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PRELIMINARY ANALYSIS AND OBSERVATIONS ON THE VERTICAL BEHAVIOUR OF WCPO SKIPJACK, YELLOWFIN AND BIGEYE TUNA IN ASSOCIATION WITH ANCHORED FADS, AS INDICATED BY ACOUSTIC AND ARCHIVAL TAGGING DATA

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Preliminary analysis and observations on the vertical behaviour of WCPO skipjack, yellowfin and bigeye tuna in association with anchored FADs, as indicated by acoustic and archival tagging data

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1. Introduction

Tropical tuna, particularly at small and juvenile stages are known to associate with floating objects (Freon and Dagorn 2000). In the WCPO which, accounts for over half of world tuna production, purse seine effort and catch on floating objects has increased significantly due to a rapid increase in the use of fixed and free-floating fish aggregation devices (FADs). FADs have been shown to alter the behaviour and movement patterns of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna (Holland et al. 1990; Cayré 1991; Schaefer and Fuller 2005; Dagorn et al. 2006). Aggregation to drifting objects, dramatically increases vulnerability to purse seine gear, particularly for juvenile and small size classes, with negative impact to stock condition. Concern over floating object fishing effort on bigeye and to a lesser extent yellowfin stresses the need to better understand the behavioural impacts of FADs. In particular, a better understanding of the vertical behaviour of tuna in mixed-species floating object aggregations may contribute to methods to avoid small bigeye and yellowfin while continuing to harvest skipjack which are considered in a robust stock condition (Langley, et al. 2005). Additional information on general habitat utilization of all species is required to reduce uncertainty in stock assessment through the analysis of improved data sources.

Archival and sonic tags are useful tools for investigating fine scale behaviours and habitat preference. Archival tags can record environmental variables such as fish depth, external and internal temperature at fine time scales with light intensity to provide geolocation estimates over time. Sonic tags emit a coded acoustic pulse train that can be received and recorded by an external receiver to provide size and species specific data (Klimley and Holloway 1999). The receivers can be used to monitor the presence of tagged fish within a known range of specific areas or objects of interest, e.g. a FAD or seamount (Ohta and Kiyoaki 2001). The coding of the signal sent by the sonic tag can also be configured to vary depending upon the fish depth. Consequently information can be obtained on not only the presence of the fish but also on its depth at fine time time steps analogous to archival data.

Archival tags have been used in a number of studies outside of the equatorial WCPO to examine tuna behaviour, including the interaction with FADs (Schaefer and Fuller 2002; Schaefer et al. 2007). The oceanography and habitat of the WCPO however is different to the Eastern Pacific Ocean (EPO) and Indian Ocean where these studies have occurred. The thermocline in the Western Pacific for example is deeper than the reported thermocline depth in the EPO. Consequently, we could expect that the thermoregulatory response of fish in the WCPO to differ in respect to vertical or depth related behaviour and the time spent by individuals in water depths susceptible to fishing to differ from other regions.

Archival and sonic tagging was carried out in support of a collaborative tuna resource assessment project implemented by the Oceanic Fisheries Programme of the Secretariat of the Pacific Community (SPC), the Papua New Guinea National Fisheries Authority (NFA) and the University of Hawaii, Pelagic Fisheries Research Program. (PFRP). The project was designed to provide data useful for stock assessments of tropical tuna in PNG and the WCPO. Information on the movement and behaviour of tuna in an area of large-scale anchored FAD deployments was investigated through the release of three tag types: conventional plastic dart tags, data logging archival tags, and acoustic (sonic) transmitting tags. Archival and sonic tagging addressed the specific objective to obtain species-specific data on the spatial and temporal behaviour of tropical tuna found in association with or near large areas of FADs subject to high exploitation rates.

In this paper we present preliminary depth information from the small number of archival tags returned so far from a medium scale tagging study that commenced in Papua New Guinea in 2006. We supplement this archival information with preliminary depth data recorded from sonic tags deployed during the same study. We use this information to identify potential similarities and differences in vertical habitat behaviour between the WCPO and elsewhere for bigeye and yellowfin tuna. Preliminary information for skipjack is also presented.

2 Methods

2.1 Tags and gear

Archival and sonic tags were deployed in the Papua New Guinea Exclusive Economic Zone during two 3 month cruises that took place in Aug-Nov 2006 and Feb-May 2007. The areas of operation were mainly within the Bismarck Sea, western Solomon Sea and areas immediately north of Manus Island and around the northern coast of Bougainville Island. Tagging was conducted on the chartered *FV Soltai 6*, a 27 m, 103 gross-t pole and line fishing vessel from the Solomon Island based company *Soltai Fishing and Processing Ltd*. Fish were captured during pole and line operations during the day and at night by using hand lines or rod and reel techniques. Smaller bigeye and yellowfin were prioritised for archival tagging during pole and line fishing as fish condition was not compromised by the fishing technique. Larger sized fish were caught with a rod and reel or hand line during the night to allow the fish to be brailed from the water using a purpose-built, dedicated sling (**Figure 1**), to minimise injury or stress.

Two different size classes of archival tag were used: (1) the larger LTD-2310 (Lotek[1]) and the Mk9 (Wildlife Computers[2]) which were surgically implanted into fish 60 cm and larger; and (2) the smaller LTD-2410 and LTD-1110 (both Lotek) which were implanted into fish 40 cm and larger. Depth, internal and ambient temperature and light level were recorded each minute for LTD-2310 and Mk9 and every 5 minutes for LTD-2410. The LTD-1110 model does not carry an external stalk and only record depth and internal temperature. The sampling rate of this tag also varies with the duration of tag deployment.

Sonic transmitting tags were deployed in skipjack, yellowfin and bigeye tuna. Only data from yellowfin and bigeye will be discussed here. All acoustic gear was manufactured by VEMCO[3]. The project deployed individually coded V9 tags for presence/absence data and coded V9P tags that provide pressure data convertible to depth with an accuracy tolerance of 0.5 m. VEMCO sonic receivers (VR2-500) were mounted directly to anchored FAD floats using 4 m of 10mm galvanized chain and shackles (**Figure 2**). The reception range of VR2 receivers mounted in this fashion with V9 and V9P tags is approximately 600 m but can vary depending on ambient noise in the environment. The tags were programmed to transmit at random intervals to reduce the likelihood of data collision with V9 and V9P tags set to transmit every 60 – 180 and 40 – 120 seconds respectively. Sonic receivers were retrieved and downloaded at intervals depending on vessel schedule and environmental conditions.

[1] http://www.lotek.com/
[2] http://www.wildlifecomputers.com/
[3] http://vemco.com/

Tuna selected for archival or sonic tagging were placed in a smooth vinyl tagging cradle or left in the vinyl landing sling if greater than 10 kg. The eyes were immediately covered with a wetted artificial chamois cloth, a sea water hose inserted in its mouth to irrigate the gills and the hook removed. If fish condition was judged suitable, an archival tag was surgically implanted. Implantation involved the insertion of the Betadine rinsed tag into the body cavity through a small incision (3cm) made with a knife-blade, which was closed using dissolvable suture after insertion. Each fish was also marked with a conventional dart tag placed below the second dorsal fin. Orange coloured dart tags were used to mark fish receiving an archival or archival + sonic tag. Green coloured tag were used for sonic tag releases. Fish were measured to the nearest cm before being released. The time of release with school and location data were recorded and stored on an Access database. The tagging operation lasted between 50 seconds and 2 minutes. Identical methods were used for the implantation of archival and sonic tags.

2.2 Tagging and tag releases

Total archival tag releases were 283 comprising 17%, bigeye, 0.7% skipjack and 82.3% yellowfin tuna (**Table 1**). Approximately 75% of releases were associated with floating objects, 2% seamounts, and 23% were in free schools (Table 1). Most of the releases (93%) on free schools were made in the Morgado Square (near Tench and Dyaul Is) and in the waters south of New Britain. The releases on schools associated with anchored FADs were more widely scattered throughout the Bismarck Sea, the Solomon Sea and on the east side of Bougainville Island (**Figure 3**). The size distribution of tagged bigeye ranged from 40 - 90 cm (**Figure 4**) and tagged yellowfin ranged from 42 – 126 cm (**Figure 5**).

The second three month segment (Cruise 2) released 211 archival tagged tuna (23 bigeye, 1 skipjack and 187 yellowfin) which was substantially more than Cruise 1 (25 bigeye, 1 skipjack and 46 yellowfin). Cruise 1 tagged one fish on a free school, 92% on anchored FADs and 7% on seamount. In comparison, Cruise 2 tagged approximately 30 % from free schools, 64 % from FADs and 6% in association with logs, whales or current lines. Night fishing using rods or hand-lines was the most effective method for capturing fish suitable for archival tagging during Cruise 1 (74%). Whereas, on Cruise 2 pole and line fishing was the most productive method (81%) due to the utilization of a purpose-built archival tagging cradle during daytime pole and line operations (**Figure 6**). **Table 2** shows the number of release by fishing gear types.

A total of 222 sonic tags were deployed in bigeye (18), yellowfin (135) and skipjack (69) tuna (**Tablel 3**). Of these releases, 195 tuna received only a sonic tag of which 58% were depth recording V9P tags. Twenty seven bigeye and yellowfin received were implanted with an archival and a sonic tag as detailed in Table 3.

