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Behavior and ecology of sea turtles from Chesapeake Bay, Virginia

Richard Allan Byles
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Behavior and ecology of sea turtles from Chesapeake Bay, Virginia

Byles, Richard Allan, Ph.D.

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BEHAVIOR AND ECOLOGY OF SEA TURTLES FROM CHESAPEAKE BAY, VIRGINIA

A Dissertation

Presented to

The Faculty of the School of Marine Science

The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Doctor of Philosophy

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by

Richard A. Byles

1988

APPROVAL SHEET

This dissertation is submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Richard A. Byles

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DEDICATION

For mom, who always loved turtles.

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ABSTRACT

Immature foraging sea turtles occupy Chesapeake Bay, Virginia annually from May through November. Telemetry was used to monitor the movements and behavior of loggerhead, Caretta caretta, and Kemp's ridley, Lepidochelys kempi, turtles during 1981-1985. Both species utilized the estuary for summer foraging, but exhibited habitat-preference and behavioral differences that amounted to resource partitioning between the species. Loggerheads oriented towards major river outflows and tended to move along channel sides with the tidal flow while ridleys occupied shallower foraging areas and did not range as far with the tide. Strong site tenacity was displayed by both species once foraging areas were established.

Differences were apparent in respiratory behavior; ridleys remained on the surface for longer and underwater for shorter periods than loggerheads. Ridleys had a tendency to stay on the surface longer during daylight than night hours, whereas loggerheads surfaced and submerged longer during night than daylight. Estimates of daylight respiration behavior of loggerheads (surface to dive time ratio of 1:17) were used to adjust estimates of population size.

Replicated aerial surveys for loggerheads yielded an unadjusted mean population over 1982-1985 of 423. A respiration adjustment factor which accounts for turtles unseen because they are below the surface (17 turtles below the surface for every one seen at the surface) yielded an average annual estimate of 7905. Reported mortality is a small percentage (1.4) of the adjusted population estimate.

Mark-recapture, aerial survey and biotelemetric techniques were used in 1980 and 1982-1985 to elucidate migrations of loggerheads and ridleys which are incapable of overwintering in Chesapeake Bay. For both species, the period of residence in the Bay was correlated with water temperature. Migrations to the Bay were linked to vernal warming; the heaviest concentrations of turtles were found south of the 18 C isotherm. Fall migration was linked less strongly with declining water temperature and appeared to be related to the onset of winter storms. Migrating loggerheads remained nearshore in southerly currents in the fall. Contact with most telemetered loggerheads was broken in the vicinity of Cape Hatteras, North Carolina. A satellite-tracked loggerhead spent two months in the vicinity of the Gulf Stream offshore before contact was broken.

BEHAVIOR AND ECOLOGY OF SEA TURTLES FROM CHESAPEAKE BAY, VIRGINIA

Chapter I. INTRODUCTION

Turtles have evolved marine forms at least three times (Pritchard, 1979). Modern sea turtles, while not relict from prehistoric times, have survived since the age of dinosaurs. In the age of man, the survival of some species of sea turtles is questionable; formerly huge populations throughout the world have been decimated by disturbance of nesting and foraging habitats and overfishing.

Little is known of the ecology and life history of marine turtles. Carr et al. (1978) described in general terms the change in ecological station that sea turtles underwent when they quit the 'lost years' stage for the juvenile life history stage. Distinct changes accompany the transition from a pelagic to a benthic existence. Diving becomes more extensive, the ability to use anaerobiosis first becomes apparent and seasonal foraging migrations are made. At the onset of maturity, juvenile migrations to foraging grounds are replaced by separate adult foraging and sexual migrations. Since researchers are best able to study females on nesting beaches, details of early life history remain cryptic. Carr (1980) cited an "urgent need to reinforce the data from tagging at nesting beaches by tagging in foraging and developmental habitat". The work presented here focused on elucidating the behavior and ecology of juvenile sea turtles in a developmental way station on foraging grounds in Chesapeake Bay, Virginia.

Five of the seven extant species of sea turtles are found on the Atlantic coast of the U.S.A. These are grouped into two families: the Dermochelyidae and the Cheloniidae. The former family includes only one species, the leatherback, Dermochelys coriacea; the latter family includes all other species. Members of the Cheloniidae that occur in western Atlantic waters are the green turtle, Chelonia mydas, the hawksbill, Eretmochelys imbricata, Kemp's ridley, Lepidochelys kempi, and the loggerhead, Caretta caretta.

Two of these species are uncommon in and one is absent from Chesapeake Bay. Leatherbacks have been recorded in the upper reaches of the Bay (Hardy, 1969) but are more often found in the lower Bay and nearby Atlantic Ocean. Leatherbacks were regularly but not commonly noted on aerial surveys in the vicinity of the Bay mouth, presumably feeding on jelly animals flushed from the Bay (Keinath et al., 1987). Green turtles were historically recorded but are now rarely found in the Chesapeake Bay (Keinath et al., 1987). The hawksbill, although recorded in New England waters (Lazell, 1980), is extremely rare north of southern Florida waters (Hopkins and Richardson, 1984). No Virginia records of the hawksbill exist.

The species most common in the Bay, Kemp's ridley and the loggerhead, are seasonal visitors. Keinath et al. (1987) report examining 80 ridley and 1024

loggerhead sea turtles during the period 1979-1986. Most of the loggerheads and all of the ridleys were immature. The majority of the live turtles seen in the Bay have been active, healthy, feeding specimens. The Chesapeake Bay should therefore be considered, as suggested by Lutcavage and Musick (1985), an important foraging habitat for juvenile loggerheads and ridleys. Hence, investigations of these populations should provide missing details of life history.

The work presented here focused on three major aspects of juvenile sea turtle biology in the Chesapeake Bay: movements and behavior of loggerheads and ridleys, population size of loggerheads, and migratory activity of both species. Descriptions of movement and behavior (Chapter II) including foraging ranges, site fidelity, depth preferences, and respiration activity were obtained through the use of telemetry. Loggerhead population size (Chapter III) was estimated from aerial survey data adjusted for respiration behavior. Migratory activity (Chapter IV) was investigated through mark-recapture, telemetric, and aerial survey techniques. All of this information will aid in the management and recovery of these threatened and endangered species of sea turtles.

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II. MOVEMENTS AND BEHAVIOR OF *Caretta caretta* AND *Lepidochelys kempi* IN CHESAPEAKE BAY, VIRGINIA

Introduction

Few investigations exist of the developmental habits and habitats of sub-adult loggerhead sea turtles, Caretta caretta, or Kemp's ridley sea turtles, Lepidochelys kempi, (Carr and Caldwell, 1956; Limpus, 1979; Mendonça and Ehrhart, 1982). Lutcavage and Musick (1985) have identified the Virginia portion of Chesapeake Bay as an annual foraging habitat for sub-adult sea turtles, particularly loggerheads and ridleys. Carr et al. (1978), when discussing gaps in the knowledge of green turtle life history, cited an

> ...urgent need for additional information on other phases of the shifting ecology of the species, especially that of the turtles in their developmental and internesting habitats. It is in these phases of the life cycle that most populations are particularly vulnerable both to exploitation and to accidental capture in nets intended for other species.

This statement is applicable to all species of sea turtles and is particularly true for Chesapeake Bay turtle populations which are nearly all sub-adults and

experience mortality due to known and unknown causes (Lutcavage and Musick, 1985).

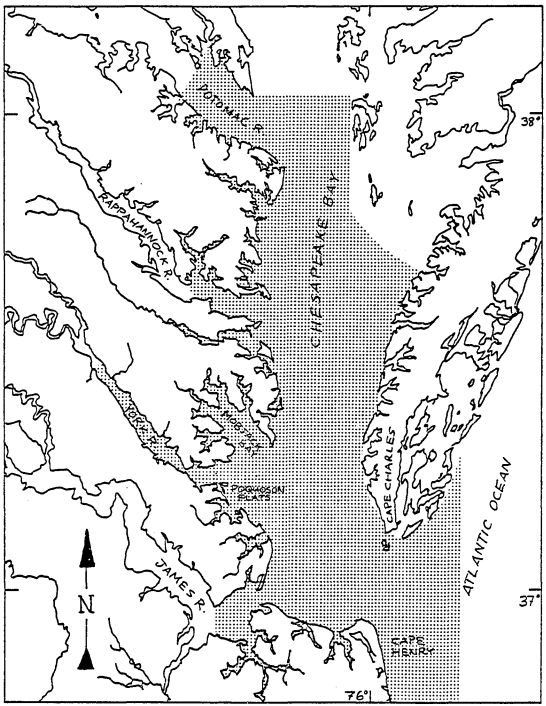
The purpose of this study was to document the natural history of populations of sub-adult sea turtles in Chesapeake Bay. The behaviors and movement patterns of particular interest in these estuarine waters include food habits, depth preferences, foraging ranges, philopatry and respiration regimes. Some information can be obtained through traditional methods, such as mark-recapture studies, examination of gut contents and feces, and casual observation. But in order to more fully elucidate these topics, methods which reveal data of greater resolution must be employed. In addition to utilizing the traditional research methods, a telemetry system for free-swimming sea turtles has been developed which allows more comprehensive data collection and greater insights into the natural history of sea turtles.

Materials and Methods

Study site.----The study site (Figure 1), located on the east coast of the U.S. within Chesapeake Bay, encompasses most of the lower Bay from the Potomac River south to the Bay mouth, an area of approximately 4000 km^2. The Chesapeake Bay, 320 km long and an average of 25 km wide, is the largest estuary in the U.S.A. Four of the five major tributaries of the Bay --- the James, York, Rappahannock, and Potomac Rivers --- drain into the study area.

The majority of the telemetric work with live specimens took place in a 350 km^2 area which included the York River mouth, the adjacent Mobjack Bay and nearby Chesapeake Bay. The York River east-southeast of Gloucester Point is 13 km long and averages 4 km wide (>50 km^2). Adjacent to the south of the York River is Poquoson Flats, a 60 km^2 shoal area. To the north is Mobjack Bay which is approximately 100 km^2 and is generally less than 6 m deep throughout its extent. The natural channel of the York River is relatively deep (12-30 m) and has flanking shoals. A dredged channel, the York River Entrance Channel, extends southeast from the

Figure 1. The study area.



York River mouth for 25 km, ending in mid-Chesapeake Bay. York Spit, a submerged sandbar, forms the northern boundary of the channel.

Specimen collection.----Live and dead turtles were collected throughout the entire study area. Live turtles were procured from commercial pound net fishermen who removed unharmed specimens from their nets, primarily in the York River area. Specimens were taken to the Virginia Institute of Marine Science (VIMS) to be examined. Turtles held for more than one week were kept in tanks with flow-through or recirculating water systems and were fed crabs or fish ad libidum. Dead turtles were reported to VIMS by the public.

Traditional procedures.----Autopsy procedures described by Wolke and George, (1981) were followed when possible. Prey item preferences were determined from a gross visual examination of the feces of live turtles held following capture and the stomach and intestinal contents of autopsied turtles.

All live turtles examined since 1979 were tagged with numbered Monel flipper tags. Photographs and measurements were taken and samples of epibiota and tissue were collected from all living turtles and from dead specimens when possible. Straight-line carapace

length (CLS, in cm), measured with forestry calipers, is the maximum carapace length taken from a position adjacent to the nuchal scute to the tip of the postcentral scute on the same side. Weights were taken with spring scales to the nearest kg.

Telemetric procedures.----A telemetric system which employed both custom-manufactured and standard equipment was developed to monitor and relocate free-swimming sea turtles on a continuous basis. The system consisted of both sonic underwater transmitters and radio transmitters, the former to maintain close contact and to pinpoint positions and the latter to determine time spent at the surface and to aid in long-distance monitoring by extending the range of the system. During the early stages of the study, only sonic devices were used on the turtles; radios were added, when possible, after the first field season.

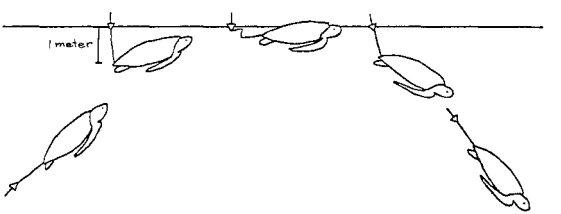
Various underwater sonic tags (26-42 KHz) were constructed or purchased and used in conjunction with directional, hand-held hydrophones and receivers (Smith Root, Inc., Vancouver, WA; Custom Telemetry and Consulting, Athens, GA) to obtain locations of the turtles from small boats. Tags were attached by stainless steel wire, electrician's ties or ferrous bolts through holes drilled in the pygal and peripheral bones

of the carapace. The corrosible ferrous bolts were used after the first year of the study to insure that the transmitters would detach within a year of application without harm to the turtle. Lithium battery systems were used for maximum transmitter longevity as these systems provide the best power characteristics on a per weight basis.

