BULLETIN OF MARINE SCIENCE, 55(l):I-15, 1994

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ABSTRACT

Four loggerhead sea turtles, ranging from 56 to 93 cm in straight carapace length and from 28 to 98 kg in weight, were released in 18- to 78-m water depths and tracked for periods of 5.0 to 10.5 months in the Gulf of Mexico. Home ranges extended from 954 to 28833 kM2 while core areas varied from 89.6 to 4,279 kM2. Core areas included several petroleum and gas structures that may have been visited on a daily, weekly or monthly basis. Average submergence times of loggerheads ranged from 4.2 min in June to 171.7 min in January. The number of submergences per day was inversely proportional to the duration of submergences per day. Loggerheads spent, on the average, over 90% of their time under water in any given season. Bottom depth location of the loggerheads was significantly correlated to Galveston's mean air temperature ($-0.56 < r < 0.28$) and mean sea surface temperature ($-0.72 < r < 0.25$). Correlation was higher ($-0.58 < r < 0.60$) when temperatures were regressed against distance from shore. Mean swimming speeds of these loggerheads were from 0.4 to 1.4 km/h, with over 95% of the values <5 km/h.

Five species of endangered or threatened sea turtles inhabit the Gulf of Mexico and Atlantic Ocean. These are the Kemp's *ridley,(Lepidochelys kempii), green (Chelonia mydas), hawksbill (Eretmochelys imbricate) leatherback (Dermochelys coriacea)* and loggerhead *(Caretta caretta).*

Loggerheads, the most abundant of these species, are distributed across continental shelves and estuaries of the Pacific, Atlantic and Indian Oceans. Their geographic range extends from waters off Newfoundland in the north to Argentina and Chile in the southern hemisphere. Nesting is concentrated in the temperate zones and subtropics. It is thought that hatchlings spend 3-5 years (Carr, 1986) in association with floating *Sargassum* mats, feeding on macroplankton, gastropods, small fish and *Sargassum.* Juveniles, <40 cm straight carapace length, are oceanic and subsequently move into estuaries and shallow coastal regions as subadults (Dodd, 1988). They feed on a wide variety of benthic fauna including but not limited to, crabs, barnacles, mollusks and gastropods. Subadults of various ages venture offshore into deeper waters where they mature at an age of 12-30 years (Frazer and Ehrhart, 1985) before returning to their nesting ground to mate. Water temperature, currents and general weather patterns may effect the distribution of these animals.

The movements and migrations of loggerheads have historically been pieced together through flipper tagging studies accompanied by the opportunistic recapture of these animals. Carr (1962), however, followed the migration of six mature female loggerheads off Cedar Keys, Florida, for periods of less than a day, using helium-filled balloons with monofilament line attached to the turtles' shells. More recently, Stoneburner (1982) tracked eight loggerheads off Cumberland Island, Georgia using satellite telemetry. His data support the theory of directed movement of these turtles into estuaries and possibly offshore to feeding grounds. Both satellite and radio telemetry were used to track the movement of a single loggerhead along the Mississippi, Louisiana and Texas coastlines (Timko and Kolz, 1982). Standora et al.

(1979) in Costa Rica, and Dizon and Balazs (1982) in Hawaii have tracked green sea turtles using radio and sonic telemetry. Standora et al. (1984) used radio telemetry to monitor the movements, diving cycles and internal temperature changes of a leatherback turtle off Newport, Rhode Island.

To efficiently manage sea turtles we must understand their life histories and determine their stage specific distributions. A survey of the literature revealed that substantial information is available on nesting, reproductive biology, and geographic ranges of sea turtles. Comparatively, knowledge on the movement and diving cycles of loggerhead and other sea turtles is scant and published mostly in gray literature.

The objective of this research was to characterize long term movement and submergence patterns of loggerheads using satellite telemetry, and to initiate the development of a database to make these behaviors more predictable.

METHODS

Sea Turtle Capture.---Four loggerhead sea turtles, sleeping adjacent to pilings of gas/petroleum structures, were captured in the Gulf of Mexico during SCUBA diving operations (15-78 m) from November 1988 through June 1990. They were placed into mesh bags (2.5-cm bar mesh, 1.3 X 1 m; Fig. 1A) with a 1-m diameter mouth opening and brought directly to the sea surface. Hinged bag openings were supported by polyvinyl chloride tubing (PVC, 1.8 to 2.5 cm diameter) or aluminum conduit (2.5 cm diameter).

Description and Application of Satellite Transmitters.---The satellite transmitter (Platform Transmitter Terminal or PTT) was packaged by Telonics Inc.[1] in a polycarbonate casing with a rectangular base plate extending one cm around the transmitter casing. An antenna, 15 cm in length, was located near the anterior portion of the PTT (Fig. 1B). The entire package weighed approximately 820 g in air and measured 14 cm X 8 cm X 5 cm. A PTT was attached above the second neural scute of each sea turtle. PTTs for three sea turtles were attached with resin and fiberglass cloth (Fig. 1B). The fourth PTT was secured with galvanized wires attached to holes in each corner of the PTT base plate and to bone screws secured in the edge of the sea turtle's carapace (Fig. 1C).

Data Description.---Service Argos Inc. (SAI)[2] provided the following information for each transmission: 1) PTT identification number, 2) latitude and longitude of PTT, 3) class location index, 4) date and time of PTT transmission, 5) date and time of the previous PTT location, and 6) the number of transmissions used to calculate a PTT position fix.

