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# USING CAMERAS TO MONITOR TUNNEL USE BY LONG-TOED SALAMANDERS (*AMBYSTOMA MACRODACTYLUM*): AN INFORMATIVE, COST-EFFICIENT TECHNIQUE

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***Abstract*.—Wildlife crossing structures must be monitored to assess their ability to restore animal movement patterns. Although cameras have been used effectively to record use of crossing structures by mammals, they have not been used to document amphibian movements. We installed four amphibian tunnels in Waterton Lakes National Park, Alberta, Canada to reduce road mortality in a declining population of Long-toed Salamanders (*Ambystoma macrodactylum*). Our goal was to determine if cameras offer an alternative to pitfall traps for monitoring tunnels for amphibians. We installed digital cameras on the ceilings of tunnel entrances to monitor tunnel floors. Cameras were set to take motion-triggered images and timed-interval images (1 photograph/minute from 2100–0600). We installed one pitfall trap at each tunnel exit to capture amphibians travelling through tunnels and assess camera performance. From May through August 2009, we captured 104 adult *A. macrodactylum* in traps, but only 58 crossings were documented by cameras, indicating that cameras missed at least 46 salamander crossings. *Ambystoma macrodactylum* failed to trigger motion detectors during 81.0% of the camera-documented tunnel crossings. Cameras revealed that salamanders moved slower at tunnel entrances than their average crossing speed, suggesting animals may have hesitated at entrances. Although cameras documented one case of snake predation, images indicated that tunnels were not significant predator traps for salamanders. Camera data revealed the same patterns of demographics and spatio-temporal variation in tunnel use for *A. macrodactylum* as did trapping; thus, cameras represent a novel, cost-efficient, noninvasive approach to monitoring amphibian tunnel use. However, we encourage managers to either augment motion-detection cameras or rely on images recorded at set time intervals to document tunnel use effectively by animals as small as, or smaller than, *A. macrodactylum*.***

*Key Words*.—*Ambystoma macrodactylum*; amphibian; camera; conservation; crossing structure; Long-toed Salamander; monitor; tunnel use.

## INTRODUCTION

The negative effects of roads on wildlife, which include increased mortality and decreased habitat connectivity, have been well documented (Fahrig et al. 1995; Forman et al. 2003; Jaeger and Fahrig 2004). As a result, crossing structures, which include underpasses, overpasses, and under-road tunnels, are being designed and incorporated into road construction and improvement projects throughout North America and Europe (Spellerberg 2002; Cain et al. 2003; Forman et al. 2003). The success of such mitigation projects is typically assessed based on the extent that they reduce wildlife-vehicle collision rates or restore animal movement patterns (e.g., Ford et al. 2009). To document the re-establishment of travel corridors, crossing structures must be monitored to determine species use, especially when wildlife population persistence and connectivity are primary concerns (Clevenger 2005; Dodd et al. 2007). Despite the inherent need to measure the success of crossing structures, monitoring programs are rarely implemented. Given the increasing number of under-road tunnels being installed, evaluation of monitoring methods that document tunnel use is a conservation priority.

We conducted a literature review of papers published between 1989–2009 using the BIOSIS Previews™ search engine and the following key terms: wildlife crossing structure, underpass, overpass, or culvert. We found 25 studies that described various methods employed to monitor use of crossing structures. We found an additional 19 studies that monitored crossing structures by conducting informal searches through a variety of databases and conference proceedings. Of the 44 studies that monitored crossing structures, we found that almost half used track plates, and 43% used remotely triggered cameras (see Pagnucco 2010 for full review).

Although track plates and cameras are effective at documenting crossing structure use by mammals, they have seldom been applied to recording use by other vertebrates, such as amphibians. Of the 44 studies examined, only 9 (20%) documented tunnel use by amphibians (Pagnucco 2010). Four of these studies used track plates, but in each case, a very limited number of amphibian tracks were observed (Yanes et al. 1995; Taylor and Goldingay 2003; Mata et al. 2005; Ascensão and Mira 2007). The remaining five studies documented amphibian use by direct observation or deployment of either funnel traps or pitfall traps at tunnel exits (Brehm 1989; Jackson and Tyning 1989; Allaback and Laabs 2003; Dodd et al. 2004; Gartshore et al. 2006). To our knowledge, no one has successfully used cameras to document tunnel use by amphibians.

