The application of the biotelemetry to yellowtail aquaculture

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ABSTRACT
In order to reveal feature of cultured yellowtail swimming behavior in the aquaculture pen, we investigated their swimming depth by the data logger in relation to the ambient water temperature between April 2004 and November 2004. The yellowtail exhibited two diel vertical swimming behavior patterns, i.e. day-shallow and night-deep pattern, and day-deep and night-shallow pattern. We defined daytime and nighttime as from 08：00 to 16：00 and from 20：00 to 04：00, respectively. Average swimming depth and ambient water temperature were calculated in the daytime and nighttime in each day. The yellowtails changed the swimming depth in accordance with the seasonal temperature fluctuations. The swimming depth shifted from the deep layer to the shallow layer as the water temperature increased in spring. In summer, the yellowtail frequently swam around 2m depth in the nighttime. However, the swimming depth deepened during periods when the thermal stratification developed and diurnal large amplitude temperature fluctuations occurred. The swimming depth was changed from shallow layer to deep layer in relation to the temperature falling in the daytime and nighttime in fall.

KEYWORS: Yellowtail, aquaculture, swimming depth, ambient temperature, seasonal variation

INTRODUCTION

Fish produced by the aquaculture are one of the important food resources. The aquaculture commonly has been conducting in the shallow coastal seas. The shallow coastal seas tend to be cooler in the winter and hotter in the summer than the open ocean in the mid-latitude area. In addition, the water temperature frequently changes with large amplitude in a few days in the coastal sea. Such seasonal and short period temperature changes influence growth, stress, metabolism, fish disease, spawning, food intake and food conversion of the cultivated fish in the aquaculture pen (Stickney, 1979).

Biotelemetry method can measure fish behavior and physiological condition such as body temperature and cardiac beat. The measurement results may provide us variation in the fish health condition and gonadal maturation. The swimming behavior analysis is useful for the setting of size of aquaculture pen. However, aquaculture studies using biotelemetry method are very few in number

Yellowtail, *Seriola quinqueradiata*, is one of the commercially important fishes for aquaculture in Japan. Kasai *et al.* (1998 and 2000) reported wild immature yellowtail behavior. According to their study, the yellowtail showed an apparent diel vertical migration pattern (day-deep and night-shallow). And they crossed thermocline during the daytime, but calmed down and remained in the shallow layer above the thermocline at night. However, the yellowtail behavior in the aquaculture pen is not known. In this study, in order to reveal features of the cultured yellowtail swimming behavior in the aquaculture pen, we investigated their swimming depth and ambient water temperature using a data logger.

MATERIALS AND METHODS

Study site and yellowtail rearing

Our experiment was conducted in Tanabe Bay, which is located in the western part of Japan (Fig. 1a). A lot of aquaculture pens are deployed in this bay head (Fig. 1b). The aquaculture pen for the experiment was set on the southern part of this bay, which is denoted by the star symbol in Fig. 1b. Longitudinal and transversal lengths of the experimental pen are 7 m and the depth is 6 m.

Data logger

The temperature and depth data logger (DST milli: Star-Oddi Ltd.) was implanted into the peritoneal cavity of sample yellowtail. After implanting, the yellowtail was released in the aquaculture pen (Fig. 1a). The logger measures the peritoneal cavity temperature and swim depth. The logger weighed 9.5 g, was 12.5 mm in diameter and 38.4 mm in length. The recording interval is 5 min.

Observation of the ambient water temperature

We measured the ambient water temperature and salinity at 0.5, 4 and bottom -1 m in the aquaculture pen with the temperature and salinity meter (COMPACT CT, Alec Electronics Co., Ltd.). Sampling interval was 1 minutes. Unfortunately, the salinity sensor was disturbed by the marine organism attachment.

