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Association of Early Juvenile Yellowfin Tuna *Thunnus albacares* with a Network of Payaos in the Philippines

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Association of early juvenile yellowfin tuna *Thunnus albacares* with a network of payaos in the Philippines

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Abstract To understand how early juvenile yellowfin tuna use the habitat and environment provided by fish aggregating devices (FADs), fish (19–31 cm FL) implanted with ultrasonic transmitters into their abdominal cavities were released in a network of payaos in Panay Gulf, the Philippines. Self-recording receivers were attached to the anchor ropes of the payaos to detect the presence of the fish. Some aspects of the behavior of juveniles were similar to those reported in adults. One juvenile showed a diurnal vertical swimming pattern, swam within a limited shallow range during the nighttime, and dived to deeper waters during the daytime. Two juveniles performed deep dives over 100 m during payao-to-payao excursion. Three juveniles showed a diurnal horizontal swimming pattern that was synchronized. In contrast, juveniles stayed <6 days in the network, shorter than adults. No juveniles returned to the same payao after an interruption of over 24 h. It is suggested that juveniles in this area are just starting to migrate and are temporarily staying around a payao for a few days to forage before continuing their migration.

Keywords FAD · Juvenile · Payao · Telemetry · Yellowfin tuna

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Introduction

Philippine waters are important regions for yellowfin tuna *Thunnus albacares* stocks because they include spawning grounds and nurseries from where juveniles start to migrate when they reach about 30 cm fork length (FL) [1]. A fish aggregating device (FAD) called a payao is traditionally used to catch pelagic species including juvenile yellowfin tuna in the Philippines. A payao is an anchored FAD composed of a bamboo raft, an anchoring rope, a cement anchor, and suspended palm fronds [2]. Most telemetry studies on tuna behavior around FADs involved adult and large juveniles >40 cm in FL using telemetry techniques [3–15]. However, no information is available on the behavior of early juveniles <40 cm in FL. Moreover, no experiment had been conducted in the Philippines, except for the work of Babaran et al. [16], who studied early juvenile yellowfin tuna around a single payao in the Philippines. They determined the feasibility of undertaking a telemetry experiment on early juveniles and found some behaviors of juveniles that were very similar to those of adults. Juvenile yellowfin tuna swam within a limited shallow range during the nighttime, dived to deeper waters during the daytime, and then moved away from the payao at midnight. The results also suggested that juveniles associate with several payao units within a network, because two juveniles were recaptured simultaneously at another payao over 3 km away from the releasing payao.

In this study, we present the results of more comprehensive telemetry studies in the Philippines to record how early juvenile yellowfin tuna use the habitat and environment provided by a network of payaos in a region where information is inadequate for management of Philippine tuna, which are part of the Pacific stocks.

Materials and methods

Installation of receivers

In Panay Gulf, several payaos were installed in the same network within a few kilometers of each other. The experiments were conducted around nine payaos (P1–9) in the same network deployed approximately 10 km off the coast of Miagao in Panay Island, Philippines (Fig. 1). The depth of the water was approximately 500 m. Before the experiment, we searched all payaos in the network and marked their positions using global positioning system (GPS). According to the rich experience gained by local professional fishermen, 6 payaos with abundant palm fronds were preselected for attachment of set receivers (VR2-DEL; Vemco Ltd., Canada). A set receiver was installed on the payao anchor line at depth of approximately 20 m by scuba diving. The receiver decodes the ID numbers and swimming depths of fish implanted with transmitters within the detection zone and records the information and time stamp in flash memory. A previous study determined the detection zone to be at least 500 m in radius [16]. In case of poor fishing, receivers were reinstalled at other payaos. Receivers were installed at P1–6 on 30 August, but those attached to P1–3 were reinstalled at P7–9 on 5 September 2006 because of poor fishing.

