EFFECTS OF SPOOL-AND-LINE TRACKING ON SMALL DESERT MAMMALS

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ABSTRACT—Spool-and-line tracking is an innovative and inexpensive way to record the movements of small mammals in a variety of habitats, and could have important applications for conservation related studies. However, the potential negative effects of the method have not been investigated. We document the effects of spool-and-line tracking on short-term change in body mass, recapture, and survival probability of banner-tailed kangaroo rats, *Dipodomys spectabilis,* in southeastern Arizona. We attached spools to *D. spectabilis* adults of both sexes during 3 y of varying environmental conditions, with total sample sizes of 90 experimental and 81 control animals. We did not attach spools to females in late pregnancy, and, to avoid entanglement, we did not attach spools to kangaroo rats located within 25 m of each other on the same night. We found no significant negative effects of spool attachment on body mass, survival, or recapture probability in either sex in any year.

RESUMEN—Rastreo de carrete y cordel es un método innovador y económico para registrar los desplazamientos de mamíferos pequeños en una variedad de hábitats, y podría tener una aplicación importante en estudios relacionados con la conservación. Sin embargo, los potenciales efectos negativos de éste método no han sido investigados. Documentamos los efectos de rastreo de carrete y cordel en cambios a corto plazo en la masa corporal, en la recaptura y en la supervivencia de las ratas canguro de cola de bandera, *Dipodomys spectabilis,* en el sudeste de Arizona. Sujetamos un cordel a adultos de ambos sexos de *D. spectabilis* durante 3 años de condiciones ambientales variadas, con una muestra total de 90 animales experimentales y 81 animales control. No sujetamos un cordel a hembras grávidas avanzadas o a ratas canguro localizadas dentro de 25 m de distancia la una de la otra en la misma noche para evitar enredo. No encontramos ningún efecto negativo significativo en la sujeción del cordel en la masa del cuerpo, ni en la supervivencia o en la recaptura, en ninguno de los sexos en ninguno de los años.

Spool-and-line tracking can be an efficient, economical, and accurate mode of collecting data on animal movement patterns. A bobbin of thread is attached to an animal so that the movements of the animal can be tracked by later following the trail of thread left behind (Boonstra and Craine, 1986). Spool-and-line tracking has been used to address both basic and conservation related topics, including foraging behavior (*Bettongia tropica,* Vernes and Haydon, 2001; *Hypsiprymnodon moschatus,* Dennis, 2002), nest location (*Rattus,* Miles et al., 1981; *Microtus pennsylvanicus,* Boonstra and Craine, 1986; *Antechinus* and *Murexia longicaudata,* Woolley, 1989; *Nectomys squamipes* and *Oryzomys intermedius,* Briani et al., 2001), habitat use (*Meles meles,* Hawkins and MacDonald, 1992; *Rattus,* Berry et al., 1987; Key and Woods, 1996; Cox et al., 2000; *Echymipera kaluba,* Anderson et al., 1988), and habitat search behavior (*Clethrionomys gapperi,* Gillis and Nams, 1998; *Tamias striatus* and *Sciurus,* Zollner, 2000). In our own studies, we applied spool-and-line tracking to document mate choice and inbreeding avoidance (Steinwald, 2004).

Despite the small size of the spool typically used in this method (less than 5% of the body mass of the tracked animal), there are many reasons why its presence might adversely affect the animal carrying it. Spool attachment procedures or the presence of the spool might cause enough stress to the animal to reduce its foraging ability. It might make the animal more visible or its movements clumsy, thereby increasing its vulnerability to predation. Thread entanglement might injure the animal or cause death from starvation or predation. In addition, adverse effects on the animal might cause it to become trap shy, thus impeding data collection. The impacts of other tracking methods on the welfare of the study animal have been reported (e.g., Aldridge and Brigham, 1988; van Vuren, 1989; Pouliquen et al., 1990; Cuthill, 1991; Daly et al., 1992; Stapp et al., 1994), but we are aware of no such analysis on the impact of spool-and-line tracking. In this study, we investigate the influence of spool-and-line tracking on short-term change in body mass, probability of survival, and probability of recapture, using the banner-tailed kangaroo rat, *Dipodomys spectabilis,* as a model for other small mammals living in desert environments.

