Automated monitoring of yellowfin tuna at Hawaiian FADs and relationship to water mass dynamics based upon satellite imagery

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Progress Report: Year 1

for

Pelagic Fisheries Research Program

Joint Institute of Marine and Atmospheric Research

University of Hawaii

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I. Summary of Overall Progress

During the first year of the grant, "Automated monitoring of yellowfin tuna at Hawaiian FADs and relationship to water mass dynamics based upon satellite imagery," APK has accomplished the following three objectives.

A. Installation of Housings for Automated Monitoring Equipment at FADs near Kaena Point

Housings for the automated fish tag monitors were installed at FADs "S", "R", and "V" off Kaena Point (Fig. 1). Each housing was attached to the chain of the FAD at a depth of 20 m. The Ultrasonic Telemetry System's MM-32 monitor is shaped like a football with a small cylindrical hydrophone protruding from one end to detect the ultrasonic signals emitted from the fish tags (see upper right, Fig. 2). The monitor fits snugly in soft molded foam in the bottom of the 15 X 36 cm cylindrical housing which is made of thick-walled PVC pipe. The hydrophone protrudes through the bottom of the housing where it is protected by a stainless steel cage. The cover of each housing is attached to the heavy duty chain of the FAD by a stainless steel cable and shackle. The rubberized cable does not directly contact the galvanized chain, thus avoiding electrolysis, an earlier concern of Mr. Henry Sakuda of the Hawaiian Department of Land and Natural Resources. Extending down one side of each housing is a thick-walled vinyl tube, slit along its length to permit a tight fit around the chain of the FAD. The soft tube is pressed down on the chain by hose clamps at both ends of the housing. Heavy-duty nylon straps pass through holes in the vinyl tube, between chain links, and around the housing at both ends to secure the housing to the chain.

An Onset Computer Corporation HOBO temperature logger is attached to the stainless steel cable leading from each of the three monitor housings to the three FADs. The logger stores 1800 measurements at sampling rates ranging from one per 0.5 sec to one per 4.8 hrs over intervals of 15 min to 360 days in non-volatile EEPROM memory. The data are retained in this memory even with power loss. Attached directly to the cover of the monitor at "V" FAD is an Onset STOWAWAY voltage logger, adapted to measure levels of irradiance by adding a light-

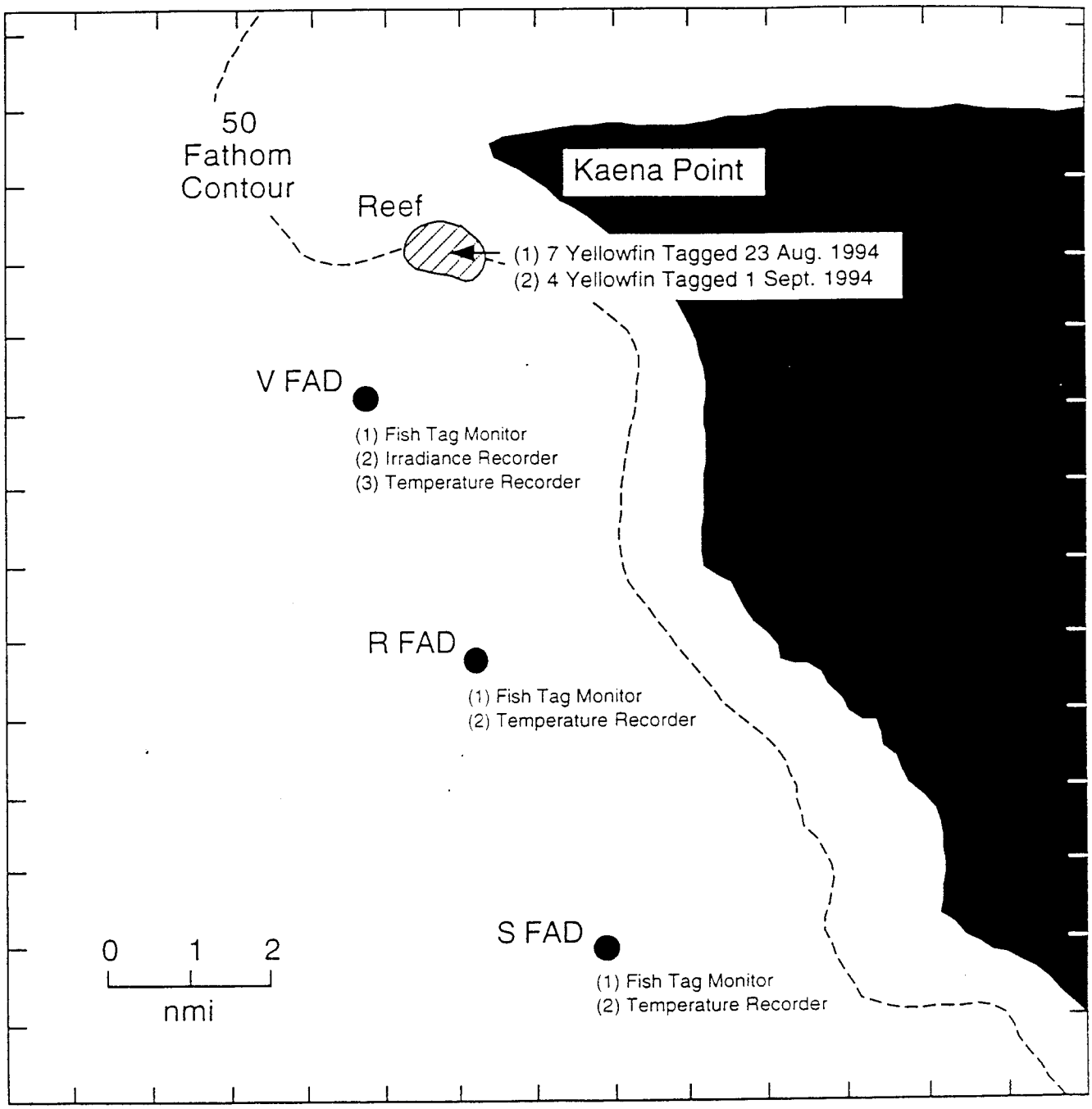

Fig. 1. Chart of waters off Kaena Point with positions of "S", "R", and "V" FADs and listings of monitoring equipment deployed on each buoy. Eleven yellowfin tuna were caught and tagged with coded ultrasonic transmitters at reef near Kaena Point.

