Seasonal Swimming Behavior and Optimum Water Temperature for Adult Ocellate Puffer Takifugu rubripes Revealed by Using Archival Tags

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Abstract: To clarify the seasonal swimming patterns of ocellate puffer Takifugu rubripes, tagging experiments using electronic archival data-storage tags were conducted from October 1997 to April 1999 in the coastal area of Mie Prefecture, Japan. Twenty one tagged fish ranging from 37 to 53 cm in total length were released and stored data from seven tags were retrieved and analyzed. The puffers mainly swam in the subsurface layer shallower than 25 m with occasional diving to near the bottom except for the spawning season from April to May, when male puffer frequently swam up to the subsurface from the bottom (20–35 m) in the spawning ground, implying male specific mating-related behavior. This result suggests that ocellate puffer usually have a pelagic swimming nature. The vertical distributions tended to be deeper in winter (deepest depth of 65–115 m) than in autumn (deepest depth of 35–80 m) indicating that ocellate puffer move offshore in winter. Although the ambient water temperature recorded in tags ranged from 11 to 29˚C throughout a year, that of the monthly average ranged from 15 to 24˚C indicating to be the optimum water temperature for adult ocellate puffer.

Key words: Ocellate puffer; Archival tag; Swimming behavior; Optimum water temperature

The ocellate puffer Takifugu rubripes is distributed from southern Hokkaido to Taiwan (Matsuura 1997). Longline fisheries are one of the most important fisheries for this species and are conducted in the Yellow Sea, the East China Sea, coastal areas of Kyushu, Seto Inland Sea and Enshu Nada (Ito 1997). Two methods of longline fishing are commonly used to exploit puffer fish. One method is a bottom longline where the gear is fixed on the bottom; the other is a surface longline in which the gear is usually floated at a shallower depth. The ocellate puffer is considered to be highly benthic, while a related species, the eyespot puffer Takifugu chinensis, is suggested to swim in the midwater layer or near the bottom based on the difference in catch by the two types of fishing gears (Fujita 1962). However, about the longline fishing of ocellate puffer, bottom longline fishing is operated in coastal areas in autumn while surface longline fishing is operated during January to March in the Chikuzen Sea, off northern Kyushu (Hidaka et al. 1988). This observation suggests that a seasonal vertical movement of ocellate puffer occurs. To the best of our knowledge, however, there is little information on the swimming behavior of ocellate puffer except for some empirical observations reported by fishermen. Moreover, it is also difficult to obtain year-round data because longline fishing is permitted only from October to February in Enshu Nada, Kumano Nada and Suruga Bay due to voluntary regulations undertaken by the fishermen (Yasui et al. 1997a).

In general, fish behavior in the open ocean is difficult to observe, because we lack the

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technical means to reliably do so. However, recent technological developments in acoustic transmitters and electronic data-storage tags have made it possible to monitor the swimming behavior of various species of marine animals such as yellowfin, bigeye, bluefin tuna, plaice and yellowtail (Holland et al. 1990; Metcalfe and Arnold 1997; Kasai et al. 2000; Kitagawa et al. 2000). Acoustic transmitters can be used to continuously monitor the horizontal position, ambient water temperature and swimming depth of fish. Yasui et al. (1997b) tracked one ocellate puffer using an ultrasonic device in Enshu Nada and reported on the swimming depth and diel activity. This study was limited however to only 39 hours due to difficulties of tracking by the research vessel. In contrast to transmitters, electronic data-storage tags can monitor temperature, swimming depth and/or light intensity for longer periods. Nakajima and Nitta (2000) reported on the swimming behavior and burrowing behavior of ocellate puffer. However, the data was based on only two individuals being 1.5 years old over a 7 month period from October to April. In this study, data from seven individuals with the same archival data-storage tags were obtained for a period of about two years. This is the first report to analyze seasonal swimming behavior of ocellate puffer, with ages ranging from 1.5 to about 4 years old. Additionally, we also document the optimum water temperature of this species using the same tag data.

