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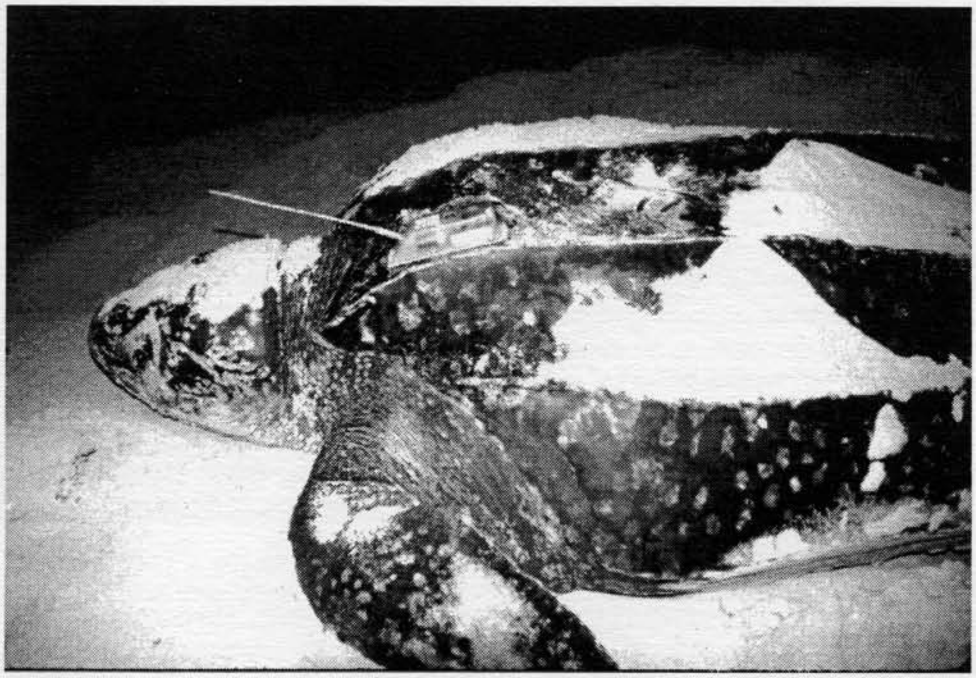

Novel attachment of satellite transmitters to leatherback turtles (see Luctavage *et al.* pp. 9-12).

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Direct Carapacial Attachment of Satellite Tags Using Orthopedic Bioabsorbable Mini-Anchor Screws on Leatherback Turtles in Culebra, Puerto Rico

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Of the sea turtles, the migratory routes and life history of the leatherback (*Dermochelys coriacea*) is shrouded in the most mystery. Unfortunately, there is compelling evidence that its enigmatic life style has not protected it from harm, since the leatherback may face global extinction, especially in the Pacific (Spotila *et al.* 1996, 2000). The incidental take of leatherbacks in fishing gear is of serious concern worldwide (Eckert & Sarti 1997; Morreale *et al.* 1996; Williams *et al.* 1996). Part of the problem is that the leatherback, like the highly migratory swordfish, tunas, and whales, spends much of its life on the high seas, and seems to select migration routes along oceanic frontal systems where food is concentrated (Lutcavage 1995), but where we have little opportunity to study it. The second formidable challenge is that the leatherback's unique leathery carapace is a bioactive matrix, resistant to fouling (Veinot 1967) and various adhesives. Consequently, conventional tag attachment methods (e.g., epoxy cement) that work well on the hard keratinous scutes of cheloniid turtles (see Plotkin 1998) are not effective on the smooth oily skin of the leatherback shell, and as a result, satellite tracking methodology has been dependent on various indirect attachment techniques. Our research objectives were to develop a new methodology of direct carapacial attachment of satellite tags on leatherback turtles and then to follow their movements in relation to the environment and to pelagic fisheries.

Researchers have successfully tracked leatherbacks for up to 90 days with towed, positively buoyant satellite tags tethered through a large hole and bolt drilled through the caudal peduncle (Duron-Dufrenne 1987; Morreale *et al.* 1996). However, this method is not completely satisfactory because the attachment material may eventually cut through the tissue, leaving a large defect and invoking an inflammatory response (which we have observed in short-term attachments of biotelemetry equipment). In addition, the towed tag may also increase susceptibility to entanglement.