Sonic receivers were mounted on five groups of anchored FADs in the Bismarck Sea, one group of FADs in the Solomon Sea and on one solitary FAD set purchased by the Project and set with the assistance of the fishing industry. **Figure 7** indicates the location of FAD clusters that were equipped with sonic receivers during the study. The length frequencies of bigeye (range 47-74 cm), yellowfin (range 37-76 cm) and skipjack (range 33 – 53 cm) implanted with sonic tags by tag type are shown in **Figures 8 – 10.**

2.3 Tag recoveries

To the 30th June 2007, 25 archival tags have been recovered including 3 fish that were also tagged with sonic transmitters. Release and recapture details are in **Table 4**. Twenty-three were from Cruise 1, representing a 30 % of recapture of fish tagged during this cruise. All tag recoveries occurred from within the Bismark Sea. The tags have all been found onboard the catcher vessel except two that were found in a Thailand cannery.

2.4 Data Analysis

Archival and sonic data were downloaded from the tags or receivers using software provided by the tag manufacturers. Most of the archival tags spent some times at minus 20 degrees Celsius in the brine wells of fishing or transshipment vessels. Six tags were returned to their manufacturer for data acquisition as they stopped operating due to this cooling process.

Four general behaviour types have been described for bigeye in the current literature (Dagorn et al. 2000, Holland et al. 1990, Schaefer and Fuller 2002): (1) fish occupy the mixed layer (10 – 100 m) at night and descend below the thermocline (200 – 350 m) during the day, but can undertake vertical forays into the mixed layer throughout the day; (2) fish do not undergo diel shifts in swimming depth at dawn and dusk and are rarely observed in depths < 50m during a 24 hr period (Schaffer and Fuller 2002); (3) fish remain near the surface (10-100 m) for the majority of the time in a 24 hr period; and (4) Deep-diving behaviour where fish undertake dives in excess of 500 m.

For yellowfin tuna, 4 behaviour types have been described in the literature (Dagorn et al. 2006, Schaefer et al. 2007): (1) Fish occupy depths less than 50m at night and do not make any dives greater than 100m during the day; (2) Fish target prey in the deep-scattering layer during the day by undertaking 10 or more dives in excess of 150 m, and nocturnal foraging in the mixed layer; (3) Surface oriented behaviour where the fish remain at depths < 10 m for periods of 10 mins or more; (4) Deep-diving behaviuor where individuals undertake 10 or more dives over 500 m in a 24 hr period.

As the thermocline in the WCPO occurs much deeper than in the EPO, the depth thresholds defined in the literature were only used as a guide. Temperature is more significant, with the depth of the 18° and 12° isobaths in the study area at approximately 200 and 300 m as observed from archival tags (**Figure 11**). To examine if similar patterns existed for big and yellowfin the mean and 95% confidence intervals (CI) for each hour of each time series were calculated and overlap in intervals examined with time in order to detect distinct use of vertical depth habitats.

3. Results

3.1 Archival tag data

3.1.1Bigeye Vertical Habitat from archival tag data

Evaluation of the depth records for bigeye for each 24 hr period resulted in the discrimination of three behaviour types:

Type 1 (**Figure 12A**). A clear diel pattern in vertical depth behaviour is evident (the difference between the lower CI for night hours and the upper CI for day hours is > 150m). Fish occupy mixed layer at night (mean 20:00-04:00 hrs < 125m) and occupy deeper waters during the day (mean 08:00-16:00 hrs >150m).

Type 2 (**Figure 12B**). A diel pattern in vertical depth behaviour is evident but less pronounced than Type 1 (the difference between the lower CI for night hours and the upper CI for day hours is < 150m). Fish may also occupy deeper mixed layer habitat at night (mean 20:00-04:00 hrs < 150m) and occupy deeper waters during the day (mean 08:00-16:00 hrs >150m).

Type 3 (**Figure 12C**). Fish occupy the top 125 m of the mixed layer in both diurnal (mean 08:00-16:00 hrs <125 m) and nocturnal hours (mean 20:00-04:00 hrs <125 m).

The diel pattern is less pronounced (the difference between the lower CI for night hours and the upper CI for day hours is < 50m).

Depth statistics and depth distributions for each individual bigeye were consistent with these rules (**Table 5 and Figure 13**).

3.1.2 Yellowfin Vertical Habitat from archival data

Evaluation of the depth records for yellowfin for each 24 hr period resulted in the discrimination of six behaviour types:

Type 1 (**Figure 14A**). A diel pattern in vertical depth behaviour is evident (the difference between the lower CI for night hours and the upper CI for day hours is > 50m). Mean depth during nocturnal hours is between 0-100 m and typically between 0-50 m) and 100-200 m during diurnal hours.

Type 2 (**Figure 14B**). A diel pattern in vertical depth behaviour is evident (the difference between the lower CI for night hours and the upper CI for day hours is > 50m), but deeper habitats are used during the day. Mean depth during nocturnal hours is between 0-100 m and 200-350 m during diurnal hours.

Type 3 (**Figure 14C**). Fish occupy the top 150 m of the mixed layer in both diurnal and nocturnal hours (mean 20:00-04:00 hrs <125 m). No diel pattern is evident.

Type 4 (**Figure 14D**). A diel pattern in vertical depth behaviour is evident (the difference between the lower CI for night hours and the upper CI for day hours is > 50m), but individuals do not use the first 50 m of the water coloumn. Mean depth during nocturnal hours is between 50-100 m and 150-250 m during diurnal hours.

Type 5 (**Figure 14E**). Fish occupy habitat below 500m for >50% of a 24 hour period..

Type 6 (**Figure 14F**). A diel pattern in vertical depth behaviour is evident, but reversed with fish occupying shallower (0-100 m) habitat during diurnal hours and deeper habitat (>100 m) during nocturnal hours.

Depth statistics and depth distributions for each individual yellowfin were consistent with these rules (**Table 6** and **Figure 15**).

3.2 Sonic tag data

3.2.1 Residence and movement from acoustic data[4]

Sonic data acquisition and quality was tested during Cruise 1 on anchored FAD groups in the west central Bismarck Sea north of the PNG mainland (see red circles, **Figure 7**). Near continuous FAD association was confirmed for up to 9 sonic tagged bigeye and yellowfin tuna over a four day period on FADs within this group. Unfortunately, the receivers did not remain in place for adequate periods of time to recover longer-term data on residence time due to vessel movements to meet other objectives.

Seven anchored FADs were equipped with VR2 receivers in a semi-discrete group of FADs west of Cape Lambert, West New Britain (**Figure 7**) Ten skipjack and 10 yellowfin were released with V9 coded sonic tags and V9P depth sonic tags were implanted in one bigeye, 16 skipjack and 22 yellowfin. This was considered an excellent release data set in a group of anchored FADs. However, none of these sonic tagged tuna remained within the array of monitored FADs for more than a week and most fish apparently left the FAD where they were tagged and released within one day. **Figure 16** displays three examples of VR2 receiver downloads from different anchored

[4] An in depth analysis of sonic data is not provided here, only preliminary observations for discussion

FADs indicating that most of the tagged individuals departed their FAD of release soon after tagging. Each horizontal line represents hundreds of sonic receptions from individual tuna (tags). Departure times of release cohorts suggests strong schooling behaviour with most tuna ranging from 40- 50 cm FL with some fish visiting neighboring monitored FADs before disappearing from the array. There was no commercial purse seine activity in this area during the experiment discounting the possibility that tagged fish were captured en mass. Two yellowfin tuna in the bottom panel of **Figure 16** remained within range of receivers for up to eight days. These yellowfin were slightly larger (64, 74 cm) and carried depth sensing V9P tags and will be discussed in the following section on vertical behaviour.

3.2.2 Vertical behaviour of skipjack, yellowfin and bigeye tuna from sonic data

Five anchored FADs were equipped with VR2 receivers off the south coast of New Britain in the western Solomon Sea. These were within an isolated group of FADs with low FAD density compared to the Bismarck Sea (see **Figure 7**). One skipjack and ten yellowfin were released with V9 coded sonic tags. Depth sensing V9P sonic tags were implanted in six skipjack, two bigeye and eight yellowfin tuna within this monitored FAD group. **Figure 17** shows a receiver download from one FAD in this group again indicating apparent schooling behaviour in a synchronous departure on March 13, 2007 but with some tuna remaining up to eight additional days.

The circled text indicate yellowfin, skipjack and bigeye tuna of similar fork length that were in apparent simultaneous residence on this FAD from 9 – 13 March 2007. All three tuna were implanted with V9P depth sonic tags that reported at regular intervals. The combined depth records from all three examples displayed over a 24 hour period are shown in **Figure 18** ordered top to bottom: skipjack 51 cm, yellowfin 54 cm, and bigeye 60 cm. The plots begin and end at midnight with the central area representing daylight hours.

Skipjack remained above 100 m with shallowing at night. Yellowfin showed the most distinct shallow night vs deeper day behaviour, descending to 120-140 m. The bigeye tuna movements suggest a deep day diurnal pattern but the entire record is shifted deeper, especially at night. **Figure 19** shows the six day record of a 74 cm yellowfin indicating strong vertical movement to the surface at night and a slightly deeper general distribution to 140 m. These are preliminary observations clearly subject to further analysis.