METHODS—*Study Animal, Period, and Site*—*Dipodomys spectabilis* is a strictly granivorous, solitary, nocturnal rodent, in which both sexes weigh about 125 g and can live up to 6 y (Vorhies and Taylor, 1922; Waser and Jones, 1991). Each adult normally lives within an intricate burrow system, marked by a conspicuous dirt mound, which provides the necessary storage area for its larderhoard (Vorhies and Taylor, 1922; Jones, 1984; Randall, 1984), refuge from predators, and a means of thermoregulation in the desert heat (Kay and Whitford, 1978). These mounds, ranging from 2 to 5 m in diameter and up to 0.5 m in height, are located at or near the center of small, non-overlapping home ranges (Schroder, 1979; Jones et al., 1988).

We censused and tracked male and female adult *D. spectabilis* between mid-May and mid-June in 1998 and 1999, as well as during February 2001, as part of a larger study of reproductive behavior and mate choice (Winters and Waser, 2003; Steinwald, 2004). The study population was located on a private cattle ranch and spanned approximately 47 ha within a larger 2-km by 3-km study site in southeastern Arizona (31°37′N, 109°5′W) at an elevation of about 1,600 m (Skvarla et al., 2004). The habitat is classified as desert grassland; however, those areas preferred by kangaroo rats tend to be open, characterized by short grasses and forbs, and by patches of bare ground (Jones, 1984; Waser and Ayers, 2003).

Environmental conditions differed among years. Extensive winter rains in 1997 and 1998 resulted in substantial winter bloom and seed set in May 1998. Winter rains failed completely during late 1998 and early 1999, and virtually no seed set occurred in May 1999. In February 2001, the winter bloom was intermediate, and study conditions were colder than in May 1998 and 1999.

Data Collection—Each year, using standard census procedures described by Skvarla et al. (2004), we trapped at all mounds for 3 consecutive nights to determine sex, reproductive state, age, and body mass (±2 g) of all *D. spectabilis* in the population. We set 3 Sherman live traps, baited with birdseed, at each mound prior to sunset and checked them prior to sunrise the following day. To reduce potential stress, we left traps open less than 10 h during the warmer periods of May and June 1998 and 1999 and less than 5 h during February 2001. These census procedures result in a 0.66 nightly probability of capture and a median probability of capturing an individual at least once during a census of 0.96 (n = 14 censuses) (Cross and Waser, 2000; Skvarla et al., 2004). All captured animals were marked with numbered ear tags for identification.

Immediately after the census, we began spool-and-line tracking of adult *D. spectabilis.* Following census protocol, we continued to trap equally at all mounds occupied by adults throughout the 2 to 4 week tracking period. During each year, we attached spools to about half the adult population; hereafter, we refer to these individuals as ''experimental'' animals and to those that were simply processed and released as ''control'' animals. Experimental and control *D. spectabilis* were interspersed evenly throughout the study site. We did not attach spools to females noticeably at the end of pregnancy (as indicated by palpitation and large body mass relative to average female size). To decrease the risk of injury due to entanglement, we did not attach spools to adults whose mounds were located within 25 m of each other. We attached spools to individual kangaroo rats up to 4 times each tracking period, thereby allowing us to investigate effects of repeated spool attachment on behavior and survival.

We used 1-cm × 3-cm cocoon spools, each consisting of 180 m of 2-ply nylon thread, weighing about 1.7 g and having no inner bobbin (Culver Textiles Corporation, West New York, New Jersey; Imperial Threads, Inc., Northbrook, Illinois). We dyed the thread bobbins 10 colors using fabric dye (Rit Dyes, Inc., Indianapolis, Indiana) to distinguish between overlapping thread trails of different animals tracked on the same night. We wrapped each spool with waterproof medical tape both to cover the exposed thread and to provide a flattened, 2-cm-wide surface on which we applied glue for attachment. This created a spooling device that allowed the thread end to trail from its center and that weighed approximately 1.9 g.

We used a modification of the spool attachment procedure of Boonstra and Craine (1986) and attached each spool at the mound site of the captured animal. We did not anesthetize the animals, and we did not shave or cut fur in preparation for spool attachment. We applied skin bond medical glue (Smith and Nephew, Inc., Bartlett, Indiana) to the flat surface of the spooling device and to an equally sized area of fur between shoulder blades of the animal. After waiting 1 min to allow for partial drying, we attached the spooling device mid-dorsally, so that the loose thread end was directed towards the tail, and then held it in place with light hand pressure for 4 min. We released the kangaroo rat while holding the trailing thread end, which we subsequently wrapped around a small rock. All *D. spectabilis* entered their mounds within 5 min of release and were immediately capable of normal, rapid movement.

When weather was cold or wet, we checked traps and attached spools at about 2200 h, giving experimental kangaroo rats enough time to move about and leave thread trails the same night. When conditions were milder, we checked traps and attached spools at about 0400 h; experimental *D. spectabilis* then stayed in their mounds and only moved about the following night. Normally, thread expired within 24 to 48 h after spool attachment, leaving only the tape casing, which fell off within 96 h of attachment.

