Ecology of bluefin tuna and longtail tuna in the Sea of Japan based on mathematical and physical fisheries science consideration using chi-square test, cluster analysis, and linear discriminant analysis

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Abstract

Differences between daily maximum and minimum water temperatures did not affect longtail tuna catches analyzed with the chi-square test. The optimum average water temperature of a longtail tuna catch is 25.56℃ according to AIC. From the results of a cluster analysis, barracuda and greater amberjack approached the Euclidean distance. Therefore, a cluster forms between barracuda and greater amberjack. Furthermore, the Euclidean distance between longtail tuna and this cluster (barracuda and greater amberjack) was also similar. Among feed species of longtail tuna (horse mackerel, sardine, and mackerel), horse mackerel was closest in Euclidean distance to longtail tuna. The results of a linear discriminant analysis indicate a discrimination hitting ratio of 97.2% (p=0.00) between tuna species (bluefin tuna and longtail tuna) and bullet tuna, and 56.5% (p=0.51) between bluefin tuna and longtail tuna.

1 Introduction

The most common tuna species in the Sea of Japan is bluefin tuna (*Thunnus orientalis*) [1], which are caught with set nets [2] or purse seine [3] methods. Bluefin tuna are known to spawn in the sea because larval tuna have collected in the area [4][5]. Some yearling bluefin tuna have been harvested off Hokkaido. This suggests that juvenile bluefin tuna in the Sea of Japan proceed northward to Hokkaido and then return to the same sea [6].

One of main fishing targets off the coast of Yamaguchi Prefecture in the western Sea of Japan is longtail tuna (*T. tonggol*). According to fishery statistics for the most recent three years, about 300 tons a year of tuna species have been harvested throughout the area.

Because of insufficient information on longtail tuna, misleading judgments on juvenile species of bluefin tuna caught around the coasts of Yamaguchi Prefecture in the western Sea of Japan occur very frequently. On the other hand, the most common tuna species caught in the eastern Sea of Japan is bluefin tuna.

The present study is intended to identify the ecology of bluefin tuna and longtail tuna in the Sea of Japan based on mathematical and physical fisheries science (chi-square test, cluster analysis, and linear discriminant analysis) in the following three contexts.

- Relationship between water temperature and longtail tuna caught by a set-net fishery off Futaoi Island (western Sea of Japan) using the chi-square test
- Analysis of catch size differences between longtail tuna and other commercial fish species caught with set nets off Futaoi Island using a cluster analysis
- Preliminary study on species discrimination using a linear discriminant analysis for juveniles of three species of the scombridae family in the Sea of Japan

2 Relationship between water temperature and longtail tuna caught by a set-net fishery off Futaoi Island (western Sea of Japan) using the chi-square test

2.1 Materials and methods

2.1.1 Collection of data

During the period 1995-2006, we conducted fisheries-oceanographical research simultaneously on longtail tuna through set-net operations performed by fishermen of Futaoi Island (see Fig. 1).

Water temperatures were observed at a depth of about 5 m every 30 minutes. The three types of thermometers, SBE 37 SM (Sea-Bird Electronics, USA), AT-32K and ACTW-CMP (Alec Electronics, Japan), were used during observation period.

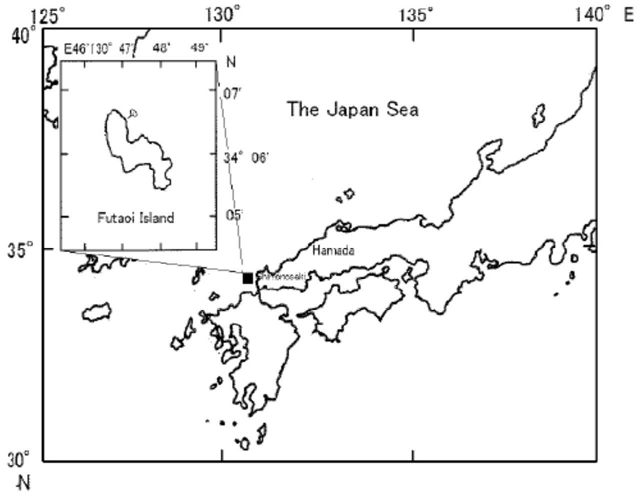

Fig.1　Set-net position off the Futaoi Island.

2.1.2 Analysis Method

First, differences between daily maximum and minimum water temperature (hereafter defined as the fluctuation range of water temperatures) were examined using the chi-square test.　Calculated with equation (1), the observed values were the frequency of days fished (sampling survey), then the expected values based on a null hypothesis were the frequency from numbers of days during the fishery period (total survey), which was from June to October, 1995-2006.

$$\chi^2 = \Sigma\ (o_i - E_i)^2 / E_i \qquad (1)$$

where　o_i= observed value,　E_i=expected value based on null hypothesis

With reference to plotting the diagram of the fluctuation range of water temperatures, numbers of classes within frequency distributions were determined from Omura [7].

Secondly, the optimum water temperature for longtail tuna catches was examined by *AIC* (AKAIKE'S INFORMATION CRITERION: An index to evaluate the aptitude for statistics model) [8]. *AIC* was calculated using average water temperatures of fished days.

$$AIC = -2(MLL - k) \qquad (2)$$

where *MLL*=maximum log-likelihood, *k*=numbers of unknown parameters

AIC(1) and *AIC*(2) were obtained with the following equations (see Appendix):

$$AIC(1) = (n/\sigma^2)[\sigma_m^2 + (\bar{x}_m - \bar{x}_0)^2] + n \cdot ln 2\pi\sigma^2 \qquad (3)$$

$$AIC(2) = n + n \cdot ln 2\pi\sigma_m^2 + 2\times 2 \qquad (4)$$

where σ^2 = population variance, σ_m^2 = sample variance of water temperature,
$\bar{x}$ = sample mean of water temperature, and $\bar{x}_0$= population mean

2.2 Results and discussion

2.2.1 The fluctuation range of water temperatures

Fig. 2 shows the frequency distribution of the fluctuation range of water temperatures on the fished day (sampling survey: see 2.2 Analysis Method). The horizontal and vertical axes represent the fluctuation range of water temperatures and fished days (171 days), respectively. The suitable number of classes for Fig. 2 verified was nine, as shown by Omura [7]. The frequency distribution was 0.4℃ relative to fluctuating water temperatures. From Fig. 2, the fluctuation range of water temperatures was from 0℃ to around 3℃. High frequencies exist below 0.8℃, and low frequencies above 2.0℃.

