NOAA Technical Memorandum NMFS-SEFC-112

MOVEMENT AND SURFACING BEHAVIOR PATTERNS OF LOGGERHEAD SEA TURTLES IN AND NEAR CANAVERAL CHANNEL, FLORIDA (SEPTEMBER AND OCTOBER 1981)

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U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE
MISSISSIPPI LABORATORIES
NATIONAL SPACE TECHNOLOGY LABORATORIES
NSTL STATION, MISSISSIPPI 39529

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John V. Byrne, Administrator
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William G. Gordon, Assistant Administrator for Fisheries

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INTRODUCTION

As part of a larger effort involving trawling and aerial surveys of loggerhead sea turtles (Caretta caretta) in the Canaveral Channel and vicinity, a radio and acoustic tracking study of these animals was conducted over a 20-day period (September 19 to October 8, 1981). Primary emphasis was to determine if tracking approaches would provide information relevant to tactical management of dredging and sea turtle recovery programs for the channel. Loggerhead sea turtles are listed as threatened species under the Endangered Species Act of 1973.

Little information exists on tracking techniques for sea turtles (summarized by Timko and DeBlanc, 1981). This meant a major portion of the tracking study had to be directed at development and evaluation of approaches and procedures for monitoring movement patterns of these animals. Recent successes with radio tracking studies of juvenile turtles (Timko and DeBlanc, 1981) provided most of the initial guidance augmented by information from satellite tracking studies in the northern Gulf of Mexico (Timko and Kolz, 1982). Besides radio and acoustical tracking, an experimental effort was conducted to continuously monitor surfacing behavior patterns of the turtles to provide information both for guiding future tracking studies and for extrapolating aerial sea turtle counts to estimates of population size.

METHODS AND MATERIALS

The tracking study was divided into three portions: radio tracking, acoustic tracking, and continuous radio monitoring. An overview of the experimental design is shown in Figure 1 and of the study area in Figure 2.

RADIO TRACKING

Small, battery-powered transmitters encased in 6.35 by 20.32 cm plastic pipes were attached to 20 turtles with nylon landyards approximately two-thirds the length of their carapaces. The transmitters operated at frequencies ranging from 165.55 to 165.75 MHz with a design output power of 10 mw. Center frequencies and relative powers for each transmitter are given in Table 1. Sufficient battery power was provided for three months of continuous operation. The plastic pipes were internally ballasted to be slightly positively buoyant and to float with the longitudinal axis vertical. This permitted a 25.4 cm transmitter antenna, which projected from the upper end of the pipe, to extend above the water when the turtle surfaced. A steel eyebolt mounted on the bottom of each of the pipes served as the attachment point for a 136 kgm monofilament nylon attaching lanyard. The opposite end of the landyard was attached to the trailing edge of the turtle's carapace by a stainless steel tab secured with two stainless steel screws.

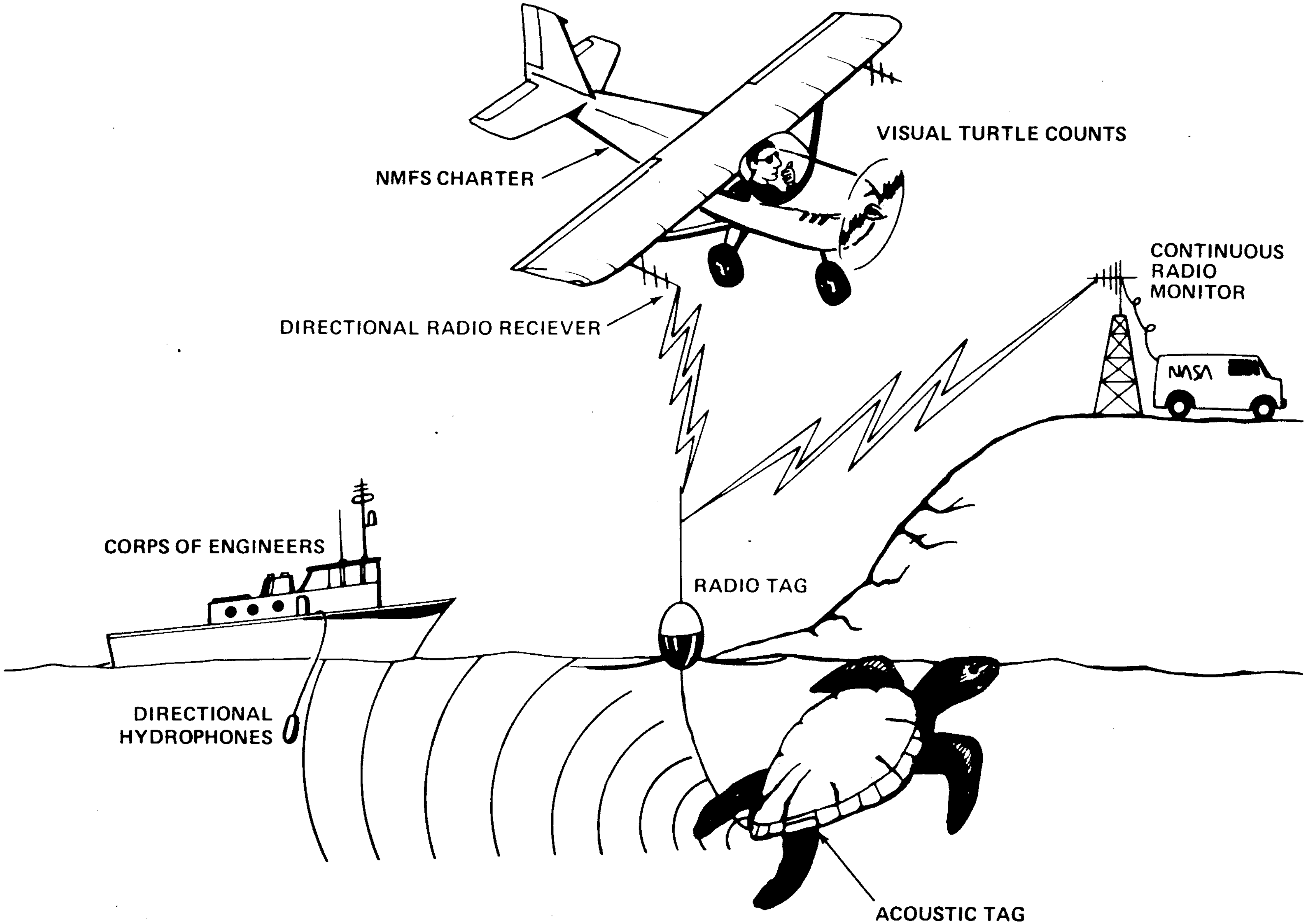

Figure 1. Conceptual Overview of Canaveral Channel Tracking Study.

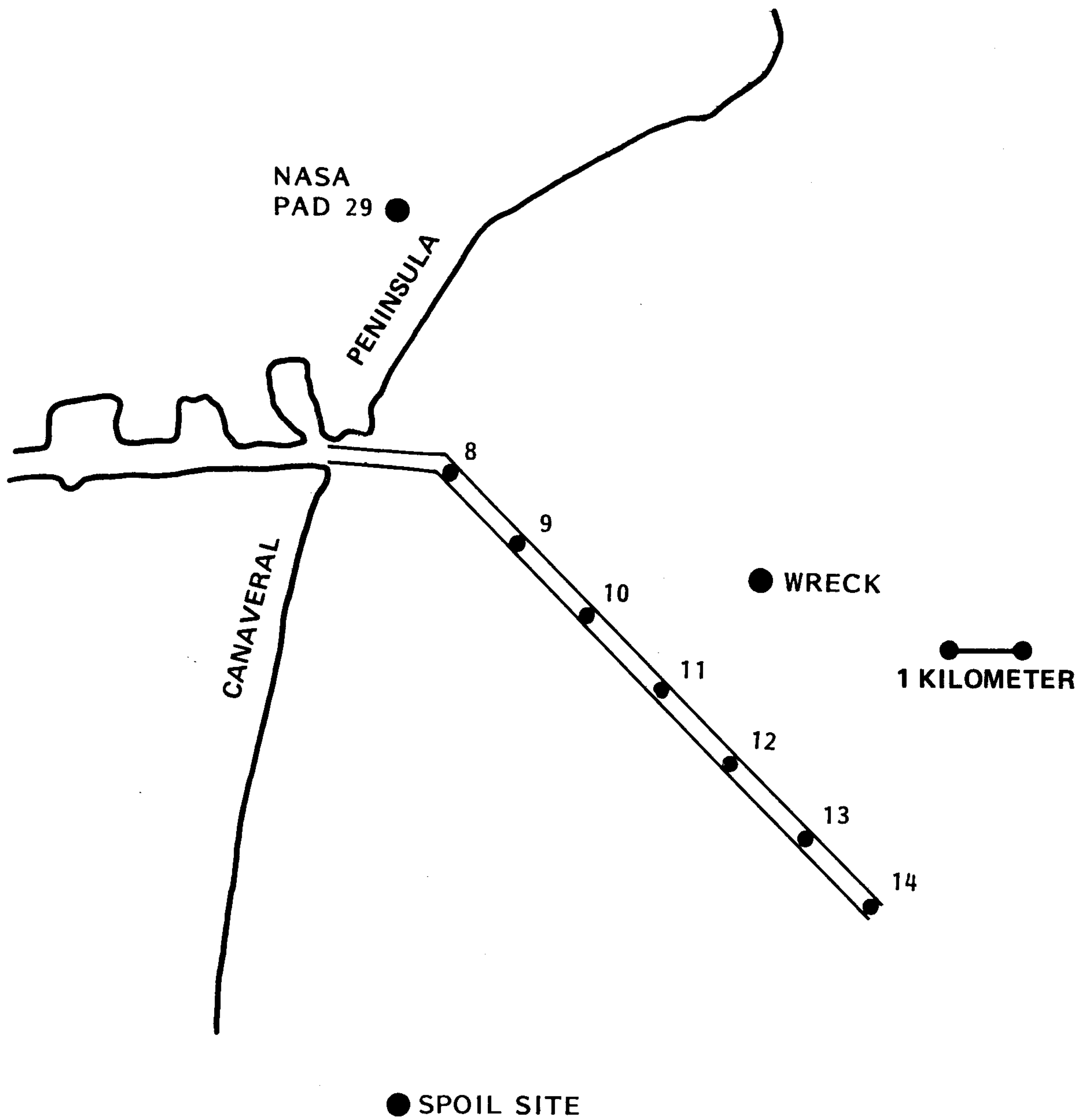

Figure 2. Cape Canaveral study area. Numbers along the channel represent permanently located NMFS sea turtle trawling stations.

Table 1. Center frequencies and relative output powers for the tracking transmitters. Output powers are relative to the strongest transmitter serial number 9300.

Transmitter Serial Number	Center Frequency (MHz)*	Relative Output Power (dBM)*
9299	165.5508	-11.70
9300	165.5607	0.00
9301 (not used)	165.5710	-18.30
9302	165.5807	-14.40
9303	165.5903	- 4.40
9304	165.6002	- 5.00
9505	165.6097	-11.20
9306	165.6202	- 3.40
9307	165.6305	- 4.60
9308	165.6402	-13.80
9309	165.6503	- 3.90
9310	165.6598	- 1.60
9311	165.6699	-17.70
9312	165.6800	- 7.40
9313	165.6897	-15.60
9314	165.7004	- 6.50
9315	165.7099	- 4.30
9316	165.7200	- 4.20
9317	165.7301	- 3.50
9318	165.7391	- 4.20
9319	165.7499	- 5.20

*Measured with a HP 8582 Automatic Spectrum Analyzer.

All radio tracking was done from a leased Cessna Model 172 aircraft. This aircraft was selected because of its high wing design and supporting struts which provided an excellent location for mounting tracking antennas. Tracking equipment consisted of directional receiving antennas mounted on each side of the aircraft, an antenna switchbox, a portable battery-powered transmitter receiver, and a Loran-C navigation receiver. Tracking flights were flown every other day during the 20-day experimental period, normally beginning at 8:00 a.m. and lasting 3-4 hours. Normally, the aircraft was flown at an altitude of about 760 meters along lines parallel to the coast. During flights, the transmitter receiver was manually tuned to individual transmitter frequencies. When a signal was detected, the antenna switchbox was used to switch between the antennas on both sides of the aircraft to determine the most probable direction of the transmitter based on relative signal strength. Once this direction was determined, the aircraft was turned toward the transmitter in a circling manner to pinpoint the location of the transmitter similar to the procedure described by Timko and DeBlanc (1981). Unfortunately, few transmitters were on the surface long enough to obtain an accurate location which meant that the majority had to be positioned based only on relative signal strengths between the antennas. Generally it requires about 5 minutes to obtain a rough location with this tracking method and about 10 minutes to insure reasonably good accuracy.

ACOUSTIC TRACKING

Acoustic pingers were attached to each of the turtles equipped with radio transmitters. The pingers were a standard commercial variety enclosed in brass cylinders 4.5 cm in diameter by 16.0 cm in length. They weighed approximately 450 gms in seawater and contained sufficient batteries for 30 days of continuous operation. The pingers operated at 10 frequencies ranging between 30 and 45 KHz with ping rates ranging between 0.5 and 5.0 pings per second. The frequencies and ping rates were selected to identify individual animals acoustically. The pingers were attached to the left rear of each turtle's carapace, opposite the attachment point of the radio transmitter, with two bolts. Figure 3 shows a turtle with both transmitting devices attached and marked with a painted number for identification during aircraft overflights.

All acoustic tracking was done from a Corps of Engineers 12.2 m steel hull crewboat. The acoustical receiving system consisted of a portable tunable receiver and directional narrow-beam hydrophone. The hydrophone was mounted on a vertical movable shaft to permit it to be manually swung in and out of the water, lowered to beneath the keel of the vessel, and rotated 360 degrees. A compass mounted on top of the shaft provided true bearings of the sensitive axis of the hydrophone (Figure 4).

