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Original Article

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ABSTRACT In road construction projects across the United States, erosion control methods (e.g., erosion control blankets [ECBs]), are mandated to stimulate seedbed regeneration and prevent soil loss. Previous reports have suggested that snakes are vulnerable to entanglement in ECBs. We conducted a literature review, field surveys, and an entanglement experiment to examine what factors increase a snake's risk of ECB entanglement. Our literature review produced reports of 175 reptiles entangled in mesh products, 89.1% of which were snakes, with 43.6% of snake entanglements occurring in erosion control products. During our field surveys, we found 10 entangled snakes ($n = 2$ alive; $n = 8$ dead). From our experiment, we found that ECBs that contain fixed-intersection, small-diameter mesh consisting of polypropylene were significantly more likely to entangle snakes compared with ECBs with larger diameter polypropylene mesh or ECBs that have woven mesh made of natural fibers. Snake body size was also associated with entanglement; for every 1-mm increase in body circumference, the probability of entanglement increased 4%. These results can help construct a predictive framework to determine those species and individuals that are most vulnerable to entanglement. © 2019 The Wildlife Society.

KEY WORDS body size, *Coluber*, experiment, mesh, *Pantherophis*, reptile, road ecology, road mortality, soil stabilization, Texas.

In the United States, wildlife interactions with roads are pervasive because 83% of the total area of the country is within 1.6 km of a road (Riitters and Wickham 2003). Effects of roads on wildlife have been well-documented and affect multiple ecological and evolutionary processes (Balkenhol and Waits 2009, Brady and Richardson 2017). Roads limit dispersal by fragmenting habitat, leading to behavioral avoidance (Shepard et al. 2008). Roads also affect population viability through direct mortality caused by collisions with cars and skewed sex ratios resulting from unequal mortality (Steen et al. 2006, Coffin 2007, Andrews et al. 2008).

Besides dangers posed to wildlife by direct interactions with vehicular traffic, road-related activities such as construction and maintenance can result in an increased risk of wildlife mortality. Road maintenance and construction occurs regularly and widely across the United States. In Texas,

USA, for example, the approximate length of active or proposed road construction projects in 2017 was 21,744 km (Texas Department of Transportation 2018c). The annual erosion rate at a construction site can be 100 times greater than that of an agricultural field (Benik et al. 2003), leading to mitigation efforts to reduce soil loss such as the deployment of erosion control blankets (ECBs). As a result, best management practices are implemented to curb the loss of soil from these areas. For example, the Texas Department of Transportation (TXDOT) procedure states that an erosion control product must be placed on unpacked soil to prevent soil loss and promote the growth of vegetation once construction is completed (Texas Department of Transportation 2018a). The contractor has the option to use any erosion control product, including ECBs, mulch, and spray blankets, as long as that product is on the Approved Products List (APL) and fits within the original plans of the project (Texas Department of Transportation 2018a). According to the TXDOT APL, ECBs can be used on construction sites if they pass 2 performance standards pertaining to 1) how well the product protects the seedbed from sediment loss in a rainfall or channel flow event, and 2) how well a product stimulates growth of warm-season

perennial vegetation (Texas Department of Transportation 2018b).

Use of ECBs can have unintentional consequences on wildlife; there have been reports of reptiles, snakes in particular, becoming entangled in these products (Barton and Kinkead 2005, Walley et al. 2005, Kapfer and Paloski 2011). Entanglement in ECBs can lead to severe lacerations as the animal tries to escape, or death by desiccation, heat exposure, or predation (Stuart et al. 2001, Barton and Kinkead 2005, Walley et al. 2005). Previous reports on wildlife entanglement in ECBs have been primarily anecdotal or small, unpublished studies testing effects of mesh size and shape on snake entanglement (Kapfer and Paloski 2011, California Coastal Commission 2012). However, no large, systematic studies that investigate relationships between risk of entanglement and properties of the erosion control products or species' traits have been conducted.

With anecdotal evidence suggesting that snakes are particularly vulnerable to entanglement, we attempted to identify factors that lead to increased probability of their entanglement in ECBs by reviewing existing literature and testing hypotheses regarding intrinsic and extrinsic factors related to entanglement. We hypothesized that larger bodied snakes would be more prone to entanglement in ECBs, and woven mesh would be less likely to entangle snakes than mesh with fixed intersections. We complimented our experimental trials with a systematic survey of TXDOT construction sites to determine if any snakes became entangled under natural field conditions.