**Materials and Methods**

**Tagging method**

Tagging experiments were conducted in the coastal area of Mie Prefecture, central Japan (Fig. 1). Releases were carried out at two locations, off Anori and off Yukiura in Mie prefecture. Ocellate puffer were caught in October by longline fishing in Enshu Nada and Kumano Nada. In spring, spawning ocellate puffer were caught off Anori by purse seine net. A total of five separate tagging experiments were conducted in October 1997 (experiment I, II), April 1998 (experiment III), October 1998 (experiment IV) and May 1999 (experiment V) using archival data-storage tags (hereafter as archival tag) (Table 1). The ocellate puffer were obtained without the teeth being cut and immediately operated to insert a tag into the peritoneal cavity of each fish at the fish market. It took about 5 minutes including the measurement of total length and body weight. The total number of 21 ocellate puffer ranged from 36.9 to 52.9 cm TL and were estimated to be from 1.5 to about 4 years old based on a previous study of the growth of ocellate puffer (Tokai et al. 1993). These fish with tags were released on the same day after being fitted with the archival tag. The archival tag is a new type of device made by Northwest Marine Technology Inc. (Seattle, WA, USA) and measures four parameters simultaneously including light intensity, internal and external temperature and water pressure. The data was set to be recorded every 128 s. in experiments I and II and every 256 s. in experiments III–V, and then data of 80 days and 160 days was stored in experiment I, II and experiment III–V, respectively. The time series log file was divided into two sections, A and B. The former section records the initial data and was never overwritten, whereas the latter is overwritten with the latest data after the memory limit has been exceeded. Each log memory section was then allocated 40 days in experiment I, II and 80 days in experiment III–V to store archival data of the above four parameters.

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Tag Code</th>
<th>Date</th>
<th>TL (cm)</th>
<th>BW (g)</th>
<th>Location</th>
<th>Fishing method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. I</td>
<td>A1−A5</td>
<td>Oct. 1−15, 1997</td>
<td>45.0−51.0</td>
<td>1,550−2,760</td>
<td>Off Anori</td>
<td>Long-line</td>
</tr>
<tr>
<td>Exp. II</td>
<td>B1−B3</td>
<td>Oct. 9−14, 1997</td>
<td>39.0−46.0</td>
<td>1,200−1,800</td>
<td>Off Yukiura</td>
<td>Long-line</td>
</tr>
<tr>
<td>Exp. III</td>
<td>C1−C5</td>
<td>Apr. 11, 1998</td>
<td>40.9−52.9</td>
<td>1,145−3,580</td>
<td>Off Anori</td>
<td>Purse seine net</td>
</tr>
<tr>
<td>Exp. IV</td>
<td>D1−D7</td>
<td>Oct. 11, 1998</td>
<td>36.9−45.0</td>
<td>960−1,720</td>
<td>Off Anori</td>
<td>Long-line</td>
</tr>
<tr>
<td>Exp. V</td>
<td>E1</td>
<td>May. 11, 1999</td>
<td>40.5</td>
<td>1,300</td>
<td>Off Anori</td>
<td>Purse seine net</td>
</tr>
</tbody>
</table>

TL and BW mean total length and body weight, respectively.
Analysis of data

It is well established that species of the genus *Takifugu* show burrowing behavior (Furukawa and Okamoto 1966; Fujita 1988) and we quantified this behavior based on a combination of constant depth and light conditions that showed zero light intensity in spite of it being daytime (Nakajima and Nitta 2000). Four cases were defined as burrowing events such as during daytime, from the daytime continuing until the following daytime, from the nighttime continuing to the following daytime and from the daytime continuing to the following nighttime. However, it was difficult to discriminate some data recorded only during the night. Then, burrowing events were identified and the number of burrowing events and the number of hours remaining buried per one event were estimated for the data of each tag. Swimming behavior was also analyzed using data excluding these estimated hours remaining buried. All data of ambient water temperature (hereafter as ambient temperature) recorded in the time series log file were used and mean values were calculated for each calendar month. Monthly CTD data was obtained by oceanic survey in Kumano Nada and Enshu Nada, which was conducted by Mie and Aichi Prefectures from January 1997 to December 1999. Six and eight oceanic survey stations shallower than about 150 m were shown in Kumano Nada and Enshu Nada, respectively (see Fig. 1).