The number and average duration of turtle submergences were computed from 0800-1959 (day) and 2000-0759 (night) local time by the PTT with the use of a salt water switch located on the tag. PTTs were programmed to disregard submergences $\leq$ 10 seconds to prevent the accumulation of spurious submergences and submergence durations caused by water splashing on the salt water switch. Submergence depth was not monitored by the PTT. Battery power of the PTT was conserved by not transmitting when the tag was under water. Duration of the last submergence and PTT temperature were provided at the time of each PTT transmission. All data were transmitted (401.65 Mhz, 50-s pulse interval) for 6-h periods, every other 6h for 5.0 and 10.5 months. Turtles were allowed 2 weeks to accustom themselves to carrying a PTT in the natural environment before data were used for analyses.

Distribution of Turtle Positions.---Turtle distribution was portrayed through various computer mapping programs. An IBM compatible home range program developed by Ackerman et al.[3] was used to develop minimum convex polygon home ranges. The home range during the study period was considered to be the area enclosing 95% of a turtle's locations. Locations outside this area were not utilized in order to exclude potential outliers in the data set. The core area was defined as the area encompassing 50% of a turtle's locations. One turtle displayed a concentrated use of three distinct areas. Since the 50% minimum convex polygon did not reflect this multimodal distribution, a 50% core area was generated using the harmonic mean method and is included in the home range map of that turtle (Fig. 2).

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[1]Telonics Inc., 932 E. Impala Ave,., Mesa, Arizona.. 85285-6699.
[2]Service Argos Inc. 1801 McCormick Drive, Suite 10, Landover, Maryland 20785, 256 p.
[3]Ackerman, B. B., F A. Leban, M. D. Samuel and E. O. Garton. Department of Wildlife, University of Idaho, Moscow, Idaho 83843.

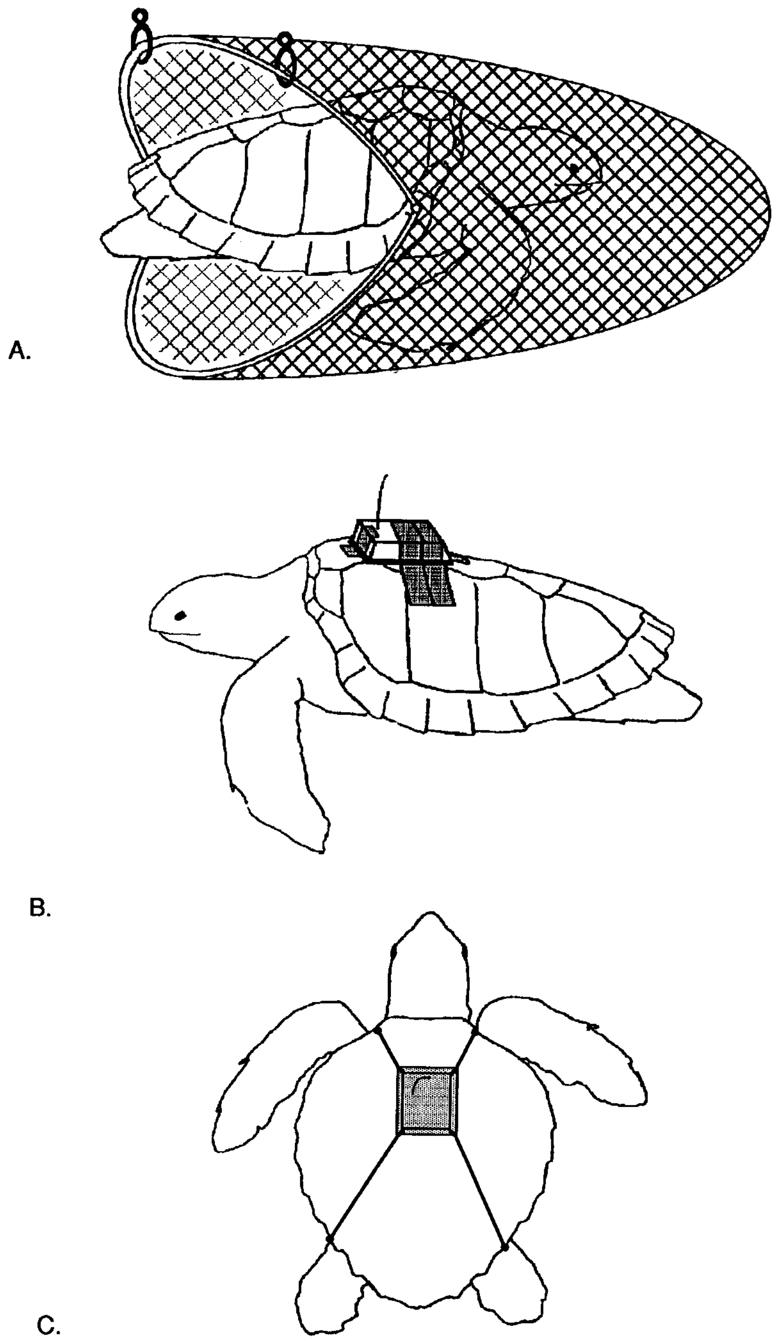

Figure 1. Schematics of loggerhead sea turtles A) in capture net, B) with PTT attached to sea turtle shell with resin and fiberglass cloth and C) with PTT wired to sea turtle shell.