Radio tags (150-151 MHz) were used to locate turtles over long distances and to determine submergence behavior. Radio waves attenuate rapidly in sea water and therefore, of the many radio housings used, nearly all were designed to float behind the turtles on a short (one m) lanyard attached to the turtle with ferrous bolts through a hole drilled through the pygal bone. The lanyard insured that the radio antenna broke the surface of the water for signal reception when the turtle surfaced (Figure 2). Monitoring for the presence or absence of a radio signal yielded a good approximation of the time spent within one m of the surface by a turtle. Receiving platforms included various surface craft with Yagi antenna arrays or hand-held antennas, and a de Havilland Beaver aircraft with Yagi antennas mounted on the wing struts.

Monitoring movements and calculating positions allowed the determination of habitat use, foraging

Figure 2. Radio transmitter attachment.



ranges, preferred areas within the foraging range, and depth preferences. Positions were determined by locating the tracking vessel directly over the turtle and recording either Loran C coordinates or compass bearings to channel markers, buoys and landmarks with a hand-held sighting compass. All positions, whether determined by Loran C or by triangulation, were recorded on National Oceanic and Atmospheric Administration (NOAA) National Ocean Survey Charts. In the case of triangulation, three to five sightings were recorded for each position to reduce the area of uncertainty promulgated by drift, rocking, and poor viewing conditions. When triangulation lines did not converge at one spot, the center of the resulting polygon was taken as the position of the turtle. Depth, state of tide, weather condition, and sea state were recorded at all position fixes.

In order to analyze angular dispersion, the direction and magnitude of point-to-point movements were calculated and a mean vector of concentration on a unit circle was determined (Batschelet, 1972). Uniformity of the circular distribution was tested by the non-parametric Rayleigh test (Zar, 1984, pp. 442-443). A bi-modal distribution appears uniform with the Rayleigh test when the modal peaks cancel one another. For bi-modal distributions, data were therefore

transformed by doubling angles prior to testing for uniformity.

Respiratory behavior was observed from the tracking vessel visually when sea state was calm, and indirectly through radio signals. Surface and submerged times were indicated by the presence or absence, respectively, of the transmitted radio signal. Times were recorded to the nearest second with a digital stopwatch.

One way analysis of variance (ANOVA) was used to test for differences among turtles, among years and among sizes for both depth preferences and surface-submergence times. Student's t-test was used to test differences between species.

Telemetered turtles, with the exception of three specimens used for displacement experiments (see section on philopatry below), were released near their point of capture at the York River mouth. After release, turtles were continuously monitored for one to three days in order to establish swimming patterns. Thereafter, an attempt was made to obtain a minimum of one location per day. More intensive, continuous tracking periods were achieved when weather permitted.

Results and Discussion

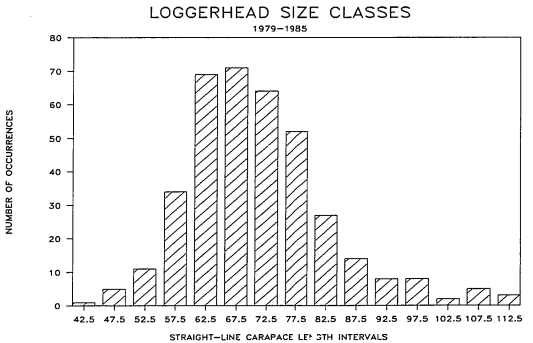
During the period from July 1981 to October 1984, two Kemp's ridleys and 12 loggerheads were monitored for 2-105 days in the Chesapeake Bay. Two of the loggerheads were tracked in two consecutive years (Table 1). Three turtles tracked for one day were dropped from the data analyses. Altogether, 158 positions were recorded for the ridleys and 736 positions were recorded for the loggerheads. The loggerheads tracked (Table 1) ranged in size from 55.0 to 75.0 cm CLS with a mean of 67.5 cm (se=7.1, n=12). This represents a reasonable cross-section of the sizes of loggerheads found in the Bay (mean=66.3, se=0.6, n=370, Figure 3a). Telemetered ridleys (51.2 and 54.6 cm) were selected from the larger end of the size range found in the Bay (mean=40.1, se=1.3, n=38, Figure 3b) in order to minimize the relative effects of transmitter drag on the animals.

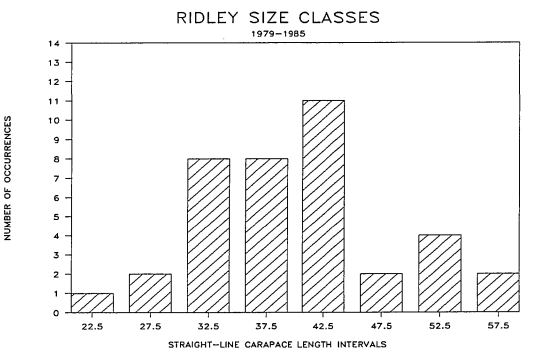
Equipment.----The lithium batteries used in both radio and sonic tags resulted in transmitter life of 9-12 months. Sonic signals could be detected regularly over distances of 2-4 km in good sea states. The best sonic reception (18 km) was recorded during unusually good

Table 1. Turtles tracked in Chesapeake Bay. The first two numbers of ID indicate year. Turtles marked with like symbols following ID were the same individuals tracked in a subsequent year. Size measured as straight-line carapace length (CLS). Species are abbreviated: Caretta caretta = CC, Lepidochelys kempi = LK.

Turtle (ID)	Species	Size (cm)	Weight (kg)	At large (days)	Located (days)
81.1	CC	62.3	36.0	54	51
81.2*	CC	66.0	43.0	39	30
82.1	CC	75.4	56.0	7	5
82.3	CC	57.7	25.0	3	3
82.4	CC	55.0	24.0	2	2
82.5	CC	59.5	28.0	21	12
82.6#	CC	62.0	40.5	36	25
82.7*	CC	69.0	--	30	10
82.8	CC	75.0	--	9	7
83.1	LK	51.2	15.7	48	25
83.2#	CC	64.5	37.0	66	37
83.3	CC	75.0	61.5	40	9
83.4	CC	77.2	68.0	13	8
83.5	CC	55.4	25.0	14	5
84.1	LK	54.6	20.0	105	56
84.2	CC	67.9	43.0	37	18

Figure 3. Size classes of Chesapeake Bay loggerheads (a) and ridleys (b).





conditions. Under adverse conditions the range of the sonic tags was reduced to less than 100 m. Heightened sea state, strong salinity gradients, bottom topography, suspended material, biological organisms and boat motors all produced conditions that refracted or blocked the sonic signal or masked it with ambient noise. A limitation imposed by the sonic system was the necessity of monitoring turtles from surface craft, which was impossible in severe weather.

Radio signals, which had a greater range than sonic signals, could be detected for 1-8 km from boats with a mast five meters above the sea surface, and 15-50 km from aircraft at 152 m altitude. The radio transmitters were used for two purposes: monitoring submergence behavior and long distance relocating of turtles that could not be detected by the sonic tag alone. The relocation of turtles using radio signals was most difficult from aircraft, even with the greater range imparted by increased platform altitude, because of the short (1-2 minutes) surface periods exhibited by the turtles. Approximate positions were often determined from radio signals and then turtles were relocated by boat using radio and sonic signals.

Depth preferences.----Carr and Caldwell (1956) reported ridleys and green turtles in grassbeds and channels

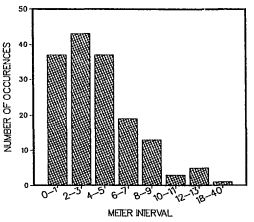
among the flats at Cedar Key, Florida, and noted that loggerheads frequented deeper water just offshore. A similar partitioning occurs in the populations using Chesapeake Bay. Loggerheads and ridleys showed preferences for specific but different water depths. A total of 736 locations and depths collected for 12 loggerheads yielded mean depths frequented by individual turtles of 7.2-11.4 m. Differences among individual loggerheads were found in the modal depth over the four years of the study (ANOVA, $F=10.03$, $p<0.001$). The two ridleys tracked yielded 158 locations and depths. There were no significant differences in the means of the two ridleys (4.1 and 4.9 m; t-test, $t=1.52$, $p=0.131$) but they preferred shallower water (mean=4.6 m) than did the loggerheads (mean=9.4 m; t-test, $t=16.89$, $p=0.0001$). Depth-frequency histograms (Figure 4a, b) illustrate the differences in depth preference for the two species.

Foraging ranges.----The term foraging range is used to indicate the home range established for feeding by individual turtles while in the Bay. Loggerheads tended to remain in channels or on the edges of channels as depicted in Figure 5 for a representative loggerhead which was tracked for 54 days. All York River loggerheads maintained foraging ranges that were oriented towards the river mouth, and none swam more than two km upriver. York Spit formed a physical northeastern

Figure 4. Depth preferences of ridleys (a) and loggerheads (b) telemetered in Chesapeake Bay.

DEPTH PREFERENCE

RIDLEY OCCURENCE BY DEPTH INTERVAL



LOGGERHEAD OCCURENCE BY DEPTH INTERVAL

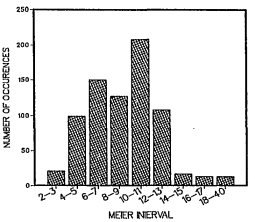
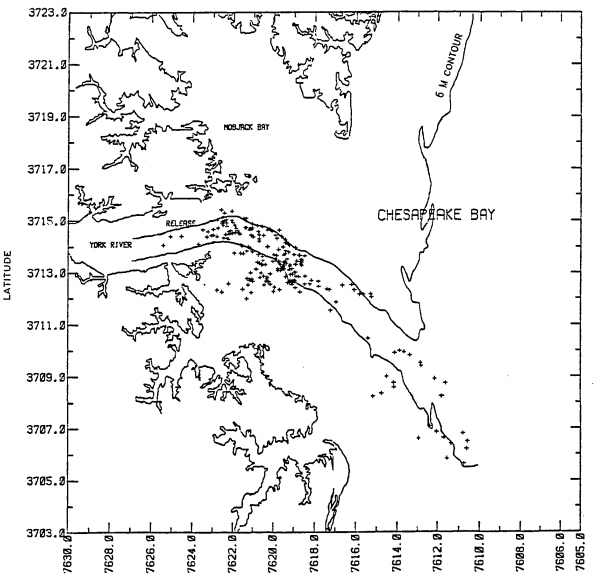


Figure 5. Channel oriented position fixes of a typical loggerhead.



boundary to the foraging ranges of all loggerheads captured in the York River (Figure 6). The only loggerheads that crossed this barrier were two turtles which were displaced from capture sites further north in Chesapeake Bay (see section on philopatry below). These two specimens returned to the rivers from which they were captured. In contrast to loggerheads, the two ridleys were often located on the York Spit. The southerly extents of ranges for York loggerheads were not as sharply delineated as the northern boundary, but were usually within the river discharge plume and bounded in the south by the gradually shoaling Poquoson Flats.

Home (foraging) range polygons (Moll and Legler, 1971), constructed for eight loggerheads, ranged from fairly restricted (10 km^2, Figure 7a) to extensive (80 km^2, Figure 7b). Evidence of a more restricted preferred area within the foraging range was demonstrated by 4 turtles; a representative example (Figure 7c) is a home range of 37 km^2 and a preferred area of 12 km^2 within the home range (Turtle 81.1, Table 1). Moll and Legler (1971) found preferred ranges within home ranges for a freshwater turtle, Psuedemys scripta, and Mendonça (1983) found a similar circumstance for green sea turtles, Chelonia mydas, in Florida.

Figure 6. All position fixes of telemetered loggerheads.

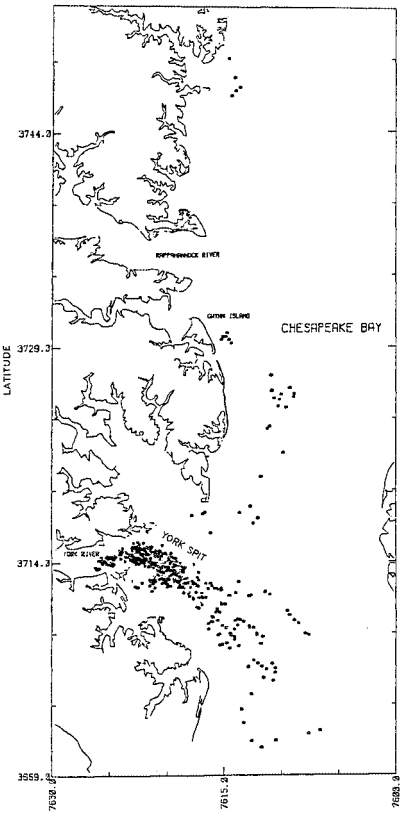
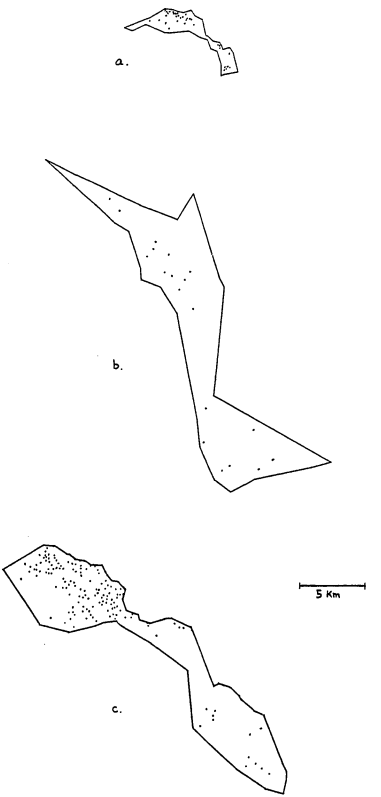


Figure 7. Comparison of restricted (a), extensive (b) and preferred (c) loggerhead foraging range polygons.

