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ORIENTATION CHARACTERISTICS OF IMMATURE KEMP'S RIDLEY
SEA TURTLES, LEPIDOCHELYS KEMPI

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ORIENTATION CHARACTERISTICS OF IMMATURE

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LEPIDOCHELYS KEMPI

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U.S. DEPARTMENT OF COMMERCE
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DISCLAIMER

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ABSTRACT

Orientation characteristics of immature Lepidochelys kemp were determined during three separate studies. In the first study, a radio tracking technique was used to record the movements of ten yearling L. kemp for a 27 day period following their release into the Gulf of Mexico. The results of the study indicate that the turtles were moving and swimming randomly, relative to geographical and wind directions. However, the turtles exhibited nonrandom movements and nonrandom swimming to current direction. Although they were displaced by the current, the turtles tended to swim against the current. Additionally, the current and the turtle's swimming exerted approximately equal effects on their movements. In the second study, the movements of 3 to 7 month old L. kemp were analyzed using a lagoon orientation arena. Results of the study indicate that the turtles were moving and swimming randomly, relative to the shore position and relative to the brightest direction, but they tended to swim against the current. During the third study, the sea-finding behavior of hatchling L. kemp was analyzed. Findings indicate that the hatchlings possessed not only a phototropotactic orientation mechanism, but also an orientation mechanism(s) that does not rely on light intensity as a cue.

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INTRODUCTION

The Kemp's ridley sea turtle, Lepidochelys kempi (Garman), is presently the most endangered of all sea turtles. Although almost all sea turtle species have been heavily exploited by man in the past 40 years, the L. kempi population is the only one that is close to extinction. The primary reason for this is that, unlike any other sea turtle, L. kempi has only one major nesting beach, where virtually the entire population nests (Carr, 1963; Hildebrand, 1963). Therefore, when the nesting females and eggs on that beach were heavily exploited by man, almost the entire population of L. kempi was extirpated. As many as 40,000 nesting females were recorded on that beach during a single day in 1947 (Carr, 1963; Hildebrand, 1963), but today less than 600 females nest there during an entire nesting season.

As a result of the drastic decline in the number of nesting females, L. kempi is presently the subject of intense conservation. Unfortunately, since little is known about the life history of this turtle, the conservational effort is primarily limited to the protection of nesting females and eggs on the beach. However, there is now a conservation project that is attempting to imprint L. kempi hatchlings to the Padre Island National Seashore and is then rearing them for 11 months in order to circumvent their high mortality in the wild (Klima and McVey, 1982). But the lack of knowledge concerning the life history of L. kempi, makes most aspects of the project experimental and speculative.

One important aspect to the captive-rearing project is the determination of an optimal location to release immature L. kempi that have been reared in captivity. No standard migration patterns have ever been determined for young L. kempi. Immature individuals have been found throughout the coastal

areas of the Gulf of Mexico and along the Atlantic coasts of North America and Europe (Pritchard and Marquez, 1973), but the actual paths traveled by these turtles and the causal basis for their movements from the nesting beach are unknown. The release area could be vital to the success of this conservation project, and the movements of the turtles following their release could be important to their survival and future breeding. For example, immature L. kempi that move into the Atlantic could be permanently separated from the breeding population by the Gulf Stream (Carr, 1980; Hendrickson, 1980).

I have conducted three separate studies of the movements of immature L. kempi, reported in the three sections of this report. The first study involved the recording and analysis of the movements of ten yearling L. kempi in the Gulf of Mexico. In the second study, the movements of immature L. kempi were recorded and analyzed through the use of an orientation arena that I constructed in a lagoon on Galveston Island, Texas. The third study consisted of the recording and analysis of the sea-finding behavior of hatchling L. kempi on the beach. These studies were conducted under Mexican permit ABC-IV-0751 Number 276/1-8786 and U.S. Fish and Wildlife permit PRT 2-4481.

SECTION I
THE ORIENTATION OF IMMATURE
LEPIDOCHELYS KEMPI
FOLLOWING THEIR RELEASE INTO THE GULF OF MEXICO

INTRODUCTION

Factors that initiate and control the movements of immature Kemp's ridley sea turtles need to be defined. This species has only one major nesting beach, located near Rancho Nuevo in the state of Tamaulipas, Mexico (Carr, 1963; Hildebrand, 1963). From this beach virtually all hatchlings enter the Gulf of Mexico. Despite this fact, immature L. kempi have been reported throughout the coastal areas of the Gulf of Mexico and along the Atlantic coasts of North America and Europe (Carr, 1956, 1957, 1980; Carr and Caldwell, 1958; Pritchard and Marquez, 1973). This indicates that immature L. kempi are capable of traveling long distances. Furthermore, immature L. kempi may exhibit migratory movements as suggested by their seasonal abundance in the Cedar Keys, Florida area (Carr and Caldwell, 1956). However, the causal basis for these movements of immature L. kempi has never been studied.

This subject is particularly important to the L. kempi captive-rearing program conducted by the National Marine Fisheries Service's Southeast Fisheries Center (SEFC), where approximately 2000 turtles per year are reared in captivity during the first eleven months of their lives. The turtles are then released into the Gulf of Mexico. Information on the movements of the turtles after release could be of vital importance to their survival and their subsequent breeding.

Previous research on the movements of immature L. kempi consisted of tagging studies by Carr and Caldwell (1956) and by the SEFC. Carr and Caldwell's study resulted in the recapture of two out of twenty-five tagged L. kempi. The two turtles were recaptured in the approximate location as their initial capture after periods of 43 and 91 days, suggesting the

possibility of a home range. Tagging studies conducted by the SEFC in 1979 resulted in the recapture of 54 turtles. They were captive-reared L. kempfi that were released in various areas of the Gulf of Mexico. Turtles released in the Bay of Florida were recaptured only along the Atlantic coast of the U.S., suggesting that the Gulf Stream played a major role in their movements. Turtles released in calmer waters near Homosassa, Florida exhibited a variety of movements, suggesting that 0.5 to 1.0 kg L. kempfi may be capable of overcoming the effects of the current in relatively calm waters. Although the previous tagging studies have recorded the movements of immature L. kempfi, they have not addressed the causal factors.

In the present study I address the two primary factors that affect the movements of sea turtles: the current and the turtle's swimming. By using a radio tracking technique, the movements of ten immature L. kempfi and the movements of two current monitors were recorded during a 27 day study. These data provided the means of quantifying the effects of the current and the effects of the turtle's swimming on the turtle's movements. The magnitudes of the two factors were compared to determine if either had a significantly greater effect on the turtle's movement. Additionally, the directions of movement and directions of swimming were analyzed relative to geographical, current and wind directions to determine if nonrandom patterns were present.

METHODS AND MATERIALS

Twelve transmitters were purchased from Wildlife Materials Inc. (Carbondale, Illinois). The 12 g units could transmit an intermittent pulse at least 24 km by air and 3 km over the water's surface on the 165 MHz to 166 MHz band. Each transmitter possessed a unique frequency to allow for individual identification.

Ten of the transmitters were sealed in housings designed to trail behind sea turtles. The housings, which resembled keeled sailboat hulls (Figure 1), consisted of plastic resin keels connected to balsa floats coated with a protective layer of epoxy paint. The transmitter was imbedded in the keel with its antenna projecting up and through the balsa float. External magnets operated the transmitter's magnetic on/off switches through the keels. Each housing was attached to a turtle's carapace with a 10 cm segment of monofilament line. The lines were securely anchored to the bow of the housing and through a hole drilled in a postcentral scute of the turtle.

The housings were effective for several reasons. They offered little hydrodynamic drag and had less than 0.5 cm of freeboard to minimize affects of the wind. To facilitate diving, the positive buoyancy of each housing was slight. The housings remained vertical in the water, even when the turtles were actively swimming. This kept the antennae upright, and was necessary for signal transmission at the water's surface.

The remaining two transmitters were sealed in housings designed to float freely as current monitors. The housings were constructed similarly to the towable housings, but were cylindrically shaped to minimize the effect of the wind.



Figure 1. Transmitter and transmitter-housing unit.

Equipment for locating and determining the geographical location of each transmitter was installed in a Piper Seneca II airplane. Transmitter locating equipment consisted of a Falcon Five variable frequency receiver (purchased from Wildlife Materials Inc.) and three antennae. The receiver could be adjusted with an accuracy of 1 KHz to frequencies from 165 MHz to 166 MHz, enabling us to identify each transmitter's pulse. A three-element, directional antenna was mounted on the underside of each wing, and an omnidirectional whip antenna was mounted under the center of the fuselage. The omnidirectional antenna was used for initial detection of a transmitter's signal, then the amplitudes of the signals received through both wing antennae were compared to deduce the heading of the transmitter. By flying in that direction and continually adjusting our heading relative to signal amplitudes through the wing antennae, Transmitter locations could be determined with a maximum estimated error of 1 km. The geographical location was then recorded using an Internav 101 Loran-C navigation unit, which was precise to 61 m.

A second Falcon Five receiver, coupled to a directional, handheld antenna was used from a boat on seven occasions during the study. The heading of any transmitter in range was deduced by manually changing the orientation of the antenna to a position of maximal signal strength.

The ten transmitters in towable housings were attached to 11 month old L. kempfi, which had been captive-reared by the SEFC. The weights and lengths of these turtles are listed in Table 1. Five of these turtles were released intermittantly among approximately 665 other L. kempfi on each of the mornings of 3 June 1980 and 5 June 1980. The area is historically known for an abundance of juvenile L. kempfi (Carr, 1955; Carr and Caldwell, 1956).

Table 1. Tag number, weight, length, and release date for each turtle used in this study.

Turtle number	Tag number	Weight (g)	Length (cm)	Release date
1	NNN643	1170	18.7	6-3-80
2	NNN087	1270	19.1	6-3-80
3	NNN021	990	17.8	6-3-80
4	NNN068	1210	19.4	6-3-80
5	NNN530	1260	19.8	6-3-80
6	NNN134	1700	17.5	6-5-80
7	NNN120	1590	16.4	6-5-80
8	NNN108	1640	17.0	6-5-80
9	NNN085	1500	18.6	6-5-80
10	NNN125	1850	17.8	6-5-80

Furthermore, the clear and shallow water together with the abundance of crustaceans should make this area an ideal habitat for L. kempi. The first release occurred at 28 47' N lat., 82 52' W long. and the second at 28 40' N lat., 82 45' W long. One current drogue was released midway through each release.

The airplane was then used at one to four day intervals, depending on weather conditions, to record the locations of the transmitters during the 27 day study. A boat was used on seven occasions to locate the transmitters for visual verification of their attachment to the turtles.

Average wind velocities during the study were obtained through the National Weather Service, from an automatic recording station located in the study area on Cedar Key.

RESULTS

The release areas and the final positions of the turtles during the study are shown in Figure 2. The dates associated with the final recorded position of the turtles varied because of premature loss of contact with certain transmitters. Loss of radio contact with two transmitters (numbers three and six) occurred very early in the study before their attachment to their respective turtle could be visually verified using a boat. Therefore, these two turtles are not included in Figure 2 or in any of the analyses that follow. Radio contact with one of the current monitors was also lost early in the study. Thus the movements of the other current monitor were used in the subsequent analysis.