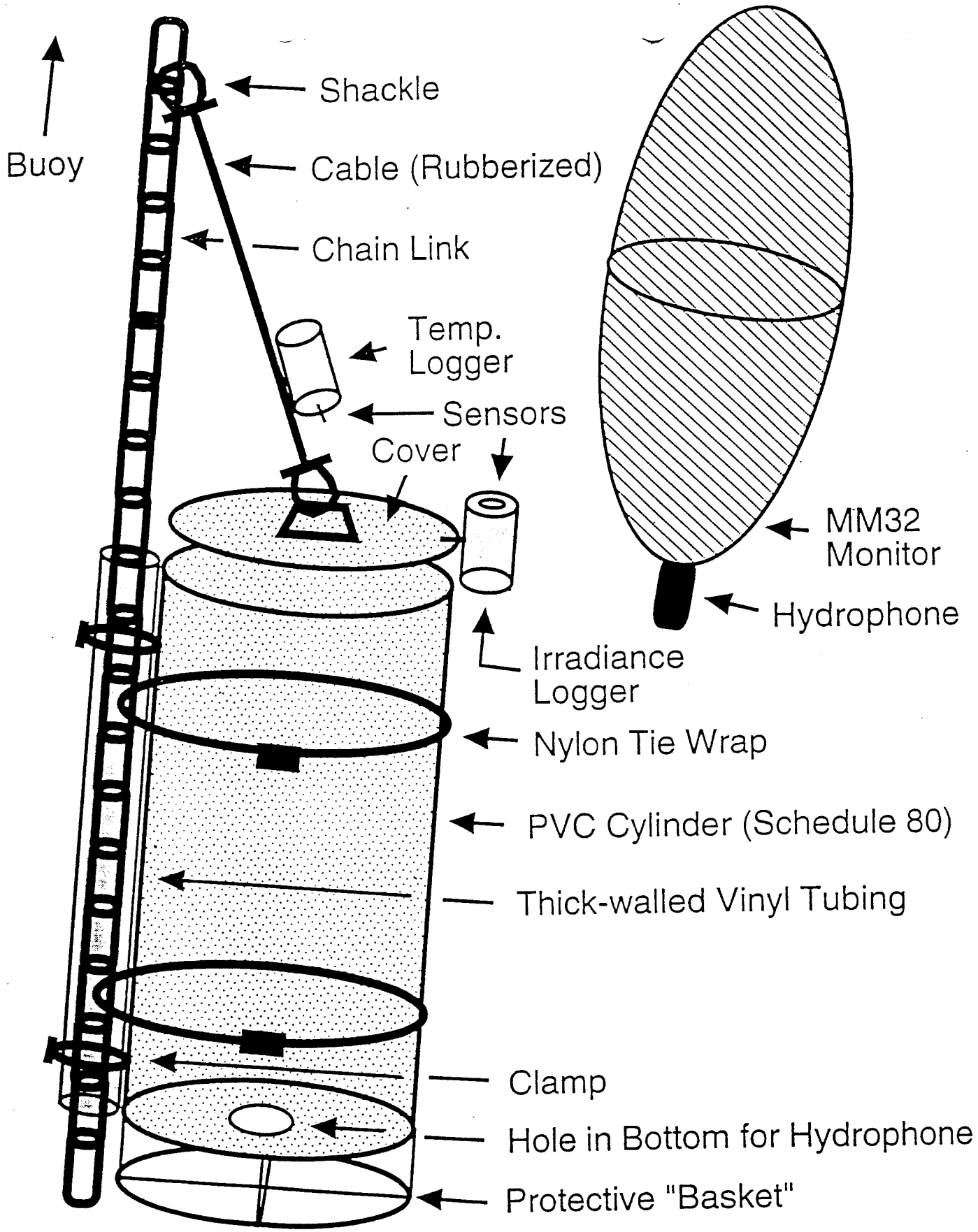

Fig. 2. Ultrasonic Telemetry Systems MM-32 fish tag monitor (upper right) and protective underwater housing (left). Also shown is an Onset Computer Corporation's HOBO temperature logger and STOWAWAY voltage logger adapted to record irradiance.

sensitive photodiode, optical gel filter, and preamplifier. The spectral response of the recorder matches that of the yellowfin tuna's eye. It is most sensitive to wavelengths around 492 nm. At this wavelength the S-potentials recorded from retinas isolated from yellowfin tuna are highest (Kawamura *et al.*, 1981). The visual sensitivity of the tuna was imitated in the following manner. The spectral response of the tuna (see outer curve with solid fill, Fig. 3) was simulated by the recorder (see curve with clear fill) by reducing the width of the spectral response of the Hamamatsu photodiode (see bimodal curve with cross-hatching) by covering it with a Kodak #44 gel filter with a much narrower spectral response (see curve with clear fill). The STOWAWAY has four times the memory of the HOBO, storing 7200 measurements in EEPROM. This permitted irradiance to be measured at two-minute intervals over a month long period before the logger needed to be interrogated. Shown is a plot of irradiance measurements over a 24 hr period (Fig. 4). The recorder is capable of measuring intensities of irradiance over a range of three log units (1 unit = 10X). The flat line on the graph during nighttime indicates that the level of irradiance was either at or below the sensitivity of the logger (i.e., 00003 $uW/cm^2/sec$).

B. Yellowfin Tunas tagged with Coded Ultrasonic Transmitters

Eleven yellowfin tunas were tagged with coded ultrasonic tags, seven on 23 August and four on 1 September 1994. All tunas were caught by rod and reel aboard a charter boat, Live Bait, operated by Mr. Dale Simmons of Makaha, Hawaii. Shown in Table 1 is the time of capture, total and fork length, and weight of each of the tunas as well as the longitude, latitude, and depth of capture. The total lengths of tunas ranged from 68.6 to 110.5 cm, and their weights from 5.4 to 16.8 kg. All were caught close to the edge of a reef near Kaena Point 3.7 km away from FAD V (see cross-hatching, Fig. 1). They were caught over bottom depths sloping from 137.2 to 289.6 m. The geographic coordinates and depths given must be considered only estimates as a hiatus often occurred between hooking the fish and reading measurements off the displays the GPS receiver and fathometer.

