

Depth-Temperature data logger revealed the fine-scale vertical movement of Mekong giant catfish *Pangasianodon gigas* in the reservoir

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ABSTRACT

In order to better understand the moving behavior of Mekong giant catfish *Pangasianodon gigas* in a reservoir, Thailand, two catfish were monitored using Depth-Temperature data loggers (UME 190DT, Little Leonardo, Tokyo, Japan) which were attached with a brand-new time-scheduled release system. The release system automatically detached the loggers from the catfish 5 days after deployment. Then we searched for VHF radio signals and found one of the two loggers approximately 2.2 km away from the release point. The other was never found because it was hidden by a dense cover of floating waterweeds. The logger that was recovered provided depth and temperature data for approximately 98 hours. Results from the data analyses found that the fish spent more than 99 % of their time above the depth of 3 m. The fish showed active vertical movement during the daytime but remained inactive during the nighttime (especially midnight). The fish made only 8 deep vertical movements greater than 4.8 m and the maximum swimming depth was 5.6 m. The differences in the ambient temperatures during these movements were less than 2.0 °C. The stable temperature might have little effect on the catfish behavior. During our experiment period, there was no thermocline although DO stratification was built up at the depth of 4 m, and the DO below 4 m deep was uniformly less than 10 %. These results indicated that the DO stratification might limit the vertical movement of the catfish. Furthermore, in 8 deep movements the descent rates were significantly lower than the ascent rate for each movement, respectively, which indicated that the fish might display the avoidance movement from the hypoxic waters.

KEYWORDS: MCTP, Mekong giant catfish, vertical movement, Depth-Temperature data logger, time-scheduled release system, Dissolved oxygen

INTRODUCTION

For the success of stock enhancement, the understanding of daily and annual movement patterns of the target species is obviously indispensable (Masuda and Tsukamoto 1998, Mitamura et al. in press, Mitamura 2005). Furthermore, the relationship between the movement patterns and the physiological and environmental condition data (e.g. temperature and dissolved oxygen) could not be ignored for the effective fisheries management. In many fish (e.g. freshwater, marine and anadromous fish), the fish movement patterns and the relationship between movements and the vertical distribution of water temperature and dissolved oxygen conditions have been investigated, and the results contributed to the effective fisheries management and the prevention of by-catch (Rahel and Nutzman 1994, Brill 1994, Block et al. 1997, Brill et al. 1999, Dargon et al. 2000, Kitagawa et al. 2000, Musyl et al. 2003, Cartamil and

Lowe 2004).

Mekong giant catfish *Pangasianodon gigas* is endemic to the Mekong River Basin and grow to colossal size. The catfish is also one of the largest freshwater fish in the world, measuring up to 3 m in length and weighing in excess of 300 kg (Rainboth 1996). The catfish shows one of the fastest growth rates of any fish in the world, reaching 150 to 200 kg in 6 years (Rainboth 1996). In the Southeast Asia, the catfish has been historically popular to the local people for a long time and has been also one of the most important fisheries around the Mekong River Basin in the Southeast Asia. Referring to the annual catch numbers of the catfish in the Chaing Khong District, Thailand from 1986-2003, the maximum catch of 62 fish was reported in 1990 while no catfish was caught from 2001-2003. This declining of the catch number implies that the wild catfish is close to extinction. Hogan et al. (2004) estimated that the total

number of the wild catfish in the Mekong River has decreased by approximately 90 %. Actually, the catfish is listed on the Convention on International Trade in Endangered Species (CITES) Appendix I and International Union for Conservation of Nature and Natural Resources (IUCN) Red List of threatened species as Critically Endangered Species.

The artificial insemination technique of the catfish developed in 1983 has produced catfish fries relatively easily in Thailand. In order to manage the stock of the catfish, attempts have been made to cultivate these hatchery-reared catfish both in earthen ponds and many reservoirs in Thailand. In order to improve the success of the stock enhancement program of the Mekong giant catfish, the long-term monitoring (> 1 year) of the catfish was conducted using acoustic telemetry in the reservoir and consequently showed that the catfish displayed the diel and seasonal movement in relation to the water temperature condition (Mitamura 2005). Although the vertical distribution of dissolved oxygen as well as water temperature also were the important factors that affected the fish behavior especially in the enclosed area such as the reservoir (Rahel and Nutzman 1994, Ultsch et al. 1999, Weltzien et al. 1999), the information about the dissolved oxygen was not included in the previous study (Mitamura 2005). Because some fishes respond physiologically to hypoxia within a few seconds (Davis 1975), it is apparently necessary to monitor the fish movement on the second time scale. However, the previous acoustic telemetry experiment provided the vertical movement data at intervals of between 20 to 60 seconds, and therefore the detailed description of both the swimming behavior and the quick reaction of the fish to the environmental condition has still to be produced.

