SCIENTIFIC COMMITTEE
SECOND REGULAR SESSION

7-18 August 2006
Manila, Philippines

# BEHAVIORAL STUDY OF SMALL BIGEYE, YELLOWFIN AND SKIPJACK TUNAS ASSOCIATED WITH DRIFTING FADS USING ULTRASONIC CODED TRANSMITTER IN THE CENTRAL PACIFIC OCEAN

**WCPFC-SC2-2006/FT IP-7**

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# Behavioral study of small bigeye, yellowfin and skipjack tunas associated with drifting FADs using ultrasonic coded transmitter in the central Pacific Ocean

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### Summary

Swimming behavior of bigeye, yellowfin and skipjack tunas associated with drifting FADs was observed using coded transmitters in the equatorial area of central Pacific in 2005 (July and August). There were two successful tracking which consisted of 105 (30 skipjack tuna, 43 yellowfin tuna and 32 bigeye tuna) individuals or about 26 days of monitoring. For several individuals, including skipjack tuna, we succeeded in monitoring for several days. Also, all three species were monitored simultaneously. Some individuals left the FAD temporarily in the daytime or night during the tracking, but the pattern was not regular. It seems that swimming depth of bigeye and yellowfin tunas was similar and related with the depth of upper limit of thermocline, that is, both species mainly stayed in or just under the mixed layer similarly, where water temperature was more than 24℃ in the first tracking and more than 26℃ in the second tracking, although they sometimes dived to the middle or lower part of the thermocline (up to about 150-200m). Swimming depth of skipjack was a little shallower than that of the other two species. Difference of swimming depth by fish size was partly observed, that is, smaller fish distributed at shallower layer than larger fish, but the difference was not always consistent. Swimming depth during night was usually shallower than that during daytime for all species, but it was not clear for several individuals. Based on the difference of swimming depth during night by species, it is suggested that it is possible to reduce the catch of yellowfin and bigeye tuna by purse seine fishery to some extent.


## 1. Introduction

Equatorial area of central and western Pacific Ocean is main fishing ground for Japanese distant water purse seine fishery targeting tropical tunas (mainly skipjack and yellowfin tunas). In the central and western Pacific, like other oceans, purse seine operation on FADs (fish aggregating devices) has come to be common since the end of the 1990s. Small yellowfin and bigeye tunas, as well as skipjack tuna, are usually caught in the operations around floating objects including FADs. The catch of bigeye tuna by purse seine fishery in the western and central Pacific has increased from about 11,000 t in 1994 to 25,000-38,000 t during 1997-2004 (Lawson, 2005). It is concerned that the large amount of catch of small individuals may have bad influence on stock utilization of both species. In addition, these small tunas, especially bigeye tuna, are less valuable in the market, so purse seine fishermen usually don’t hope to catch them. Therefore, it is desirable to find out a way to

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prevent or reduce catching them.

It is supposed that, in the fish school consisting of skipjack, yellowfin and bigeye tunas, skipjack tuna is distributed in the shallowest layer, bigeye tuna in the deepest layer, and yellowfin tuna in the middle of them. If this hypothesis is true, it might be possible to catch each of these species especially skipjack tuna selectively and reduce or prevent the catch of small bigeye and yellowfin tunas by adjusting the depth of the net of purse seine. However, behavior of tunas aggregated around floating object has so far scarcely been known, especially as for drifting FADs.

In recent years ID pinger (coded transmitter), that is, ultrasonic telemetry system which enables to identify more than one individuals simultaneously, has been developed. By using this system, accurate swimming depth and rough horizontal position of more than one individual can be monitored simultaneously. Japanese research vessel Shoyo-maru is equipped with this biotelemetry system which enables to monitor maximum 56 individuals by ID pingers (Matsumoto *et. al.*, 2002).

Under these situations, we have conducted study of monitoring tuna school behavior aggregated with floating objects (mainly FADs) in 2001 and 2003 by using Shoyo-maru in cooperate with purse seine vessel in the equatorial area of central Pacific. Summary of these studies has been reported to last year's WCPFC meeting (Matsumoto *et. al.*, 2005). During these studies we succeeded in monitoring several yellowfin and bigeye tuna individuals at the same time for a certain period during two tracking (for about five and six days, respectively) and have found that swimming depth differs depending on species, fish size, time of day and water temperature profile, that is, bigeye tuna sometimes distributed deeper than yellowfin, larger size of fish dived deeper than smaller fish, swimming depth during daytime was usually deeper than that of night and both species usually distributed in the mixed layer or around the upper limit of the thermocline. However, we were not able to get information of each size of fish simultaneously especially as for small yellowfin tuna (smaller than 50cm), and the number of individuals was not enough. Also, almost no data were obtained for skipjack tuna because in most cases they left the FAD immediately after released. Therefore, we conducted additional study in 2005 aiming at monitoring each species including skipjack and each size of fish simultaneously. It was also aimed to collect information in the different season and area and compare the results. These kinds of information may also serve to elucidate fish school behavior around floating objects necessary for the analyses of stocks and stock assessment studies.

## 2. Method

Research cruise by Japanese research vessel Shoyo-maru was conducted from June to September 2005. Behavioral studies of tuna were conducted in the equatorial area of central Pacific (0°S-7°N, 169°E -177°W) from late June through late August.

Drifting FADs released or found by Japanese distant water purse seine vessel No. 18 Taijin-maru (chartered by JAMARC (Marine Fisheries Research and Development Center of Fisheries Research

Agency, former Japan Marine Fisheries Resources Research Center)), which were made of log, wood or steel pipe and net, were used for this study. Pictures of floating objects are shown in Fig. **1**.

ID pinger (Vemco coded transmitter, V16P-1H, 62mm in length, 16mm in diameter, 9g in water and V16P-3H, 74mm in length, 16mm in diameter, 14g in water, 51 to 60 KHz for both) was used in this study. The pinger transmits its ID code and depth data. Signals from ID pinger were received and analyzed by the biotelemetry systems (Vemco Track170 and Track 28) equipped in Shoyo-maru, which enable to monitor real time depth and horizontal bearing and distance of maximum 56 pingers, although horizontal bearing and distance are not so accurate. The pinger we used transmitted data irregularly at 20 to 69 seconds interval but data couldn't be received when signals from more than one pinger were given at the same time. Therefore, the biotelemetry systems received and recorded data from a certain pinger approximately once in one minute. Using ID pingers and biotelemetry systems shown above, effective signals from the pingers were able to correctly reach about 1000m distance to the vessel.

The fish to be monitored with ID pinger were caught mainly by angling (jigging) by Shoyo-maru or small boat loaded on Shoyo-maru and partly by trolling by small boat, targeting mainly skipjack tuna. Additional catch and release was conducted once or twice a day (in the evening and/or morning) during tracking. A pinger was attached on a fish body between first and second dorsal fins using plastic bands ("tie-wraps") or special (custom-made) instrument which was made of wire. The special instrument was usually used in combination with fishing hooks. The instrument made of wire, which is considered to do less damage to the fish, was mainly used for skipjack. Instruments and how to attach the pinger are shown in Fig. 2. Fork length of the fish was measured and released. Attachment of pinger and measurement of length were usually conducted using a cradle filled with seawater. Shoyo-maru normally stayed about 250 to 600 m away from the floating object (as a rule at the leeward of the floating object for the safety reason) during tracking and sometimes shifted the vessel so that we can receive as many signals as possible.

To investigate oceanographic environment around the FADs, XBT or XCTD observation was conducted every six or eight hours during tracking and CTD observation was also conducted one or two times in each FAD.

## 3. Results and discussions

A total of five times of tracking was conducted between late June and late August during 2005 cruise, but only two of them were regarded as successful tracking, during which a total of 105 (30 skipjack tuna, 43 yellowfin tuna and 32 bigeye tuna) fish were monitored for over ten days each. Table 1 shows summary of two successful tracking. Positions of these tracking are shown in Fig. 3 and length frequencies of the fish released are shown in **Fig. 4**. These two tracking was conducted around drifting FADs dubbed "FAD6" and "FAD8", respectively. In other tracking, only a few individuals were monitored because of poor catch by angling and also the duration of the monitoring was very short (less than 32 hours). In this paper we will detail the results of two successful tracking.

### 3.1 Tracking around FAD6

This tracking was started at around 1°05’N, 176°42’E (east of Gilbert Islands) on July 9 2005 and finished at 0°21’S, 175°02’E on July 21, that is, the tracking lasted for about 12 days. Species composition of the school based on purse seine catch just after the tracking (July 21) by estimation of fishermen’s eyes was 65t skipjack and little yellowfin and bigeye tunas. At first, 10 skipjack, 7 yellowfin and 7 bigeye tunas were released from the catch of jigging by Shoyo-maru and small boat in the morning of July 9. However, most of the fish released at that time left the FAD within several hours. Additional catch and release was conducted from the next day onward. Catch and release was conducted daily until July 19 and a total of 6 skipjack, 16 yellowfin and 19 bigeye tunas were caught by jigging and released additionally and several yellowfin and bigeye tuna individuals stayed around the FAD. Fig. 5 shows appearance of signals from each pinger. For several individuals the tracking ended because of shedding of the pinger (shown by a triangle in the graph) judging from the sinking rate. For skipjack tuna, all the fish left the FAD or the pinger shed shortly after released. One skipjack tuna (SKJ5982 38.9cm), which also had left the FAD shortly after released, returned to the FAD about 1 day after release, but it left the FAD again about 10 hours after and never came back. As for yellowfin and bigeye tunas, some of the fish continually stayed around the FAD for several days up to about 1 week or longer. Several fish left the FAD temporarily (for several hours) and returned to the FAD again but the pattern was not regular, that is, some fish left the FAD during daytime and others during night and also the cycle was not fixed. It is interesting to note that many fish left the FAD in the morning of July 14 and returned in the evening on the same day almost at the same time. Also, many fish left the FAD during July 19-20 and only one individual (BET2311 60.5cm) remained when the tracking ended in the early morning of July 21. These movements suggest that some fish are moving together. Most of smaller yellowfin and bigeye tunas (smaller than 40cm) left the FAD within one day after release.

Fig. 6 shows time series swimming depth of each species. Both yellowfin and bigeye tunas are separately shown by size category (under and over 60cm in fork length). As for skipjack tuna, although data are very few and mostly those during the daytime, they usually distributed between 50 and 100m depth. Both bigeye and yellowfin tunas distributed mostly in the layer shallower than 100m (in the mixed layer or upper part of thermocline) during night, where water temperature was around or higher than 24℃. During daytime they mainly distributed between 50m and 120m depth, although some of them dived to around or deeper than 150m (in the middle or lower part of the thermocline), where water temperature was about 16 to 22℃. Daily pattern of vertical movement was observed for both species, but it was at times not distinct. No clear difference was observed for the swimming depth between size categories for both species, although there were not many data for smaller yellowfin tuna. Also, the difference of swimming depth between bigeye and yellowfin was not clear.