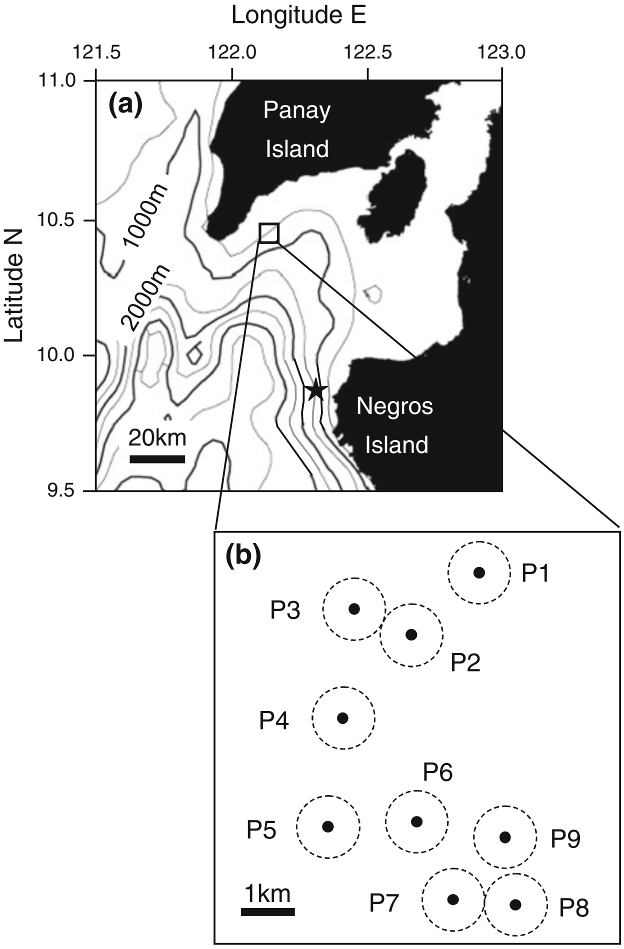


Fig. 1 **a** Bathymetric map of the Panay Gulf. *Black lines* and *gray lines* are isobaths per 1000 and 500 m, respectively. The *black star* indicates the recapture point of YT10. **b** Formation of payaos in the network. *Dotted circles* indicate the approximate detection distance of receivers attached to payaos, 500 m in radius

Fishing and tagging

A professional fisherman captured experimental fish around the payaos at depth of approximately 30 m by hand line. Sixteen yellowfin tuna (YT01–16, 19–31 cm FL) were captured from 1 to 20 September 2006. Juvenile yellowfin tuna in the Western and Central Pacific Ocean grow up to about 50 cm FL per annum and mature at about 120 cm FL [17, 18]. Tagged juveniles are estimated to be age 0+ and immature. The details of each fish are given in Table 1. The fish were implanted with coded ultrasonic transmitters (V9P-2H-S256 or V7-2L-R256; Vemco Ltd.). The V9P transmitter, which has a pressure sensor, weighs 2.9 g in water and measures 9 mm in diameter and 46 mm in length. This transmitter emits a train of eight pings at output power of 147 dB every 40 ± 20 s for identification and depth measurement [19]. The accuracy of the pressure sensor is ±10 m. The battery life is 64 days. The V7 transmitter, which does not have a pressure sensor, weighs 0.9 g in water, has diameter of 7 mm, and measures 20 mm long. This transmitter emits a train of six pings at output power of 136 dB every 80 ± 40 s only for identification. The battery life is 48 days. Because our previous study indicated high fishing pressure [16], 3 fish tagged with V7 transmitters were also implanted with data loggers (DST micro; Star-Oddi Ltd., Iceland) to record time-series data of swimming depth and body temperature in expectation of recapture. The data logger weighs 1.9 g in water and measures 8.3 mm in diameter and 25.4 mm in length. The accuracy of the temperature and pressure sensor is ±0.2°C and ±1.5 m, respectively. The sampling interval was set at 1 min. Tag implantation was conducted according to the procedure described by Babaran et al. [16]. The surgical operations were performed just after catching the fish and took <90 s for each fish. The fish were released immediately after the operation. To facilitate retrieval of recaptured fish, notices of monetary rewards were distributed in nearby fishing communities and fish markets.

