Biological Conservation **18** (1980) 289–298

NESTING ACTIVITY OF THE LOGGERHEAD TURTLE *CARETTA CARETTA* IN SOUTH CAROLINA, II. PROTECTION OF NESTS FROM RACCOON PREDATION BY TRANSPLANTATION†

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ABSTRACT

Small mammals are significant predators of unhatched marine turtle nests in many parts of the world. Raccoons Procyon lotor *destroy over 95% of the loggerhead turtle nests laid on some South Carolina beaches. To remove developing eggs from nest-associated clues which could aid raccoons, we transplanted whole and partially preyed-upon nests on Kiawah or Cedar Islands in 1972, 1973, 1977 and 1978. Eggs were moved to man-made cavities near the original nest cavities in erosion-free areas. Care was taken not to transfer clues from the original nest. Predation on wild (control) nests ranged from 55·1% (Cedar, 1978) to 93·8% (Kiawah, 1972). Transplant predation was significantly lower in all cases, ranging from 6·1% (Kiawah, 1972) to 18·7% (Kiawah, 1973). Hatching success of transplants was not significantly different from that of hatchery-reared or control clutches (60–81%). Transplanting may be an easier, less expensive method for protection of nests from predation or erosion than other procedures such as predator control, chemical aversion conditioning, or hatcheries, and merits further testing at other turtle rookeries.*

INTRODUCTION

Marine turtles nest on sandy beaches in many tropical and temperate parts of the world. Hatchling production on many of these beaches has been extensively studied, and Hirth (1971) summarised numerous factors that affect hatching success of the green turtle *Chelonia mydas*. One of the major causes of mortality among

† Contribution No. 294 of the Belle W. Baruch Institute for Marine Biology and Coastal Research.

Biol. Conserv. 0006-3207/80/0018-0289/$02·25

developing turtle eggs or emerging hatchlings is predation by small or medium-sized mammals. At Tortuguero, Costa Rica, dogs and coatis destroyed about 25% of *Chelonia mydas* nests surveyed in 1977 (Fowler, 1978) and coyotes are known to be predators of nests of the Atlantic ridley *Lepidochelys kempi* in Mexico (Carr, 1967). Domestic and feral hogs are nest predators on the Pacific coast of Costa Rica (Zahl, 1973), the Gulf and Pacific coasts of Mexico (INIBP, 1966) and the barrier islands of Georgia, where they take up to 100% of the unprotected nests of the loggerhead turtle *Caretta caretta* (Hillestad *et al.*, 1977; C. Blanck, pers. comm.). In many parts of the world human predation on nests has a significant impact on hatching success (Hirth, 1971).

In the southeastern United States, the major nest predator is the raccoon *Procyon lotor marina* (Worth & Smith, 1976; Davis & Whiting, 1977; Hopkins *et al.*, 1978). On Cape Island, South Carolina, where an estimated 1072 nests were laid in 1977, raccoons destroyed 37% of the nests in June, 45% in July, and 93% in August on the night they were laid (Stancyk, Talbert, Miller and Dean, unpublished data). During the same period, Hopkins *et al.* (1978) found that raccoons destroyed an average of 56·1% (range: 16·4–86·3%) of all nests laid on four different barrier islands in South Carolina. W. P. Baldwin and J. P. Lofton found that raccoon predation occurred at only 5·6% of the 600 recorded nests on Cape Romain in 1939 (Caldwell, 1959).

Although published studies of the subject are lacking, it appears that mammalian predators can use a variety of clues to find nests, including visual clues such as adult tracks and body pits, and olfactory clues such as the smell of the adult, eggs or the lubricating fluid which is exuded from the cloaca during oviposition. The objective of our experiments was to test whether predation would be reduced by careful removal of eggs from sites where visual and olfactory clues were present to locations on the same beach that lacked them. If successful, nest transplantation would be less labour-intensive and a more natural process than other hatchling production methods currently in use.

