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Study on behavioral characteristics of wild and hatchery-reared red tilefish

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ABSTRACT
The diel activity of red tilefish *Branchiostegus japonicus* was studied using two different methods: analysis of biotelemetry records and video observation. We have acquired the biotelemetry tracking records of the red tilefish which were released in Maizuru Bay and tracked from January 2003 to February 2004. The records ware compared to the time of sunrise and sunset, the duration of sunshine, and the lunar cycle, which may influence on light conditions. Whilst the fish showed diel activity, the fish changed their behaviors along with the time of sunrise and sunset; the fish probably moved out of their burrows in the daytime and retreated into the burrows at night. We could not find a clear relationship between the behavior and the other two factors. In the laboratory, the behavior of one hatchery-reared individual was recorded by video for five days in the experimental tank where the light condition changed periodically over 24 hours. The fish was more active in the light periods (550 lx) compared to in the dark periods (0 lx). Since the results from the two methods probably compliment one another, further experiments using the two methods will reveal the detailed behavior of red tilefish.

KEYWORDS: red tilefish, *Branchiostegus japonicus*, sea-farming, hatchery-reared fish, acoustic biotelemetry, video observation, diel activity

INTRODUCTION

The red tilefish *Branchiosegus japonicus* is one of the commercial fishes found on the muddy silt substrate at depths of 30-200 m off the Japanese Archipelago and in the East China Sea (Okumura, 2000). After the stock of this species dramatically decreased in 1980s, it has subsequently remained at low levels （website of Fisheries Agency; URL: http://www.jfa.maff.go.jp/）. Therefore, basic studies for enhancing the stock of red tilefish are crucially important.

Unlike yellowtail *Seriola quinqueradiata*, and milk fish *Chanos chanos*, red tilefish are not suitable to be fed and raised to a commercial size under artificial condition, since red tilefish is a slow-growing species. In contrast, because red tilefish are probably not highly migratory (Kiyono et al., 1977), this species is nominated as a highly recommended candidate for “Sea-farming” (Okumura, 2000). Sea-farming is one of the fishery management strategies; artificially produced seedlings are reared within the carrying capacity in the natural waters using empty or under-used ecological niches, and are to be introduced into the stock. In modern sea-farming for many fish species, captured or hatchery-reared larvae are raised under artificial condition to avoid starvation and predation, and only juveniles that have passed through the “critical period” are used as seedlings and released in the natural waters.

In the sea-farming for red tilefish, the technique for artificial insemination was established in late 1990s, and so yearly production of more than one hundred thousand settled juveniles has been achieved in Miyazu Station of Japan Sea-Farming Association (JASFA), which has been changed to the Miyazu Station, National Center for Stock Enhancement, Fisheries Research Agency (Hondoh et al., 2001). The subsequent step is developing the strategy for releasing seedlings to the natural waters. For the establishment of the releasing strategy, enhancing the survival rate of released seedlings is crucial, and behavioral characteristics of hatchery-reared fish may affect post-stocking mortality and effect of stocking (Masuda and Tsukamoto, 1998; Tsukamoto et al., 1999). However, information about the behavior of red tilefish is limited, except that red tilefish display territorial behavior (Okumura, 2000), and construct burrows (Toriyama, 1975; Hondoh et al., 2002).

From January 2003 to February 2004, in order to reveal the behavior of red tilefish in the natural waters, wild and hatchery-reared red tilefish were released in Maizuru Bay and tracked using “Acoustic Biotelemetry” technique (Yokota et al., 2004; Mitamura et al., 2005). In acoustic biotelemetry studies, ultrasonic wave is used as data carrier so that information about the released fish in the natural waters can be acquired from a distant place for longer periods. The above release experiment of red tilefish revealed that the fish of both origins were tracked more than three months, from which the diel pattern along with the alteration of day and night was observed (Yokota et al., 2004; Mitamura et al., 2005).

The diel activity of fish has been observed in many species (Tabata, 1988), and may be the result of their adaptation to the natural habitats. In order to acquire more information about the behavioral characteristics of red tilefish, first of all, a detailed study on the diel activity should be conducted. Previous studies have shown that fish behavior can be influenced by environmental factors, by comparing the biotelemetry records to water temperature (Kitagawa et al., 2000; Ohta et al., 2005), tidal height (Hiraoka et al., 2003), dissolved oxygen (Mitamura, 2005), and so on. Therefore, it is probable that the diel activity of the released red tilefish is related to diurnal varied factors such as alteration of night and day or fluctuation of light intensity.

