Management and Conservation Article

Ecology and Translocation-Aided Recovery of an Endangered Badger Population

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ABSTRACT Southern British Columbia, Canada, is the northwestern range limit of the American badger (*Taxidea taxus*) and supports a nationally endangered subspecies. We initially investigated space-use, diet, and demography in southeastern British Columbia to characterize range-limit ecology. Resident badgers in the northern part (NP) of our study area were extirpated or nearly so during our study ($\lambda = 0.7$), whereas the southern (SP) badger population remained viable ($\lambda = 1.2$). This apparent difference in viability between NP and SP may have been confounded by timing because research occurred later in SP; litter size, number of Columbian ground squirrels (*Spermophilus columbianus*) consumed, and home range size were each correlated nearly equally to latitude and date of research, and survivorship was greater later in the study for both the NP and SP. Collectively, these factors indicated temporal, not just spatial, variability. Therefore, we translocated badgers into the NP to 1) determine whether the NP had lost its capacity to support badgers or had merely experienced the variability expected at a range limit and, if the latter, 2) initiate recovery. Translocated animals and their offspring had kit production equivalent to that of SP residents, adult survivorship intermediate between the NP and SP residents, and no confirmed kit mortality, with population growth projected ($\lambda = 1.3$). Diet of translocated individuals was similar to that of residents. Home ranges of translocated females were intermediate between the 2 resident groups, and home ranges of translocated males were not different than either resident group. Juvenile dispersal dates and distances were similar to those of residents for each sex. Our results were consistent with the extirpation of the NP being driven by temporally variable conditions or the effect of random events expected at range limits. The extirpation of NP did not appear to have been primarily due to any permanent loss of the NP's capacity to support badgers. At 3.5 years after starting translocations, badgers remained in the NP within an apparently growing population. We found translocation to be a useful diagnostic and conservation tool for badgers at their northern limit. Its utility may extend to countering the fluctuations typical of other rare, range-limit species. (JOURNAL OF WILDLIFE MANAGEMENT 72(1):113–122; 2008)

The northwestern limit of American badgers (*Taxidea taxus*) is in southern British Columbia, Canada, where they occur mainly in open habitats at lower elevations (Rahme et al. 1995, Newhouse and Kinley 2000, Apps et al. 2002). The subspecies present there, *T. taxus jeffersonii*, occurs through much of northwestern and southwest-coastal United States but is endangered in Canada, is red-listed by the provincial Conservation Data Centre, and has a provincial population of <600 distributed over 120,000 km^2 (Long 1972, Cannings et al. 1999, Newhouse and Kinley 2000, Committee on the Status of Endangered Wildlife in Canada 2006).

Range limits are expected to be dynamic, with populations near them typically occurring at low, variable densities and exhibiting source-sink patterns (Guo et al. 2005, Lomolino et al. 2006). Given British Columbia's peripheral location in badger range and its low-density population, we anticipated that badger ecology might differ from more central parts of its range, including having unstable population dynamics. In 1996, we initiated telemetry-based research in southeastern British Columbia to gain an understanding of space-use characteristics, diet, and demographic trends. We compared animals living near the extreme range limit (the northern portion of this population; NP) to those farther south (SP). During the 10-year study, there was evidence that the NP (where research began) was at or near extirpation, whereas the SP (where research was completed) remained relatively

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viable. Because of the simultaneous shift of research effort in both time and space, we investigated whether the observed differences in autecology between NP and SP were more attributable to temporal or spatial variability. Results were ambiguous, so we translocated badgers to NP beginning in 2002 to test this question more directly.

We used translocation to determine whether extirpation from the NP reflected a permanent decline in the conditions required to support badgers or merely the temporal variability expected at a range limit. Associated with this, our goal was to re-establish a badger population in the recently extirpated area.

STUDY AREA

Our study was centered on the Rocky Mountain Trench in southeastern British Columbia, Canada, extending north about 250 km from 49°N (United States border) to 51°N. The Trench had a minimum elevation of 695 m and separated the Rocky Mountains to the east from the Purcell Mountains to the west (max. elevations of 3,618 m and 3,457 m, respectively). We monitored radiotagged badgers making forays into the Rocky or Purcell mountains, but all captures and almost all badger activity occurred within a 4,000-km^2 area of the Trench or at the mouths of major tributary valleys. Zonal ecosystems in this region followed an elevation sequence from the Ponderosa Pine (PP) biogeoclimatic zone at the lowest elevations in the warmest, driest areas, through the Interior Douglas-fir (IDF), Montane Spruce (MS), Engelmann Spruce–Subalpine Fir

(ESSF), and Interior Mountain-heather Alpine (IMA) zones. The Interior Cedar–Hemlock (ICH) zone occurred in place of the MS where precipitation was greater (Braumandl and Curran 1992; Research Branch, Ministry of Forests and Range 2006). The PP and IDF corresponded roughly to the Trench and were historically dominated by open forests of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) on zonal sites, grass-shrublands on more xeric sites, and extensive marsh and forested riparian habitat along rivers. However, human settlement had resulted in much residential, recreational, road, and agricultural development along the valley bottoms, along with conifer encroachment into formerly open habitats due to fire suppression (Machmer 2002). Climax forests in the MS, ICH, and ESSF were closed-canopy stands of, respectively, hybrid white spruce (*Picea glauca* × *engelmannii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*), and Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). However, the MS, ICH, and ESSF had a history of fire and timber harvesting, so they also included roads, cutblocks, burns, and younger forest stands with a high proportion of lodgepole pine (*Pinus contorta*) and other trees. The IMA was nonforested.

