Wildlife Society Bulletin 44(4):756–759; 2020; DOI: 10.1002/wsb.1145

Tools and Technology

Tunnel Diameter as a Noninvasive Method of Detecting Pocket Gopher (Geomyidae) Occupancy

BRITTANY T. BRITO,[1] *University of Wyoming, 1000 E University Avenue, Laramie, WY 82071, USA*
JAHSHUA F. SANCHEZ, *University of Wyoming, 1000 E University Avenue, Laramie, WY 82071, USA*

ABSTRACT Challenges in monitoring rare and elusive species often involve low detection and sampling success. Noninvasive methods have allowed researchers to more efficiently monitor rare and elusive species while reducing costs of more invasive, traditional techniques. We evaluated the use of a noninvasive method as an alternative to live-trapping pocket gophers. We found that tunnel diameter can be used to help distinguish between occupancy by the Wyoming pocket gopher (*Thomomys clusius*; a species of conservation concern) and its more abundant and widespread congener, the northern pocket gopher (*T. talpoides*). Our method reduces reliance on more invasive methods of monitoring occupancy (i.e., live- or kill-trapping) for co-occurring pocket gopher species, and likely can be extended to survey for other species of fossorial mammals.

KEY WORDS fossorial, noninvasive methods, northern pocket gopher, occupancy, *Thomomys clusius*, *Thomomys talpoides*, tunnel diameter, Wyoming, Wyoming pocket gopher.

Traditional methods of monitoring species occupancy and distribution (e.g., live-trapping, kill-trapping) are invasive and often time-consuming and expensive. Noninvasive methods (e.g., camera traps, track and scat surveys, hair snares, eDNA, etc.) are viable alternatives, many of which reduce the stress, injury, and mortality associated with traditional methods (Pauli et al. 2010). Further, such noninvasive sampling methods are commonly used to study rare or elusive species because they can increase detection and sampling success (García-Alaníz et al. 2010, Mills et al. 2015, Diggins et al. 2016, Alibhai et al. 2017).

Noninvasive techniques could improve management efforts for rare and elusive species that exhibit fossorial lifestyles. Fossorial animals can be categorized as semi-fossorial or subterranean (Shimer 1903). Semi-fossorial rodents, such as ground squirrels (e.g., *Ictidomys* spp., *Urocitellus* spp.) and prairie dogs (*Cynomys* spp.), are regularly seen aboveground and use burrows principally for rearing young and protection from predators and weather (Murie and Michener 1984, Hoogland 1995). The conspicuousness aboveground facilitates species identification and field observation, without needing to trap individuals (Slade and Balph 1974, Fagerstone and Biggins 1986, Menkens et al. 1990, Proulx et al. 2012, Boulerice et al. 2019). In contrast, subterranean species spend their lives almost entirely underground and, as a result, are often poorly understood and difficult to detect.

Subterranean species, such as pocket gophers (Family Geomyidae), excavate extensive tunnels below the surface for foraging and nesting and are rarely active on the surface (Huntly and Inouye 1988, Reichman and Seabloom 2002, Romañach et al. 2007). Pocket gophers are typically solitary animals that rarely interact with conspecifics outside of the breeding season (Hansen and Miller 1959, Howard and Childs 1959). Geomyids are widely distributed across North America, with geographic ranges of species that are frequently non-overlapping (i.e., allopatric or parapatric; Vaughan 1967, Hoffman and Choate 2008). Where there is no overlap in geographic ranges, conspicuous mounds can be used to document pocket gopher presence. However, at interspecific contact zones, different species can be found in close proximity to each other (Kennerly 1959, Vaughan 1967, Thaeler 1968, Reichman and Baker 1972, Patton et al. 1984). In such cases, researchers have historically resorted to live- or kill-trapping to identify species (Vaughan 1967, Hoffman and Choate 2008, Keinath et al. 2014).

