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A REVIEW OF THREAD-TRAILING DEVICES FOR EASTERN BOX TURTLES (*TERRAPENE CAROLINA CAROLINA*)

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Abstract. —Thread-trailing is a tracking technique used to monitor precise movements of turtles, but there are positive and negative aspects to using this method. Thread-trailing is inexpensive but can be labor-intensive, and there are often issues with the apparatus itself. We employed thread-trailing devices to track Eastern Box Turtles (*Terrapene carolina carolina*) in a suburban wetland habitat in middle Tennessee, USA. Unfortunately, we had limited success that was likely due to insufficient attachment and wet weather conditions at our field site. However, many researchers have used thread-trailing devices successfully, and this method is often used in conjunction with other tracking methods, such as radio-telemetry or mark-recapture. We discuss the pros and cons of thread-trailing based on our experiences with this method, compare thread-trailing to other common tracking methods, and make recommendations about the thread-trailing apparatus. This information will aid other researchers in determining if the thread-trailing technique is appropriate for monitoring turtles in their study, and if so, how to best construct the thread-trailing device.

Key Words.—mark-recapture, movement, radio-telemetry, thread-trailer, tracking

Tracking is a useful way to monitor turtles and gather important information on their ecology, such as movement patterns, home range size, and habitat usage. Several tracking techniques have been used to observe movements and estimate home range size of turtles, including thread-trailers, mark-recapture, and radio-telemetry, with each having distinct advantages and disadvantages. Thread-trailing is a common tracking method for box turtles (e.g., Stickel 1950; Legler 1960; Hallgren-Scaffidi 1986; Donaldson and Echternacht 2005) and is often used in conjunction with radio-telemetry (e.g., Donaldson and Echternacht 2005) or mark-recapture (e.g., Hallgren-Scaffidi 1986) because it provides more accurate measures of movement than radio-telemetry or mark-recapture by recording actual movement pathways (Iglay et al. 2006).

Breder (1927) was the first to use a thread-trailing device in hopes of more closely following turtles to observe their day-to-day behavior. Breder (1927) created this device to better understand homing instinct, travel routes, movement within the home range, migratory patterns, mating activity, nesting activity, use of water, and behavioral patterns, which are not always easy to observe with radio-telemetry or mark-recapture alone. Breder's (1927) device consisted of a spool of thread held by a wire that was wound through a hole cut in the turtles' marginal scute. Breder's (1927) device has been modified over time, with more modern thread-trailing devices consisting of a spool of thread housed in some type of container. The container is affixed to the turtle's shell, and as the turtle moves the thread unwinds and can be collected and measured.

While thread-trailing is very useful for obtaining detailed movement information, it is vulnerable to mishaps, such as thread breaking or running out prematurely, and it is labor-intensive (Breder 1927; Dodd 2001). For thread-trailing studies, turtles need to be

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checked daily to add additional thread and to ensure the apparatus is still properly attached, as well as to verify that the turtle has not become entangled.

Another tracking technique, mark-recapture (i.e., marking the individual with a unique identifier for future identification), is often used in home range studies because turtles are easy to mark for future identification, and it is inherently inexpensive (Cagle 1939; Dolbeer 1969; Stickel 1989; Dodd 2001). Although the marks are semi-permanent, they can nonetheless be lost if the periphery of the carapace wears or is chewed by a predator. In mark-recapture studies, researchers are not guaranteed to find an individual turtle multiple times to accurately estimate home range size or observe movement patterns. However, use of turtle-tracking dogs has proven to be a useful technique for increasing the number of recaptured turtles (Schwartz and Schwartz 1974; Kapfer et al. 2012). Kapfer et al. (2012) used wildlife detector dogs for two consecutive days in an 11 ha study area and captured 25 box turtles (three of which were recaptures on day two), while only 22 box turtles were found in 316.5 h of visual encounter surveys in the same 11 ha site.

