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RECENT PROBLEMS WITH THE AGING OF NORTHWEST ATLANTIC MACKEREL, ESPECIALLY CONCERNING THE 1977 AND 1978 YEAR CLASSES

by

Louise M. Dery and Emory D. Anderson

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National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole Laboratory
Woods Hole, Massachusetts 02543

ABSTRACT

A discrepancy in age determination of Atlantic mackerel has been evident between the US and Canada (Maritimes) during the last several years. Differences were particularly great with respect to the 1977 and 1978 year classes. Discussions and otolith exchanges have indicated that a weak hyaline ring formed after the first annulus was interpreted as a check by the US and as an annulus by Canada (Maritimes). In this report, three validation procedures are presented to assess the reliability of interpretating the weak hyaline ring as a check, including analyses of seasonal otolith edge formation, length frequencies, and backcalculation of fish length at annulus formation. Random samples of otoliths collected in 1976 and 1978-1981 were examined, and length frequency data for 1975-1981 were analyzed. Results based on data analysis for the 1973-1981 year classes tend to support the interpretation of the weak hyaline ring as a check. Density-dependent growth was observed based on backcalculated length data. Further evaluation of samples where readers interpreted the weak hyaline ring as an annulus is recommended in an attempt to achieve greater consistency in the aging of Northwest Atlantic mackerel.

INTRODUCTION

In the course of assembling the relevant information for assessing the status of the Northwest Atlantic mackerel (Scomber scombrus) stock in 1981 (Anderson 1981), a considerable discrepancy was observed between US and Canadian Maritime age determinations of 1980 samples, particularly with respect to the 1977 and 1978 year classes. The 1980 Canadian Maritime catch from NAFO SA 4, based on age compositions provided by Hunt[1], included a significantly higher proportion of 1977 year-class fish relative to 1978 year-class fish than was evident in either the Canadian Newfoundland SA 3-4 catch (Moores[2]) or US SA 5-6 catches (commercial and research vessel). The ratio between 1977 and 1978 year-class fish was 1.58:1 for the Maritimes compared to 0.18:1 for Newfoundland and 0.03:1 for the US. Based on an examination of the data, these differences were due primarily to disparity in age interpretation from otoliths, and only to a minor degree due to dissimilar length compositions in the various areas.

Discussions and otolith exchanges in 1981 between US and Maritime age readers identified a weak hyaline ring formed after the first annulus as the principal source of disagreement. US

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[1]Joseph J. Hunt, Fisheries and Oceans Canada, Marine Fish Division, St. Andrews, New Brunswick, personal communication.

[2]John A. Moores, Fisheries and Oceans Canada, Research and Resource Services, Northwest Atlantic Fisheries Center, St. John's, Newfoundland, personal communication.

age readers consistently interpreted this weak hyaline ring as a check, whereas Maritime age readers interpreted it as an annulus. Initial backcalculation of fish lengths at annulus formation based on the age determinations by US age readers corresponded well with observed modes in length frequencies from both commercial and research vessel catches during 1979-1981. Therefore, for the purpose of the 1981 assessment, US age/length keys were applied to the 1980 Canadian Maritime length frequency data to estimate numbers at age in the catch.

Examination of 1981 age composition data for the 1982 mackerel assessment (Anderson 1982) indicated a continuing but less pronounced discrepancy in aging. The 1977:1978 year class ratio was 0.44:1 for the Maritimes (compared to 1.58:1 for 1980 samples), 0.18:1 for Newfoundland (no change from 1980), and 0.04:1 for the US (compared to 0.03:1 in 1980). However, lacking adequate US age/length keys to apply to the Maritime length frequencies for 1981, the 1981 Maritime age compositions as provided by Hunt[1] were used in the 1982 assessment (Anderson 1982).

A weak hyaline ring between the first and second annuli has been observed by US age readers since routine aging of mackerel began at the Woods Hole Laboratory in the early 1970's and has consistently been interpreted as a check. Extensive examination

of otoliths in 1976 (Penttila[3]) indicated the presence of this check in more than 50% of all age 2 otoliths, with a subsequent weakening or disappearance of the check at older ages. A substantial discrepancy was evident at ages 2-3 in USSR age/length keys for 1976 submitted to ICNAF (Anderson et al. 1976). Although the reason for the discrepancy was never identified, it is likely that this check was interpreted as an annulus by USSR age readers, resulting in many age 2 fish being incorrectly classified as age 3.

This report describes the aging criteria employed by US readers, and presents a validation of the interpretation of the weak hyaline ring as a check instead of an annulus. The validation procedure included analysis of seasonal otolith edge formation, backcalculation of fish length at annulus formation, and analysis of length frequency data. Current and historical data were examined; in particular, aspects of the age and growth of the 1977 and 1978 year classes were compared to those of the 1974 class.

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[3]Judith A. Pentilla, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole Laboratory, Woods Hole, MA, personal communication.

MATERIALS AND METHODS

Source and Preparation of Samples

Mackerel length and otolith samples used in this study were obtained from a number of sources. Samples were collected during NMFS, NEFC bottom trawl surveys conducted in the spring (March-May), summer (July-September) and autumn (September-November) in SA 4-6. Information collected included fork length (nearest mm), weight (nearest gm), sex, and sexual maturity, as well as otoliths. Samples of about 30 fish each were collected from commercial catches in SA 5-6 landed in various months of the year. Substantial numbers of age samples were also obtained from trawl surveys conducted in cooperation with other countries (including Poland, the USSR, GDR, and FRG). In addition, samples from foreign catches in SA 5-6 were collected by US foreign fisheries observers.

Mackerel otoliths were mounted for aging in black plastic trays with 10 x 5 rows of circular depressions. After a brief drying period in ethyl alcohol, the otoliths were imbedded in the synthetic resin Permount[4] or fiberglass casting resin, both of which dry clear and hard. Mackerel otoliths viewed in the resin exhibited excellent contrast between translucent (hyaline or winter) and opaque (summer) zones, and enabled precise determination of accreted edge as hyaline or opaque.

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[4]Reference to trade names does not imply endorsement by NMFS.

Aging Methods

Since 1973, mackerel otoliths have been aged at the Woods Hole Laboratory by two experienced age readers. The aging criteria applied by these age readers has been consistent in most respects, with a high level of agreement (>90%) in age interpretation between the two. The first annulus has been interpreted to be the first hyaline zone formed away from the nucleus during the first winter after spawning. All subsequent zones are judged as annuli only if they are consistent in formation and strength around the periphery of the otolith. The relative spacing of hyaline zones away from the nucleus is also considered.

On some otoliths, a usually weak and irregular ring, appearing to be different in formation from zones interpreted as annuli, has been evident within the second summer of growth following the first annulus. This ring is most evident on the posterior end of the otolith where it may closely resemble an annulus. It is faint or absent on the rostrum and/or dorsal/ventral edges of the otolith. In a few cases, a similar ring has been observed during the third or fourth summers. This ring has consistently been interpreted as a check.

Seasonal Otolith Edge Formation

For the analysis of edge formation, otoliths from fish of age 1, 2, and 3 were subsampled from 1976 and 1978-1981 collections. Since check formation did not appear to be frequent during the third and fourth summers of age 2-3 otoliths, edge

formation was documented for comparison with age 1 otoliths. The years 1978-1981 were chosen to include the 1977 and 1978 year classes at ages 1-3, whereas 1976 was chosen to provide comparison data, as aging discrepancies between the US and Canada (Maritimes) were not apparent in that year.

