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# Review of Radio Transmitter Attachment Techniques for Turtle Research and Recommendations for Improvement

**WILLIAM I. BOARMAN**

USGS-Biological Resources Division  
Department of Biology, University of California, Riverside  
Riverside, California 92521, USA  
e-mail: william-boarman@usgs.gov

**TRACY GOODLETT**

On-Track Consulting and Research  
429 West Pettis Avenue, Ridgecrest, California 93555, USA

**GLENN GOODLETT**

On-Track Consulting and Research  
429 West Pettis Avenue, Ridgecrest, California 93555, USA  
e-mail: ggoodlett@aol.com

and

**PAUL HAMILTON**

USGS-Biological Resources Division  
Department of Biology, University of California, Riverside  
Riverside, California 92521, USA

*Abstract*—How a radio, sonic, or satellite transmitter is attached to a turtle or tortoise may affect the transmitter's transmission range and the animal's behavior, survival, and reproductive success. We reviewed 113 scientific papers, reports, and semi-technical articles reporting on radio-tracking projects with turtles and conclude that little information is available in the literature to evaluate the effects of transmitters on the study animals. We also provide step-by-step directions on a successful method we used to attach transmitters to desert tortoises (*Gopherus agassizii*) that minimizes potential of affecting the animal's behavior, physiology, reproduction, or survival while maximizing distance of transmission. We believe this method can be used on many other species of turtles and tortoises.

Biotelemetry has become indispensable for studying turtle migration, dispersal, home range, habitat use, physiology, and the effectiveness of relocation efforts. The most common types of telemeters used on turtles are radio, sonic, and satellite transmitters, which each have advantages depending on the specific applications. An important consideration for using radio transmitters and D marking techniques is assuring they do not affect significantly the behavior, physiology, reproductive success, and survival of the animals (Anonymous 1987; Brander and Cochran 1969; Ireland and Kanwisher 1978; Kaufmann 1992a; Renaud et al. 1993b; Schubauer 1981; Schwartzman and Ohmart 1977). Therefore, non-invasive methods of transmitter attachment must be developed and tested (Anonymous 1987). Furthermore, as there are tradeoffs between transmitter weight, transmitter longevity, and transmission range (Brander and Cochran 1969; MacDonald and Amlaner 1980), transmitter attachment methods should be developed to optimize performance to meet study objectives.

We reviewed 113 published and unpublished accounts of the use of radio, sonic, and satellite tracking of turtles to determine the attachment methods used and to identify problems for the study animals caused by the transmitters. We also outline the method we have used for five years to attach transmitters to desert tortoises (*Gopherus agassizii*) without causing physical harm to the study animals, while maximizing transmitter longevity and range. This method can be used for multi-year applications with other species of turtles.

*Review of Transmitter Attachment Methods and Their Problems.*—In the 113 publications, articles, and reports we reviewed, radio transmitters, which consist of three major components (body

of transmitter, battery, and antenna), were attached externally to the carapace of turtles by several means: cemented on with epoxy, silicone sealant, dental acrylic, or some other adhesive; strapped on with harnesses; or attached via bolts, wire, cable or nylon ties, or monofilament line passed through holes drilled in the carapace, usually through the posterior carapace or marginal scutes (Table 1). These methods were used to attach either the transmitter and battery directly to the carapace or to allow the transmitter to trail loosely behind the animal.

Some less conventional modes of attachment were used. In one instance, transmitters were sewn onto the carapace of soft-shelled turtles (Plummer and Shirer 1975). Transmitters also were attached with some success using black plastic electrical tape (Eckler et al. 1990; Moll and Legler 1971). Whereas implantation is the norm in snakes (Fitch and Shirer 1971; but see Ikeda et al. 1979), it has been rarely employed in turtles (Table 1). Many authors (23%) did not mention how or where transmitters were attached, making it difficult to evaluate the potential effect of the transmitter on the animals, and hence the possible limitations on interpreting study results.

Problems caused by transmitters are well documented for birds and mammals (Kenward 1987; White and Garrott 1990), but are poorly known for turtles. We know of only three limited studies designed in part to test the effects of different transmitters or attachment methods on turtles. Tirnko and Kolz (1982) estimated that a satellite transmitter caused a captive loggerhead turtle to spend twice as much time on the water surface, but concluded the transmitter caused no "radical" change in behavior. However, their sample size was one, and no control was reported. Kennerly et al. (1983) found that after equipping 20 loggerhead turtles with transmitters, the turtles spent more time on the surface during the first 3 days than the following 17 days of study. Beavers et al. (1992) found three different adhesive attachment methods had no effect on loggerhead turtle behavior, but their sample size was one per method and they made no mention of methods or criteria.