Fig. 7 shows frequency distribution of swimming depth by day and night for each individual which was monitored for more than 24 hours. As for skipjack tuna, although data for only one individual and data for daytime are available, the fish mostly distributed between 50 and 100m depth. As for yellowfin tuna, most individuals showed difference of swimming depth between day and night; the mode was 0 to 10m during night and 70 to 80m during daytime. For some individuals another mode was observed between 60s and 100s m during night. However, the range of swimming depth for day and night mostly overlapped each other. The relationship between fish size and swimming depth was not clear. However, smaller fish (smaller than 40cm) distributed mostly in the layer shallower than 100m during daytime and shallower than 50m during night, and some larger fish distributed deeper. In the case of bigeye, the difference of swimming depth between day and night was less clear than that of yellowfin. For several individuals (for example, BET2314 and BET2311) there was almost no difference of swimming depth between day and night. Like yellowfin, the relationship between fish size and swimming depth was usually not clear, but smaller fish (smaller than 40cm) seems to have distributed shallower (usually shallower than 100m) than larger fish, some of which sometimes distributed deeper than 100m.

### 3.2 Tracking around FAD8

This tracking was started at 5°30’N, 177°27’E (east of Marshall Islands) on August 10 2005, and finished at 6°29’N, 177°19’W on August 24, that is, the tracking lasted for about 14 days. Species composition of the school based on purse seine catch before this study by estimation of fishermen’s eyes was 35t skipjack, 6t yellowfin and 4t bigeye tuna. Yellowfin and bigeye were mainly caught by jigging and partly by trolling and skipjack mainly by trolling and partly by jigging. The tracking began with three yellowfin tuna caught and released by jigging in the morning (about 6:00) of August 10, 2005. Additional catch and release was made during tracking twice a day (in the morning and evening) until August 21 by jigging and trolling. A total of 14 skipjack, 20 yellowfin and 6 bigeye tunas were caught and released including the first three yellowfin tuna. All of the bigeye tuna individuals released were less than 50cm because no fish greater than 50cm were caught. In this tracking, not only yellowfin and bigeye but also several skipjack tuna individuals stayed around the FAD for more than two days (up to about 6 days) as is shown in Fig. 8. Also, as for yellowfin and bigeye, the proportion of the individuals stayed around the FAD was higher than that for FAD6. One yellowfin tuna (YFT3036, 46.0cm) stayed for almost entire period of the tracking (for about 14.5 days). A total of 12 individuals (3 skipjack, 7 yellowfin and 2 bigeye) remained around the FAD until the end of the tracking. Thus we were able to monitor more than 10 fish at the same time for most of the period of tracking. Some skipjack tuna left the FAD temporarily during night. For example, SKJ2791 (39.9cm), which was monitored for about 2.5 days, temporarily left the FAD during the night on the first and second day (mainly during the first half of the night) and finally left the FAD in the evening of the third day. SKJ2790 (39.8cm) also left the FAD temporarily during the first half of the night on the second day. SKJ2809 (64.0cm), which was released in the evening of August 18 and left the FAD shortly after released, returned to the FAD before the down on the next day. However, this type of movement was not observed for the other skipjack tuna individuals except for very short period of leaving. As for yellowfin tuna, YFT3035 (91.3cm) temporarily left the FAD between dusk and around midnight almost every day. YFT2806, YFT2808, YFT2801 and YFT3037 also occasionally left the FAD mainly during the first half of the night, but the pattern was not regular. As for bigeye, similar pattern of displacement was observed for BET3029 and BET2802, but otherwise they usually stayed around the FAD almost continuously.

Fig. 9 shows time series swimming depth of each species. Both skipjack and yellowfin tunas are separately shown by size category (under and over 40cm and 60cm fork length, respectively). As mentioned above, all the bigeye tuna individuals monitored were smaller than 50cm. Skipjack tuna usually distributed in the layer shallower than 100m both in the day and night, which was the mixed layer or upper part of the thermocline where water temperature was usually higher than 26℃. Skipjack tuna usually showed comparatively distinct difference of swimming depth between day and night, that is, they usually distributed in the layer shallower than 50m during night and between 50 and 100m during daytime. For several skipjack individuals, swimming depth in the second half of the daytime was shallower than that in the first half of daytime. The difference of swimming depth by fish size was usually not clear, but SKJ2809 (64.0cm), which was the largest among the skipjack tuna individuals in this tracking, sometimes dived deeper than the other individuals. As for yellowfin tuna, they usually distributed between near the surface and about 100m depth (mixed layer or upper part of thermocline) during night and between 50 and 200m (from the mixed layer to the lower part of thermocline) during daytime. Water temperature at 200m depth was around 12℃. Difference of swimming depth by size category was not observed. Swimming depth and its difference between day and night of bigeye were similar to those of yellowfin tuna. They also dived to the layer where water temperature was about 12℃. Fish size of bigeye tuna was almost the same for most individuals but sometimes swimming depth differed depending on individuals.

Fig. 10 shows frequency distribution of swimming depth for each individual which was monitored for more than 24 hours. Skipjack tuna mostly distributed in the layer shallower than 100m both during the day and night. Swimming depth during night was shallower than that during daytime for all the individuals, although the difference was little as for SKJ2791 (39.9cm) and SKJ2809 (64.0cm). During night the mode was between 0 to 30m for many individuals. During daytime the mode was observed between 50s and 80s m and the frequency distributions of swimming depth were comparatively similar among all the individuals, most of which were almost in normal distribution. Yellowfin tuna usually distributed in the layer shallower than 150m and the majority of the depth was shallower than 100m during daytime and the layer shallower than 100m during night. During night, two modes, one at 30s m or shallower and the other between 40s and 90s m, were observed for many individuals. During daytime a mode was observed between 60s to 90s m, which was a little deeper than that of skipjack tuna. Many of the smaller fish (smaller than 40cm) distributed mostly shallower than 100m, which was shallower than the swimming depth of many larger fish, although some larger fish also distributed mostly in the layer shallower than 100m (for example, YFT3313 (79.9cm)). As for bigeye, swimming depth during night was bimodal (one at 20s m and the other at 80s or 90s m) for two (BET2802 and BET2804) and with only one clear mode between 50s and 70s m for the other three individuals. In either case, the fish mostly distributed in the layer shallower than 100m during night. During daytime only one mode was observed between 70s and 80s m for all individuals, which was similar to that of yellowfin. Bigeye tuna rarely exceeded 150m depth except for BET2802 (46.1cm), although some yellowfin did (for example, YFT2801 (79.0cm)). This is possibly because of the difference of fish size (all the bigeye tuna were less than 50cm and some yellowfin more than 50cm).

### 3.3 Comparison of swimming depth among species

Fig. 11 shows frequency distribution of swimming depth of all the individuals aggregated by species, FAD and day and night. As for FAD6, during daytime, skipjack tuna mostly distributed in the layer shallower than 100m, although both yellowfin and bigeye sometimes dived to deeper than 100m and even deeper than 150m. The position of the mode of depth was similar for all the species (80s or 90s m). During night yellowfin showed clear mode in the layer shallower than 10m, which was not observed as for bigeye. Both yellowfin and bigeye distributed between 10s and 100s m almost evenly during night. As for FAD8, the distribution of swimming depth during daytime was similar to that of FAD6 for each species except for minor differences. During night all three species showed clear mode in the layer shallower than 20m. However, the proportion of distribution in the layer shallower than 20s m was greater for skipjack than the other two species. Also, both yellowfin and bigeye showed another mode at 80s m depth, which was hardly observed as for skipjack. Therefore, it was demonstrated that swimming depth of skipjack during night was on average shallower than that of yellowfin or bigeye. Compared swimming depth between yellowfin and bigeye, they were comparatively similar except for the distribution of yellowfin near the surface (shallower than 10m) during night.

## 4. Summary and discussions

Based on the present study, difference was observed for swimming depth between skipjack and the other two species, that is, swimming depth of skipjack tuna was a little shallower than that of yellowfin and bigeye tunas both during day and night. As for purse seine operations around floating objects including FADs, the net is usually set just before dawn. Therefore, catchability by purse seine around floating objects may be affected by the swimming depth of the fish during night. Based on the results of this study, it is suggested that it is possible to reduce the catch of yellowfin and bigeye tunas to some extent by adjusting the depth of the net.

Compared swimming depth of yellowfin and bigeye tuna between two tracking during daytime, swimming depth around FAD8 was a bit shallower than that around FAD6. That is probably because of the difference of oceanographic environment. Water temperature and dissolved oxygen concentration were lower around FAD8 than those around FAD6 at the same depth, as is shown in Fig. 6, Fig. 9 and Fig. 12. Around FAD8, dissolved oxygen was less than 1.0ml/l below 180m depth (Fig. 12). Hanamoto (1975) reported that bigeye tuna are caught in the waters where dissolved oxygen concentration is greater than 1ml/l in the eastern Pacific. Bigeye tuna rarely dived below 200m depth around FAD8 as is shown in Fig. 9, Fig. 10 and Fig. 11. This may be related with low dissolved oxygen concentration near the 200 m layer.

There was little difference of swimming depth between yellowfin and bigeye tunas around the same FAD but difference of swimming depth by fish size was partly observed, that is, smaller fish distributed shallower than larger ones. Also, both yellowfin and bigeye tunas distributed mainly in the mixed layer or upper part of themocline especially during night. These results are basically similar to those of the past studies in 2001 and 2003 (Matsumoto *et. al.*, 2005). For example, in 2003 study, the depth of mixed layer was about 150m and both yellowfin and bigeye tunas dived up to about 150m during night. For the case of 2001 study, both the depth of mixed layer and swimming depth for the two species were shallower than those of 2003 study (about 60 to 80m and usually shallower than 100m during night, respectively). However, in the 2003 study, bigeye tuna sometimes dived deeper than yellowfin (bigeye tuna sometimes dived to 300m or deeper where water temperature was between 10℃ and 12℃, but yellowfin tuna mostly distributed shallower than 200m). The reason of this difference is not clear. One possible cause is the difference of dissolved oxygen concentration. In the area of 2003 study, dissolved oxygen concentration at 300m depth was close to 3.0 ml/l, although it was about 2.0 ml/l around FAD6 of the present study.

In this study, more fish remained around the FAD especially as for FAD8 compared with the past studies (Matsumoto *et. al.*, 2005). In the studies of both 2001 and 2003 cruises, many fish were released using the purse seine catch and most of them swam away from the floating object shortly after released. Two possible causes are, as mentioned by Matsumoto *et. al.* (2005), that, by the purse seine operation, most of the fish school aggregated may be caught and not many fish remained around floating object. Therefore, the fish caught and released with ID pinger may not be able to meet school and therefore will leave the floating object. The other is that, it takes about two hours from gear setting to release by purse seine, so it may be that the fish have much stress. Thus, it is considered that purse seine catch are not suitable for pinger tracking. Based on these results, in this study all the fish for monitoring with ID pinger were caught by jigging or trolling. These fish are considered to be better for tracking than those caught by purse seine and maybe that is why many fish remained around the FAD in this study. Furthermore, many fish were caught around the FADs in this study (a total of about 800 fish around FADs 6 and 8) by jigging and trolling, which enabled us to select the fish of good condition. Compared the two tracking in this study, the probability of fish remaining around the FAD was higher as for FAD8 than FAD6 especially for skipjack. Several reasons are considered for that difference. One is that the fish released around FAD6 contained more small fish (smaller than 40cm) than those released around FAD8 as is shown in Fig. 4. Smaller fish may be more vulnerable to handling than larger ones. As for skipjack, all the fish were caught by jigging and for most fish pinger was attached with tie-wraps around FAD6. On the other hand, nine of fourteen skipjack were caught by trolling and for all the individuals pinger was attached with special instrument made of wire (Fig. 2) and fishing hooks, which is considered to do less damage to fish than using tie-wraps. It is also considered that our skill in selecting and handling fish improved as the research was going on. All these things are considered to have contributed to higher percentage of fish remaining around the FAD.

