

Technical Report

The Jumby Bay Hawksbill Project

Survivorship, Mortality, Recruitment
and
Reproductive Biology and Behavior
of
Adult Female Hawksbill Sea Turtles
(*Eretmochelys imbricata*)
Nesting at Pasture Bay, Long Island, Antigua, W.I.

1987-1992

Prepared by

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WIDECAST
Antigua



Georgia Sea Turtle Co-op



JUMBY BAY

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25 July 1993

EXECUTIVE SUMMARY

The Jumby Bay Hawksbill Project has completed six years (1987-1992) of intensive tagging with adult female hawksbill sea turtles (*Eretmochelys imbricata*) nesting at Pasture Bay, Long Island, Antigua, W.I. The results are presented in this technical report. Pasture Bay is a natural beach of calcareous sand, with a community of mixed tropical hardwood trees and shrubs providing suitable nesting habitat. The beach (160m) is patrolled exhaustively by a team of two biologists on hourly intervals from dusk until dawn during the 150-day principle nesting season (15 June-15 November). The purpose is to record the activity and identity of each turtle on every nesting visit. The number of such events that are missed by the patrol team is less than 5% of total nesting activities. Loss of individual flipper tags is estimated at 5-10% over a 2-yr or 3-yr period. Turtles are protected from unnecessary harassment arising from research or other interpretive activities. The nesting beach is owned and managed by Jumby Bay Club and Resort. The research program is directed by the Georgia Sea Turtle Cooperative.

Ninety-one individuals have been tagged to date. The number of females nesting each season has ranged from 22-38 individuals. The proportion of untagged turtles during each of the last two seasons (1991-1992) has held relatively constant at <20%. Thus, annual recruitment to the nesting population can be no greater than 20% and is probably less by some number of turtles on long remigration intervals and by possible tag loss. Turtles usually return on 2-yr and 3-yr remigration intervals, with a mean ($n=51$) of 2.53 years. Nine of 60 individuals (15%) have not returned in 4 years, and this represents potential bias for the remigration interval reported. The calculation of annual survivorship is difficult and perhaps premature with a short-term tagging study of 6 years, but best minimal estimates to date range from 0.98 (1987 turtles) to 0.89 (1988 turtles). Annual survivorship values are expected to increase with additional years of tagging data and improved tagging methods.

Individual turtles lay 4.52 clutches per season (a predicted mean), with five clutches being the dominant mode. Mean clutch size is 157 eggs. An individual turtle will lay approximately 700 eggs per nesting season or 280 eggs per year of its reproductive life. The mean inter-nesting interval is 14.8 days ($n=489$), with some evidence that the first interval (15.2 days) is longer than the remaining intervals (14.4 days). The average nesting season, derived from a sample of 716 nests, describes a clear peak of activity in late August and early September. There is apparent bi-weekly periodicity in nesting activity that may even be synchronized across nesting seasons. Social facilitation has not been ruled out. Most females exhibit a propensity for arriving each nesting season on a date predictable for the individual, suggesting the existence of an accurate biological clock that coordinates the behavior of each turtle and defines the shape of the nesting season.

There have been 716 nests recorded for the six seasons, or a mean of 119 nests per survey season (15 June-15 Nov.). Since some minimal nesting occurs on every month of the year, an additional 20% of this value (± 150 clutches) may represent nesting activity outside of the survey season. Mean hatching success has been >80%. An estimated 100,000 hatchlings have been produced during the last six years (1987-1992), speaking to the importance of Pasture Bay as a nesting beach for the endangered hawksbill in the Caribbean. The Jumby Bay Club and Resort and the Georgia Sea Turtle Cooperative are working together to see that the future for the Pasture Bay hawksbills is secure. Efforts are underway to improve nesting habitat at the site. The program to gather important population data on the nesting females will continue.

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NOTE: Authorship statement. This document is a technical report of results collected by the Jumby Bay Hawksbill Project, 1987-1992. There has been no attempt to survey other hawksbill studies or contrast the results of the Jumby Bay project to these other studies, particularly the important regional work on-going at Mona Island (PR) and Buck Island (USVI). This report is not to be considered a publication; the contents of the report will be submitted for publication in the near future as selected papers in appropriate journals. The data contained in this report are managed by the Georgia Sea Turtle Cooperative for the Jumby Bay Hawksbill Project. Publishing rights are reserved for those individuals who have participated directly with the project over the last half dozen years. In lieu of existing publications, this technical report and its contents may be quoted and referenced as an unpublished technical report by obtaining permission of the second author.

INTRODUCTION

Data presented in this technical report have been collected entirely from observations of adult hawksbill sea turtles (*Eretmochelys imbricata*) nesting at Pasture Bay, Long Island, Antigua, from 1987 until 1992. Long Island is a 300-acre, privately-owned island situated approximately 2km off the northeastern coast of Antigua. Preliminary results from the project have been published by Corliss *et al.* (1989), Mrosovsky *et al.* (1992), Richardson *et al.* (1989), and Ryder *et al.* (1989). These documents are attached to this technical report as Appendices I, II, III, and IV.

The Jumby Bay Hawksbill Project is named for Jumby Bay Club and Resort which owns Long Island in its entirety. Mr. John Fuller, attorney, sea turtle conservationist, and a resident of Antigua, invited Jim Richardson to visit Pasture Bay in March of 1985. They hoped to initiate a hawksbill research project with the Georgia Sea Turtle Cooperative Program at the University of Georgia's Institute of Ecology. Following a preliminary survey in 1986 to ensure that research on the nesting females would be possible without undue harassment of the animals, full scale tagging was begun by Lynn Corliss in 1987. This technical report summarizes the first six seasons of results from Pasture Bay, 1987-1992. The Jumby Bay Hawksbill Project is funded and managed cooperatively by Jumby Bay Club (Mr. Roland Franklin, President), Jumby Bay Resort (Mr. Paul Zuest, President), and the Georgia Sea Turtle Cooperative (Dr. James Richardson, Scientific Director), with continuing support from John and Sarah Fuller, Hodges Bay, Antigua. The Jumby Bay Hawksbill Project figures prominently in the Sea Turtle Action Plan for Antigua and Barbuda (Fuller *et al.* 1992).

Acknowledgements: An enormous amount of appreciation goes to the hardy tagging crews, the "turtle ladies" as they are fondly known in Antigua, who have braved long bouts of inclement weather and biting insects and many nights of "no turtle" boredom to gather the impeccable field records that provide the foundation for the results presented in this technical report. These individuals, who have covered the Pasture Bay beach from dusk to dawn for a collective 919 nights, are Lynn Corliss, Kevin Holloman, and Cheryl Ryder (1987), Lynn Corliss and Cheryl Ryder (1988), Lynn Corliss and Anna Bass (1989), Anna Bass and Carla Melucci (1990), Meg Hoyle and Michelle Zacks (1991), Ximena Prudencio and Wendi Weber (1992), and now Ximena Prudencio and Heather Mayers (1993). Add to this group Rebecca Bell who has come each year as an assistant scientific director to assist with training neophyte "turtle ladies." The administration and staff of Jumby Bay Club and Resort have been especially supportive of the project, particularly Karen and Don Tate, Paul Richnow, Paul Zuest, and Paul Himmelman during the early years when support was so very much needed and appreciated. Roland Franklin gathered the support of the Jumby Bay Club members behind the project. These members picked up the expenses of the Jumby Bay Hawksbill Project in 1991 at a time when the Georgia Sea Turtle Cooperative could no longer carry the financial burden by itself. The Jumby Bay Resort has provided much needed room and board for the research teams since the beginning of the project. John and Sarah Fuller have been a "Rock of Gibraltar" and a "home away from home" for the project and all of its participants, including the Scientific Director. There are many others, such as Dr. Nicholas Mrosovsky who provided funds and laboratory expertise to measure the sex-determining pivotal temperature for Pasture Bay hawksbill hatchlings. Finally, to all those who have provided numerous acts of support and encouragement to the Jumby Bay Hawksbill Project, I express my appreciation and sincerely apologize for any omission of personal reference in this acknowledgement statement.

Sincerely,

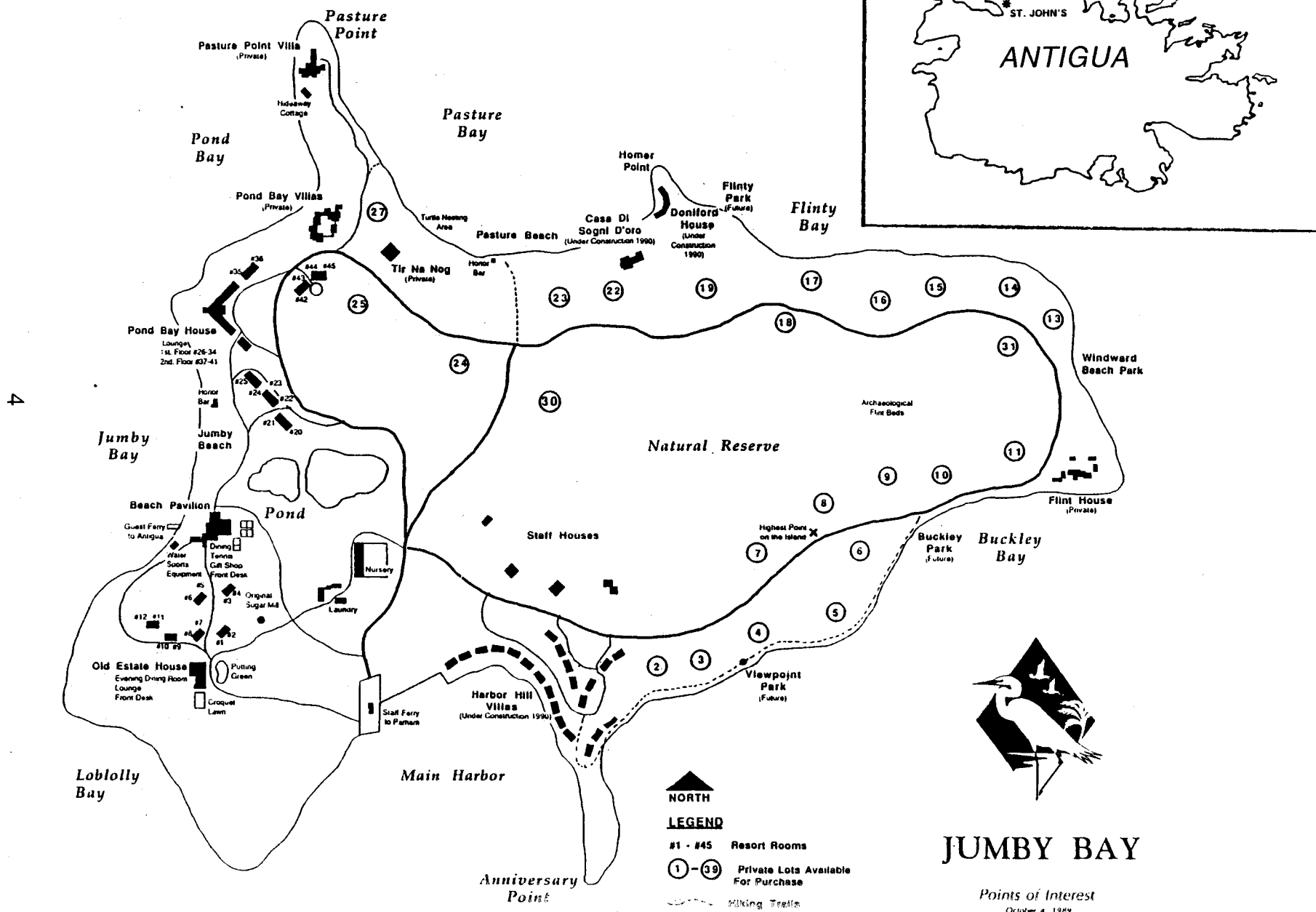
Jim Richardson, Ph.D.,
Scientific Director,
Jumby Bay Hawksbill Project.

SITE DESCRIPTION

The beach at Pasture Bay is historical and natural, although it has been greatly modified in the last century by man. Pasture Bay forms a cul-de-sac facing into the easterly prevailing winds, with extensive shallow reefs of coral and marine algae occurring immediately offshore (**Fig. 1**). Wave chains entering the Bay from the east are deflected to the southwest by Homer Point so as to apply maximum energy levels to the central portions of the Bay. Beach sand is calcareous, derived primarily from fragments of calcareous algae and, to a lesser extent, from coral. Historically, Pasture Bay beach vegetation was a mixed maritime forest community of trees and shrubs growing densely to the high water line. Sand, moved by wind and waves onto the beach, was trapped within a few meters of the water's edge by the dense vegetation. Wind rows of algae and marine grasses were deposited at the high tide line, providing a source of nutrient-rich organics to be mixed with the sand. A sloping dune of 1-3m in height, stabilized by the shrubs and trees, rose gradually from the water's edge to provide the nesting habitat most preferred by Caribbean hawksbills. Because of the protection provided by shallow offshore reefs and the tenacious woody plants (and root systems) of the beach community, the shoreline probably did not fluctuate by more than a meter in any year. An extensive deposit of sand was held by the beach forest to provide continuously available nesting habitat, regardless of the erosional or depositional cycle of the shoreline.

At some time in previous decades, the maritime forest was cleared from Pasture Bay for grazing sheep (thus, the Pasture Bay name) and, later, for recreational access to a sandy beach, with scattered clumps of sea grapes and a few trees left for aesthetic purposes. As a result, foreshore (0-10m) beach sand was blown back and away from the high water line (HWL), forming a vegetated rear dune too distant from the water for hawksbill use. The problem has been exacerbated in recent years by intense cleaning of the beach and berm in the middle third of Pasture Bay, such that no blade of grass or fragment of leaf was left to slow the wind with its drifting sand. Without dynamic offshore sand bars to replenish the loss, existing supplies of sand were "robbed" from the lateral ends of Pasture Bay, and the overall shoreline has receded, perhaps as much as 10m from historic dimensions. By 1986, conditions had deteriorated until significant portions of the beach were rendered unsuitable for nesting because of exposed limestone rock, cobble beach,

Figure 1: Pasture Bay, Long Island, and the relationship of the study site to the island of Antigua, W.I.



eroded root mats, and permanent pasture. Of the 220m (720ft) of Pasture Bay, only 160m (525ft) were available for nesting in 1985, with no more than 100m (330ft) of "quality" nesting habitat.

The current administration and owners of Jumby Bay have taken emergency measures in the last few years to improve the nesting habitat at Pasture Bay, including the use of construction setback lines to protect existing vegetation and the planting of new vegetation to stop sand loss caused by wind erosion. Beach cleaning has been reduced to a minimum, with flotsam (sea grasses, etc.) now left on the beach to mulch new plantings. An extensive period of new home construction (1990-1993) has been weathered by the nesting turtles, and the time is soon approaching for a comprehensive, long-term management plan for Pasture Bay that will consider nesting habitat, lighting disorientation, and adequate protection of nesting females and hatchlings from disturbance. There is an excellent opportunity for Pasture Bay to be reclaimed as one of the premier hawksbill nesting beaches in the Caribbean, all within the protective boundaries of the Jumby Bay Club and Resort. A summary of nesting requirements and management options for Pasture Bay has been published (Ryder *et al.* 1989) and is appended to this report.

METHODS

Project philosophy: The Jumby Bay Hawksbill Project employs a saturation tagging program with the objective to witness every nesting event for the population. The responsible females are identified for each nest laid during an entire nesting season across a comprehensive portion of the nesting habitat for a significant number of consecutive nesting seasons. By so doing, experimental error as a compromising factor in measuring population parameters is reduced to a minimum, and the accuracy and precision of each population parameter is greatly improved. The estimate of individual fecundity is maximized, real population size is minimized, annual survivorship is maximized, annual mortality is minimized, annual recruitment is minimized, and peripheral parameters such as remigration interval and internesting interval are more precisely measured. A discussion on the value of saturation tagging to sea turtle studies has been presented by Tucker (1989).

Survey season: The tagging study is usually maintained from mid-June until the third week of November (150-160 days), depending on the anticipated return of certain nesting females during the last week of the survey. Although there is usually some minimal nesting activity noted in every month of the year at Pasture Bay, the combined "off-season" months of December through May apparently represent less than 20% of annual nesting effort, based on off-season crawl counts. Because the modal frequency of seasonal nests per turtle is five (see **Fig. 5**, p.28), each individual is usually seen on the nesting beach over an extended period of 60 days. Individuals nesting just before or after the survey season are usually identified (tagged) while also nesting within the survey season. In other words, any turtle nesting not earlier than May 1 or later than 31 December, within an 8-month nesting season, would be expected to be seen (tagged) during the 5-month survey season. The visual symmetry and extrapolated end points of the seasonal nesting frequency curve (see **Fig. 8**, p.33) support the premise that the survey season encompasses the most important months of the annual Pasture Bay nesting season. Furthermore, there is no evidence to suggest that hawksbills nesting on other Caribbean beaches exhibit a different nesting season.

Patrol area: The entire length of Pasture Bay available for nesting (160m) is included in the hourly patrols (**Fig. 1**, p.4). Adjacent Pond Bay and Flinty Bay and the remainder of Pasture Bay (60m) do not have suitable nesting habitat but are checked regularly for any sign of turtle nesting activity. There have been two occasions of turtles from Pasture Bay that were found wandering on lawns behind Pond Bay, but they were not able to nest. Jumby Bay beach (**Fig. 1**, p.4) could provide acceptable nesting habitat in its present condition. This "other" large beach (300m) has been artificially nourished with offshore sand and developed for use of resort guests. The early history of Jumby Bay beach is unknown, but it is noteworthy that only a single crawl (an unsuccessful nesting attempt) has been recorded at this site in six years of surveys. Great Bird Island (3km distant) and several mainland beaches (3km distant) are the most proximate acceptable habitats with occasional hawksbill nesting activity. In summary, the nesting at Pasture Bay is surprisingly focused within the patrolled study area and, therefore, exhaustively monitored. It is most unusual when the patrol does not record an individual turtle for at least five nesting visits during a season. The fidelity of the hawksbills to their traditional nesting beach and the management implications for protecting historic nesting sites are self-evident.

Patrol schedule: Except for September 16th and 17th, when Hurricane Hugo struck the island of Antigua in 1989, Pasture Bay beach has been patrolled for every night of the survey season on hourly intervals for six years. The first patrol begins at or just after dusk, and the last patrol finishes at dawn, a schedule that captures nearly all of the nesting events (see Fig. 7, p.32). A turtle requires more than an hour (average 1.5-2.0 hours) to complete the nesting sequence, so the hourly survey schedule is sufficient. It takes no more than 10 minutes for two individuals to patrol Pasture Bay. Hawksbills apparently nest diurnally in the Seychelles on a regular basis (J. Mortimer, *pers. comm.*) but not in Antigua.

Patrol efficiency: There is no aspect more important for a quantitative population study of nesting sea turtles than patrol efficiency, including:

- the frequency with which nesting turtles and/or nests are missed by the patrol team,
- the frequency with which nesting events are erroneously identified as a false crawl (unsuccessful nesting event),
- the frequency with which false crawls are erroneously recorded as successful nesting events.

Not identifying or tagging a turtle on a false crawl (unsuccessful nesting attempt) is of trivial quantitative importance, particularly at a site such as Pasture Bay where individual turtles persist in their efforts until they are able to nest successfully. On the other hand, the patrol is designed with singular purpose to intercept (identify and tag) every female involved in a successful nesting visit, and the number of such missed events is the measure of patrol efficiency.

More than any other species of sea turtle, the hawksbill has a propensity to slip onto a nesting beach across a stony section of shoreline or under vegetation growing at the water line, such that entrance and exit crawls may be virtually invisible. Such a turtle can easily complete a nest without anyone on the beach knowing of its presence. To cover for this important contingency, every portion of the Pasture Bay beach that does not show clear crawl traces is equipped with "trip sticks." These are .25in diameter dowels painted white for visibility and placed as a "fence," each dowel about 40cm (16in) distant from the next one. Any turtle crossing the "fence" must knock down one or more of the trip sticks. This survey trick has proved to be of enormous value to the

Pasture Bay project, for it can be said with absolute confidence that no hawksbill sea turtle can nest at Pasture Bay without leaving evidence of its visit, either tracks in the sand or fallen sticks on the ground.

Table 1 summarizes survey efficiency for six seasons at Pasture Bay. "Missed nests" are defined by the team as apparent nesting events during which the turtle was missed for various reasons, usually because of observer sickness, violent weather, or too much time spent with another turtle nesting simultaneously on the beach. Because it is difficult for an observer to identify the outcome of a hawksbill crawl trace within dense shrubbery (missed nest), there is the potential for observer error; some "missed nests" may actually have been unsuccessful nesting attempts. "Missing nests" are expected visits from individual turtles which do not appear on schedule, identified by a single 30-day internesting interval instead of two intervals of 15 days each. Frequently, a "missed nest" and a "missing nest" occur simultaneously, providing strong evidence that a particular "missing" turtle was responsible for the missed nest. It is also possible that a Pasture Bay turtle could occasionally nest on neighboring beaches. At the very least, patrol efficiency for the Jumby Bay Hawksbill Project is as high or higher than for any other saturation tagging program of its kind, and the proportion of missed and missing nests is small relative to total nests.

Tagging and tag loss: Another source of experimental error that has crippled the accuracy of other sea turtle tagging surveys is tag loss. Some tag loss will inevitably occur, no matter what the precautions taken. Each Pasture Bay turtles receive two small Inconel tags (Size 681), one on the posterior edge of each front flipper. The tags are standard livestock ear tags manufactured by National Band and Tag Company and distributed by the U.S. National Marine Fisheries Service with a Miami return address. The unique series used for Pasture Bay hawksbills is PPN-001 to PPN-100 (100 tags) and QQB-901 to QQB-000 (100 tags).

In addition to flipper tags, a diagnostic pattern of holes is drilled in the trailing edge of the postcentral scutes, in a location where inert scute tissue allows drilling without affecting the turtle. Because scutes grow "out" like finger nails, the holes remain no more than 3-4 years, but the drill pattern provides a unique mark for any turtle which might have lost its flipper tags within that time frame.

Table 1: Survey efficiency for Pasture Bay, Long Island, Antigua, W.I.
 "Missed nests" are defined as apparent nesting events where, in the opinion of the survey team, a nesting turtle was missed by the team for various reasons. "Missing nests" are expected nesting visits from individual turtles that do not appear on schedule during a 30-day internesting interval.