The tunas were brought to the side of the boat as quickly as possible, lifted into the boat in

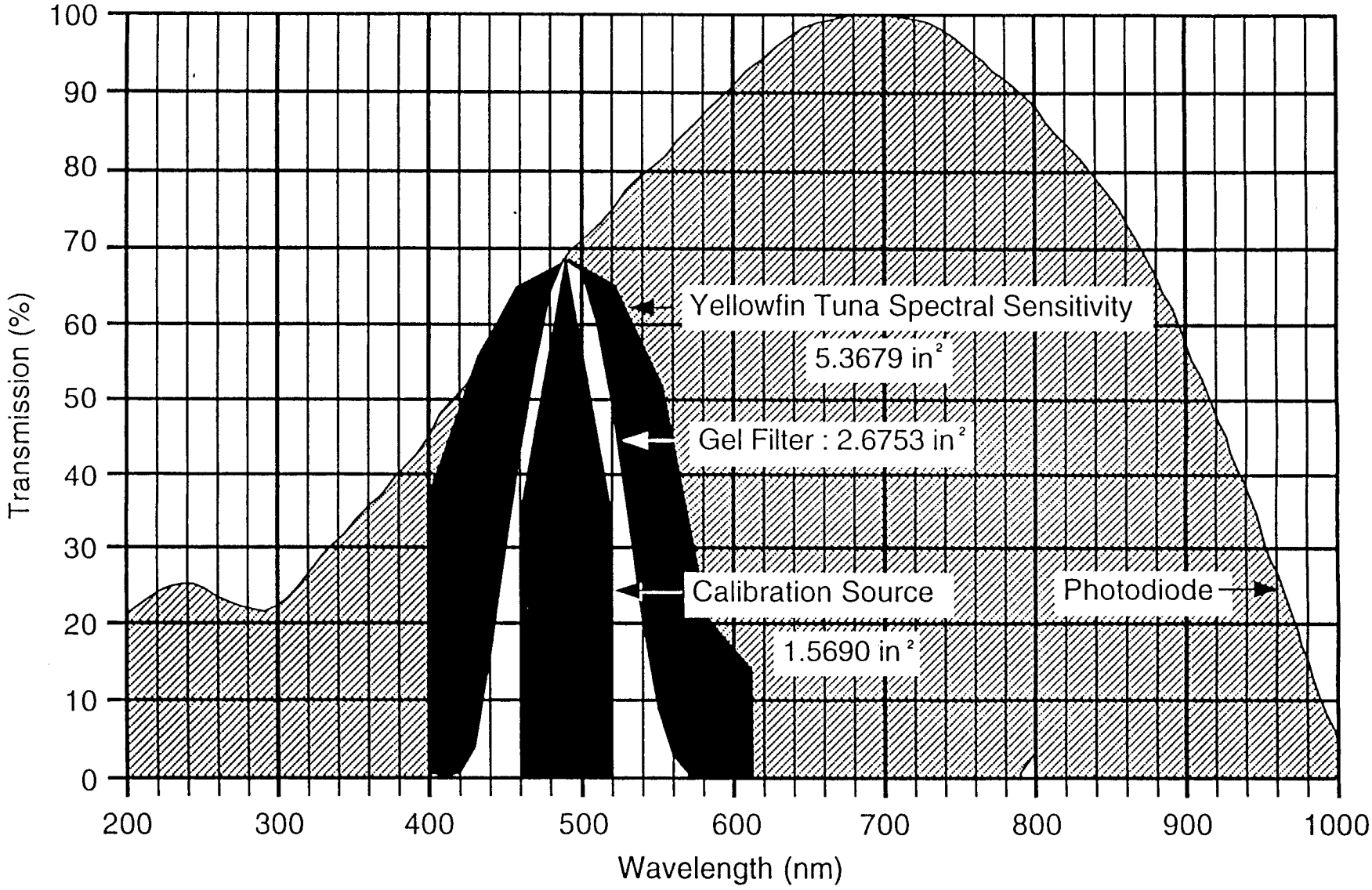

Fig. 3. Spectral response curves for the Hamamatsu photocell (crosshatching), yellowfin eye (outer solid), Kodak gel filter (clear), and calibration source (inner solid). The sensor can be calibrated either to peak transmission or transmission per nm wavelength: the latter requires measurement of the areas under the spectral responses curves (see values in square inches).