In each of the years sampled, a minimum of ten (unless fewer than that number were available) otoliths interpreted as age 1 and as ages 2-3 (Tables 1 and 2, Figure 1) were chosen randomly by sample number from samples collected in each of the following periods: March-April, May, June, July, August, September, and October-November. Otolith edge was interpreted chronologically as hyaline, narrow opaque, opaque, or narrow hyaline, according to the terminology of Jensen (1965). Hyaline or narrow hyaline edge, indicating slow growth, was associated with the formation of checks or winter annuli. Opaque or narrow opaque edge was associated with rapid "summer" growth.

Length Frequency

Length frequency data (percent frequency of the mean catch per tow in numbers) from the NMFS, NEFC 1975-1981 spring bottom trawl surveys were examined for modal indication of length at age of the 1974-1980 year classes (Figure 2). The spring survey catches provided the most consistent year-to-year data and corresponded with the time of year when winter annulus formation was completed. Superimposed on the length frequency data for comparison was the percent age composition at each centimeter of the survey catches at ages 1-3. The percentages of age 4 and older were not plotted in Figure 2.

Backcalculation of Fish Length

Otoliths used for the backcalculation analysis were measured with an ocular micrometer at 15X from the nucleus to the edge of the postrostrum (at its longest extension) and to the outer edge of the first, second, and third annuli, including the weak ring (check) after the first annulus. A total of 124 otoliths aged as 1, 2, or 3 (fish lengths were 15-37 cm) were initially measured to determine the relationship between fish length and postrostral otolith length. A linear regression with an r^2 of 0.87 best described the relationship between these parameters. With an intercept on the axis of otolith length of 30 ocular units (0.02 mm), the following formula was used to compute backcalculated fish length at each ring:

$$L_i = \frac{p_i - c}{p - c} L$$

where

p_i = postrostral radius at a given hyaline ring i

p = total radius of the postrostrum

c = X intercept (30 ocular units)

L = total fish fork length (mm)

L_i = backcalculated fish length at hyaline ring i

A random sample of at least 20 otoliths from each age group (1-3) was taken, when possible, from available collections in each year (1976, 1978-1981) (Tables 3-4).

RESULTS

Seasonal Otolith Edge Formation

Seasonal otolith edge formation for age 1 and age 2-3 mackerel from the 1975-1980 year classes is described in Tables 1 and 2 and Figure 1. Data from March and April and from October and November were combined since edge type was not observed to change substantially from one month to the next during those periods.

During March-April, active growth had apparently resumed for only a few fish, because the hyaline (winter) ring was still present on the edge of the otolith.

By June, most otoliths from all three age groups were actively forming an opaque (summer) edge. Hyaline edge forming on 1 of 16 age 1 otoliths examined was deposited primarily on the posterior edge after some initial accretion of opaque material, and this edge was interpreted as a check for 6% (1 of 16) of the otoliths (Table 1). A hyaline edge was also visible on 10% of the age 2-3 otoliths (Table 2), but these otoliths had not yet formed any detectable opaque edge for the summer, and hyaline edge was strongly visible around the entire periphery of the otolith.

In July, 21% of the age 1 otoliths had either hyaline, narrow hyaline, or narrow opaque edges associated with the deposition of a weak, discontinuous hyaline ring (Table 1). Included in the 21% were 14% which appeared to be forming the hyaline ring at the time they were collected. On an additional 20% of the age 1 otoliths, a weak hyaline ring had already formed

between the first annulus and the edge. Narrow opaque or opaque edge was being formed on most (83%) of the age 2-3 otoliths in July (Table 2), but some of the otoliths were also apparently forming checks.

By August, 37% of the age 1 otoliths had hyaline or narrow hyaline edge. This percentage included 20% with completed summer growth (continuous hyaline edge) and 17% still forming a check on the edge. Although the latter percent is uncertain since some of the otoliths were actually forming winter annuli, a stippling of thin checks just inside the edge of those otoliths was observed to be associated with the formation of the weak hyaline ring and not with an annulus on age 2-3 otoliths. In August, 54% of the age 1 otoliths had already formed (before the edge) a weak, irregular hyaline ring after the first annulus (Table 1). Of the age 1 and age 2-3 otoliths in August, 65% and 82%, respectively, were still forming either narrow opaque or opaque edge, indicating continued growth in this month for the majority of age 1, 2, and 3 fish.

By September, most (78%) of the age 2-3 otoliths were forming winter annuli (Table 2). Little data (6 observations) were available for the age 1 otoliths (Table 1). A check had been formed before the edge on all of these otoliths.

In the final months sampled (October-November), most otoliths for all three age groups were forming a winter annulus. Of the age 1 otoliths, 59% exhibited the weak discontinuous hyaline ring or check which was apparently formed during the previous summer season, primarily in July. No attempt

was made to analyze edge formation by year class as all of them appeared to follow a similar pattern.

Between 55% and 71% of the age 1 otoliths from four separate year classes possessed a weak hyaline ring (check) in October-November, suggesting that formation of the ring is not a unique phenomenon for particular year classes at age 1. In fact, checks also form during the third or fourth summers on some otoliths, although this was not specifically documented in terms of percent occurrance of the check. However, the check was observed to be significantly more prominent on the otoliths of recent year classes in comparison to the 1974 year class.

Length Frequency

Examination of the 1975-1981 survey catch length frequencies (Figure 2) indicates very pronounced modes in each year which, when the otoliths were read, corresponded to different age groups. Also evident is the trend towards larger fish from 1975 to 1981, reflecting the passage of the relatively strong 1974 year class through the stock. This year class dominated (in terms of numbers of fish) the SA 2-6 international catch every year from 1976 through 1981 (Anderson 1982).

Percent age compositions at length correspond to the modal size distribution of the relatively strong 1974 year class in 1975, 1976, and 1977 at age 1, 2 and 3, respectively (Figure 2). In general, percent age compositions of the three age groups for all year classes correspond very well to length frequency modes, with no apparent tendency (especially at ages 1 and 2) to

split observed modes into several age groups. Because of the relatively short spawning period of 1-2 months and the rapid growth rate of mackerel during the early years of life, distinct length frequency modes corresponding to separate ages would be expected for at least ages 1 and 2.

There is also an increase in length at age especially at age 2 and 3 between 1975 and 1981 (Figure 2). Special note should be made of the 1980 length frequency with a strong mode present between approximately 25 and 33 cm. All of the fish sampled from this length range were interpreted as age 2 (1978 year class). If a large number of these fish were age 3 (1977 year class), which would be implied by the interpretation of the weak hyaline ring as an annulus, considerably more age 2 fish should have been present in the 1979 length frequency than were actually observed. In 1979, fish between 19 and 25 cm were interpreted as age 1 due to the presence of only one hyaline ring formed on the edge of the otolith.

