# Blanding's Turtles (Emydoidea blandingii) Avoid Crossing Unpaved and Paved Roads

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ABSTRACT.—Fragmentation of natural landscapes by linear anthropogenic features, such as roads, has several negative consequences, including decreasing connectivity between habitats, inhibiting animal movements, and isolating populations. Roads limit animal movements through behavioral avoidance and mortality during crossing attempts. We investigated the impact of a road network on the movement patterns of Blanding's Turtles (*Emydoidea blandingii*) in Québec, Canada. We tested the hypothesis that roads act as a barrier to movements. We monitored 52 Blanding's Turtles (22 females, 24 males, and 6 juveniles) via radiotelemetry during their active season from May to August 2010. Road avoidance was quantified for each individual by comparing the number of inferred road crossings with the number of expected road crossings predicted by 1,000 movement path randomizations. Overall, Blanding's Turtles significantly avoided crossing roads. Roads were a significant barrier to movement for 3–6 of the 52 turtles, and an individual's tendency to cross roads was not influenced by its sex or by the road surface (unpaved or paved). Preserving demographic and genetic connectivity of animal populations separated by roads is a major conservation challenge for species at risk such as the Blanding's Turtle.

Roads cause habitat loss, degradation, fragmentation, and direct mortality (Forman and Alexander, 1998; Fenech et al., 2000; Lode, 2000; Jaeger et al., 2005). In addition, roads can disturb wildlife behaviors such as mating, nesting, and migration and can also impact foraging success and increase predation risk (Jaeger et al., 2005). As ecological impacts of roads have been estimated to extend outward more than 100 m and to affect up to 15–20% of the total land area of most nations (Forman, 2000), it is an important and pressing conservation issue.

Roads are often barriers to wildlife movements and thereby decrease connectivity: the ability of an individual to move through the landscape unimpeded (Epps et al., 2005; Bowne et al., 2006, Dixo et al., 2009). The hindrance of animal movement by roads is a phenomenon known as the barrier effect, which results in the subdivision of animal populations into smaller, more vulnerable, and partially isolated local populations (Arnold et al., 1993; Lode, 2000; Rico et al., 2007; Holderegger and Giulio, 2010). The barrier effect can manifest itself through road avoidance behavior (Bruns, 1977; Van Dyke et al., 1986; Merriam et al., 1989; Dyer et al., 2001), through mortality during crossing attempts (Rosen and Lowe, 1994; Fahrig et al., 1995; Ashley and Robinson, 1996), or both (Trombulak and Frissel, 2000).

Freshwater turtles are a group of high conservation concern and sometimes show a reduced tendency to cross roads (Forman and Alexander, 1998; Shepard et al., 2008; Refsnider and Linck, 2012). Whether roads act as barriers to movements for Blanding's Turtles, *Emydoidea blandingii* (Holbrook, 1838), is unknown. Blanding's Turtles are currently listed as "Threatened" in Canada (COSEWIC, 2005), and the increased fragmentation by road networks is perceived as a threat. Blanding's Turtles have delayed age at maturity, low reproductive output, and extreme longevity (Congdon et al., 1993; Gibbs and Shriver, 2002). Because of these life-history characteristics, Blanding's Turtles require high adult survivorship to maintain stable populations (Brooks et al., 1991; Shepard et al., 2008; Congdon et al., 2011). Long-term demographic studies of various turtles indicate that 2–3% additive annual adult mortality is more than

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most turtle species can absorb and still maintain stable populations (Condgon et al., 1993; Gibbs and Shriver, 2002).

The goal of this study was to test the hypothesis that roads pose a barrier to the movements of Blanding's Turtles. If roads are avoided, we predicted that the number of inferred road crossings by each individual should be smaller than the number of road crossings if turtles moved randomly with respect to roads. We calculated the number of inferred road crossings from movement data obtained via radiotelemetry on 52 individuals. We generated the number of expected road crossings in the absence of avoidance by 1,000 randomizations of the movement path for each individual. Also, we predicted that the degree of road avoidance should differ by sex and road type. As female Blanding's Turtles have been reported to travel long distances in search of suitable nesting habitats, we predicted road avoidance to be stronger in males (Ross and Anderson, 1990; Joyal et al., 2000). Finally, we predicted road avoidance to be more marked for paved vehicular roads as these are generally wider and have higher traffic volumes than unpaved roads.

