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Schooling behavior of juvenile yellowfin tuna *Thunnus albacares* around a fish aggregating device (FAD) in the Philippines

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Abstract – A fish aggregating device (FAD) called a payao is conventionally installed to catch pelagic species in the Philippines. The waters around the Philippines are important regions for yellowfin tuna stocks because they include spawning grounds and nurseries. To understand the schooling behavior of juvenile yellowfin tuna *Thunnus albacares* around a payao, 13 juveniles (20.5−24.0 cm fork length) double tagged with ultrasonic transmitters (V7-2L-R256; Vemco Ltd.) and data loggers (DST-micro; Star-Oddi Ltd.) were released around a payao. A self-recording receiver (VR2-DEL; Vemco Ltd.) was attached on the mooring rope of the payao to follow the horizontal movements and data loggers recorded the vertical movements of tagged juveniles. Nine juveniles were recaptured simultaneously by ring net at the same payao after 4-7 days. One juvenile was recaptured by hand line at another payao 12 km away from the tagging site after 6 days. Recaptured juveniles showed a diurnal schooling pattern suggesting different school shape and foraging strategy between daytime and nighttime. Juveniles showed a diurnal horizontal moving pattern, concentrated near the payao during daytime, while they were distributed around the payao at nighttime. The fluctuations of swimming depth were synchronized among fish. Juveniles also showed a diurnal vertical movement pattern in surface mixed layer. They concentrated in a shallow and narrow range (11.2 ± 8.2 m, mean ± SD) at nighttime, while they were distributed to a deep and wide range (20.0 ± 11.8 m) during daytime. The maximum vertical neighbor distance indicated the vertical thickness of the school and showed a peak around noon. Higher vertical movement speed during daytime indicated vertical foraging in a water column, while at nighttime the juveniles might forage horizontally following the diurnal migration patterns of prey in the surface layer.

Keywords: Telemetry / juvenile / fish school / FAD / payao / swimming behavior / Yellowfin tuna

1 Introduction

A fish aggregating device (FAD) called a payao is conventionally installed to catch pelagic species including juvenile yellowfin tuna *Thunnus albacares* in the Philippines (Aprieto 1991). A payao is a moored FAD composed of a bamboo raft, mooring rope, an anchor and palm fronds as an aggregator (Babaran et al. 2008). Yellowfin tuna in the Western and Central Pacific Ocean (WCPO) grow up to approximately 50 cm fork length (FL) per annum (Yang et al. 1969; Wankowski 1981). The waters around the Philippines are important regions for yellowfin tuna stocks in the WCPO. They include spawning grounds and nurseries from where juveniles start to migrate when they reach about 30 cm FL (Aprieto 1991). However, little is known about the behavior of juveniles less than 30 cm FL (0+) around a payao.

Babaran et al. (2009) determined the feasibility of undertaking a telemetry experiment on early juveniles around a payao. Mitsunaga et al. (2012) conducted more comprehensive telemetry studies in a network of payaos. They revealed aspects of the behavior of juveniles that were similar but moderate compared to those of adult yellowfin tuna. Some juveniles showed a diurnal vertical swimming pattern in the surface mixed layer. They swam within a limited shallow range during nighttime and dived to deeper water up to 100 m during daytime, while an adult individual dived over 1000 m (Dagorn et al. 2006). All juveniles stayed around a single payao or associated with a network of payaos for less than 6 days, while adult yellowfin tuna stayed around a single FAD for a maximum of 55 days (Ohta and Kakuma 2005) and 151 days with a network of FADs (Dagorn et al. 2007). During the short stay, some juveniles showed a synchronized horizontal swimming pattern, assuming that they stayed near a payao during daytime and away from the payao at night time simultaneously. The result suggests that they were swimming in the same school as they were tagged in rapid succession around the same payao.

