Fish Sci (2009) 75:175–182
DOI 10.1007/s12562-008-0026-4

ORIGINAL ARTICLE Biology

Habitat use and movement of hatchery-reared F2 Mekong giant catfish in the Mae Peum reservoir, Thailand, studied by acoustic telemetry

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Received: 1 May 2008 / Accepted: 29 September 2008 / Published online: 18 December 2008

Abstract The horizontal and vertical movements of eight immature hatchery-reared (F2) Mekong giant catfish *Pangasianodon gigas* were monitored using acoustic telemetry in the Mae Peum reservoir, Thailand, from September to December 2005. All tagged fish were successfully monitored throughout the study period. All fish moved throughout the reservoir for approximately 1 month after release. Subsequently, their utilized areas became small, and the fish utilized deep areas of the reservoir. The fish displayed diel spatial movement patterns between deep areas in the day and shallow areas in the night. The vertical movements of the fish were related to the environment declination such as existence of hypoxic water and thermocline. Our results suggest that the establishment of a protected area in addition to conventional fisheries regulations may sustain the fish population in this reservoir.

Keywords Diel movement · Dissolved oxygen · Endangered species · *Pangasianodon gigas* · Second-generation fish · Water temperature

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Introduction

In Southeast Asia, freshwater species are harvested by fishermen in a variety of water bodies, including lakes, reservoirs, canals, wetlands, and rivers [1, 2]. The freshwater fisheries of the Mekong basin produce approximately 3 million tons of fish with an estimated value of US$ 2 billion per year [1]. Freshwater animals, especially fish, play a major role as the principal source of animal protein for local people [1–3].

The Mekong giant catfish *Pangasianodon gigas* is a herbivorous migratory species that is endemic to the Mekong River basin and is one of the largest freshwater fish in the world, measuring up to 3 m in length and weighing in excess of 300 kg [4, 5]. This species is also one of the world's fastest growing fish and can reach 150–200 kg in 6 years but requires many years to reach maturity (e.g., wild fish 6–8 years, captive fish 15 years) [5]. Furthermore, giant catfish is a major fisheries species that has a rich cultural significance in the Mekong region [6]. However, the catch amount in the Mekong River have declined because of river basin development and overfishing [2, 7, 8]. At present, the catfish is listed in the Convention on International Trade in Endangered Species (CITES) Appendix I and in the International Union for the Conservation of Nature and Natural Resources (IUCN) Red List as a critically endangered species.

Artificial propagation techniques for the catfish (F1) were developed by the Thai Department of Fisheries in 1983 [2, 9], and a second generation (F2) of catfish was successfully produced in 2001 [2, 9]. Both F1 and F2 hatchery-reared juveniles and young immature catfish have been released by the Thai Department of Fisheries into reservoirs, as well as the Mekong River, in Thailand for use by local fisheries [2, 5]. The genetic diversity of hatchery-reared fish is generally not high and the genetic diversity of a small population of wild giant catfish in a definite water body may decrease and the adaptive flexibility of the population will be affected by release of hatchery-reared giant catfish. Therefore, the release of F2 giant catfish is restricted in water reservoir [10]. Various sizes (>100 kg) of giant catfish have recently been harvested from reservoirs by local fishermen and have been valuable in market trade [5]. Given the need for sustainability of the giant catfish in reservoirs, science-based fisheries management should be established and research in fisheries biology of the fish will be indispensable [1–3]. Among this biological research, detailed understanding of habitat use and movement patterns with environmental fluctuation is prominently important for design of protected areas (residential and spawning areas) [11–14]. However, only a few studies have described the habitat, movement patterns, and migration of giant catfish [15–19] as well as other catfishes [20–23]. In the Mekong River, wild giant catfish may use deep holes as residential habitat and may also engage in long-distance spawning migration [4, 24, 25]. A pilot study using acoustic telemetry in the Mae Peum reservoir in northern Thailand, in which a number of F1 and F2 hatchery-reared giant catfish had been introduced and harvested, showed that hatchery-reared (F1) fish utilized deep areas [19]. Based on the limited available information, hatchery-reared (F2) giant catfish were assumed to exhibit habitat use of deep areas of the reservoir, similar to the F1 fish. To evaluate this assumption and to describe the movement patterns of this species, an acoustic telemetry study of F2 giant catfish was conducted in the Mae Peum reservoir.