Backcalculation of Fish Length

Backcalculated fish lengths at the time of annulus formation for the 1973-1980 year classes at ages 1, 2, and 3 are given in Tables 3 and 4. Estimates of fish length at the weak hyaline ring (check) are also included in Table 3. Relatively few backcalculations were possible for the check because only 30-50% of the otoliths sampled exhibited checks strong enough for accurate measurement. Since the outer edge of each hyaline ring was measured corresponding to the spring season, backcalculated

fish lengths could be compared directly to the spring survey length frequency data in Figures 2. Backcalculated lengths at age were frequently calculated from several age groups. Since age 3 fish were the oldest to be backcalculated, fewer measurements of the third annulus were available.

Lee's phenomenon was not evident. The distribution of backcalculated lengths at age for a given annulus was either similar for different age groups or a reverse Lee's phenomenon was apparent. For example, backcalculated lengths at age 1 from age 1 otoliths were actually slightly lower than the backcalculated lengths at age 1 from an age 3 otolith.

The distribution of backcalculated lengths and mean lengths (Tables 3-4) was comparable to the modes observed in the length frequencies (Figure 2). A graphic comparison of the backcalculated lengths with the age composition at length is seen in Figure 3.

Mean backcalculated lengths at the check (Table 3), however, did not correspond to modes in the length frequency. Instead these mean lengths corresponded to spaces between the modes (Figure 3) or overlapped slightly on the mode for age 2 fish (1976, 1977, and 1980) possibly because the check is formed closest to the second annulus (Figure 4 and Table 5). Included in Table 3 are the observed fish lengths for the June-August otoliths with a check on the edge. The correspondence of the observed lengths with the backcalculated lengths in Table 3 indicates that the same ring was interpreted as a check in both analyses. Examination of the growth increments given in Table 5

indicates a continuous decrease in increments between ages 0-1, 1-2, and 2-3. If the check was interpreted as an annulus (age 2), it would imply a smaller growth increment between ages "2-3" than between ages "3-4". In most species, annual growth increments decrease with increasing age. There may be situations where growth could suddenly increase because of a change in diet, food supply, etc., accompanying a change in area or life history stage, but this has not been observed in previous age and growth studies of Northwest Atlantic mackerel (Anderson and Paciorkowski, 1980).

The backcalculation data revealed year class variations in backcalculated length distribution and mean length at age. Mean length at ages 1-3 and the check were plotted in Figure 4 for the 1973-1980 year classes to describe these trends. Mean length at age 1, approximately 18-19 cm for the 1973 and 1974 year classes, increased steadily to 23 cm for the 1977 year class, decreased to 20 cm for the 1978 year class and remained at 20-21 cm for the 1979 and 1980 year classes. The trends of mean length at the check and for ages 2 and 3 clearly parallel the fluctuations at age 1. For the most recent year classes, such as 1978 and 1979, the growth increment between the first and second annuli appears to be unusually large. This large increment, in addition to an increase of almost 2 cm in fish length at age 1 compared to the 1974 year class, may explain the significant increase in fish length at age 2 and, to a lesser extent, age 3 observed for recent year classes. The increase in length at age 2 for the 1977 year class, however, seems to be due to a large size at age

1 (23 cm), 5 cm larger, on average, than the 1974 year class at that age (Table 5).

The observed differences in mean length at age for the 1973-1981 year classes indicate a possible relationship between mean length at age and year-class size. Mean length at age 1 and estimated year-class size at age 1 (Anderson 1982) are plotted in Figure 5. A linear regression fit to the data resulted in an r^2 of 0.62. If the 1975 and 1977 points, which deviate somewhat from the pattern exhibited by the other year classes, are omitted, the regression has an r^2 of 0.99. Mean length at age 2 and estimated year-class size at age 2 are plotted in Figure 6 and exhibit a relationship comparable to that at age 1 (r^2 = 0.68). The results in Figures 4 and 5 indicate an inverse relationship between mean length and year-class size and strongly suggest density-dependent growth for mackerel. Previous work by others (MacKay 1979, Lett 1980) has also indicated density-dependent growth.

DISCUSSION

The analysis of seasonal otolith edge formation identifies May-September as the season when active deposition of opaque (summer) edge occurs on the otoliths of age 1-3 mackerel. The pattern of edge formation was similar for all the year classes investigated (1973-1980). More importantly, it was observed that a weak, discontinuous hyaline ring was formed on the edge of many age 1 otoliths (55-71%) between June and August, but particularly in July. This ring differed from an annulus in that it formed primarily on the posterior edge and was immediately preceded by a stippling of thin hyaline rings.

Although this ring could be interpreted as an early forming winter annulus, the predominant edge type in August for all age groups was opaque, indicating that most fish were still actively growing. It is important to note that this ring was generally more prominent on the age 1 otoliths of recent year classes. Therefore, it could easily be misinterpreted as an annulus if certain criteria, such as discontinuity of the hyaline zone around the otolith periphery, were not emphasized. This weak ring or check was also observed to form on several otoliths of age 2-3 mackerel.

The reason for the formation of this check is not known. Strong checks are often associated with wide growth increments on the otoliths of some species. Examples include the second summer check of silver hake otoliths from SA 6 (Anon. 1977) and the first summer check on the otoliths of some butterfish (Dery, personal observation). The second summer check is particularly

strong on mackerel otoliths of recent year classes having an unusually large growth increment between the first and second annuli.

Correspondence between percent age composition at length and length frequency modes from NMFS research vessel survey catches supports the interpretation of the weak ring as a check. Modes in the length frequencies corresponding to age 1 or age 2 do not include more than a single age group each. Modal progression of year classes at ages 1, 2, and 3 is predictable over the years 1975-1981. There is also some indication that fish size at ages 2 and 3 has increased during this time.

Backcalculation analysis provided further evidence that the weak hyaline ring is a check. Modal fish lengths at annuli 1, 2, and 3 from backcalculation corresponded very closely to those observed in the length frequencies, whereas modal lengths at the check did not. Backcalculated lengths at the check compared directly to observed lengths at the time of check formation during the summer months (particularly July).

CONCLUSION

Age composition data are a vital component of the overall information base needed to assess the status of mackerel in the Northwest Atlantic. Aging is currently done independently by age readers from the US, Canadian Maritimes, and Newfoundland. Therefore, it is important that all aging be consistent with respect to the criteria applied to the interpretation of

annuli. Attempts have been made to resolve differences in interpreting the first, second, and third annuli leading to the observed aging discrepancies in the last several years. Results presented in this paper tend to validate the interpretation of the first three annuli using the aging criteria described herein. Further evaluation of the samples aged by others is recommended in an attempt to achieve greater consistency in the aging of Northwest Atlantic mackerel.

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Table 1. Percent of Atlantic mackerel age 1 otoliths with hyaline (H), narrow opaque (NO), opaque (O), and narrow hyaline (NH) edge for given months and year classes. Also given are percent of otoliths with a second summer check formed on the edge and percent with this check formed before the edge.