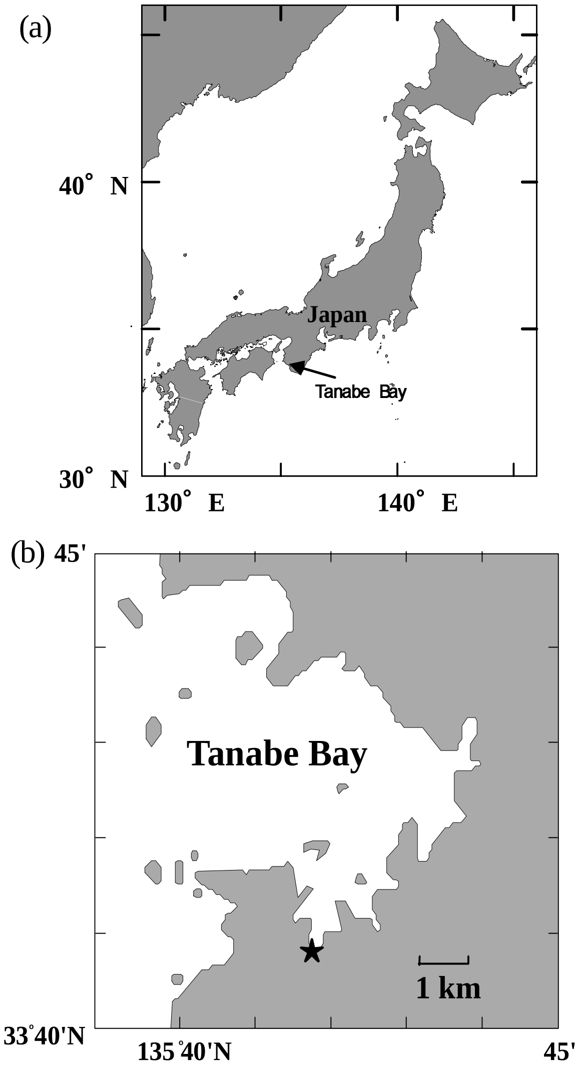

Fig. 1. Map of Japan (left) and Tanabe Bay (right). The star symbol indicates the position of the study site.

Table 1. Summary of ID, date, fork length and body weight.

ID	Date (2004)	Fork length (cm)	Weight (kg)
M5889	**16 Apr. - 3 Jun.**	**-**	**2.1**
M6186	**18 May. - 2 Aug.**	**55**	**3.8**
M6199	**28 Aug. - 12 Nov.**	**52**	**2.3**

Sample fish

Twenty yellowtails were reared in the pen since 4 April 2004. These fishes were originated from wild juveniles, and were reared for one year before this experiment. Yellowtails were fed compound food at 16:30 everyday except on Sunday and in bad weather conditions.

Four cultured yellowtails were used in this study. We measured fork length and body weight before data logger implanting. Fork lengths of these fishes ranged from 50 to 55 cm. Fork length of yellowtail M5889 was not measured. Detailed information of these four fishes is listed in Table 1.

Judging from the variation in the ambient water temperature, the study terms were divided into three －spring (cold to warm season) , from April to May; summer (warm and stratified season), from June to August; fall (warm to cold season), from September to November. Measuring period of M5889, M6186 and M6199 corresponded to spring, summer and fall, respectively. Therefore, the measured data of each sample fish were analyzed as corresponding each season.

RESULTS

Diel vertical swimming

Figure 2 shows a part of the time-series data of swimming depth obtained from yellowtail M5889. This result indicates the typical diel vertical swimming pattern. The yellowtail swam around 4.8 m, whiche is near the bottom of the aquaculture pen, in the daytime. In the nighttime, the swimming depth shifted to the shallow layer. The diel vertical swimming pattern was common among the four yellowtails (not shown).

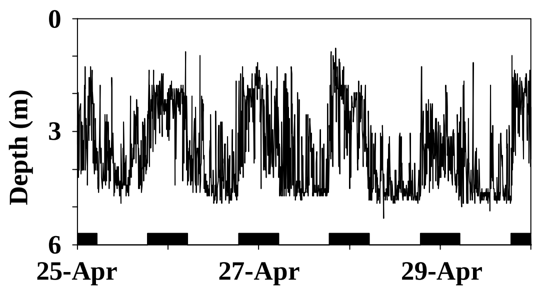

Fig. 2. Typical diel vertical swimming pattern of the yellowtail (ID; M5889). The dark horizontal bars indicate the nighttime.