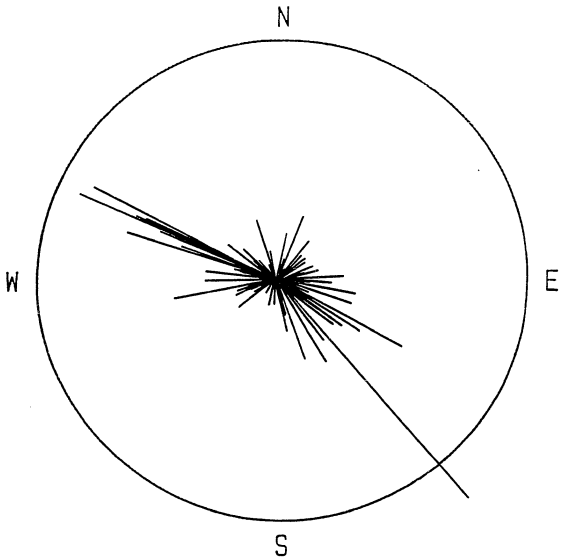


Swimming behavior.----Two general types of movements were exhibited by loggerheads in the foraging ranges: (1) long-term, generally circular paths which had durations of one to many tidal cycles and (2) straight line or elongate oval paths that traversed up and down river channels coincident with the tidal cycle. Turtles were also able to remain stationary at a preferred spot regardless of tidal conditions. Although movement patterns were variable, the typical pattern was generally less than eight km in the long axis. However on 18 August 1985, one loggerhead (82.5; Table 1) traveled 27 km away from the York mouth to a mid-Bay location prior to returning to its previously established foraging area.

Tides strongly influenced loggerhead movements. Direction diagrams constructed for loggerheads showed a strong northwest-southeast component that coincided with tidal direction near the river channel (Figure 8). When a crude estimate of the tidal component (from NOAA tide charts) was removed by vector subtraction from three turtles' preferred direction vectors, the residual movement vectors showed no preferred direction (Rayleigh's test, $z=0.583$, $p<0.05$).

Even though tracked loggerhead turtles were strongly influenced by the tide, most individual turtles

Figure 8. Typical loggerhead movement vectors. The length of the longest movement vector is approximately 12 km.



displayed the ability to remain stationary or swim perpendicularly to the tidal direction. Displacements due to tidal forces occurred while turtles were occupying a foraging area, returning to preferred sites or exiting the Bay in the fall. In foraging areas, loggerheads tended to drift with the tide, probably just over the bottom in search of food. Use of the tidal currents to encounter food would presumably be energetically advantageous.

In contrast to the loggerheads' preference for channels and their orientation toward the York River mouth, the two telemetered ridleys frequented much shallower water, and were found nearer to shore over shoal areas of less than five meters depth (Figure 9). There was no notable orientation to channels as seen for the loggerheads. One ridley (83.1; Table 1) travelled 13 km upon release from the York River to Mobjack Bay and then exhibited more circumscribed movement associated with foraging behavior. The other ridley (84.1; Table 1) was released in Mobjack Bay and then swam around Guinea Marsh, which separates Mobjack Bay from the York River mouth, and 20 km up the York River before returning three days later to Mobjack Bay, where it remained for the rest of the tracking period (Figure 10). This was the furthest upriver that any telemetered turtle swam. The habitat frequented by these foraging ridleys was

Figure 9. All position fixes of telemetered ridleys.

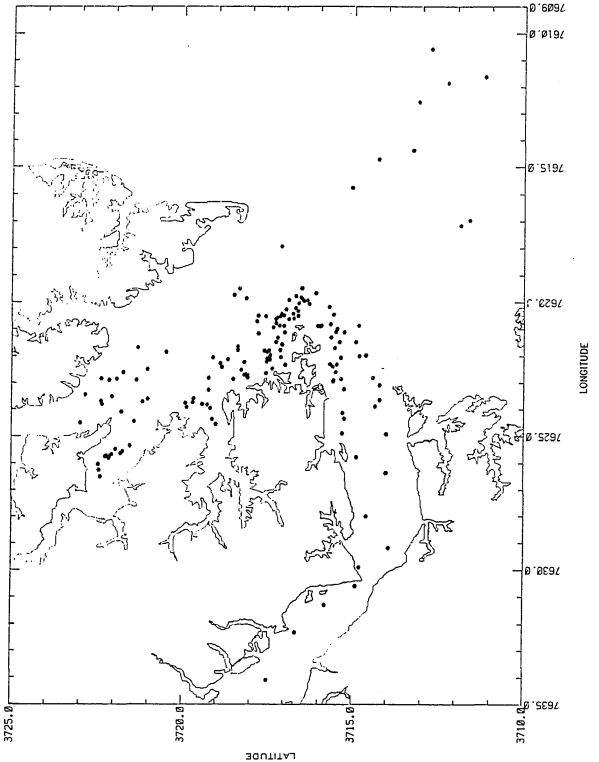
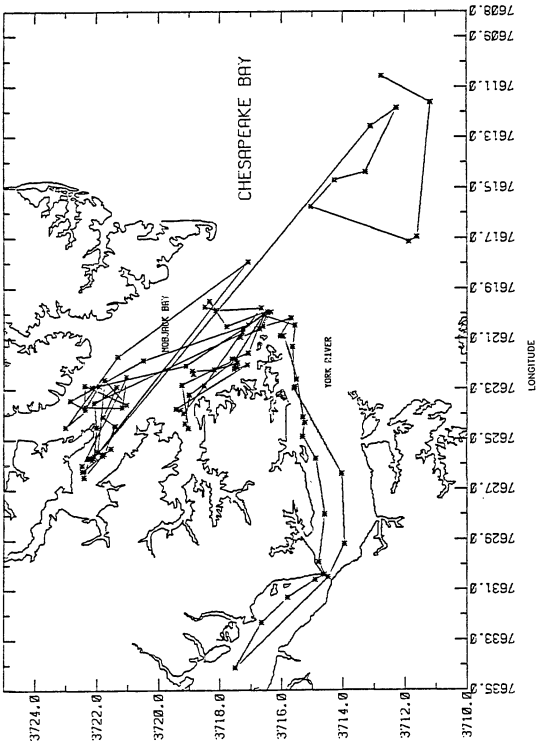


Figure 10. Movement track of one ridley.



characterized by extensive beds of submerged vegetation, predominantly Zostera marina and Ruppia maritima. The seagrass meadows of the lower Chesapeake Bay are important nursery areas for blue crabs, Callinectes sapidus (Heck and Thoman, 1984). Relocations for both ridleys were usually amidst the many crabpots placed in the area by commercial fishermen, which is not surprising in view of the ridleys' strong preference for blue crabs (Lutcavage and Musick, 1985).

No nightly sleeping sites were found for either species, contrary to the use of such sites by green turtles in a Florida lagoon (Mendonça, 1983). Although nightly sleeping sites were not noted, three different loggerheads were observed to remain at a location for extended periods without detected surfacing or moving. Turtle 81.1 (Table 1) remained submerged 24 hours on 23-24 July 1981 and for 16 hours on 3-4 September 1981. On the former occasion, the turtle was monitored continuously for eight hours with no detected surfacing; after a four hour interruption, it was relocated at the same position and monitored for three hours with no surfacing. On the latter occasion, this individual was monitored for five hours, followed by a seven hour interruption and was then relocated at the same position and monitored for four more hours before respirations were detected. That the turtle remained submerged the

entire time on both occasions can not be stated unequivocally, but continuous submergence seems likely in light of the lack of respirations before and after the monitoring interruptions and locations of the turtle in exactly the same position during both events. Another turtle (83.3; Table 1), after 60 days of tracking, became stationary and showed no evidence of surfacing during 147 hours of periodic monitoring from 27 September to 12 October 1983. During the stationary period, repeated, identical LORAN position fixes were obtained on ten occasions. Although continuous monitoring was not possible, the repetition of exact position fixes suggest that the turtle was stationary or at least returning to the same position for a minimum of eight days. On 12 October 1983, this turtle had disappeared from the location it had maintained for so long and could not be relocated. A third turtle (84.2; Table 1) was submerged for a minimum of 6 hours and 46 minutes during continuous monitoring the evening after release on 8 October 1984.

Loggerheads are known to 'mud in' regularly during summer in Florida and are often seen in this condition by divers (Norine Rouse, pers. comm.). It may be that this activity (summer anaerobiosis) is more common than we have previously had reason to believe, and that 'mudding in' occurs throughout the year. Anecdotal information reported by a VIMS scientist, R. Gammisch,

may support this contention. On September 1 and 5, 1985, he observed small turbidity plumes in otherwise clear water under the U.S. Army Corps of Engineers Pier, Duck, North Carolina in an area of a mud lens. The bottom surrounding the ocean pier is sand except where wave scour made a depression that collected the mud lens. Three loggerheads, two estimated at 0.5 m and one at one m carapace length, surfaced and swam slowly towards the northeast. The turtles' heads, proximal flippers and carapaces were covered with mud; plumes of mud trailed as they swam through water of approximately three m visibility. That the turtles burrowed in the mud is a certainty. Whether or not they remained below the surface longer than a normal (30-60 minutes submerged) respiration cycle is conjecture.

Loggerhead philopatry.----Turtles marked with numbered metal tags have returned to the Bay annually from wintering areas (see Chapter IV). Loggerhead turtles display a strong tendency to return to the same area each season and, when intentionally displaced, to return to the same area within the season. A loggerhead (81.2, 82.7; Table 1) that was tracked in 1981 and recaptured and tracked again in 1982, was found stranded dead within the Chesapeake Bay in 1983. A loggerhead (82.6, 83.2; Table 1) that was tracked at the York River mouth in 1982 was recaptured from the same location (same pound net)

and tracked again in 1983. Both of these recaptured turtles occupied nearly the same foraging ranges and exhibited movement behaviors similar to that each had established the previous year. Other multi-annual returns have been recorded from the Bay (see Chapter IV) through conventional mark-recapture studies. Site fixity was recorded for several turtles returning annually and being captured in the same nets in which they were first tagged by cooperating pound net fishermen.

Experimental evidence also supports strong philopatry. Two loggerheads captured in pound nets near the mouths of the Rappahannock and the Potomac Rivers in 1983 were displaced to the mouth of the York River for release. Both turtles returned from the release site to their respective capture sites. One turtle (83.3; Table 1) was released on 8 August 1983 and contact was lost 11 August 1983 due to equipment failure. Contact was re-established on 13 September 1983 near the original capture point at Gwynns Island, just south of the Rappahannock River mouth, approximately 40 km from the release site. The other displaced turtle (83.4; Table 1) was captured in the Potomac River mouth and released for tracking in the York River on 6 September 1983. Daily contact was maintained with this turtle as it swam more than 75 km in eleven days back to the Potomac River. This turtle achieved a net directional movement of nearly

seven km per day. However, within each day, its actual movement had a bi-directional tidal influence. The course doubled back on itself, in a two steps forward, one step back manner, as the turtle returned to its capture site.

Evidence from one loggerhead specimen (81.2, 82.7; Table 1) that was captured and tracked in the York River in 1981 and recaptured in the James River late in the 1982 season shows a multi-annual return to a different river system. However, when this specimen was displaced in 1982 to the York River for tracking, it resumed its prior year's orientation to the York mouth and did not return to the James River.

Respiration.----Respiration behavior in loggerheads occurred in three distinct phases: surfacing, respiring and diving. The respiratory cycle followed the general pattern described for aquatic turtles by Jackson (1979). Two modes of surfacing behavior were observed. Turtles usually approached the surface slowly, and often remained motionless or nearly so within the top meter of the water column, sometimes for several minutes before rising the last 50 cm or so, and breaking the surface with the carapace before raising the head above the surface. Occasionally a steep approach to the surface was noted, as also observed in aquaria, where the head

broke the surface first, and the animal exhaled explosively before inhaling. The resulting positive buoyancy allowed floating, at which point respiration proceeded as in the slow rising mode.