Estimates of the paths comprising the net movements of the turtles and of the current monitor are shown in Figure 3. The initial point of each path represents the release location. However, the release location was not used in the analysis of these paths since the boat used for the releases did not have a Loran-C unit, thus preventing the precise recording of where the releases occurred. Each path consists of lines connecting all of the positions where an individual transmitter was located during the study. Therefore each segment of a path represents a net movement of a turtle or the current monitor during a certain portion of the study. The daily net movements of each turtle were estimated from these paths and their magnitudes ranged from 1.1 to 27.2 km per day with mean values for individual turtles ranging from 5.1 to 17.2 km per day. The magnitudes of each turtle's daily net movements were compared to those of each of the other turtles and no significant differences were detected (Kruskal Wallis, $P > 0.05$). The

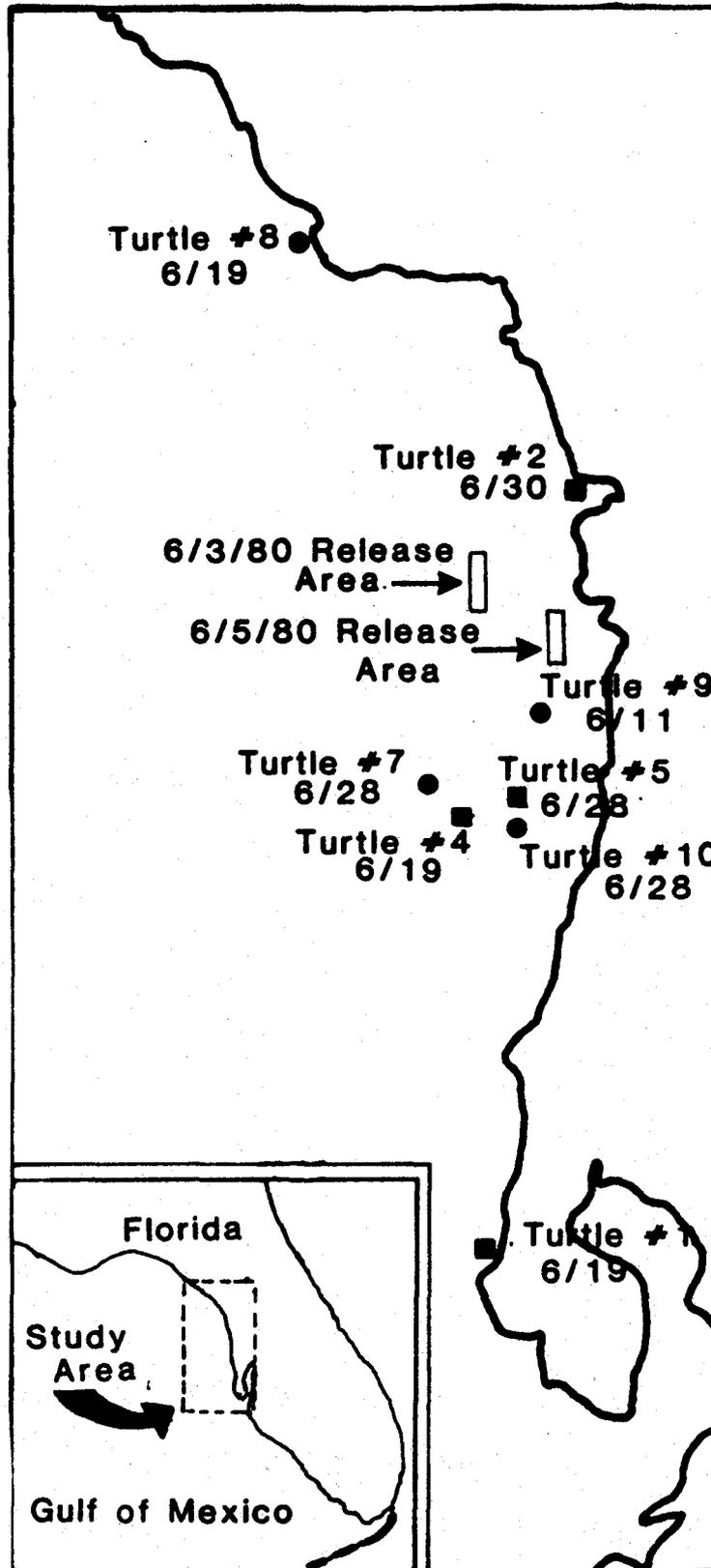


Figure 2. Release areas and final recorded positions of the turtles during the 27 day study. Squares indicate turtles released on 3 June 1980 and dots indicate turtles released on 5 June 1980.

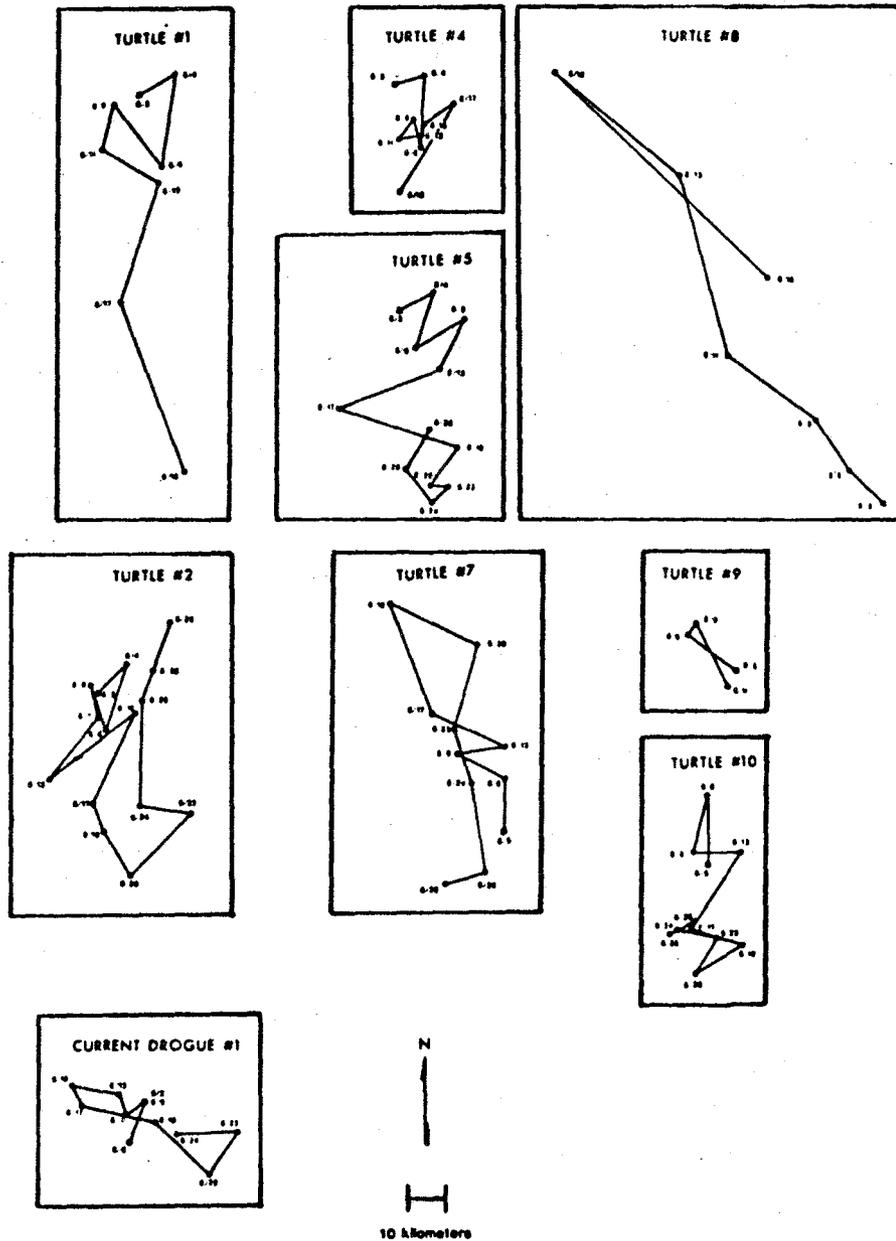


Figure 3. Estimates of the paths taken by the turtles during the radio tracking study.

directions and magnitudes of each turtle's net movements are listed in Table 2.

The movements of these turtles resulted primarily from the effects of two factors: the current and swimming. The effects of these factors on the movements of the turtles can be estimated from the paths shown in Figure 3. An estimate of the current's movements can be obtained from the current monitor's path. However, the current monitor was not continually close to all of the turtles. Nevertheless, its movements offer a reasonable estimate of the current's movements in the study area, since the currents in this region of the Gulf of Mexico are primarily the results of tides, which are similar throughout the study area (Mofjeld, 1974). Thus, each segment of the current monitor's path provides an estimate of the current's movement that affected the corresponding segment of each turtle's path.

The movements of a passively floating turtle should approximate the movements of the current monitor. Therefore, if a difference exists between the movement of the current monitor and the movement of a turtle, this difference represents an estimate of the effect of the turtle's swimming. This effect can be quantified for each segment of a turtle's path by subtracting from each segment the corresponding segment of the current monitor's path (Figure 4). This procedure generates vectors which represent the effect of swimming. The direction of each vector estimates the net direction of swimming and the length of each vector estimates the magnitude of the swimming effect. This magnitude represents the distance of movement a turtle's swimming would produce in the absence of current. Daily swimming rates were estimated from the swimming vector magnitudes. These values ranged from 0.9 to 28.6 km per day with mean values for individual turtles ranging from 5.2 to 13.9 km per day. Comparisons of each turtle's

Table 2. Directions and rates of the turtles' net movements.

Turtle	Time period	Mean rate of movement (km/day)	Direction of movement in degrees relative to		
			North	Net current direction	Net wind direction
1	6/4-6/6	13.1	191	NA	269
1	6/6-6/9	7.2	327	307	125
1	6/9-6/11	6.4	200	322	010
1	6/11-6/13	9.0	125	144	073
1	6/13-6/17	8.6	201	308	129
1	6/17-6/19	25.3	163	062	273
2	6/4-6/6	9.5	199	NA	290
2	6/6-6/9	4.3	341	321	139
2	6/9-6/11	4.4	172	294	342
2	6/11-6/13	10.8	220	239	147
2	6/13-6/16	10.0	053	134	351
2	6/16-6/17	27.2	207	053	341
2	6/17-6/19	1.7	162	061	272
2	6/19-6/20	13.9	153	120	284
2	6/20-6/23	7.8	046	013	185
2	6/23-6/24	13.9	278	011	147
2	6/24-6/26	15.0	002	NA	135
2	6/26-6/28	11.4	020	NA	176
2	6/28-6/30	7.2	191	NA	325
4	6/4-6/6	10.0	184	NA	275
4	6/6-6/9	2.6	344	324	142
4	6/9-6/11	3.1	218	340	028
4	6/11-6/13	3.1	080	099	007
4	6/13-6/16	1.1	015	096	313
4	6/16-6/17	4.7	054	260	188
4	6/17-6/19	14.2	212	111	322
5	6/4-6/6	8.1	196	NA	287
5	6/6-6/9	5.2	055	035	213
5	6/9-6/11	3.9	202	276	070
5	6/13-6/17	7.4	246	353	174
5	6/17-6/19	17.0	106	005	216
5	6/19-6/20	12.8	213	080	344
5	6/20-6/23	1.7	090	057	229
5	6/23-6/24	6.1	224	317	353
5	6/24-6/26	5.8	320	NA	267
5	6/26-6/28	6.4	028	NA	184
7	6/6-6/9	4.8	298	278	096
7	6/9-6/13	3.2	080	154	308
7	6/13-6/17	5.4	294	042	222
7	6/17-6/19	6.4	339	238	089
7	6/19-6/20	26.1	116	343	247

Table 2 continued.