An external harness assembly has given good tracking results ranging from weeks to over one year periods for post-nesting females (Eckert 1999; Eckert *et al.* 1986; Hughes *et al.*, 1998; Keinath & Musick 1993). Although it is the only successful tagging technique so far to yield long-term migration data on leatherbacks, this method is not always optimal because the harness requires sizing and can chafe the turtle if not perfectly fitted (Keinath & Musick 1993). Although it is assumed that a harness does not affect the behavior of leatherbacks tracked with satellite transmitters, there are no comparable data from other satellite tagging methods that could be used for comparison. In coastal areas such as New England, where fixed gear (e.g., lobster pots and gillnets) is widespread, concerns remain that a harness or towed tag may increase the chance of entanglement. The development of a simple tag attachment system that would allow tracking devices to be attached directly onto leatherbacks, as in other sea turtles, remains an important research and conservation milestone. A simple direct attachment method would increase the feasibility of studying the fate and behavior of leatherbacks released by fisheries observers in offshore fisheries.

We theorized that since the leatherback's bone structure is similar to mammalian bone (Rhodin 1985; Rhodin *et al.* 1981), human orthopedic fixation methodology might be successfully adapted for transmitter attachment directly into bone. Our design model was a small satellite transmitter secured to the anterior carapacial bone with small orthopedic biodegradable mini-anchor screws and heavy nonabsorbable sutures. We hoped thereby to achieve (1) a low-profile secure bony attachment of a small transmitter on the highest part of the carapace, (2) optimal antenna exposure and signal strength (3) minimal invasiveness with tiny drill holes, (4) no permanent biofouling through the use of biodegradable implanted screws, (5) minimal entanglement problems, and (6) eventual release of transmitters after long-term monitoring. We here report our results from the first three applications of this new methodology and discuss the problems encountered.

We used orthopedic mini-anchor screws (Biologically Quiet™ Mini Screw Suture Anchors, Instrument Makar, Inc., Okemos, MI) developed for shoulder surgery in humans. The screws (length 15 mm, diameter 3.81 mm) are made of a bioabsorbable material (85/15 D,L lactic and glycolic acid) which allows bone tissue to grow into the matrix of the anchor. The screw is eventually absorbed in about 12 weeks. A heavy nonabsorbable synthetic suture, # 5 Ethibond, was threaded through a transverse hole halfway along the length of the screw. The screw and attached suture were secured in four drilled holes in bone using custom surgical tools. Pull-out strength of these screws measures 63 lbs in cancellous bone and 68 lbs in cortical bone when tested in mammals (Barber & Cherf 1997).

We used a small Argos-compatible satellite transmitter and time-depth recorder (TDR) unit (SDRT10, Wildlife Computers, Inc.) measuring 12.5 x 6.5 x 3.5 cm, potted in a streamlined epoxy, and weighing about 335 g. The TDR unit was attached to a Delrin base plate with four pre-drilled holes. The anchor screws' sutures were drawn through the holes, then tied with multiple surgical knots and epoxied directly onto the transmitter housing.

Transmitter attachment location was along the medial edge of the first lateral carapacial ridge just posterior to the leading anterior edge of the carapace, adjacent to the highest point of the carapace. Two screws were anchored in the first lateral ridge, where bone thickness is approximately 6–8 mm. Two additional screws were anchored more medially in the trough between the midline and the lateral ridge, where bone thickness is only 3–4 mm. Prior to surgical attachment we cleaned and anesthetized the site with Betadine and isopropyl alcohol and a topical freezing agent (ethyl chloride). The animals did not respond to the drilling and did not appear to suffer any trauma from the brief procedure.