METHODS

Literature Review
We surveyed the existing literature to compile a comprehensive list of reported reptile entanglements in mesh netting material. To better understand correlates of reptile entanglement, we extracted the following information from each reference (when reported): 1) taxonomy (species and family), 2) number of individuals, 3) condition (dead or alive), 4) mesh aperture size, 5) mesh material, 6) mesh type, 7) mesh application (4 general categories: wildlife exclusion, soil stabilization, packaging, or fencing), and 8) locality. When the exact number of individuals was not reported, we assigned reports that estimated the number of individuals to be "several" a value of 2 individuals, reports that estimated the number of

individuals to be "about 5" a value of 5, and unreported numbers a value of 1.

Field Surveys
We located 9 areas across 3 TXDOT construction projects that contained ECBs located in Houston County, Texas. We conducted 20 surveys totaling 65 site visits over a 43-day period, from 27 April 2018 to 8 June 2018 (details on the surveys and sites can be found in Table S1, available online in Supporting Information). The number of sites surveyed on any given day varied throughout the study as new sites were discovered and ECB material was removed from sites by contractors under the direction of TXDOT in an effort to reduce the threat to wildlife. In total, across the 9 sites, ECBs covered an area of 2,108 m² with an average of 234 m² of ECB material deployed over the entire period (Table S1). All sites contained the same type of ECB (ErosionControlBlanket S32 BD) that consisted of 2 polypropylene mesh layers (mesh size = 12.7 × 12.7 mm) with an agricultural straw-fiber matrix between the layers. We carefully searched around the ECBs to look for entangled animals. We carefully removed, measured, and then released animals that were found alive in the mesh; dead animals were cut from the mesh and brought to the lab for processing.

Entanglement Trials
Snakes used in this study were collected using box traps, minnow traps, or by hand in Houston, Newton, Nacogdoches, Jasper, Angelina, and Trinity counties, Texas (Burgdorf et al. 2005). For each snake, we recorded head width with digital calipers to the nearest 0.1 mm, snout–vent length, tail length (both with a meter stick to the nearest mm), and circumference of the snake at the widest point using a tape measure to the nearest mm.

We constructed 2 7.62-m × 2-m arenas with hardware cloth and aluminum flashing siding in the Stephen F. Austin Experimental Forest in Nacogdoches County, Texas. At each end of the arena, we staked down 2-m × 3.35-m sections of ECB. We tested 3 types of ECBs from the TXDOT APL: 1) BioMac SC (Maccaferri Inc., Rockville, MD, USA), 2) Nedia KoirMat 700 (Nedia Enterprises Inc., Ashburn, VA, USA), and 3) Tenax Multimat 100P (TENAX, Vigano LC, Italy; Table 1, Fig. S1, available online in Supporting Information). In the center of the arena was a 1-m × 2-m patch of bare ground where the

Table 1. Comparison of the properties of the erosion control blankets used in the entanglement experiments in Texas, USA, from May 2018 to July 2018. Some blankets had 2 layers of mesh, indicated by "top" and "bottom." The height of the blanket is the measurement of how tall the erosion control blanket is while on the ground. The diameter of the mesh is the average diameter of the individual fibers in the mesh.

Product name	Material (%)	Layers	Mesh size (mm)	Mesh fixed	Height of blanket (mm)	Diameter of mesh (mm)
Tenax Multimat 100P	100% Polypropylene	3	12 × 16	Yes	20.0	0.96
BioMac SC	70% Straw, 30% coconut, polypropylene netting	2	Top: 12.7 × 12.7 Bottom: 19.05 × 19.05	Yes	7.62	Top: 0.13 Bottom: 0.25
Nedia KoirMat 700	100% Coconut	1	Varying sizes	No	9.0	3.80

