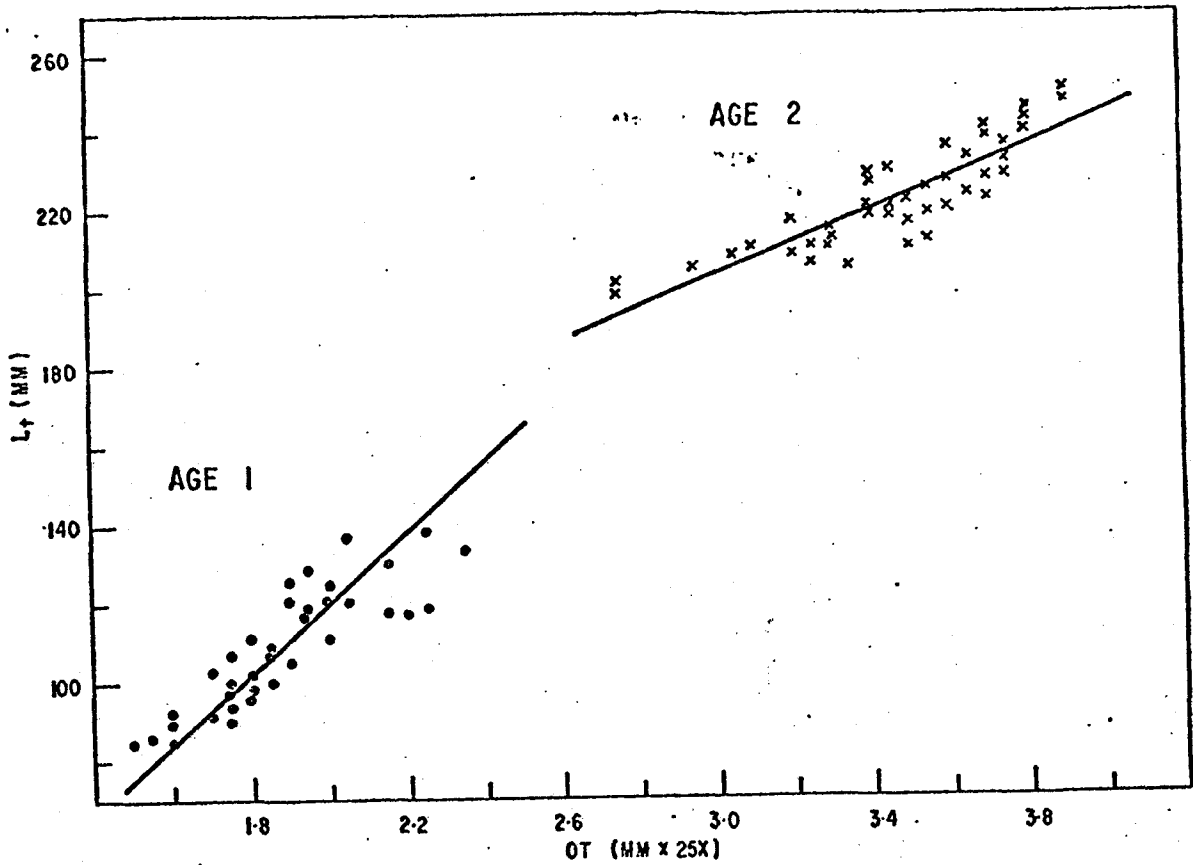
Fig. 3. Relationship of total otolith (O_T) radius to observed total length (L_T) at age 1 (L_T = 90.0 O_T - 60.2, r = 0.99) and at age 2 (L_T = 40.93 O_T + 80.50, r = 0.96).
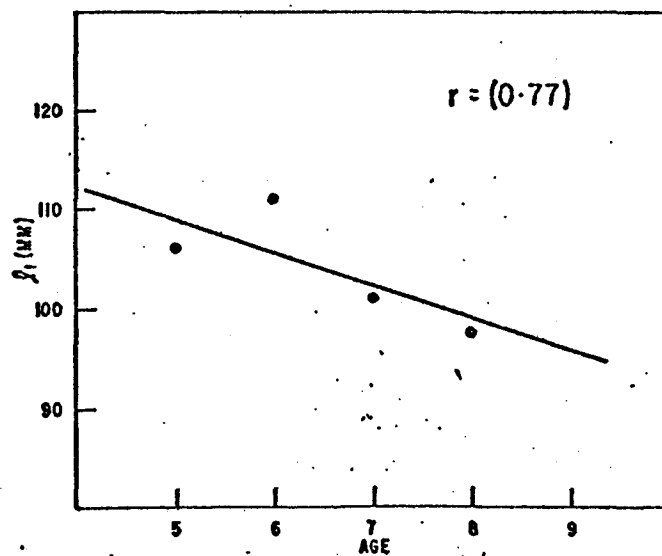
Fig. 4. Relationship of ℓ_1 with age in Fortune Bay herring.
