Analysis of relationship between water temperature and catches of longtail tuna and Pacific bluefin tuna off Futaoi Island (western Sea of Japan) using exponential approximation

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Abstract

The relationship between water temperature and number of tuna species (longtail tuna and Pacific bluefin tuna) caught by a set-net fishery off Futaoi Island (western Sea of Japan) is examined using an exponential approximation. Fishing season of longtail tuna was from June to October. And, the main fishing season of tuna was from July to September. On the other hand, the fishing season of Pacific bluefin tuna was January, February, and March. And, the main fishing season was January and February. The optimum water temperature of longtail tuna was within the range of 24 - 26 ℃, and the highest catch was found at 24 ℃. The range of 13 - 14 ℃ was suitable for catching Pacific bluefin tuna, and the catch was highest at 14 ℃. We identify the range of optimum water temperature(x) for catching longtail and Pacific bluefin tuna species(y) using $y = 1294.5e^{-0.2829x}$ and $y = 208e^{-0.3655x}$, respectively.

1 Introduction

In general, tuna species in the Sea of Japan are caught using set net [1], purse seine [2], or line fishing [3] methods. Most tuna species caught in the Sea of Japan are Pacific bluefin tuna (*Thunnus orientalis*) and longtail tuna (*T. tonggol*). At the Toyama Prefectural Fishery Experimental Station [4], this year (2011), individual Pacific bluefin tuna were caught in the Sea of Japan in spite of lower temperatures than average. Concerns about the relationship between water temperature and tuna catch prompted studies on Pacific bluefin tuna [5]-[8] and longtail tuna [9]-[11].

Because these tuna species resemble each other, longtail tuna are often mistaken for juvenile Pacific bluefin tuna. But, there is a shortage of information on longtail tuna compared to other main tuna species: Pacific bluefin tuna, Atlantic bluefin tuna (*T. thynnus*), southern bluefin tuna (*T. maccoyii*), albacore (*T. alalunga*), bigeye tuna (*T. obesus*), and yellowfin tuna (*T. albacares*).

Some studies on longtail tuna are as follows. Nakamura [12] reported that many longtail tuna were caught with set nets in September in Wakasa Bay (northwestern part of Fukui Prefecture). Mohri *et al*. [13] identified the period June-October as the fishing season for longtail tuna off Futaoi Island, Shimonoseki City, Yamaguchi Prefecture.

Itoh *et al*. [14] identify the catch points of adult and juvenile longtail tuna in the Sea of Japan. And, Itoh *et al*. [15] considered 24-26℃ to be the optimum water temperatures for longtail tuna. Unfortunately, this study did not examine the close relationship between catches of longtail tuna and water temperature at the catch point. Mohri *et al*. [13] found the optimum water temperature for juvenile longtail tuna to be around 24℃ off the eastern Sea of Japan off Yamaguchi Prefecture.

However, these studies did not apply adequate statistical methods. Consequently, this paper aims to clarify the relationship between water temperature and catch size for two tuna species using an exponential approximation. The exponential approximation was selected as the index because it is the most suitable function for providing results in liners, logarithms, and exponentials, etc.

2 Materials and methods

2.1 Materials

During the period from 1998 to 2009, we conducted fisheries oceanography research on longtail and Pacific bluefin tuna simultaneously through set-net operations performed by fishermen off Futaoi Island. Water temperature was observed at a depth of 5 m every 30 min(0:00-23:30). Three types of thermometer were used during the observation period: SBE 37 SM (Sea-Bird Electronics, USA), and AT-32K and ACTW-CMP (Alec Electronics, Japan).

Fig. 1 shows the location of Futaoi Island and the position of the set net. Futaoi Island is located at 34° 06′ N 130° 47′ E and the set net was placed in an area northeast of the Island.