Results

In the present study, ten of the released fish were recaptured within the area of Suruga Bay, Enshu Nada, Ise Bay and Kumano Nada (Table 2, Fig. 1). The fish B-2 released off Yukiura

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Tag Code</th>
<th>Date</th>
<th>Tag</th>
<th>Sex</th>
<th>Days at liberty</th>
<th>Location</th>
<th>Fishing method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-3</td>
<td>Apr.1, 1998</td>
<td>△</td>
<td>-</td>
<td>173</td>
<td>Off Yaizu</td>
<td>Set net</td>
</tr>
<tr>
<td>Exp. II</td>
<td>B-1</td>
<td>Mar.1, 1998</td>
<td>○</td>
<td>F</td>
<td>143</td>
<td>Off Nansei</td>
<td>Long-line</td>
</tr>
<tr>
<td></td>
<td>B-2</td>
<td>Apr.6, 1998</td>
<td>○</td>
<td>M</td>
<td>175</td>
<td>Off Anori</td>
<td>Purse seine net</td>
</tr>
<tr>
<td>Exp. III</td>
<td>C-1</td>
<td>Apr.23, 1998</td>
<td>○</td>
<td>M</td>
<td>12</td>
<td>Off Irago</td>
<td>Trawl net</td>
</tr>
<tr>
<td></td>
<td>C-2</td>
<td>Oct.11, 1998</td>
<td>○</td>
<td>F</td>
<td>183</td>
<td>Off Yukiura</td>
<td>Long-line</td>
</tr>
<tr>
<td></td>
<td>C-3</td>
<td>Apr.16, 1999</td>
<td>○</td>
<td>M</td>
<td>371</td>
<td>Off Anori</td>
<td>Purse seine net</td>
</tr>
<tr>
<td>Exp. IV</td>
<td>D-1</td>
<td>May.21, 1999</td>
<td>△</td>
<td>M</td>
<td>222</td>
<td>Ise Bay</td>
<td>Trawl net</td>
</tr>
<tr>
<td></td>
<td>D-2</td>
<td>Oct.25, 1998</td>
<td>△</td>
<td>-</td>
<td>14</td>
<td>Ise Bay</td>
<td>Trawl net</td>
</tr>
<tr>
<td>Exp. V</td>
<td>E-1</td>
<td>Nov.19, 1999</td>
<td>○</td>
<td>M</td>
<td>192</td>
<td>Off Maisaka</td>
<td>Long-line</td>
</tr>
</tbody>
</table>

Open circles in Tag show archival tags that were successfully retrieved and open triangles show tags that data could not be retrieved.

![Fig. 1. Release and recapture locations of ocellate puffer implanted with archival tags. Open circles and closed circles indicate release and recapture locations, respectively. Open squares show stations for the monthly oceanic survey which was conducted by the Fisheries Research Institutes of Mie and Aichi Prefectures.](image-url)
in the previous autumn was recaptured at the spawning ground off Anori about 6 months later and the fish C-3 was also caught at the same spawning ground one year later. Of these ten fish, data from seven tags were successfully retrieved and used for further analysis. At release, total length of the fish B-1, B-2 and D-1 were 39–41 cm (1.5 years old), those of the fish C-1, C-3 and E-1 were 41–43 cm (2 years old) and that of the fish C-2 was 52 cm (about 4 years old) (Table 2). The fish B-1 and C-2 were female and the others were male. The days at liberty ranged from 12 to 371 days (average 180 days) and the analysis periods covered almost all seasons of 1998 and 1999.