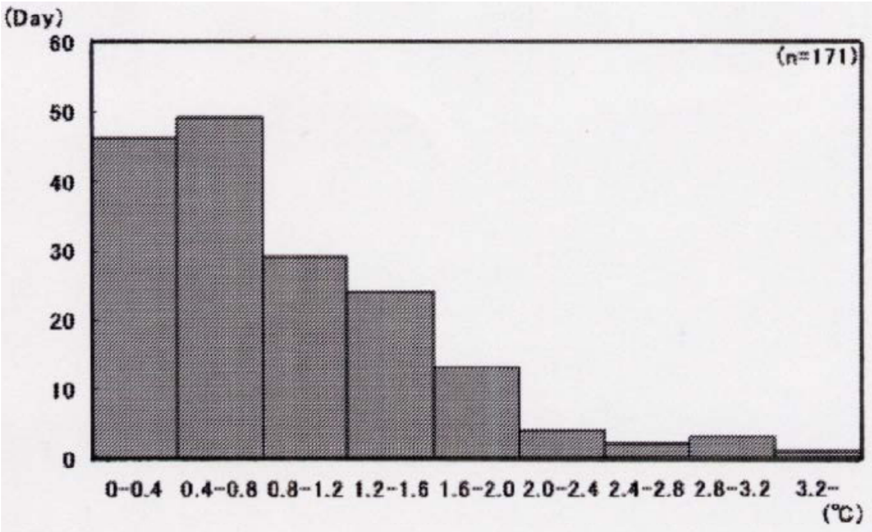

Fig.2 Frequency distribution of the fluctuation range of water temperatures on the fished day (sampling survey).

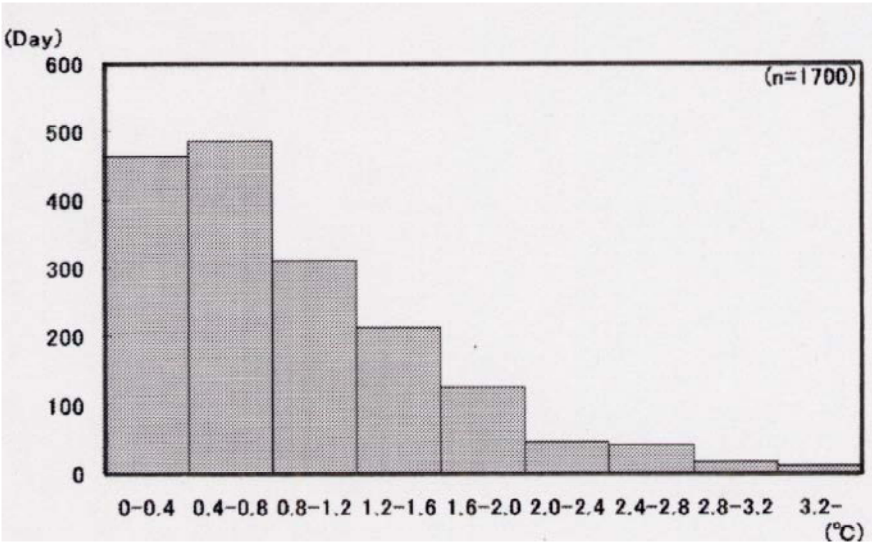

Fig. 3 Frequency distribution of fluctuating water temperatures using numbers of days in all fishery periods (total survey) .

In Fig. 3, the frequency distribution of fluctuating water temperatures is shown using numbers of days in all fishery periods (total survey: see 2.2 Analysis Method). The horizontal and vertical axes represent the fluctuation range of water temperatures and numbers of days in all fishing periods (1700 days). Fig. 3 appears to be analogous to Fig. 2 at high frequencies below 0.8℃ and low frequencies above 2.0℃.

Table 1 represents degrees of freedom, fluctuation ranges of water temperatures, observed values, and expected values (see inside parentheses). Observed total values were required to correspond to expected total values for the chi-square test. In this paper, expected values were referred to outside parentheses with the aim to being consistent with the total (171) of these two values.

Table 1 Degrees of freedom, fluctuation ranges of water temperatures, observed values and expected values.

	Range (℃)	Observed (Day)	Expected (Day)
1	0-0.4	46	46.6 (463)
2	0.4-0.8	49	48.9 (486)
3	0.8-1.2	29	31.1 (309)
4	1.2-1.6	24	21.1 (211)
5	1.6-2.0	13	12.5 (124)
6	2.0-2.4	4	4.4 (44)
	2.4-2.8	2	4.0 (40)
	2.8-3.2	3	1.4 (14)
	3.2-	1	0.9 (9)
	Total	171	171 (1700)

We examined water temperature ranges in the variable region using the chi-square test. Thus, the null hypothesis is the variable region of water temperature that does not affect the longtail tuna catch, and an alternative hypothesis is the variable region of water temperature that affects the longtail tuna catch. The calculation was performed using equation (1) and the result was χ^2 =0.58…. According to the chi-square distribution table, χ^2 is 11.07 if significance level = 0.05 and degree of freedom = 5. As the probability that a null hypothesis occurs is above 5%, this hypothesis is not rejected. Ultimately, the variable region of water temperature does not affect the longtail tuna catch.

2.2.2 Optimum water temperature of longtail tuna catch

Fig. 4 shows frequency distributions of average water temperature during the fished days. In this figure caption, σ^2= population variance, $\sigma_m{}^2$= sample variance, and $\bar{x}$ = sample mean. From this figure, average water temperature during the fished days ranged broadly from 19℃ to 31℃. From the fact that n = 171 was large enough, the authors substituted a normal distribution for the frequency distribution in Fig. 4 [7]. Optimum average water temperature was examined for longtail tuna catch using the *AIC* based on Shibata [9].