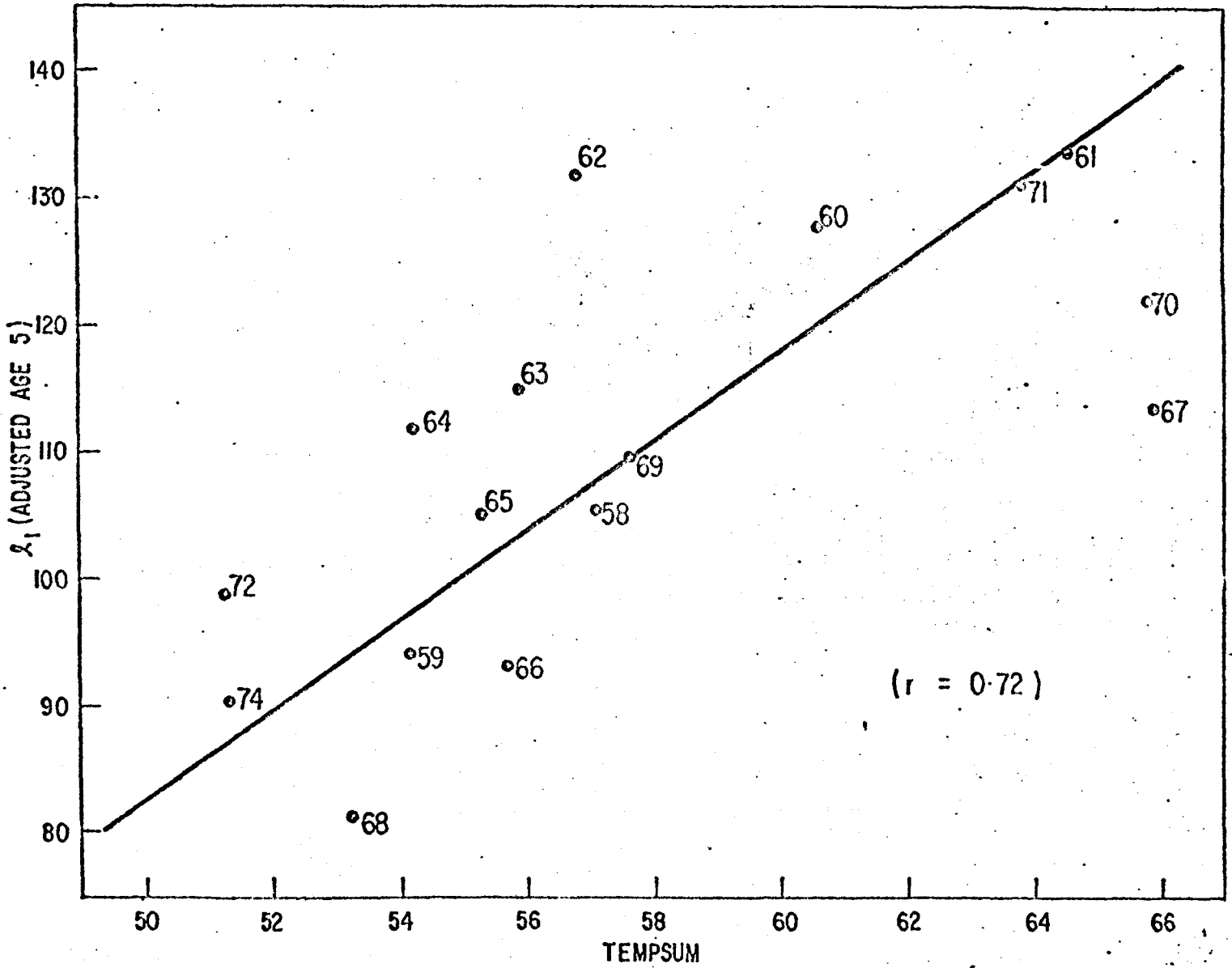
Fig. 5. Regression of tempsum (May-Dec., Station 27) against ℓ_1 of herring from Fortune Bay.
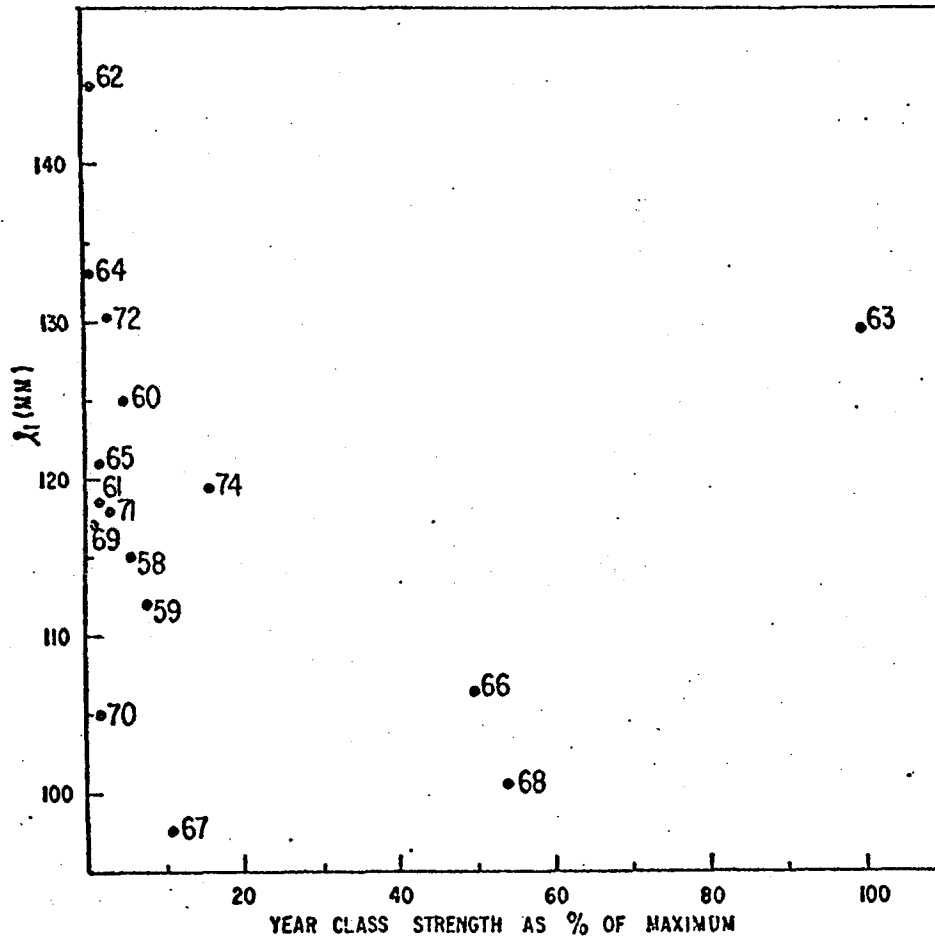
Fig. 6. ℓ_1 (adjusted to 60°C) against year-class size of Fortune Bay herring.