Acoustic tracking was done every other day of the experiment period. A series of listening stations were established initially (Figure 5) to provide complete coverage of the study area based on preliminary test results off Mississippi with the hydrophone and several pingers. These tests indicated a detection range between 1.6 and 3.2 km. However, subsequent tests in the Canaveral Channel indicated detection ranges of only about 0.5 km, presumably due to vessel traffic noise and high turbidities. This resulted in the coverage

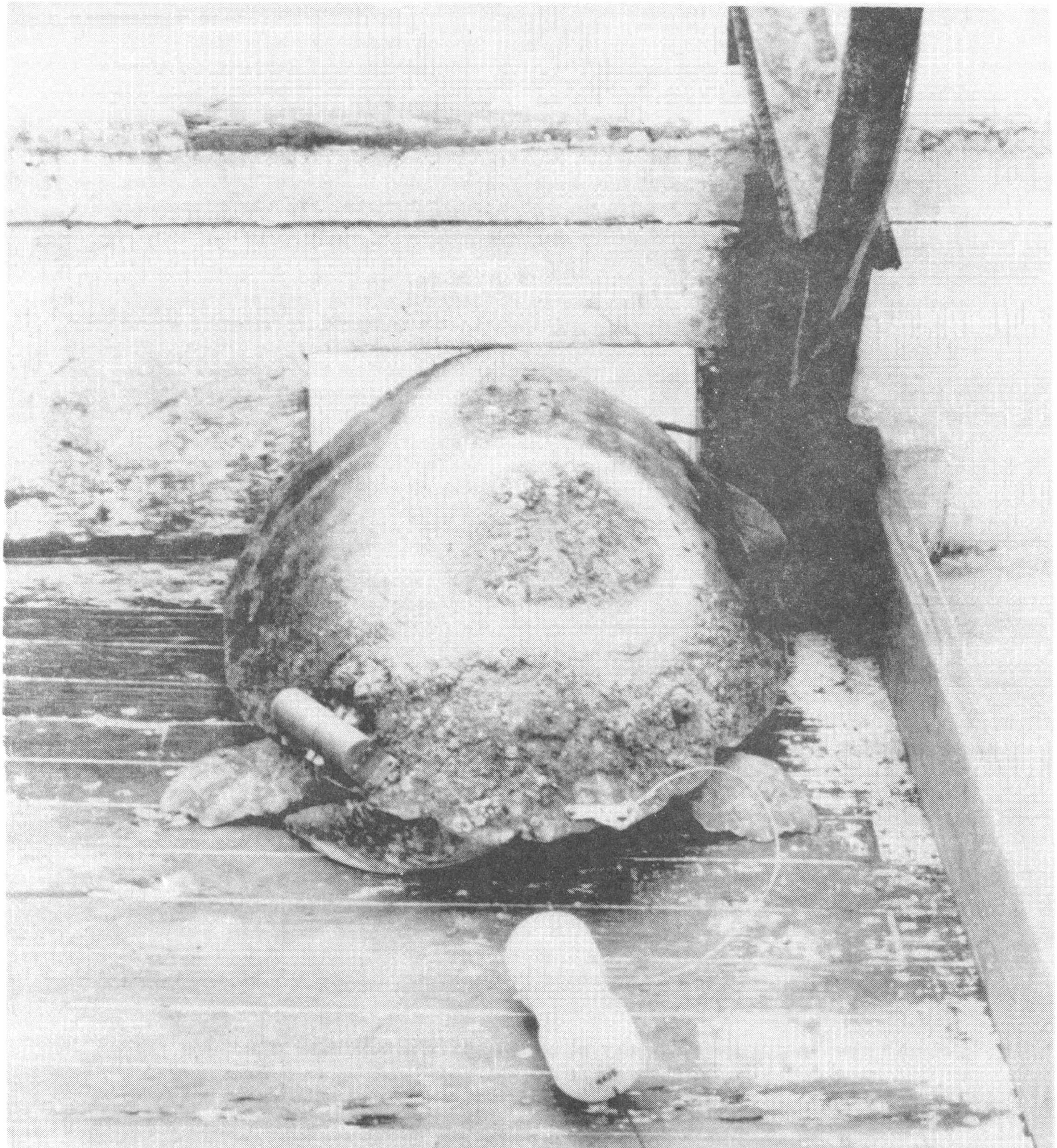

Figure 3. Loggerhead sea turtle with radio and acoustic tags. The number painted on the turtle's carapace was for aerial identification.

Figure 4. Configuration and operation of the acoustic tracking system from the Corps of Engineer's crew boat.

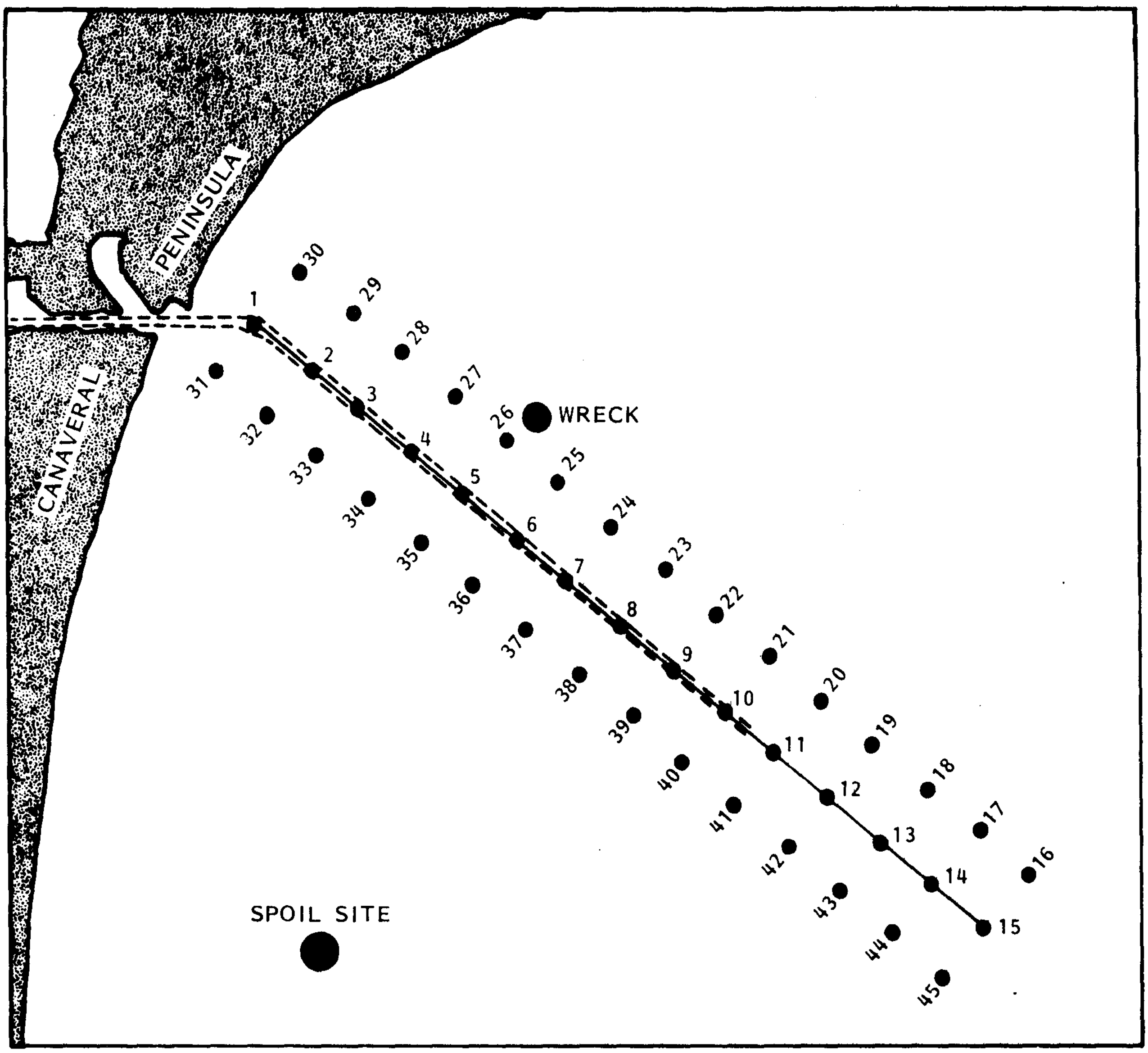

Figure 5. Location of acoustic stations for acoustic positioning of loggerhead sea turtles.

area being reduced to include only the channel and the area around a wrecked vessel. The general procedure used to locate turtles was to stop at each station and manually tune the receiver through the pinger frequencies. Individual pingers could be recognized by their frequency and ping rate. When a pinger was detected, the bearing of the hydrophone and location of the vessel (Loran-C) were recorded and the vessel was run toward the turtle to obtain a second bearing approximately 0.4 km from the original detection point. Triangulation was used to locate the pingers based on bearing and vessel location data.

CONTINUOUS RADIO MONITORING

A basic assumption for this portion of the study was that continuous monitoring of the radio transmitters attached to the turtles would provide data representing surfacing behavior of the animals.

Essentially, transmitted signals are completely attenuated when the transmitter antenna is beneath the water. Conversely, signals from a transmitter can be detected when the antenna is out of the water. The absence or presence of a radio signal thus was assumed to correspond to periods when a turtle was beneath or at the surface of the water.

The receiver used to continuously monitor the radio frequencies corresponding to the 20 radio-tagged turtles was a Hewlett-Packard (HP) Model 6566 Spectrum Analyzer which operated in an automatic mode under the control of a HP Model 9825 desk top computer. Data were recorded on a HP Model 9825 plotter. Figure 6 shows the configuration of the equipment. The spectrum analyzer was programmed to scan the frequency spectrum containing the 20 turtle transmitters every 100 ms. On each scan, the maximum signal level for each transmitter frequency was recorded and the data were accumulated over a 30-sec time interval. The data were then digitally filtered to remove extraneous noise and compared to empirically derived threshold criteria developed during a test phase prior to the experimental period. If the data satisfied these criteria, a point was printed by the printer on the data record. Each printed point thus represented one or more signals assumed to be from a given transmitter.

The spectrum analyzer and supporting equipment were located in a mobile instrument van adjacent to the channel study area. A vertically polarized yagi antenna to receive the signals was mounted on an existing NASA tower (Pad 29) located at 80°35' and 28°5'. The major antenna sensitivity lobe was approximately 60 degrees in beam width and was directed south-southwest at approximately 150° to cover both the Canaveral Channel and spoil site. Verification of antenna coverage and system performance was obtained during the test phase where a maximum detection range of about 10 km along the major axis was determined. This range dropped to about 6 km 30° off-axis.

All data were initially recorded on the HP plotter record and then manually transcribed onto computer load forms. Data transcribed included transmitter number and start and stop times of each transmission period for a given transmitter. A certain amount of editing was performed during the transcription including elimination of obvious noise (e.g. point occurs at the same time in all data channels) and identification of time periods the spectrum analyzer was not operating due to power failures or similar problems.

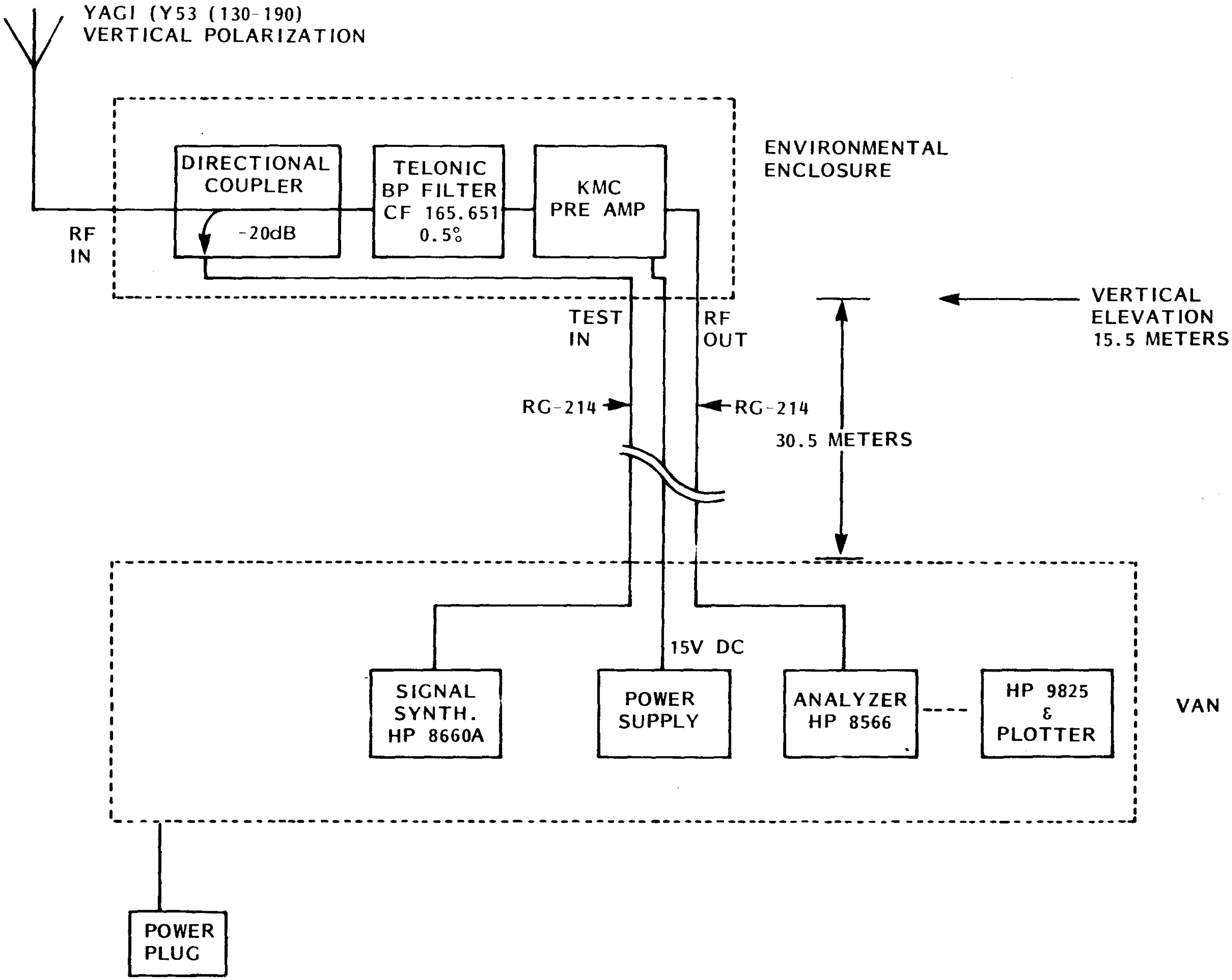

Figure 6. Block diagram of continuous monitoring system for radio transmitter equipped sea turtles.

CAPTURE AND RELEASE OF TURTLES

The loggerhead sea turtles were captured in two groups on September 19 and 20, 1981, from the Canaveral Channel with a NMFS chartered shrimp trawler. Size and weight measurements were taken from the captured turtles and sex was determined when possible. The turtles were either released in the channel or at a dredge spoil site located approximately 8 km south of the channel. Turtles released at the spoil site were selectively tagged with the most powerful radio transmitters; no selection was made with the acoustic pingers. The turtles captured on September 19 were tagged and released the same day into the channel and the ones captured on the second day were all tagged and released at the spoil site. A summary of biological measurements and tagging data is given in Table 2. The operation of each acoustic pinger and radio transmitter was verified prior to release of a turtle.

RESULTS AND DISCUSSION

RADIO AND ACOUSTIC TRACKING

Results from radio and acoustic tracking portion of the study were disappointing. Figure 7 summarizes the radio tracking data. The tracking of six turtles was terminated before the end of the experimental period due to the transmitters breaking off the turtles. Normally, a detached transmitter is easy to identify because it transmits continuously. Three of the detached transmitters were recovered; the remaining three drifted too far from the study area for practical recovery. The reason why most of the turtles detected were from the release made at the spoil site is probably because they had the most powerful transmitters (Table 1). Unfortunately, few of the detections resulted in positions due to very brief and infrequent surfacing periods. These periods were found to average less than 3 min which is significantly less than the 5 min required for a rough estimate of location.