Swimming depth and ambient water temperature recorded in the tags

The original swimming depth and ambient temperature of the fish B-2 recorded in the time series log file A and B are shown as an example in Fig. 2. Because distinct differences were not found between internal and external temperatures, only external temperature is shown in Fig. 2. The fish B-2 was released off Yukiura on 14 October, 1997 and recaptured at the spawning ground off Anori on 6 April, 1998 (Tables 1 and 2). The swimming depth of this individual fish was in most cases shallower than 20 m with occasional diving mostly shallower than 30 m during the period from October 14 to November 22 in the time series log file A. The ambient temperature during this period gradually dropped from 22˚C to 19˚C. The deepest depth was recorded as 78 m with the lowest temperature of 15.5˚C on 21 October. This fish usually swam near the surface shallower than 10 m with diving to depths deeper than 30 m, in particular a maximum depth of 91 m on 28 February in the time series log file B. However, ambient temperature was maintained stably at around 17˚C during the period till March 14. Then, the vertical depth preference started to change from around March 18 and the fish continued to swim at around 35 m with repeated rising to the subsurface at around 10 m from March 28 till April 6 when the fish was recaptured. Ambient temperatures were stably maintained at around 15.5˚C at the depth of 35 m.

![Fig. 2. Changes in swimming depth (thick line) and ambient water temperature (thin line) of the fish B-2 illustrated separately for time series log file A during Oct. 14 - Nov. 23, 1998 (upper) and time series log file B during Feb. 25 - Apr. 6, 1999 (lower).](image-url)
Burrowing behavior

Burrowing events of the fish B-2 are shown as an example in Fig. 3. Burrowing events were obtained at least for 6 times and the number of hours remaining buried was estimated to be from 1.4 to 41.1 hours per each event during the period of March 18-23 based on the definition stated in the materials and methods. Such a burrowing behavior was recognized for all seven fish and the analyzed results are shown as follows. The number of hours remaining buried per one event ranged from 8 minutes to 74.9 hours (about 3 days) and the mode shorter than 5 hours accounted for 62%. Here, monthly burrowing occurrence rate is defined as follows; percentage of the number of days when burrowing behavior was recognized per total number of recorded days in each month. The monthly burrowing occurrence rates ranged from 0% to 90% with an average rate of 45% (Table 3). The burrowing events irregularly occurred and diel burrowing patterns were not observed. Moreover, average burrowing depths for the fish B-1, B-2 and D-1 in winter (Dec.-Feb.) were 35.4m, 36.3m, 41.5m and deeper than in autumn (Oct. and Nov.) which was 26.2m, 13.1m, 31.5m, respectively. The relationship between the deepest depth at which burrowing occurred and the deepest diving depth occurred on the same day were illustrated for the fish B-2, C-2 and E-1, being 1.5, 2, 4 years old at release, respectively in Fig. 4. Positive and significant correlations were found between daily burrowing depth and deepest depth for the fish B-2 (r² = 0.9053, ANCOVA, P < 0.01), E-1

Table 3. Monthly burrowing occurrence rates estimated for individual fish

<table>
<thead>
<tr>
<th>Month</th>
<th>B-1</th>
<th>B-2</th>
<th>C-2</th>
<th>C-3</th>
<th>D-1</th>
<th>E-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>77.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>-</td>
<td>-</td>
<td>35.5</td>
<td>71.0</td>
<td>-</td>
<td>21.1</td>
</tr>
<tr>
<td>June</td>
<td>-</td>
<td>-</td>
<td>56.7</td>
<td>63.3</td>
<td>-</td>
<td>33.3</td>
</tr>
<tr>
<td>July</td>
<td>-</td>
<td>-</td>
<td>57.1</td>
<td>-</td>
<td>-</td>
<td>30.0</td>
</tr>
<tr>
<td>Aug.</td>
<td>-</td>
<td>-</td>
<td>71.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sep.</td>
<td>-</td>
<td>-</td>
<td>70.0</td>
<td>-</td>
<td>-</td>
<td>40.7</td>
</tr>
<tr>
<td>Oct.</td>
<td>72.7</td>
<td>33.3</td>
<td>72.7</td>
<td>-</td>
<td>36.8</td>
<td>16.1</td>
</tr>
<tr>
<td>Nov.</td>
<td>55.6</td>
<td>45.5</td>
<td>-</td>
<td>-</td>
<td>90.0</td>
<td>72.2</td>
</tr>
<tr>
<td>Dec.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>54.8</td>
<td>-</td>
</tr>
<tr>
<td>Jan.</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feb.</td>
<td>60.7</td>
<td>0*</td>
<td>-</td>
<td>25.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mar.</td>
<td>-</td>
<td>45.2</td>
<td>-</td>
<td>29.0</td>
<td>42.3</td>
<td>-</td>
</tr>
<tr>
<td>April</td>
<td>-</td>
<td>40.0</td>
<td>-</td>
<td>26.7</td>
<td>63.3</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>66.7</td>
<td>-</td>
</tr>
</tbody>
</table>