snakes were introduced at the beginning of each experimental trial. We conducted trials between 30 May 2018 and 19 July 2018. Trials lasted for 3 min or until snakes became entangled, with intervals of ≥5 min between trials. Snakes that did not come into contact with the mesh within the first minute of the trial were gently prodded with a snake hook to encourage movement. We repeated this at the 2-min mark if the snake still had not come into contact with the mesh (unless we determined that prodding would further discourage movement, such as when an eastern hognose snake [*Heterodon platirhinos*] played dead). Snakes that did not come into contact with mesh during the entire trial were tested on that same mesh again at a later time before being tested on the next mesh type. During a trial, we recorded how many times, if any, the snake passed through the mesh. When a snake became entangled and it was clear it could not escape on its own, we stopped the trial and the carefully cut the snake out of the mesh. If a snake was clearly struggling without making progress forward or backward, we considered it entangled. During preliminary trials we found that if we left the snakes in the mesh too long, they began to twist to attempt to free themselves and ended up with minor injuries. Although we could have let the trials run longer to see if the snakes eventually escaped, we did not want to risk any injury to the snakes. We recorded the layer of mesh in which the snake was entangled when applicable. There were challenges in obtaining large numbers of individual snakes, so we were limited by the number of snakes that could be tested in the entanglement experiments. Therefore, we tested each snake once on each of the 3 ECBs. To determine if there were carryover effects from prior trials, order of trials was determined with a Latin square design. We randomly assigned individual snakes a sequence of trials so that all combinations of sequences would be equally represented. This study was conducted under approved Stephen F. Austin State University Animal Use Protocol (IACUC #2018-007).

Statistical Analyses

Each snake was exposed to all 3 ECB types in a crossover design of 2 orthogonal Latin squares. Ordered ECB pairs occurred an equal number of times and sample sizes were similar in ordered pairs and within each trial period. The response variable was binary: "yes" if the snake attempted to pass through the ECB or "no" if the snake did not attempt to pass through the ECB. We used a repeated-measures logistic regression model with generalized estimating equations to determine if the odds of attempting to pass through differed among ECB types. The model included ECB and trial as fixed effects and individual snake as a random effect. We included the potential effects of carryover from the previous ECB trials.

We used logistic regression to identify which morphological characteristics (snout–vent length, tail length, body circumference, head width) were associated with the odds of attempting to pass through an ECB. To avoid using the same snake twice in this analysis, we modeled each ECB type separately. Once a snake attempted to pass through an ECB, it either became entangled or passed through successfully. We used logistic regression to identify the morphological characteristics associated with being entangled, given that the snake had tried to pass through an ECB. In this model, we used only snakes that attempted to pass through an ECB. Again, we modeled each ECB type separately to avoid analyzing the same snake twice. We set alpha (α) at 0.05.

RESULTS

Literature Review

Our literature search produced 18 references that reported reptile entanglement in mesh products. Of 175 individual reptiles found entangled in mesh, 89.1% were snakes, 9.1% were lizards, and 1.7% were turtles (Table S2, available online in Supporting Information). Of the 20 snake species identified, the majority were from the family Colubridae ($n = 16$ species), while the remaining species were from the family Viperidae ($n = 4$ species; Fig. 1, Table S2). Snakes were most frequently entangled in wildlife exclusion netting (45.5%; $n = 13$ species), followed by soil stabilization blankets (43.6%; $n = 12$ species; Fig. 2, Table S2). Mesh size was reported in 60.9% of the snake entanglements, with mesh sizes ranging from a 12-mm × 7-mm × 7-mm × 7-mm trapezoid to a 37-mm × 20-mm rectangle (Table S2). Out of 98 cases when mesh material was reported for snake
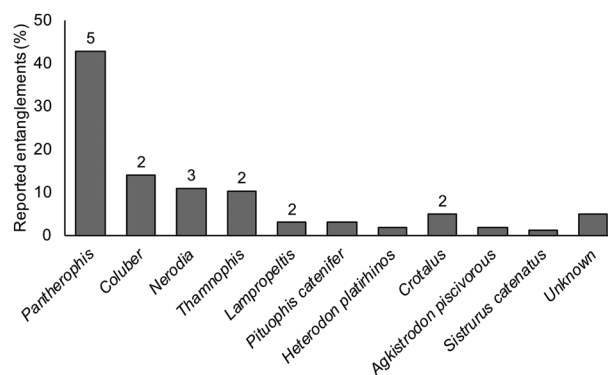

