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# A BACKPACK METHOD FOR ATTACHING GPS TRANSMITTERS TO BLUETONGUE LIZARDS (*TILIQUA*, SCINCIDAE)

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*Abstract.*—**Global positioning system (GPS) transmitters provide detailed information but require external attachment of relatively large units. We describe a backpack system that we developed to attach GPS units to free-ranging bluetongue lizards (*Tiliqua multifasciata* and *T. scincoides intermedia*). An inner layer of supergrip fabric was glued to an outer layer of nylon mesh, to form a vest around the animal's chest and a collar around its neck, secured with superglue and cable-ties. We fitted 16 lizards with backpacks mounted with GPS units and successfully tracked them for up to 86 days to obtained detailed data on movement patterns and habitat use. Field monitoring in northern Australia showed that the units were durable and stayed in place unless the lizard wore through the backpack or shed its skin. No lizards became entangled in vegetation.**

*Key Words.*—bluetongue lizard; GPS; habitat use; movement patterns; radio telemetry; *Tiliqua multifasciata*; *Tiliqua scincoides intermedia*

## INTRODUCTION

Detailed information on an animal's movements over long time periods can provide insights into habitat use, foraging, and social structure (e.g., Kerr and Bull 2006a, 2006b). However, direct visual monitoring is impossible for many taxa, especially those that are cryptic and active only intermittently, common traits of ectotherms (Neilson et al. 2004). Radio tracking can provide such information reliably, and with less interference by the observer, but requires a major investment of observer time if animals are to be relocated frequently. Recent developments provide another option: Global Positioning Satellite (GPS) technology, to provide a continuous record of locations at a higher spatial and temporal resolution than is available from conventional very high frequency (VHF) telemetry (e.g., Zhang et al. 2005; Flesch et al. 2009).

Attaching GPS units to an animal poses challenges. Conventional VHF transmitters are considerably smaller than GPS units. GPS units are larger in size because they require direct line-of-sight to satellites to obtain locational data. As a result, most studies using GPS tracking have been conducted on relatively large mammals (e.g., Fischhoff et al. 2007; Kjaer et al. 2008; Tucker et al. 2008), birds (e.g., Grémillet et al. 2004; Grémillet et al. 2006) or aquatic taxa (e.g., Wilson et al. 1997; Ryan et al. 2004; Schofield et al. 2007) where the mass of the tracker has less effect on animal movement. In these cases, GPS units generally have been attached via collars or adhesives.

Small terrestrial taxa pose greater challenges for GPS tracking (Goodman et al. 2009). Some progress has been made with terrestrial reptiles. Flesch et al. (2009) recently developed an attachment technique to GPS-track Lace Monitors (*Varanus varius*). This method overcame some of the problems of using a large unit and allowed precise information about the timing and distance of animal movement to be obtained. However, Lace Monitors are one of Australia's largest monitor species, growing up to 10 kg and two meters in total length (Cogger 2000), and further modifications of attachment methods are still required if GPS technology is to be applied to smaller reptilian taxa. We developed a backpack to GPS-track bluetongue lizards (genus *Tiliqua*) in northwestern Australia. These lizards are one of the largest members of the skink family (Scincidae) with a snout-vent length (SVL) up to 370 mm; they are viviparous, heavy-bodied, terrestrial, and short-limbed (Shea 1998; Storr et al. 1999; Cogger 2000). Because the lizards use burrows and hide beneath logs, it was vital to design a backpack that remained in place and did not become lodged or entangled in vegetation, or prevented the animal from entering or exiting refugia.

Despite the fact that bluetongue lizards are large and are relatively common, detailed ecological studies on this widely distributed lizard remain limited (Shea 1998). Research has primarily focused on two species from agricultural lands in southern Australia (*T. adelaidensis* and *T. rugosa*: e.g., Bull 1987; Dubas and Bull 1991; Souter et al. 2007; Fenner and Bull 2009), and on an urban population of the east-coast species *T. scincoides scincoides* (Koenig et al. 2001). Most of these studies utilized VHF transmitters to investigate ecological parameters such as movement patterns, habitat use, and sociality. To our knowledge only one study has previously used GPS technology to examine *Tiliqua* species in Australia (Leu et al. 2010).