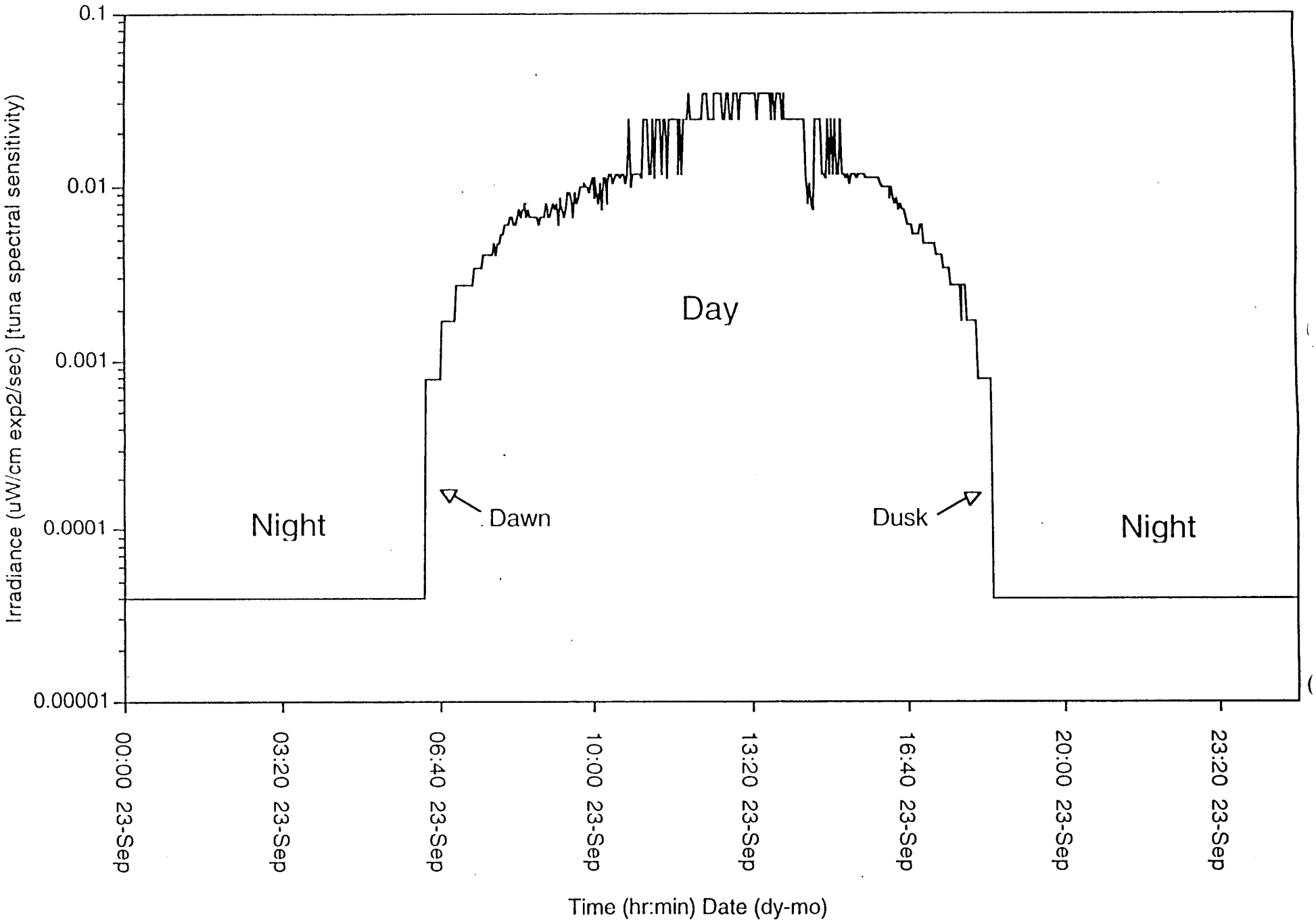

Fig. 4. Levels of irradiance recorded over 24 hr period on 23 September 1994 on "V" FAD at 20 m depth by STOWAWAY voltage logger. Measurements made at 2 min intervals.

No.	Date (dy mo yr)	Time (hrs)	Total Length (cm)	Fork Length (cm)	Weight (kg)	Longitude (deg min.dec)	Latitude (deg min.dec)	Site (FAD, Reef,)	Depth (m)
1	23 Aug. 1994	1216	------	------	10.9	158° 17.916'	21° 33.083'	Reef	287.1
2	23 Aug. 1994	1216	110.5	97.8	16.6	158° 17.916'	21° 33.083'	Reef	287.1
3	23 Aug. 1994	1308	77.5	72.4	8.6	158° 18.072'	21° 33.093'	Reef	274.1
4	23 Aug. 1994	1431	68.6	88.9	16.8	158° 18.009'	21° 32.989'	Reef	289.6
5	23 Aug. 1994	1509	83.8	77.5	9.1	158° 18.025'	21° 33.763'	Reef	179.8
6	23 Aug. 1994	1520	80.0	71.1	7.0	158° 17.835'	21° 33.300'	Reef	213.7
7	23 Aug. 1994	1537	81.3	74.9	9.5	158° 18.141'	21° 33.196'	Reef	168.2
8	1 Sept. 1994	0745	71.1	63.5	5.9	158° 17.810'	21° 33.165'	Reef	152.4
9	1 Sept. 1994	0820	73.7	66.0	5.9	158° 17.777'	21° 33.296'	Reef	152.4
10	1 Sept. 1994	0822	71.1	64.8	5.4	158° 17.777'	21° 33.296'	Reef	152.4
11	1 Sept. 1994	0924	81.3	71.1	7.7	158° 17.481'	21° 33.492'	Reef	137.2

Table 1. Catch information for 11 yellowfin tuna tagged with coded ultrasonic transmitters. Recorded at the time of capture were: 1) date, 2) time, 3) total and fork length, 4) weight, 5) longitude/latitude, 6) site, and 7) depth.

a net equipped with a scale from which their weight was recorded, and then placed on a wet towel. One person immobilized the fish by holding its head and tail while another person measured the total and fork lengths of the tuna. The latter person then made a 4 cm incision in a dorsal-ventral direction just above the anus through which a transmitter was inserted into the peritoneal cavity. The incision was then closed with one to three stainless steel staples applied with a surgical staple gun. The tuna was then lifted up and gently placed in the water. All eleven tunas appeared to survive the surgical procedure in good condition because they accelerated immediately upon return to the water and swam without hesitation. The tunas were out of the water no longer than a minute and a half.

C. Deployment of Automated Equipment for Detection of Tunas and Acquisition of Oceanographic Data

The first two fish tag monitors and temperature loggers were installed in the housings at FAD "S" and "R" on 31 Aug. 1994. Four more tunas were tagged on the following day with coded ultrasonic transmitters. The third tag monitor, equipped with an irradiance logger as well as a temperature logger, was deployed at FAD "V" on 2 August. The instruments at FADs "S" and "R" were deployed for 38 days until retrieved on 7 Oct.; the equipment at FAD "V" for 36 days. None of the 11 tagged yellowfin was detected by monitor at FAD "S" during the 38 days of operation. No attendance records were obtained for the two other FADs. The fish tag monitor at "R" flooded with salt water, and the monitor at "V" lost power due to the loss of a battery connection.