Distribution of Swimming Velocities.----Distance between consecutive locations was calculated for each sea turtle. Using the time intervals between locations, swimming speed was estimated in km/h.

Submergence Behavior.---The number of submergences, average submergence time, percent of time spent under water and PTT temperature were analyzed by season for individual and all loggerheads combined, using analysis of variance with alpha set at 0.05. Duncan's Multiple Range Test was applied to determine significant differences among data cells. For analytical purposes, seasons were defined as winter (December-February), spring (March-May), summer (June-August) and fall (September-November).

It is understood that serial correlation can occur in time series observations. Present behavior is influenced by past behavior. Serial correlation should decrease as the time interval increases, until an interval is reached in which correlation is insignificant. The level of serial correlation for behavioral variables was determined using stepwise multiple regression at progressive time intervals, until an interval was reached in which all correlation was insignificant at $P = 0.05$. This interval was found to be 5 days. Since data were grouped by season for analysis of variance the effect of serial correlation was considered to be negligible.

Correlations with Temperature and Depth.---Linear regressions were computed using air and sea surface temperatures (National Weather Service Monitor at Pier 25, Galveston, Texas) plotted against bottom depth and distance from shore for each turtle location. Since temperature might have more influence on movements during cooler months, separate regressions were calculated using data from November through February. Kendall's tau, used for small sample sizes, was determined in addition to Pearson's r for samples of $N < 60$.

RESULTS

Four loggerhead sea turtles, ranging from 56 to 93 cm in straight carapace length and from 28 to 98 kg in weight, were released in 18- to 78-m water depths in the Gulf of Mexico and tracked for periods of 5.0 to 10.5 months (Table 1). The first sea turtle (L1) was released in June 1989 and the last recorded transmission was from sea turtle L4 in January 1991. Mean bottom depth for sea turtle locations ranged from 13 to 72 m (Table 2). Water depths were similar for loggerheads L2, L3 and L4 (15-16 m) while sea turtle L1 was in water >65 m. Mean distance from shore ranged between 49 and 54 km for L2, L3 and L4, and up to 169 km for L1.

PTT Life and Failure.---Battery life of PTTs was estimated to be 1 year by TeIonics Inc. This assumed turtles spent at least 95% of their time under water. Since PTT life did not exceed 10.5 months it is believed that 1) PTT battery life was reduced because turtles spent less than 95% of their time under water or 2) PTTs became dislodged from the turtles.

It is likely that variability in individual behavior of the loggerheads accounted for differences in PTT battery drainage, and the observed 5.5 month range in PTT transmissions. One PTT, used experimentally prior to its placement on L4, had a reduced life expectancy of 6 months. This PTT did last 5.0 months.

Under offshore environmental conditions, PTTs attached with epoxy and fiberglass cloth transmitted from 5.0 to 10.5 months. L1's PTT, secured with galvanized wire, transmitted for 8.5 months. LI was sighted 9 months later with the PTT still mounted on the turtle's back.[4] Although PTT detachment in the offshore environment is possible, it was not considered a major problem. Loggerheads are

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[4]Personal Communication, Mike Parker, Exxon Oil Company, PO. Box 60606, New Orleans, Louisiana 70160.

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Figure 2. Estimated home ranges and core areas for turtles tracked from June 1989 through January 199 1. Solid lines: core area (minimum convex polygon). Dashed lines: home range (minimum convex polygon). Gray shaded lines: core area (harmonic mean).