Turtle	Time period	Mean rate of movement (km/day)	Direction of movement in degrees relative to		
			North	Net current direction	Net wind direction
7	6/20-6/23	8.0	195	172	334
7	6/23-6/24	16.0	163	256	295
7	6/24-6/26	12.5	171	NA	304
7	6/26-6/28	5.6	253	NA	049
8	6/6-6/9	5.6	325	305	123
8	6/9-6/11	14.7	304	066	114
8	6/11-6/13	25.9	342	001	269
8	6/13-6/16	14.8	307	028	265
8	6/16-6/19	27.1	131	030	265
9	6/6-6/9	6.5	030	010	272
9	6/9-6/11	5.6	150	272	320
10	6/6-6/9	4.8	194	174	352
10	6/9-6/13	3.2	091	165	319
10	6/13-6/17	6.3	214	321	142
10	6/17-6/19	7.2	109	008	219
10	6/19-6/20	15.0	239	106	010
10	6/20-6/23	3.9	030	357	169
10	6/23-6/24	11.1	282	015	051
10	6/14-6/26	1.1	245	NA	018
10	6/26-6/28	3.9	063	NA	219

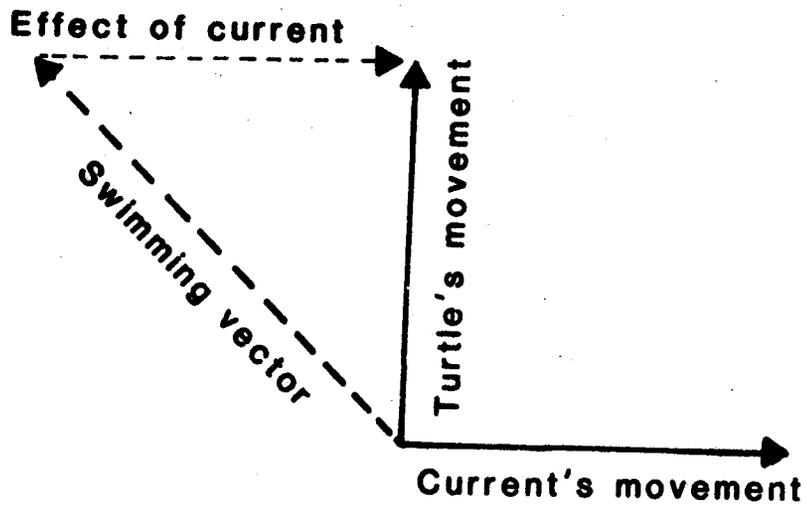


Figure 4. Example of how a swimming vector can be graphically generated from the movement of a turtle and the movement of the current.

swimming vector magnitudes with those of the other turtles revealed no significant differences (Kruskal Wallis, $P > 0.05$). The magnitudes and directions of each turtle's swimming vectors are listed in Table 3.

The magnitudes of each turtle's swimming vectors were compared to the magnitudes of the corresponding current movements to determine if the current or the turtle's swimming contributed significantly more than the other to each turtle's movements. These comparisons revealed no significant differences between the magnitudes of these two factors (Sign tests, $P > 0.05$).

In order to analyze the turtles' directions of swimming and directions of movements, circular statistical tests were performed on each turtle's path and on each turtle's swimming vectors. However, current statistical methods cannot prove that paths of this sort are either random or nonrandom, because of a problem with the independence among the data points (Batschelet, 1972). However, Batschelet suggests a modest approach of using a test formulated by Hodges, while assuming that the animals we are tracking are occasionally choosing new headings that are independent of their previous headings. Because of the limited number of data points associated with each turtle path, I used a Rayleigh test (Batschelet, 1965) as an alternative to the Hodge's test. The Rayleigh test analyzes a group of headings for randomness and can thus be used to gain insight about the directions of movement and the directions of swimming of each turtle. Before the Rayleigh test can be applied, a reference direction must be chosen. Then the headings of the segments of each path and the headings of the swimming vectors can be measured relative to the reference direction.

Table 3. Estimates of the directions and rates of the turtles' net swimming.

Turtle	Time period	Mean rate of swimming (km/day)	Direction of swimming in degrees relative to		
			North	Net current direction	Net wind direction
1	6/6-6/9	5.7	292	272	090
1	6/9-6/11	4.6	174	296	344
1	6/11-6/13	11.6	133	152	060
1	6/13-6/17	7.3	183	290	111
1	6/17-6/19	22.1	187	086	287
2	6/6-6/9	2.6	275	255	073
2	6/9-6/11	4.2	129	251	299
2	6/11-6/13	12.7	208	227	135
2	6/13-6/16	13.3	067	148	005
2	6/16-6/17	24.5	218	064	352
2	6/17-6/19	8.6	259	158	009
2	6/19-6/20	8.1	285	152	056
2	6/20-6/23	3.2	065	032	204
2	6/23-6/24	4.7	041	134	170
4	6/6-6/9	2.3	240	220	038
4	6/9-6/11	1.1	160	282	330
4	6/11-6/13	4.4	121	140	048
4	6/13-6/16	4.6	087	168	025
4	6/16-6/17	12.5	025	231	159
4	6/17-6/19	20.0	240	139	350
5	6/6-6/9	3.2	105	085	263
5	6/9-6/13	4.1	177	251	045
5	6/13-6/17	4.7	244	351	172
5	6/17-6/19	6.8	110	009	220
5	6/19-6/20	22.2	279	146	050
5	6/20-6/23	4.2	194	161	333
5	6/23-6/24	13.1	104	197	233
7	6/6-6/9	5.8	255	235	053
7	6/9-6/13	4.9	089	163	317
7	6/13-6/17	3.9	324	071	252
7	6/17-6/19	23.0	318	217	068
7	6/19-6/20	9.5	071	298	202
7	6/20-6/23	12.6	201	168	340
7	6/23-6/24	25.6	122	215	251
8	6/6-6/9	4.6	279	259	077
8	6/9-6/11	14.3	316	078	126
8	6/11-6/13	23.0	343	002	270
8	6/13-6/16	11.1	318	039	256
8	6/16-6/19	19.5	138	037	272
9	6/6-6/9	2.6	198	178	356
9	6/9-6/11	10.0	132	254	302
10	6/6-6/9	9.6	197	177	355

Table 3 continued.

Turtle	Time period	Mean rate of swimming (km/day)	Direction of swimming in degrees relative to		
			North	Net current direction	Net wind direction
10	6/9-6/13	5.0	096	170	324
10	6/13-6/17	4.5	191	298	119
10	6/17-6/19	2.9	267	166	017
10	6/19-6/20	28.6	283	150	054
10	6/20-6/23	0.9	211	178	350
10	6/23-6/24	6.9	056	149	185

The most obvious reference direction would be the geographical direction north. However, if a turtle was constantly moving relative to a stimulus that was independent of a geographical direction, the turtle might appear to be moving randomly when analyzed relative to north. For example, if a turtle was continually floating with the current, it would be moving nonrandomly relative to the current. But, if the current direction shifted periodically and independently of geographical direction, the turtle may appear to be moving randomly relative to north. It is therefore advantageous to conduct multiple testings of a turtle's directions of movement and direction of swimming using numerous reference directions that are independent of one another. For this reason, several reference directions were used to analyze their movements and swimming. North was used to determine if they were moving and/or swimming randomly relative to geographical direction. Additionally, current direction and wind direction were used as reference directions to determine if the turtles were moving and/or swimming randomly relative to these two stimuli. Estimates of the net current direction corresponding to each segment of their paths were obtained from the movements of the current monitor, and estimates of net wind direction corresponding to the segments of each turtle's path were calculated from data recorded by the National Weather Service's recording station on Cedar Key. Estimates of the net current direction and net wind direction for the time periods corresponding to the segments of the turtles' paths are listed in Table 4. Estimates of the net directions of their movements and swimming are listed in Tables 2 and 3.

Rayleigh tests were performed on the directions of movement and swimming of each turtle using north, net current direction and net wind direction as the reference directions (i.e. six groups of headings tested per turtle).

Table 4. Current and wind directions for time periods corresponding to the segments of the turtles' paths.

Time period	Mean current direction (in degrees relative to north)	Mean wind direction
6/4-6/6	NA	269
6/6-6/9	020	202
6/9-6/11	238	190
6/9-6/13	286	132
6/11-6/13	341	073
6/13-6/16	279	062
6/13-6/17	253	072
6/16-6/17	154	226
6/17-6/19	101	250
6/19-6/20	133	229
6/20-6/23	033	221
6/23-6/25	267	231
6/24-6/26	NA	227
6/26-6/28	NA	204
6/28-6/30	NA	226

These tests revealed that of the 48 groups of headings tested (eight turtles, six groups of headings per turtle), the headings of two groups were distributed nonrandomly ($P < 0.05$). Those two groups were turtle number eight's directions of movement relative to current direction and turtle number ten's directions of swimming relative to current direction. However, when analyzing 48 groups to a significance level of 0.05, one would expect 2.4 groups to be significantly nonrandom because of chance. Therefore, when analyzing the movements and swimming of individual turtles, we must assume that they are moving and swimming randomly.

A problem encountered when analyzing their paths was the relatively small number of segments per path (13 or less). The small sample sizes decreased my ability to detect nonrandom movements and/or nonrandom swimming by the turtles. In an attempt to overcome this problem, the directions of movement and the directions of swimming of all the turtles were pooled to form two groups. The two groups represented the directions of movement and swimming of the entire group. Testing both groups with the Rayleigh test relative to the three reference directions mentioned above (total of six groups tested) revealed that the headings of two of the six groups tested were distributed nonrandomly ($P < 0.05$). These two groups were the headings of the turtles' movements relative to the current direction and the headings of the turtles' swimming relative to the current direction. Both of these groups of headings are illustrated in Figure 5.

A modified form of the Rayleigh test known as the V test (Batschlet, 1972) was also performed on these two significantly nonrandom groups of headings. This test leads to significance only if the headings are sufficiently clustered around a predicted direction. A movement with the current was chosen as the predicted direction when testing the net directions

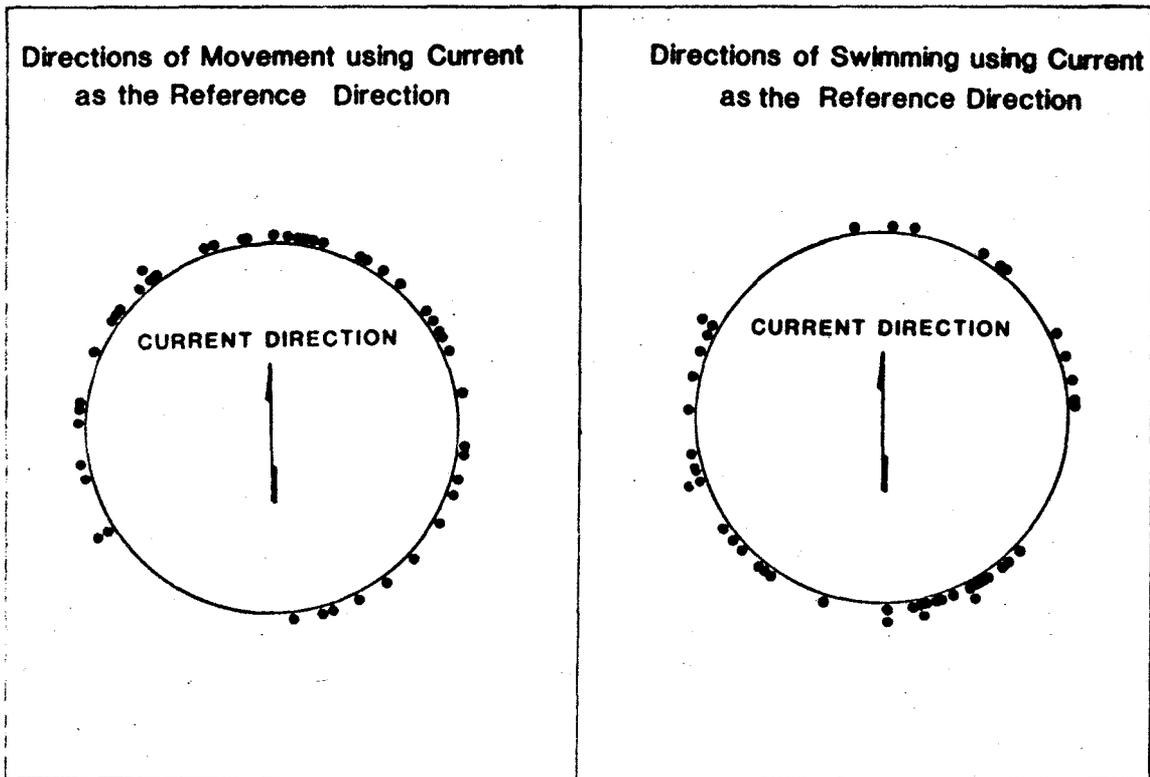


Figure 5. Directions of the turtles' movements and swimming relative to current direction. Each dot represents a heading that corresponds to a segment of a turtle's path or to a turtle's swimming vector.

of the turtles' movements relative to current direction. This predicted direction was chosen because it is logical to assume that the current should displace the turtles. The V test indicated that there was a significant clustering of headings in the general direction of the current ($P < 0.05$). When the V test was performed on the directions of the turtles' swimming relative to the current direction, a predicted direction of swimming against the current was chosen. This predicted direction was chosen for two reasons. First, if a turtle exhibited territoriality, it would have to swim against the current to remain in the same general area relative to bottom topography. Secondly, if a turtle fed on stationary organisms, it would have to swim against the current while obtaining its prey so as not to be swept downcurrent from the prey. The V test indicated that there was a significant clustering of headings in a general direction opposite the current direction.

