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AGE AND GROWTH STUDY BASED ON MODAL ANALYSIS FOR THE WESTERN ATLANTIC BLUEFIN TUNA

T. Nagai
Far Seas Fisheries Research Laboratory

SUMMARY

An age and growth study was made by modal analysis of length composition for western Atlantic bluefin tuna. Normal curves were applied to break down 24 size frequencies into 81 age groups. Mean fork lengths of these modal groups were examined and used for fitting to Von Bertalanffy's growth equation, while the relationship between those mean lengths and their standard deviations are being investigated.

RESUME

Une étude sur l'âge et la croissance est effectuée pour le thon rouge de l'Atlantique par l'analyse modale de la composition de taille. Les courbes normales sont appliquées pour décomposer 24 fréquences de taille en 81 groupes d'âge. La longueur fourche moyenne de ces groupes modaux est examinée et utilisée pour un ajustement à l'équation de croissance de von Bertalanffy, alors que le rapport entre ces tailles moyennes et leurs déviations standards fait l'objet de recherches.

RESUMEN

Se realizó un estudio de edad y crecimiento por medio de análisis modal de la composición por tallas del atún rojo del Atlántico Oeste. Se aplicaron curvas normales para dividir 24 frecuencias de talla en 81 grupos de edad. Se examinaron las medias de longitud a la horquilla de estos grupos modales que se ajustaron a la ecuación de crecimiento de Von Bertalanffy, mientras se investigaba la relación entre dichas medias y sus desviaciones típicas.

Age and growth studies for the Atlantic bluefin tuna have already been made by several scientists. As a result, it has been made clear that the life span of this species is more than 20 years. The methods used by them included counting of growth ring appearing in hard tissue such as of fin rays (Compean-Jimenez and Bard, 1980; Rey and Cort, 1983), otoliths (Butler, Caddy, Dickson and Burnett, 1977) and vertebrae (Rodriguez-Roda, 1964) etc, that of based on mark-recapture data (Parrack and Pharse, 1979) and that of a combination of several methods (Mather and Schuck, 1960) and so forth. Estimated figures of parameters in von Bertalanffy's growth equation calculated by these methods are almost close to each other but there are some which are considerably different.

Formerly in bluefin tuna, length-age conversion from catch by size to catch-at-age data depended upon von Bertalanffy's growth equation (Sakagawa and Coan, 1974). But the standing committee on research and statistics of ICCAT recommended that in order to improve stock assessment, different growth rates among individuals and sexes should be taken into consideration (Anon., 1984). It is not easy, however, to estimate growth equations by sex because of limited data. In addition, there are not so much information about sex ratio with which we can make separate the catches into sex specific size frequencies. One of the methods solving the problem would be to separate the catches into age groups by using a growth equation within the size range of no significant sex specific difference in length-age relationship whereas if the fish is larger than the size of sexual dimorphism becoming apparent, it would be deal with all ages collectively, or in other words, not to decompose by age. In order to develop a length-age conversion model in which differences of growth among individuals are taken into consideration, it is necessary to check up on the relationship between mean fork length by age and its standard deviation beforehand. It is regretted that no studies have so far been made about the relationship between the two. And it is a matter of fact that few papers have so far presented worthwhile standard deviations that could be used for this purpose.

The purpose of this paper is to estimate the parameters used in von Bertalanffy's growth equation for the western Atlantic bluefin tuna stock, compare them with existing other estimates and thereby find out the relationship between mean fork length by age and its standard deviation.

Materials and Methods

A total of 22 samples of size frequencies of the catches were used. From one of these samples, samples of each for male and female were made available. As a result, 24 samples of size frequencies were used in this study. The breakdown of these by country by gear (type of fishery) is given in the table below. Most of these size frequencies are recorded in the DATA RECORD of ICCAT. Japanese data are recorded collectively together with other samples. It is noted here that the sexed size frequencies in the Gulf of Mexico are reported by Nagai (1984a). Then, 2 cm intervals were used as a length class in the present analysis.

Country	Gear (ICCAT CODE)	No. of sample	Remarks
Canada	PS	6	
U.S.A.	PS	11	
	RR	2	
Japan	LL	3	
	LL	2	Sexed data
Total		24	

It goes to the question of non linear least squares estimation to decompose size frequencies into groups of different age by applying normal curves to polymodal size frequencies. For this work to be done, use of electric computer is indispensable and some programs have been developed in recent years. There are, for example, NORMSEP (Hasselblad, 1966) by steepest descent method and SNORMSEP (Shimadzu, 1980) using Marquardt's algorithm, etc. These differ in their methods to minimize defined function of the sum of squares. In the steepest descent method, even if initial value is away from true value, it rapidly converges to right direction. However, it tends to become slow in its convergence speed in the vicinity of solution. In contrast, this shortcoming is gotten rid of in the Marquardt method (Shimadzu, 1980).

In this paper, SNORMSEP was used for decomposing aforementioned size frequencies into length groups. As a criterion of minimization, x^2 was used this time though either the sum of squares or x^2 could be taken up in this program. In SNORMSEP, search range is not limited in estimating parameters of normal distribution. Because of this, in case if the quality of data was poor, it sometimes resulted in obtaining irrational solutions such as, for example, extremely large standard deviations. In such cases, size frequencies were reexamined and run again in computers after excluding part of size range. As to the excluded part of size range, no analysis was done. Or in case if it seemed to include relatively clear mode, its mean value was taken and, after examining various normal curves by using small computers, by referring to standrad deviations of neighbouring size groups, appropriate one was selected by visual approximation from among the curves.

RESULTS

Decomposition of size frequencies

Each of the 24 size frequencies was decomposed and a total of 81 length groups were obtained. Table 1 shows estimated parameters for these length groups. Spawning of Atlantic bluefin tuna takes place once a year and its prime season is from April to June (Richards, 1976). Therefore, these length groups are thought to belong, in principle, to age groups. It is, however, practically difficult to assign ages to length groups decomposed from size frequencies and to do so is dangerous. In assessing ages to length group, if available, any other information should be used at that time. As a convenient method, it is to use conventional growth equations obtained from other than modal analysis.

