Cluster analysis of differences in catch size between juvenile Pacific bluefin tuna and other commercially fished species taken by surface-and-mid water trawl net fishing in western Sea of Japan

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Abstract

Differences in catch sizes between juvenile Pacific bluefin tuna and other commercially fished species taken by surface-and-mid water trawl net fishing in the western Sea of Japan are examined using a cluster analysis. The results show that the Euclidean distances of silver driftfish and Japanese common squid are similar. Consequently, a cluster is formed of these two species. Furthermore, the Euclidean distances of juvenile Pacific bluefin tuna and this cluster (silver driftfish and Japanese common squid) are also similar. Accordingly, a cluster is formed of silver driftfish, Japanese common squid and juvenile Pacific bluefin tuna.

1 Introduction

Eight tuna species of Thunnini are distributed in the western Pacific Ocean [1]. Many of the tuna species are also found in the Sea of Japan along the Tsushima warm current, with the sea marking the northern-most edge of the distribution areas. In particular, Pacific bluefin tuna, *Thunnus orentalis*, is the most important fisheries species, and it is fished with various gears including purse seine, trawling, set net, and longline. Concerns about the relationship between water temperature and tuna catch prompted studies on Pacific bluefin tuna [2]-[5]. It is known that Pacific bluefin tuna spawn in the Sea of Japan based on the frequent occurrence of larvae [6][7] and catches of mature fish[8]-[10].

Recently, Abe *et al*. [11] and Mohri *et al*. [12] studied larval and adult Pacific bluefin tuna, respectively. However, there is little information on recruitment environments because of difficulties involved in surveying catches of juvenile Pacific bluefin tuna. Consequently, surface-and-mid water trawl-net operations were conducted by the National Research Institute of Far Seas Fisheries, Fisheries Research agency from August to September in 1999 to study the distribution of Pacific bluefin tuna juveniles in the Sea of Japan. Research on differences among species is back-breaking at the juvenile stage of Pacific bluefin tuna due to tiny morphological differences between each species. Chow and Inoue [13] have provided diagnostic DNA markers for identifying Thunnini species. DNA analysis was useful for identifying the species of samples of small Thunnini juveniles.

Mohri *et al*. [14] examined "Biodiversity as observed from catch size differences between longtail tuna and other commercial fish species with a set net off Futaoi Island (western sea of Japan)." However, this study did not sufficiently examine the objective relationship between longtail tuna and other commercial fish species. The present study identifies inter-specific relationships between juvenile Pacific bluefin tuna and other commercially fished species based on mathematical and physical fisheries science. The authors selected the cluster analysis because it was considered to be best means of providing suitable results for mathematical and physical fisheries science.

2 Materials and methods

2.1 Materials

Fig.1 shows 42 points where juvenile Pacific bluefin tuna were tried to catch in the western Japan Sea. The period of the examination was from August 13 to September 6, 1999. We made oceanographic observations with a conductivity-temperature-depth device (CTD), and examined areas between 35° 30′ N-131° E off Yamaguchi Prefecture and 39° N-139° E off northern Sadogashima Island in Niigata Prefecture.

The trawl was 89.1 m long; its net mouth was 30.0 mm in diameter; and, its mesh size at the cod end was 17.5 mm. We conducted a surface-layer tow with the top of the net at the sea surface for one hour. We also conducted a two-layers tow with the top of the net at a depth of 30 m for 30 minutes, followed by a surface-layer tow for 30 minutes. Seventeen points were examined with the surface-layer tow and 25 points with the two-layers tow. These points are divided into latticed circles per latitudinal and longitudinal 30 minutes in Fig.1.

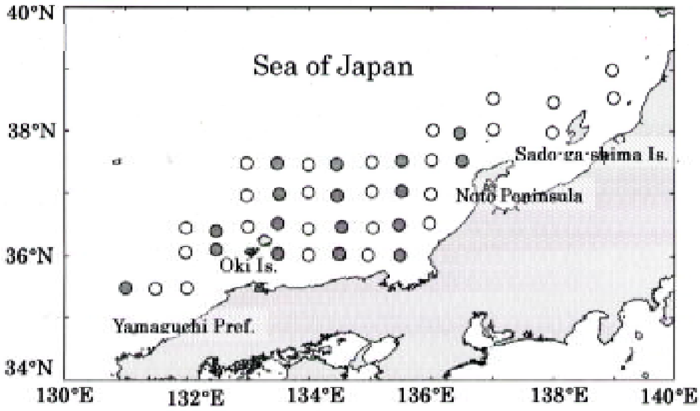

Fig.1 42 tow points in 1999, with gray circles representing surface-layer tow and open circles two-layers tow.