Measurement of ambient water temperatures

To understand the horizontal distribution of water temperature, data loggers (DST milli; Star-Oddi Ltd.) were attached to the receivers at P1–3 or P6–8 and the ambient

Table 1 Details of tagged fish

ID	FL (cm)	Tag	Release		CRT (days)	IRT (days)	Remark
			Date	Site			
YT01	20	V7-1L	2 Sept	P9	–	–	
YT02	22	V7-1L	2 Sept	P9	–	–	
YT03	19	V7-1L	2 Sept	P9	–	–	
YT04	22	V7-1L	2 Sept	P9	–	–	
YT05	20	V7-1L	2 Sept	P9	<6	<6	
YT06	26	V9P-2H	13 Sept	P5	–	–	
YT07	26	V9P-2H	13 Sept	P5	–	–	
YT08	25	V9P-2H	13 Sept	P5	<1	<1	
YT09	31	V9P-2H	13 Sept	P5	<1	<1	
YT10	25	V9P-2H	13 Sept	P5	–	–	Recapture
YT11	25	V9P-2H	13 Sept	P7	3	3	
YT12	25	V7 & DST	13 Sept	P7	4	4	
YT13	25	V7 & DST	13 Sept	P7	5	5	
YT14	26	V7 & DST	13 Sept	P7	4	4	
YT15	28	V7-1L	20 Sept	P9	–	–	No data
YT16	26	V7-1L	20 Sept	P6	>1	>1	Recapture

water temperatures were recorded every 10 min. To understand the vertical profiles of water temperature, a data logger (DST milli) was submerged from the surface to 300 m depth at P3, recording water temperature every 10 m, at the beginning of the experiment on 31 August 2006. The accuracy of the temperature and pressure sensor is ±0.1°C and ±1.2 m, respectively.

Data analysis

Detection rate as defined by Ohta and Kakuma [13] was calculated to relate the swimming patterns of juvenile yellowfin tuna with known patterns of adult yellowfin tuna. They suggested five patterns of adult yellowfin tuna associated with FADs. Pattern A was characterized by a higher detection rate during nighttime than daytime, while pattern B was characterized by a higher detection rate during daytime than nighttime. Meanwhile, pattern C was characterized by a few hours absence at around sunset, and pattern D was characterized by several hours absence beginning around noon. Pattern E was assigned to individuals that showed no clear pattern. Hourly detection numbers were divided by the maximum number of transmissions determined by the average transmission interval of each transmitter. Continuous residence time (CRT) and intermittent residence time (IRT) were also calculated. CRT indicates the duration for which a tagged fish was continuously monitored at a single payao without absence over 24 h, whereas IRT indicates the duration for which a tagged fish stayed within the network of payaos. To examine diurnal swimming patterns, daytime was defined from sunrise to sunset at 10.5°N, 122.0°E. When more than one receiver detected a tagged juvenile fish, its horizontal moving speed was roughly estimated using the middle recording time of each receiver and the distance between each receiver. Vertical moving speed during both ascent and descent was also roughly estimated using differences of time and depth between successive time-series data points. Statistical analyses were computed using Statcel2 statistical software (OMS, Japan). Values are presented as mean ± standard error (SE).

Results

Payao-associated behavior of juvenile

P4 was destroyed, possibly due to bad weather, but the attached receiver was salvaged by a fisherman on 7 September. P5 disappeared because of the appearance of a 15th typhoon in 2006 (Xangsane) on 25 September, and no records were obtained. The receivers at P6–9 remained until 7 October.

YT01–05 were released between 09:35 and 09:55 on 2 September at P9. When these fish were released, no receiver was installed at P9 yet. When a receiver was reinstalled at 13:10 on 5 September, YT01–04 were not detected and remained missing until the end of the experiment. CRTs and IRTs were unknown. YT05 was released at 09:55 on 2 September at P9 and detected by the reinstalled receiver at P9 from 13:10 on 5 September soon after it was reinstalled until 13:46 on 7 September. The fish was monitored continuously without any interruption over 24 h until the end of recording. CRT or IRT was <6 days because the behavior until 5 September was unknown and then the fish was not detected by any other payao.

YT06–10 were released at 06:24–07:06 on 13 September at P5. Unfortunately, P5 disappeared because of a typhoon on 25 September and no records were obtained. YT06 and YT07 were missing until the end of the experiment. CRTs and IRTs were unknown. YT08 was released at 06:42 on 13 September at P5 and detected at P8 from 00:43 to 01:18, at P9 from 01:38 to 01:46, and at P6 from 02:08 to 02:12 on 14 September. CRT was <1 day. IRT was also <1 day because the fish was detected by the payaos within 24 h. Horizontal moving speed was estimated as 44 cm/s (1.8 FL/s) between P8 and P9 and as 83 cm/s (3.3 FL/s) between P9 and P6. Figure 2 shows the time-series data of the swimming depths of YT08 during the excursion. YT08 was swimming close to the surface until 5 min before leaving P8. Suddenly, the fish dived to deeper waters over 90 m with maximum vertical moving speed of 76 cm/s (3.0 FL/s) then swam out of the detection zone of P8. When the fish was detected by P9 and P6 again, it continued to swim in relatively deep waters of about 60 m. YT09 was detected by P7 from 15:30 to 15:47 on 13 September. At that time, the fish was swimming in deeper waters ranging from 195 to 207 m. CRT and IRT were <1 day, the same as YT08. YT10 was also missing but was recaptured by a ring netter on 24 September at another southern payao over 60 km away. CRT and IRT were unknown.