MATERIALS AND METHODS

Transplantation experiments were conducted on two barrier islands over four nesting seasons: Kiawah Island, South Carolina (1972, 1973), and Cedar Island, South Carolina (1977, 1978). Kiawah is larger (length of beach: 16·4 km), more developed, and contains more suitable nesting habitat than Cedar Island (beach length: 5·0 km), which is eroding along a significant portion of its length (Stephens *et al.*, 1975; Stancyk, Talbert, Miller and Dean, unpublished data). The general procedure is described below. Slight variations in methods from year to year are discussed with the results for that year.

On many occasions, nests were attacked by predators on the night of laying but not completely destroyed, and the remaining eggs were transplanted the next day.

Some whole clutches were also transplanted in 1973 and 1978. Nests were moved either the night they were laid, the morning after, or within 24 h after they were opened by predators. Transplants were placed between 3 and 30 m from the original nest cavity, in locations where it appeared that the eggs would be safe from erosion or overgrowth by dune vegetation. Transplants were sometimes placed directly in paths used by raccoons in order to learn whether they would be detected there. Determination of predation or hatching success was done by counting unhatched eggs, hatchlings, and empty shells in and around the nest cavity.

Raccoons have extremely keen tactile, visual and olfactory senses, so extreme care was taken to avoid carrying any trace of the old nest over to the transplant site. Once a transplant site was chosen, a new nest cavity was dug, to match the original site. We found that a hand-sized valve of the giant Atlantic cockle *Dinocardium robustum* helped us to dig through well-packed sand and scoop out an urn-shaped cavity as deep as the original cavity. Eggs were carefully removed from the nest cavity, cleaned of sand and yolk from torn eggs, and placed on a cloth. They were never washed. The whole batch of eggs was then taken to the new nest cavity in the cloth, and each egg was carefully placed into the new cavity. Eggs and sand from the original nest cavity, or hands which had been handling the eggs, never came in contact with the sand around the new cavity. Once all of the eggs were in the cavity, sand was scraped in and packed gently, then more firmly, until the cavity was filled. Thus, eggs were not embedded in sand, but massed beneath a packed layer of sand. Filling and packing took place in small, alternate steps. After the cavity was filled, sand was kicked or brushed over the area to obliterate traces of activity. Markers were placed at known distances and directions from the transplant to prevent raccoons or human predators (poachers) from using them to find eggs.

RESULTS

In 1972, 33 whole or partial clutches were transplanted on Kiawah Island, South Carolina, on the morning following egg deposition (Table 1). For comparison, 182 nests served as natural controls, and 65·9 % of these suffered first night predation. Eighteen control nests became partial-clutch transplants after they were partially devoured by raccoons, because any nest discovered by raccoons and not transplanted ultimately suffered 100 % mortality.

First night predation took 39·9 ± 15·8 % of a clutch in 1972; variation was possibly due to changes in the number and appetites of the raccoons, as well as the number of nests available on the beach on a given night. The incubation times of whole or partial-clutch transplants were not significantly different at $p = 0{\cdot}05$ (Student's T test), which indicated that transplantation of small or partial clutches did not affect development time. Hatching success of whole or partial-clutch transplants and the few control nests which survived on the beach (n = 16) was not significantly different.

TABLE 1
FATES OF TRANSPLANTED, NATURAL AND HATCHERY NESTS, KIAWAH ISLAND, SC, SUMMER 1972 AND 1973

Year		*Number*	*Original egg. no.* ($\bar{x} \pm$ sd)*	*Incubation time days* ($\bar{x} \pm$ sd)*	*Hatching success* (%) ($\bar{x} \pm$ sd)*	% *Preyed upon*
1972	Transplants					
	Whole clutches	15	108·0 ± 18·4	61·0 ± 6·2	61·6 ± 22·8[a,b]	—
	Partial clutches	18	115·3 ± 20·6[b]	62·4 ± 10·2	59·7 ± 27·5[a,b]	—
	Total transplants	33	111·8 ± 19·6	61·7 ± 8·4	60·6 ± 25·0	6·1 (post-transplant)
	Natural nests (controls)	182			66·8 ± 18·2[b]	65·9 (first night) 93·8 (total)
1973	Transplants (whole clutches only)	16	123·1 ± 18·4	58·0 ± 5·6	68·4 ± 22·8[b]	18·7
	Hatchery nests	55	133·0 ± 2·3[c]	—	80·6 ± 1·8[c]	—
	Natural nests (controls)	28	111·4 ± 21·3	—	72·5 ± 19·1[b]	74·4

[a] One nest with 0 % hatch.
[b] Based on counts of shells, post-predation or post-hatch.
[c] Mean ± standard error of mean.
* Differences between whole and partially-devoured nests not significant at $p = 0{\cdot}05$ (Student's t test).