Another approach for revealing fish behaviors in the natural waters is estimating them indirectly from the phenomena observed in experimental tanks. Hondoh et al. (2002) has shown that hatchery-reared red tilefish construct tube-shaped burrows of a size of 75 mm total length in tanks. Unlike biotelemetry techniques, behaviors of fish in tanks are easily observed directly under artificially controlled conditions. If the behavior of fish changes along with the variations of light condition in the aquarium, tank experiments will be one of the useful methods to compliment the behavior estimated only from the biotelemetry records.

To test whether the diel activity of red tilefish is related to the light condition, we conducted the following analysis and experiment. First, the biotelemetry records of the released red tilefish tracked from January 2003 to February were compared to the time of sunrise and sunset, the duration of sunshine in the daytime, and the lunar cycle. Then, one hatchery-reared red tilefish was tentatively observed in an experimental tank where light intensity varied periodically over 24 hours. In this paper, based on the analysis and experiment, the relationship between the diel activity and variation of light intensity is verified, and capability of further study for the behavior of red tilefish is also described.

MATERIALS AND METHODS

Analysis of biotelemetry tracking records

Acoustic biotelemetry tracking on red tilefish was conducted in Maizuru Bay from January 2003 to February 2004 (Yokota et al., 2004; Mitamura et al., 2005). The summary of the tracking is described as follows. Ten wild fish (A1-10: 322±31 mm total length (TL), 431±126 g body weight (BW)) and four hatchery-reared fish (B1-4: 315±13 mm TL, 443±27 g BW) were used in this experiment (Table 1). The ultrasonic transmitter (V8SC-6L, transmits one signal at random interval of 20-60 seconds, VEMCO Ltd., Canada) was surgically inserted into the peritoneal cavity of the fish under anesthesia. After the surgical treatment, the fish were kept in black polycarbonate tanks (500 L) for two to five days to observe any negative effect of the operation. The fish were released one after another from the surface water in the central part of Maizuru Bay which is a typical semi-closed water area (Table 1, Fig. 1). Major part of the release site has a water depth of less than 20 m with a muddy silt substrate. After the release, signals from the released fish were monitored using ultrasonic receivers (VR2, VEMCO Ltd., Canada) moored around the release point (Fig. 2). The receiving range was within 350 m if V8SC-6L was used with VR2.

Table 1 Summary of origin, body weights (BW), total lengths (TL), release dates, dates of the last records, diel activity periods, and video recording period of the sample fish.

Fish	Origin	BW (g)	TL (mm)	Release	Last record	Diel rhythm
A1	Wild	322	288	17 Jan 2003	28 Jan 2003	–
A2	Wild	334	310	17 Jan 2003	28 May 2003	05 Feb – 26 May 2003*
A3	Wild	650	364	17 Jan 2003	26 May 2003	22 Feb 03 – 22 Apr 2003
A4	Wild	502	330	17 Jan 2003	21 Jan 2003	–
A5	Wild	514	334	15 Aug 2003	15 Aug 2003	–
A6	Wild	446	323	15 Aug 2003	28 Aug 2003	–
A7	Wild	204	258	15 Aug 2003	20 Aug 2003	–
A8	Wild	516	351	15 Aug 2003	16 Aug 2003	–
A9	Wild	390	334	15 Aug 2003	16 Aug 2003	–
A10	Wild	434	328	15 Aug 2003	16 Aug 2003	–
B1	HR**	438	318	12 Aug 2003	28 Feb 2004	18 Aug 2003 – 22 Feb 2004***
B2	HR**	416	300	12 Aug 2003	17 Aug 2003	–
B3	HR**	436	312	12 Aug 2003	03 Sep 2003	19 – 22 Aug 2003
B4	HR**	480	332	12 Aug 2003	14 Nov 2003	09 Oct – 24 Oct 2003
B5****	HR**	450	308	–	–	–

* There were terms where circadian rhythm was ambiguous.