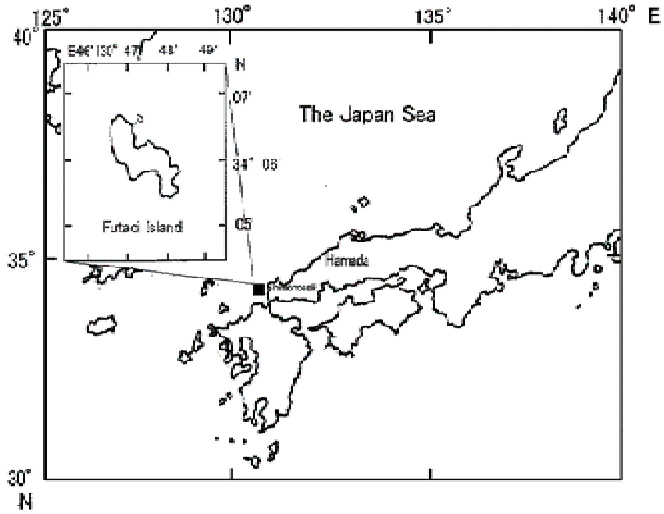

Fig. 1 Location of Futaoi Island and the position of the set net.

2.2 Analytical methods

2.2.1 Items analyzed

The Futaoi Island branch office of the Yamaguchi Prefecture Fishermen's Cooperative Association recorded data on adult tuna species caught with set nets during the period from 1998 to 2009. We used these catch data for our calculations.

From Mohri *et al.* [16], individual Yokowa (local name) caught mainly in winter were thought to be Pacific bluefin tuna. So, we regard the species to be Pacific bluefin tuna.

First, we calculated the average of water temperatures obtained using thermometers on Day 1 for tuna species caught with a set net. Next, when we performed an exponential approximation, water temperatures at which individual tuna were caught at increments of 1 ℃ or 0.5 ℃ arranged in the order of larger to smaller catches.

2.2.2 Exponential approximation

First, the least squares method was applied as follows:

When $(x,y)= (x_1,y_1),(x_2,y_2),,, (x_i,y_i),,,(x_n,y_n)$, the linear regression equation is for a and b with $y=ax+b$ using the following expressions ((1) and (2)).

$$a = \frac{n\Sigma xiyi - \Sigma xi\Sigma yi}{n\Sigma xi^2 - (\Sigma xi)^2} \qquad (1)$$

$$b = \frac{\Sigma xi^2 \Sigma yi - \Sigma xiyi\Sigma xi}{n\Sigma xi^2 - (\Sigma xi)^2} \qquad (2)$$

In general, exponentially curved regression eq. Is known as (3).

$$y = Be^{Ax} \qquad (3)$$

where A= constant, B=constant.

Logarithmic eq. of (3) is

$$logy = logB + Ax \qquad (4)$$

Here, A and B are given as (5), (6) from (1), (2).

$$A = \frac{i\Sigma(xilogyi) - (\Sigma xi\Sigma logyi)}{i\Sigma xi^2 - (\Sigma xi)^2} \qquad (5)$$

$$logB = \frac{((\Sigma xi^2 \Sigma logyi) - (\Sigma xilogyi\Sigma xi))}{i(\Sigma xi^2) - (\Sigma xi)^2)} \qquad (6)$$

where x_i =number of data for 0.5 ℃, y_i =number caught at 0.5 ℃, i =number of data.

We performed the exponential approximation using Eq. (5) and Eq. (6).

3 Results and discussion

3.1 Fishing seasons of longtail tuna and Pacific bluefin tuna

In Fig. 2, the monthly total catches of longtail tuna using a set net off Futaoi Island are shown for the years 1998-2009. From this Figure, the fishing season of the species was found to be the period from June to October. It is clear that the main fishing season is from July to September, in which 90 % longtail tuna were caught.

Table 1 shows the monthly and yearly catches of longtail tuna by a set net fishery off the Island. The fishing season of the species was also from June to October, but the main fishing season in Table 1 differs from Fig.1. The main fishing seasons were July (2006), August (1997, 2000, and 2002), September (1996, 1999, 2001, 2003, and 2009), and October (2010).