The NP and SP differed in several respects. North of 49° 54′N, the Trench was narrower (3–12 km vs. 12–30 km wide), lacked northern pocket gophers (*Thomomys talpoides*), lacked the PP zone, had slightly higher valley-bottom elevations, included several locations where villages or resort communities extended across ≥1 side of the Trench from valley floor to mountainside, and included the normal limit of badger distribution.

We trapped translocated badgers about 100 km beyond the southern study area boundary near the south end of the Rocky Mountain Trench in the cities of Kalispell and Whitefish, Montana, USA, and at the southern end of the Salish Mountains, 30–50 km west of Kalispell. Trap sites of all translocated badgers were in the IDF zone (Demarchi et al. 2000).

METHODS

Capture and Monitoring

We identified trap sites in British Columbia by checking locations of sightings reported by the public, areas where we found badger burrows, colonies of Columbian ground squirrels (*Spermophilus columbianus*), and the burrows of already-tagged badgers (to capture kits or replace failing radiotransmitters). We trapped badgers at burrow entrances, generally using unbaited size 1.5 soft-catch leghold traps, and checked traps at least daily. We noosed and hand-injected trapped badgers with either 10 mg/kg of tiletamine hydrochloride–zolazepam hydrochloride mixed at 100 mg/mL, or a combination of 0.3 mg/kg of midazolam mixed at 1.0 mg/mL and 9 mg/kg of ketamine hydrochloride mixed at 100 mg/mL. We conducted surgical implantation of intraperitoneal transmitters (model TL-5920 with a mortality sensor detecting lack of movement over 4 hr; Advanced

Telemetry Systems, Isanti, MN) either in a veterinary clinic or in the field following Hoff (1998). While badgers were immobilized, we took samples of blood, feces, and hair and an upper premolar tooth. When badgers were alert, we released them at the trap sites, if burrows were still intact, or at nearby burrows. We aged collected teeth by counting cementum annuli at Matson's Laboratory (Milltown, MT). All methods were approved by the British Columbia Animal Care Committee, Ministry of Water, Land and Air Protection, Victoria, British Columbia (approval no. CB05-7106).

We used northwestern Montana as a source for badgers to translocate because of its proximity, its location in the range of the same subspecies (Long 1972), genetic similarities to badgers in our study area (Kyle et al. 2004), and classification indicating a more secure status there (Montana Fish, Wildlife and Parks 2002). The location for trapping badgers for translocation was selected by Montana Fish, Wildlife and Parks staff based on high-density badger populations. We targeted individuals captured in Kalispell and Whitefish due to complaints of badgers in urban areas. All handling methods were the same as in British Columbia except that we dewormed and applied flea ointment to badgers from Montana. We obtained all required federal (United States and Canada), state, and provincial approvals or inspections for each badger. We released badgers the day after capture or, if veterinarian services or inspection personnel were unavailable, up to 3 days after capture. We released badgers at currently unoccupied badger burrows in active Columbian ground squirrel colonies. We selected release sites based on 1) location in the NP (i.e., north of 49°54′N), 2) high habitat quality extending over a large area, based on habitat suitability modeling and subjective assessments (Apps et al. 2002), 3) dense ground squirrel populations, 4) known recent use by badgers, 5) low risk of vehicle collisions (i.e., few roads or little traffic), and 6) little or no human settlement. We radiotagged kits born in British Columbia to translocated females, following methods identical to those we used for residents.

We monitored badgers using an airplane from June 1996 to February 2006, using standard radiotelemetry techniques (Samuel and Fuller 1996). Generally, we located animals weekly from April through September and twice monthly to monthly from October through March. In searching for badgers that were not readily located, we periodically extended monitoring flights northward in the Rocky Mountain Trench to 75 km beyond the northernmost radiolocation, southward to the area where translocated badgers were trapped, and up to 15 km into the Purcell, Salish, and Rocky mountains, an area of about 20,000 km². For 41% of locations we used ground-based telemetry to locate badgers in their burrows. From 1996 to 2000, we marked locations on 1:20,000 air photos and transferred them to 1:20,000 provincial forest inventory planning maps, from which we determined Universal Transverse Mercator (UTM) grid coordinates. After 2000 we used Global Positioning System units to record UTM coordinates. With

the probable exception of some air-only locations, all data points were of badgers in burrows rather than above ground. When we detected a mortality signal, we visited the site, recovered the carcass or implant to confirm that the badger had died, and recorded evidence of the cause of death where possible.

Demographic Investigations

From May through July we checked for kits at burrows of all radiotagged females ≥1 year old. Kits typically spent considerable time playing above ground at the burrow site. In addition, we checked all females at the time of capture for signs of lactation. For resident badgers, we developed linear regressions of litter size in relation to both UTM northing and year. Logistic relationships would be more likely over the entire range and history of badgers, but our study area covered <10% of the latitudinal range of badgers and a relatively short period. We did not wish to make predictions beyond the limits of our study (see Guthery and Bingham 2007), and our data fit linear better than logistic patterns for this and comparisons described below (based on root mean square error [RMSE]), so we report linear regression results here. We conducted F-tests for significance of regression equations. We used FINDGRAPH Version 1.782 (Uniphiz Lab Software, Vancouver, BC, Canada) to compare logistic to linear regression and performed all other statistical tests with the program JMP IN Version 5.1 (SAS Institute, Cary, NC).