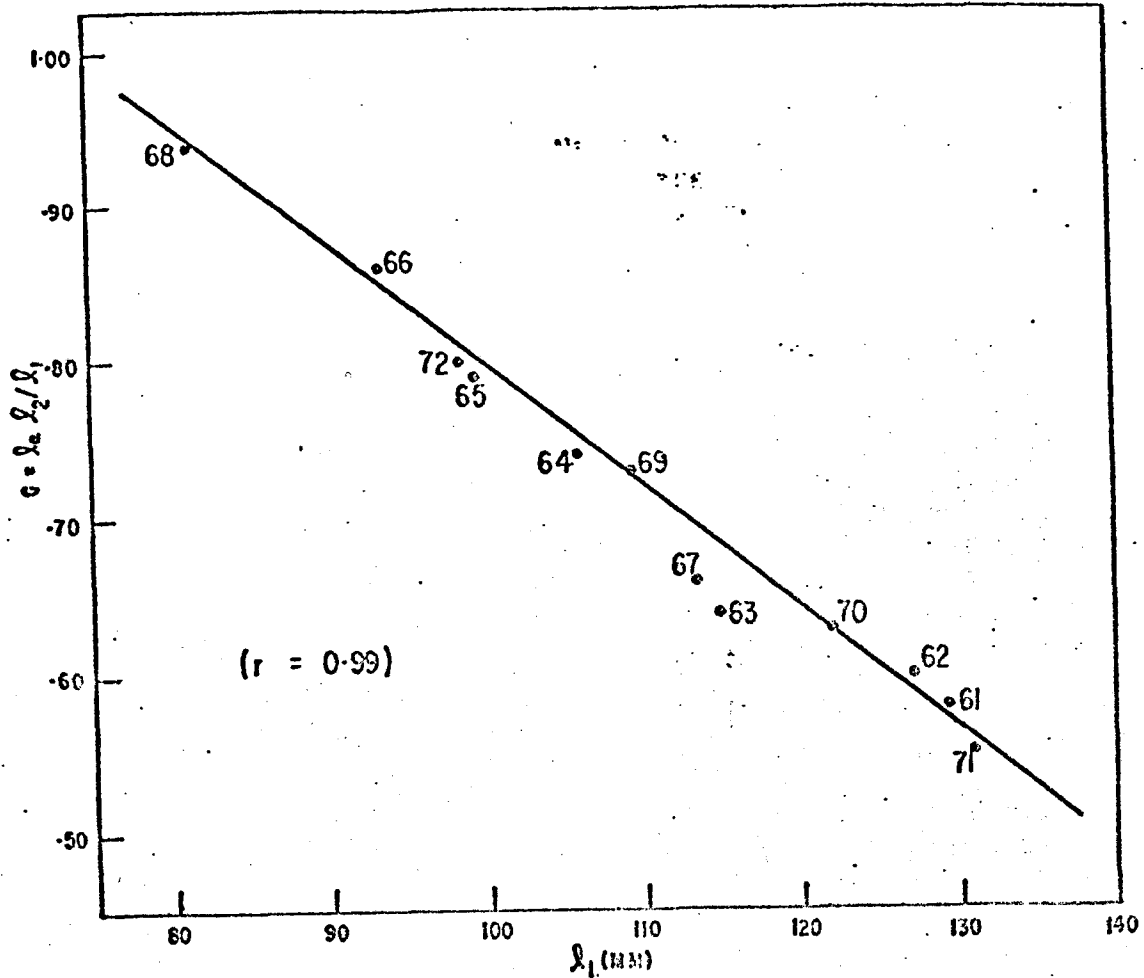
Fig. 7. Comparison of instantaneous growth rate and ℓ_1 for Fortune Bay herring.
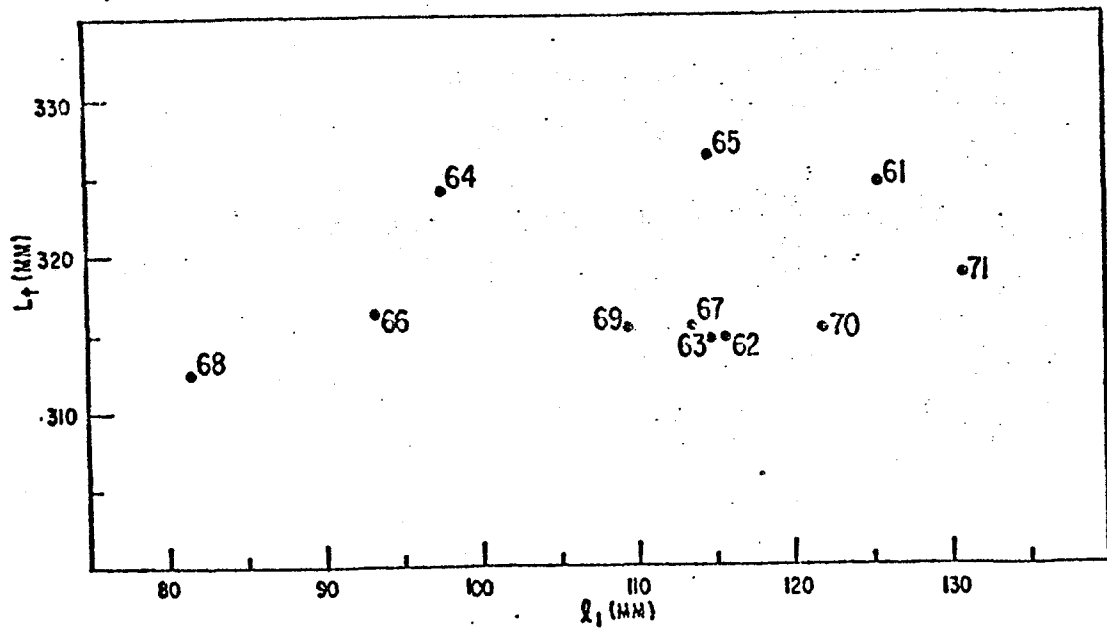
Fig. 8. Observed length at age 5 (L_T) and back calculated ℓ_1 at age 5 for Fortune Bay herring.