### MATERIALS AND METHODS

*Study Area and Study Species.*—The Blanding's Turtle, *E. blandingii*, is a semiterrestrial medium-sized turtle characterized by a bright yellow throat and chin. It inhabits wetlands and upland habitats (Ross and Anderson, 1990; Joyal et al., 2000) and is typically found in marshes, creeks, wet prairies, fens, and the edge of lakes and ponds (Rowe and Moll, 1991; Hartwig and Kiviat, 2007). Blanding's Turtles roam up to 2 km into upland habitats principally to nest, exploit food supplies, and to reach other wetlands (Ross and Anderson, 1990; Rowe and Moll, 1991; Beaudry et al., 2010; Congdon et al., 2011; Millar and Blouin-Demers, 2011).

The study area was located along the Ottawa River in southern Québec, Canada (45°50′N, 75°64′W) and ranged from Gatineau Park (Collines-de-l'Outaouais County) to Clarendon (Pontiac County). The site is comprised of wetlands intermixed with forest and agricultural land and was bisected by roads open to vehicular traffic, unpaved and paved, as well as other transportation infrastructure closed to vehicular traffic, such as bicycle paths and railroads.

*Road Avoidance.*—In spring 2010, we captured 52 Blanding's Turtles (22 females, 24 males, and 6 juveniles) by hand or using hoop nets and attached radio transmitters (model AI-2F, 33 g, 36

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FIG. 1. Map showing one Blanding Turtle's inferred movement path (in **bold**, 12 road crossings) and two of its 1,000 random movement paths (dashed lines).

months, Holohil Systems, Carp, Ontario, Canada) to their carapaces. During the active season of 2010 (May to August, Millar and Blouin-Demers, 2011), all individuals were tracked every 2 to 4 days for 1,783 locations (mean number of locations per individual = 34.3).

The coordinates of each turtle location were entered into ArcMap10 (ESRI, Redlands, CA) to map the inferred movement paths of all radio-tracked individuals. The minimum number of times each individual crossed a road during the study (inferred crossings) was determined by counting the number of times the straight lines linking successive locations intersected a road. To estimate the number of times each individual would have crossed a road if it had moved randomly with respect to roads (expected crossings), we generated 1,000 random walk paths for each individual. We used the inferred sequence of distances moved between each tracking location, but we randomized the direction (angle) of movement for each leg of the path (Row et al., 2007; Robson and Blouin-Demers, 2013; Fig. 1). We then determined how many times these randomized movement paths crossed roads.

Although random walks without consideration for habitat type have been used to quantify expected road crossings and, thus, road avoidance, in terrestrial turtles and snakes (Row et al., 2007; Shepard et al., 2008; Robson and Blouin-Demers, 2013), this approach may not be ideal for Blanding's Turtles. Blanding's Turtles are semi-aquatic; therefore, most of their movements are within wetlands and fewer are overland. In such a case, using a random walk without consideration for habitat type is likely to overestimate the number of expected road crossings: too many movements would be in the abundant overland habitat compared to a real turtle, and roads are more often overland than in wetlands. In turn, overestimating the number of expected crossings would overestimate road avoidance. To correct for this potential habitat bias in movements in semi-aquatic species, we used a simplified habitat map (from Fortin et al., 2012) that only had aquatic and terrestrial categories, and we classified each inferred turtle movement as either terrestrial (the turtle had to use terrestrial habitat, could not use only aquatic habitat to move between the two consecutive locations) or aquatic (could use only aquatic habitat to move between the two consecutive locations, did not have to use terrestrial habitat). We then calculated the proportion of terrestrial to aquatic movements for each individual. We repeated the random walk analysis, but this time we applied a habitat restriction to the randomization to ensure that the proportion of terrestrial to aquatic movements for each individual was the same ( $\pm$  0.15) as the one we calculated from the inferred movement paths. Therefore, this second randomization not only preserved the inferred sequence of distances moved for each individual but also the proportion of movements that occurred overland (Proulx et al., in press).