In the present paper, mean fork length by age was calculated from Parrack and Pharse (1979) in which mark-recapture data were used and by referring to this, ages were assigned for each length group as in the following way. The difference between the mean length of separated length group and that obtained from the growth equation referred to above is relatively small until ages of 1 to 3 (Fig. 1 a – c), or at times, it is relatively large (Fig. 1 d, e). In both of these cases, it is thought that the length groups consist of single age groups and accordingly, it is relatively easy to assign ages. In view of the fact that growth equation is no other than the one giving the averaged growth of a typical cohort, such a difference should be allowed. It becomes difficult, however, to assign ages for the fish older than 4 years old since for these age groups, it is difficult to judge whether or not a given length group consists of single age even if that group appears to be of single mode (see Fig. 1 a, c and d). This is because difference of length by age is masked by time lag of spawning period, errors and biases resulting from distribution of the fish, availability of fish schools and sampling, etc. As long as we rely on size frequencies, it cannot be denied that there is a limit of such a sense. Accordingly in this paper, for the purpose of obtaining t_0 which cannot be estimated unless ages are known beforehand, estimated values for the fish younger than 3 years old are mainly used. And in case if that is not necessary, values of other than as such shall also be used with examining the results of decomposition at the same time.

The sexed length frequency compositions were shown for the Atlantic bluefin tuna caught by Japanese longliners in the Gulf of Mexico in 1978 (Fig. 1 f, g). It is known from this figure that the fork length of female ranges from 202 to 280 cm and that of male from 214 to 302 cm. Clearly separated modes each of which class mark being at 239 cm, 249 cm and 257 cm are seen in case of female while those of 239 cm, 249 cm, 259 cm and 263 cm for male. It is interesting that of the male's fork length modes the first three are the same ones as those of female's. Under the assumption that each mode appeared in the sexed length compositions indicating existence of the individual length group, four length groups were obtained for each sex. With regard to the fourth length group of female, however, it is not clearly identifiable in itself; it emerges after deducting number of fish belonging to the three length groups from the total number of fish. The differences in modes for these length groups are 9.5 cm, 9.2 cm and 6.8 cm in female and 10.0 cm, 8.5 cm and 8.5 cm in male. It shows that the difference in modal length decreases for the bigger fish. The standard deviations of these length groups range from 2.0 to 2.8. The modal length do not change a little for the composition combined sexes (Fig. 1 h). Four length groups were separated from the combined composition. Each of the mean fork lengths combined sexes lies between that of male and that of female separately obtained. Though mean length of the four groups of both sexes almost agrees, there is no proof for the time being that shows a pair of four length groups consisting of male and female each are of the same age. It seems, however, rational to think that since those modes are well separated and the differences in modal length get decreased with increasing the body length of fish, at least each length group decomposed by sex represents a single age group.

Estimation on the parameters of von Bertalanffy's growth equation

Modal analysis has inconveniences as described above and yet, it is sufficiently effective to estimate parameters of growth equation.

From the data of Table 1, mean fork lengths of two neighbouring length groups, namely l_t and l_{t+1} were plotted on the Ford-Walford graph (Fig. 2). Here, l_t and l_{t+1} indicate the fork lengths at age t and t+1 respectively. On this graph, von Bertalanffy's growth equation is expressed by the straight line shown below (Ricker, 1975).

$$l_{t+1} = l_\infty \ (1 - e^{-k}) + e^{-k} \cdot l_t \qquad \cdots\cdots\cdots\cdots \qquad (1)$$

Accordingly, l_∞ is obtained from the point of intersection between regression line and 45 degrees line, and from the regression line, growth coefficient k is obtained. A total of 47 points can be plotted from all the mean lengths by length groups given in Table 1. In this case, l_∞ and k were assumed to be 386 cm and 0.0713 with the contribution ratio (r^2) of 0.9891. Incidentally, the growth equation given by Parrack and Pharse (1979) is shown by a dotted line in Fig. 2. It is noted here that almost all points are found gathered close to the straight line if fork length at age t is smaller than 90 cm. In contrast to this, it seems that in the fork length range of 95 to 150 cm, the number of points found off from the line increase. As already described in the foregoing section, it becomes difficult to judge whether or not a given length group consists of single age even if that group appears to be of single mode for the fish older than 4 years old. In consideration of this fact, it was decided to exclude almost all points within the range of l_t being between 95 cm and 150 cm. These points correspond to those of checked with question mark in age in Table 1. A total of 13 points were thus excluded. And for the remaining 34 points, the equation (1) was applied again. As a result, l_∞ and k were assumed to be 394 cm and 0.0654 respectively with r^2 being equal to 0.9963. The regression line applied in this way well fits mean lengths obtained from the sexed length composition of bluefin tuna caught by Japanese longliners in the Gulf of Mexico. In this paper, therefore, the latter values of l_∞ and k are used. The regression line based on the growth equation given by Parrack and Pharse (1979) is, it is noted here, clearly off from the mean fork lengths by sex in the Gulf of Mexico (Fig. 2).

As described in the foregoing, in order to obtain growth equation's parameters l_∞ and k, it is possible even if age itself is not known provided that if each of the length groups consists of same age fish. Concerning t_0, however, it is necessary to determine age beforehand by assuming spawning date and correcting the time difference taken sampling date into considerations. If age is known, von Bertalanffy's growth equation can be modified as follows and t_0 can be calculated from this equation.

$$t_0 = t + \frac{1}{k} l_n (1 - \frac{l_t}{l_\infty}) \quad .... \quad (2)$$

If t_0 is calculated for each age group excluding those of checked by "question mark" in Table 1, the mean value of all the t_0s becomes -1.21. By doing so, the following growth equation for the western Atlantic bluefin tuna was obtained.

$$l_t = 394 (1 - e^{-0.0654(t + 1.21)}) \quad .... \quad (3)$$

Incidentally, parameters of von Bertalanffy's growth equation for the western Atlantic bluefin tuna that have been published so far are compared with those of present paper and summarized in Table 2. From the table, it is known that the smallest l_∞ is that of given by Butler et al. (1977) being 287 cm in male and 277 cm in female whereas the largest l_∞ is that of Sakagawa and Coan (1974) being 437 cm in both sexes are combined.

Table 3 shows mean fork lengths by age calculated using the parameters of the growth equation given in Table 2. It is known that the figures of age length relationship between Sakagawa and Coan (1974) and present paper are very well in agreement. Likewise, that of Butler et al. (1977) and that of Parrack and Pharse (1979) are relatively similar. It must be pointed out here, however, that there is a considerable difference between the former two and the latter two figures. There is no significant difference until ages 7 to 8 between the figures of present paper and those of Parrack and Pharse (1979). After these ages, the difference between the two gradually increases and at age 15, the difference reaches 18 cm in fork length. The mean fork length at age 15 in the former two corresponds to that of age 18 in the latter two. With regard to this kind of difference, discussions shall be made in the later part of this paper.