YT11–14 were released in rapid succession between 07:38 and 07:51 on 13 September at P7. YT11 was released at 07:38 on 13 September at P7 and continued to swim in the detection zone of P7 from time of release until 10:05 on 15 September. The fish was monitored continuously without interruption over 24 h during the recording period. CRT was 3 days. IRT was also 3 days because the fish was not detected by any other payao. There was no difference in the hourly detection rate during daytime and nighttime (Mann–Whitney test, $P > 0.05$). Figure 3 shows the time-series data of the swimming depth of YT11, which exhibited a diurnal vertical swimming pattern. The fish frequently stayed in a relatively shallow and narrow layer between 5 and 10 m during the nighttime; in daytime, the fish swam at a wider depth range between 10 and 40 m (Fig. 4). The fish swam in significantly deeper waters (24.8 ± 0.2 m, $n = 1833$) during daytime than nighttime (6.7 ± 0.1 m, $n = 1738$) (Mann–Whitney test, $P < 0.01$). The fish swam vertically at significantly higher speed (12.1 ± 0.2 cm/s, $n = 1832$) during daytime than nighttime (2.3 ± 0.1 cm/s, $n = 1737$) (Mann–Whitney test, $P < 0.01$). There was no difference in the vertical moving speed between ascent and descent during either daytime or nighttime (Mann–Whitney test, $P > 0.05$). YT12–14 showed a diurnal horizontal swimming pattern. YT12 was released at 07:44 on 13 September at P7 and stayed in the detection zone of P7 from release to dusk on 13 September. Then, the hourly detection rate declined at dusk and remained low until dawn (05:09) on 14 September. The horizontal moving pattern continued for 2 days. Finally, the fish left the payao at 08:08 on 16 September. CRT was 4 days because the interruptions were <24 h. IRT was also 4 days, because the fish was not detected by any other payao. YT13 was released at 07:48 on 13 September at P7 and also showed the diurnal pattern for 4 days and left the payao at 16:47 on 17 September. CRT and IRT were 5 days. YT14 was released at 07:51 on 13 September at P7 and showed the diurnal pattern for 3 days, leaving the payao at 08:53 on 16 September. CRT and IRT were 4 days. There were significant differences in the hourly

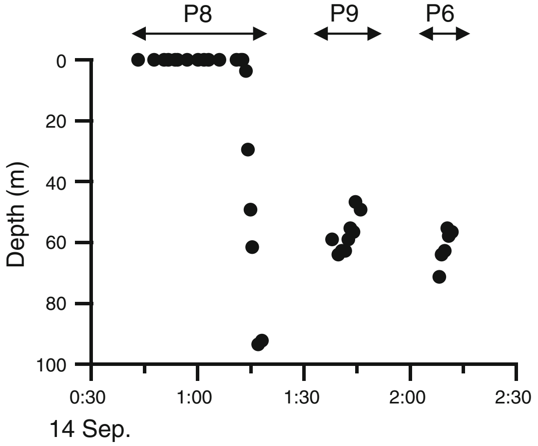


Fig. 2 Time-series data of swimming depth of YT08 during payao-to-payao excursion. *Horizontal double-headed arrows* indicate the recording duration by each payao