Before exhalation, approximately 5-10 cm of the carapace showed above the surface with the head completely submersed. Both front flippers were then raised simultaneously so that the tips extended 5-7 cm out of water. This was followed by a downstroke with both flippers as the turtle's neck arched up and head extended nearly straight up out of the water at an angle of greater than 60-80 degrees. It was after the first inhalation that the turtle would immediately dive if any disturbance occurred. Paired exhalations and inhalations occurred approximately every ten seconds while a turtle was floating at the surface. Each respiration pair involved a flipper downstroke, although the flipper tips did not always break the surface. Occasionally an extended period occurred between the first and second inhalations. Turtles often remained for a considerable period (up to several minutes) floating on the surface after the last respiration. Often the turtle turned slowly between inhalations, each downstroke of the flippers rotating the animal in the horizontal plane approximately 5-15 degrees in the same direction,

most often clockwise. The resultant orientation was rarely the same orientation as when first surfacing.

Two modes of diving behavior were observed, a slow dive and an immediate dive. In a slow dive, the dive angle was shallow, as the turtle swam forward in a straight line. It often took a minute or so for the turtle to achieve a depth of one meter, which was marked by the disappearance of the radio antenna. A rapid dive was usually initiated by the approach of the tracking vessel or another boat. The head was 'ducked' and the first simultaneous stroke of the front flippers pitched the body down to a steeper angle (10-30 degrees) and the second stroke was sufficient to propel the turtle several m at the steeper angle.

Loggerheads averaged 1.4 (range=0.43-4.48) minutes per respiration event and 18.9 (range=8.2-67.1) minutes per dive. One-way ANOVA revealed significant differences among individuals for mean surface time ($F=3.36$, $p<0.0016$) and mean dive time ($F=4.6$, $p<0.00001$). However, the mean ratio of surface:submergence time (7.3%) did not differ significantly among individual loggerheads. Kemmerer et al. (1983) reported no significant differences in surface time among six sub-adult loggerheads monitored in Florida. However, they reported only a few minutes on the surface per hour

(2.2), and did not extract submergence times from their data set, so direct comparisons to the present data set were not made. Loggerheads tended to remain on the surface longer at night than during the day (Figure 11); Kemmerer et al. (1983) found the same trend.

Ridleys spent significantly more time at the surface during each respiration (2.1 minutes) and less time submerged during each dive (12.7 minutes) than did loggerheads (t-tests, t=4.78 and -4.11, respectively, p=0.05). Respiration behavior of the two ridleys also differed significantly for surface and submerged times (t-test, t=4.74 and -6.13, respectively, p=0.05). As opposed to loggerheads, these two ridleys tended to remain on the surface longer during the day than the night (Figure 12). Mendonça (in Pritchard, 1980) found that adult females telemetered at the Rancho Nuevo nesting beach spent much less time at the surface (mean=23.74 seconds) and nearly twice as long submerged (mean=22.74 minutes) as did the juveniles studied here. Differences would be expected for two reasons: (1) adults have different respiratory cycles because of lower metabolism and greater lung capacities due to their larger sizes and (2) the behavior of gregarious adults involved in mating and egg production, attempts at mating or mating avoidance are not behaviors in the repertoire of solitary, foraging juveniles.

Figure 11. Loggerhead diurnal surface and submerged times.

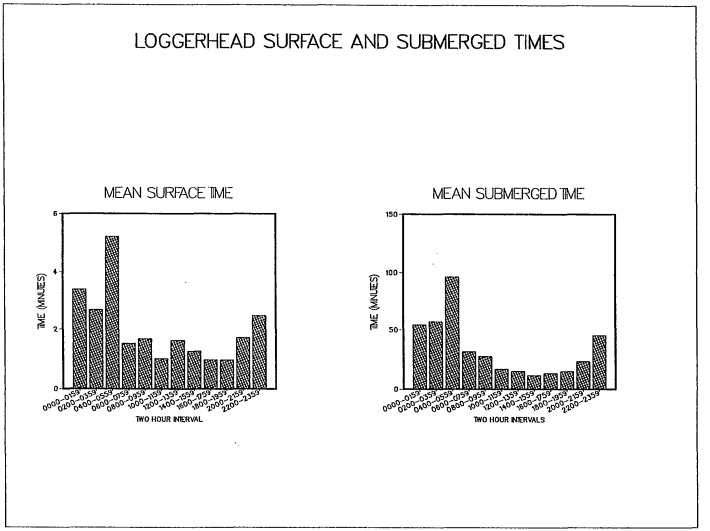
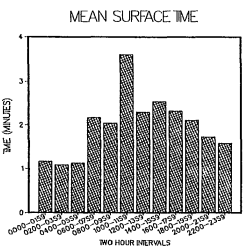
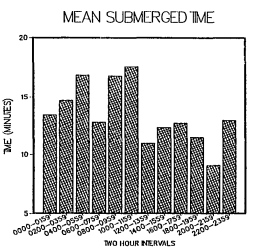


Figure 12. Ridley diurnal surface and submerged times.

RIDLEY SURFACE AND SUBMERGED TIMES





Floating behavior.----An unusual event was documented at the start of one loggerhead's (83.5; Table 1) fall migration (see Chapter IV) out of the Bay on 17 October 1985. This individual headed due east from the York Spit to mid-Bay, and maintained its course against perpendicularly oriented flood and ebb tides for one day. As the next ebb tide started, the turtle stayed on the surface for the entire ebb cycle before resuming the typical pattern of surfacing only to breathe. On ebb tide, surface waters flow more swiftly out of the Bay than do those at depth. The behavior of this turtle conferred the advantage of maximizing its movement while expending little energy. Only rarely was prolonged time at the surface recorded for turtles telemetered during this study and never to the degree that was recorded for this turtle. Prolonged surface behavior in flotillas is known for loggerheads from the Pacific Coast of Mexico (Cliffton et al., 1981; R. Marquez, pers. comm.).

Summary and Conclusions

The Chesapeake Bay is occupied annually by immature foraging sea turtles from May through November when surface water temperatures exceed 18 C (see Chapter IV). The predominant species are loggerheads, Caretta caretta, and Kemp's ridleys, Lepidochelys kempi. Radio and sonic telemetry was used to monitor the movements and behavior of 12 loggerheads and two Kemp's ridleys in the lower Chesapeake Bay for periods of 2-105 days during 1981-1985. Although the majority of the telemetered turtles were captured, released and tracked in the vicinity of the York River, conclusions concerning behavior will likely apply to all other lower Chesapeake river systems as well.

Both species utilized the estuary for summer feeding, but exhibited habitat-preference differences and behavioral differences that amounted to resource partitioning between the species. The loggerheads oriented towards major river outflows, tended to move along channel sides with the tidal flow and, as noted by Lutcavage and Musick (1985), fed primarily on horseshoe crabs, Limulus polyphemus. The ridleys, in contrast,

occupied shallower foraging areas over extensive sea grass beds (Zostera marina and Ruppia maritima), did not range as far with the tide and fed mostly on blue crabs (Callinectes sapidus). Strong site tenacity was displayed by both species once foraging areas were established.

Differences were also apparent in respiratory behavior, with the ridleys remaining on the surface for longer and underwater for shorter periods than the loggerheads. Ridleys also had a tendency to stay on the surface longer during daylight than night hours, whereas loggerheads stayed on the surface longer and also remained submerged longer during the night. An important aspect of behavior obtained from the telemetric study was the determination of daylight surface behavior of loggerheads which was used in estimation of the population size from aerial surveys (see Chapter III). Turtles deeper than approximately one m are not readily seen from the air due to the summer turbidity of the Bay. The average ratio of time spent at or near the surface, versus below, can be used to represent the ratio of the average numbers of turtles at the surface, versus submerged. These data can be used to correct for behavior the densities obtained from aerial surveys so that more accurate estimates of abundance can be calculated.

Annual occupation of areas such as Chesapeake Bay is an important stage in the life history of sub-adult loggerheads and ridleys that has only recently received attention by managers and scientists. The differences of habit, habitat and resource partitioning illustrated here stress the importance of managing these endangered and threatened reptiles at the species level rather than simply as "sea turtles."

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III. POPULATION ESTIMATES OF *Caretta caretta* IN CHESAPEAKE BAY, VIRGINIA

Introduction

The purpose of this study was to determine residence time and abundance of loggerhead sea turtles, Caretta caretta, foraging in lower Chesapeake Bay, Virginia each summer. Previous work by Lutcavage and Musick (1985) documented, through a stranding network, mortality in the Bay of this threatened species. For management purposes, it is important to know the population size and the percent of the population annual mortality represents. Using mark-recapture techniques, Lutcavage and Musick (1985) estimated the Bay population at 3000, although they warned that their data did not meet all the assumptions inherent in the model used. Their estimate may have suffered from inconsistent annual sampling effort, unknown emigration and immigration and unknown tag loss rates, and is likely an underestimate.

A major focus of work presented was to obtain population estimates using aerial survey methods. Aerial surveys of lower Chesapeake Bay were made bi-weekly during the foraging seasons of 1982-1985. The actual number of turtles observed on the survey transects was the minimum population occupying the Bay. This

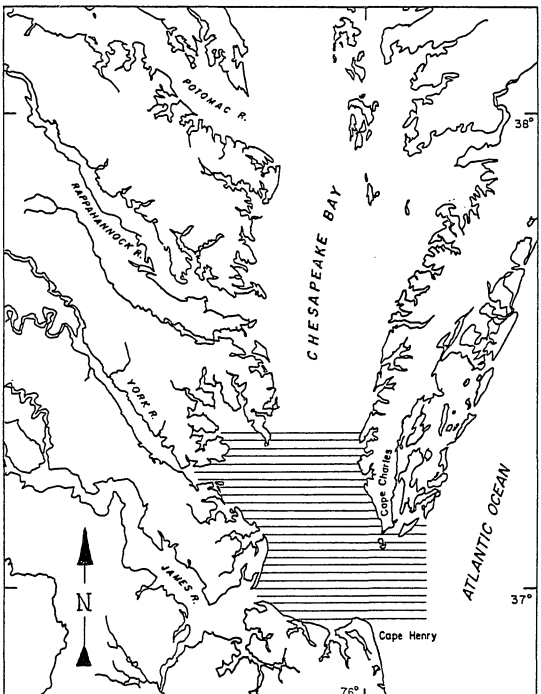
number was extrapolated to the larger study area to estimate the population size based on the density of turtles observed at the surface. Two correction factors were also separately applied to estimate population size. An adjustment factor representing the time loggerheads spend on the surface as opposed to below the surface accounts for submerged turtles which cannot be seen from the air. Such a correction factor is clearly necessary, but the requisite behavioral information had not previously been obtained. Individual turtles may also be unseen due to visual limitations imposed by sighting distance. Another adjustment factor, based on calculated detection probability curves (see Burnham et al., 1980; Buckland, 1985), compensates for sighting-distance difficulties. I made a modification of usual line transect procedures to deal with technical difficulties of the data set. The two correction factors are applied separately; each yields an estimate of the summertime density of loggerheads in lower Chesapeake Bay. Corrected and uncorrected population estimates may then be compared with mortality data to determine the impact of observed mortality on the population.

Materials and Methods

Aerial survey procedures.----Aerial surveys were performed in lower Chesapeake Bay (Figure 1) during the residence period (see Chapter IV) of sea turtles in 1982-1985. Surveys commenced approximately in May and usually extended through October. Each year, exploratory flights in the Bay region and along the Atlantic coastal region south to southern North Carolina were also made to document spring and fall migrations (see Chapter IV) and to determine the starting and ending aerial survey dates. All surveys were made from a high-winged military observer aircraft, a de Havilland Beaver, at a speed of 148 km per hour and an altitude of 152 m. Flights were made under Federal Aviation Administration Visual Flight Rules between 1000 and 1300 Eastern Daylight Time on a roughly bi-weekly schedule. The exact day and hour of flights was dictated by prevailing weather conditions. Due to difficulties in observing turtles, flights were precluded or aborted when sea states were above Beaufort 3 (winds of greater than 5 m/sec).

The study area (Figure 1) was divided into six blocks of four east-west transect lines. The transect

Figure 1. Aerial survey study area.



lines were not of equal length; end points were usually determined by shorelines. Each of the 24 possible transect lines were 1.85 km from adjacent lines. For each survey flight, four equidistant replicate lines, one in each block, were selected based on a first line randomly chosen by the roll of a die. The first line (always the northernmost) was flown from west to east and each ensuing line was flown in alternating directions. Two trained observers were present on each flight, one to record turtle sightings on each side of the aircraft. Flight time on the transects was usually less than forty minutes and entire flights were less than 1.5 hours. The short flights made it unnecessary to rotate observers. Data recorded included: species, time of sighting (to the nearest second), angle of inclination to the turtle (taken with a Suunto hand held inclinometer), activity (submerging, on surface, etc.), and approximate compass direction of each turtle's orientation. Information on sea surface conditions, weather conditions and amount of reflected glare were also noted throughout each flight. Data were recorded simultaneously on tape recorders and data sheets, and were later cross-verified.