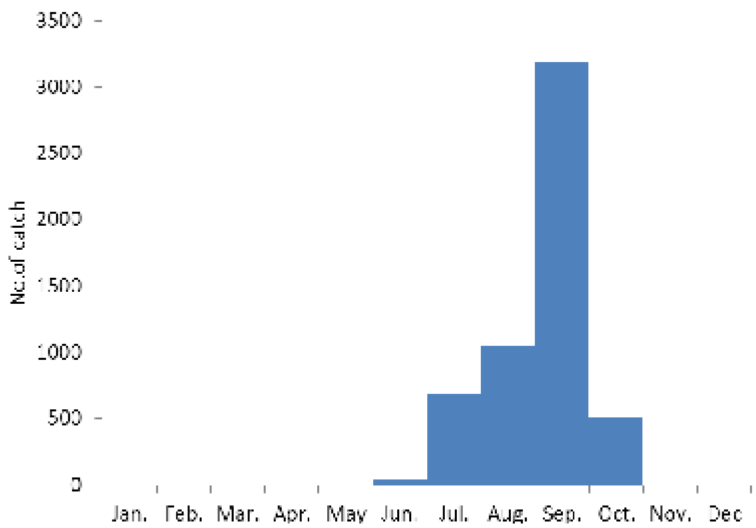

Fig. 2 Total monthly catches of longtail tuna by set net fishery off Futaoi Island.

Table 1 Monthly and yearly catches of longtail tuna by set net fishery off Futaoi Island.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec	total
1995							15	13		6			34
1996							210	32	442	30			714
1997						14		173	20				207
1998						14		14	37				65
1999								8	90	7			105
2000							164	315	139				618
2001								20	129	8		5	162
2002						3	63	159	77	21			323
2003							30	35	126	45			236
2004							15	41	10				66
2005									37			1	38
2006							106	53	45	2	1		207
2007									8	35			43
2008						8		33	46	2			89
2009						2	86	147	1864		1		2100
2010								10	114	362			486
total	0	0	0	0	0	41	689	1053	3134	518	2	6	5493

The total monthly catches of Pacific bluefin by the set net fishery off the Island are described in Fig. 3. According to Fig. 3, the fishing season of the species was January, February, and March. The main fishing season was January and February. We examine monthly and yearly catches of Pacific bluefin tuna by the set net fishery off the Island in Table 2. This Table, indicates that many individual Pacific bluefin tuna were caught in January (2001, 2005, and 2010) or February (2008).

We consider differences of water temperature to cause high or low catches of these two tuna species. Therefore, the relationship between water temperature and catch for longtail and Pacific bluefin tuna are examined in the next section (3-2).

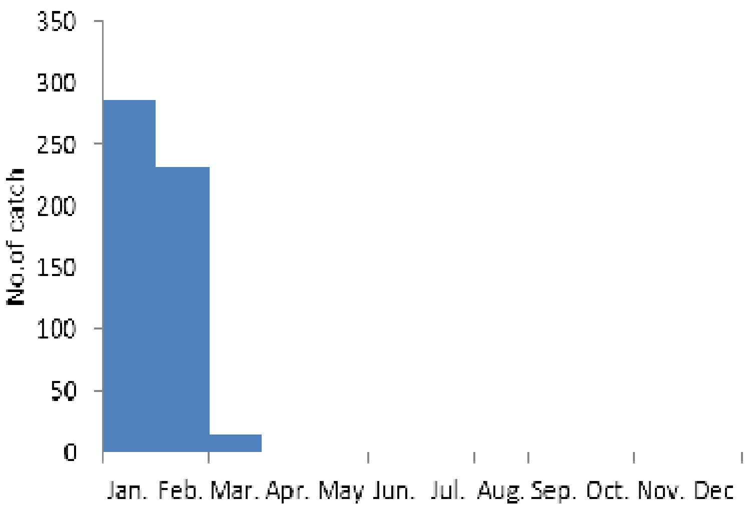

Fig. 3 Total monthly catches of Pacific bluefin by set net fishery off Futaoi Island.