Figure 1. Reports of individual snakes entangled in mesh products compiled from the literature and grouped by genus ($n = 156$ individuals). The number above the bar represents the number of species within that genus. The unknown category consists of unidentifiable snake skeletons.
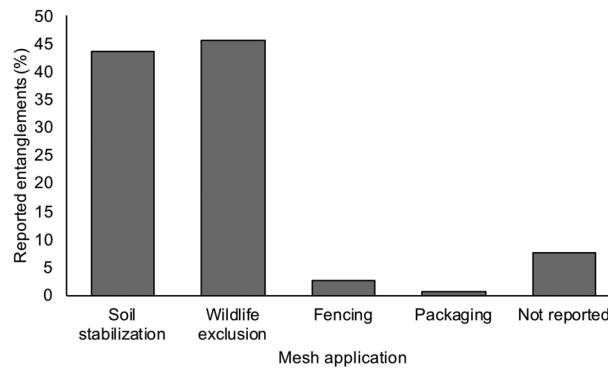
Figure 2. Percentage of reported snake entanglements for each mesh type ($n = 156$ individuals). Reports were compiled from the literature and separated into categories based on mesh function.

entanglements, 96 of these snakes were entangled in a mesh made of synthetic plastic (Table S2).

Field Surveys

We found 10 individual snakes entangled at 4 of the construction sites, representing 4 species (Table 2). Seven were found dead entangled in the ECBs and 3 were found alive (Table 2). Two of the snakes that were found alive were immediately released. The third snake that we found alive (*Pantherophis obsoletus*) was badly injured and was brought back to the lab to treat its wounds, but it later died of its injuries. Two female *Coluber constrictor* that died in the mesh were gravid, with 25 and 21 eggs. The average body length of entangled snakes was 1,403 mm and the average head width was 14.25 mm (Table 2).

Entanglement Trials

We tested 128 individual snakes representing 14 species that spanned a large range of body sizes (SVL range:

Table 2. All snakes found during surveys of road construction sites, from 27 April to 8 June 2018 in Houston County, Texas, USA. Some snakes were decomposed or partially scavenged to the extent that determining sex was not possible (designated "UM" for unmeasurable). For this same reason, we could not measure snake circumference in all cases. SVL stands for snout–vent length.

Species	Condition	Sex	Body length (mm)	Head width (mm)
Coluber constrictor	Alive		Total: 1,130	
C. constrictor	Dead		Total: 910	~15.00
C. constrictor	Dead	F	SVL: 1,100/ Tail: 360	16.07
C. constrictor	Dead	F	SVL: 915/ Tail: 300	16.00
Coluber flagellum	Dead	F	SVL: 1,088/ Tail: 361	14.03
C. flagellum	Dead	M	SVL: 1,062/ Tail: 286	13.03
C. flagellum	Dead	UM	Total: ~1,351	15.86
Nerodia erythrogaster	Dead	UM	SVL: 533/ Tail: 142	9.97
Pantherophis obsoletus	Alive		Total: ~700	
P. obsoletus	Alive[a]	F	SVL: 820/ Tail: 163	14.04

[a] Snake died of its injuries at a later date.

270–1,346 mm; head width range: 5.1–21.2 mm; circumference range: 14–104 mm; Table S3, available online in Supporting Information). Our crossover design revealed that there were no significant carryover effects; the probability that a snake would attempt to pass through an ECB was not affected by the order in which the 3 ECBs were tested. We found that snakes were more likely to attempt to pass through the BioMac SC (67% of snakes attempted) than either the Tenax Multimat 100P or Nedia KoirMat 700 ($P < 0.001$; Table 3). There was no difference between the odds of a snake attempting to pass through the Tenax Multimat 100P (39.1% of snakes attempted) and Nedia KoirMat 700 (29.7% of snakes attempted; $P = 0.09$, Table 3). Of the snakes that attempted to pass through the ECBs, none became entangled in Nedia KoirMat 700 ($n = 38$ snakes attempted to pass), and only one snake became entangled in Tenax Multimat 100P ($n = 50$ snakes attempted to pass). Approximately 45% of snakes that attempted to pass through the BioMac SC became entangled ($n = 86$ snakes attempted to pass). Of the snakes that became entangled in BioMac SC, 18 were caught in the top mesh, 18 were caught in the bottom mesh, and 3 were caught in both layers.

The BioMac SC was the only material that entangled multiple snakes; therefore, we only used data from those trials for the morphometric analysis ($n = 86$). We found a positive relationship with snake circumference and the probability of becoming entangled ($P = 0.014$; Table 4, Fig. 3). Specifically, we observed that for every 1-mm increase in circumference, the probability that the snake will become entangled increased by 4%.

