Geographic Variation of the Larval Skipjack Tuna, *Katsuwonus pelamis* (LINNAEUS), from the Pacific Ocean

Hiroshi KOHNO*, Makoto SHIMIZU*, and Yukio NOSE*

Abstract

There appears significant variation in morphometric characters among larvae of skipjack tuna, *Katsuwonus pelamis* (LINNAEUS), from nine localities in the Pacific Ocean. Cluster analyses have revealed morphological relationships between the specimens from the nine localities, which indicates structure of the species population. The adjusted mean values of each character in the southern hemisphere groups are generally higher than those in the northern ones. Within each hemisphere group, there seems to be a general tendency that the values become higher in groups located at lower latitude. Although the west- and east-wards differences are not clear, it should be noted that in the northern Pacific the eastern group (around Hawaii Is.) possesses higher values when comparing with those in the western one (near Japan). At least three clusters, the northern and southern hemispheres and equatorial eastern Pacific, are recognized to exist in the Pacific Ocean. These clusters, especially those of northern and southern hemispheres, are separated by more or less steep clines, as far as characters examined in this study are concerned. Such possibility is also demonstrated that the clusters of both hemispheres are respectively divided into two or three subgroups. The necessity to collect further information is emphasized especially on the western Pacific skipjack tuna. It is concluded that, as far as examined, the larval characters are by no means inferior to the adult ones with regard to an ability to know the population structure.

Introduction

The skipjack tuna, *Katsuwonus pelamis*, is widely distributed in the tropical and sub-tropical waters of the world, and in the western Pacific Ocean it occurs commonly from about 40°N to 40°S, while it occurs from about 30°N to 30°S in the eastern Pacific (FORSBERGH, 1980). Due to the commercial importance, a great deal of knowledge has been accumulated on the biological aspects of the species (FORSBERGH, 1980). The population structure, or geographic variation, of the species in the Pacific Ocean has been also well studied by many authors (KASAHARA, 1968 : SUDA, 1971 ; FORSBERGH, 1980). Nevertheless, there has been no unity of views on the population structure of the species. In the present time, two, three, or more

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*Department of Fisheries, Faculty of Agriculture, University of Tokyo. Bunkyo-ku, Tokyo 113.

subpopulations are proposed to exist. On the other hand, many researchers have endeavored to have knowledge on the larval stages of the species (MATSUMOTO, 1958; UEYANAGI, 1974; UEYANAGI *et al*., 1974; NISHIKAWA, 1975). However, there is no report on the geographic variation during the larval stages. It is the purpose of the present study to examine the geographic variation of the skipjack tuna larvae in the Pacific Ocean through the morphometric comparison.

Materials and Methods

A total of 200 skipjack tuna larvae was used in this study. These larvae were collected from the Pacific Ocean during the period of 1961-1981, on the cruises of R/V Shunyo Maru and Shoyo Maru of Fisheries Agency, Japan. The collecting method was reported by NISHIKAWA *et al*. (1978). Based on the collecting area, these larvae were divided into 9 groups listed as follows, in which the collecting locality, number of stations constituting each group, number of specimens, and size range are given in order:

A : 23°31′9-29°31′2N, 126°26′5-129°49′0E; 8 stations; 26 specimens; 3.35-7.95 mm in SL (standard length).

B : 21°41′0-27°15′8N, 161°31′5-177°54′0W; 5; 38; 4.20-7.65 mm in SL.

C : 08°36′0N, 127°59′0E; 1; 18; 4.20-6.30 mm in SL.

D : 03°30′0N, 150°59′0E, and 04°04′5N, 150°55′5E; 2; 32; 3.20-7.35 mm in SL.

E : 00°07′0S, 179°36′0E, and 00°17′5N, 179°14′5E; 2; 27; 3.25-6.20 mm in SL.

F : 08°39′0S, 151°33′0E; 1; 13; 3.70-7.00 mm in SL.

G : 12°00′0-16°35′0S, 146°07′8-151°00′0E; 5; 13; 3.70-7.00 mm in SL.

H : 12°55′0S, 165°19′0E; 1; 21; 3.65-6.55 mm in SL.

I : 11°14′5N-7°49′6S, 115°58′2-147°48′2W; 8; 12; 4.75-7.50 mm in SL.

More detailed collecting data about materials are shown by each group in Table 1, and Fig. 1 demonstrates the geographic position of stations forming each group. All specimens were fixed by 10% formalin, preserved in 70% alcohol, and have been deposited in Far Seas Fisheries Research Laboratory, Japan.

Table 1. The collecting data of 9 groups of skipjack tuna larvae. The collecting date, collecting locality, number of specimens, and size range are represented by each station which constitutes each group.