Movement patterns of four turtles determined from radio tracking data are shown in Figure 8. All four of these turtles were released at the spoil site on September 20, 1981. All returned to the channel within a few days after release and at least two of the turtles apparently remained in or near the channel for most of the experimental period.

The acoustic tracking data are summarized in Figure 9. Only 10 of the 20 released turtles were detected at least once acoustically during the 20-day study period. Of these, 4 were released in the channel and 6 at the dump site. Difficulty was reported in detecting the slower ping rates, but this difficulty was not reflected in the data. Of the 26 detections reported, 12% were from pingers with 0.5 pings/sec transmission rates, 35% from pingers with 1.0/sec rates, 0% from pingers with 2.0/sec rates, 35% from pingers with 3.0/sec rates, and 19% from pingers with 5.0/sec rates.

Table 2. Summary of turtles receiving radio and acoustic transmitters

Turtle Number	Sex*	Carapace (cm)		Radio Tag		Acoustic Tag			Release Data	
		Length	Width	Number	Freq.(MHz)	Number	Freq.(KHz)	Pings/Sec	Date	Location
0	M	91.2	68.2	9299	165.55	1324	30	2.0	9/19	28°23'04 80°31'96
1	M	91.9	68.6	9300	165.66	1341	41	0.5	9/20	28°19'52 80°33'52
2	I	69.6	56.6	9302	165.58	1329	33	2.0	9/19	28°23'50 80°32'90
3	I	64.0	52.8	9303	165.59	1338	41	2.0	9/20	28°19'52 80°33'52
4	I	70.6	55.9	9304	165.60	1321	41	3.0	9/20	28°19'52 80°33'52
5	I	69.3	56.6	9305	165.61	1330	33	3.0	9/19	Station 10
6	F	88.6	67.6	9306	165.62	1340	42	5.0	9/20	28°19'52 80°33'52
7	I	79.0	59.7	9307	165.63	1342	43	1.0	9/20	28°19'52 80°33'52
8	I	65.0	54.9	9308	165.64	1325	33	3.0	9/19	Station 10
9	I	64.5	53.8	9309	165.65	1336	43	0.5	9/20	28°19'52 80°33'52
10	I	81.0	61.2	9310	165.66	1344	43	5.0	9/20	28°19'52 80°33'52
11	I	76.7	60.5	9311	165.67	1331	33	5.0	9/19	Station 11
12	I	73.9	61.7	9312	165.68	1326	35	5.0	9/19	Station 10
13	I	93.6	60.2	9313	165.69	1327	36	0.5	9/19	Station 10
14	I	73.2	58.2	9314	165.70	1334	38	2.0	9/19	28°23'04 80°31'96
15	M	88.6	69.9	9315	165.71	1332	38	0.5	9/19	28°23'50 80°32'90
16	I	73.7	61.2	9316	165.72	1333	40	1.0	9/19	28°23'50 80°32'90
17	I	66.3	57.4	9317	165.73	1339	43	3.0	9/20	28°19'52 80°33'52
18	I	65.0	54.1	9318	165.74	1337	45	1.0	9/20	28°19'52 80°33'52
19	F	91.9	73.9	9319	165.75	1343	45	3.0	9/20	28°19'52 80°33'52

*M = Male; F = Female; I = Immature (not possible to determine sex)

TURTLE NUMBER	RELEASE LOCATION	DAY FROM START																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	CHAN	NONE																			
1	DUMP							X													
2	CHAN			X		X		X	TERM ①												
3	DUMP			X		X		X				X		X		X					
4	"			X		X		X		X	TERM ①										
5	CHAN			X		X															
6	DUMP									X				X						X	
7	"			X		X								X		X		X		X	
8	CHAN					X		X	TERM ①												
9	DUMP					X		X				X	TERM ②								
10	"	NONE																			
11	CHAN							X										X			
12	"							X		X				X		X		X	TERM ②		
13	"	NONE																			
14	"	NONE																			
15	"			X																	
16	"					X						X				X	TERM ②				
17	DUMP	NONE																			
18	"									X				X		X		X			
19	"	NONE																			

① RECOVERED

② TRANSMITTING CONTINUOUSLY; NOT RECOVERED

Figure 7. Summary of Aircraft Tracking Results (X's indicate that a signal was received on that day. TERM indicates that tracking was terminated for this animal.)

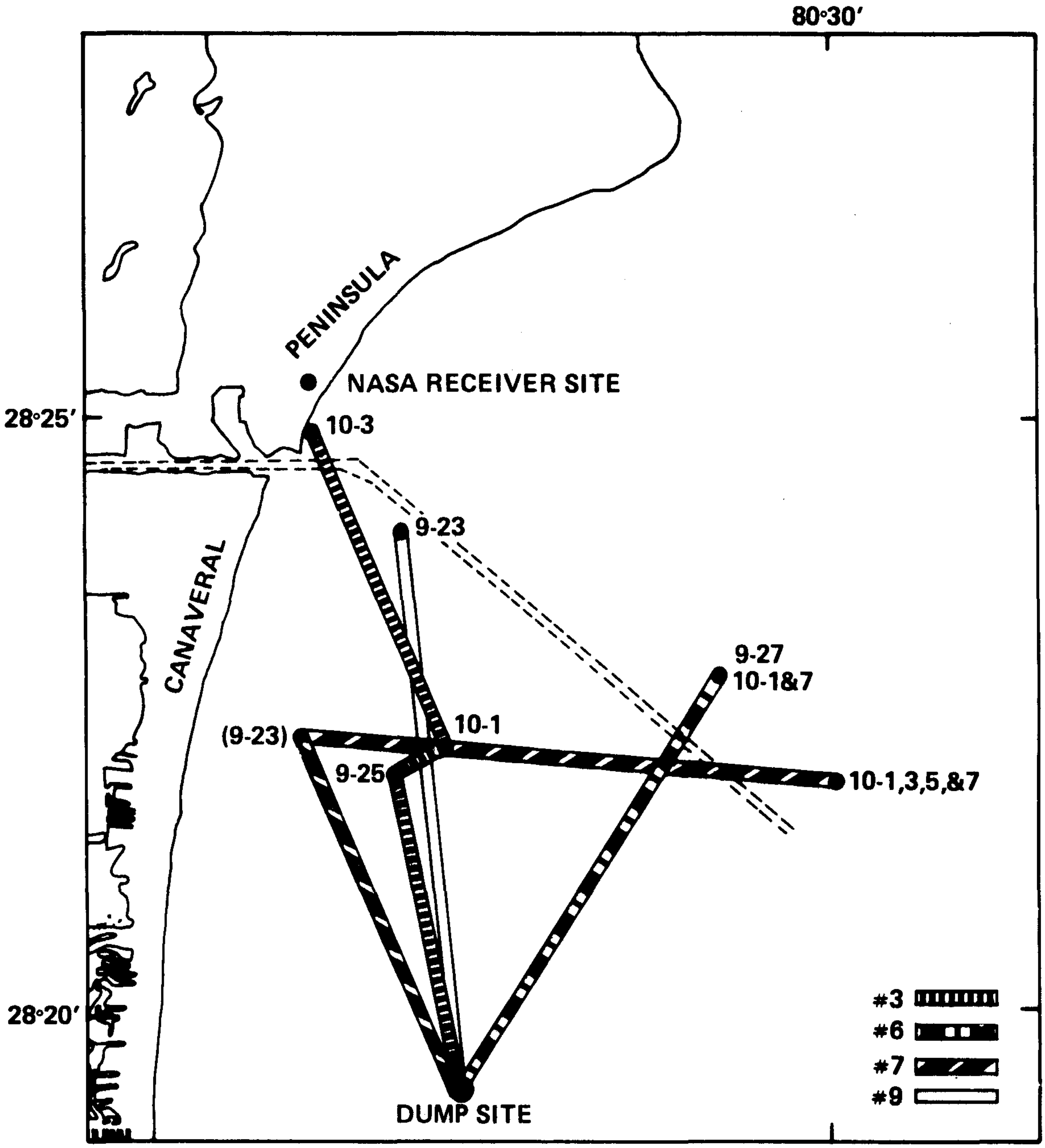

Figure 8. Movement patterns of four turtles determined from aircraft tracking of their radio transmitters. Dates of each positioning (1981) are given next to the estimated location.

TURTLE NUMBER	RELEASE LOCATION	DAY FROM START																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	CHAN	NONE																			
1	DUMP						X														
2	CHAN	NONE																			
3	DUMP	NONE																			
4	"	NONE																			
5	CHAN	NONE																			
6	DUMP	NONE																			
7	"										X										
8	CHAN		X		X		X		X		X										
9	DUMP								X		X										
10	"	NONE																			
11	CHAN		X										X								
12	"		X		X										X						
13	"	NONE																			
14	"	NONE																			
15	"	NONE																			
16	"		X						X				X						X		X
17	DUMP						X														
18	"						X				X								X		
19	"				X		X								X						

Figure 9. Summary of acoustic tracking data. (X's indicate that the animal was detected by the survey vessel on that day.)

Nine of the 10 turtles detected acoustically were located with sufficient accuracy for tracking (Figure 10). All of the positions were outside but near the channel and, with one exception, were north of the channel. The lack of very many locations for most of the detected turtles makes interpretation of the data questionable, but there was an indication that most movement was generally parallel to the channel. There also was an indication of a reaction of several turtles to vessel traffic as some of the turtles appeared to move when approached by the tracking vessel.

The disappointing results from the acoustic tracking were due to high ambient noise levels and signal attenuation by turbid waters in the study area. Future studies should attempt to increase transmitter range by reducing signal frequency, increasing transmitter power, or a combination of these factors. Additionally, future studies should consider a change in tracking procedures from the general survey approach attempted in this study to tracking of individual animals over extended time periods.

A comparison of radio and acoustic tracking data failed to produce anything of significance except to show that 8 of the 10 turtles released at the spoil site returned to the channel within 13 days after release. This return has been documented in other NMFS studies based on traditional tagging approaches. The rate of return apparently is rapid. The minimum period shown by this study was 3 days, the maximum 13 days, and the mean 7 days. This rate of return, however, should be used with caution as it probably reflects maximum time periods; i.e. the turtles could have arrived back at the channel much sooner than indicated from the tracking data.

CONTINUOUS RADIO MONITORING

A summary of results from the continuous radio monitoring portion of the study is presented in Figure 11. As noted for the radio tracking, six of the transmitters became detached from the turtles prematurely. This was determined almost immediately from the continuous monitoring data due to the characteristic consistent and continuous signals from the detached transmitters.

The continuous radio monitoring data were subjected to an initial and final series of edits to account for detached transmitters, background and periodic radio noise and interference, periods of receiver inoperation, and periods when the turtles were out of the range of the receiver. The first initial edit was performed automatically in the frequency domain based on frequency characteristics of the transmitted signals. A second initial edit also was performed automatically to threshold all returns to a pre-established level. Even with these two edits, however, a considerable amount of radio noise was noted in the data record and an attempt was made by the system operators to manually edit the data to eliminate the noise. This may have introduced some operator bias into the data in the initial edit as it was based to some degree on the relatively consistent surfacing behavior patterns of the turtles during periods of relatively little ambient noise. And finally, the entire data record for transmitter 9310 was omitted in the initial edit due to transmissions in this channel from an unknown source.

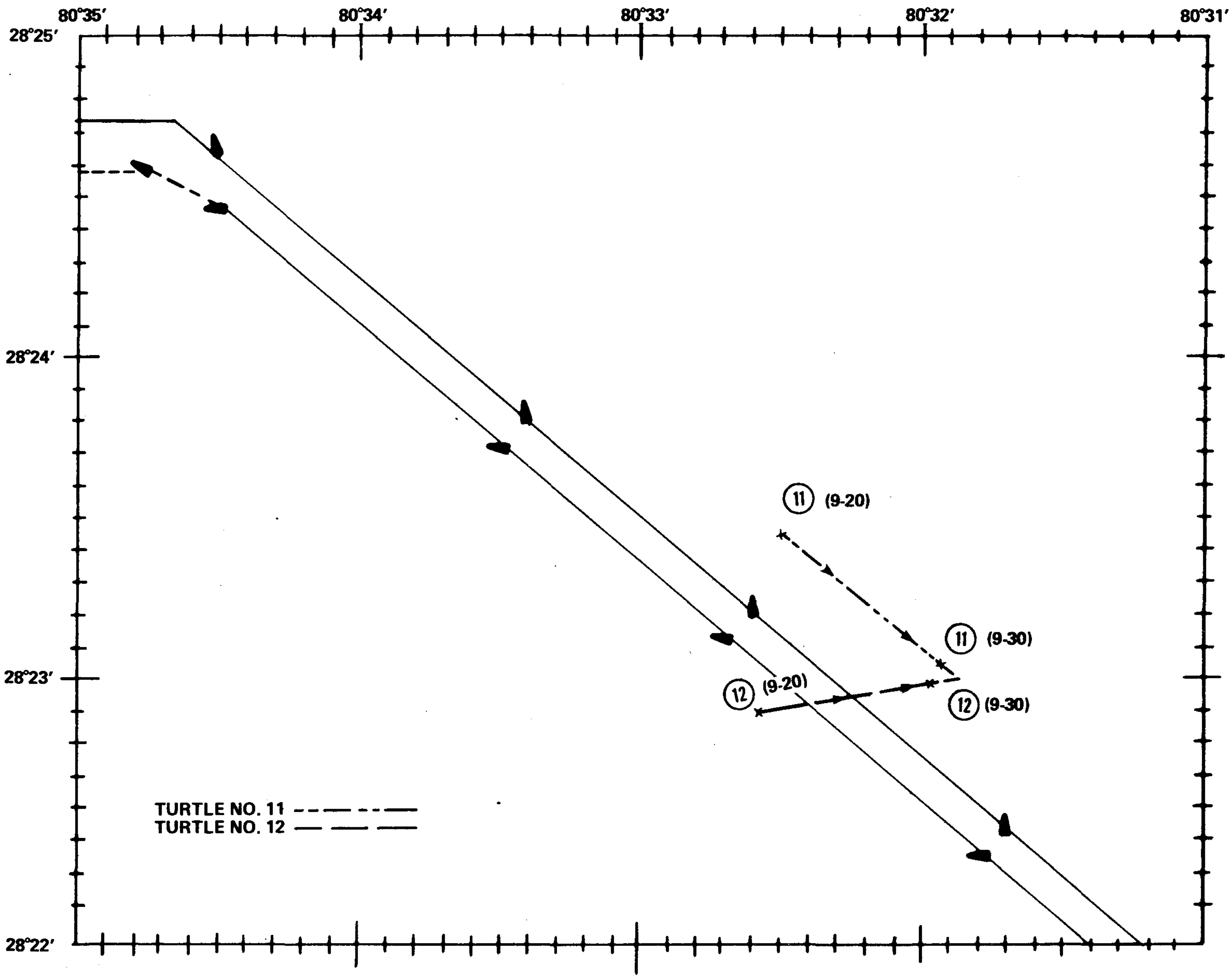

Figure 10a. Acoustic tracks of turtles 11 and 12.

