

Home Range and Movements of Boreal Toads in Undisturbed Habitat

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I sampled movements and amount of area used by boreal toads (*Bufo boreas*) between June and October for 3 yr. Females were found farther from the breeding site than were males, and mean home ranges, as calculated by the adaptive kernel method, were four times larger for females than for males. Temperature and snow accumulation were comparable over the study, but data collection was hampered by mortality of animals caused by an outbreak of amphibian chytridiomycosis in yr 2. These data provide insight into use of habitat by boreal toads in undisturbed areas but may not be typical of a completely healthy population.

BOREAL toads are found at higher elevations in the southern Rocky Mountains (2000–3500 m, Hammerson, 1999) and are an endangered species in the state of Colorado. Habitat destruction has not been identified as a significant factor in this decline (Muths and Corn, 2000), in part because these toads are found in areas that are typically under federal or state protection, for example, National Park Service, USFS or BLM lands. However, with increased use of the backcountry and increased development around ski areas, a need to understand the use of habitat and habitat requirements of the boreal toad has become imperative. The aims of this study were to (1) determine overall home-range size defined by the maximum area used by a toad during its postbreeding active season (June to October), (2) determine maximum and minimum distances moved from the breeding site, and (3) examine differences between male and female toads for these two parameters. I radio tracked boreal toads resident in a single drainage in Rocky Mountain National Park. The population appeared to be robust at the beginning of this study (Corn et al., 1997) but continued monitoring revealed a sharp decline in the number of male toads and identification of the lethal chytrid fungus (*Batrachochytrium dendrobatidis*) in live and dead toads collected in the drainage (Muths et al., in press).

Knowledge regarding the home range, or amount of area used by toads, is limited. Brattstrom (1962), Zug and Zug (1979), Bayliss (1995), and Seebacher and Alford (1999) discuss movements and the use of habitat by cane toads (*Bufo marinus*). Griffin and Case (2001) discuss terrestrial habitat preferences in Arroyo toads, Parker and Gittins (1979) discuss home range in the common toad (*Bufo bufo*) and Denton and Beebee (1996) examine habitat occupancy by juvenile natterjack toads (*Bufo calamita*). Dispersal and migration distance have been the subject of a number of studies; for example,

Kusano et al. (1995, *B. japonicus*), and Miaud et al. (2000, *B. calamita*). Other investigations have addressed aspects of toad ecology and behavior related to the use of habitat: migration and movements (Sinsch, 1988, 1990, *B. bufo*); homing (Sinsch, 1990, *B. bufo*); and use of refugia (Denton and Beebee, 1993, *B. bufo* and *B. calamita*). Information specific to boreal toads is, however, limited. Campbell (1970) reports on movements of boreal toads between breeding sites, Hailman (1984) discusses activity patterns, and Bartelt (2000) addresses distances moved from the breeding site and biophysical parameters affecting habitat selection in Idaho. Jones (Colorado Division of Wildlife boreal toad research progress report, p. 1–19, 1999, unpubl.) discusses home-range and movements.

MATERIALS AND METHODS

Toads were captured by hand at one breeding site in the North Fork drainage of the Big Thompson River in Rocky Mountain National Park. Captured animals were routinely given a PIT (passive integrated transponder) tag to identify individuals (Camper and Dixon, Evaluation of a microchip marking system for amphibians and reptiles, Texas Parks and Recreation Dept. Research Publication 7100–159:1–22, 1988, unpubl.) and snout–vent length (SVL), mass, and sex were determined. Fourteen adult boreal toads (six females and eight males) were fitted with radio transmitters between 1998 and 2000 and tracked throughout their postbreeding active season. Sizes of toads used for telemetry averaged 39.5 g (males) and 76.4 g (females); SVL averaged 65.4 mm (males) and 81.7 mm (females). The mass of the transmitter, including the belt used for attachment was 1.82 g, less than or equal to 5% of the mass of the lightest toad tracked. I used BD-2G transmitters from Holohil Systems® with an average battery life of 9–16 weeks. Transmitters were fitted to

toads using a modification of the belt system of Bartelt and Peterson (2000). I used 5 mm flexible rubber tubing with a 1.5 mm diameter hole. Inside the tubing, I used stainless steel, nylon-covered wire (#27 Sevalon Tackle Corp., Long Beach, CA). The transmitter was threaded onto this metal wire and the wire crimped shut with 9 mm long, 4 mm diameter metal leader sleeves. The rubber tubing prevented most all chafing of the animal's skin. Wire ends were clipped flush with the metal sleeve. Fitting an animal with the radio collar took from 3–6 min, and animals were monitored until they disappeared into the underbrush, usually less than 3 min after release.