We first tested our proposed methodology in November 1997 on a stranded adult leatherback in Bourne, Massachusetts. It had been damaged by lobster pot entanglement during the fall and became trapped in Cape Cod Bay, stranding barely alive on 17 November and dying within a few hours. A necropsy was performed immediately on the fresh carcass and we attached a satellite transmitter using our described methodology. We then attempted to dislodge the attached transmitter with forceful manual pulling, but it remained secure. Our assessment was that this methodology and location might be successful for long-term attachments.

In 1998, we obtained permission from the Puerto Rico Department of Natural Resources to test our new methodology on nesting leatherbacks in Culebra. We attached the first transmitter to a nesting leatherback (# 27579, DNR # NNV674, CCL 154 cm) on 7 June 1998 (see Raloff 1998). After the turtle had begun to oviposit the transmitter was attached using our described methodology. After attachment the transmitter could not be dislodged with strong manual tension. The turtle did not respond to any of the interventions, and began to cover her nest as we completed the attachment.

The transmitter reported position (Fig. 1) and dive data for about ten days. This turtle had previously nested seven times during the season and apparently had completed its nesting cycle, since it headed directly offshore and was about 400 km northeast of Culebra when data transmission ceased. Frequency histograms were constructed from binned diving data, and detailed findings are reported in Lutcavage (1999). The turtle had maximum dive depths between 402–501 m, routine breath holds of 20–30 min, and a mean travel speed (estimated from position data) of 1.6 ± 0.5 kts.

On 30 May 1999 we deployed two additional transmitters on nesting leatherbacks on Playa Brava, Culebra. The two females (# 27577, PIT tag # 029-281-819, CCL 144 cm; and # 27580, PIT tag # 029-353-568, CCL 158 cm) were instrumented in identical fashion to the 1998 animal except that the second, larger female only had three screws instead of four for fixation (due to problems with screw breakage). Location and dive data were transmitted for eight (# 27577) and six (# 27580) days, respectively, before transmissions ceased. At their last reported locations, both turtles were within 19 km of the nesting beach and probably had not completed their seasonal nesting cycle.

In all three cases, since there was no change in the quality of the reported positions before transmissions ceased, we surmised that the transmitters probably became suddenly detached. If the tags had remained partially attached, we would expect partial transmissions or poor location fixes before losing the signal altogether. All three transmitters failed between 6–10 days after deployment, suggesting a common source of failure. There was no evidence from dive data that turtles were acting abnormally or harmed by the tagging procedure. Unfortunately, neither we nor the DNR beach patrol had opportunities to observe or document the condition of the transmitter attachment site at a later date that season.