Population estimates.----Population size may be underestimated if turtles at the surface are missed due to rough sea state, glare, or other factors. Except for bright-colored floats, fishing buoys, etc., only large

objects were detected at the altitude flown. We estimated that turtles of less than 30-40 cm in length were probably not seen from the air so the surveys were biased towards larger individuals. Juvenile ridleys that occupy the Bay are more cryptically colored and generally smaller than loggerheads, hence, aerial surveys could not be reliably used to estimate ridley population size. Biases due to observer, glare and sea state were examined with chi-square tests. In addition, within-year and among-year comparisons were made.

Population estimates of sea turtles are also affected by respiration behavior --- the relative time animals spend at and below the surface --- because only turtles at the surface can be observed. Radio telemetry was used to determine the mean proportion of surface to submergence time for loggerheads (see Chapter II). The inverse of this ratio was multiplied by the unadjusted density estimate to compensate for submerged turtles. The adjusted density estimate was then divided by the fraction of the study area that was observed in order to extrapolate population size from the strip transect measurements. This method corrects for respiration behavior but does not correct for other technical difficulties (i.e., sighting distance) inherent in the sampling procedure.

The aerial surveying procedures used did not meet the strip census assumption (Gates, 1979) that all individuals within the sampling strip are observed. More appropriate for the present data set is line transect theory, a fundamental property and advantage of which is that not all individuals will be detected (Burnham et al., 1980). Major assumptions are that all individuals on the transect line are observed, but the further an object is from the transect line, the lower its probability of detection. Necessary data are turtles observed and sighting distances, from which abundance is inferred through the generation of a detection function. The detection function, $g_{(x)}=Pr(\text{object observed}|x)$, describes the probability of observing an object in terms of its distance from the transect line. The detection function from truncated data was modelled with Hermite polynomial estimation using a computer program provided by S. T. Buckland, University of Aberdeen, Old Aberdeen, Scotland. In addition, a modification was applied to attempt to account for violation of the assumption that all individuals on the transect line are observed (see Results and Discussion).

Mortality estimates.----Procedures for collecting mortality information follow those outlined by Lutcavage and Musick (1985). Requests to the public (including commercial fishermen) and facilities (including military,

law enforcement and beach cleaning personnel) yielded information on species and condition of stranded sea turtles. Virginia Institute of Marine Science (VIMS) personnel examined stranded turtles and recorded carapace straight-line length (CLS, in cm), as well as the presence of tags and injuries. Necropsies (Wolke and George, 1981) were performed on fresh strandings, and when possible, sex was determined by gross gonadal examination or histologically and stomach and intestinal contents were collected.

Results and Discussion

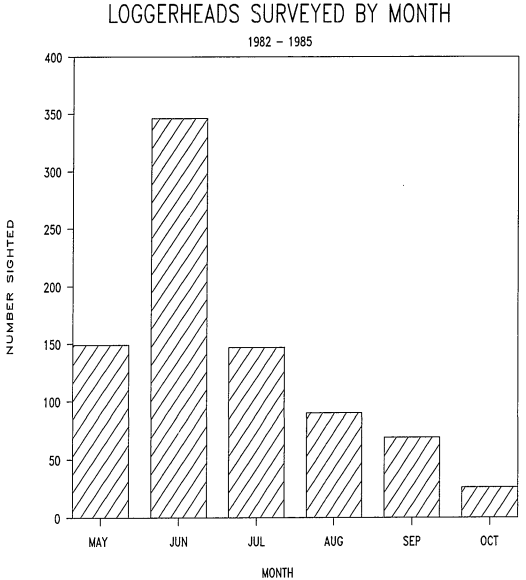
Aerial survey sampling variation.----Summary information for each of the four years of the study is presented in Table 1. Flights at the beginning or end of each season, during which no turtles were observed, were not included in the analyses (the season was considered not to have begun or to have ended at these times). Flights in mid-season on which no turtles were observed were included in the analyses. The total number of flights and area observed differed slightly from year to year and, because transect lines were of unequal length, the area per flight also differed from year to year. Four to five percent of the study area was sampled on each survey flight.

The total number of turtles observed over a year ranged from a low of 168 in 1982 to a high of 272 in 1983 (Table 1), and unadjusted densities varied significantly among years (chi-square=49.4). The number of turtles observed per flight peaked near the beginning of each season (Figure 2) and decreased as turtles dispersed throughout the lower Bay. Within each year,

Table 1. Loggerhead densities from aerial surveys.

Year	Flights (number)	Total area observed (km^2)	Average area per flight (km^2)	Total turtles observed (number)	Average turtle density (number/km^2)
1982	10	632	63.2	168	0.266
1983	12	721	60.1	272	0.377
1984	10	629	62.9	207	0.329
1985	11	699	63.5	176	0.252

Figure 2. Loggerheads sighted by month summed over 1982-1985.



variation in numbers sighted among flights was high (range=0-57; chi-square=1020).

Differences in numbers of turtles recorded due to observer, glare and sea state were all significant. Sea state and amount of glare contributed the most bias (Table 2), fewer turtles being seen with increased glare and increased surface disturbance. No attempt was made to adjust for these biases as they were all negative (reduced the number of turtles that could be observed) and tended to make the resultant estimate more conservative. Since methods were being employed to adjust for unseen turtles, my goal was to deal conservatively with other factors.

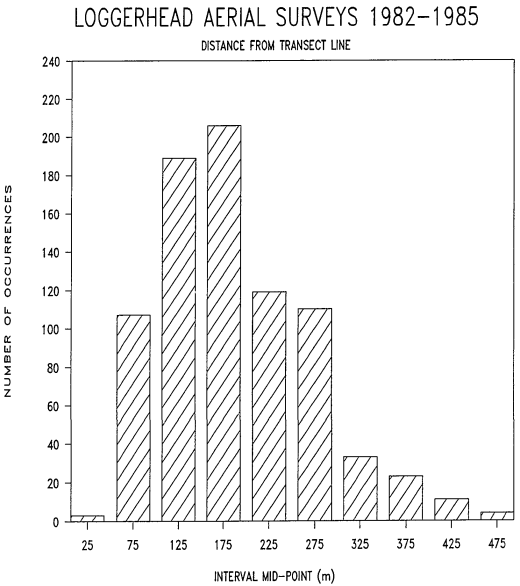
The number of turtles observed changed over the potential viewing strip of 0 to greater than 500 m on each side of the flight path (Figure 3). At 0-50 m turtles could not be adequately viewed from the lateral windows of the aircraft, and sightability dropped precipitously at greater than 300 m from the aircraft. Accordingly, an effective strip width of 250 m on either side of the plane (50-300 m) was used for the basic calculation of loggerhead densities in Table 1.

Unadjusted population densities.----Densities were calculated for each year by summing the number of turtles

Table 2. Biases on survey flights affecting turtle sightability. Expected values for observers are total turtles observed, multiplied by the percentage of the total km that each observer flew during the study. Expected values for sea state and glare are the total turtles observed divided equally between the factors. Sea states are Beaufort states 0-3. Glare is 1=little or none, 2=moderate, 3=severe.

Factor	Observed Frequency	Expected Frequency	Chi-square	
Observer				
1	113	118	0.178	
2	69	65	0.302	
3	188	169	2.157	
4	288	254	4.495	
5	170	223	12.484	
			19.616	d.f.=4
Sea State				
0	164	207	8.93	
1	435	207	251.13	
2	107	207	48.31	
3	132	207	27.17	
			335.54	d.f.=3
Glare				
1	767	276	873.48	
2	57	276	173.77	
3	14	276	248.71	
			1295.96	d.f.=2

Figure 3. Distance-frequency histogram of loggerheads sighted on all transects averaged over 1982-1985.



seen on all flights and dividing by the area observed. The area observed was equal to the total linear distance flown over suitable habitat multiplied by the effective strip width (250 m x 2). Suitable habitat was defined as water in excess of three meters depth. Loggerheads were not found in waters less than three meters depth during extensive telemetric monitoring (see Chapter II). Transect lines were terminated at the three meter contour line (National Oceanic and Atmospheric Administration (NOAA) navigation charts) and the study area of 1383 km^2 also reflected this restriction. This procedure yielded the surface density of turtles sampled on the flight path, which, when extrapolated to the study area, gave a minimum, unadjusted population size (uncorrected for submerged animals or observation biases). Unadjusted and extrapolated abundance averaged over all years was 423 turtles per season (Table 3).

Behaviorally-adjusted estimates.----To more realistically estimate population size, the unadjusted densities were corrected for respiration behavior based on daytime telemetric information (Table 4). The radio telemetry study was designed to record turtles within the top m of the water column as being at the surface (see Figure 2, Chapter II). These data provide an appropriate correction factor because turbidity in the Bay during the summer season prevented aerial

Table 3. Population estimates of loggerhead numbers per year in the 1383 km^2 study area. Behaviorally-adjusted estimates are based on a correction factor of 18.7 for unseen, diving turtles. Line transect-adjusted estimates are based on a Hermite polynomial estimation for detection probability equations to correct for unseen turtles on the surface (see text).

Year	Unadjusted	Behaviorally-adjusted	Line transect-adjusted
1982	367	6862	420
1983	521	9743	516
1984	454	8490	236
1985	348	6526	314
mean	423	7905	372
se	80	1496	122

Table 4. Loggerhead surface and submergence times. Data are based on radio telemetry from daylight hours only from 1982 and 1983. The first two numbers of the turtle ID are the year in which that individual was tracked.

Turtle (ID)	Size CLS (cm)	Weight (kg)	Mean time on surface (minutes)	Mean time submerged (minutes)	Ratio	n
82.2	75.4	56.0	1.3	34.2	26.3	38
82.5	59.5	28.0	1.0	11.6	11.6	103
82.6	62.0	40.5	0.4	9.6	24.0	118
82.7	69.0		3.1	67.2	21.6	31
83.3	75.0	61.5	0.6	9.9	16.5	41
83.4	77.2	68.0	0.6	10.8	18.0	90
83.5	55.4	25.0	1.8	11.2	6.2	47
		mean	1.3	22.1	17.7	
		se	0.9	21.8	7.1	

observations of turtles at depths greater than one meter. In respiration studies (Chapter II), loggerheads were observed to spend 17.7 minutes submerged for every minute on the surface. This 17.7:1 ratio implies that for each turtle on the surface there were 17.7 turtles below the surface. Therefore, a turtle observed on the surface was taken to represent 18.7 turtles.

The assumptions of this procedure are that (1) surfacing behavior among turtles was independent (2) turtles were counted only once and (3) both the observed and unseen turtles were exhibiting behavior similar to that of turtles in the biotelemetric study of respiration behavior. Based on field observation, the first assumption appears valid. The survey design insured compliance with the second assumption: transect lines flown during a survey were always separated by a distance (11 km) greater than the distance that loggerheads can swim in the approximately 20 minutes required to complete two adjacent transect lines. The third assumption cannot be directly tested, but hundreds of contact-hours indicate that telemetered loggerheads reverted to 'normal' (or at least reasonably predictable) behavior a few hours after release. The principal reaction of all telemetered turtles upon release was to flee a disturbance (the boat). This was marked by frequent (several hundreds per hour), short

(5-10 seconds) respirations and straight-line, high-speed (2-3.5 km per hour) swimming. Within hours, this behavior changed to a more leisurely meandering, with less frequent respirations and longer periods spent both at and below the surface. Distinctive respiration patterns, which remained characteristic throughout the monitoring of given individuals, developed rapidly. None of the 12 loggerheads tracked in the Bay took longer than a day to settle down to what was considered "undisturbed" respiration behavior. Kemmerer et al. (1983) telemetered Florida loggerheads and omitted as non-normal respiration data from the first three post-release days for each turtle. Likewise, the adjustment factor applied here was based on data obtained after a 'settling down' period of one day.

The assumption that telemetered turtles and those observed aerially exhibited the same respiration behavior is supported by further information. Most importantly, both groups of turtles came from the same stock, i.e., loggerheads that migrated into Chesapeake Bay. Since all of these animals were exhibiting the same behavior (foraging), major differences in respiration would be unlikely. However, the current adjustment factor of 17.7 should not be applied to turtles outside the Bay, since coastally migrating turtles may spend more time at the surface and less time feeding, and hence may

display different respiration behavior. Loggerheads may spend as much as 17% of their time at the surface before entering or after leaving the Bay (Keinath et al., 1987), as opposed to 5.6% at the surface in the Bay.