Fig.2 depicts the two towing methods: surface-layer tow at a depth of 0-30 m and two-layers tow at a depth of 0-60m. We confirmed the depth of the towing net with two water depthmeters (SBT-500, Murayama Denki Ltd. in Japan) set at the top and the bottom of the net, respectively. Towing survey was conducted at night by Shunyo-maru, a research vessel (396 tons) of the National Research Institute of Far Seas Fisheries of the Fisheries Agency of Japan, and the vessel speed was maintained constant at 5 knots over the entire sampling period.

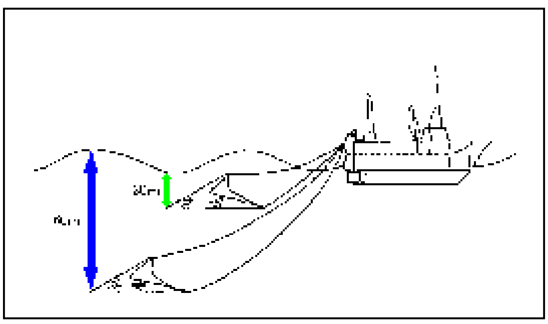

Fig.2 Schematic diagram of towing depth range.

2.2 Items analyzed

We analyzed the following items after *et al*. [15]. Data were from 42 tow points, because 30-60 tow had no catches during mid-water trawl net fishing in 2004 from the Seventh Kaiyou-maru (499 tons) belonging to Japan Ocean Company, which was chartered by the Far Seas Fisheries Research Laboratory. Mohri *et al*. [15] analyzed catch size differences between adult longtail tuna and other commercial fish species taken by set-net fishing from 1998 to 2008 off Futaoi Island (Yamaguchi Pref.) using a cluster analysis. On the other hand, this study examined differences in catch size between juvenile Pacific bluefin tuna and other commercially fished species taken by surface-and-mid water trawl net fishing in 1999 from Yamaguchi Pref. to Niigata Pref. (western Sea of Japan).

First, we calculated the T-score (= (score - average)・10 / standard deviation + 50) for catches of juvenile Pacific bluefin tuna and other commercial species. The relationship was examined using a cluster analysis. The reason why we calculated the T-score is as follows:

With surface-and-mid water trawl-net fishing, several juvenile Pacific bluefin tuna are caught in the same nets with many other commercially fished species. In this case, we could not calculate the Euclidean distance necessary for the cluster analysis. Therefore we used the T-score to perform this analysis effectively.

2.3 Cluster analysis

There are several methods of performing a cluster analysis. We comparatively examined the following four analytical methods [16].

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 described above, the group average method is used in the field of biology because of its effectiveness when variables within a 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 mingled 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 [16]:

$$d_{ij} = \sqrt{(x_{i1} - x_{j1})^2 + (x_{i2} - x_{j2})^2} \quad (1)$$

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

Using the group average method, the degree of dissimilarity d_{XY} (Euclidean distance) is computed from the combined cluster x and combined cluster y [17]:

$$d_{XY} = \frac{1}{n_X n_Y} \sum_{i \in Cx} \sum_{j \in Cy} d_{ij} \quad (2)$$

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} = degree of dissimilarity computed from object i and object j.

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 shortest distance between targets. We calculated all distances between a cluster and newly formed targets, and combined the shortest 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 Results and discussions

The area for collecting juvenile Pacific bluefin tuna in 1999 ranged from western Oki-shoto Islands (36° N-132° 30′ E) to Sadogashima Island (39° N-139° E). Fig.3 shows points where the tunas were caught by surface-layer tow and two-layers tow. Of 17 surface-layer tows, 12 collected juvenile Pacific bluefin tuna; and of 25 two-layers tows, six collected the same species.

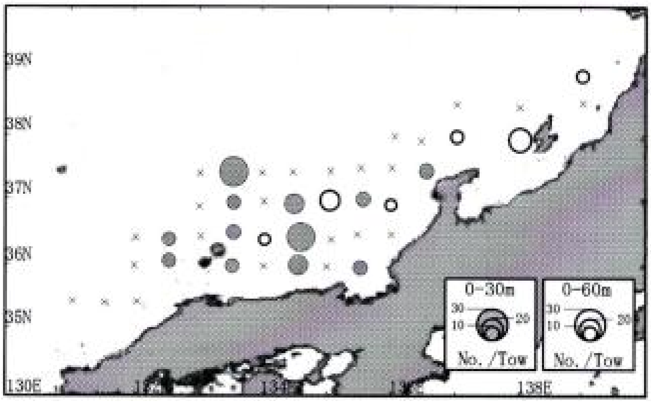

Fig. 3 Distributions of juvenile Pacific bluefin tuna in 1999, with gray circles representing surface-layer tow and open circles two-layers tow.

