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A cost-efficient open-source 3D printed harness for GPS logger use in small terrestrial turtles

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The technology used to monitor the home range and movements of Chelonians has advanced significantly over the past century. Early approaches included simple capture-recapture studies (Cagle, 1944; Sexton, 1959), and thread-spool trailing (Stickel, 1950). As the technology became less expensive and more readily available, manual very high frequency (VHF) radiotelemetry became a common, albeit time-intensive methodology (Inman et al., 2009; Blake et al., 2023). Further supplementation with sophisticated VHF receiver arrays (Tucker et al., 2014) substantially reduces effort once installed, although it remains a more cost-prohibitive method. More recently, satellite telemetry has increased in popularity in both larger marine species and smaller aquatic species (Luschi et al., 1998; Lamont et al., 2021). Though it is largely considered to be cost-prohibitive, once installed satellite tags are completely passive and allow for increasingly accurate data as technology has improved (Zbinden et al., 2007). In recent years, the use of smaller and/or modified Global Positioning System (GPS) loggers has become more common for terrestrial and semi-aquatic turtle species (Schofield et al., 2007; Christensen and Chow-Fraser, 2014; Markle and Chow-Fraser, 2014). These smaller tags are cheaper, and more cost-effective compared to satellite tags (> 1000 US dollar per unit), and don't require the same subscription services to download data (e.g., argos). However, even with these benefits, drawbacks exist. Most GPS loggers have shorter battery life than VHF tags, and while some can transmit similarly to array systems (Stemle et al., 2022) others small enough for many turtle species require regularly downloading of data, and thus are often used in tandem with VHF transmitters to ensure data collection (Cochrane et al., 2019).

Application of GPS tags is performed externally using an epoxy to attach and cover the logger (Goodlett et al., 1998). This strategy poses its own set of challenges, especially if the logger is used on smaller species, given the weight limitations that small turtles have, which inhibits the overall size of usable units and batteries, resulting in lower life span. This necessitates regular removal and reapplication of the device to upload data, charge, and/or replace the logger. The amount of time an animal is handled during this process may trigger stress responses in some species, which may even impact home ranges (Currylow et al., 2017; Varty et al., 2024). From a personnel perspective, additional work hours are required to apply the equipment which has both financial and physical implications, especially in harsh field environments. Other forms of attachment, such as hardware-based clips or "harnesses" that can hold loggers, have been used to remedy the time-consuming process in larger terrestrial chelonians (Rubke et al., 2019). However, the harnesses used in these practices might require more extensive hardware knowledge and are still much too large to use in smaller turtle species.

The advent of readily available inexpensive three-dimensional (3D) printing technology has already made its mark in the field of wildlife research with life like model/decoys for behavioural studies (Tetzlaff et al., 2020), prosthetic pieces and treatment equipment for recovery (Hung et al., 2022), and even for GPS collars (Foley and Sillero-Zubiri, 2020). Here we describe the development and deployment of a cost-effective 3D printed harness used in Florida Box Turtles (*Terrapene carolina bauri*). We evaluated its usage in field tests to facilitate more efficient and less stressful data collection processes to expedite research.

Materials and Methods

Study species and site. Florida Box Turtles (*Terrapene carolina bauri*) are a predominantly terrestrial species

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that occurs from the Florida Keys through the Florida peninsula into southern Georgia (Dodd, 2001). We performed our study as part of an established population monitoring project in southwestern Florida. The site is a coastal grassland surrounded by mangrove forest and dune habitats, along with tidal lagoons, freshwater swales, and patchy coastal hammocks, for additional information on habitat see Donini et al. (2024). We chose Florida Box Turtles for this study, largely in part to an on-going home range study started in June 2020. However, the size and general ecology of Florida Box Turtles, made them ideal candidates for testing these loggers.