Statistical Analyses.—To quantify road avoidance for each individual, we compared the number of inferred and expected road crossings. For each individual, a distribution of the number of expected road crossings was built based on the 1,000 random paths, and the individual was deemed to significantly avoid roads if its number of inferred road crossings fell below the 5% percentile of expected road crossings (i.e., one-tailed  $P \leq 0.05$ ). Quantifying the degree of road avoidance at the population level was done by using a paired *t*-test to compare the median expected number of road crossings and the inferred number of road crossings. The median was used because it is less sensitive to extreme observations than the mean (Hogg and Tanis, 2005), and the expected road crossings were often not normally distributed.

Because the barrier effect of roads is thought to be dependent on the type of road surface (Fenech et al., 2000), roads open to vehicular traffic and those that are not were analyzed separately, and unpaved and paved roads were also analyzed separately. Furthermore, as the movement patterns could be affected by differences in behavior between sexes (Morreale et al., 1984; Congdon et al., 1993; Aresco, 2005; Row et al., 2007), road avoidance was compared between females and males. The number of inferred crossings was subtracted from the mean expected value for each individual and analyzed using a Kruskal–Wallis test.

All statistical analyses were performed using R 2.14.1 (R Development Core Team, Vienna, Austria). Tests were accepted as significant at alpha = 0.05, and means are reported  $\pm$  1 SE.

## RESULTS

Twenty-four of the 52 radio-tracked Blanding's Turtles crossed roads. Although 36 of the 52 individuals crossed roads fewer times than expected if they were moving randomly in relation to roads (inferred crossings <50% percentile expected crossings), only 6 individuals crossed roads statistically significantly fewer times than expected by chance (inferred crossings <5% percentile expected crossings). Blanding's Turtles crossed roads on average 2.00  $\pm$  0.42 times (maximum inferred number of crossings = 12, minimum = 0) during the active season, but if



FIG. 2. Mean (+1 SE) inferred and expected number of road crossings over different road types by Blanding's Turtles (*Emydoidea blandingii*) in Québec, Canada (N = 52). Vehicular roads represent the sum of both unpaved and paved roads.

moving randomly in relation to roads, they would have crossed an average of  $6.06 \pm 0.03$  times (maximum number of crossings = 55, minimum = 0).

Roads not open to vehicular traffic were crossed on average  $0.90 \pm 0.25$  times, whereas they would have been crossed on average  $3.16 \pm 0.02$  times if turtles had moved randomly in relation to roads. Roads open to vehicular traffic, on the other hand, were crossed on average  $1.09 \pm 0.32$  times (unpaved =  $1.02 \pm 0.30$ ; paved =  $0.08 \pm 0.05$ ), whereas they would have been crossed on average  $2.90 \pm 0.02$  times (unpaved =  $2.60 \pm 0.02$ ; paved =  $0.30 \pm 0.01$ ) if turtles had moved randomly in relation to roads (Fig. 2).

Overall, Blanding's Turtles crossed roads significantly less than expected if turtles had moved randomly in relation to roads (paired t = 5.736, df = 51, P < 0.001). Contrary to our predictions, avoidance of roads open to vehicular traffic was not more marked than the avoidance of roads closed to vehicular traffic (Kruskal–Wallis,  $\chi^2 = 7.83$ , df = 11, P = 0.73), nor was there a significant difference in the avoidance of unpaved and paved roads (Kruskal–Wallis,  $\chi^2 = 7.38$ , df = 4, P = 0.12). Finally, males did not exhibit a stronger road avoidance than females (Kruskal–Wallis,  $\chi^2 = 21.00$ , df = 21, P = 0.46, Fig. 3).