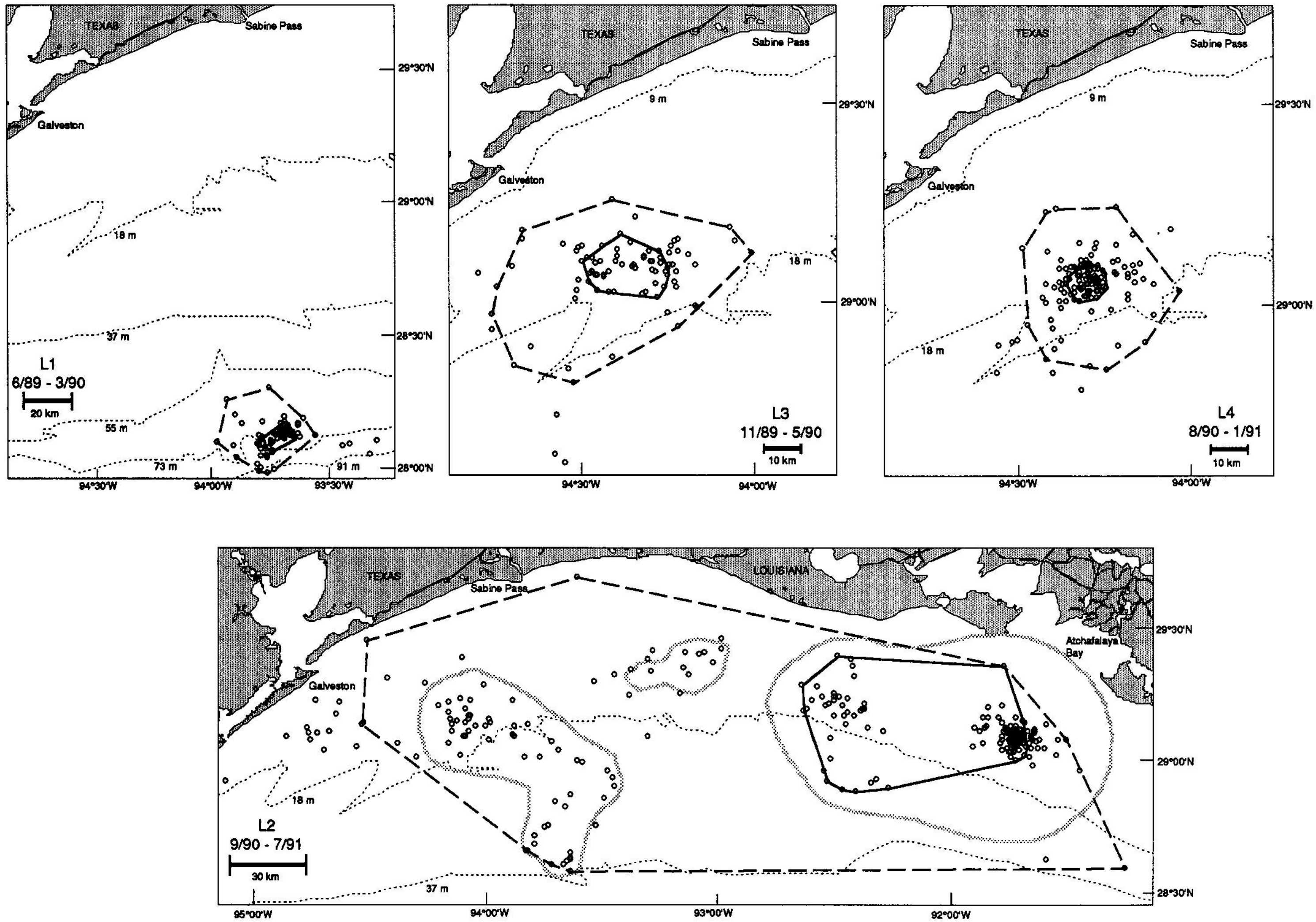
TEXAS
Sabine Pass
Galveston
29°30'N
29°00'N
28°30'N
28°00'N
18 m
37 m
55 m
73 m
91 m
L1
6/89 - 3/90
20 km
94°30'W
94°00'W
93°30'W
9 m
L3
11/89 - 5/90
10 km
L4
8/90 - 1/91
LOUISIANA
Atchafalaya Bay
L2
9/90 - 7/91
30 km
95°00'W
93°00'W
92°00'W

Table 1. Information on the capture and release dates and locations, lengths and weights, for loggerhead sea turtles tracked in the Gulf of Mexico

Sea turtle	Capture date location and water depth	Release date location and water depth	Last date location and water depth	Straight carapace length (cm)	Weight (kg)
L1	10 Nov 1988 28°05.7′N 93°46.2′W 72-m depth	20 Jun 1989 28°03.1′N 93°19.9′W 78-m depth	10 Mar 1990 27°54.2′N 94°27.8′W 110-m depth	75	69.1
L2	31 Aug 1989 29°07.5′N 94°04.4′W 18-m depth	03 Sep 1989 29°07.5′N 94°04.4′W 18-m depth	20 Jul 1990 29°04.2′N 91°51.6′W 13-m depth	56	27.6
L3	08 Oct 1989 29°03.7′N 94°16.1′W 18-m depth	21 Oct 1989 29°03.7′N 94°16.1′W 18-m depth	02 May 1990 29°03.3′N 94°13.6′W 16-m depth	93	97.7
L4	06 Jun 1990 29°08.2′N 94°12.4′W 11-m depth	15 Aug 1990 29°03.7′N 94°16.1′W 18-m depth	01 Jan 1991 28°56.2′N 94°23.9′W 18-m depth	62	31.8

known to wedge themselves into confined areas near gas and petroleum platforms. This type of behavior could result in the detachment of a PTT.

PTT malfunctions lead to erroneous data transmissions prior to the total shut down of a tag. This was not observed and no PTT was considered to malfunction during this study.

Distribution of Turtle Locations.—The maximum distance travelled by a loggerhead from its capture site was 290 km by L2. Distances for L1, L3 and L4 were 90, 60 and 35 km respectively. The latter three turtles returned to, or within 1 km of their capture site after being at these max distances. L2 relocated to Louisiana and never returned to Texas during the study period.

L1, tracked from 20 June 1989 to 3 March 1990, was released on an artificial reef 24 km to the east of its original capture site. It returned to its capture site in 17 days, and spent the next 6 months within an 8 km radius of that point (Fig. 2). Its core area, approximately 98.2 km^2, included approximately 125 platform structures. Overall home range encompassed 954 km^2. During the last 3 months of tracking, L1 moved 115 km to the west but was sighted 9 months later within 8 km of its capture site. Renaud et al.[5] found similar homing behaviors from green

[5] Unpublished data. Renaud, M. L., J. A. Carpenter, S. A. Manzella, and J. A. Williams. 1993. Telemetric tracking of Green Sea Turtles (*Chelonia mydas*) in Relation to Dredged Channels at South Padre Island, Texas July Through September 1992. Final Report to U.S. Army Corps of Engineers (Galveston and New Orleans Districts). 55 p.