** HR: Hatchery-reared

*** Diel activity pattern was observed and day and night were reversed.

**** Fish B5 was observed in the experimental tank.

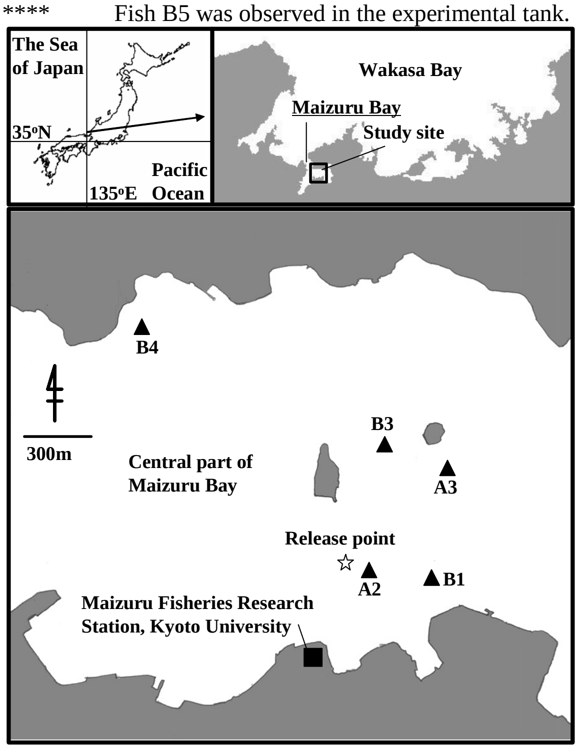

Fig. 1 Location of the release site, central part of Maizuru Bay. The star mark shows the release point. The filled triangles show the positions where fish stayed for long periods (A2, 3, B1, 3, 4).

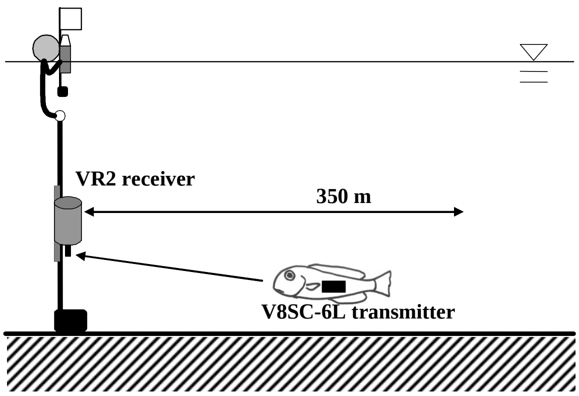

Fig. 2 Schematic drawing of the tracking system. The VR2 is a submersible receiver stationed in the study site for long-term monitoring. The receiver automatically records the ID number and the time stamp from transmitters when a tagged fish is within the receiving range; the range is about 350 m if V8SC-6L is used with VR2.

For each fish, records of the VR2s were rearranged in time-series order, and frequency of signal reception every 60 minutes was calculated. The records of the fish were compared to the time of sunrise and sunset, the duration of sunshine, and the lunar cycle, which may have influence on light condition in the release site. The time of sunrise and sunset was referred to the website of National Astronomical Observatory of Japan (URL: http://www.nao.ac.jp/). The hourly duration of sunshine in Maizuru City was referred to the website of Japan Meteorological Agency (URL: http://www.jma.go.jp/JMA_HP/jma/index.html), and was compared to hourly numbers of recorded signals in each 60 minutes; in this comparison, if signals of one individual were recorded continuously by more than two VR2s, the record of the only one VR2 which had received signals most frequently was used. The lunar cycle was referred to the website of Astro Arts (URL: http://www.astroarts.co.jp/). We investigated whether the diel activity pattern was disturbed in the new or full of the moon.