Because Key and Woods (1996) found that trapping an animal with an attached spool increased its risk of entanglement and injury, we never trapped the population for 2 sequential nights. Separating sequential trapping sessions by 48 h ensured that all animals either had lost their spools by the next trapping night or had exhausted the thread so that they carried only the empty tape casing of the spooling device. When we recaptured an animal with a tape casing still attached, we removed it with a pair of fine scissors.

In 2001, to investigate the effect of spool presence on behavior, we observed 4 experimental and 4 control animals via night-vision goggles. We observed one focal animal per night, and average observation time per night was 7 h $\pm$ 42 min per focal animal.

Analysis—We analyzed data from each year separately to control for potential differences in environmentally induced stress that might influence individual behavior and mortality. We performed statistical analyses using SAS System 8e for Windows (SAS Institute, Inc., Cary, North Carolina). We calculated post-hoc statistical power using the calculator at http://members.aol.com/johnp71/postpowr.html (accessed May 2004).

We first tested whether experimental animals lost more body mass than control animals within 7 d following initial capture. We calculated the mean body mass at first capture of experimental and control animals of each sex each year and used a 2-sample *t*-test to ensure that there was no initial bias in the data set. We then calculated the mean change in body mass between spool attachment and next capture or between first and second captures, for experimental and control animals, respectively. We did this analysis for each sex each year and combined, and again used a *t*-test for comparisons. We used data from each animal only once.

We also combined data from both sexes and all years and used multiple regression to test for a relationship between spool attachment and decrease in body mass. We included sex, year, latency to recapture (in days), and all interactions in the model to test whether spool attachment had greater effect on either sex or in any year. For this analysis, we excluded all females that were pregnant during the tracking period, all animals for which we did not have body mass measurements at both first and second captures, and all animals not recaptured within 7 d of their first capture.

Next, we examined the effect of spool attachment on survival by comparing the numbers of experimental and control animals that were captured during the census following the tracking period. The next censuses occurred 8 weeks later in 1998 and 1999, and 14 weeks later in 2001. We performed the initial analyses using Fisher's exact tests for each year and sex separately. We then used logistic regression to analyze the effects of spool attachment, and included sex, year, and all interactions in the model. To model the effects of spooling, we used a continuous variable: the total number of times spooled during the tracking period. We reasoned that, if spooling did have a negative effect, increasing the number of times spools were attached to an experimental animal would decrease its survival probability.

We then examined the effect of attaching spools on the willingness of the subject to reenter traps by comparing the numbers of experimental and control animals recaptured during the same tracking period. Although some experimental individuals had spools attached more than once, we only considered the effects of the first spool attachment; control animals were those that were captured but never carried spools. If spool attachment did result in trap shyness, we would expect to recapture experimental animals less often than controls.

We first compared recapture success separately for each sex in each year with Fisher's exact test, then performed a logistic regression including the same explanatory variables (and interactions) as used in investigating survival, except we modeled spooling with a simple yes-no variable. We excluded experimental and control animals from the analyses if they were first captured less than 2 trapping days before the end of the tracking period.

RESULTS—We attached spools to 26 of 46 adult males and 25 of 40 adult females captured in the population in 1998. In 1999, we

TABLE 1—Change in body mass of adult *Dipodomys spectabilis* between first attachment of spool of thread (experimental) or first capture with no spool attached (control) and recapture during the next 7 days. For either males or females overall, sample sizes gave us power to detect real experimental effect as small as 3.6 g.

		Change in body mass (g)						
		Experimental			Control			
Year	Sex	Mean	*SE*	*n*	Mean	*SE*	*n*	P^a
1998	Male	−1.1	1.2	19	−1.8	1.3	13	0.70
	Female	−1.1	1.7	20	0.3	2.6	9	0.65
	Combined	−1.1	1.1	39	−0.9	1.3	22	0.92
1999	Male	−3.1	4.0	7	−10.3	4.4	4	0.27
	Female	−3.4	2.3	9	−1.4	3.0	5	0.61
	Combined	−3.3	2.1	16	−5.3	2.9	9	0.57
2001	Male	−0.3	3.8	4	−2.4	2.0	9	0.63
	Female	4.7	2.3	3	−0.4	1.5	16	0.15
	Combined	1.9	2.4	7	−1.1	1.2	25	0.26
Overall	Male	−1.4	1.3	30	−3.3	1.2	26	0.30
	Female	−1.2	1.3	32	−0.3	2.0	30	0.62
	Combined	−0.7	0.9	62	−2.7	0.9	56	0.76

[a] Two-sample *t*-tests checked for equal variances.

attached spools to 12 of 21 adult males and 13 of 20 adult females; in 2001, we spooled 8 of 19 adult males and 6 of 25 adult females. For all years combined, sample sizes were therefore 46 of 86 adult males (53%) and 44 of 85 adult females (52%).