Months	Year classes	Otolith edge type (%) H	NO	O	NH	Total numbers	Check on edge (%)	Check formed before edge (%)
Mar-Apr	1975	90	5	5	-	*20*	-	-
	1977	80	10	-	10	*10*	-	-
	1978	100	-	-	-	*38*	-	-
	1979	89	11	-	-	*9*	-	-
	1980	90	10	-	-	*20*	-	-
	Mean	93	5	1	1		-	-
Jun	1975	-	-	100	-	*5*	-	-
	1977	9	-	91	-	*11*	9	-
	Mean	6	-	94	-		6	-
Jul	1975	-	3	77	19	*31*	19	6
	1977	-	-	100	-	*8*	-	25
	1978	8	8	83	-	*12*	8	8
	1979	9	9	64	18	*11*	27	27
	1980	3	10	80	7	*30*	10	33
	Mean	3	7	79	11		14	20
Aug	1975	-	10	50	40	*10*	10	50
	1978	9	13	52	26	*54*	19	56
	Mean	9	14	51	28		17	54
Sep	1979	50	17	-	33	*6*	-	100
Oct-Nov	1975	25	-	17	41	*12*	-	67
	1977	67	-	-	33	*9*	-	56
	1978	43	-	15	43	*40*	-	55
	1979	29	-	-	71	*7*	-	71
	Mean	41	-	12	47		-	59

Table 2. Percent of Atlantic mackerel age 2 and 3 otoliths with hyaline (H), narrow opaque (NO), opaque (O), and narrow hyaline (NH) edge for given months and year classes.

Months	Year classes	Otolith edge type (%) H	NO	O	NH	Total numbers
Mar-Apr	1973-74	81	-	5	14	*21*
	1975-76	92	-	-	8	*12*
	1976-77	100	-	-		*4*
	1977-78	75	14	-	11	*28*
	1978-79	72	28	-		*18*
	Mean	79	11	1	10	
May	1973-74	76	14	10	-	*21*
Jun	1973-74		-	100	-	*14*
	1975-76	29	14	57	-	*7*
	Mean	10	5	86	-	
Jul	1973-74	-	5	91	5	*32*
	1975-76	-	-	63	37	*8*
	1976-77	-	25	75	-	*5*
	1977-78	5	-	85	10	*30*
	Mean	2	4	83	11	
Aug	1973-74	24	-	57	19	*21*
	1976-77	-	-	100	-	*10*
	1979-80	-	35	65	-	*17*
	Mean	10	13	69	8	
Sep	1973-74	40	-	-	60	*10*
	1977-78	39	-	39	23	*13*
	Mean	39	-	22	39	
Oct-Nov	1973-74	42	-	10	48	*31*
	1975-76	20	-	50	30	*10*
	1976-77	50	-	-	50	*6*
	1977-78	47	-	18	35	*17*
	1978-79	10	-	10	80	*10*
	Mean	37	-	16	47	

Table 3. Distribution of back calculated fish lengths at annulus 1 and the second summer check for the 1973-1980 year classes of Atlantic mackerel.

Annulus 1									Check in second summer										
Year class	1973	1974	1975	1976	1977	1978	1979	1980	1973	1974	1975	*1975*[a]	1976	1977	1978	*1978*[a]	1979	*1979*[a]	*1980*[a]
Backcalculated age	3	2	1,3	2,3	1-3	1-3	1,2	1	3	2	1,3		2,3	1-3	1-3		1-2		
Fork length (cm)																			
14	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	4	7	4	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
17	5	6	5	1	1	4	-	4	-	-	-	-	-	-	-	-	-	-	-
18	8	7	6	1	1	15	-	3	-	-	-	-	-	-	-	-	-	-	-
19	4	9	7	7	2	19	5	2	-	-	-	-	-	-	-	-	-	-	-
20	1	1	10	4	6	28	5	1	-	2	-	1	-	-	-	-	-	-	-
21	2	-	6	3	8	25	12	3	1	1	-	-	-	-	-	-	-	-	1
22	1	1	4	4	3	12	4	2	2	-	1	1	1	-	-	-	-	-	-
23	-	1	-	1	11	9	3	2	1	3	-	2		-	1	-	-	-	3
24	-	1	-	-	9	2	1	2	2	1	2	2	3	-	2	1	-	-	2
25	-	-	1	1	9	3	-	1	1	2	2	-	2	3	7	4	1	1	-
26	-	1	-	-	8	-	-	-	-	-	3	-	4	1	13	5	1		-
27	1	-	-	-	3	-	-	-	-	-	1	-	2	-	11	5	2	3	-
28	-	-	-	2	3	-	-	-	-	1	-	-	1	-	11	4	-	-	1
29	-	-	-	-	-	-	-	-	-	-	-	1	1	2	3	-	3	-	-
30	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	2	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-
N	26	35	45	24	65	117	30	21	7	10	9	8	14	8	50	19	10	4	
$\bar{L}$	18.5	18.3	19.1	21.1	23.2	20.3	20.9	20.1	23.0	23.2	25.0	24.4	25.6	27.5	26.7	26.4	28.3	26.5	23.7
s	2.31	2.35	2.11	2.73	2.77	1.76	1.29	2.69	1.31	2.36	1.41	3.20	1.76	2.35	1.55	1.18	1.85	0.87	1.98

[a]Observed fish lengths for otoliths with a 'check' forming on the edge (from analysis of seasonal otolith edge formation).

Table 4. Distribution of backcalculated fish lengths at annulus 2 and annulus 3 for the 1973-1979 year classes of Atlantic mackerel.

	Annulus 2							Annulus 3					
Year class	1973	1974	1975	1976	1977	1978	1979	1973	1974	1975	1976	1977	1978
Backcalculated age	3	2	3	2,3	2,3	2,3	2	3	3	3	3	3	3
Fork length (cm)													
22	-	1	-	-	-	-	-	-		-	-	-	-
23	-	-	-	-	-	-	-	-		-	-	-	-
24	1	7	-	-	-	1	-	-		-	-	-	-
25	6	7	3	-	-		-	-		-	-	-	-
26	3	10	-	-	2	1	-	-		-	-	-	-
27	10	1	5	3	1	2	-	1		-	-	-	-
28	2	3	6	7	1	5	-			-	-	-	-
29	1	3	6	3	3	15	2	6		-	-	-	-
30	2	1	-	2	3	18	4	6		2	-	-	-
31	-	2	1	2	4	20	3	6		4	-	-	-
32	1	-	1	3	4	14	4	5		3	-	-	-
33	-	-	-	1	6	4	1	1		6	-	-	5
34	-	-	-	2	2	2	1	1		6	3	3	9
35	-	-	-		2	-	1	-		-	1	2	5
36	-	-	-	1	-	-	-	-		1	1	4	8
37	-	-	-	-	-	-	-	-		-	2	2	-
N	26	35	22	24	28	82	16	26		22	7	11	27
$\bar{L}$	26.9	26.1	28.0	30.0	31.1	30.3	31.3	30.5		32.6	35.3	35.5	34.6
s	1.80	2.11	1.69	2.49	2.45	1.71	1.65	1.50		1.49	1.08	1.08	1.10

Table 5. Growth increments (L_i-L_{i-1}) between mean backcalculated fish lengths at annulus 1, second summer check (c2), annulus 2, and annulus 3 for Atlantic mackerel. Also given is percent of total length at annulus 2 (L_2).