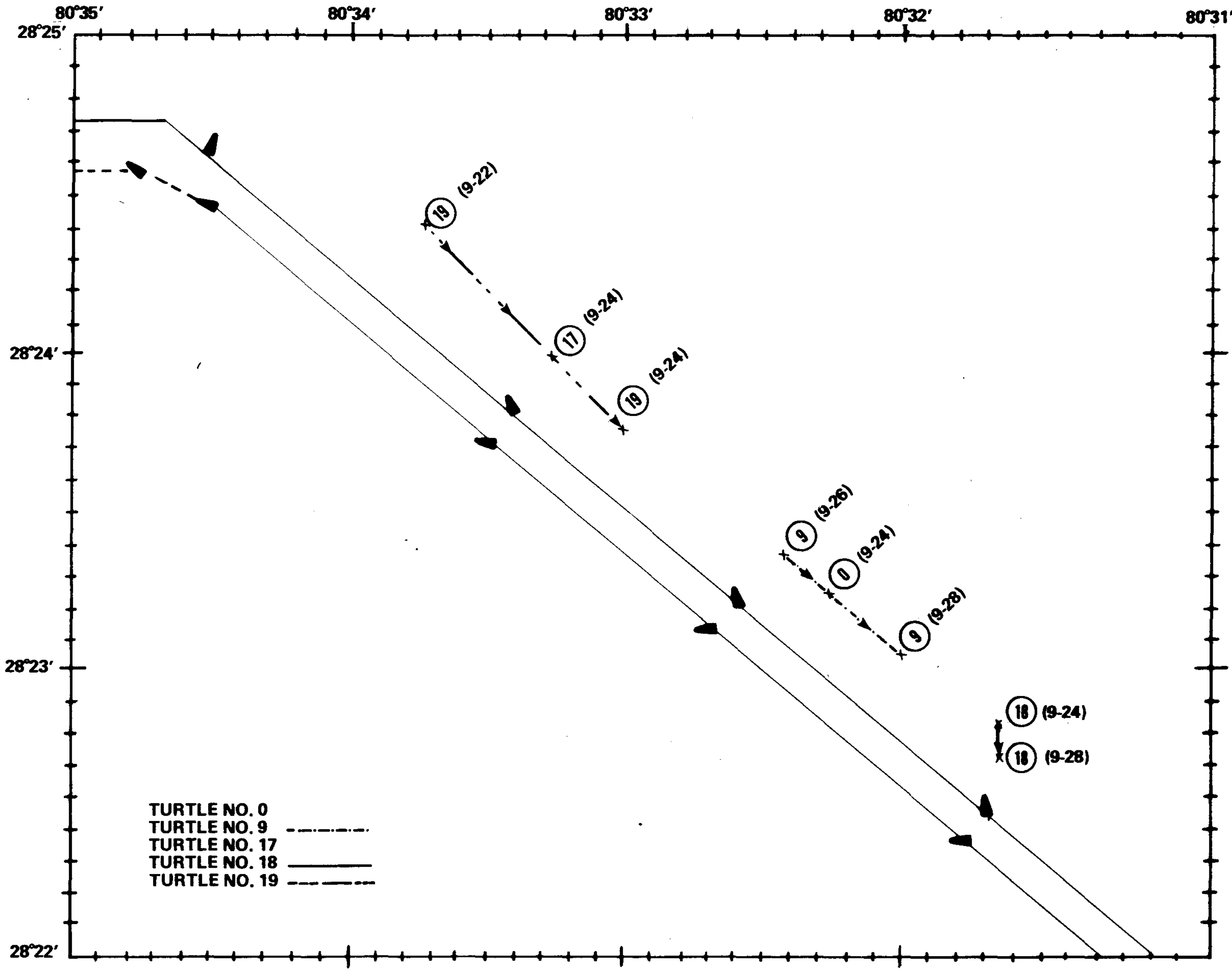

Figure 10b. Acoustic tracks of turtles 0, 9, 17, 18, and 19.

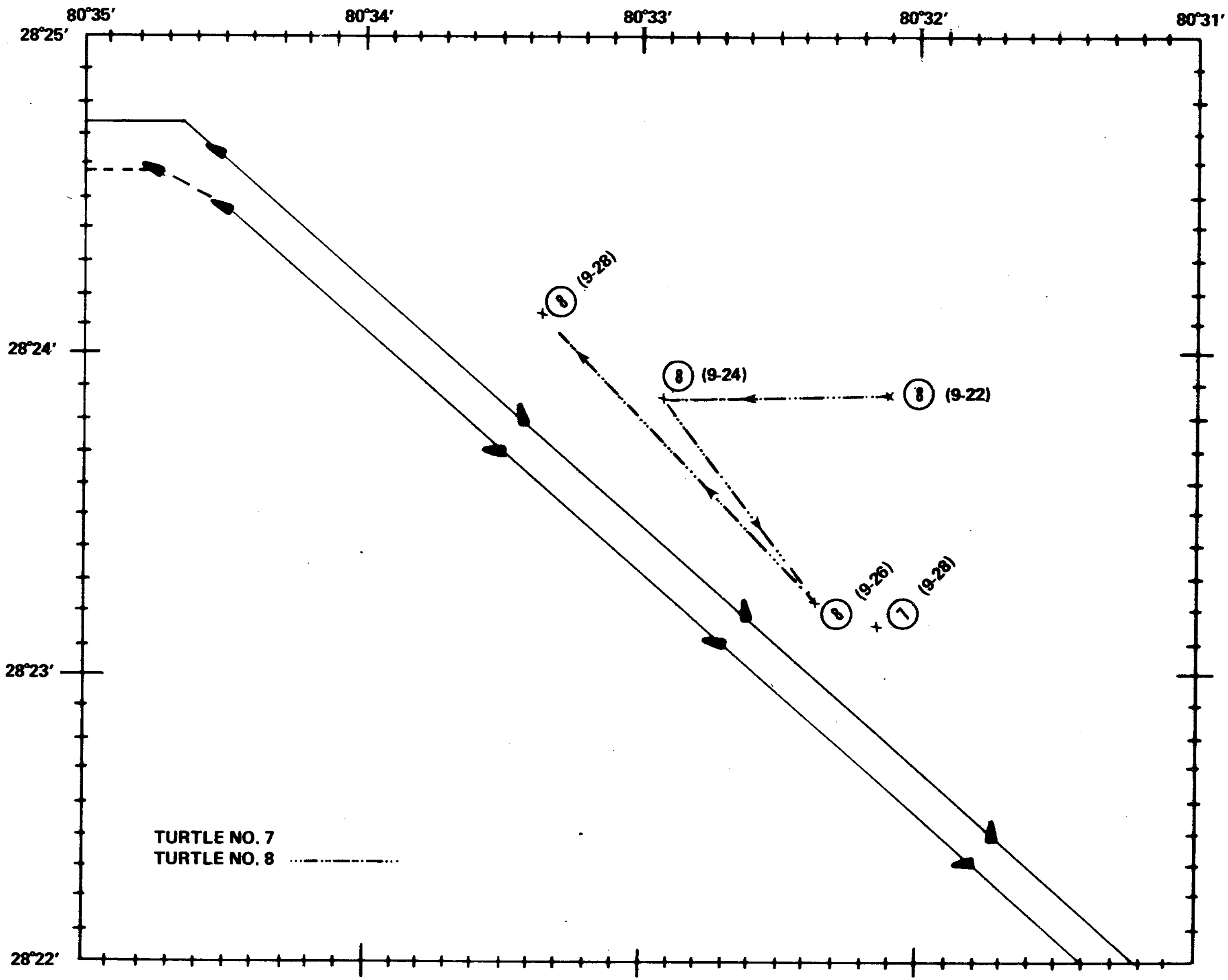

Figure 10c. Acoustic tracks of turtles 7 and 8.

TURTLE NUMBER	RELEASE LOCATION	DAY FROM START																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	CHAN	NONE																			
1	DUMP	NONE																			
2	CHAN	X	X	X	X	X	X	X	TERM (1)												
3	DUMP		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
4	"		X	X			X				TERM (1)										
5	CHAN	X						X												X	
6	DUMP		X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	
7	"		X	X	X	X		X	X		X	X			X	X		X	X	X	X
8	CHAN	X	X	X	X	X			TERM (1)												
9	DUMP		X	X	X	X	X	X	X	X	X	X	X	TERM (2)							
10	"			X																	
11	CHAN	X																	X		
12	"	X	X	X							X				X				TERM (2)		
13	"	X	X															X		X	
14	"						X		X			X	X	X	X						
15	"	X	X	X							X	X		X	X						
16	"	X	X	X												TERM (2)					
17	DUMP		X	X	X	X	X	X	X	X	X	X	X								
18	"											X									
19	"													X	X						

(1) RECOVERED

(2) TRANSMITTING CONTINUOUSLY

Figure 11. Summary of continuous radio monitoring data. (X's indicate that a signal was received on that day. TERM indicates that tracking of this animal was terminated.)

The final edit was performed after the data had been transcribed onto computer tape. An example of a 24-hour data record is given in Figure 12. This edit consisted first of eliminating from the data record all signals from detached transmitters, all time periods when the receiver was not operating and all hours with simultaneous noise across the 20 channels. The last edit was a subjective attempt to eliminate time periods for individual turtles when obstensively they were out of the range of the receiver. The criterion used to edit the data was that if fewer than 3 or 4 surfacings were recorded during a 12-hour period, the entire 12-hour period was eliminated. In all instances, if there was any uncertainty about a record, either due to frequent noise or the lack of many turtle surfacings, the entire record was omitted.

Summaries of the continuous monitoring data are presented by day of experiment in Figure 13, by turtle number in Figure 14, and by time of day in Figure 15. Results are presented in 1-hour periods with each hour representing a 60-minute period in the edited data record for an individual turtle. A total of 848 hours was recorded with the majority of the hours recorded during the first half of the experiment (Figure 13). The first three days of the monitoring period were omitted from any statistical analysis, however, because of differences noted in the surfacing behavior of the turtles during this period, presumably due to effects of handling and adjustment by the turtles to the radio and acoustic tags. Only records from six turtles were judged to be reliable indicators of behavior after the data edits (and elimination of the first 3 days), and of these six animals, only four contributed significantly to the data base (Figure 14). There was a pronounced diurnal periodicity in the data records due primarily to increased radio frequency noise in the Cape Canaveral area during daylight periods (Figure 15).

The three behavior parameters examined from the continuous monitoring data records were time duration of each surfacing, number of surfacings per hour, and the percent surface time per hour. An hour was considered to represent an individual sample for the latter two parameters. If a surfacing occurred during any given hour and extended into the next, it was assigned to the initial hour. Graphical summaries of the three parameters are presented by time of day and day of experiment in Figures 16 through 21. Tables 3, 4, and 5 provide numerical summaries of the data by time of day, day of experiment, and turtle, respectively. In computing the summary data, hourly statistics were derived by summing through day and turtle, daily statistics by summing through hour and turtle, and individual turtle statistics by summing through day and hour. The entire edited data set, with the exception of the first three days, was used for each summary.

The first three days of the experimental period were omitted from all analyses to allow for a presumed behavioral adjustment period for the turtles. All three parameters were much higher during the first three days than for the remaining days (Table 4). This division was somewhat arbitrary although apparently reasonable based on means and standard deviations from the daily measurements.

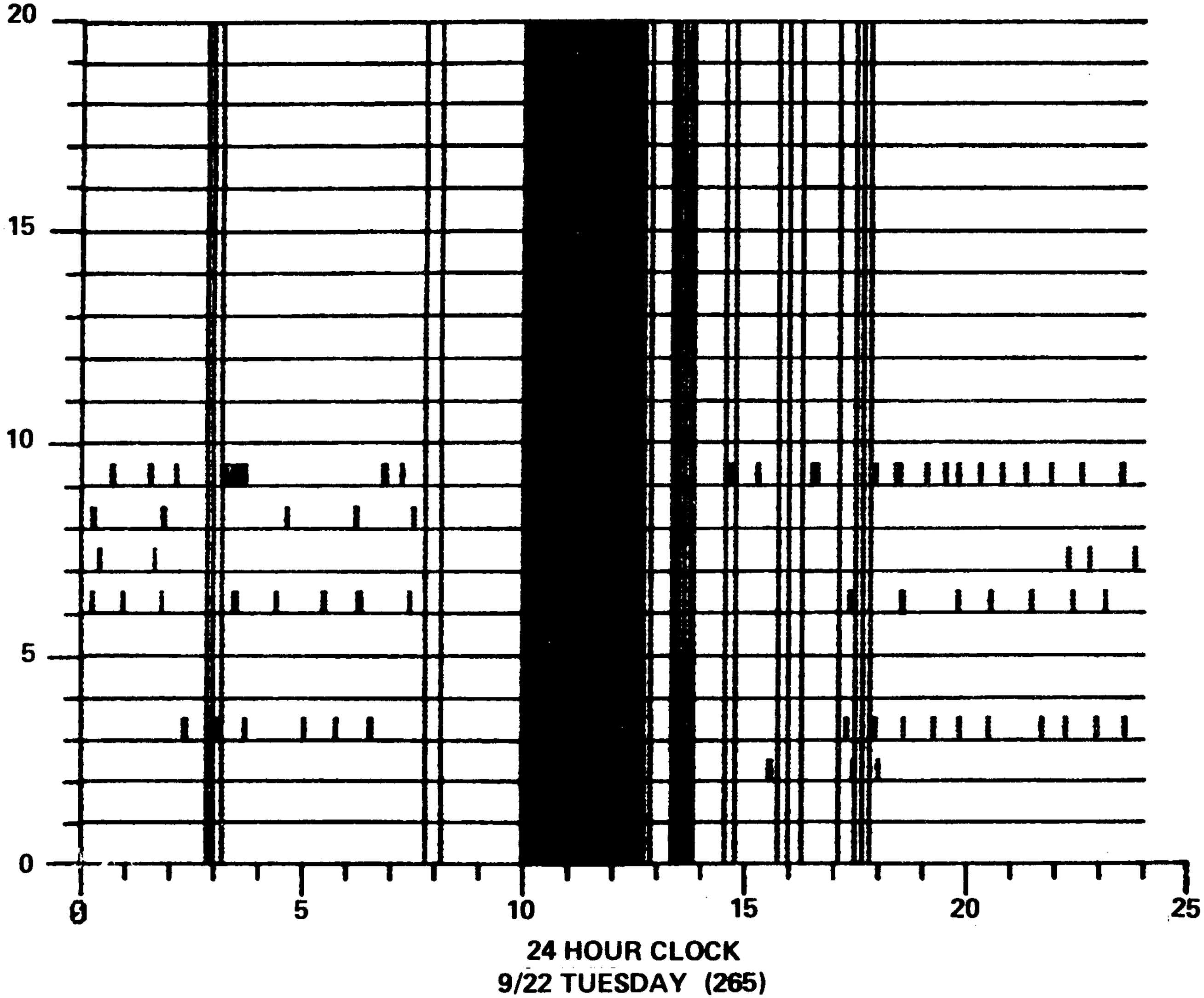

Figure 12. Example of a continuous monitoring data record for 24 hrs from September 22, 1981. Each horizontal line represents an individual turtle record. Widths of the bars perpendicular to the horizontal lines correspond to reception periods for the respective turtles. The narrow vertical lines represent noise spikes and the wide vertical bar is a period when the receiver was not operating.