In this study, early juveniles of yellowfin tuna were double tagged with ultrasonic transmitters and data loggers to

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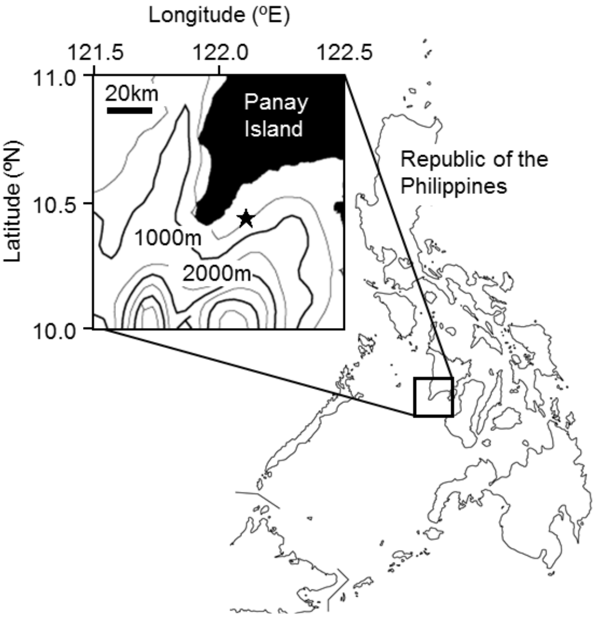

Fig. 1. Bathymetric map of the Panay Gulf. The black and graylines are isobaths per 1000 and 500 m, respectively. The black star indicates the experimental payao.

understand the schooling behavior around a FAD in the Philippines where information is required for management of the WCPO stocks. Horizontal movements were followed by ultrasonic transmitters and vertical movements were recorded by data loggers around a single payao.

2 Materials and methods

2.1 Field site

The experiment was conducted around a payao installed approximately 10 km off the cost of Miagao in Panay Gulf, Panay Island, Philippines (Fig. 1). The water was approximately 500 m deep. A self-recording receiver (VR2-DEL; Vemco Ltd., Canada) was attached on the mooring rope ata depth of approximately 15 m by scuba diving with a hydrophone directed to the bottom. The receiver decodes the ID numbers of fish implanted with coded ultrasonic transmitters within the detection zone and records the ID and time stamp in flash memory. A previous study determined the potential detection zone to be 500 m in radius (Babaran et al. 2008). The receiver was installed from 19 to 30 October 2007.

2.2 Tagging and release

An artisanal fisherman captured experimental fish nearby the payao using hand lines. Thirteen juveniles (YT 0701-0713, 20.5−24.0 cm FL) were captured from 22 to 25 October 2007. The details of each fish are given in Table 1. The fish were implanted with ultrasonic transmitters (V7-1L-R256; Vemco Ltd.) and data loggers (DST-micro; Star-Oddi Ltd., Iceland). The transmitter weighs 1.4 g in air, has a diameter of 7 mm, and measures 18 mm long. This transmitter emits coded pulses at an output power of 136 dB every 80 ± 40 s for identification (Voegeli et al. 1998). The battery life is 48 days. The data logger weighs 3.3 g in air, it has a diameter of 8.3 mm, and measures 25.4 mm long. This data logger includes temperature and presser sensors. The resolution is 0.03 °C and 0.12 m, respectively. The sampling interval was set at 60 s.

The surgical operations were performed just after catching the fish according to the procedure described by Babaran et al. (2009) and took less than 100 s for each fish. The fish were released immediately after the operation nearby the payao. To facilitate the retrieval of recaptured fish, notices of monetary rewards were distributed in nearby fishing communities and fish markets.

2.3 Environmental factors

To understand the vertical profiles of water temperature and salinity, a data logger (DST-CTD; Star-Oddi Ltd.) was submerged from the surface to180 m depth around the payao during the experiment.

2.4 Data analysis

The hourly detection rate and continuous residence time (CRT) as defined by Ohta and Kakuma (2005) were calculated to relate the horizontal swimming patterns. CRT indicates the duration for which a tagged fish was continuously monitored at a single FAD without interruption over 24 h. To examine diurnal swimming patterns, daytime was defined from sunrise (05:40) to sunset (18:30) in local time astronomically.