Relationship between mean fork length and its standard deviation

Fig. 3 shows the relationship between mean fork lengths by age and the corresponding standard deviations. It is relatively apparent from this figure that as the mean fork length increases, standard deviation also tends to increase for the fish of 50 - 120 cm in mean fork length. In the range of 120 to 160 cm in mean fork length, the standard deviations fluctuate between 3.0 and 5.0. But on average, it seems that the relationship between fork length and standard deviation is constant. The number of points on the graph decreases if mean fork length exceeds 160 cm. According to the figures calculated from the data of Japanese longliners, the mean fork length was in a range of 239 cm and 266 cm and the standard deviation was comparatively small at 2.4 to 2.6.

From the studies of above described mean fork lengths (X) and standard deviations (Y), a quadratic curve was applied. As a result, the following equation was obtained ($r^2 = 0.5105$).

$$Y = -0.0779 + 0.0502X - 0.000158X^2 \quad \ldots\ldots\ldots \quad (4)$$

Fig. 4 shows this in which mean fork length by age and corresponding standard deviation are either quoted from existing reports or calculated from figures and tables of original papers. As for those figures in the western Atlantic, in order to obtain necessary data, calculation was made from the data given in Table 1 of Mather and Schuck's report (1960) in which vertebrae and scales were used. As for the data of eastern Atlantic including the Mediterranean sea, those of Table 14 in Rodoriquez-Roda (1964)'s report in which vertebrae were used for age determination were quoted. Further, mean fork length and standard deviations were calculated from the data of Fig. 2 of Compean-Jimenez and Bard's report and from Table 1 of Rey and Cort (1984)'s report in both of which dorsal fin rays were used.

The equation relating to mean fork length by age and standard deviation estimated in the foregoing paragraph is shown by a dotted line in Fig. 4 which is in well agreement with that of Compean-Jimenez and Bard (1980). Except for ages 4 to 7, estimated figures of the author and those of Rodorigeuz-Roda (1964) agree very well. However, author's estimates do not agree with those of remaining two, that is, Mather and Schuck (1960)'s and Rey and Cort (1984)'s in the level of standard deviation. It is surprising to know that even though both authors, Compean-Jimenez and Bard (1980) and Rey and Cort (1984), used the dorsal fin rays for age determination, there was a difference of about two times in standard deviation betweem them. Based on the original Tables 1 and 2 of Butler et al. (1977) who used otoliths to determine ages, it is indicated that the standard deviations for the fish older than 15 years old can often exceed 10 cm (Table 4). Except for the case of Butler et al. (1977) examining only the aged fish, standard deviations on the whole seem to be within a small range in young fish of ages 1 to 3, and tend to become relatively large in ages of 4 to 9 while becoming small again in ages of over 10 with showing occasional big variation for those ages because of the smaller sample size (Fig. 4).

It is possible to make a model of length composition for the parental stock from the mean fork lengths by age and standard deviations given by Butler et al. (1979). It is an approximated length composition of a given population. It is interesting in this sense to compare length composition of samples such as, for example, that of caught by Japanese longliners in the Gulf of Mexico. The standard deviations of mean fork length by age are available for the fish older than 15 years old (Table 4). Therefore, the population number at age 15 is supposed to be 1 as a relative value with assuming that being constant irrespective of year classes. Under these assumptions, the population number of each age can be calculated by multiplying survival rate by the population number of preceding cohort. In so doing, natural mortality coefficient is assumed to be 0.2 and fishing mortality coefficient is likewise assumed to be constant at 0.2 irrespective of ages. These assumed values are not so much off from those of estimated so far by VPA runs for the Atlantic bluefin tuna (Nagai, 1984b). It will do enough to calculate from the age of 15 to 24 since the instantaneous rate of total mortality becomes 0.4 in the end. Table 5 shows all the values used for calculations in the present study. Fig. 5 shows length compositions of modeled populations obtained together with those of samples caught in the Gulf of Mexico. Incidentally, the same method was applied for the purpose of comparison, based upon mean fork length by age and standard deviations obtained in the present report (Table 5, Fig. 5). In this case, calculations were done from age 12 to 21.

A smooth monomodal curve is obtained from the values of Butler et al. (1977) (Fig. 5). In contrast to this, from the values of present report, a series of clearly separated modes are observed. The height of these modes becomes gradually smaller as the fork length increases. If the standard deviations for the fish younger than 14 years old are already known, it will be more interesting. But still, the following can be pointed out from this Fig. 5. Namely, if the growth equation and standard deviations of mean fork length by age given by Butler et al. (1977) are correct, the length composition of large sized fish older than 15 years ought to show up as monomodal distribution; polymodal distribution cannot happen. If it is a characteristic behavior for the species concerned to make a school consisting of similar sized fish, the modes appeared in length composition could change randomly. It is hard to say that the modal appeared in length of the bluefin tuna caught by longliners in the Gulf of Mexico is random.

DISCUSSIONS

In the present paper, in view of the fact that size frequency of the catches of the bluefin tuna in the western Atlantic shows polymodal distribution, age and growth of this species were studied by modal analysis. The studies on growth have so far been made mainly on the basis of counting of growth rings appearing in hard tissues or on the basis of mark-recapture data. Modal analysis has been used as secondary information for studying of growth of young fish. It is said that in concrete terms, growth of the fish up to age 6 can be analysed by this method (Anon, 1978). Previously, size frequency studies have been made by using data of both sexes combined. However, the author dealt with the sexed size data of large sized bluefin tuna caught by Japanese longliners in the Gulf of Mexico. The total number of male and female samples used in the present study was 970 individuals. There have been no cases so far in which fork length of so many individuals of large sized fish in the spawning ground was measured by sex. From the length compositions by sex, four length groups were separated for each sex. These length groups were thought to correspond to age groups from the fact that each mode was clearly separated and from the fact that the difference between two successive modes decreased for the larger fish. It was not possible, however, to estimate ages of each length group by sex. The mean fork lengths of these age groups were plotted on the Ford-Walford's graph together with mean fork lengths of young age fish which are caught by purse seine or rod and reel gears. By so doing, of the parameters of von Bertalanffy's growth equation, l_∞ and k were obtained unbiasedly. The reason why l_∞ given by Parrack and Pharse (1979) is small may probably be attributable to the fact that almost all the recaptured fish were smaller than 140 cm in size and accordingly, the estimated length using their equation are biased for the large fish. In age determination by otoliths, there are such problems as it is difficult to identify the position of nucleus, counting of bands in the younger fish is difficult and it is not known whether or not annuli correspond to annual ring in the older fish (Butler et al., 1977: Anon., 1978).