Table 1 Fork lengths and numbers of individuals in 1999.

fork length (mm, FL)	number of individuals: surface layer tow (Aug.28-Sep.6)	number of individuals: two layers tow (Aug.16-Aug.27)
FL≦50		3
50＜FL≦100		13
100＜FL≦150	26	34
150＜FL≦200	57	1
200＜FL≦250	12	
250＜FL≦300		
incapable of measuring	9	6
Total	104	57
minimum (mm)	108 (Sep. 4)	47 (Aug. 16)
maximum (mm)	216 (Sep. 5)	155 (Aug. 27)

Table 2 Matrix of Euclidean distances among species.

	j.u. bluefin tuna	common squid	jack mackerel	chub mackerel	bullet tuna	Jap. scad	Jap. anchovy	black scraper	silver driftfish	Jap. sardine
ju. bluefin tuna	0	42.9	66.5	64.2	50.3	67.7	44.4	68.6	48.2	69.0
Jap. common squid	42.9	0	62.2	62.3	44.8	66.9	42.8	53.6	29.2	65.0
Jap. jack mackerel	66.5	62.2	0	51.8	64.0	63.5	62.6	62.7	63.6	37.4
chub mackerel	64.2	62.3	51.8	0.0	61.4	65.1	58.6	54.3	64.8	48.9
bullet tuna	50.3	44.8	64.0	61.4	0	65.1	33.7	58.8	50.6	64.4
Jap. scad	67.7	66.9	63.5	65.1	65.1	0	63.8	57.6	60.5	62.6
Jap. anchovy	44.4	42.8	62.6	58.6	33.7	63.8	0	63.0	50.5	62.2
black scraper	68.6	53.6	62.7	54.3	58.8	57.6	63.0	0	64.5	56.3
silver driftfish	48.2	29.2	63.6	64.8	50.6	60.5	50.5	64.5	0	65.6
Jap. sardine	69.0	65.0	37.4	48.9	64.4	62.6	62.2	56.3	65.6	0

Table 1 describes fork length and numbers of juvenile buefin tuna in 1999. According to Table 1, the surface layer tow produced more individuals with a longer fork length than the two-layers tow. It is clear from these facts that juvenile Pacific bluefin tuna individuals were distributed vertically at 0-30 m in depth based on their growth, but that minimum and maximum fork lengths of the species did not always correspond to their growth.

Table 2 is the matrix of Euclidean distances among fish species from data in 1999. In this table, we select the top-ten commercially fished species - silver driftfish (*Psenes maculatus,* F.L.18-25cm), Japanese common squid (*Todarodes pacificus,* M.L.3-33cm), juvenile Pacific bluefin tuna (*Thunnus orientalis,* F.L.4-21cm), bullet tuna (*Auxis rochei,* F.L.3-25cm), Japanese anchovy (*Engraulis japonicas,* F.L.0-22cm), Japanese jack mackerel (*Trachurus japonicas,* F.L.2-25cm), Japanese sardine (*Sardinops melanostictus,* F.L.10-22cm), chub mackerel (*Scomber japonicas,* F.L.6-27cm), Japanese scad (*Decapterus maruadsi,* F.L.3-12cm) and black scraper (*Thamnaconus modestus,* F.L.4-17cm) - with horizontal and vertical distributions coinciding with juvenile Pacific bluefin tuna. Among juvenile Pacific bluefin tuna and the other commercially fished species, Japanese common squid, bullet tuna, Japanese anchovy and silver driftfish had Euclidean distances similar (from 42 to 50) to juvenile Pacific bluefin tuna.

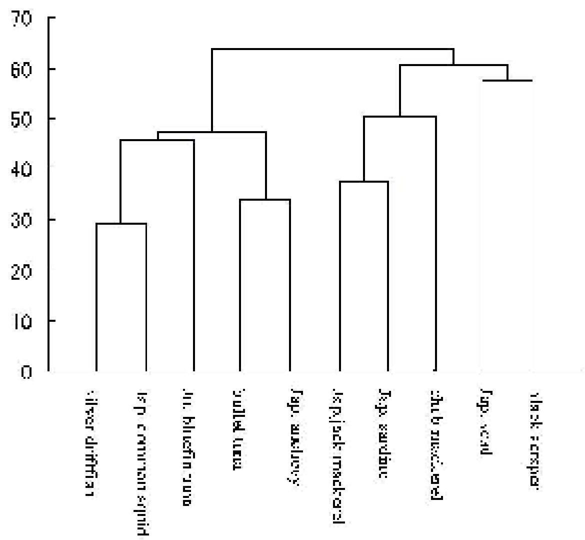

Fig. 4 Tree diagram of Euclidean distances among species (1999).