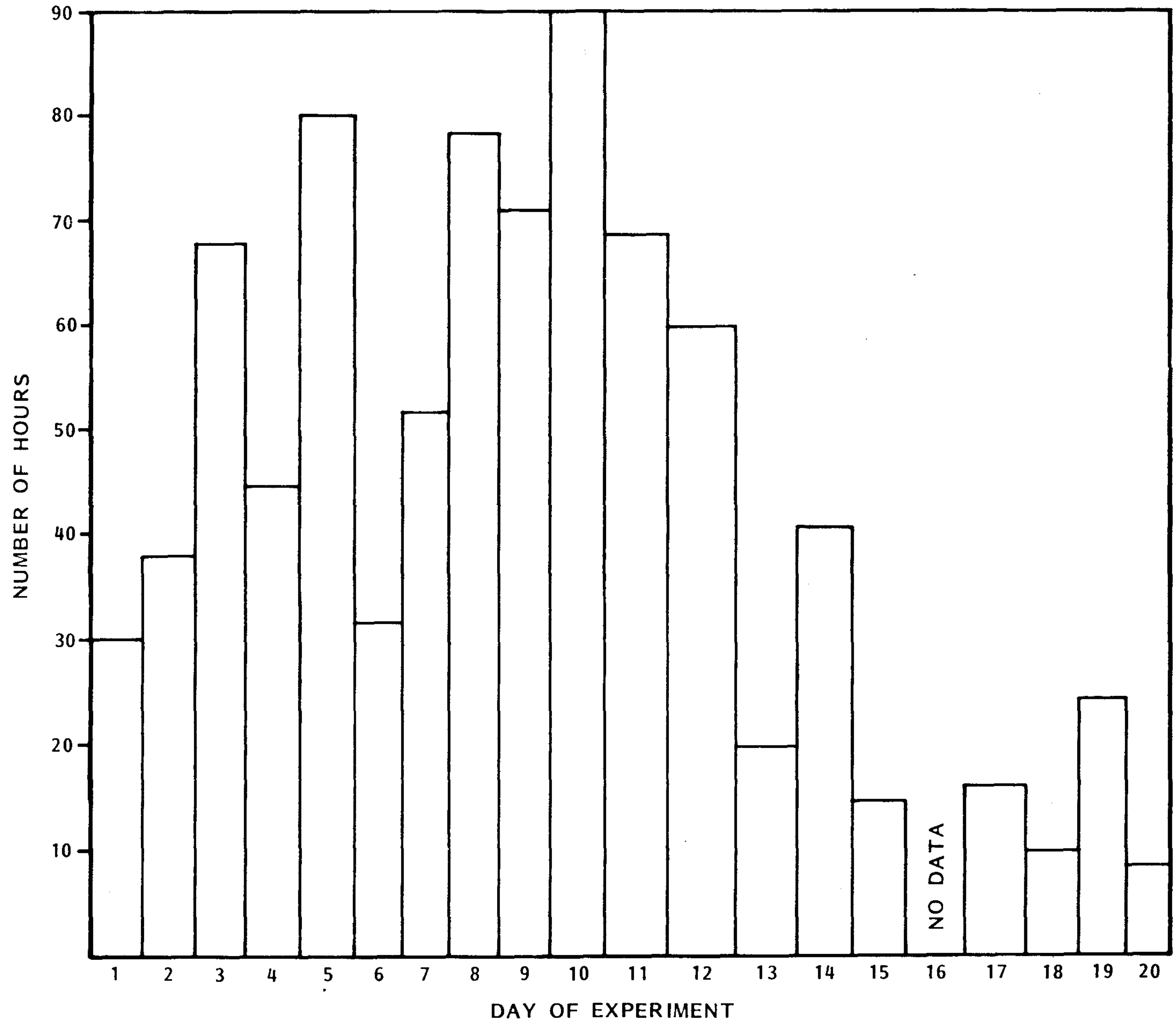

Figure 13. Number of data hours by day of experiment after edit. Includes all turtles and times (N = 848 hours).

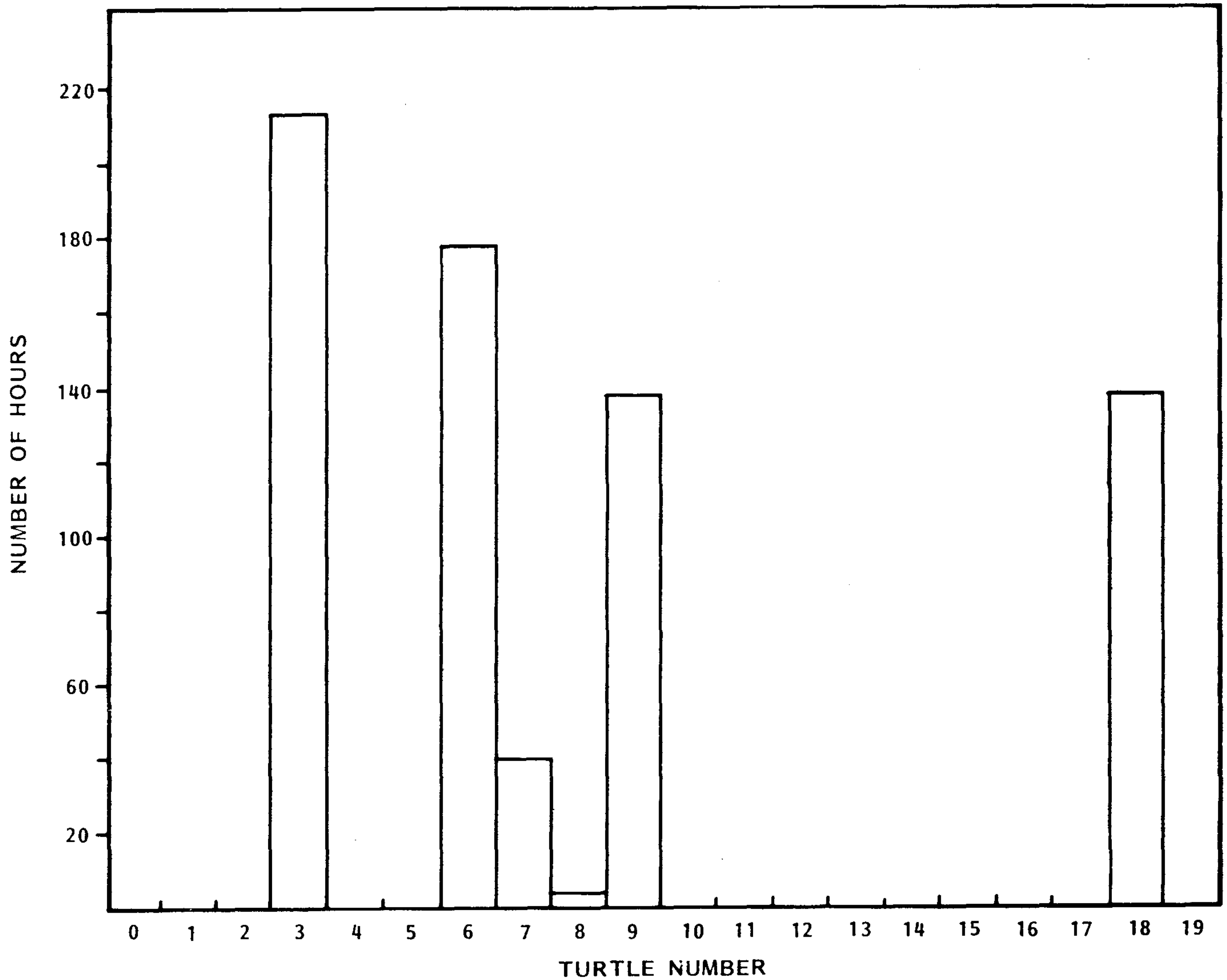

Figure 14. Number of data hours for each turtle after data edit and elimination of first 3 days of experiment. Includes all days and hours (Total N = 712 hours).

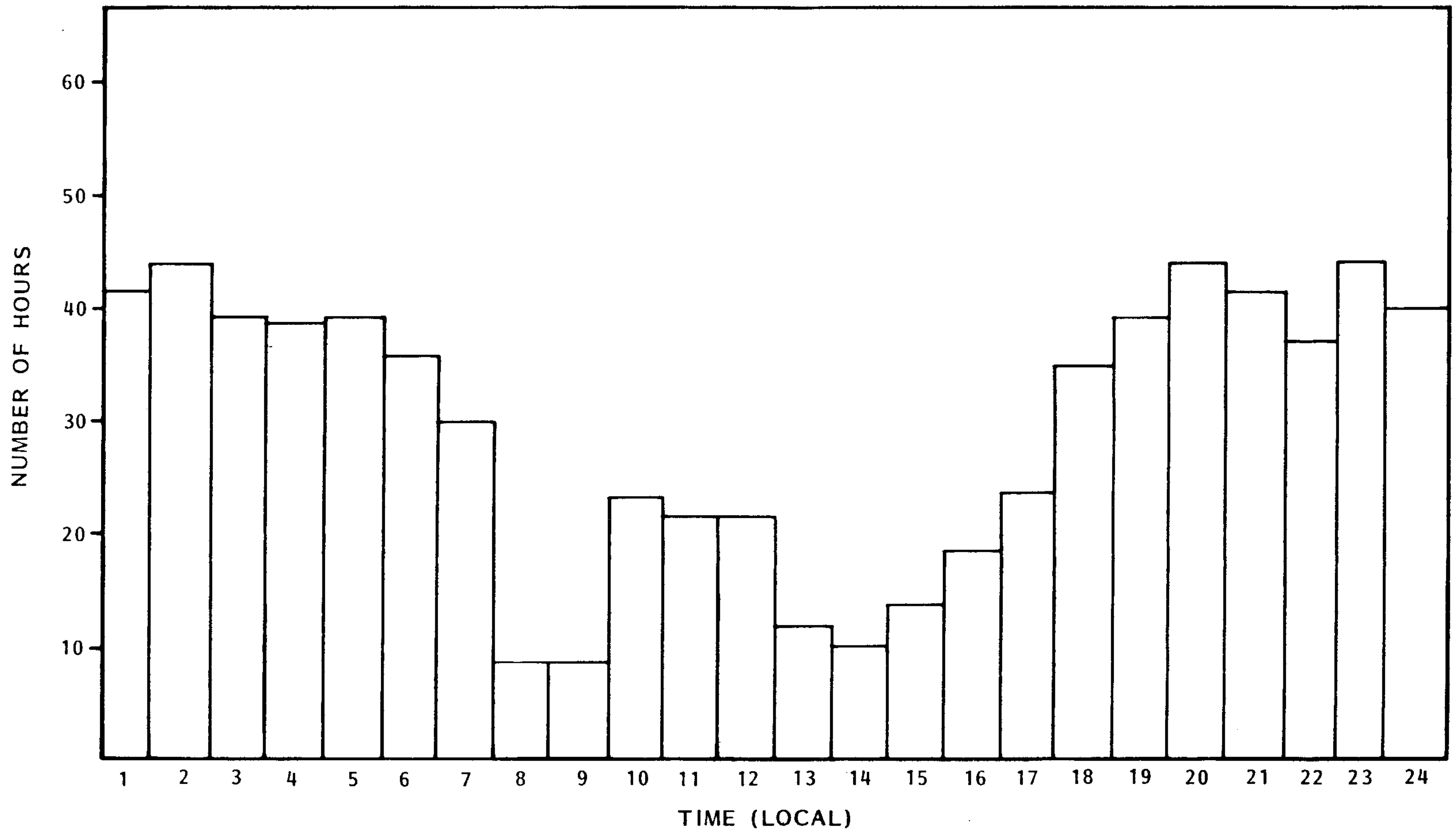

Figure 15. Number of data hours by time of day after edit and elimination of first 3 days of experiment. Includes all turtles and days (N = 712 hours).

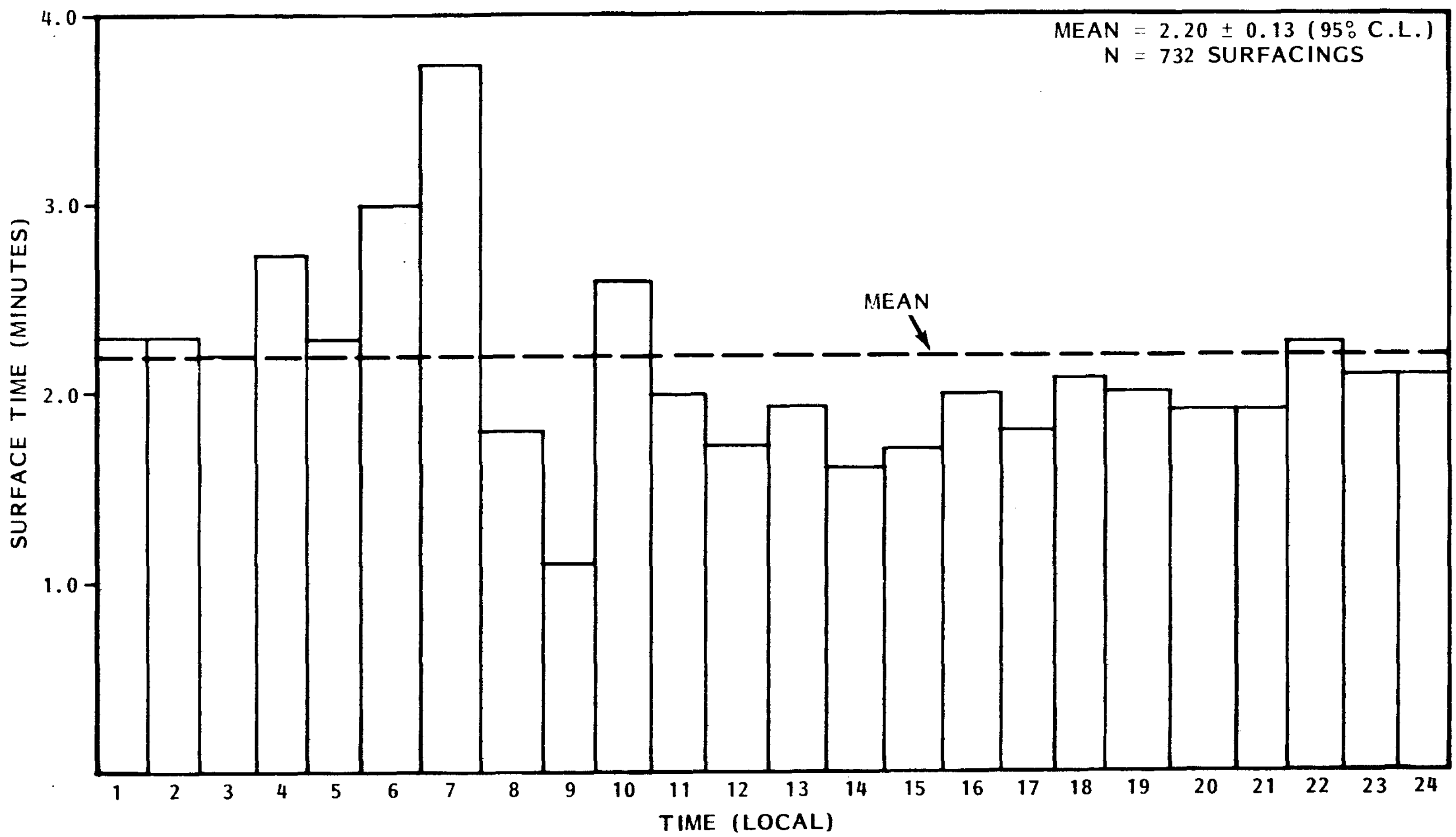

Figure 16. Mean surface time per turtle surfacing by time of day. First 3 days of experiment omitted.