The geographic range of the widespread and abundant northern pocket gopher (*Thomomys talpoides*) encompasses that of the Wyoming pocket gopher (*T. clusius*), one of the most geographically-restricted mammals in North America. Due to the restricted geographic range and increasing energy development (e.g., natural gas, wind power) throughout its range, the Wyoming pocket gopher has been categorized as a

Received: 11 February 2020; Accepted: 13 June 2020
Published: 23 December 2020

[1]*E-mail: brito.britt@gmail.com*

Tier 1 Species of Greatest Conservation Need in Wyoming (Wyoming Game and Fish Department 2017). Multiple petitions for listing have been submitted to the United States Fish and Wildlife Service (USFWS); however, USFWS was limited by the data required to initiate a status review (United States Fish and Wildlife Service 2016). Additionally, overlap in geographic ranges and low capture success have limited the ability of managers to monitor the Wyoming pocket gopher. An alternative method of assessing pocket gopher occupancy would, therefore, improve management strategies by increasing detection, while simultaneously reducing costs associated with time- and labor-intensive trapping methods.

Previous research has established a relationship between pocket gopher body mass and tunnel diameter (Vleck 1979, 1981; Roberts et al. 1997; Wilkins and Roberts 2007; Griscom et al. 2010; Keinath et al. 2014). However, the relationship has not yet been tested as a means of determining pocket gopher species occupancy. We tested tunnel diameter as a predictor of occupancy for 2 species of pocket gopher: the Wyoming and northern pocket gopher, averaging 60 and 100 g, respectively. Further, because pocket gopher species typically and markedly vary in size (e.g., *T. bottae* [$\bar{x} = 109$ g], *Geomys breviceps* [$\bar{x} = 120$ g], *G. bursarius* [$\bar{x} = 148$ g], *G. personatus* [$\bar{x} = 274$ g]; Miller 1964, Wilkins and Roberts 2007), and tunnel diameters are proportional to the relative body mass of gophers (Vleck 1979, 1981; Wilkins and Roberts 2007; Keinath et al. 2014), we expect that our methods can be extended to other contact zones or areas in which ≥2 species of pocket gopher co-occur.

STUDY AREA

We studied pocket gophers in ca. 2,000 km^2 across Carbon and Sweetwater counties in south-central Wyoming, USA. Our study area ranged from 1,980 to 2,440 m in elevation and was characterized by an average winter temperature of −4° C, average summer temperature of 20° C, and average annual precipitation of 27 cm (range of 13–50 cm; Wiken et al. 2011, Keinath et al. 2014). The topography of the area featured hills, plateaus, and ephemeral water features. Shrubs dominated our study area, including big sagebrush (*Artemisia tridentata*), birdfoot sage (*A. pedatifida*), Gardner's saltbush (*Atriplex gardneri*), and winterfat (*Krascheninnikovia lanata*). Sandberg bluegrass (*Poa secunda*), Indian ricegrass (*Achnatherum hymenoides*), western wheatgrass (*Pascopyrum smithii*), and needle-and-thread grass (*Hesperostipa comata*) were common grasses. The land was predominately owned and managed by the Bureau of Land Management (BLM) and private landowners. Oil and gas development, including roads, pipelines, and other associated buildings, occurred throughout the study area.

METHODS

We selected sites for live-trapping using a combination of previous capture locations and randomly generated points (ArcMap v. 10.1, Esri, Redlands, CA, USA) for predicted Wyoming pocket gopher occurrence (Keinath et al. 2014). Trap sites were 640-km^2 quarter sections located on BLM land. At each site, we conducted surveys for the presence of gopher mounds (Griscom et al. 2010). Surveyors walked 16 linear north-south transects within each site, spread 50 m apart, and searched within a 20-m buffer on either side of the transect. When mounds were found, the surveyor counted the number of fresh and old mounds within a 20-m search radius and marked the location of the freshest mounds with a handheld GPS (GPSMAP 64S, Garmin Ltd., Olathe, KS, USA). The surveyor then continued to search the transect for additional mounds.