DISCUSSION

The results of this study indicate that these yearling L. kempi were moving randomly relative to geographical direction and wind direction. However, the turtles did not appear to move randomly relative to the current direction. Their net directions of movement relative to current direction (Figure 5) suggest that they were significantly displaced by the current.

Ocean currents have long been suspected of being the primary factor affecting the movements of young sea turtles (Carr, 1955, 1967; Witham, 1976, 1980). There is a paucity of data pertaining to this subject, and little data exists on the life history of young sea turtles in general. This stems from the difficulty in obtaining data on young sea turtles in open ocean and has led to the term "lost year" being applied to the posthatchling stage of sea turtles. It is believed that during this stage sea turtles are too small to overcome the effects of ocean currents and must therefore assume a planktonic existence (Carr, 1980). However, most aspects of the lost year are speculative, including the time period associated with this stage and the size that a sea turtle must attain in order to overcome the effects of ocean currents.

One might suspect that the current was the primary factor affecting the movements of the turtles in this study, since the current apparently displaced them. However, this does not appear to be the case. Comparisons of current magnitude estimates with the turtles' swimming vector magnitude estimates revealed no significant differences. We must therefore assume that the current and the turtles' swimming contributed equally to the movements of the turtles. This indicates that the L. kempi in this study appeared to be at a stage in their life history corresponding to the end of the lost year.

Furthermore, it suggests that the time period that is implicitly indicated in the term "lost year" is correct for these yearling L. kempi, at least in this area of the Gulf of Mexico.

A unique facet of this study was the ability to estimate the turtles' swimming vectors from the data collected. The preceding paragraph already demonstrated the usefulness of these swimming vectors in analyzing sea turtle movements. Additionally, swimming vectors provide a means of gaining insight as to the swimming abilities and the swimming orientation of sea turtles in the wild.

Estimates of each turtle's net rates of swimming were calculated from their swimming vectors, and the mean values for individual turtles ranged from 5.2 to 13.9 km per day. The rates indicate that the turtles, which were reared for eleven months in relatively small containers (Klima and McVey, 1980), were active swimmers following their release into the Gulf of Mexico. No significant differences could be detected when comparing each turtle's net swimming rates to those of the other turtles. However, the greatest net swimming rate (28.6 km per day) and the greatest mean net swimming rate (13.9 km per day) were estimated from the swimming vectors of the largest turtle (turtle number ten).

Analysis of the turtles' directions of swimming indicates that these L. kempi were swimming randomly relative to geographical direction and wind direction. But, they appeared to swim nonrandomly relative to the current direction. The turtles' net directions of swimming relative to the current direction (Figure 5) suggest that they were swimming against the current. However, it is beyond the scope of this study to determine the orientation mechanism(s) responsible for the observed behavior.

The results of this study not only provide information about the swimming and movements of yearling L. kempi, but also can be used to evaluate certain facets of the captive-rearing program, specifically the release area and the length of captive-rearing. In one respect, the results suggest that the study area was an acceptable place to release the turtles, since the current was not strong enough to displace these turtles from this propitious environment. However, since the turtles appear to move randomly relative to geographical directions, the location of this release area (versus areas in the western Gulf of Mexico) may cause greater percentages of L. kempi to move into the Atlantic. This type of movement increases the turtles distance from the nesting beach and therefore may increase the difficulty of future nesting migrations. In reference to the length of captive-rearing, the results indicate that an eleven month period provides sufficient growth to allow the L. kempi to exhibit swimming abilities that equal the effects of the current in areas with currents similar to the study area.

In conclusion, the radio-tracking technique used in this study has provided valuable information on the movements and swimming of yearling L. kempi. Additionally, this study has provided information that is of importance in the design and evaluation of a comprehensive captive-rearing program for sea turtle conservation.

SECTION II
THE ORIENTATION OF IMMATURE
LEPIDOCHELYS KEMPI
IN A LAGOON ORIENTATION ARENA

INTRODUCTION

After leaving the nest, hatchling sea turtles move rapidly down the beach and into the water. Although the sea-finding behavior of sea turtles has been the subject of many studies, the behavior of young sea turtles after entering the water has received only scant attention. This is primarily the result of the small size of hatchlings which has prevented an effective tagging technique from being developed. Therefore when young sea turtles are captured, their nesting beach (and more importantly their net movement from the nesting beach) cannot be determined.

The movements of a small number of hatchling sea turtles have been recorded after they enter the water. Frick (1976) visually tracked Chelonia mydas hatchlings after they entered the water by swimming behind them or by following close behind them with a boat. Ireland et al. (1978) attached sonic transmitters and chemical lights to hatchlings and then followed them at a distance in a boat. The results of these two studies suggested that after entering the water, hatchling C. mydas swim in a direction that approximates a right angle to the beach. However, the logistical aspects of tracking sea turtles in open ocean permitted only a small number of hatchlings (21 or less) to be tracked for short time periods (4 h or less) during each of these studies. Furthermore, the logistical aspects of tracking young sea turtles in open ocean together with the difficulty of tagging hatchling sea turtles have resulted in a total lack of knowledge concerning the long term movements of young sea turtles during their first year of life (Carr, 1967). However, the radio-tracking study (Section I) has analyzed the movements of eleven month old captive-reared L. kemp following their release into the Gulf of Mexico. The results of that study suggested

that they were moving and swimming randomly relative to geographical direction and wind direction, but were moving and swimming nonrandomly relative to current direction. Although this radio-tracking technique proved to be an effective means of monitoring sea turtle movements in open ocean, the logistics and cost of the technique permitted the monitoring of only ten turtles.

General characteristics of the movements of young sea turtles in open ocean have been suggested from the above studies; however, the small numbers of turtles tracked in each study limit the certainty of those suggested characteristics. To obtain an accurate knowledge of their movements, larger numbers of sea turtles need to be studied. Therefore, in order to study the movements of young L. kempi in the water, I constructed an orientation arena in a lagoon on Galveston Island, Texas. The arena provided the means of recording and analyzing the movements of relatively large numbers of young L. kempi that were being captive-reared by the Galveston Laboratory. This section reports and discusses the results of that study.

METHODS AND MATERIALS

An orientation arena was constructed in the East Lagoon on the northeastern portion of Galveston Island, (Figure 6) to record the movements of young L. kempi in a natural environment. This lagoon is approximately 2 km long and varies in width from 150 m to 250 m. To determine if the direction of L. kempi movement changes as the relative position of certain environmental factors (such as the position of the shore and the position of the area of greatest light intensity) change, the arena was used at two different locations during the study. Initially it was positioned near the western shore of the widest region of the lagoon. Then after the first half of the study was completed, it was moved across the lagoon and positioned near the eastern shore.

The orientation arena is depicted in Figure 7. Since the arena was always located near shore, the water's depth in the arena ranged from 0.5 m to 1.0 m. To prevent any of the turtles from escaping into the lagoon, a net wall was positioned around the perimeter of the the arena at a distance of 7 m from the arena's center. The net was suspended from a PVC pipe, 1.9 cm in diameter, that encircled the arena. When experiments were being conducted, this pipe was suspended approximately 5 cm to 10 cm above the water's surface by eight poles, made from PVC pipe 5 cm in diameter, that were securely inserted into the sandy bottom of the lagoon. These eight poles were symmetrically positioned around the perimeter of the arena and projected approximately 0.3 m out of the water. At a radius of 5 m from the arena's center, 32 poles, made from PVC pipe 1.9 cm in diameter, were symmetrically positioned around the arena. These poles formed a 32 section scoring circle

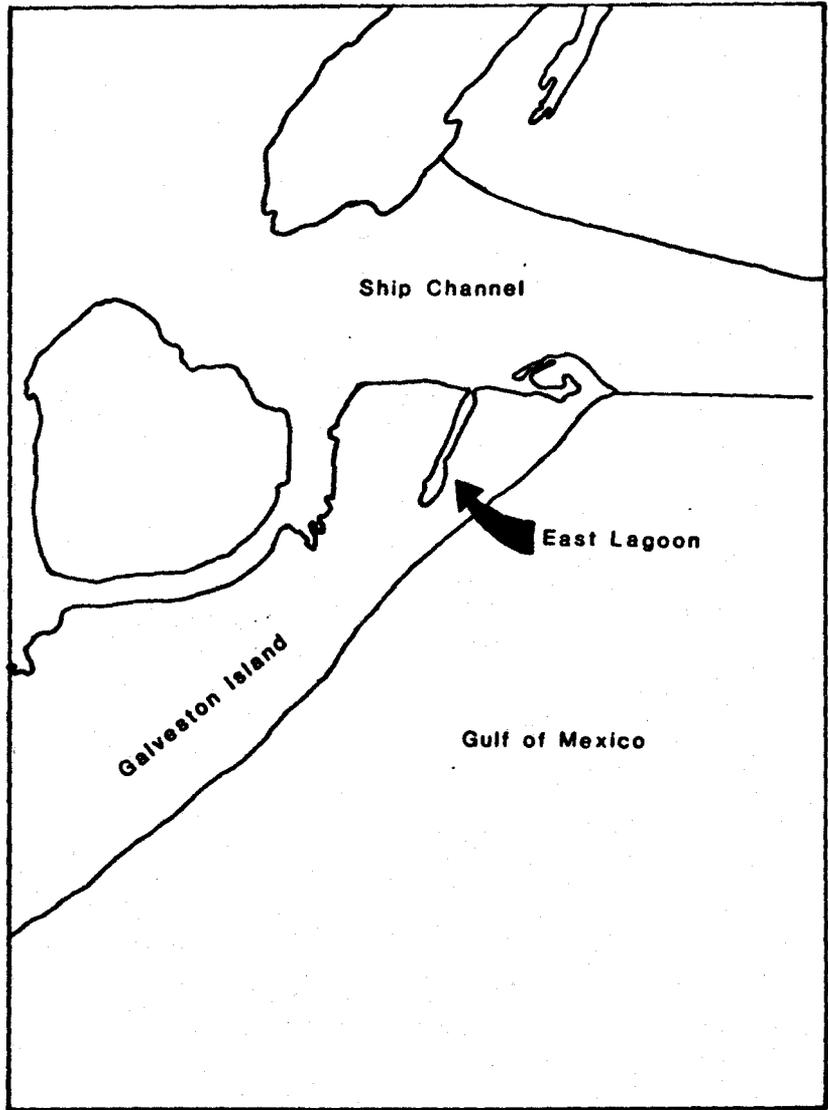


Figure 6. Location of East Lagoon.