APK has taken actions to prevent both types of equipment failure in the future. Firstly, the fish tag monitor that will replace the flooded unit was exposed within a hyperbaric chamber to the pressure occurring at a depth of 70 feet. This is 10 feet deeper than the depth at which the monitor will be deployed. The record of a HOBO pressure logger contained within the monitor is shown in Fig. 5. The internal pressure of 14.67 psi (atmospheric pressure at sea level) increased only 0.20. psi despite an increase of 31.50 psi to an external pressure of 46.20 psi (ca 3

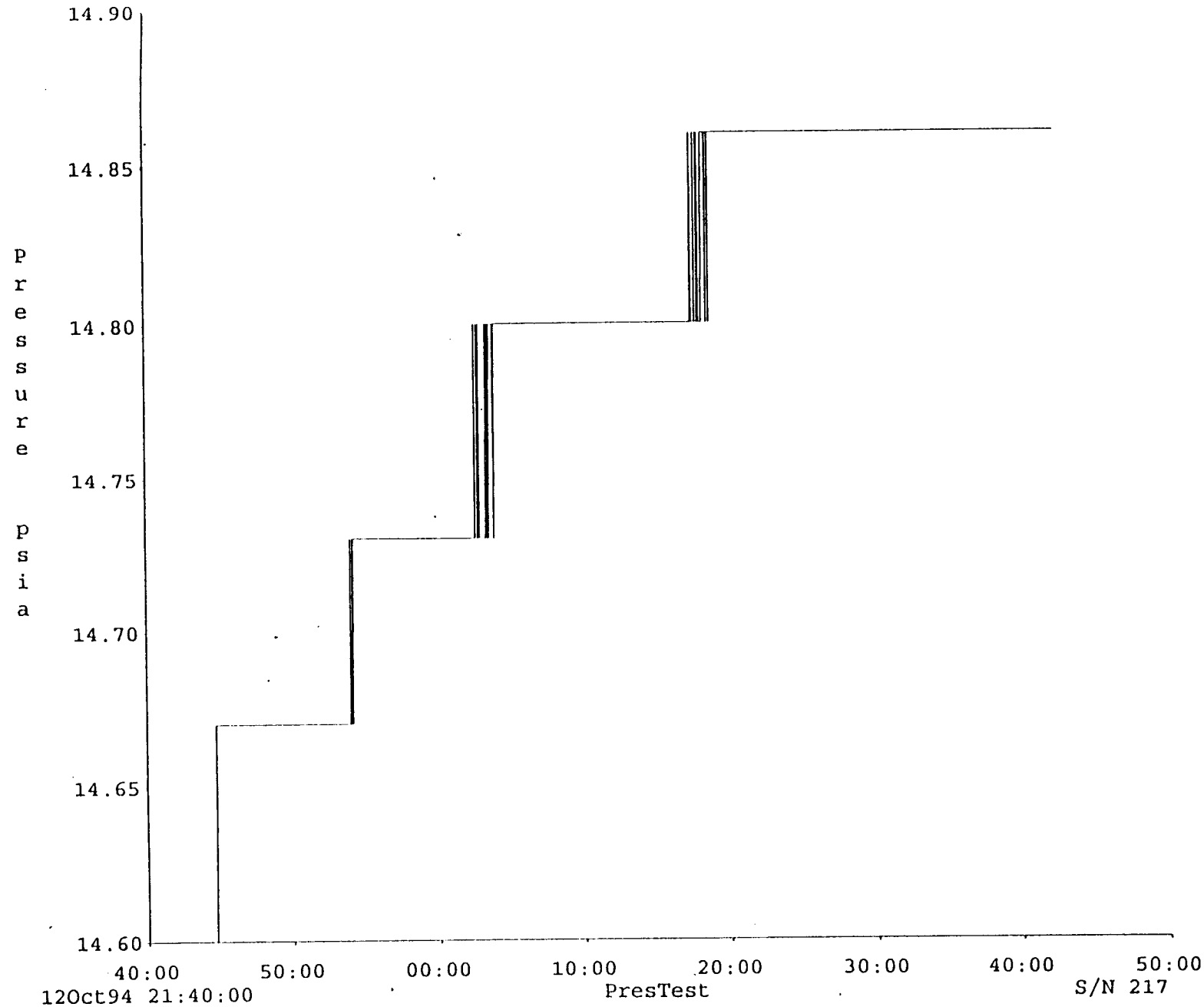

Fig. 5. Pressure (in psi) measured by HOBO logger inside fish tag monitor when exposed to external pressures found at depths up to 70 feet. Note negligible 0.20 psi pressure increase in housing due to compression of "O" ring during test period.

atmospheres at 70 feet). The small increases in internal pressure measured were in response to the two halves of the housing being forced slightly closer together by the elevated external pressure. The step on the curve at 55 min occurred as the external pressure was increased from 14.7 psi (sea level) to 31.7 psi (40 foot depth), the step on the hour when pressure increased to 36.7 psi (50 feet), and the step at 20 min when external pressure was elevated from 41.2 psi (60 feet) to 46.2 psi (70 feet). No step was recorded in the monitor during the change in external pressure from 36.7 to 41.2 psi. APK also replaced the batteries in all three monitors with lithium batteries with solder tabs. The tabs at the ends of each battery were soldered to the contacts on either side of each battery receptacle in order to prevent future loss of battery contact, and subsequent loss of data stored in RAM.

The tuna attendance record from the monitor at FAD "S" is shown in Fig. 6. Note that the chronology of the daily records is reversed with the first day at the end of the file and the last day at the beginning. The monitor's continuous operation throughout the sampling interval was verified by moving a "test" transmitter first inside and then outside the reception range of the monitor. Detection of the tag's signal was indicated by a flash of a light-emitting diode within the monitor. This test was carried out both before and after each monitor was submerged and attached to the FAD. Thus, test unit #10 is shown on the record of the monitor deployed at SITE 01 (FAD "S") to arrive at 06:57 and depart at 06:58 on 31 Aug., and unit #11 arrives at 09:23 and 09:30 and departs at 09:28 and 09:32 on 7 Oct. 1994, respectively. Note the absence of arrivals and departures with the dates of each of the 38 days when the monitor was deployed.