Vertical moving speed during both ascent and descent was calculated using differences of time and depth between successive time-series data points. Vertical neighbor distance (VND) was calculated using differences of depth at the same sampling time between two individuals in all combinations. Maximum VND indicates the distance of the farthest combination. To evaluate the synchronism, the correlation coefficient was calculated using fluctuations of swimming depth between two individuals in all combinations.

Statistical analyses were computed using Statcel2-statistical software (OMS, Japan). Values are presented as mean ± standard deviation (SD).

3 Results

Nine juveniles (YT 0702, 03, 05, 06, 07, 09, 10, 11, 12) were recaptured simultaneously by ring net at 05:33 on 28 October 2007 at the same payao as the tagging site. YT 0713 was recaptured by hand line at 06:31 on 31 October 2007 at the other payao 12 km away from the tagging site. The details of each recaptured fish are also given in Table 1. Ring netters used a fish-luring light the previous night. To avoid the influence of the light on schooling behavior, data during the period was not used for analysis.

Table 1. Details of experimental fish.

Fish ID	Tagging and release			CRT	Recapture			
	Date	Time	FL (cm)	(day)	Date	FL (cm)	Growth rate (mm day^{-1})	Stomach contents Species (size)
YT 0701	22 Oct.	10:06	22.0	6				
YT 0702	22 Oct.	10:43	22.0	<7	28 Oct.	24.0	2.9	Lantern fish (7 cm)
YT 0703	22 Oct.	10:59	21.0	<7	28 Oct.	22.5	2.1	Lantern fish (7 cm), Squid (5 cm)
YT 0704	23 Oct.	08:43	21.0	>1				
YT 0705	23 Oct.	08:47	23.0	<6	28 Oct.	23.5	0.8	Squid (6 cm)
YT 0706	25 Oct.	15:24	24.0	<4	28 Oct.	24.0	0.0	Squid (6 cm)
YT 0707	25 Oct.	15:27	20.5	<4	28 Oct.	22.0	3.8	Lantern fish (6 cm)
YT 0708	25 Oct.	15:32	23.0	>1				
YT 0709	25 Oct.	15:35	24.0	<4	28 Oct.	24.5	1.3	Squid (5 cm)
YT 0710	25 Oct.	15:41	22.0	<4	28 Oct.	23.0	2.5	Empty
YT 0711	25 Oct.	15:46	23.0	<4	28 Oct.	24.0	2.5	Empty
YT 0712	25 Oct.	15:49	23.0	<4	28 Oct.	24.5	3.8	Bone of fish (4 mm)
YT 0713	25 Oct.	15:52	22.0		31 Oct.	23.0	1.4	Squid, fish

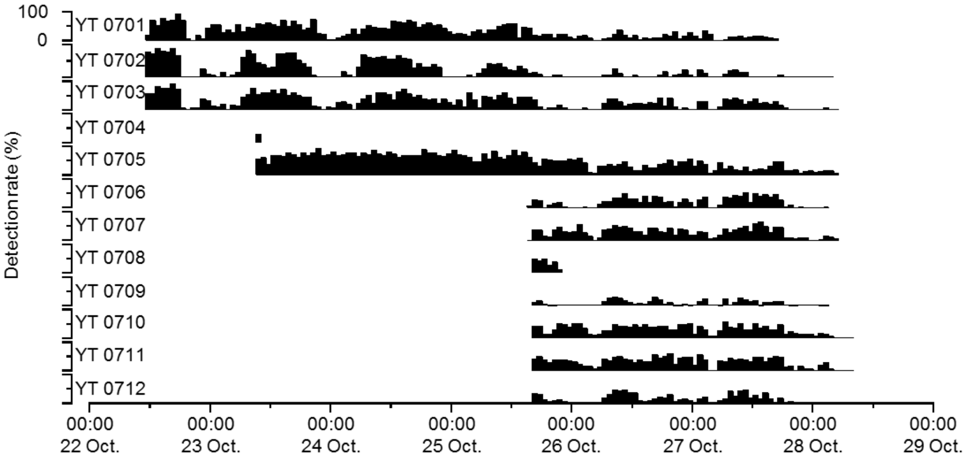

Fig. 2. Time-series data of the hourly detection rates of each juvenile.