## 5. Future outlook of this study

Based on the present study and the past studies, behavior of tunas aggregated with floating object has become clearer to some degrees. Also, it is valuable that we have succeeded in monitoring three species including skipjack tuna at the same time. These results will become information both for elucidating fish behavior and increasing the efficiency of purse seine fishery. It is desired that more detailed analyses including analyses of horizontal movement or analyses of similarity of swimming depth for each individual are conducted in the near future.

As the data are not yet sufficient especially as for skipjack, any more studies are desired. Also, it is important to collect data from different season, area and fish schools with different species composition, to compare the results and to know general pattern of swimming behavior around FADs.

**Acknowledgements**

We are thankful to the crew of research vessel Shoyo-maru, to the crew of purse seine vessel No. 18 Taijin-maru and to the staff of Marine Fisheries Research and Development Department of Fisheries Research Agency (JAMARC), who cooperated to our study. Also, we are thankful to the staff of Fisheries Agency of Japan, who coordinated research cruises and to the staff of National Research Institute of Far Seas Fisheries, who joined the research cruise or helped us to plan our study.

References

Hanamoto, E. (1975). Thermocline and dissolved oxygen content in relation to tuna longline fishing grounds in the eastern tropical Pacific Ocean. La mer (Bulletin de la Société ranco-japonaise d'océanograhie) 13(2). 6-19. (in Japanese with English summary).

Lawson, T. A. (ed.) (2005). Western and Central Pacific Fisheries Commission Tuna Fishery Yearbook 2004. Western and Central Pacific Fisheries Commission. 188pp.

Matsumoto, T., N. Miyabe, H. Okamoto, M. Toyonaga and T. Oshima (2005). Behavioral study of small bigeye and yellowfin tunas aggregated with floating object using ultrasonic coded transmitter. WCPFC/BI WP-5. 14pp.

Matsumoto, T., N. Miyabe, H. Saito, M. Okazaki and S. Chow (2002). Report of 2000-2001 research cruise by R/V Shoyo-maru conducted under the ICCAT's BETYP. Col. Vol. of Sci. Pap. ICCAT. 54(1). 68-90.

Table 1 **Summary of each pinger tracking of tunas.**

**BET: bigeye tuna, YFT: yellowfin tuna, SKJ: skipjack tuna.**

| Track No. | FAD No. | Date and time of initial release | End of tracking | Duration of tracking (hr) | Method of capturing fish | Position of initial release | Amount of catch by purse seine vessel No.18 Taijin-maru (based on the estimation of fishermen on board) | Number of individuals released with ID pinger | Size of the fish (cm)* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 2005/7/9 7:20-10:02 | 2005/7/21 3:13 | 283 | Jigging | 01-04.5N 176-42.3E | 2005/7/21 Total 65t SKJ:65t, YFT and BET:little | SKJ 16, YFT 23, BET 26, Total 65 | SKJ:38.9, YFT:35.8-93.1, BET 37.7-85.5 |
| 2 | 8 | 2005/8/10 5:30-7:19 | 2005/8/24 20:27 | 350 | Trolling and jigging | 05-39.6N 178-05.2E | 2005/7/31 Total 45t SKJ:35t, YFT:6t and BET:4t | SKJ 14, YFT 20, BET 6, Total 40 | SKJ:36.0-64.0, YFT:36.9-91.3, BET 40.8-47.3 |

*Limited to the fish which were monitored for more than 24 hours including temporary lost of contact.

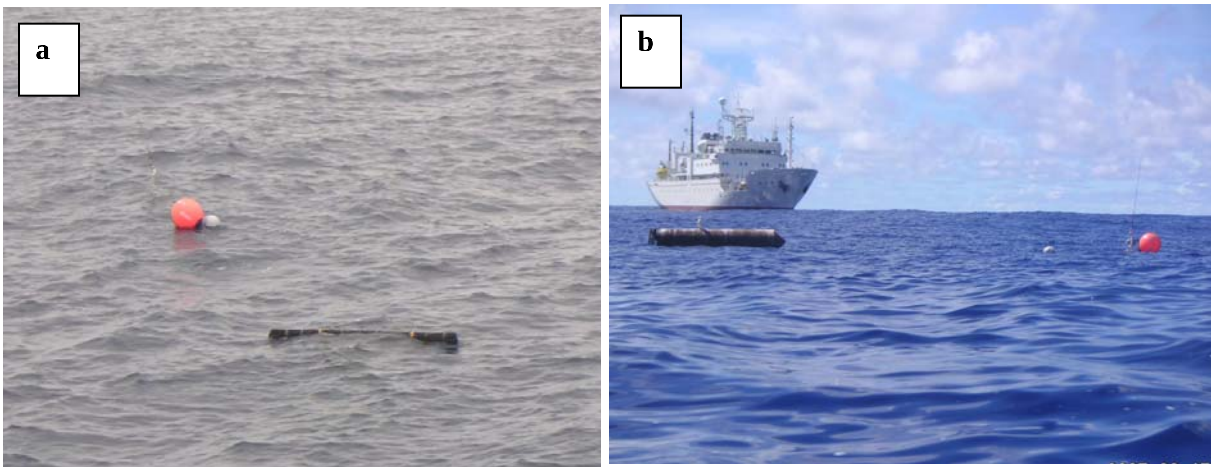


**Fig. 1 Floating objects around which this study was conducted. a: FAD6, b: FAD8.**

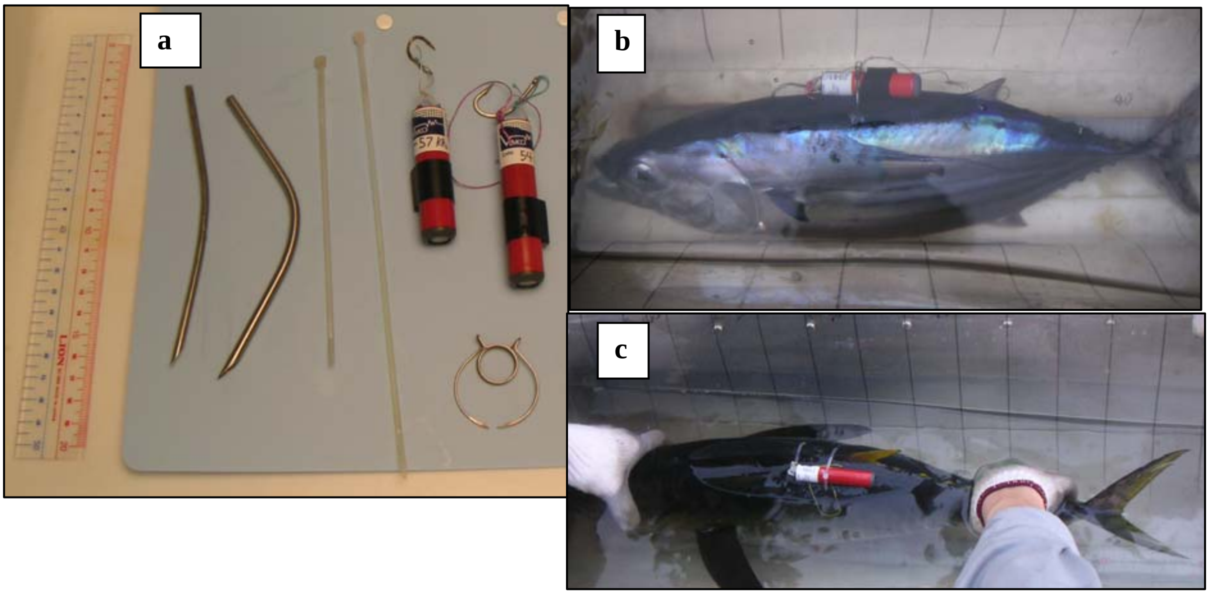


**Fig. 2 Instruments for attaching pingers and how to attach a pinger. a: pingers (left: V16P-1H, right: V16P-3H) and instrument for attachment. Lower right is special instrument for attachment made of wire. b; skipjack tuna with a pinger attached by fishing hooks and the instrument made of wire. c: yellowfin tuna with a pinger attached using tie-wraps.**

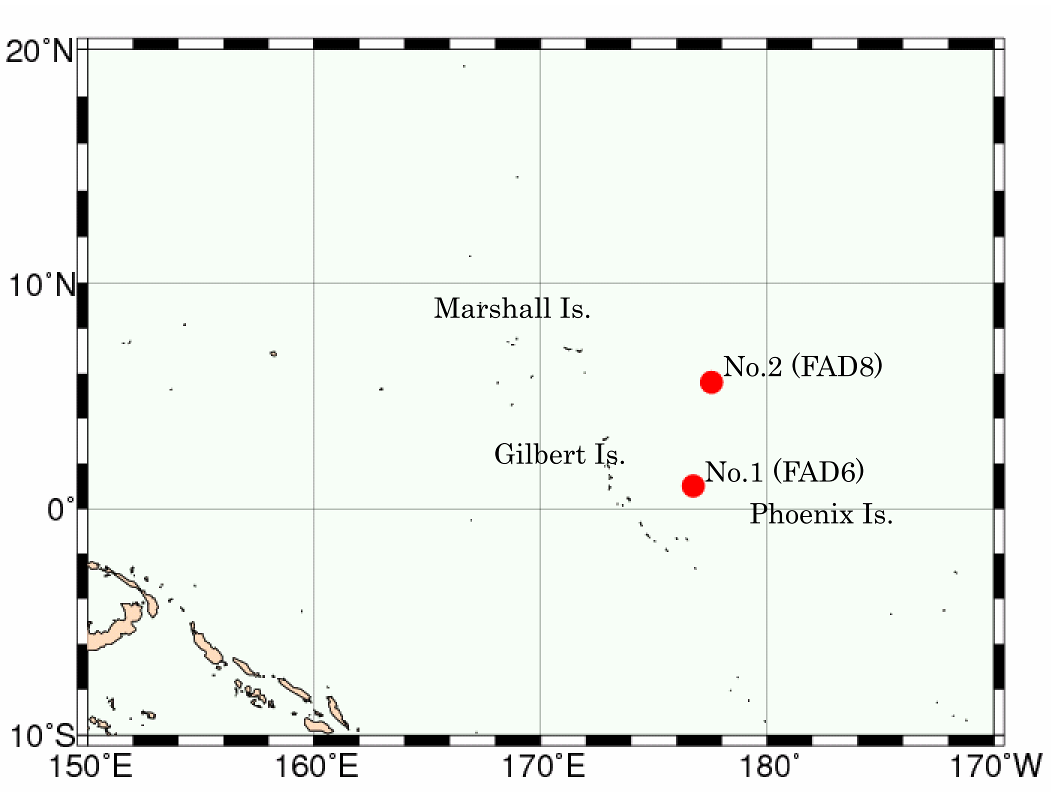


**Fig. 3 Position of start of the pinger tracking. The numbers in the map show the sequential number and FAD number of pinger tracking written in Table 1.**