Table 2 Monthly and yearly catches of Pacific bluefin tuna by set net fishery off Futaoi Island.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec	total
1995	1												1
1996													0
1997		4											4
1998													0
1999	2												2
2000	11												11
2001	34	2											36
2002	7	1											8
2003													0
2004													0
2005	74		3										77
2006	29	25											54
2007													0
2008	21	129											150
2009	57	61	10										128
2010	50	10	1										61
total	286	232	14	0	0	0	0	0	0	0	0	0	532

3.2 Relationship between water temperature and catch for longtail and Pacific bluefin tuna

Fig. 4 indicates the relationship between longtail tuna catch and water temperature in increments of 1 ℃. Water temperature was within 19 - 30 ℃ and 80 % of the total catch were observed at 24 - 26 ℃. For the highest catch of 1662, the water temperature was 24 ℃. As a result, the optimum water temperature for the species was within the range of 24 - 26 ℃, and the catch was highest at 24 ℃.

Fig. 5 depicts the relationship between Pacific bluefin tuna catch and water temperature in increments of 1 ℃. Water temperature was at 13 - 17 ℃, with 70 % of the total catch observed at 13 - 14 ℃. For the highest catch of 188, the water temperature was 14 ℃. As a result, the optimum water temperature for the species was within the range of 13 - 14 ℃, with the highest catch at 14 ℃.

Subsequently, we examined the optimum water temperature for catching the above two tuna species in detail. Water temperatures in ranges greater than 24 ℃ at increments of 0.5 ℃ were selected. 24 ℃ and 13 ℃ were selected because 90% of longrail tuna and 95% of Pacific bluefin tuna were caught in that renge, respectively.

Fig. 6 presents the relation between longtail tuna catch and water temperature in the range greater than 23.5 ℃. Water temperature was 24.0 - 27.5 ℃ and about 70 % of total catch was observed at 24.0 - 25.0 ℃. For the highest catch of 1087, the water temperature was 24.5 ℃.

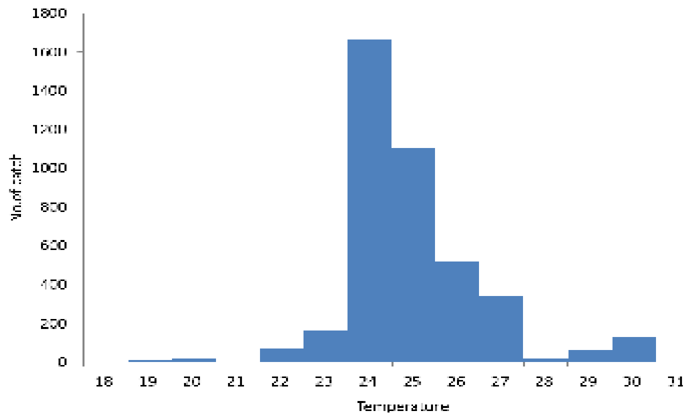

Fig. 4 Relation between longtail tuna catch and water temperature at increments of 1 ℃.

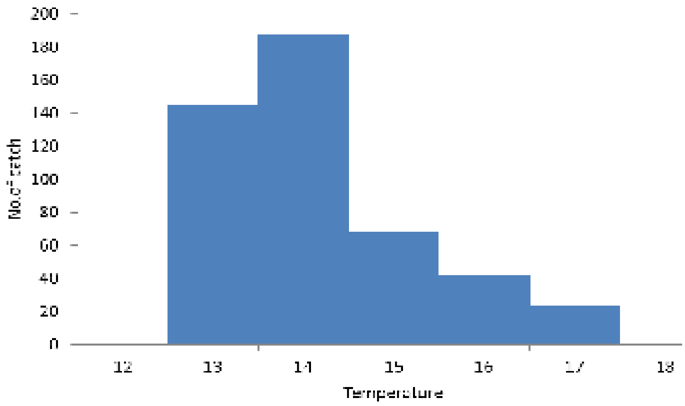

Fig. 5 Relation between Pacific bluefin tuna catch and water temperature at increments of 1 ℃.