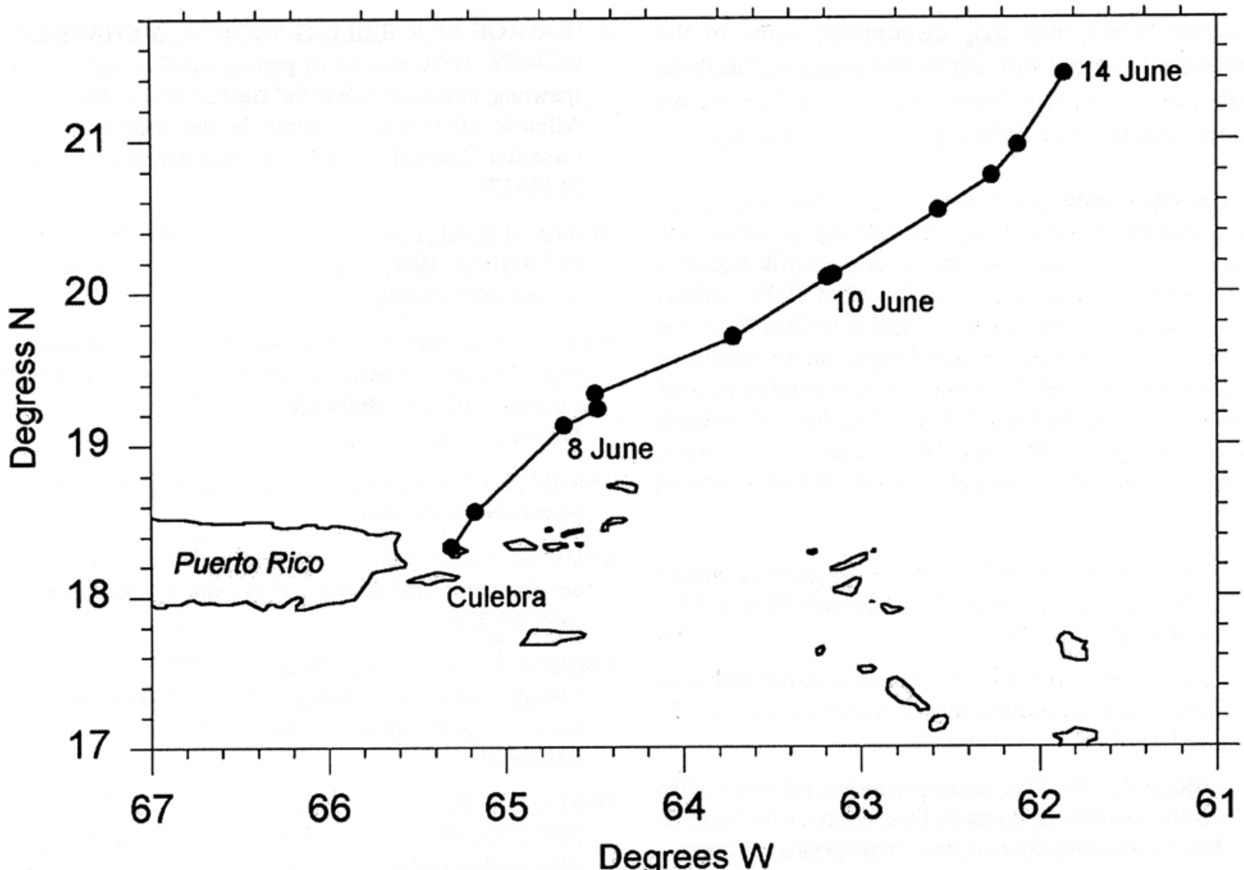

Figure 1. Post-nesting movement of leatherback 27579 tagged on 7 June 1998, Culebra, Puerto Rico (location classes 0 and 1 used).

We hypothesize that transmission failure was most likely caused by loss of fixation by the bioabsorbable screws, probably through shearing through the transverse suture hole. Though the screws have excellent pull-out strength they are quite brittle under significant torque or bending stress. In addition, the glycolic acid polymer has a relatively short shelf-life leading to increased brittleness of the screw with storage. Thicker carapacial bone requires higher screw torque pressures to achieve insertion — during placement of the screws on the larger thicker-boned 154 and 158 cm females, several screws broke, whereas no screws broke on the smaller thinner-boned 144 cm female. Wave action and animal movement could cause movement of the tag on the carapace surface, putting strain on the heavy suture, which may have fractured the screw through the suture hole. Though highly unlikely, it is also possible that the sutures alone may have ruptured.

Screws may have pulled out of the bone without breaking, although our observations on the fresh carcass bone suggested that the carapace bone was indeed thick enough to provide initial solid fixation. However, under conditions of constant micro-toggling the screws could have gradually become dislodged. Another less likely explanation for transmission failure not related to the screws is premature electronic failure of the transmitter itself.

In assessing the results of our first three applications, we concluded that the use of the biodegradable screws likely led to transmitter loss. In the future, the use of non-absorbable stainless steel or titanium orthopedic bone screws or anchors might solve the fixation problem (even in thin carapacial bone), especially if they were used for direct attachment of the transmitter to the carapace. These would probably remain in the carapace, but pathology would not be expected: sea turtles have often been found with metal harpoon tips or hooks lodged in their shells. Recent developments in transmitter technology may also present other solutions. For example, pop-up archival satellite tags, micro-transmitters (with light, depth, and temperature sensors encased in a streamlined, pressure-resistant housing) have been successfully used for long term attachments on giant bluefin tuna and other pelagic species (e.g. Lutcavage *et al.* 1999). Pop-up tags and smaller TDR's may help circumvent some of the problems we faced with our methodology and as these transmitters undergo further reductions in size, we expect that this will reduce attachment challenges.

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