Although the conservation status of bluetongue lizards in Northwestern Australia has not been evaluated by the International Union for Conservation of Nature (IUCN), recent studies have shown that bluetongues in this region are imperilled by invasive Cane Toads (*Rhinella marina*), with this iconic lizard exhibiting dramatic population declines as a result of fatal ingestion of toads (Price-Rees et al. 2010). Such impacts on the conservation status of bluetongue lizards mean that we need quantitative data on the ecology of this genus, particularly in the northern regions of Australia. Our study used GPS technology to obtain fine scale data on movements and habitat use of two species of bluetongue lizards, the Northern Bluetongue (*Tiliqua scincoides intermedia*) and the Centralian Bluetongue (*T. multifaciata*). Such information will not only increase our limited knowledge of these species, but also provide vital information for developing appropriate management strategies.

## MATERIALS AND METHODS

Between November 2009 and March 2010, we tracked 16 bluetongue lizards (eight *T. s. intermedia*; eight *T. multifaciata*) within Keep River National Park, Northern Territory, Australia. The *T. s. intermedia* had an average body mass of 586.75 g (± 64.90 g) and an average snout-vent length (SVL) of 319.5 mm (± 12.81 mm). The *T. multifasciata* had an average body mass of 312.43 g (± 25.93 g) and an average SVL of 261.4 mm (± 12.39 mm). We fitted each lizard with a SirTrack µGPS data logger fastened to the backpack with a custom-made attachment plate (mass ~ 24 g; SirTrack Ltd., Havelock North, New Zealand; Fig. 1). Bluetongue lizards have been shown to be most active in the early morning and late afternoon (Koenig et al. 2001; Christian et al. 2003): therefore, we programmed each GPS unit with four duty cycles that incorporated two periods of high activity (0600 to 1300; 1700 to 2300) and two periods of low activity (2300 to 0600; 1300 to 1700). During high activity cycles we logged the location of individual lizards every 15 min, and during low activity cycles we logged lizard positions every hour. These settings provided fine-scale and precise data on movement and habitat use (Fig. 2). Because of the high frequency of fixes (63 per day), we recharged the GPS loggers every seven to 10 days. We also fitted each GPS unit with a single stage VHF transmitter are most active (see above). We captured animals by hand and placed them in bags for transport to the field base. Upon initial capture, we marked individuals with a Trovan Unique™ ID-100B animal implantable transponder (Microchips Australia Pty Ltd., Keysborough, Victoria, Australia). Prior to attaching the GPS transmitters (Battery life at 30 ppm = 10 months; mass = 7 g), we determined the sex of lizards and so that we could relocate animals throughout the study and retrieve GPS transmitters if they became detached from the animal. We located lizards every one to two days (depending on accessibility) for up to 19 weeks to record additional habitat data and to ensure the backpack had not become caught or detached.

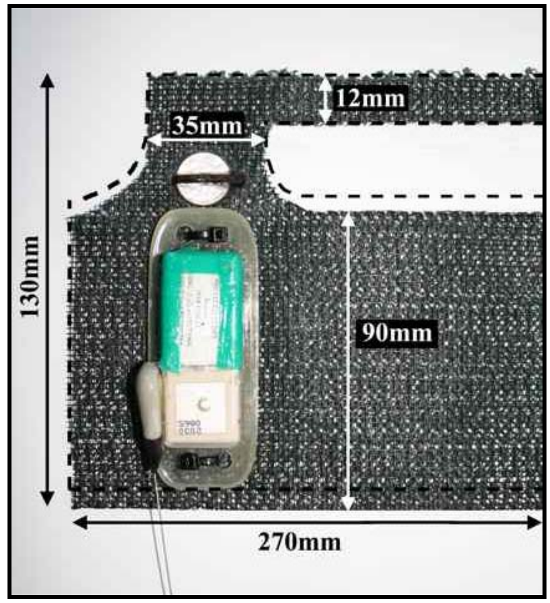


**FIGURE 1**. Vest style design with GPS, VHF transmitters attached showing dimensions of the vest. Dotted line indicates a medium sized vest 5–10 mm smaller than large size. The round object anterior to the transmitter is a Thermochron® iButton® temperature logger. The GPS unit is secured to the backpack via two cable-ties at either end of the additional attachment plate.