All 1973 transplants on Kiawah were performed at night on whole clutches only, soon after the female had laid. A hatchery containing 55 nests was also maintained. Hatching success of hatchery-reared nests was significantly higher than that of either transplants or control nests (Table 1), but none of the hatching percentages for either year are outside the range of other reported values (e.g. Raj, 1976).

Table 1 shows a highly significant reduction in predation on transplanted nests as compared with control nests in both years, from 93·8 % to 6·1 % in 1972 and 74·4 % to 18·7 % in 1973. There was no difference in the rate of predation on whole or partial-clutch transplants in 1972. Predation on night-transplanted whole clutches was higher in 1973, even though the total predation on controls was substantially lower in that year (74·4 % compared with 93·8 % in 1972).

On Cedar Island in 1977, only partially devoured clutches were transplanted (n = 18), on the morning after they were laid (Table 2). A large proportion of all nests was washed away by a storm that occurred in late July. Of the transplants, 44·4 % were known to be lost to erosion at that time, and the markers for an additional 16·7 % of the transplants were also lost. Only three transplants hatched successfully, all with hatch rates above 71 %. Predation occurred on 11·1 % of the transplants,

TABLE 2

FATES OF TRANSPLANTED NESTS ON CEDAR ISLAND, SC, SUMMER 1977. FOR COMPARISON, FIRST NIGHT PREDATION ON CONTROLS WAS 57·5% (n = 165)

Nest number	*Date*	*Total no. of eggs*[a]	*No. eggs transplanted*	*% predation per nest*	*Fate*
1	2 June	—	—	—	Eroded
2	3 June	92	52	43·5	Hatched—undetermined
3	4 June	—	—	—	Eroded
4	5 June	117	31	73·5	Devoured
5	6 June	—	7	—	Eroded
6	7 June	124	114	8·1	Eroded
7	10 June	88	18	79·5	Eroded
8	11 June	85	6	92·9	Hatched—71 %
9[b]	12 June	160	48	70·0	Eroded
10	12 June	102	12	88·2	Unknown
11	13 June	84	8	90·5	Eroded
12	18 June	117	64	45·3	Infertile
13	20 June	133	85	36·1	Unknown
14	22 June	109	77	29·4	Eroded
15	3 July	128	99	22·7	Hatched—100 %
16	5 July	?	120	—	Hatched—100 %
17	6 July	115	22	80·9	Unknown
18	12 July	70	44	37·1	Devoured
Mean ± sd		108·6 ± 23·9		56·98 ± 28·3	Eroded: 44·4 % Hatched: 22·2 % Unknown: 16·7 % Devoured: 11·1 %

[a] Based on counts of shells, post-predation.
[b] Devoured 5 days after laying.

which was about one-fifth of the first-night predation rate on control nests. Even if all of the transplants whose ultimate fate was unknown suffered predation, the rate on transplants would still be only 27·8 %, about half that of natural nests. Storm erosion on Cedar Island beaches was as effective as predation in reducing hatchling production in 1977.