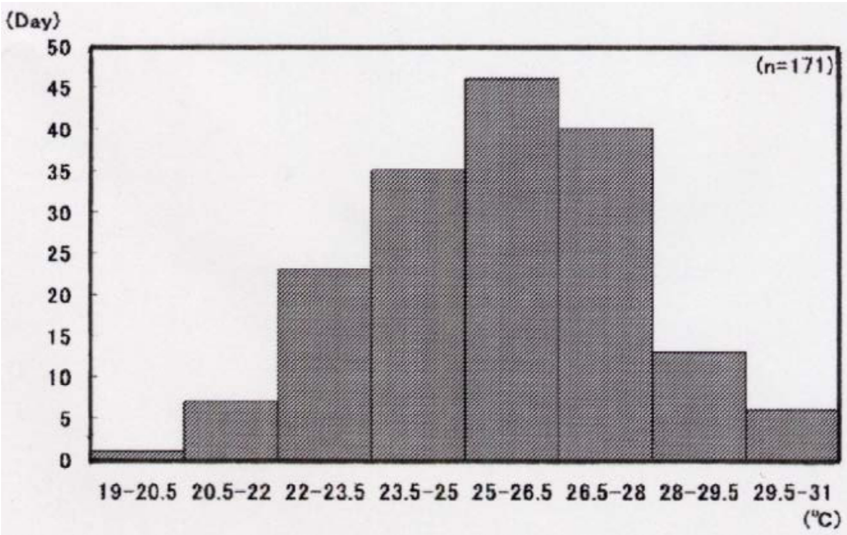

Fig. 4 Frequency distributions of average water temperature during the fished days.(σ^2=4.57⋯, σ_m^2=4.55⋯, $\bar{x}$ =25.56⋯)

In this paper, population = average represents water temperatures during the fishery days, *AIC*(1) is 24℃(according to Mohri *et al*. [10]) and *AIC*(2) is 25.56℃ (sample mean). The result is that the optimum average water temperature for longtail tuna catch was 24 ℃ from *AIC*(1) < *AIC*(2) or 25.56 ℃ from *AIC*(1) > *AIC*(2).

In the case of n = 171, σ^2 = 4.57, σ_m^2 = 4.55, $\bar{x}$ = 25.56 and $\bar{x}_0$= 24.5, the results of equations (3) and (4) were *AIC*(1) = 786.40 and *AIC*(2) = 748.35, respectively. The optimum average water temperature for longtail tuna catch was 25.56℃ from *AIC*(1) > *AIC*(2).

2.3 Conclusion

Because the longtail tuna catch is affected greatly by oceanographic environments (oxygen, salinity, etc.), further study is required using oceanographic observations and fisheries data on longtail tuna. The present study is very helpful for supporting the utilization, conservation, and management of longtail tuna resources.

3 Analysis of catch size differences between longtail tuna and other commercial fish species caught with set nets off Futaoi Island using a cluster analysis

3.1 Materials and methods

3.1.1 Materials

The Futaoi Island branch office of the Fisheries Cooperative Association of Yamaguchi Prefecture recorded the data on adult longtail tuna caught with set nets during the period from 1998 to 2008. We used this daily catch data for our calculations. The top ten commercially fished species during the longtail tuna fishing season were chosen for this study.

3.1.2 Items analyzed

We analyzed the following items.

First, we calculated the T-score for yearly and monthly catches of longtail tuna and other commercial fish species, and the relationship was examined by using cluster analysis. The reason why we calculated the T-score was as follows:

With set- net fishing, several longtail tuna are caught in the same nets with many other commercial fish species. In this situation, we could not calculate the Euclidean distance necessary for cluster analysis. So we used the monthly T-score to effectively perform this analysis.

3.1.3 Cluster analysis

Cluster analysis includes several methods. So we comparatively examined the four following methods of analysis [11].

1. Shortest distance method

Among objects belonging to two clusters, this method defines the distance between the nearest objects as the cluster distance.

2. Longest distance method

Among objects belonging to two clusters, this method defines the distance between the farthest objects as the cluster distance.

3. Group average method

Distances of all combinations of objects belonging to two clusters are examined. Subsequently, the average distance is defined as the cluster distance.

4. Barycentre method

The barycentre, or centre of mass, is set as the measurement point for the cluster. The cluster distance is defined as the distance between these barycentric points.

Of the four methods stated above, the group average method is used by field of biology because of its effectiveness when variables within the group are clear. Related dendrograms have a high level of consistency and results are easy to interpret.

In this study, we used the group average method. Using this method, we were able to examine the fishing season and diet of the subject fish species, even when schools of different species were mixed with each other. Furthermore, using early results for clusters distances (Euclidean distance) we were able to determine the composition of the diet of longtail tuna. Euclidean distances were obtained with the following equation [11]:

$$d_{ij} = \sqrt{(x_{i1} - x_{j1})^2 + (x_{i2} - x_{j2})^2} \tag{5}$$

where x_{i1} = number of the T-score catches for monthly fish species i of the first calculation target, x_{i2} = number of the T-score catches for monthly fish species i of the second calculation target, x_{j1} = number of the T-score catches for monthly fish species j of the first calculation target, x_{i2} = number of the T-score catches for monthly fish species j of the second calculation target, (x_{i1}, x_{i2}) = i -th data and (x_{j1}, x_{j2}) = j -th data.

In group average method, the degree of dissimilarity d_{XY} (Euclidean distance) is computed from the combined cluster x and combined cluster y [12]:

$$d_{XY} = \frac{1}{n_X n_Y} \sum_{i \in Cx} \sum_{j \in Cy} d_{ij} \tag{6}$$

where C_X = cluster x, C_Y = cluster y, n_X = number of objects belonging to C_X, n_Y = number of objects belonging to C_Y, $i \in C_X$ = object i belonging to C_X, $j \in C_Y$ = object j belonging to C_Y, d_{ij} = the degree of dissimilarity computed from the object i and object j.

3.1.4 Process of cluster analysis

First, we measured the distance between each target, and obtained the distance for a case combining a cluster. All distances between individual targets were calculated, and we decided the first cluster based on the smallest distance between targets. We calculated all the distances between a cluster and newly formed targets, and combined the smallest distance between targets. The process explained above was continued until all clusters were combined.

Second, we drew a dendrogram to show the processes for combined clusters, and divided it into groups by cutting it at a suitable distance. We examined the target that included each group and identified the characteristics of groups.

3.2 Results

Table 2 gives the matrix of Euclidean distances among fish species from data provided from 1998 to 2008. In this table, we selected the top ten commercially fished species (horse mackerel, sardine etc. (sardine, anchovy and red-eye round herring), barracuda, greater amberjack, mackerel, J.S.mackerel (Japanese Spanish mackerel), longtail tuna, yellowtail amberjack, Japanese amberjack, juvenile b. tuna (juvenile bluefin tuna)) with a fishing season coinciding with longtail tuna [13]. Among longtail tuna and the species they feed on (horse mackerel, sardine and mackerel), it was horse mackerel that had a Euclidean distance (30.685) nearest to longtail tuna.