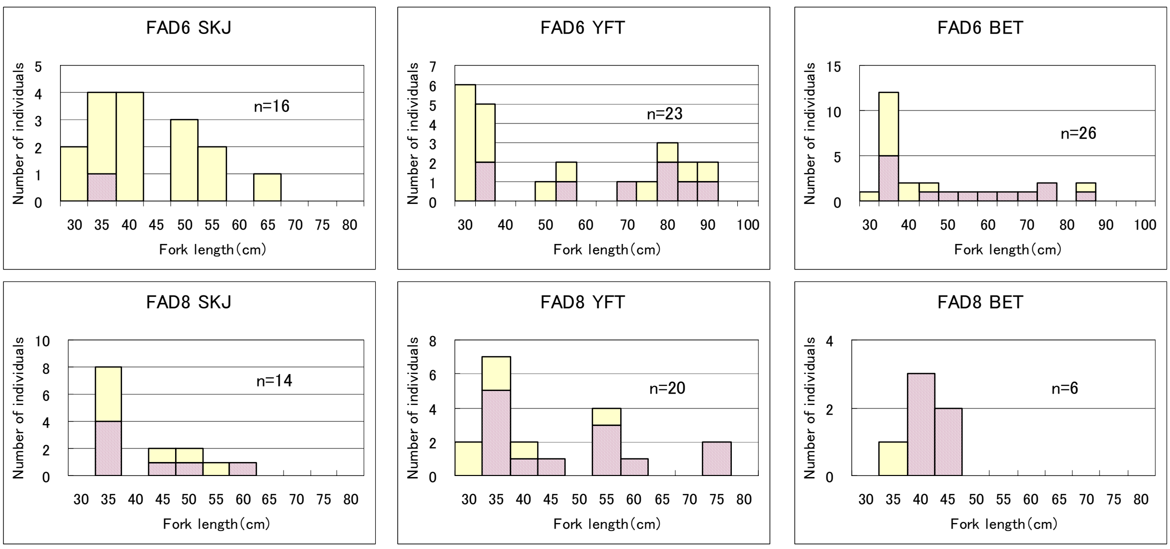


**Fig. 4 Length frequency of the fish released with ID pinger. Shaded zones show the individuals which were monitored for more than 24 hours.**

**SKJ: skipjack tuna, YFT: yellowfin tuna, BET: bigeye tuna.**

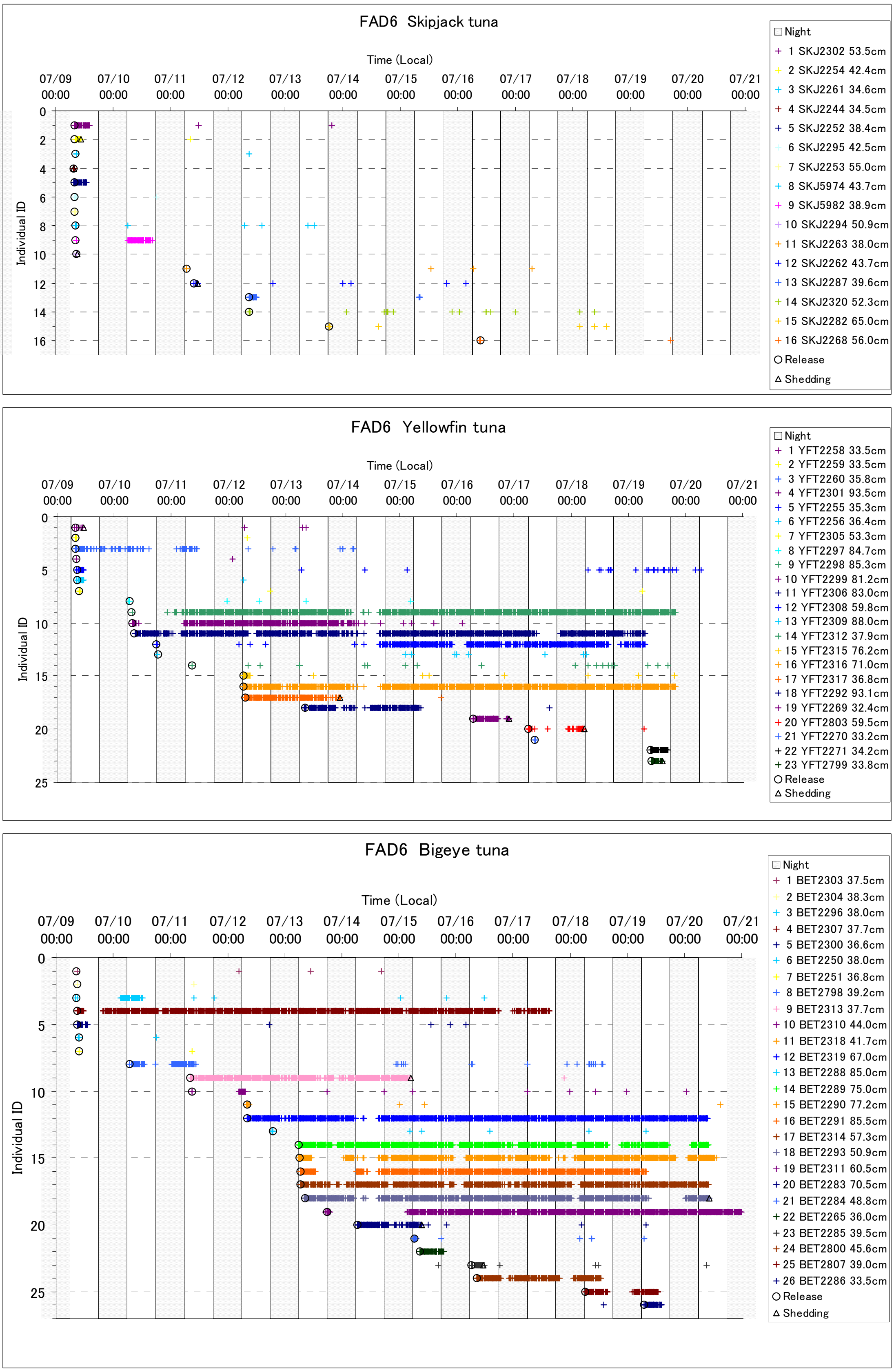


Fig. 5 Time series status of receiving signals from ID pingers for tracking around FAD6. Shaded zones show nighttime. The legends show individual ID in vertical axis, species, pinger number and fork length of the fish.

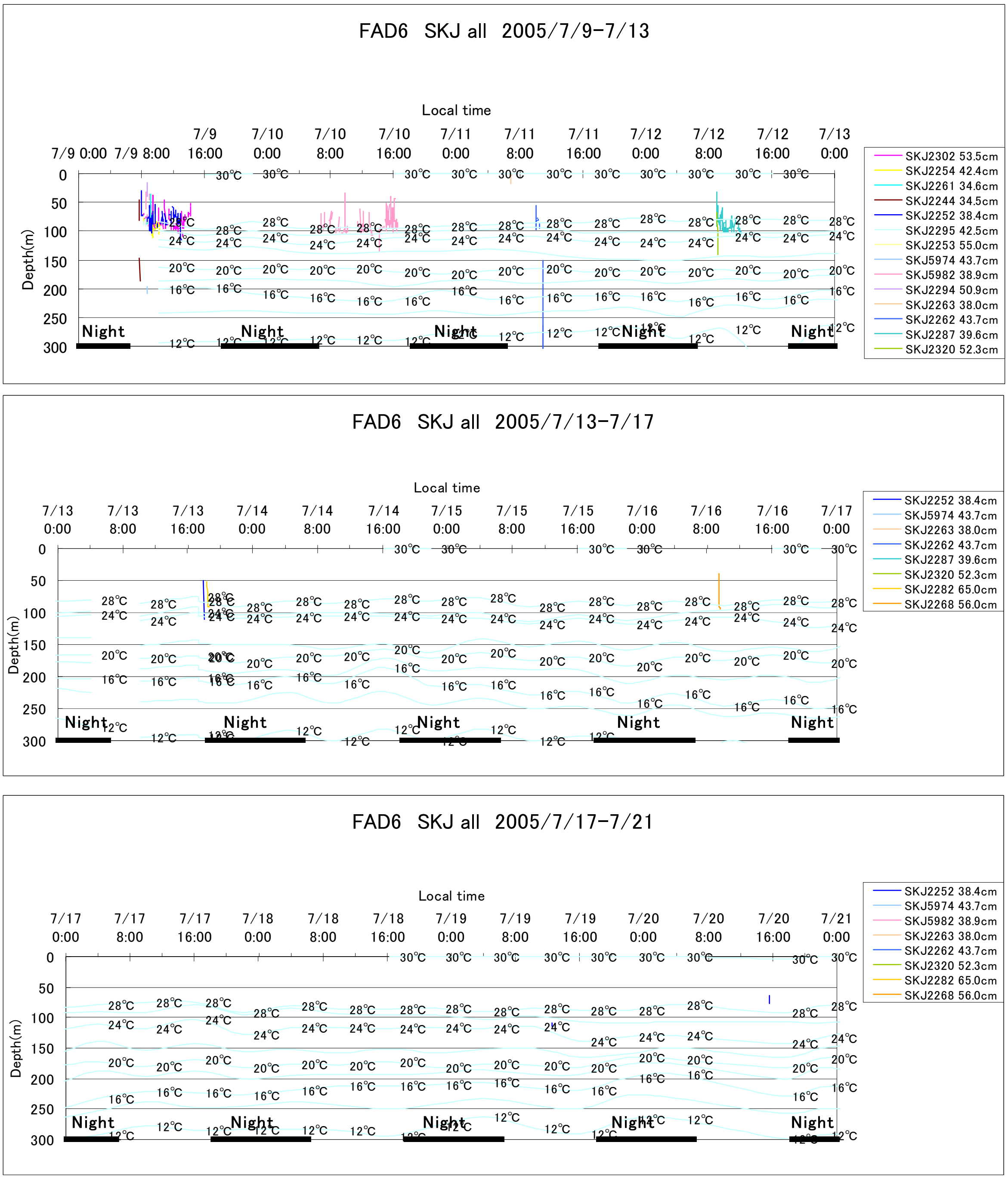


Fig. 6. Time series swimming depth of each species and size measured by ID pingers (tracking around FAD6). The legends show pinger number and fork length of the fish.