In 1978, 56 transplants were made, all on the morning following egg deposition or later (Table 3). Whole clutches were not transplanted until after 9 July. Control nests were undisturbed until they hatched, eroded, or were attacked. Partially-devoured control nests were subsequently transplanted, so the total in Table 3 is not a direct sum of wild nests and transplants. As in 1978, erosion was an important mortality factor on Cedar Island, taking 41 % of the control nests and 27 % of the transplants. Predation was even more significant, as first-night predation on control nests was 55·1 %. Transplants, however, suffered only 14·2 % predation on whole clutches and 7·1 % on partial clutches, for an overall rate of 8·9 %. As in other years, transplants had a normal incubation time, and hatching success was very high. Hatch success of

TABLE 3

FATES OF TRANSPLANTED AND INTACT NESTS ON CEDAR ISLAND, SC, SUMMER, 1978

	Number	*No. eggs transplanted* *Range*	*No. eggs transplanted* $\bar{x} \pm$ sd	*Percent infertile*	*Percent eroded*	*Percent lost by predation*	*Percent hatched*	*Incubation time—days* $\bar{x} \pm$ sd	*Hatching success (%)* $\bar{x} \pm$ sd
Transplants									
Whole clutches	14	62–153	115·0 ± 27·5	0·0[a]	21·4 (3)[a]	14·3 (2)[a]	64·3 (9)[a]	60·9 ± 4·7	92·9 ± 8·3 (9)
Partially-devoured clutches	42	3–145	61·9 ± 41·6	7·1 (3)[a]	31·0[a](12)	7·1 (3)[a]	54·8[a](23)	60·7 ± 7·2	83·4 ± 21·2 (23)
Total transplants	56	—	—	5·4	26·8	8·9	57·1		[c]
Natural nests (controls)	89	—	—	41·6		55·1[b]	3·4 (3)		80·0 ± 13·0 (n = 3)
Total nests	132	—				55·0[b]			

[a] Post-transplant.
[b] First night predation only.
[c] Based on shell counts, post-hatch.

partial transplants was not significantly lower than that of intact transplants (Student's T test). Only 3, or 3·4 %, of the control nests hatched successfully, albeit with reasonable hatching success. This low percentage of hatchling productivity is not unusual for barrier islands in South Carolina in recent years (Hopkins *et al.*, 1978; Stancyk, Talbert, Dean and Miller, unpublished data).

DISCUSSION

Data from a total of 123 transplanted loggerhead nests on two different islands over four years indicate that in all cases transplanted nests were significantly less heavily preyed upon by raccoons than control nests. In addition, transplantation did not significantly affect either incubation time or hatching success of clutches. The differences between control and transplanted hatch rates were far outweighed by the dramatic reduction in mortality brought about by moving nests. The simple procedure of transplantation, therefore, appears to be a successful deterrent to raccoon predation. We have evidence from tracks that raccoons returned to sites of partially-devoured clutches which we had subsequently transplanted, and actually sat upon the transplanted clutches without discovering them. In other cases, raccoons partially excavated transplant sites, but did not discover the eggs. Excavations by raccoons are not unusual in natural body pits left by laying female loggerheads. Eggs moved the night they were laid suffered less of the heavy first-night predation that was observed in all years. However, the procedure might make it possible for raccoons that observed the process to achieve higher success in finding transplanted clutches (Table 1, 1973). The number of nests transplanted at night was however, small, and this possibility needs further testing. There is some evidence that our all-night monitoring of nesting activity on the beach actually reduced raccoon predation. Talbert, Stancyk, Dean and Will (in press) found a significant difference in the amount of predation on lightly patrolled sectors ($\bar{x} = 85\%$) and more heavily patrolled sectors ($\bar{x} = 66\%$) of Kiawah Island in 1973.

At least four other methods used to help reduce predation on nests have disadvantages. Chemical deterrents such as lithium chloride have been tried, but have not been effective with raccoons (S. Hopkins, pers. comm.). Even if chemical deterrents were effective in reducing predation, the fact that we know nothing about their effects on the morphology, development or behaviour of hatchlings precludes their use as management practices.

Trapping (Klukas, 1967) and shooting (S. Hopkins, pers. comm.) raccoons have been effective, but are labour-intensive. Removal of raccoons, which are an important component of the coastal marsh community, might have negative effects on the ecosystem or conflict with management policies on government-controlled lands.