<u>Observation</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>
<u>Total nests</u> during survey season.	103	154	129	77	139	114
<u>Missed nests</u> : a nesting event during which the turtle was not identified by a tag number.	7	6	4	2	1	1
Proportion of total nests missed.	0.07	0.04	0.03	0.03	0.01	0.01
<u>Missing nests</u> : an expected nesting turtle that did not appear on schedule.	1	4	5	0	6	6

There has never been any evidence of tag corrosion. Defective applicator pliers were responsible for some within-season tag loss in 1990. [Note: The 1993 season has produced the first (and only) confirmed example of an untagged turtle remigrating to Pasture Bay with torn flippers, where tags were once present. The appearance of this turtle makes it imperative that internal PIT tags are considered for the Jumby Bay project in the near future.]

Table 2 summarizes all available information on tag loss at Pasture Bay to date. Although the sample size is small, **Table 2** may be used to provide rough approximations of the probability that a single tag could be lost. Average tag loss was approximately 10% over a 2-yr or 3-yr period, indicating that a double-tagged individual with properly applied Inconel tags should be expected to return after two or three years with at least one readable tag remaining in 99% of the cases. With the addition of carapace drill marks mentioned above, and the possible addition of PIT tags, tag loss at Pasture Bay has not been and apparently will not be an insurmountable problem for the study. The implications of tag loss as a confounding factor in the measurement of remigration and survivorship values will be discussed in appropriate sections of this report.

Concern for harassment: It has always been a tenet of the Jumby Bay Hawksbill Project that zest for data not compromise the integrity of the study, ...the possible result of eager scientists harassing nesting females. The possibility of driving turtles away from protected Pasture Bay to nest on unprotected mainland beaches has been a real concern, although there is no evidence to suggest that this has happened. Nesting hawksbills have a reputation, perhaps anecdotal and unfounded, for being ultra-sensitive to the presence of people on the beach. However, no tagged Pasture Bay animal has ever been found on another nesting beach away from Long Island, although very few of these occasional mainland-nesting animals are ever checked for flipper tags. The high rate of return to Pasture Bay by remigrating turtles and the high frequency of clutches per female reinforces project confidence that much needed science has not lost sight of conservation ethics. The presence of resort guests, club members, and other observers on the beach has also not had a measurable effect on the behavior of the Pasture Bay turtles.

For reasons discussed above, the present research and interpretive educational design of the Jumby Bay Hawksbill Project will be continued

Table 2: Analysis Of Tag Loss: Expectation that a tag may have been lost on a returning turtle after a known number of years.

Year of application	Expected Duration of Tag on Turtle											
	2-yr tags			3-yr tags			4-yr tags			5-yr tags		
	n	lost	%	n	lost	%	n	lost	%	n	lost	%
1987	18	1	5.5	4	0	0	12	1	8.3	4	1	25.0
1988	11	0	0	18	1	5.5	10	2	20.0	0	--	--
1989	18	1	5.5	8	1	12.5	0	--	--	0	--	--
1990	21	4	19.0	0	--	--	0	--	--	0	--	--
Total	68	6	8.8	30	2	6.6	22	3	13.6	4	1	25.0

until otherwise indicated. Flashlights and vehicle lights are kept to a minimum on the nesting beach. Extreme caution is exercised not to disturb a turtle on the beach during any part of the nesting cycle except when it is laying eggs, and only then for the necessity of tagging or other essential research activities. A turtle that fails to nest successfully is allowed to return to the water without harassment of any kind, including the application or reading of flipper tags and the use of flash cameras. Turtles are never restrained, which means that body weights are not recorded at Pasture Bay, and untagged turtles will not be tagged until they are encountered during a successful nesting visit. Some researchers may find fault with this extreme "hands off" policy, but the goal of the Project has always been to measure population parameters of remigration, fecundity, and survivorship. This goal is not compromised by such a protective policy. The behavior of the nesting turtles is allowed to remain as natural and untouched as is possible while still maintaining a quality research program.

RESULTS

Structure of the Nesting Population:

A variety of observations have been recorded on data forms for nesting activities and for the analysis of post-hatching nest contents and hatching success (Appendix V). Results for the survey period 1987-1992 are summarized in Table 3.

Potential for error: Several important population parameters are presented in this report, such as recruitment, survivorship, mean remigration interval, etc., for which there is a distinct possibility for bias of the estimates. Bias is an error that is associated with the inability of the research team to locate the nesting turtles. Experimental error is always a problem for sea turtle tagging studies. Two objectives of the Jumby Bay Hawksbill Project have been to minimize experimental error (see the detailed discussion of experimental design in the Methods section, p. 5-12) while remaining aware of unavoidable limitations in the survey when analyzing the results. Several results are presented as "maximum" or "minimum" values, recognizing that these measured values are biased approximations of real population parameters. There are a number of reasons suspected of causing error, any of which could be acting individually or, in concert, to bias the results. For example,

tag loss: If a turtle sheds its tags and retains no marks or tag scars, it will be identified erroneously as an unmarked animal (neophyte) that is new to the population instead of a tagged animal (remigrant) that has been seen before. Tag loss affects several important estimates such as survivorship (negative bias), recruitment (positive bias), and population size (positive bias).

nesting outside the survey season: If a Pasture Bay turtle is laying its last clutch at the beginning of the survey season (mid-June), or if it is nesting for the first time at the end of the survey season (mid-November), then there is a chance that the individual could be "captured" during one season and missed on another season. There are several turtles that have been seen just once in mid-June that could fit into this category.

Table 3: Summary of the Jumby Bay Hawksbill Project. Results of tagging and reproductive surveys (1987-1992) with nesting hawksbill sea turtles, Pasture Bay, Long Island, Antigua, West Indies.

<u>Results</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>
Annual Number of Nesting Females	22	38	30	21	34	31
Number of Tagged Remigrants	0	0	17	15	28	25
Number of Untagged Turtles	22	38	13	6	6	6
Proportion of Untagged Turtles	1.00	1.00	0.43	0.29	0.18	0.19
Begin Patrol Date	VI/20	VII/02	VI/16	VI/18	VI/15	VI/16
End Patrol Date	XI/20	XI/29	XI/29	XI/11	XI/18	XI/15
Duration of Survey Season (days)	154	151	157	147	157	153
Mean Internesting Interval (days)	14.1	14.8	14.8	14.6	15.0	14.8
Total Nests During Survey Season	103	154	129	77	139	114
Total Crawls During Survey Season	165	229	206	120	230	190
Mean Nests/Night	0.67	1.02	0.82	0.52	0.89	0.75
Mean Crawls/Night	1.07	1.52	1.31	0.82	1.46	1.73
Maximum Nests/Night	5	5	5	3	5	4
Mean Nests/Turtle (observed)	4.68	4.05	4.30	3.66	4.08	3.68
Mean Nests/Turtle (calculated)	4.8	4.4	4.7	4.3	4.2	4.0
Maximum Nests/Turtle	6	6	6	5	6	6
Mean Crawls/Nest	1.60	1.49	1.60	1.56	1.65	1.66
Mean Nests/Crawl	0.62	0.67	0.63	0.64	0.60	0.60
Mean Hatching Success	0.79	0.85	0.84	0.74	0.79	0.89
Mean Incubation (days)	61	68	63	62	-	-
Mean Clutch Size (eggs)	157	147	151	150	148	153
Minimum Clutch Size (eggs)	65	70	96	68	94	124
Maximum Clutch Size (eggs)	215	203	196	202	225	229
Est. Hatchlings/Survey Season	12,775	19,242	16,362	8,547	16,252	15,523

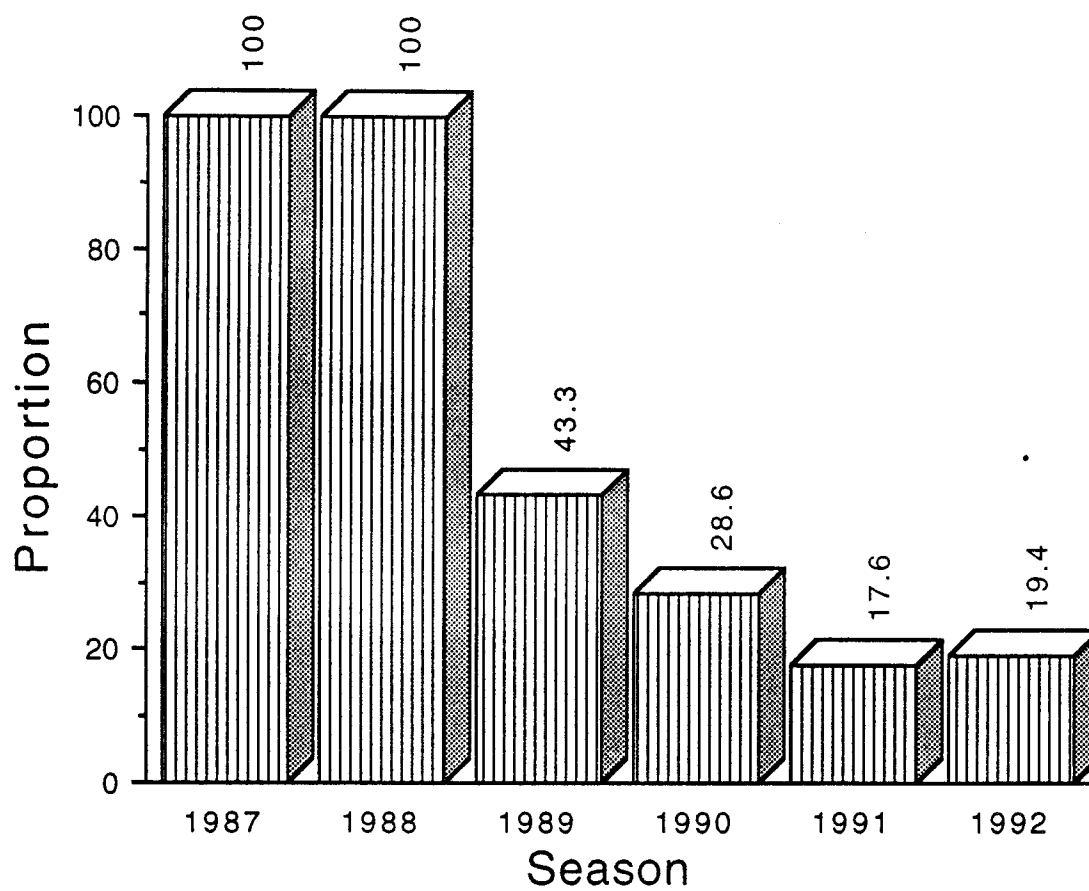
nesting outside the survey area: If a Pasture Bay turtle nests on another beach on the mainland or on an adjacent island, then it will be missed by the Pasture Bay survey crew while nesting actively in the Antiguan area. There are several turtles that have been seen only once during the middle of a survey season. These animals could have made a brief nesting visit to Pasture Bay and then returned to their regular nesting beach.

Maximum population size: Ninety-one individual females have been seen at Pasture Bay during the 6-year survey period. One or more of these animals may have returned with lost tags and been counted twice in the total, but there has been no evidence of flipper scarring during the first six years to support this possibility.

Tagging the population: The proportion of untagged turtles seen each season has become less during the six survey years (**Fig. 2**), as would be expected. Tagged turtles returning from previous nesting seasons (remigrants) have increased from none during the first two years (1987-88) of the tagging study to >80% of the annual nesting cohort during the last two years (1991-92). **Fig. 2** reflects experimental design (tagging history), and only indirectly can it be considered a statement on the biology of nesting hawksbills. Since there are no Pasture Bay records of annual remigration in hawksbills, it is understandable that marked turtles do not appear until the third year (1989) of a tagging study.

It is less understandable why the proportion of untagged turtles does not continue to decrease each year (**Fig. 2**), as would be the case if there was low recruitment of young turtles into the population, low mortality, no tag loss, and all of the turtles consistently nested at Pasture Bay during the survey season. If the Pasture Bay population was closed in a statistical sense, all existing turtles would eventually be tagged, and the annual proportion of untagged turtles would approach zero. The number of years to reach zero would depend on how many seasons the tagging team was willing to cover Pasture Bay for the last of the turtles to appear, particularly those animals with long remigration intervals (many years) between nesting visits. Of course, sea turtle populations are not closed. The trend in **Fig. 2** suggests that the proportion of untagged turtles seen annually at Pasture Bay may stabilize at $\pm 20\%$ and not approach zero.

Figure 2. Proportion of untagged turtles observed in each seasonal cohort of nesting hawksbills, 1987-1992, Pasture Bay, Long Island, Antigua, W.I.



Maximum annual recruitment to the nesting population: Real recruitment of new animals to the nesting population cannot be greater than 20% (a maximum value) and is probably less. The 20% annual proportion of untagged turtles at Pasture Bay may represent real recruitment into the population, or some of the untagged animals may be tag loss errors or visitors from adjacent beaches. However, six years is too short a period of time to estimate recruitment from tagging records, given the existence of long remigration intervals of 5-10 years in loggerheads (C. Limpus, *pers. comm.*). If a single untagged turtle in 1992 happened to have been missed by the survey team, the evidence for a downward trend in the proportion of untagged animals observed each season (**Fig. 2**, p.16) would have continued.

Individual remigration intervals: Appendix VI provides a summary of remigration intervals for each individual nesting turtle observed at Pasture Bay, 1987-1992. Clearly, 2-yr and 3-yr remigration intervals are quite common and account for a majority of the Pasture Bay turtles studied to date (**Table 4**). For a sample of 60 individuals (1987, 1988) that have been followed for four years, 85% (51/60) returned within the four year period. Twenty-eight individuals (47%) returned on a 2-yr remigration interval, 19 individuals (32%) returned on a 3-yr remigration interval, and four animals (7%) returned on a 4-yr interval. Nine females (15%) have not been seen again; at least, they have not been recognized on the beach. Given the frequent occurrence of 2-yr and 3-yr intervals (79%) and the rarity of 4-yr intervals (7%), it is surprising that nine animals are still "missing." Tag loss must always be suspected. If not tag loss, then:

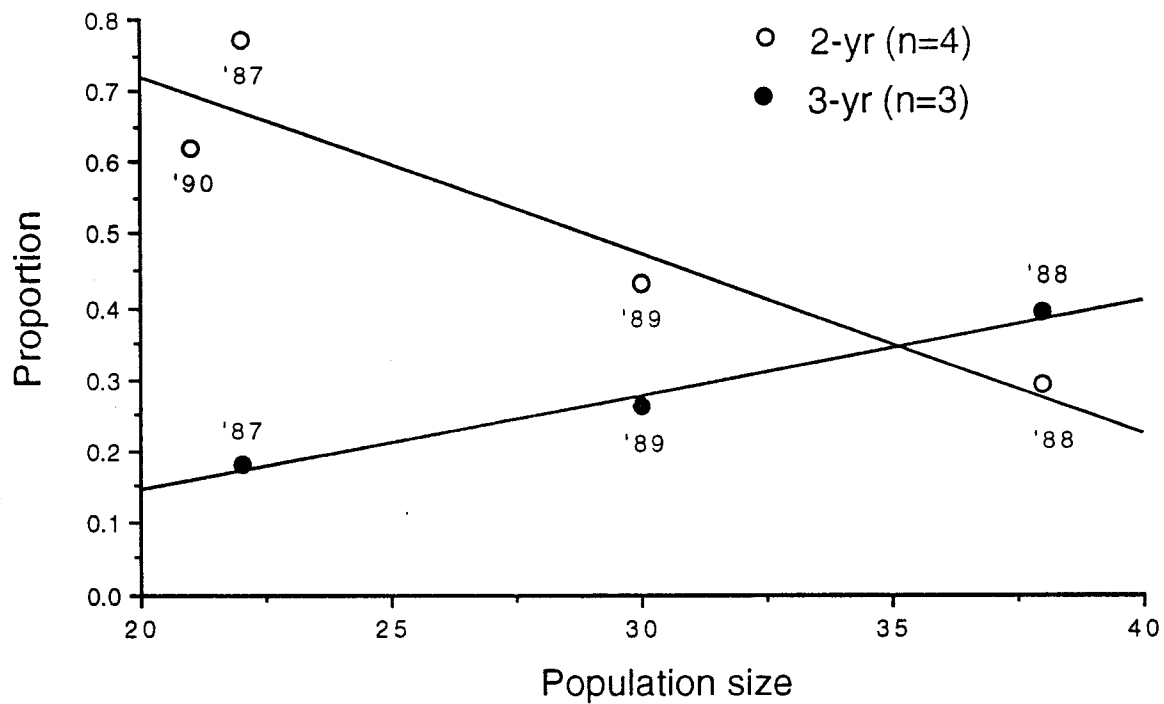
- 5-yr and greater intervals may become more common (doubtful), or...
- there could have occurred a mass departure from the 1988 Pasture Bay nesting population (doubtful), quite unlike the 95% return rate (21/22 returning animals) observed for the 1987 nesting cohort, or...
- there could be a bi-modal remigration pattern of regular (2-yr and 3-yr) remigrants and delayed remigrants (doubtful).

There is a weak statistical indication (**Fig. 3**) that a "big" year (1988) contains a larger proportion of females exhibiting remigration intervals of greater than 2-yr duration, while the reverse would be true for a

Table 4: The number and frequency of remigration intervals recorded for each seasonal cohort of nesting hawksbill sea turtles, Pasture Bay, Long Island, Antigua, 1987-1992.

<u>Year</u>	<u>Cohort</u>	<u>Observed remigration interval (years)</u>					<u>No return</u>
		<u>1-year</u>	<u>2-year</u>	<u>3-year</u>	<u>4-year</u>	<u>5-year</u>	
1987	22	0 (0.0)	17 (0.77)	4 (0.19)	0 (0.0)	0 (0.0)	1 (0.05)
1988	38	0 (0.0)	11 (0.29)	15 (0.39)	4 (0.11)	-	8 (0.21)
1989	30	0 (0.0)	13 (0.43)	8 (0.27)	-	-	9 (0.30)
1990	21	0 (0.0)	13 (0.42)	-	-	-	8 (0.38)
1991	34	0 (0.0)	-	-	-	-	34 (1.00)
1992	31	-	-	-	-	-	31 (1.00)

Figure 3. The relationship of seasonal cohort size of nesting hawksbill sea turtles to the proportion of 2-yr and 3-yr remigration intervals observed in these cohorts, 1987-1992, Pasture Bay, Long Island, Antigua, W.I.



"small" year (1987, 1990). This correlation might indicate that the ranks of regular 2-yr remigrants are occasionally swelled by 3-yr or greater remigrants, causing a "big" year. If so, a meaningful statistical basis for the correlation must await confirmation from the next half dozen years of tagging results.

Mean remigration interval for the population: Using only the cohorts from 1987 (22 animals) and 1988 (38 animals), representing both low and high population years, the observed mean remigration interval for the combined group of 51 remigrating turtles is 2.53 years, not counting the nine animals that have not (yet?) returned. Short term tag loss and the possibility that some of the nine animals may have gone to other beaches or have been missed at Pasture Bay will not bias this estimate. The possibility of mortality, long term remigration intervals, and/or long term tag loss will cause a biased estimate that is too small, and, therefore, the 2.53 year estimate is probably too small by some unknown amount. If eight of the nine missing turtles are apportioned (subjectively) as 3-yr (two animals), 4-yr (four animals), and 5-yr (two animals) remigrants and added to the known remigrants, the estimated population mean would increase only to 2.73 years. It is probably safe to assume that the real population mean for the remigration interval of 60 turtles is within the range of 2.5-2.7 years.

One other comment should be made concerning the relationship of remigration interval and mortality. The longer the remigration interval, the more negatively biased is the frequency of that interval by the effect of mortality. However, if annual mortality is small (<5%), the bias will be trivial. For example, if the effect of an annual survivorship value of 0.95 (hypothetical) is removed from the remigration results in **Table 4** (p.18), the observed remigration interval of 2.53 years per nesting season for the sample of 51 returning animals (1987, 1988) would become 2.55 years per nesting season, with a predicted sample size of 58 returning (remigrating) animals.

Annual Survivorship:

Mortality: Death among adult female sea turtles is almost always inferred (wrongly) from the absence of known individuals from the nesting beach. Mortality is rarely measured directly, and such is the case for

most of the Pasture Bay hawksbills. However, two exceptions exist. QQB-932 was captured by a fisherman in Dominican waters a few weeks after it was tagged while nesting at Pasture Bay on 18 June 1991. Details of the capture were never obtained, but it would be unusual for a fisherman to release alive such a prize. A second turtle, PPN-028, became confused by construction lights on her third nesting visit the evening of 5 August 1992. She fell into an excavation pit at Pasture Bay and was butchered the next morning by the construction crew before the turtle team knew of her predicament. PPN-028 was a 2-yr remigrant, having nested previously in 1988 and 1990.

Measuring annual survivorship: Given that mortality is rarely recorded, the measure of hawksbill annual survivorship represents a daunting challenge for the population ecologist. Hawksbills have never been known to nest annually, returning most commonly on 2-yr and 3-yr intervals (Table 4, p.18), and occasional remigration intervals of 10 years and more have been documented for Australian loggerheads (*C. Limpus pers. comm.*). The Pasture Bay study, with its intensive beach coverage and saturation tagging, represents the best available opportunity to measure annual survivorship of nesting hawksbill sea turtles.

The values for annual survivorship presented in this technical report represent underestimates that hopefully approximate real values. The absence of a turtle in a returning cohort may indicate that the animal has died since last seen, but its absence may also not be related to mortality; ...thus, the underestimate in calculating annual survivorship mentioned above. For instance, 9 out of 60 females (15%) observed during the 1987 and 1988 nesting seasons have not been seen again at Pasture Bay for at least four years (as of the 1992 nesting season). The absence of these nine animals could have been caused by any of several factors, as follows:

1. Some may have lost their tags and show no evidence of characteristic tag scars on their return to the nesting beach. As mentioned earlier, the 1993 season has produced the first documented example of a previously tagged turtle with torn tag scars. The summary of tag loss (Table 2, p.11) suggests that perhaps 10% of turtles tagged with a single tag may have lost this tag after three years away from the beach. Double tagging began in 1989. Although the sample size for the analysis of tag

loss is small (Table 2, p.11), it is doubtful that more than two or three of the 9 animals could be in this category.