We used the staggered-entry Kaplan–Meier method to determine juvenile survivorship, including for residents, translocated badgers, and the offspring of translocated badgers (Pollock et al. 1989). We assumed a 15 April birthdate given our northern location and terminated the analysis at 52 weeks (Messick and Hornocker 1981). We calculated and plotted the survivorship function and 95% confidence intervals for each week. We entered into the adult sample for further analysis badgers tagged as juveniles that survived to 15 April of the following year. We also used the Kaplan–Meier method to determine adult survivorship, both for residents and translocated animals (including descendents ≥1 yr of age). From this, we extrapolated annual adult survivorship by taking the nth root of the cumulative weekly survivorship, where n was the number of years. All resident animals from the NP died prior to the analysis completion date, so an extrapolation of annual rates using Kaplan–Meier methods was not possible. Thus, we also calculated annual adult survivorship for all classes using the Mayfield method (Winterstein et al. 2001). Unless there was evidence of the exact time of death, we assumed it to be midway between the last live telemetry date and the date on which we found the animal. For data censored due to lost telemetry contact, we assumed the censor date to be the midway point between the last successful telemetry location and the first failed attempt thereafter.

For residents of each of the NP and SP and for the re-established northern population (translocated animals and their descendents) we estimated the geometric growth rate (λ) by adding the annual adult survivorship to the product of the proportion of females, kits observed per adult female, and survivorship to age 1 year of radiotagged kits. We assumed an even sex ratio, based on the trapped sample of residents.

Diet Analysis

We manually extracted scats upon capture and obtained digestive tracts upon retrieval of carcasses, when possible. We also retrieved digestive tracts from nontagged badgers hit by vehicles within the Trench and reported to us. We identified skeletal remains from scat and digestive tract samples (Pacific Identifications Inc., Victoria, BC, Canada). We used Pearson chi-square tests to compare northern and southern residents with regard to the incidence of Columbian ground squirrels in samples and the incidence of having no animal remains, then we used the same tests to compare northern residents to the re-established northern population. For residents, we used linear regression analysis to compare the minimum number of Columbian ground squirrels per sample against date and UTM northing of each sample. We used F-tests to determine statistical significance for all linear regression analyses.

Space-Use Determination

Fixed kernel (FK) estimates of home range have been found to have lower bias and lower surface fit error than other methods so we estimated adult home range size as the 95% FK contour (Seaman et al. 1999). We also estimated 95% adaptive kernel (ADK) and 100% minimum convex polygon (MCP) home ranges to facilitate comparisons with studies that used other methods, and in the case of MCP, also as an indication of the gross area covered by each badger. We calculated ADK and FK ranges with THE HOME RANGER Version 1.5 (Hovey 1999), using a grid resolution of 100 pixels and standardizing x- and y-coordinates with multivariate normal scores, and determined MCP ranges with the ANIMAL MOVEMENT extension Version 2.4 (Hooge and Eichenlaub 2000). In cases where sequential locations were <4 days apart, we deleted the second telemetry location. Kernel home range estimates are influenced by sample size (Seaman et al. 1999). We did not include animals with <25 locations or <1 year of monitoring after an assumed first birthday of 15 April. For resident badgers and the re-established NP population separately, we compared home range sizes between sexes using Student's t-tests. We also used Student's t-tests to compare home range sizes between 1) NP and SP residents, 2) NP residents and the re-established NP population, and 3) SP residents and the re-established NP population. For both male and female resident badgers, we regressed MCP and FK home ranges linearly against median UTM northings and median dates of telemetry and regressed median UTM northing linearly against median date of telemetry. We conducted F-tests for the linear regression equations.

We considered juvenile dispersal distance to be the length from the point of capture (generally the maternal burrow) to the farthest point recorded through telemetry, regardless of
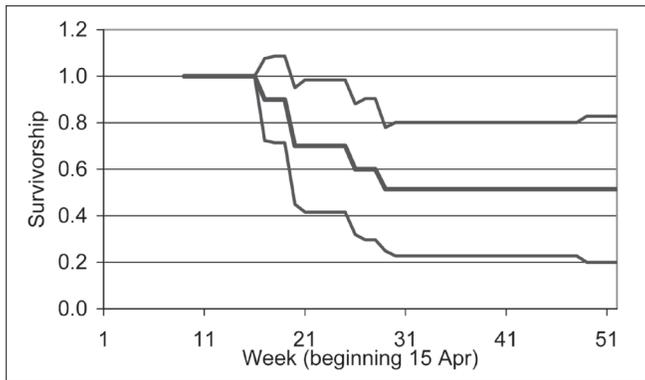
Figure 1. Kaplan–Meier survivorship (based on weekly intervals) and upper and lower 95% confidence intervals for 11 resident juvenile badgers, Rocky Mountain Trench, southeastern British Columbia, Canada, July 1997–April 2002.

age at which this occurred. Age at first dispersal was the date midway between the last telemetry location at the maternal burrow and the first telemetry location >1 km from the burrow. We determined age at first dispersal, age at maximum dispersal, and maximum dispersal distances separately for male and female kits, comparing these variables between offspring of resident mothers and descendents of translocated females. We did not assess badgers translocated as juveniles, because there was no maternal burrow from which to measure dispersal and all juveniles were rapidly lost from radio contact.

RESULTS

Residents

Between 1996 and 2002, we captured 33 badgers (16 M, 17 F; NP: 3 ad M, 4 ad F [one of which died of complications from surgery]; SP: 7 ad M, 6 ad F, 6 juv M [2 of which were too small to tag], 7 juv F). Only one NP animal was captured after 1998; we detected no other burrows of nontagged badgers in the NP from 1999 to 2002, and prior to translocating badgers to the NP we had evidence of only 2 nontagged animals there, both roadkills. Captures in the SP were from 1997 through 2002. We detected no substantial trap-related injuries. We obtained 1,554 telemetry locations ($\bar{x}$ = 51 locations/badger, range 8–178). As the study progressed, we captured and monitored study animals progressively farther south (median UTM northing vs. median telemetry date: linear r^2 = 0.83, P < 0.001, RMSE = 26 km).