In order to monitor the fish on the second time scale, I made use of recent bio-logging technology. Depth-Temperature data loggers are capable of monitoring the free-ranging fish behavior at regular intervals of 1 second. However, animal-borne data loggers require the recapture of animals for data retrieval and it is very difficult to recapture the instrumented free-ranging catfish. In this study, we used a brand-new developed time-scheduled release system. The system releases the data logger from the catfish and allows the logger to be retrieved via VHF radio signals. That is, recapture of the catfish is therefore not necessary.

In attempting to fill the gap in our knowledge, the objective of this study was set to quantify the detailed movement of the catfish, especially in relation to the vertical condition of the dissolved oxygen.

MATERIALS AND METHODS

Two hatchery-reared immature Mekong giant catfish were used in the experiment. Individual 1 (Total

Length: 79 cm, Body Weight: 4.5 kg) and Individual 2 (Total Length: 81 cm, Body Weight: 5.6 kg) were released at the shoreline on the dammed side of the Mae Peum reservoir (Fig. 1) on 2 August 2004, respectively, after instruments had been attached to their backs as follows.

The instruments were composed of a data logger (UME 190DT: 15 mm in diameter, 49 mm in length, 14 g in air, Little Leonardo), a float, a VHF radio transmitter, a plastic cable and a time-scheduled release mechanism. The data logger with 12-bit resolution, which recorded depth and temperature at 1 second intervals, was attached to a float made of balsa wood, in which a VHF radio transmitter with a 20 cm antenna was embedded (Fig. 2). A plastic cable connected to a time-scheduled mechanism (Little Leonardo) was attached through the back of the catfish under anesthesia (Fig. 2). The release mechanism included a timer that was activated 5 days after attachment. Once the release mechanism had been activated, the plastic cable was severed by an electric charge from the battery of the device, and the float was released from the catfish. The float floated to the surface of the reservoir and was located via VHF radio signals.

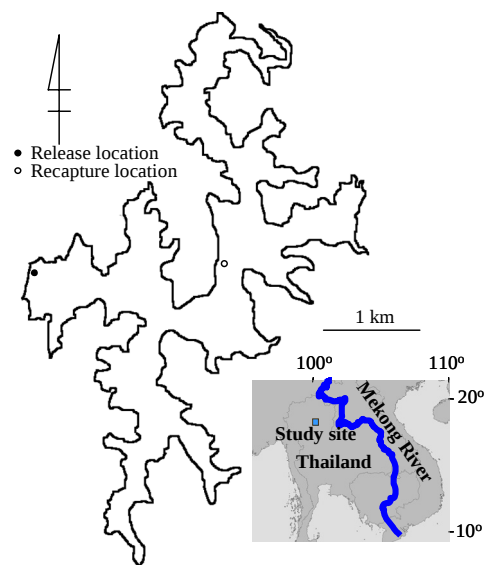


Fig. 1. Map of the Mae Peum reservoir at Phayao Province, Thailand. Small filled and open circles represent fish-release location and logger-recapture location, respectively.

Water temperature and dissolved oxygen

The vertical profiles of the water temperature and dissolved oxygen were measured at the intervals of 1 m in depth at seven sites all over the reservoir on 2 August 2004 using a dissolved oxygen meter (Model 58, YSI Inc.).

Table 1. Swimming depth and ambient temperature (mean $\pm$ S.D.) during the day and at night for one fish over 3 days.

Date	day/night	Mean depth (m)	S.D.	Mean temperature (°C)	S.D.
4-Aug	Day	1.5	0.6	29.0	0.3
	Night *1	1.3	0.7	29.3	0.3
5-Aug	Day	1.2	0.5	29.0	0.3
	Night	1.7	0.7	28.9	0.2
6-Aug	Day *1	1.6	0.8	28.6	0.2
	Night	1.3	0.7	29.3	0.3

Day: 6:00-19:00, Night:19:00-6:00.