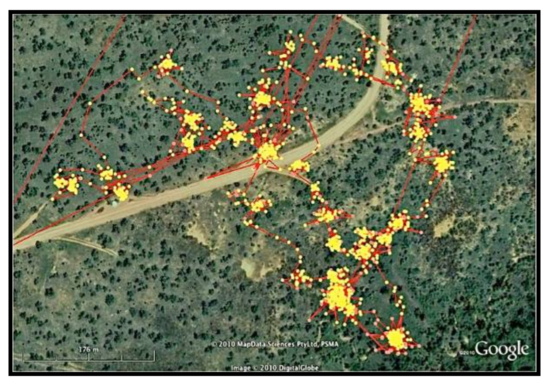


**FIGURE 2**. Google Earth map showing the GPS logger locations of an individual Northern Bluetongue Lizard (*Tiliqua scincoides intermedia*) tracked for 55 days.

***Capture and animals.***—We located bluetongue lizards by slowly driving along roads within Keep River National Park, Northern Territory. Roads were traversed in the morning between 0600 and 1000 and in the late afternoon between 1700 and 2100 to coincide with the time of day bluetongues recorded a series of morphometric measurements (mass, head width, SVL, hindleg-, frontleg-, tail-, and head-length).


**FIGURE 3**. Vest style backpack used to secure GPS transmitters to bluetongue lizards (A) dorsal view of backpack showing the position of the cable ties that secure the harness when fitted, (B) *Tiliqua scincoides intermedia* and (C) *T. multifasciata* in the field.

***Attachment of GPS units.***—We modified the Warner et al. (2006) harness design for VHF transmitter attachment to the agamid lizard *Amphibolurus muricatus*, with changes dictated by the Bluetongue's cylindrical body shape and smooth scales (rendering adhesives ineffective). We constructed the backpack from an outer layer of black nylon flyscreen mesh (mesh size = 1 mm, available from most hardware stores) and an inner layer of super-grip fabric (available from fabric stores), combined with an adhesive spray (Fuller SprayBond™, H.B. Fuller Australia Pty Ltd., Dandenong South, Victoria, Australia). To minimize interference with limb movement, we constructed a wrap-around vest with a neck collar to prevent the vest from sliding backwards (Fig. 1). The back of the vest was shaped to fit snugly onto the chest, leaving space around the limbs. We made two sizes of the vest (to fit large and medium lizards; Fig. 3B, C) using cardboard templates that were then traced onto the combined materials (Fig. 1). The width of the chest section depends on the size of the transmitter (in our case, SirTrack µGPS data logger with VHF transmitter; ~31 g total). To accommodate the 8.5 cm long logger, the chest section of the vest was 9 cm long. Prior to attachment, we positioned the transmitter centrally and attached it by threading cable-ties (100 mm x 2.5 mm) through holes at either end of the attachment plate (Fig. 1). In addition, we attached a Thermochron® iButton® (model DS1921G-F5, Maxim Integrated Products, Inc, Sunnyvale, California, USA) temperature logger in front of the GPS unit using a cable-tie, superglue, and silicone (Fig. 1).