Body masses at first capture averaged 131.9 ± 1.6 g for experimental animals and 132.7 ± 2.0 g for controls, with no differences between experimental and control animals for either sex in any year or combined ($P = 0.17$ to 0.87 for different sexes and years, based on 2-sample *t*-tests checked for equal variances). For both sexes and all years, experimental and control animals tended to lose body mass after their first spool attachment or capture (Table 1). However, the standard errors associated with this trend were large; 2-sample *t*-tests indicated that experimental animals of either sex did not lose more body mass than controls.

Regression analyses also showed no effect of spool attachment on short-term change in body mass ($P = 0.39$, $n = 118$). There were no significant effects of sex, latency to recapture, year, or any interactions on short-term change in body mass ($P = 0.09$ to 0.95, $n = 118$).

No differences between the numbers of experimental and control animals surviving to the next census were found for either sex in any year (Table 2). When we combined the data across years, however, female experimental *D. spectabilis* were significantly more likely to survive than their control counterparts ($P = 0.01$, $n = 85$). This unexpected result was stronger when combining both sexes in all years: experimental animals survived significantly more often than controls ($P = 0.001$, $n = 171$).

Logistic regression revealed that animals that had spools attached more often were more likely to survive to the next census ($P = 0.03$, $n = 171$). When data were combined across years, both experimental and control males were significantly more likely to survive than females ($P = 0.02$, $n = 171$). No effects of year or interactions among the variables were detected ($P = 0.08$ to 0.98, $n = 171$).

We found no differences in the numbers of experimental and control animals recaptured within the same tracking period for either sex in any year (Table 3). Regression analyses also showed no effect of spool attachment on recapture probability ($P = 0.99$, $n = 163$). We detected no significant effects of sex, year, or their interactions ($P = 0.37$ to 1.00, $n = 163$).

Our night-vision observations showed no differences in activity levels between the experimental and control groups. Individuals of both

TABLE 2—Proportions of adult *Dipodomys spectabilis* that survived to the next census. Experimental = subjects with spool of thread attached; control = subjects without spool. Overall, our sample sizes gave us the power to detect experimental effect as small as 0.20 for females and 0.18 for males.

		Proportion of adults that survived				
Year	Sex	Experimental	*n*	Control	*n*	*P*[a]
1998	Male	0.85	26	0.80	20	0.49
	Female	0.84	25	0.60	15	0.09
	Combined	0.84	51	0.71	35	0.15
1999	Male	0.75	12	0.78	9	0.65
	Female	0.69	13	0.29	7	0.10
	Combined	0.72	25	0.56	16	0.31
2001	Male	0.88	8	0.55	11	0.15
	Female	0.50	6	0.47	19	0.64
	Combined	0.72	14	0.52	30	0.16
Overall	Male	0.83	46	0.73	40	0.27
	Female	0.75	44	0.49	41	0.01
	Combined	0.79	90	0.60	81	0.001

[a] Fisher's exact tests.

groups spent approximately equal amounts of time aboveground per night, remained primarily at their respective mound sites, and engaged in foraging, sandbathing, and footdrumming behaviors at similar intervals and for equivalent total time periods. These observations agreed with extensive observations done by Randall (1981, 1984, 1987, 1989) on non-manipulated adult *D. spectabilis*. When experimental animals moved rapidly, the thread trail sometimes snagged on vegetation and broke, but this did not visibly impede locomotion.

Although each spool was attached near the dorsal scent gland (Randall, 1986), we noticed no unusual scent marking behavior either when experimental animals were released or during our night-vision observations. We also noticed no irritation of the gland when ani-

TABLE 3—Proportions of adult *Dipodomys spectabilis* recaptured within a tracking period. Experimental = subjects with spool of thread attached; control = subjects without spool. Overall, our sample sizes gave us the power to detect real experimental effect as small as 0.06 for females, 0.13 for males.