In order to estimate average swimming depth under the light (daytime) and no-light (nighttime) conditions and to exclude the swimming behavior due to feeding, we defined the daytime and nighttime as from 08:00 to 16:00 and 20:00 to 04:00, respectively. Each time range is completely a light condition or no-light condition in our study area. Average and standard deviation of the swimming depth were estimated at each time zone. We analyzed the swimming depth in relation to the ambient water temperature. The temperature was estimated average value and standard deviation at same time zone.

Spring (cold to warm season)

Figure 3a shows time series of averaged swimming depth of yellowtail (ID: M5889) in the daytime and nighttime in spring. M5889 changed the swimming depth in the daytime from shallow layer to deep layer between 17th April to around 28th April, and stayed in the deep layer after that (Fig. 3a). In the nighttime, the depth tended to shift from deep layer to shallow layer during the experiment period. In relation to shifts of the swimming depth, the vertical swimming pattern in the daytime and nighttime reversed at around 23th April. The swimming depth in the daytime was shallower than that in the nighttime until 21th April. The clear diel vertical swimming was not seen from 21th April to 25th April. After 25th April, the vertical swimming pattern reversed from day-shallow and night-deep pattern to day-deep and night-shallow pattern.

Figure 3b shows raw ambient water temperature at 0.5 m and 4 m depth in spring. The temperatures at both depths are almost same in spring, and the clear thermal stratification might be undeveloped in spring. The temperature decreased from 22th April to 29th April, and increased rapidly from 4th May to 15th May. After that, moderate rising of the temperature was seen until 2th June. Fig. 4 shows relationships between the average water temperature at 4 m depth and the average swimming depth. The swimming depth in both daytime and nighttime has no correlation with temperature before shift of diel vertical swimming pattern (17th － 25th April). After 26th April, although the swimming depth in the nighttime tended to increase as water temperature increasing, the correlation was not seen in the daytime.

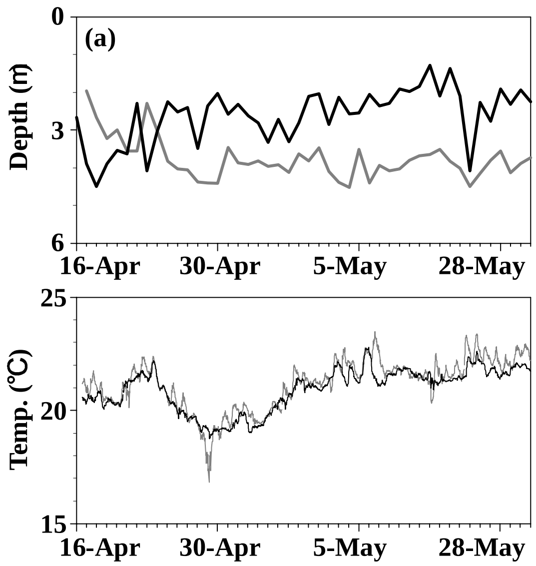

Fig. 3. (a) Time series data of average swimming depth of yellowtail (ID; M5889) in the daytime (gray line) and in the nighttime (black line). (b) Changes of ambient water temperature at 0.5 m depth (gray line) and 4 m (black line) in spring.

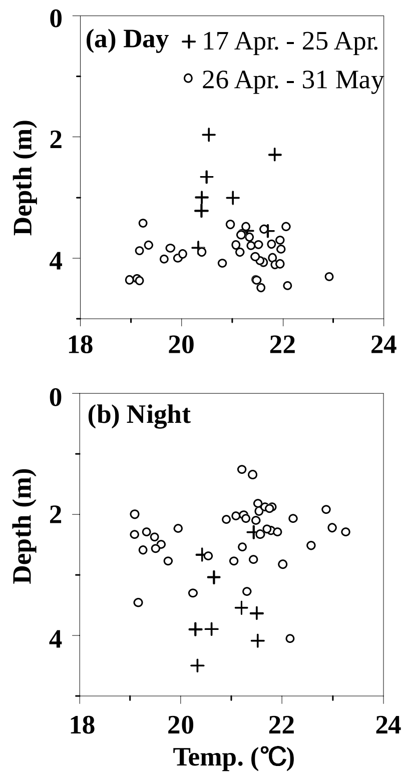

Fig. 4. Relationship between the ambient water temperature (4 m) and the average swimming depth of yellowtail (ID; M5889) in the daytime (upper) and the nighttime (lower) in spring. Plus and circle symbols indicate the data from 17 April to 25 April and from 26 April to 31 May, respectively.