Monthly percentages of burrowing occurrence (days during which burrowing behavior was observed / data recorded days) were calculated in each fish. Month in the left row was lined up in the order of release month to recapture month for each fish. Asterisk marks show that data recorded days were less than 5 days in that month.

Fig. 3. Illustration of burrowing events of the fish B-2 observed during Mar. 18-23, 1999. The gray shading zones are the time when tag sensor could not sense light intensity.

Fig. 4. Relationship between daily burrowing depth and deepest depth obtained on the same day for B-2, C-2 and E-1.
data were shown by age and season (Fig. 5). The mode of swimming depth of the fish B-1 appeared at the depth of 20–25 m in October and November and then changed to the depth of 0–5 m and 5–10 m in January and February, respectively. The monthly deepest

Seasonal swimming behavior

The swimming depth and the deepest depth (hereafter as swimming pattern) of all tag

Fig. 5. Seasonal change of swimming depth for all fish. Age of each fish represents the age at release. Swimming depth crossing to X-axis indicate the maximum depth obtained in each period. M.28 for B-2 and A.28-M.5 for D-1 in Spring represent March 28 and April 28-May 5, respectively.
depth became deeper from 40 m in October and November to 65 m and 85 m in January and February, respectively. The mode of the fish B-2 appeared at the depth of 0–5 m in October and November and was very different from that of the fish B-1, but was similar to that of B-1 in February. The monthly deepest depth also became deeper from 35 m in November to 95 m in February. The swimming pattern of the fish D-1 in October and November was similar to values of the fish B-2 in October and B-1 in November, respectively. However, the swimming pattern of the fish D-1 in December was also similar to those of B-1 and B-2 in February. Overall, the deepest depth had a tendency to become deeper in winter (Dec. – Feb.) compared to autumn (Oct. – Nov.) for all fish of B-1, B-2 and D-1. The mode of swimming depth of the fish E-1 in October was somehow a mixture of the pattern shown by B-1 and B-2 in October.

During the spawning season from March to May, vertical movement of the fish B-2 shifted to swim at around 30–35 m with frequent movements to shallower depths (Fig. 2). Such a specific behavior was also observed for C-1 and C-3. It lasted for at least 10 days (March 28 – April 6) for B-2, 3 days (April 21 – 23) for C-1 and 2 days (April 15, 16) for C-3 till recapture (Fig. 5). On the other hand, the fish D-1 showed the same swimming pattern for 8 days from April 28 to May 5, but the mode was observed at about 15–20 m. Before shifting to this specific swimming pattern, the mode of swimming depth of the fish B-2 continued to be 0–5 m but daily deepest depth became shallower to be 45 m during the period of March 18 to 27. Such changes of the deepest depth were observed for the fish D-1 during April 1 to 27 and C-3 during April 1 to 14. In the case of the fish C-1, only the mode of swimming depth deepened to be 10–15 m, though the deepest depth did not change on 19 and 20, April (Fig. 5).

After the spawning season, the mode of swimming depth of the fish D-1 on 6–21, May showed at the depth of 15–20 m being similar in November. Swimming pattern of the fish C-3 and E-1 in May and June was similar to that of B-2 in November. On the contrary, the mode of swimming depth of the fish C-2 gradually changed to become deeper from 0–5 m in April and May, 10–15 m in June and to 20–25 m from July to September. However, the monthly deepest depths of C-2 were deeper than 110 m with the maximum depth of 155 m (in June) which was rather deeper than that of D-1, C-3 and E-1 with ranging from 40–85 m.