*1 Night on 4 August and Day on 6 August were 0:00-6:00 and 6:00-14:30, respectively.

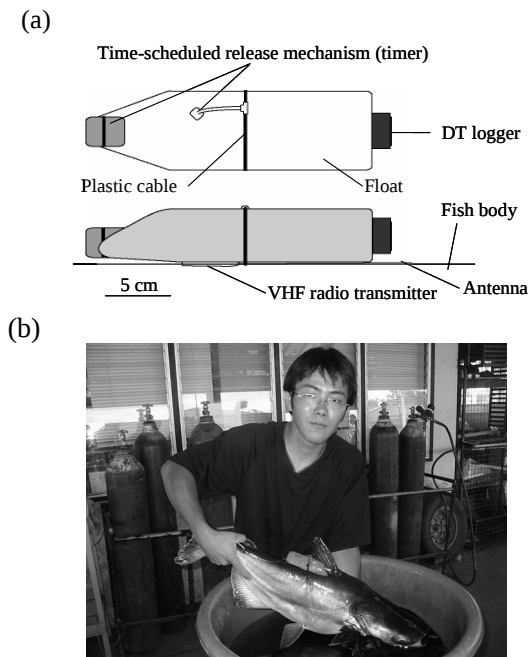


Fig. 2. Top and side views of a time-scheduled release system with a micro-data logger (a). Mekong giant catfish with the time-scheduled release system (b)

RESULTS

Two time-scheduled release mechanisms worked well as planned, and one of the floats was successfully retrieved from the Individual 1. The float was found approximately 2.2 km away from the release point, 5 minutes after activation of the release mechanism (Fig. 1). The DT logger provided approximately 98 hours of data (Fig. 3). The ambient temperature difference of the first 36 hours was greater than those in the following hours. Therefore we suspected that the fish might have been influenced by the float attachment within these periods and thus these data were removed from further analyses. Unfortunately, the other float could not be retrieved from the Individual 2 due to a dense cover of floating waterweeds. This point was approximately 300 m away from the release point.

The fish (Individual 1) spent more than 99 % of its time above the depth of 3 m. Mean swimming depth was 1.4 ± 0.7 (S.D.) m. Ambient temperature was almost constant over the swimming depth of the fish. Mean ambient temperature was 29.0 ± 0.3 °C, which indicated that the fish stayed in the thermally mixed waters. The daily average swimming depth and ambient temperature for both the daytime and the night-time are given in Table 1. The fish showed vertical movement almost continuously through our experiment. Maximum swimming depth was 5.6 m. The fish made only 12 deep vertical movements greater than 4.5 m (Table 2). These vertical movements were made at dusk, night and dawn. The durations of these movements ranged 27 to 112 seconds (mean: 55 seconds) (Table 2). The difference of the ambient temperature during these movements ranged 0 to 2.0 °C (Table 2). The descent rate and the ascent rate of the fish just before and after the maximum swimming depth of each movements ranged from 0.06 ± 0.06 m s⁻¹ to 0.24 ± 0.11 m s⁻¹ and from 0.10 ± 0.06 m s⁻¹ to 0.48 ± 0.28 m s⁻¹, respectively. The descent rates when the fish moved below the depth of 4.8 m were significantly lower than the ascent rate for each vertical movement, respectively (*t*-test, *P* < 0.05). In 3 of 6 vertical movements up to the depth of 4.5-4.6 m, the descent rates were significantly lower than the ascent rate (Table 2).

Standard deviation of hourly vertical movement data were defined as the activity index (Fig. 4). Standard deviation for the midnight (23:00-2:00) was smaller than those for the daytime, which indicated that the fish did not show active movement during the midnight. Figure 5 shows typical profiles of swimming depth and ambient temperature of the fish during the daytime and nighttime, respectively. The fish showed the vertical movement almost continuously during the daytime, and did not change the swimming depth during the midnight which implied that the fish stayed at the shallower bottom.