To minimize struggling as the units were fitted, we restrained the lizards between rolled-up towels within a plastic box, or mildly sedated them using an inhalation anaesthetic (Halothane BP 1mL/mL, Laser Animal Health©, West Eagle Farm, Queensland, Australia). To mildly sedate a lizard, we placed it in a seven litre, 20 x 30 x 10 cm container (klip IT, Sistema©, Penrose, Auckland, New Zealand). We poured Halothane (4.5 ml) into a tube containing cotton wool and placed that tube in the container. We then closely monitored the lizard until it lost its righting ability (between 20 to 45 min). At this point we removed the lizard from the container. Anesthesia also facilitated accurate sex determination by enabling us to evert the hemipenes and measure these powerful animals. To fit the harness: (1) we super glued the back section of the harness (i.e., the part that extends from the back of the neck to below the shoulders) to the lizard (Fig. 3A); (2) we super glued the collar to the lizard's neck, with the excess length overlapped around the back of the neck before being trimmed; (3) we threaded two cable-ties (100 mm x 2.5 mm) through either side of the back of the neck (Fig. 3A) to further attach the collar to the main harness; (4) we glued the main vest to the lizard's chest (to prevent the vest from shifting when the lizard drags itself along the ground) and secured to the outer edge of the harness with superglue; (5) we firmly wrapped the harness over the transmitter (already calibrated and switched on) with any excess material trimmed, leaving enough material to form a ~1 cm folded hem; (6) we secured the edge of the vest with five cable-ties (100 mm x 2.5 mm) threaded along the lateral region (Fig. 3), with an additional cable-tie threaded through the excess material at either end of the transmitter; and (7) we smeared silicone (Selleys Pty. Limited, Roof & Gutter Silicone Sealant, Padstow, New South Wales, Australia) over the neck and scapular region to increase the durability of the vest. We filled any gaps with silicone to prevent objects becoming lodged. We also smeared silicone around each cable-tie to prevent tearing. Before release, we transferred the lizard to a temporary enclosure for a few hours to allow the glue to dry.

The harness did not have to be removed from the lizard to access the transmitter. The GPS unit could be downloaded, or its batteries recharged, by removing the posterior most cable-tie and the first two lateral cable-ties. The cable-ties could then be replaced, additional silicon applied and the lizard re-released. We did not see any overt signs of tissue irritation.

## Results

The total harness system (backpack, GPS unit, and VHF transmitter) weighed approximately 45 g (transmitter = 30 g; backpack = 15 g), which was between 1.7 and 6.4% of the lizards' body mass. We tracked individual lizards for seven to 86 days; during this time we physically located lizards using the VHF transmitter 314 times. None of the located lizards had become entangled in vegetation and no objects had become lodged within the harness. One lizard became trapped (twice) within narrow, deep, and steep sided black soil cracks (black Vertosol, cracking clay under the Australian Soil Classification [ASC] of Isbell 1996). The backpack likely did not contribute to the entrapment as we have previously found snakes trapped within such soil-cracks for long periods, until rain loosens the soil (Richard Shine, unpubl. data). Three harnesses became detached when the lizard shed (twice from the same lizard) and two harnesses became detached due to wear on the collar and chest. One harness became detached for unknown reasons. Other lizards also shed during the study, but were caught just prior to or during the shedding process. This enabled us to replace the backpack once shedding was completed. All other backpacks remained in place, and in good condition for up to five weeks (after which minor repairs were made or the backpack was replaced as a precautionary measure). Lizards had moved from their previous location 92% of the time, and 91% of records were under or within the following habitat classes: leaf litter, burrows, *Spinifex*, logs, grass clumps, pandanus, and tree roots. Most of the lizards we located within such understory structures were inactive. The small proportion of lizards (9%) we located in more open areas tended to be active and likely were either foraging or relocating.

## Discussion

The backpacks provided an effective and inexpensive means to track bluetongue lizards using GPS technology. A variety of other backpack styles have been used to secure radio transmitters to small lizards (Fisher and Muth 1995; Richmond, 1998; Ussher, 1999; Warner et al. 2006; Doody et al. 2009; Goodman et al. 2009). However, none of these studies attached GPS units. To our knowledge, only two other studies have fitted GPS units to a reptile as small as our own study species (Leu et al. 2010, in press). These studies also examined a tiliquine skink (*T. rugosa*). In contrast to our own study species, *T. rugosa* has armour-like scales and a short, wide, stumpy tail that does not exhibit autotomy (i.e. cannot be shed; Pianka and Vitt 2003; Bateman and Fleming 2009). These attributes enabled Leu and his colleagues to attach the GPS unit to the lizard's tail using surgical adhesive tape, which was not possible in our study.