We live-trapped pocket gophers from June to October, 2017–2019. We dug from the center of fresh mounds until a tunnel was located, then set one trap per tunnel opening. We used Sherman live traps (Model SFG, H.B. Sherman Traps, Inc., Tallahassee, FL, USA) and custom-built Harmony traps (Harmony Metalworks, Laramie, WY, USA) baited with sweet potato. To mimic the continuation of gopher tunnels and provide insulation from weather, we placed traps level with the tunnel opening, placed a black trash bag over the trap, and buried them with soil. We checked traps hourly throughout the day and left them open overnight for 3 consecutive days. Upon capture of a gopher, we recorded body mass, sex, and diameter of the tunnel. We did not record individual age class because accurate classification is difficult to determine without euthanasia (Howard and Childs 1959, Hansen 1960). To measure the widest part of the tunnel to the nearest millimeter, we used a shovel to cut a vertical cross-section. All procedures adhered to the guidelines for use of wild mammals in research recommended by the American Society of Mammalogists (Sikes et al. 2016) and met the requirements of the University of Wyoming Animal Care and Use Committee (Protocol: 20170410JG00273-02).

To determine if either species displayed sexual dimorphism, we conducted a t-test to compare mean body mass between species. We quantified the relationship between tunnel diameter and occupancy of both Wyoming pocket gopher and northern pocket gopher with logistic regression ($\alpha = 0.05$) using occupancy (presence-absence) data. We modeled pocket gopher species as the response variable (0 = northern pocket gopher; 1 = Wyoming pocket gopher) and tunnel diameter as a predictor variable. To evaluate the goodness of fit of the model, we used Nagelkerke's pseudo-R^2 (Nagelkerke 1991). We validated the model using area under the receiver operating characteristic curve (AUC; Swets 1988, Manel et al. 2001). All analyses were conducted in Program R (v. 3.4.3, R Core Team 2017).

RESULTS

We captured a total of 64 northern pocket gophers and 50 Wyoming pocket gophers from June 2017 to October 2019. There was no difference in mean body mass between northern pocket gopher males and females ($\bar{x} = 80.85$ g, SE = 4.81; $\bar{x} = 80.72$ g, SE = 5.09 respectively, $t(39) = -0.02$, $n = 41$, $P = 0.98$). Similarly, there was no difference in mean body mass between male and female Wyoming pocket gophers ($\bar{x} = 53.87$ g, SE = 1.68; $\bar{x} = 50.0$ g, SE = 2.29 respectively, $t(43) = -1.32$, $n = 45$, $P = 0.19$). Tunnel diameter measurements were collected for 110 pocket gophers ($n = 63$ northern pocket gophers; $n = 47$ Wyoming pocket gophers). Mean tunnel diameter was 47.38 mm (range = 34–66 mm, SE = 1.04) and 61.95 mm (range = 44–78 mm, SE = 1.10) for Wyoming pocket gophers and northern pocket gophers, respectively. The probability of occupancy by Wyoming pocket gophers was related to lower values of tunnel diameter ($\beta = -0.22$, $n = 110$, Nagelkerke's $R^2 = 0.59$, $P \leq 0.001$; Fig. 1). The overall model accuracy was high (AUC = 0.90). The logistic output equation for pocket gopher species occupancy was $\ln(p/1 - p) = (-0.22 * \text{diameter}) + 11.78$.

DISCUSSION

We implemented a noninvasive sampling method to quantify occupancy of a rare fossorial species. The probability of Wyoming pocket gopher occupancy can be determined from tunnel diameter measurements, with probability increasing in tunnels <53 mm in diameter. In contrast, the probability of northern pocket gopher occupancy increases in tunnels >53 mm in diameter. We recommend the following classification percentages at various tunnel diameter categories: <40 mm = >95.2% chance of Wyoming pocket gopher occupancy; 40–50 mm = 95.2–68.2% chance of occupancy; 50–60 mm 68.2–19.5% chance of occupancy; 60–70 mm = 19.5–2.6% chance of occupancy; >70 mm = <2.6% chance of occupancy. The use of this method can reduce financial costs, time, tunnel disturbance, and negative factors associated with live-trapping (e.g., stress, injury, mortality). As energy development continues to expand throughout their restricted geographic range, tunnel-diameter measurements serve as an effective means of predicting Wyoming pocket gopher occupancy that can allow managers to more efficiently designate conservation interventions.