Table 2. Sea turtle weights, average bottom depths and distance to shore of all sea turtle locations and for November through February (N = number of locations received from the satellite)

Turtle	Wt (kg)	N		Depth (m)		Distance (km)	
		All months	Nov–Feb	All months	Nov–Feb	All months	Nov–Feb
L1	69	71	9	72	63	169	153
L2	28	83	41	16	17	49	50
L3	98	215	53	13	19	49	65
L4	32	134	53	15	16	54	54

Table 3. Frequencies of swimming speeds by loggerhead sea turtles. Numbers may sum to more than 100% due to rounding errors (N = number of locations used to determine speed between points)

Sea Turtle	N	Swimming speeds in km/h <1	1.1 to 5.0	5.1 to 10	>10.0
LI	71	91.7	8.3	0.0	0.0
L2	233	73.4	24.5	1.3	1.0
L3	132	83.6	13.0	3.5	0.0
L4	85	64.4	29.6	4.6	*1.5*

sea turtles *(Chelonia mydas)* at rock jetty habitats in south Texas. Green sea turtles exhibited a diel periodicity with respect to night resting spots. Although home range was up to 1,300 m, turtles always returned within 10 m of night resting spots at the end of the day.

L2 was tracked for 10.5 months (9 September 1989 to 20 July 1990) and exhibited more movement than any other sea turtle. Initially this sea turtle spent 97 days mostly within 8 km of its release site. However, in December 1989, L2 apparently responded to cold front by moving further offshore in search of warmer water. A severe cold front stalled in the Houston, TX region for 2 weeks with sub-freezing air temperatures, as low as –10^{o}C, during 72 consecutive h. Mean water temperatures (as transmitted by PTIS) 48 km offshore of Texas dropped over 6^{o}C in less than a week. After the cold front passed, this sea turtle did not return to its release site but moved east into waters off Louisiana spending 39, 46 and 58 days in three different locations off of the Louisiana coast before the PTT stopped transmitting data (Fig. 2). The home range for this turtle included 28,833 km^2. Core area covered 4,279 km^2. Over 100 gas or petroleum structures were within each of the four subareas of L2's core.

L3, tracked for 6.5 months (21 October 1989 to 2 May 1990), remained for all practical purposes within 8 km of its capture and release site off Galveston, Texas (Fig. 2). It was sighted, with the PTT still attached, by recreational divers and personnel on oil company vessels at its capture site 10 months following its release. Home range and core area encompassed 2,408 and 309 km2 respectively.

Movement of L4 was monitored for 5.0 months, 15 August 1990 to 11 January 1991. Aside from excursions to the south of its release site during the first 2 weeks following release, L4 also remained within 8 km of its release site (Fig. 2). It was seen during radio tracking studies and also by personnel on oil company vessels at its release site during the 5.0 month tracking period. Extent of home range, 1,435 km^2, and core area, 89.6 km^2 were similar to that of L3.

Distribution of Velocities.---Location information was collected for these sea turtles 522 times. Mean swimming speeds for turtles ranged between 0.4 and 1.4 km/h. Velocities between consecutive locations ranged from 0.02 to 22.2 km/h (Table 3). Speeds values were $\leq$5.0 km/h 100%, 97.9%, 93.9% and 96.5% of the time for L1, L2, L3 and L4 respectively. Speeds in excess of 10 km/h were calculated twice for L2 and twice for L4. It is important to note that inherent errors in these speeds may be due to 1) the assumption of continuous straight line movement, 2) class location index error and 3) consecutive surfacings being out of satellite view. Sea turtles may swim short distances, sleep, or backtrack toward their earlier surface location before surfacing again. Therefore, actual swimming speeds of these turtles are probably higher.

Table 4. Mean values for the number of dives, average dive time, percent of time during spent under water and PTT temperature for 12-h day or night periods, by sea turtle by season (a dash no data available)

Sea Turtle		Winter	Spring	Summer	Fall
L1	Sample (N)	4/6	---/---	17/13	11/25
	No. dives	159/31	---/---	29/23	17/16
	Ave. dive	65/53	---/---	26/39	51/60
	Pct. under	82/88	---/---	86/92	88/93
	Temp. ^{o}C	22/25	---/---	29/28	28/28
L2	Sample (N)	12/37	41/53	28/30	22/33
	No. dives	44/4	103/38	273/148	74/24
	Ave. dive	71/209	19/42	3/5	22/61
	Pct. under	85/96	93/93	92/88	96/95
	Temp. ^{o}C	18/19	25/25	32/32	27/27
L3	Sample (N)	22/16	28/30	---/---	13/9
	No. dives	9/5	16/17	---/---	16/29
	Ave. dive	96/178	49/50	---/---	53/36
	Pct. under	95/97	94/91	---/---	95/94
	Temp. ^{o}C	26/26	29/29	---/---	29/30
L4	Sample (N)	9/22	---/---	1/3	51/66
	No. dives	85/24	---/---	79/31	76/31
	Ave. dive	29/80	---/---	9/26	17/28
	Pct. under	94/96	---/---	96/96	94/94
	Temp. ^{o}C	18/19	---/---	31/32	27/28

Submergence Behavior.---Number of submergences, average submergence time, and percent of time spent submerged per 12-h period were significantly different by season for individual and all four animals combined (Table 4). The data set for all turtles combined covered all months of the year. All text data are presented as mean ± standard error. These loggerheads had the lowest number of submergences in winter (1 1.9 ± 3.4/night and 45.1 ± 12.0/day) and highest number in summer (80.4 ± 9.3/night and 178.8 ± 22.6/day). Mean number of submergences for the spring was 74.3 ± 11.4 (day) and 30.6 ± 4.7 (night), and 60.5 ± 5.3 (day) and 26.2 ± 1.9 (night) in the fall. Turtles made significantly more submergences during the day than the night in all seasons (Fig. 3A).