Group	Station	Date	Locality		Number of specimens	Size range (mm in SL)
A	1	1980-6-11	26°55′5N,	126°26′5E	6	3.35 - 7.35
	2	1980-6-12	23°31′9N,	129°37′6E	1	7.95
	3	1980-6-13	25°09′0N,	129°11′0E	1	4.90
	4	1980-6-14	27°56′0N,	127°39′6E	1	4.45
	5	1980-6-15	25°40′0N,	129°49′0E	2	4.25, 5.10
	6	1980-6-15	27°22′5N,	128°13′5E	13	3.65 - 7.30
	7	1980-6-17	27°17′5N,	127°22′7E	1	6.10
	8	1980-6-18	29°31′2N,	128°25′8E	1	5.30

To be continued

Table 1. Continued.

Group	Station	Date	Locality		Number of specimens	Size range (mm in SL)
B	1	1961-8-5	27°15′8N,	169°50′4W	7	4.20 - 5.40
	2	1961-8-7	25°14′0N,	165°40′0W	6	4.60 - 6.25
	3	1961-8-8	24°26′0N,	163°54′0W	10	4.35 - 5.65
	4	1961-8-9	23°24′6N,	161°31′5W	4	3.45 - 5.35
	5	1961-8-24	21°42′5N,	174°18′7W	6	4.60 - 7.25
C	1	1963-5-31	8°36′0N,	127°59′0E	18	4.20 - 6.30
D	1	1979-12-13	3°30′0N,	150°59′0E	19	4.05 - 7.35
	2	1979-12-16	4°04′5N,	150°55′5E	13	3.20 - 5.30
E	1	1981-2-4	0°07′0S,	179°36′0E	3	6.00 - 6.20
	2	1981-2-5	0°17′5N,	179°14′5E	24	3.25 - 5.90
F	1	1973-11-15	8°39′0S,	151°33′0E	13	3.70 - 7.00
G	1	1973-11-4	16°35′0S,	147°05′5E	1	5.05
	2	1973-11-11	15°28′0S,	150°00′0E	1	6.90
	3	1973-11-12	15°01′0S,	146°07′8E	4	3.70 - 6.95
	4	1973-11-14	13°02′0S,	150°58′5E	2	4.25, 5.60
	5	1973-11-15	12°00′0S,	151°00′0E	5	4.55 - 7.00
H	1	1964-11-25	12°55′0S,	165°19′0E	21	3.65 - 6.55
I	1	1964-2-4	8°40′6N,	115°58′2W	3	4.85 - 7.50
	2	1964-2-13	6°22′0S,	131°42′3W	2	4.75, 5.00
	3	1964-2-16	7°49′6S,	136°42′4W	1	6.05
	4	1964-2-17	3°09′7S,	140°12′0W	2	4.80, 5.30
	5	1964-2-20	5°02′1N,	145°59′0W	2	5.15, 5.20
	6	1964-2-21	8°11′1N,	147°48′2W	1	4.80
	7	1964-2-22	11°14′5N,	145°59′8W	1	6.10

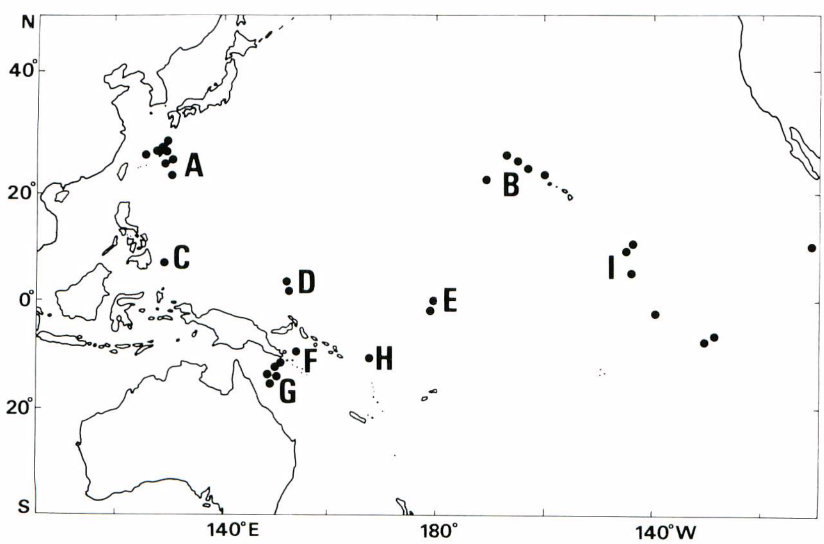

Fig. 1 Geographic distribution of each group (A-I) in skipjack tuna larvae. See text and Table 1 for details.