The author is interested in up to what size of fish in length, one growth equation can be used commonly to both sexes. According to Maguire and Hurlbut (1984) who studied bluefin tuna caught by trap in Canada, no significant difference is recognized in the sex ratio up to the size of 234 cm in fork length. Accordingly, it is thought that there is no need to take sexual dimorphism into consideration at least up to the size of 234 cm since there is not any difference in the growth of the fish between both sexes. The fork length of 234 cm corresponds to the fish of about 13 years old in age, according to the author's growth equation.

The age specific mean fork length being small, the standard deviation was small. But as the length increased, the standard deviation tended to increase up to certain degree and then decrease again. This phenomenon is thought to indicate what is known as growth compensation (Ricker, 1969). Then, the author applied a quadratic equation for mean fork length by age and its standard deviation with including the points that were excluded at the time of finding l_∞ and k in this case. This was because the author judged that even if those points were excluded, the shape of the curve would not much change and, in addition, it was not necessary to study the relationship between mean fork length and its standard deviation more detailedly than be required in the present paper.

References

Anon. 1978: Proceedings of Atlantic bluefin tuna aging workshop., Int. Comm. for the Conserv. of Atlantic Tunas, CVSP, VII: 332-348.

Anon. 1984: Proceedings of the eighth regular meeting of the commission Part II (Annex 10-SCRS Report)., Int. Comm. for the Conserv. of Atlantic tunas, i+65-207p.

Butler, M. J. A., J. F. Caddy, C. A. Dickson, J. J. Hunt, C. D. Burnett 1977: Apparent age and growth, based on otolith analysis, of giant bluefin tuna (Thunnus thynnus thynnus) in the 1975-1976 Canadian catch (SCRS/76/86)., Int. Comm. for the Conserv. of Atlantic Tunas, CVSP, VI:318-330.

Compean-Jimnez, G. and F. X. Bard 1980: Age and growth of east Atlantic bluefin tuna as determined by reading of fin rays cross section (SCRS/79/67)., Int. Comm. for the Conserv. of Atlantic Tunas, CVSP, IX: 547-552.

Hasselblad, V. 1966: Estimation of parameters for a mixture of normal distribution., Technometrics, 8(3): 431-444.

Maguire, J. J. and T. R. Hurlbut 1984: Bluefin tuna sex proportion at length in the Canadian samples 1974-1983 (SCRS/83/84)., Int. Comm. for the Atlantic Tunas, CVSP, XX: 341-346.

Mather III, F. J., H. A. Schuck 1960: Growth of bluefin tuna of the western north Atlantic., Fish. Bull. 61 (179): 39-52.

Nagai, T. 1984a: Atlantic bluefin tuna sex ratio in the catches obtained by Japanese longliners (SCRS Doc.)., Int. Comm. for the Conserv. of Atlantic Tunas, 6p.

Nagai, T. 1984b: Stock assessment of the Atlantic bluefin tuna assessed with use of separable VPA (SCRS/83/42)., Int. Comm. for the Conserv. of Atlantic Tunas, CVSP, XX: 384-398.

Parrack, M.L. and P.L. Pharse 1979: Asspects ot the growth of Atlantic bluefin tuna determined from mark-recapture data (SCRS/78/37)., Int. Comm. for the Conserv. of Atlantic Tunas, CVSP, VIII: 356-366.

Rey, J. C. and J. L. Cort 1983: Una clave talla/Edad por lectura de Espinas para el atun rojo (Thunnus thynnus, L.) del Atlantico este (SCRS/83/36)., Int. Comm. for the Conserv. of Atlantic tunas, CVSP, XX: 337-340.

Richards, W.G. 1976: Spawning of bluefin tuna (Thunnus thynnus) in the Atlantic Ocean and adjacent Seas (SCRS/75/97)., Int. Comm. for the Conserv. of Atlantic Tunas, CVSP, V: 267-278.

Ricker, W. E. 1969: Effects of size-selective mortality and sampling bias on estimates of growth, mortality, production, and yield., J. Fish. Res. Bd. Canada, 26 (3): 479-541.

Ricker, W. E. 1975: Computation and interpretation of biological statistics of fish populations., Bull. of the Fish. Res. Bd. of Canada, 191, XViii+382p.

Rodriguez-Roda, J. 1964: Biologia del Atun, Thunnus thynnus (L.), de la costa sudatlantica de Espana., Inv. Pesq. 25: 34-146.

Sakagawa G. T. and A. L. Coan 1974: A review of some aspects of the bluefin tuna(Thunnus thynnus thynnus) fisheries of the Atlantic Ocean (SCRS/73/60)., Int. Comm. for the Conserv. of Atlantic Tunas, CVSP, II: 259-313.

Shimadzu, Y 1980: [An alternative method for estimating age composition from length fregrency data] ., [Report of the 1979 sectional meeting for demersal fish around the western Japan.] , 36-48p., Fisheries Agency, Japan.

Table 1. Summary table of normal curves fitted by using SNORMSEP for 24 size frequencies of the western Atlantic bluefin tuna. The numeral in parethesis indicates age assigned. (upper; component ratio in per mille: middle; mean: bottom; standard deviation)

Country	Gear	Year (M/Q)	No. of fish measured	Length Group 1	2	3	4	5	Source
CAN	PS	1965 AUG	174	148 58.9 2.18 (1)	307 81.4 2.14 (2)		240 136.5 4.00 (5)	333 147.0 4.00 (6)	DR 2
		1970 JUL-AUG	1,571	491 53.6 2.26 (1)	382 74.7 2.97 (2)	65 92.3 3.85 (3)		62 127.2 4.20 (5?)	DR 2
		1973 AUG	2,199	38 57.5 2.50 (1)	630 77.3 2.80 (2)	270 102.3 2.90 (3)	50 128.2 3.00 (4?)		DR 4
		1975 JUL-AUG	1,412	143 57.0 2.51 (1)	836 75.2 2.51 (2)				DR 8
		1978 Quart 3	1,307	83 64.3 2.60 (1)	120 86.0 3.20 (2)	555 108.5 3.80 (3)	60 137.0 4.00 (4?)	140 154.0 4.00 (5?)	DR 13
		1981 JUN	520	625 79.7 3.78 (2)	379 105.1 3.89 (3)				DR 20
USA	PS	1973 JUL	12,068	92 56.4 2.07 (1)	605 75.4 2.67 (2)		78 147.0 3.00 (6?)	195 156.0 3.00 (7?)	DR 4
		1973 AUG	76,635	59 57.5 3.10 (1)	595 76.7 2.92 (2)	283 102.4 3.32 (3)	79 127.0 2.83 (4?)		DR 4
		1973 SEP	2,690	58 57.7 3.20 (1)	522 76.5 2.88 (2)	244 102.7 2.92 (3)	80 126.7 2.78 (4?)		DR 4
		1974 JUL	25,382	456 53.8 1.89 (1)	312 78.1 2.74 (2)	266 93.9 3.20 (3)			DR 6
		1974 AUG	16,542	178 55.9 1.95 (1)	233 82.5 3.36 (2)	339 98.0 4.62 (3)	178 126.3 4.80 (4?)	65 145.0 4.20 (5?)	DR 6
		1974 SEP	21,500	830 60.5 1.70 (1)	77 85.4 2.73 (2)	109 102.0 3.07 (3)			DR 6