Temperature was recorded at 20 minute intervals by loggers at all three FADs, irradiance at 2 minute intervals at only the "V" FAD. The mean temperature at the three FADs increased by slightly less than a degree over the period of deployment (see upper two and lower left graph, Fig. 7). Superimposed upon this steady increase in temperature was considerable variation. This was greatest at FAD "V". For instance, temperature varied 1.9° during a 24 hr period during 23-24 Aug., rising from a minimum of 25.5° at 0800 to a maximum of 27.4° at 1400-1600 hrs. The level of irradiance varied by only a single log unit (factor of 10 X) during daytime whereas the level

DATA COLLECTED AT SITE 01

TIME OF COLLECTION 10:12.15 10-07-94

TIME	ARRIVALS	DEPARTURES
09:32		11
09:30	11	
09:28		11
09:23	11	

10 - 6 - 94

10 - 5 - 94

10 - 4 - 94

10 - 3 - 94

10 - 2 - 94

10 - 1 - 94

9 - 30 - 94

9 - 29 - 94

9 - 28 - 94

9 - 27 - 94

9 - 26 - 94

9 - 25 - 94

9 - 24 - 94

9 - 23 - 94

9 - 22 - 94

9 - 21 - 94

9 - 20 - 94

9 - 19 - 94

9 - 18 - 94

9 - 17 - 94

Fig 6.4 Traffic [illegible] recorded from 17 Sept to 7 Oct 1994 recorded by MM32 monitor

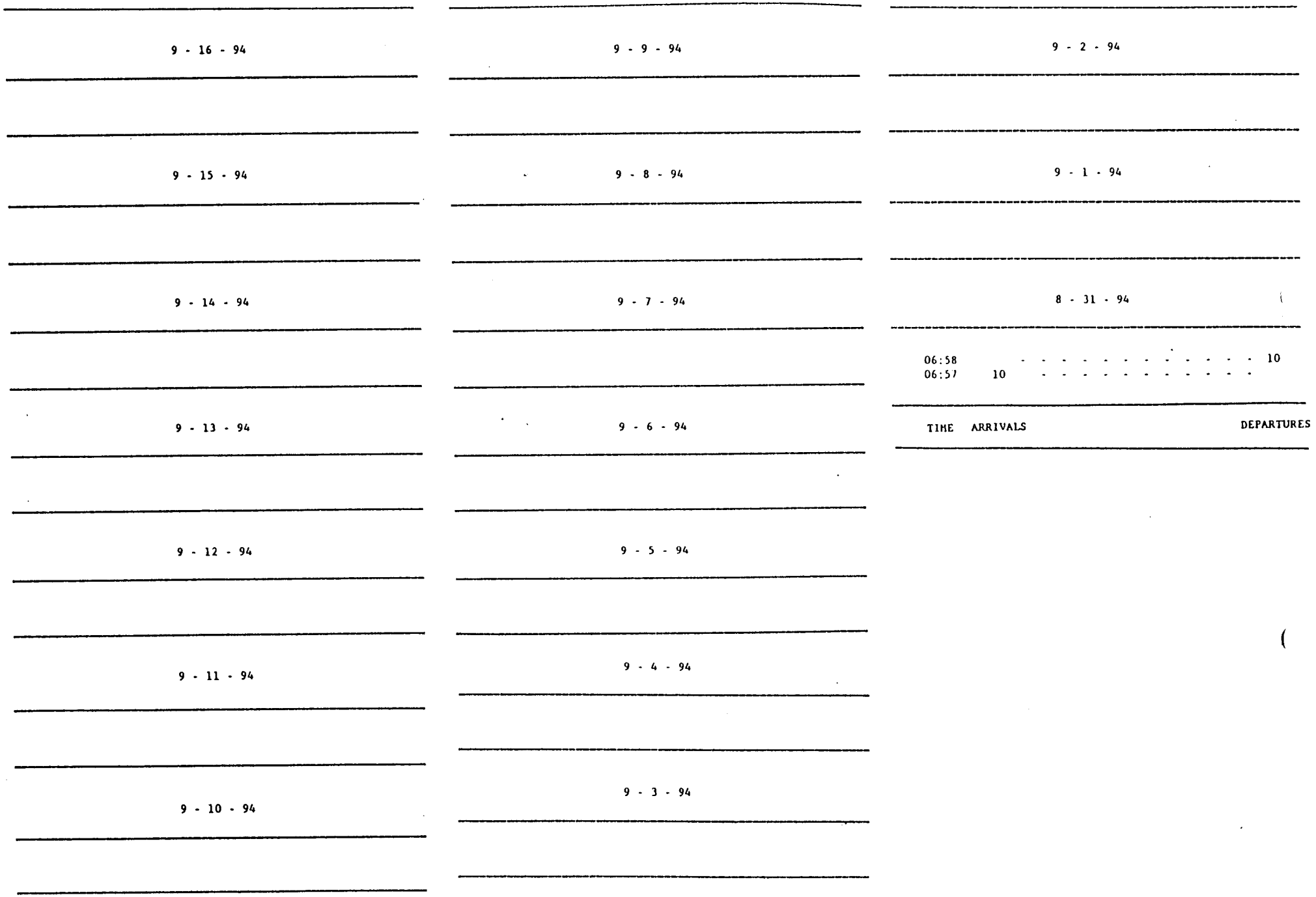

Fig. 6B. Tuna attendance at "S" FAD from 31 Aug. to 16 Sept. recorded by MM32 monitor.