Table 2 Matrix of Euclidean distance among fish species.

	horse mackerel	sardine etc.	barracuda	greater amberjac	mackerel	J.S. mackerel	longtail tuna	amberjack	amberjack	juvenile b. tuna
horse mackerel	0.000	51.803	42.281	41.159	55.985	54.794	30.685	35.685	50.459	48.972
sardine etc.	51.803	0.000	52.821	53.568	55.589	55.626	54.430	48.203	44.848	48.482
barracuda	42.281	52.821	0.000	4.883	45.705	39.260	17.575	26.893	54.603	47.127
greater amberjack	41.159	53.568	4.883	0.000	47.336	40.800	16.734	26.705	54.023	46.969
mackerel	55.985	55.589	45.705	47.336	0.000	24.401	51.048	51.396	54.632	47.371
J.S.mackerel	54.794	55.626	39.260	40.800	24.401	0.000	45.661	51.432	56.331	31.237
longtail tuna	30.685	54.430	17.575	16.734	51.048	45.661	0.000	20.460	54.595	47.649
yellowtail amberjack	35.685	48.203	26.893	26.705	51.396	51.432	20.460	0.000	56.723	51.738
Japanese amberjack	50.459	44.848	54.603	54.023	54.632	56.331	54.595	56.723	0.000	52.544
juvenile b. tuna	48.972	48.482	47.127	46.969	47.371	31.237	47.649	51.738	52.544	0.000

Fig. 5 shows the tree diagram of Euclidean distances among fish species (1998-2008). The horizontal and vertical axes represent the fish species and distances. From this figure, we can determine that barracuda and greater amberjack are close in Euclidean distance. So a cluster is formed between these two species. Furthermore, this cluster (barracuda and greater amberjack) and longtail tuna are also close in Euclidean distance.

Accordingly, a cluster is formed between barracuda, greater amberjack and longtail tuna. Similarly, further clusters are later formed among other fish species with a close Euclidean distance.

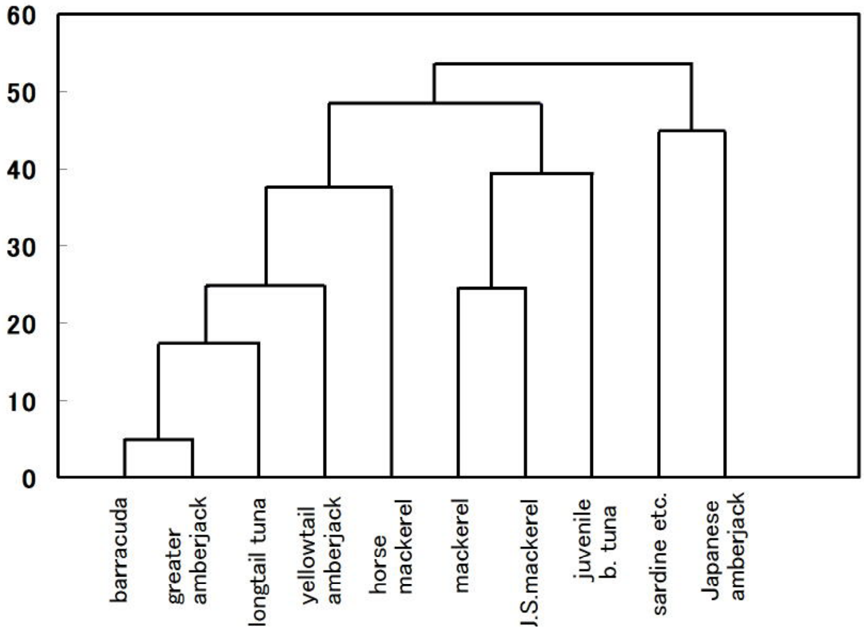

Fig. 5　Tree diagram of Euclidean distance among fish species (1998-2008).

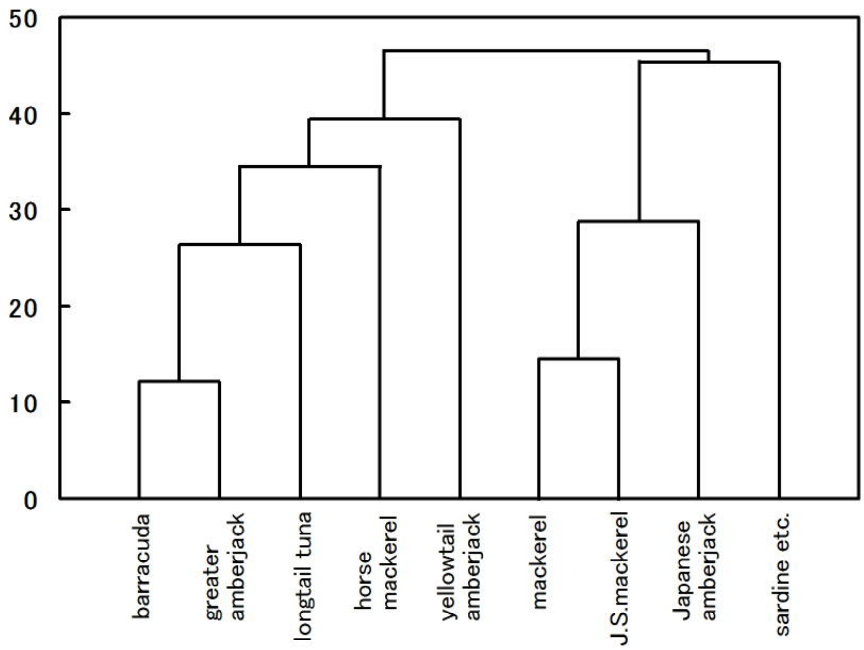

Fig. 6　Tree diagram of Euclidean distance among fish species (2003).

Fig. 6, 7 and 8 represent the tree diagrams of Euclidean distance among fish species in 2003, 2004 and 2005 (years when the recorded water temperature did not vary greatly from the average [14]) respectively. From these figures, we can determine the fish species of barracuda, greater amberjack and longtail tuna were close in Euclidean distance.