Eight measurements including the standard length were used and defined as follows:

1) Standard length: The distance from the tip of snout to the posterior end of notochord; this corresponds to the notochord length of POTTHOFF (1980) and KOHNO *et al.* (1983).
2) Preanus length: The distance from the tip of snout to the posterior margin of anus opening.
3) Head length: The distance from the tip of snout to the posterior margin of gill cover, irrespective of whether or not the preopercular spine outlines from the posterior margin of gill cover.
4) Maximum body depth: The maximum vertical dimension of the body excepting the finfold.
5) Body depth at anus: The vertical dimension at the anus, exclusive of the finfold.
6) Snout length: The distance from the tip of snout to the anterior edge of orbit.
7) Eye diameter: The diameter of eye taken parallel to the body axis.
8) Upper jaw length: The distance from the anterior tip of premaxilla to the posterior margin of maxilla.

Measurements were made under a binocular microscope with an ocular micrometer, read to the nearest 0.05 mm.

The size of larvae dealt with is, as mentioned above, limited to that between 3 and 8 mm in SL. Within the limits of this larval size, a linear regression is expected in the relation between the standard or head length and other measurements. Therefore, the statistical analysis was mainly based on the linear regression. The statistical method followed to SNEATH and SOKAL (1973) and SNEDECOR and COCHRAN (1980). The actual analysis was proceeded as mentioned below.

1) Homogeneity of larval size of each group. The variance and mean of standard length were compared among the groups for examining the homogeneity of larval size of each group. The uniformity of variance was examined by the Bartlett's test, and that of mean was tested by the analysis of variance. And then, between each group, the differences of the variance and mean of standard length were tested. The variance ratio test was used for comparing the variance of each pair of groups. When the variance was not different between groups then each mean was compared by the t test. On the other hand, when a significant difference of variance was recognized between groups, the Welch's test was used for comparing the mean between them.

2) Analysis of regression. Four measurements, the preanus length, head length, maximum body depth and body depth at anus, were related to the standard length, and the remaining three ones, the snout length, eye diameter and upper jaw length, were done to the head length. The regression statistics, *i. e.* the regression coefficient, intercept, and correlation coefficient, were calculated.

3) Analysis of covariance. The analysis of covariance was applied to the test for comparing each linear regression. In the first place, the analysis was done for each character of all groups. The residual variance was tested by the Bartlett's test, and the regression coefficient

and adjusted mean were done by the analysis of covariance. The next analysis was, by using the analysis of covariance, to compare these three items between each pair of groups by the characters. This analysis seems to demonstrate the differential matter of characters between each group, and it appears to outline the character showing a geographic variation and which group shows a significant difference.

4) Comparison of adjusted means. The adjusted means were compared for having knowledge on the tendency of geographic variation in each character. The characters showing no significant difference among the groups in the preceding test were excluded from this comparison. The adjusted mean was calculated on the basis of the common regression coefficient estimated from all specimens when the regression coefficient is not significantly different in the test among the groups, and when the test shows a significant difference, it was done on each regression coefficient.

5) Relationships of each group. For representing the relationships of each group, the cluster analysis was used in the present study. The standardized Euclidean distance based on the adjusted mean was adopted, because it is easy to calculate and its concept is simple to image some dimensional spaces. Finally, each group was clustered by using the single and complete linkage cluster analyses.

Results

Homogeneity of larval size of each group

Any significant difference is not recognized on both the variance ($\chi^2=16.70$, d.f.=8) and mean (F=1.40, d.f.=8, 191) of standard length among the groups. The results of the comparison between each pair of groups are shown in Table 2. Out of 36 pairs, a total of 9 ones shows a significant difference of the variance, and only four are exemplified as unequal on the mean. However, it is hard to consider these differences being as essential ones, because, as mentioned above, any significant difference is not found among the groups. Therefore, these groups are regarded as comparable, and they should be analyzed on the assumption that the larval size of each group is homogeneous.

Table 2. The test on standard length in each pair of groups in skipjack tuna larvae. The result of variance is shown in the left column, and that of mean is done in the right column. —, not significant ; *, significant at 5 % level ; * *, singgficant at 1 % level. A — I, each sample group.

	B		C		D		E		F		G		H		I	
A	—	—	* *	—	—	—	*	—	—	—	—	—	*	*	—	—
B			*	—	—	—	—	—	—	—	—	—	—	*	—	—
C					* *	—	—	—	*	—	* *	—	—	*	—	—
D							—	—	—	—	—	—	—	—	—	—
E									—	—	*	—	—	—	—	—
F											—	—	—	—	—	—
G													*	—	—	—
H															—	*

Analysis of regression

In Table 3, the regression statistics for the linear relations between the standard length or head length and each character are summarized by characters. All values of correlation coefficients are high. Therefore, each linear relation is considered to be highly significant.