Behaviorally-corrected population estimates for the summer foraging stock of loggerheads in the study area ranged from 6526-9743 (Table 3). Extrapolations to the entire Bay were not made because habitat and extent of occupation by turtles outside the study area have not been well examined. Exploratory aerial surveys between the Rappahannock and Potomac Rivers in 1984 and as far as the Patuxent River in 1985 and 1986 indicated that loggerheads were not as abundant in the upper as in the lower portions of the Bay (Keinath et al., 1987).

Line transect-adjusted estimates.----In addition to the respiration-behavior adjustment, several other methods could be used to produce corrected population estimates from the raw density information. Commonly used strip census methods (Gates, 1979) were not applied because the assumption that all, or nearly all, of the individuals in the strip are seen was violated. Frequency of observed turtles decreased with increasing distance from the aircraft (Figure 3). Line transect methods outlined by Burnham et al. (1980) assume that not all individuals on the transect are observed and corrects, by use of a

probability density function which estimates a detection function, animals unseen due to distance from the observer. With the data presented here, the major line transect assumption that all individuals on the transect line are observed is violated. To accommodate line transect theory, the data were modified by omitting the 100 m directly below the plane (where turtles were impossible to see) and abutting the effective strip widths from either side of the aircraft. This technique has been suggested (Blaylock, in press) to correct aerial survey data for animals unobserved on the transect line.

Line transect analysis of the survey data produced a probability density function best modelled by a Hermite polynomial function (Buckland, 1985). The density function $f_{(x)}$ relates to the detection function $G_{(x)}$: $G_{(x)} = \mu f_{(x)}$. Calculation of $f_{(x)}$ by iteration was performed by a computer program supplied by S. T. Buckland (see Buckland (1985) and Burnham et al. (1980) for complete discussions of the models and issues of line transect theory). Results of the program were estimates of $f_{(x)}$ and best fit statistics (chi-square and log-likelihood) for Hermite polynomial functions with 1,2,3 and 4 terms. The models provided only moderately good fits to data sets for 1982-1985 or all years combined (Table 5) perhaps due to the underlying shapes of the detection curves. The best fit for each year was used

Table 5. Estimates of $f_{(0)}$ using Hermite polynomials.

Year	$f_{(0)}$	se	Chi-square	Log-likelihood	No.Terms
1982	4.5734	0.1175	6.96,df=5	-15.304	2
1983	3.9567	0.4332	6.54,df=4	-18.747	3
1984	2.0818	0.4891	6.61,df=3	-16.749	3
1985	3.6061	0.8214	4.99,df=2	-12.598	3
All	3.2291	0.3049	15.49,df=3	-26.441	4

to calculate turtle densities, $\hat{D}=nf_{(0)}/2L$, where $\hat{D}$ is the estimated density, n is the number of turtles seen, $f_{(0)}$ is the probability density function evaluated at 0 (the transect line), and L is the length of the transect line. These corrected densities (Table 3) are comparable, for three of the four study years, to the unadjusted densities calculated from strips on either side of the transect line. The fit of the density function to data for 1984 resulted in a 50% decrease in the density estimate.

Mortality estimates.----What then is the annual mortality rate of loggerheads in Chesapeake Bay? How does the estimated annual mortality rate compare with the estimated population size? Since the work reported by Lutcavage and Musick (1985), VIMS has maintained a stranding network to obtain an annual index of mortality. The number of dead turtles stranded on the beach or trapped in nets and observed by network participants and VIMS personnel was obviously an underestimate of the total number of mortalities, but it is difficult to say by how much. Virginia has over 9,000 km of shoreline, much of it undeveloped or difficult to survey; many dead turtles may be undetected. Dead turtles are also not observed if they decompose at sea and do not float to shore. Annual reported mortalities ranged from 51 to 131, which was 15-30% of unadjusted population estimates

and 16-52% of line transect adjusted estimates (Table 6). The known mortality rate of the Bay population estimate adjusted for diving behavior averaged 1.3% (Table 6). Since a population estimate adjusted for behavior is most realistic, it may be that the true annual mortality rate of loggerheads in Chesapeake Bay is less than 10 percent.

Table 6. Reported mortality and mortality rates based on population estimates for loggerheads within the study area.

Year	Mortality	Mortality rates		
		Unadjusted	Behaviorally-adjusted	Line transect-adjusted
	(number)	(%)	(%)	(%)
1982	113	30	1.6	27
1983	131	25	1.3	25
1984	124	27	1.5	52
1985	51	16	0.8	16
mean	105	25	1.3	30
se	37	6	0.4	15

Summary and Conclusions

The earlier estimate of 3000 loggerheads in Chesapeake Bay (Lutcavage and Musick, 1985) was based on mark-recapture techniques and is probably an underestimate. The survey methodologies presented here yield estimates of loggerhead abundance in lower Chesapeake Bay based on replicated aerial surveys coupled with adjustment factors. The mean population estimate (7905) adjusted for respiration behavior accounts for turtles unseen because they are below the surface, and so probably more accurately depicts the true population size than unadjusted densities. Density estimates that do not account for diving turtles estimate only the population at the surface of the water. Another method was separately used to adjust raw densities: line transect theory adjusts for turtles which were at the surface, but not observed due to distance (Burnham et al., 1980). This method should theoretically be suitable for estimation of the population but equipment limitations (aircraft) and the behavior (diving) of the animals preclude viewing all the turtles on the transect line, violating a major assumption of the theory. A modification of the method yielded an

average annual population size of 372 loggerheads. This was done for purposes of comparison to the basic estimates calculated from selected strips on either side of the transect line, but should not be applied without thorough testing.

The behaviorally-adjusted estimates are considered to be the best estimates available. This method is conservative because it does not correct for sighting difficulties (turtles at the surface but not observed, as well as negative biases such as glare, sea state, etc.) An ideal estimation technique would incorporate (1) line transect methods with the proper aircraft to accurately estimate the numbers of loggerheads on the surface, (2) a respiration-behavior correction factor drawn from a large sample to account for unseen, diving turtles and (3) corrections for the negative biases.

The estimates of annual migrations of 6,500 to 9,700 loggerhead turtles in lower Chesapeake Bay reflect the importance of the Bay as a major foraging area for immature turtles on the eastern seaboard of the United States. Although loggerheads are found from the Gulf of Mexico and Caribbean to Canada (Carr, 1952; Lazell, 1980) and Europe (Brongersma, 1972), such a concentration of juveniles as found in Chesapeake Bay has not been reported elsewhere. Chesapeake Bay is among the largest

and most productive estuaries in the world and is clearly the most important nursery or foraging habitat for the juvenile life history stage of loggerhead turtles yet to be described.

Population and mortality estimates presented here were based on procedures that require verification for accuracy, but methods used were conservative. The reported mortality is a small percentage of the estimated population, but this is surely an underestimate because an unknown percentage of dead turtles were missed. Man-induced mortality accounts for the majority of the determinable cause of death in loggerheads in the Bay (Keinath, et al., 1987). Such sources of mortality can and should be eliminated. However, for the vast majority of mortalities (greater than 70%), cause of death cannot be determined. We must continue to investigate the reasons for these mortalities if we are to promote the recovery of this threatened species.

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IV. MIGRATION OF *Caretta caretta* AND *Lepidochelys kempi* FROM CHESAPEAKE BAY, VIRGINIA

Introduction

Juvenile sea turtles --- primarily loggerheads, Caretta caretta, and Kemp's ridleys, Lepidochelys kempi --- appear annually in Chesapeake Bay, Virginia. Lutcavage and Musick (1985) maintained, on the basis of live capture and stranding records, that both species occupy the Bay from May through October. This contention has been verified in the present study with aerial survey data (Chapter III). The activity of Bay populations during the remainder of the year has not been documented. Two possibilities exist: sea turtles may migrate to and from the Bay, or they may overwinter in the Bay.

Overwintering would require brumation, which refers to a state of reduced physiological activity during winter dormancy in ectotherms (Mayhew, 1965). Whittow (1973) states that true hibernation as applies to endotherms cannot occur in ectotherms. Sea turtles, like most temperate fresh water turtles, can overwinter by burrowing in the substrate and undergoing brumation (Carr et al., 1981; Felger et al., 1979). However, it is unlikely that sea turtles can overwinter in the Bay by brumation because very cold temperatures (1-5 C)

penetrate to the substrate in the winter months. Sea turtles have been shown to succumb to temperatures below 10 C (Schwartz, 1978). Evidence presented here suggests migration of sea turtles to warmer waters each fall and remigration in the spring. Several questions about these seasonal migrations are germane: What is the temporal pattern of migrations? What are the migratory pathways between summer and winter habitats? At what sites are the turtles overwintering?

These questions may be approached through a variety of techniques. Mark-recapture studies (Lutcavage and Musick, 1985), which have been continued in the present study, are important for point-to-point locations but yield little behavioral information. Additional information concerning the spatial and temporal paths of migrations, which can also be correlated with environmental conditions, can be inferred from aerial survey data. Biotelemetric techniques can further elucidate migratory behavior. Turtles tagged with radio and sonic transmitters and tracked with small craft (boats and planes) permit description of migratory pathways. But technical limitations of tracking from small craft call for other methods to obtain long-term, open-water movements and to determine overwintering sites. Tracking turtles via orbital satellites reduces the need of an extensive outlay of manpower and equipment

to follow free-swimming turtles. Information from these three approaches for 1980 and 1982-1985 is reported and synthesized here.

Materials and Methods

Mark-recapture methods.----Mark-recapture studies (Lutcavage and Musick, 1985) were continued from 1982-1984. Capturing and marking sea turtles was accomplished with the aid of cooperating poundnet fishermen who regularly removed live turtles from the impoundment heads of their net fish traps. Turtles so removed were marked on the front flippers with numbered Monel tags. Recapture data were recorded from previously tagged turtles by watermen. In addition, the Virginia Institute of Marine Science (VIMS) stranding network obtained data on stranded, dead turtles. Procedures follow those outlined by Lutcavage and Musick (1985) for the same populations studied in 1981 and 1982.

Aerial surveys.----Non-systematic, longshore aerial surveys were flown in the spring and fall of 1982-1985 to follow the progress of turtle migrations. All survey flights were conducted with a pilot and one or two observers in a de Havilland Beaver, high-winged monoplane. Flights were made between 1.8 km and 18 km from shore at an altitude of 152 m and a speed of 140 or 190 km per hour. Locations of turtles were plotted on

National Oceanic and Atmospheric Administration (NOAA) oceanic charts which were annotated with sea surface temperatures from various sources. Sources for sea surface temperatures included weekly satellite infrared radiometry charts supplied by NOAA (Anonymous, 1982-1985), water temperatures recorded at piers and fishing vessels working in the area, and temperatures recorded from surface craft while monitoring telemetered turtles on migration.

Telemetric methods.----Telemetry was used to monitor migrations during the autumns of 1980 and 1982-1985. In 1980 a ridley was radio-tracked in the mid-Atlantic Bight (Byles, 1982). During 1982-1984 turtles outfitted with sonic underwater transmitters and/or radio transmitters were tracked from small craft following methods outlined in Chapter II.

In fall of 1985, a satellite telemetry system for use with large, migrating loggerheads was applied. This method utilized the Tiros-Argos satellite system. The Tiros portion of the system consists of two polar-orbiting NOAA satellites which make between three and ten passes over a section of earth daily. The number of passes depends on the latitude of the point of reference (study area); more passes are made at higher latitudes. The Argos portion of the system, which is administered by

the French space agency (CNES) under a bi-national agreement between the U.S.A. and France, collected data from the satellites and disseminated processed results. Access to System Argos was accomplished with a computer link through the international network Tymnet to computers in Toulouse, France.

Transmitters certified for use with System Argos are manufactured by several companies. The prototypes developed for this study were custom-built by Telonics, Inc., of Mesa, Arizona, U.S.A. The transmitter was sealed in a 11.4 x 7.0 x 1.3 cm metal container. Power was provided by three d-cell sized, three volt lithium batteries. The transmitter, power supply and antenna were all packaged in a housing which I constructed out of schedule-40 polyvinyl chloride. The housing was 7.6 cm in diameter and 30.5 cm long, with caps cemented at either end. The antenna penetrated one end-cap of the housing with an O-ring-sealed pressure feed-through. The attachment eye that penetrated the other end-cap of the housing was cast in polymer resin. The housing was resistant to pressures in excess of 40 atmospheres. Attachment to the turtle was by stainless steel cable with an eyebolt fastened through holes drilled in the pygal bone of the carapace. A ferrous, corrosible link was used to insure the transmitter would eventually detach from the turtle.