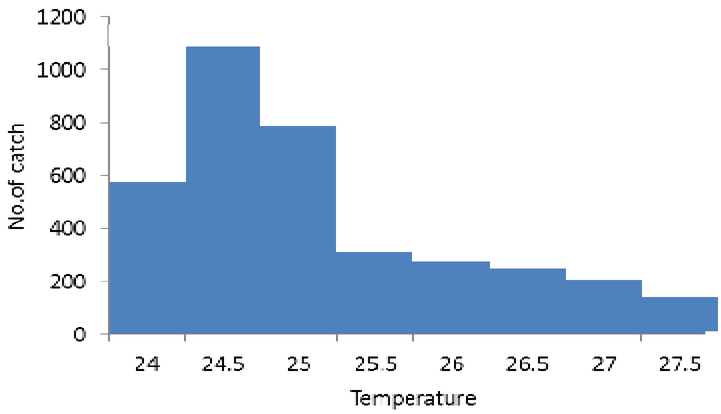

Fig. 6 Relation between longtail tuna catch and water temperature in the range greater than 23.5℃ at increments of 0.5℃.

Fig. 7 describes the relation between Pacific bluefin tuna catch and water temperature in the range greater than 13℃ at increments of 0.5℃. Water temperature was 13.5 - 16.5 ℃ and about 75 % of the total catch was observed at 13.5 - 14.5 ℃. For the highest catch of 145, water temperature was 13.5 ℃.]

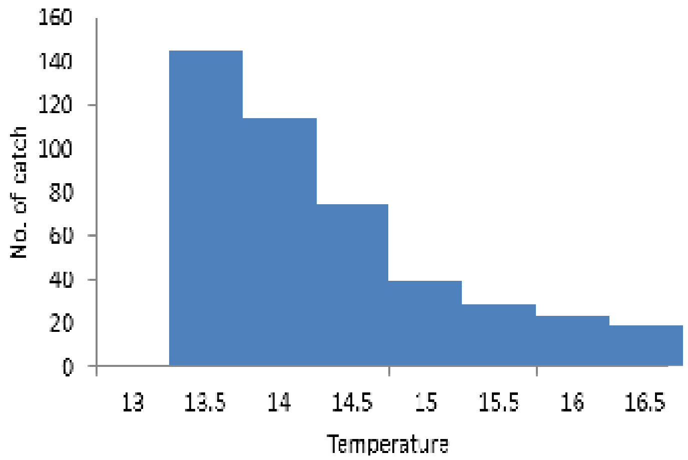

Fig. 7 Relation between Pacific bluefin tuna catch and water temperature in the range greater than 13℃ at increments of 0.5℃.

3.3 Relationship between water temperature and catch for longtail and bluefin tuna using exponential approximation

Here, water temperatures of individual tuna caught at increments of 0.5 ℃ are arranged in order of larger to smaller catches. We calculated the exponential approximation (Eq. (5) and Eq. (6)) and obtained following equations for longtail tuna (Eq. (7), R^2 =0.9583) and for bluefin tuna (Eq. (8), R^2=0.9705):

$$y = 1294.5e^{-0.2829x} \quad (7)$$

$$y = 208e^{-0.3655x} \quad (8)$$

We identified the optimum water temperature range to catch longtail and bluefin tuna species using Eq. (7) and Eq. (8).

We show the relation between water temperature and catch using an exponential approximation curve in Fig. 8 (longtail tuna) and Fig. 9 (Pacific bluefin tuna). We can predict the catch at every water temperature from Eq. (7) and Eq. (8).i