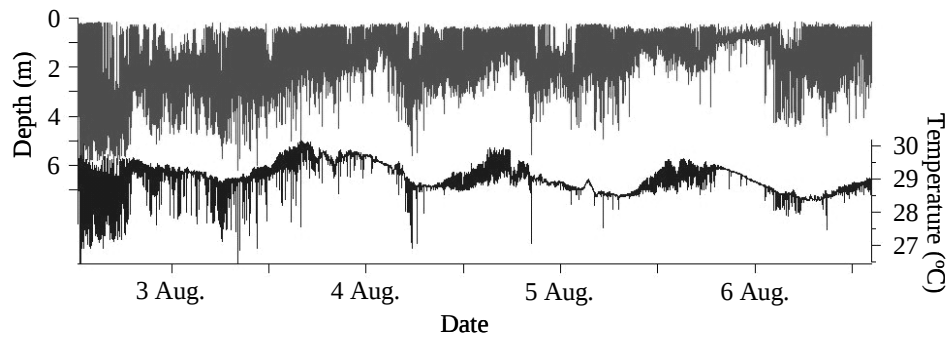


Fig. 3. Time series data of swimming depth and ambient temperature.

Vertical distribution of the water temperature and dissolved oxygen determined by the dissolved oxygen meter

Vertical profiles of water temperature and dissolved oxygen during our experiments are provided in Fig. 6. Water temperature was almost uniform from the surface layer to the depth of 4 m. There was not a sharp thermocline and water temperature gradually decreased up to the bottom from the depth of 4 m (Fig. 6). The mean water temperature ranged from 29.5 (surface) to 24.8 (bottom) °C. Dissolved oxygen stratification was built up at the depth of 4 m. The dissolved oxygen below 4 m deep was uniformly less than 10 % saturation, which indicated that the fish could not survive within this water column. The difference of the vertical distribution of both water temperature and dissolved oxygen among the measurement locations was not found.

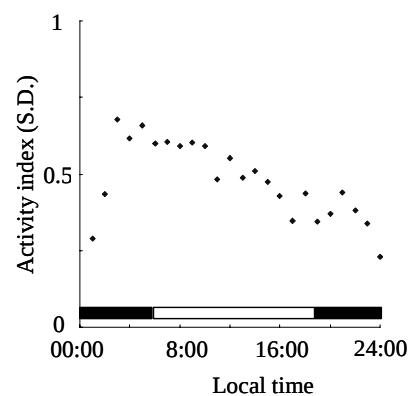


Fig. 4. Hourly activity determined using the standard deviation of hourly swimming depth data. The dark and white horizontal bars indicate the nighttime and the daytime.

Table 2. Ascent and descent rates of deep vertical movements greater than 4.5 m. *T*-tests were used to determine whether ascent and descent rates differed.

Maximum depth (m)	Duration (sec) *1	Temperature difference (°C) *2	Descent rate Mean±S.D.(m/sec)	Ascent rate Mean±S.D.(m/sec)	<i>t</i> -test <i>P</i> -value
5.6	17	1.9	0.12±0.07	0.30±0.19	<0.05
5.6	17	2.0	0.16±0.05	0.30±0.09	<0.05
5.5	9	1.7	0.20±0.08	0.43±0.17	<0.05
5.2	17	1.8	0.10±0.06	0.24±0.13	<0.05
4.9	19	1.1	0.08±0.07	0.25±0.19	<0.05
4.8	8	1.1	0.18±0.09	0.39±0.20	<0.05
4.6	16	0.0	0.06±0.06	0.25±0.11	<0.05
4.6	5	0.4	0.24±0.08	0.48±0.28	<0.05
4.6	6	0.9	0.24±0.11	0.27±0.20	>0.05
4.6	9	1.2	0.15±0.10	0.20±0.06	>0.05
4.5	10	0.4	0.13±0.07	0.23±0.11	<0.05
4.5	14	0.5	0.10±0.06	0.10±0.06	>0.05

*1 The duration of each movement below the depth of 4 m.

*2 The difference in ambient temperature during each movement.