Table 3. Regression statistics of each character on the standard or head length in skipjack tuna larvae. The preanus length, head length, maximum body depth and body depth at anus are related to the standard length, and the snout length, eye diameter and upper jaw length are done to the head length.

Preanus length (PL)

group	Number of specimens (NS)	Mean of SL (M. SL)	Mean of PL	Regression coefficient (b)	Intercept (a)	Correlation coefficient (r)
A	26	5.525	3.021	0.737	−1.051	0.965
B	38	5.318	2.910	0.789	−1.285	0.969
C	18	5.375	2.944	0.837	−1.555	0.953
D	32	5.143	2.815	0.767	−1.129	0.991
E	27	4.953	2.748	0.734	−0.885	0.967
F	13	5.080	2.853	0.779	−1.103	0.989
G	13	5.276	2.961	0.678	−0.617	0.987
H	21	4.776	2.673	0.842	−1.348	0.983
I	12	5.366	2.983	0.726	−0.913	0.987

Head length (HL)

group	NS	M.SL	Mean of HL	b	a	r
A	26	5.525	2.340	0.573	−0.823	0.949
B	38	5.318	2.271	0.659	−1.236	0.965
C	18	5.375	2.219	0.577	−0.884	0.934
D	32	5.143	2.179	0.581	−0.810	0.988
E	27	4.953	2.218	0.673	−1.113	0.964
F	13	5.080	2.196	0.575	−0.726	0.974
G	13	5.276	2.365	0.573	−0.658	0.991
H	21	4.776	2.121	0.649	−0.977	0.989
I	12	5.366	2.425	0.537	−0.457	0.960

Maximum body depth (MBD)

group	NS	M.SL	Mean of MBD	b	a	r
A	26	5.525	1.857	0.409	−0.400	0.914
B	38	5.318	1.855	0.442	−0.496	0.946
C	18	5.375	1.863	0.445	−0.527	0.939
D	32	5.143	1.790	0.424	−0.388	0.987
E	27	4.953	1.820	0.475	−0.533	0.926
F	13	5.080	1.830	0.420	−0.304	0.974
G	13	5.276	1.869	0.378	−0.126	0.955
H	21	4.776	1.740	0.472	−0.515	0.962
I	12	5.366	1.933	0.404	−0.234	0.952

To be continued

Table 3. Continued.

Body depth at anus (BDA)

group	NS	M.SL	Mean of BDA	b	a	r
A	26	5.525	1.298	0.343	−0.598	0.943
B	38	5.318	1.228	0.350	−0.634	0.951
C	18	5.375	1.238	0.395	−0.882	0.884
D	32	5.143	1.192	0.340	−0.555	0.963
E	27	4.953	1.207	0.305	−0.306	0.932
F	13	5.080	1.253	0.334	−0.443	0.988
G	13	5.276	1.307	0.295	−0.250	0.979
H	21	4.776	1.200	0.394	−0.684	0.971
I	12	5.366	1.329	0.323	−0.403	0.919

Snout length (SL)

group	NS	Mean of HL (M.HL)	Mean of SL	b	a	r
A	26	2.340	0.951	0.424	−0.041	0.967
B	38	2.271	0.943	0.431	−0.035	0.986
C	18	2.219	0.913	0.533	−0.269	0.966
D	32	2.179	0.876	0.428	−0.056	0.974
E	27	2.218	0.896	0.450	−0.102	0.970
F	13	2.196	0.907	0.475	−0.136	0.992
G	13	2.365	0.965	0.429	−0.049	0.979
H	21	2.121	0.873	0.397	−0.032	0.973
I	12	2.425	1.029	0.434	−0.037	0.964

Eye diameter (ED)

group	NS	M.HL	Mean of ED	b	a	r
A	26	2.340	0.728	0.262	0.115	0.972
B	38	2.271	0.681	0.259	0.093	0.975
C	18	2.219	0.691	0.204	0.239	0.881
D	32	2.179	0.696	0.270	0.109	0.981
E	27	2.218	0.688	0.231	0.177	0.971
F	13	2.196	0.696	0.261	0.123	0.976
G	13	2.365	0.726	0.273	0.081	0.981
H	21	2.121	0.657	0.303	0.015	0.982
I	12	2.425	0.700	0.251	0.092	0.930