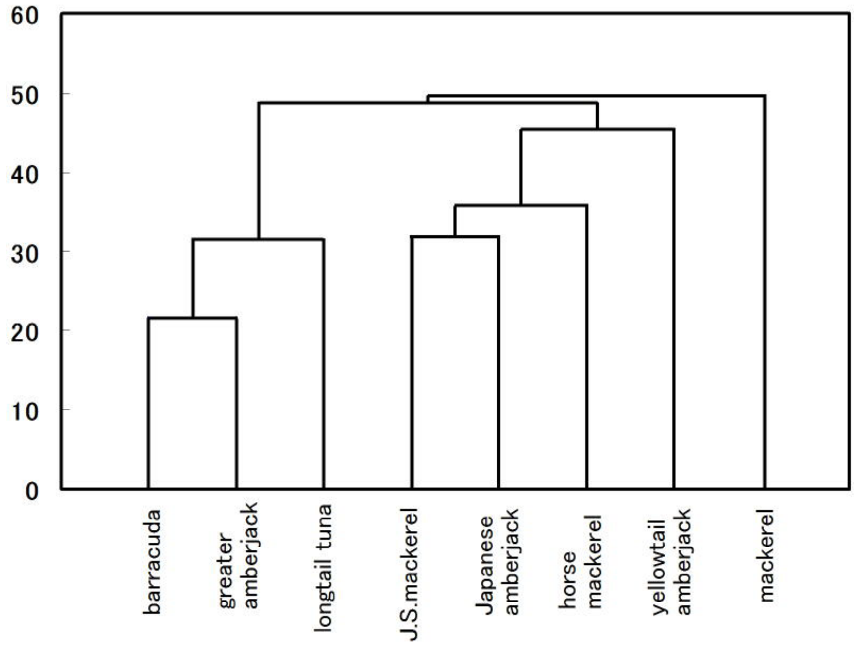

Fig. 7　Tree diagram of Euclidean distance among fish species (2004).

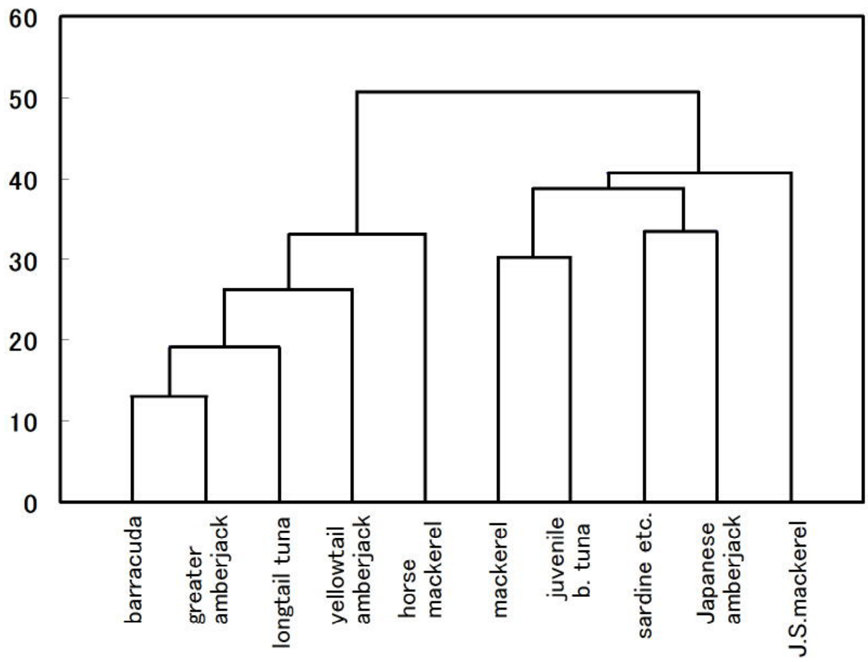

Fig. 8　Tree diagram of Euclidean distance among fish species (2005).

Fig.9 is the tree diagram of Euclidean distance among fish species in 2007 (the year when recorded water temperatures were significantly warmer than average [14]). Looking at this tree diagram, we can see the cluster of barracuda and greater amberjack were far from longtail tuna in Euclidean distance.

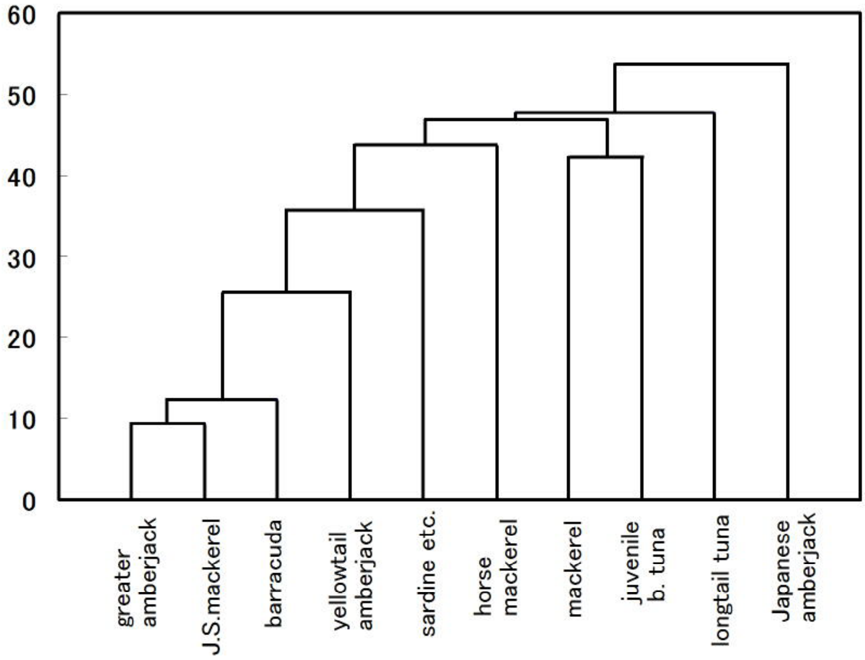

Fig. 9 Tree diagram of Euclidean distance among fish species (2007).