Growth increment (cm)	Year class							
	1973	1974	1975	1976	1977	1978	1979	1980
L_1-L_0	18.5	18.3	19.1	21.1	23.2	20.3	20.9	20.1
% of L_2	*69*	*70*	*68*	*70*	*75*	*67*	*67*	-
L_{c2}-L_1	4.5	4.9	5.9	4.5	4.3	6.4	7.4	-
% of L_2	*17*	*19*	*21*	*15*	*14*	*21*	*24*	-
L_2-L_{c2}	3.9	2.9	3.0	4.4	3.6	3.6	3.1	-
% of L_2	*14*	*11*	*11*	*15*	*12*	*12*	*10*	-
L_2-L_1	8.4	7.8	8.9	8.9	7.9	10.0	10.5	-
% of L_2	*31*	*30*	*32*	*30*	*25*	*33*	*34*	-
Total L_2	26.9	26.1	28.0	30.0	31.1	30.3	31.3	-
L_3-L_2	3.6	-	4.6	5.3	4.4	4.3	-	-
Total L_3	30.5	-	32.6	35.3	35.5	34.6	-	-

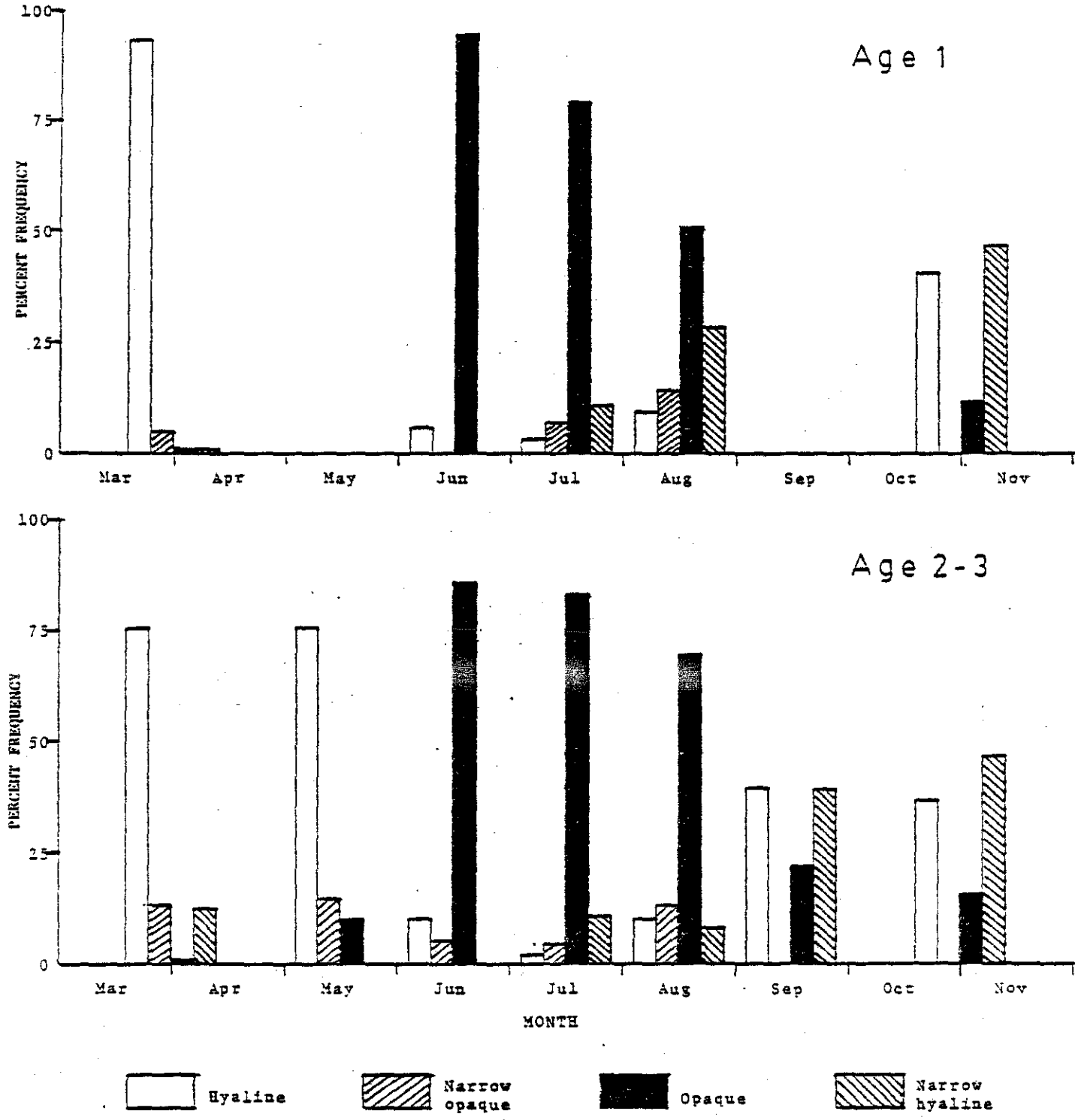

Figure 1. Percent of Atlantic mackerel age 1 and age 2-3 otoliths with hyaline, narrow opaque, opaque, and narrow hyaline edge for given months, and for the year classes given in Tables 1 and 2.