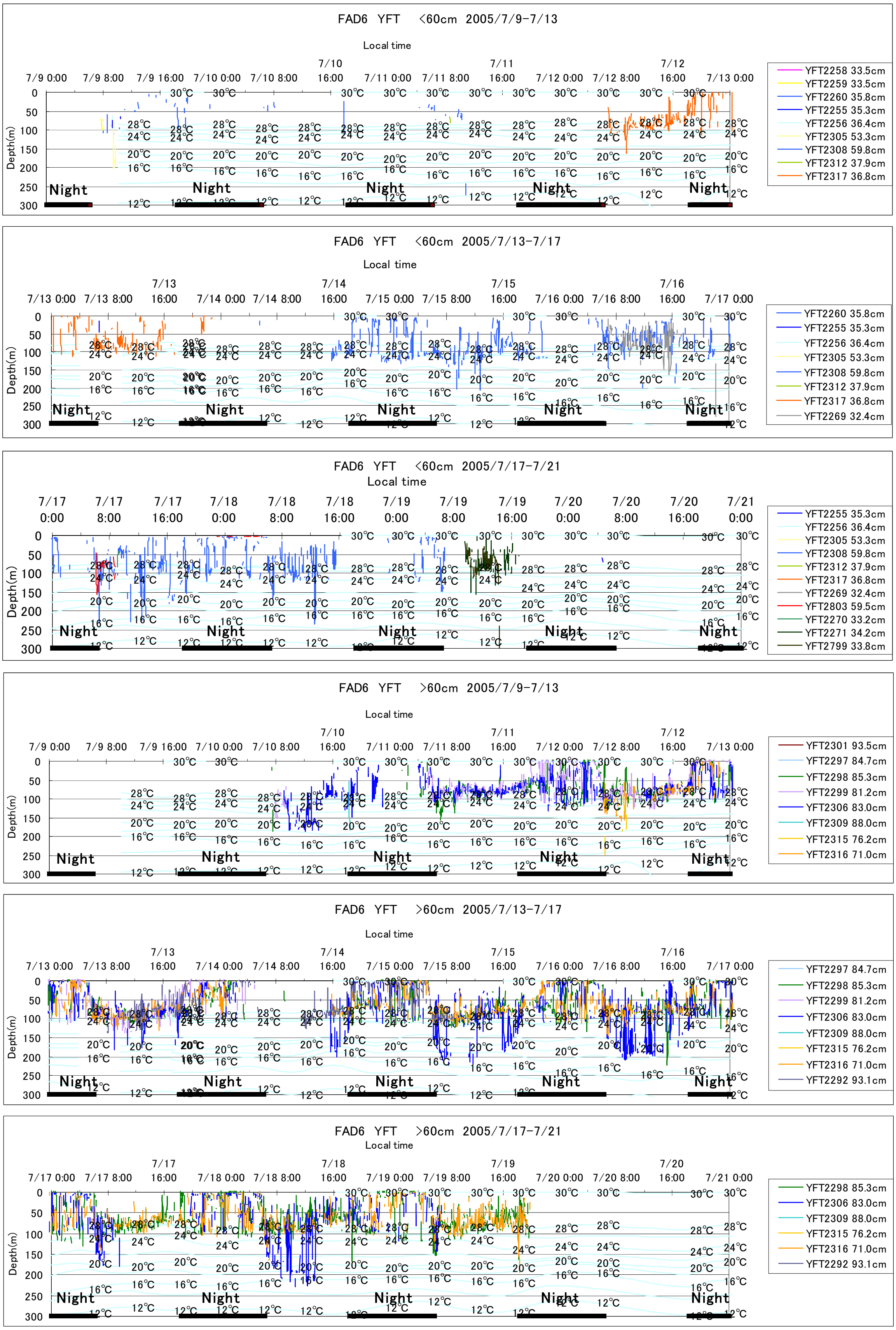


Fig. 6 (continued).

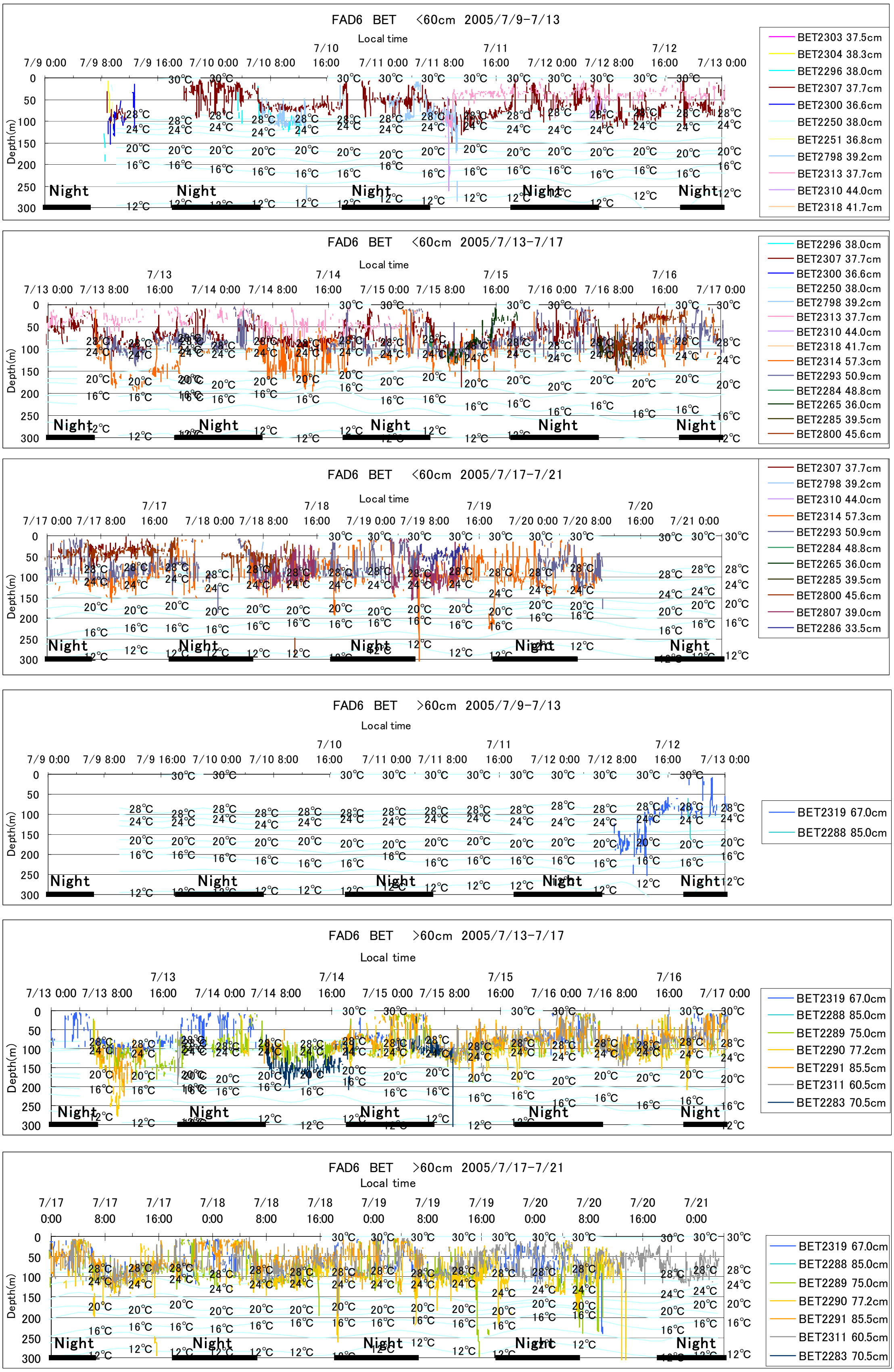


Fig. 6 (continued).

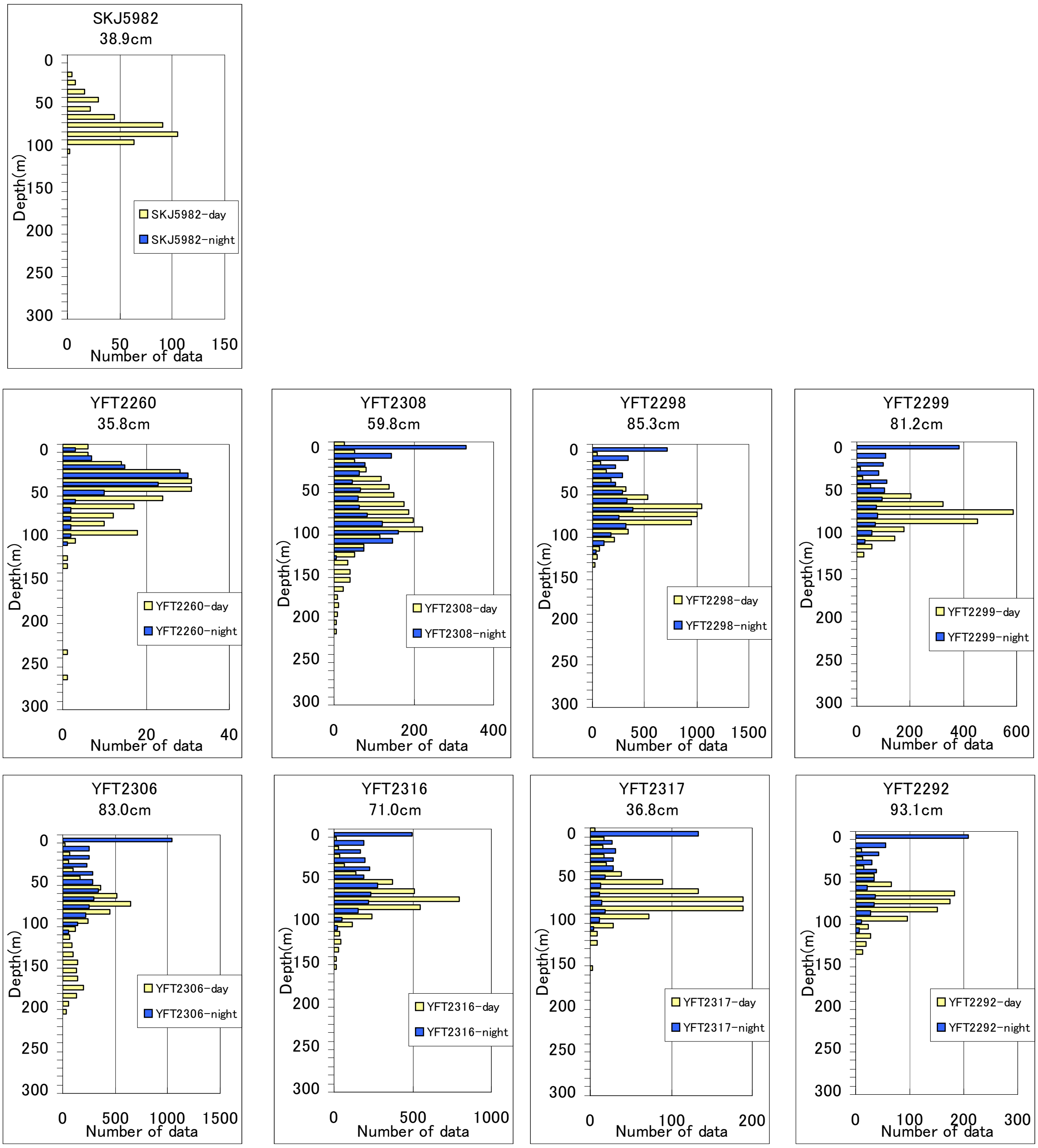


Fig. 7. Frequency distribution of swimming depth of day and night for each individual of tracking around FAD6 (limited to the individuals which were monitored for more than 24 hours including temporary lost of contact). Title in the graph shows species (SKJ: skipjack tuna, YFT: yellowfin tuna, BET: bigeye tuna), pinger number and fork length of the fish.