Materials and methods

Study site

The Mae Peum reservoir (area approximately 8.3 km^2 [2], maximum depth approximately 15 m) is located in the province of Phayao, Thailand (Fig. 1). The water level of the reservoir is regulated by overflow and was mostly stable during the year of the study. At the study site, there are two main seasons: the dry season, which occurs from December to May, and the rainy season, which occurs from May to November. The hot season is usually from March to May, and the cold season is in December. Algae as a potential food source for herbivorous giant catfish are abundant along the shallow inshore areas of the reservoir.

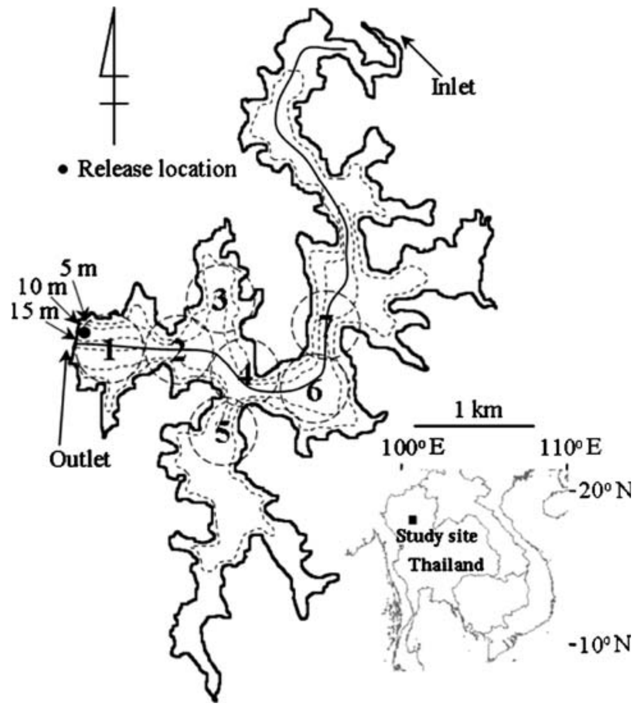

Fig. 1 Map of the Mae Peum reservoir in the province of Phayao, Thailand. Numbers (*1-7*) represent the locations of monitoring receivers. *Dashed circles* represent the expected signal detection range of the coded ultrasonic transmitters. The *small filled circle* represents the location of fish release. The *line between the inlet and the outlet* represents an estimated old river

Tagging and monitoring system

All fish used in the study were immature [5], second-generation, hatchery-reared (F2) fish that were produced by artificial propagation using first-generation hatchery-reared fish (Table 1). Both the F1 and F2 fish had been reared in a fish pond (40 m × 80 m, 1 m deep) after artificial propagation. Hatchery-reared giant catfish of this size are often harvested from reservoirs throughout Thailand. On 30 August 2005, ultrasonic coded transmitters (V9P-1H; Vemco Ltd., Halifax, NS, Canada; 9 mm diameter, 40 mm long, 2.7 g weight in water; 69 kHz, depth accuracy ±20 cm, transmission interval 40–120 s) were surgically implanted into the peritoneal cavity of fish under anaesthesia induced using 0.1% 2-phenoxyethanol. The wound was closed using operating needle and sutures, and antibiotics oxytetracycline hydrochloride and polymixin B sulfate were applied. A previous experiment demonstrated that intraperitoneal implantation had no discernible effect on survival or growth over a period of approximately 2 months [26].

Table 1 Summary of eight Mekong giant catfish, *Pangasianodon gigas*, monitored using acoustic telemetry