2. Some may have returned with tags in subsequent nesting seasons but were missed by the survey. The proportion of nesting events for which a female was not seen (uniquely identified by tag number) is approximately 5% (Table 1, p.9). Considering that the great majority of individuals nest five times during the season (see Fig. 4, p.26), the chances that a nesting female in this category will escape notice on all of its nesting visits during a nesting season is remote and can probably be discounted. A turtle nesting outside of the survey area could be missed (p. 15).
3. Some may have gone elsewhere to nest in subsequent seasons. A quantitative measure for this contingency has not been obtained, given that occasional hawksbills do nest on adjacent mainland and island beaches, and these animals have not been checked for tags. However, there have been no recoveries of tagged Pasture Bay females on any other beach. Furthermore, the preponderance of 5-time nesting turtles (see Fig. 4, p.26) at Pasture Bay with almost no gaps in the nesting sequence (identified as a small proportion of "missing nests" in Table 1, p.9) indicates that these Antigua hawksbills are particularly faithful to their preferred nesting beach. The probability that one or more of the missing nine turtles are among this category is a complete unknown.
4. Some may be on remigration intervals exceeding four years, as has been shown for loggerheads (C. Limpus *pers. comm.*). The proportion of such animals in the nesting population is probably low and certainly unknown at this time. Only one turtle from the 1987 nesting cohort has not been seen again, and she did not appear on the fifth year after tagging (1993). Whether any of the eight missing turtles from the 1988 nesting cohort will reappear on a 5-year cycle in 1993 remains to be seen.

In summary, we have no evidence to prove or even suggest that the missing nine turtles from 1987 and 1988 remain alive or are dead. The combined possibilities listed above for the absence of these turtles could account for all of the turtles, or none of them! The cumulative knowledge gained from the results of future survey years will certainly help to

clarify this question. If a nesting turtle does not appear on the nesting beach two years after last being seen, then clearly there is a significant probability that it is not dead and that it will return to nest another season. If five years elapse without an animal being seen, then the probability grows significantly greater that it will not be seen again, although the magnitude of this probability has yet to be measured.

Minimum Annual Survivorship: **Table 5** lists various estimates of annual survivorship for each season's cohort (year class) of nesting females and for each year following the nesting season. If an animal was noted at Pasture Bay several years after its previous nesting season, it was classified as being alive in each of the previous interim years (see tagging and remigration chart: Appendix VII). If the most recent nesting season (1992 for this report) is taken as the calculation year, very little can be said about the survivorship of the non-nesting members of the cohort in question. For example, if the 1987 cohort of 22 animals is analyzed, only 27% of this cohort is known conclusively to have been alive in 1992 (calculation year), providing an unrealistically low guaranteed minimum annual survivorship value of 0.77 for the previous five years (1987-1992 in **Table 5**). Using 1991 as the calculation year and the information gathered from both the 1991 and 1992 nesting seasons, it can now be proven that 86% of the 1987 cohort was alive in 1991, providing a more realistic minimum annual survivorship value of 0.96 for the previous three years. Clearly, the highest calculated value of annual survivorship (bold type in **Table 5**) will be the most realistic value to accept for each cohort, although we know that any calculated value will be less than the actual (unmeasurable) value for this elusive population parameter.

The best estimates of minimum annual survivorship (**Table 5**) range from **0.98** (1987 nesting cohort, 3-year duration, 1987-1990) to **0.89** (1988 nesting cohort, 3-year duration, 1988-1991) and **0.84** (1989 nesting cohort, 2-year duration, 1989-1991). The more recent a cohort, the more biased and in error will be the estimate of annual survivorship in a decreasing direction. It is anticipated that the minimal estimates for annual survivorship provided here (bold type) will continue to rise, hopefully approaching (but probably never reaching) 1.00 as missing turtles reappear in future nesting seasons. The more recent nesting cohorts (1990, 1991, 1992) have not been followed for sufficient seasons to provide meaningful estimates of annual survivorship at this time.

Table 5: Minimal Annual Survivorship Values: The number and proportion of animals known to have survived for a given number of years, and the annual survivorship calculated over this length of time. Hawksbill sea turtles, Pasture Bay, Long Island, Antigua, West Indies.

Cohort size	Cohort year	<u>Animals surviving after "X" years</u>					Annual survivorship	Interval (years)	Calculation year
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>			
22	1987	21/22	21/22	21/22	19/22	6/22	-	-	-
		0.9545					0.9545	1	1988
			0.9545				0.9769	2	1989
				0.9545			0.9845	3	1990
					0.8636		0.9640	4	1991
						0.2727	0.7711	5	1992
38	1988	30/38	30/38	27/38	12/38	-	-	-	-
		0.7894				-	0.7894	1	1989
			0.7894			-	0.8885	2	1990
				0.7105		-	0.8923	3	1991
					0.3157	-	0.7496	4	1992
30	1989	21/30	21/30	8/30	-	-	-	-	-
		0.7000			-	-	0.7000	1	1990
			0.7000		-	-	0.8366	2	1991
				0.2666	-	-	0.6436	3	1992

It would be convenient and provide a more realistic opportunity for extrapolating survivorship values from short term (2-3 years) data if the Antiguan hawksbills displayed a consistent, predictable pattern of remigration intervals. However, as discussed previously (p.17 and **Table 4**, p.18), a predictable pattern is not evident at this time. Seventeen of 22 individuals (77%) from the 1987 nesting cohort returned in 1989 on a 2-year remigration interval, but only 11 of 38 animals (29%) returned in 1990 on a similar 2-yr remigration interval from the 1988 nesting cohort. Nine of 13 new (untagged) individuals from the 1989 nesting cohort of 30 animals (30%) have not reappeared as of the 1992 nesting season (three years), suggesting that these animals are either gone from the nesting population (doubtful) or somehow on a remigration interval of greater than three years (hopefully). In contrast, only one of 22 animals (5%) in the 1987 nesting cohort failed to return (and/or was not recognized because of tag loss) after three years. Repeating once again, patterns of remigration intervals are not yet predictable for Antiguan hawksbills.

Fecundity:

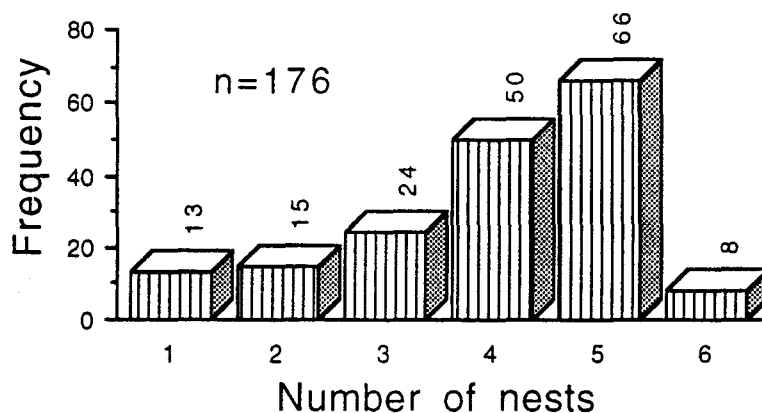
Sea turtle population fecundity, i.e. the fecundity of a cohort of nesting females over their reproductive years, is the product of:

1. adult annual survivorship of the nesting females,
2. mean remigration interval,
3. mean clutches per nesting season, and
4. mean clutch size.

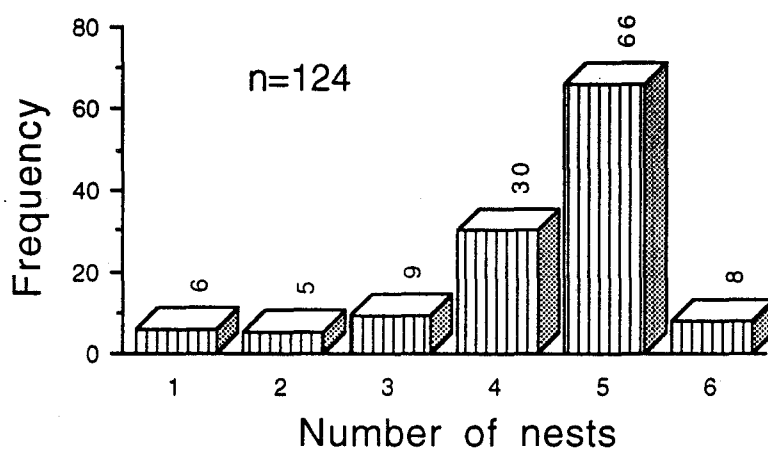
Clutches per nesting season: As in other calculations, clutches per season will be a minimum value. There are three ways to calculate this value (**Fig. 4**), including:

1. all observations during the survey season,
2. mid-season observations, including activities only of those individuals beginning and ending their nesting season entirely within the survey season, and
3. predicted clutches per season, including a few "missing nests" that should have been recorded (see **Table 1**, p.9) and have been added to the mid-season observations.

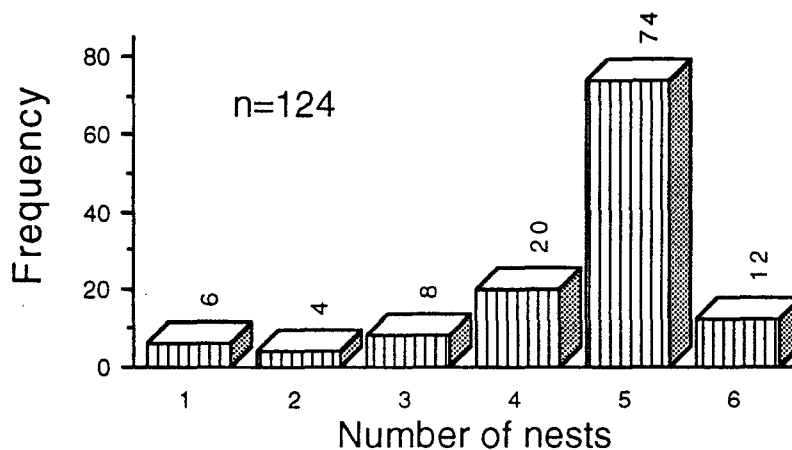
Figure 4: Number of Nests Per Individual Per Season (All Observations), Hawksbill Sea Turtles, Pasture Bay, Antigua, W.I.



Number of Nests Per Individual Per Season (Mid-season Observations), Hawksbill Sea Turtles, Pasture Bay, Antigua, W.I.



Number of Nests Per Individual Per Season (Predicted), Hawksbill Sea Turtles, Pasture Bay, Antigua, W.I.

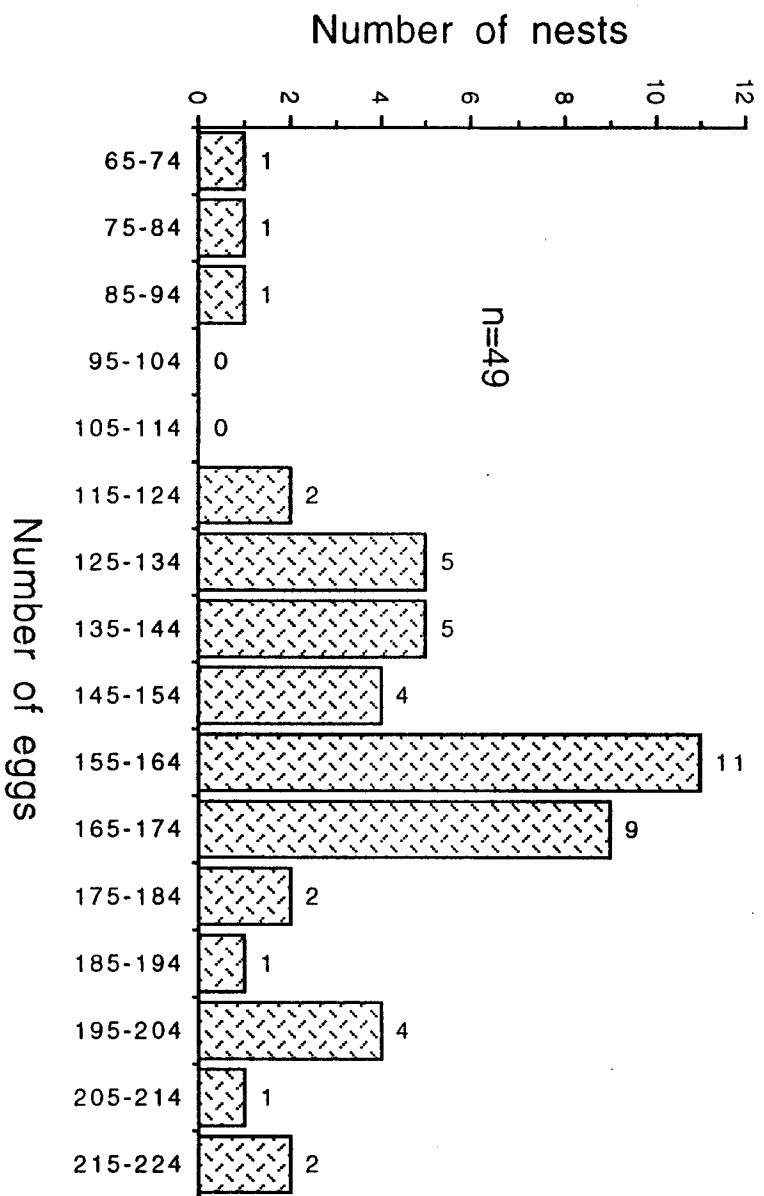


Clearly, "all observations" gives a gross underestimate of the true value, since a number of turtles are just ending their nesting season in June or just beginning their season in November. The mean value calculated in this way is **3.94** clutches per turtle. Obvious examples of these "overlap" turtles may be rejected from the sample by discounting any individual which has nested within 20 days of the beginning or end of the survey season and has nested four or fewer times during the survey period. The resulting mean value for "mid-season observations" is **4.44** clutches per turtle. Only slightly higher is the "predicted" mean, **4.52** clutches per turtle, achieved by adding a nest to the record of any "mid-season" turtle with a 30-day (double) internesting interval. It is clear from **Fig. 4** (p. 26) that the dominant modal class is **five** clutches per turtle.

Average clutch size: It is a policy of the Jumby Bay Hawksbill project to cause the least amount of disturbance to the nesting turtles while gathering only essential data on the population. Freshly laid nests are not excavated for the single purpose of counting clutch size, in case the unnecessary handling of the eggs may reduce fitness of the hatchlings. Although there have been more than 700 nests on Pasture Bay during the six survey years, only 49 fresh clutches were counted, mostly from the 1987 season (**Fig. 5**). A mean of **157** eggs per clutch has been calculated for this sample. From 1988 to 1992, many other nests have been excavated after a hatch, and clutch size has been estimated from nest contents, including fragments of egg shells. During these years, clutch size (estimated) has been roughly **150** eggs per clutch, with annual means ranging from 147 to 153 eggs per clutch (**Table 3**, p.14). Annual means of loggerhead clutches from Georgia range $\pm 5\%$ around the grand population mean (J. Richardson, *pers. comm.*), and the same may be true of the larger than normal hawksbill clutch size value for 1987. However, a mean of **157** eggs is the only value that has been measured without error, and it is the opinion of the project that clutch size estimated from nest contents is susceptible to negative bias because of the many fragments of egg shell that are usually not counted as being indicative of a whole egg.

Mean remigration interval: A mean remigration interval of 2.5 years between nesting seasons has been calculated (p. 20).

Figure 5. The distribution of clutch sizes (egg counts) by hawksbill sea turtles, Pasture Bay, Long Island, Antigua, W.I.



Individual fecundity: Without considering mortality or variance of the estimates, an individual female hawksbill from Pasture Bay might be expected to produce approximately 279 eggs....

$$[(155 \text{ eggs} \times 4.5 \text{ clutches})/2.5 \text{ yrs}]$$

per annum of its reproductive life.

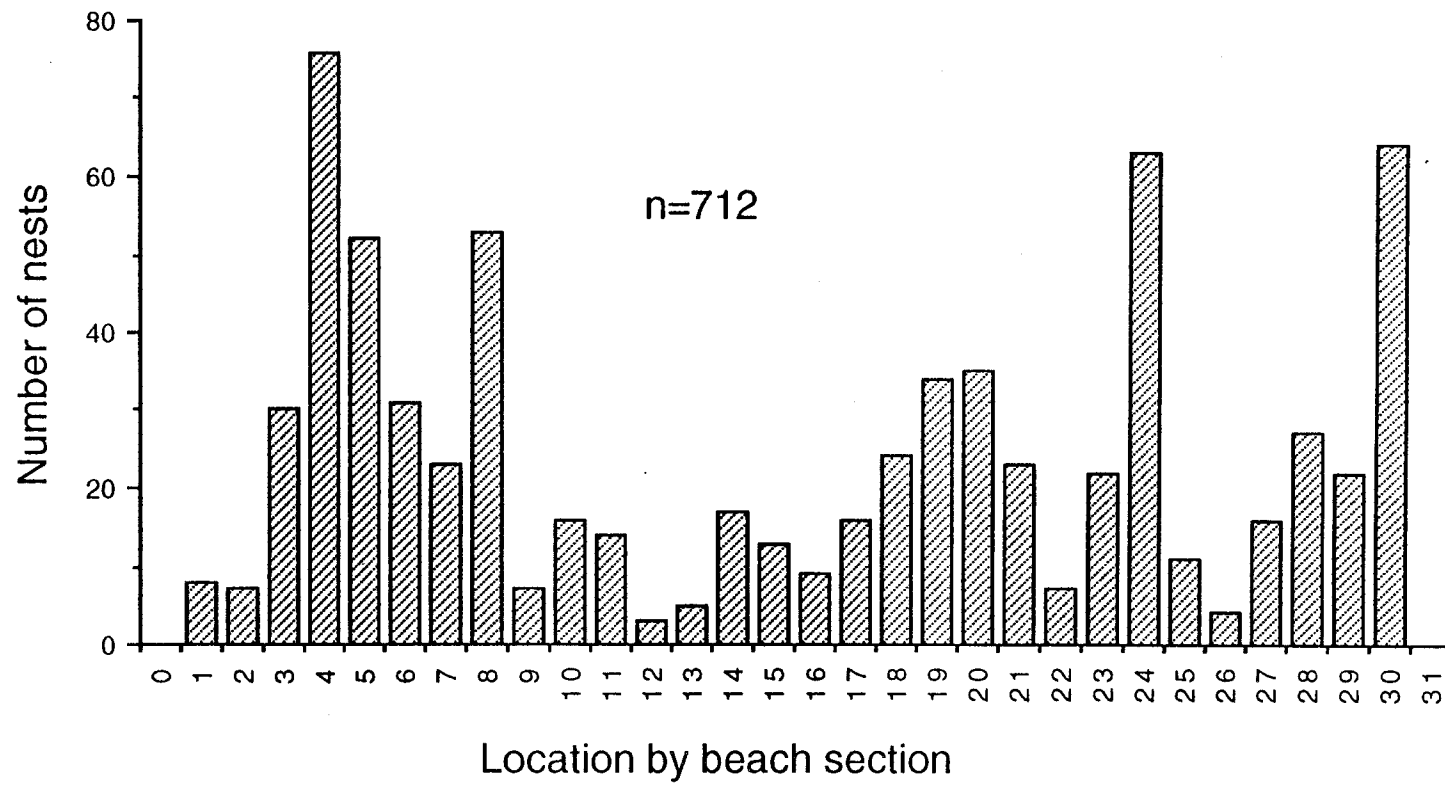
Cohort fecundity: A cohort of recruits would produce at the above rate on their first nesting year and then decrease in productivity by the product of the best estimate for annual survivorship for each subsequent year. Thus, if 0.90 is the best estimate for annual survivorship (see **Table 5**, p.24), a cohort of ten animals might produce 2790 eggs (averaged annually) on the first reproductive year, 2511 eggs (2790×0.90) on the second reproductive year, 2260 eggs ($2790 \times (0.90)^2$) on the third reproductive year, etc.

Nesting Activity:

Pasture Bay survey results for nesting and hatching (1987-1992) are presented in **Table 3**, p. 14. A combined **716** nests were recorded during the six survey periods (15 June-15 November), or **119** nests per survey period. This equates to **0.78** nests per night, or three nests per four nights. Nesting activity outside the survey period (1 May-15 June; 15 November-31 December) is roughly estimated to be 20% of nesting activity within the survey period. Thus, annual nesting at Pasture Bay might be approximated at 140-145 nests/year. Total crawls always exceed total nests (**Table 3**, p. 14), because not all nesting attempts are successful. The mean of **1.60** crawls per nest (seasonal mean range of 1.49-1.66) is an important sampling statistic for Pasture Bay, in that crawl counts gathered during non-survey periods can be converted to nest counts with a fair degree of confidence.

Spatial distribution of nesting: Nesting is not evenly distributed along the Pasture Bay beach (**Fig. 6**). Preferred areas are those with trees or shrubs close to the water's edge where there is an opportunity for the emerging turtle to crawl directly from the water into the protection of the vegetation. Sections not used as frequently are along cleared portions of the beach with a distant vegetative horizon, or areas with an approach

Figure 6. The spatial distribution of nests along the Pasture Bay beach, Long Island, Antigua, W.I., 1987-1992.



across cobbles or rock ledge, or areas where erosion has left an impenetrable barrier of roots and branches. An extended analysis of nesting requirements and preferences of Pasture Bay hawksbills has been published by Ryder *et al.* (1989) and is appended to this report.

Diel distribution of nesting: Pasture Bay hawksbills emerge to nest most commonly between 2000 hours and 0100 hours in the night (**Fig. 7**), but a nesting event is possible at any time from dusk until dawn. There has been one record of a daytime nesting event, when the turtle arrived at dawn and did not finish until the sun was high. There have been several records of turtles discovered on the first evening patrol while in the final stages of nesting. These animals must have begun their nesting crawl before dusk. A turtle that fails to nest successfully will usually return later the same night or on the following night for a second nesting attempt. A few turtles make numerous visits to the beach and/or excavate numerous nest holes before a successful nest is achieved.

Seasonal distribution of nesting: There is a great deal of discussion about "nesting season" in hawksbills, particularly the dates that frame a nesting season. Hawksbills are known to nest in every month of the year, but the major nesting season for Pasture Bay is clearly less than a year (**Fig. 8**). The combined nesting activity for the six survey years shows a clear mode of maximum activity in late August and early September, with decreasing activity toward the beginning (15 June) and end (15 November) of the survey season. It is also clear from the shape of **Fig. 8** that some nesting activity should be expected before and after the survey period, and this has been shown to occur. The truncated ends of the nesting distribution in **Fig. 8** are an anomaly of the start and finish dates of the survey season. It is not known how far the geographic application of the Pasture Bay nesting season may be extended to other nesting beaches, but Mona Island (Puerto Rico) hawksbill nesting data appear to fit within the Pasture Bay season (J. Richardson, *pers. comm.*).