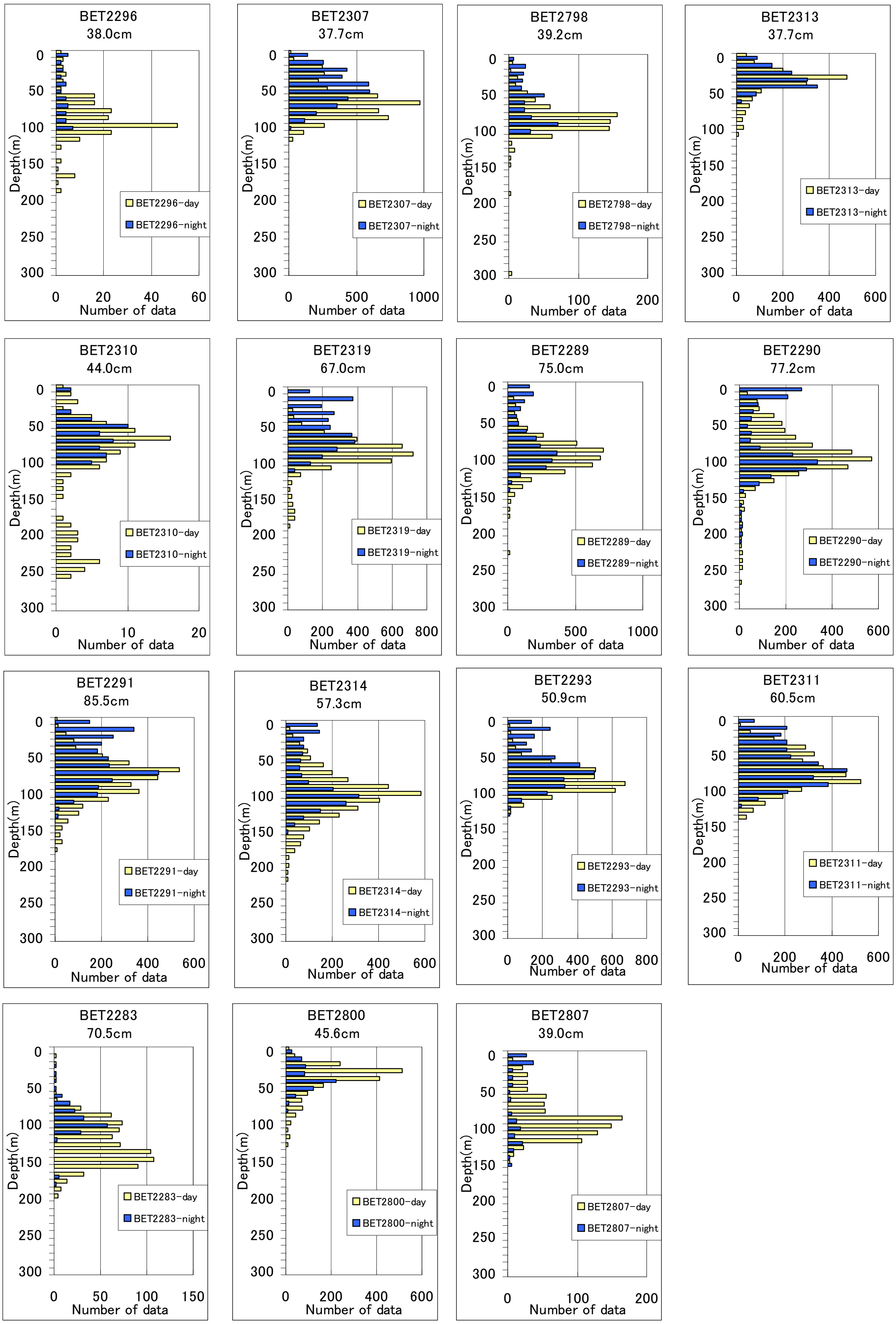


Fig. 7 (continued).

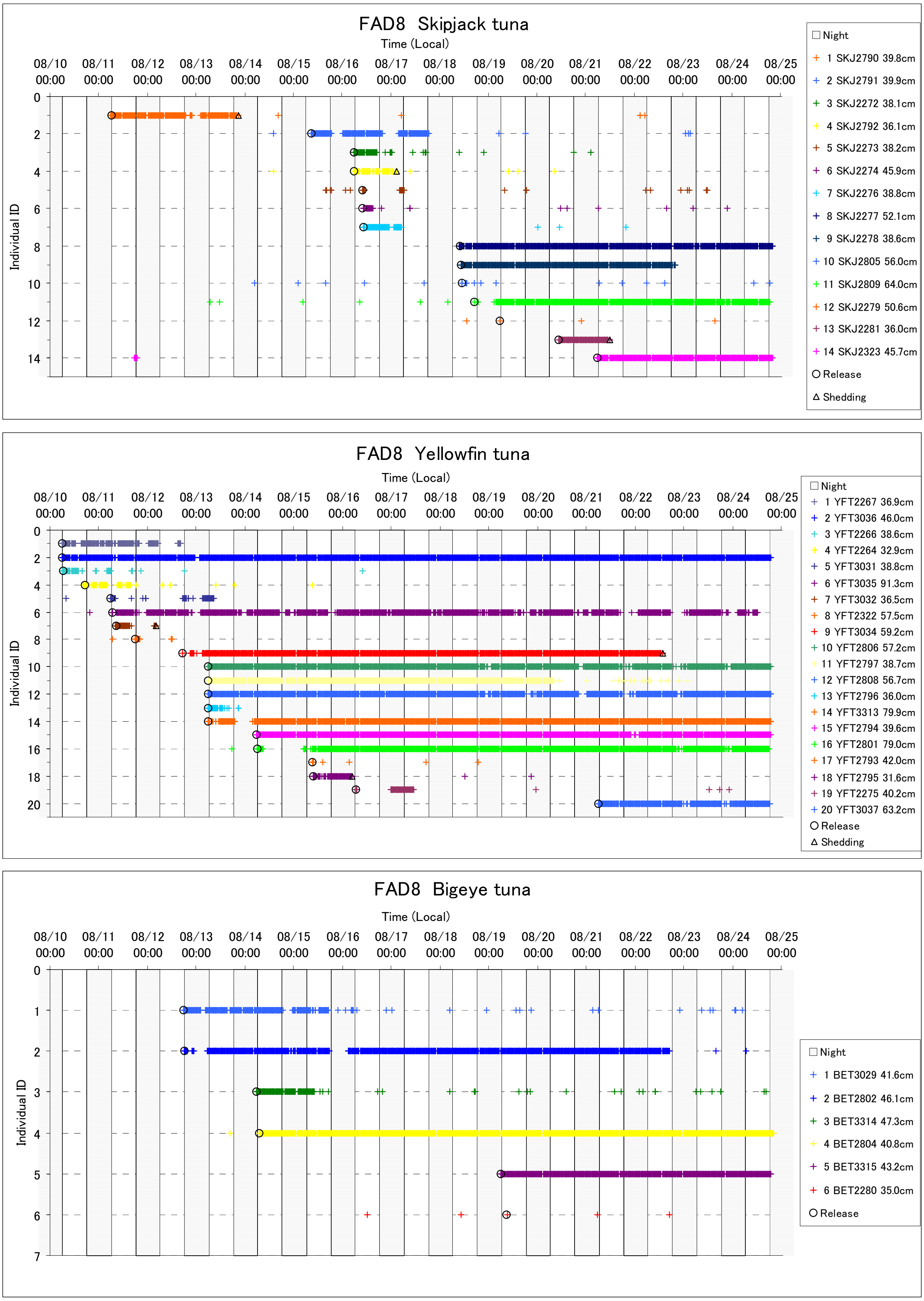


Fig. 8 Time series status of receiving signals from ID pingers for tracking around FAD8. Shaded zones show nighttime. The legends show individual ID in vertical axis, species, pinger number and fork length of the fish.

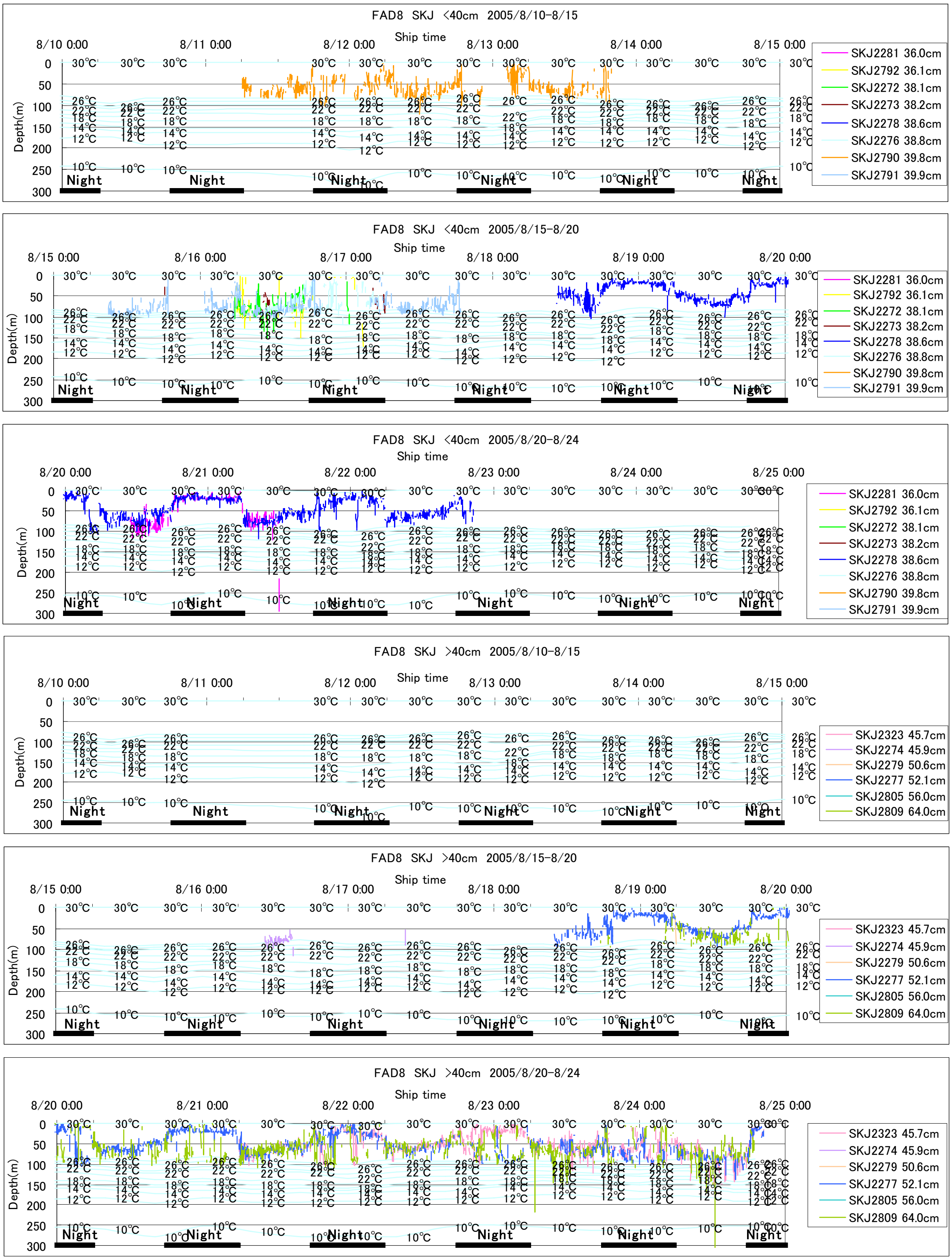


Fig. 9. Time series swimming depth of each species and size measured by ID pingers (tracking around FAD8). The legends show pinger number and fork length of the fish.