The design enabled the transmitter to trail behind the turtle during activity, and because it was positively buoyant, it broke the surface when the turtle was within one m of the surface (see Figure 2, Chapter II). An external flotation collar, constructed of closed-cell foam and coated with layers of epoxy resin, insured aerial exposure and vertical orientation of the antenna when the turtle was at the surface. This was necessary because radio signals attenuate rapidly in sea water and would not be picked up by the satellite unless the antenna was fully clear of the water. The transmitter repeated a message every 58 seconds consisting of identification, activity counter and water temperature. Signals were received only when the turtle was on the surface and one of the satellites had that section of the earth in its view. Generally an azimuth of greater than ten degrees to the satellite was necessary for signal reception. For position calculations to be made by System Argos from Doppler frequency shifts, the turtle had to be on the surface for a minimum of four minutes during a satellite pass. When a message that was not of sufficient duration to calculate a definite position fix, the ID, activity and temperature were all that was received. After extensive testing on a captive loggerhead in a pen constructed in the York River, Virginia, transmitters were deployed in the mid-Atlantic Bight on two loggerhead turtles in 1985.

Results and Discussion

Mark-recapture information.----Lutcavage and Musick (1985) postulated that spring migrations into Chesapeake Bay commenced from the south. They based their contention on two individuals, a ridley and a loggerhead, both tagged in Florida and subsequently recaptured in Chesapeake Bay. The ridley (1; Table 1) was a small specimen (16 cm CLS) that had been hatched and reared in the Kemp's ridley Headstart Program, released on the west coast of Florida in May 1979, and captured alive in Chesapeake Bay in July 1980. The activity of this turtle may not be representative of the normal migration pattern due to its unusual rearing and release. It was substantially smaller than the next smallest ridley reported from the Bay (25.1 cm CLS; see Figure 3b, Chapter II), and may have been released where currents brought it to the Bay earlier in its life cycle than if it had had a natural pelagic stage. The loggerhead (2; Table 1) which moved from Florida in March of 1980 to Chesapeake Bay in June of 1981, is presumably representative of a normal migrating population; it was, at least, not a headstarted animal.

Table 1. Tagged turtle recaptures, ordered by mark and release date. Individual turtles are identified in the text by reference number. Species abbreviations are: Lepidochelys kempi-Lk and Caretta caretta-Cc. Size measured as straight line carapace length (CLS) unless noted as curved carapace length (CLC). Place name abbreviations are: Banks-Bk, Bay-B, Beach-Bh, Cape-Cp, Channel-Ch, Creek-Ck, Inlet-In, Island-I, Point-Pt, Port- Pr, and River-R. Condition (Cd) abbreviations are: live-L and dead-D. Turtles 1 and 2 reported by Lutcavage and Musick (1985).

				Mark and release----------		Recapture----------		
Ref	Sp	Tags	Size (cm)	Date (dy/mo/yr)	Location	Date (dy/mo/yr)	Location	Cd
1	Lk	G2123	16.0	05/09/79	Homassassa FL	07/01/79	Chisholm Ck. VA	L
2	Cc	MS3310		03/18/80	Pr. Canaveral VA	06/10/81		L
3	Cc	K467	51.0	06/04/80	Cherry Pt. VA	08/12/80	Potomac R. VA	L
						10/ /80	Potomac R. VA	L
4	Cc	K487	69.9	06/24/80	Potomac R. VA	06/10/81	Cherry Pt. VA	D
5	Cc	K490	64.0	06/28/80	Potomac R. VA	10/ /80	Potomac R. VA	L
						06/ /81	Potomac R. VA	L
6	Cc	K439	69.0	06/30/80	Potomac R. VA		Potomac R. VA	L
						10/ /80	Potomac R. VA	L
7	Cc	K474		07/12/80	Cherry Pt. VA	08/20/80	Potomac R. VA	L
						10/ /80	Potomac R. VA	L

Table 1. Continued.

Ref	Sp	Tags	Size (cm)	Mark and release---------- Date (dy/mo/yr)	Location	Recapture---------- Date (dy/mo/yr)	Location	Cd
8	Cc	G1010	71.1	07/30/80	York R.	08/08/80	Virginia Bh.	L
		G1012	(CLC)		VA		VA	L
						06/05/81	York R.	L
							VA	
9	Cc	K727		08/07/80	Potomac R.	06/27/82	Haven Bh.	L
					VA		VA	
10	Cc	K728		08/20/80	Potomac R.	10/30/30	Lynnhaven	L
					VA		VA	
11	Lk	AAD109		02/04/81		08/25/81	Lynnhaven	D
					FL		VA	
12	Cc	K804		06/12/81	Lynnhaven	05/19/82	New River In.	L
					VA		NC	
13	Cc	K595		06/24/81	York R.	07/15/80	York R.	L
					VA		VA	
14	Cc	G1013	62.3	07/11/81	York R.	10/10/81	Ca. Henry	L
		G1015			VA		VA	
15	Lk	K2141	40.8	07/28/81	York R.	04/29/82	Bogue Bk.	L
		K2142			VA		NC	
16	Cc	K778	60.0	09/09/81	York R.	09/25/82	Hampton Roads	L
		G1017			VA		VA	
17	Cc	K2003	66.0	09/14/81	Cherry Pt.	06/07/82	Milford Haven	L
					VA		VA	
18	Cc	AAB734		02/03/82	Canaveral Ch.	07/14/82	Cherry Pt.	L
		AAB735			FL		VA	
19	Cc	K2094		05/ /82	Buckroe B.	05/31/82	York R.	D
					VA		VA	

Table 1. Continued.

Ref	Sp	Tags	Size (cm)	Mark and release---------- Date (dy/mo/yr)	Location	Recapture---------- Date (dy/mo/yr)	Location	Cd
20	Cc	K2187 K2193	90.0	09/20/82	Potomac R. VA	07/01/83	Potomac R. VA	L
						07/07/84	Potomac R. VA	L
						07/23/84	Potomac R. VA	L
21	Cc	K2153		04/02/83	Buckroe VA	06/ /83	Potomac R. VA	L
22	Cc	K2790		06/ /83	Buckroe VA	07/05/83	Ca. Henry VA	L
23	Cc	K2767 K2768	63.0	07/26/83	York R. VA	08/09/83	York R. VA	D
24	Cc	K2176 K2177	62.0	09/16/83	York R. VA	06/22/83	York R. VA	L
25	Cc	K4676 K4677 K4678	64.7	06/01/84	Gwynns I. VA	07/06/84	Potomac R. MD	L
26	Cc	K4685 K4686	67.5	06/01/84	Lynnhaven VA	09/20/84	Delaware B. DE	L
27	Cc	K4653 K4654	81.4	06/15/84	Potomac R. VA	07/12/84	Potomac R. VA	L
28	Cc	K4661 K4662	70.3	06/18/84	Potomac R. VA	07/02/84	Potomac R. VA	L
29	Cc	K4668 K4669	48.4	06/22/84	Potomac R. VA		Potomac R. MD	L
30	Cc	K2756 K4640 K4641	65.1	07/ /84	Potomac R. VA	09/13/84	Potomac R. VA	L

Table 1. Continued.

Ref	Sp	Tags	Size (cm)	Mark and release---------- Date (dy/mo/yr)	Location	Recapture---------- Date (dy/mo/yr)	Location	Cd
31	Cc	GA3174 GA3119			GA	07/31/83	Smith I. VA	L
32	Cc	0577 (U.S. Nat. Res.)				07/06/82	Lynnhaven VA	D

Continued mark-recapture efforts have provided additional information about turtles tagged and released outside the Bay. A loggerhead (18; Table 1) in addition to the one reported by Lutcavage and Musick (1985), and one ridley (11; Table 1) tagged and released during winter trawling operations in Canaveral Channel, Florida (Henwood, 1987) have been recovered in subsequent summers in Chesapeake Bay. A loggerhead (31; Table 1) tagged and released in Georgia, and one tagged at an unknown location outside of the Bay (32; Table 1) have also been recorded in the Bay.

Recaptures of turtles tagged and released in Chesapeake Bay fall into three categories: (1) recaptures in the Bay within the same year, (2) recaptures in the Bay in subsequent years, and (3) recaptures outside the Bay. Turtles show strong site fidelity in the Bay (see Chapter II). Most within-year recaptures were in the vicinity of the release site, and many turtles were recaptured in the same pound nets in which they were originally captured.

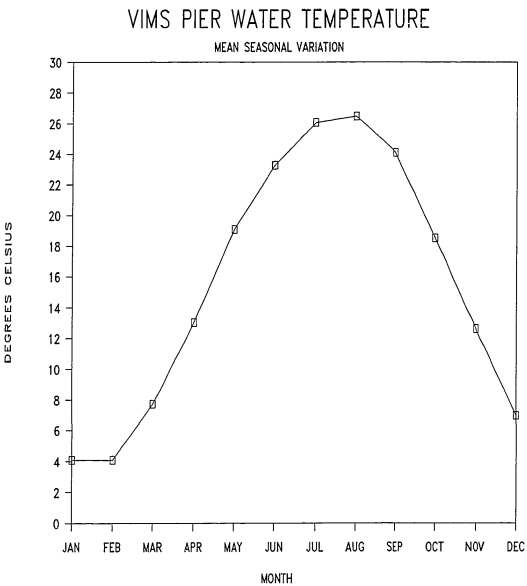
Annual and multi-annual returns of tagged turtles suggest remigration to the Bay, since there is no evidence that turtles are capable of overwintering in cold inshore waters. Schwartz (1978) described lethal temperatures for loggerheads and ridleys kept in outside

tanks during a winter in North Carolina. Temperatures between 10 and 14 C induced torpid floating in both species. When temperature fell below 10 C, loggerheads died; ridleys were able to survive to 6.5 C in a torpid state. The relatively shallow water of Chesapeake Bay is well mixed by winter storms and water regularly drops below temperatures which would prove fatal to loggerhead and ridley sea turtles (Figure 1).

Winter brumation, sometimes mistakenly called hibernation, has been described for loggerheads and ridleys by Carr et al. (1981). They found both species concentrated at Canaveral Channel, Florida, partially buried in the fine silt of the channel bottom. Water temperatures were 11 C but the turtles' body temperatures, as well as the sediment at 25 cm, were 13-15 C. Other torpid turtles have been found in Florida (Ehrhart, 1980) in a floating and moribund state in Mosquito Lagoon (near Canaveral) when water temperatures were 4 C. Clearly there is a thermal minimum at which overwintering and possibly brumating turtles float to the surface with little ability to escape the cold.

Brumation does not appear to occur in Virginia waters. Although some observations (epizootic distribution patterns on the carapace) suggest that turtles have previously spent time buried, turtles seen

Figure 1. Mean monthly water temperatures, 1951-1985, measured at VIMS pier. These temperatures of the York River mouth are representative of lower Chesapeake Bay.



in the early spring rarely have signs of recent brumation (fresh mud on carapace, etc.). In deep areas near the mouth of the Bay, where brumating turtles might be expected, a crab dredge fishery occurs. None of 15 interviewed crabbers, who are familiar with the species, encountered turtles. Hence, for seven loggerheads, (4, 8, 9, 16, 17, 20 and 24; Table 1) tagged and subsequently recaptured in the Bay, it was concluded that winters were passed somewhere outside the Bay. The turtles must also leave the mid-Atlantic Bight to overwinter since temperatures below 10 C persist well into spring (Davis, 1979).

Loggerheads and ridleys not only immigrate to the Bay from the south, they also emigrate from the Bay to warmer waters. Three turtles tagged and released in the Bay have been recaptured outside of the Bay. One ridley (15; Table 1) was recaptured at Bogue Banks, North Carolina. Two loggerheads, (12 and 14; Table 1) were recaptured at New River Inlet, North Carolina and three miles east of Cape Henry, Virginia, respectively. A third recaptured loggerhead (26; Table 1) behaved differently. It was found in Delaware Bay in September after being tagged in June at the mouth of Chesapeake Bay. Two turtles (16 and 20; Table 1) were recaptured in three consecutive years. Multi-annual returns demonstrate that turtles spend a portion of the juvenile

stage in the same foraging grounds, and also suggest that a portion of the population migrating annually to Chesapeake Bay forms a coherent group.

Aerial surveys.----Longshore aerial surveys have corroborated the evidence of Shoop et al. (1980) that sea turtles migrate north in shallow waters along the eastern seaboard in the spring and return south in the fall. Correlating surface water temperatures (Anonymous, 1982-1985) with charted sightings of loggerheads within the Bay and along the shore indicates that turtles are found primarily in water with temperatures of at least 18 C. Shoop et al. (1981) found loggerheads to generally be present in waters of surface temperatures of greater than 16 C, regardless of latitude. In the present study, both loggerheads and ridleys were found progressively northward as nearshore waters warmed in the spring. Likewise, turtles seemed to be forced out of the Bay and down the coast by declining temperatures in the fall.