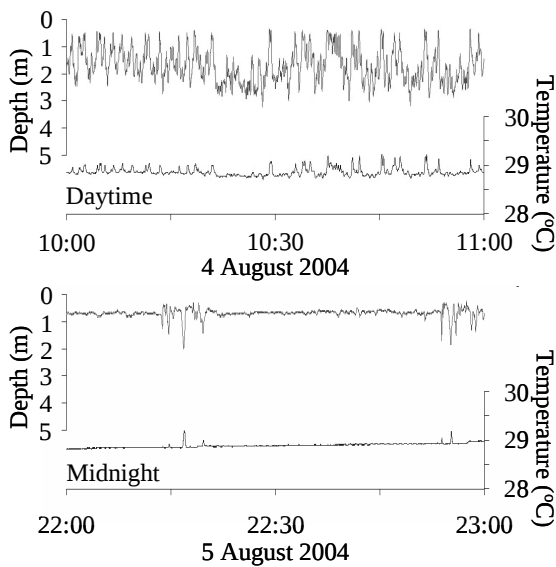


Fig. 5. Typical vertical movement with vertical profiles of the water temperature during the daytime and the midnight time. The catfish showed the active vertical movement during the daytime while it did not change the swimming depth during the midnight time.

DISCUSSION

Diel vertical movement determined by the data logger

As described by Mitamura (2005), the Mekong giant catfish showed the distinct vertical movement. In this study, the fish repeatedly displayed the vertical movement between the surface and middle (3 m deep) waters during the daytime, and remained at the relatively shallow depth during the night time (Figs. 3 and 5). This daily periodicity was similarly observed by the former study (Mitamura 2005). In the rainy season, the fish swam in the deeper waters during the daytime than during the night time (Mitamura 2005). However our results showed that the fish did not differently utilize the shallower and deeper columns between during the daytime and at night. The fish spent more than 99 % of their time above the 3 m depth, and their narrow vertical movement distribution might not attribute to the separately utilization of the swimming depth. Figure 4 indicated that the fish remained largely inactive during the midnight (23:00-2:00). This indicated that the fish might have rested on the bottom at the shallower depth during this period. Giant catfish feed primarily on algae (Rainboth 1996) and the fish might feed more on algae near the reservoir shore during the night time than during the daytime (Mitamura 2005). This suggests that giant catfish may exhibit diurnal feeding activity around dusk and dawn. Many other catfishes, *Silurus biwaensis*, *Silurus asotus*, *Schilbe intermedius*, *Ameiurus nebulosus* and *Clarias gariepinus* displayed the diel vertical movement as well as our catfish (Takai et al. 1997, Hossain et al.

1999, Dedual 2002, Katano et al. 2003, Goudswaard 2004). However, these catfishes appeared to be nocturnal in contrast to our catfish, and had tended to remain inactive during the daytime.

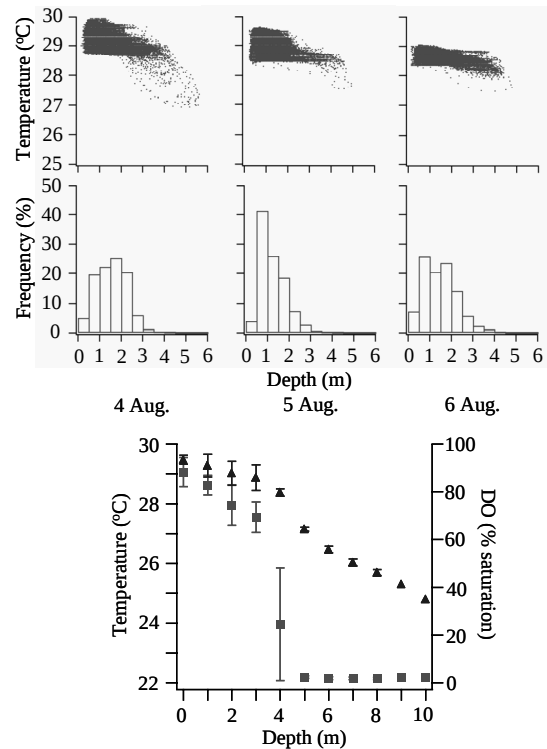


Fig. 6. Frequency of swimming depth with vertical profile of ambient temperature of the catfish in the upper figure and the vertical distribution of the temperature and dissolved oxygen measured by the dissolved oxygen meter in the lower figure. Triangle, square and vertical bar in the lower figure mean the temperature, the dissolved oxygen and S.D..