3.1 Horizontal movement followed by ultrasonic transmitters

Figure 2 shows the time-series data of the hourly detection rate of fish. YT 0701–03 were released between 10:06 and 10:59 on 22 October. They showed a diurnal pattern, characterized by a higher detection rate during daytime than nighttime (Mann-Whitney test, $p < 0.01$). YT 0701 left from the payao at 15:40 on 27 October. CRT was 6 days. YT 0702 and 03 were monitored continuously without any interruption over 24 h until recapture. CRTs were more than 7 days. YT 0704 and 05 were released at 08:43 and 08:47 on 23 October, respectively. YT 0704 was monitored for only 25 min and was missing until the end of the experiment. CRT was less than 1 day. YT 0705 was monitored continuously until recapture. CRT was more than 6 days. There was no significant difference in the detection rate of YT 0705 during daytime and nighttime (Mann-Whitney test, $p > 0.05$). YT 0706-13 were released between 15:24 and 15:52 on 25 October. YT 0708 was monitored for only 6 hours and was missing until the end of the experiment. CRT was less than 1 day. YT 0713 was not monitored just after release, probably due to a fault of the transmitter. CRT was unknown. The remainders were monitored until recapture and showed the above-mentioned diurnal horizontal swimming pattern (Mann-Whitney test, $p < 0.01$). CRTs were more than 4 days. Mean detection rate declined as the number of fish increased.

3.2 Vertical movement recorded by data loggers

Figure 3 shows the whole time-series data of swimming depth of recaptured fish. The maximum swimming depth was 159 m performed by YT 0713 at 05:01 on 30 October. The maximum vertical moving speed was 175 cm s^{-1} performed by YT 0702 (8 FL s^{-1}) at 22:01 on 24 October during descent from 28 to 133 m in 60 s. Juveniles showed a diurnal vertical swimming pattern in surface mixed layer (Fig. 4). The vertical profile of water temperature was stratified weakly. From the surface to 110 m depth, water temperature gradually decreased from 30 °C to 26 °C. A thermocline existed from 120 to 170 m, where the water temperature declined from 26 °C to 19 °C. There was no halocline. Juveniles concentrated in a shallower and narrower range (11.2 ± 8.2 m, $n = 18\,760$) at nighttime, while distributed to a deeper and wider range (20.0 ± 11.8 m,