Duration of submergence was inversely proportional to the number of submergences made during any given period. Average submergence time (AST) during 12-h day or night periods was calculated by the PTT The mean AST was shortest in the summer (11.6 ± 1.8 min/day and 23.0 ± 2.7 min/night) and longest in the winter (74.0 ± 9.0 min/day and 156.4 ± 11.8 min/night). Mean AST for the spring was 29.8 ± 3.3 min/day and 44.7 ± 3.4 min/night. In the fall mean AST was 26.7 ± 2.8 min/day and 42.9 ± 2.9 min/night. Turtles made significantly longer submergences during the night in all seasons (Fig. 3B).

Total submergence time (the number of submergences per 12-h period multiplied by the AST for that period) was used to calculate the percent of time a sea turtle spent under water. By season, total submergence time ranged from a mean of 90.0 ± 0.6% during summer days to a mean of 95.3 ± 0.6% in winter nights (Fig. 3C).

Individual sea turtles exhibited varied submergence patterns. Mean values for number of submergences, average submergence time, and percent of time spent submerged are summarized by season for each sea turtle in Table 4. Extremes for the mean number of submergences per 12-h period were 8.5 ± 0.8 (L3, Winter)

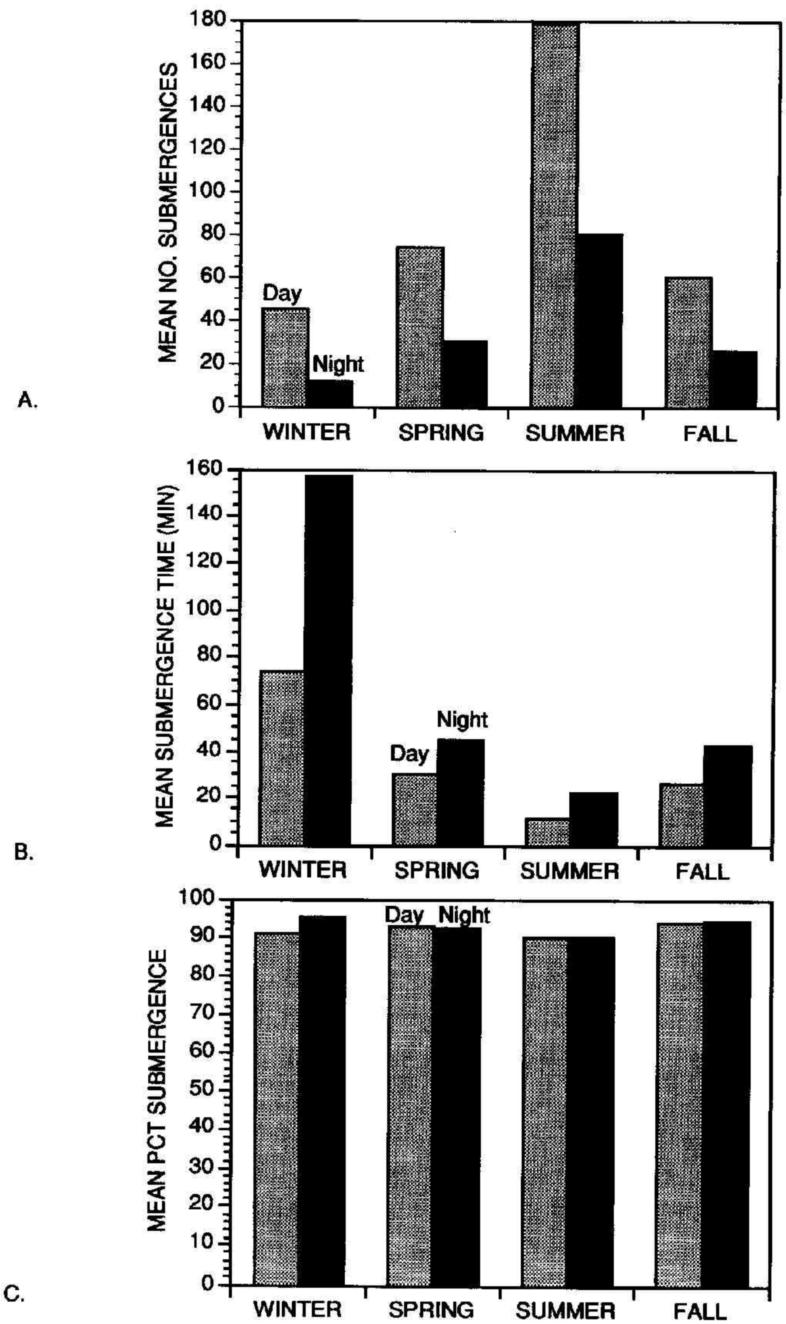

Figure 3. Mean A) number of submergences, B) duration of submergences and C) percent submergence by day, night and season pooled for 4 loggerhead turtles. Significant differences ($P \leq 0.05$) existed between day and night values for the mean number of submergences and mean duration of submergence.