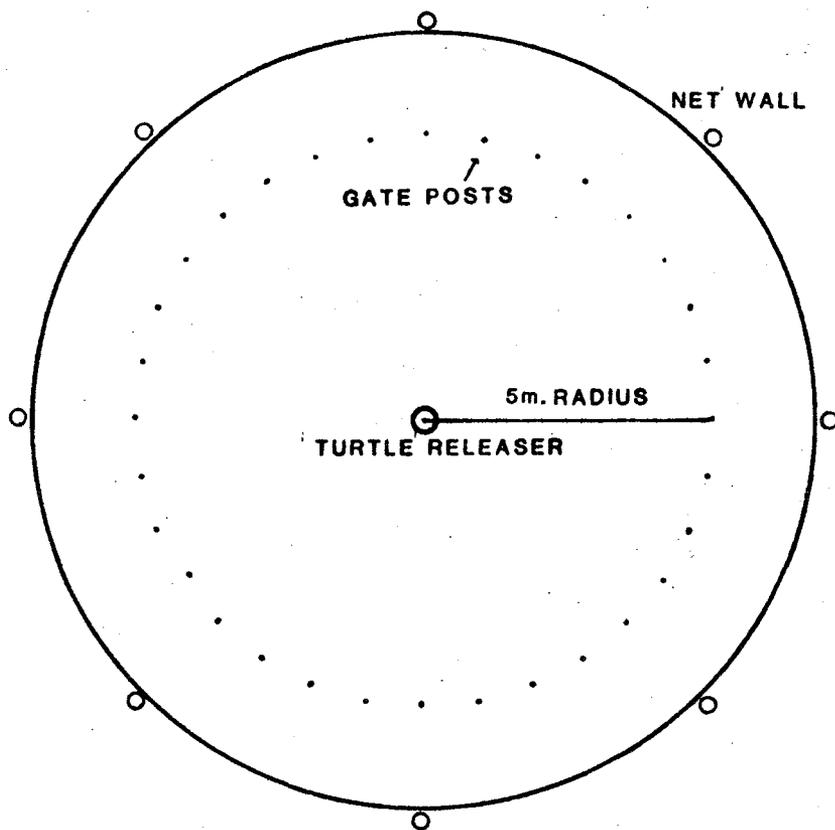


Figure 7. Diagram of the lagoon orientation arena.

for quantifying the movements of turtles that were released from the center of the arena. Each section (the area between two adjacent poles) comprised approximately 11.25 degrees of the arena's perimeter. Each pole was securely inserted into the sandy bottom of the lagoon and projected out of the water. The length of each pole was adjusted so that approximately 2 to 5 cm of pipe would project out of the water.

The releasing device depicted in Figure 8 was positioned at the center of the arena. This device provided a method of releasing turtles from the center of the arena without requiring the presence of someone in the arena. The device consisted of a turtle holding chamber mounted on two telescoping PVC poles. The lower pole was securely inserted into the sandy bottom of the lagoon. The upper pole was prevented from sliding down onto the lower pole by a release pin that was inserted through holes in both of the poles. The turtle holding chamber of the device was 40 cm in diameter with a 15 cm high plastic wall on its perimeter. The floor of this chamber was plastic and contained numerous holes to allow for the free flow of water. By adjusting the amount of the lower PVC pole that was inserted into the bottom of the lagoon, the height of the releasing device could be adjusted. During the experiments, the height of the releasing device was adjusted so that 3/4 of the turtle holding chamber was filled with water (Figure 8). After a turtle was placed into the chamber, it could be released into the arena by the removal of the release pin, which caused the chamber to slowly sink below the surface of the water. A 20 m string attached to the release pin allowed an observer, who was positioned onshore, to remove the pin.

The L. kempi used in this study were maintained at the Galveston Laboratory. They ranged from three months to seven months of age.

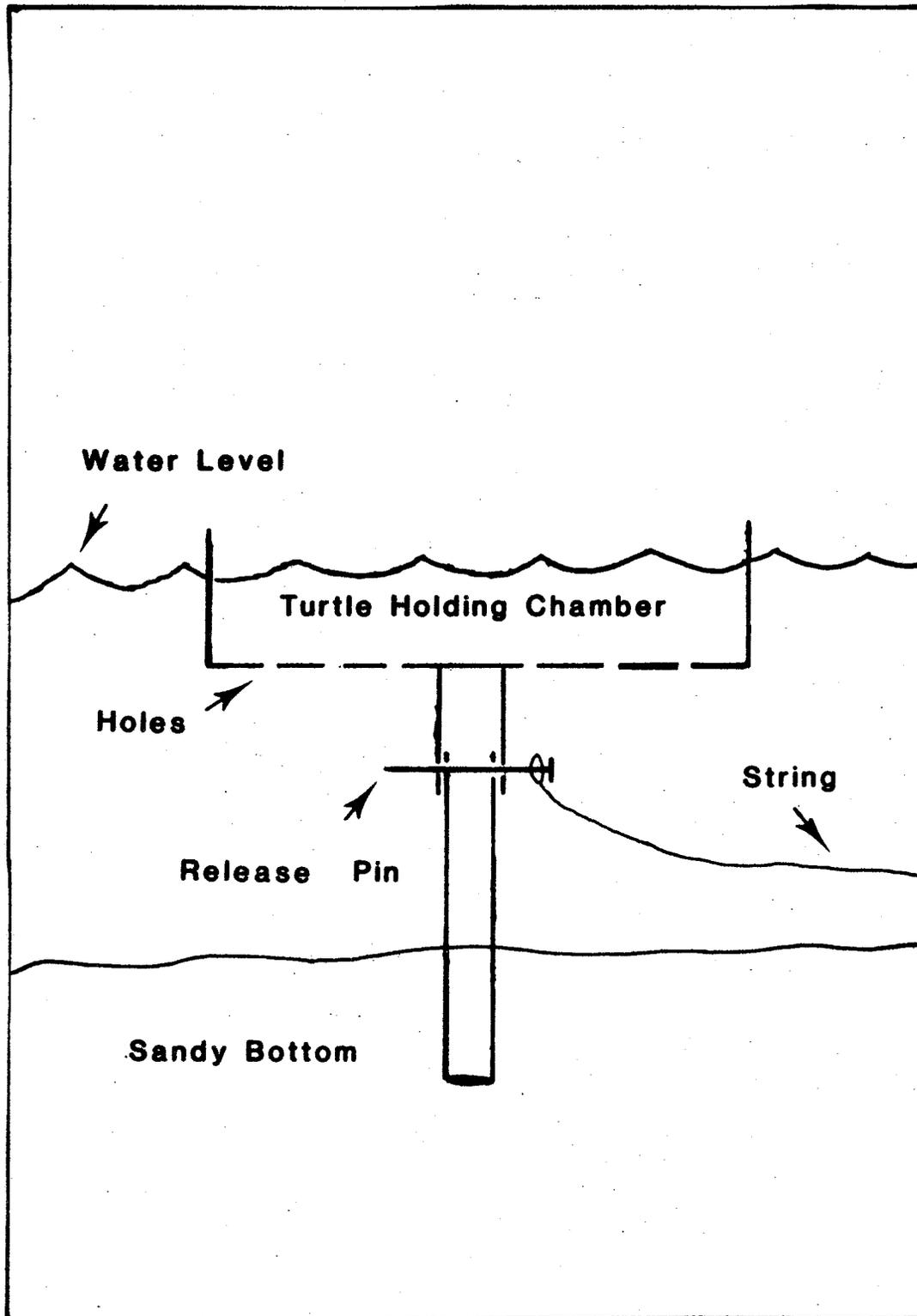


Figure 8. Diagram of turtle releasing device.

Each turtle was initially placed into the releasing device and allowed to acclimate to the lagoon water for a two minute period. During that time, the observer would move back onto shore and situate himself behind the tall reeds (Phragmites australis) that line the shore of the lagoon. This way the observer would camouflage himself while observing the turtles. After the two minutes, the observer pulled the string attached to the pin and released the turtle. He then recorded the section of the scoring circle that the turtle moved through and the time required by the turtle to reach the scoring circle. Using this procedure, an estimate of the direction of movement and an estimate of the rate of movement were recorded for each turtle used in this study.

During the arena experiments, the turtles were exposed to wind generated currents in the lagoon. In order to estimate the effects of these currents on the movements of the turtles in the arena, a float was made that approximated the general size and density of turtles used in this study. By using the turtle releasing device to release the float, its direction of movement and rate of movement were recorded in the arena immediately after approximately every four turtles tested in the arena during the study.

Light intensity appears to be an important factor affecting the sea-finding orientation mechanism(s) of L. kempi. To determine if L. kempi continue to use light intensity as an orientation cue when they are in the water, estimates of the horizontal light field surrounding the arena were taken during this study. Light readings were taken from the center of each of the 32 sections of the arena using the same procedures described in section three. An estimate of the horizontal light field was recorded immediately before and after approximately every eight turtles tested in the arena.

As stated previously, the orientation arena was positioned at two different locations during the study. At each of these locations, the experimental procedures described above were conducted from 9:30 A.M. to 4:30 P.M. CST. The times and dates of individual experimental sessions varied because of weather and tidal conditions. While the arena was located on the west side of the lagoon, the movements of 92 turtles were recorded using the procedures described above. This initial portion of the study was conducted between 11 September 1980 and 28 October 1980. The orientation arena was then disassembled, moved to the east side of the lagoon and reassembled. The movements of 72 L. kempfi were then recorded in the orientation arena according to the procedures described above. This second portion of the study was conducted between 13 December 1980 and 29 January 1981.

RESULTS

Upon release, most of the turtles swam at a moderate rate near the water's surface. However, some of the turtles appeared to exhibit an escape behavior and would swim rapidly in whatever direction they were facing. Other turtles exhibited low activity levels, using primarily their back flippers while floating with the current.

Turtles which exhibited either an escape behavior or a low activity level could confound the results of this study. Therefore, an objective method was developed in an effort to remove these turtles' movements from the results. This method was based on the swimming rates of the turtles. The experimental design of this study provided the means of trigonometrically generating a swimming vector for each turtle by subtracting the estimated movement of the current in the arena from the movement of each turtle in the arena. The swimming rate was then calculated by dividing the magnitude of the swimming vector by the time taken by the turtle to reach the scoring circle. The average swimming rate of the 170 turtles used in this study was 0.15 m/s with a standard deviation of +0.08 m/s. To rid the results of the possible confounding movements that were mentioned above, only turtles with swimming rates that were plus or minus one standard deviation unit from the mean were analyzed (rates greater than 0.07 m/s and less than 0.23 m/s). Therefore the following results reflect the movements of 119 of the 170 turtles used in this study.