Logger application. In July 2021, modified GPS loggers (i-GOT-U-GT 120) as described by Paden and Andrews (2020) were applied to a set of 14 turtles that were already part of the aforementioned VHF transmitter study. Loggers measured an average of 43.2 ± 0.6 mm L x 26.3 ± 0.6 mm W x 13.7 ± 1.0 mm H, weighing an average of 27.4 ± 1.6 g. All turtles selected for the study had a weight > 450.0 g on initial capture ($\bar{x}$ = 535.8 ± 44.7 g). VHF transmitters (SOPR 2380, Wildlife Materials Inc.) were affixed to the anterior portion of the shell on the left or right side at a slight angle to avoid inhibition of reproductive activities, with GPS loggers affixed to the opposite side for balance. The total weight of VHF Transmitters, GPS loggers and epoxy did not exceed 11% of the animal's body weight, with most occurring at or under the recommended 10% maximum (HACC, 2004). For the first five months of study this process required affixing tags using epoxy putty (J-B Water Weld) and painting them using oil-based paints to help blend into the surrounding environment. Battery charges lasted approximately 30 days, requiring tags to be removed for data uploads and charging monthly, followed by re-affixing and painting of the same tag (or available spares in some instances) taking approximately ~2.0 hours per turtle. The process took approximately 10 hours per period with 2–3 people participating, not including the relocation of turtles each session (2–3 field days).

Development of harness. We purchased a miniature 3D printer (Easythread K7 3D Printer; Amazon.com; 98.99 US dollar) and a compatible spool of 3D Polylactic Acid Thermoplastic filament (SUNLU PLA Filament, 1.75 mm, 1.0 kg, black; Amazon.com; 22.99 US dollar) to develop functional harnesses for GPS loggers in order to expedite the data collection application process. The open-source program Tinkercad (Autodesk, 2022) was used to design and manipulate basic geometric shapes for the outlined harness. Once developed, the plans for the harness were imported into the open-source software and Ultimaker Cura (Ultimaker B.V.; v4.13.0. https://ultimaker.com/software/ultimaker-cura/), a designated "slicing" program, in which customised thickness and layering were set allowing for the optimisation of harness production. Each harness took approximately one hour to print. The final model was a cuboid design with concave bottom for contouring with curvature of a turtle's shell (Fig. 1). The basic 3D plan may be accessed freely at Sketchfab.com (https://sketchfab.com/3d-models/gps-harness-model-for-tbauri-d42ef225f7554e598abd90d82338c8fd).

When a final harness design was developed and deemed ready to field test, we relocated and processed turtles as usual, this time attaching the harness via epoxy with the opening facing the posterior portion of the turtle's shell to help limit entanglement and facilitate more dynamic movements (Fig. 2). Once epoxy cured, GPS loggers were then inserted into the harness and secured with a zip tie through designed slots. We trimmed the excess zip tie length with wire clippers to reduce additional sources of drag and entanglement. A small hole (~5 mm diameter) was added to the anterior

Figure 1. Lateral view of 3D printed GPS logger harness. Anterior view of 3D printed GPS logger harness. American penny (1¢) used for scale. Photo by Jordan Donini.

Figure 2. Florida Box Turtle (*Terrapene carolina bauri*) with radio transmitter (foreground) and GPS logger in 3D Printed harness (background). Photo by Jeffery Haney.

side of the harnesses to allow for a file or pencil to be inserted to aid in pushing loggers out of the harness during the logger process.

To confirm limits of mobility, a subset of three animals were flipped over onto their carapace to check righting abilities with harnesses affixed and monitored until righting was achieved (< 1 minute per animal). Turtles were then monitored during our regular 1–3 times weekly tracking schedule in addition to monitoring the health status of the animals with attached harnesses.

Results and Discussion

All final harness models had the standard black colour as described in the purchased spools, and were not given any additional paint. The size of each harness purposely varied slightly to accommodate the heterogeneity of the customised GPS logger sizes. On average harnesses measured 48.1 ± 0.62 mm L x 35.1 ± 0.57 mm W x 21.2 ± 1.0 mm H and a weight of 9.9 ± 0.4 g. The average weight of each full unit (with installed GPS unit and cured epoxy) was 56.2 ± 3.2 g (51–61.7 g). Care was taken to ensure some of the slightly larger GPS loggers were only applied to the largest individuals. However, during changing of GPS loggers, there was variation in logger size based on whichever replacement unit was available. In the interest of time and stress limitation, we used replacement loggers of similar size and did not weigh the animal during each change.