Summer (Warm and Stratified season)

The averaged swimming depth of M6186 in the daytime was deeper than that in the nighttime in summer (Fig. 5). The averaged depths during this season were 3.3 m in the daytime and 1.9 m in the nighttime. The swimming depth variation indicated large daily change in both nighttime and daytime.

The water temperature increased in step with time (Fig. 5b). In the daytime, the average swimming depth tended to be shallow as temperature increased (Fig. 6a). There was no relationship in the nighttime (Fig. 6b). The temperature difference between 0.5 m and 4 m depth was frequently large, for example from 27th June to 5th July and from 15 July to 24 July. The difference might be caused by development of thermal stratification. The temperature largely fluctuated in a day during the stratification periods. The swimming depth during stratified and large diurnal variation periods was deeper than in other periods. Standard deviation of temperature in the daytime and nighttime indicates the strength of the variation in the temperature in a time. Fig. 7 shows the relationship between standard deviation of the temperature at 4 m and the swimming depth in the daytime and nighttime. The swimming depth in the nighttime tended to be deep as the standard deviation value increased, although there is no relationship in the daytime.

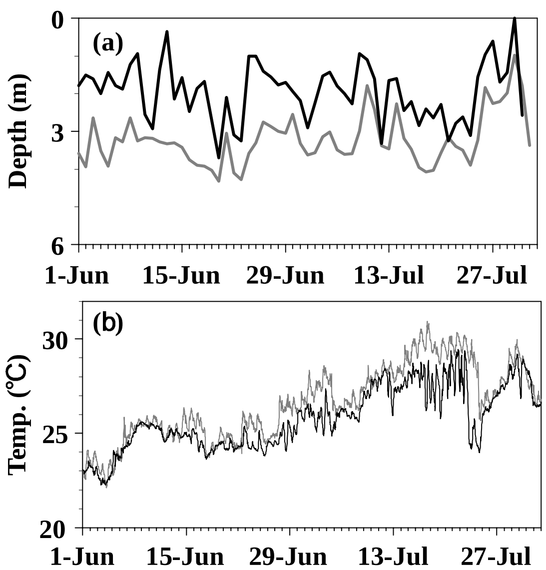

Fig. 5. (a) Time series data of average swimming depth of yellowtail (ID; M6186) in the daytime (gray line) and in the nighttime (black line). (b) Changes of ambient water temperature at 0.5 m depth (gray line) and 4 m (black line) in summer.

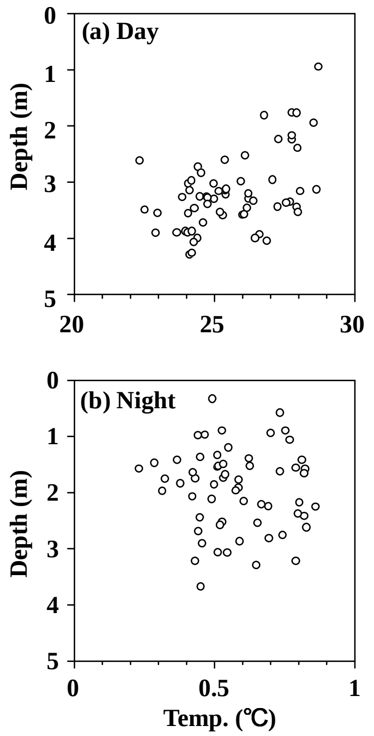

Fig. 6. (a) Relationship between the average ambient water temperature (4 m) and the average swimming depth of yellowtail (ID; M6186) in the daytime (upper) and nighttime (lower).