3.3 Conclusion

From the tree diagram of Euclidean distance among fish species (1998-2008), we determined that barracuda and greater amberjack were close in Euclidean distance. Therefore, a cluster is formed between them. Furthermore, this cluster (barracuda and greater amberjack) and longtail tuna are close in Euclidean distance. So we concluded that the main fishing season (from July to September) of these three fish species was close. This quantitative result differed from a qualitative study by Mohri *et al*. [14] (determining that the fish species of barracuda, yellowtail amberjack and longtail tuna were qualitatively close in distance).

Regarding the relationship between longtail tuna and the fish species they feed on (horse mackerel, sardine and mackerel), it was horse mackerel that had the Euclidean distance nearest to longtail tuna. This quantitative result was the same as the qualitative study by Mohri *et al*. [14]

The cluster of barracuda and greater amberjack were far from longtail tuna in Euclidean distance in 2007. Because 2007 was an unusual year of particularly high recorded water temperatures, the main fishing season of longtail tuna was different from usual years, occurring in the later months of September and October.

3.4 Future prospects for study

In this study, we examined the "monthly catch relationship between longtail tuna and other commercial fish species" by cluster analysis only using the number of fish caught. As a result, this relationship in 2007 (the year of significantly higher than average recorded water temperatures) differed from standard years. In future, we need to study the relationship between longtail tuna and other commercial fish species after consideration of other additional factors such as water temperature.

4 Preliminary study on species discrimination using a linear discriminant analysis for juveniles of three species of the scombridae family in the Sea of Japan

4.1 Materials and methods

4.1.1 Parts of samples measured

This study used Pacific bluefin tuna (n=16, cultured in Fisheries Laboratory, Kinki University), longtail (n=8), and bullet (n=13) tuna, which were collected in August, 2012 onboard the training ship Tenyo Maru belonging to the National Fisheries University in the western Sea of Japan. Juvenile longtail and bullet tuna identified with a DNA analysis were adopted. Parts measured of juvenile Pacific bluefin and longtail tuna of more than 17 cm [15] in length were fork length (A-E), head length (A-B), and length of pectoral fin (C-D) (Fig.10).

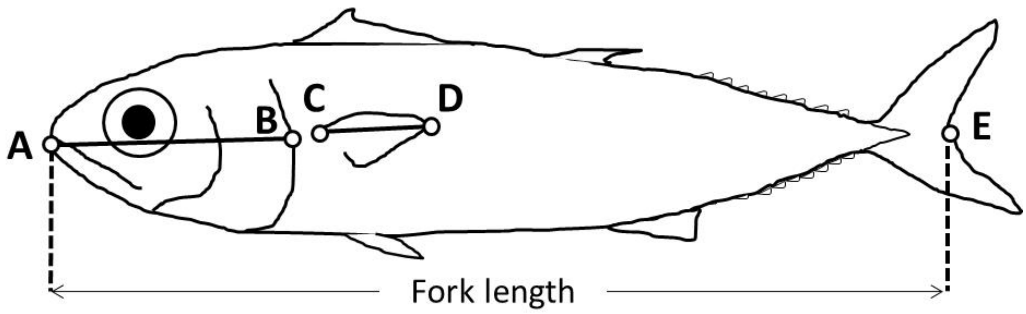

Fig. 10 Measured parts of specimens.
A-E: Fork length. A-B: Head length. C-D: Length of pectral fin.

4.1.2 Analysis

A linear discriminant function (LDF) was used to make judgments on species. LDF was obtained based on a linear equation of variable －x 1 , x2, …xp － (equation of the first degree). Discriminant was calculated with the following equation.

$$y= a1x1+a2x2+\cdot\cdot\cdot\cdot+apxp+b \qquad (7)$$

(y: objective variable, xp: explanatory variable, ap: discriminant coefficient, b: constant term).

The discriminant score was calculated using LDF with the value (standardized C-D / A-E and C-D / A-B) of tuna species (bluefin and longtail tuna) vs. bullet tuna and bluefin vs. longtail tuna. Furthermore, C-D / A-E and C-D / A-B were described on a histogram and form differences were examined.

4.2 Results

4.2.1 Judgment on species using discriminant analyses

When judging species using LDF with the value of tuna species (bluefin and longtail tuna) vs. bullet tuna, the discriminant hit percentage was 97.2% (Fig.11). The discriminant equation was obtained with the following:

$$y=-30.4CD/AB^{**} +285.8CD/AE^{**}-18.0 \qquad (8)$$

(p=0. 00 ** p<0. 01)

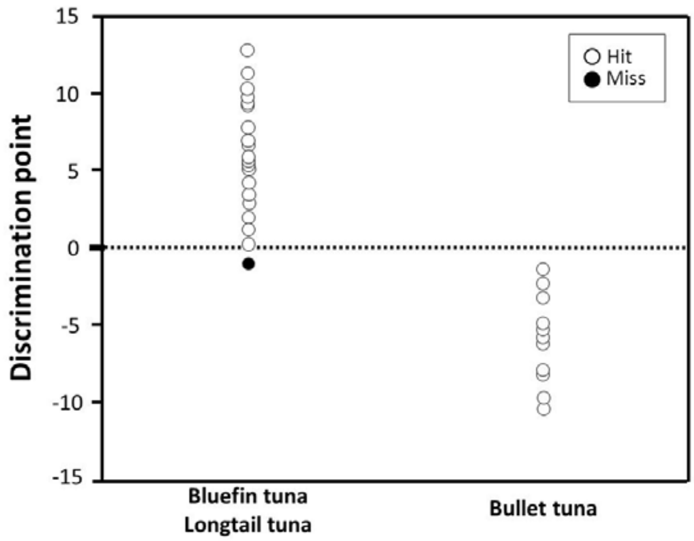

Fig. 11 Discrimination points among bluefin tuna, longtail tuna, and bullet tuna.

The distinction hit percentage of bluefin vs. longtail tuna was 56.5% (Fig.12).