Upper jaw length (UJL)

group	NS	M.HL	Mean of UJL	b	a	r
A	26	2.340	1.636	0.711	−0.028	0.980
B	38	2.271	1.607	0.638	0.159	0.988
C	18	2.219	1.611	0.738	−0.026	0.980
D	32	2.179	1.521	0.654	0.096	0.979
E	27	2.218	1.548	0.710	−0.027	0.979
F	13	2.196	1.550	0.670	0.080	0.982
G	13	2.365	1.657	0.664	0.079	0.986
H	21	2.121	1.502	0.622	0.183	0.975
I	12	2.425	1.691	0.578	0.290	0.956

Analysis of covariance

First, all of 9 groups are tested by the Bartlett's test for the residual variance and by the analysis of covariance for both the regression coefficient and adjusted mean. The results of these tests are represented in Table 4 by each dependent character. The Bartlett's test for comparing the residual variance shows a significant difference only in the maximum body depth and body depth at anus. It should be noted that only these two characters are vertical dimension in the measurements. The analysis of covariance for the regression coefficient among the groups indicates no significant difference with an exception of that in the eye diameter, in which it is significant at 5% level. On the other hand, the adjusted mean shows a considerable difference among groups in all but two characters, the snout length and upper jaw length. These results suggest that it is unjustifiable for 9 groups to be derived from a common origin.

The next analysis is the test for characters between each pair of groups by using the analysis of covariance. The results of this test are summarized in Table 5. As represented in Table 5, one or more significant differences are perceived between each pair of groups excepting that of the groups E and F. With an exception of the difference of residual variance, the pair of A and D and combinations of F, G, and I show a single significant difference. The former pair locates in the northwestern and equatorial western Pacific, and the latter ones locate in the southwestern and equatorial eastern Pacific. On the other hand, the pair of C and H possesses no character considered as a homogeneous. In the pairs of C-G and B-E, 6 out of 7 characters are significantly different.

The numbers of significant difference in Table 5 are counted by each character (Table 6). Only the regression coefficient of maximum body depth shows no difference in each pair. Although it is unreasonable to simply compare the scores in Table 6, the preanus length, head length, body depth at anus, and eye diameter as the dependent characters are apt to fluctuate between groups.

Comparison of adjusted means

The adjusted means of five characters excepting the snout length and upper jaw length, which show no significant difference among groups in the analysis of covariance (Table 4), are compared one another in this section. The common regression coefficients are used for charac-

Table 4. The test for comparing the residual variance (Fr), regression coefficient (Fb), and adjusted mean (Fa) among each group in skipjack tuna larvae. —, not significant ; *, significant at 5% ; **, significant at 1%.

	Preanus length	Head length	Maximum body depth	Body depth at anus	Snout length	Eye diameter	Upper jaw length
Fr	—	—	**	*	—	—	—
Fb	—	—	—	—	—	*	—
Fa	**	**	**	**	—	**	—

Table 5. The analysis of covariance of characters between each pair of groups (A - I) in skipjack tuna larvae. For Fr, Fb and Fa, see Table 4. —, not significant ; *, significant at 5 % ; * *, significant at 1 %.