Table 5. Pearson's r and Kendall's tau (*) for Galveston air and sea surface temperature against location bottom depth and location distance from shore (n = no significant correlation at *P* = 0.95).

		All months		Nov though Feb		
Sea Turtle		Depth	Distance	Depth	Distance	
LI	Air temp	0.28	0.57	0.42n	0.70	*r*
				0.22n	0.61	*
	Water temp	0.25	0.60	0.49n	0.81	*r*
				0.22n	0.61	*
L2	Air temp	-0.66	-0.54	-0.41	-0.61	*r*
				-0.32	-0.43	*
	Water temp	-0.72	-0.58	-0.74	-0.90	*r*
				-0.49	-0.71	*
L3	Air temp	-0.32	-0.45	-0.23n	-0.53	*r*
				-0.14n	-0.40	*
	Water temp	-0.46	-0.52	-0.44	-0.71	*r*
				-0.12	-0.50	*
L4	Air temp	-0.08n	-0.05n	-0.12n	-0.52	*r*
				-0.08n	-0.31	*
	Water temp	-0. I In	-0.08n	-0.13n	-0.40	*r*
				-0.15n	-0.42	*

to 273.1 ± 23.2 (L2, Summer) during the day and 4.4 ± 0.4 (L2,Winter) to 148.4 ± 11.0 (L2, Summer) during the night. Mean ASTs ranged from 3.1 ± 0.4 min (L2, Summer) to 95.9 ± 8.7 min (L3, Winter) in the day and 5.1 ± 0.4 min (L2, Summer) to 209.1 ± 17.6 min (L2, Winter) at night.

Correlations with Temperature and Depth.----Air and sea surface temperature likely influence sea turtle movements. Significant correlation of Galveston's mean air and sea surface temperatures against bottom depth for L1 were 0.28 and 0.25 respectively. Correlation was higher (r = 0.57 and 0.60) when air and sea surface temperatures were regressed against distance from shore. Restricting the analysis to November through February increased the revalue for every combination (Table 5). All correlations of mean Galveston temperature against bottom depth or distance from shore were negative and significant (r = -0.54 to -0.72) for L2 for its entire tracking period. From November through February, r-values increased for all comparisons except mean Galveston air temperature against bottom depth (Table 5). Use of Kendall's tau reduced correlations, but they remained significant.

Correlations were significant and negative for mean Galveston air (r = -0.32) and sea surface temperature (r = -0.46) against bottom depth for L3 (Table 5). Higher correlation coefficients were present for Galveston's air and sea surface temperatures against distance from shore, -0.45 to -0.52 respectively. Restricting the data set to the months of November through February lowered the revalue for bottom depth correlations and increased the r-values for the distance from shore correlations. All correlations remained significant except mean Galveston air temperature against bottom depth. Analyses using Kendall's tau reduced correlations for all combinations. Correlations with bottom depths were no longer significant.

There were no significant correlations for mean Galveston air or mean sea surface temperature against distance from shore or bottom depth of location for L4 over the full tracking period (Table 5). This sea turtle exhibited the least movement of the four loggerheads. When restricting the analysis to the months of November through February, significant correlations were present between daily mean Galveston air temperature (r = -0.52) and sea surface temperature (r -0.40) against distance from shore. Similar significance and correlation parameters were obtained using Kendall's tau.

The internal temperature of a PTT is a good estimator of ambient water temperature. PTT temperature was relayed with the submergence information during each PTT transmission. Mean ambient day and night temperatures were not statistically different during any season with the exception of winter for L1 and L2. In both instances night temperature was higher than day temperature. However, mean seasonal PTT temperatures were all significantly different from each other. Hottest mean temperatures occurred during the summer and fall from May through October (25.9^{o} to 31.7^{o} C) with August having the highest values. Cooler mean temperatures ranged from (18.6 ^{o} to 21.9 ^{o} C) from November through April with February having the lowest values. Mean temperatures ranged from 21.2^{o} in the winter to 30.5^{o}C in the summer.

DISCUSSION

Satellite telemetry has been used to track animals since the early 1970's. Craighead et al. (1972) were the first to monitor animals (elk, *Cervus elaphus),* using satellite telemetry. Since then, birds (Keating et al., 1991; Priede and French, 1991), fish (Priede, 1984), polar bears (Fancy et al., 1988), seals (McConnel, 1986), manatees (Mate et al., 1986, Mate et al., 1988), deer (Clute and Ozoga, 1983), whales (Mate, 1984), dolphins (Jennings and Gandy, 1980), and sea turtles (Byles 1989a, 1989b; Byles and Dodd, 1989; Daniel, 1980; Gitschlag et al., 1992; Hays et al., 1991; Keinath et al., 1989; Stoneburner, 1982; and Timko and Kolz, 1982) have been tracked successfully using satellite telemetry.

Technology of telemetric animal tracking with PTTs evolved rapidly with the increased needs of biologists. Early prototypes transmitted only geographic position. It is now possible to monitor physiological (body temperature, heart rate) behavioral (diving information, activity patterns) and ecological (air temperature, water depth and altitude) data. PTTs are especially effective for gathering information on animals that cannot be easily observed or captured. This methodology is a valuable tool for studying animals, although it is not without drawbacks.