**Monthly change of ambient water temperature**

Ambient temperatures are shown by calendar month in Fig. 6 using all the tag data. Ambient temperatures ranged from 11.2°C to 29.2°C and monthly average one gradually increased from 15.1°C in March to 24.4°C in September (except August) and then decreased toward December. This figure also shows the monthly average water temperature at the depth of 10 m obtained by the oceanic survey in Kumano Nada and Enshu Nada (hereafter as oceanic temperature) from January 1997 to December 1999 as the mode of swimming depth was mainly observed at the depth of about 10 m. The changes of ambient temperatures and average oceanic temperatures showed close agreement except for August being lower (average 21.1°C). The data of ambient water in August was obtained only for the fish C-2 with the mode of swimming depth being observed at the depth of 20–25 m with an average depth of 28.6 m. Average oceanic temperature in August was 25.6°C, 23.3°C and 21.1°C at the depth of 10 m, 20 m and 30 m, respectively and did not differ markedly from those for July.
and September, 1998 in Kumano Nada and Enshu Nada. The average ambient temperature of the fish C-2 coincided well with the oceanic temperature at the depth of 30 m in August.

Ambient temperatures at the depth of 30–35 m of the fish B-2 were recorded as 14.7–15.5°C from March 28 to April 6 and those of C-1 were recorded as 18.3–18.5°C from April 21–23 in 1998 when spawning behavior was observed. Ambient temperatures of the fish C-3 at the depth of 33 m were also recorded as 14.4–14.9°C on 15 and 16 April and those of the fish D-1 at the depth of 15–20 m were recorded as 16.2–17.0°C from April 28 to May 5 in 1999.

Discussion

Seasonal swimming behavior of ocellate puffer

There has only been limited information published on the swimming behavior of ocellate puffer, based on data obtained from tracking experiments using bio-telemetry over a short period of only 39 hours (Yasui et al. 1997b). In the present study, swimming behavior of field-monitored ocellate puffer were obtained ranging from 12 to as long as 371 days (average 180 days) from the release dates. All of the tagged fish were recaptured within the area of Suruga Bay, Enshu Nada and Kumano Nada. Moreover, two tagged fish were recaptured at the spawning ground off Anori after 175 days and 371 days from the release date. These results do not differ from data obtained in previous studies using conventional tagging method (Yasui and Hamada 1996; Ito et al. 1999; Nakajima and Nitta 2005). This suggests that the archival tag did not seriously affect the migration and swimming behavior of the tagged fish.

Hidaka et al. (1988) reported that bottom longline fishing operates in the coastal area in autumn while surface longline fishing is carried out from January to March at depths of around 100 m in the Chikuzen Sea, off Northern Kyushu, where ocellate puffer are caught at a depth of 10–20 m. First of all, we analyzed the swimming behavior in detail focusing on the longline fishing season. In autumn (October, November), the mode of swimming depth fluctuated individually from 0–5 m (B-2), 0–10 m (D-1, E-1) to 20–25 m (B-1). The deepest depth ranged from 40–80 m. The fish with the ultrasonic device mainly swam at the depth of 10–15 m with frequent dives to near the bottom of 20–25 m in September in Enshu Nada (Yasui et al. 1997b). This observation was similar to the swimming pattern of the fish B-1 with the deepest depth of about 40 m in autumn. Conversely, in winter (December, January and February), all fish (B-1, B-2, D-1) swam mainly near the surface shallower than 10 m with the deepest depth from 65 to 115 m with a tendency to be deeper in winter than in autumn. Furthermore, the depths at which burrowing occurred indicating the depth of the bottom supports this seasonal change. As a result, we conclude that ocellate puffer (1–2 years old) distribute vertically from near the surface to 25 m in the coastal area shallower than about 50 m in autumn and then swim shallower than 10 m with moving toward offshore at the depth of around 100 m in winter. This agrees with the observation of Hidaka et al. (1988). In Mie Prefecture, the surface longline fishing is operated only in Kumano Nada because the area of the continental shelf shallower than about 200 m is very narrow and the preferable fishing season is generally from December to February. We consider that surface longline is potentially an effective fishing method based to the swimming behavior of ocellate puffer in the winter season.