Ages of adults at the time of capture varied from 1 year to 12 years. A NP-SP comparison was limited by the small sample, but no gross age-class differences were evident. Mean and median ages of adult badgers in the north were 5.0 years (SE = 1.3, n = 7) and 3 years, respectively, and those in the south were 4.6 years (SE = 0.9, n = 12) and 4 years, respectively.

We monitored 11 females during the kit-rearing period for 1–4 years each, providing a sample of 25 animal-years. In the NP, we observed zero kits in 10 animal-years (n = 4 ad F), whereas in the SP there were ≥19 kits from 12 successful

litters across 15 animal-years (n = 7 ad F). Correspondingly, there was a general tendency for litters to be larger farther south within our study area (linear r^2 = 0.57, P < 0.001, RMSE = 0.6) and later in the study (linear r^2 = 0.39, P < 0.001, RMSE = 0.7). Of 3 SP females observed at age 1, 2 had successful litters, compared to zero successful litters of one female in the NP.

Of the 11 juveniles radiotagged (all from the SP), 5 died in their first year of life and one was lost from radio contact. Annual Kaplan–Meier survivorship was 51%, with lower mortality from 6 months to 1 year of age (Fig. 1). Mortality causes included one train kill, one probable starvation, one possible cougar (*Felis concolor*) or bobcat (*Lynx rufus*) predation, and 2 unknown. Adult mortality causes included roadkill (4), probable cougar predation (1), probable bobcat predation (1), probable old age (1), and unknown (2). The oldest animal at the time of death was a 13.6-year-old female from the NP. Curves for resident adults indicated a lower mortality rate over roughly the last half of the study (Fig. 2). Based on Mayfield survivorship, λ estimates for the NP, SP, and combined, were 0.7, 1.2, and 1.0, respectively (Table 1). We obtained the same values using the Kaplan–Meier method for SP and combined (Table 1).

Resident badger prey was primarily Columbian ground squirrels, but included other rodents, birds, amphibians, and insects (Table 2). Comparing NP to SP, there was no difference in the proportion of samples lacking animal remains (χ^2 = 0.02, P = 0.885) nor in those containing ground squirrels (χ^2 = 0.68, P = 0.409). However, the number of ground squirrels per sample was weakly related to both northing (negative linear r^2 = 0.11, P = 0.039, RMSE = 0.8) and date (positive linear r^2 = 0.24, P < 0.001, RMSE = 0.7) within the bounds of our study area and period.

There was high variability in the data but home ranges were generally larger for males, especially when considering MCP (Table 3). For example, MCP home ranges were roughly an order of magnitude larger for males than females among all residents combined (P = 0.027; Table 3). Home range size was, in general, positively correlated to median UTM northing, particularly for MCP home ranges (M: P = 0.006; F: P = 0.023; Fig. 3). Home range was also negatively correlated to the median date at which data were collected, with the relationship being stronger for MCP among males (P = 0.008) and for FK among females (P = 0.037; Fig. 4) within the time and area where we collected data.

Translocated Animals and Their Offspring

We translocated 16 badgers from 2002 through 2004, including 8 adult males, 4 adult females, 2 juvenile males, and 2 juvenile females. We released all individuals within the NP and radiolocations were entirely within the NP, with the exception of 2 males having 3% and 23% of their locations in the SP, respectively. We also radiotagged 6 juveniles (4 F, 2 M) in our study area that were offspring of either translocated females or their kits. All juvenile radiolocations were in the NP but animals lost from radio contact may have dispersed beyond study area boundaries. We obtained 663 telemetry locations from translocated
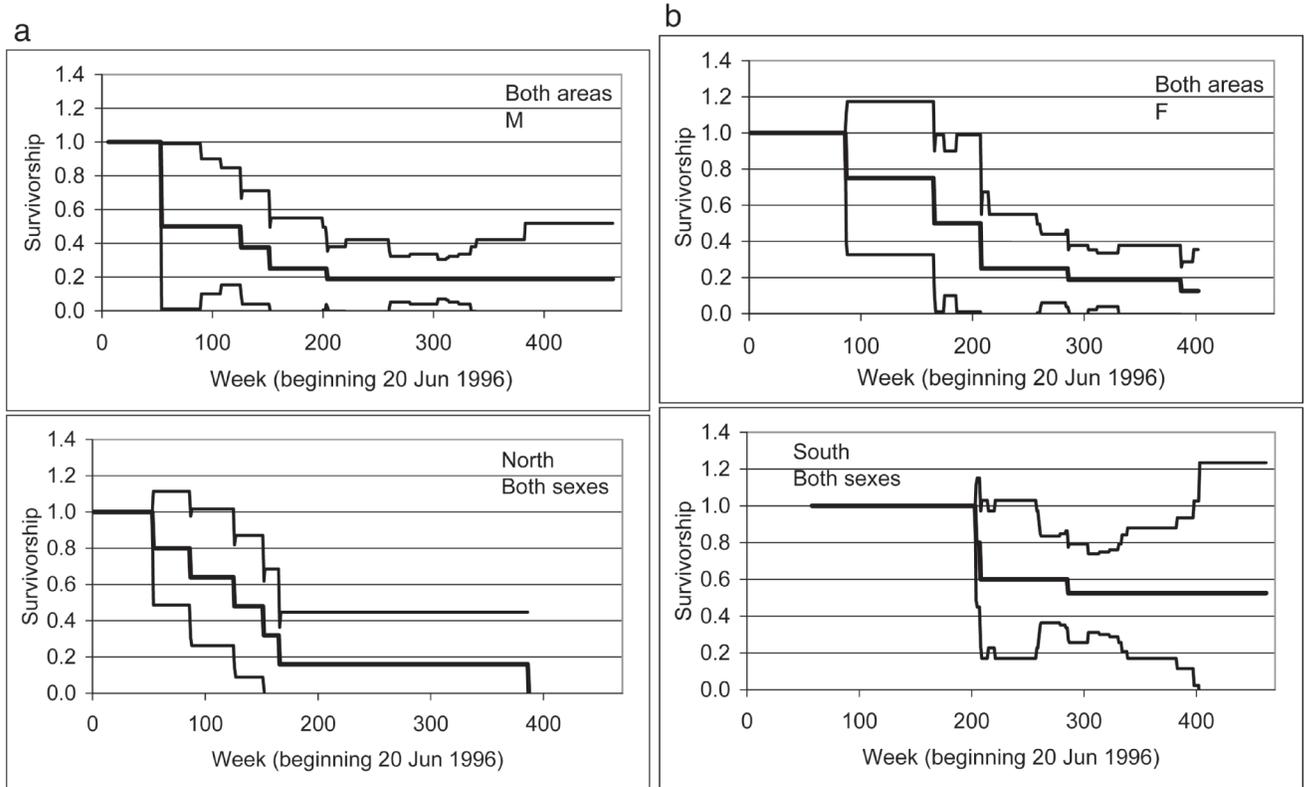
Figure 2. Kaplan–Meier survivorship (based on weekly intervals) and upper and lower 95% confidence intervals for resident adult badgers, Rocky Mountain Trench, southeastern British Columbia, Canada, June 1996–February 2006. Data for "both areas, females" end with censoring of last animal (loss of radio contact); data for "north, both sexes" end with mortality of last animal.

