INDICES OF POPULATION SIZE FOR BURROWING MAMMALS

ANNE H. HUBBS,^{1,2} Division of Life Sciences, University of Toronto at Scarborough, Scarborough, Ontario M1C 1A4, Canada
TIM KARELS, Division of Life Sciences, University of Toronto at Scarborough, Scarborough, Ontario M1C 1A4, Canada
RUDY BOONSTRA, Division of Life Sciences, University of Toronto at Scarborough, Scarborough, Ontario M1C 1A4, Canada

Abstract: There are few quick, precise indices for predicting population size of semifossorial mammals. We assessed the utility of powder-tracking and infrared thermal imaging to predict population size in the Arctic ground squirrel (*Spermophilus parryii*) in the boreal forest of southwestern Yukon. Density estimated from live-trapping was strongly and linearly correlated with both indices ($r = 0.81$ for powder-tracking; $r = 0.91$ for infrared imaging). The slope of the relationship between density and the infrared index (0.10) deviated from a slope of 1. The slope of the relationship between density and the powder-tracking index (0.82) did not deviate from a slope of 1, but our power to detect departures from this slope using this index was low (0.10). We recommend infrared imaging and powder-tracking for monitoring population sizes of semifossorial mammals.

JOURNAL OF WILDLIFE MANAGEMENT 64(1):296-301

Key words: Arctic ground squirrel, burrowing mammals, infrared thermal imaging, population indices, powder-tracking, *Spermophilus parryii*, Yukon.

Indices of population abundance are commonly used in ecology, although relatively few studies have related these indices to absolute abundance (Krebs et al. 1987, Beier and Cunningham 1996, Forsys and Humphrey 1997, Mallick et al. 1997). For semifossorial mammals, burrows are ideal sites to obtain estimates of population density. Signs at burrow entrances, such as fresh diggings, tracks, scats, and cleared vegetation, have been used to assess burrow activity and, in turn, to estimate small mammal abundance (Lord et al. 1970, Schmutz and Hungle 1989, Boonstra et al. 1992). Similarly, counts of burrow entrances or above-ground animals have been correlated with estimates of ground squirrel abundance (Owings and Borchert 1975, Nydegger and Smith 1986, Weddell 1989, Biggins et al. 1993). However, counts of burrow entrances are generally poor estimators of ground squirrel densities (Powell et al. 1994, Van Horne et al. 1997), and counts of aboveground animals provide imprecise estimates of population density when used during periods of low aboveground activity (Biggins et al. 1993) or during periods of rapid population change (Menkens et al. 1990).

Estimates from signs and counts may be imprecise for several reasons. Signs and burrows are long lasting and cannot reflect small to moderate fluctuations in abundance, because bur-

row persistence can differ spatially and temporally, observers may differ in their counting of burrow entrances and animals, and density may be underestimated when multiple species occupy a burrow because burrow counts cannot differentiate among species (Van Horne et al. 1997). Drennan et al. (1998) used aluminum plates covered with chalk and alcohol inside plastic stations to index the abundance of 4 sciurid species and found that these track stations provided density estimates that were highly correlated with trapping estimates. However, these track stations required bait to attract animals (Drennan et al. 1998), thereby making them unsuitable for studies of movement patterns.

We assessed powder-tracking boards and infrared thermal imaging for estimating abundance of semifossorial mammals. Tracking techniques (e.g., smoked paper, smoothed sand, and plates covered with talcum powder) have been used frequently to determine the activity of burrowing mammals (Justice 1961, Jike et al. 1988, Boonstra et al. 1992), but rarely to estimate relative population abundance (Drennan et al. 1998). Thermal imaging, which converts far-infrared energy (3–14 μm) emitted by objects above absolute zero into visible images (Hill and Clayton 1985), has been used to census large mammals and bats (Wiggers and Beckerman 1993, Sabol and Hudson 1995, Nangle et al. 1996), but never burrowing mammals. We evaluated powder-tracking and thermal imaging

¹ Present address: Department of Zoology, University of Western Ontario, London, Ontario N6A 5B7

medium-sized (approximately 500 g) burrowing rodent, the Arctic ground squirrel. These methods, like those of burrow counts and signs, rely on correlations between burrows and population size.