Vertical movements of the fish B-2, C-1 and C-3 changed drastically when the main swimming depths shifted to around 30–35 m with frequent rising to about 10 m during the spawning season. This swimming pattern was exhibited for at least 10, 3, 2 days, respectively prior to recapture at the spawning ground off Anori with the depth of around 35 m (Nakajima and Nitta 2000; Nakajima 2005). On the other hand, the fish D-1 showed the same swimming pattern during the periods from April 28 to May 5 with the deepest depth mostly at 15–20 m, being coincident with the spawning ground located at the depth of around 20 m off Irago, Aichi Prefecture (Shirakiya et al. 2002).
It is well established that males of this species remain longer and engage in spawning activities multiple times in known spawning grounds (Fujita 1988). The maturation age of males is 2 years old for this species (Matsuura 1997; Tokai et al. 1993) and the fish B-2, C-1, C-3 and D-1 were all males and 2 years old at the time of recapture. These observations confirm the habit of male ocellate puffer fish. The above-mentioned swimming behavior, which is characterized as staying near the bottom with repeated episodes of rising toward surface is suggested to be related to specific spawning behavior of male ocellate puffer. Moreover, it is suggested that male ocellate puffer remain at the same spawning ground for at least 8–10 days and this data agrees well with previous papers (Matsuura 1997; Fujita 1988). Furthermore investigations will be also required to clarify the specific behavior of females which has not been well clarified.

To make clear the homing behavior, it may be a clue to understand the pre-spawning swimming activity. Chum salmon are observed to decrease frequencies of the up-and-down behaviors and tend to stay in the surface waters when the fish change to migrate from the offshore waters to the coastal waters (Wada and Ueno 1999). Nakajima and Nitta (2005) estimated that ocellate puffer started to move toward the spawning grounds from around March with the observation of daily longitudinal locations obtained by the tag data. Male ocellate puffer (B-2, D-1 and C-3) adapted their vertical distribution gradually to the above specific swimming behavior by undergoing such vertical movements for 10–27 days and agreed with the estimation mentioned above. However, the fish C-1 was found to move rapidly toward the spawning ground only in about 2 days. We need to further analyze the vertical behavior related to locations and sea conditions.

Related to the period during post-spawning season until September, it is not denied that ocellate puffer swim relatively in the shallower layer though the monthly deepest depths were different from 40–85 m for the fish D-1, C-3 and E-1, 110–155 m for the fish C-2, respectively. The fish C-2 was estimated to be about 4 years old while other fish were 2 years old. This also indicates the possibility that ocellate puffer expand their habitat into deeper areas with increase of age. Concerning the distribution of fish with age, there are several papers for 0 age fish such as red sea bream, bastard halibut (Hanabuchi 1980; Kiso 1985; Takama 1981; Kamei 1980; Kawashima and Sioya 2006), but there is not much information about the relationship between age and habitat for immature and mature fish. In the case of red sea bream, 1–3 age fish are mainly caught at fishing grounds deeper than 20 m, but 4 and older age fish are deeper than 50 m (Ochiai and Tanaka 1986). Our data is the first report for ocellate puffer and considered that both these fish species tend to show the similar increasing depth distributions with the increase of age.

In conclusion, it is evident that adult ocellate puffer (older than 1 year old) swim mainly at the depth shallower than 25 m with diving to near the bottom except for the spawning season. Fujita (1988) reports that ocellate puffer are suggested to be highly benthic since they are mainly caught by bottom longline fishing. However, our results indicate that ocellate puffer do in fact possess a rather pelagic swimming habit. Ito et al. and Kobayashi also document such a swimming behavior shallower than 20 m with intermittent diving in northwest coastal area of Kyushu and Sea of Japan using the same archival tags. These observations further support our results and also indicate that this swimming behavior of ocellate puffer is ubiquitous.