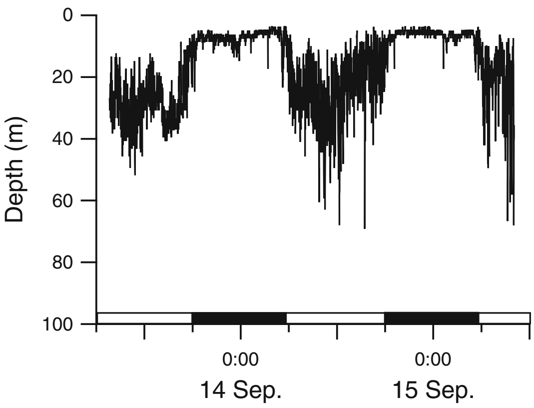


Fig. 3 Time-series data of swimming depth of YT11 on P7. The juvenile swam within a limited shallow range during nighttime (indicated by a *horizontal black bar*) and dived to deeper waters during daytime (*white bar*)

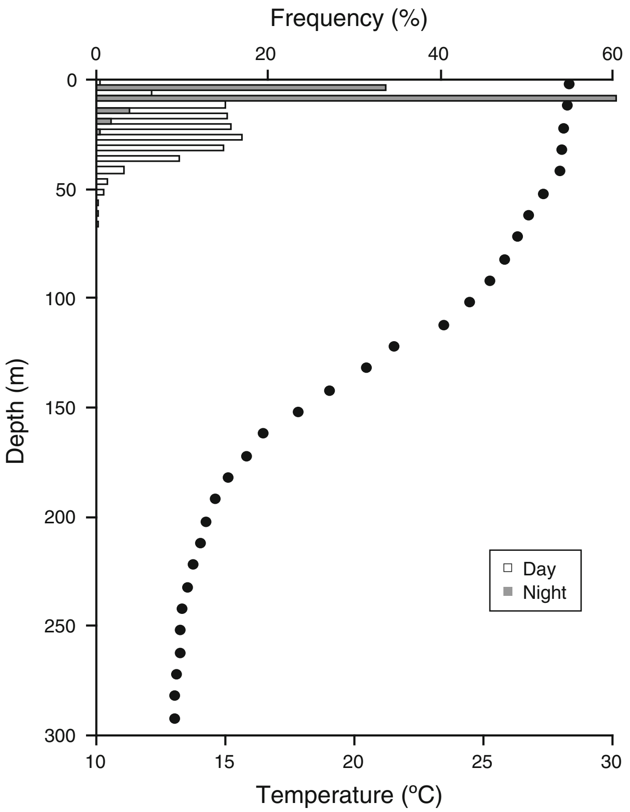


Fig. 4 Daytime (*open*) and nighttime (*solid*) depth distribution of YT11 and vertical profile of ambient water temperature. The juvenile was swimming in significantly deeper waters during the daytime. A thermocline existed from 120 to 160 m where the water temperature declined from 24°C to 17°C

detection rates of YT12–14 during daytime and nighttime (Mann–Whitney test, $P < 0.01$).

YT15 was released at 08:17 on 20 September at P9. The fish was not detected from right after its release until the end of the experiment, probably because the transmitter was broken. CRT and IRT were unknown.

YT16 was released at 08:52 on 20 September at P6. The fish also showed a diurnal horizontal swimming pattern. The fish stayed in the detection zone of the payao from release to dusk on 20 September. The next morning, the fish returned to P6 and was recaptured by a ring netter. CRT and IRT were >1 day because the fish might have stayed around the payao without the recapture.

Payao-associated pattern of juveniles

Figure 5 shows the sufficiently long time-series data of the hourly detection rate of fish that were detected by some receivers. YT05 and YT11 were monitored continuously without interruption during the recording period, being assigned to pattern E, i.e., no clear pattern. YT12–14 showed a diurnal horizontal swimming pattern that matched pattern B, characterized by a higher detection rate during daytime than nighttime. YT16 also showed a pattern similar to that of YT12, and YT14 matched pattern B.

Ambient water temperature

Water temperatures recorded by data loggers attached to the receivers were stable in the range from 28°C to 29°C. There was no remarkable difference in temperature at the location of payaos during the recording period. The vertical profile of water temperature was stratified as shown in Fig. 4. From the surface to 120 m depth, water temperature gradually decreased from 28°C to 24°C. A thermocline existed from 120 to 160 m, where the water temperature declined from 24°C to 17°C. From 160 to 300 m, the water temperature decreased moderately from 17°C to 13°C