ID	Total length (cm)	Body mass (kg)	Total detection	Frequency (%) of days detected in Sep.[a]	Frequency (%) of days detected in Oct. to EDB[a]	Average swimming depth ± SD in day/night	*P*-value
1	62.5	2.1	11112	96.7	61.5	2.3 ± 0.6/1.9 ± 0.8	<0.001
2	63.0	2.0	2759	76.7	25.6	2.0 ± 0.7/2.0 ± 1.2	>0.05
3	63.0	2.2	7194	73.3	43.6	2.4 ± 0.5/1.7 ± 0.8	<0.001
4	68.0	3.3	9654	100.0	53.8	1.5 ± 0.8/1.2 ± 0.8	<0.001
5	63.0	2.2	4719	96.7	56.4	1.3 ± 0.5/1.1 ± 0.9	>0.05
6	65.0	2.0	10575	83.3	35.9	2.7 ± 0.3/2.6 ± 0.6	>0.05
7	64.5	2.2	5164	90.0	53.8	2.1 ± 0.6/1.8 ± 0.5	<0.001
8	59.5	2.0	13383	96.7	69.2	2.0 ± 0.5/1.4 ± 0.8	<0.01
Average ± SD	63.6 ± 2.4	2.2 ± 0.4	8070 ± 3682	89.2 ± 10.2	50.0 ± 14.2	2.0 ± 0.5/1.7 ± 0.5	

The EDB (estimated date that transmitter batteries would expire) was 8 November 2005

[a] Data recorded at the station 5 receiver were excluded from the analysis

Battery life of the transmitters was estimated at 71 days, but a longer life is sometimes observed. The estimated date of battery expiration (EDB) was 8 November 2005.

Seven fixed monitoring receivers (VR2 system; Vemco Ltd.) were used to monitor the tagged fish (Fig. 1). The monitoring receivers logged data on the presence (identity, ID) and swimming depth of all tagged fish. Each receiver was moored at mid-water depth (5–7 m) offshore near deep areas along an old river channel in the reservoir for 100 days from 1 September to 9 December 2005 (Fig. 1). Range tests indicated that the detection range was 150–300 m (Fig. 1).

All tagged fish were released individually in the reservoir on 1 September 2005 (Fig. 1). Data from all monitoring receivers were downloaded on 17 September and 9 December 2005, with the exception of the receiver at station 5 (Fig. 1), which could not be located on the latter date.

Water temperature and dissolved oxygen

Vertical profiles of water temperature and dissolved oxygen (DO) were measured at seven sites in the reservoir in daylight on 7 September and 9 December 2005, using a DO meter (Model 550A; YSI/Nanotech Inc., Kawasaki, Japan; temperature accuracy ±0.3°C, oxygen accuracy ±0.3 mg/l, Fig. 1). The data of vertical profiles of water temperature and DO, measured at 4–14 sites throughout the reservoir on 29 July, 17 December 2003, 2 August, 10 October, and 21 December 2004, were reused in order to help understand the environment in the reservoir [18, 19].

Data analyses

Although the monitoring duration (100 days) was longer than the estimated battery life of the transmitters, all data were used to determine the horizontal distributions of the fish because detection might not depend on the location, even if the transmitter battery expired (although the number of detections might be lower).

Data from all monitoring receivers (except for station 5 due to loss of the receiver) were used for the analysis of the frequency of days on which each fish was detected. Fish showed variation in their horizontal distribution between September and the period October to December. The frequencies of days detected for September and the period of October to the EDB (Oct–EDB period) were compared using a paired *t*-test. Potential diel horizontal movement patterns of all fish were examined during the Oct–EDB period. The numbers of daytimes (06:00–18:00) and nighttimes (18:00–06:00) during which each fish was detected were compared using a paired *t*-test.

To avoid analyzing data that included simultaneous detections by several receivers, the detection area of the receiver that detected each fish with the highest frequency within 1 h was defined as the hourly area used by each tagged fish. This hourly area was used for the analysis of excursions of the fish from primary utilized areas (stations 6 and 7).

Potential vertical movement patterns for all tagged fish were examined. For cases of simultaneous detection of a particular transmitter by more than one receiver, one reading at that point in time was used. To understand the relationship between swimming depths and environment, the maximum swimming depth (MsD) of each fish was calculated as the average of the 10% deepest swimming depths for each fish during the first and second half of each month. If there were fewer than 20 data points in the 10% deepest depths for each period, these data were removed from the analysis.

The potential diel vertical movement patterns of all fish were examined during the Oct–EDB period. Hourly average swimming depths of each fish were compared between daytime (06:00–18:00) and nighttime (18:00–06:00) using Mann–Whitney *U*-test.