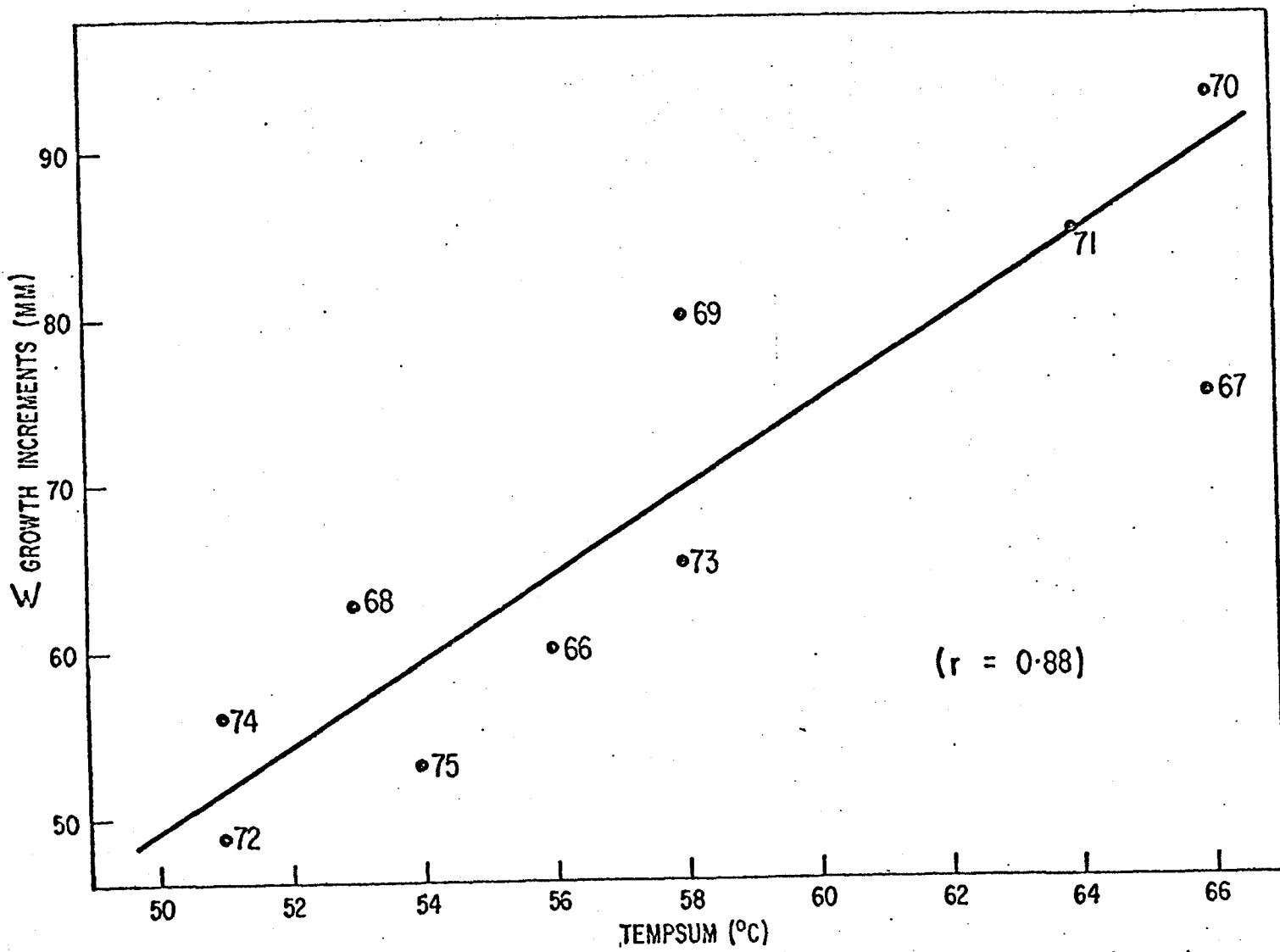
Fig. 9. Growth increments of Fortune Bay herring versus tempsum (May-Dec.) for Station 27.
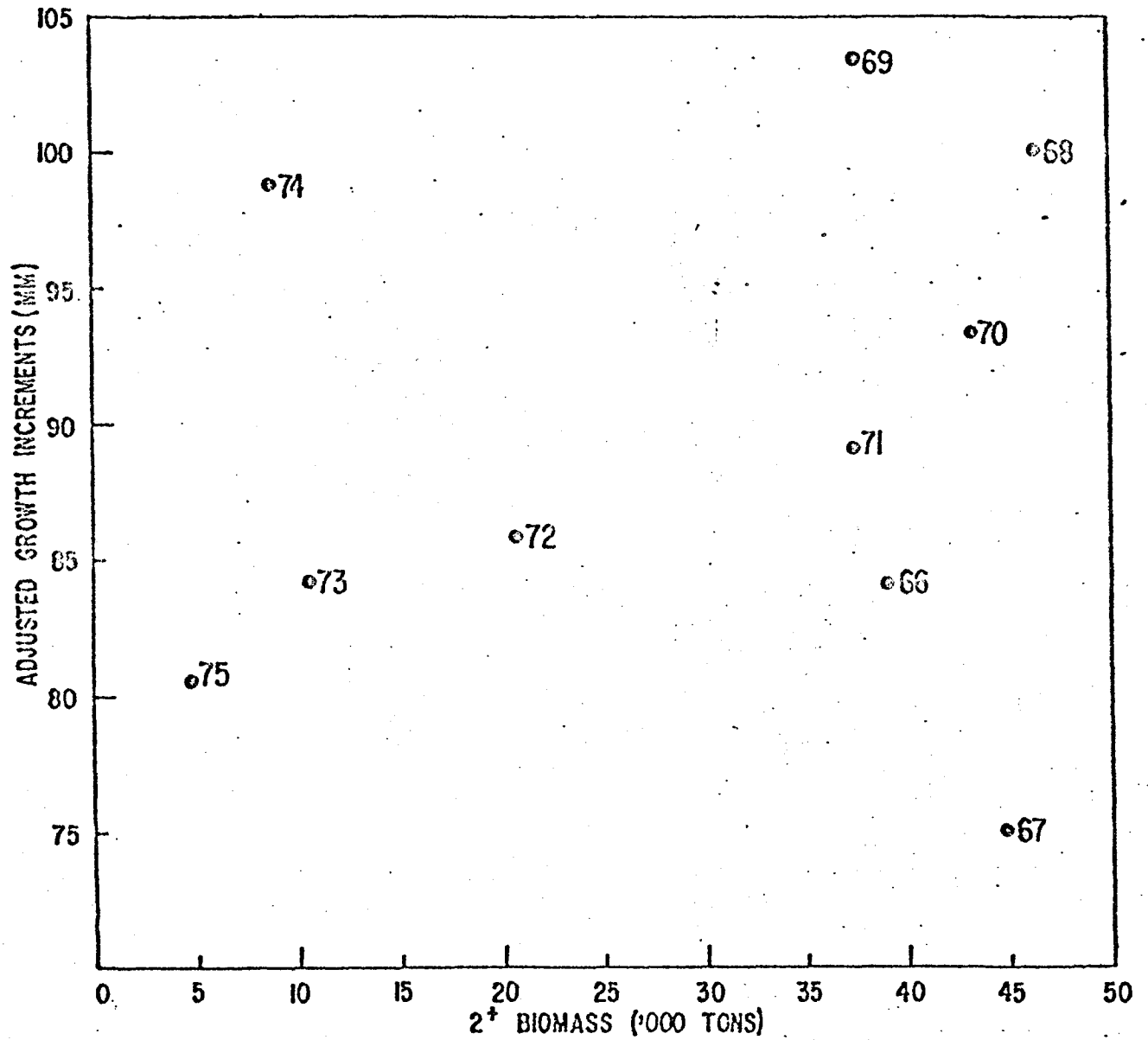
Fig. 10. Growth increments of Fortune Bay herring, adjusted to 66°C
vs 2+ biomass of herring.