animals and their descendents ($\bar{x} = 30$ locations/badger, range 3–104).

Among translocated adult females and their female descendents, there were $\geq$10 kits from 5 successful litters across 8 animal-years of monitoring ($n = 5$ F including 3 >1 yr old). Of the 4 animals translocated as juveniles and the 6 radiotagged locally as juveniles, 4 survived to their first birthday, 6 were lost from radio contact prior to that date (including all 4 translocated as juv), and none were known to have died, corresponding to a 100% survivorship to age 1 yr.

Sources of mortality for translocated adults included roadkills (3), probable predation (2), and probable roadkill (1). Based on the Kaplan–Meier and Mayfield methods, annual translocated adult survivorship for males, females, and combined sexes was 74% and 74%, 77% and 81%, and

77% and 77%, respectively (Fig. 5). Based on either the Kaplan–Meier or Mayfield survivorship estimates and assuming an even sex ratio, $\lambda = 1.39$.

Translocated badgers consumed a variety of prey, with 5 of 12 samples containing ground squirrels, 5 with unidentified small mammals, one each of red squirrel (*Tamiasciurus hudsonicus*), possible red squirrel, *Microtus* spp. (most likely meadow vole, *M. pennsylvanicus*), and unidentified fish, and 2 containing no animal remains. The incidence of samples lacking prey remains did not differ between translocated animals and either NP ($\chi^2 = 0.10$, $P = 0.748$) or SP residents ($\chi^2 = 0.06$, $P = 0.804$), nor did the incidence of Columbian ground squirrels ($\chi^2 = 0.02$, $P = 0.899$ vs. NP residents; $\chi^2 = 1.16$, $P = 0.281$ vs. SP residents).

Though highly variable, home range sizes among trans-

Table 1. Annual survivorship of resident adult badgers, Rocky Mountain Trench, southeastern British Columbia, Canada, June 1996–February 2006.

	Method		
	Mayfield	**Kaplan–Meier**	
Area and sex	**Survivorship (%)**	**Survivorship (%)**	**95% CI**
North, both sexes ($n = 6$)	68.1	—[a]	
South, both sexes ($n = 13$)	90.2	92.0	0–100
Both areas, M ($n = 10$)	83.8	82.6	0–92.8
Both areas, F ($n = 9$)	81.2	76.4	0–82.6
All animals ($n = 19$)	82.4	81.8	0–91.9

[a] Could not be calculated; all animals died prior to end of monitoring period.

Table 2. Incidence of prey items in resident badger scats and stomachs from the Rocky Mountain Trench, southeastern British Columbia, Canada, 1996–2004, based on prey skeletal analysis.

	Samples having prey type (%)	
Prey type	North ($n = 9$)	South ($n = 30$)
Columbian ground squirrel	44	60
Chipmunk (*Tamia* spp.)	0	3
Possible red squirrel	0	3
Northern pocket gopher	0	3
Vole, possibly southern red-backed (*Clethrionomys gapperi*)	22[a]	0
Unidentified small mammal	0	7
Unidentified hair	11	10
Common loon (*Gavia immer*)	11[b]	0
Varied thrush (*Ixoreus naevius*)	0	3
Frog or toad	11	0
Long-toed salamander (*Ambystoma macrodactylum*)	0	3
Insect	33	13
No animal remains	22	20

[a] 2 badgers, one of which contained parts of ≥15 voles.
[b] One badger, containing parts of ≥3 loons.