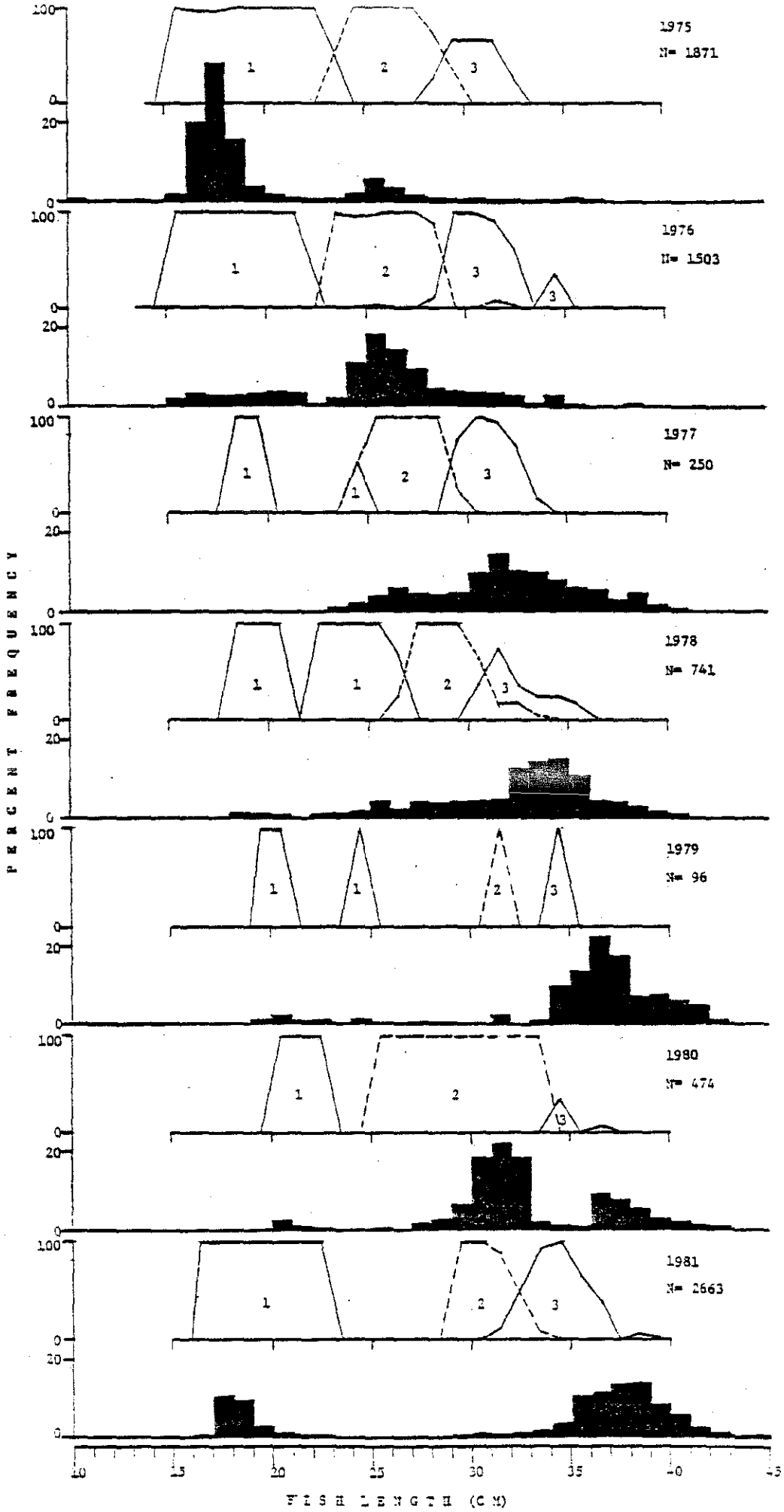

Figure 2. Comparison of percent age composition at length for ages 1-3 with percent frequency(solid histograms) of catches of Atlantic mackerel in 1975-1981 NMFS spring bottom trawl surveys.

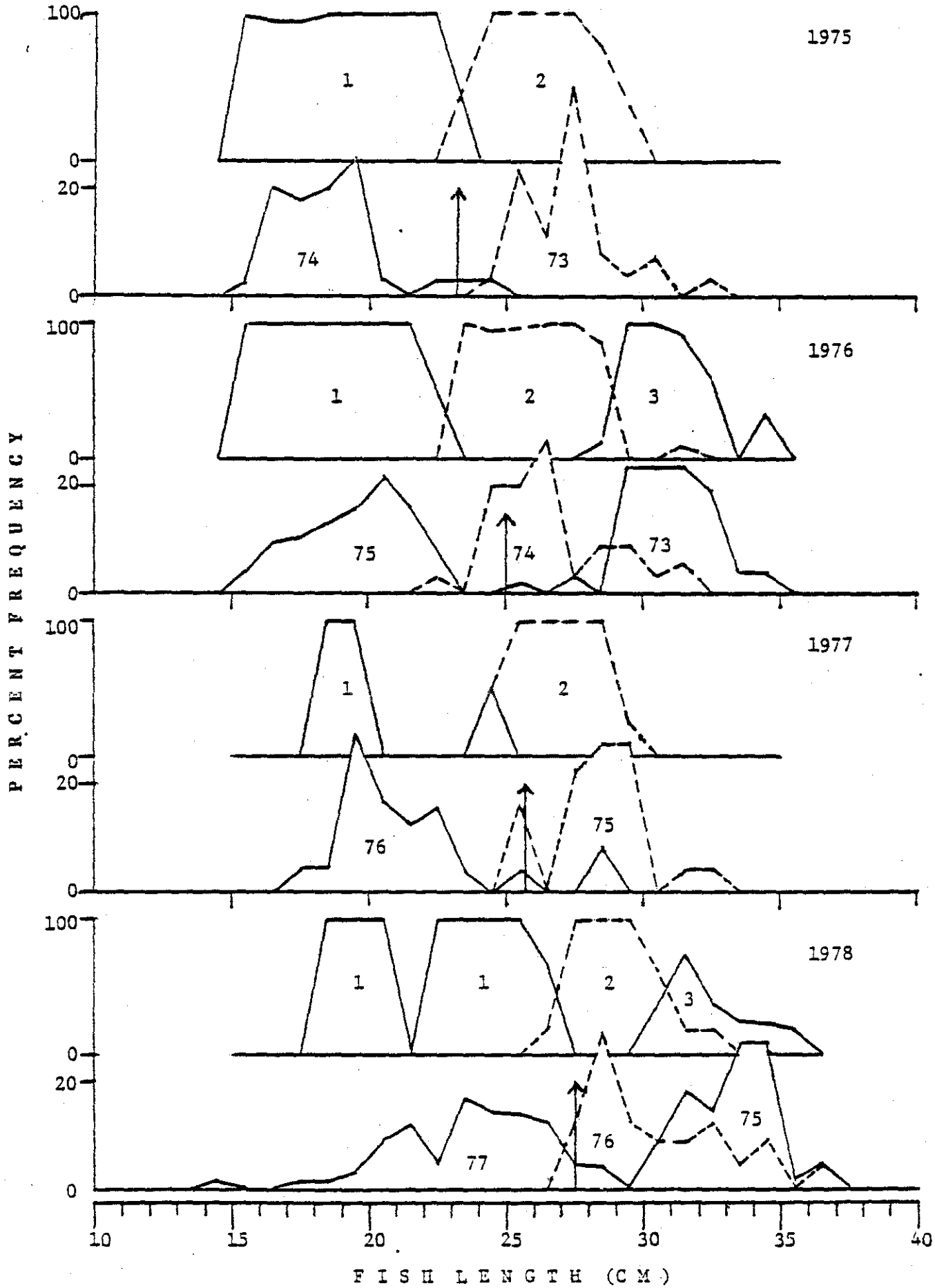

Figure 3A. Comparison of percent age composition at length(labeled as 1,2, or 3) from NMFS spring bottom trawl survey catches of Atlantic mackerel with percent frequency distribution of backcalculated fish lengths of the corresponding year classes, for 1975-1978. Mean backcalcul-