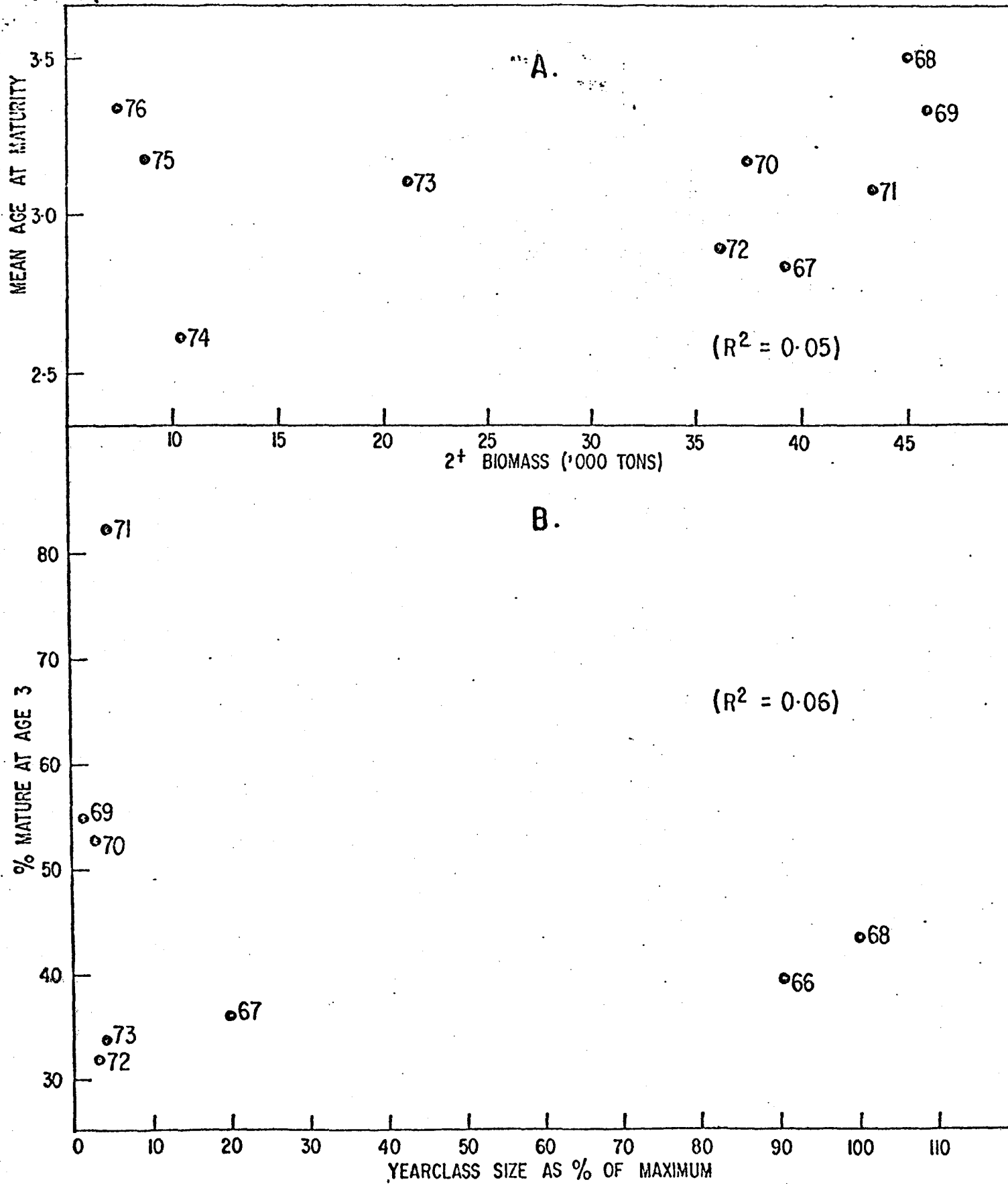
Fig. 11. A. Mean age at maturity versus 2+ biomass (logged by 1 year) of
Fortune Bay herring.
B. % mature at age 3 by year-class versus year-class size for
Fortune Bay herring.