Results

All fish were successfully monitored for 100 days between 1 September and 9 December 2005. Each of the seven receivers detected all tagged fish, and the total number of transmitter detections recorded for each fish ranged from 2,759 to 13,383 (Table 1). The average ± standard deviation (SD) total number of days on which each fish was detected was 61.9 ± 9.8 (percentage frequency relative to the whole monitoring period 61.9 ± 9.8%, range 44–79 days, $n = 8$).

Horizontal movement

The fish exhibited variation in their horizontal distribution between September and the period of October to December. The fish used large areas of the reservoir for approximately 1 month (September) after their release (Fig. 2) and subsequently began to be detected by primarily two (stations 6 and 7) monitoring receivers (Fig. 2). The percentage frequency of days detected was significantly larger in September than during the Oct–EDB period (September 89.2 ± 10.2%, Oct–EDB period 50.0 ± 14.2%, paired *t*-test, $df = 7$, $P < 0.001$; Table 1). The low frequency of detection during the Oct–EDB period indicated that the fish spent their time in both relatively small areas (stations 6 and 7) and adjacent areas; otherwise, they would have been detected by at least one other receiver if they frequently exhibited wide-scale movements (Fig. 2). Thus, the utilized area of the fish was relatively small, although the fish made a few excursions to other areas (stations 1–4) outside their primary utilized areas (stations 6 and 7; Fig. 2). The percentage frequency of days on which each fish made excursions was 10.9 ± 10.2% (range 0–28.2%). For example, on 3 October 2005, one fish (ID 4) had an hourly area of 4, excluding stations 6 and 7, indicating that on that date the fish spent its time in all detection areas except for the primary utilized area.

The fish exhibited diel horizontal movement patterns: they were detected significantly more often during the daytime than at nighttime (daytime 17.3 ± 5.3 days; nighttime 13.4 ± 6.1 nights, paired *t*-test, $df = 7$, $P < 0.001$). Because the monitoring receivers were primarily installed in deep areas along the old river channel in the reservoir (Fig. 1), these results indicate that fish spent more time in deep areas during the daytime than during the nighttime.

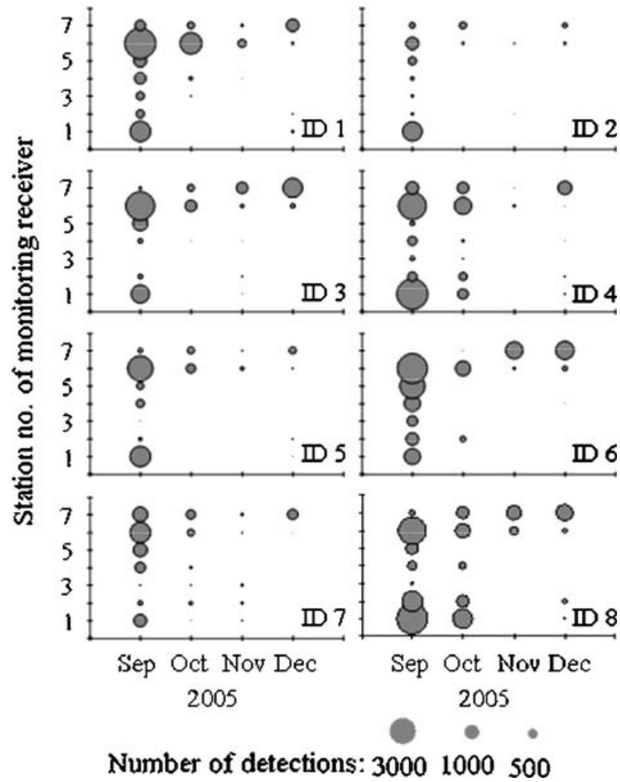

Fig. 2 Monthly horizontal distribution of each fish. Each *filled circle* in a month indicates the transmitter signal numbers detected by each monitoring receiver