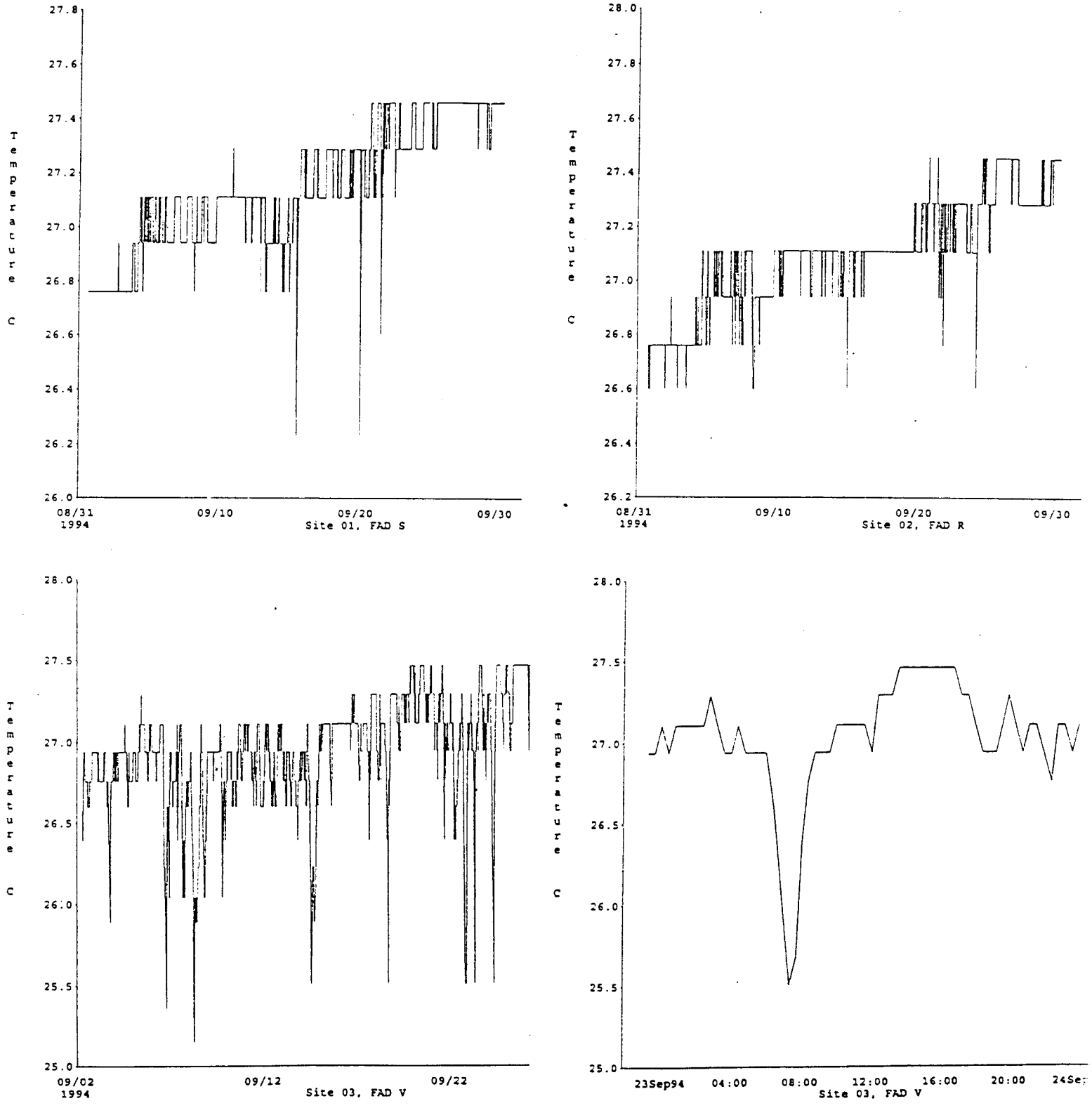

Fig. 7. Temperatures measured at 20 min intervals during Aug./ Sept. 1994 at a depth of 20 m on FADs "S" (upper left), "R" (upper right), and "V" (lower left) by HOBO loggers. High resolution plot of temperatures recorded over 24 hr interval at "V" FAD during 23/24 Aug. 1994.

dropped about three log units at nightime (see Fig. 4). The day-night oscillations of irradiance measured over a 36 day period at FAD "V" are shown in Fig. 8. Note that the curve on the graph for irradiance is flat during nighttime because the level is at or below the sensitivity of the logger (i.e., 00003 uW/cm^2/sec). The sudden drop in level at 1120 hrs on 6 October 1994 was due to the logger being placed in a dark carrying case after removal from the FAD earlier that day.

D. Plans for Year 2

During Year 1, APK accomplished the following three objectives: 1) attached to three FADs equipment for detecting tagged tunas and recording environmental data, 2) tagged 11 yellowfin tuna with coded-ultrasonic tags, and 3) deployed monitoring equipment during one 36-day period. With the accomplishment of these goals, the proposed research plan has been shown to be feasible. However, the yellowfin tuna tagged on 23 Aug. and 2 Sept. 1994 were not detected at "S" FAD during the month after tagging. Their absence may be due to yellowfin visiting only certain sites. The reef at which all of the tunas were tagged is 14.8 km away from "S" FAD where the only operative monitor was deployed. Klimley *et al.* (1988) found that scalloped hammerhead sharks returned to the site of tagging but not another site centered less than 240 m away using the same type of monitors with coded tags. On the contrary, Holland *et al.* (1990) tracked a tuna tagged at "S" FAD (from which an attendance record existed) along the 50 fathom contour to Kaena Point past where the 11 yellowfin tuna were tagged.

The main obstacle to the study's success so far has been the absence of recruitment of yellowfin tuna to the FADs. Throughout the grant period, tunas have rarely been caught at any of the FADs. According to Mr. Bill Aila, harbormaster at Waianae, and Mr. Dale Simmons, a charter-boat captain who fishes regularly near Kaena Point, in past years yellowfin tunas arrived at the FADs in late December and stayed through April. APK is now prepared for this recruitment event. The monitors have been tested in the field, and are now ready for further use. Nine transmitters will be delivered next week from Ultrasonic Telemetry Systems. As soon as Year 2's