Variation in body mass between species of pocket gopher influences tunnel shape (Vleck 1979, Wilkins and Roberts 2007); therefore, our method requires an initial validation of species-specific tunnel metrics through live trapping before implementing with additional species or in other locations not evaluated here. In some cases, sexual dimorphism (e.g., a female of species *A* and a male of species *B*) may result in overlap of tunnel diameters and increase the possibility of species misidentification, although the potential for such overlap was minimal in the current study. Similar body mass at different life stages (e.g., an adult of species *A* and a juvenile of species *B*) may also result in overlap of tunnel diameters. Under both scenarios, it would be necessary to collect repeated tunnel measurements within a trapping area to determine a range of tunnel diameters. If the range of measurements coincides with intermediate values of the species-specific tunnel measurements, then data on habitat characteristics can further improve our overall ability to determine species occupancy. For example, vegetation and soil composition at sites occupied by Wyoming pocket gophers differ from sites occupied by northern pocket gophers, with Wyoming pocket gopher sites containing more Gardner's saltbush (*Atriplex gardneri*) and soil with greater clay content (Keinath et al. 2014). It is important to note that additional survey techniques should be used when the consequences of misidentification are high.

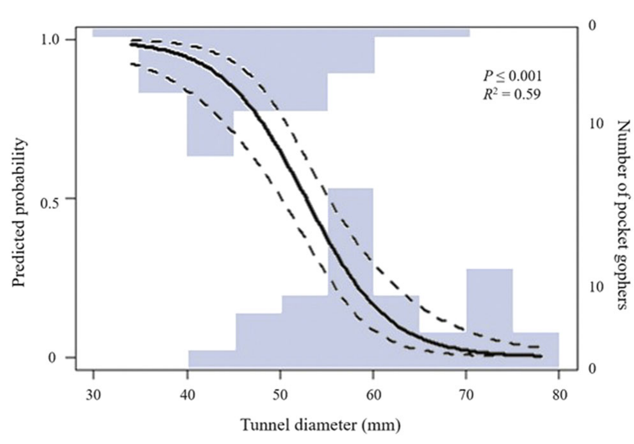

Figure 1. Fitted logistic regression curve displaying the probability of Wyoming pocket gopher occupancy based on tunnel diameter measurements collected in south-central Wyoming, USA, 2017–2019. Histograms represent the number of tunnel diameter measurements collected for Wyoming pocket gopher (top) and northern pocket gopher (bottom) at a given tunnel diameter.

The use of tunnel-diameter measurements to determine occupancy could be extended to other fossorial mammals, such as other species of pocket gophers and tuco-tucos (*Ctenomys* spp.). For example, the geographic range of the widespread northern pocket gopher in Wyoming not only encompasses that of the Wyoming pocket gopher, but also encompasses those of the Idaho pocket gopher (*T. idahoensis*) and Sand Hills pocket gopher (*Geomys lutescens*, formerly *G. bursarius lutescens*; Genoways et al. 2008, Chambers et al. 2009). The 50 g Idaho pocket gopher should occupy tunnels with smaller average diameters than that of the 100 g northern pocket gopher. In contrast, the 190 g Sand Hills pocket gopher should occupy tunnels of larger average diameters than northern pocket gopher. Our noninvasive sampling method could also be applied to tuco-tucos, a South American rodent with ecological roles comparable to that of North American pocket gophers. Some species of tuco-tuco are solitary (Lacey et al. 1998) and spend large quantities of time in underground tunnels. Because most species of tuco-tuco exhibit allopatric or parapatric distributions (Kubiak et al. 2015), tunnel diameter measurements could improve occupancy estimates in areas of interspecific contact zones.

We have developed a noninvasive and quantitative method to predict occupancy of pocket gophers within interspecific contact zones. Our intent is not to replace comprehensive habitat and observational approaches, but rather to provide a low-cost, readily implemented assessment of pocket gopher occupancy. Our method can reduce reliance on more invasive methods of monitoring occupancy (i.e., live- or kill-trapping) and could be applied to other subterranean mammals where detection estimates are low and species' ranges come into contact.

ACKNOWLEDGMENTS

A special thanks to Z. Walker and N. Bjornlie with the Nongame Program of the Wyoming Game and Fish Department. We would like to thank field technicians T. Thorvaldson, F. Ngo, S. Kemp, T. Park, T. Cooke, B. Flickinger, C. Burdett, and J. Boulerice for their contribution to the project. We thank the J. Goheen Lab, R. Applegate (Associate Editor), J. Wallace (Editorial Assistant), and 2 anonymous reviewers for their helpful comments on this manuscript. Funding from the Wyoming Governor's Endangered Species Account Funds and the University of Wyoming's Department of Zoology and Physiology made this project possible.