METHODS

Study sites were located in the Shalakw Trench, east of Klwane Lake in the southwest-ern Yukon Territory, Canada (61°N, 138°W; Hubbs and Boonstra 1997). Arctic ground squirrels were live-trapped on 3–8 sites from late April to late August, 1991–93. The sites were approximately 10 ha in size and located predominantly in open spruce habitat. Two sites were controls and 6 sites were experimentally manipulated as part of a long-term study designed to investigate community organization in the boreal forest (Krebs et al. 1995). We used these experimental sites to provide a range of population densities to test our techniques.

We trapped each site 3 times on 2 consecutive days during the active season: after adult emergence from hibernation (late Apr–early Jun); after juvenile emergence from natal burrows (Jul); and just before squirrel immersion into hibernation (Aug) of each year. Single Tomahawk traps (16.5 × 16.5 × 48.0 cm or 14 × 14 × 41 cm; Tomahawk Live Trap, Tomahawk, Wisconsin, USA) baited with peanut butter were set outside burrow entrances. Two or 3 traps were placed at sites with ≥5 burrow entrances or where >1 squirrel had been seen. All squirrels captured were marked in both ears with uniquely numbered tags (Monel #1 fingerling tags, National Band and Tag, Newport, Kentucky, USA).

Powder-tracking boards were black tiles (5 × 11 cm) covered with a thin film of machinist's oil (Tellus Oil 10, Shell Canada Products Limited, Toronto, Canada) and talcum powder. We placed these tiles partway down all ground squirrel burrows within a 1.6–2.9-ha area on 6 live-trapped sites in 1991 and within 2 1.6-ha areas (90 m apart) on each of 3 live-trapped sites in 1993. To ensure that squirrels did not move the tiles, we drilled a hole in the top of each tile and used a metal peg to hold the tile in place. Tiles were placed in burrows between 0800 and 0900 hr and examined for footprints of ground squirrels 7 hr later. A burrow was considered active if ≥1 footprints were present. Powder-tracking was conducted for 2–3 days on

(29 Jul–22 Aug) in 1991 and after emergence from hibernation (12–17 Jun) in 1993.

We used the far-infrared thermal sensor Thermovision 210 (Agema Infrared Systems, Danderyd, Sweden), which detects infrared radiation from 2 to 5 μm . This radiation is seen as a white glow against a dark background. After squirrels emerged from hibernation in 1992 (26 May–26 Jun), we determined burrow activity within a 1.6–7.3-ha area on 8 live-trapped sites. We also determined burrow activity just before immersion into hibernation (6 Aug) on 1 of these sites. We obtained a thermal image of each burrow between 0430 and 0630 hr to assess if a burrow was occupied (active). The early hour was used to maximize the temperature differential between the burrow entrances and the surrounding soil. A burrow was considered active if it had a white thermal image (i.e., infrared radiation from squirrel's body heat) against a dark background. It took 1–4 days to assess the activity of all burrows within an area.

We assessed potential bias among observers in classifying the activity of burrows with the Thermovision 210. On 18 August 1992 at 0600 hr, 3 observers alternated in assessing the activity of each burrow within a 0.81-ha area in an untrapped shrub habitat.

We used linear and nonlinear regression to examine the relationship between number of active burrows per ha from powder-tracking and infrared indices (independent variables) and squirrel density (dependent variable) to determine if our index of population abundance increased at a rate different than true abundance. Densities were based on the absolute number of squirrels captured within an area during the trapping session closest to the time of powder-tracking or infrared imaging. Because densities were estimated for each 1.6-ha area, we treated the 2 powder-tracking areas on each of 3 live-trapping sites in 1993 as independent data points. To determine the precision in which our indices predicted changes in squirrel abundance, we tested the slope of the regression against the null hypothesis of slope = 1 using a *t*-test with $\alpha = 0.05$. We used the Program PS by Dupont and Plummer (1992) to determine statistical power in detecting changes in slopes of regressions given our sample sizes and variance.