The turtles' directions of movement in both arena locations are illustrated in Figure 9 (A and B) relative to north. Rayleigh tests (Batschelet, 1965) were performed on these two groups of headings to

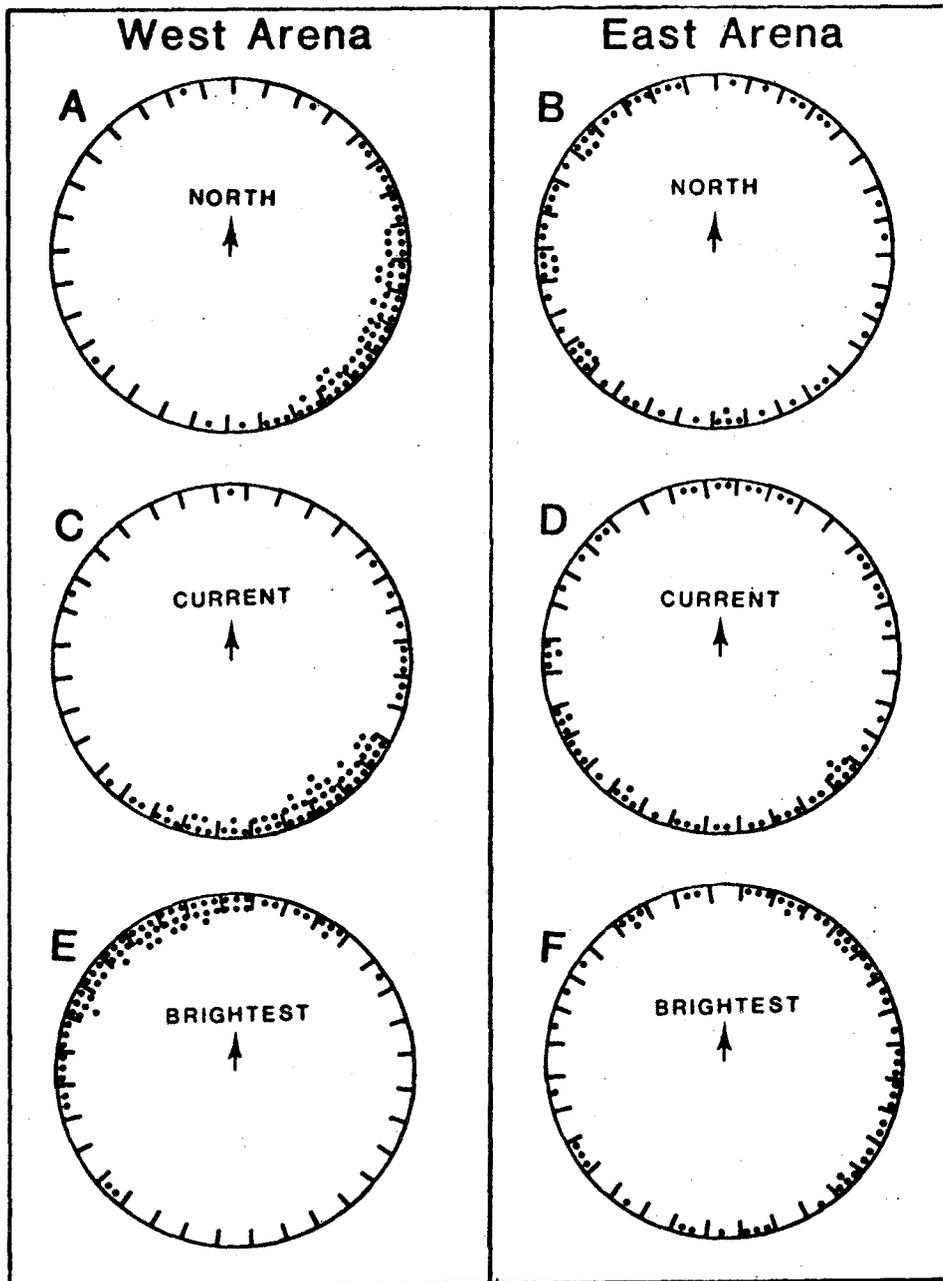


Figure 9. Headings of the turtles' directions of movement in the lagoon orientation arena. Each dot represents the heading of a turtle's movement.

determine the randomness of the headings. These tests indicated that the directions of these turtles' movements were nonrandomly distributed relative to north. To determine if these turtles, like the hatchling C. mydas followed by Frick (1976) and Ireland et al. (1978), were moving in directions that approximated right angles to the shoreline, V tests (Batschelet, 1972) were performed on these two groups of headings. As reported in chapter one, the V test leads to significance only if there is a sufficient clustering of headings around a predicted direction. In this situation the predicted direction chosen in each arena was the heading that approximated the most direct path away from shore (90 degrees relative to north in the west arena and 270 degrees relative to north in the east arena). The V tests indicated a significant clustering of headings around the predicted direction in both arenas ($P < 0.01$).

As discussed in chapter one, it is advantageous to use a variety of reference directions when analyzing the randomness of headings. To determine if the current in the arena or the light field surrounding the arena affected the orientation of these turtles, estimates of these two parameters were recorded throughout the study. Thus for each turtle movement recorded during the study there is also a coincidental estimate of each of these two parameters. As a result, the movements of each turtle could be analyzed with respect to the current direction and the direction of greatest light intensity (brightest direction). Figure 9 (B,C,D, and E) shows the turtles' directions of movement in each arena relative to the two reference parameters mentioned above. Rayleigh tests were performed on each of these four groups of headings and these tests indicated that the headings in all four groups were nonrandomly distributed ($P < 0.01$). A V test was then performed on each

of these four groups of headings. The predicted direction of movement that was chosen for testing the groups of headings that were analyzed with respect to the current was a direction 180 degrees from the current direction. This direction was chosen since the L. kempfi studied in chapter one apparently exhibited a tendency to swim against the current. The V tests indicated that the headings of the turtles' movements (relative to the current direction) were significantly clustered in a direction opposite the direction of the current in both arena locations ($P < 0.01$). The predicted direction of movement that was chosen, when testing the two groups of headings that were analyzed with respect to the direction of greatest light intensity, was the direction of greatest light intensity. This predicted direction was chosen since hatchling sea turtles are reputed to move in the brightest direction after they emerge from the nest (see section three). The Y tests indicated that the headings of the turtles' movements (relative to the brightest direction) were significantly clustered around the brightest direction in the west arena ($P < 0.01$), but they were not significantly clustered around the brightest direction in the east arena ($P > 0.05$).

The preceding analysis examined the turtles' directions of movement relative to three different parameters in an attempt to characterize the orientation of these young L. kempfi in the water. However, the recorded movement of each turtle was a combination of the turtle's swimming and the movement of the current. This prevents the preceding analysis from examining the actual swimming orientation of these turtles. To overcome this problem, an estimate of each turtle's direction of swimming was trigonometrically determined using the resultant movement of each turtle in the arena and the coincidental movement of the current in the arena.

Figure 10 (A and B) illustrates the turtles' directions of swimming relative to north in each of the arena locations. Rayleigh tests were performed on these two groups of headings and these tests indicated that the headings in the west arena were nonrandomly distributed ($P < 0.01$), but the headings in the east arena appeared to be distributed randomly ($P > 0.05$). V tests were performed on these two groups of headings using the direction that approximates the most direct path away from shore as the predicted direction of swimming. These tests indicated that there was a significant clustering of headings around the predicted direction in the west arena ($P < 0.01$), but there was not a significant clustering around the predicted direction in the east arena ($P > 0.05$).

To determine if the current in the arena or the light field surrounding the arena was affecting the swimming orientation of the turtles, the current direction and the brightest direction were used as reference in generating two new headings for each turtle's direction of swimming. Figure 10 (C,D,E, and F) illustrates the headings of the turtles' swimming directions in both arena locations relative to the current and brightest direction. Rayleigh tests indicated that when the swimming directions were analyzed with respect to the current direction, the headings were nonrandomly distributed in both arena locations ($P < 0.01$). However, when the swimming directions were analyzed with respect to the brightest direction, the headings were nonrandomly distributed in only the west arena ($P < 0.01$). V tests were performed on these four groups of headings, using a direction 180 degrees from the current direction as the predicted direction relative to the current, and using the brightest direction as the predicted direction relative to the light field. These tests indicated that the headings

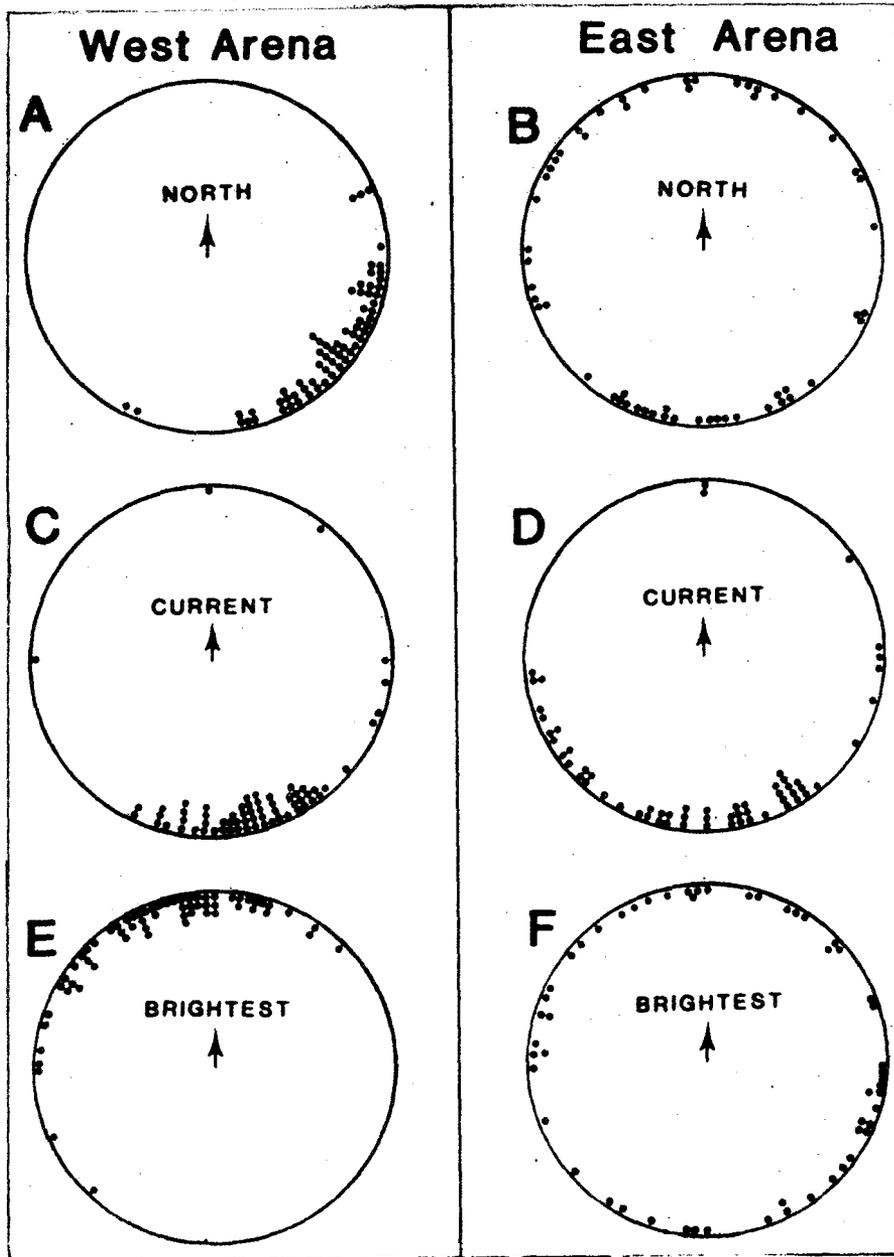


Figure 10. Headings of the turtles' swimming in the lagoon orientation arena. Each dot represents a heading swam by a turtle.

analyzed with respect to the current direction were significantly clustered in both arena locations around a heading 180 degrees from the current direction ($P < 0.01$), but the headings analyzed with respect to the brightest direction were significantly clustered around the brightest direction only in the west arena ($P < 0.01$).

The results of the statistical analyses described in this section are summarized in Tables 5 and 6.