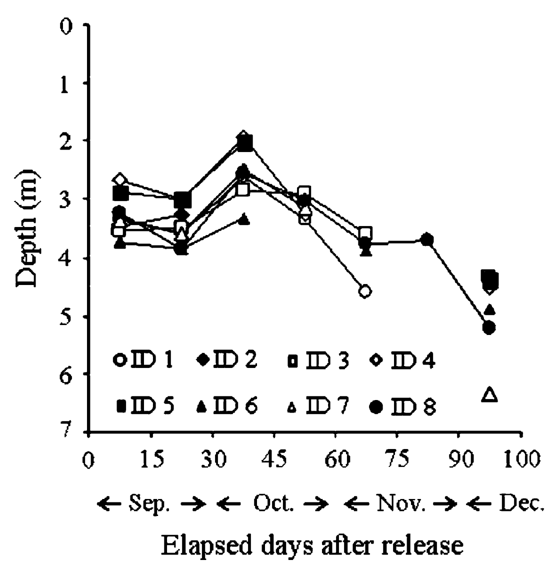

Fig. 3 Maximum swimming depth of each fish calculated as the average of 10% deepest swimming depth data ($n > 20$) for each fish in each first and second half of a month. The maximum bottom depth around stations 6 and 7 is approximately 12 m

Vertical movement

The fish spent their time in low depth (Fig. 3). Most (97%) MsDs of the fish were shallower than 4 m between

September and the EDB (8 November; Fig. 3). In contrast, all MsDs of the fish were deeper than 4 m in December (Fig. 3). The depths of DO stratification (3–4 m deep) in a day in September of the study year corresponded to the MsDs for the fish (Fig. 5), and the DO stratification in a day in December of the study year became deeper, and the MsDs of fish also increased (Fig. 5).

Tagged fish displayed distinct diel vertical movement patterns. Most (63%) fish spent their time at significantly greater depths during the daytime than at nighttime (Mann–Whitney U-test, n_{daytime} 26–156, $n_{\mathrm{nighttime}}$ 6–111, $P < 0.01$; Table 1).

Discussion

Long-term monitoring

The horizontal and vertical movement patterns of F2 hatchery-reared Mekong giant catfish in the Mae Peum reservoir were monitored for more than 3 months. The fish used large areas of the reservoir for approximately 1 month after release (Fig. 2). During this period, the fish may have been searching for suitable habitats within the reservoir. After the first month, the utilized areas of the fish grew smaller (Fig. 2). The areas where fish were detected most often (stations 6 and 7) are part of the old river channel and are deep areas of the reservoir. Mitamura et al. demonstrated that the F1 fish released in May 2003 showed the same post-release movement patterns: they utilized large areas of the reservoir for approximately 40 days after the release, and subsequently the utilized areas became smaller [19]. Furthermore, they used several deep areas of the reservoir as habitat and seldom used shallow areas such as inlets [19]. Thus, both F1 and F2 hatchery-reared giant catfish favored deep areas such as the river channel area, where they might freely swim primarily above the DO stratification because the bottom of the reservoir itself might not limit vertical movement. These observations correspond to local fishermen's knowledge and experience that giant catfish can be harvested using gill nets along the old river channel in the reservoir. Moreover, our findings are supported by previous reports that these fish prefer deep holes for habitat in the Mekong River [24, 25]. Interestingly, a fisherman at the Sirikit Dam reservoir, in which giant catfish have also been introduced and harvested, related that several giant catfish were often caught at one time using gill nets along an old river channel in that reservoir. This fisherman's experience and our results both indicate that in general, hatchery-reared giant catfish may aggregate in deep areas of this type.

The present study showed the relationship between the vertical movements of the fish and the environment.