Table 1. (Continued)

Country	Gear	Year (M/Q)	No. of fish measured	Length Group 1	2	3	4	5	Source
USA	PS	1975 6/29-7/5	312	199 57.5 1.70 (1)	635 74.9 2.83 (2)	85 108.0 3.20 (3?)	120 120.0 3.20 (4?)		DR 8
		1975 7/6-7/12	975	832 74.4 2.97 (2)		107 116.4 3.00 (4)			DR 8
		1975 7/20-7/26	1,634	126 56.6 1.83 (1)	880 75.0 2.26 (2)				DR 8
		1975 8/3-8/9	1,477	281 57.8 1.74 (1)	500 76.5 2.41 (2)	65 108.0 3.20 (4?)	130 120.2 2.80 (5?)		DR 8
		1979 JUN	830	176 79.2 2.87 (2)	403 101.2 4.71 (3)	425 127.0 4.64 (4?)			DR 16
	RR	1979 JUN	1,146	442 61.0 2.57 (1)	537 81.5 3.44 (2)	45 99.0 3.10 (3)			DR 16
		1979 JUL	965	350 64.1 2.42 (1)	559 84.3 3.26 (2)	89.4 102.9 3.33 (3)			DR 16
JPN	LL	1976 NOV-DEC	202	60 187.0 3.50	940 201.0 4.00				YZ/52/8
		1976/77 DEC-FEB	360	855 115.5 5.20	145 135.5 4.80				YZ/52/8
		1978 FEB-MAY	520 (Female)	195 238.5 2.20	290 248.0 2.80	320 257.2 2.60	62 264.0 2.00		SCRS/84/30
		1978 FEB-MAY	450 (Male)	140 239.0 2.80	195 249.0 2.00	280 257.5 2.40	300 266.0 2.60		SCRS/84/30
		1978 FEB-MAY	970	164 238.7 2.50	239 248.5 2.40	292 257.4 2.50	167 265.7 2.60		SCRS/84/30

REMARKS DR; DATA RECORD: YZ; YAIZU FILE.

Table 2. Comparison of growth parameter of von Bertalanffy's equation for the western Atlantic bluefin tuna.
M and F indicate male and female, respectively.

Sources	Materials		L_∞	k	t_0	Fork length investigated
Sakagawa and Coan (1974)*	Vertebrae		437	0.055	-1.49	34-257 cm
Butler et al. (1977)	Otoliths	M	287	0.134	-0.328	233-288 cm except a fish of 150 cm
		F	277	0.116	-0.800	
Parrack and Pharse (1978)	Mark-recapture data		313	0.090	-0.961	Mainly less than 140 cm with five exceptionally big fish
Present report	Size frequencies		394	0.065	-1.21	44-300 cm

* The data of Mather and Schuck (1960) were used for the analysis.

Table 3. Age-fork length relationship calculated from von Bertalanffy's growth equation.

Age	Sakagawa and Coan(1974)*	Butler et al.(1977) male	female	combined	Parrack and Pharse(1978)	Present report
1	55.9	46.8	52.2	49.5	50.6	52.7
2	76.3	76.9	76.8	76.9	73.2	74.2
3	95.6	103.3	98.7	101.0	93.9	94.3
4	113.9	126.3	118.3	122.3	112.7	113.2
5	131.2	146.5	135.7	141.1	130.0	130.9
6	147.5	164.1	151.1	157.6	145.7	147.4
7	163.0	179.5	164.9	172.2	160.1	162.9
8	177.7	193.0	177.2	185.1	173.3	177.5
9	191.6	204.8	188.1	196.4	185.3	191.1
10	204.7	215.1	197.9	206.5	196.3	203.9
11	217.1	224.1	206.5	215.3	206.3	215.8
12	228.9	232.0	214.2	223.1	215.5	227.0
13	240.0	238.9	221.1	230.0	223.9	237.6
14	250.6	244.9	227.2	236.1	231.6	247.4
15	260.6	250.2	232.7	241.4	238.6	256.6
16	270.0	254.8	237.5	246.2	245.0	265.3
17	278.9	258.9	241.9	250.4	250.8	273.4
18	287.4	262.4	245.7	254.0	256.2	281.0
19	295.4	265.5	249.1	257.3	261.1	288.1
20	303.0	268.2	252.2	260.2	265.5	294.7

*: The data reported Mather and Schuck (1960) were used for the analysis.

Table 4. Mean lengths and standard deviations by ages calculated from Butler et al. (1977) data.
2cm intervals were used for calculation.

Sexes		Age 15	16	17	18	19	20	21	22	23	24	25	26
Female	Sample size	1	1	6	1	5	5	10	10	3	3	1	1
	Mean	233.0	241.0	246.7	241.0	253.8	255.8	252.8	259.8	257.0	245.0	259.0	251.0
	S.D.	--	--	5.1	--	9.9	13.0	11.9	9.9	9.2	5.3	--	--
Male	Sample size	3	12	14	4	18	16	23	25	20	8	3	3
	Mean	252.3	258.3	258.4	259.0	264.9	265.5	266.5	268.0	268.1	277.8	267.0	279.7
	S.D.	16.2	6.8	9.4	14.7	11.3	8.2	8.3	10.2	6.9	6.5	13.9	5.0
Sexes combined	Sample size	4	13	20	5	23	21	33	35	23	11	4	4
	Mean	247.5	257.0	254.9	255.4	262.5	263.2	262.3	265.6	266.7	268.8	265.0	272.5
	S.D.	16.4	8.1	9.9	15.1	11.8	10.1	11.3	10.6	7.9	16.4	12.0	14.9

Table 5. Mean fork lengths and standard deviations of Atlantic bluefin tuna for calculation of the modeled population size frequencies, in April 1.