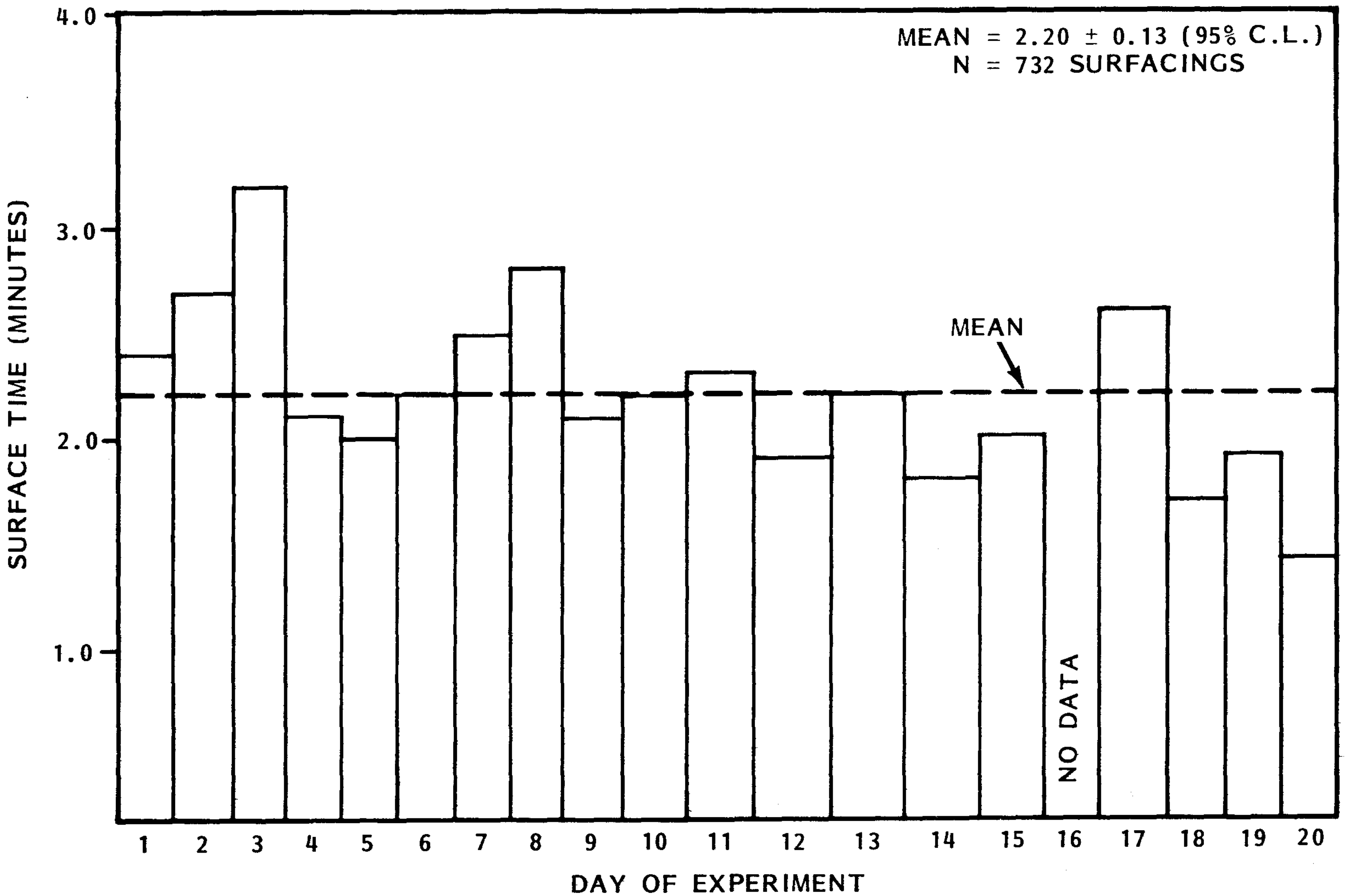

Figure 17. Mean surface time per turtle surfacing by day of experiment. First 3 days of experiment are not included in computation of mean.

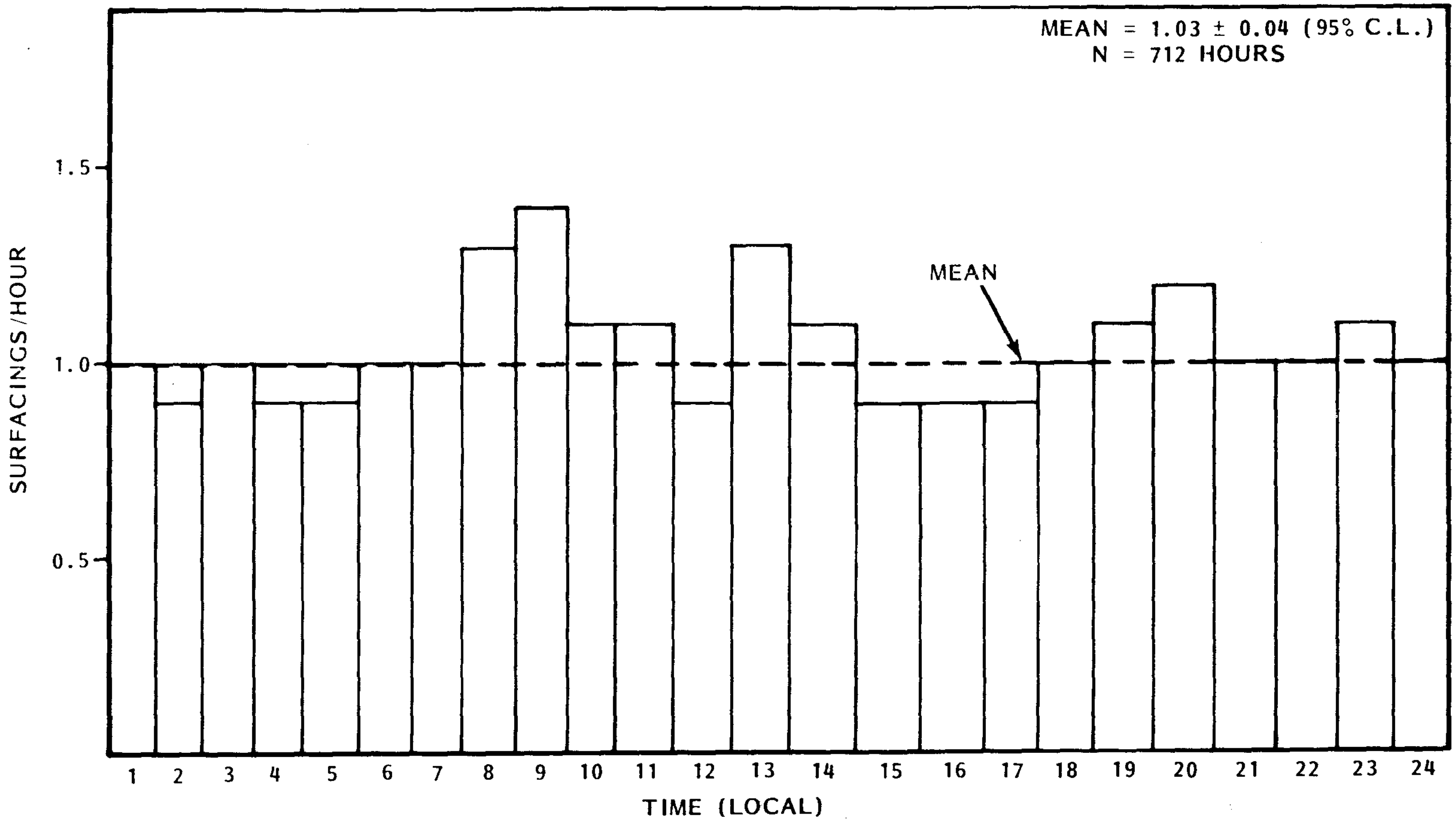

Figure 18. Mean number of turtle surfacings per hour by time of day. First 3 days of experiment omitted.

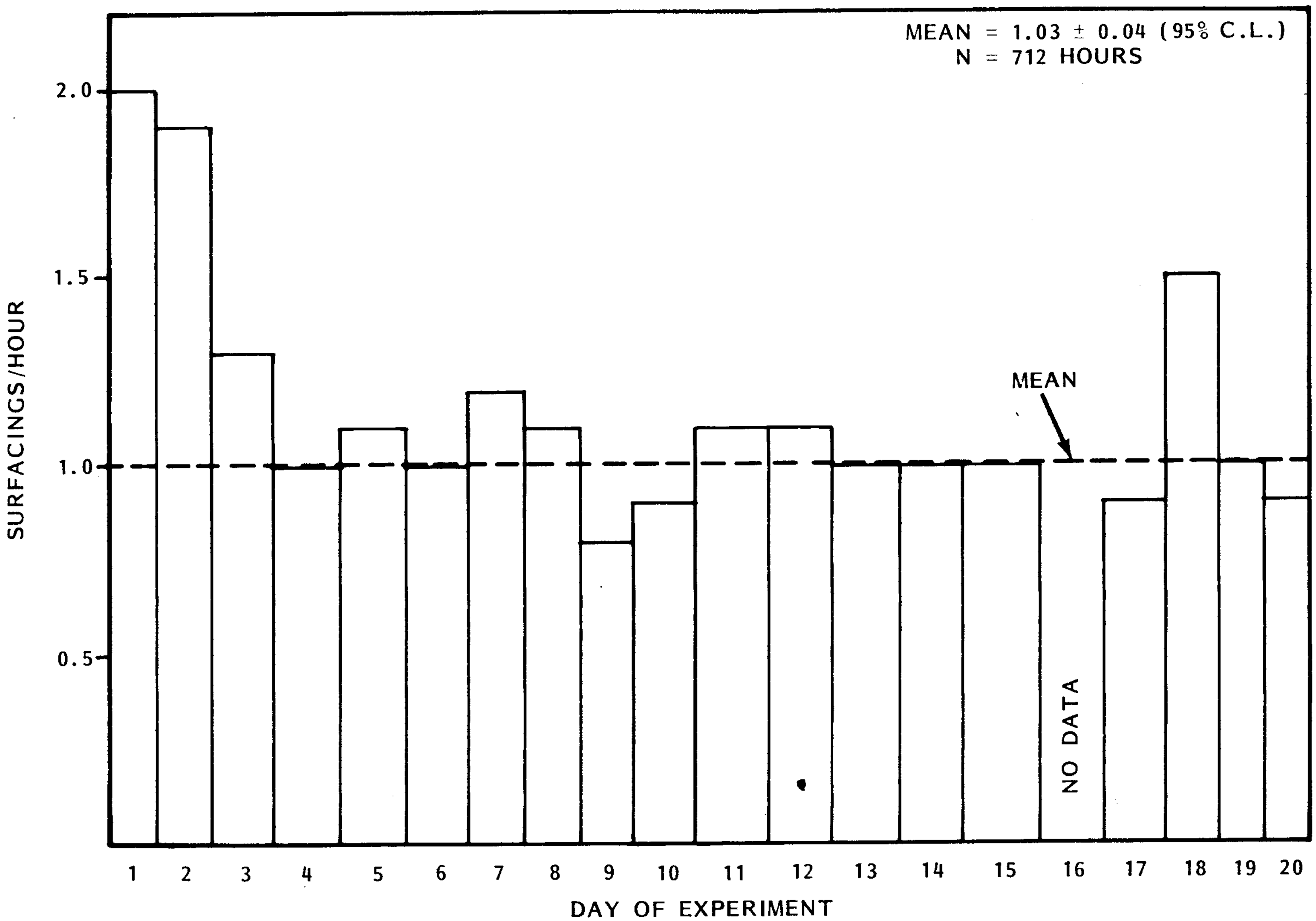

Figure 19. Mean number of turtle surfacings per hour by day of experiment. First 3 days of experiment are not included in computation of mean.

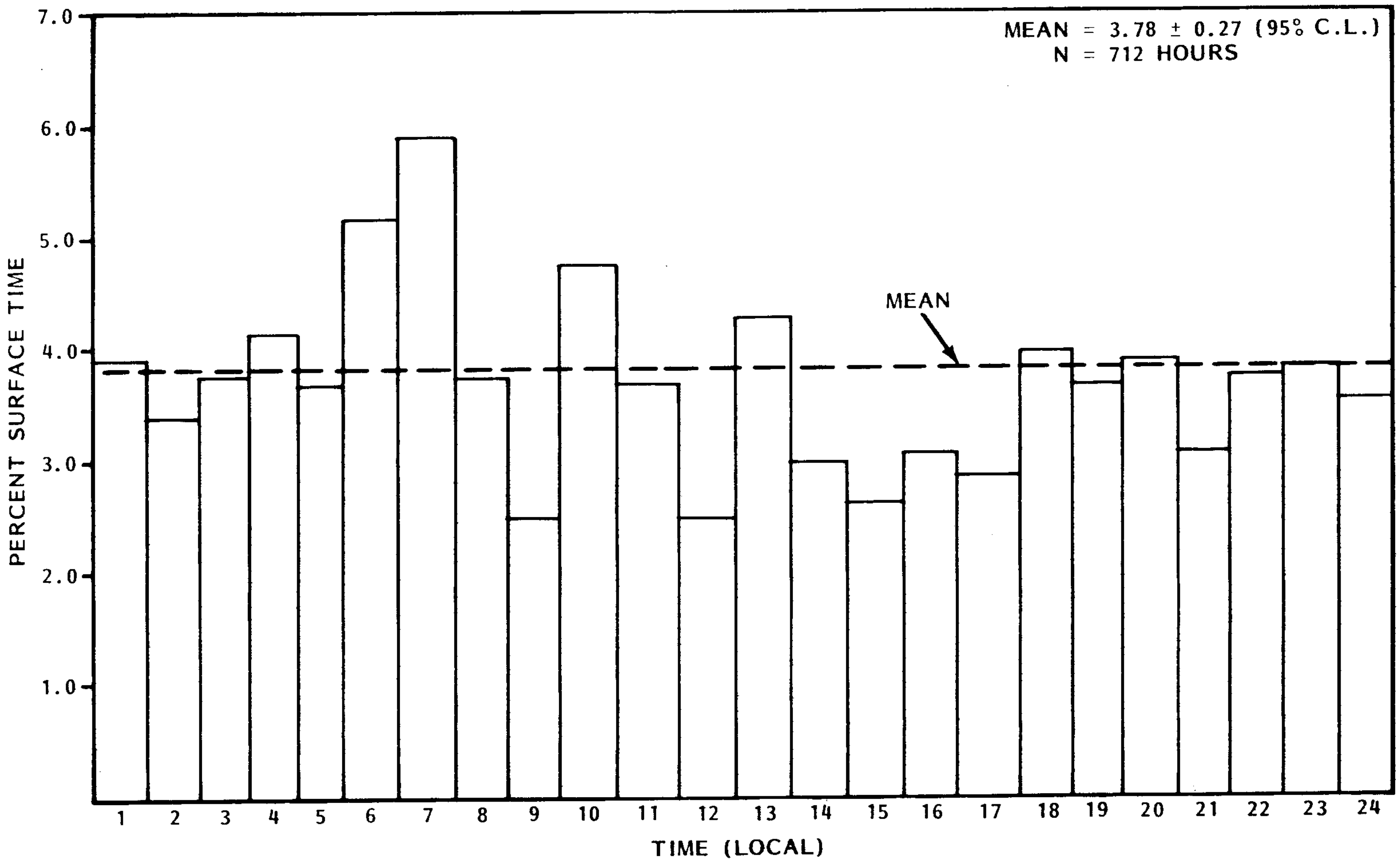

Figure 20. Mean percent surface time per turtle by time of day. First 3 days of experiment omitted.