A hawksbill "nesting season" is the sum of the combined activities of a season's cohort of individual turtles. Each individual hawksbill arrives at the nesting beach on a given date and usually remains to nest 4-6 times on 15-day intervals (see discussion on internesting intervals, p. 34), adding its presence to the nesting season for a period of about two months (± 2 wks). Loggerheads nesting along the Southeastern U.S. arrive synchronously and lay approximately the same number of clutches

Figure 7. Hourly arrival times of hawksbill sea turtles nesting at the Pasture Bay beach, Long Island, Antigua, W.I.

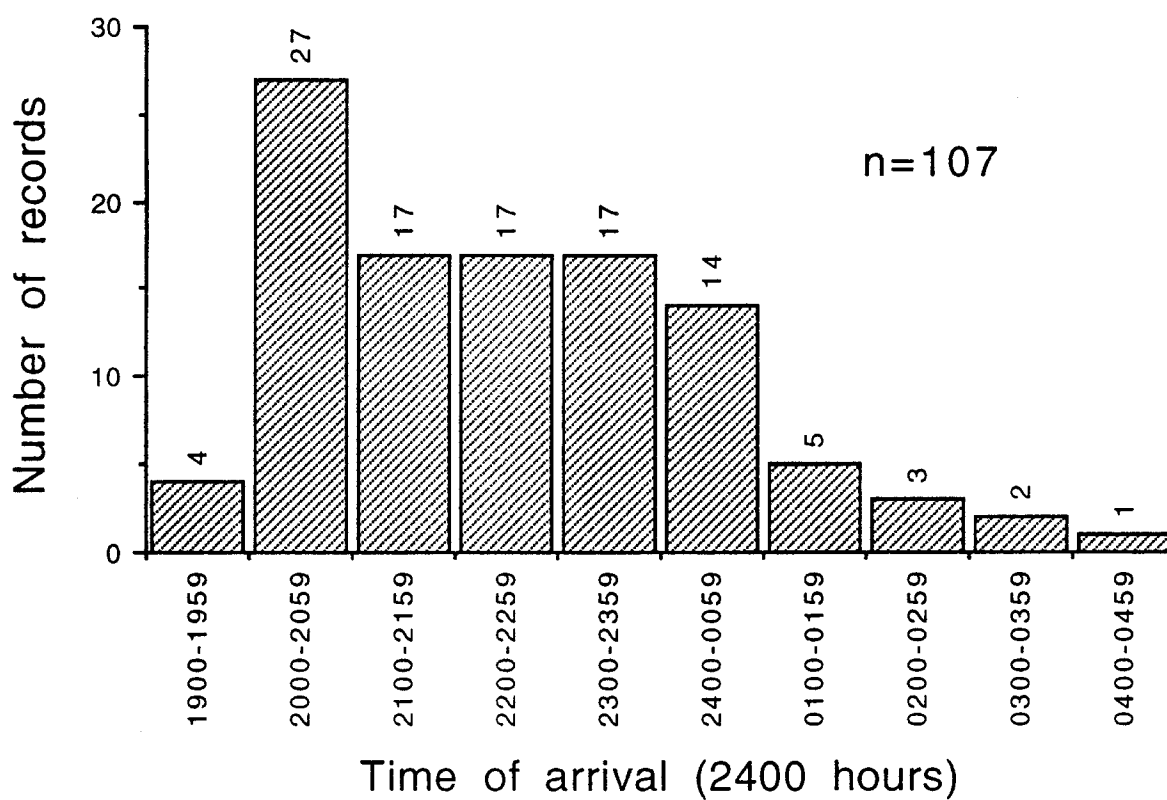
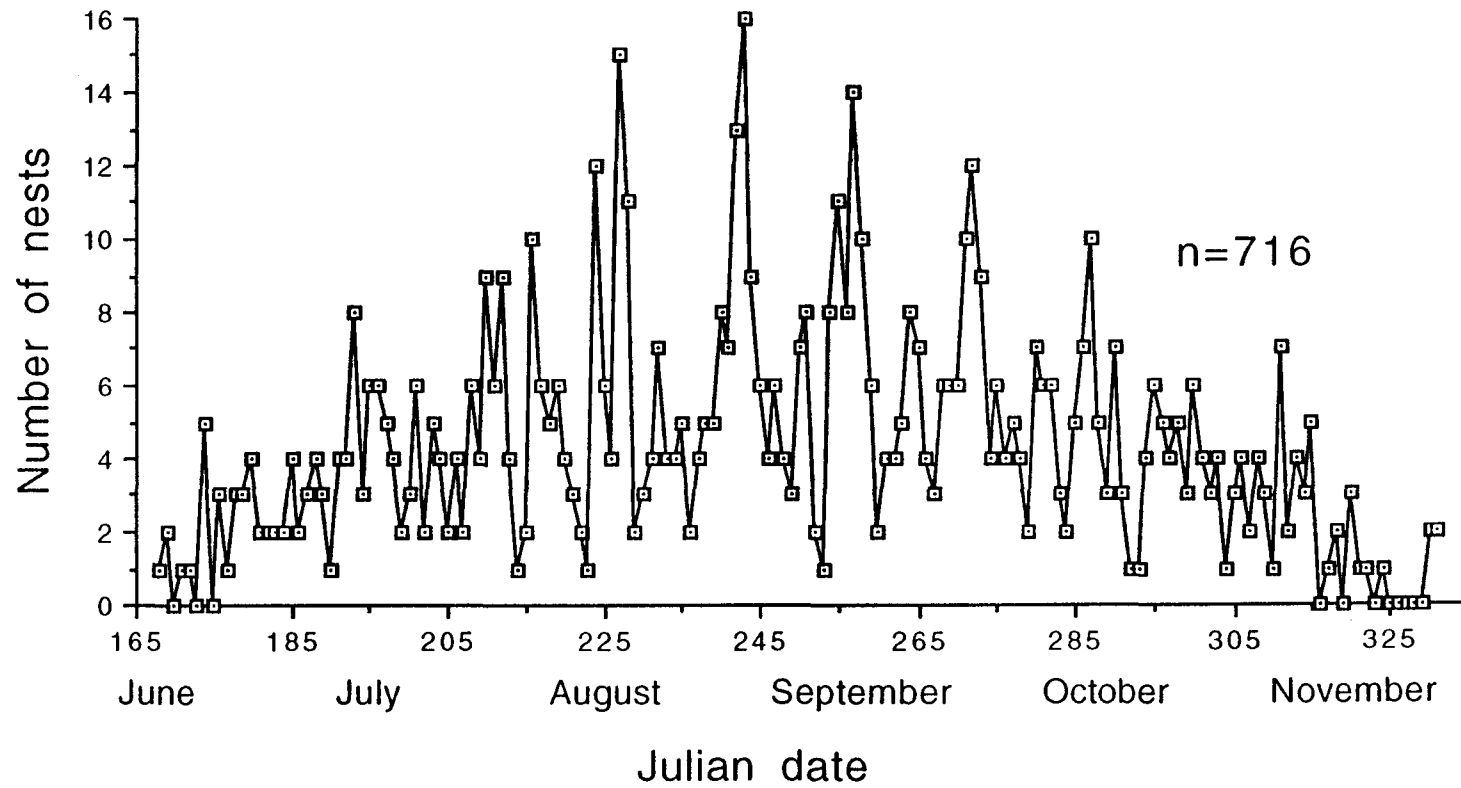


Figure 8. The combined distribution of hawksbill sea turtle nests (1987-1992) plotted by Julian date, Pasture Bay, Long Island, Antigua, W.I.

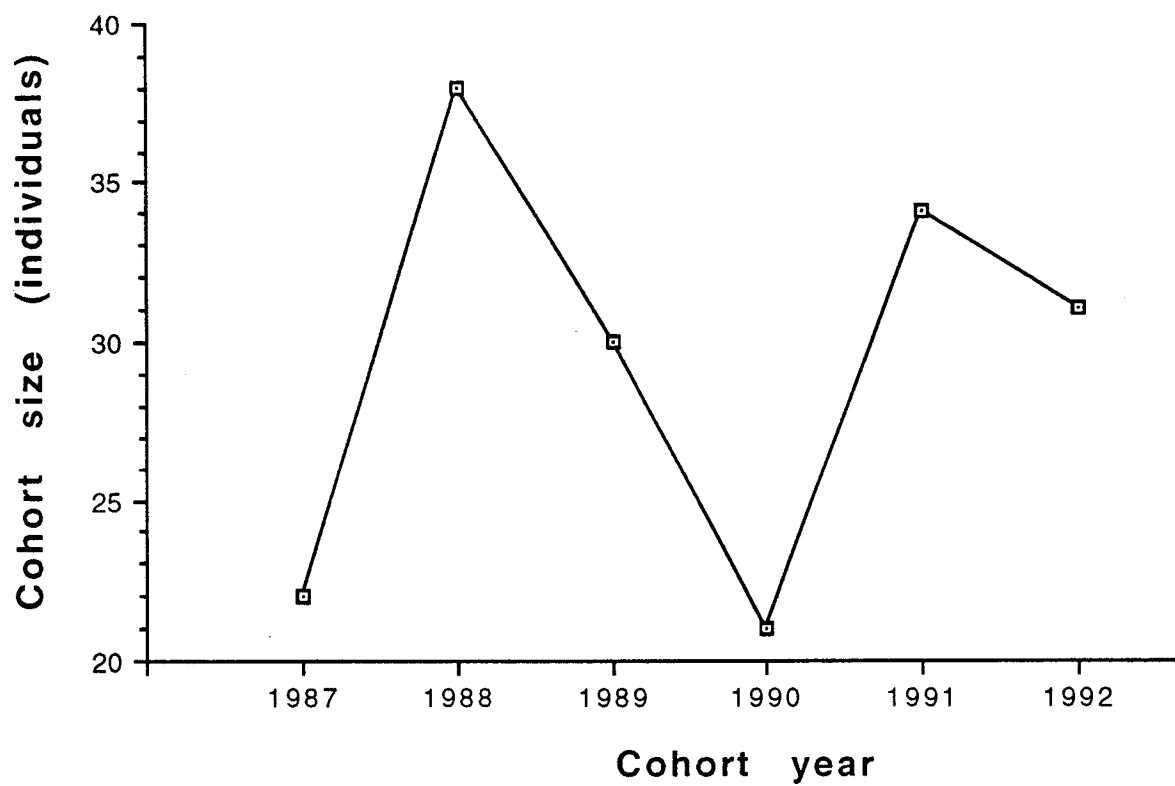


(J. Richardson, *pers. comm.*). Thus, the majority of loggerhead nesting is contained within a 70-day period (20 May-30 July). Hawksbills, on the other hand, arrive asynchronously at the nesting beach (June-September), producing a long (150-day) nesting season that gradually builds and recedes around an August-September peak (**Fig. 8**, p.33). Only when many hundreds of nesting events are combined does this trend become apparent. When investigations are short term or incomplete and the number of nesting individuals is low, the nesting season may appear to be early or late, peaked or disbursed, seasonally focused or with several modes of activity, depending on the "luck of the draw." Because remigration intervals are of various lengths and change between seasons and within the behavior pattern of a single individual (Appendix VI), the observed "nesting season" at most locations with few turtles would be expected to change its appearance from year to year.

Perceived variations in a hawksbill nesting season are caused primarily by the behavior of the individuals making up the season cohort rather than by environmental influences such as weather and water temperature. Because annual remigration is not known for hawksbills at Pasture Bay, a "small" nesting season would be expected to be followed by a "big" nesting season, and vice versa (**Fig. 9**). In fact, the 1993 season is turning out to be a very "small" year, and so it may be expected that 1994 will be a "big" year.

In addition, Bass and Richardson (manuscript *in prep.*) have noted an indication of synchronous remigration arrival times within the behavior of each individual turtle. They used only first arrival dates in an analysis of paired values for 23 individuals in their study. The nesting dates were distributed in the following manner: 1987-'89 (n=14), 1988-'90 (n=5), and 1987-'90 (n=4). It appears that the arrival time of a nesting female is not random; fifteen of the remigrating animals returned within ± 10 days of their previous first arrival date two or three years before. Mean separation of paired arrival dates for the 23 hawksbills was 10.5 days [2S.E.(0.062)], while the sample mean of 66 randomly generated, paired arrival dates for a 120-day season was 17.0 days, and the variance of the random sample [2S.E.(0.128)] was twice that of the observed data. The pattern has continued for the 1991 and 1992 seasons. Although temperature cannot be ruled out, it appears that a hawksbill's "decision" to arrive at the nesting beach at a particular time of year is tied strongly to its individual biological clock, with the controlling factor perhaps

Figure 9. The annual cohort size of nesting hawksbill sea turtles observed during the survey period, 1987-1992, Pasture Bay, Long Island, Antigua, W.I.



being photoperiodicity. Sea turtles have very large pineal bodies in comparison to other tropical vertebrates, and the pineal body could provide a system to translate the length of day into a highly precise endocrine-based biological clock (Owens, 1980.).

Inter-nesting intervals: Several references have been made in this report concerning internesting intervals of ± 15 days by Pasture Bay hawksbills. The mean of 489 intervals is 14.8 days (Fig. 10), with a clear mode of 14-day and 15-day intervals. This sample represents nest-to-nest intervals, since very few turtles are disturbed for the purpose of reading tags during an unsuccessful nesting crawl. The interval from nest date to first return date could be less by perhaps 0.5 days. It is also of interest that the first internesting interval (mean of 15.2 days) between nest #1 and nest #2 is apparently greater than any of the following intervals of approximately 14.5 days (Fig. 11). The variance of these means has not been calculated for this technical report, so the significance of the difference between the first and subsequent intervals is not known.

Periodicity in seasonal nesting activity: The 2-week rule for internesting intervals means that a chance grouping of nesting turtles within a period of several days will set off a bi-weekly periodicity lasting for several months while the group completes its set of five clutches per turtle. It has been surprising, however, that obvious bi-weekly periodicity has been the rule for each of the six nesting seasons for the duration of the 150-day survey period, involving many turtles that have entered and exited during the season at very different times. It was even more surprising that the periodicity has remained obvious after the nesting activity of six seasons was combined into a single relationship (Fig. 8, p.33). If these data are then smoothed with a 3-day running average, the visual evidence for periodicity becomes even more dramatic (Fig. 12). The greatest amplitude for this periodicity occurs toward the middle of the nesting season, when the greatest number of turtles are present. Obvious environmental cues (moon phase, tidal cycles, etc.) are not synchronized between years in a way that could explain the results. Random mechanisms that might have generated the periodicity are not obvious. The authors find no immediate, logical explanation for such an unexpected result. The implied periodicity in Fig. 12 is most interesting and deserves more thought for the future.

Figure 10. The distribution of interesting intervals by length (days) exhibited by nesting hawksbill sea turtles, Pasture Bay, Long Island, Antigua, W.I.

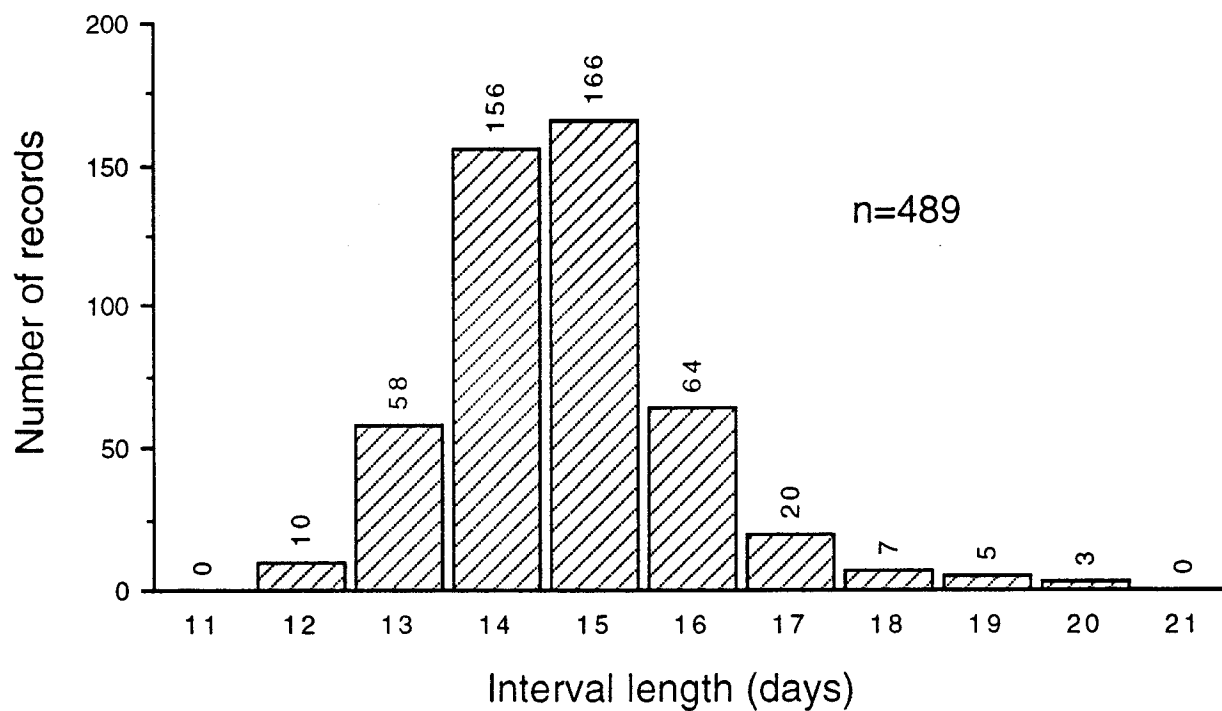


Figure 11. The relationship of the length of the internesting interval (days) to the sequence of clutches laid by hawksbill sea turtles, 1987-1992, Pasture Bay, Long Island, Antigua, W.I.