	Butler et al. (1977)				Present report		
	Male		Female		Sexes combined		
Age	Mean	S.D.	Mean	S.D.	Age	Mean	S.D.
15	254.5	(5.1)	237.2	(5.1)	12	236.7	2.96
16	258.5	(5.1)	241.5	(5.1)	13	246.6	2.70
17	262.1	5.1	245.4	5.1	14	255.9	2.43
18	265.2	(9.9)	248.9	(9.9)	15	264.6	2.16
19	268.0	9.9	251.9	9.9	16	272.7	(2.16)
20	270.3	13.0	254.7	13.0	17	280.3	(2.16)
21	272.4	11.9	257.1	11.9	18	287.5	(2.16)
22	274.3	9.9	259.3	9.9	19	294.2	(2.16)
23	275.9	9.2	261.2	9.2	20	300.5	(2.16)
24	277.3	5.3	263.0	5.3	21	306.4	(2.16)

The numerals in the parentheses were assumed.

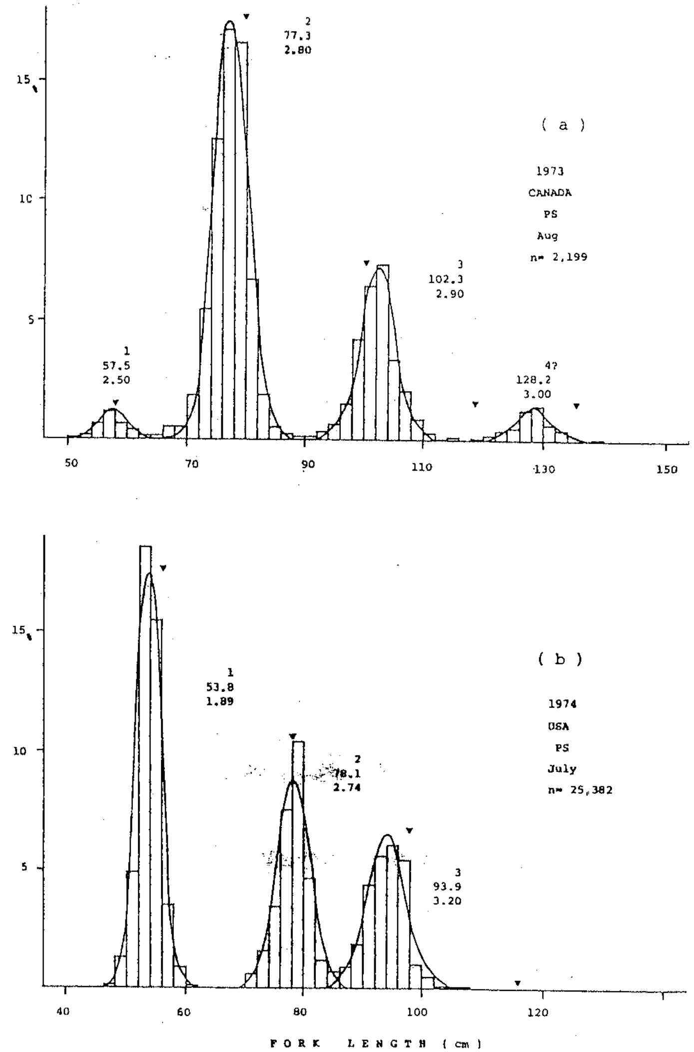

Fig. 1. Size frequency histograms and normal curves fitted by using SNORMSEP for the western Atlantic bluefin tuna data.
The numerals in the figure indicate age, mean length, S.D., respectively. The triangles represent the calculated mean lengths from Parrack and Pharse(1978).

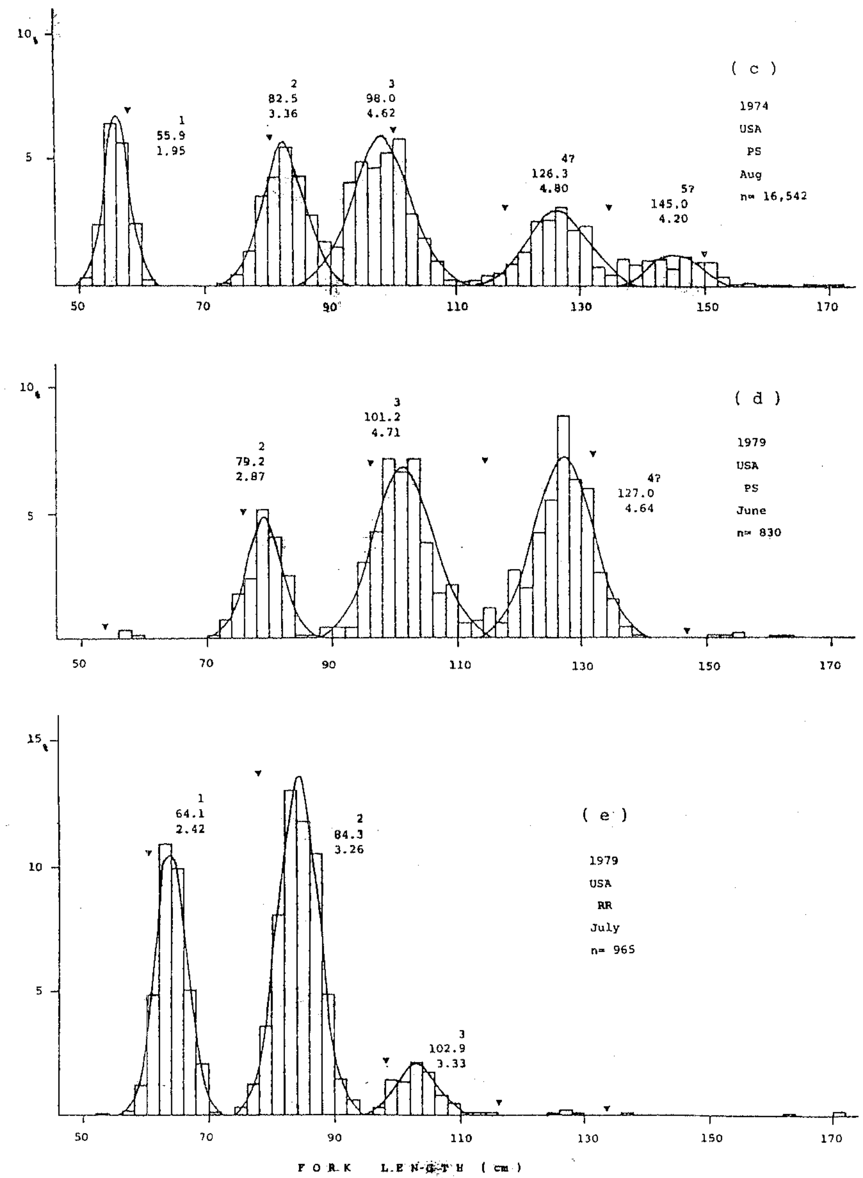

Fig. 1. (Continued)