located badgers were generally much larger for males than females (e.g., 20-fold difference based on MCP [$P = 0.036$; Table 3]). Within the limitations of small samples, translocated female home ranges appeared to be smaller than those of NP residents (unpooled *t*-test $t = 2.88$, $P = 0.067$ for 100% MCP; $t = 4.53$, $P = 0.088$ for 95% ADK; and $t = 5.30$, $P = 0.073$ for 95% FK) and was similar to those of SP residents ($t = -1.09$, $P = 0.358$ for MCP; $t = -1.64$, $P = 0.222$ for ADK; and $t = -1.64$, $P = 0.215$ for FK; Table 3). Translocated male home ranges were similar to those of NP residents ($t = -0.22$, $P = 0.832$ for MCP; $t = -1.08$, $P = 0.333$ for ADK; and $t = -1.09$, $P = 0.327$ for FK) and possibly larger than those of SP residents ($t = -3.02$, $P = 0.048$ for MCP; $t = -2.16$, $P = 0.111$ for ADK; and $t = -1.98$, $P = 0.131$ for FK; Table 3).

Compared to the 6 female kits born to SP residents, the 3 female kits of translocated females did not differ in age at first dispersal (106 days for residents vs. 100 days for translocated, $t = 0.60$, $P = 0.571$), age of maximum dispersal (176 days vs. 242 days, $t = -0.53$, $P = 0.636$), or maximum dispersal

distance (11.0 km vs. 38.8 km, $t = -1.66$, $P = 0.230$). For males, the 4 born to residents showed some indication of making first dispersals later than the 3 born to translocated females (325 days for residents vs. 104 days for translocated, $t = 2.73$, $P = 0.071$) and possibly making maximum dispersals at a later age (495 days vs. 268 days, $t = 2.18$, $P = 0.118$), but had identical maximum dispersal distances (both 26.1 km, $t = -0.0005$, $P = 1.000$).

DISCUSSION

Our demographic results pointed to a growing resident badger population in the SP but a declining resident population in the NP. With no reproduction in the NP nor evidence of live, untagged animals there, the resident population was likely extirpated with the death of our study animals. Considering this in conjunction with the viability of the SP, there appeared to be spatial variability in ecological or anthropogenic conditions along the Trench. However, demographic, space-use, and diet characteristics varied equally (though inversely) when considering date instead of latitude, which indicates that conditions may have varied temporally, not just spatially. Translocated badgers and their descendents in the NP showed demographic, space-use, and diet characteristics that were equivalent to or more positive than those of the original NP residents, in some cases more positive than in the SP, and indicative of growth, which is consistent with the temporal-variation possibility and also indicates that the study area likely did not represent a permanent source (SP)–sink (NP) situation.

Results from the SP also suggest temporal or spatial variability (or both) within the SP. Home ranges of females in the SP were similar to those reported for Colorado and Illinois, USA, but SP male home ranges were 4–7 times larger than reported in Colorado and Illinois (Tables 3, 4). Diet was similar to that reported in other studies (Salt 1976, Lampe 1982, Messick 1987). If female ranges are dictated mainly by food availability and those of males by the number of females, the similar diet and small female home ranges but large male home ranges suggest a locally adequate food supply but few animals. This would be consistent with patchiness in foraging opportunities or with a lag in population growth following recently improved foraging

Table 3. Minimum convex polygon (MCP), adaptive kernel (ADK) and fixed kernel (FK) home ranges of resident badgers in northern and southern portions of the Rocky Mountain Trench, southeastern British Columbia, Canada, 1996–2006 and adult badgers translocated to northern portion of Trench, 2002–2006.[a]

Area and sex	n	100% MCP (km²) $\bar{x}$	SE	P	95% ADK (km²) $\bar{x}$	SE	P	95% FK (km²) $\bar{x}$	SE	P
North resident M	3	654	107	0.032	185	80	0.318	99	49	0.466
North resident F	2	79	8		79	13		55	8	
South resident M	6	125	48	0.076	70	29	0.073	47	19	0.075
South resident F	5	18	6		5	2		3	1	
All resident M	9	301	98	0.027	108	35	0.056	64	21	0.070
All resident F	7	35	12		26	14		18	10	
Translocated M	4	702	185	0.036	343	123	0.076	194	72	0.082
Translocated F	3	34	14		14	6		9	3	

[a] Sample includes only animals with ≥25 radiolocations across ≥1 yr after an assumed first birthday of 15 April. *P*-values refer to unpooled *t*-test for differences between sexes.
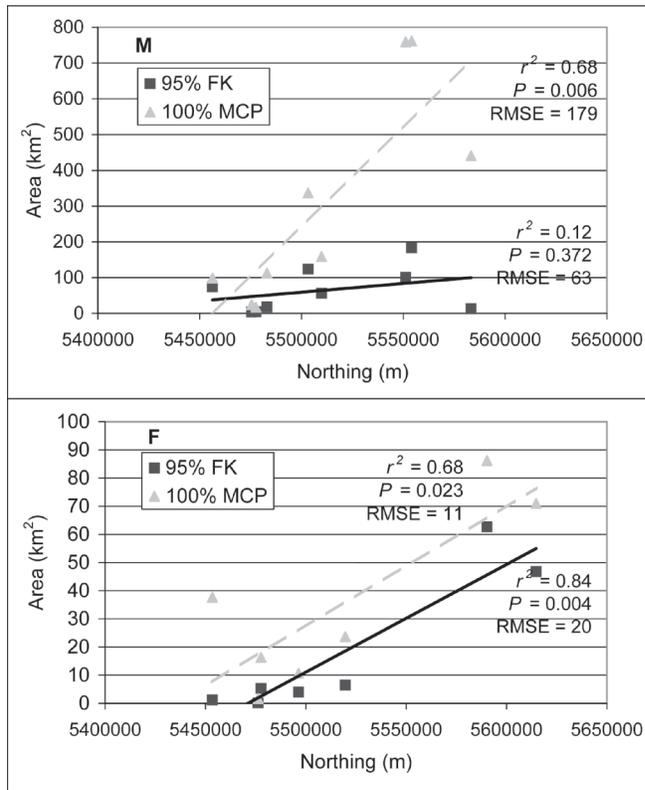
Figure 3. Resident badger home range size in relation to median Universal Transverse Mercator northing of telemetry locations, Rocky Mountain Trench, southeastern British Columbia, Canada, June 1996–February 2006. Measures based on minimum convex polygon (MCP) and fixed-kernel (FK) estimators. Sample includes only animals with ≥25 locations across ≥1 year of monitoring after an assumed first birthday of 15 April. RMSE indicates root mean square error.