The placing of screens over developing nests has also been used to reduce predation. This method has been moderately effective (G. Heins, pers. comm.) but has four major disadvantages: (1) the cost of materials makes protection of a large number of nests expensive; (2) unless screening is very carefully done, raccoons are able to dig around or through the screens to the eggs; (3) screens provide no security against erosion; and (4) they must be removed prior to hatching, so the hatchlings can go to the sea. This requires repeated visits to the nest sites and might increase exposure of the protected eggs to predation during the hatch.

Hatcheries, where clutches are moved to a single area, are quite effective in deterring predation, and often have excellent hatch rates (Raj, 1976; Talbert *et al.*, in press). But like screens, hatcheries are labour-intensive, and when placed on the beach itself there is a risk of high mortality from flooding (Ragotzkie, 1959; Talbert *et al.*, in press) or infection by soil microflora (J. I. Richardson, pers. comm.). When clutches are placed in styrofoam boxes, problems of flooding and infection are avoided, but repeated visits are required to maintain moisture levels in the incubators and to release hatchlings. Also, such material as styrofoam might release substances which would modify normal development of the hatchlings in subtle, virtually undetectable ways (A. Carr, pers. comm.). In incubators hatching times may be longer than on the beach (Mrosovsky, 1978; Talbert *et al.*, in press). Yntema (1976) has shown that temperature modifications of only a few degrees celsius can significantly alter sex ratios of freshwater and terrestrial chelonians. Prolonged incubation periods in styrofoam boxes are often a result of slightly cooler incubation temperatures as compared with those of the natural beach, and could cause similar effects.

Transplantation of eggs to a single beach site (for incubation) increases the risk of mortality due to flooding, erosion, discovery by predators, or infestation. However, removal of nests which are certain to be flooded to sites that are less likely to erode could reduce losses. On Cape Romain, South Carolina, for example, many *Caretta* nests are deposited at the bases of large scarps. Removal of these nests to areas on top of and behind the scarps (a distance of less than 10 m) could save large numbers of hatchlings.

Many questions concerning the transplant method remain. First, we have been unable to test it on a beach that is heavily utilised by both turtles and raccoons. Cape Island, for instance, had an estimated 1120 nests in 1978 (Talbert, Stancyk, Dean and Miller, unpublished data); but because of predation and erosion, only one of these is known to have successfully hatched. Whether transplantation would be effective where raccoon activity and erosion are so great is an important question. Secondly, the ability of the method to deter predation by mammals other than raccoons is unknown. On Ossabaw Island, Georgia, hogs are the major predator, and the results of one year of transplantation there were ambiguous (C. Blanck, pers. comm.). Thirdly, we know that great care must be taken during transplantation to avoid subsequent detection by raccoons, but we do not know the degree of care required to safeguard nests from other predators, nor the effectiveness of the method if it were utilised by a large force of relatively untrained individuals like volunteers.

Finally, the effectiveness of moving clutches at night, immediately after they have been deposited, should be tested further.

Despite these problems, the transplantation method has great conservation potential on nesting beaches where erosion and predation by small mammals are important factors. Compared with other methods currently in use, transplantation is the cheapest, simplest and most natural way to avert predation that has yet been attempted. It requires relatively little labour and avoids many of the pitfalls of the other methods. Unless histories of individual nests are being monitored nest sites must be visited only once, when the clutch is buried. No chemicals are introduced, optimal beach sites can be chosen, and development in the natal beach takes place at normal beach temperatures. Hatching is not affected by human activities. What is needed now is for additional trials of the method to be carried out, in different parts of the world, where other species of sea turtles nest, and where different predators eat turtle eggs.

ACKNOWLEDGEMENTS

This work was supported in part by the Kiawah Beach Company, National Science Foundation Grant (SOS—No. Gy-10818), the South Carolina Sea Grant Program and the Belle W. Baruch Institute for Marine Biology and Coastal Research. We would like to thank the Heritage Trust Program and the Non-game and Endangered Species section of the South Carolina Wildlife and Marine Resources Department for their cooperation. We especially thank the individuals who helped with transplants over the years: T. McKee, W. Frampton, M. Collins, M. Molony, B. Talbert, A. Miller and R. Aiken. This article is dedicated to the memory of Jane Frick, whose concern for the plight of marine turtles and efforts on their behalf continue to inspire.

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