DISCUSSION

Previous reports have asserted that plastic netting poses a risk to wildlife and provided numerous accounts of wildlife entanglement (Fauth and Welter 1994, Leatherman 1996, Bonine et al. 2004, Mitchell et al. 2006). Our literature review suggests that snakes have the greatest risk of entanglement compared with other reptile groups because they are the most frequently reported reptile group found in mesh products, including ECBs (Stuart et al. 2001, Barton

Table 3. Results of the entanglement experiments comparing the likelihood of snakes to attempt to pass through each erosion control mesh type in Texas, USA, from May 2018 to July 2018.

Contrast	Odds ratio	SE	Lower CL	Upper CL	χ^2	P
BioMac SC vs. Nedia KiorMat 700	0.205	0.059	0.117	0.361	30.20	<0.001
BioMac SC vs. Tenax MultiMat 100P	0.315	0.092	0.178	0.560	15.54	<0.001
Nedia KiorMat 700 vs. Tenax MultiMat 100P	0.652	0.165	0.397	1.069	2.87	0.09

Snakes were more likely to attempt to pass through BioMac SC than either Nedia KoirMat 700 or Tenax Multimat 100P. Alpha (α) was set at 0.05.

and Kinkead 2005, Low 2005, Kapfer and Paloski 2011). Results from our field surveys and experiment suggest that both extrinsic factors (i.e., ECB attributes) and intrinsic factors (e.g., snake behavior and morphology) are underlying causes that lead to the observed patterns of ECB entanglement.

Our literature review revealed that the largest proportion of entangled reptiles are found in wildlife exclusion netting. However, this type of netting is usually used on a small scale and in residential areas where people are more likely to encounter (and potentially free) entangled animals. Erosion control blankets can be deployed over much larger areas and are not monitored frequently (if at all). The increased surface area of ECBs coupled with their infrequent or absent monitoring may cause them to pose a greater threat to reptiles and other wildlife. Results from our field surveys seem to corroborate this because we found 10 snakes in the span of only 6 weeks and in an area that had a relatively small amount of ECB cover.

Of the 3 ECBs tested in this study, those with photodegradable polypropylene mesh were more likely to entangle snakes than those with biodegradable mesh consisting of natural fibers. In our experiment, all of the entanglements occurred in ECBs with plastic mesh, and >97% of the entangled snakes became entangled in the portion of the BioMac SC ECB that consists of photodegradable polypropylene mesh. The BioMac SC mesh is very thin in diameter, which may make it more difficult for the snakes to detect and may be a reason we observed more attempts to pass through this ECB compared with the other 2 ECBs tested. The BioMac SC ECB also consists of 2 mesh layers with 2 different size meshes. The range of snake body sizes vulnerable to entanglement increases in ECBs that contain multiple mesh sizes, because we observed some snakes that were able to pass through the larger mesh became entangled in the smaller mesh of the BioMac SC. The Nedia KoirMat 700, with the thickest-diameter mesh, may have been detected more easily by snakes, which then passed over or under the mesh. The Nedia KoirMat 700 is woven and has moveable fibers, so mesh size is not fixed and the mesh opening can adjust to the size of the snake as it passes through. The Tenax Multimat 100 P consists of a much stiffer plastic mesh material compared with the BioMac SC, and during the experiment we observed that some snakes that entered the mesh were able to back out without becoming trapped, while those snakes that entered the BioMac SC typically could not.

In addition to the ECB attributes, we found several intrinsic factors that increase a snake's risk of encountering and subsequently becoming entangled in an ECB. All snakes found entangled in the ECBs during our field surveys utilize active foraging strategies (Tennant 1984, Secor 1995, Saenz et al. 1999, Gibbons and Dorcas 2004). Active foraging snakes are more susceptible to vehicular mortality because they travel greater distances and subsequently increase their encounter rate with roads compared with sit-and-wait foragers (Bonnet et al. 1999). Similarly, the probability of coming into contact with, and entanglement in, ECBs may be greater for actively foraging snakes compared with sit-and-wait foragers.