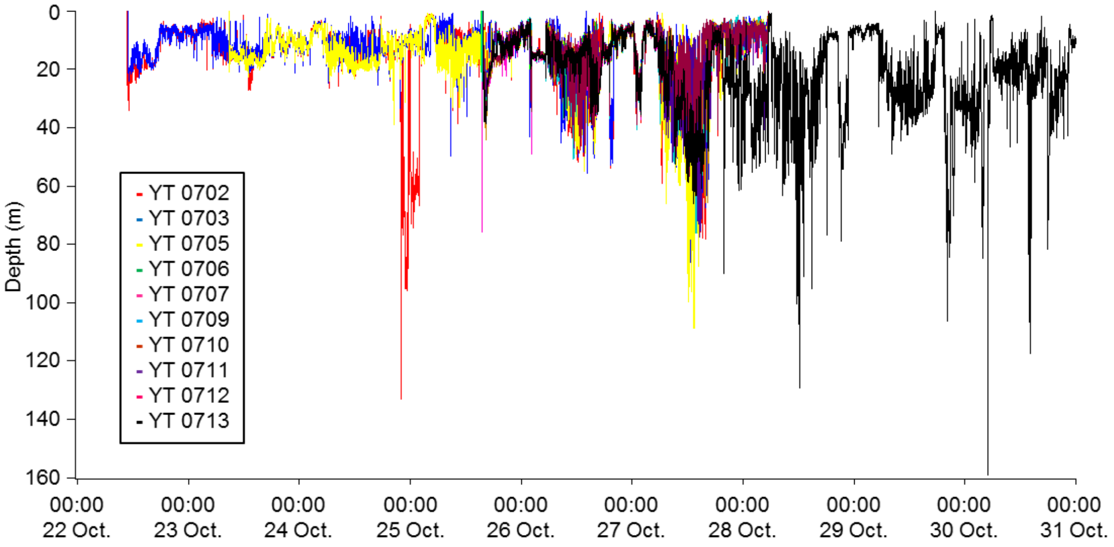

Fig. 3. Whole time-series data of the swimming depth of recaptured fish.

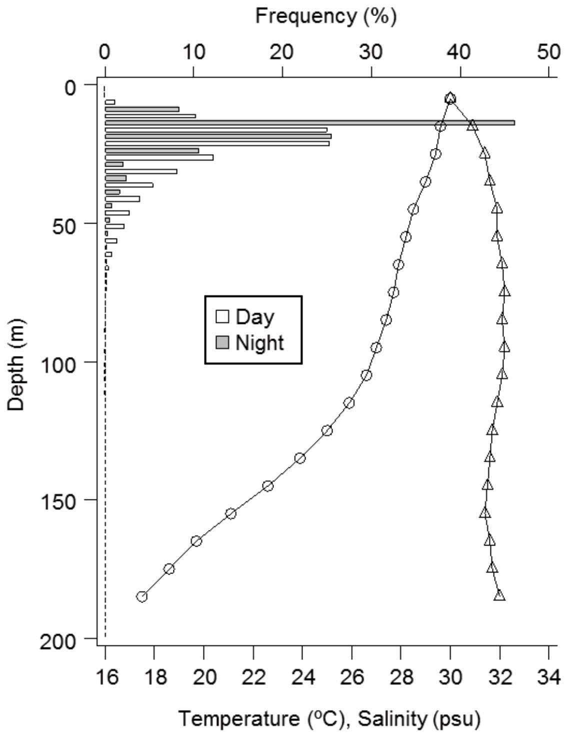

Fig. 4. The daytime (white bar) and nighttime (grey bar) depth distribution of juveniles and the vertical profile of ambient water temperature (circle) and salinity (triangle).

n = 24 238) during daytime (Mann-Whitney test, $p < 0.01$). The fish moved vertically at significantly higher speed (Mann-Whitney test, $p < 0.01$) during daytime (6.5 ± 7.5 cm s^{-1}, n = 24 238) than nighttime (2.7 ± 3.8 cm s^{-1}, n = 18 760). There was no difference in the vertical moving speed between ascent and descent during either daytime or nighttime (Mann-Whitney test, $p > 0.05$).

The fluctuations of swimming depth were synchronized among fish. The correlation coefficient was up to 0.87 between YT 0707 and 13. Figure 5 shows an example of the time-series data of swimming depth. During daytime, all juveniles distributed to a deep and wide range. At dusk, they concentrated in a shallow and narrow range. YT 0705 swam to the surface at 19:00 then merged with the others at 19:16. YT 0702 and 03 swam to the bottom at 19:09 and maintained the same depth then merged with the others at 20:26 simultaneously. Thereafter during nighttime, all juveniles maintained the same depth among fish. At dawn, juveniles started to distribute to a deep and wide range again. Consequently, VNDs were significantly higher (Mann-Whitney test, $p < 0.01$) during daytime (8.6 ± 9.4 m, n = 83 310) than nighttime (2.3 ± 6.2 m, n = 64 990). Maximum VND showed a peak around noon (Fig. 6).