Video observation in the laboratory

One hatchery-reared fish (B5: 308 mm TL, 450 g BW) was used in this experiment. This experiment was carried out in an equipment (Fig. 3) provided by the Maizuru Fishery Research Station, Kyoto University. One part of the room equipped with a light which was turned on 7:00-19:00 (light period) and off 19:00-7:00 (dark period) automatically closed off with a blackout curtain. An acrylic aquarium (90×45×45 cm) was set just under the light. A video camera (HOGA, Japan) was placed at about 1 m distance from the aquarium to record the entire aquarium at once. An infrared illuminator was also placed beside the aquarium so that the fish was recorded during the dark period. Sea water and air were supplied continuously to the aquarium. The light intensity in the light period was 550 lx (SLX-1332D, Shiro Industry Co., Japan), while that in the dark period was 0 lx. The fish was introduced into the aquarium during the light period (10:00) and recorded for five days continuously. After the recording, we counted number of "turn behavior" (the fish changes its orientation more than 180 ^{o}) every ten minutes. The comparison was conducted using *t*-test between the numbers of turns in the both periods excluding the data of 7:00-8:00 and 19:00-20:00, in order to eliminate the trauma of the abrupt change of light condition (Blaxter, 1969).

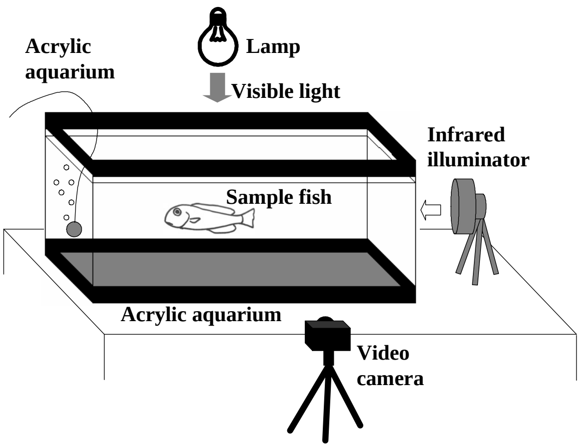

Fig. 3 Schematic drawing of the experimental tank in which fish B5 was recorded by video.

RESULTS AND DISCUSSION

Analysis of biotelemetry tracking

The signals from the seven wild fish (A1, 4-10) and one hatchery-reared individual (B2) were tracked for only 13 days after the release, and then were lost from the central part of Maizuru Bay. In contrast, the two wild fish (A2, 3) and three hatchery-reared individuals (B1, 3, 4) were tracked for 21-200 days, from which diel pattern was detectable; signals were recorded with high frequency in the daytime and with low frequency at night (data of fish A2 is shown as an example in Fig. 4), except for one hatchery-reared fish B1 which was mainly detected at night. The diel pattern of records might indicate a diel behavioral change of fish; the fish moved out of their burrows during the daytime and retreated into the burrows at night (Fig. 5), considering the habit of constructing burrows (Toriyama, 1975; Hondoh et al., 2002) and the attenuation of acoustic signals by bottom substrate (Starr et al., 2002).

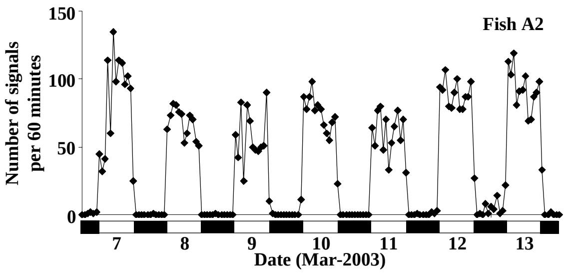

Fig 4 Hourly number of recorded signals of wild fish A2 from 7 to 13 March 2003. The bar at the bottom of the graph shows daytime (6:00-18:00) and nighttime (18:00-6:00). Signals were recorded with high frequency in the daytime and with low frequency at night.

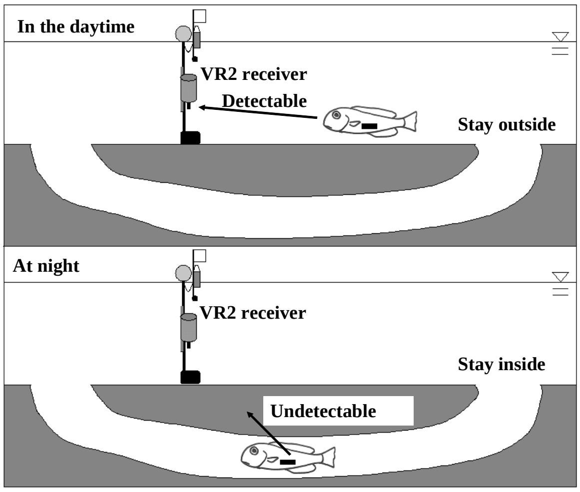

Fig. 5 Imaginary illustration of diel behavioral change of red tilefish. They move out from the burrow during the daytime and retreat into the burrow at night.