Radio-telemetry is a useful and efficient tracking method that is normally less labor-intensive because it involves tracking that is dependent upon a set sampling protocol (e.g., monthly, weekly, bi-weekly, tri-weekly) rather than finding turtles every day, which is typically required for thread-trailer studies (Dodd 2001). Radio-telemetry also generally allows for continuous monitoring of individual movements over longer time-periods. However, radio-telemetry is not used for real-time tracking and therefore does not track exact movement pathways resulting in the loss of detailed movement information that is available when using thread-trailing. Additionally, radio-telemetry equipment (i.e., transmitters, receivers, antennae) is more expensive than equipment required for other tracking methods (Waddell et al. 2016). While radio-transmitters are normally smaller than thread-trailing devices, they may also fall off the turtle depending on attachment method, and the battery in the transmitter can malfunction or become depleted sooner than expected, potentially resulting in loss of the turtle.

If placed and monitored correctly, thread-trailers can be used to observe many aspects of turtle movement often in conjunction with another tracking method. For example, Hallgren-Scaffidi (1986) used thread-trailers to track box turtles and estimated a home range of 0.955 ha, but with mark-recapture data from repeated captures, the average home range estimate was only 0.733 ha. Iglay et al. (2006) compared thread-trailers and radio-transmitters and found that thread length from thread-trailers was significantly longer than straight-line distance obtained from GPS locations of radio-tracked turtles. Iglay et al. (2006) emphasized how thread-trailing may provide more accurate measure of turtle movements than radio-telemetry, which often underestimates movement patterns as it relies solely on point captures and straight-line distances rather than actual distances that can be acquired with thread-trailing. This is especially the case for researchers interested in capturing information on detailed movements of turtles, such as meandering movement patterns (Iglay et al. 2006). For example, Claussen et al. (1997) used thread-trailers to study detailed movement characteristics of Ornate Box Turtles (*Terrapene ornata ornata*), such as net displacement, mean turning angle, and sinuosity. Claussen et al. (1997) described how thread-trailing is an inexpensive and efficient method for studying more exact movements of turtles, but at times it is subjective (i.e., assuming that the thread is deposited in the exact pattern that the turtle moved when mapping the thread-trail path), and analyses are time-consuming. For a long-term study, checking on turtles with thread-trailers daily can be especially tedious, and only a few turtles can be tracked at a time (Stickel 1950; Jim Basinger pers. comm.). However, for short-term studies (e.g., Claussen et al. 1997 who tracked each turtle only 1–5 d), this method may be appropriate, especially in conjunction with other tracking methods. For instance, Marchand et al. (2004) also noted that thread-trailing more accurately measured actual distance traveled than radio-telemetry that only measured straight-line distance, whereas radio-telemetry was especially useful for estimating home range size and habitat usage. Marchand et al. (2004) used thread-trailers to monitor hourly movement of Eastern Box Turtles in a wetland habitat and found that turtles moved an average of 10.3 m per hour. While we did not measure the accuracy of thread-trailing compared to radio-telemetry or mark-recapture methods in this study, we concur that all three have inherent benefits and weaknesses.

The goal of this project was to use thread-trailers to track fine-scale movements of Eastern Box Turtle (*Terrapene carolina carolina*) movements in a suburban wetland habitat in middle Tennessee in order to better understand their movement ecology as it pertains to habitat usage. We describe our experiences with the thread-trailing device and the advantages and disadvantages of thread-trailers realized from their use in this study. We also compare the use of thread-trailers to other tracking methods, namely mark-recapture and radio-telemetry, and make general recommendations based on our experiences.

The Thread-trailing Device

We attached thread-trailers to six adult Eastern Box Turtles found at Nickajack Trace and Black Fox Wetlands, Murfreesboro, TN, USA between April–June 2013. We utilized several different thread-trailer models that were similar to those described in Claussen et al. (1997) and Donaldson and Echternacht (2005). Thread-trailers weighed between 30–50 g and consisted of either a small plastic pill bottle or a small plastic film canister with a spool of sewing thread inside (Fig. 1). The spool of thread was either a spool of store-bought polyester thread or a wooden spool (Woodworks Ltd., Fort Worth, TX, USA) on which we spun nylon thread. The spool was suspended by a wooden dowel and housed within the plastic container, which had a small hole drilled in it to allow the thread to unwind. The ends of the dowel generally extended well beyond the edges of the plastic container; therefore the dowel was held in place by placing wooden caps on each end (see Fig. 1). All wooden components were stained to protect them from the elements. Making sure the shell was free of dirt and debris, we attached thread-trailers to the posterior region of the carapace