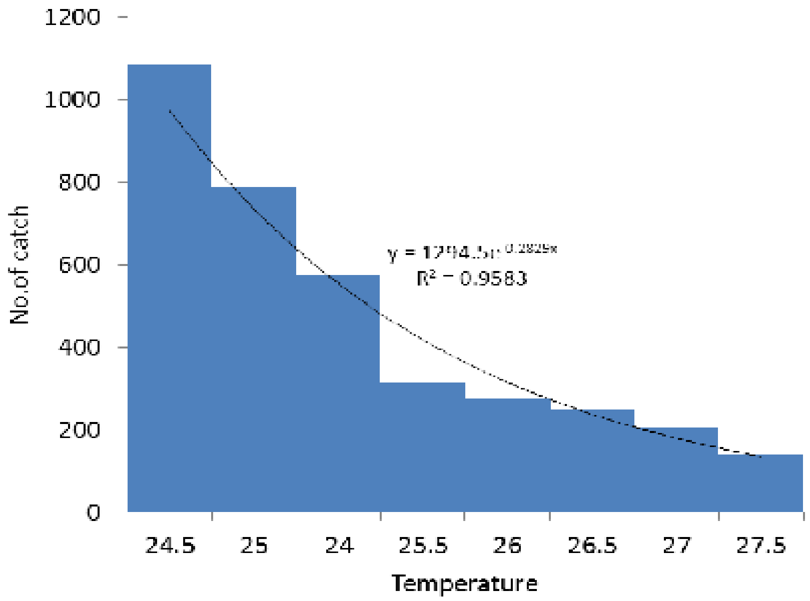

Fig. 8 Relation between water temperature and longtail tuna catch using exponential approximation curve.

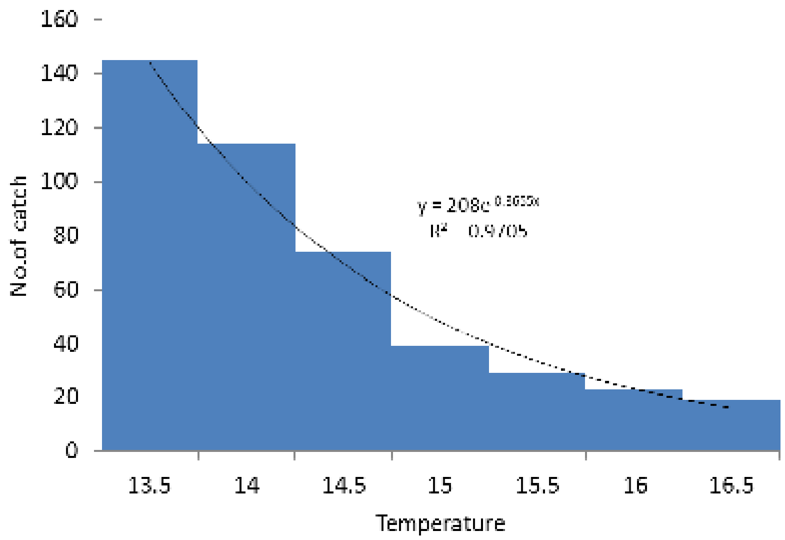

Fig. 9 Relation between water temperature and Pacific tuna catch using exponential approximation curve.

4 Conclusion

1. Fishing seasons of longtail tuna and Pacific bluefin tuna

The fishing season of individual longtail tuna was from June to October. The main fishing season for tuna was from July to September. The fishing season of Pacific bluefin tuna was January, February, and March. The main fishing season was January and February.

2. Relationship between water temperature and catch for longtail and Pacific bluefin tuna

The optimum water temperature for catching longtail tuna was within the range of 24 - 26 ℃, and the highest catch was found at 24 ℃. The range of 13 - 14 ℃ was suitable for catching Pacific bluefin tuna, and the catch was highest at 14 ℃.

3. Relationship between water temperature and catch for longtail and Pacific bluefin tuna using exponential approximation

We identify the range of optimum water temperatures for catching longtail and Pacific bluefin tuna species using $y = 1294.5e^{-0.2829x}$ and $y = 208e^{-0.3655x}$, respectively.

5 Future subjects for study

In this study, we examined the relationship between water temperature and catch size of longtail and Pacific bluefin tuna off Futaoi Island (western Sea of Japan) using an exponential approximation. We need to increase the volume of data in the future and further examine the relationship between water temperature and catch size of these two tuna species. Furthermore, we would like to analyze the relationships among catch size, oceanographic factors except water temperature (salinity and dissolved oxygen etc.), and other factors (other species, fishing methods, and fishing grounds etc.).

6 Acknowledgements

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