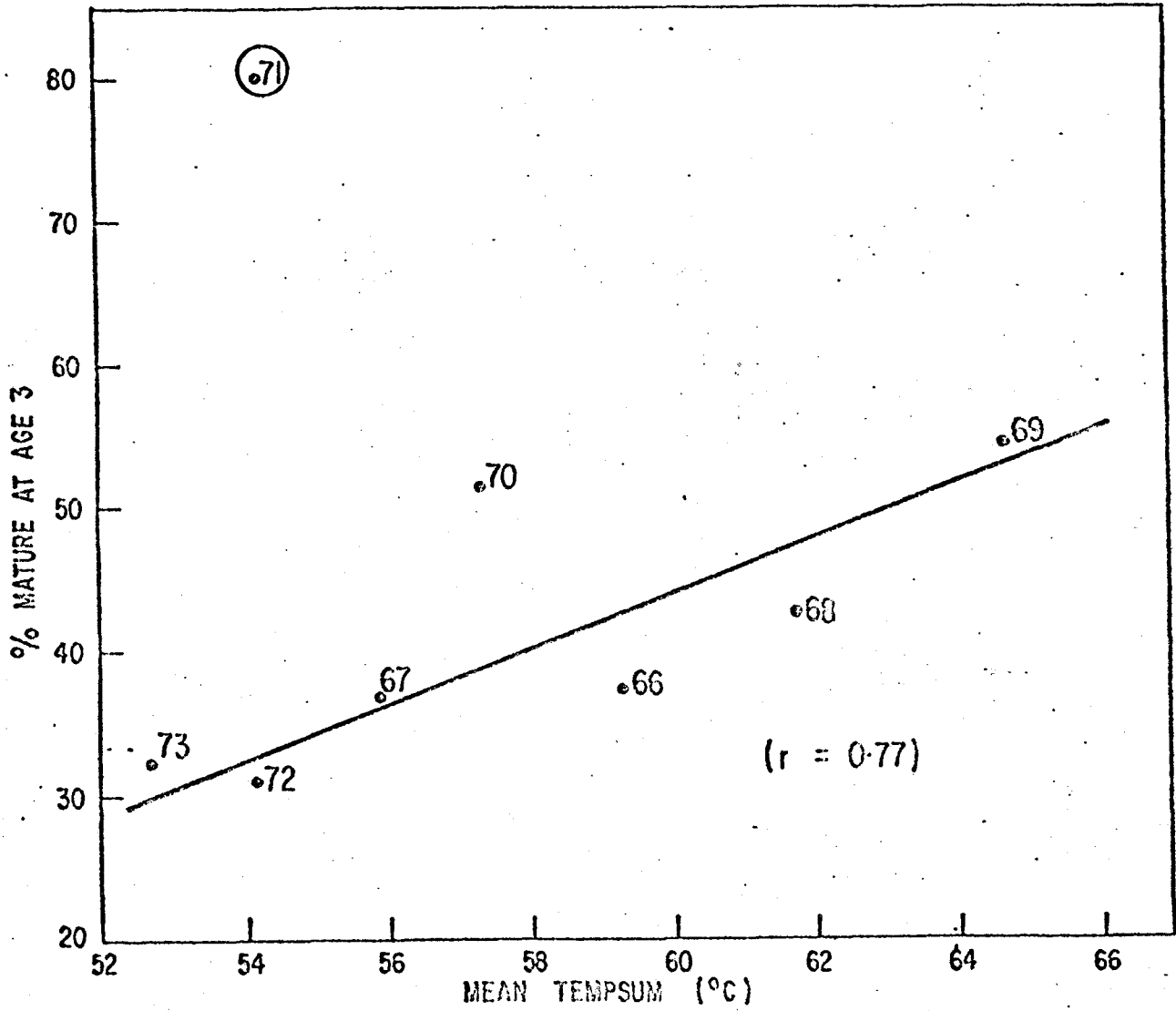
Fig. 12. Fortune Bay % maturity at age 3 is mean tempsum (2 years previous)
[1971 point excluded from analysis as sample was obtained in catch