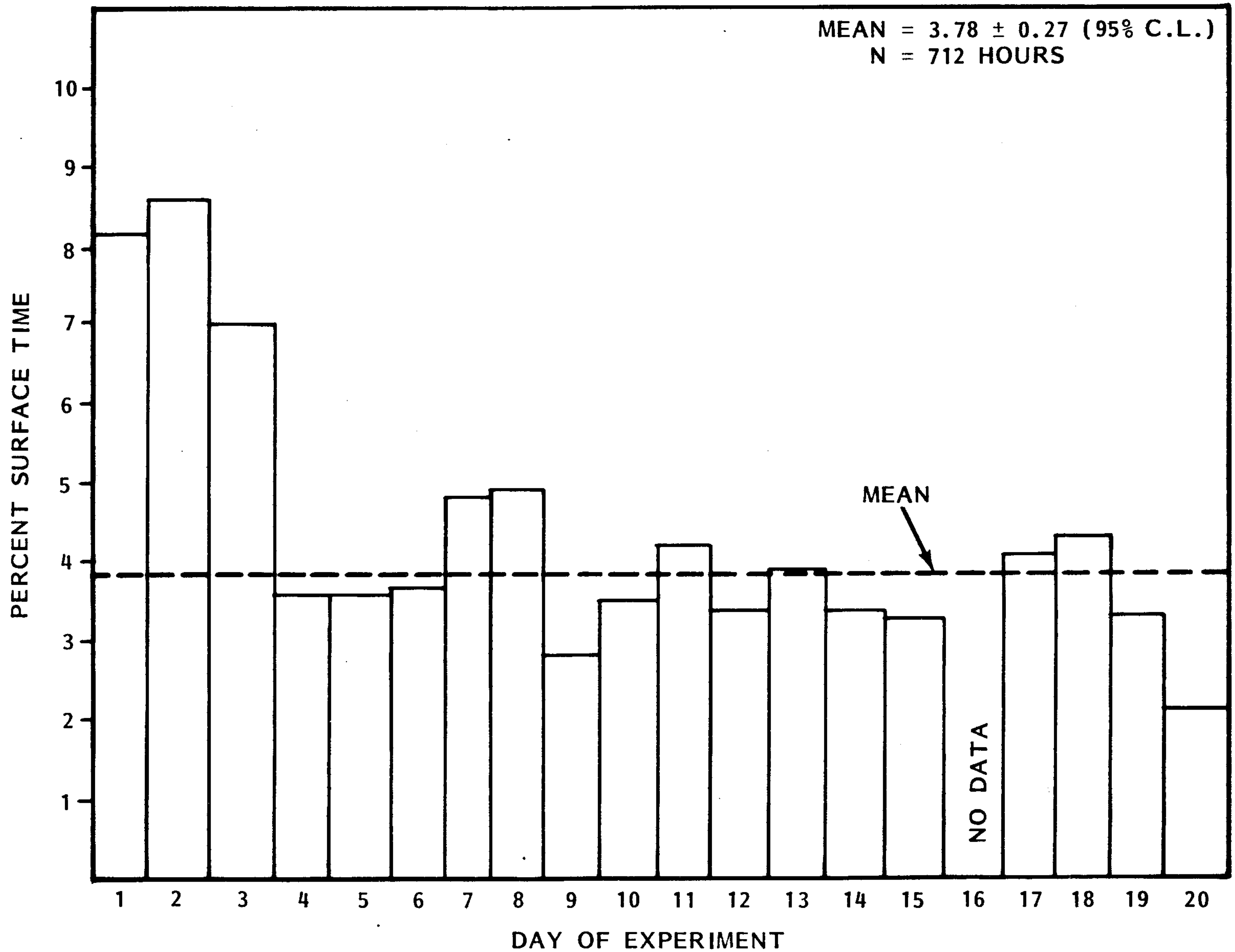

Figure 21. Mean percent surface time per turtle by day of experiment. First 3 days of experiment are not included in computation of mean.

Table 3. Summary of turtle surfacing measurements after omission of first 3 days of experiment. Measurements include six turtles over 17 days.

Hour	Surface Time (min)			Surfacings/Hour			Percent Surfacing Time		
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s
1	42	2.3	1.6	42	1.0	0.4	42	3.9	2.9
2	40	2.3	1.0	44	0.9	0.6	44	3.4	2.6
3	40	2.2	1.1	39	1.0	0.4	39	3.7	2.4
4	35	2.7	3.8	38	0.9	0.4	38	4.2	6.2
5	37	2.3	1.9	39	0.9	0.6	39	3.6	4.3
6	37	3.0	3.2	36	1.0	0.6	36	5.2	6.7
7	29	3.7	3.9	30	1.0	0.4	30	5.9	6.7
8	10	1.8	1.0	8	1.3	0.9	8	3.7	3.3
9	11	1.1	0.3	8	1.4	0.5	8	2.5	1.3
10	26	2.6	2.5	24	1.1	0.6	24	4.7	4.7
11	24	2.0	0.9	22	1.1	0.6	22	3.6	2.4
12	20	1.7	0.7	22	0.9	0.8	22	2.5	2.3
13	16	1.9	0.9	12	1.3	0.7	12	4.3	2.2
14	11	1.6	0.7	10	1.1	0.6	10	3.0	1.7
15	13	1.7	0.9	14	0.9	0.5	14	2.6	1.8
16	17	2.0	1.0	18	0.9	0.6	18	3.1	2.7
17	23	1.8	0.8	25	0.9	0.6	25	2.8	2.2
18	40	2.1	1.9	35	1.1	0.5	35	4.0	3.5
19	41	2.0	1.2	39	1.1	0.6	39	3.6	3.0
20	54	1.9	0.8	44	1.2	0.8	44	3.9	2.4
21	42	1.9	1.0	42	1.0	0.5	42	3.1	2.1
22	36	2.3	0.8	37	1.0	0.6	37	3.7	2.7
23	48	2.1	0.9	44	1.1	0.6	44	3.8	2.2
24	40	2.1	1.6	40	1.0	0.8	40	3.5	3.2
TOTAL	732	2.2	1.8	712	1.0	0.6	712	3.8	3.7

Table 4. Summary of turtle surfacing behavior by day after start of experiment. All days included but first 3 days of the experiment are not included in totals

Day	Surface Time (Min)			Surfacings/Hour			Percent Surfacing Time		
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s
1	61	2.4	1.1	30	2.0	1.0	30	8.1	4.4
2	73	2.7	2.0	38	1.9	0.7	38	8.6	6.3
3	83	3.2	4.3	68	1.3	0.9	6.3	7.0	9.6
4	45	2.1	1.2	44	1.0	0.7	44	3.6	2.8
5	88	2.0	0.9	80	1.1	0.5	80	3.6	2.2
6	33	2.2	1.1	32	1.0	0.6	32	3.7	2.9
7	61	2.5	2.0	52	1.2	0.7	52	4.8	3.9
8	82	2.8	3.5	78	1.1	0.5	78	4.9	6.6
9	57	2.1	0.9	72	0.8	0.5	72	2.8	2.0
10	85	2.2	1.4	92	0.9	0.6	92	3.5	3.0
11	74	2.3	2.3	68	1.1	0.6	68	4.2	4.7
12	64	1.9	1.7	60	1.1	0.5	60	3.4	3.1
13	21	2.2	2.0	20	1.0	0.7	20	3.9	4.1
14	45	1.8	0.9	41	1.1	0.7	41	3.4	2.5
15	15	2.0	0.8	15	1.0	0.5	15	3.3	2.0
16	0	-	-	0	-	-	0	-	-
17	15	2.6	1.2	16	0.9	0.6	16	4.1	3.1
18	15	1.7	1.3	10	1.5	1.0	10	4.3	3.1
19	25	1.9	0.9	24	1.0	0.6	24	3.3	1.9
20	7	1.4	0.5	8	0.9	0.4	8	2.1	1.2
TOTAL*	732	2.2	1.8	712	1.0	0.6	712	3.8	3.7

*Measurements from first three days omitted from totals.

Table 5. Summary of surfacing behavior measurements for individual turtles. Measurements from first 3 days of experiment omitted.

Turtle Number	Carapace Length (cm)	Surface Time (min)			Surfacings/Hour			Percent Surface Time		
		n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s
3	64.0	255	2.2	2.1	213	1.2	0.7	213	4.3	4.5
6	88.6	142	2.2	1.2	179	0.8	0.5	179	3.0	2.5
7	79.0	49	2.2	1.8	40	1.2	0.4	40	4.5	3.2
8	65.0	3	3.3	1.5	4	0.8	0.5	4	4.2	3.5
9	64.5	151	2.2	1.9	138	1.1	0.5	138	4.0	3.8
18	65.0	132	2.2	1.7	138	1.0	0.6	138	3.5	3.3
TOTAL	-	732	2.2	1.8	712	1.0	0.6	712	3.8	3.7

Mean surfacing time by time of day ranged from a low of 1.1 min to a high of 3.7 min with an overall mean of 2.20 ±0.13 min at a 95% confidence level (Figure 16 and Table 3). From the fourth to the last day of the experiment, mean surfacing time by day ranged from 1.4 min to 2.8 min (Figure 17 and Table 4). By individual turtle, mean surface time ranged from 2.2 min to 3.3 min with all but one of the means equaling the overall mean of 2.2 min (Table 5). A one-way analysis of variance was applied to the data to test for effects of turtle, time of day, and day of experiment on surface times (Figure 22). Only time of day was significant (99% confidence level) suggesting that surface time per surfacing varied with time.

The mean number of turtle surfacings per hour was relatively consistent over time averaging 1.03 ±0.04 (95% confidence limits) with a range of 0.9 to 1.4 mean surfacings per hour (Figure 18 and Table 3). The parameter also was relatively consistent by day of experiment with daily means ranging from 0.8 to 1.5 surfacings per hour (Figure 19 and Table 4). The range in mean number of surfacings by turtle was relatively small with a low of 0.8 and a high of 1.2. Significant differences, however, were found with this parameter between turtles and day of experiment (Figure 23).

Percent surface time was a key parameter for the experiment and it was found to average 3.78 ±0.27% (95% confidence limits). The range in hourly means was 2.5 to 5.9% (Figure 20 and Table 3) and in daily means from 2.1 to 4.9% (Figure 21 and Table 4). For the six turtles, the mean percent surface time ranged from 3.0 to 4.5%. A one-way analysis of variance applied to the percent surface times showed significant differences between turtles (99% confidence limits) with no significant differences by time of day or by day of experiment (Figure 24).

To determine if diurnal trends in the surfacing behavior of the turtles existed, time averaging was applied to hourly values for each of the three parameters. Two averages were used to minimize data variability. Mean surface time per surfacing demonstrated a definite trend with the surfacing periods increasing just before dawn to a peak shortly after dawn and then dropping rapidly off to the shortest period about mid-day (Figure 25). After mid-day, surfacing periods gradually increased to about the overall mean value by the beginning of the next day. Less of a trend was indicated by time-averaged surfacings/hour, but some trending was suggested (Figure 26). The number of surfacings/hour were lowest just before dawn increasing to a maximum about mid-morning. Following the mid-morning high, the averaged values decreased to a low in mid-afternoon followed by another peak just before sunset.

A well-defined trend occurred with the time-averaged percent surface time values (Figure 27). The maximum period on the surface was shortly after dawn (i.e. 7:00 a.m.) after which percent surface time dropped rapidly to a low about mid-afternoon. This apparent rapid change in the amount of time spent on the surface by a turtle as a function of time of day could have significant implication for any investigation dependent on surface observations of turtles. One should recognize, however, that this particular trend was not supported statistically (Figure 24).

A. Turtle

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Turtles	5	4.4296	0.8859	0.2633
Error	726	2442.8327	3.3648	
TOTAL	731	2447.2623		

B. Time of Day

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Hours	23	152.7163	6.6398	2.0487**
Error	708	2294.5460	3.2409	
TOTAL	731	2447.2623		

** Significant 99% Confidence

C. Day of Experiment

Source of Variation	Degrees of Freedom	Sum of Square	Mean Square	F
Days	15	65.3281	4.3552	1.3092
Error	716	2381.9342	3.3267	
TOTAL	731	2447.2623		

Figure 22. Analysis of variance of the effect of turtle, time of day, and day of experiment on amount of surface time per surfacing. Excludes first 3 days of experiment.

A. Turtle

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Turtles	5	19.1284	3.8257	11.7281**
Error	706	230.3098	0.3262	
TOTAL	711	249.4382		

** Significant at 99% Confidence

B. Time of Day

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Hours	23	7.5839	0.3297	0.9380
Error	688	241.8543	0.3515	
TOTAL	711	249.4382		

C. Day of Experiment

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Days	15	9.6781	0.6452	1.8729*
Error	696	239.7601	0.3445	
TOTAL	711	249.4382		

* Significant at 95% Confidence

Figure 23. Analysis of variance of the effect of turtle, time of day, and day of experiment on number of surfacings per hour. Excludes first 3 days of experiment.