Processing time for each unit was reduced dramatically as the process now just involved removing the zip tie and logger unit followed by the charging and download process before reinserting the logger. Excluding relocations, the entire process was reduced to ~4 hours per period from the initial ~10 hours with the same amount of personnel.

General tracking and observation of animals allowed for regular status visual health assessments (body condition, brightness, etc.). Most observations were unremarkable, with animals exhibiting normal behaviours, and general home range movements of animals were found to not statistically vary between years (Donini et al., 2024), indicating limited impact of GPS unit attachment. However, two negative outcomes were observed. The first was observed in an adult female turtle which saw a brief entanglement in Muhly grass (*Muhlenbergia* sp.) due to an improperly installed zip tie. The zip tie was installed inversely and not trimmed short enough, leading to entanglement. The animal was observed at 08:30 h and was likely not entangled long before the zip tie was removed and replaced, given its general alert behaviour and the lack of any signs of overheating or distress. No further entanglement incidents were observed. The second notable negative outcome involved two incidences in which the harness itself was damaged or cracked, possibly due to investigation by predators. One of these cracked harnesses needed complete replacement due to the severity, but the logger itself remained undamaged. The second incidence of damage was a minor crack along the lateral side of the harness, which was easily repaired using a small amount of epoxy. While predators could have caused the damage, these observations may also indicate the need for more specifically targeted UV/weatherproof plastic printing materials depending on the environment and exposure to sunlight, and burrowing behaviour among other variables. The material we used was a standard Polylactic acid thermoplastic (PLA) but recent tech advances have seen the production of fortified PLA filament along with Acrylonitrile styrene acrylate (ASA) filament, both of which may be more durable in field studies. Two animals still had their harnesses and GPS loggers attached during the landfall of Hurricane Ian in September 2022, in which storm surge estimates for the area were 2–4 meters. Both turtles were found alive after the storm with harnesses and GPS loggers undamaged.

We also documented two cases of mortality during the study. Two turtles were found deceased during the final week of the study, both with harnesses and loggers intact. The first animal, an adult female, was found flipped on her carapace with her back inguinal region ripped open on both sides. Additionally, she was found alongside a pile of mammal scat, an apparent sign of a raccoon or similar predator (Seigel, 1980). We do not believe the animal's ability to overturn itself was directly impaired by the harness, but we do accept the possibility that even a slightly extended time in an exposed condition like that could have provided an opportunity for a predator to take advantage. The second individual, another adult female, was found underneath a mangrove patch in an upright, normal position, with no obvious signs of predation or injury other than standard decay. The animal had been directly observed moving and foraging normally only five days prior with no apparent issues, so we are unsure what may have the caused its death.

Overall, our harnesses appeared adequate and effective but did approach the recommended weight ratio for turtles when combined with VHF transmitters (HACC, 2004). However, Parlin et al. (2018) performed a similar study with GPS and VHF combinations in *T. carolina carolina* with no reported negative impacts. Additional modifications should be considered to benefit study animals as much as possible, such as exploring DIY options to reduce the weight of the custom GPS loggers (Cain and Cross, 2018), or even simply optimising epoxy quantity and type to further reduce weight. As with most tracking technology, reducing size and weight without losing functionality should be the goal, but we believe this harness design is sufficient for moderate to large sized terrestrial and semi aquatic turtles allowing for optimisation of data collection, while reducing labour time, and overall stress to individual turtles. In fact, similar designs are already being applied in ongoing projects with terrestrial species such as Radiated Tortoises (*Astrochelys radiata*) and Elongated Tortoises (*Indotestudo elongata*) (Griffioen, 2024; Nelson et al., 2024), demonstrating the advantages of this low cost, open-source approach, particularly for early stage and financially limited projects.

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