RESULTS

Linear models for both powder-tracking and

Fig. 1. Relationship between density of active burrows as determined by powder-tracking and density of Arctic ground squirrels (A) on 1.6–2.9-ha areas on 6 sites in 1991 and 3 sites in 1993 ($r^2 = 0.65$, $y = 0.82x - 0.84$, $P < 0.01$). There was 1 area per site in 1991 and 2 areas per site in 1993. Squirrel density was estimated from livetrapping. Relationship between density of active burrows as determined by infrared imaging and density of Arctic ground squirrels (B) on 1.6–7.3-ha areas on 8 livetrapped sites in 1992 ($r^2 = 0.83$, $y = 0.10x + 0.51$, $P < 0.001$). Infrared imaging was performed twice on 1 site at different times of year. Squirrel density was estimated from livetrapping.

ground squirrel abundance, therefore there was no bias in the response of our indices to changes in population density. Both indices were strongly related to squirrel density (powder-tracking: $r^2 = 0.65$, $n = 12$, $P < 0.01$, Fig. 1A; infrared: $r^2 = 0.83$, $n = 9$, $P < 0.001$, Fig. 1B). For the powder-tracking index, the slope of the relationship (0.82; 95% CI = 0.40–1.25) did not depart from slope = 1 (2-tailed $t = 0.93$, $df = 10$, $P > 0.20$). However, our power to detect this difference in slope (0.18) was low (power = 0.10). For the infrared index, the slope of the relationship was 0.10 (95% CI = 0.06–0.14), which departed negatively from slope = 1 (2-tailed $t = 53.1$, $df = 7$, $P < 0.001$).

To examine the differences in slope that we could detect given the variation and sample size of our data, we constructed a power curve. For a given change in slope from 1 (Δ slope), we had a greater probability of detecting changes

Fig. 2. Power of infrared imaging and powder-tracking to detect changes in slope (Δ slope) between burrow activity and Arctic ground squirrel density. There was a greater probability of detecting changes in slope for infrared index than powder-tracking index.

in slope for the infrared index than for the powder-tracking index (Fig. 2). Indeed, we could detect small changes in slope (± 0.07) for the infrared index with a power of 0.80. However, we could only detect changes in slope of ± 0.80 for the powder-tracking index with a power of 0.80. Thus, the infrared index provides a more precise estimate of population abundance than the powder-tracking index.

We tested for differences among 3 observers in assigning burrows within a 0.81-ha area as either active or inactive using the infrared technique. Assignment of burrow activity was independent of observer ($G = 3.9$, $df = 2$, $P = 0.14$; $n = 39$ burrows). Burrow activities were 35.9%, 53.9%, and 56.4% according to the 3 observers. Thus, there was no systematic bias among observers.

DISCUSSION

Both indices showed strong associations with squirrel abundance (Fig. 1) and showed no evidence of overestimating or underestimating population abundance relative to livetrapped densities. Because trappability of Arctic ground squirrels in this area was high (mean minimum trappability 67–100%; Hubbs and Boonstra 1997), we are confident that livetrapping data provided reliable estimates of absolute abundance. In our study areas, the proportion of marked boards or thermal images per squirrel remained constant with changes in density (i.e., did not depart from linearity). Significant departures from a linear relationship would have revealed additional information about the biol-

ogy of the study animal. For example, an increasing rate of change would have indicated that proportionally more powder-tracking boards were active per squirrel as density increased, possibly because of increased dispersal at higher density. Conversely, a decreasing rate of change would have indicated that proportionally fewer boards were active per squirrel as density increased, perhaps because of more burrow sharing at higher density. This reasoning also could be applied to departures from linearity with the infrared index.

The slope of the infrared index departed negatively from a slope of 1, whereas the powder-tracking index did not, however, our power to detect departure using this index was low (Fig. 2). The number of active powder-tracking boards was nearly equivalent to the number of squirrels (1.2 boards marked per squirrel) whereas the number of thermal emitting burrows was much higher (10.0 thermal emitting burrows per squirrel).

Of the various non-livetrapping methods used to assess densities of burrowing mammals (i.e., signs at burrow entrances, counts of burrows and aboveground animals), powder-tracking and infrared imaging techniques may be the most precise. In addition, powder-tracking may permit one to differentiate among different species occupying the same burrow (if footprints of the species differ noticeably) and infrared thermal imaging avoids observer bias in assessing burrow activity.