LITERATURE CITED

Alibhai, S., Z. Z. Jewell, and J. Evans. 2017. The challenge of monitoring elusive large carnivores: an accurate and cost-effective tool to identify and sex pumas (*Puma concolor*) from footprints. PLoS ONE 12(3): e0172065.

Boulerice, J. T., E. A. Saldo, B. T. Brito, and P. J. Majoney. 2019. Use of visual stimuli increases count estimates for prairie dogs. Wildlife Society Bulletin 43:191–197.

Chambers, R. R., P. D. Sudman, and R. D. Bradley. 2009. A phylogenetic assessment of pocket gophers (*Geomys*): evidence from nuclear and mitochondrial genes. Journal of Mammalogy 90:537–547.

Diggins, C. A., L. M. Gilley, C. A. Kelly, and W. M. Ford. 2016. Comparison of survey techniques on detection of northern flying squirrels. Wildlife Society Bulletin 40:654–662.

Fagerstone, K. A., and D. E. Biggins. 1986. Comparison of capture–recapture and visual count indices of prairie dog densities in black-footed ferret habitat. Great Basin Naturalist Memoirs 8:94–98.

García-Alaníz, N., E. J. Naranjo, and F. F. Mallory. 2010. Hair-snares: a noninvasive method for monitoring felid populations in the Selva Lacandona, Mexico. Tropical Conservation. Science 3:403–411.

Genoways, H. H., M. J. Hamilton, D. M. Bell, R. R. Chambers, and R. D. Bradley. 2008. Hybrid zones, genetic isolation, and systematics of pocket gophers (Genus *Geomys*) in Nebraska. Journal of Mammalogy 89:826–836.

Griscom, H. R., D. A. Keinath, and M. D. Anderson. 2010. Pocket gopher surveys in southwestern Wyoming: final project report. Report prepared for the Wyoming Game and Fish Department by the Wyoming Natural Diversity Database, University of Wyoming, Laramie, USA.

Hansen, R. M. 1960. Age and reproductive characteristics of mountain pocket gophers in Colorado. Journal of Mammalogy 41:323–335.

Hansen, R. M., and R. S. Miller. 1959. Observations on the plural occupancy of pocket gopher burrow systems. Journal of Mammalogy 40:577–584.

Hoffman, J. D., and J. R. Choate. 2008. Distribution and status of the yellow-faced pocket gopher in Kansas. Western North American Naturalist 64:483–492.

Hoogland, J. L. 1995. The black-tailed prairie dog: social life of a burrowing mammal. University of Chicago Press, Illinois, USA.

Howard, W. E., and H. E. Childs. 1959. Ecology of pocket gophers with emphasis on *Thomomys bottae mewa*. Hilgardia 29:277–358.

Huntly, N., and R. Inouye. 1988. Pocket gophers in ecosystems: patterns and mechanisms. BioScience 38:786–793.

Keinath, D. A., H. R. Griscom, and M. D. Andersen. 2014. Habitat and distribution of the Wyoming pocket gopher (*Thomomys clusius*). Journal of Mammalogy 95:803–813.

Kennerly, T. E. Jr. 1959. Contact between the ranges of two allopatric species of pocket gophers. Evolution 13:247–263.

Kubiak, B. B., D. Galiano, and T. R. Ochotorena de Freitas. 2015. Sharing the space: distribution, habitat segregation and delimitation of a new sympatric area of subterranean rodents. PLoS ONE 10(4):e0123220.

Lacey, E. A., S. H. Braude, and J. R. Wieczorek. 1998. Solitary burrow use by adult Patagonian tuco-tucos (*Ctenomys haigi*). Journal of Mammalogy 79:986–991.

Manel, S., H. C. Williams, and S. J. Ormerod. 2001. Evaluating presence–absence models in ecology: the need to account for prevalence. Journal of Applied Ecology 38:921–931.