Toads were tracked using a Telonics TR-4 radio receiver and a Yagi antenna (Telonics model RA-14). Range of the radio signal varied depending on the habitat. I received signals from as far away as 0.5 km, whereas other signals were not audible until I was within 5 m. I searched for toads once per week; time between locations was at least five days. When animals were located, the position was noted using GPS (error \leq 8 m). I determined the substrate that the toad was sitting on and the orientation of the toad. I double-checked the animal's identity using a PIT tag scanner but did not assess mass and SVL at each capture. These measurements were taken 2–3 times during the season to monitor general health of the animal. Transmitters were removed before battery life was expected to run out.

Air and water temperatures were monitored throughout the study (May to October) using HOBO temperature loggers (Onset Computer Corp.[®]) located at the breeding site. Snowpack (measured in snow water equivalents [swe]) and precipitation were measured by the USDA Natural Resources Conservation Service, National Water and Climate Center (<http://www.wcc.nrcs.usda.gov/factpub/ads/adscosnt.html> and <http://www.wcc.nrcs.usda.gov/factpub/ads/adscopcp.html>, respectively).

I used the program CALHOME (CALHOME: A home range analysis program, MS-DOS vers. 1.0, J. G. Kie, 1994) and the adaptive kernel method (Worton, 1989) to calculate the 95% area home range used by each animal during the active season. Nonindependence was addressed by taking the animal, rather than the location as the sampling unit (Aebischer et al., 1993). No changes were made to the default settings on the CALHOME program. Home-range size (m^2) was compared to provide relative values for area used by female and male toads.

The straight-line distance from each location of each individual toad to the center of the

breeding site was calculated in ARCVIEW using the "near" function. These data were analyzed using PROC MIXED (SAS/STAT user's guide, vers. 6. 4th ed. SAS Institute, Cary, NC, 1990). Because repeated locations were taken on each toad through time, PROC MIXED was used to model the covariance structure of the data (SAS[®] System for Mixed Models, R. C. Littell, F. A. Milken, W. W. Stroup, and R. D. Wolfinger, SAS Institute, Cary, NC, 1996) for appropriate estimation of mean distance from center of breeding pond by sex. Sex, date (as Julian day), and sex \times date were included in the mixed model as fixed effects and toad nested within sex was the experimental unit (subject) on which repeated measurements were taken. The within-subject covariance structure of the data was assessed using the full sex \times date model. Akaike's information criterion corrected for small sample size (AICc; Anderson et al., 2001) was used to rank unstructured, compound symmetry (random effects), compound symmetry with heterogeneous variances, and temporal autocorrelation covariance models (SAS/STAT user's guide, vers. 6. 4th ed. SAS Institute, Cary, NC, 1990). The information-theoretic approach and AIC is the most appropriate method of analysis, it avoids the use of arbitrary significance (α) levels and is based on the principle of parsimony (Anderson et al., 2001). This approach advocates a criterion for model selection that incorporates model fit as well as the number of parameters in the model (Burnham and Anderson, 1998). Missing values were accounted for by temporally aligning the time each location was taken between toads (SAS[®] System for Mixed Models, R. C. Littell, G. A. Milken, W. W. Stroup, and R. D. Wolfinger, SAS Institute, Cary, NC, 1996). Unequal time intervals were accounted for by using the spatial power structure for covariance, which is a generalization of the temporal autocorrelation structure for measurements taken at unequal time intervals.

Using the best model for the covariance structure, as indicated by the lowest AICc value, a sex + date and sex model was run to find the most parsimonious model to examine differences by sex. Once the covariance and structural model were chosen (based on minimum AICc values), least-square means in PROC MIXED (SAS[®] System for Mixed Models, R. C. Littell, G. A. Milken, W. W. Stroup, and R. D. Wolfinger, SAS Institute, Cary, NC, 1996) was used to estimate mean distance to center of breeding pond by sex and the difference in mean distance to center of breeding pond between sexes. Type III sum-of-squares was used for all hy-

TABLE 1. THE NUMBER OF TIMES EACH TOAD WAS LOCATED (=LOCATIONS) AND AREA USED, DATES TOADS WERE TRACKED AND SEX OF RADIO-TRACKED TOADS.