Figure 4. Resident badger home range size in relation to median date of telemetry locations, Rocky Mountain Trench, southeastern British Columbia, Canada, June 1996–February 2006. Measures based on minimum convex polygon (MCP) and fixed-kernel (FK) estimators. Sample includes only animals with ≥25 locations across ≥1 year of monitoring after an assumed first birthday of 15 April. RMSE indicates root mean square error.

conditions. Similarly, the relatively late dates of dispersal for residents, compared to roughly 60–75 days and 70–120 days in 2 Idaho populations, may be interpreted as either inhibited dispersal, as through habitat patchiness, or quality habitat capable of providing food for family groups over extended periods (Messick et al. 1981). Quality habitat over prolonged periods should have led to a large badger population and small home ranges for both sexes, suggesting recently improved conditions. The higher survivorship later in the study for both the NP and SP is indicative of temporal variation. Thus, it is likely that north–south differences reflected temporal in addition to spatial variability in key ecological or anthropogenic factors.

Population distributions often change dramatically and quickly, sometimes through congregation when density is low and outward movement from high-density areas (Taylor and Taylor 1977, 1979). Thus, the original loss of residents in the NP may have been related to a temporary worsening in habitat conditions or human impacts there, but our confidence is therefore also limited in assuming that growth following translocations is definitive evidence of long-term recovery. Predicting the future status of the new NP population would be aided by knowing the causal factors for the original decline or whether it was due to probabilistic phenomena. Range limits can be viewed as the result of
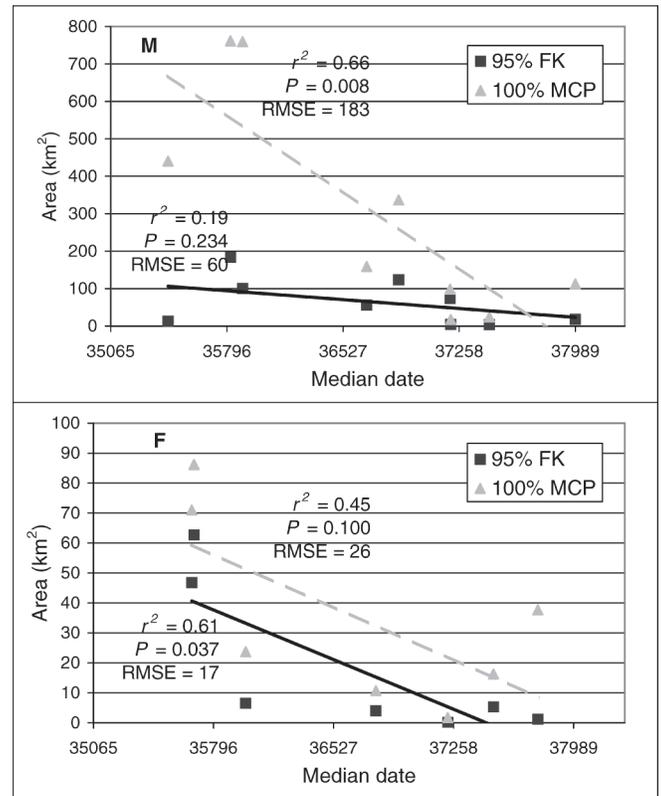
gradients in habitat availability, extinction rates, or colonization success (Holt and Keitt 2000, Holt et al. 2005), which all presumably become more limiting as the Trench narrows northward along a peninsula at the badger's northern limit. However, there is also a temporal component to range limits. Columbian ground squirrels were first provincially protected on public land in 1992 and they were slightly more common in badger diet later in the study, so there may have been an upward trend in prey (i.e., habitat quality). Local extinction rates should relate to increasing human populations through roadkill rates, but the lack of confirmed shootings or trapping of badgers may have reflected the subspecies' recent listing status, or outreach associated with our project, and suggest an opposing trend. Similarly, cougars declined across southeastern British Columbia during our study so predation on badgers should also have declined (G. Mowat, British Columbia Ministry of Environment, unpublished data). Colonization success is linked to landscape connectivity, which may decrease as resort and residential development occurs within the Trench, particularly in the NP (Taylor et al. 1993). Regardless, colonization is less likely with increasing distance from range centers, as in the NP. Considering both typical and dynamic conditions in habitat, extinction rates, and connectivity rates, it is likely that connectivity
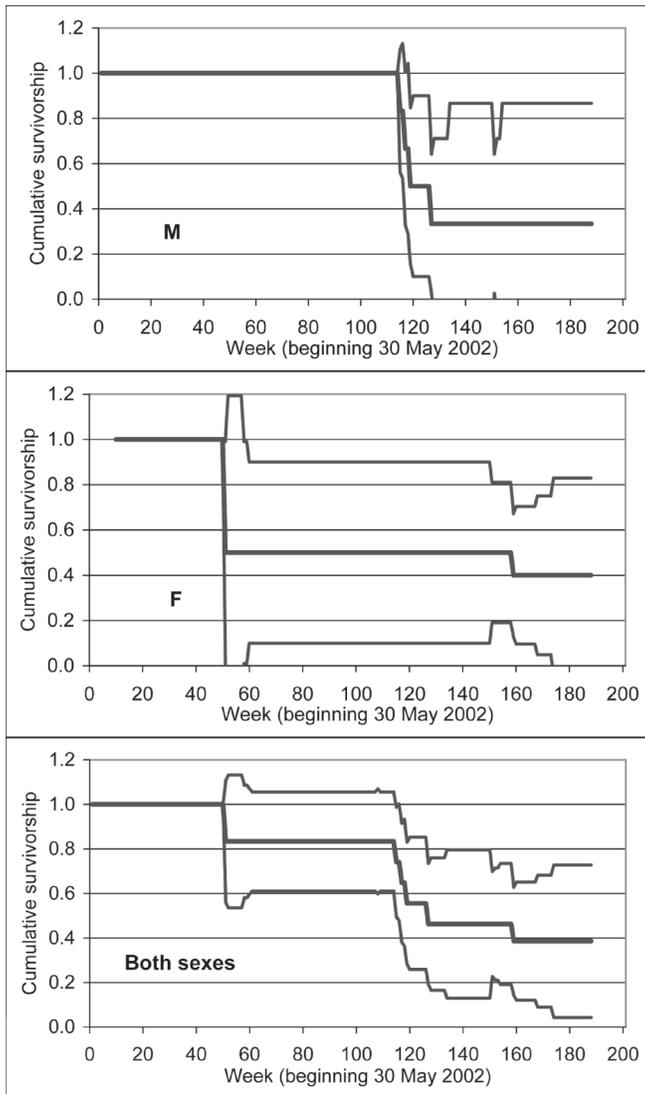
Figure 5. Kaplan–Meier survivorship (based on weekly intervals) and upper and lower 95% confidence intervals for adult badgers translocated to southeastern British Columbia, Canada, from northwestern Montana and adult offspring of translocated badgers, May 2002–February 2006.