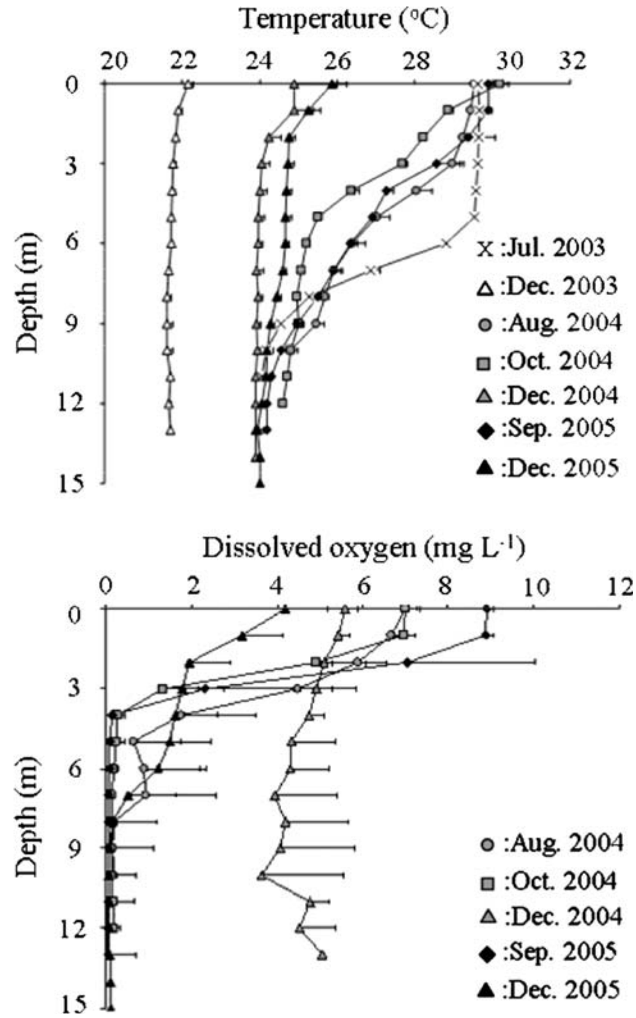

Fig. 4 The *upper figure* shows the vertical temperature distribution and the *lower figures* show the vertical distributions of dissolved oxygen in the Mae Peum reservoir, Thailand. *Horizontal bars* indicate SD

The fish spent their time even in the low DO concentrations (<3 mg/l) just above the DO stratification (Figs. 4 and 5). This suggests that the giant catfish might be tolerant of lower DO conditions. The MsDs of fish corresponded to the depth of DO stratification in a day of both September and December. Furthermore, temperatures between the surface and the bottom in December (<2°C) were very similar and likely did not affect fish behavior. These results, in spite of the small number of environmental data, suggest that hypoxic water in the deep layers may limit the vertical movement of fish. However, in September, the possibility that the thermocline as well as hypoxic water limited the vertical movement of the fish cannot be discounted. This hypothesis is supported by a previous report that hypoxic water might limit the vertical movement of F1 giant catfish [18]. Similar movement patterns in relation to hypoxic water have also been observed in both marine and

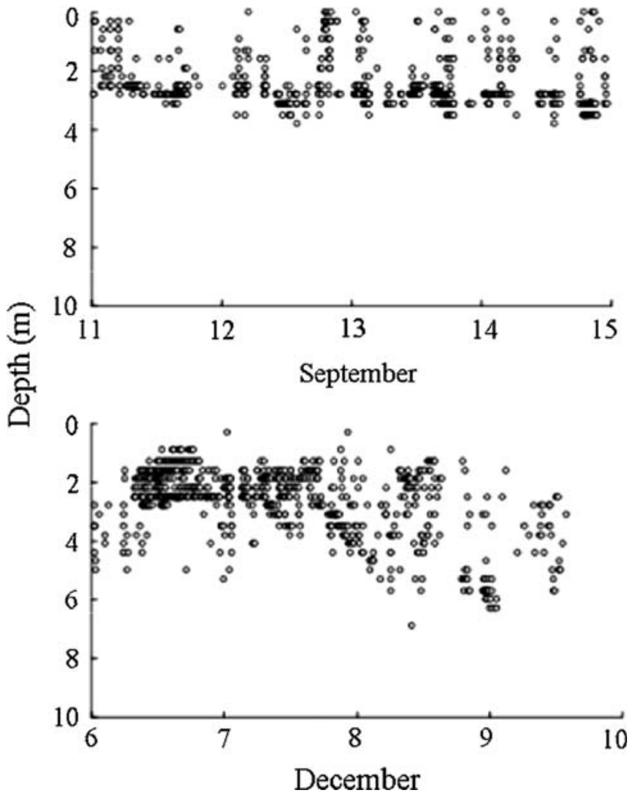

Fig. 5 Typical vertical movements of the fish (ID 1) in September and December 2005

freshwater fishes [27–29], although fish sometimes dive down in hypoxic water; for example, the mudminnow occasionally dives below DO stratification to forage [28]. However, the giant catfish was rarely recorded below the DO stratification area. This difference in vertical movement patterns may be related to differences in prey items. Herbivorous giant catfish likely do not have to dive in hypoxic water because algae are abundant in shallow inshore areas [4].