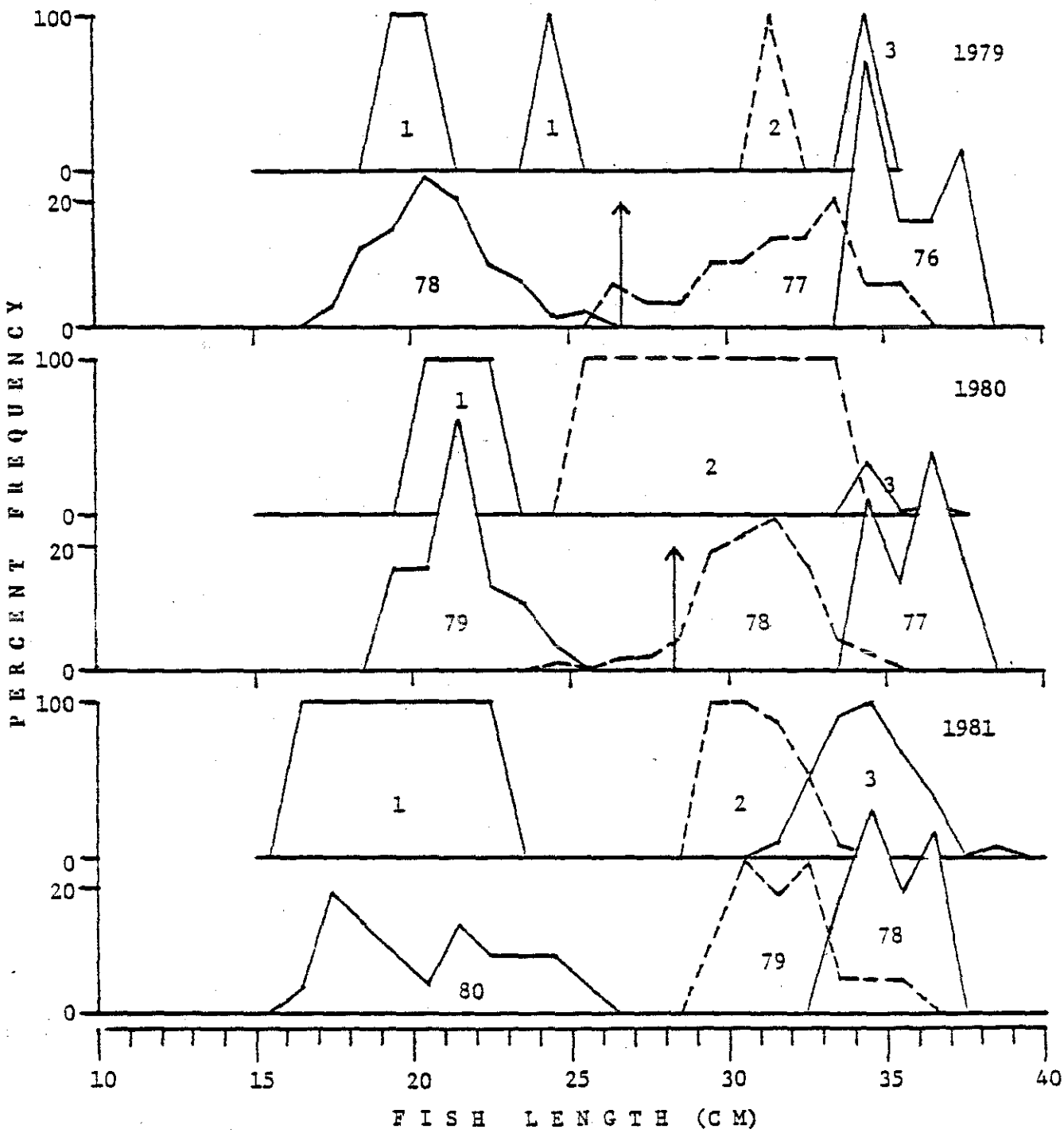

Figure 3B Comparison of percent age composition at length(labeled as 1,2 or 3) from NMFS spring bottom trawl survey catches of Atlantic mackerel with percent frequency distribution of backcalculated fish lengths of the corresponding year classes, for 1979-1981. Mean backcalculated fish length at the check is indicated by an arrow.

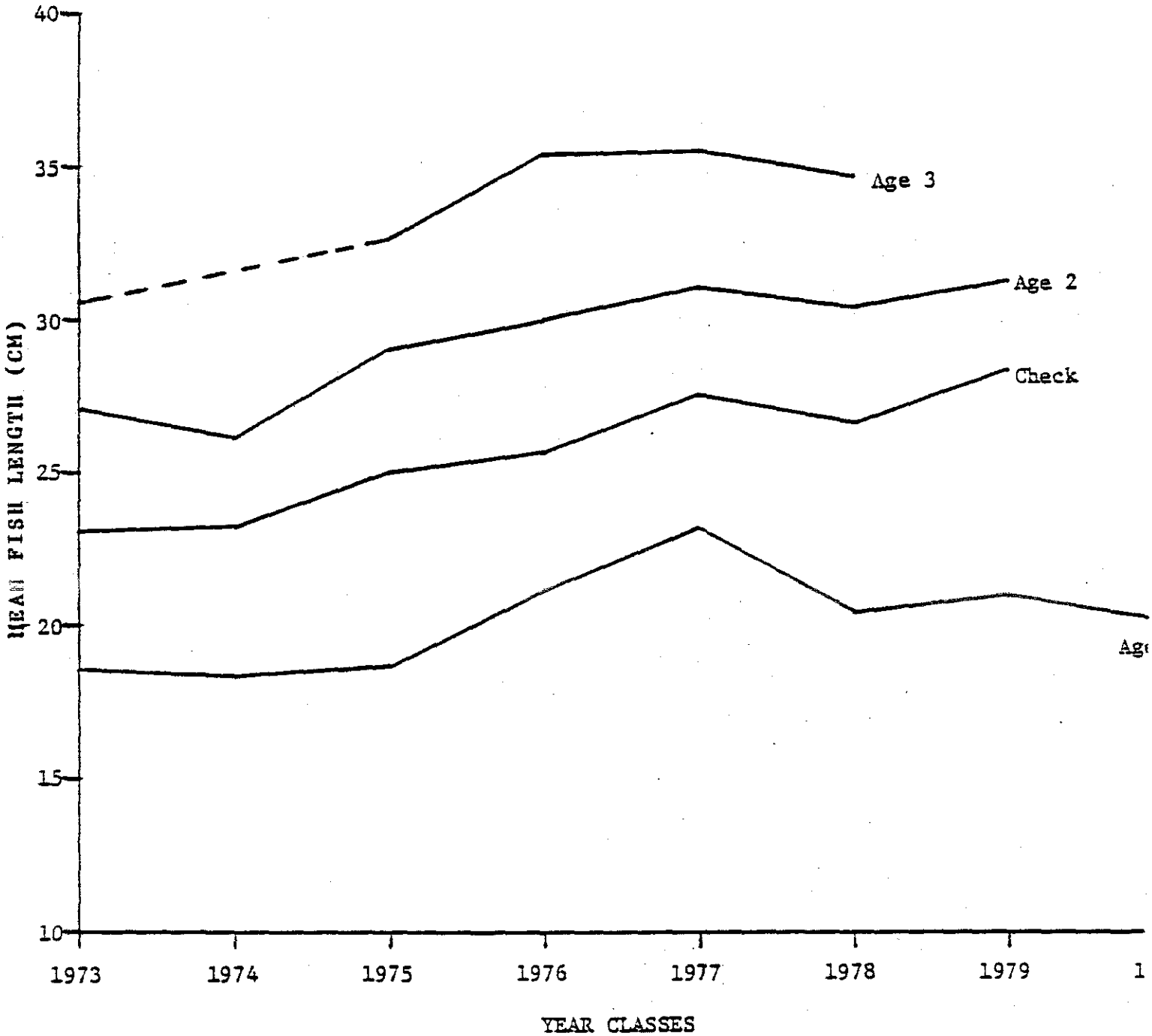

Figure 4. Changes in backcalculated mean lengths at ages 1-3 and second summer check for the 1973-1980 year classes of Atlantic mackerel. Dashed line indicates no data for 1974.