We obtained qualitatively similar results when we repeated the analyses based on the habitat-restricted random walks, but this habitat restriction did reduce the expected number of road crossings for each individual and is probably more realistic for Blanding's Turtles. Although 28 of the 52 individuals crossed roads fewer times than expected if they were moving randomly in relation to roads, only 3 individuals crossed roads statistically significantly fewer times than expected by chance. Blanding's Turtles moving randomly in relation to roads would have crossed roads on average 5.68  $\pm$  0.04 times (maximum number of crossings = 248, minimum = 0) during the active season. Roads not open to vehicular traffic would have been crossed on average 3.28  $\pm$  0.03 times, whereas roads open to vehicular traffic would have been crossed on average 2.37  $\pm$  0.02 times (unpaved =  $2.26 \pm 0.02$ , paved =  $0.13 \pm 0.003$ ). Overall, Blanding's Turtles crossed roads significantly less than expected if turtles had moved randomly in relation to roads (paired t =4.966, df = 51, P < 0.001). Again, no difference was found between roads open to vehicular traffic and roads closed to



FIG. 3. Mean (+1 SE) inferred and expected number of road crossings for different reproductive classes of Blanding's Turtles (*Emydoidea blandingii*) in Québec, Canada (N = 52).

vehicular traffic (Kruskal–Wallis,  $\chi^2 = 47.11$ , df = 41, P = 0.24), nor was there a significant difference between unpaved and paved roads (Kruskal–Wallis,  $\chi^2 = 20.22$ , df = 13, P = 0.09). Finally, there was no difference between males and females (Kruskal–Wallis,  $\chi^2 = 20.56$ , df = 19, P = 0.36).

## DISCUSSION

Several studies have documented road avoidance behavior in reptiles, including turtles, indicating that roads are a barrier to their movements (Forman and Alexander, 1998; Bowne et al., 2006; Row et al., 2007; Shepard et al., 2008). Overall, we demonstrated that Blanding's Turtles avoid crossing roads, but there was no significant difference in the degree of avoidance between types of roads or between the sexes. Road avoidance could have several negative consequences, such as creating isolated subpopulations, restricting gene flow, and increasing the chance of extinction of each subpopulation (Dyer et al., 2002; Shepard et al., 2008; Holderegger and Giulio, 2010). As Blanding's Turtles are long lived and late maturing, the negative genetic effects resulting from isolation may only become observable in the future.

Only 3-6 of the 52 individual turtles crossed roads statistically significantly fewer times than expected (but 28-36 individuals crossed fewer times than expected) if turtles moved randomly with respect to roads. Although a significant barrier effect in terms of road avoidance was not observed for the remaining turtles, crossing roads increases the risk of mortality because of collisions with vehicles. Traffic related mortality is a major cause of mortality for many animals, including reptiles (Bernardino and Dalrymple, 1992; Langevelde and Jaarsma, 2009). Therefore, roadkill can contribute to the barrier effect even in the absence of road avoidance but also has direct negative demographic consequences. Because of the life-history characteristics that typify turtles (Bernardino and Dalrymple, 1992; Gibbs and Shriver, 2002; Rico et al., 2007), the direct negative demographic consequences of roadkill are probably of more immediate conservation concern than their barrier effect. Although the results from the habitat-restricted random walks were qualitatively similar to those of the unrestricted random walks, this novel approach did reduce the number of expected road crossings for our semi-aquatic study animal. The habitatrestricted approach is probably more realistic, and we suggest that taking habitat bias in movements into account is important when assessing road avoidance.

Documenting the factors affecting the spatial ecology of species at risk is central to their conservation and is important to make informed decisions about land use, management, and recovery (Liao and Reed, 2009; Millar and Blouin-Demers, 2011; Fortin et al., 2012). Other engineering solutions can be used to mitigate the effects of roads (Ree et al., 2009). Wildlife crossing structures such as overpasses, tunnels, and culverts, in conjunction with exclusion fencing, can help maintain habitat connectivity and reduce road mortality (Clevenger and Sawaya, 2010), which in turn can alleviate the negative effects of fragmentation, of population isolation, and of demographic stochasticity (Bennett, 1990; Saunders et al., 1991; Dixo et al., 2009). Population viability modeling cannot only be used to determine the negative effects of threats such as road mortality on animal populations (Row et al., 2007) but can also be used to assess the effectiveness of wildlife crossing structures. Responsible road design must be implemented to minimize the ecological impacts of the current road network and its future expansion.

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