Fig. 4 is a tree diagram of Euclidean distances among species (1999). The horizontal and vertical axes represent species and distances. From this figure, we can determine that silver driftfish and Japanese common squid have similar Euclidean distances. Consequently, a cluster is formed of these two species. Furthermore, Euclidean distances of this cluster (silver driftfish and Japanese common squid) and juvenile Pacific bluefin tuna are also similar. Accordingly, a cluster is formed of silver driftfish, Japanese common squid, and juvenile Pacific bluefin tuna. Moreover, we can determine that the second cluster (silver driftfish, Japanese common squid, and juvenile Pacific bluefin tuna) and third cluster (bullet tuna and Japanese anchovy) seen from the left have similar Euclidean distances as shown in Fig. 4. As a result, a cluster is formed of these five species. Likewise, further clusters are formed later of other species with similar Euclidean distances.

4 Conclusion

From the tree diagram of Euclidean distance among fish species (1999), we determined that the Euclidean distances of silver driftfish and Japanese common squid are similar. Therefore, they form a cluster. Furthermore, the Euclidean distance of this cluster (silver driftfish and Japanese common squid) and juvenile Pacific bluefin tuna are also similar. Moreover, we determined that the second cluster (silver driftfish, Japanese common squid, and juvenile Pacific bluefin tuna) and third cluster (bullet tuna and Japanese anchovy) from the left have similar Euclidean distances from the tree diagram. As a result, a cluster is formed of these five species. Therefore, we conclude that the main horizontal and vertical distributions of these five fish species are similar.

Regarding the relationship between juvenile Pacific bluefin tuna and the other species, the Euclidean distance of Japanese common squid was closest to that of juvenile Pacific bluefin tuna.

5 Future research

In this study, we examine the surface-and-mid water trawl-net catch relationship between juvenile Pacific bluefin tuna and other commercial species with a cluster analysis using only the number of fish caught. In the future, we need to study the relationship between juvenile Pacific bluefin tuna, and other commercially fished species after considering additional factors such as morphological viewpoints, water temperature, stomach contents, and some information about other tuna species of Thunnini etc.

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References

[1] BB Collette and CE Nauen: FAO species catalogue, Scombrid of the World, FAO, Rome, 1983.

[2] T. Kitagawa, H. Nakata, S. Kimura, T. Itoh, S. Tsuji and A. Nitta: Effect of ambient temperature on the vertical distribution and movement of Pacific bluefin tuna (*Thunnus thynnus orientalis*), *Marine Ecology Progress Series,* **206**(2000), 251-260.

[3] T. Kitagawa, H. Nakata, S. Kimura and S. Tsuji: Thermoconservation mechanism inferred from peritoneal cavity temperature recorded in free swimming Pacific bluefin tuna (*Thunnus thynnus orientalis*), *Marine Ecology Progress Series,* **220**(2001),253-263.

[4] T. Kitagawa, S. Kimura, H. Nakata, H. Yamada Thermal:adaptation of Pacific bluefin tuna *Thunnus orientalis* to temperate waters, *Fisheries Science,* **72**(2006), 149-156.

[5] Y. Tanaka, M. Mohri and H.Yamada: Distribution, growth and hatch date of juvenile Pacific bluefin tuna *Thunnus orientalis* in the coastal area of the Sea of Japan, *Fisheries Science,* **73**(2007), 534-542.

[6] M. Okiyama: Occurrence of the Postlarvae of bluefin tuna, *Thunnus thynnus,* in the Japan Sea, *Bull. of Japanese Regional Fisheries Research Laboratory,* **25**(1974), 89-97.

[7] Y. Nishikawa: Occurrence of larval bluefin tuna in the sea of Japan in August, 1984 and 1985, *Bull. of the Japanese Society of Fisheries Oceanography,* **50** (1986), 186-187.

[8] T. Yorita: On the bluefin tuna of the Japan Sea coast of Hokkaido, *Journal of Hokkaido Prefectural Fisheries Experimental Station,* **33C** (1976), 2-11.