*Burrowing behavior*

The behavior of ocellate puffer has been mainly divided into swimming and burrowing...
behaviors in culture ponds (Takai et al. 1959). This indicates that burrowing behavior is very important for ocellate puffer. Burrowing behavior was observed when water temperatures fell below 10˚C in winter or rose above 28˚C in summer in culture ponds (Takai et al. 1959). Burrowing behavior is also observed in *Takifugu niphobles* and *T. pardalis*, and it is considered that these species often burrow at night or as a predator avoidance behavior or to rest (Fujita 1988). They are also speculated to burrow under unfavorable environmental conditions or in response of prevention of disease based on observations in tanks, ponds and the sea (Fujita 1988). On the other hand, Furukawa and Okamoto (1966) suggested that burrowing behavior is not necessary for puffer groups as puffer can be successfully reared in the culture cage or without sand in the tank. However, detailed information about burrowing of ocellate puffer has not been clarified under field conditions. Burrowing behavior was observed frequently throughout the entire year for all seven fish in this study. The monthly burrowing occurrence rates ranged from 0 to 90% (ave. 45%). This means that ocellate puffer showed burrowing behavior on average at least every 2 days. The number of hours remaining buried per one event varied greatly with an estimated 72 hours as the longest. Furthermore, ocellate puffer often burrowed regardless of temperature, season, time of day or body size. Consequently neither diel regularity nor seasonal changes was observed. It is reasonable to speculate that burrowing behavior is related to rest among the reasons mentioned above. This idea is supported by such comments that the ocellate puffer often sleep on the bottom of culture cages and sleeping keeps puffer better condition for grow and to restore health if infected with some disease (Kumamoto Prefecture 2001). We believe that investigating the ecological functions of burrowing behavior is still necessary to understand this species.

**Optimum temperature for ocellate puffer**

Takai et al. (1959) estimated the safe water temperature zone for ocellate puffer to be between 8 and 29˚C and judged that optimal water temperature zone was from 16 to 23˚C based on the relationship between temperature and the beat count of the opercula in a tidal pond. Fujita (1988) reported that in culture ponds, puffer grew well under temperatures higher than 18˚C but growth decreased when temperatures became lower than 15–16˚C. It is also reported that water temperatures higher than 28˚C in summer must be avoided to prevent severe physiological stress in cultured puffer. As for the optimum water temperature of ocellate puffer in natural ocean conditions, there is little information available except for the relationship between longline fishing grounds and related water temperature. Achiha (2006) showed that the optimum temperature for the growth of this species was over 16˚C which was the monthly mean water temperature at around 100 m in western Enshu Nada. However, water temperature at the swimming depth was directly obtained in this study. Monthly ambient water temperature ranged from 11.2 to 29.2˚C through a whole year and averaged from 15 to 24˚C. This result corresponds well with that of the previous papers mentioned above (Takai et al. 1959; Achiha 2006). We conclude that the optimum water temperature for adult ocellate puffer is around 15–24˚C in natural field conditions. Additionally, it is indicated that the optimum water temperature shifts to be lower with the increase of age as shown for the fish of C-2 in August.

Furthermore, there are some information about spawning habit of ocellate puffer which exist at the bottom of 10–50 m with water temperatures around 15–18˚C from late March to late May in Japan (Matsusura 1997; Fujita 1988). In this study, the ambient water temperatures at the bottom of spawning grounds were 14.4–18.5˚C from late March to early May. This data agree with these previous papers. Moreover, it is the first report that the spawning season is suggested to already begin from the end of March if the water temperature rises up to the optimum in this study area.
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References


アーカイバルタグ標識放流試験で明らかになったトラフグの
遊泳行動の季節変化と適水温

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トラフグの季節的な遊泳行動を明らかにするため、1997年10月から1999年4月にかけて、アーカイバルタグ標識を装着したトラフグ21個体（全長37〜53 cm）を三重県沿岸域に放流した。回収された7個体について解析したところ、トラフグは、産卵期を除き、主に水深25 m 以浅を遊泳し、時々潜泳行動を示した。一方、産卵期においては、雄のトラフグは産卵場の海底20〜35 m に留まり、頻繁に表層まで浮上する行動を示した。このことから、トラフグは通常表層遊泳性であると考えられた。トラフグの鈍直行動は、秋季は最大水深35〜80 m、冬季は65〜115 m と変化し、冬季になると、沖合に移動することが示唆された。アーカイバルタグが記録した水温範囲は11〜29℃であったが、トラフグの適水温は15〜24℃と判断された。