3.2.3 Simultaneous recording from archival and sonic data

Twelve bigeye tuna, 2 yellowfin and 3 skipjack were released on a VR2 monitored FAD in the Bismarck Sea during Cruise 1. Five of the bigeye were also implanted with LTD 1110 archival tags that record internal temperature and depth. Two of these bigeye have been recaptured with archival data successfully downloaded. Unfortunately, the VR2 unit was retrieved after only three days but both sonic+archival tagged bigeye reported to the FAD-mounted receiver: one for 24 hours and the other remained in constant reporting range of the FAD during the entire period. **Figure 20** shows the archival diving record of the double tagged bigeye; both measuring 67 cm in fork length at release. The times when they were acoustically monitored on the anchored FAD are indicated with upturned brackets.

Figure 21 provides a closer look at the archival data for bigeye 11775 during the time it was confirmed at the FAD by sonic data receptions.

The relatively shallow vertical behaviour seen during the time period when the tagged bigeye were within transmission distance of the FAD-mounted receiver persisted for close to 13 days from 20 October – 2 November. This behaviour was classified as Bigeye Type 3 shallow behaviour through independent analysis of archival tag data presented here (see **Figure 12C**). Additional archival data from the same bigeye tuna 11775 is presented in **Figure 22.** Type 3 shallow behaviour is evident from 20 – 22 November after which Type 1 "classic" bigeye behaviour of "deep daytime" vs "shallow night behaviour becomes established. However, further analysis is required.

4. Discussion

Yellowfin tuna in the size range from 40 to 120 cm were implanted with archival and sonic tags during the 2 cruises. The project is expecting a 20-30% tag return rate over the next 2 years and this should provide for a robust comparison of depth and temperature habitat utilization by size. The size range and number of bigeye tuna tagged however was smaller in comparison (40 – 90 cm). This result was reflective of the entire tagging program with bigeye numbers lower than anticipated. A continuation of the overall project, focusing on the Solomon Sea and Solomon Islands is planned for November 2007 and January 2008. Larger bigeye tuna will be the priority for archival tagging during this cruise.

The greater number of archival and sonic tags implanted in Cruise 2 was most likely in response to the installation of 2 additional tagging cradles, dedicated to archival/sonic tagging on Cruise 2 (see Figure 6). Two or more dedicated archival and sonic tagging stations are worth considering for future tagging programs, given the substantial increase in fish tagged.

As of June 2007, only one bigeye archival tag return with a time-series longer than 30 days had been analysed. The vertical habitat behaviour identified for this fish was consistent with the general observations on bigeye in the EPO. The time-series of a further 6 individuals where time at large is less than 30 days are also consistent with the EPO observations. In general the depth range of bigeye demonstrating Type 3 behaviour was greater in the WCPO than that observed in the EPO. This difference is most likely in response to the greater depth of the thermo-cline in the WCPO. In contrast to the EPO, diel behaviour was evident for all three types with individual BET occurring higher in the water column during nocturnal hours in comparison to diurnal hours. When individual's exhibited type 2 or type 3 behaviours in the WCPO they occupied water depths (0-200 m) that would be susceptible to capture by purse seine fishing. Bigeye Type 3 behaviour defined in this study is generally consistent with that described by Schaefer and Fuller (2002) as associated with a floating object.

The vertical habitat use identified for the 15 yellowfin from archival data (6 with time-series longer than 30 days) was also consistent with general observations on yellowfin in other oceans. Three types of diel behaviour were evident in the WCPO with fish occupying shallower depths at night and deeper depth during the day. A fourth diel behaviour was also observed which was the reverse of the typical pattern (ie. shallower during the day and deeper at night). A substantial proportion of data were also recorded in depths <10 m, when fish were occupying shallower habitats, which was consistent with the surface orientated behaviour described in the EPO (Schaefer et al. 2007).

The archival tag data from two bigeye tuna confirmed to be less than one km of an anchored FAD by an internal acoustic tag and independent categorization of Type 3 shallow behaviour is encouraging. Unfortunately, the sonic record was brief and did not span the time period when vertical behaviour changed radically. Rapid departures and throughput of some sonic tagged schools also limited the amount of data obtained by the project, but may suggest relatively short term residence on these FADs within this region. However, more work is clearly required.

The simultaneous depth record of skipjack, yellowfin and bigeye tuna within the same anchored FAD aggregation is noteworthy. However, data analysis will continue to include all depth records to see if these patterns are reinforced. While the fish did stratify deeper from skipjack (shallow) to bigeye (deep), the differences were not great enough to suggest that shallowing purse seine nets would be an effective means of avoiding small bigeye tuna. This is particularly clear when examining the vertical depth distributions between 0400 – 0600 when the majority of floating objects sets are conducted in the region. However, archival and sonic tagging of larger bigeye and yellowfin will be required.

The results from the small number of returns already achieved are encouraging and suggest that with further returns a larger more integrated analysis that incorporates depth, temperature and horizontal movement in combination with the sonic data will be plausible to examine hypotheses about habitat use and the influence that of FADs on tuna behaviour.

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6. Tables

Table 1: total archival tag release numbers by species and school association

Species	Free school	Fad	Drifting Fad	Log	Whale Shark	Current line	Seamount	Total	%
BET	6	41	1					**48**	17
SKJ		2						**2**	0.7
YFT	59	156		8	2	2	6	**233**	82.3
Total	**65**	**199**	**1**	**8**	**2**	**2**	**6**	**283**	100
%	23.0	70.3	0.4	2.8	0.7	0.7	2.1	100.0	

Table 2: total archival tag release numbers by gear type

Fishing gears	2006	2007	Total
P&L	18 (25%)	171 (81%)	189 (67%)
Rod-handline	53 (74%)	29 (14%)	82 (29%)
Trolling	1	11(5%)	12 (4%)
Total	72	211	283

Table 3: total archival tag release numbers by species and tag model

Archival tag type	Sonic tag type	BET	YFT	SKJ	Total
	V9 coded	6	49	27	82
	V9P depth/coded	4	67	42	113
	Sonic tag only	**10**	**116**	**69**	**195**
TD 1110		0	34	1	35
LTD 2410		37	71	1	109
LTD 2310		1	43	0	44
MK9		2	66	0	68
Archival tag only		**40**	**214**	**2**	**256**
LTD 1110	V9 coded	5	8	0	13
LTD 2410	V9 coded	1	0	0	1
MK9	V9 coded	1	5	0	6
TD 1110	V9P depth/coded	0	1	0	1
LTD 2410	V9P depth/coded	0	1	0	1
LTD 2310	V9P depth/coded	1	3	0	4
MK9	V9P depth/coded	0	1	0	1
	Archival + Sonic	**8**	**19**	**0**	**27**
Total with a Sonic Tag		18	135	69	**222**
Total with an Archival Tag		48	233	2	**283**

Table 4: Archival tag recoveries details

Model	Species	Length	Release date	Release time	Release association	Days at liberty	Distance (NM)	Recapture association
LTD-2410	BE	58	28/08/2006	18:00	FAD	3	2	FAD
LTD-2410	BE	65	28/08/2006	3:50	FAD	3	2	FAD
LTD-2410	BE	51	20/09/2006	19:02	FAD	12	108	FAD
LTD-2410	BE	62	21/09/2006	8:53	FAD	15	11	FAD
LTD-2410	BE	59	21/09/2006	8:26	FAD	25	213	?
LTD-1110	BE	67	20/10/2006	19:23	FAD	20	215	FAD
LTD-1110	BE	67	20/10/2006	23:14	FAD	101	98	FAD
LTD-2410	SJ	64	21/09/2006	9:10	FAD	202	188	drifting fad
MK9	YF	104	5/09/2006	19:10	FAD	42	232	FAD
LTD-2410	YF	71	20/09/2006	5:45	FAD	61	?	?
MK9	YF	90	20/09/2006	6:05	FAD	15	1	FAD
LTD-2410	YF	54	20/09/2006	5:48	FAD	12	108	FAD
LTD-2410	YF	54	20/09/2006	2:58	FAD	12	108	FAD
LTD-2410	YF	56	20/09/2006	6:25	FAD	12	108	FAD
LTD-2410	YF	68	20/09/2006	9:11	Seamount	48	28	FAD
LTD-2410	YF	60	20/09/2006	9:30	Seamount	164	431	FAD
LTD-2310	YF	101	21/09/2006	19:57	FAD	14	65	?
LTD-2310	YF	101	21/09/2006	20:25	FAD	13	22	drifting fad
LTD-2410	YF	59	21/09/2006	8:48	FAD	10	14	FAD
LTD-2410	YF	55	21/09/2006	9:03	FAD	54	200	drifting log
MK9	YF	102	24/09/2006	18:57	FAD	10	17	?
MK9	YF	98	24/09/2006	21:10	FAD	134	?	?
LTD-1110	YF	97	2/10/2006	19:14	FAD	74	293	FAD
LTD-2410	YF	46	16/03/2007	13:01	FAD	4	18	free school
LTD-2410	YF	50	16/03/2007	14:32	FAD	3	6	FAD