This pattern continued the next day. However, YT 0713 dived to 90 m at 19:51 on 27 October then swam to a different depth from the others and the remainder were recaptured (Fig. 3). After the dive, YT 0713 swam significantly deeper (24.1±15.3 m, n = 4959) than before (18.0±11.7 m, n = 3119) until recapture (Mann-Whitney test, $p < 0.01$).

4 Discussion

A fish school is a social aggregation of fish, swimming in the same direction and maintaining near-constant spacing relative to neighboring conspecifics (Pitcher and Parrish 2003). The fluctuations of swimming depth were synchronized among 10 recaptured juveniles around single payao. Even if the horizontal spacing in the detection zone is unknown, it seems reasonable to suppose that the juveniles recognized each other in the same school. In order to recognize each other, sufficient eyesight and luminous intensity are needed. Tunas have a good vision (Bushnell and Holland 1997). In addition, during the logging period, the weather was fine and the age of the moon was 13.5−15.5 days, near full moon.

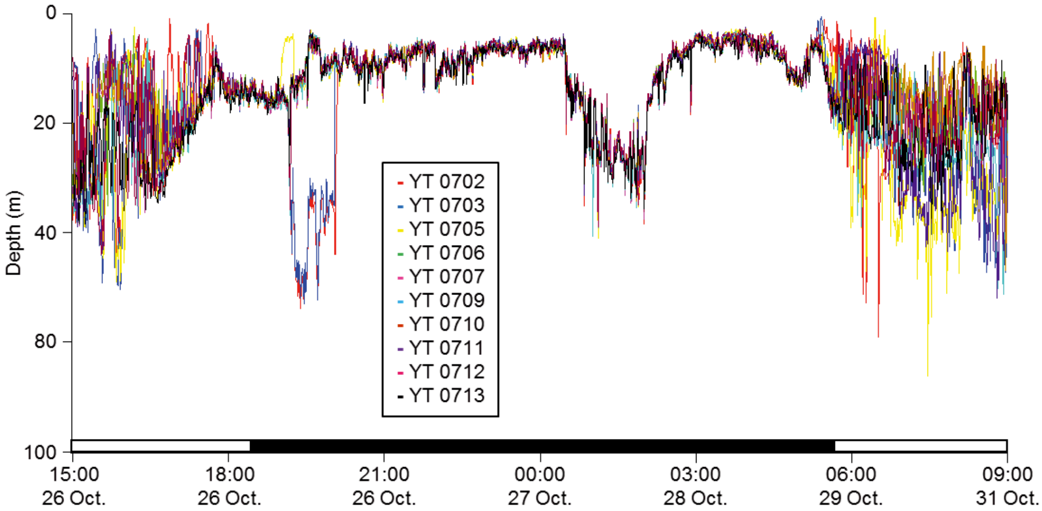

Fig. 5. Example of time-series data of swimming depth of recaptured fish. The black and white bars on the horizontal axis indicate night and day, respectively.

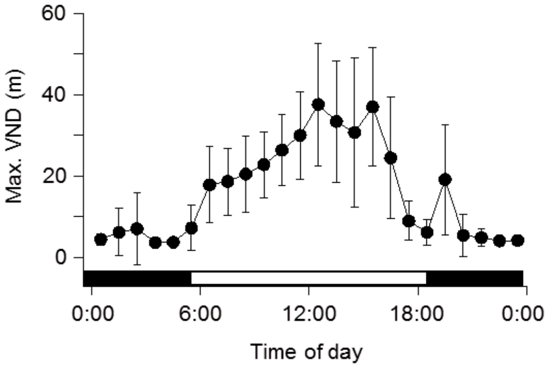

Fig. 6. Time-series data of the hourly maximum vertical neighbor distance. The black and white bars on the horizontal axis indicate night and day, respectively. The vertical bar indicates SD.

Torisawa et al. (2007) reported that juvenile Pacific bluefin tuna formed a school under 0.05 lx light intensity, which is darker than under full moon. Mitsunaga et al. (2012) considered that juveniles formed a school as they were tagged in rapid succession. In this study, juveniles tagged not only in succession, but also on other day formed a school. It seems that they were in the same school originally and were picked up from the school one by one.