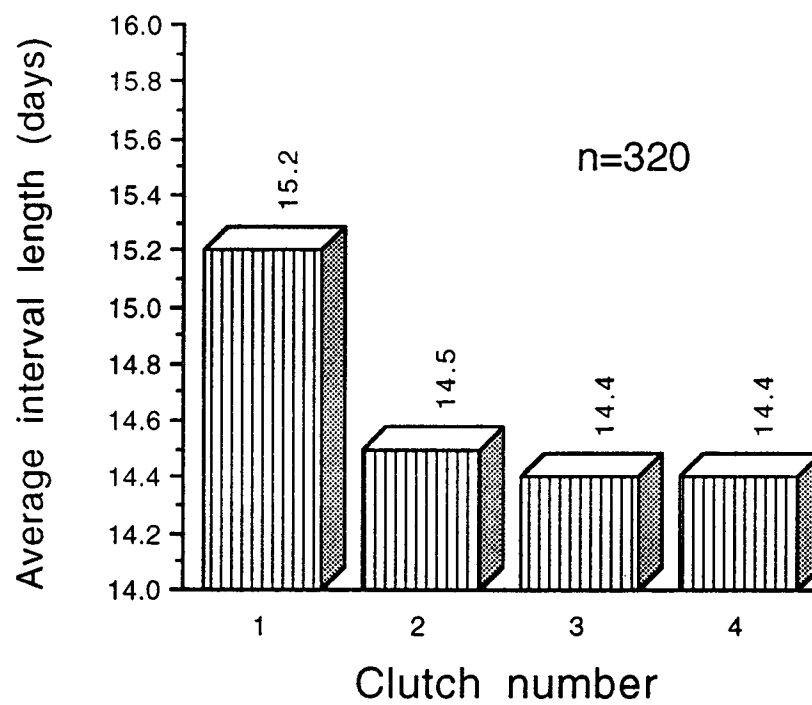
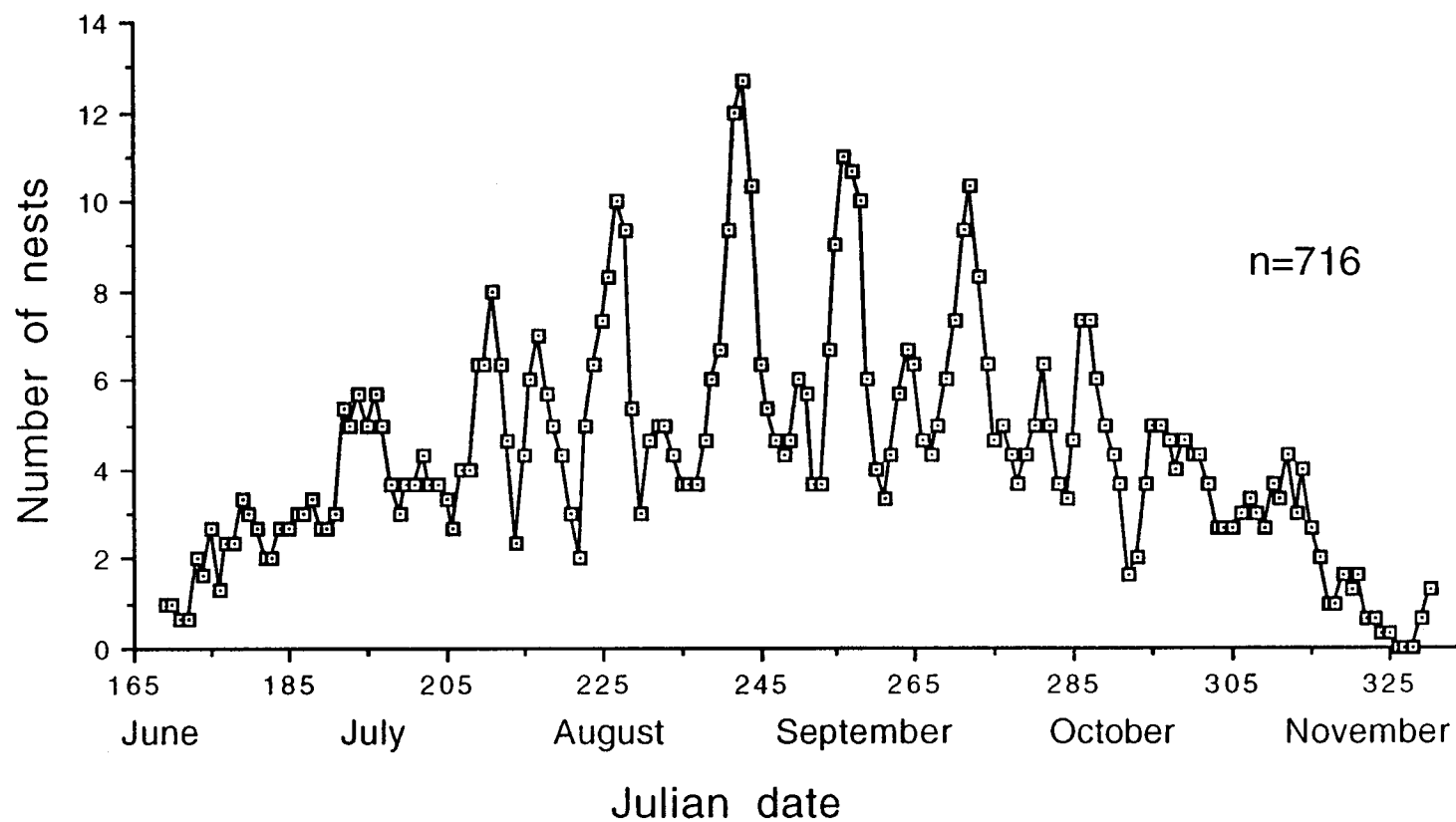
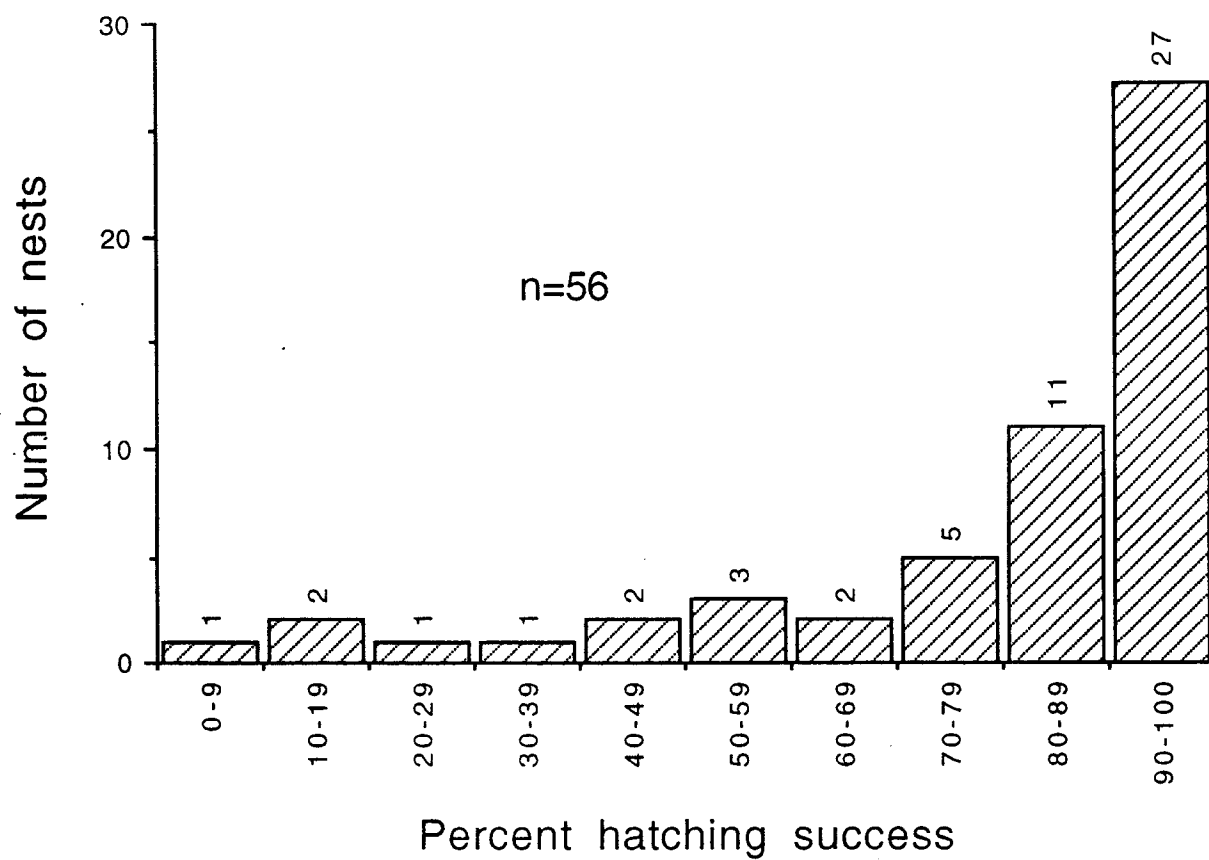


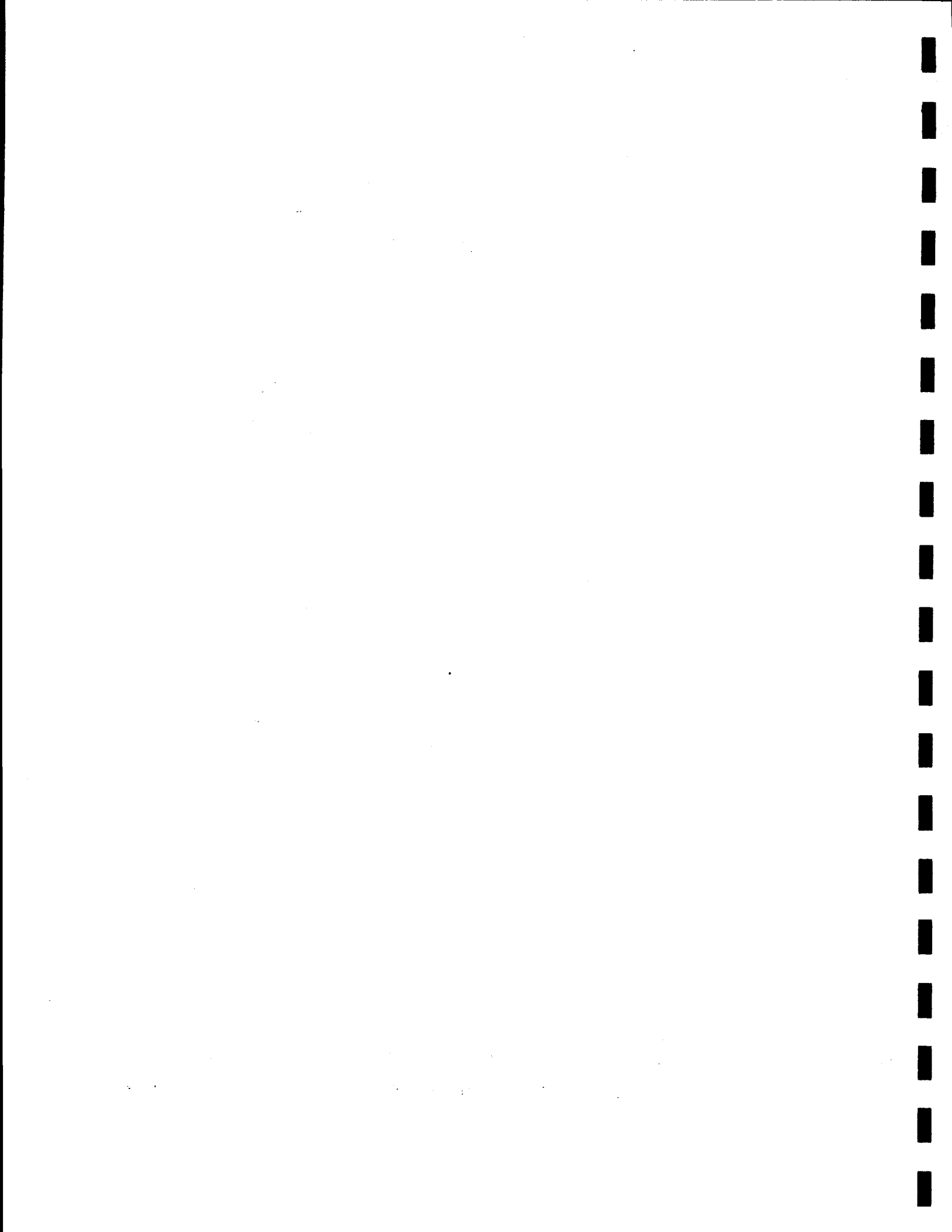
Figure 12. The combined distribution of hawksbill sea turtle nests (1987-1992) plotted by Julian date as a 3-way smoothed running average, Pasture Bay, Long Island, Antigua, W.I.



Hatching success and production of hatchlings: Fifty-six clutches have been included in an analysis of hatching success (**Fig. 13**). Nests at Pasture Bay are protected from poachers and exotic predators (dogs, cats, mongooses), but crabs and ants are present. The effect of the native predators can presumed to be included in the sample. Mean hatching success was **82%**, which appears to be generally higher than natural hatching success for other sea turtle species. The modal success rate of 90%-100% is surprisingly high and speaks well for the adaptability of the hawksbill to a variety of nesting habitats ranging from clean sand to forest soil with significant levels of humus and other organics present. The product of hatching success and number of clutches for each survey season (**Table 3**, p. 14) provides an estimate in excess of 88,000 hatchlings produced during the 6-year survey period, or 14,784 hatchlings per survey season. Considering the additional $\pm 20\%$ of nesting that occurs outside of the survey season, the Pasture Bay production of hawksbills from 1987 to 1992 could approach 100,000 hatchlings. This is a spectacular record for an endangered species!

Figure 13. The hatching success of a sample of hawksbill sea turtle clutches, Pasture Bay, Long Island, Antigua, W.I.





DISCUSSION

The Jumby Bay Hawksbill Project is gathering invaluable statistical information on survivorship, mortality, and recruitment of adult female hawksbill sea turtles and the reproductive biology and behavior of their nesting activity. The density and focused distribution of the nesting activity on Pasture Bay beach provides a unique opportunity to employ a saturation tagging program with the nesting population. Six years of survey work provide an excellent indication of the quality of the data collected to date and the future for the project to open ever more precise windows of understanding. Some of the population parameters that have been measured are both accurate and precise and are predicted not to change in the future. Included in this category are individual within-season fecundity, shape of the Antigua nesting season, and the nesting behavior of the hawksbills on the Pasture Bay beach.

Other population parameters from Pasture Bay represent the best estimates available for nesting hawksbills, but the precision and accuracy of the estimates are still suspect, given nagging questions of possible tag loss and the relatively "short" (six years) duration of the study. Included in this category are the important parameters of recruitment, survivorship, mortality, and remigration behavior. The methods used to gather the Pasture Bay data have been elaborately described in this report. The purpose is to allow individuals using the data for modeling purposes or other reasons to draw their own conclusions as to the error associated with the estimates of population parameters presented here. Long remigration intervals and associated possible tag loss represent the greatest uncertainty, affecting calculations of recruitment and annual survivorship. An intuitive range of values around selected means increases confidence for certain parameters. At least one parameter, the population mean for remigration intervals, appears to be very sensitive to error arising from long remigration intervals and possible tag loss, but the same parameter is much less sensitive to the uncertainties of mortality and its effect on a measured remigration mean for the population.

The Jumby Bay Hawksbill Project is unique in what it can offer the world conservation community. With only six years of intensive tagging completed, the Project has only now begun to unravel the mysteries of

survivorship and recruitment in the elusive hawksbill. International managers of endangered sea turtles are in great need of these critical data coming from Pasture Bay. The purpose of this technical report is to make available immediately the results of the Pasture Bay research, without waiting for other avenues of publication. As the Jumby Bay Hawksbill Project moves toward a decade of work, each additional season will add enormously to the reputation of the program, for tagging data are cumulative, and critical questions of population ecology can only be answered with a retrospective analysis of many years of past research results.

Finally, it should be kept in mind that the Pasture Bay hawksbills are a rare gathering of individuals representing a severely endangered species. A possible 100,000 hatchlings produced in six years is unprecedented on hawksbill beaches of a size approximating Pasture Bay. The collecting of research data from these animals must never become so disruptive of the turtles that nesting behavior could be changed and the potential for further research be compromised by the effect of the research itself. The integrity of the nesting beach and the behavior of the nesting females and hatching young must be protected from the eager participation of resort guests and club members and from the development of elegant homes along the length of Pasture Bay. Luckily, the nesting hawksbills have proven to be most resilient to these disruptions. There is every reason to believe that continuing efforts by Jumby Bay will successfully protect Pasture Bay beach for the nesting hawksbills and that hawksbills and people will share a common resource for the mutual benefit and pleasure of both parties. Jumby Bay is already becoming a classic example of intelligent ecotourism and environmental responsibility.

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THE HAWKSBILLS OF JUMBY BAY, ANTIGUA, WEST INDIES

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The hawksbill (*Eretmochelys imbricata*) is not generally a colonial nesting animal. It tends to nest singly or in low numbers on small, remote beaches with dense shrubbery and little open sand. Given the substantial dollar value of hawksbill shell on the international market, the continuing presence of this endangered species in Caribbean waters may be the serendipitous result of its reclusive reproductive behavior. Consequently, demographic studies of the hawksbill are rare to nonexistent. However, an exception to the general rule concerning hawksbill nesting behavior has been found off the north coast of Antigua in the West Indies. A remote yet accessible gathering of hawksbills nests each year along Pasture Bay beach (500 m) on Long Island, a small resort island (300 acres) known by its commercial name - Jumby Bay. The beach and nearshore waters are protected from tortoiseshell hunters and turtle egg gatherers, and there are no natural nest predators on the island. This report summarizes the first three years of an intensive investigation of the Jumby Bay hawksbills.

HISTORY AND PHILOSOPHY OF THE PROJECT

The presence of hawksbill nesting at Pasture Bay has been known locally for many years. In 1984 John Fuller identified the location to James Richardson with the hope that a study of the Jumby Bay hawksbills might be initiated. Richardson, Corliss, and Bell began a preliminary survey in 1986, using that season to test the effectiveness of an intensive research design that would not cause undue disturbance to the nesting females. Tagging was begun in 1987 and continued in 1988. In addition, environmental education and resource management have been important elements of the program.

METHODS

Saturation tagging means that no nesting event is allowed to occur within the study area without the adult female being identified. Studies of this kind on leatherbacks and loggerheads have provided new understanding of nesting effort (fecundity) by individual turtles and new estimates of population numbers derived from crawl counts (see Tucker in these Proceedings). The Pasture Bay beach is patrolled nightly at hourly intervals from 2000-0500 hrs from middle June to late November. Nesting females are measured and marked redundantly in three different ways: monel flipper tags; a diagnostic pattern of drill holes in the trailing edge of the postcentral scutes; a photographic record of the barnacle pattern on the carapace. Nests are marked, and the contents are examined for hatching success after natural emergence has occurred.

RESULTS

Two seasons (1987 and 1988) of tagging data are presented in Table 1. Although scattered nesting occurs in every month of the year, the major nesting season runs from mid-June until mid-November. Since five is the modal number of nests per turtle, a nesting season for an average female hawksbill would be 56 days. The extended (± 150 day) nesting season for the Jumby Bay population indicates that the initial arrival of hawksbills at the Pasture Bay nesting beach is distributed widely (mid-June to late September), similar to the asynchronous arrival of leatherbacks at St. Croix, U.S. Virgin Islands (Eckert, personal communication), but quite different from the synchronous arrival of loggerheads (late May to mid-June) at Little Cumberland Island on the temperate Georgia coast. It may be assumed that the remigration interval for Jumby Bay hawksbills is two or more years, because no turtle present in 1987 was seen in 1988.

DISCUSSION

Jumby Bay hawksbills exhibit higher seasonal fecundity than previously recorded. If we estimate that an average individual female will lay ± 700 eggs/season and produce ± 560 hatchlings/season (80% hatch rate), then we can predict that 61 females collectively produced roughly 34,000 hatchlings during the last two nesting seasons. Thus, it can be seen that Pasture Bay beach is a major source of neonate hawksbills from the Leeward Islands of the West Indies.

It should also be noted how tenuous the continuing survival of the Jumby Bay turtles would be without proper protection. A single gatherer of tortoiseshell could have easily poached all 61 females in the last two seasons, if Pasture Bay beach had not been protected. More than half of these animals were on the beach after 30 September, the opening day for the legal take of nesting females under Antigua's Turtle Ordinance of 1927. Evidently, the offshore location of Pasture Bay beach was an important factor in protecting the nesting females before Long Island was designated as a private nesting sanctuary.

The Jumby Bay hawksbills exhibit extreme site fidelity to Pasture Bay beach, perhaps to a greater extent than has been documented for any other species of sea turtle. The majority of females are seen nesting on five occasions during the season. Only rarely does a female not show up for an expected nesting visit. Pasture Bay beach is a natural beach with an east-northeasterly exposure. An adjacent, artificial beach (Jumby beach) with a northerly exposure seemingly provides adequate nesting habitat but has no crawl activity. Additional natural beaches on the adjacent mainland are less than a mile away with hawksbill nesting activity, yet the Jumby Bay hawksbills appear not to use these beaches, either.

The future of the Jumby Bay nesting colony appears guarded but good. The resort is excited about the nesting turtles and supportive of a research/management/education program. They realize that nesting hawksbills are good for business. Resort guests find pleasure in observing the nesting turtles, and the turtles appear not to be affected by the presence of the guests under controlled conditions. Interpreting the nesting turtles to inquisitive guests is a high priority of the program. Construction along Pasture Bay beach is being modified to protect the turtles and their nesting habitat. Houses are set back behind critical nesting habitat, and house lights are screened to prevent disorientation of hatchlings on the beach.

Environmental education is another part of our program that is growing in importance. In order to encourage more local involvement, we intend to invite a local Antiguan teacher to participate as a research intern during the 1989 season. Furthermore, Corliss has introduced sea turtle education programs into a number of the local schools with great success. It is hoped that our achievements at Jumby Bay will spread to other beaches of Antigua and Barbuda, and the sea turtle conservation efforts of this important West Indian nation will grow.

Table 1: Results of a two year hawksbill study at Jumby Bay, Antigua, West Indies.

Season value	1988	1987
1. Number of females	39	22
2. Patrol season	2 July- 29 Nov.	20 June- 20 Nov.
3. Patrol length (days)	151	154
4. Internesting interval (days)	14.8	14.1
5. Total nests	156	99
6. Total crawls	227	164
7. Mean nests/night	1.03	.64
8. Mean crawls/night	1.50	1.06
9. Max. nests/night	5	5
10. Observed mean nests/turtle	3.9	4.2
11. Calculated nests/turtle	4.4	4.8
12. Max. observed nests/turtle	6	6
13. Mean seasonal crawls/turtle	5.8	7.5
14. Mean crawls/nest	1.46	1.66
15. Mean nests/crawl	.68	.60
16. Mean hatching success	85%	79%
17. Incubation to emergence (days)	68	61
18. Mean clutch size	147	157
19. Range of clutch sizes	70-203	65-215



Pivotal and beach temperatures for hawksbill turtles nesting in Antigua

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Eggs of hawksbill turtles, *Eretmochelys imbricata*, from Antigua were incubated at constant temperatures. The pivotal temperature (the temperature at which 50% of each sex is produced) for the sample was estimated to be 29.2°C. Sand temperatures at the depth of turtle nests were recorded over two nesting seasons at Pasture Bay, Antigua. Although sand temperatures were sometimes higher than the pivotal temperature, more often they were lower. On this basis, it is unlikely that hatchling hawksbill turtles in this area have the highly female-biased sex ratios reported for some other reptiles.

MROSOVSKY, N., BASS, A., CORLISS, L. A., RICHARDSON, J. I., et RICHARDSON, T. H. 1992. Pivotal and beach temperatures for hawksbill turtles nesting in Antigua. *Can. J. Zool.* 70 : 1920–1925.

Des oeufs de la tortue *Eretmochelys imbricata* d'Antigua ont été gardés à température constante durant l'incubation. La température de pivotement (température à laquelle 50% de tortues de chaque sexe est obtenue) de l'échantillon a été estimée à 29,2°C. La température du sable à la profondeur des nids des tortues a été enregistrée au cours de deux saisons de nidation à Pasture Bay, Antigua. Bien que la température du sable se soit parfois avérée supérieure à la température de pivotement, le plus souvent elle lui était inférieure. D'après ces données, il est peu probable qu'à l'éclosion ces tortues aient le fort pourcentage de femelles qu'on enregistre chez les autres reptiles.

[Traduit par la rédaction]

Introduction

Temperature prevailing during incubation influences the phenotypic sex of many reptiles (Raynaud and Pieau 1985; Ewert and Nelson 1991), including those sea turtle species that have been studied so far. No planned studies on the effects of temperature on sex ratio have been published for hawksbill turtles, *Eretmochelys imbricata*, although it has been inferred that they are sensitive to temperature from the finding that only males were present in a large sample from a clutch laid in Florida very late in the year (October 25), when it was relatively cool (Dalrymple et al. 1985).

Detailed information on the temperatures that produce male or female phenotypes might be especially interesting in the case of hawksbill turtles because they commonly lay their eggs high up on the beach, underneath shrubs or trees (Diamond 1976; Witzell and Banner 1980; Limpus et al. 1983; Ryder et al. 1989; Horrocks and Scott 1991). From recorded temperatures of beaches used by other turtle species, it might be assumed that eggs laid in such places would be cooler, on average, than those laid in open sunny areas. At Playa Nancite, Costa Rica, where olive ridleys nest, at some times of year the sand is 4.8°C cooler in the shade than in exposed areas (Standora and Spotila 1985). In Florida, exotic Australian pines lower mean sand temperatures at 22 cm depth by about 1.5°C (Schmelz and Mezich 1988). At Tortuguero, Costa Rica, it is close to 2°C cooler in the shade than in the open beach at the depths of green turtle nests (Spotila et al. 1987). Nests covered with palm thatching, to simulate the condition of natural nests dug under the vegetation at Tortuguero, are about 3°C cooler than unshaded nests (Morreale et al. 1982). However, covering the nests of the freshwater turtle *Podocnemis expansa* with pieces of wood brought their temperatures down by <1°C, although this was enough to

affect the sex ratio (Alho et al. 1985). Probably much depends on the type of vegetation, duration of shade, strength of wind, and other meteorological conditions. To our knowledge, no studies directed specifically at the thermal characteristics of hawksbill turtle nesting sites have been reported, although a few hawksbill turtles nest at Tortuguero, where beach temperatures have been recorded (Spotila et al. 1987).