Table 5. Summary of behaviour information for each bigeye archival tag

Individual	Classified Behaviour Type	Days	Depth (m)			
			18:00 - 06:00 hrs		06:00 - 18:00 hrs	
			Mean	CI	Mean	CI
11775	1	44	70	1	262	2
	2	31	84	1	160	3
	3	25	79	1	84	2
A13566	1	3	84	5	295	5
	2	15	73	2	159	4
	3	6	68	3	89	3
11774	1	2	75	21	280	8
	2	2	73	5	113	11
	3	15	82	2	80	2
A13576	1	0				
	2	8	93	2	156	5
	3	6	89	3	95	2
A13518	1	0				
	2	0				
	3	12	71	2	90	2
A12746	1	0				
	2	1	57	9	171	12
	3	1	50	6	86	5
A12592	1	0				
	2	0				
	3	2	52	5	88	5

Table 6. Summary of behaviour information for each yellowfin archival tag

Individual	Classified Behaviour Type	Day	Depth (m) 18:00 – 06:00 hrs Mean	CI	06:00 – 18:00 hrs Mean	CI
A13555	1	85	47	1	115	1
	2	1	17	4	168	27
	3	75	40	1	76	1
	4	1	92	26	190	13
390133	1	76	38	0	129	1
	2	6	43	1	226	2
	3	21	41	1	89	1
	4	20	51	1	171	1
11772	2	1	183	48	581	44
	3	12	73	3	46	2
	5	14	734	28	910	25
	6	46	62	2	150	4
A13527	1	44	36	1	125	2
	2	1	64	6	183	19
	3	14	34	2	82	2
A13578	1	31	54	1	118	2
	3	22	46	2	83	2
A13547	1	9	47	2	113	6
	3	38	42	1	77	1
390008	1	18	44	1	116	1
	2	2	52	2	203	3
	3	14	38	1	78	1
	4	7	66	1	153	2
390128	1	7	34	1	145	2
	3	6	47	1	85	1
	4	1	47	2	162	6
B041	1	8	38	1	124	1
	3	1	36	2	88	2
	4	4	44	1	156	3
B067	1	7	37	1	118	1
	3	4	29	1	76	1
	4	1	26	2	180	4
A13531	1	3	26	3	105	5
	3	8	29	2	73	3
A13525	1	3	62	3	117	5
	3	7	64	2	80	3
	6	1	96	6	83	8
A13540	1	2	69	4	111	6
	3	9	74	2	74	2
A13568	1	4	40	4	108	3
	3	6	37	3	90	3
390130	1	5	32	1	125	2
	3	4	32	1	69	1