of a spawning school].
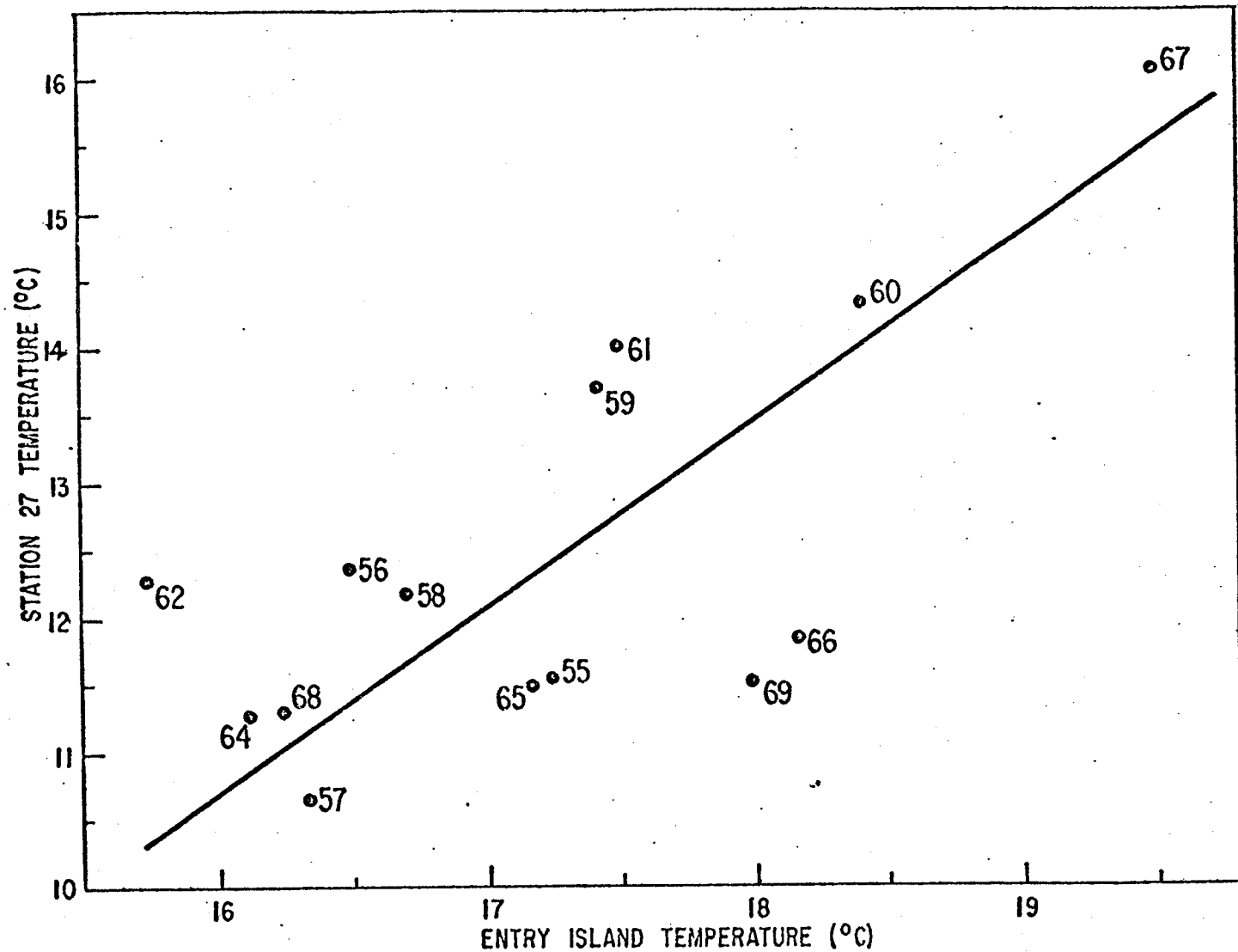
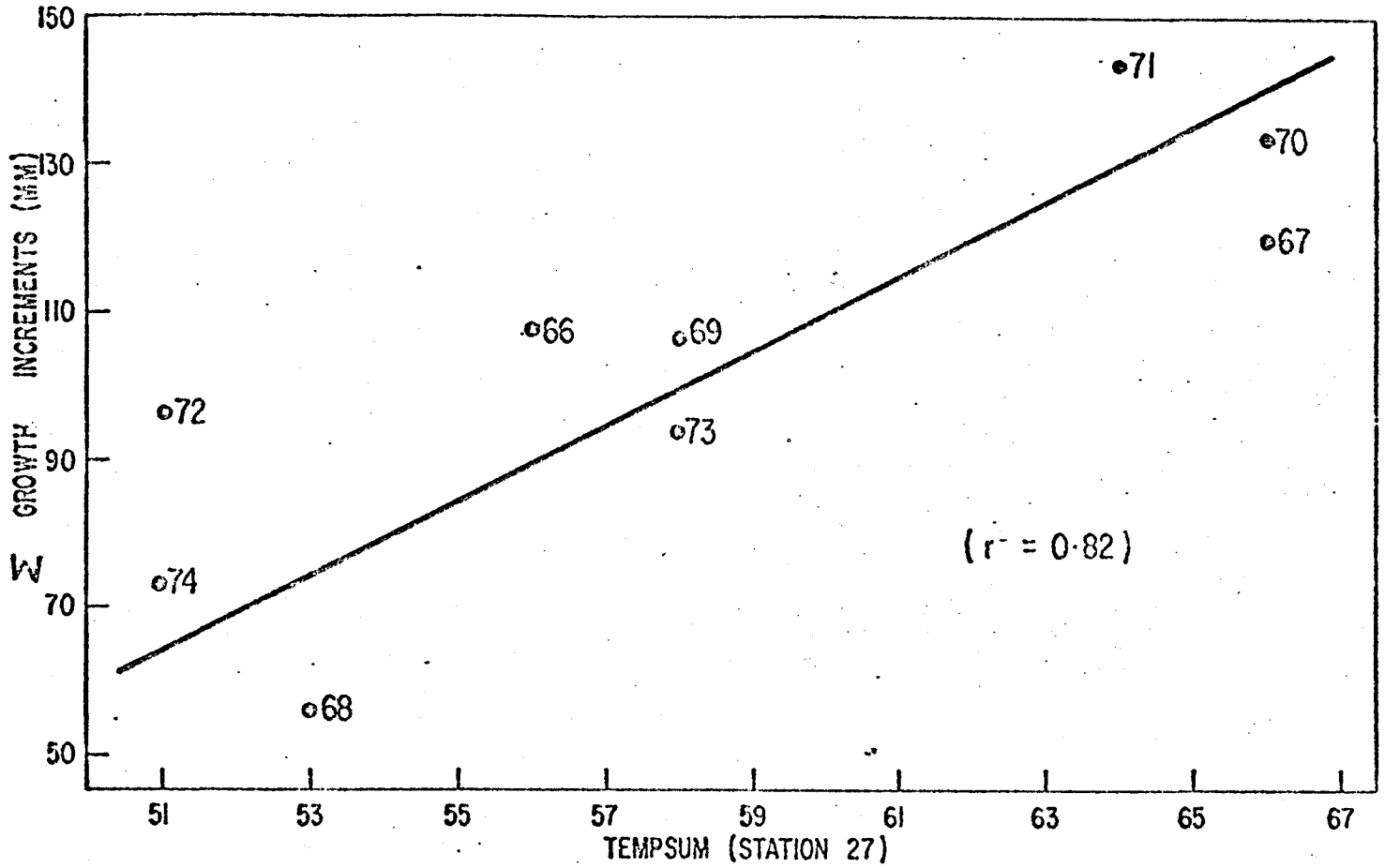Fig. 13. Correlation of temperatures between Station 27 and Entry Island.