(colonization rate) and possibly roadkill (extinction rate) will be driving factors in establishing whether or how frequently the future badger range limit includes the NP. A key question is whether the Allee Effect, in which reproductive success often declines as populations drop, will be strongly expressed (Keitt et al. 2001). If badgers are induced ovulators and males accompany each female only briefly, the reduced opportunities for repetitive mating at very low population densities could lead to lower pregnancy rates (Messick and Hornocker 1981).

Our results point to the value of long-term monitoring of populations at range limits or of endangered populations generally. If trends relating to persistence vary dramatically over time, then short-term observations indicating that certain areas have lost their ability to support a species may be misleading. Population augmentation provides a test of whether long-term, deterministic factors have made a given area unsuitable or whether observed losses are the result of short-term fluctuations. In the event that the latter is true, augmentation through translocation or other means also provides a means of initiating recovery. In the case of badgers in the northern part of the Rocky Mountain Trench, the translocation of wild-caught animals succeeded in establishing a population that was small but apparently growing 3.5 years after release. Long-term monitoring will be essential as there is no indication of improvement among several of the factors potentially contributing to initial negative trends, such as highway traffic volumes and landscape connectivity.

MANAGEMENT IMPLICATIONS

Local losses of species-at-risk may be brought about by probabilistic or temporary effects on small populations. Adding badgers from more secure populations and modestly improving ecological conditions provides a low-risk experiment that may initiate recovery. A preponderance of males among translocated badgers should increase pregnancy rates because of polygamous mating and the possibility of induced ovulation. The value of unbalanced sex ratios among translocated individuals may hold for other wide-ranging carnivores where greater male movements lead to roadkill risk. Translocated kits appeared to quickly abandon release

Table 4. Mean home ranges (km^2) of resident adult American badgers, southeastern British Columbia, Canada, 1996–2006, in relation to those reported in other studies, based on 100% minimum convex polygon (MCP), 95% adaptive kernel (ADK), and 95% fixed kernel (FK) methods.

Study location	Source	n		100% MCP		95% ADK		95% FK	
		F	M	F	M	F	M	F	M
ID	Messick and Hornocker (1981)	7	3	2	2				
WY	Goodrich and Buskirk (1998)	6	9			3	12		
WY	Minta (1993)	15	18			3[a]	8[a]		
CO	Hoff (1998)	9	5			8	25		
IL	Warner and Ver Steeg (1995)	7	5	13	44				
South-central BC	Weir[b]		5[c]		81				38
Southeastern BC	This study	7	9	35	301	26	108	18	64

[a] Calculated as 95% harmonic mean contour.
[b] R. D. Weir, Artemis Wildlife Consultants, unpublished report.
[c] Excluding animals with <25 locations or <1 yr of data.

sites, whereas adult females and offspring born in future years showed site fidelity. Conservation goals might be best served by leaving independent juveniles in the source area, allowing later removal as adults. The critically important initial population growth can be aided by the targeted implementation of existing programs that restore the historically open habitats needed by Columbian ground squirrels, planning to ensure movement bottlenecks do not become further restricted by development, and possibly using fencing and crossing structures in key roadkill locations (Finch 2000, Keitt et al. 2001, Machmer 2002).

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