7. Figures

Figure 1. Purpose built landing and tagging sling for large tuna

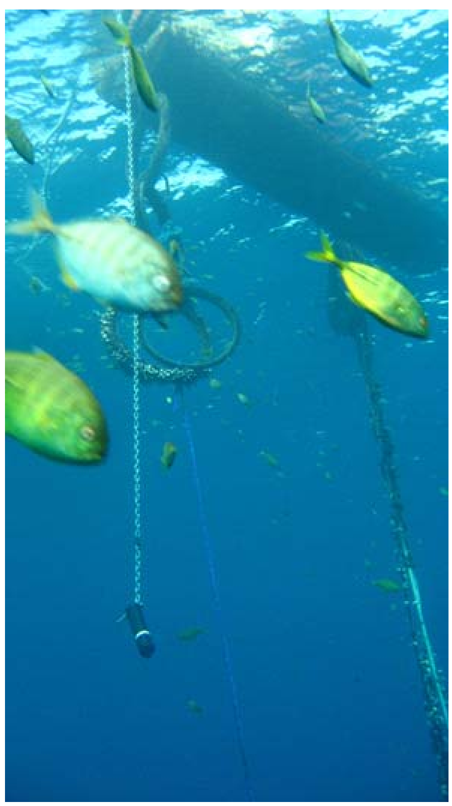

Figure 2. Sonic receiver mounted beneath an anchored FAD in the Bismarck Sea

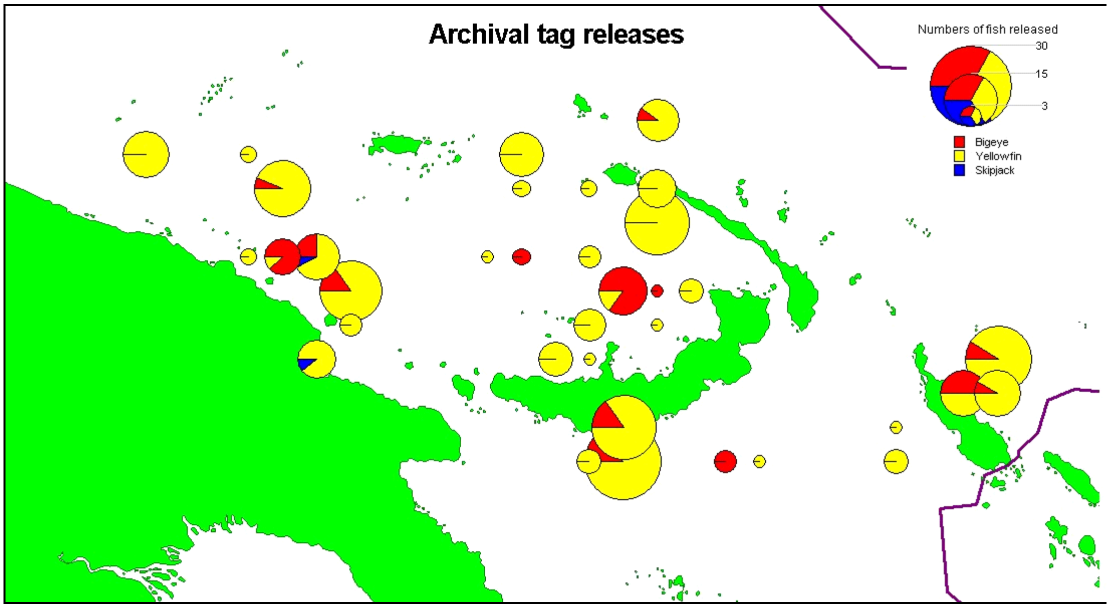

Figure 3. Spatial distribution of archival tag releases by species

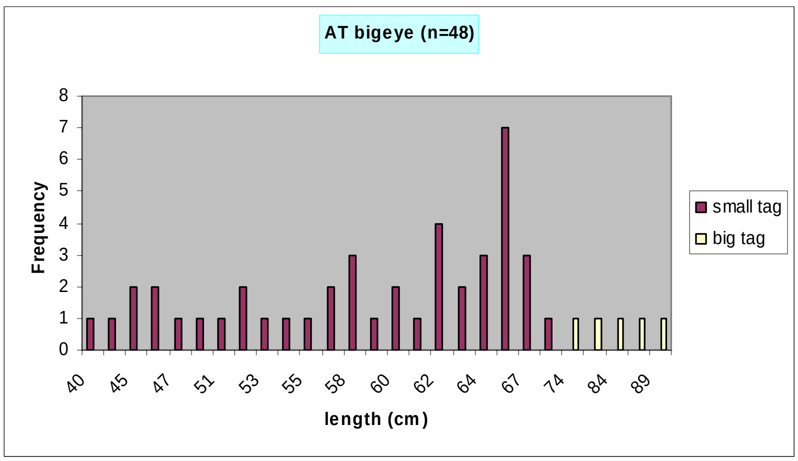

Figure 4. size distribution of archival tagged bigeye

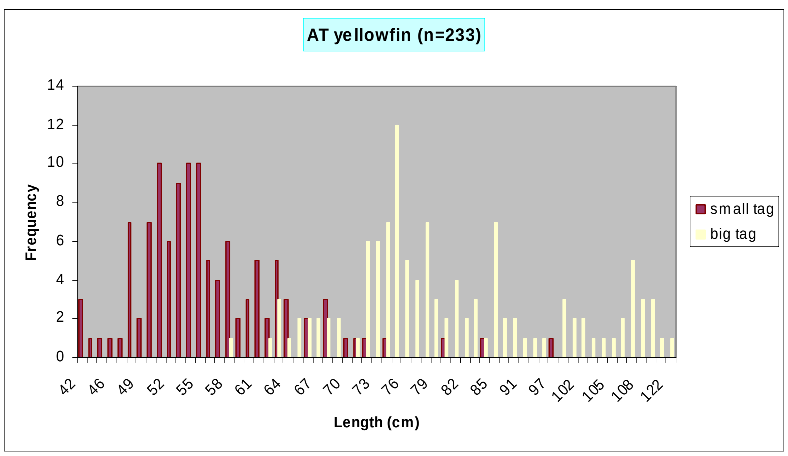

Figure 5. size distribution of archival tagged yellowfin

Figure 6. Archival/sonic tagging cradle on the bow

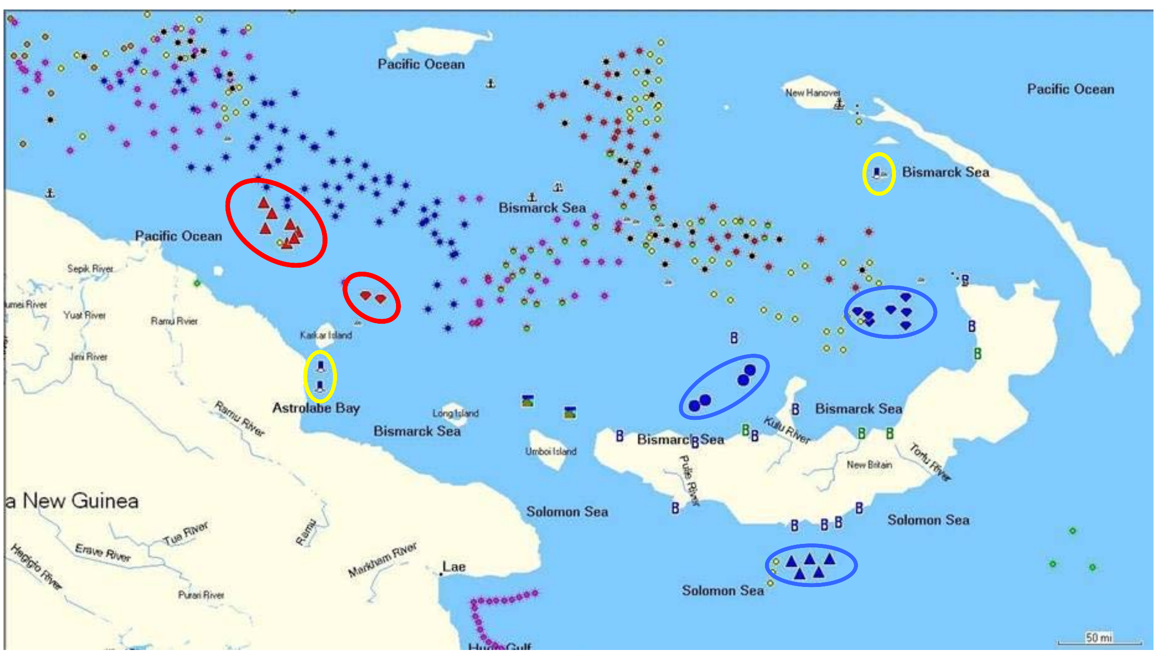

Figure 7. Anchored FAD positions and FADs equipped with sonic receivers (circled)

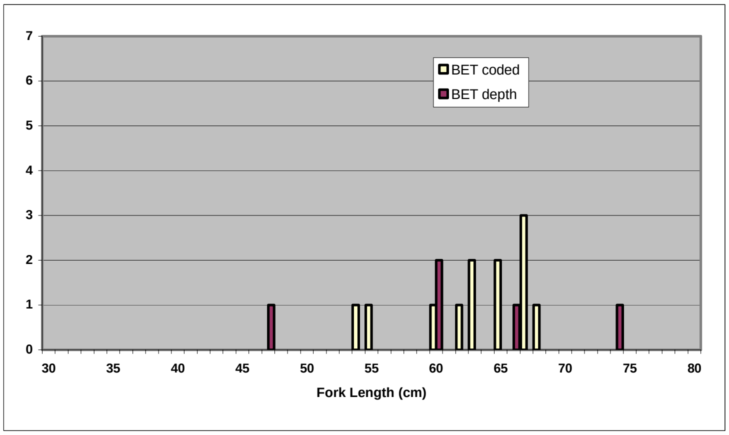

Figure 8. Length frequency of bigeye sonic tag releases (coded n=12; depth n=5)

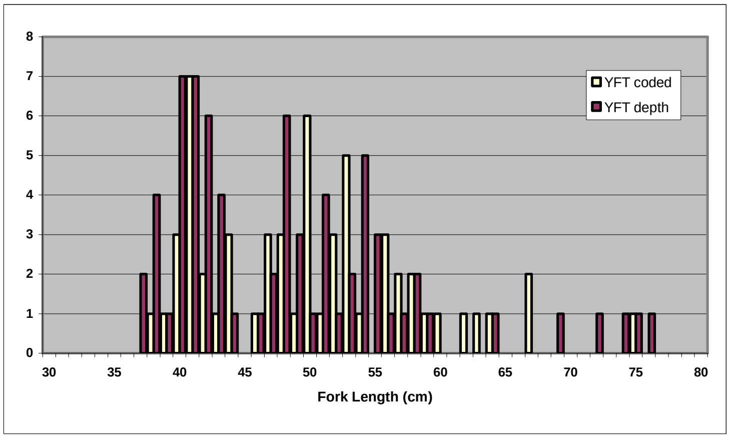

Figure 9. Length frequency of yellowfin sonic tag releases (coded n=57; depth n=71)

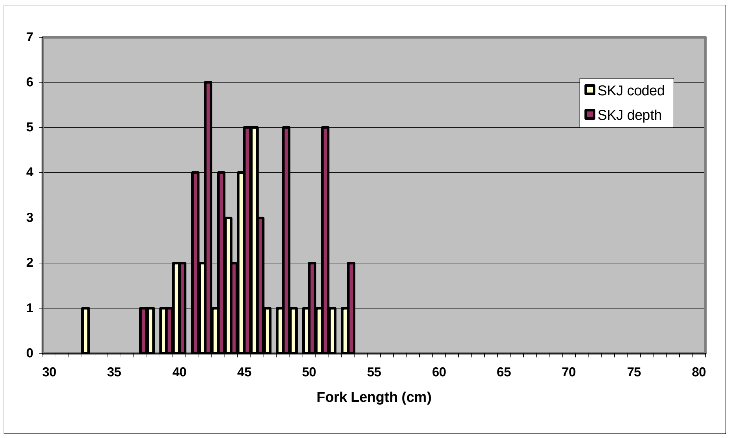

Figure 10. Length frequency of skipjack sonic tag releases (coded n=27; depth n=42)

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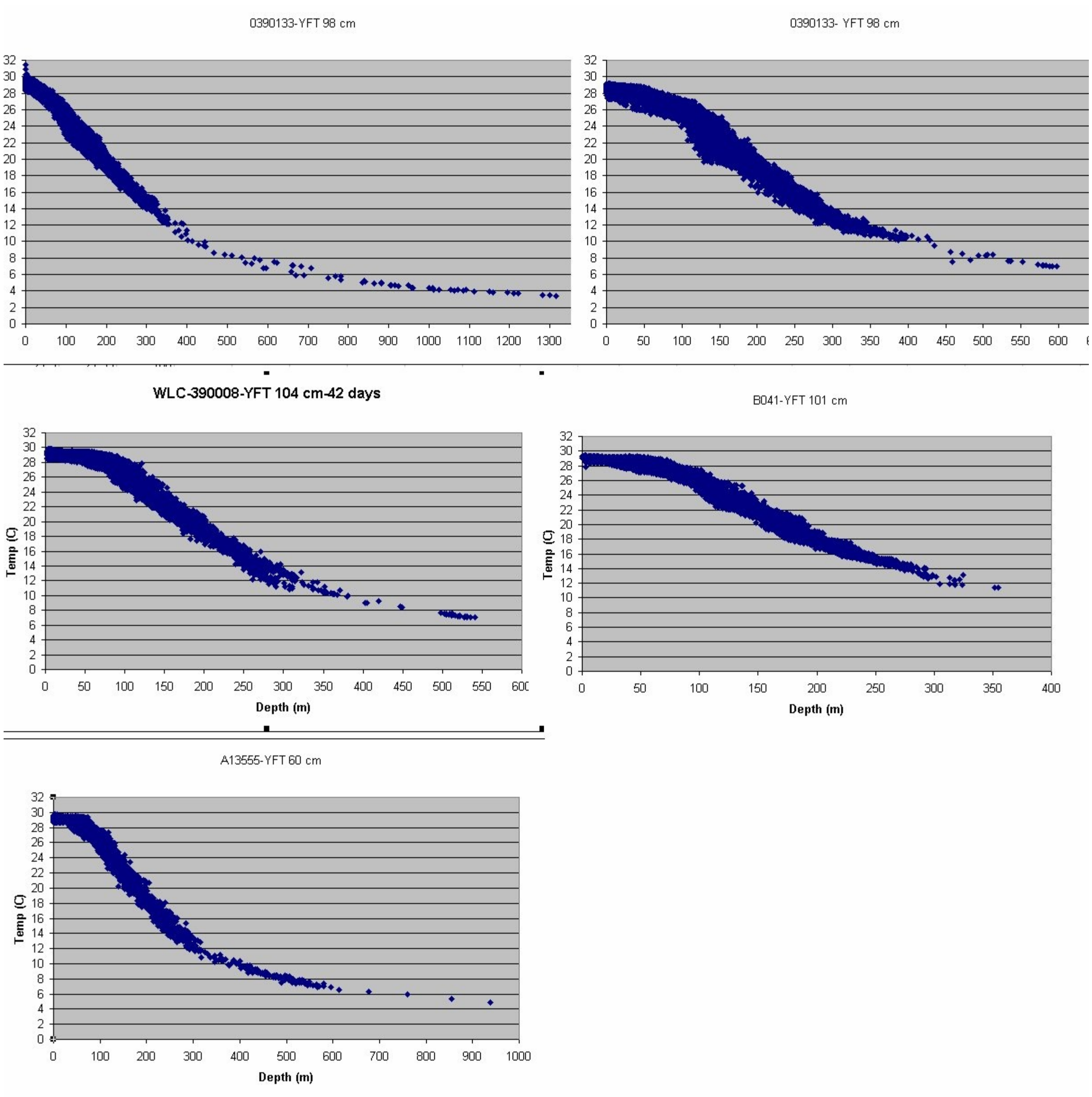