		B			C			D			E			F			G			H			I		
		Fr	Fb	Fa	Fr	Fb	Fa	Fr	Fb	Fa	Fr	Fb	Fa	Fr	Fb	Fa	Fr	Fb	Fa	Fr	Fb	Fa	Fr	Fb	Fa
	1	—	—	—	—	—	—	* *	—	—	*	—	*	*	—	*	—	—	—	* *	—	* *	* *	—	—
	2	—	—	—	*	—	—	* *	—	—	*	—	* *	—	—	—	* *	—	*	* *	—	* *	—	—	*
	3	*	—	—	* *	—	—	* *	—	*	—	—	* *	*	—	*	—	—	—	* *	—	* *	*	—	*
A	4	—	—	—	—	—	—	—	—	—	*	—	* *	* *	—	*	*	—	*	* *	—	* *	—	—	—
	5	* *	—	—	—	*	—	—	—	—	—	—	—	*	—	—	—	—	—	*	—	—	—	—	—
	6	—	—	* *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	*	—	—	—	—	* *
	7	*	*	—	* *	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1				—	—	—	* *	—	—	—	—	*	—	—	*	—	*	—	*	—	* *	*	—	—
	2				—	—	—	* *	*	—	—	—	* *	—	—	—	—	—	*	* *	—	* *	—	—	*
	3				—	—	—	* *	—	—	—	—	* *	—	—	—	—	—	—	—	—	* *	—	—	—
B	4				—	—	—	—	—	—	—	—	* *	*	—	* *	—	—	* *	—	—	* *	—	—	*
	5				—	* *	—	—	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	6				—	—	*	—	—	* *	—	—	*	—	—	* *	—	—	—	—	*	—	—	—	—
	7				—	*	*	—	—	—	—	*	—	—	—	—	—	—	—	—	—	—	—	—	—
	1							—	—	—	—	—	*	—	—	* *	—	*	—	—	—	* *	—	—	—
	2							—	—	* *	—	—	* *	—	—	* *	—	—	* *	*	—	* *	—	—	* *
	3							—	—	—	*	—	* *	—	—	*	—	—	—	—	—	* *	—	—	—
C	4							—	—	—	—	—	* *	*	—	* *	—	—	*	*	—	* *	—	—	*
	5							—	*	—	—	—	—	—	—	—	—	*	—	—	* *	—	—	—	—
	6							—	*	—	—	—	—	—	—	—	—	*	—	—	* *	—	—	—	*
	7							—	—	* *	—	—	* *	—	—	—	—	—	*	—	*	*	—	*	—
	1										—	—	*	—	—	*	—	*	—	—	—	* *	—	—	—
	2										*	*	* *	—	—	—	—	—	* *	—	*	* *	—	—	* *
	3										* *	—	* *	—	—	*	* *	—	—	—	—	* *	—	—	—
D	4										—	—	* *	*	—	* *	—	—	*	—	—	* *	—	—	—
	5										—	—	—	—	—	—	—	—	—	—	—	—	—	—	*
	6										—	*	*	—	—	—	—	—	—	—	—	* *	—	—	* *
	7										—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1													—	—	—	—	—	—	—	—	—	—	—	—
	2													—	—	—	—	*	—	* *	—	—	—	*	—
	3													—	—	—	—	—	—	—	—	—	—	—	—
E	4													—	—	—	—	—	—	—	*	—	—	—	—
	5													—	—	—	—	—	—	—	—	—	—	—	—
	6													—	—	—	—	*	—	—	* *	—	—	—	* *
	7													—	—	—	—	—	—	—	—	—	—	*	—
	1																—	*	—	—	—	—	—	—	—
	2																—	—	—	* *	—	* *	—	—	—
	3																—	—	—	—	—	—	—	—	—
F	4																—	—	—	—	*	*	*	—	—
	5																—	—	—	*	—	—	—	—	—
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	7																—	—	—	—	—	—	—	—	—
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1 : Preanus length
2 : Head length
3 : Maximum body depth
4 : Body depth at anus
5 : Snout length
6 : Eye diameter
7 : Upper jaw length

ters with an exception of that in the eye diameter, in which since the regression coefficient is significantly different among groups (Table 4), the individual regression coefficient of each group is used. The adjusted means are calculated on the standard length of 5.201 mm for characters excepting the eye diameter, for which it is based on the head length of 2.249 mm. The standard length of 5.201 mm and head length of 2.249 mm are the grand mean value of both lengths for all specimens examined. The calculated adjusted means are depicted in Fig. 2 by characters of each group with their 95% confidence limits.

Table 6. The number of characters indicating a significant difference between all pairs of groups in skipjack tuna larvae, showing by each character. For Fr, Fb and Fa, see Table 4.

	Preanus length	Head length	Maximum body depth	Body depth at anus	Snout length	Eye diameter	Upper jaw length
Fr	8	11	10	9	3	1	2
Fb	6	7	0	3	6	7	6
Fa	13	19	13	20	2	13	6

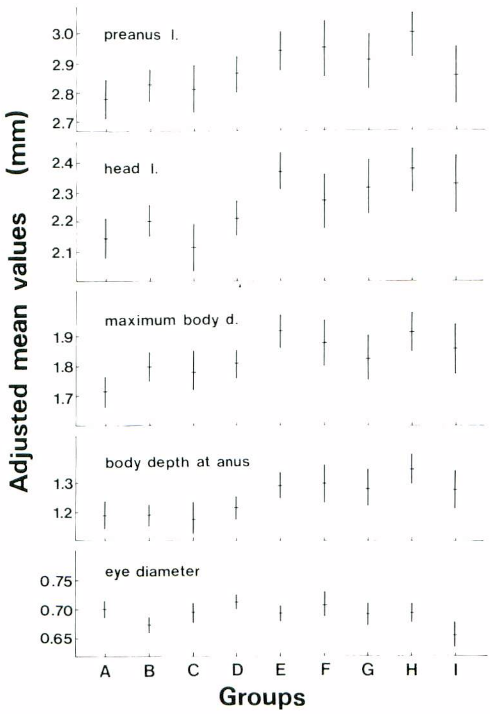

Fig. 2. Adjusted mean values in skipjack tuna larvae, with 95 % confidence limits. Preanus length, head length, maximum body depth and body depth at anus are adjusted for the standard length of 5.201 mm, and eye diameter is done for the head length of 2.249 mm.