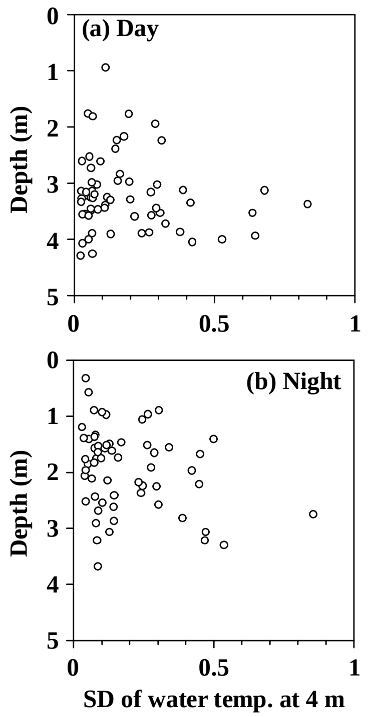

Fig. 7. (a) Relationship between standard deviation of the ambient water temperature (4 m) and the average swimming depth of yellowtail (ID; M6186) in the daytime (upper) and nighttime (lower).

Fall (warm to cold season)

M6199 conducted day-deep and night-shallow type diel vertical swimming pattern, and was seen to have similar swimming pattern in the daytime and nighttime through the experiment (Fig. 8a). The swimming depth varied day by day until 9th September, and the yellowtail suddenly changed the depth to deep layer on around 12th September. The depth became shallow layer until 25th September and after 25th September gradually shifted to deep layer. Furthermore, the differences of the depth between the daytime and the nighttime got smaller and became finally less than 1m depth after 25th September.

Although the water temperature at 0.5 m and 4 m depth indicated the stepwise decreasing in this season, the differences of the temperature among both the depths sometimes became large (e.g. 11th—18th September and 14th—20th October). Comparing between the swimming depth and the temperature at 4 m depth, the swimming depth tended to deepen as the temperature descended. However, the relationship was separated into two periods, such as during 1th September to 23th September and during 24th September to 11th November (Fig. 9). The gradient of linear regression formula between the depth and the temperature in former period (daytime: $y = -0.91x + 28.4$, $R^2 = 0.41$; nighttime: $y = -0.56x + 19.5$, $R^2 = 0.28$) was gentler than that in later period (daytime: $y = -0.37x + 11.5$, $R^2 = 0.78$; nighttime: $y = -0.17x + 7.5$, $R^2 = 0.50$) in the daytime and the nighttime.

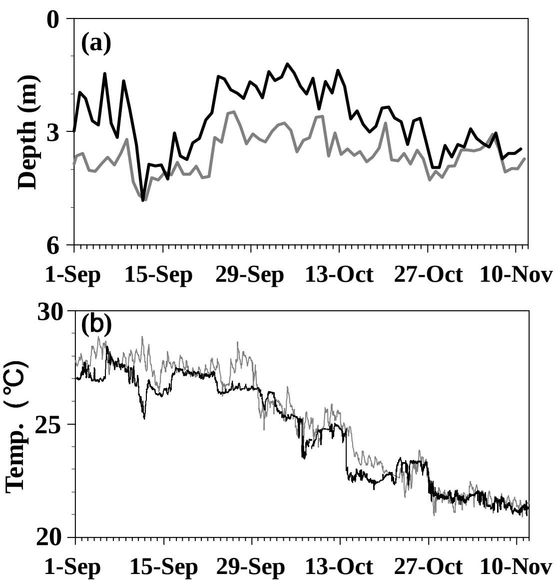

Fig. 8. (a) Time series data of average swimming depth of yellowtail (ID; M6199) in the daytime (gray line) and in the nighttime (black line). (b) Changes of ambient water temperature at 0.5 m depth (gray line) and 4 m (black line) in fall.