Menkens, G. E., Jr., D. E. Biggins, and S. H. Anderson. 1990. Visual counts as an index of white-tailed prairie dog density. Wildlife Society Bulletin 18:290–296.

Miller, R. S. 1964. Ecology and distribution of pocket gophers (*Geomyidae*) in Colorado. Ecology 45:256–272.

Mills, C. A., B. J. Godley, and D. J. Hodgson. 2015. Take only photographs, leave only footprints: novel applications of noninvasive survey methods for rapid detection of small, arboreal animals. PLoS ONE 11(1):e0146142.

Murie, J. O., and G. R. Michener. 1984. The biology of ground-dwelling squirrels: annual cycles, behavioral ecology, and sociality. University of Nebraska Press, Lincoln, USA.

Nagelkerke, N. J. D. 1991. A note on a general definition of the coefficient of determination. Biometrika 78:691–692.

Patton, J. L., M. F. Smith, R. D. Price, and R. A. Hellenthal. 1984. Genetics of hybridization between the pocket gophers *Thomomys bottae* and *Thomomys townsendii* in Northeastern California. Great Basin Naturalist 44:431–440.

Pauli, J. N., J. P. Whiteman, and M. D. Riley. 2010. Defining noninvasive approaches for sampling of vertebrates. Conservation Biology 24:349–352.

Proulx, G., K. MacKenzie, and N. MacKenzie. 2012. Distribution and relative abundance of Richardson's ground squirrels, *Urocitellus richardsonii*, according to soil zones and vegetation height in Saskatchewan during a drought period. Canadian Field-Naturalist 126:103–110.

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reichman, O. J., and R. J. Baker. 1972. Distribution and movements of two species of pocket gophers (Geomyidae) in an area of sympatry in the Davis Mountains, Texas. Journal of Mammalogy 53:21–33.

Reichman, O. J., and E. W. Seabloom. 2002. The role of pocket gophers as subterranean ecosystem engineers. Trends in Ecology & Evolution 17:44–49.

Roberts, H. R., K. T. Wilkins, J. Flores, and A. Thompson-Gorozpe. 1997. Burrowing ecology of pocket gophers (Rodentia: Goemyidae) in Jalisco, Mexico. Southwestern Naturalist 42:323–327.

Romañach, S. S., E. W. Seabloom, and O. J. Reichman. 2007. Costs and benefits of pocket gopher foraging: linking behavior and physiology. Ecology 88:2047–2057.

Shimer, H. W. 1903. Adaptations to aquatic, arboreal, fossorial and cursorial habits in mammals. III. American Naturalist 37:819–826.

Sikes, R. S., and The Animal Care and Use Committee of the American Society of Mammalogists. 2016. 2016 Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97:663–688.

Slade, N. A., and D. F. Balph. 1974. Population ecology of Uinta ground squirrels. Ecology 55:989–1003.

Swets, J. A. 1988. Measuring the accuracy of diagnostic systems. Science 240:1285–1293.

Thaeler, C. S., Jr. 1968. An analysis of three hybrid populations of pocket gophers (Genus *Thomomys*). Evolution 22:543–555.

United States Fish and Wildlife Service. 2016. 90-day finding on a petition to list the Wyoming pocket gopher (*Thomomys clusius*) under the U.S. Endangered Species Act. Federal Docket No. FWS-R6-ES-2016-0094.

Vaughan, T. A. 1967. Two parapatric species of pocket gophers. Evolution 21:148–158.

Vleck, D. 1979. The energy cost of burrowing by the pocket gopher *Thomomys bottae*. Physiological Zoology 52:122–136.

Vleck, D. 1981. Burrow structure and foraging costs in the fossorial rodent, *Thomomys bottae*. Oecologia 49:391–396.

Wiken, E., F. J. Nava, and G. Griffith. 2011. North American terrestrial ecoregions-level III. Commission for Environmental Cooperation, Montreal, Quebec, Canada.

Wilkins, K. T., and H. R. Roberts. 2007. Comparative analysis of burrow systems of seven species of pocket gophers (Rodentia: Geomyidae). Southwestern Naturalist 52:83–88.

Wyoming Game and Fish Department. 2017. State wildlife action plan. Wyoming Game and Fish Department, Cheyenne, USA.

Associate Editor: Applegate.