		Proportion of animals recaptured				
Year	Sex	Experimental	*n*	Control	*n*	*P*[a]
1998	Male	0.92	24	0.80	20	0.25
	Female	0.96	24	0.93	15	0.63
	Combined	0.94	48	0.86	35	0.20
1999	Male	0.90	10	0.67	9	0.25
	Female	0.90	10	0.71	7	0.36
	Combined	0.90	20	0.69	16	0.12
2001	Male	1.00	8	1.00	11	1.00
	Female	1.00	6	1.00	19	1.00
	Combined	1.00	14	1.00	30	1.00
Overall	Male	0.93	42	0.83	40	0.14
	Female	0.95	40	0.93	41	0.51
	Combined	0.94	82	0.88	81	0.17

[a] Fisher's exact tests.

mals were recaptured. A few experimental animals lost hair along with the spooling device by the time we recaptured them, but this effect was temporary, and all surviving animals were fully furred by the next census.

DISCUSSION—Although we repeated the study over 3 y characterized by a wide range of temperature, rainfall, and, presumably, food levels, we detected no adverse effects on body mass, recapture, or survival attributable to the spool-and-line tracking technique. Subjectively, this result corroborated our impression that, after the initial few minutes following attachment, during which some individuals scratched vigorously at their spools, animals seemed to ignore the spools. The fact that the behavior of experimental animals observed via night vision equipment agreed with the observations by Randall (1981, 1984, 1987, 1989) of nonmanipulated *D. spectabilis* further confirms that spool presence did not impinge upon the ability of an animal to perform normal activities.

One concern we had when we began this study was the possibility of strangulation reported by Key and Woods (1996). However, only one animal became entangled: we recaptured a female that had been spooled 2 nights previously with thread wrapped tightly around her leg, causing a shallow cut and swelling of the lower half of the leg. However, upon recapture 4 nights later, the swelling had subsided and the cut was nearly healed; the animal survived to the next trapping season.

The observation that both experimental and control males survived more often than females is consistent with a larger scale analysis (Waser and Jones, 1991) that found that males survived better at high population density. However, the apparent positive effect of spool attachment on survival was a surprise. We considered several possible causes for this counterintuitive result.

Because we found no difference in the initial body masses of experimental and control animals, we had no evidence of differences in health between the 2 groups at the start of the study. We therefore asked whether we had unintentionally attached spools to animals that lived in better locations, either patches of more productive habitat or in the interior of the population (so that control animals were more isolated and, therefore, more susceptible to predation). However, by retrospectively plotting the mound locations of experimental and control animals, we found that both were dispersed homogenously throughout the study site, and that experimental and control animals were most often neighbors.

We then considered the possibility that the control group might have included some transient animals; however, all control animals were caught at least once during the initial census and again during the following tracking period. The temporal distribution of captures did not differ between experimental and control animals.

We also considered the possibility that experimental animals received more food due to our trapping protocol. Because we exerted equal trapping effort at all mounds, it seems unlikely that we were making more food available to some animals than to others. However, experimental animals that were trapped more frequently had spools attached more frequently, and because *D. spectabilis* usually had cheek pouches filled with birdseed when we released them, it is conceivable that animals that were trapped more often collected more seeds during the tracking period.

Lastly, we considered the possibility that, by avoiding attaching spools to females that were noticeably near the end of pregnancy, we unintentionally biased our data set so that animals in the control group, though not under stress due to spool-and-line tracking, were under greater stress than experimental animals from reproductive demands. This is the most plausible explanation for the apparently positive effect of spool-and-line tracking on survival, as the effect was strongest in females. We examined this possibility further by repeating the female survival analysis excluding, from both experimental and control groups, all females who were pregnant, lactating, or that shared mounds with not yet dispersed juveniles. These exclusions resulted in the elimination of approximately equal proportions of animals from both the experimental and control groups. The resultant survival rates of the non-parental females were higher than those of all females combined, as expected if parental investment increases maternal mortality. However, the direction of the apparent spooling effect remained the same: 83% of experimental and 70% of control females survived to the next census. These rates are similar to those of experimental and control males (Table 3), and the difference between spooled and unspooled females is no longer significant ($P = 0.36$ for females, $P = 0.12$ for sexes combined, Fisher's exact tests). Whatever the cause of the apparent high survival rate of experimental animals, we can confidently conclude that attaching spools to *D. spectabilis* had no negative effect.

We emphasize that, to decrease the risk of entanglement within traps, we took considerable precautions to avoid capturing animals still carrying threaded spooling devices. Many studies using spool-and-line technique have taken place in relatively open habitats, such as desert scrub, grassland, or agricultural fields, where entanglement with vegetation has not occurred. Although the technique has also been successfully applied in more cluttered habitats, we are aware of no systematic assessment of its risks under such circumstances. With this caveat, our analyses support the view that the spool-and-line tracking technique is an excellent method for gathering data on animal movements.

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