When comparing each character between the groups in the northern and southern hemispheres, such general tendency is perceived that the values are higher in the southern hemisphere groups, E～H (E, F, G and H) than in the northern ones, A～D. Within each group of northern and southern hemispheres, the values of each character are generally apt to become higher in groups located at lower latitude. This tendency is ascertained in the preanus length and maximum body depth of the groups A, C, and D in the northern hemisphere (Fig. 2). Although this tendency is reversed in order in the other three characters between the groups A and C (Fig. 2), any significant difference is not detected between them by the analysis of covariance (Table 5). The relations of each character between the groups A and B show a tendency that the values in eastern locality, B, are higher than those in western one, A (Fig. 2). However, this tendency is indistinct in other areas, and thus it is hard to be generalized.

Relationships of each group

The standardized Euclidean distances between each pair of 9 groups are summarized in Table 7. The clustering processes, *i. e.* the results of clustering, are shown as the phenograms in Fig. 3 with the schematical drawings representing the spatial positions of each group.

Apart from the group I, two main clusters, A～D and E～H, are recognized in Fig. 3. Within the cluster composed of groups A, B, C, and D, the groups A and C constitute a subcluster, though the groups B and D are unstable on their clustering position, *i. e.* the group B makes a subcluster with the groups A and C by the single linkage clustering, but the group D does so by the complete linkage clustering. On the other hand, two subclusters are constructed by both the single and complete linkage cluster analyses within the cluster of groups E, F, G, and H, that is, E-H and F-G. On relations between the clusters A～D and E～H, the group D shows smaller distant value with the group G (4.07) or with F (4.77) (Table 7).

The clustering position of group I is unstable, *i. e.* it stands alone by the single linkage analysis, while it belongs to the cluster composed of groups E～H by the complete linkage anal-

Table 7. Triangular matrix of standardized Euclidean distances between each group (A－I) of skipjack tuna larvae. For details, see text.

	A	B	C	D	E	F	G	H	I
A	–	5.00	1.65	4.52	23.42	16.62	12.55	31.66	18.68
B		–	2.38	5.36	13.17	11.78	6.74	20.61	5.87
C			–	2.96	17.78	12.26	9.79	25.72	14.12
D				–	9.50	4.77	4.07	15.10	13.56
E					–	2.21	2.27	1.49	7.03
F						–	1.89	3.42	10.94
G							–	4.67	5.01
H								–	11.04
I									–

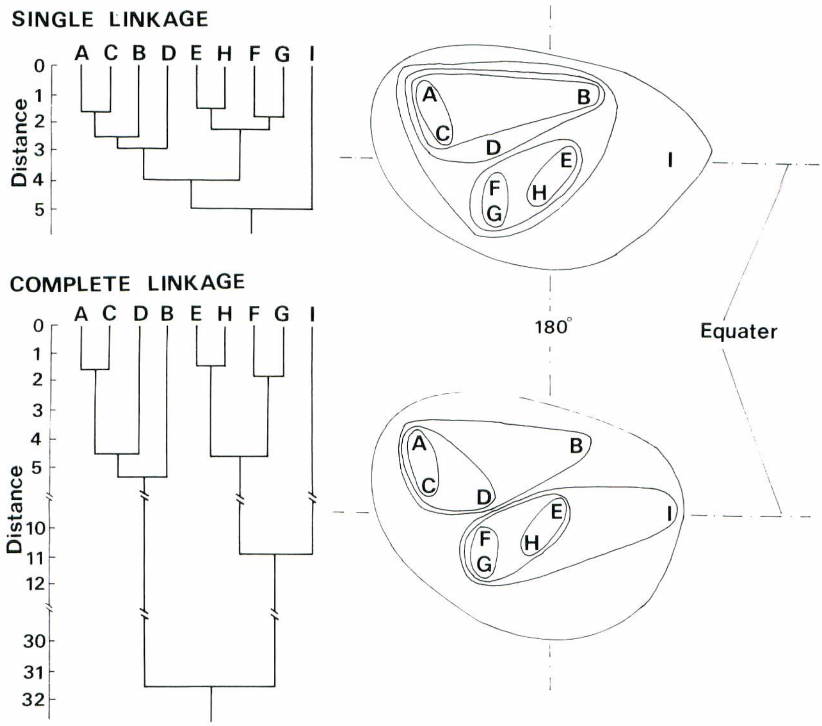

Fig. 3. Phenograms of the single and complete linkage cluster analyses on 9 groups (A-I) of skipjack tuna larvae. The spatial positions of each group are also shown.