FIG. 1. Eastern Box Turtle (*Terrapene carolina carolina*) AJX with an attached thread-trailer made with a film canister (A); turtle AJX with an attached thread-trailer with the thread tied to a limb at the point of capture (B); and turtle BCJ with an attached thread-trailer made with a pill bottle (C). All thread-trailers pictured are held in place by epoxy glue and epoxy putty and painted black to reduce their conspicuousness.

using some combination of epoxy glue, epoxy putty, and/or duct tape to stabilize and hold it in place. If epoxy glue or putty was used, it was allowed to set overnight (i.e., >8 h) while the subject was housed in a small plastic container or cardboard box. For the last three turtles with thread-trailers attached, we painted the epoxy and parts of the apparatus black with fingernail polish to make it less conspicuous. We tied the end of the thread to an object (e.g., small tree or log) at the point of capture, used flagging tape to mark the area, recorded a GPS point (Garmin Etrex 30, Olathe, KS, USA), and released the turtle to move freely.

RESULTS AND DISCUSSION

Most of the thread-trailers employed in this study only remained attached to the box turtle for one day or less. All five turtles which had a thread-trailer made of a pill bottle either ran out of thread or lost the thread-trailer within a day (Table 1). The single turtle which had a thread-trailer made from a film canister ran out of thread followed by the device falling off within a week. The average length of thread collected from the six turtles was only 11.6 ± 6.89 m (2.7–23.2 m). For the five box turtles whose thread-trailer device only remained attached for at most one day, one turtle moved 23.2 m and another only moved 2.7 m before losing the device. The single turtle who retained the thread-trailer for several days moved only 7.5 m before running out of thread. Although we attempted to employ small, compact thread-trailers, we were unable to obtain proper attachment or have enough thread.

HABITAT CONSIDERATIONS AND RECOMMENDATIONS

It is important to consider habitat conditions when choosing an appropriate tracking method. Thread-trailers may not work well for tracking precise movements in open areas where there is no possibility for the thread to “catch” on vegetation (Claussen et al. 1997). Furthermore, thread-trailers may not stay attached in exceptionally wet habitats, which is what we experienced. It is possible that our wetland site was simply too wet for the thread-trailer device that repeatedly fell off in the water or after a rain event even with tape, epoxy putty, and epoxy glue. We believe that at least three of the six turtles lost their thread-trailer primarily due to rain events (individuals HJK, BCV, and ABX). Turtle ABX most likely lost their thread-trailer due to a combination of weather conditions and entanglement because we found the thread-trailer amongst tree roots in the creek after a rain event. Stickel (1950) mentioned the importance of replacing tape periodically, especially after heavy rainfall. Jennings (2003) experienced loss of thread-trailers on juvenile Florida Box Turtles (*T. c. bauri*) due to humid and wet conditions in Florida. It is also necessary to wipe away any moisture from inside the thread-trailer each time you check on a turtle because, as Basinger (pers. comm. — http://boxturtle.dreamhosters.com/Thread%20 Trailing.html; http://archive.fo/y3B0o) noted, if the thread-trailer becomes wet, the thread may jam inside the apparatus, but cotton or polyester thread will generally break so a turtle does not become trapped. However, nylon thread will not break as easily and could lead to entanglement (Legler 1960). Interestingly, in nearly all thread-trailer studies, only tape (not glue or putty) was used to hold the thread-trailer on the shell (e.g., Stickel 1950, Claussen et al. 1997, Iglay et al. 2006). We are uncertain why in all cases duct tape, glue, and epoxy putty were not sufficient for securing thread-trailers on the shell for extended time frames, but we do feel that the weather conditions contributed to the problem. Perhaps the large size and rounded shape of the apparatus also inhibited secure attachment or maybe the pill bottle surface was too smooth or made of a harder plastic that the tape, glue, and putty could not adhere to.

TABLE 1. Tracking and demographic information for six adult Eastern Box Turtles (*Terrapene carolina carolina*) tracked with thread-trailers. The approximate length of thread represents the thread released before loss of the device, which was collected and measured.