In May 2008, Parks Canada installed four concrete tunnels under the Entrance Road in Waterton Lakes National Park, Alberta, Canada. These are the first amphibian tunnels installed in a Canadian National Park, and to our knowledge, only the second set of tunnels constructed in Canada (Gartshore et al. 2006). Structures were deployed to reduce road mortality for a declining population of Long-toed Salamanders (*Ambystoma macrodactylum*) and to improve connectivity of seasonal habitats.

Our overall goal was to determine if remote cameras could be used to monitor tunnel use by *A. macrodactylum* and other amphibians as an alternative to direct observation or pitfall traps. Specific objectives were threefold. First, we determined whether motion-detection or timed-interval image capture was the most effective method for recording amphibians using tunnels. Second, we quantified diel patterns in tunnel use by *A. macrodactylum* and potential predators, as well as how quickly *A. macrodactylum* navigated the tunnels. These data represent information that trap data alone cannot reveal. Lastly, we compared data obtained using cameras and traps in their ability to document: (1) temporal patterns in use of tunnels by *A. macrodactylum*; (2) variance in body size and sex ratios of migrating salamanders; and (3) differences between the four tunnels in terms of timing/frequency of Long-toed Salamander use. Determining when and where most *A. macrodactylum* use tunnels will allow optimization of monitoring efforts. In addition, determining the size classes and sex ratios for salamanders recorded crossing tunnels will document whether only certain individuals within a population use these structures. If cameras document comparable spatio-temporal and demographic patterns as exit traps, then cameras represent a viable alternative to the more invasive monitoring method of pitfall trapping.

## MATERIALS AND METHODS

***Study site.***—We conducted our field work at Linnet Lake (49°04'N, 113°54'W) in Waterton Lakes National Park. Details concerning the site can be found in Pagnucco (2010). Each of the four amphibian tunnels installed in the park was 60 cm wide by 52 cm high (Fig. 1), while the internal dimensions were 50 cm in width by 33 cm in height (AT500 Amphibian Tunnels, ACO Technologies, Shefford, UK). Each concrete section had slots along the top to allow air, moisture, and light into the tunnel. Tunnel segments were placed together to span the width of the road and the sidewalk (12 m) and were placed 80–110 m apart (Fig. 2).

***Monitoring tunnel use with pitfall traps.***—To monitor tunnel use by *A. macrodactylum* in 2009, we installed directional fencing made of plastic erosion-control material angled towards tunnel entrances, and a rectangular plastic pitfall trap (76 cm in width, 20 cm in length, and 18 cm in depth) at the exit of each tunnel based on the dominant direction of salamander movement (Fig. 2). From 22 April – 19 May 2009, exit traps were located on the east side of the road to catch individuals immigrating to Linnet Lake to breed (Fig. 2). Traps were moved to the west side of the road to catch salamanders emigrating from Linnet Lake to upland habitats from 20 May – 19 August 2009. We intended exit traps to capture all *A. macrodactylum* travelling through tunnels and thus assess the performance of cameras in documenting tunnel use. We checked traps daily between 0600 and 1000, and we recorded the age class, sex, snout-vent-length (SVL; measured from the tip of the snout to the caudal portion of the cloacal vent), total length (TL), and mass (g ± 0.1 g) for each captured salamander. We used Visible Implant Elastomer (VIE; Northwest Marine, Shaw, Washington, USA) to mark every captured salamander prior to releasing it on the opposite side of the road in the direction that it was headed.