Diel movement

The F2 giant catfish exhibited clear diel spatial movement patterns within its habitat, and fish were detected more often during the daytime than at nighttime. Hourly detections declined linearly as the distance of the fish from a monitoring receiver increased [12]. Our results suggest that either the fish tended to use areas closer to the shallow inshore, away from monitoring receivers, or that they used adjacent areas (outside the detection range of stations 6 and 7) at night. The areas adjacent to stations 6 and 7 were shallower than the primary utilized area (Fig. 1). Therefore, the fish likely exhibited diel horizontal movement patterns between deep areas during the daytime and shallow areas at night. The fish also showed diel vertical movement patterns probably above the DO stratification. The majority (63%) of fish spent their time at significantly greater depths during the daytime than at nighttime, which corresponded to the observed patterns of diel horizontal movement. Thus, the fish may generally exhibit spatial movement patterns between deep areas during the day and shallow inshore or adjacent areas during the nighttime.

A few studies have described the diel movement of the herbivorous giant catfish under natural conditions [18, 19]. However, very little is known about reasons for diel movement. Differences in the depths used by fish during the daytime and nighttime may be related to deep hypoxic waters and/or the thermocline. The shore of the reservoir is steep, and the bottom areas above the hypoxic water and/or the thermocline, which could kill the fish, were small. The giant catfish is a diurnal species and is inactive at night [18, 19]. Because the fish spend the nighttime in shallow inshore or adjacent areas, their inactivity may allow them to completely avoid deeper layers at night. We cannot, however, discount the possibility that the daytime–nighttime variation of fish depths may be just related to that of the DO stratification and/or the thermocline, although DO and temperature were not measured at night in this study.

Diel movements, in some cases associated with feeding, foraging, antipredator, and sheltering behavior, have been previously documented in marine demersal fish, including herbivorous fish [30–32], reef fish [33–35], ocean pelagic fish [14, 36], and freshwater fish, including a catfish [22, 23, 37]. No predators of the relatively large (>0.6 m) study fish were present in this study. We assume that the diurnal, herbivorous, and migratory giant catfish freely spent their daytime in inshore areas for feeding as well as offshore of deep areas.

Implications for reservoir fisheries

The tagged fish which had been reared in the fish pond survived for more than 3 months in the reservoir. This indicates that catfish may be cultivated in the reservoir for the enhancement of stock. The use of protected areas has increased globally and has contributed to the recovery of endangered populations and to sustainable fisheries of target species [12, 38, 39]. The habitat use and diel movement patterns of the giant catfish have important implications for effective fishery management. The utilized areas of the fish were relatively small, and the fish utilized deep areas around the old river channel. One approach for developing a sustainable giant catfish fishery in the reservoir may be the establishment of a protected area that encompasses the utilized areas of the fish. The giant catfish requires many years to reach maturity [5]. An effective protected area might sustain the fish population regardless of high fishing pressure in the reservoir if immature fish could reach maturity within the protected area. Furthermore, the fish occasionally made excursions outside their habitat, suggesting that movement across protected area boundaries could supply fish to an adjacent fishery, even if a protected area were established in the reservoir.

Second-generation (F2) immature giant catfish clearly utilized deep areas, and their movement patterns might be related to the environment. However, these factors, as well as spawning areas, have been understudied in juvenile and mature (F1 and F2) giant catfish. If the spawning area is located far from the habitat, it should also be protected from the fishery and from potential damage. Additional comprehensive studies are necessary to better manage the giant catfish fishery in the Mae Peum reservoir, as well as in other reservoirs throughout Thailand.

Acknowledgements We sincerely thank all staff of Phayao Inland Fisheries Research and Development Centers, Thailand, for their kind support and contributions to the research. We would like to express our appreciation to T. Yasuda and J. Okuyama for kind advice about analysis and for providing valuable feedback. This study was partly supported by a Grant-in-Aid for Science Research (16255011 and 16658081), Grant-in-Aid for JSPS Fellows (15–5686 and 18-2409), the 21st Century Center of Excellence Program "Informatics Research Center for Development of Knowledge Society Infrastructure," and the Global COE program "Informatics Education and Research Center for Knowledge-Circulating Society," Japan.

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