We located six papers reporting problems observed during the course of field studies with turtles. Keinath and Musick (1993) reported the transmitter and harness cemented to a leatherback turtle (*Dermochelys coriacea*) were bitten by a tiger shark (*Galeocerdo cuvieri*), the resultant damage causing the harness to chafe the turtle's skin. Equipment poorly attached to harnesses slapped against and severely damaged the carapaces of leatherback turtles (Eckert and Eckert 1986). Implanting transmitters into the oviducts of northern long-necked turtles (*Chelodina rugosa*) caused oviducal adhesion in at least two turtles, reducing reproductive output in the year studied, and the surgical procedure resulted in the death of one turtle (Kennett et al. 1993). The act of attaching transmitters may have caused up to 55% of female yellow mud turtles (*Kinosternon flavescens*) to move to new nesting locations (Iverson 1990); the transmitter attachment method was not noted, however. Brill et al. (1995) found submergence behavior of green turtles (*Chelonia mydas*) was affected for up to three hours after they attached transmitters to the rear marginals of the carapace by inserting nylon straps (tie-wraps) through drilled holes. Some shell deformation occurred in hatchling gopher tortoises (*Gopherus polyphemus*) because epoxy holding on the transmitters encroached growth areas between scutes (Butler et al. 1995). On the other hand, Hopkins and Murphy (1981) reported no damage to carapace or flippers from transmitters on 37 loggerhead turtles.

Although not published, other problems have occurred. For instance, J. Congdon (pers. comm.) found transmitters placed on the carapaces of painted turtles (*Chrysemys picta*) became en-

tangled in filamentous algae preventing the turtles from diving. C. K. Dodd, Jr. (pers. comm.), has made similar observations on common mud turtles (*Kinosternon subrubrum*). H. Avery (pers. comm.) observed female desert tortoises impeded by transmitters, which were mounted on the anterior carapace, that got hooked by stems of desert shrubs. We found one desert tortoise shell that became deformed because normal shell growth was inhibited by a transmitter antenna that was attached improperly for one year. Similar results from desert tortoises were reported by K. Berry (pers. comm.) and A. Karl (pers. comm.). Such deformation is most likely to occur in animals that experience relatively rapid growth during the course of study (e.g., juveniles or animals equipped for several years). Although unreported, drilling holes into the shell and underlying bone may lead to potentially harmful infection, and this effect may not be observable until some time after the transmitters have been removed (B. Homer, pers. comm.). Bertram (1979) did comment on the absence of any wounds after removing a transmitter that had been bolted onto the carapace of a hingeback tortoise (*Kinixys belliana*) two years earlier.

Transmitters may attract the attention of predators (Keinath and Musick 1993; cf. Renaud et al. 1993b) or people (Stoneburner 1982). To reduce the potential for such effects, transmitters should be camouflaged in some way. For instance, Dizon and Balazs (1982) covered their transmitters with roofing tar and sand before attaching to Hawaiian green turtles (*Chelonia mydas*). Schwartzman and Ohmart (1977) mixed neutral color compounds to the epoxy or painted the dried epoxy after attachment to desert tortoises. Satellite transmitters placed on sea turtles are routinely painted black (C. K. Dodd, Jr., pers. comm.).

Authors occasionally mention transmitter failures, problems, or malfunctions (Table 1), but rarely are the causes known, mentioned, or hypothesized. We found several accounts in the literature of the loss of transmitters. Stoneburner (1982) laments the theft of seven out of eight buoy transmitters attached to loggerhead turtles (*Caretta caretta*). Tirnko and DeBlanc (1981) lost 4 of 22 transmitters and Tiniko and Kolz (1982) lost their only transmitter when the linen lanyard used to attach floating transmitters to Kemp's ridley turtles and a loggerhead turtle became abraded and parted (see also Renaud et al. 1992; Renaud et al. 1993b; Renaud and Carpenter 1994; Schubauer 1981). After being in place for five months, the vertically protruding antenna broke off a transmitter attached to a hingeback tortoise (*Kinixys belliana*, Bertram 1979). In one study of the desert tortoise, 9% of transmitters (10 of 111) fell off the animals over four years (EG&G 1993).