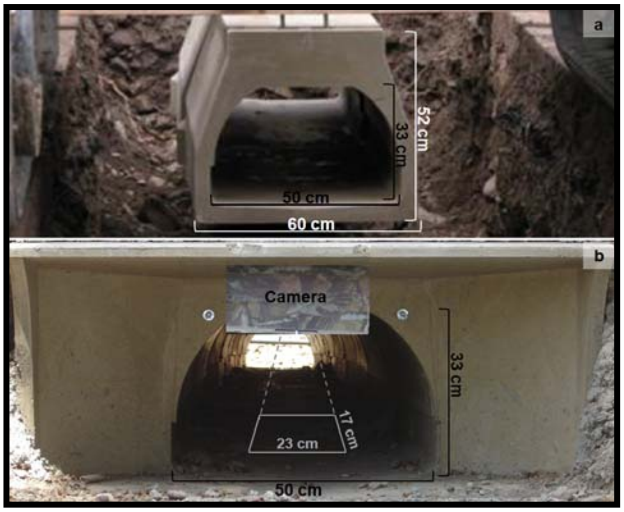

**FIGURE 1**. Dimensions of tunnel entrance characteristics (a) and the field-of-view of camera (b). The base of the camera, placed within a security enclosure, covered in camouflage duct tape, and installed on the ceiling of the tunnel is labelled ("Camera") in b. (Photographed by Parks Canada [a] and Katie Pagnucco [b]).

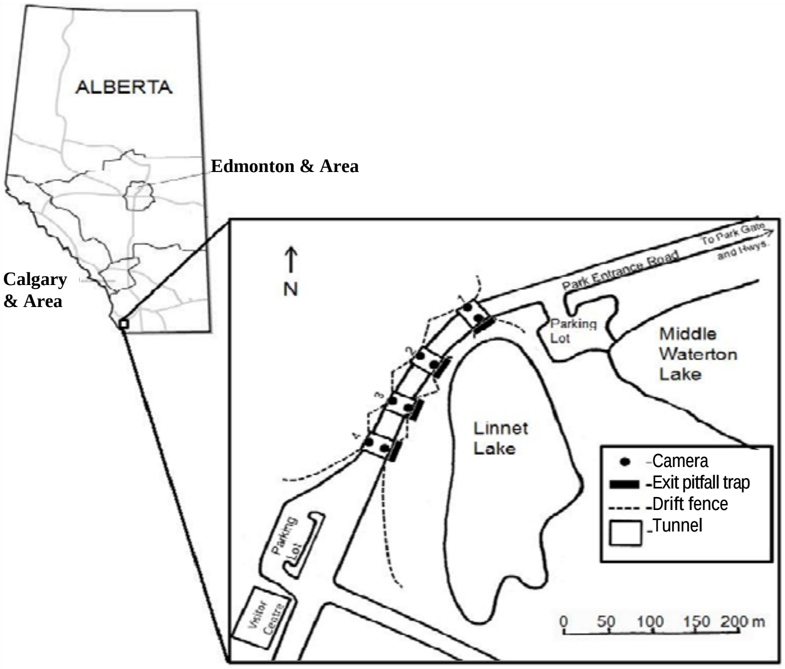

**FIGURE 2.** Map of Linnet Lake area in Waterton Lakes National Park, Alberta, Canada, including locations of under-road tunnels, exit pitfall traps, and drift fences in 2009. Adapted from Fukumoto (1995).

***Monitoring tunnel use with cameras.***—We conducted a pilot study from 28 August – 3 November 2008 to test the effectiveness of cameras in documenting tunnel use by amphibians. We installed a motion-detecting camera (Reconyx™ RapidFire series PC85, Holmen, Wisconsin, USA) at the mouth of each tunnel on both sides of the road (eight cameras; Fig. 2). Cameras were placed inside steel security enclosures and installed on tunnel ceilings so that they monitored tunnel floors (Fig. 1). The tunnel floor available for salamander crossing was 50 cm wide, and the camera's field of view captured 23 cm (46%) of this area (Fig. 1). Cameras were set to take three images at one second intervals when movement was detected, regardless of the time of day (i.e., motion-triggered images). We set motion detectors at maximum sensitivity in an effort to capture movement of small, slow amphibians. We also programmed cameras to take one image at one minute intervals from 2100–0600 daily (i.e., timed-interval images). Images taken during night and low light conditions were automatically augmented with infrared illumination. As opposed to flash photography with light of shorter wavelengths, the infrared illumination used by these cameras had a peak wavelength of 890 nm (Jamie Ratajczek, pers. comm.). The visible spectrum of the closely related Tiger Salamander (*Ambystoma tigrinum*) lies between 450–700 nm (Cornwall 1984). Therefore, the infrared illumination emitted by cameras should not affect the behavior of *A. macrodactylum*. All images were time stamped. Because of the number of images being recorded (540 images/camera/night using the timed-interval method, in addition to any motion-triggered events), we used a high-capacity memory card (4 GB) in each camera, which could hold about 20,000 photographs 0.2 MB in size. In 2009, cameras were set to take images from 22 April – 14 October at both entrances of each tunnel, using the same methods as in 2008.