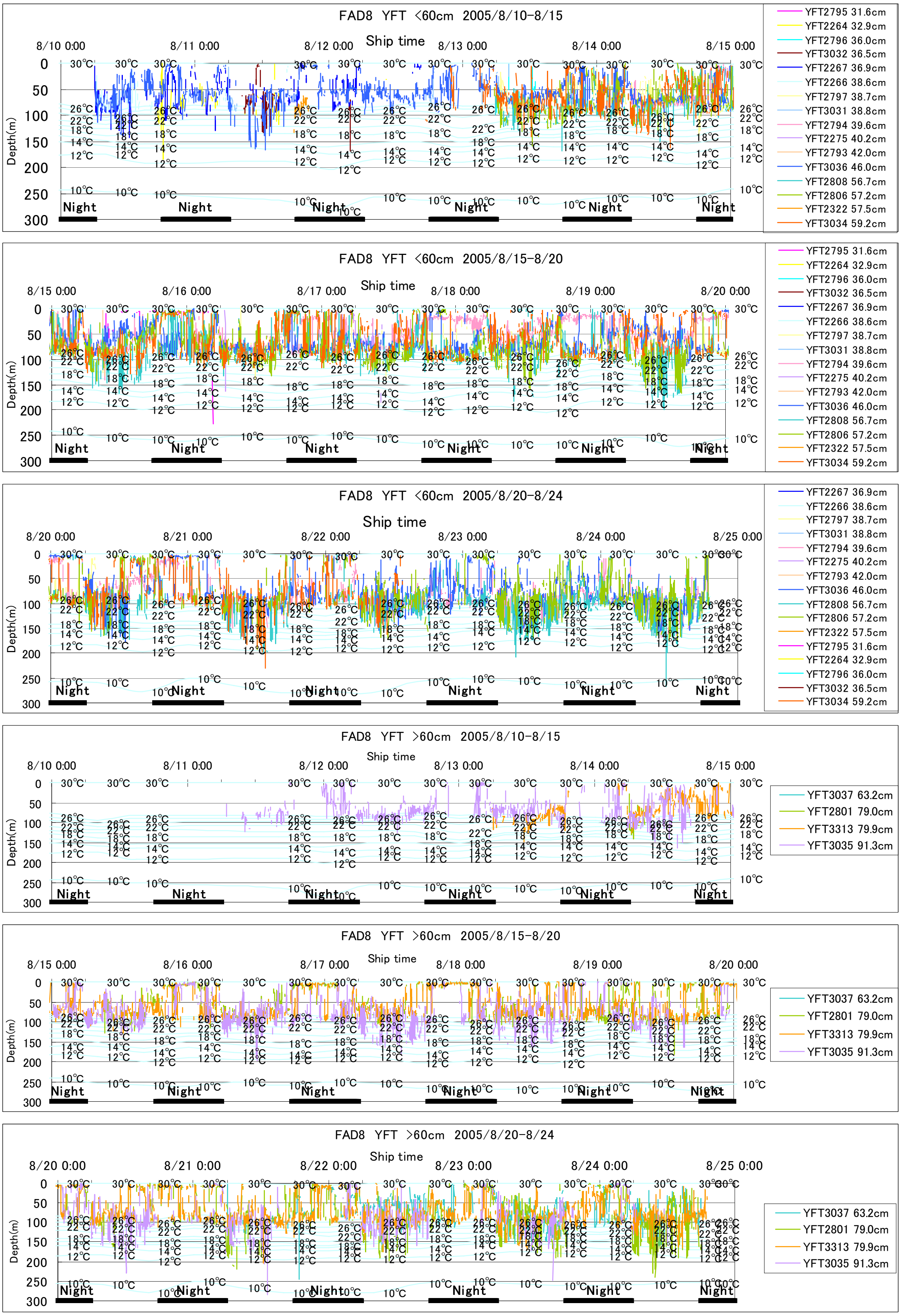


Fig. 9 (continued).

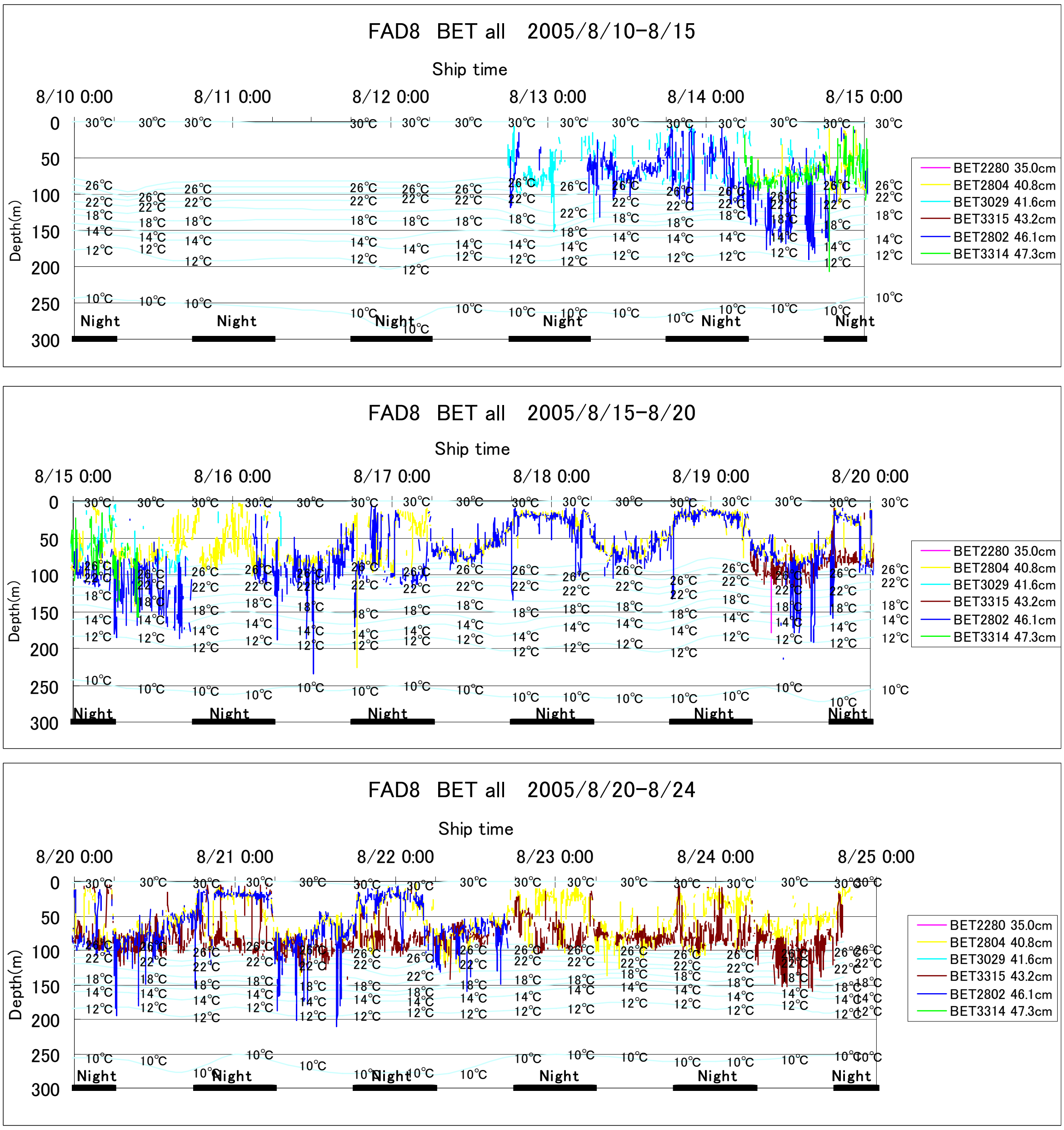


Fig. 9 (continued).