A. Turtle

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Turtles	5	222.9605	44.5921	3.3222**
Error	706	9475.9775	13.4221	
TOTAL	711	9498.9380		

** Significant at 99% Confidence

B. Time of Day

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	
Hours	23	380.0375	16.5234	1.2466
Error	688	9118.9005	13.2542	
TOTAL	711	9498.9380		

C. Day of Experiment

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Days	15	298.8417	19.9228	1.5072
Error	696	9200.0963	13.2185	
TOTAL	711	9498.9380		

Figure 24. Analysis of variance of the effect of turtle, time of day, and day of experiment on percent surface time. Excludes first 3 days of experiment.

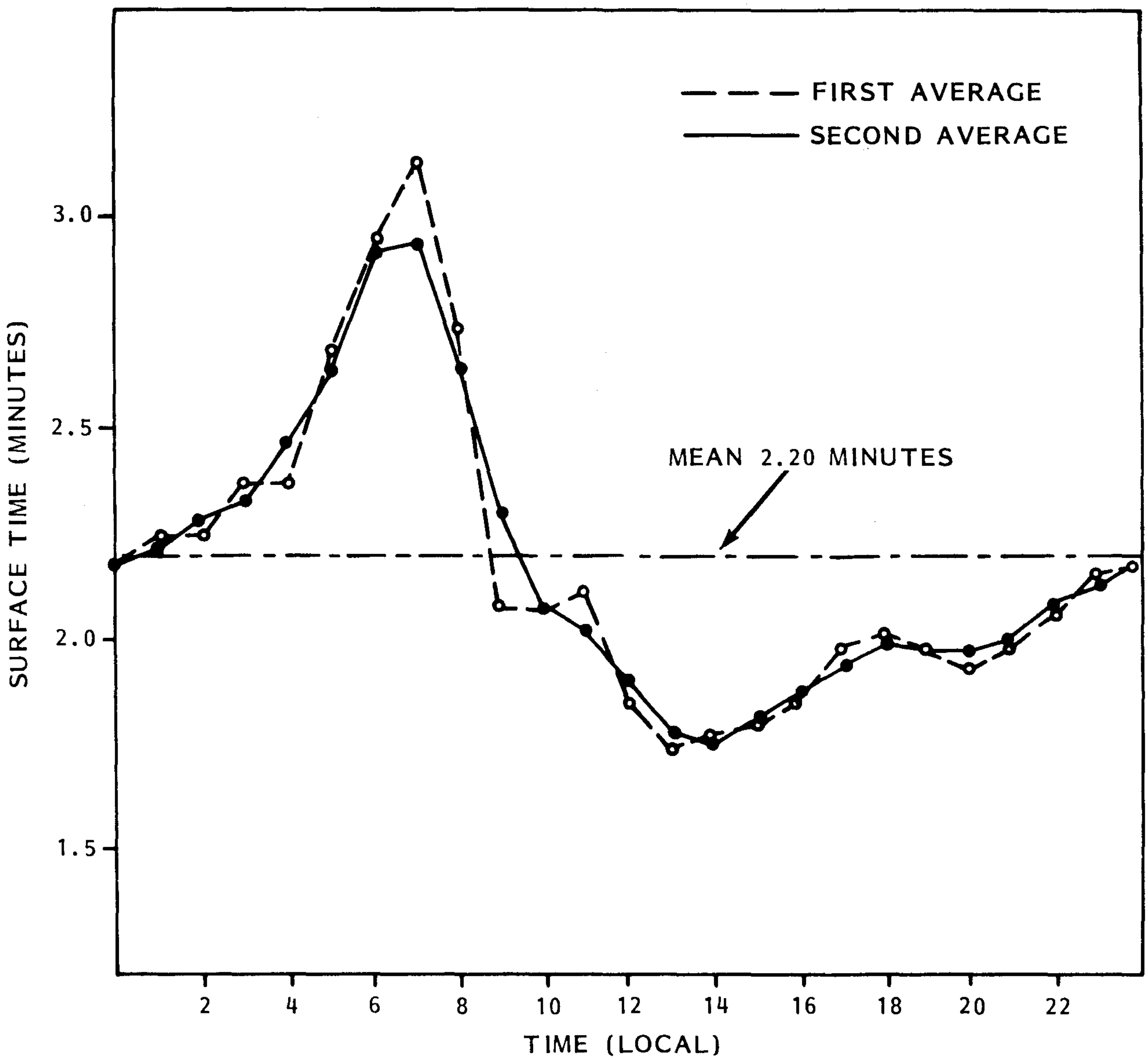

Figure 25. Time averaged diurnal surfacing periods (surface time per surfacing) of loggerhead sea turtles. Averaging done by combining data from adjacent hours on either side of a given hour with data from that hour. Second averaging done in a similar way, but with averaged results from the first averaging. (N = 732; data from first 3 days of the experiment omitted).

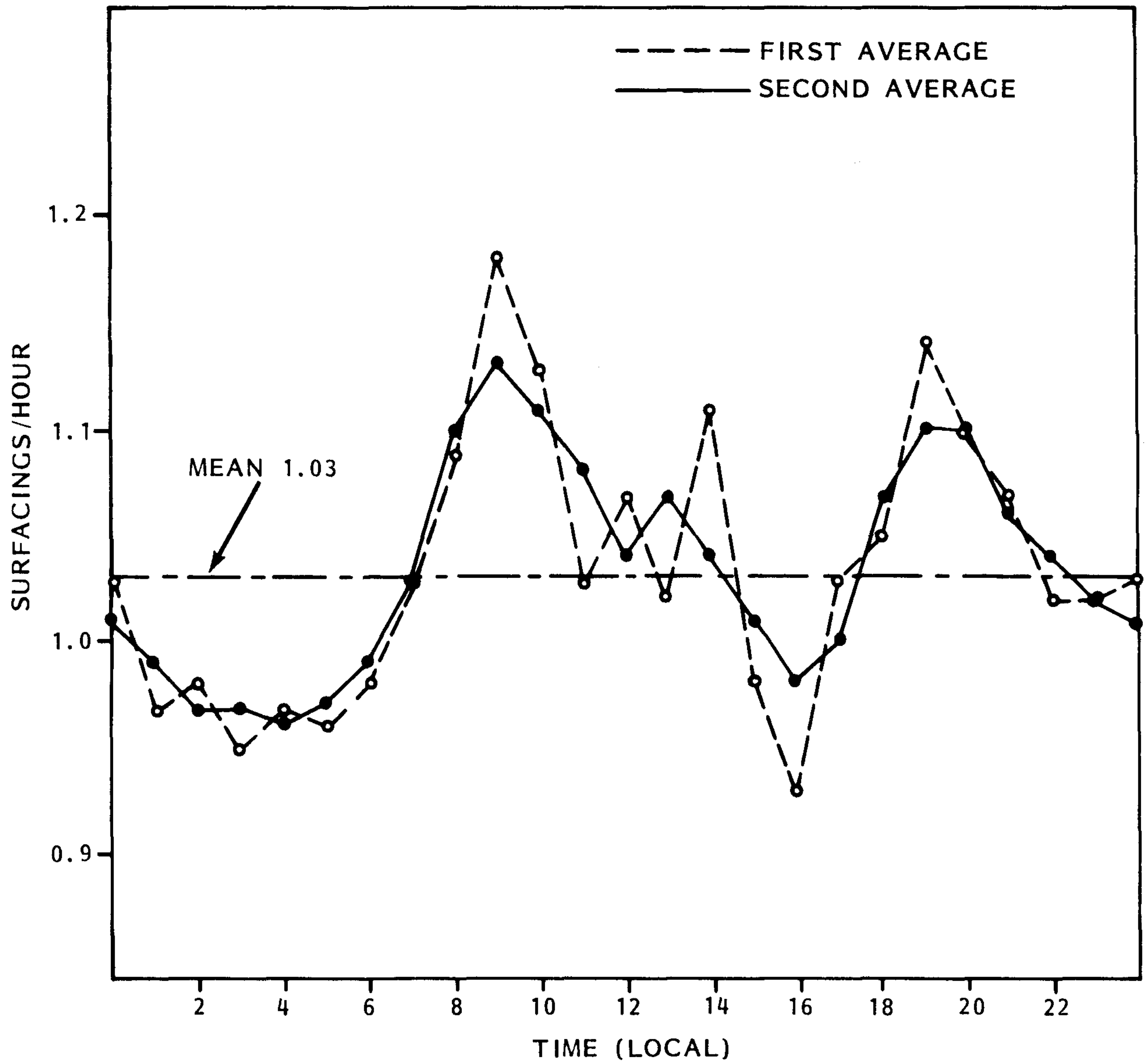

Figure 26. Time averaged diurnal surfacing patters (surfacings/hour) of loggerhead sea turtles. Averaging done by combining data from hours on either side of a given hour with data from that hour. Second averaging done similar to the first, but with averaged results from the first averaging. Data from first 3 days of experiment omitted.

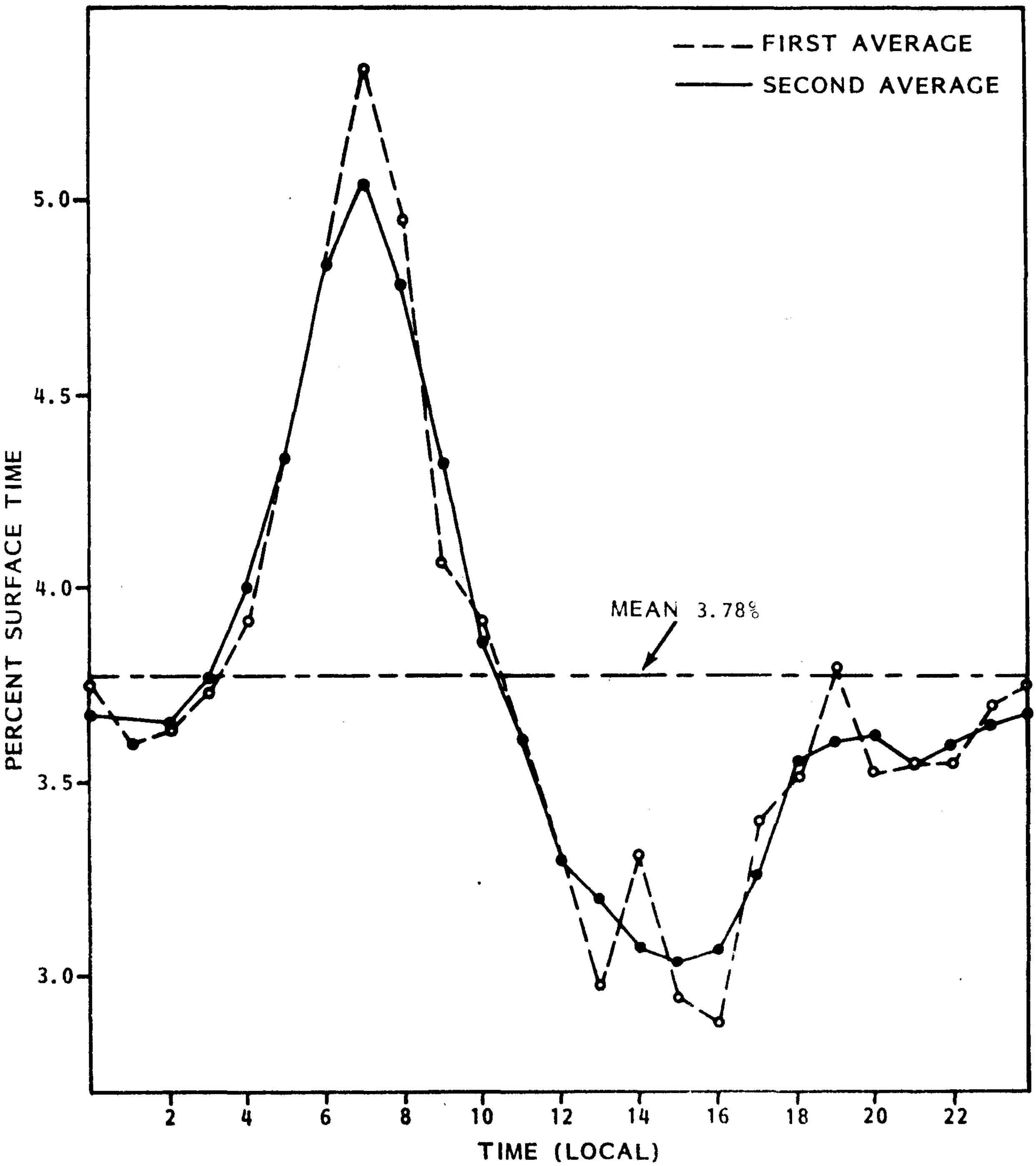

Figure 27. Time averaged diurnal surfacing pattern (percent surface time) of loggerhead sea turtles. Averaging done by combining data from adjoining hours of an hour with data from that hour. Second average done similar to first, but with average values from the first averaging (N = 712; first 3 days omitted).

SUMMARY AND CONCLUSIONS

A 20-day experiment was conducted in and near Canaveral Channel, Florida, beginning on September 19, 1981, to monitor movement and surfacing behavior patterns of loggerhead sea turtles. Movements were determined by radio and acoustic tracking with neither of the approaches giving very satisfactory results. Radio tracking was limited by very short and infrequent periods spent by the turtles on the surface. Acoustic tracking was limited by the relatively short detection range of the transmitters (approximately 0.5 km) due presumably to high ambient noise levels and excessive turbidities. Studies to monitor and characterize surfacing patterns of the turtles were much more successful with six turtles being monitored periodically during the experimental period. These studies depended on a continuous monitoring radio receiver positioned adjacent to the study area.

Probably the most significant finding from the radio and acoustic tracking studies was that at least 8 of the 10 turtles captured in the Canaveral Channel and released at a spoil site approximately 8 km south of the channel returned to the channel. All 8 of the turtles returned within 13 days with an average minimum return time of 7 days. Additionally, observations during the acoustic tracking portion of the studies indicated that at least some of the turtles appeared to react to the approach of the tracking vessel.

Results from the continuous monitoring portion of the experiment suggested a period of about 3 days was needed for captured, tagged, and released turtles to normalize their surfacing behavior patterns. The mean time spent by a turtle during a surfacing was 2.20 ±0.13 min (95% confidence limits). The turtles surfaced an average of 1.03 ±0.04 (95% confidence limits) times an hour and spent an average of 3.78 ±0.27% (95% confidence limits) of their time at the surface. A trend analysis suggested a diurnal periodicity in all three of the behavior parameters with pronounced peaks in surfacing activity occurring near and shortly after dawn. The lows in surfacing behavior activity normally appeared to occur near mid-afternoon.

Recommendations from the experiment are that future radio tracking studies should consider development of a receiver system capable of detecting and locating a surfacing turtle within 2 minutes. Ideally, this system should be usable from an aircraft. Future acoustic tracking studies need to consider approaches to increase detection range such as lower frequencies and greater transmitter power, as well as a change in tracking tactics. The continuous monitoring portion of the experiment was relatively successful, but significantly greater success probably could be achieved if additional methods to reduce effects on ambient noise and provide an indication of transmitter location had been applied. Examples of these methods include greater and stabilized transmitter power, the use of reference transmitters, monitoring of signal amplitude as an indicator of range, and multiple directional antennas to gain estimates of transmitter bearings.

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