*Attaching Transmitters to Desert Tortoises.*—For nearly two decades, researchers have been attaching transmitters to the carapaces of desert and gopher tortoises with epoxy cement (for example, see Schwartzman and Ohmart 1977). We modified the methods used by Schwartzman and Ohmart (1977), Mike Cornish (pers. comm.), Charles Peterson (pers. comm.), and others to attach radio transmitters securely to desert tortoises apparently without causing shell deformation, predator attraction, mating disruption, or transmitter loss, while also yielding greater transmitter range. We present the following step-by-step description of the protocol we used so that the method can be adapted to other species of turtles and tortoises.

We used three different types of transmitters depending on the size of the tortoise. Two-stage battery-powered transmitters (AVM Instruments SB-2\*), weighing 35 g, were attached 108 times to 43 tortoises (171–296 mm midline carapace length [MCL], 1075–5200 g). One-stage battery-powered transmitters (AVM Instruments SM-1H), which are smaller (26 g) and weaker, were attached 24 times to 14 tortoises between 146 and 239 mm MCL (800–3150 g).

One-stage solar-assisted transmitters (AVM Instruments SM-1H-solar), weighing 4.2 g, were attached 41 times to 21 immature and subadult tortoises between 97 and 207 mm MCL (220-1800 g). Whip antennas on the larger two transmitters ranged from 280 to 320 mm in length and were made of 20 gauge, insulated, stranded wire. The whip antennas for the solar transmitters were 150 mm long and made of single 24 gauge, insulated, stranded wire.

We used the following step-wise procedure to attach the non-solar assisted transmitters to 57 desert tortoises (Fig. 1a):

1. We tested the transmitter to confirm that it worked.
2. All dirt was brushed off of the carapace.
3. We pre-positioned the transmitters to the first left or first right costal scute of the tortoise's carapace, as flush to the carapace as possible.
4. To position the antenna, we cut short sections of flexible 3 mm plastic tubing, and epoxied each section to the first four vertebral scutes (see also Butler et al. 1995). Each section was cut slightly shorter than its associated scute. Super glue was used to hold each section of tubing in place while we applied a quick drying, pliable putty epoxy (Power Pox Adhesives, Inc., Power Pox® #40001 \*) over each section of tubing in a continuous layer from the scute surface on one side of the tube to the scute surface on the opposite side of the tube. We were cautious not to get any epoxy on the scute sutures or on neighboring scutes.
5. We ran the antenna through the tube sections leaving approximately 50-120 mm of antenna hanging loose beyond the posterior of the animal.
6. The transmitter was then attached with putty epoxy, using care not to bridge the scute margins. Spaces between the transmitter and carapace were filled in with epoxy to prevent the transmitter from getting caught in vegetation.
7. Both the transmitter and the putty epoxy were painted with a flat colored, lead-free paint to reduce reflectivity and contrast.
8. Finally, the transmitter was checked again for proper operation and the tortoise was released immediately.

The entire procedure takes approximately 15 min. The transmitters were removed about every two years for battery replacement by cutting through the epoxy with a pocket knife, a simple process that took less than 10 min.

Using similar procedures, solar-assisted transmitters were attached to the fifth vertebral scutes of 21 tortoises using putty epoxy, but the antenna was left loose. We did not use any tubing to attach the antenna to the tortoise. Some transmitters were attached with the antenna oriented vertically and others horizontally.

To simplify and expedite transmitter removal during future scheduled battery replacement, we initially attached a brass base plate with Devcon® Five-Minute Epoxy®\* to the carapace, then attached the transmitter to a metal post on the plate. Transmitters attached in this manner became detached 22 times between day 1 and 26 months later. No additional losses were experienced after eliminating use of the brass plate (i.e., using the methods described above).

For the first two years, we attached the antenna to the marginals, partially encircling the animal. Later, we began attaching the transmitter to the first right or left costal, as described above, which facilitated placement of the antenna over the vertebral scutes and letting the distal 50-120 mm of antenna trail behind the tortoise. This improvement increased transmission range by approximately 20% (pers. obs.). Diverting the antenna down to the last one or two costal scutes on females would keep it from possibly interfering with copulation, although we have observed unimpeded

copulations with the antenna attached to all vertebral scutes. Leaving antennas loose on solar-assisted transmitters caused antennas to break 19 times, but was necessary to maximize the range of these weaker transmitters. Vertical orientation of antennas also resulted in greater range compared to horizontal orientation, but made the antenna more vulnerable to breakage. To reduce the breakage problem, a smaller, more resilient gauge antenna was used and the base of each antenna was enclosed in a small spring.