Cost Constraints.-----Although the investment for a PTT and a year of data may reach $8,000, use of satellite tags is cost effective, even over periods as short as 3 months. PTTs eliminate the high cost of research vessels and around-the-clock manpower requirements.

Accuracy of Turtle Locations.-----The accuracy of latitude and longitude calculations by the satellite is dependent on the number and temporal spread of transmissions received by a satellite, as well as, the angle to the satellite from the PTT. SAI has modelled these parameters and arrived with a class location index (CLI) assigned to each calculated latitude and longitude. The CLIs determine the 95% confidence area for calculated latitudes and longitudes. Circular confidence areas have radii of 150 m, 350 m and I km for CLI-3, CLI-2 and CLI-1, respectively. SAI set no limits of accuracy for CLI-0.

Limitations.---The PTT of marine animals must be on the water's surface for approximately 4 min or at several different times during the 7-min satellite pass to get a class 3 location index (± 150 m). It is rare for loggerheads to be on the surface for more than 2 to 3 consecutive min or to surface several times as mentioned above, so most of the locations received during this study were class 0 and have an error of $\pm$ I km. One must decide if these location data are acceptable for research on sea turtles, keeping in mind that location is not the only information programmed into a satellite tag. PTTs typically need only one unlink with a satellite to transfer behavioral, physiological or environmental information. These data may be more important than location accuracy as long as one knows the general area of the PTT.

Verification of Data.----PTTs transmit data accumulated from on-board computers. Although tested by the manufacturer, there is no way to verify data transmissions once a PTT has been deployed. On our tags, a fail-safe code signifies the inactivity of the saltwater switch over a 24-h period. This flags possible inconsistencies in the data stream. One may choose to disregard the data for such a transmission.

If you are receiving submergence information from a PTT you can be certain that your animal is still alive. However, if you are no longer receiving information from the PTT, then the tag has either used up its battery life, totally malfunctioned or fallen off the experimental animal. It is also possible that the animal has died and sunk to the bottom. Satellites cannot receive transmissions from PTTs under salt water. There is no way to tell which of the above scenarios occurred. On the other hand, if you continually receive transmissions from the PTT without updated submergence information, the animal may be floating dead at the surface, stranded on the beach, or perhaps someone has obtained the tag and it is sitting outside transmitting. In any case, data from PTTs were not verified. One must have confidence in the PTT manufacturer and the limits of the positions that are calculated for you.

Tag Types.-----Two models of PTT are presently available for sea turtles: the backpack model and the trailing model. Each has advantages and disadvantages dependent on the habitat occupied by the animal. Standora et al. (1979, 1984, 1989, and 1990), Byles (1988) and Byles and Dodd (1989), Timko and DeBlanc (1981), Timko and Kolz (1982) and Stonebumer (1982) have utilized trailing tags to monitor sea turtle movements. Trailing tags, secured to the shell with bolts and cables, can last up to two years. This can be a problem, however, if the tag becomes snagged underwater. A weak link in the cable or cable attachments will allow the tag to break free and prevent an entangled animal from drowning. Trailing transmitters are effective in open water environments without underwater obstructions.

More recently, Telonics Inc.[1] and Byles[6] have developed a low profile, compact backpack PTT with minimal drag that can be fiberglassed to the turtle's carapace. This method of tag attachment has been used successfully with radio and satellite tags by Byles, 1989b; Renaud et al., in press, Renaud et al.[5], Manzella et al., 1990; Stewart et al., 1989. No adverse effects of backpack tags on sea turtle behavior have been noted, either in the laboratory or the field (Renaud et al., in press). Tags fiberglassed to the turtle's carapace will detach if severely bumped or jarred when experimental animals wedge themselves into confined areas (Renaud et al.[5]). Thus, there is essentially no risk to the animal with regards to entanglement with backpack tags.

PTT Restrictions.-----The feasibility of using backpack-type transmitters is dependent on sea turtle weight. A 5% ratio in air, of tag weight to body weight of experimental animal, for attached devices is considered safe by Aldridge and Bringham (1988), Bradbury et al. (1979), Brander and Cochran (1969), Gessaman and Nagy (1988), Kolz et al. (1980), and Massey et al. (1988).

[6] U.S. Fish and Wildlife Service, PO. Box 1306, Albuquerque, New Mexico 87103.

Recommendations.----If properly attached, the use of either trailing or backpack transmitters to monitor sea turtle movements and behavior is not a risk to these animals. It is the responsibility of the researcher to be familiar with the acceptable methods of attachment, limitations and size restrictions of the tags, general behavior of the animals and the characteristics of the probable environment the animal may venture into with a tag.

Our work represents only the tip of the iceberg with respect to accumulating a substantial data set on the movement patterns and diving behaviors of loggerhead sea turtles. Definite seasonal patterns for the number and duration of submergences by day and night existed for our experimental animals. We know that they spent from 90 to 95% of their time under the water. Their movements were influenced both by gradual and sharp air temperature fluctuations. Size of home ranges and core areas varied considerably between turtles. Further distinctions may exist in other areas of the world. The real task at hand will be the compilation and subsequent dissemination of data from numerous researchers abroad. This work is our modest attempt to lay the groundwork for such a data base.

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