Turtle Code	Tracking Start	Tracking Finish	Type of Thread Used	Attachment Method	Approximate Length of Thread (m)	Age Class (y)	Sex	Mass (g)
HJK	19 April 2013	20 April 2013	Polyester	Duct Tape	23.2	20+	F	390
BCV	10 May 2013	11 May 2013	Nylon	Duct Tape and Epoxy Glue	2.7	10–14	M	435
ABX	10 May 2013	11 May 2013	Nylon	Duct Tape and Epoxy Glue	12.6	10–14	F	350
AJX*	2 June 2013	8 June 2013	Nylon	Epoxy Glue and Epoxy Putty	7.5	10–14	M	365
AIW	10 June 2013	11 June 2013	Polyester	Epoxy Glue and Epoxy Putty	13.6	10–14	M	530
BCJ	30 June 2013	1 July 2013	Polyester	Epoxy Glue and Epoxy Putty	10.2	15–19	M	428

Notes: *Indicates the single turtle that ran out of thread but retained the thread-trailer device for up to one week. All other turtles lost their thread-trailer within one day. Turtle AJX was the only turtle that had a film canister thread-trailer rather than a pill bottle.

History of Thread-trailing

Over the years, several researchers have employed different versions of thread-trailers to find the most suitable model for studying box turtle movements (Table 2). The first model of the thread-trailer was attached by making a hole in a posterior marginal scute and running wire through the hole (Breder 1927). A spool of thread was held by the wire and dragged on the ground behind the turtle as it moved (Breder 1927). Breder (1927) found that this prototype simply did not contain enough thread and that the thread often broke. This model also did not provide any housing or protection for the spool of thread, so the apparatus was dragged through the substrate wherever the turtle moved (Breder 1927). Subsequently, Stickel (1950) attempted to use Breder's (1927) wired-spool thread-trailer, but after the device failed due to entanglement, she created a new model. Stickel's (1950) thread-trailer consisted of a spool of number 80 white thread (~503 m) contained within part of a tin can that was affixed to the turtles' shell with waterproof tape, eliminating the need for making holes in the scutes or for the spool to drag unprotected on the ground. Stickel (1950) custom cut each tin can to fit on the shell of each individual turtle and trimmed the inner core of each spool in order to add more thread. Stickel (1950) described the difficulties of the thread-trailer method due to the need to check on turtles daily and resupply the thread as it ran out, meaning that only a few individuals could be tracked at a time. Legler (1960) used Stickel's (1950) tin can model but used nylon thread instead of cotton thread. Legler (1960) also cut down the spool so it would hold ~550–730 m of thread. Hallgren-Scaffidi (1986) successfully used a device similar to Stickel's (1950). Schwartz and Schwartz (1974), Claussen et al. (1997), Donaldson and Echternacht (2005), and Iglay et al. (2006) all used a variant of Stickel's (1950) can-method by using a small, plastic 35-mm film canister to hold the thread and duct tape (and epoxy glue in the case of Donaldson and Echternacht 2005) to affix the apparatus to the shell. We most closely followed the methods of Schwartz and Schwartz (1974), Claussen et al. (1997), Donaldson and Echternacht (2005), and Iglay et al. (2006), but we were not as successful as others.

Apparatus Considerations and Recommendations

To properly construct and utilize a thread-trailer, it is important to consider all aspects of the apparatus as well as the overall goals of the study. Careful consideration should go into determining size and placement of the device as well as thread size (i.e., length and thickness), material, and color. Few published studies provide thorough details of the thread-trailer device and thread used; therefore we provide recommendations based on our experiences with thread-trailers.

We sought to minimize the overall size of the device by using small pill bottles and film canisters because we found that larger pill bottles were too bulky and too cumbersome for turtles even though they held more thread. We also realized that it would be beneficial to rethink placement and/or size of the thread-trailing device to prevent any interference with mating, especially for females (Iglay et al. 2006). Iglay et al. (2006) placed thread-trailers on the top of the shell on females, but care should be taken to ensure the thread-trailer is not protruding from the shell so much that it impedes movements when turtles go underneath objects or rest in their forms (i.e., shallow depression in the ground).