In the records of fish A2, 3, B4 during diel pattern periods, a change in the pattern of signal reception synchronized with variations of the time of sunrise and sunset (data of fish A2 are shown as an example in Fig. 6), and occurred less than 30 minutes before sunrise and less than 30 minutes after sunset (data of fish A2 are shown as an example in Fig. 7). The habitat of wild red tilefish ranges at water depths of 30-200 m (Okumura, 2000), and the light intensity of their habitat is lower than that of the surface. Therefore red tilefish in their habitat might adapt to low light intensity conditions.

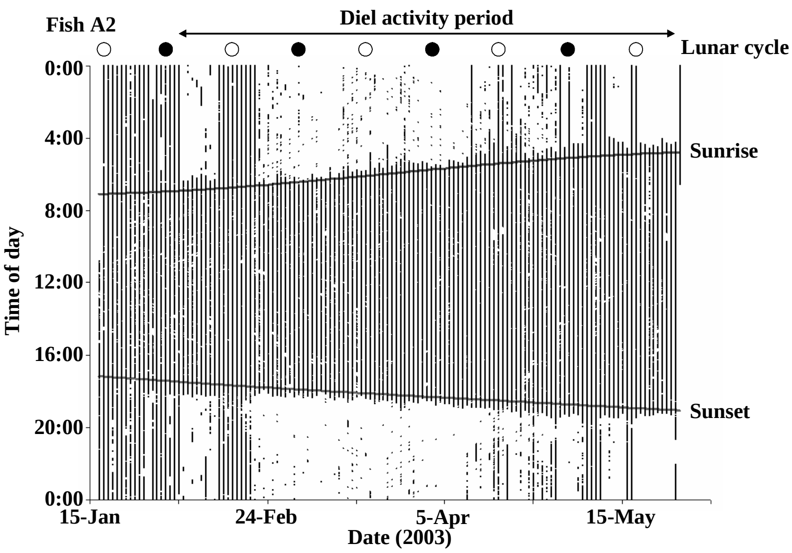

Fig. 6 Times of all recorded signals from wild fish A2. Times of sunrise and sunset are also inserted. In the VR2 records of A2, diel pattern was clear from 5 February to 26 May 2003 (shown by the two-headed arrow). During these periods, a change in the pattern of signal reception synchronized with variations of the time of sunrise and sunset. The circles at the top of the graph show lunar cycle; filled circles show the new moon, and open circles show full moon.

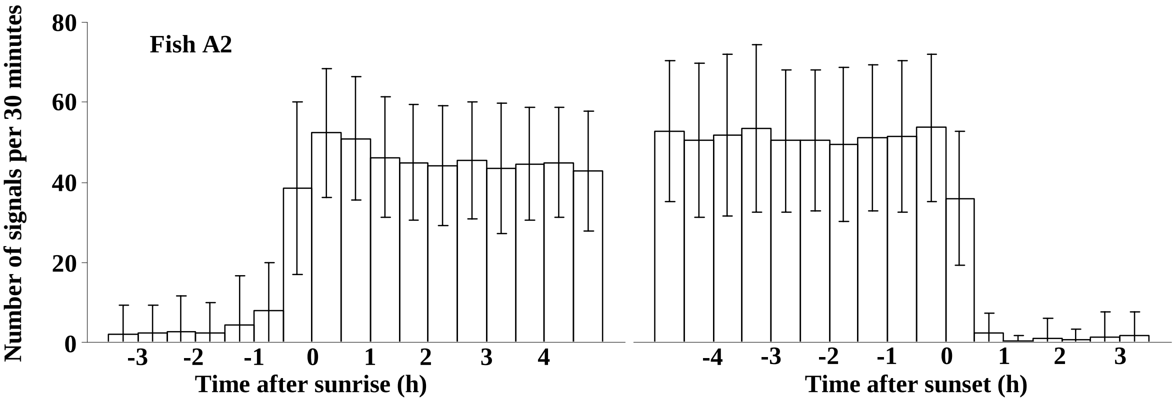

Fig. 7 Number of recorded signals per 30 minutes after sunrise and sunset in the diel pattern of A2. While showing diel pattern, changes in the pattern of signal reception happened in less than 30 minutes before sunrise and in less than 30 minutes after sunset.