| Toad id | Sex | Dates tracked | Number of locations | Area (m ²) |
|---------------------------------|-----|---------------|---------------------|------------------------|
| 221 | F | Jun-Jul 1998 | 7 | 118,200 |
| 219 | M | Aug-Oct 1998 | 16 | 266,814 |
| 184 | M | Jun-Aug 1998 | 12 | 32,190 |
| 309 | M | Aug-Oct 1998 | 13 | 8,870 |
| 015 | F | Jul-Sep 1999 | 10 | 714,300 |
| 155 | F | Jul-Sep 1999 | 10 | 22,887 |
| 103 | F | Jun-Aug 1999 | 16 | 587,600 |
| 132 | M | Jul-Sep 1999 | 9 | 87,710 |
| 065 | M | Jul-Sep 1999 | 15 | 24,030 |
| 194 | M | Jul-Sep 1999 | 9 | 25,852 |
| 232 | M | Jul-Sep 1999 | 10 | 18,170 |
| 566 | F | Jul-Oct 2000 | 10 | 12,750 |
| 618 | F | Aug-Sep 2000 | 5 | 20,264 |
| 593 | M | Aug-Sep 2000 | 9 | 2,746 |
| Total locations: F = 58; M = 93 | | | | |

pothesis tests to account for unequal sample sizes.

RESULTS

Toads were tracked between June and October each year. Toads were caught and radios attached after breeding during routine site surveys; therefore, the number of locations and time of year when tracking took place varied among toads (Table 1). The mean home range of females was four times larger than the mean male home range (Table 2).

The covariance model with the lowest AICc was the temporal autocorrelation model (78.6 AICc units lower than the second best model). Using this model for the covariance structure, I compared the sex × date model to the sex + date model and sex model. The sex × date model had the lowest AICc value (4.9 AICc units lower than the sex + date model and 8.7 AICc units lower than the sex model) and was used to estimate distance to center of breeding pond by sex and the difference in distance to center of breeding pond between sexes.

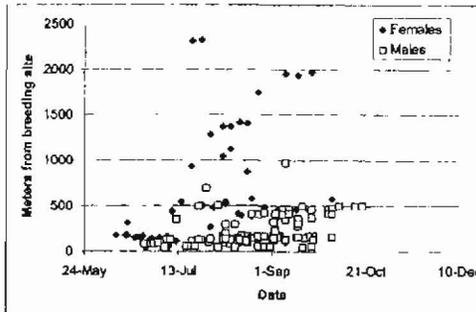


Fig. 1. Distance of toads from breeding pond after the breeding season (all years and all locations plotted for each animal: females n = 58, males n = 93).

The estimated mean distance at which female toads were found away from the center of the breeding pond was 721.46 m (SE = 167.21); the estimated mean distance for males was 218.15 m (SE 142.19). The mean distance for females was 3.0 times as far away as for males. The difference in the least-square means between sexes for distance was 503.31 (SE = 219.49; df = 121; *t* = 2.29; *P* = 0.04; Fig. 1). The maximum mean distance of locations away from the breeding pond was two times greater for female toads than for male toads. The minimum distance was three times greater for females than males (Table 2). The longest distance traveled away from the breeding pond in one season was 2324.3 m (female) and 970.8 m (male).

Between 1998 and 2000, average monthly air (June to August) and water (June to September) temperatures varied by ≤ 2.8 and ≤ 3.0 C, respectively. October water temperature average varied from 6 to 17 C, and the October air temperature average varied from 22 to 16 C (there were no air temperature data for September and October 1999). Interannual variation in snowpack and precipitation was negligible (24.0, 24.2, and 25.5 swe; and 109, 114.8, and 113.8 inches), respectively for 1998, 1999, and 2000.

Beginning in 1999, toads of the appropriate size to radio were difficult to find in spite of

TABLE 2. AREA OF HOMERANGE; MEAN (ESTIMATED VALUES FROM PROC MIXED), MEAN MAXIMUM AND MEAN MINIMUM DISTANCES OF TOAD LOCATIONS AWAY FROM THE CENTER OF THE BREEDING POND.

| Sex | N | Mean area (m ²) | Range (m ²) | SD | Mean distance (m) | Mean maximum distance (m) | Mean minimum distance (m) |
|--------|---|-----------------------------|-------------------------|------------|-------------------|---------------------------|---------------------------|
| Female | 6 | 246,000.2 | 701,550 | 318,581.23 | 721.46 | 905.154 | 392.003 |
| Male | 8 | 58,298.8 | 264,068 | 88,148.63 | 218.15 | 461.903 | 130.978 |

increased efforts, caused by the reduced numbers of animals present. Eleven of the animals tracked were healthy when last seen, and three were symptomatic of chytrid fungus (Muths et al., in press) when they were collected at death.

DISCUSSION

Size of home range.—The home ranges of female toads may be larger than the home ranges of males because of increased energetic demands and food requirements in females preparing for reproduction. Female boreal toads reach sexual maturity at five or six years of age (Carey et al., in press) and probably do not breed annually (Muths and Corn, 2000; Carey et al., in press). The length of time to maturity is likely a function of the energetic expense of vitellogenesis. At elevations typical of boreal toad habitat, growing seasons are short such that the production of a clutch of eggs by a female may require multiple seasons.