We recommend better preparing both the turtle shell and the thread-trailer for proper attachment. The shell should be washed thoroughly of any dirt and debris using alcohol or water and a cloth for cleansing. Also, an abrasive, such as sandpaper, could be used to roughen the surface of the plastic container and

TABLE 2. Description of various thread-trailer models used to study box turtle movements. The approximate length of thread indicates how much thread was on the spool used in each model.

Study	Species	Device used	Attachment Method	Weight of Device(s) (g)	Approximate Length of Thread (m)	Color and Type of Thread
Breder (1927)	*T. c. carolina*	Wired spool	Wire	30	229–274	cotton, basting
Stickel (1950)	*T. c. carolina*	Tin can	Waterproof tape	unknown	503	white, number 80
Legler (1960)	*T. o. ornata*	Tin can	Duct tape	unknown	550–730	nylon
Schwartz and Schwartz (1976)	*T. c. triunguis*	Film canister	Duct tape	unknown	unknown	white
Hallgren-Scaffidi (1986)	*T. c. carolina*	Tin can	Duct tape	unknown	320	white
Claussen et al. (1997)	*T. o. ornata*	Film canister	Duct tape	25	300	white, cotton
Jennings (2003)	*T. c. bauri*	Bobbin	Duct tape	<2	250	unknown
Marchand et al. (2004)	*T. c. carolina*	Bobbin	Unknown	<10	50	unknown
Donaldson and Echternacht (2005)	*T. c. carolina*	Film canister	Duct tape and epoxy glue	19 and 24	180 and 250	extra-strength cotton
Iglay et al. (2006)	*T. c. carolina*	Film canister	Duct tape	unknown	unknown	unknown
Basinger (unpub.)	*T. c. carolina*	Bobbin	Epoxy glue	unknown	205–250	white, polyester or cotton-poly mix
Dodd (unpub.)	*T. c. bauri*	Bobbin	Aquarium sealer	unknown	unknown	white

allow more surface area for the glue to set. Basinger (pers. comm.) drills holes in the bottom of plastic caps to allow glue to bead and solidify inside the holes. Because both the turtle's shell and the plastic containers had a rounded surface, there was little overall surface area where the glue came into contact with both the shell and the plastic container in our study. While epoxy putty helped with stabilization, perhaps using a plastic container with a flatter surface, such as Basinger's flat cap, would allow better attachment.

The thick nylon thread used in this study was stronger and more resistant than polyester or cotton thread, and the neon orange color was easy to spot against the leaf litter, although white cotton thread is often chosen (e.g., Stickel 1950; Claussen et al. 1997). Legler (1960) emphasized that turtles were unable to break nylon thread, and while cattle tangled the thread, they were also unable to break it. Therefore, it may be difficult for turtles to break nylon thread should they become caught or entangled. Consequently, if the researcher frequently finds entangled turtles, they should consider switching to a type of thread that breaks more readily than nylon.

It is also important to consider the length of thread and frequency of checking, knowing that less thread equates to checking on the turtle more often (i.e., at least once every day) or potentially losing the turtle. We predict that the thick nylon thread likely prevented us from winding enough thread on the spool, especially considering that turtle AJX's thread-trailer only contained 7.5 m of thread (Table 1). Interestingly, individual AJX was the only turtle to have a film canister thread-trailer (all others had pill bottle thread-trailers) and the only turtle to retain the thread-trailer more than one day. AJX's device remained attached even after the thread ran out. If we had been able to add more thread, it is possible that the film canister model may have been more successful. However, Turtle AJX's thread-trailer was subsequently found lying on the trail one week later, and we cannot say for certain that the thread-trailer was attached during that entire time frame. Turtle AJX's thread-trailer appeared to have been chewed, meaning a predator may have removed it from the turtle, or it may have been chewed after falling off the turtle. Turtle AJX was found again several times throughout the study, indicating that if it was a predator that removed the thread-trailer, it did not seem to harm the turtle. We realize that applying fingernail polish of an appropriate color on the whole apparatus may have been a better choice for making the thread-trailer blend in with the turtles' shell in order to prevent increased predation risk.