Although our study indicates that infrared imaging can be useful in censusing burrowing mammals, it only can be used in conditions where the ambient temperature is low relative to the heat emitted from an animal or burrow and where vegetation cover is low (Boonstra et al. 1994). We do not know how infrared imaging responds to animals that share their burrows with conspecifics or other species. If burrow sharing is suspected, then caution should be taken when interpreting results because population sizes may be underestimated if the frequency of burrow sharing increases with population density. For connected burrow systems, the accuracy of the infrared index may depend on the number of animals underground and the shape of the burrow system. The infrared index may not be accurate for connected burrow systems where 2 or more entrances converge differently on the exact same spot underground (e.g., V-shaped system versus U-shaped system).

In the V-shaped type of system, both entrances would emit equal amounts of infrared radiation. In the U-shaped system, the entrance farthest from the animal may emit less radiation than the entrance closest to the animal. Inaccuracies would arise if animals were close together near a single entrance. The far-infrared thermal sensor we used was very expensive (Boonstra et al. 1994), but there are now a number of relatively inexpensive devices on the market (e.g., \$2,000–\$3,000 US) and this should increase their use in wildlife applications.

Powder-tracking is a precise, inexpensive, simple, and rapid technique for censusing burrowing mammals. However, it was less precise than the infrared index. Several factors must be considered before employing this method. To predict density, powder-tracking must be validated against precise estimates of density, which are usually based on livetrapping. However, its application may be restricted only to the specific conditions of the calibration (Eberhardt and Simmons 1987). Under certain circumstances, it may not be feasible to obtain absolute estimates of population size using mark-recapture methods because of a low budget, limited time, or restrictions on handling animals (e.g., they are endangered, dangerous, etc.). In these situations, powder-tracking may still be useful for measuring changes in abundance (i.e., relative densities).

The precision of powder-tracking in estimating population densities may vary with the mobility of the study species, the number of individuals per burrow, and the degree of connectedness of the burrow systems. Densities may be overestimated when powder-tracking is used for highly mobile species, for sedentary species that have periods of dispersal, or for species with large home ranges or interconnected burrow systems that encompass several powder-tracking tiles. In these situations, a single animal may walk on several powder-tracking tiles, thereby inflating density estimates. In contrast, densities may be underestimated when >1 individual of the same species (or different species if footprints are indistinguishable) occupies the same burrow. Arctic ground squirrels have exaggerated movements in mid-late April during the breeding season and again in July when most juveniles disperse (Lacey 1991). Because powder-tracking occurred outside of these periods, our density estimates should not have been inflated by increased movement. However, squir-

rels did occupy burrow systems with multiple entrances and had home ranges that encompassed several powder tiles (Hubbs and Boonstra 1998). These conditions could have affected the precision of our density estimates.

We suggest that powder-tracking and far-infrared thermal sensors are useful methods for predicting densities of burrowing mammals, including sciurids (*Spermophilus* spp.), heteromyids (*Perognathus* spp. and *Dipodomys* spp.), microtines (*Microtus* spp.) and pikas (*Ochotona* spp.), if coupled with validation by live-trapping. When live-trapping is not feasible, these techniques are still useful for measuring changes in relative abundance. Both techniques are simple, rapid, and efficient. They are especially useful for sedentary species in which a single animal occupies a burrow system with only a few entrances (e.g., eastern chipmunk, *Tamias striatus*). Researchers should avoid using powder-tracking during periods of peak dispersal when density may be overestimated. We suggest that the usefulness of both indices in estimating absolute abundance be tested by employing powder-tracking and infrared imaging under varying conditions (e.g., different habitats, seasons etc.) to determine if the relationship between these indices and live-trapping remains constant.

ACKNOWLEDGMENTS

We thank J. S. Millar and the Small Mammal Discussion Group at the University of Western Ontario for their comments. We thank L. Aus, A. Byrom, and C. Hutchison for field assistance and the Arctic Institute of North America, Kluane Lake Base for facilities. This research was funded by a Collaborative Special Project grant and an individual operating grant (to R.B.) from the Natural Sciences and Engineering Research Council of Canada. This is contribution number 114 of the Kluane Boreal Forest Ecosystem Project.

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Received 23 June 1998.

Accepted 21 June 1999.

Associate Editor: Helligren.