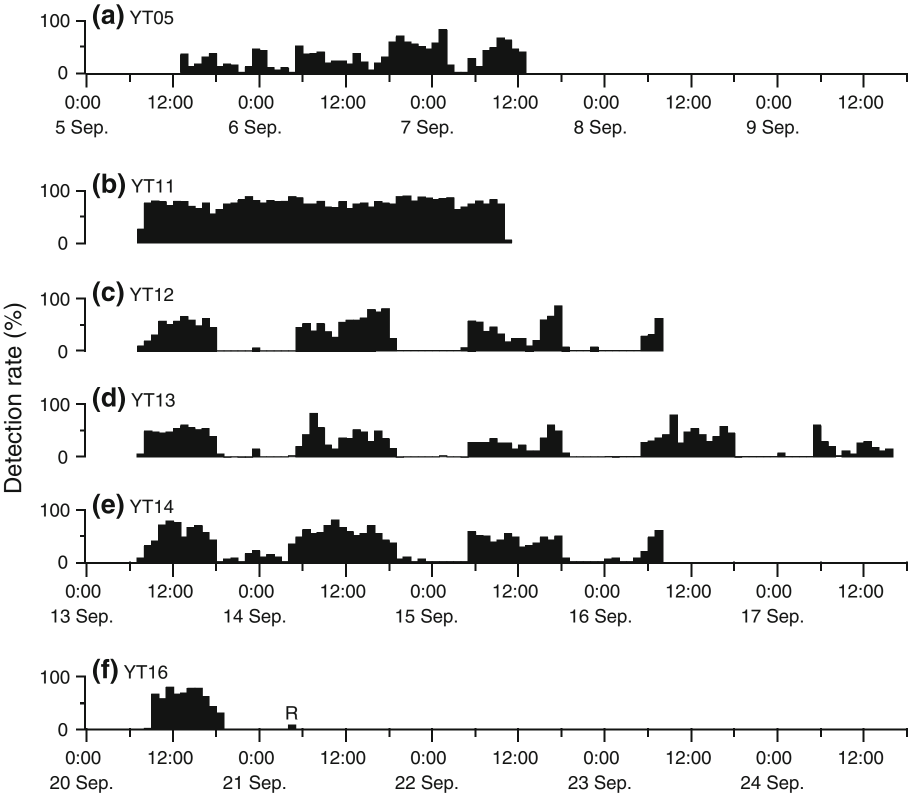
Discussion

Horizontal movement around a payao after release

YT05 and YT11 were assigned to pattern E. Babaran et al. [16] also assigned an individual to pattern E and mentioned the possibility that such observations of juvenile yellowfin tuna may be just one of several association patterns. YT12–14 showed a diurnal horizontal swimming pattern that matched pattern B. Holland et al. [3] also reported a diurnal pattern of adult yellowfin tuna and indicated feeding excursions. In addition, as all the tagged fish were captured by hand line, the presence of prey was an important factor in the association of juvenile yellowfin tuna with a payao. Small fish usually make a school to avoid predators and to find prey effectively [20]. Therefore, as they were caught in rapid succession around the same payao, they were probably swimming together in the same school. Babaran et al. [16] suggested that juveniles were swimming around a payao in the same school. Klimley and Holloway [8] reported the school fidelity and homing synchronicity of adult yellowfin tuna. While YT12 and YT14 left P7 in the morning on 16 September, YT13 only remained until the evening on 17 September. More observations are needed to reveal the schooling behavior.

All tagged fish left the payao where they were released in daytime. Babaran et al. [16] reported an individual that left the payao in the middle of the night. Departure from the tagging site at nighttime has also been reported in adult yellowfin tuna [3]. These observations of juvenile yellowfin tuna may be just some among the alternative payao-associated patterns.

Fig. 5 Time-series data of the hourly detection rates of each juveniles. **a** YT05 at P9, **b** YT11 at P7, **c** YT12 at P7, **d** YT13 at P7, **e** YT14 at P7, and **f** YT16 at P6. "R" indicates recapture



Vertical movement around a payao

YT08 and YT09 were released at P5. Unfortunately, P5 disappeared because of a typhoon, so we do not know the time of their departure from P5 due to the lack of the receiver. However, YT08 and YT09 were detected by other payaos. YT08 was detected near 3 other payaos at nighttime, swimming in deep waters over 90 m. YT09 was also detected by another payao and reached deeper swimming depths of over 200 m. Holland et al. [3] also reported deep diving of adult yellowfin tuna during FAD-to-FAD excursion.