Placed on the vertebrals, the tubing allowed the antenna to be pulled through the tubes as the tortoise grew, thus preventing shell deformation. We have attached antennas in this manner to 57 tor-

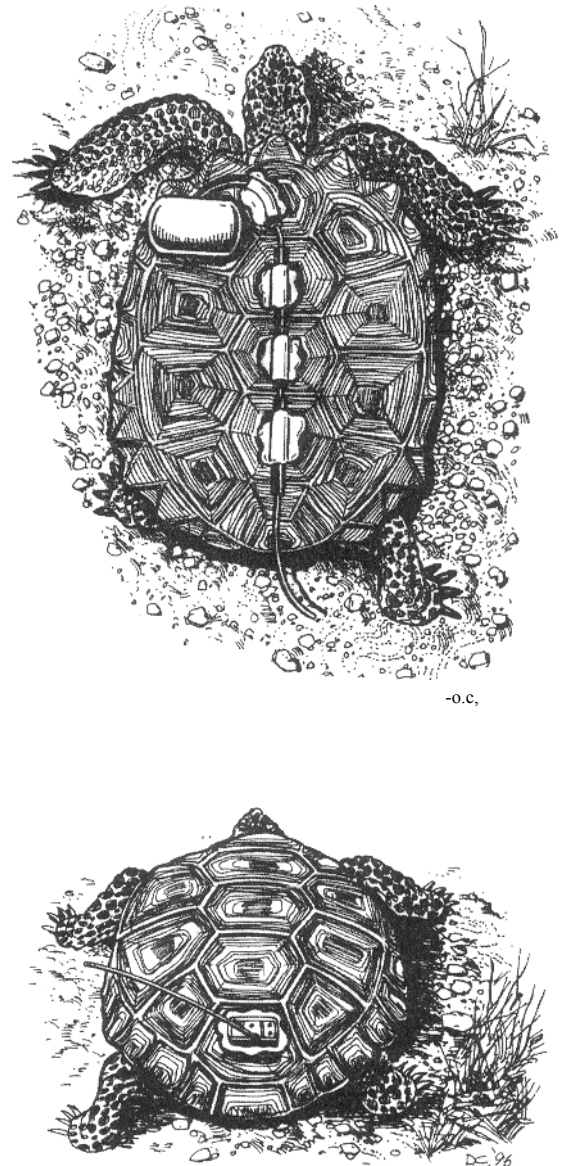


FIG. 1. Drawing showing how we attached radio transmitters to the carapaces of desert tortoises: (a) larger battery-powered transmitters were attached to tortoises larger than 146 mm (midline carapace length; 800 g) and (b) smaller solar-assisted transmitters were attached to immature and subadult tortoises between 97 and 207 mm (220-1800 g).

TABLE 1. Methods of transmitter attachments in chelonians. Methods are categorized as one of the following classifications: "adhesive" (transmitter was attached to the shell of the turtle with glue, epoxy, dental acrylic, or fiberglass), "harness" (transmitter was strapped around the shell without otherwise disturbing the shell), "hole in shell" (holes were drilled, screwed, or punched through the shell, and bolts, string, wire or other filament was strung through the hole[s] to attach the transmitter), "implantation" (transmitters were surgically implanted within the body), "tape" (transmitter was attached with electrical tape), "sewn" (the transmitter was sewn into the shell of a soft shell turtle), or "not mentioned" (method was not evident). Papers that reported on problems are indicated by superscripts. An "\*" notes data on effect of the transmitter on the health, development, behavior, or ecology of the turtle. A "+" denotes problems with transmitters failing off or otherwise being lost from the turtle. A "t" notes a non-specified problem with transmitter use on a turtle.