During diel pattern periods, there was no relationship between the hourly number of recorded signals in the daytime and the hourly minutes of sunny periods (R^2 = 0.0061 for fish A2, R^2 = 0.0043 for fish A3, and R^2 = 0.0103 for fish B4). In the VR2 records, the frequency of signal detections may reflect the ratio of time that the released red tilefish are outside their burrows, unless they move horizontally more than a few hundreds meters. Therefore, the behavior of the fish might not have been influenced by the fluctuation of a high level of light intensity in the release site (less than 20 m deep) in the daytime, but a relative low level at dawn and dusk. However, in this analysis, we did not consider height of sun altitude and water turbidity which may directly influence on the light conditions in the release site. Therefore, we can not deny that hourly duration of sunshine alone did not reflect the light condition in the release site so that the relationship was not observed clearly.

In VR2 records of fish A2, 3 and B4, the disturbances of diel pattern did not always happen at full moon (data of fish A2 are shown as an example in Fig. 6). It is to be determined whether behavior of red tilefish might change along with the lunar cycle or not. However, we can not completely deny that the fish might have felt the faint moonlight and stayed outside their burrows, since the release site is a shallow bay having a water depth of less than 20 m. Incidentally, the lunar cycle relates not only to the light condition at night but also to the magnitude of the tidal current. Therefore, like the estimated inshore migration of larval Japanese flounder *Paralichthys olivaceus* (Burke et al., 1995), the fish might have felt the tidal current and changed their behavioral pattern.

Video observation in the laboratory

The turn frequency of fish B5 fluctuated along with the alteration of the light and dark conditions (Fig. 8). Since the number of turns in the light periods (15.1±5.2 terns per 10 minutes) were statistically larger compared to that in the dark periods (7.4±5.8 turns per 10 minutes) (*t*-test, $P<0.05$), the fish B5 was more active in the light periods than in the dark periods. This variation of activity was consistent with the diel behavioral change estimated from the biotelemetry tracking experiment.

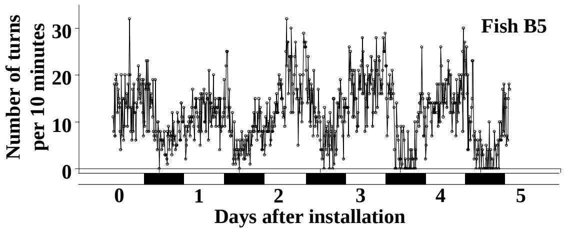

Fig. 8 Number of turn behaviors that one hatchery-reared fish B5 displayed every 10 minutes in the experimental tank. The bar at the bottom of the graph shows light periods (7:00-19:00) and dark periods (19:00-7:00). The fish were more active in the light periods compared to in the dark periods.

CONCLUSION

In the analysis of biotelemetry records, the behavior of the fish was clearly related to the sunrise and sunset. In contrast, we could not find the relationship between the behavior and the other factors: the duration of sunshine and the lunar cycle. At least, red tilefish in the natural waters might change their activity at a relative low light intensity threshold. Further biotelemetry tracking with the measurement of light intensity will reveal detailed reactions to the fluctuation of light intensity in the natural waters. The laboratory experiment revealed that diel activity of red tilefish can be observed under artificial conditions in the tank. However, it is probable that such rapid changes of light condition in this laboratory experiment seldom happen in the natural waters. The reactions of fish will be observed more clearly, if sample fish are observed in tanks where the light condition changes gradually as it does in the natural waters. Further observations of many individuals in the tank will reveal the differences among the fish, since there is one hatchery-reared individual (B1) which showed opposite pattern of diel activity in the natural waters.

The procedures of both biotelemetry and video observation for the study on the behavior of red tilefish are established. Therefore, detailed experiments using the two methods will reveal the behavioral characteristics which can be applied for the development of the releasing strategy of red tilefish.

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