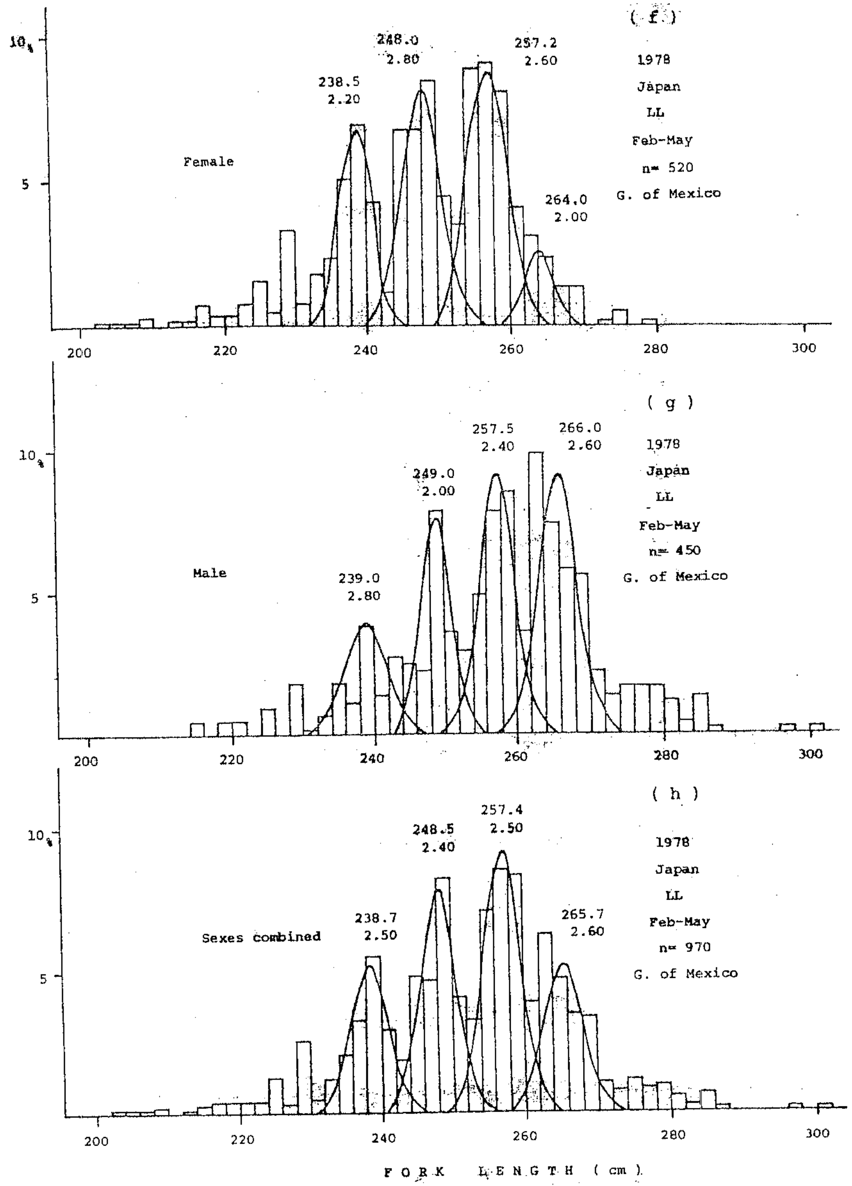

Fig. 1. (Continued)

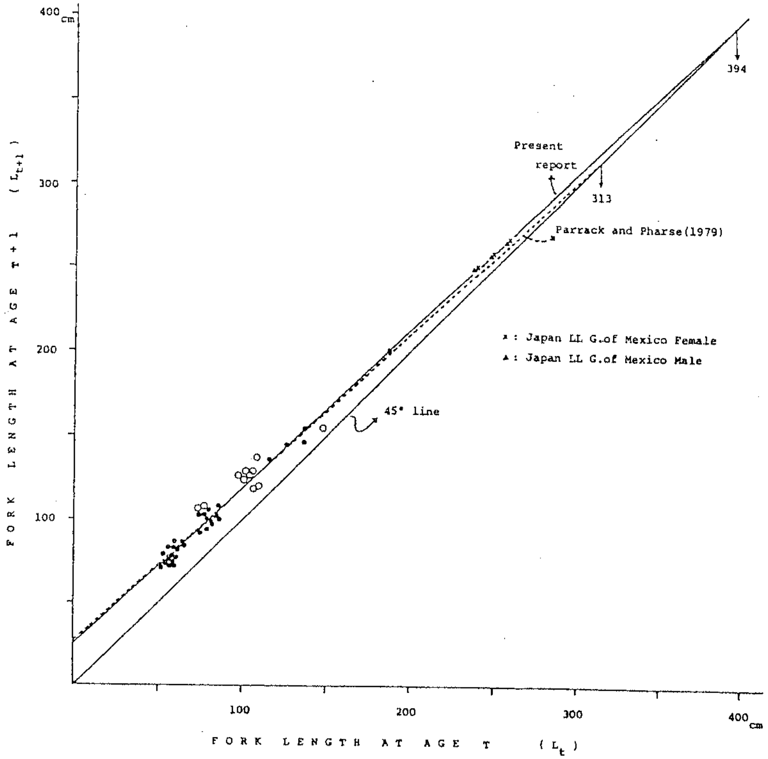

Fig. 2. Map showing a Ford-Walford graph for the western Atlantic bluefin tuna.

The mean fork lengths obtained from the size composition combined sexes were used for fitting a straight line by least squares in case of Japanese longliners in the Gulf of Mexico. The open circles indicate the values excluded on fitting the growth equation.