Table 5. Analyses of the turtles' directions of movement. (S = significant, N = nonsignificant)

Headings relative to	West arena		East arena	
	Rayleigh test	V test	Rayleigh test	V test
North	S	S	S	S
Current direction	S	S	S	S
Brightest direction	S	S	S	N

Table 6. Analyses of the turtles' directions of swimming. (S = significant, N = nonsignificant)

Headings relative to	West arena		East arena	
	Rayleigh test	V test	Rayleigh test	V test
North	S	S	N	N
Current direction	S	S	S	S
Brightest direction	S	S	N	N

DISCUSSION

The headings of the turtles' movements in the west arena were nonrandomly distributed relative to all three reference directions (Table 5). Additionally, these headings were significantly clustered around all three predicted directions of movements used in the V tests. This indicates that these turtles were moving nonrandomly and that the turtles could have been moving in any one or all three of the predicted directions. These findings could have resulted from the similarity of the predicted direction of movement. The current direction and the brightest direction were relatively consistent during all of the experiments in the west arena. Furthermore, the brightest direction was approximately opposite the current direction ($\bar{x} = 185$ degrees, $s = + 41$ degrees) and was relatively close to the direction of the most direct path away from the shore ($\bar{x} = 58$ degrees, $s = + 31$ degrees). Thus all three predicted directions of movement were relatively close to one another in the west arena. Therefore, the significant clustering of headings around all three predicted directions of movement could have resulted from a significant number of turtles moving in only one of the predicted directions.

The current directions in the east arena experiments were variable because of seasonal changes in wind direction. This variability in the current direction decreased the similarity of the predicted directions of movement in the east arena. Nevertheless the headings of the turtles movements in the east arena were also distributed nonrandomly relative to all three reference directions (Table 5). The V tests, however, indicated that the headings of the turtles movements were significantly clustered around only two of the three predicted directions of movement (Table 5). Those two

predicted directions were the direction approximating the most direct path away from shore and the direction opposite the current direction.

The above results indicate that the turtles in the east arena were also moving nonrandomly. They also indicate that the turtles were not moving in the brightest direction, but could have been moving away from shore or against the current. However, if the turtles were moving in one of those two directions, their movements were not consistent enough to provide an accurate indication of the specific direction of movement. This could be the result of the effect of the current on the turtles movement. For example, the turtles could be swimming in only one general direction, but the variable strength and direction of the current could effectively result in a broad range of movements. In an effort to circumvent the possible confounding effect of the current, the swimming directions of each turtle were determined trigonometrically and then analyzed.

The swimming directions of the turtles in the west arena were nonrandomly distributed relative to all three reference directions (Table 6). Additionally, the swimming directions were significantly clustered around the three predicted directions of swimming used in the V tests (Table 6). These results indicate that the turtles in the west arena were swimming nonrandomly, but they do not indicate a specific direction of swimming. Unfortunately the similarity of the predicted directions of swimming in the west arena may have prevented the determination of a specific direction of swimming. The east arena, however, should not have this problem. The variability of the current directions during the experiments in the east arena decreased the similarity of the predicted directions of swimming used in the V tests (Table 6). Furthermore, by using the headings of the turtles swimming rather than the headings of their movement, the possible confounding

effects of the current should not be present. Therefore the swimming directions obtained from the east arena data should provide accurate and specific information on the swimming orientation of these turtles.

The headings of the turtles swimming in the east arena appeared to be randomly distributed when referenced to north and the brightest direction (Table 6). However, when the headings were referenced to the current direction, they were nonrandomly distributed (Table 6). Furthermore, V tests showed that the direction opposite the current direction was the only one of the three predicted directions that had had a significant number of headings clustered around it. These results indicate that the turtles in the east arena were swimming nonrandomly against the current. Therefore these results agree with the results of the first chapter in suggesting that young L. kempi show a tendency to swim against the current. It is beyond the scope of this study to determine the advantages of such a behavior, however, if the turtles were reacting to the inertial effects of the current. This behavior offers a logical explanation of how hatchling sea turtles could move in an oriented fashion away from the nesting beach. The waves moving toward shore could act as a stimulus that the hatchlings swim against. In that way, the hatchlings would always swim in a direction away from shore.

In conclusion, the results of this study have suggested that young L. kempi exhibit a tendency to swim against the current. Additionally, this study has shown that an orientation arena positioned in natural environment is a viable tool for the study of sea turtle movements and swimming.

SECTION III
THE SEA-FINDING ORIENTATION OF HATCHLING
LEPIDOCHELYS KEMPI

INTRODUCTION

The ability of hatchling sea turtles to find the sea from the nest where they hatch is of interest for two reasons. First, because it is a phenomenon in its own right and second, because the orientation mechanism(s) responsible for this behavior may aid in explaining the long distance migrations of sea turtles (Carr and Ogren, 1960). This has been the rationale for the many previous studies of sea turtle sea-finding behavior (for a review see Mrosovsky, 1972). However, these studies have never investigated this behavior in the Kemp's ridley sea turtle, L. kempi. Considering that interspecific differences in the sea-finding behavior of sea turtles are known to occur (Mrosovsky and Shettleworth, 1975), a study of L. kempi sea-finding behavior would be of interest from a comparative viewpoint. Additionally, this subject is of special interest because of the following unique aspects of L. kempi sea-finding behavior: 1) Unlike the hatchlings of other sea turtle species, which primarily move from the nest to the sea nocturnally, L. kempi hatchlings primarily move from the nest to the sea during early daylight hours. 2) Virtually all L. kempi nesting occurs on a single nesting beach (near Rancho Nuevo in the state of Tamaulipas, Mexico). Therefore, unlike hatchlings of other sea turtle species, virtually all L. kempi hatchlings must move in the same general direction from the nest in order to reach the sea.

Previous sea-finding studies using sea turtle species other than L. kempi present valuable information concerning the sea-finding behavior of sea turtles. Experiments conducted by Ehrenfeld and Carr (1967) indicated that sea-finding orientation was primarily a visual process. Additionally, their study indicated that hatchlings were obtaining orientation cues primarily

from an area within four degrees above the surface of the beach. Many authors have proposed that the principal mechanism by which hatchling sea turtles find the sea is by a tropotactic reaction to light (Mrosovsky, 1967, 1972; Ehrenfeld, 1968; Mrosovsky and Shettleworth, 1968, 1974; Verheijhen and Widlschut, 1973; Mrosovsky, et al., 1979). That is, a hatchling apparently compares the intensities of light that are received through each eye and then turns its body until both eyes receive equal intensities of light. The hatchling then moves forward in that direction.

Although a phototropotactic reaction has been suggested as the principal mechanism in sea-finding orientation, Parker (1922) and Limpus (1971) have suggested that the distribution of silhouette patterns along the horizon may also be a major orientation cue. Furthermore, following a variety of experiments with hatchling Chelonia mydas, Van Rhijn (1979) indicated that their sea-finding behavior could not be solely explained in terms of a phototropotactic reaction and that this behavior is probably a result of a "multiple input unit system".

The above information demonstrates the need for further studies of the sea-finding behavior of sea turtles and in particular for studies of the sea-finding behavior of L. kempi. Previous studies of L. kempi sea-finding behavior have been prevented by this species' small population size and by the remoteness of its only major nesting beach. However, a cooperative conservation program involving Mexico and the United States has recently provided a source of hatchling L. kempi. This source of hatchlings facilitated a study of the sea-finding behavior of L. kempi during the summer of 1980. The findings of that study are reported in this section.

METHODS AND MATERIALS

The L. kempi hatchlings used in this study were obtained from the Galveston Laboratory's captive-rearing program. The turtles were transported, in portable holding tanks, by motor vehicle, to the study site located on a Galveston Island beach (Figure 11).

In order to quantify the direction of the hatchlings movement on the beach, a circular arena, similar to that used by Mrosovsky and Carr (1966), was constructed at the study site. It was positioned above the intertidal zone and its center was approximately 18 m from the dunes bordering the island side of the beach. The beach surface within the arena was clear of vegetation and the sea was not visible at turtle eye level from anywhere within the arena. The arena was 12 m in diameter and a 0.3 m by 0.3 m trench was dug around its perimeter. The trench's walls were steeply dug to prevent any hatchlings from escaping. The trench was divided into 16 sections (each comprising 22.5 degrees of the arena's perimeter) using wood partitions. The sections of the trench were positioned so that if a line was drawn from the center of the arena through the partition between sections 16 and 1, it would extend north. Additionally, if a line was drawn from the center of the arena through the partition between sections 6 and 7, it would approximate a perpendicular line to the sea.

Throughout this study, the following experimental procedure was repeatedly conducted using groups of 15 hatchlings. All hatchlings were used only once and the maximum age of the hatchlings was 16 days. Prior to each experiment, 15 hatchlings were placed in a wire mesh enclosure (0.5 m in diameter) located at the center of the arena. After a 2 minute acclimation

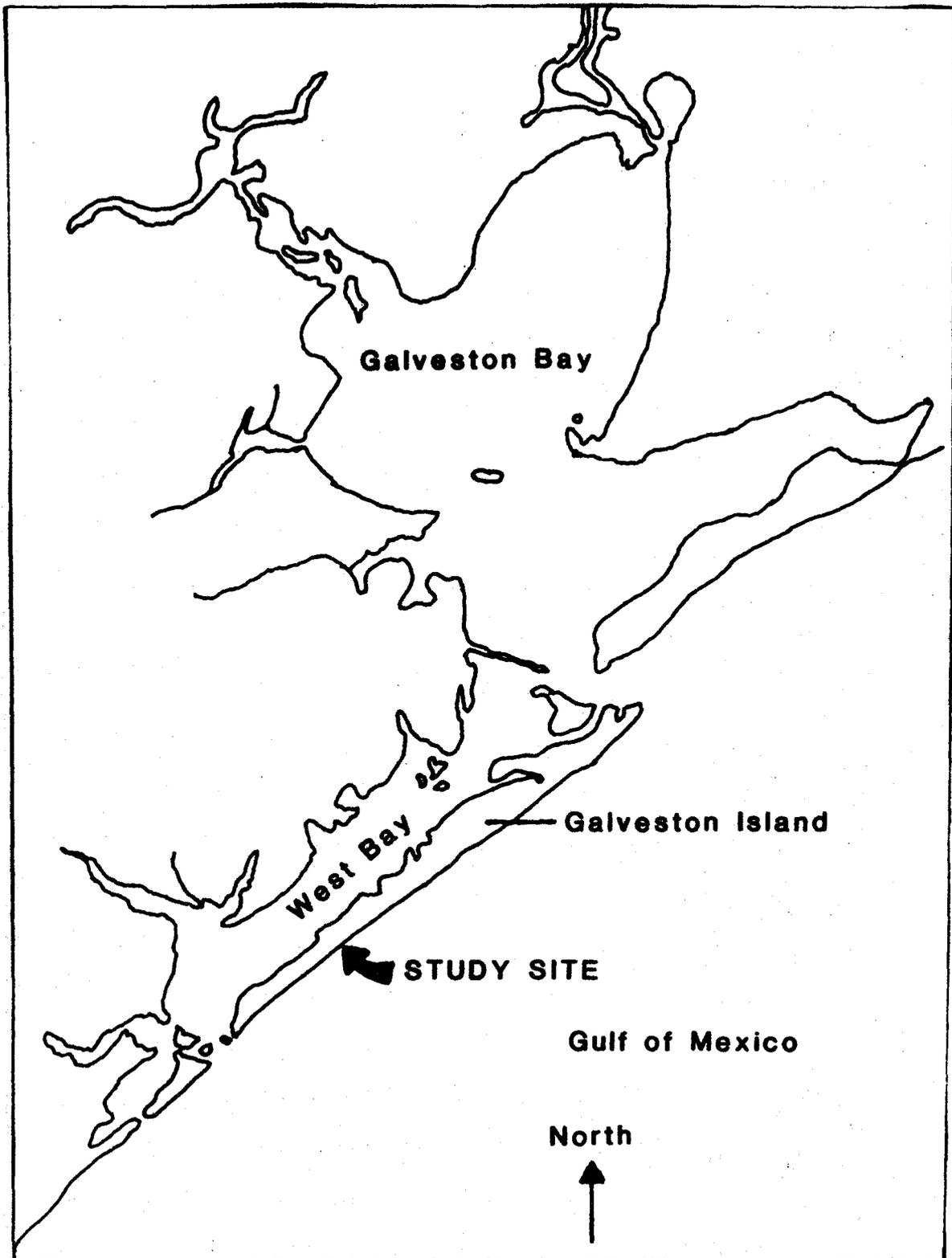


Figure 11. Location of the study site for the sea-finding experiments

period the wire enclosure was removed by an observer who quickly moved out of the arena and behind the dunes. The hatchlings were then allowed to move freely within the arena for a maximum of 10 minutes or until all hatchlings had fallen into the trench. Following that time period, the number of hatchlings in each section of the trench was recorded. If a hatchling had not reached the trench at the end of 10 minutes, it was excluded from the results.