[9] T. Yorita: Maturity of the ovaries of bluefin tuna *Thunnus thynnus* (LINNAYEUS), on the Japan Sea off western coast of Hokkaido, *Journal of Hokkaido Prefectural Fisheries Experimental Station,* **38**(1981), 211-221.

[10]T. Kawaguchi: On the larger size bluefin tuna caught by purse-seiner net in Sakaiminato, Tottori Prefecture, *Bull. of the Japanese Society of Fisheries Oceanography,* **41** (1982), 92-98.

[11]O. Abe, W. Doi, S. Shimizu, D. Ishihara, Y. Hashimoto, A. Nagata, N. Suzuki, Y. Aonuma, H. Morimoto, N. Iguchi, D. Inagaki, K. Segawa, M. Okazaki, M. Masujima, D. Abe, A. Kimoto, Y. Ishihara, M. Yanagi, Y. Abe, M. Horie, Y. Hirate and M.Mohri: Large-scale research on larval bluefin tuna distribution in 2011, Abstracts for the Annual Meeting of the Japanese Society of Fisheries Science (2012), 57.

[12]M. Mohri, K. Yamamura, K. Sadamitsu, O. Abe and T. Kamano: Consideration on Thunnini from gonad index of adult individuals and catch distribution of juvenile

individuals around Mishima-island, Yamaguchi Prefecture, Abstracts for the Annual Meeting of the Japanese Society of Fisheries Science (2013), 15.

[13]S. Chow and S. Inoue: Intra-and interspecific restriction fragment length polymorphism in mitochondrial genes of Thunnus tuna species, *Bull. of National Research Institute For Far Seas Fisheries,* **30** (1993), 207-225.

[14]M. Mohri, T. Sakaki, R. Ohgaki, T. Kamano, T. Enoshima, H. Gotoh and S. Satoh: Biodiversity as observed from catch size differences between longtail tuna and other commercial fish species caught with set net off Futaoi Island (western sea of Japan), *Fisheries Engineering,* **50**(2014), 213-218.

[15]M. Mohri, K. Miyaji, T. Nishida and S. Watanabe: Analysis of catch size differences between longtail tuna and other commercial fish species by set-net fishing off Futaoi Island (western Sea of Japan) using cluster analysis, Mathematical and Physical Fisheries Science, 8(2010), 54-67.

[16]Y. Nagata and M. Munechika: Multivariate analysis guide, Science Press, 2008.

[17]A. Nakayama: Excel solver － multivariate analysis, Nikkagiren Press, 2010.

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Appendix Table 1 Positions and number of catches.

latitude (N)	36-26.3	37-02.5	36-59.3	38-01.0	38-59.0	37-59.2	37-31.0	37-02.3	36-00.5
longitude (E)	134-00.4	135-01.4	135-59.9	137-01.3	138-58.8	137-59.2	136-31.7	135-32.3	135-29.4
juvenile bluefin tuna	3	16	2	7	7	22	2	4	4
Jap. common squid	25	40	24	34	11	33	21	9	8
Jap. jack mackerel	12	7	80	0	89	48	1368	5	10
chub mackerel	8	0	0	450	0	18	219	11	5
bullet tuna	6	196	0	86	10	0	23	47	364
Jap. scad	2	0	0	19	0	0	0	261	0
Jap. anchovy	0	184	8	3858	0	2	0	0	458
black scraper	0	2	3	18	1	0	2	0	7
silver driftfish	0	1	1	0	0	0	0	2	0
Jap. sardine	0	0	0	57	0	0	160	3	10

latitude (N)	36-01.4	36-28.0	36-58.5	37-29.0	36-59.5	36-31.8	36-01.6	36-06.2	36-24.1
longitude (E)	134-30.7	134-32.9	134-29.2	133-29.6	133-31.8	133-30.4	133-29.9	132-30.0	132-29.9
juvenile bluefin tuna	11	27	13	24	4	6	5	3	1
Jap. common squid	3	30	84	72	6	1	3	9	45
Jap. jack mackerel	3	12	22	1	35	135	6	2	20
chub mackerel	42	15	9	77	80	18	324	12	6
bullet tuna	1	0	102	419	7	0	4	5	50
Jap. scad	38	4	25	3	24	148	8	44	87
Jap. anchovy	23	1	0	73522	37	29	612	2264	261
black scraper	0	2	2	0	0	0	0	8	33
silver driftfish	1	2	15	6	0	0	0	0	0
Jap. sardine	0	0	0	2	1	5	20	170	0