Importantly, none of our lizards became entangled as a consequence of the backpack apparatus. Other studies (Warner et al. 2006; Goodman et al. 2009) that have used backpack methods to attach tracking devices have reported cases where the telemetry units or harness mechanisms became entangled in vegetation (albeit infrequently). Lack of entanglement in our study may reflect the snug fit and compact nature of the backpack package. Securing the GPS unit within the backpack did not impede its ability to obtain satellite location data. Failed fixes were only recorded when line-of-sight was completely obstructed (e.g. when an animal was inside a burrow). The material covering the unit protected it against adverse weather conditions and abrasion.

The materials withstood harsh substrate conditions (i.e. rocky, hard, and dry), spiky vegetation (e.g. *Spinifex*), and extreme weather conditions (ambient temperatures of up to $45^{o}$ C). Wear as a consequence of drag along the ground was effectively rectified by the addition of a thick smear of silicone on the chest and dorsal neck region. Inclusion of the super-grip fabric helped to keep the backpacks in place, and the nylon mesh enhanced the strength of the harness. The porous material allowed the glue and silicon to absorb into the fabric, creating a robust and firmly anchored package. Glues other than superglue could be used to initially attach the backpack. Superglue dries hard and rigid and tends to crack when a twisting motion is applied, which potentially weakens attachment and may result in the loss of the backpack. A contact adhesive (e.g. Selleys Pty. Limited, Kwik Grip, Contact Adhesive, Padstow, New South Wales, Australia) that remains rubbery and flexible when dry may be a better alternative.

Ideally, attachment packages would be lighter than the 15 g unit we constructed, but those packages also need to be sturdy. In this study we have no comparative data for untagged individuals; however, the lizards' movements were not overtly impeded or restricted by the backpacks. Lizards were able to negotiate confined refuge sites (e.g. burrows and hollow logs) and dense vegetation and frequently moved long distances. No mortality occurred as a result of predation. The daily distances travelled (5 to 526 m) for *T. s. intermedia* were consistent with other studies that have used smaller (2.5 to 5.2 g) VHF transmitters to track this species (Koenig et al. 2001; Christian et al. 2003) suggesting that the GPS unit was not a hinderance. Likewise, Leu et al. (2010) and Leu et al. (in press), who attached a 37 g GPS logger to a *Tiliqua* species of equivalent size, did not report any impacts on the lizards' movements, activity, or behavior. Overall, bluetongues are slow moving, and accordingly do not rely on rapid locomotion either for foraging or for defense against predators (John-Alder et al. 1986; Shea 1998).

The backpack design results in detachment as soon as the lizard sheds, a useful feature in terms of an animal's ability to escape its harness if it cannot be recaptured (e.g., if the transmitter fails: Goodman et al. 2009). Regular relocation of animals can ensure that shedding animals are recognized and their units re-attached without loss of data. In our study, most lizards consistently shed once a month, at around the same time each month, making it possible for us to prioritize the capture of specific individuals. For many reptiles the detachment of tracking devices due to shedding appears to be unavoidable, particularly for transmitters that have been attached using backpacks or adhesives (e.g. Tozetti and Martins 2007; Flesch et al. 2009; Tozetti et al. 2009). This problem can only be overcome by surgically implanting transmitters, which is not possible with GPS units (Goodman et al. 2009).

Backpack designs similar to ours, but fine-tuned to the morphology and behavior of the study species, may prove useful for other GPS studies, or for research on large-bodied lizards using conventional VHF transmitters (e.g., Goodman et al. 2009). We were able to obtain extremely high resolution movement data, and to track multiple animals simultaneously. Up to 3759 location points were recorded per lizard, far more than could realistically be obtained with conventional VHF telemetry in the same time frame. We also were able to quantify movement paths with more precision than would be possible with VHF telemetry. Consequently, parameters such as daily movements are likely to be underestimated by VHF-based studies. Home-range estimates also are highly sensitive to sample size (number of locations: Girard et al. 2002; Harless et al. 2010). GPS technology enabled us to overcome these problems, and provided insights and understanding that would not have been achieved with older technologies.

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