Adult yellowfin tuna is a deep diver. Dagorn et al. [14] reported an adult individual that dived over 1000 m, experiencing a minimum temperature of 5.8°C, representing a difference of over 20°C in ambient water temperature. From the measurements of ambient water temperature, there was no remarkable difference horizontally. Vertically, a thermocline existed at depth ranging from 120 to 150 m. In the case of YT09, the coldest temperature was 14°C and the difference of ambient water temperature was 14°C. Dickson [21] revealed that 20.7 cm FL tunas can elevate their body temperatures significantly above ambient water temperature by using vascular countercurrent heat exchangers. YT09 was the largest fish in this experiment and 31 cm FL was larger than 20.7 cm to maintain body temperatures elevated above ambient water temperature.

YT11 stayed around the releasing payao and did not show such deep dives. The fish demonstrated the diurnal vertical swimming pattern in the surface mixed layer. Josse et al. [6] indicated the important role of the sound scattering layer (SSL), assimilated as food, in vertical and horizontal tuna movements, during daytime and nighttime. Babaran et al. [16] also suggested the possibility of coincidence of swimming depth of juveniles and prey. In this study, YT11 demonstrated a diurnal vertical swimming pattern, as if following the diurnal migration patterns of prey organisms in the SSL. All tagged fish were captured during the daytime by hand line at depth of approximately 30 m, which coincides with the swimming depth of YT11 during daytime. As mentioned above regarding horizontal movements, presence of prey is an important factor in the association of juvenile yellowfin tuna with a payao, because they are at a life stage in which they need to grow quickly.

Moving speed

The estimated horizontal moving speed of YT08 in the network of payaos was between 1.8 and 3.3 FL/s. Holland et al. [3] tracked four adult yellowfin tuna, averaging 2.1 FL/s. Meanwhile, Yuen [22] observed that yellowfin tuna averaging 51.9 cm long swam at 0.5 to 14.4 BL/s. Dewar and Graham [23] calculated the optimal swimming velocity of 51 cm yellowfin tuna as 2.0 FL/s. Dewar and Graham [24] calculated the maximum swimming velocity of 40 cm yellowfin tuna at 25°C as 27 FL/s. The horizontal moving speed of YT08 was within these ranges. The maximum vertical moving speed at 76 cm/s (3.0 FL/s) demonstrated by YT08 was also within these ranges.

YT08 moved horizontally at nighttime. YT12–14 and YT16 also showed a diurnal horizontal swimming pattern, assuming that they stayed near a payao during daytime and away from the payao at nighttime, while YT11 stayed in the detection zone all day and moved vertically at significantly higher speed during daytime than nighttime. High horizontal moving speed at nighttime and high vertical moving speed during daytime might be related to presence of prey as mentioned above.

Associative behavior of juvenile with a network of payaos

No tagged juveniles returned to the same payao after an interruption over 24 h. YT08 and YT09 moved to other payaos but within 24 h and did not stay around any payao in the network. So, we could not distinguish between CRT and IRT clearly. Ohta and Kakuma [13] reported that adult yellowfin tuna stayed around a single payao for a maximum of 55 days, while Dagorn et al. [14] reported a maximum duration of 151 days with a network of FADs. In those two studies, some individuals returned to the same FAD after an interruption over 24 h. In the current study, not only CRTs but also IRTs were <6 days for all juveniles. These results suggest that the juveniles were probably starting to migrate.

In this study, we revealed some aspects of the behavior of juvenile yellowfin tuna in a network of FADs in the Philippines. Growing juveniles might stay around a payao for a few days, forage in a school, and then continue with their migration while associating with other payao networks. The distribution of horizontal water temperature is stable and does not seem to limit the horizontal movement of juveniles. However, the vertical distribution of water temperature may limit the vertical movement of juveniles in the surface mixed layer during association with a payao except during excursion between payaos. Unlike other regulated regions such as Okinawa and Hawaii waters, the actual numbers and positions of payaos and networks were not clarified in this region. Additional comprehensive studies are needed to reveal the behavior of juveniles swimming among numerous networks of payaos for the management of Pacific yellowfin tuna stocks. A juvenile with data logger attached was not recaptured in this study, but a relatively high recapture rate (12.5%, two of sixteen) resulting from high fishing pressure will provide an opportunity to clarify the behavior of juvenile yellowfin tuna in greater detail for a longer period in a larger area.

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