The bobbin thread-trailer method (e.g., Wilson 1994; Carter et al; 2000; Waddell et al. 2016; Fig. 2; Table 2) may be a solution to housing more thread in a smaller, less conspicuous apparatus. This device consists of a bobbin-type spool of thread that is more compact and often contains more thread than traditional spools of thread. Wilson (1994) encapsulated cocoon bobbins in plastic wrap and plastic dip, glued them to the shell, and successfully tracked Striped Mud Turtles (*Kinosternon baurii*) to their nesting sites. Wilson's (1994) bobbins weighed between 2.3 and 5.3 g and were between 4 and 5 cm long and 1 and 1.5 cm wide. Similarly, John Roe (pers. comm.) used heat-shrink tubing to encapsulate a thread bobbin (white with 1 km of thread), while leaving a small hole on one end for the thread to unwind. Roe (pers. comm.) used duct tape for attachment for short-term purposes but used epoxy glue for extended tracking of Eastern Long-necked Turtles (*Chelodina longicollis*) in Australia. Basinger (pers. comm.) used small, plastic make-up containers or bottle caps to house a

FIG. 2. An example of a bobbin thread-trailer attached to an adult Florida Box Turtle (*Terrapene carolina bauri*). This device is made of flexible plastic tubing and contains a cocoon bobbin of white thread. One end of the tubing is sealed with aquarium sealer, and the apparatus is attached to the shell with the same aquarium sealer. Photographed by C. Kenneth Dodd, Jr. and used with permission.

205-m bobbin, which was attached with 5-minute epoxy glue to Eastern Box Turtles. Kenneth Dodd (pers. comm.) used a small piece of flexible, plastic tubing to house a cocoon bobbin and aquarium sealer to seal one end of the tubing and to attach the apparatus to adult Florida Box Turtles (Fig. 2). Dodd (pers. comm.) experienced issues with thread breakage and device attachment and suggested that epoxy rather than aquarium sealer would be necessary for long-term use due to brushy habitat and rainy/humid weather conditions. Waddell et al. (2016) used a 500-m nylon thread cocoon bobbin held in an elastic harness around the carapace to successfully track movements of the Twist-neck Turtle (*Platemys platycephala*) and other wildlife in a wet tropical rainforest. Carter et al. (2000) used Wilson's (1994) bobbin method and attached thread-trailers with epoxy putty to Bog Turtles (*Glyptemys muhlenbergii*) that already had radio-transmitters. Carter et al. (2000) found that thread distances were 6.5 times longer than point distances. Jennings (2003) successfully used Wilson's (1994) bobbin technique to study the microhabitat of Florida Box Turtles with an emphasis on juvenile movement patterns (see also Hamilton 2000 and Jennings 2007). We think the cocoon bobbin technique may prove to be a more successful and efficient method for tracking box turtles as it is much smaller (e.g. 2 g versus 50 g) than traditional thread-trailers yet contains just as much, if not more, thread. Additionally, it is capable of providing more accurate data on movement patterns that may be overlooked with radio telemetry or mark-recapture alone (e.g., Carter et al. 2000)

Ultimately, it is often beneficial to use a combination of tracking methods to estimate home range and describe movement patterns of turtles, given the advantages and disadvantages to each method. Thread-trailers are economical and can be used to obtain more exact movement data, but the method is very time consuming, allows tracking of only a few individuals at a time, and there are often issues with the apparatus itself. Mark-recapture can also be used in conjunction with other tracking methodologies, but without a tracking device, the same individual turtles are not guaranteed to be found again for observing patterns of movement, and marks may wear over time. While radio-telemetry allows tracking of multiple turtles for a long time-period, it is more expensive than other methods, may suffer from attachment issues or device malfunction, and does not provide as much detail on movement patterns as thread-trailing. Therefore, radio-telemetry may underestimate true distance moved. We recommend experimenting with various thread-trailing models in order to minimize size of the apparatus while maximizing length of thread, which can be accomplished with the bobbin method. Additionally, as several others noted (e.g., Stickel 1950; Jennings 2003; Waddell et al. 2016), wet weather conditions can be problematic when using thread-trailers, and this should be taken into consideration when selecting a field site and tracking method. Future box turtle movement studies can utilize this information when choosing appropriate tracking methods for turtles at their particular field site and for designing thread-trailing devices if that is the chosen method.

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