Method	Species	Source
adhesive	<i>Caretta caretta</i>	Beavers et al. 1992; Hays et al. 1991; Renaud et al. 1992+; Renaud and Carpenter 1994
	<i>Chelonia mydas</i>	Renaud et al. 1992+; Renaud et al. 1993b+
	<i>Chelydra serpentina</i>	Ireland and Kanwisher 1978
	<i>Clemmys guttata</i>	Lovich 1990, pers. comm.
	<i>Clemmys marmorata</i>	Rathbun et al. 1992
	<i>Clemmys muhlenbergii</i>	Fickler et al. 1990t; Larson 1984; Lovich et al. 1992, pers. comm.
	<i>Dermochelys coriacea</i>	Standora et al. 1984t
	<i>Gopherus agassizii</i>	Barrett 1990; Bulova 1994; Burge 1977b-, Esque 1994; Goldsmith and Shaw 1994; Martin 1995; O'Connor et al. 1994a, b; Peterson 1993; Schwartzman and Ohmart 1977; Stewart 1993; Turner et al. 1984; Zimmerman et al. 1994 Tom 1994
	<i>Gopherus flavomarginatus</i>	Butler et al. 1995*; Diemer and Moler 1982; Diemer 1992t; Smith 1995; Wilson et al. 1994
	<i>Gopherus polyphemus</i>	Renaud et al. 1993a
	<i>Lepidochelys kempii</i>	Beavers and Cassano 1996; Plotkin et al. 1995, 1996
	<i>Lepidochelys olivacea</i>	Dodd et al. 1988
	<i>Sternotherus depressus</i>	Madden 1975+
	<i>Terrapene carolina</i>	Nieuwolt 1993
	<i>Terrapene omata</i>	Moll 1994, pers. comm.
	<i>Trachemys scripta</i>	Geffen and Mendelsson 1988t, 1989
	<i>Testudo kleinmanni</i>	Belzer and Reese 1995
	generic	Stonebumer 1982+
harness	<i>Caretta caretta</i>	Ireland 1980; Standora et al. 1982
	<i>Chelonia mydas</i>	Duron-Duffrenne 1987; Eckert and Eckert 1986*; Eckert et al. 1986; Keinath and Musick 1993*
	<i>Dermochelys coriacea</i>	Byles 1989*+
hole in shell	<i>Lepidochelys kempii</i>	Byles and Dodd 1989+; Hopkins and Murphy 1981*; Keinath et al. 1989*+, Kemmerer et al. 1983; Standora et al. 1982; Renaud and Carpenter 1994; Wibbels et al. 1990t; Yano and Tanaka 1991
	<i>Caretta caretta</i>	Baldwin 1973; Brill et al. 1995*; Dizon and Balazs 1982; Mendonça 1983; Ogden et al. 1983f
	<i>Chelonia mydas</i>	Froese 1974; Galbraith et al. 1987t; Ireland and Kanwisher 1978; Brown and Brooks 1991; Brown et al. 1990; Obbard and Brooks 1981
	<i>Chelydra serpentina</i>	Taylor and Nol 1989; Christens and Bider 1987t
	<i>Chrysemys picta</i>	Kaufmann 1995, 1992a, b
	<i>Clemmys insculpta</i>	Ross and Anderson 1990; Rowe and Moll 1991
	<i>Emydoidea blandingii</i>	Diemer 1992t
	<i>Gopherus polyphemus</i>	Bertram 1979+
	<i>Kinixys belliana</i>	Byles 1989*+; Tiniko and DeBlanc 1981 +
	<i>Lepidochelys kempi</i> .i.	Harrel et al. 1996; Sloan and Taylor 1987
	<i>Macrochelys temminckii</i>	Buhmann and Vaughan 1991
	<i>Pseudemys concinna</i>	Doroff and Keith 1990; Elinor and Karasov 1993; Legier 1971
	<i>Terrapene ornata</i>	Florence 1975t; Moll and Legier 1971t; Schubauer et al. 1990
	<i>Trachemys scripta</i>	Schubauer 1981
	generic	Kennett et al. 1993*t
implantation	<i>Chelonia rugosa</i>	Swingland and Frazier 1980
	<i>Geochelone gigantea</i>	Aguirre et al. 1984
sewn tape	<i>Gopherus flavomarginatus</i>	Plummer and Shirer 1975
	<i>Apalone mutica</i>	Eckler et al. 1990
not mentioned	<i>Clemmys muhlenbergii</i>	Moll and Legier 1971t
	<i>Trachemys scripta</i>	Moll 1980
	<i>Batagur baska</i>	Soma and Ichihara 1977; Soma 1985; Timko and Kolz 1982+
	<i>Caretta caretta</i>	Ireland 1979; Carr 1967
	<i>Chelonia mydas</i>	Ultsch and Lee 1983