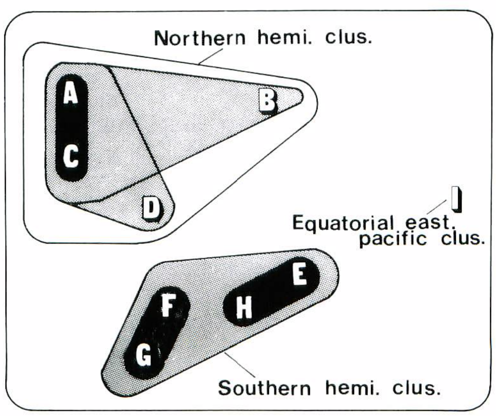

Fig. 4. Clusters of 9 grousp (A-I) of skipjack tuna larvae in the Pacific Ocean. The depth of shade connecting each group indicates the degree of relations between the groups ; the deeper it becomes, the closer the groups are related.

ysis (Fig. 3). Thus, it is difficult to decide to which the group I belongs. The smallest distant value of group I is 5.01 with the group G, and the 5.87 of group B follows.

In conclusion, three clusters are recognized to exist in the Pacific Ocean as depicted in Fig. 4, and they, especially those of the northern and southern hemispheres, appear to be separated by more or less steep clines, as far as characters examined in this study are concerned.

Discussion

The study on the population structure of the Pacific skipjack tuna has been carried out on the basis of the various adult characters (SCHAEFER, 1963 ; KAWASAKI, 1964 ; ROTHSCHILD, 1965), and FORSBERGH (1980), KASAHARA (1978), and SUDA (1971) summarized the information on the skipjack tuna population structure in the Pacific Ocean. With the development of immunological techniques, on the other hand, the genetic data have been accumulated on the species (FUJINO, 1970, 1972 ; SHARP, 1978), and FUJINO *et al.* (1981) synthesized a large amount of data on the recent immunological studies about the species.

The results of cluster analysis conducted in the present study are roughly, though not completely, in agreement with those of the previous authors referred above. This seems to suggest that the larval stages reflect a natural condition of skipjack tuna population structure measurably, and thus it is possible to say that the larval characters are by no means inferior to the adult ones with regard to an ability to test the population structure.

Of the results obtained in this study, the relationships of the western Pacific groups are especially discussed here. FUJINO (1972) recognized two groups in the western Pacific Ocean, one originates from the spawning in the northern summer, and the other from that in the northern winter. These two groups were, however, admitted to be the members of the same subpopulation, because they can interchange the genes each other through the spawning twice each year or the overlapping spawning seasons (UEYANAGI, 1970 ; NAGANUMA, 1979). The groups A and C (originated from the spawning in the northern summer) and D (from that in the northern winter) correspond to the above-mentioned two groups (Fig. 1 and Table 1), and they are grouped into a cluster as expected by the previous authors. While, although the southeastern Pacific groups, E ~H, originate from the spawning in the northern winter like as the group D, they constitute another cluster. This condition seems to point out the possibility of subgrouping of the western Pacific skipjack tuna population. In the respect noted above, it should be mentioned that RICHARDSON (1978), who recognized two subpopulations, the western and eastern ones, in the Pacific, proposed the possibility to be a third subpopulation off New Zealand based on the gene frequency. Moreover, LEWIS (1980a, b) and WANKOWSKI (1981) pointed out the existence of at least three partially mixing components, which are composed of separate spawning units, in the western Pacific. These studies are believed to support the results concluded in this study. Further information on the spawning and geographic variation during both the adult and larval stages of the western Pacific skipjack tuna has to be collected in respect to the question.

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太平洋産カツオ，*Katsuwonus pelamis* (LINNAEUS)，仔稚魚の地理的変異

河野　博・清水　誠・能勢　幸雄

摘　要

太平洋産カツオ仔稚魚(200 個体；体長，3.20～7.95 mm)の地理的変異を形態測定学に基づいて明らかにした。各形質の修正平均値は北半球のものに比べて南半球のもののほうが大きかった。各半球では一般に低緯度のものほど大きい値を示し，特にこの傾向は北西～西赤道太平洋のもので顕著にみられた。北半球では各修正平均値が西（日本近海）から東（ハワイ近海）に向かって大きくなる傾向が認められた。クラスター分析によると少なくとも 3 群（北太平洋群・南太平洋群・東部赤道海域群）の存在が認められた。さらに，北太平洋群と南太平洋群はそれぞれ 3 または 2 亜群に分けられることが示唆された。これらの結果から仔稚魚の形質は系群構造を知るうえで有益な手がかりになると判断した。