If hawksbill turtles nest in cooler places than other sea turtles, then it would be expected that either they would produce relatively more males or they would have a lower pivotal temperature (the temperature giving 50% of each sex; Mrosovsky and Pieau 1991).

The present work had two aims: first, to estimate the pivotal temperature for hawksbill turtle eggs, and second, to compare temperatures in places where hawksbills typically nest with those in open unshaded areas of the beach.

Methods

Study area and location of thermocouples

Pasture Bay, Antigua, is the site for one of the largest nesting aggregations of hawksbill turtles in the Caribbean. The habitat has been described by Ryder et al. (1989). Pasture Bay is part of the Jumby Bay Resort. Some of the beach has been altered by sweeping up debris and cutting back vegetation. For the present study, we concentrated on the north end of the beach, which remains in a natural condition. The predominant vegetation here is sea bush (*Croton lineatus*) and sea grape (*Coccoloba uvifera*), with occasional other trees and shrubs (e.g., *Lantana camara*). Thermocouples were buried in the sand under the vegetation in places typical of those selected by nesting hawksbills. In fact, a number of turtles nested within 1 m of our thermocouples. In addition, 1 sampling site was toward the south end of the beach in a shaded spot beneath clumps of sea grape often frequented by nesting turtles. To elucidate the thermal consequences of nesting beneath vegetation, we also sampled

temperatures in some open parts of the beach. Occasionally hawksbills nest in such places. In 1989, 5 temperature-sampling sites were in generally shaded spots, and 5 in the open, making a total of 10 sites (for definition of shaded, see below). The same or almost the same sampling sites were used in 1990; in addition, 1 other shaded site was studied in 1990.

At each temperature-sampling site, thermocouples were buried at both 30 and 60 cm depth: 30 cm depth corresponds to the mid or mid to upper part of the egg mass. Depths at the top and bottom of hawksbill clutches average 25.4 and 43.4 cm in Costa Rica (Carr et al. 1966), 25.7 and 43.2 cm in Australia (Limpus et al. 1983), and 27.0 and 46.2 cm in Western Samoa (Witzell and Banner 1980). In Pasture Bay, the bottom of the egg mass averages 45.5 cm deep ($n = 21$). The 60-cm depth was added to facilitate comparisons of the thermal characteristics of Pasture Bay with those of other beaches where measurements have been made at 60 cm depth. At 60 cm depth, diurnal variation is attenuated and often not $> 1^{\circ}\text{C}$ (Mrosovsky et al. 1984; Mrosovsky and Provancha 1989). Some approximate comparisons can therefore be made, even if the measurements in different studies were not made at the same time of day.

Sampling methods, equipment, and calibration

Thermocouples were read every 2 h over 24-h periods on the following 8 occasions in 1989: 27–28 July, 10–11 and 24–25 August, 7–8 and 21–22 September, 5–6 and 19–20 October, and 2–3 November. In 1990, readings were taken on 13–14 and 27–28 July, 10–11 and 24–25 August, 7–8 and 21–22 September, 6–7 and 20–21 October, and 2–3 November. In 1989, owing to apparatus malfunction or torrential rain, on 3 occasions (7 and 21 September, 5 October) readings from all temperature probes were based on 11 instead of 12 round-the-clock measurements. In addition, on 14 other occasions readings from individual probes were discarded because of poor electrical connections (readings differed from previous or subsequent readings by $> 1^{\circ}\text{C}$ at 60 cm, $> 2^{\circ}\text{C}$ at 30 cm). In 9 other instances, values for missing readings were obtained by interpolation. For 1989, the total number of missing data points represented 3.8% of the intended readings. In 1990, on 2 occasions (13 and 27 July) values for all probes were based on 11 instead of 12 round-the-clock readings because researchers were occupied with nesting turtles. On September 7, all data for one probe were lost because of poor connections, and in 1 instance a single reading was discarded for the same reason. In 5 other instances values were obtained by interpolation. For 1990, the total number of missing data points represented 2.4% of the intended readings.

The main nesting season in Antigua lasts from about early June to late November, with most laying in August, September, and October (Richardson et al. 1989). Thus, our temperature measurements covered much of the main nesting season. During hurricane Hugo (16 September 1989), a number of our sites were washed over. A few centimetres of extra sand deposited at some sites were removed to maintain the thermocouples at standard depths.

Thermocouples were read to the nearest 0.1°C with BAT-12 digital thermometers (Sensortek Inc.). The BAT recorders were calibrated against mercury thermometers that had themselves been calibrated against Sybron/Taylor mercury thermometers; the latter had certified calibration against platinum resistance thermometers that had been calibrated by the U.S. National Bureau of Standards. Calibration was checked periodically during the season. Minor correction factors ($< 0.25^{\circ}\text{C}$) were used for different BAT recorders. However, it should be noted that throughout, the same recorder was nearly always used on any one sampling day. Therefore temperature differences between different sites, e.g., sunny and shaded sites, were not affected by such corrections and were accurate to 0.1°C .

Whenever a temperature reading was made during daytime, except when it was cloudy, a 26 cm diameter circle was centered around the thermocouple. Shade within this area was estimated as being nearest to either 0, 25, 50, 75 or 100%. Based on at least 32 such estimations in each year for each site, sites were categorized, on the basis of mean percent shade, as shaded (65–85%) or sunny (5–30%).

Pivotal temperatures

Eggs came from 4 clutches laid on Pasture Bay. Clutches J and K were laid on 6–7 September 1989 and clutches L and M on 26–27 September 1990. The tag numbers of the mother turtles were PPN-089-R, QQB-901-R, PPN-017, and PPN-045, respectively. The numbers of eggs collected, out of the total clutch, were 21/124, 159/159, 80/202, and 80/?, respectively.

The eggs were transported to Toronto, where they were in incubators within 27 h (clutches K and M) or 51–54 h (clutches J and L) of laying. Eggs were incubated by the methods given in detail and illustrated by Mrosovsky (1988), except that more water was added to the eggs on days 15–16 and 36–37 of incubation, a difference of no more than 2 days from previous procedures. The vermiculite and sponge substrate for the eggs was kept thoroughly moist at all times. Sexing was based on histological methods (see Mrosovsky et al. 1984).

Many of the eggs from clutch J contained stringy threads in their shells. These have been seen in loggerhead turtle eggs and appear to be associated with lower hatch rates (Mrosovsky 1988). Therefore, only 21 eggs out of the total of 124 were taken from clutch J. Three of the eggs from clutch K were used for measurements of temperatures within the egg (see Mrosovsky 1988 for methods), and are therefore not included in the data for hatch rates or sex ratio. Temperatures from one of these eggs were discarded because of calibration errors. The other two eggs were on average 0.5°C cooler than a mercury thermometer placed nearby. Also, the temperature of one egg from clutch M was 0.4°C lower than was registered by a nearby thermometer. Therefore, a 0.5°C correction factor for evaporative cooling of the egg was applied to all readings of ambient temperature in the incubators. This correction factor (rounded to the nearest 0.5°C) is the same as that found previously for loggerhead turtle eggs (Mrosovsky 1988). Nevertheless, the matter of such correction factors, and how they might vary in larger samples and between different methods of incubation, requires more extensive study. Evaporative cooling of eggs has generally been ignored in work on pivotal temperatures. Readers who prefer to think in terms of ambient temperature rather than estimated egg temperature can add 0.5°C to all values that were obtained during the laboratory part of the project.

Eggs were placed in one of five incubators with mercury thermometers on each shelf. Because the lower shelf of the coolest incubator was appreciably cooler than the upper shelf in 1989, 6 temperature groups were constituted for that year: 29.0 ± 0.5 , 28.5 ± 0.4 , 27.9 ± 0.4 , 27.4 ± 0.4 , 26.4 ± 0.3 , and $25.9 \pm 0.6^{\circ}\text{C}$. For 1990 there were 5 temperature groups: 30.3 ± 0.5 , 29.8 ± 0.3 , 29.5 ± 0.3 , 29.0 ± 0.5 , and $28.5 \pm 0.4^{\circ}\text{C}$. The ranges given do not include a temporary 0.5°C rise that occurred during adjustments to one of the incubators on the 4th day of incubation.

Results

Temperatures in the sand in shaded areas were not consistently lower than those in sunny areas (Figs. 1 and 2). Mean diel sand temperatures were compared between sunny and shaded sites at 30 and 60 cm for 1989 and 1990, using a pooled variance estimate ($F \geq 1.88$, $df = 40, 40$, $\alpha = 0.05$) of Student's t -test. There was no significant difference between sun and shade ($t \geq 2.0003$, $t \leq -2.0003$, $\alpha = 0.05$, $df = 60$) for either depth or year. Toward the end of the season there was, if anything, a tendency for the shaded sites to be warmer (Figs. 1 and 2). Mean daily temperatures at 30 and 60 cm depth were close, although variation within a 24-h span was less, of course, at 60 cm. Following hurricane Hugo there was a 2 – 3°C drop in sand temperatures.

Hatch rates for clutches J, K, L, and M were 57.1, 88.5, 23.8, and 74.7%, respectively. The stringiness of the eggshells in clutch J was confounded with the extra day it remained in Antigua before transport; either might have been

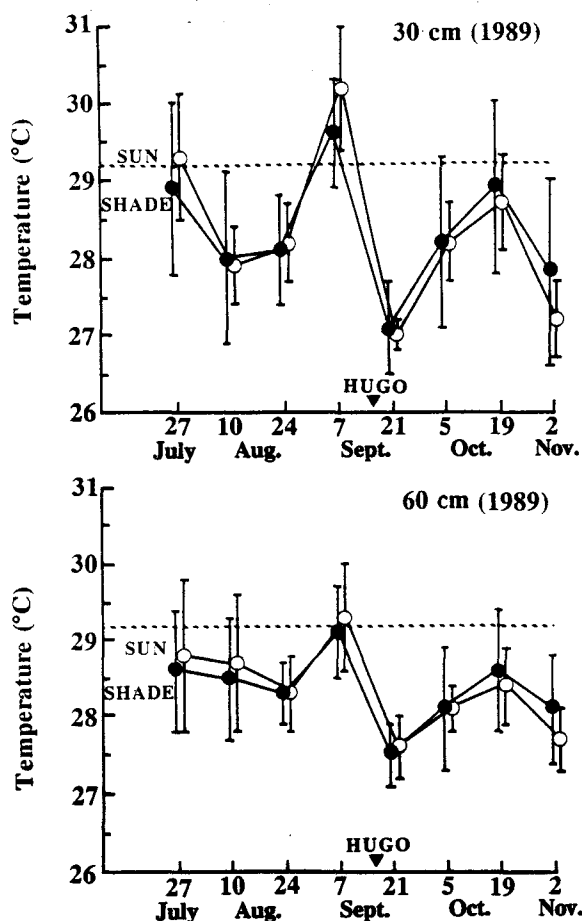


FIG. 1. Comparison of mean daily temperatures in shaded and sunny sites in Pasture Bay, Antigua, in 1989. For each temperature probe (i.e., a particular site and depth) a 24-h mean was first calculated from the round-the-clock readings (see Methods) to produce a value for that particular probe on that day of the season. Means $\pm$ 2 SDs of these daily values were then plotted for shaded ($n = 5$) and sunny ($n = 5$) sites. The dates show the days on which these round-the-clock measurements began. The data for the sunny and shaded sites are slightly displaced from these dates on the x-axis to avoid confusion. "Hugo" refers to hurricane Hugo.

responsible for the lower hatch rate. The reason for the poor hatch rate of clutch L is not known. However, since many of these eggs exhibited white patches on arrival, early embryonic death associated with the longer transit time might have been the cause. Table 1 gives sample sizes and details for the two clutches. The pivotal temperature (at which 50% of each sex is produced, estimated by interpolation) of this sample of hawksbill turtles was close to 29.2°C.

Discussion

Some reptiles produce females at both high and low incubation temperatures (Ewert and Nelson 1991). If the hawksbill turtle has a low-temperature female-producing zone, its pivotal temperature must be below 25.9°C, since at this temperature all males were obtained (Table 1). A female-producing zone below 25.9°C (incubation duration 79.6 days; Table 1), if it exists, is not likely to be of importance in Antigua because nests seldom get this cool. The longest incubations obtained in the field (laying to emergence), from a sample of 76 nests laid in June–November 1988, were 83–85 days (Richardson et al. 1989). Subtracting a few days for the time between

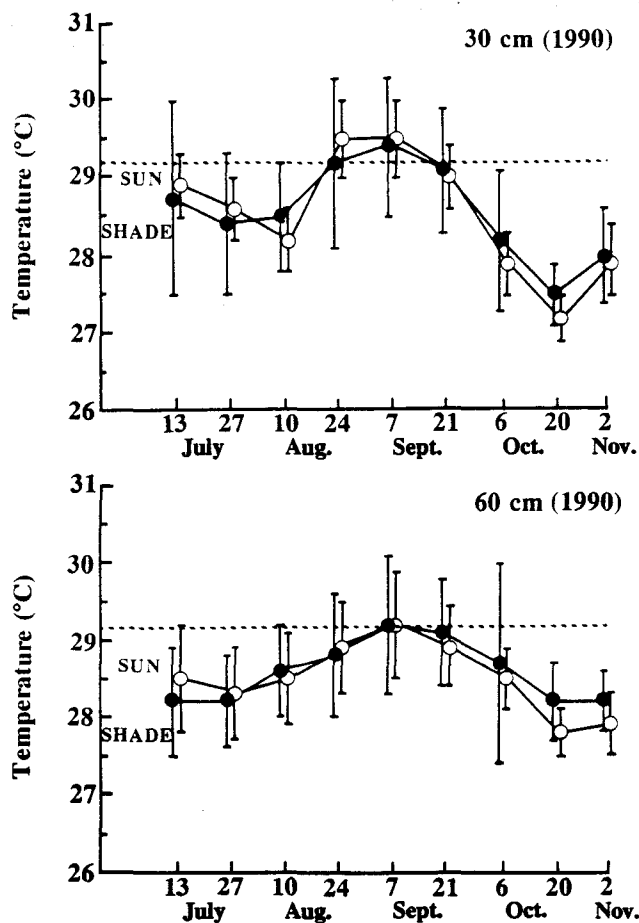


FIG. 2. Comparison of mean daily temperatures in shaded ($n = 6$) and sunny ($n = 5$) sites in 1990. For conventions see Fig. 1.

hatching and emergence, this is close to the incubation time of 79.6 days at 25.9°C (Table 1), i.e., even the lowest temperatures (longest incubation times) in Antigua are in the male-producing range covered by our laboratory study. Therefore, natural sex ratios will be determined largely by the pivotal temperature of ca. 29.2°C.

A pivotal temperature $>29.0^\circ\text{C}$ is surprising in two ways: it is high relative to the soil temperatures obtained (Figs. 1 and 2), and it is high relative to the pivotal temperature (29.1°C) of loggerhead turtles, which nest on warmer beaches. Before these points are discussed, the possibility of sampling error should be noted.

The laboratory data on hawksbills might have been obtained from atypical clutches. In loggerhead turtles it is known that pivotal temperatures can vary by as much as 1°C between different clutches (Mrosovsky 1988). However, the present estimate of the hawksbill's pivotal temperature is based on data from 4 different clutches, and the data are internally consistent (Table 1). It seems unlikely that the average value for larger samples would be much lower.

Sampling error might also apply to the measurements of sand temperature. Perhaps 1989 and 1990 were thermally atypical at Antigua and temperatures there are usually warmer, even in the shade. Sand temperatures in different years may be indirectly assessed using data on the duration of incubation. The information available so far on incubation duration does not, however, suggest that the years of the present study were atypical (Table 2).

In the absence of any clear indication of sampling errors,

TABLE 1. The percentage of female hawksbill turtles produced at different incubation temperatures and the duration of incubation

	25.9°C	26.4°C	27.4°C	27.9°C	28.5°C	29.0°C	29.5°C	29.8°C	30.3°C
No. of eggs set									
Clutch K	16	16	31	31	30	32			
Clutch J			11	10					
Clutch L					9	17	24	18	12
Clutch M					9	17	24	17	12
Percent female									
Clutch K	0 (15)	0 (14)	0 (28)	0 (26)	0 (25)	16 ^a (31) ^b			
Clutch J			0 (5)	0 (7)					
Clutch L					0 (4) ^b	0 (8) ^d	83 (6)	67 (3)	100 (2)
Clutch M					0 (9)	27 (15) ^c	86 (21) ^b	92 (12) ^d	100 (10) ^c
All clutches	0	0	0	0	0	17	85	87	100
Duration of incubation (days)	79.6	77.7	69.8	65.6	62.3	59.0	57.5	56.8	54.2

NOTE: Numbers in parentheses show the number of turtles sexed.

^aIncludes 1 hatchling with some intersexual characteristics.^bOne sexed embryo did not complete hatching.^cTwo sexed embryos did not complete hatching.^dThree sexed embryos did not complete hatching.

TABLE 2. Durations of incubation (laying to emergence) of hawksbill turtle nests at Pasture Bay in different years

Year	Duration (days)			
	Mean	Range	2 SDs	n
1987	60	55–68	5.6	31
1988	66	58–76	8.3	81
1989	64	56–72	7.7	54
1990	62	56–70	7.3	29

NOTE: n is the number of clutches; SD, standard deviation.

one may ask why the pivotal temperature of these hawksbills is high relative to the beach temperature. Could more than minimal numbers of females be produced on this beach? First, it should be noted that the mean temperatures at some probe sites do sometimes rise above the pivotal level (Figs. 1 and 2). Second, although more often the average temperatures over 24-h spans are below the pivotal level, there are times of day and parts of the season when temperatures are, at least briefly, above the pivotal level; this is evident from the fact that when all individual readings for shaded and sunny sites are considered together, the upper 95% confidence intervals are >30°C (Table 3). Third, it should be recalled that turtle embryos alter their thermal habitat to some extent through metabolic warming, and this is true of hawksbills also (Raj 1976). Although it is thought that this metabolic warming occurs mainly after the critical period during the middle third of incubation when temperature is important (Mrosovsky and Yntema 1980; Maxwell et al. 1988), it is possible that there is some overlap between sensitivity to temperature and metabolic warming. Perhaps this overlap is greater for hawksbills. Systematic investigations of metabolic warming have not been undertaken. It is unlikely that the amount of such warming is much greater in hawksbills than in loggerhead turtles. Hawksbill eggs weigh about 25 g (Limpus et al. 1983; Witzell 1983).

TABLE 3. Mean temperatures (°C) with 95% confidence intervals (± 2 SDs) over the whole season and at all times of day at 30 cm depth in sunny and shaded sites in Pasture Bay, Antigua

Year	Site	n	Mean	95% confidence interval	
				Upper	Lower
1989	Sunny	925	28.3	30.4	26.2
1989	Shaded	921	28.3	30.2	26.6
1990	Sunny	1060	28.5	30.2	26.8
1990	Shaded	1259	28.5	30.0	27.1

Clutch size at Pasture Bay is about 152 (Corliss et al. 1989). Total mass of a clutch would therefore average about 3800 g. Loggerhead turtle eggs weigh about 39 g (Dodd 1988); in Florida clutch sizes average 110 (Ehrhart 1979). The mass of loggerhead clutches is therefore about 4290 g. However, some quantitative difference, such as increased sensitivity to swings in temperature above pivotal levels, combined with metabolic warming, might mean that the effective thermal environment of hawksbill eggs was warmer than the sand temperatures indicated. (This does not negate the use of sand-temperature measurements in investigations of sex ratio. For comparing thermal characteristics of different habitats, it is much simpler to use the temperature of the sand than that of the nest. If comparisons are made on the basis of temperatures within the clutch, one has to take into account clutch size and developmental stage. The endeavor requires much larger samples, and becomes more complicated. And it still remains to be demonstrated that metabolic warming is commonly important before the temperature-sensitive period of incubation is over.)

The second surprising aspect of a pivotal temperature of 29.2°C for hawksbills arises from comparing their situation with that of loggerhead turtles. In Florida, loggerhead turtles nest on open, relatively bare dunes; sand temperature at the depth of the nests is 30.5°C or more for much of the nesting season (Mrosovsky and Provancha 1989, 1992). The pivotal

temperature of loggerheads in the southeastern U.S.A. is close to 29.1°C (Mrosovsky 1988). In Antigua, hawksbills appear to have a similar or slightly higher pivotal temperature, yet they nest in sand that is often about 28.5°C, i.e., some 2°C cooler than on the loggerhead beaches in Florida. It is puzzling that turtles nesting in cooler sand would have a similar pivotal temperature to those nesting in warmer sand. Perhaps, however, it is the situation of the loggerheads that is odd, with sand temperatures often 2°C above the pivotal level. This results in a sex ratio highly skewed toward females.

An unanticipated finding for the Pasture Bay beach was that the thermal differences between shaded and sunny sites were not as great as those reported for other turtle beaches (see Introduction). In fact, no consistent differences were detected in our study. Among factors that might be responsible for this situation are the trade winds, a layer of fallen leaves on the ground beneath shrubs, and reflectance from the white coral sand. Despite the lack of clear differences between sunny and shaded areas, the sand at turtle-nest depth on Pasture Bay is somewhat cooler than at some other turtle beaches (see references in Introduction; Mrosovsky et al. 1984; Mrosovsky and Provancha 1989).

In summary, the pivotal temperature of the Antiguan hawksbills is probably near to 29.2°C. Sand temperatures, although often lower than this, do sometimes rise above this level. Some years might provide longer spells of warmer weather. Some clutches might have slightly lower pivotal temperatures. A pivotal temperature of 29.2°C should enable hawksbills to produce some individuals of each sex, but it would be unlikely to favor strongly female-biased sex ratios. In Barbados, out of a total of 67 hatchlings found dead on the beach, 58% were female (Horrocks and Scott 1991).

Research on other reptiles is not extensive enough to establish whether a female-biased or 1:1 sex ratio is the normal pattern. Both female-biased (e.g., Ferguson and Joanen 1982; Mrosovsky and Provancha 1989) and approximately equal sex ratios (e.g., Mrosovsky et al. 1984) have been reported, but these studies are not conclusive. Perhaps different species or populations have different sex ratios, or perhaps equilibrium states are not represented by present-day populations (Mrosovsky and Provancha 1992). To understand the relationship between pivotal temperature and sex ratio of hatchlings, there seems little alternative to the laborious task of building a solid data base for a number of reptilian species.