(p=0. 51)

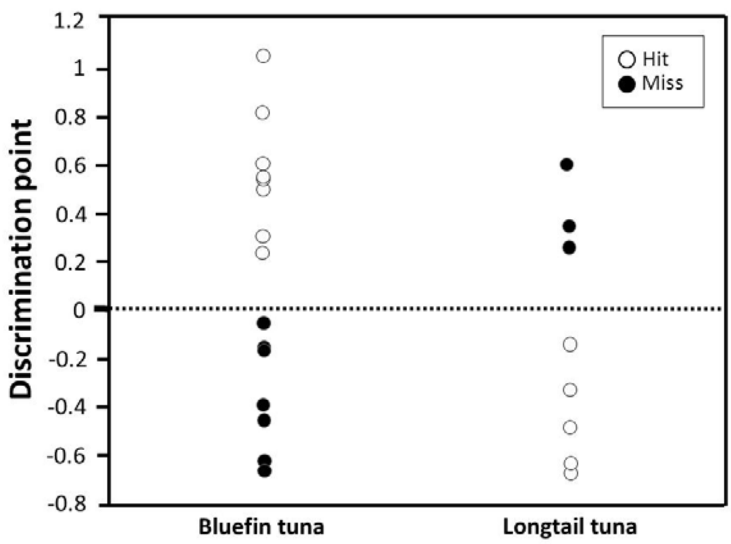

Fig. 12 Discrimination points between bluefin tuna and longtail tuna.

4.2.2 Analysis of form measurements

In the frequency distribution of values that standardized C-D / A-E, clear differences were found in bluefin vs. bullet tuna (Steel-Dwass p=0.00) and longtail vs. bullet tuna (Steel-Dwass p=0.00). There was no significant statistical difference between longtail and bluefin tuna (Steel-Dwass p=0.96) (Fig.13).

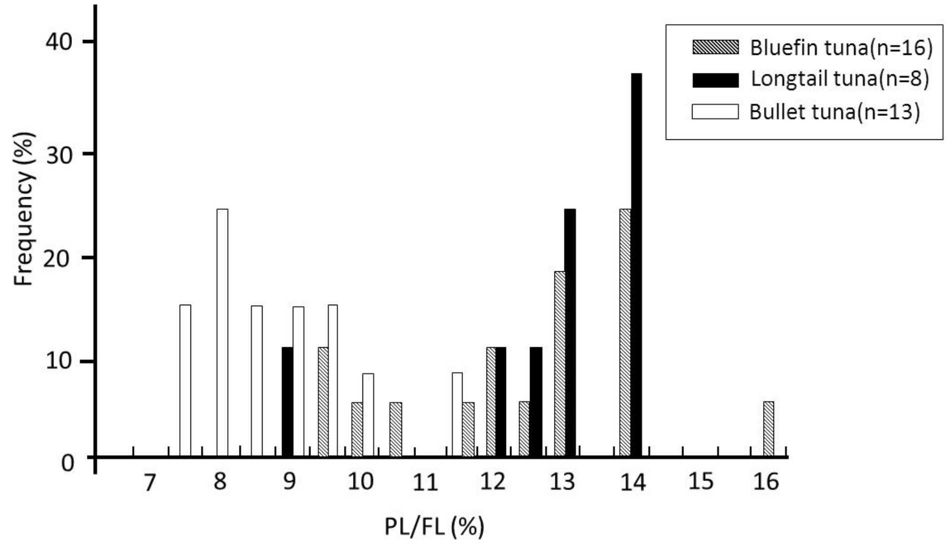

Fig. 13 Frequency distribution of ratio of length of pectoral fin (C-D) / fork length (A-E) .

On the other hand, in the frequency distribution of values that standardized C-D / A-B, small differences in bluefin vs. bullet tuna (Steel-Dwass p=0.02) and longtail vs. bullet tuna (Steel-Dwass p=0.04) were found. There was no significant statistical difference between longtail and bluefin tuna (Steel-Dwass p=0.77) (Fig.14).

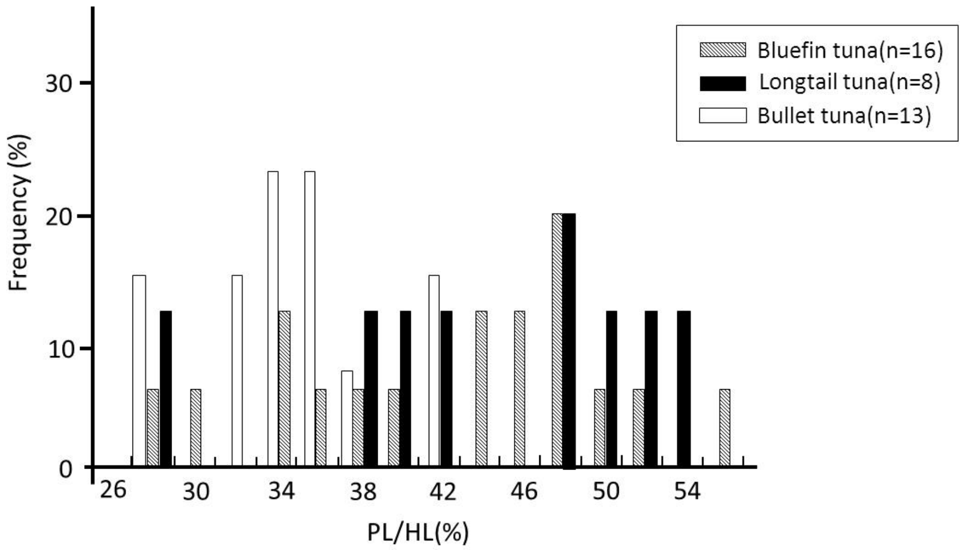

Fig. 14 Frequency distribution of ratio of length of pectoral fin (C-D) / head length (A-B) .

4.3 Consideration

In this study, LDF was used to make judgments on bluefin, longtail, and bullet tuna collected in the western Sea of Japan. As a result, clear differences were displayed between tuna species (bluefin and longtail tuna) and bullet tuna. Therefore, LDF can be used with the values (standardized C-D / A-E and C-D / A-B) when collecting small numbers of tuna species from among most of the bullet tuna individuals.

On the other hand, because there were no differences in the lengths of pectoral fins between longtail and bluefin tuna individuals (below 17 cm) used in this study, a significant statistical difference could not be found between the two species. In the future, the following three points need to be clarified: i) relation between lengths of pectoral fin and sizes of individual bluefin and longtail tuna; ii) judgment on species using form measurements except length of pectoral fin; and, iii) extracting the most suitable part for form measurements and identifying the influence on discriminant score.

Next, differences among parts for form measurements affecting the results of discriminant analyses are considered. As shown in Fig. 15, eight parts were chosen for form measurements. Each part/fork length was calculated for the discriminant analyses.