The temporal aspect of migration was more sharply defined in the spring than in the fall. In the spring, turtles moving northward were concentrated in waters of 15-20 C (Anonymous, 1982-1985). The resultant migration pattern as seen from the air was a wave or pulse of turtles moving northward which became diffuse as the turtles reached foraging waters and coincided with the

June stranding peak described by Lutcavage and Musick (1985). In the fall, the migrating population was not as cohesive; individuals trickled out of the Bay. Shoop et al. (1981) described a similar pattern for loggerheads on the eastern seaboard of the U.S. They reported that loggerhead ranges were limited to the southern regions of their study area (North Carolina) during winter and expanded northward to Massachusetts by September when the autumn migration again commenced.

The residence period in Chesapeake Bay can be generally predicted by water temperatures --- turtles are present when Bay waters are 18 C or above (Lutcavage and Musick, 1985). This threshold temperature was reached with regularity in late May and again in October of each year (Figure 1). The rate of temperature change is steep enough to predict with reasonable precision the arrival and departure times of sea turtles.

Telemetric data.----Radio and sonic telemetry from surface and air craft, which proved successful within the Bay (Chapter II), was also used in the open waters of the Atlantic Ocean to track migrating turtles. Tracking procedures were not easily applied to migrating turtles because the use of small surface craft at the onset of winter storm weather was impossible. However, I was able to monitor departure from summertime Bay foraging grounds

and the initial phases of migrations out of the Bay and southward into the Atlantic Ocean from a small boat. Aircraft tracking was initiated when small boat tracking became impossible, but long subsurface periods and subsequently short transmission times limited the data gained from this hit-or-miss operation.

In November of 1980, a 42 cm ridley was monitored for four days from the Bay mouth to a point 51 km east-southeast of the release point (Byles, 1982). This turtle, the only migrating ridley tracked in this study, was also the only monitored turtle of either species that swam more than 10 km from shore. A final destination could not be determined, but a continuation of its course would have taken it to warm Gulf Stream waters. A shift of direction to the south would also have taken the turtle to warmer waters. The offshore travel of this individual conflicts with the ridley mark-recapture data presented above and the essentially littoral nature of the animal. Since a continuation of the observed travel direction would have taken the turtle further offshore and away from usual juvenile habitat, perhaps a change of direction to the south occurred after telemetric contact was broken. The other warm water refuge available to the turtle was the Gulf Stream. Although benthic feeding is unlikely at the depths involved (greater than 200 m), floating prey such as jellyfish may have been available

(Shoop et al., 1981). Small Kemp's ridleys are found stranded in Europe, Great Britain and Madeira (Brongersma, 1972), Morocco (C. Caillouet, pers. comm.), the Azores (Deraniyagala, 1939) and Bermuda (Mowbray and Caldwell, 1958) and Gulf Stream transport may be part of the juvenile ridley migratory cycle. However, I tend to agree with Zwinenburg (1977) who believed that eastern Atlantic immature ridleys were passive drifters, caught in the Gulf Stream and accidentally transported across the Atlantic.

The distribution of size classes on the Atlantic seaboard of North America, with the smallest in New England (Carr, 1980) and larger sizes in Georgia and eastern Florida, led Pritchard and Marquez (1973) to postulate a different life cycle. They suggest immature ridleys, entrained in the Florida Current, left the Gulf of Mexico and were transported northward. These turtles would have to reach New England at a size (about 30 cm carapace length, Lazell, 1976) where they actively swam and could reverse direction and migrate southward. By the time these turtles reached the Gulf of Mexico, they would be subadults, ready to mature and join the breeding population. The intermediate size of Chesapeake Bay ridleys (mean about 40 cm) certainly supports this theory if the migrating turtles took several years to traverse the coast of the U.S. and warm water refugia were

available. Ridley turtles seen alive in the Bay are, as Lazell (1980) states for New England ridleys, active, healthy, feeding specimens that do not seem to come to these areas just to die. This scenario does not rule out using warm waters near the Gulf Stream as a winter refuge from cold temperatures. Evidence for use of Gulf Stream influenced waters as a winter refuge has also been obtained for a loggerhead tracked by satellite (see below).

The remaining turtles successfully tracked during migration were loggerheads. As supported by aerial surveys, the timing of fall emigrations for Chesapeake turtles was during the last weeks of October, when water temperatures dropped precipitously and winter storms first occurred. In 1982, three turtles were being monitored the week of 20 October when water temperature declined from 18 C to 14 C. Two of the turtles had been tracked for a month, and one had just been released (19 October). All three turtles left the York River mouth and moved to the middle of the Bay. Two of the turtles had radio tags and were followed by air southward 2.5 to 5 km offshore well into North Carolina waters. Contact with the third was maintained until it reached Cape Hatteras, where contact ceased after 11 November.

A loggerhead leaving the York River on 17 October 1983 remained at the surface for an ebb tide cycle, possibly deliberately taking advantage of passive conveyance to the Bay mouth (see Chapter II). Five days later, this turtle was last located approximately 3 km offshore at the Virginia-North Carolina border.

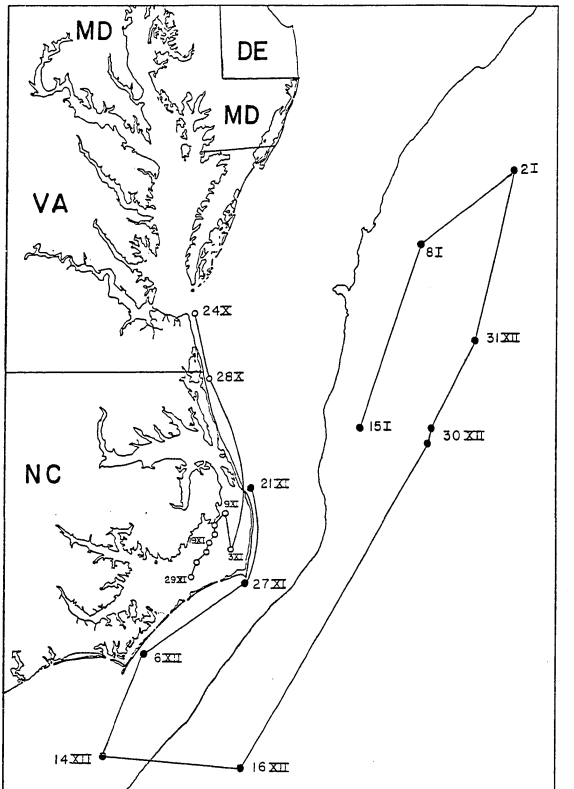
In October of 1984, a loggerhead and a ridley were being monitored in the York River and Mobjack Bay, respectively. The loggerhead had been tracked for more than a month and the ridley for more than 100 days when both ceased their circumscribed foraging behavior and started swimming much longer distances which, if continued, could have taken them out of the Bay. Contact was broken when both turtles were in mid-Bay by 26 October. A week of inclement weather prevented relocation of either turtle by boat or aircraft. By 8 October, water temperature was 16 C at this locale but was 20 C just south of the Bay mouth. These two turtles did not have radios and were not located again. Two loggerheads, tagged with radio transmitters, were released at the Bay mouth on 8 and 17 October. These turtles headed south, close (0.5 km) to shore, presumably aided by a longshore current. The surface current was measured by the tracking boat at 3.5-5.5 km per hour at ebb tide and was reduced to 1-1.5 km per hour at flood tide. The current remained in a southerly direction

throughout the tidal cycle. Contact with the loggerhead released on 8 October was lost immediately. The loggerhead released on 17 October reached northern North Carolina by 20 October; it was approximately 3 km from shore and had slowed its southerly progress. By 22 October, it had reversed direction and moved north 15 km. Several location fixes were made in the following eight days in the same 30-40 km nearshore area. Last contact was at the Virginia-North Carolina border on 2 November.

Migration of radio-tagged loggerheads was also monitored via satellite. Two other studies have used satellite tracking to monitor the movements of loggerheads at sea: Timko and Kolz (1982) monitored a loggerhead in the Gulf of Mexico and Stoneburner (1982) monitored eight loggerheads off the coast of Georgia. Both studies had successful aspects, as did the present study, and pointed out the utility of the technique for determining movements of marine turtles at sea.

The results of the 1985 satellite tracking, summarized in Figure 2, demonstrate not only the success of the method, but also its utility in obtaining previously undocumented information about loggerheads. I anticipated that during the fall migration out of Chesapeake Bay, turtles would simply swim south to warmer waters. One turtle (Figure 2, open circles) was released

Figure 2. Tracks of two satellite-telemetered loggerheads. Open and closed circles represent the two individuals.



on 24 October and swam southward from Chesapeake Bay mouth to Oregon Inlet, North Carolina where it entered the sounds behind the barrier islands. Based on previous radio-tracking experience, the movement of this turtle into the sounds was unexpected. However, during the week this turtle swam through the sounds a severe storm with hurricane force winds occurred on the coast of North Carolina. The storm may have influenced the behavior of the turtle. Winter water temperatures in the sounds, which are nearly as cold as Chesapeake waters, probably prevent overwintering. Hence, the turtle would soon have to leave the sounds to reach warmer waters. However, after a week the transmission pattern in Currituck Sound changed from intermittent to continuous; the transmitter had become separated from the turtle. Overflights for three days after the change in transmission pattern revealed heavy shrimp trawling in the area. The floating transmitter could not be retrieved, exited the sound and essentially became a drifting buoy that transmitted temperatures from locations in the Atlantic Ocean for nine months.

A second loggerhead, released on 21 November at Oregon Inlet, North Carolina, was tracked for 56 days (Figure 2, closed circles). It swam south of Cape Hatteras, North Carolina and then presumably entered the Gulf Stream and was transported northward to waters from

400-600 m in depth. At a point near latitude 38 N, it turned and again moved in a southerly direction. The turtle was still in relatively warm water (16 C), and may have been in a Gulf Stream warm core ring, when transmissions ceased nearly two months after deployment. The position of the Gulf Stream and the presence of the warm core ring were inferred from sea-surface temperature charts on which the positions of major features are calculated for fisheries and oceanography purposes (Anonymous, 1982-1985).

Summary and Conclusions

A variety of techniques have been used to define loggerhead and ridley sea turtle migrations to and from Chesapeake Bay. Data from mark-recapture studies have shown that both species migrated to the Bay from as far as Florida and that repeated annual returns to the Bay were made by given individuals. Site fidelity was documented from within-year recaptures of turtles from the same area and not infrequently from the same pound nets. Other evidence supporting strong philopatry comes from telemetry studies (Chapter II). Turtles marked with Monel tags in the Bay have been recaptured migrating out of the Bay in the fall as far south as southern North Carolina.

Longshore aerial surveys showed loggerheads (ridleys were not easily observed from the air due primarily to coloration and small size; see Chapter III) began migrating from points south to the Bay in early spring. The migration times were linked to vernal warming; the heaviest concentrations of turtles were found south of the 18 C isotherm. For both species, the period of residence in the Bay was correlated with water

temperature. The spring appearance of turtles could be predicted by water temperature rising to 18-20 C. Fall migration was linked less strongly with declining water temperature, and appeared to also be related to the onset of winter storms.

Radio and sonic telemetry supported the previous evidence of strong site fidelity when turtles were occupying the Bay, and also aided in the delineation of residence period. Telemetry techniques that were highly successful in the Bay were only marginally successful in the open waters of the Atlantic. Rough seas and logistical problems prevented the use of small surface craft for continuous tracking. Respiration behavior (limited surface and therefore signal periods) of the turtles made it difficult to maintain contact with radio-tagged animals from aircraft.

Monitoring with small boats and aircraft at the start of the fall migration revealed that loggerheads remained nearshore in strong southerly currents near the Bay mouth. For all loggerheads telemetered via aircraft, contact was broken in the vicinity of Cape Hatteras, North Carolina. It is reasonable to assume these individuals continued southward. The one migrating radio-tagged ridley behaved differently. This turtle swam east-southeast in nearly a straight line and

covered 51 km in four days before contact was lost. Three scenarios could be reasonably constructed for the completion of the ridley's migration: (1) it maintained course to the Gulf Stream and was transported across the Atlantic, (2) upon reaching waters of more suitable temperature, it turned south or (3) it remained in warm water near the Gulf Stream but was able to maintain it's postion relative to the coast of the U.S. as did one loggerhead tracked by satellite. Although ridleys are occasionally reported in Europe (Brongersma, 1972), it seems more likely for ridleys to remain coastally oriented on the eastern seaboard of the Atlantic.

The satellite system has proven successful, and even with limited trials, data have been collected that could not have been otherwise obtained without a much greater investment in time and money. Two loggerheads were tracked for short periods and two very different migration patterns were revealed: one turtle entered Currituck Sound, North Carolina and the other swam offshore, in a Gulf Stream-influenced loop.

The development and application of a telemetric system for sea turtles has permitted the elucidation of facts not obtainable by less technologically-advanced means. The state-of-the-art satellite tracking system holds the greatest promise for definitively elucidating

the migration patterns and overwintering sites of loggerhead and ridley sea turtles. This will require monitoring turtles over the course of a year or more. Knowledge of sea turtle migrations will aid us in recovering these species from threats of extinction.

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