Figure 11. Vertical temperature data from archival tags recovered from yellowfin in the study area

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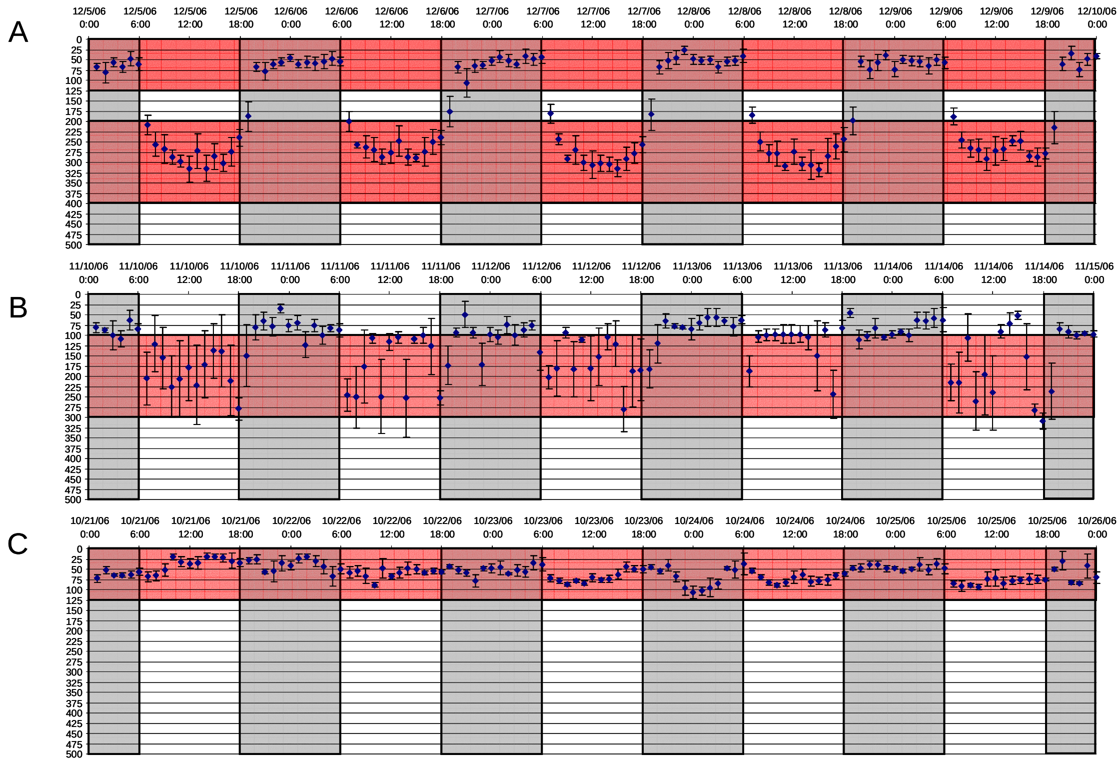

Figure 12. Bigeye vertical behaviour types. Vertical grey shading represents approximate nocturnal hours. Orange horizontal shading represents the depth zones of interest for each classification.

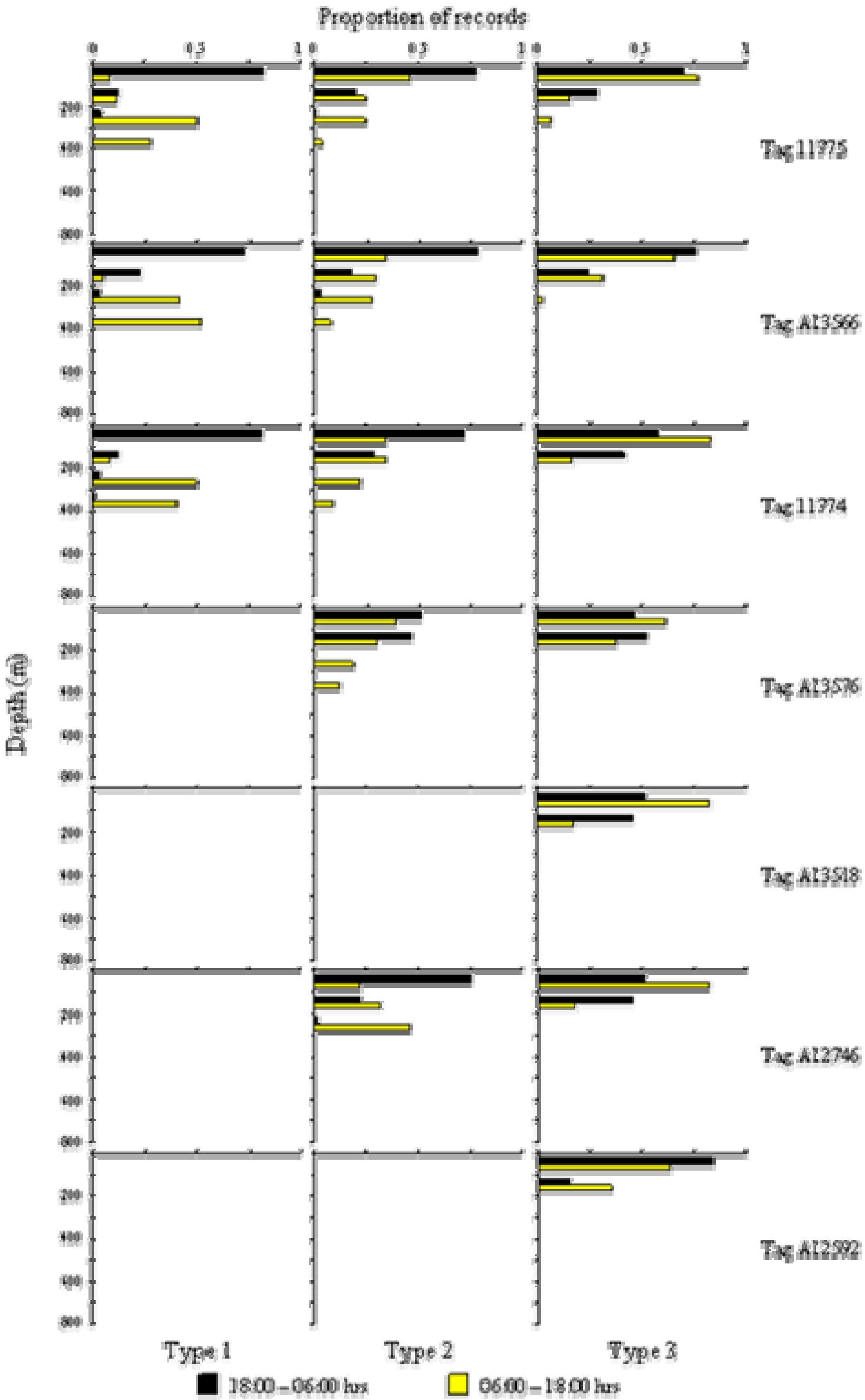

Figure 13. Histograms of depth distributions for each individual bigeye in each behaviour category

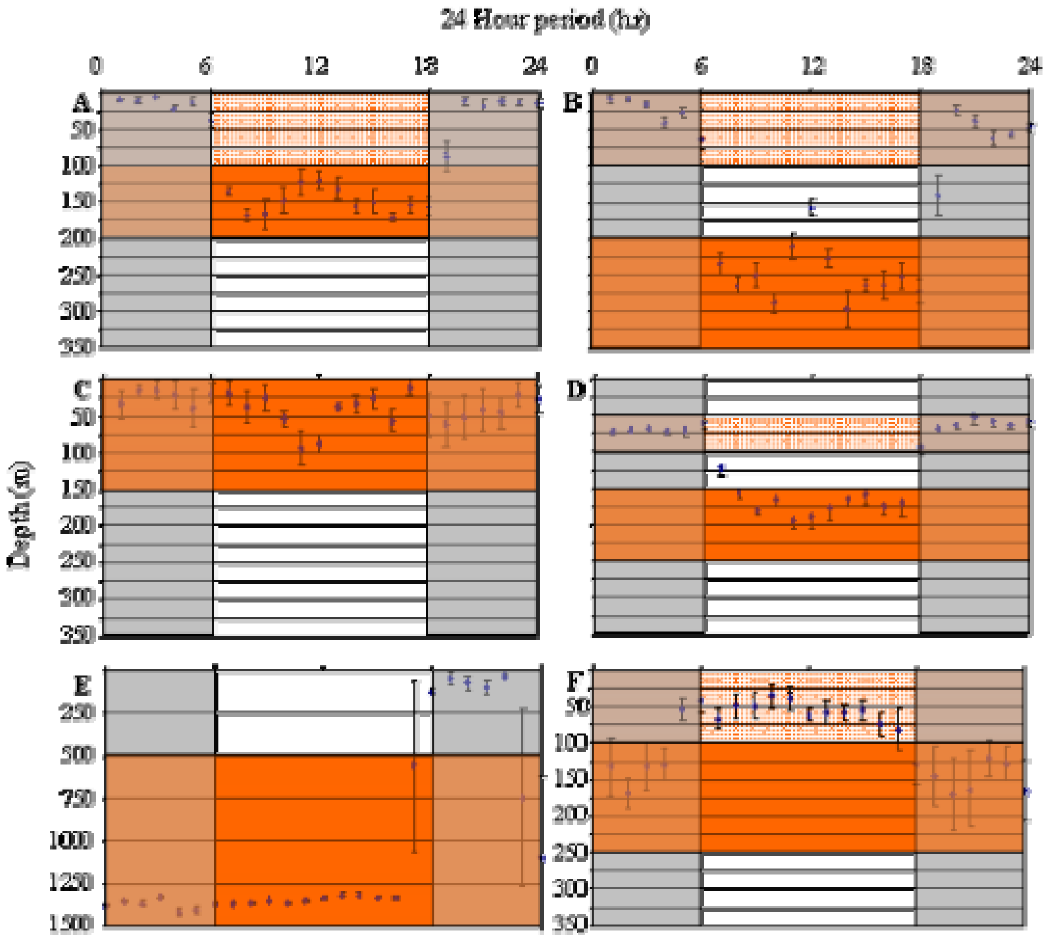

Figure 14 Yellowfin behaviour types. Vertical grey shading represents approximate nocturnal hours. Orange horizontal shading represents the depth zones of interest for each classification.