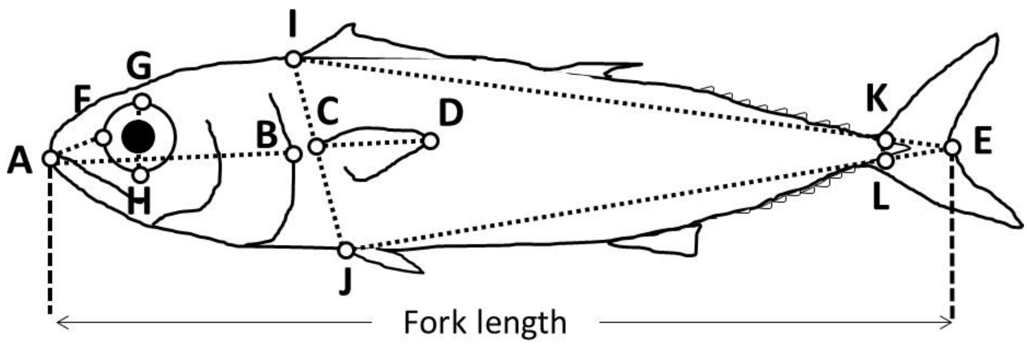

Fig. 15 Reconsideration of measured parts of specimens.
A-E: Fork length. A-B: Head length. C-D: Length of pectoral fin. A-F: Snout length. I-J: Body height. G-H: Eye diameter. I-E: Length of basal part of dorsal fin to part of fork. J-E: Length of basal part of pelvic fin to part of fork. K-L: Depth of caudal peduncle.

From the discriminant score percentage of 91.3% between bluefin and longtail tuna using the above eight parts (Fig.16), the following equation was obtained.

$$y=-92.4AB/AE+227.0AF/AE-215.8IJ/AE^{**}-61.525GH/AE+70.2CD/AE$$
$$+79.3IE/AE-129.8JE/AE^{*}+252.0KL/AE+80.1 \qquad (9)$$

(p=0.02　**p<0.01 *p<0.05)

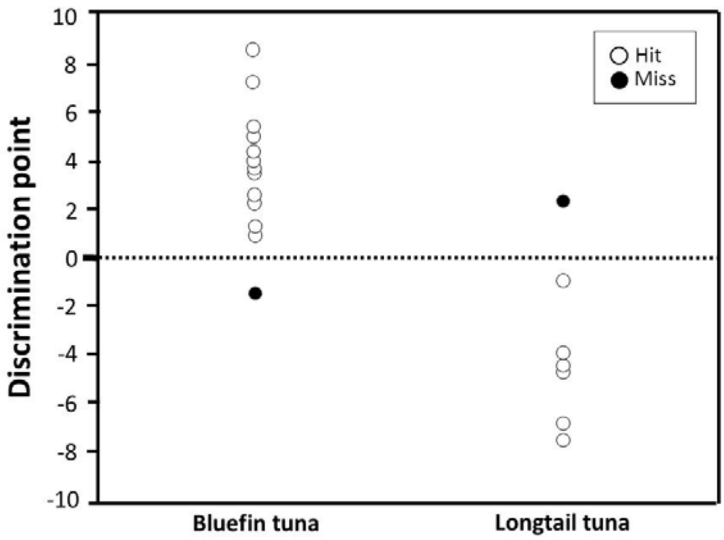

Fig. 16　Discrimination points between bluefin tuna and longtail tuna.

Form measurements were examined using a frequency distribution calculating I-J / A-E (p=0.00) and J-E / A-E (p=0.03) with this equation, and clear differences in I-J / A-E (Mann Whitney' s U, p=0.00) (Fig. 17) were found. Therefore, suitable parts can be extracted for form measurements from among many parts using a discriminant analysis and characteristics of forms regarding each species can be identified.

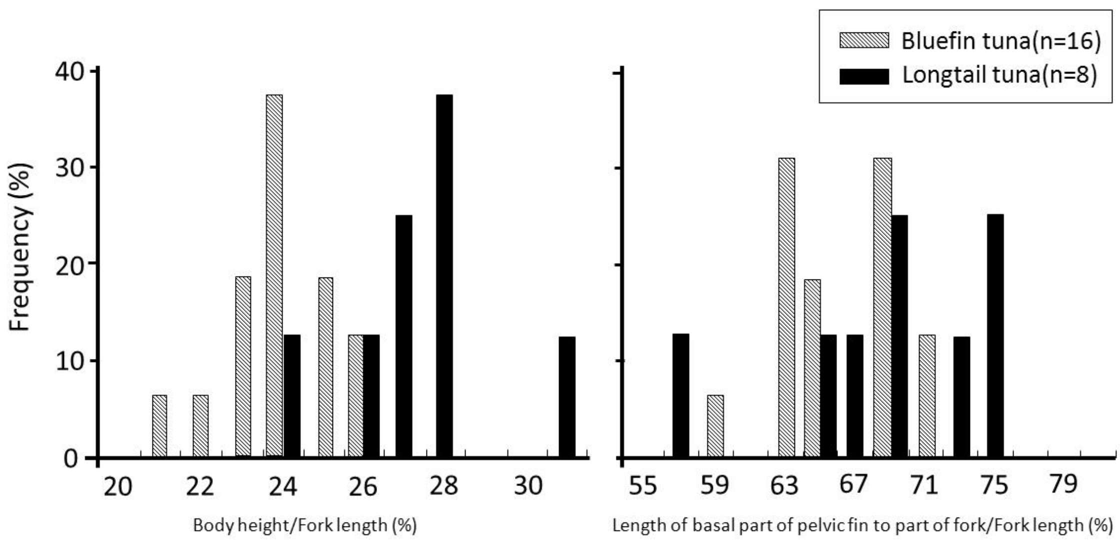

Fig. 17　Frequency distribution of ratio of body length (I-J) / fork length and length of basal part of pelvic fin to part of fork (J-E) / fork length.

This study, found that LDF could be used to make judgments about bluefin, longtail, and bullet tuna when small numbers of tuna species were collected from among many other individuals.

LDF calculated using data from samples was clearly supported by DNA analyses. In the future, the hit rate needs to be obtained with the calculation method in this study for judgments on other samples and to show the effectiveness of LDF quantitatively. The discriminant score was calculated using LDF with the value (standardized C-D / A-E and C-D / A-B). However, these values may change with juvenile fish and immature adult individuals. Therefore, a decision needs to be made on parts for form measurements from growth stage differences among bluefin, longtail, and bullet tuna.

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