Fig. 14. Relationship of growth increments of herring from the southern
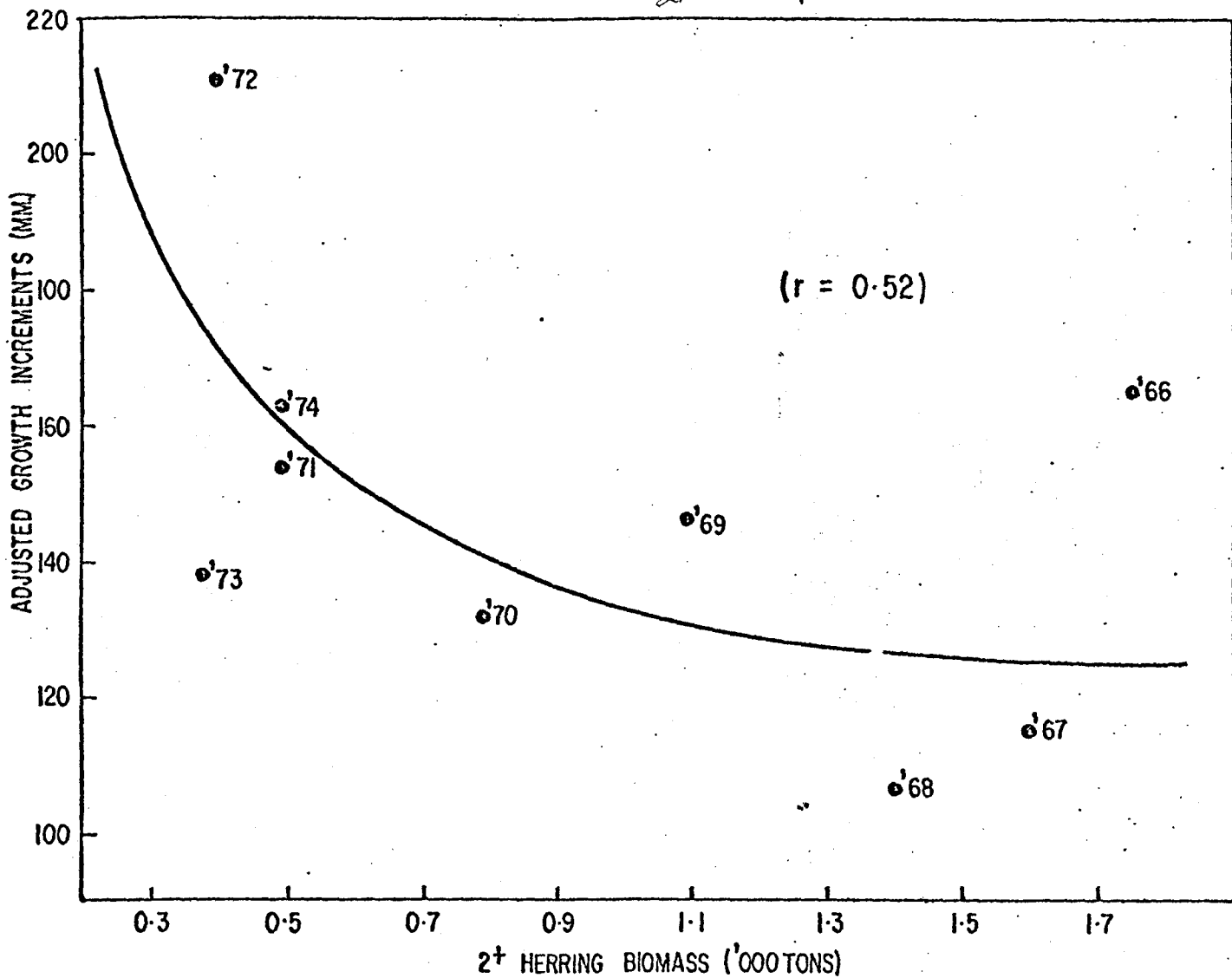Gulf of St. Lawrence herring stock and Station 27 temperatures.

Fig. 15. Influence of herring (2+) biomass on the temperature adjusted growth increments of Southern Gulf herring.
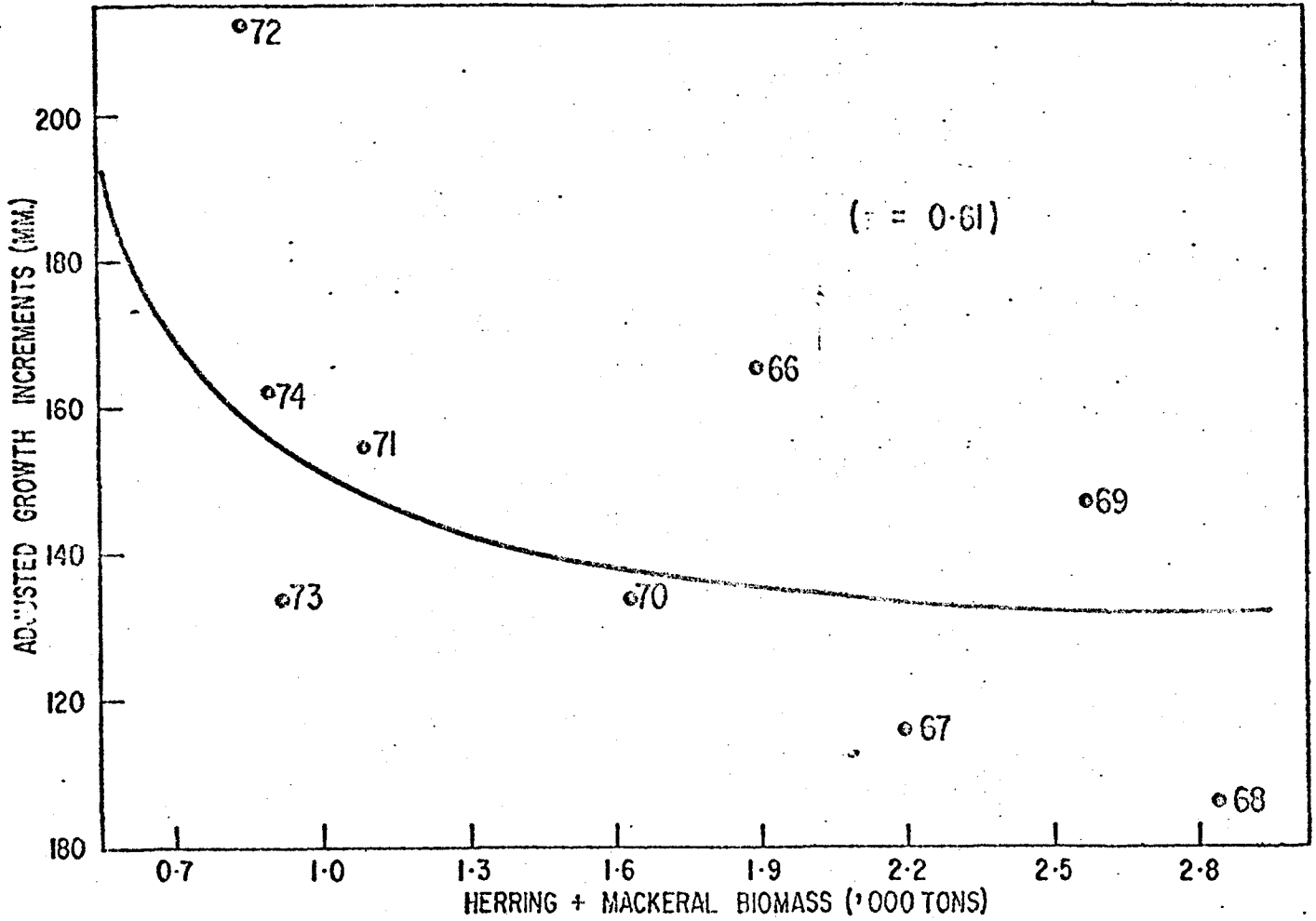
Fig. 16. Influence of the combined herring (2+) and mackerel biomass on the temperature adjusted growth increments of Southern Gulf herring.