TABLE 1. cont'd

Method	Species	Source
not mentioned	<i>Gopherus agassizii</i>	Berry 1974; Burge 1977a; Christopher et al. 1993; DeFalco 1995; EG&G 1993*+; Henen 1994; Jennings 1993; Turner et. al. 1987, 1986; Wallis et al. 1992
	<i>Gopherus potyphei-nus</i>	McRae et al. 1981
	<i>Kinosternonflavescens</i>	Iverson 1990*
	<i>Kinosternon subrubum</i>	Burke et al. 1994
	<i>Mauremysjaponica</i>	Yabe 1992
	<i>Pseudemydura umbrina</i>	Fullagar1967
	<i>Terrapene carolina triunguis</i>	Kiester et al. 1982; Schwartz et al. 1984
	<i>Testudo hermanni</i>	Swingland et al. 1986

toises for up to five years, and have observed only ond shell that became slightly deformed when the widened distal end of the antenna failed to slide through the tubing. We now use antennas with continuous surfaces rather than ones with additional insula- tion at their ends.

Attachment to the first right or left costal prevented the trans- mitter from interfering with mating when males mounted females. We did not measure the effect of transmitters on tortoise behav- ior, but did observe several instances of males mounting females unobstructed by the transmitter and two transmitted animals successfully righting themselves after falling on their carapace.

Attaching the transmitter to the first right or left costal scute generally resulted in a fairly flush alignment with the top of the carapace, thus minimizing problems that could occur when tor- toises with transmitters turn around inside their burrows. Three of our transmitted animals were found stuck in collapsed bur- rows following an unusually rainy winter, but we were unable to determine if the transmitters contributed to burrow collapse or tortoise entombment. None of three known mortalities of our transmitted animals were attributed to the presence of the trans- mitter (one was a road kill, one probably died from a respiratory disease, and one died of unknown causes).

*Discussion.*-Based on five years of observation, the method described herein successfully reduced loss of transmitters, in- creased transmission range, and prevented deformation of the shells, while minimally altering the animals'behavior. However, experiments designed explicitly to measure transmitter effect were not conducted.

Transmitter design is a three-way compromise between battery size, longevity, and transmission range (Brander and Cochran 1969; Macdonald and Amlaner 1980; Mech 1983). We found an- tenna orientation to affect transmission range. We found that trans- mission range was increased by allowing the antenna to lie across the top of the carapace. This orientation likely reduced nulls in the transmission signal caused by an open loop and reduced slightly ground attenuation (Mech 1983).

Allowing the transmitter and/or antenna to bind together two or more scutes may cause deformation of the shell as the animal grows. If the antennas were attached directly to the shell with epoxy, they would connect several scutes together for as long as the transmitter was attached; which may be the life of the animal if the animal becomes lost with the transmitter still attached. This would be particularly critical in rapidly growing turtles (e.g., hatchlings and juveniles). Although undocumented, shell defor- mations could be hazardous if they impede normal behavior or damage underlying tissues (B. Homer, pers. comm.).

We found that our transmitted tortoises were still able to mate apparently unimpeded by the transmitter and were able to suc- cessfully right themselves if tipped over during mating or aggres- sion. Eckler et al. (1990) also observed the behavioral effect of attaching transmitters to 45 bog turtles (*Clemmys muhlenbergii*), and reported seeing successful foraging, mating, and nesting. They epoxied the transmitters to the fourth costal scute and attached the antennae directly to the carapace.

The method chosen for attaching radio transn- titters depends on the size, behavior, potential future growth, and catchability of the species, as well as characteristics of the environment and the prin- cipal study objectives (e.g., length of study, type of data desired). It is essential that the transmitter not affect significantly the be- havior, survival, or reproductive success of the study animals. Therefore, for relatively long-term applications (the length of time depends on the animal's growth rate, which depends in part on the animal's age), attachment should avoid causing shelf defor- mation. Studies should be conducted to evaluate the effect that transmitters and their attachment methods have on turtles and tor- toises with the results reported in the literature. Furthermore, stud- ies usinc, radio transmitters should provide sufficient detail on attachment methods to allow readers to evaluate the potential ef- fect the transmitters may have on the animals and the study's re- sults.

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