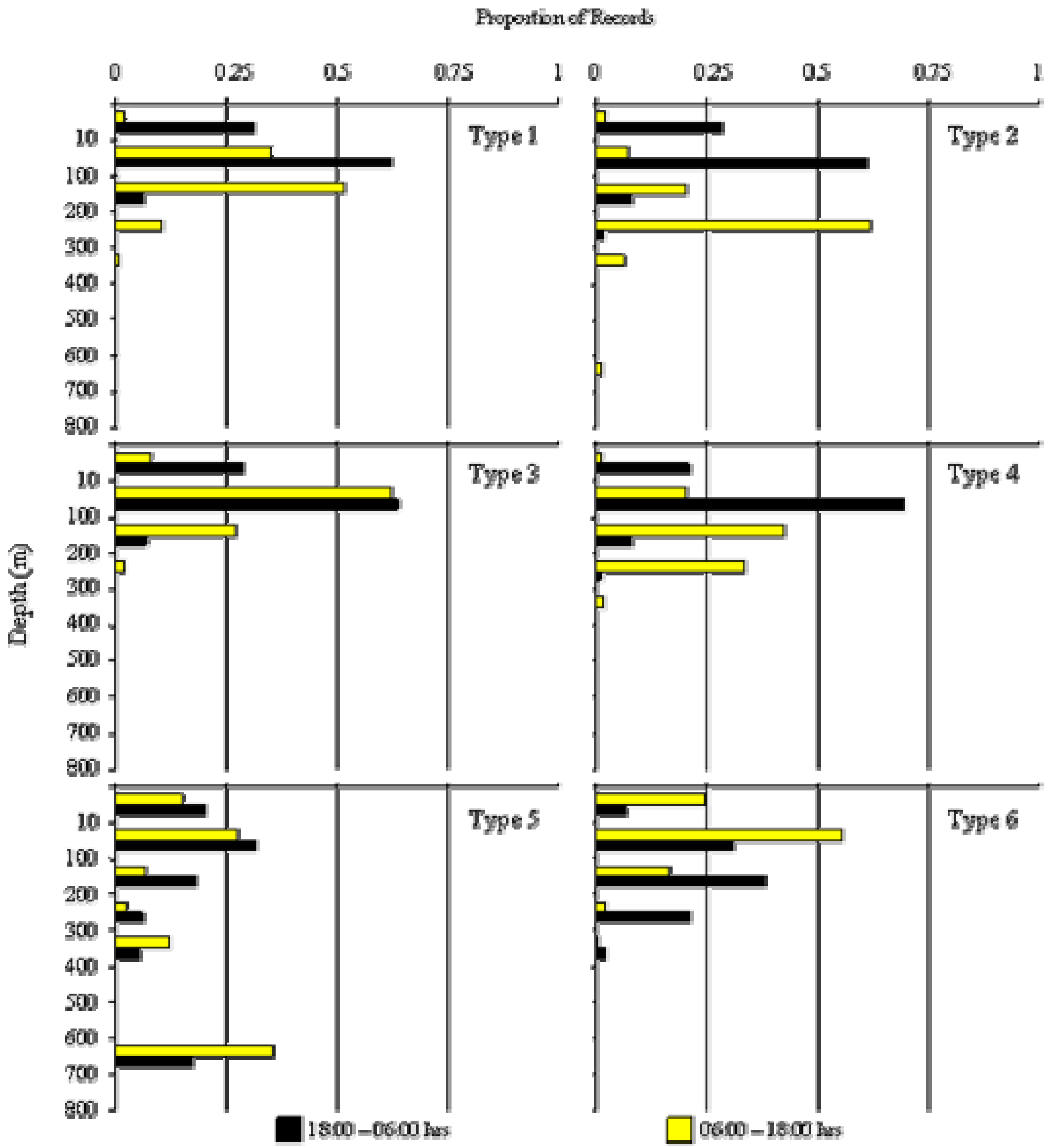

Figure 15. Histograms of depth distributions for each all yellowfin in each behaviour category

Figure 16. Data examples from VR2 receivers indicating presence of sonic tagged tuna.

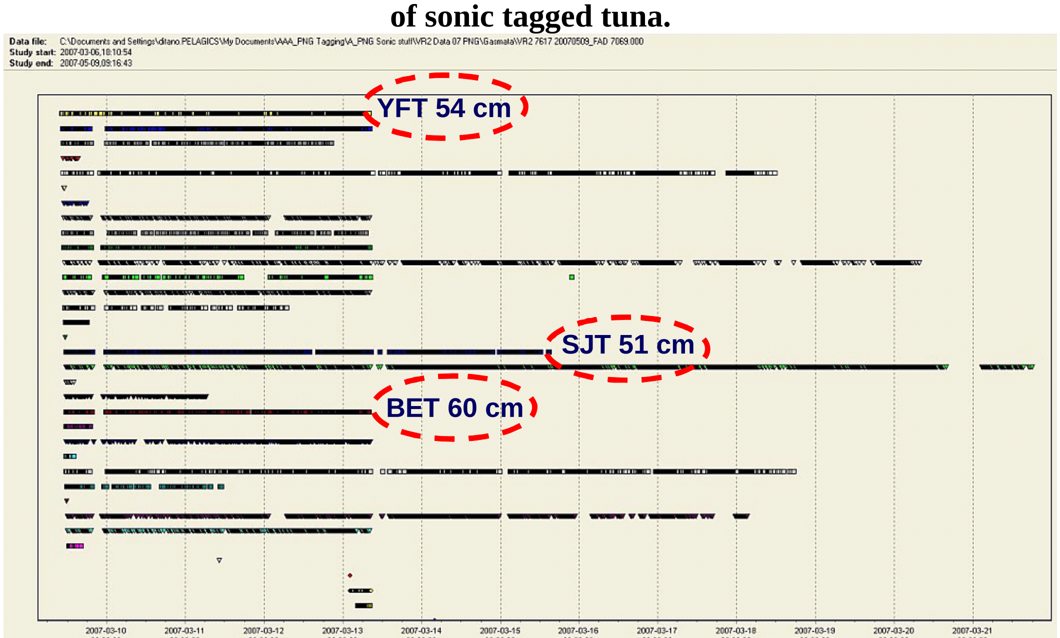

Figure 17. Synchronous departures of sonic tagged tuna from an anchored FAD including three species of tuna with depth sonic tags

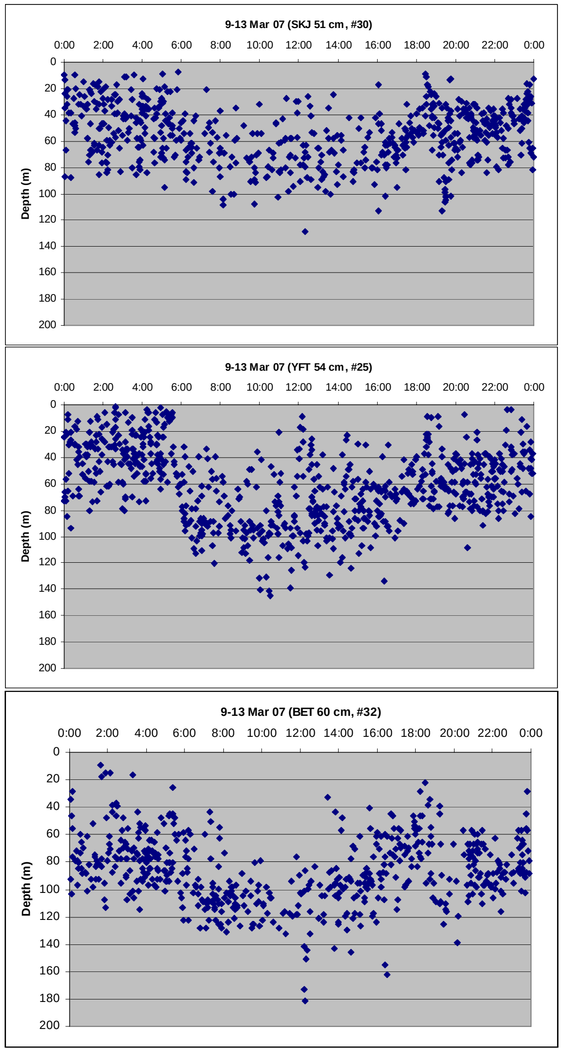

Figure 18. Simultaneous residence of (top to bottom) skipjack, yellowfin and bigeye tuna on the same anchored FAD over a four day period.