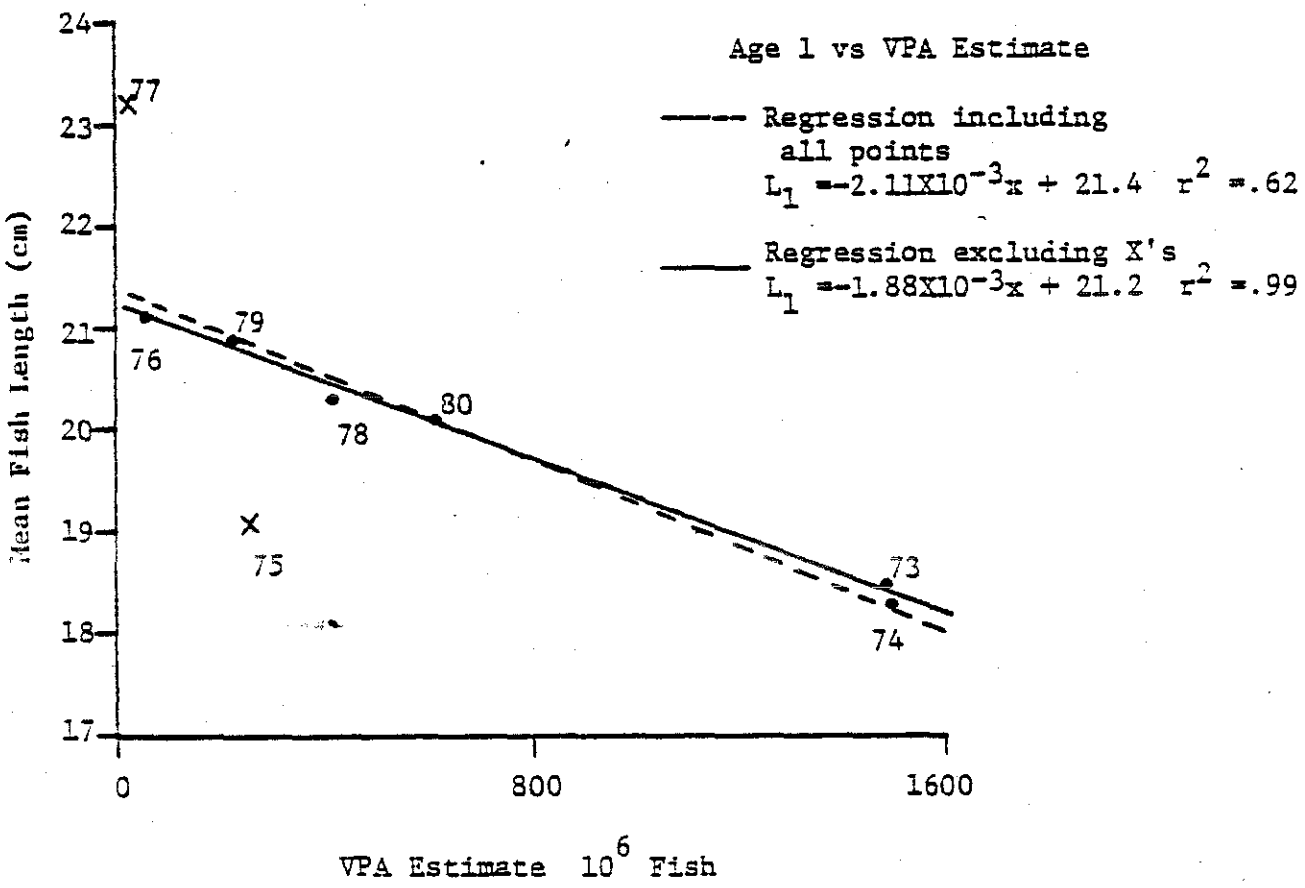

Figure 5. Regression of mean backcalculated fish length at age 1 against the virtual population analysis estimate(age 1) for the 1973-1980 year classes of Atlantic mackerel.

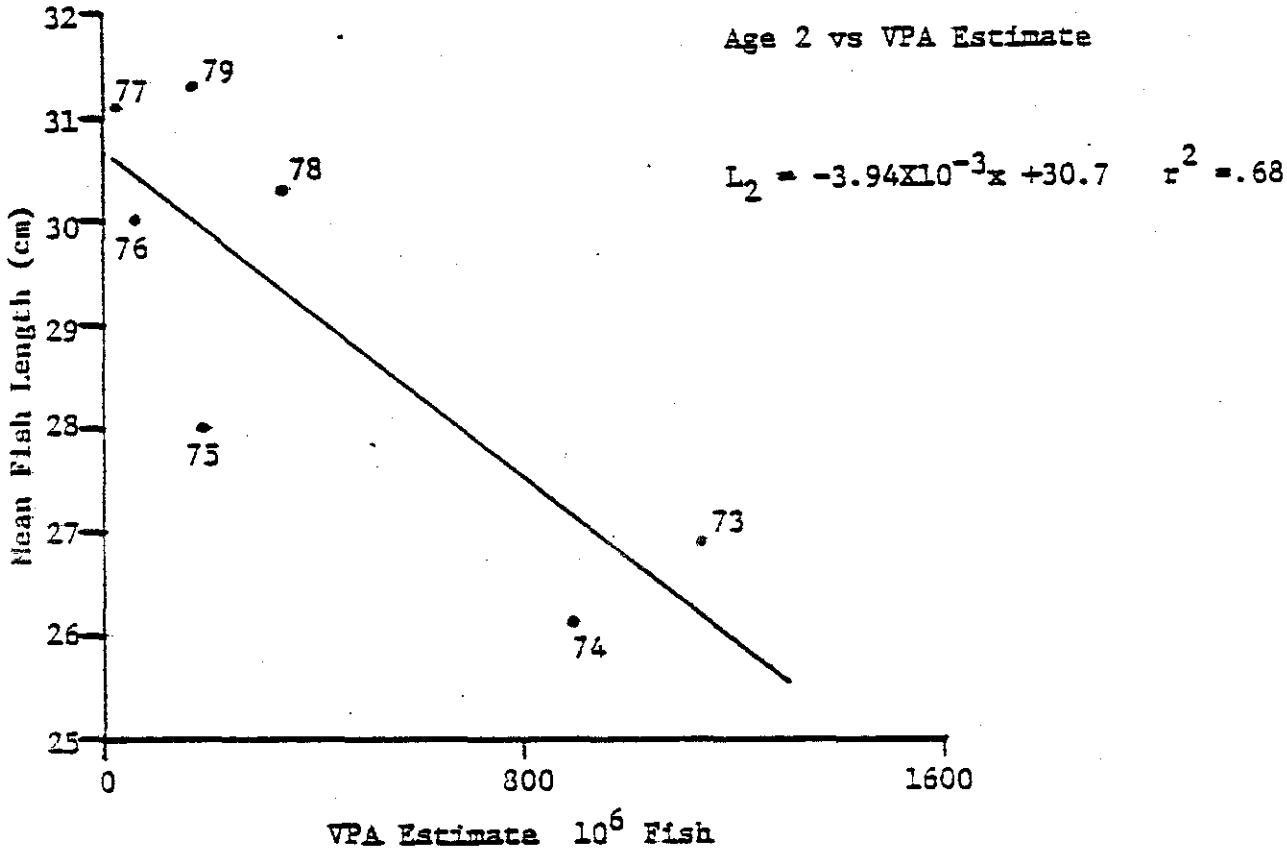

Figure 6. Regression of mean backcalculated fish length at age 2 against the virtual population analysis estimate(age 2) for the 1973-1979 year classes of Atlantic mackerel.