A year-long study by Jones (Colorado Division of Wildlife boreal toad research progress report, p. 1–19, 1999) used the fixed kernel method to estimate home range sizes in boreal toads. Although home ranges were smaller overall than the present study, female home ranges were still 2.4 times larger than male home ranges. Postbreeding activity areas were measured at 220 m² ($n = 15$) for Japanese toads (Kusano et al., 1995); much smaller than the home ranges reported here. Differences may be related to a number of factors: the duration of the studies (1 yr [Jones, Colorado Division of Wildlife boreal toad research progress report pp 1–19, 1999] and 4 mo. [Kusano et al., 1995]); habitat, (a heavily disturbed mining site [Jones, Colorado Division of Wildlife boreal toad research progress report, p. 1–19, 1999.] and a human-modified garden and agricultural landscape [Kusano et al., 1995]); or size, Japanese toads are larger (> 100 mm SVL, Kusano et al., 1995) than boreal toads.

Distances moved from breeding site.—I found that females moved farther from the breeding site than males and that mean minimum and maximum distances were also greater for females. Natterjack toads in Spain, tracked during the nonbreeding season, did not show differences between sexes in the distances they moved from the breeding site (Miaud et al., 2000). However, Bartelt (2000) found that female boreal toads in Idaho moved significantly farther from the breeding site than males ($P = 0.041$). He found the greatest distance traveled by a male to be 0.94 km and the greatest distance moved by a

female to be 2.44 km, 2.6 times greater than the male. In the present study, the greatest distance traveled by males and females was nearly the same (0.97 km and 2.3 km, respectively) and the ratio of female to male maximum distance traveled is comparable at 2.4. The similarity between these two studies of boreal toads at different locations within their range suggests that these distances are representative.

Miaud et al. (2000) found that 95% of the movements by natterjack toads were within 700 m of the breeding site. In the present study, 92% of the movements were within 700 m of the breeding site (99% of the movements by male toads, but only 74% by female toads; Fig. 1). Toads appear to move in linear patterns away from the breeding site (Bartelt, 2000).

Movement patterns of anurans may be influenced by environmental conditions such as temperature and moisture availability (Sinsch, 1988; Bayliss, 1995; Bartelt, 2000). For this study, weather conditions were comparable throughout, suggesting that these factors did not significantly affect the between-year variation in movements and area used by these toads.

Management implications.—Ski area expansion is one example of development that is occurring in habitats occupied by boreal toads. Ski areas require a good deal of infrastructural support such as lift operations, lodging, residences, food service, and parking facilities. Current regulations may not provide sufficient buffers between habitats used for toads and developments. For example, the setback requirement for the Cucumber Gulch Overlay Protection District in the town of Breckenridge, Summit County, Colorado is 300 feet (91 m) from "the edge of wetlands containing principal water bodies" (Town of Breckenridge, Council Bill No. 36, Series 1999; Ordinance #9, Series 2000). Countywide setback regulations in Summit County are presently at 25 feet (7.6 m) for all wetlands in the county but are under revision. The use of upland habitat by semiaquatic animals, including amphibians, has been documented (e.g., Dole, 1965; Semlitsch, 1981; Griffin and Case, 2001). In their study of freshwater turtles, Burke and Gibbons (1995) found that federally delineated wetland boundaries failed to protect any nests or hibernation burrows at their study site and suggested that there is a real need to protect upland habitat beyond federal wetland boundaries. My study found that boreal toads use wet meadows and upland areas up to 2 km away from the breeding site but does not document the intensity of the use of habitat at breeding sites versus postbreeding locations. Other stud-

ies suggest that boreal toads travel in straight lines from the breeding site to summer refugia (Bartelt, 2000). Semlitsch (1981) found that another amphibian, the mole salamander (*Ambystoma talpoideum*), travels to and from breeding sites in a nonrandom manner. However, this study discriminated between linear movements that are migratory versus movements within a home range (Semlitsch, 1981). To my knowledge, the difference between movements to and movements within postbreeding habitat, has not been addressed for toads. Therefore, it is unclear whether larger areas around toad breeding sites need to be protected or whether corridors leading to protected areas centered on more distant postbreeding habitat are a tenable alternative. This study as well as other studies on various herpetofauna suggest that protecting nonbreeding habitat in areas of extensive development presents a challenge.

Data from this study provide useful guidelines for determining areas of toad habitat conservation that should be considered in management decisions. As human development continues, knowledge about habitat requirements for small animals such as the boreal toad becomes more critical. More detailed work is clearly needed to define the spatial use of habitat by boreal toads with equal emphasis on wetland and upland habitats.

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