Juveniles also showed a diurnal detection rate pattern, characterized by a higher detection rate during daytime than nighttime, except for YT 0705. Mitsunaga et al. (2012) also reported the synchronized diurnal pattern among 3 juveniles around a payao. These results indicate that the juveniles concentrated near the payao during daytime, while distributed around the payao during nighttime over 500 m in radius, the potential detection zone. Maximum VND seems to be reflected by the vertical thickness of a school as higher VNDs during daytime likely make a thick school, while shorter VNDs during nighttime make a thin school. In addition, juveniles concentrated in a shallow and narrow range at nighttime, while distributed to a deep and wide range during daytime. Although the horizontal neighbor distances were not able to be calculated, the shapes of the school could be estimated as a lump during daytime and a film during nighttime.

Juveniles usually form a school to avoid predators and to find prey effectively (Godin and Morgan 1985). Even if any doubt remains about the influence of fish-luring light, the dominant stomach contents of the recaptured fish were lantern fish and squid (Table 1). These species are reported to form a sound scattering layer (SSL) and showed the same diurnal vertical migration as tuna (Bertrand et al. 1999). Josse et al. (1998) indicated the important role of the SSL, assimilated as food, in vertical and horizontal tuna movements, during daytime and night time. Babaran et al. (2008) also suggested the possibility of the coincidence of swimming depth of juveniles and prey around a payao. Mitsunaga et al. (2012) reported a diurnal vertical swimming pattern of a juvenile, as if following the diurnal migration patterns of prey organisms in the SSL. They also indicated that the presence of prey is an important factor in the association of juvenile yellowfin tuna with a payao, because they are at a life stage at which they need to grow quickly. The maximum growth rate from release to recapture was 3.8 mm day^{-1} in this study. Yellowfin tuna grow up to approximately 50 cm FL per annum (Yang et al. 1969; Wankowski 1981), equivalent to 1.4 mm day^{-1} in linear. However, Fukuda et al. (2011) reported the rapid growth of juvenile Pacific bluefin tuna up to 5 mm day^{-1}. Considering an exponential growth curve, the specific growth rate seems to be reasonable to obtain rapid growth by aggressive feeding. Higher vertical movement speed during daytime indicates vertical foraging in a water column, while at nighttime the juveniles might forage horizontally following the diurnal migration patterns of prey in the surface layer.

CRTs of YT 0704 and 08 were less than 1 day. CRT of YT 0702 was 6 days. These short CRTs were reported before on juveniles (Babaran et al. 2008; Mitsunaga et al. 2012). These results suggest that the juveniles were on a start line to start to migrate when they reach about 30 cm FL (Aprieto 1991).

No record was obtained on unlucky YT 0713 probably due to a fault of the transmitter. We cannot say for certain when the fish depart from the tagging site but it is likely that the fish depart for the other payao 12 km away when the fish dived to 90 m at 19:51 on 27 October. After this dive, the fish swan at a different depth from the others and swam deeper than before. Mitsunaga et al. (2012) reported a juvenile that reached deeper swimming depths of over 200 m during payao-to-payao excursion. Holland et al. (1990) also reported deep diving of adult yellowfin tuna away from FAD. These results suggest different swimming patterns between near and far FAD. We hope the potential record of data loggers attached to juveniles, such as YT 0702, 04 and 08 will reveal the difference.

5 Conclusion

Juvenile yellowfin tuna formed a school around a FAD. The juveniles showed a diurnal schooling pattern suggesting different school shape and foraging strategy between daytime and nighttime. Although the high recapture rate derived from the high fishing pressure in this region provided these results, the results are effective in the efficiency of artisanal fisheries, while in the regulation or catch-selectivity of industrial fisheries. Accumulation of this scientific evidence is important for sustainable fishery in the WCPO.

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