Our results support previous assertions that larger bodied snakes are more at risk of entanglement (Fauth and Welter 1994, Stuart et al. 2001, Kapfer and Paloski 2011). Specifically, snakes with a larger circumference are more likely to become entangled in thin, flexible plastic netting. These results can help construct a predictive framework for those species and individuals that are most vulnerable to entanglement. For example, species that are larger bodied and active foragers, such as coachwhips (*Coluber flagellum*), may be at greater risk than smaller bodied species such as western ribbon snakes (*Thamnophis proximus*) or sit-and-wait foragers such as copperheads (*Agkistrodon contortrix*). It is notable that 2 of the snakes that were found dead during the field surveys were gravid female racers (*C. constrictor*). Gravid females have an increased circumference compared with nongravid females of the same species, which increases their risk of becoming entangled. Loss of sexually mature females, especially those that are gravid (Bonnet et al. 1999), can lead to population declines and skewed sex ratios, as has been seen in aquatic turtle populations (Gibbs and Steen 2004, Steen et al. 2006). Many cases of reptile entanglement in ECBs go unnoticed or unreported, so we echo Kapfer and Paloski's (2011) call to conduct long-term and large-scale surveys of sites where ECBs are deployed to assess their effects on snake populations.

From our literature review, field surveys, and experiment, we demonstrated that entanglement in ECBs is an agent of mortality for snakes. However, in the experiment, we only

Table 4. Odds of snakes becoming entangled in BioMac SC based on morphological traits in Texas, USA, from May 2018 to July 2018. Snakes were only used in this analysis if they attempted to pass through the BioMac SC during their trial ($n = 86$ snakes). SVL is snout–vent length. Circumference exhibited a significant positive relationship with entanglement.

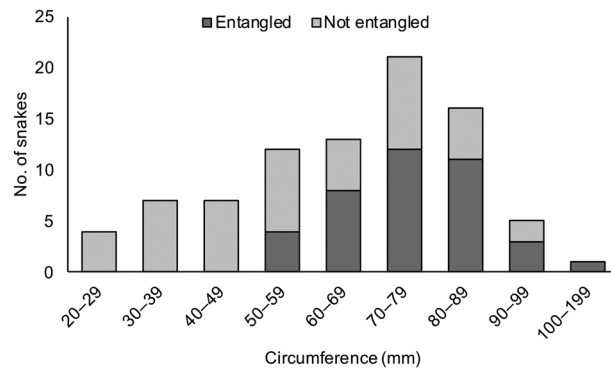| Parameter	DF	Estimate	SE	Wald χ^2	$P > \chi^2$
Intercept	1	−5.1230	1.4326	12.79	<0.001
SVL	1	−0.00164	0.00220	0.55	0.46
Tail length	1	0.000473	0.00421	0.01	0.91
Circumference	1	0.0734	0.0299	6.03	0.01
Head width	1	0.0924	0.1468	0.40	0.53

Figure 3. Circumference (mm) of snakes that were and were not entangled during the entanglement trials, separated by size classes. The graph includes only snakes that attempted to pass through the BioMac SC because this was the only erosion control blanket in which multiple snakes became entangled ($n = 86$ snakes). Snakes were collected from Newton, Nacogdoches, Angelina, Trinity, Jasper, and Houston counties in Texas, USA, from May 2018 to July 2018.

tested 3 out of the 110 erosion control products on the TXDOT APL. Future efforts should attempt to isolate and identify factors that increase an animal's risk to entanglement (e.g., mesh size) as well as determine whether there are alternative methods that can be used (e.g., hydromulch). Snakes cannot become entangled unless they first attempt to pass through the mesh; therefore, future studies on installation methods (e.g., burying the edge of the ECB vs. staking down the ECB) would be useful in determining which practices might reduce the likelihood of snakes attempting to pass through, and therefore reduce the risk to snakes. Many studies have explored numerous direct and indirect effects of roads on reptiles (Andrews et al. 2008 and references therein), but until recently ECB mortality has not been recognized as an additional source of road-related mortality (Barton and Kinkead 2005, Kapfer and Paloski 2011). Results from this project provide some initial guidelines on the types of ECBs that threaten snakes, but future efforts need to determine the effect of this additional agent of mortality on snake population structure and persistence. In addition to ECB product specifications, timing, location, and installation methods are all potentially important and need to be further studied to inform managers.