Vertical movement in relation to the environmental condition

The catfish showed the vertical movement between the bottom and surface water when the natural environment of the reservoir did not affect the vertical movement, namely the water between the surfaces and the bottom was mixed (Mitamura 2005). However, during our experiment period the fish spent more than 99 % of their time above the depth of 3 m. In this study, what limited the vertical movement of the catfish? The water temperature measured by the dissolved oxygen meter was almost uniform between the surface layer and the depth of 4 m. This uniformity of the water temperature was also supported by the ambient temperature of the fish (Fig. 6). During this period the water temperature of the bottom was approximately 25 °C. This temperature was the same degree as the temperature between the surface water and the bottom in the dry season (December 2003), and the fish could survive even in the waters of the relatively low temperature (24 °C)

(Mitamura 2005). The vertical movements of some fishes might be generally limited by the magnitude or rate of change in water temperature, rather than absolute temperature (Brill 1994, Brill et al. 1999, Cartamil and Lowe 2004). During our experiment period there was no sharp thermocline and the water temperature difference between the surface water and the bottom was less than 5 °C. Furthermore in this study the fish made only 4 deep vertical movements greater than 5 m and the differences of the ambient temperature during these movements were less than 2 °C. The stable water temperature might have little effect on the fish behaviour. Therefore, during this period these fish might have not been limited by the vertical distribution of the water temperature.

In contrast to the temperature condition, the dissolved oxygen stratification was built up at the depth of 4 m (Fig. 6). The dissolved oxygen below 4 m deep was uniformly less than 10 % (temperature: 24.8 to 27.2 °C). Therefore, the vertical movement of the fish might have been limited by the dissolved oxygen stratification. Reduction in the level of available oxygen has a remarkable effect on many physiological, biochemical, and behavioral processes in fish (Davis 1975, Brill 1994). Low dissolved oxygen thresholds that influence fish behavior, metabolic rate, swimming ability and viability were different among fish species (Davis 1975, Wannamaker and Rice 2000). However, most of the fishes might avoid the water column of the appropriate 10 % saturation to survive (Davis 1975). During our experiment, the fish showed 12 vertical movements to the hypoxic column (greater than 4.5 m) (Table 2). The physiological responses to the hypoxia are rapid and some fishes were affected within a few seconds (Davis 1975). The durations of all these movements ranged from 27 to 112 seconds in this study. All the descent rates when the fish moved below the depth of 4.8 m were significantly lower than the descent rates for each vertical movement (Table 2). Moreover, in these movements the small difference of ambient temperature had little effect on the fish behavior. Therefore, our results showed that relatively long-term exposure to the lower oxygen might render the fish to display the avoidance movement from the hypoxia. This was strongly supported by the fact that fish generally became more active in hypoxic water and attempted to move away from the low oxygen column (Davis 1975, Weltzien et al. 1999, Suthers and Gee 1986, Phil et al. 1991, Wannamaker and Rice 2000).

In this study, we found that the vertical movement of the catfish was limited by the dissolved oxygen stratification in the reservoir. This indicated that the hatchery-reared catfish had the ability to recognize and avoid the hypoxia. To our knowledge, this paper provides the first detailed description of avoidance reaction of freshwater fishes to the hypoxia revealed by direct measurement in the field

experiment. Many researchers reported that the vertical movements of many freshwater and marine fishes were limited by the dissolved oxygen stratification as well as the thermocline although some fishes (e.g. tunas, mudminnow) made efforts to repeatedly dive below them (Phil et al. 1992, Brill 1994, Rahel and Nutzman 1994, Takai et al. 1997, Ultsch et al. 1999, Dargon et al. 2000, Baldwin and Beauchamp 2002, Nusyl et al. 2003, Cartamil and Lowe 2004, Wilsom et al. 2005). Various explanations have been proposed for these vertical movements in relation to the environmental physical conditions, most of which focus on prey acquisition as the primary motivation for diving activity. In general the exposure to the hypoxia for a long time might have great effect on the fish behavior and respiration activity, which might lead to death (Davis 1975, Kramer 1987). During our experiment period, the fish rarely moved below the dissolved oxygen stratification. The catfish primarily feeds on algae (Rainboth 1996) and in the study site there were many algae which would be fed by the fish near the reservoir shore above the stratification. Therefore, the fish did not make effort to repeatedly dive below the dissolved oxygen stratification.

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