Acknowledgements

We thank the Jumby Bay Resort and staff for their continued support of the hawksbill turtle conservation project. We are especially grateful to John and Sarah Fuller for their help on numerous occasions, and to Peggy Salmon, Marianna Tzabiras, and Carla Melucci for assistance. Paul Richnow gave us useful information. We also thank Rebecca Bell and Karen Bjørndal for encouragement. Support came from the Natural Sciences and Engineering Research Council of Canada and, with the help of Stephen Edwards and Karen Bjørndal, from the International Union for Conservation of Nature and Natural Resources.

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DEMOGRAPHIC PATTERNS OF CARIBBEAN HAWKSBILLS, JUMBY BAY, ANTIGUA

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Recovery and management of an endangered species requires precise understanding of its population ecology. However, meaningful demographic studies of sea turtles take many years to complete because sea turtles are very long-lived animals. Caribbean hawksbills are particularly difficult to study; their low numbers, dispersed nesting beaches, and elusive nesting behavior account for the lack of population data available in the literature. This poster session presents preliminary (2 yr) results of a demographic study of nesting hawksbills at Jumby Bay (see Corliss et al. in these Proceedings).

METHODS

We use saturation tagging with intensive nighttime patrols to study nesting behavior (see Tucker in these Proceedings). During the 151 days of continuous patrol in 1988 (2 July - 29 November), only six of 156 nests (4%) on Pasture Bay beach (Jumby Bay, Antigua, West Indies) were discovered after the female had departed. This permits us to obtain an accurate measure of seasonal fecundity per turtle, arrival and departure of individual females at the nesting beach, and total stock numbers.

RESULTS

The primary nesting season runs from June through November, although occasional nesting occurs throughout the year. The 1987 season (Figure 1) started very late in June, peaked in September, and ended the middle of November. We gambled on a repeat of this behavior in 1988 and lost(!); there were at least 10 females active in June before the start of the survey on 2 July. This accounts for the abrupt start of nesting activity observed in Figure 2 (1988) which is, of course, an anomaly of our experimental design and not hawksbill behavior. Whereas 1987 nesting activity peaked in September, 1988 nesting activity was distributed rather evenly from July to November (Figure 2). The dramatic weekly modulation of numbers of active females in both 1987 and 1988 is apparently a random phenomenon induced by a precise 2-week internesting interval (Figure 3) and not an indication of group nesting behavior; the choice of a seven day interval of measurement is a human prerogative and not an attribute of turtle biology. The modal shift in the internesting interval from 14 days (1987) to 15 days (1988) has not yet been explained (Figure 3), but may be related to water temperature.

Because each turtle nests an average of five times per season (Figure 4) on two week intervals (Figure 3), the distribution of nesting activity during a 180-day season is determined by the initial arrival dates of individual females (Figure 5). Arrival rates for the 1987 nesting population accelerated in early July and again in early August and then decelerated for the rest of the season. As a result, the overall nesting rate in 1987 (Figure 6) peaked in September when a maximum number of females were active at the same time. In 1988, arrival rates accelerated in late June/early July and then again in September (Figure 5). Thus, it can be seen why the overall nesting rate in 1988 remained fairly steady from July to early November (Figure 6); the two largest groups of arriving turtles were separated by two months and, therefore, did not overlap their nesting activity.

DISCUSSION

We predict that the initial arrival times of nesting hawksbills at Pasture Bay beach may be largely random from June to September and, as a result, that the shape of a June-November nesting activity curve (Figure 6) will probably vary dramatically and unpredictably each season. The fewer the animals in the population, the more unpredictable will be the schedule of a nesting season; potential egg predators . . . take note!

Except for initial arrival time at the nesting beach, Jumby Bay hawksbills are highly regular and predictable. Individuals lay more clutches per season (± 5) than we expected. Similarly, a lot of activity (156 nests during the 1988 survey) proved to be the effort of a relatively few animals (39 turtles). We estimate 40 actively nesting turtles and 190-200 nests for the 1988 calendar year at Pasture Bay beach. Stock assessment formulae that use less than 5 clutches per turtle are in danger of grossly overestimating total numbers of nesting females, the price to be paid for an inadequate sampling plan. We have much still to learn; additional studies of hatchling sex ratios and adult remigration intervals will begin in 1989. Estimates of recruitment and loss of adults to the Jumby Bay population will require 10 years of continuous surveys.

Fig. 1: Active Adult Females at Pasture Bay During Peak Nesting Season (1987)

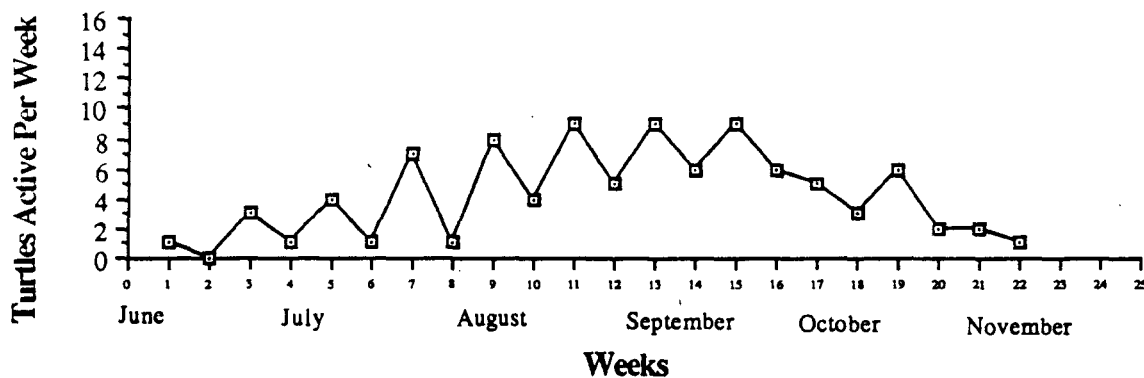


Fig. 2: Active Adult Females at Pasture Bay During Peak Nesting Season (1988)

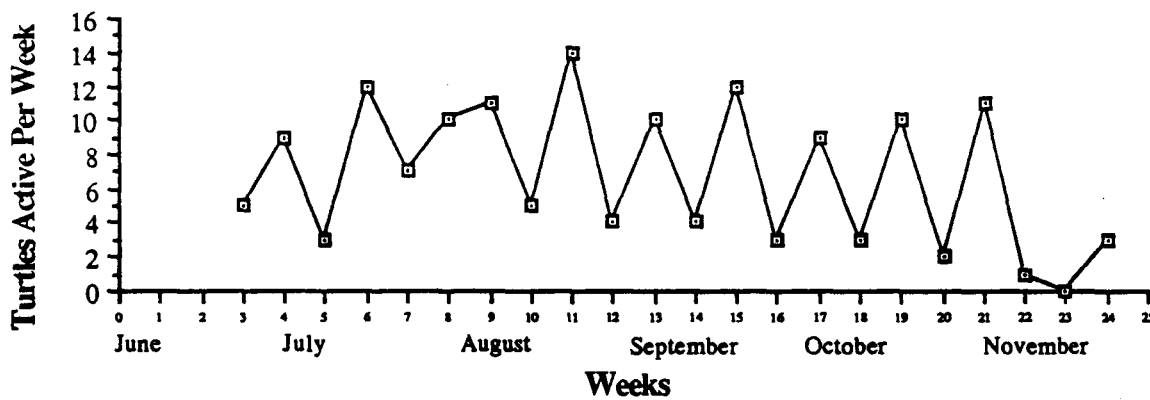


Fig. 3: Duration in Days Between Nesting Events

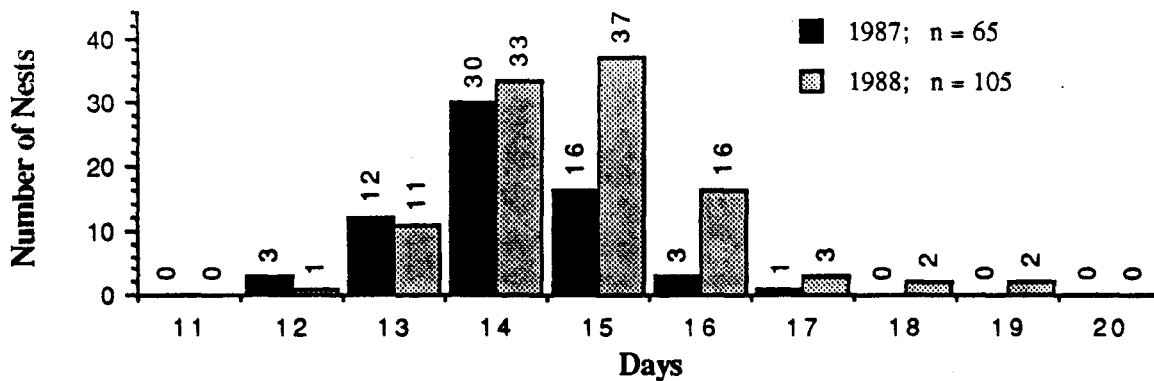


Fig. 4: Midseason Nests Per Turtle (Missing Intervals Filled) at Pasture Bay

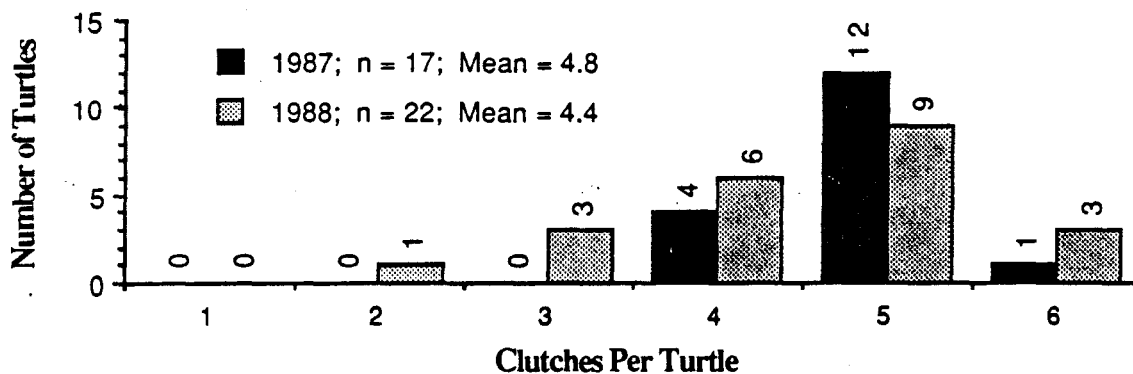


Fig. 5: Cumulative Adult Female Turtles in Pasture Bay Population During Peak Nesting Season

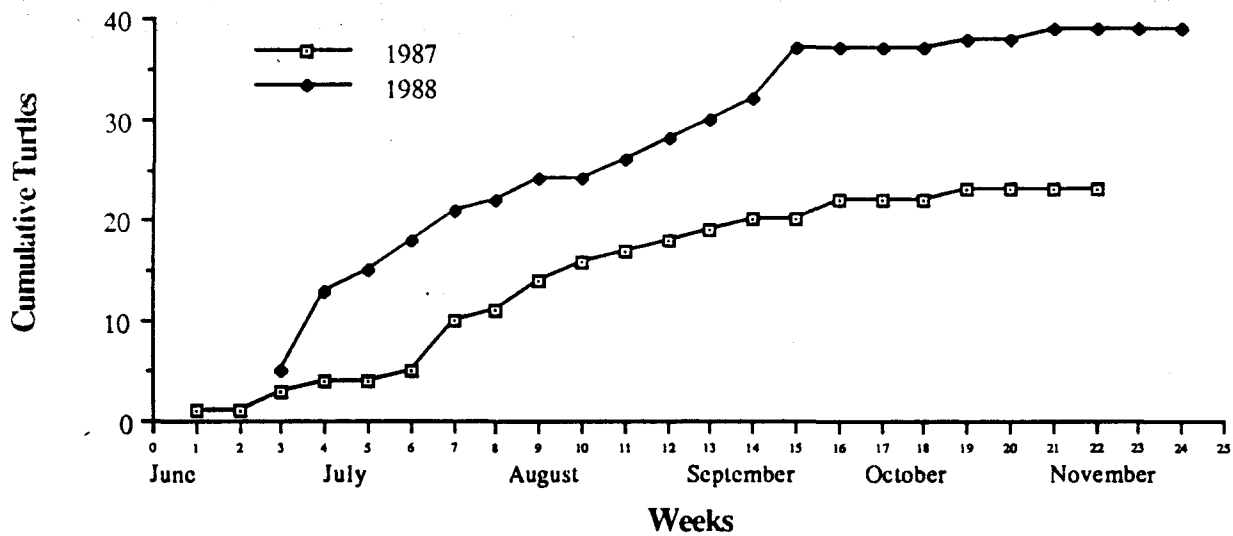


Fig. 6: Cumulative Nests at Pasture Bay During Peak Nesting Season

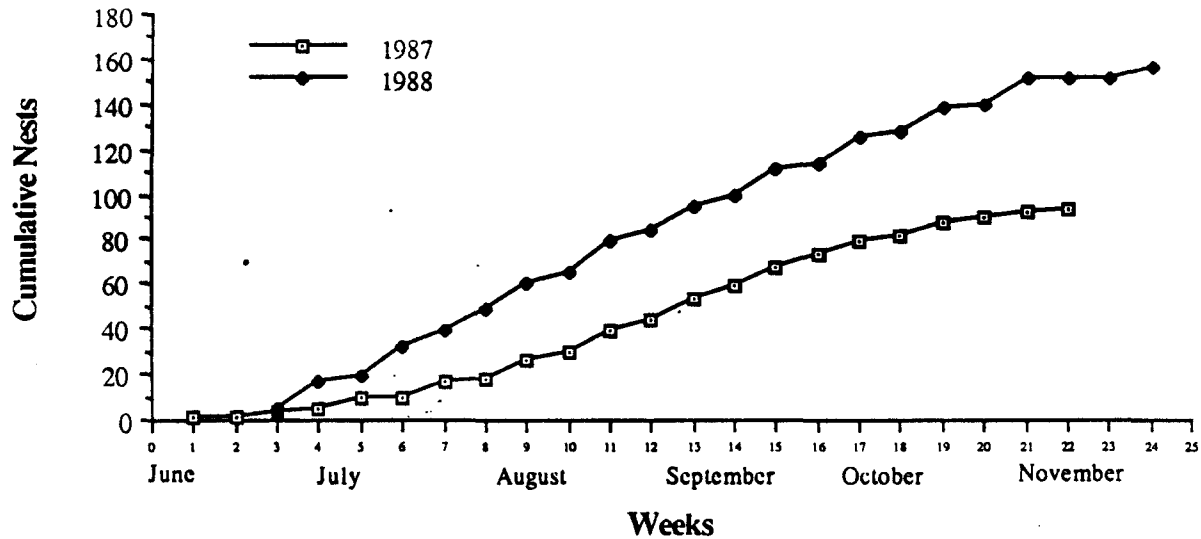
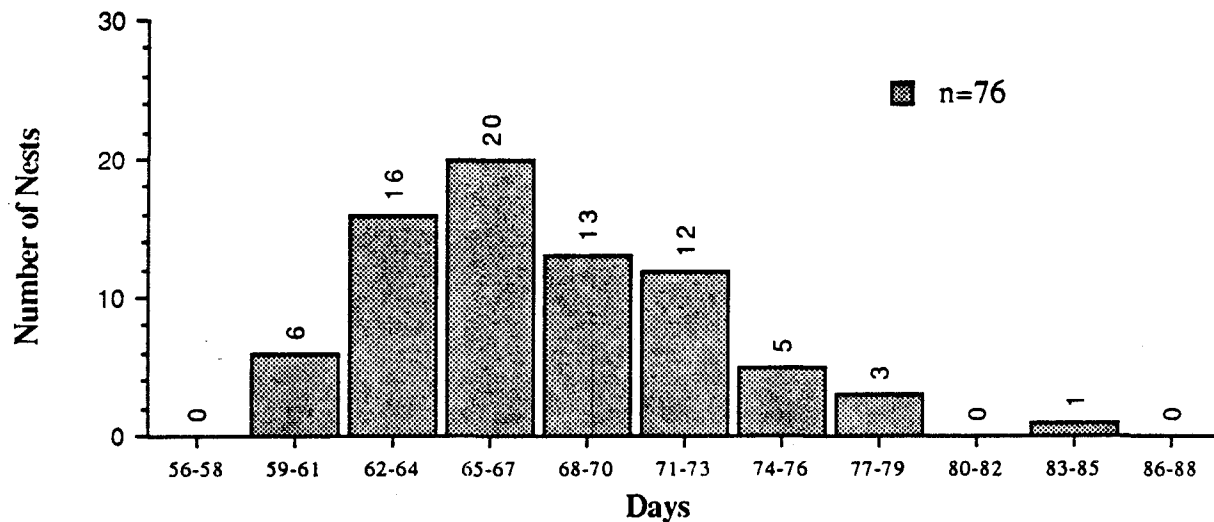


Fig. 7: Clutch Development Time (1988)



HABITAT PREFERENCE AND BEACH MANAGEMENT FOR NESTING HAWKSBILL, JUMBY BAY, ANTIGUA, WEST INDIES

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Protection and management of nesting beaches is crucial to the recovery of the endangered Caribbean hawksbill. The needs of man and turtle are too often mutually exclusive, and the turtle is coming up the loser. This poster session reports on an exciting research and management program to integrate critical beach habitat needs for hawksbills with man's economic development needs on a resort island near Antigua. The Jumby Bay hawksbills (see Corliss et al. and Richardson et al. in these Proceedings) represent an extremely important nesting population of Caribbean sea turtles whose welfare has now become a top management priority for the resort.

Pasture Bay beach has approximately 1700 feet (=510 m) of utilizable nesting habitat and an additional 450 feet (=135 m) of pasture-fronted beach degraded many years ago by previous owners and now unusable for nesting. Within recent memory, the majority of Pasture Bay beach was a complex thicket of open sand patches, seagrape (*Cocoloba uvifera*), salt shrub (*Suriana maritima*), and a variety of other native woody shrubs and trees. Intensive raking for aesthetic purposes has now opened much of the beach in various ways, such that there are five beach types (Table 1) that offer a combination of nesting habitat types for the hawksbills. The differing response of the turtles to the five habitat types is the essence of our research design.

Nesting is distributed discontinuously along the beach (Figure 1), such that various habitat types have very different importance values (Table 1). Mixed shrub thicket with a narrow berm (Section 1) and scattered "islands" of mature seagrape leading to the water's edge (Section 4) are preferred habitats. As the shrubbery setback increases (Sections 2, 3), the importance value drops off (Table 1), even though these sections are backed by excellent nesting habitat. Since the frequency of false crawls (0.53 per successful nesting crawl) is low and distributed evenly among beach types (Sections 1-4), the management challenge is to entice the turtle onto the beach. Once on the beach, a hawksbill will search persistently for an adequate nest site and will usually locate some vegetative cover into which she will crawl several meters to place the nest (Figure 2). Occasionally a turtle will nest in the open (Figure 2). Hatching success is high (>80%) across all beach types at Pasture Bay.

In shrub thicket (Section 1), where the distribution of plants does not affect turtle movement, the preferred distance from mean high water for nests was 4-6 m (Figure 3). Thus, a 10 m band of persistent vegetation would provide adequate nesting habitat if its proximity to the water made it accessible. The discontinuous array of seagrape "island" clumps in Section 4 induces a more even nest distribution which does not reflect a normal behavioral preference by the turtle (Figure 4). Within this section, turtles most often choose to emerge where vegetation is closest to the water's edge (Figure 5) and follow a chain of shrub "islands" to an acceptable nesting site. Since the decision to emerge is the most important factor in nesting success, a study is underway of ambient darkness and horizon height at the water's edge and offshore, as these parameters affect nesting behavior.

Pasture Bay beach is degrading slowly because of raking and beach cleaning. The finite supply of sand is being wind blown to a shrub line too far away from the water for acceptable nesting habitat. A steep, vegetated berm is being replaced by a low, flat beach without vegetation. Where the sand has been eroded at the water's edge, patches of flint cobbles and limestone reef-rock are being exposed. Remaining trees are becoming isolated on pedestals of sand, as the surrounding sand is being removed by wind. A single tree in sector 15 close to the water's edge is all that is left in the area of wide beach habitat (Section 3) to

attract turtles out of the water; its loss will render Section 3 almost unusable for nesting. Remaining patches of vegetation are beginning to receive too much nesting use, as nests are disturbed by other nesting turtles. Luckily, the problems have been identified, and Jumby Bay intends to rebuild and protect the beach for their hawksbills. Replanting will stop wind erosion, and sand can be replenished from other sources. Properly placed seagrass clusters can lead hawksbills to preferred nesting habitat in a stepwise fashion. A steep, vegetated berm will provide a magnificent private swimming beach for guests and a quality nesting beach for turtles. Homes are being placed back from the beach, with lights screened by vegetation. There are plans to convert the additional 450 feet of unusable cobble beach into usable nesting habitat. Jumby Bay is on the road to becoming a prototype of recreation, industry, and endangered species management working in harmony. The time is none too soon for Caribbean hawksbills!

Table 1: Beach characterization, nesting frequency (1987 + 1988), and habitat importance values for various sections of Pasture Bay beach, Jumby Bay, Antigua.