MANAGEMENT IMPLICATIONS

Some states have erosion control guidelines in place that minimize the risk of wildlife mortality. For example, Minnesota and California, USA, recommend using biodegradable material, mesh that has movable joints, rectangular-shaped mesh, using products that do not contain netting, and promptly removing temporary products (California Coastal Commission 2012, Minnesota Department of Natural Resources 2013). Where endangered or threatened species are potentially present, Indiana, USA, requires that mesh used in these areas either be woven or have net openings of ≥2 inches (Natural Resources Conservation Service Indiana 2013). Species that are considered threatened in some states have been found entangled in erosion control netting (Leatherman 1996, Walley et al. 2005, Kapfer and Paloski 2011). Barton and Kinkead (2005) and Walley et al. (2005) suggest using

alternative erosion control materials in areas where threatened or endangered species reside to reduce mortality because a loss of even one individual can be detrimental. Stone or woodchip-based mulches are common erosion control methods that would be viable alternatives that do not use mesh (Benik et al. 2003, California Coastal Commission 2012, Natural Resources Conservation Service Indiana 2013). Woven ECBs have also been suggested as an alternative to other ECBs because they are less dangerous to snakes (Kapfer and Paloski 2011). We suggest that entanglement threat to wildlife should be considered when determining whether an erosion control product should be listed on the APL. Agencies using ECBs should be informed about erosion control products that will pose the lowest risk to wildlife and result in the lowest number of entanglements while assuring soil retention.

ACKNOWLEDGMENTS

LITERATURE CITED

Andrews, K. M., J. W. Gibbons, and D. M. Jochimsen. 2008. Ecological effects of roads on amphibians and reptiles: a literature review. Pages 121–143 *in* J. C. Mitchell, R. E. Jung Brown, and B. Bartholomew, editors. Urban herpetology. Society for the Study of Amphibians and Reptiles, Salt Lake City, Utah, USA

Balkenhol, N., and L. P. Waits. 2009. Molecular road ecology: exploring the potential of genetics for investigating transportation impacts on wildlife. Molecular Ecology 18:4154–4164.

Barton, C., and K. Kinkead. 2005. Do erosion control and snakes mesh? Journal of Soil and Water Conservation 60:33–35.

Benik, S. R., B. N. Wilson, D. D. Biesboer, B. Hansen, and D. Stenlund. 2003. Evaluation of erosion control products using natural rainfall events. Journal of Soil and Water Conservation 58:98–105.

Bonine, K. E., E. W. Stitt, G. L. Bradley, and J. J. Smith. 2004. *Crotalus atrox* (western diamond-backed rattlesnake). Entrapment and opportunistic courtship. Herpetological Review 35:176–177.

Bonnet, X., G. Naulleau, and R. Shine. 1999. The dangers of leaving home: dispersal and mortality in snakes. Biological Conservation 89:39–50.

Brady, S. P., and J. L. Richardson. 2017. Road ecology: shifting gears toward evolutionary perspectives. Frontiers in Ecology and the Environment 15:91–98.

Burgdorf, S. J., D. C. Rudolph, R. N. Conner, D. Saenz, and R. R. Schaefer. 2005. A successful trap design for capturing large terrestrial snakes. Herpetological Review 36:421–424.

California Coastal Commission. 2012. Wildlife-friendly plastic-free netting in erosion and sediment control products. Water quality fact sheet series. <https://www.coastal.ca.gov/nps/Wildlife-Friendly_Products.pdf>. Accessed 14 Aug 2018.

Coffin, A. W. 2007. From roadkill to road ecology: a review of the ecological effects of roads. Journal of Transport Geography 15:396–406.

Fauth, J. E., and S. M. Welter. 1994. *Nerodia sipedon* (northern water snake). Fatality. Herpetological Review 25:29.

Gibbons, J. W., and M. E. Dorcas. 2004. North American watersnakes: a natural history. University of Oklahoma Press, Norman, USA.

Gibbs, J. P., and D. A. Steen. 2004. Trends in sex ratios of turtles in the United States: implications of road mortality. Conservation Biology 19:552–556.

Kapfer, J. M., and R. A. Paloski. 2011. On the threat to snakes of mesh deployed for erosion control and wildlife exclusion. Herpetological Conservation and Biology 6:1–9.

Leatherman, B. M. 1996. *Phrynosoma coronatum blainvillii* (San Diego horned lizard). Conservation. Herpetological Review 27:80.

Low, J. 2005. Synthetic netting nabs serpents. Journal of Kansas Herpetology 13:9.

Minnesota Department of Natural Resources. 2013. Wildlife-friendly erosion control. <https://files.dnr.state.mn.us/eco/nongame/wildlife-friendly-erosion-control.pdf>. Accessed 14 Aug 2018.