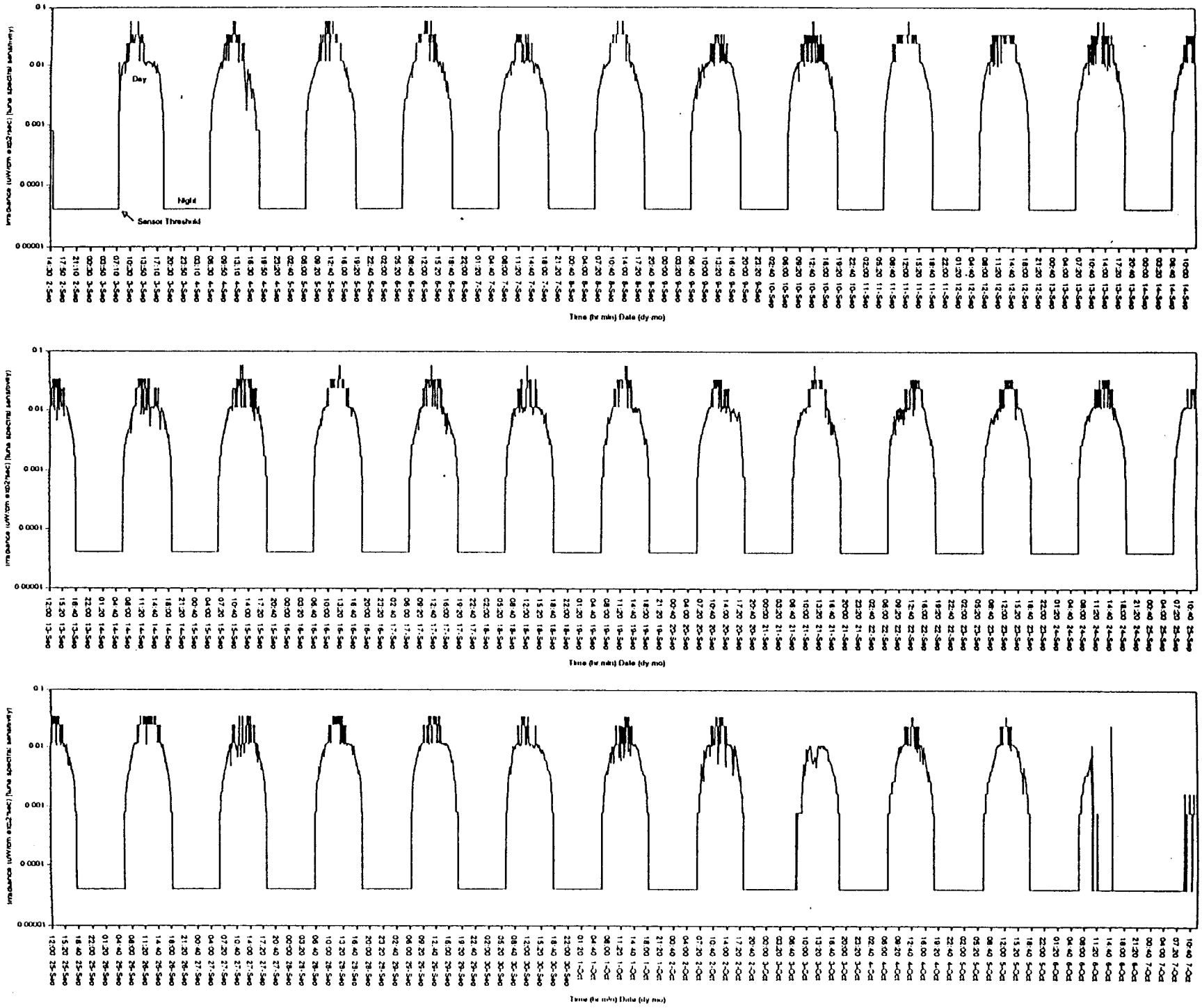

Fig. 8. Irradiance levels measured at a depth of 20 m on " FAD" at 2 min intervals over 36 day

funding is received, APK will order the second years supply of 108 transmitters. When the schools of small yellowfin tunas arrive at the FADs, Mr. Dale Simmons will immediately begin tagging them with coded tags. He is willing to catch, measure, and tag the tunas if paid their market value. APK has provided him with tagging equipment (i.e., scalpels and staple guns), coded transmitters, an ultrasonic receiver for verifying transmitter operation, and a form for recording data (Fig. 9). An alternative to waiting for a recruitment event at FADs "S", "R", and "V" is would be to deploy a new FAD and monitor at the reef near Kaena Point where yellowfin are presently being caught. If this plan of action were taken, additional funds would have to be provided to purchase a fourth monitor and another FAD.

In the immediate future, APK would like to hire on a half time basis two undergraduate students in the University of Hawaii's Marine Options Program. Their responsibilities would consist of assisting Mr. Dale Simmons tag tunas, fishing at the FADs in APK's boat in order to tag more tunas, and retrieving the monitors and data loggers on a bi-weekly basis for interrogation. The advantage of having two half time assistants rather than a single full time employee is that they could serve as dive buddies when getting the monitors.

Return to: Dr. A. Peter Klimley, Bodega Marine Laboratory, Univ. of Calif., Davis, P.O. Box 247, Bodega Bay, CA 94923, (707) 875-2055

No.	Date (mm/dd/yy)	Time (hh:mm)	Tag OK (yes*)	Total Length (inches)	Fork Length (inches)	Weight (lbs)	Longitude (deg min.dec)	Latitude (deg min.dec)	FAD (S,R,V)	Depth (feet)	Cost ($$)

*Listen with Dukane Receiver for tag signal, every 12 to 18 seconds. If hear no pulse, use tag that pulses and return "silent" tag to APK.

Fig. 9. Data sheet provided to Mr. Dale Simmons. The undergraduate students from the Marine Options Program will assist him and take data while capturing yellowfin tuna and tagging

E. Literature Cited

Holland, K.N., R.W. Brill, and R.K.C. Chang. 1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. *Fish. Bull.*, 88:493-507.

Kawamura, G, W., W. Nishimura, S. Ueda, and T. Nishi. 1981. Color vision and spectral sensitivity in tunas and marlins. *Bull. Jap. Soc. Sci. Fish.*, 47:481-485.

Klimley, A.P., S.B. Butler, D.R. Nelson, and A.T. Stull. 1988. Diel movements of scalloped hammerhead sharks, *Sphyrna lewini* Griffith and Smith, to and from a seamount in the Gulf of California. *J. Fish. Biol.*, 33:751-761.

F. Budgetary Explanation for Year 2

Two budgets are submitted. The one with the costs shown on the left is a conservative budget. Fifty transmitters are requested -- the number for the second year in the original proposal. This minimal number of transmitters were budgeted because the monitors were capable at that time of recognizing only a limited number.

Mr. James McKibben of Ultrasonic Telemetry Systems has informed me that now the monitors can easily be upgraded to recognize 128 tags. The Steering Committee should consider providing more funds for tags. The likelihood that the monitors will detect fish at the FADs is dependent upon the number of fish tagged during the study. There would be no obstacle to deploying more tags -- 15 yellowfin were recently caught during a single trip to the study area. The cost to the grant of a single transmitter and a live tuna for tagging is $418. The budget with amounts to the right is the same as the left except that funds are requested to purchase 108 transmitters, the difference between the number of tags deployed during the first year (20) and maximum number a monitor will recognize (128). Also included in the second budget is cost of purchasing a similar number of live fish for tagging. Although JIMAR may not be able to provide the amount requested, any additional funds to purchase more transmitters would be well spent now that the monitors are in place.