During this study, two series of experiments were conducted. In the first series the experimental procedure described above was conducted repeatedly during the morning and afternoon to compare hatchling behavior when the sun was in different positions. On 10 July 1980 and 14 July 1980 these experiments were conducted between 9:44 A.M. and 10:24 A.M. and between 1:50 P.M. and 2:45 P.M. (CTS, daylight savings time).

During the second series of experiments, an estimate of the light field surrounding the arena was recorded immediately following the arena experiments in order to determine if the hatchlings were moving in the brightest direction. On 24 July 1980 this procedure was carried out both in the morning (between 9:43 A.M. and 10:30 A.M. CST, daylight savings time) and in the afternoon (between 2:10 P.M. and 3:07 P.M. CST, daylight savings time). Estimates of the light intensity from each section of the arena were taken from the center of the arena using a Lightmate/Spotmate photometer system (Photo Research, Burbank, California) which was sequentially directed toward the center of each of the 16 sections of the arena. The photometer measured the light intensity from a circular area one degree in diameter. Although no study has investigated the spectral sensitivity of L. kempi, research conducted on C. mydas suggests that the use of a photometer was justified. A two degree angle of elevation from the beach surface was used

when directing the photometer since the study conducted by Ehrenfeld and Carr (1967) indicated that hatchling C. mydas obtain orientation cues primarily from an area within four degrees above the beach surface.

RESULTS AND DISCUSSION

The results of the first series of arena experiments are shown in Figure 12. The movements of the hatchlings during the morning experiments were very consistent and no significant differences were detected between the results of the individual experiments (Chi-square tests, $P > 0.05$). The movements of the hatchlings in the afternoon experiments were not as consistent as those of the hatchlings in the morning experiments. Unlike the morning experiments, hatchlings were recorded in as many as four different trench segments following the afternoon experiments. Furthermore, the movements of the hatchlings during experiment number seven were significantly different than those of the hatchlings during experiment number twelve (Chi-square test, $P < 0.05$). However, no other significant differences were detected when the results of the afternoon experiments were compared to one another (Chi-square tests, $P > 0.05$). Comparisons of the results of the morning experiments to those in the afternoon revealed that the hatchling's movements in the morning were significantly different than their directions of movements in the afternoon (Chi-square tests, $P < 0.05$). These results are consistent with the current theory that sea turtles use primarily a phototropotactic reaction to find the sea. That is, if the hatchlings were reacting tropotactically to light, one would expect their direction of movement to shift as the sun (and thus the light field surrounding the arena) shifts. Therefore the results of the first series of experiments suggest that the L. kempi hatchlings were reacting tropotactically to the light field surrounding them. Mrosovsky (1970) recorded similar results with C. mydas.

The results of the second series of arena experiments together with the diagrams representing the light field surrounding the arenas are shown in

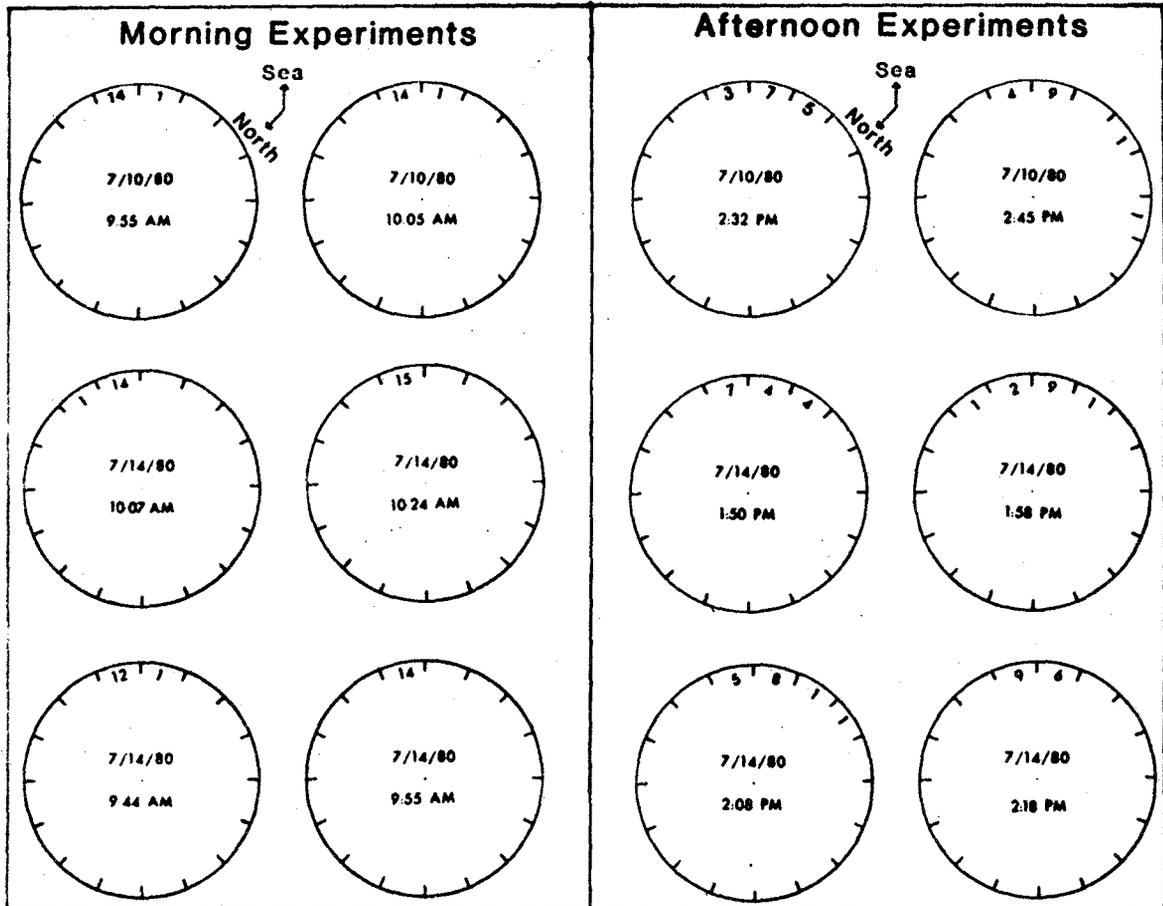


Figure 12. Directions of the hatchlings sea-finding movements. Each number represents the number of hatchlings that fell into the individual trench sections.

Figure 13. As in the first series of experiments, there was a significant difference between the directions of the hatchlings movements in the morning and those in the afternoon (Chi-square tests, $P < 0.05$). Figure 13 shows that the brightest region of the light field during the morning experiments was considerably more intense than the brightest region of the light field during the afternoon experiments. If this were true during the first series of experiments, it could be responsible for the more consistent movements of the hatchlings during the morning experiments. Figure 13 also shows that brightest region of the light field surrounding the arena shifts during the day. However, the brightest regions of the surrounding light field did not coincide with the sections of the trench into which the majority of hatchlings fell. In fact, no hatchlings fell into the trench sections that coincided with the brightest regions of the surrounding light field. But, if one were to divide the arena in half using a perpendicular line to the sea, the results of the second series of arena experiments show that significantly more hatchlings moved into the trench sections of the brightest half of the arena (Chi squared, $P > 0.05$). These results suggest that a phototropotactic reaction may be influencing the hatchlings, but their sea-finding behavior cannot be explained solely in terms of this reaction.

In both series of arena experiments the majority of hatchlings always fell into at least one of the two trench sections bordering the perpendicular line to the sea, yet the light measurements taken during the second series of arena experiments indicate that these sections were not the brightest regions of the light field surrounding the arena. This suggests that the movements of these hatchlings were also influenced by an orientation mechanism (or mechanisms) that did not rely on brightness as a cue, but in some way

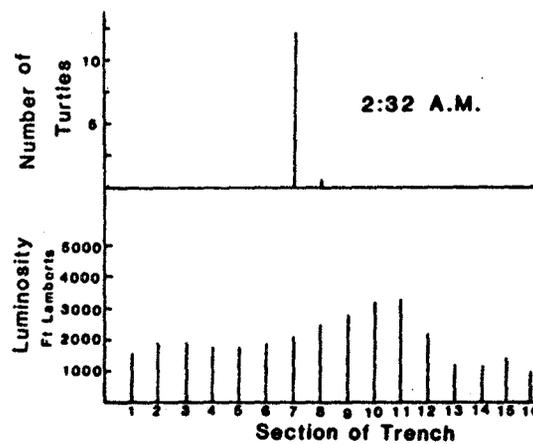
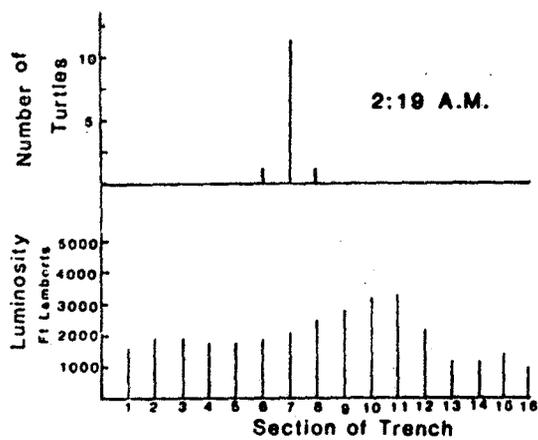
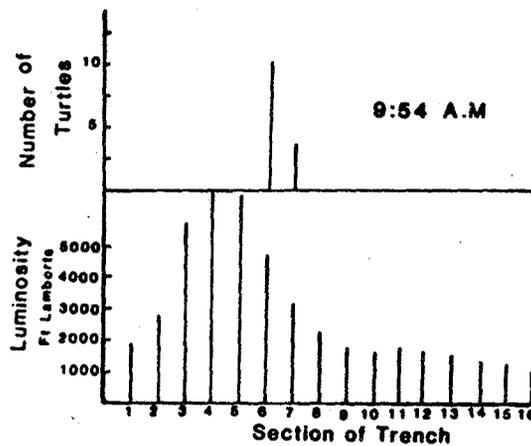
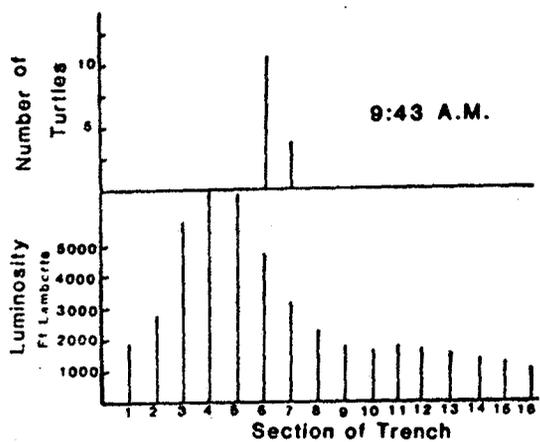


Figure 13. Directions of the hatchlings sea-finding movements together with the estimate of the light field surrounding the arena.

indicated the probable direction to the sea. Unfortunately, it is beyond the scope of this study to suggest the additional mechanism(s) responsible for the observed results.

In conclusion, this study indicates that the sea-finding behavior of L. kempfi hatchlings possesses not only characteristics of a phototropotactic reaction but also characteristics of an orientation mechanism that does not rely on light intensity as a cue.

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