Mitchell, J. C., J. D. Gibson, D. Yeatts, and C. R. Yeatts. 2006. Observations on snake entanglement and mortality in plastic and horticultural netting in Virginia. Catesbeiana 26:64–69.

Natural Resources Conservation Service Indiana. 2013. Guidelines for use of snake-friendly erosion control blankets. Biology fact sheet. <http://profilelibrary.info/Files/NRCS%20Biology%20Fact%20Sheet.pdf>. Accessed 14 Aug 2018.

Riitters, K. H., and J. D. Wickham. 2003. How far to the nearest road? Frontiers in Ecology and the Environment 1:125–129.

Saenz, D., C. S. Collins, and R. N. Conner. 1999. A bark-shaving technique to deter rat snakes from climbing red-cockaded woodpecker cavity trees. Wildlife Society Bulletin 27:1069–1073.

Secor, S. M. 1995. Ecological aspects of foraging mode for the snakes *Crotalus cerastes* and *Masticophis flagellum*. Herpetological Monographs 9:169–186.

Shepard, D. B., A. R. Kuhns, M. J. Dreslik, and C. A. Phillips. 2008. Roads as barriers to animal movement in fragmented landscapes. Animal Conservation 11:288–296.

Steen, D. A., M. J. Aresco, S. G. Bielke, B. W. Compton, E. P. Condon, C. K. Dodd Jr., H. Forrester, J. W. Gibbons, J. L. Greene, G. Johnson, T. A. Langen, M. J. Oldham, D. N. Oxier, R. A. Saumure, F. W. Schueler, J. M. Sleeman, L. L. Smith, J. K. Tucker, and J. P. Gibbs. 2006. Relative vulnerability of female turtles to road mortality. Animal Conservation 9:269–273.

Stuart, J. N., M. L. Watson, T. L. Brown, and C. Eustice. 2001. Plastic netting: an entanglement hazard to snakes and other wildlife. Herpetological Review 32:162–164.

Tennant, A. 1984. The snakes of Texas. Texas Monthly Press, Austin, USA.

Texas Department of Transportation. 2018a. TXDOT erosion control introduction. <https://www.txdot.gov/inside-txdot/division/maintenance/erosion-control.html>. Accessed 7 Aug 2018.

Texas Department of Transportation. 2018b. TXDOT approved products list.<https://www.txdot.gov/inside-txdot/division/maintenance/erosion-control.html>. Accessed 7 Aug 2018.

Texas Department of Transportation. 2018c. Project tracker. <http://apps.dot.state.tx.us/apps-cq/project_tracker/>. Accessed 20 Aug 2018.

Walley, H. D., R. B. King, J. M. Ray, and J. Robinson. 2005. What should be done about erosion mesh netting and its destruction of herpetofauna? Journal of Kansas Herpetology 16:26–28.

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SUPPORTING INFORMATION

Additional supporting material may be found in the online version of this article at the publisher's web-site.

Figure S1. The 3 types of erosion control blankets used in the entanglement experiments: (A) Tenax Multimat 100 P; (B) Nedia KoirMat 700; (C) BioMac SC. The images are meant to show the mesh material and are not to scale.

Table S1. Details of field survey effort, dates, and sites. All sites had the same erosion control blanket (ECB) deployed: 2 layers of fixed-intersection polypropylene mesh with straw fibers in between, and an aperture size of 12.7 mm. Field surveys were conducted from 27 April 2018 to 8 June 2018 in Houston County, Texas, USA.

Table S2. Compilation of reported reptile entanglements in mesh products. Blank cells indicate when data were not reported for that category. The superscript (a) indicates that exact numbers were not reported. In those instances, reports that estimated the number of individuals to be "several" were assigned a value of 2 individuals, reports that estimated the number of individuals to be "about 5" were assigned a value of 5, and unreported numbers were given a value of 1. Erosion control blanket is abbreviated as "ECB", and those ECBs that had internal and external meshes are designated by the abbreviations "in" and "ex." Taxonomy follows Uetz et al. (2018).

Table S3. Snout-vent length, head width, and circumference measurements (in mm) for all snake species used in the erosion control blanket entanglement trials. Snakes used in the entanglement trials were collected across Houston, Nacogdoches, Newton, Angelina, Jasper, and Trinity counties, Texas, USA, from May 2018 to July 2018.