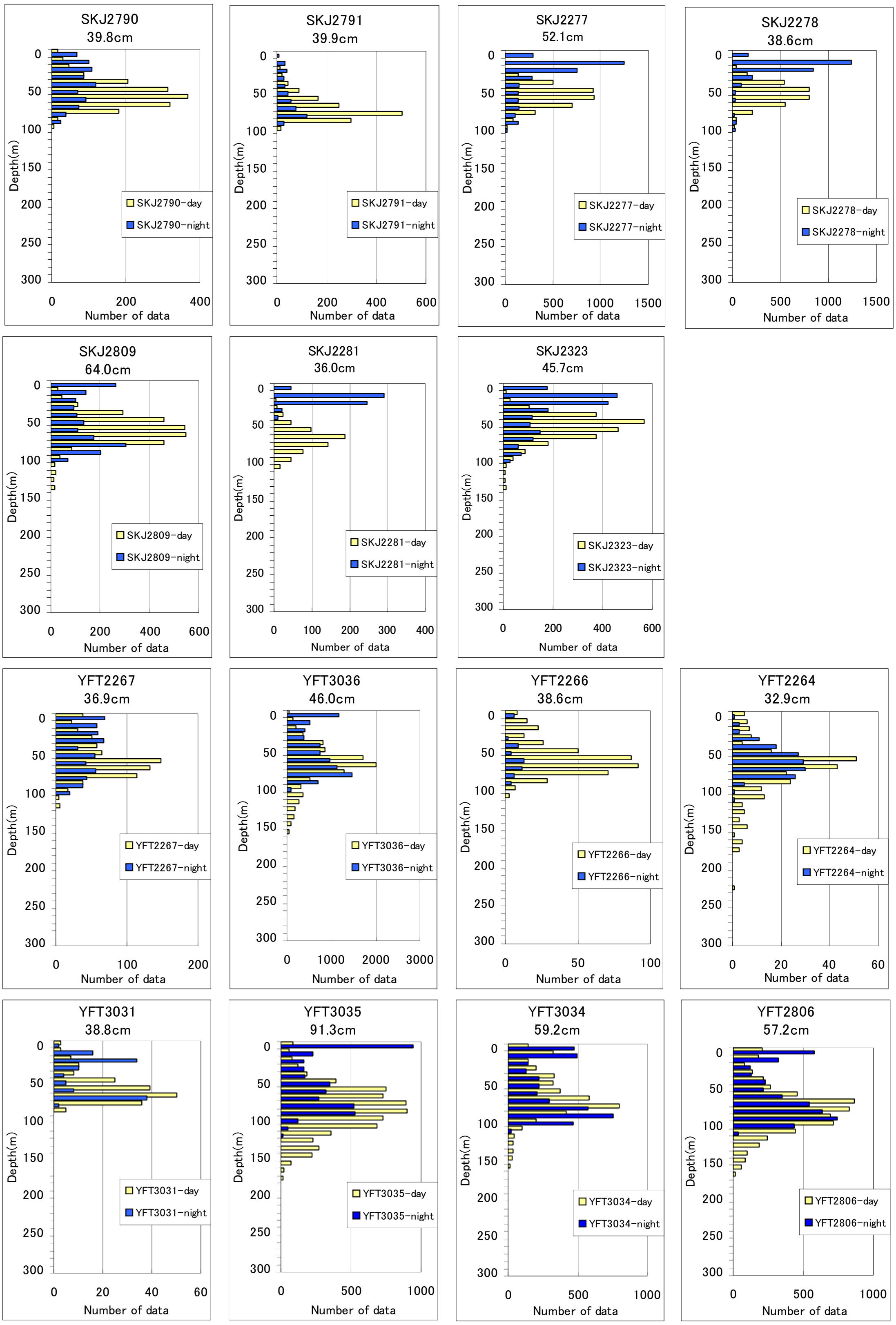


Fig. 10 Frequency distribution of swimming depth of day and night for each individual of tracking around FAD8 (limited to the individuals which were monitored for more than 24 hours including temporary lost of contact). Title in the graph shows species (SKJ: skipjack tuna, YFT: yellowfin tuna, BET: bigeye tuna), pinger number and fork length of the fish.

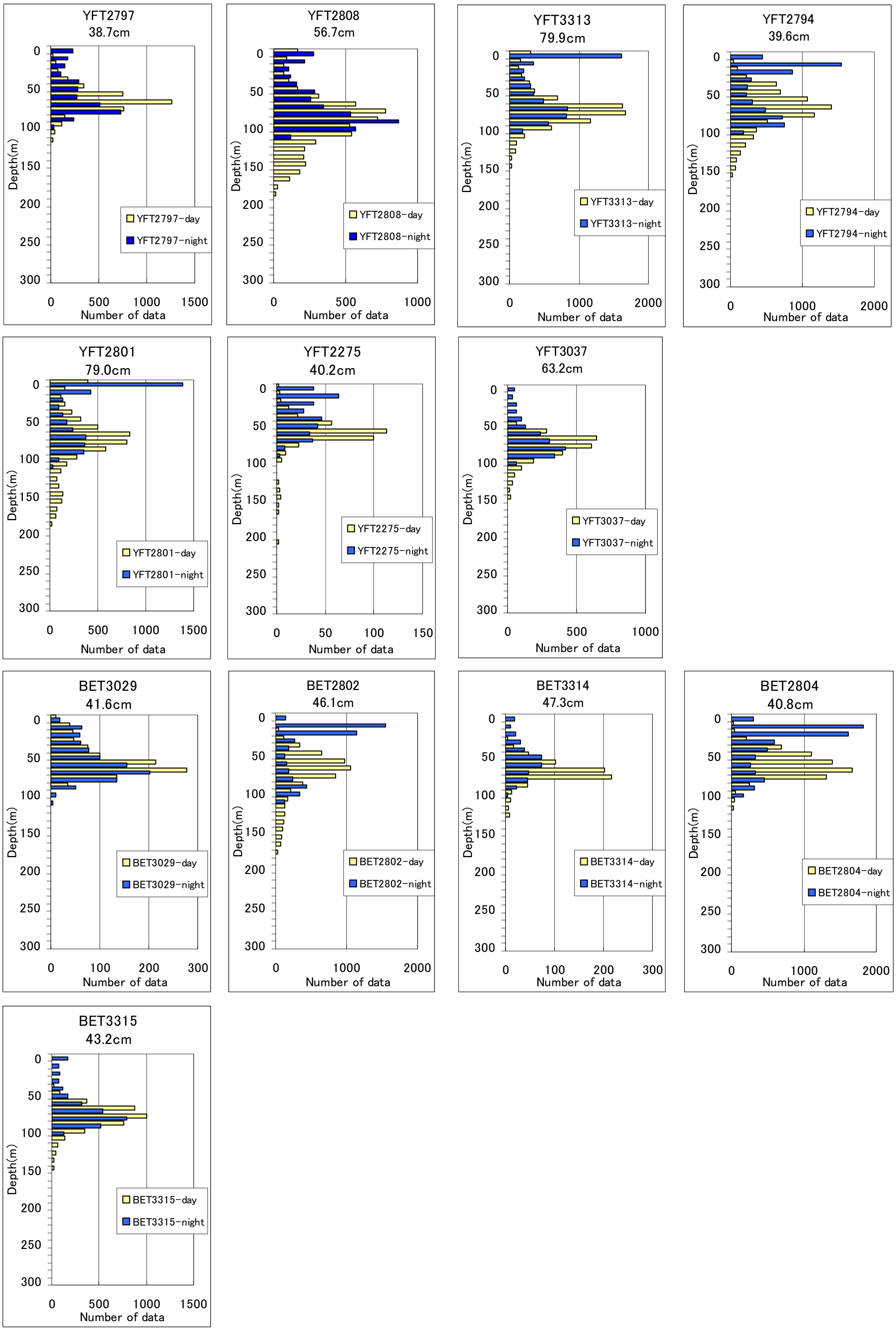


Fig. 10 (continued).

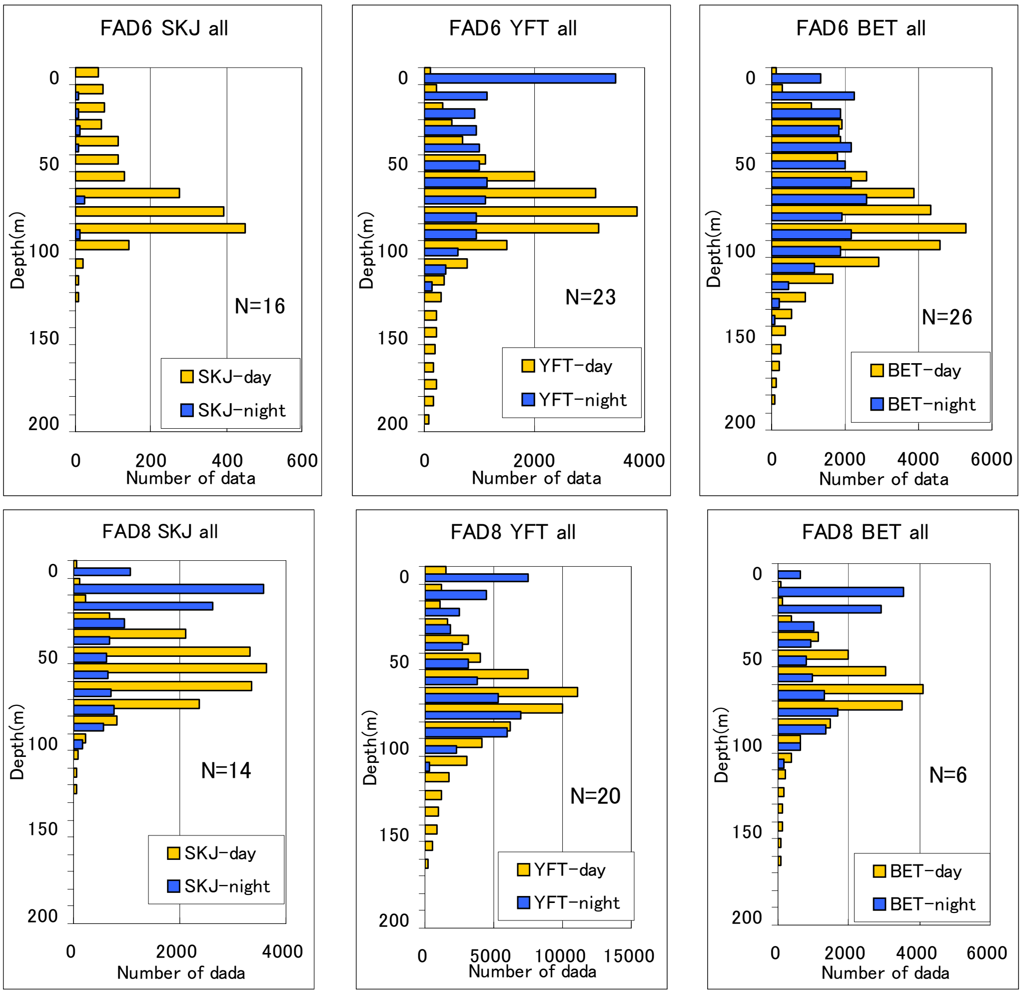


Fig. 11 Frequency distribution of swimming depth of day and night for all individuals aggregated by species and tracking. N shows the number of individuals.

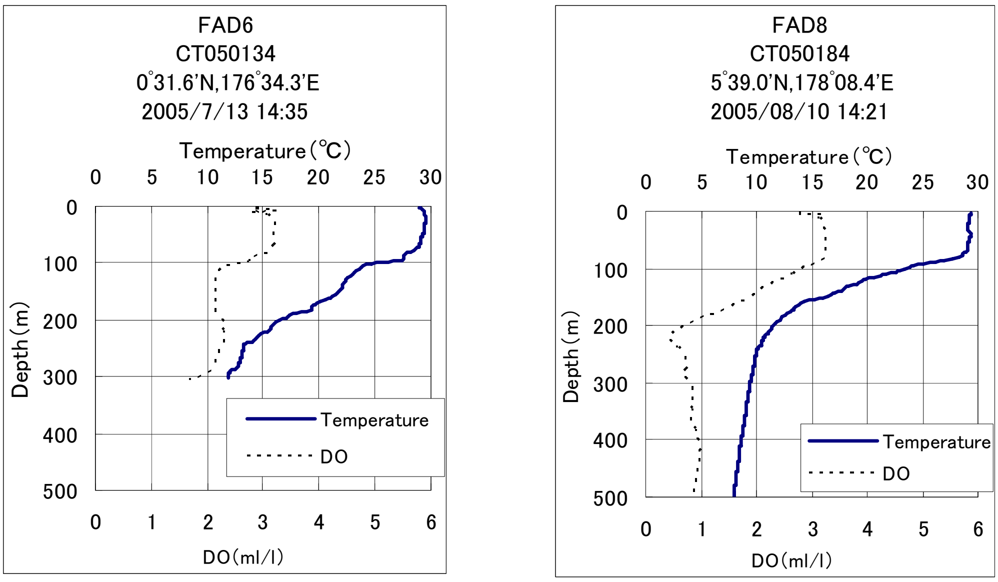


Fig. 12 Water temperature and dissolved oxygen (DO) concentration profile around each FAD based on CTD.