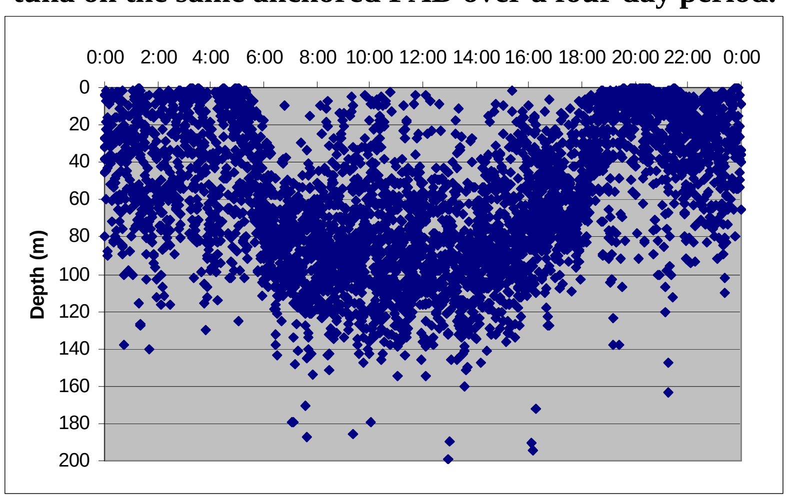

Figure 19. Six day record of 74 cm yellowfin tuna from sonic tagging data.

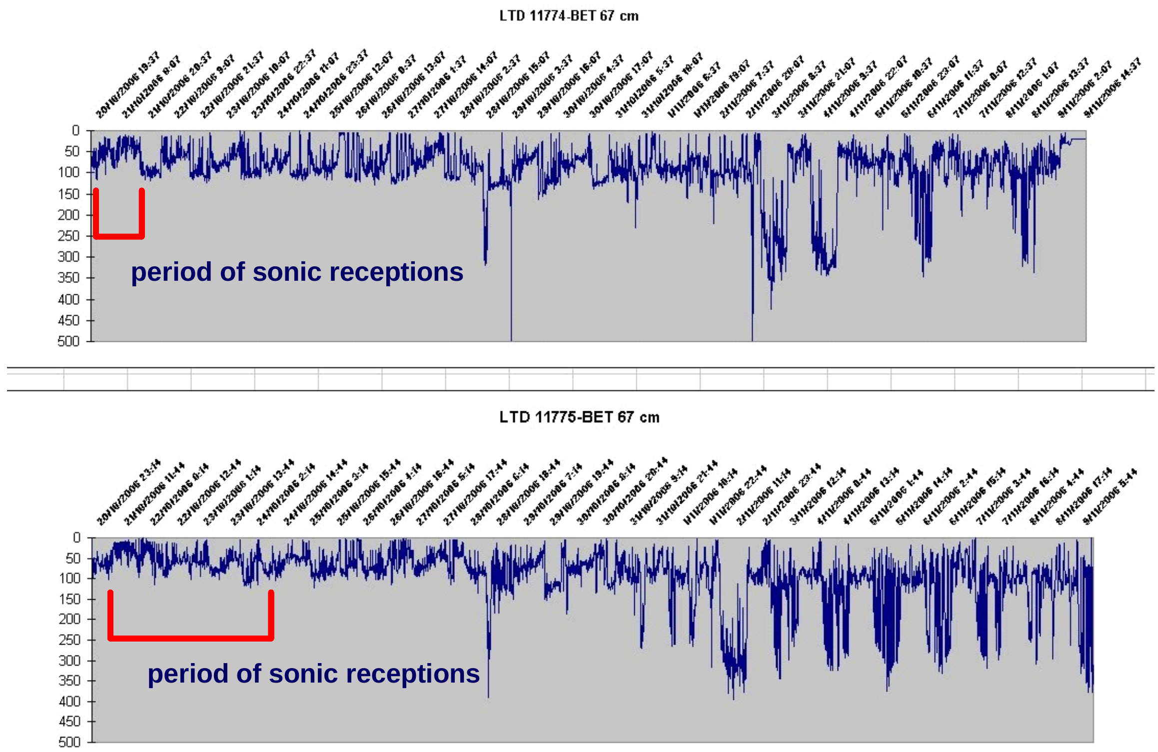

Figure 20. Concurrent archival record of two bigeye tuna also monitored with sonic tags.

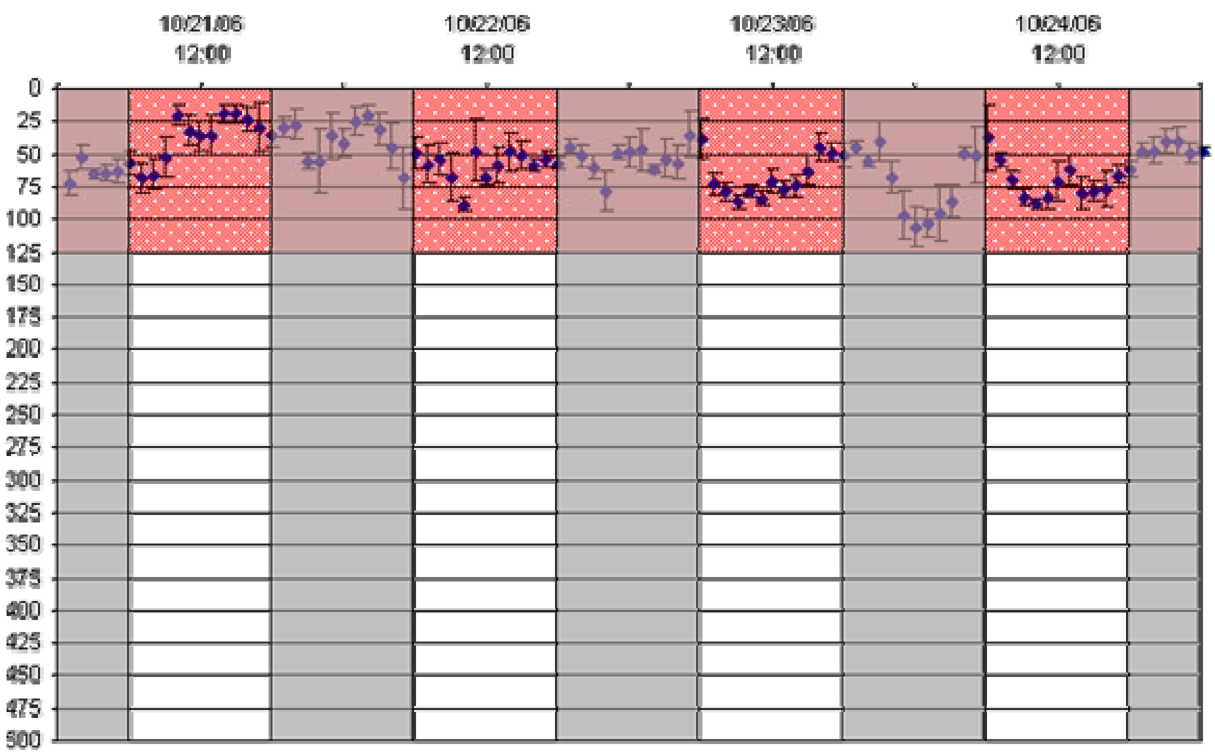

Figure 21. Archival tag time-series for a bigeye tuna that was also sonic tagged. The timestep is the period the fish was confirmed at a FAD by the sonic receiver.

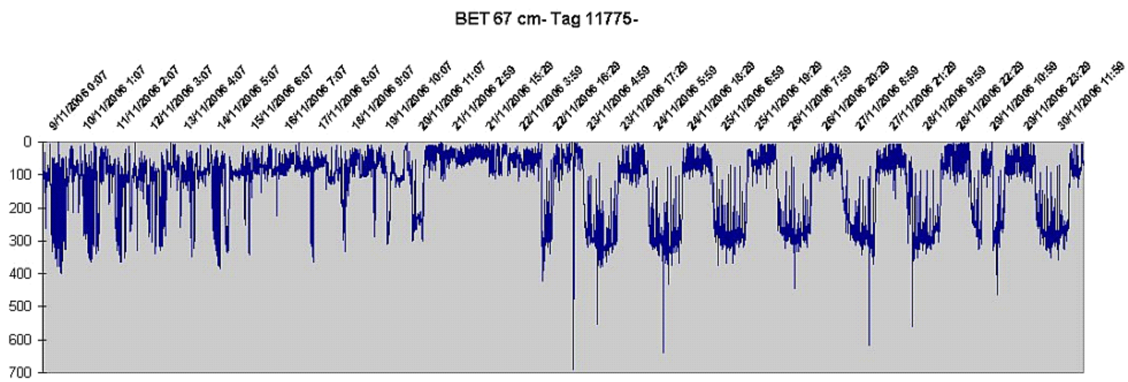

Figure 22. Continuation of bigeye archival data from Figure 20 (bottom panel).