Section	Beach Type	Sector	Approx. Length	Total Nests	Nests per 10'	Importance value	Shrubby setback
1	Mixed shrub	23-31	460'	86	1.87	4.7	0-4m
2	Narrow beach	17-22	320'	37	1.16	2.9	10-20m
3	Wide beach	10-16	400'	32	.80	2.0	30-40m
4	Sea-grape	4-9	360'	96	2.67	6.7	variable
5	Lawn	1-3	150'	6	.40	1.0	>100m

Fig. 1: Nest Concentration by Beach Sector (1987 + 1988)

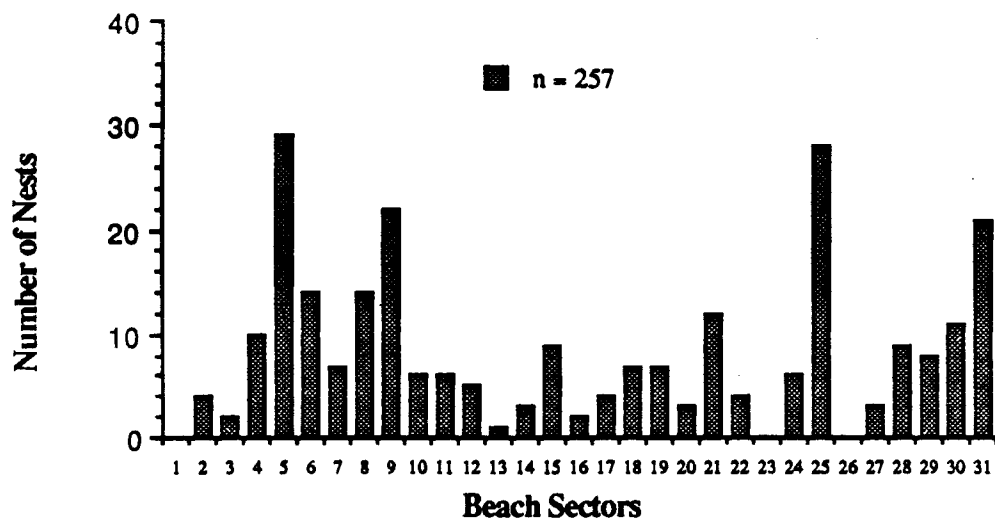


Fig. 2: Distance of Nests from Edge of Vegetative Cover

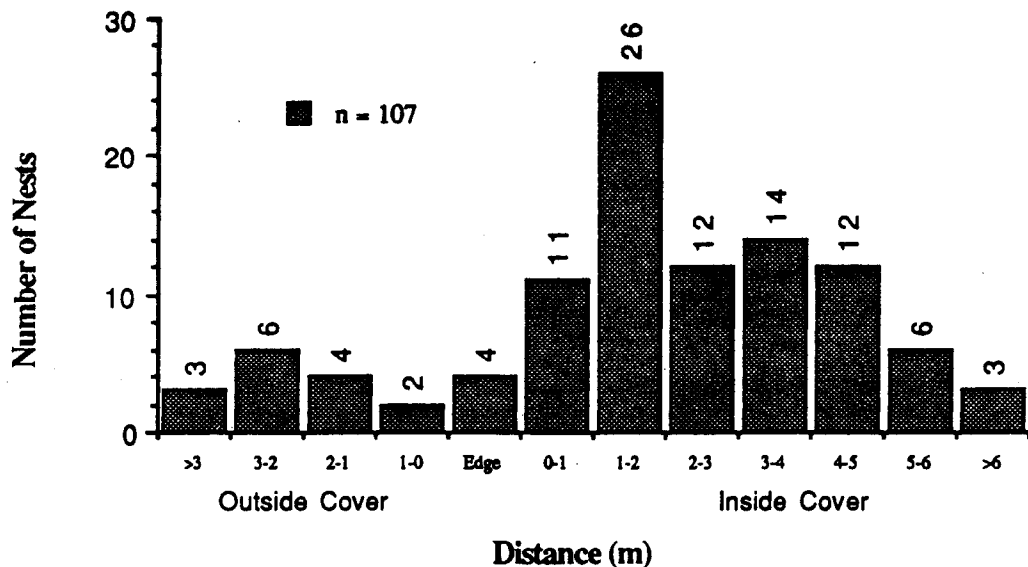


Fig. 3: Nest Distance Above High Water Line: Mixed Shrub Habitat

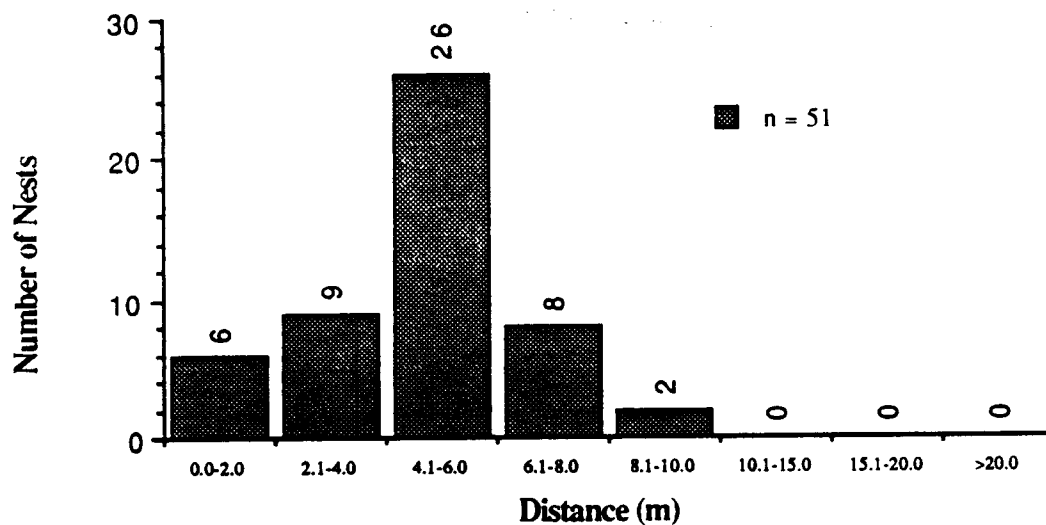


Fig. 4: Nest Distance Above High Water Line: Seagrass Clump Habitat

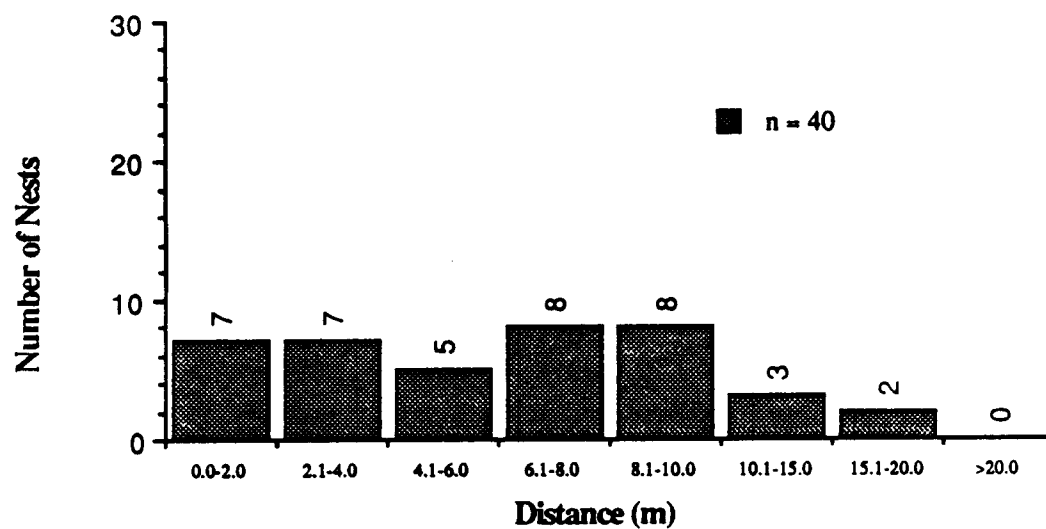
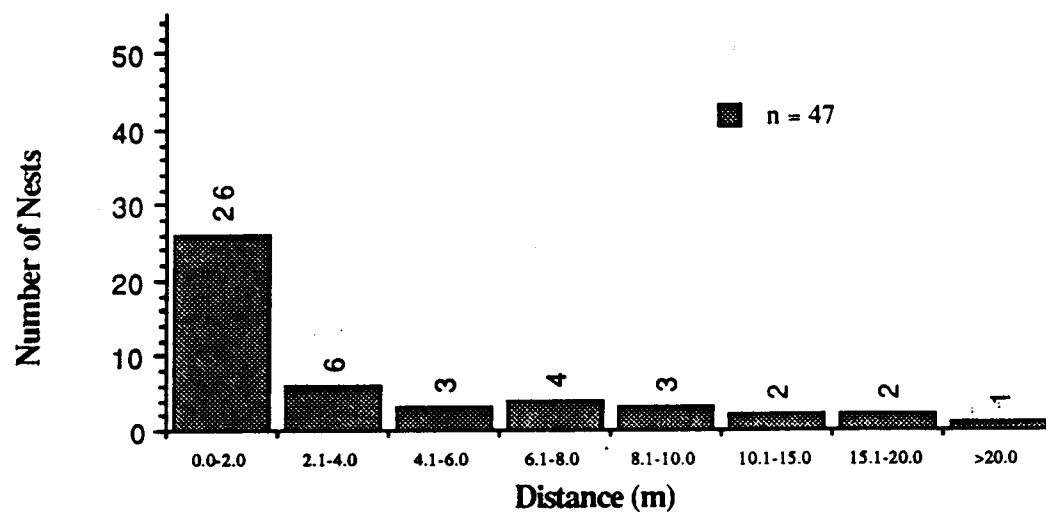


Fig. 5: Open Terrain: High Water Line to Cover: Seagrass Clump Habitat



Appendix V: Field record data sheets used for recording nesting activities (p. 69) and for the analysis of post-hatching nest contents and hatching success (p. 71) by hawksbill sea turtles at Pasture Bay, Long Island, Antigua, W.I.

PASTURE BAY, LONG ISLAND, ANTIGUA
1988 HAWKSBILL SEASON

Transcribed from the original field records by _____

SEASON RECORD _____
DAILY RECORD _____
ORIG. TAG # _____

Date _____

Old tag(s) _____ Old drill pattern _____

New tag(s) added _____ Tag(s) removed _____

If this turtle was UNTAGGED, do scars indicate it was tagged before? YES NO

New drill pattern* _____ Old pattern redrilled* _____
(*Explain with diagram on back of data sheet)

Crawl location _____ Stakes _____

Action _____ Antigua time _____

Results: LAY (Nest # _____) FALSE CRAWL (Reason _____)
(Mark location of crawl and nest on back of sheet)

Observations on turtle _____

_____ (use diagram, if necessary)

Observation and position of nest _____

Weather _____

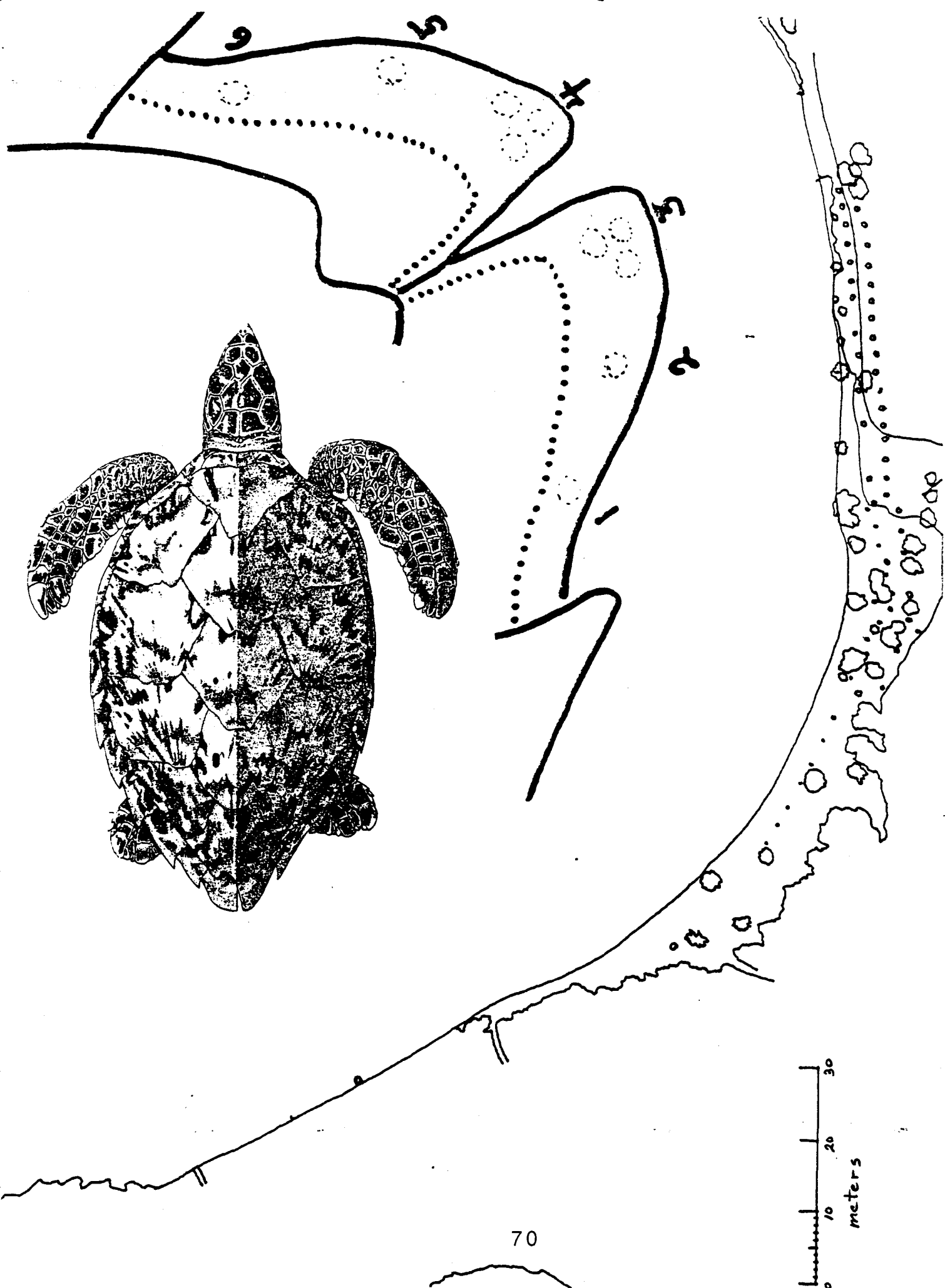
Precipitation (24-hr. period) _____

Carapace length (O.C.) nuchal notch to posterior tip _____ cm.

Other comments:

Observer(s) LC CR Other _____ (Circle recorder)

Guests present _____



1993 JUMBY BAY HAWKSBILL PROJECT
NEST DATA SHEET

P. _____

NEST NO: _____; CRAWL SHEET NO: _____; DEPOSITED: _____

MAMA'S TAGS _____, _____; DRILL SERIES _____

LOCATION _____

_____; STAKES _____ & _____

DISTANCE TO HIGH WATER _____m; LOCATION: SHADE SUN MIXED

DISTANCE TO VEG. EDGE _____m; VEG.: SEAGRAPE GRASS SHRUB OPEN

1° EMERGE: DATE: _____; ESTIMATED TIME _____; RELEASE NO _____

EVIDENCE _____

PRECISION OF ESTIMATE _____

2° EMERGE: DATE: _____; ESTIMATED TIME _____; RELEASE NO _____

EVIDENCE _____

PRECISION OF ESTIMATE _____

NEST CLEANED: DATE _____ BY _____

NEST CONTENTS: HATCHED SHELLS _____; LIVE HATCHLINGS _____;
DEAD HATCHLINGS _____; ROTTEN/UNDEVELOPED _____;
"FRESH"/UNDEVELOPED _____; EMBRYOS _____;
DEFORMED HATCHED _____; DEFORMED UNHATCHED _____;
YOKELESS EGGS _____; OTHER _____: _____(explain).

EST. RELEASE _____; EST. CLUTCH SIZE _____; EST. HATCH SUCCESS _____%

DEPREDATION _____

COMMENTS _____

Instructions for NEST DATA SHEET

Initiate a nest data sheet as soon as a nest is known to be on the beach. Nest data sheets can be maintained in a 3-ring binder in housing quarters. Observations on nests can be maintained in a field book and transferred to the nest data sheet at a later date. All nests on the beach should be checked at least weekly, preferably more often, for signs of disturbance (ants, excavation by another turtle, etc.) or pre-emergence (collapse of the nest core). Check for presence of nest tag. If recently displaced, the tag might be found and replaced, or the nest could be located and marked in an alternate way. Enter such observations, dated and initialed, in the comments section.

1. Nest number (NEST NO) should be the same as on nest tag and on crawl data sheet. Provide crawl data sheet number (CRAWL SHEET NO) for cross reference. Also, provide nest data sheet page number on the crawl data sheet for further cross reference. If nest occurred prior to patrol, establish an alternate numbering system: A1, A2, etc. If nest occurred during patrol but can't be correlated with a crawl data sheet, establish an alternate numbering system: B1, B2, etc.

2. Provide the date when the clutch was deposited (DEPOSITED*). Asterisk (*) is a reminder that any date should be given as a **split** date. Most nesting and emergence times will be close to nightfall or during the night. Any event between 12:00 noon of one day and 12:00 noon of the following day shall be dated as the midnight split date. Thus, an event at 7:00pm on 13 September and an event at 2:00am on 14 September would both be dated 9/13-14/92.

3. Mama's tags (record both, if two are present) and drill series should match crawl data sheet. If turtle not seen, enter UNKNOWN. If you think you know, enter predicted number and GUESS.

4. Location refers to a verbal description of nest site and location similar to what is on the crawl data sheet. Same for location between nearest two stakes. See map for permanent stake locations.

5. Distance to high water is closest distance, measured with a meter tape. Same for distance to edge of vegetation. Edge is defined as canopy edge, so a nest under the lone button mangrove may be inside the vegetation canopy edge but appear to be in the open. Identify whether the nest is located inside, on, or outside the vegetation edge. The location (LOCATION) refers to openness around the nest, ...whether it is in a shaded, sunny, or mixed location. The vegetation (VEG) in the immediate vicinity of the nest should be categorized as SEAGRAPE (clump or mixed forest), GRASS (sea oats or other prominent non-woody vegetation), SHRUB (mixed shrub community not over 2 meters in height) or OPEN (bare sand, chairs, trash containers, or under solitary trees such as coconut palm or button mangrove. A somewhat subjective decision may have to be made.

6. Time and date of emergence is of considerable interest, but don't guess wildly. Use split dates. If you can guess the number of hatchlings gone (RELEASE NO), say so. Describe how you determined an emergence: noticed collapsed nest, observed hatchlings, observed tracks, etc. Under precision of estimate, describe how sure you are with the observation. Date refers to when you think the emergence occurred, not when you observed the fact. If you believe the nest emerged two or more days earlier, use that date and state confidence of observation. If there is a second emergence of significance on a subsequent date, record under secondary (2°) emergence.

7. Time of nest cleaning is not crucial, but it should follow closely on the major or primary emergence. If several days or more elapse, this is acceptable, but nest contents are rapidly rotting and becoming hard to identify. How you excavate the nest is also important. If you do it roughly, you will destroy important evidence. You will tear egg shells into smaller fragments, making the estimate of number of emerged hatchlings much more difficult. You will also puncture unhatched or undeveloped eggs and possibly injure yet-to-emerge hatchlings. It is suggested that all of the contents be removed from the nest cavity before being cleaned of sand and debris and before being sorted. Again, treat the contents gently so as not to tear shell fragments. When cleaning a nest, try to stay within nest content categories. A given "egg" should not appear in more than one category. If a dead hatchling is found, don't count its egg shell as a HATCHED SHELL, as this category is reserved for shells from hatchlings emerged and gone. Live hatchlings plus hatched shells should equal estimated release number; all categories sum to clutch size; release/clutch size=hatch success.

8. Depredation refers to eggs or hatchlings, in the nest or on the way to water's edge. Common predators include ants, crabs, humans, night herons, rats, etc. A permanently incapacitated hatchling is "dead". If eggs or hatchlings killed by roots, wave wash, etc., place under comments.

Appendix VI: Crawl chart for individual nesting female hawksbill sea turtles, Pasture Bay, Long Island, Antigua, West Indies.
A "bullet" indicates that the turtle was seen on the beach for the corresponding year.

<u>Female</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>
PPN001	•		•			•
PPN002	•					
PPN003	•		•		•	
PPN004	•		•			•
PPN005	•		•		•	
PPN006	•			•		
PPN007	•			•		•
PPN008	•		•		•	
PPN009	•		•		•	
PPN010	•		•		•	
PPN011	•		•		•	
PPN012	•			•		•
PPN013	•		•		•	
PPN015	•		•		•	
PPN016	•		•		•	
PPN017	•			•		
PPN018	•		•		•	
PPN019	•		•		•	
PPN020	•		•		•	
PPN021	•		•			•
PPN022	•		•		•	
PPN074	•		•			•

<u>Female</u>	<u>----</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>
PPN024		•			•	
PPN025		•			•	
PPN026		•				•
PPN027		•		•		
PPN028		•		•		•
PPN029		•				•
PPN030		•			•	
PPN030		•		•		•
PPN032		•			•	
PPN033		•				

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A "bullet" indicates that the turtle was seen on the beach for the corresponding year.

<u>Female</u>	<u>----</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>
PPN034		.			.	
PPN035		.		.		.
PPN036		.				
PPN037		.			.	
PPN038		.			.	
PPN039		.				
PPN040		.		.		.
PPN041		.				
PPN042		.				
PPN044		.		.		.
PPN045		.		.		.
PPN047		.		.		.
PPN048		.				
PPN049		.			.	
PPN050		.				.
PPN051		.				.
PPN052		.			.	
PPN055		.			.	
PPN056		.			.	
PPN057		.		.		
PPN058		.		.		.
PPN059		.			.	
PPN060		.			.	
PPN061		.				
PPN062		.				
PPN064		.			.	
PPN066		.		.		
PPN069		.			.	

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A "bullet" indicates that the turtle was seen on the beach for the corresponding year.

<u>Female</u>	<u>----</u>	<u>----</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>
PPN073			•			
PPN075			•			
PPN077			•			•
PPN078			•			•
PPN079			•			
PPN081			•			
PPN083			•			
PPN084			•			
PPN085			•			•
PPN087			•			
PPN088			•			•
PPN092			•			
QQB902			•			

<u>Female</u>	<u>----</u>	<u>----</u>	<u>----</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>
PPN095				•		•
PPN098				•		
QQB920				•		
QQB921				•		
QQB923				•		•
QQB925				•		•

<u>Female</u>	<u>----</u>	<u>----</u>	<u>----</u>	<u>----</u>	<u>1991</u>	<u>1992</u>
QQB931					•	
QQB932					•	
QQB933					•	
QQB935					•	
QQB946					•	
QQB948					•	

Appendix VI: Crawl chart for individual nesting female hawksbill sea turtles, Pasture Bay, Long Island, Antigua, West Indies.
A "bullet" indicates that the turtle was seen on the beach for the corresponding year.

<u>Female</u>	<u>----</u>	<u>----</u>	<u>----</u>	<u>----</u>	<u>----</u>	<u>1992</u>
QQB973						.
QQB982						.
QQB991						.
QQB992						.
QQB996						.
QQB998						.