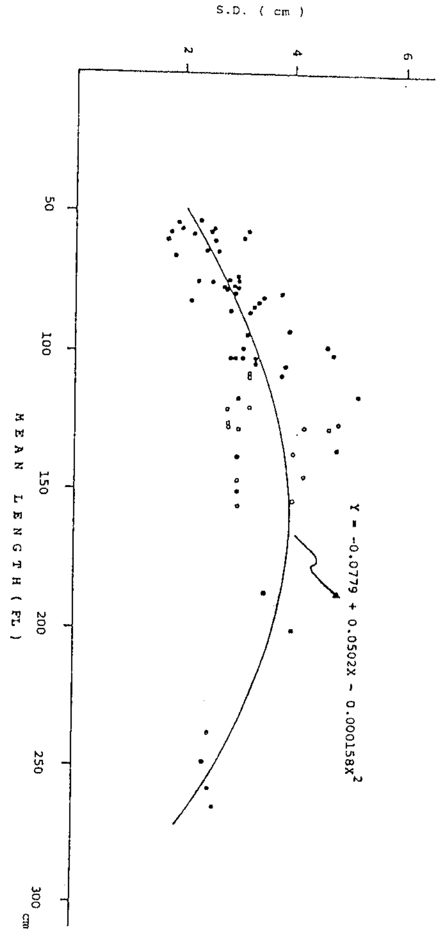

Fig. 3. The relationship between mean fork length by age and its standard deviation for the western Atlantic bluefin tuna.

All of the points in the figure were used for fitting a quadratic curve. The open circles indicate the points excluded on fitting von Bertalanffy's growth equation.

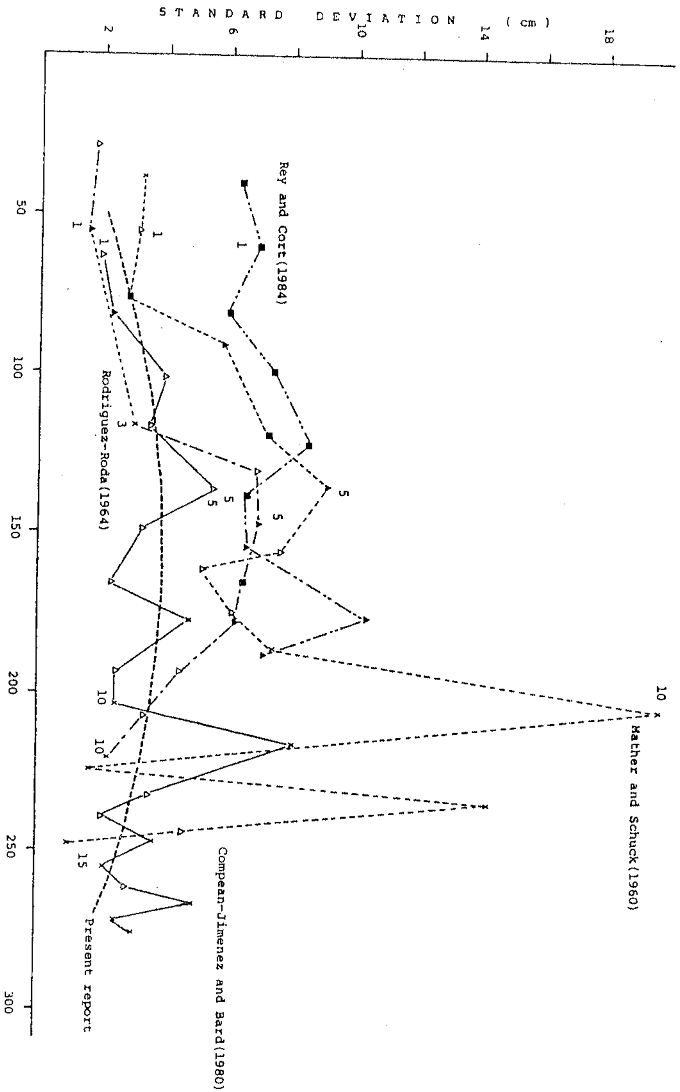

Fig. 4. Comparison of the relationship between mean fork length and its standard deviation reported for the Atlantic bluefin tuna.

The numerals in the figure represent ages estimated.

(Sample size: X 0-6; △ 7-15; ▲ 16-30; ■ > 31)

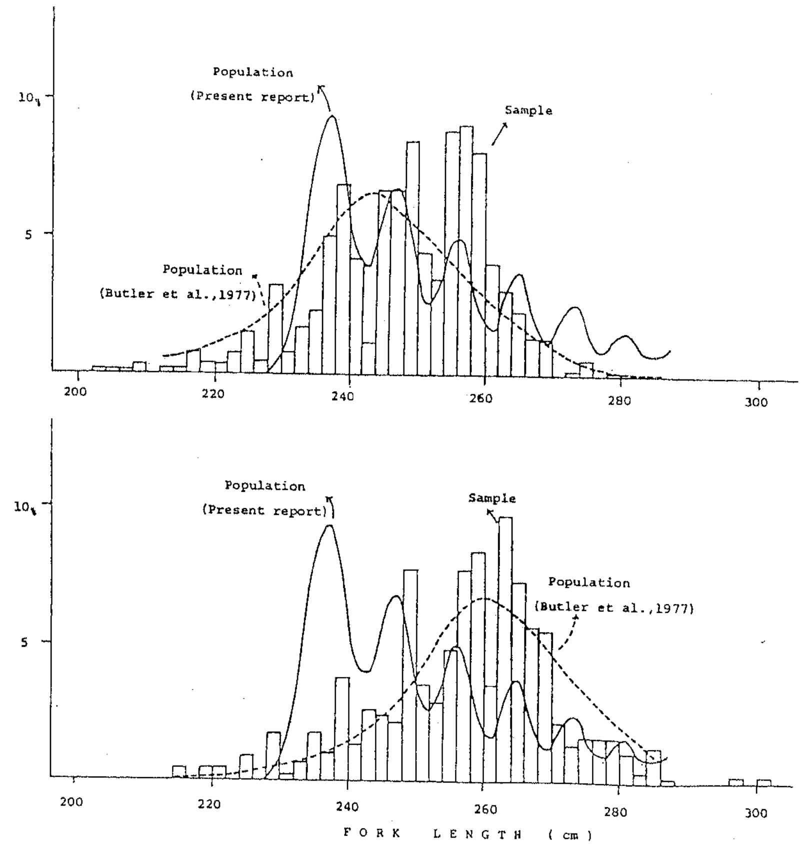

Fig. 5. Map showing two types of modeled population size frequencies and those of sample observed in 1978 in the Gulf of Mexico by Japanese longliners.