DISCUSSION

Diel vertical swimming pattern was observed in the behavior of many kinds of fishes including the yellowtail in the natural environment (e.g. Block *et al*., 1997; Kasai *et al*., 1998 and 2000). Cultured yellowtail also exhibited the diel vertical swimming pattern, and consistent with wild yellowtail behavior (Kasai *et al*., 1998 and 2000). Kasai *et al*. (2000) suggested that wild immature yellowtails exhibit the diel movement in relation to feeding. Although cultured yellowtails were fed the compound food at 16:30 only, diel vertical swimming behavior was observed (Fig. 2). The diel vertical swimming might not only relate with feeding.

Yellowtail (ID: 5889) in spring shifted the diel vertical swimming pattern from day-shallow and night-deep to day-deep and night-shallow (Fig. 3). This shift has not reported in wild yellowtail (Kasai *et al*., 1998 and 2000). However, their investigation was conducted in only fall. Wild yellowtail also possibly conduct the shift of diel vertical swimming pattern. Yellowtail exhibited the

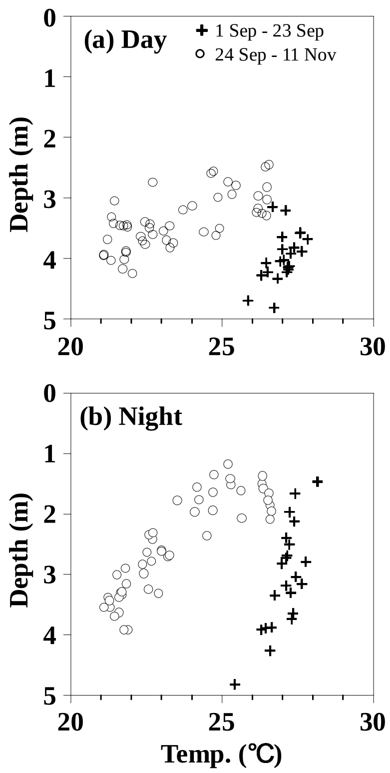

Fig. 9.Relationship between the average ambient water temperature at 4 m depth and the average swimming depth of yellowtail (ID;6199) in the daytime (upper) and the nighttime (lower) in fall.

day-shallow and night-deep swimming pattern only five days. There is no doubt that further experiments are necessary to clarify this mechanism.

We found two types of relationship between the swimming depth of yellowtail and ambient water temperature. Yellowtail in spring (ID: M5889) changed the swimming depth in the nighttime from deep layer to shallow layer in accordance with the increase of water temperature. On contrary, the swimming depth of M6199 became deep as temperature decreased in the daytime and nighttime in fall. The seasonal variations in the swimming depth accorded with the seasonal changes of ambient water temperature.

The swimming depth did not clearly relate with seasonal water temperature change in summer. However, the large amplitude temperature fluctuations induced the deepening of the yellowtail swimming depth in the nighttime. When the thermal stratification developed in the sea, the internal tide frequently occurs and induces the large amplitude temperature fluctuation. This vigorous fluctuation of water temperature probably influences on the yellowtail.

Cultured yellowtail in the aquaculture pen exhibited diel and seasonal variation in the swimming depth. Previous studies suggested that the variation in the swimming depth of yellowtails, like many other fish spices, relate with feeding behavior (e.g. Kasai *et al.* 2000; Holland *et al.* 1990). The swimming depth change of the fish induces the experienced temperature change. The water temperature change influences the metabolism and food digestion of the fish. The yellowtail may adjust the swimming depth to control metabolism and food digestion.

Generally, aquaculture pen which has the 4 m to 10 m depth is used for yellowtail aquaculture. Cultured yellowtail changed the swimming depth diel and seasonally. If the cultured yellowtail change their swimming depth to control the metabolism and food digestion, the deeper aquaculture pen may be effective for rearing the yellowtail behavior.

In this study, we applied the biotelemetry method to the yellowtail rearing in the aquaculture pen and revealed the seasonal change of swimming behavior, except for in winter. In this study, we reared twenty yellowtails in the aquaculture pen. In the case of commercial aquaculture, the 500 yellowtails are reared in the same size of the pen. There is no doubt that further experiments are necessary. Now, we have continuously conducted this experiment. Furthermore, we plan to investigate the swimming depth with different size of yellowtail.

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