Images of a metric ruler were taken to calibrate the size of animals in tunnels. We then used a ruler to measure SVL (mm) and TL (mm) of all *A. macrodactylum* in images on a computer screen. When possible, sex was determined from photographs by observation of physical characteristics by an experienced researcher. In cases where salamanders triggered motion detectors and multiple images were taken of a single crossing, we were able to calculate speed as the distance travelled divided by the time recorded by the camera.

***Statistical analyses.***—We compared temporal patterns in the use of tunnels by *A. macrodactylum*, based on data from camera images and exit trap captures during the peak migration period in 2009, using a two-sample Kolmogorov-Smirnov test. The peak migration period in 2009 was defined as the period between the 5th and 95th percentile of total salamander captures (Paton and Crouch 2002). We also tested the relationship between the number of *A. macrodactylum* crossings detected by camera and trap data using a linear regression, where the total number of images containing *A. macrodactylum* per day was the dependant variable and the total number of trap captures per day was the independent variable.

We compared SVL and TL as measured by hand at exit traps, versus measurements taken from images, using t-tests. Data from males and females were analyzed separately for a total of four comparisons. For each of

**TABLE 1**. Summary of the species and number of amphibians and reptiles using the under-road tunnels identified using camera data from 2008 (28 August – 3 November) and 2009 (22 April – 14 October) in Waterton Lakes National Park, Alberta, Canada.

| Species | | Number of events | |
|---|---|---|---|
| Common name | Scientific name | 2008 | 2009 |
| Long-toed Salamander | *Ambystoma macrodactylum* | 2 | 58 |
| Barred Tiger Salamander | *Ambystoma mavortium* | 1 | 6 |
| Western Toad | *Anaxyrus boreas* | 0 | 5 |
| Wandering Garter Snake | *Thamnophis elegans vagrans* | 5 | 48 |
| | TOTAL | 8 | 117 |

**TABLE 2.** Summary of the number of Long-toed Salamanders documented using tunnels with traps only [Traps (+), Cameras (-)], cameras only [Traps (-), Cameras (+), or both [Traps (+), Cameras (+)], as well as totals for each monitoring method.

| | Traps (+) | Traps (-) | Total |
|---|---|---|---|
| Cameras (+) | 32 | 26 | 58 |
| Cameras (-) | 72 | N/A | |
| Total | 104 | | |

the two sampling methods (i.e., cameras and traps), we used chi-square to test for differences in the proportion of male and female salamanders found immigrating and emigrating to the breeding lake, and in the proportion of salamanders using each of the four tunnels. We used SPSS v.16 (SPSS Inc., Chicago, Illinois, USA) and we deemed all tests to be statistically significant at $P < 0.05$.

## RESULTS

***Quality of photographic images taken using cameras.***—Preliminary monitoring in 2008 showed timed-interval and motion-detection methods both provided high resolution images during both low-light night conditions, and daylight conditions (Fig. 3). Time stamping of images was successfully used to quantify travel speeds of animals in tunnels (m/min, Fig. 3).

***Total images and trap captures.***—Including motion-triggered and timed-interval methods, tunnel cameras took over 260,000 images from 28 August – 3 November 2008, and another 750,000 images from 22 April – 14 October 2009. A variety of herptiles were photographed using the tunnels to travel safely between habitats (Table 1). In addition, cameras captured 507 images of small (e.g., *Peromyscus maniculatus*, voles, shrews) and medium-sized (e.g., *Spermophilus columbianus, Tamiasciurus hudsonicus, Tamias minimus, Lepus americanus, Mephitis mephitis, Procyon lotor)* mammals in 2008 and 1352 images in 2009.

In 2009, 104 adult *A. macrodactylum*, four Barred Tiger Salamanders (*Ambystoma mavortium*) and seven Western Toads (*Anaxyrus boreas*) were caught in exit pitfall traps after successfully travelling through tunnels. Of the 58 *A. macrodactylum* photographed using tunnels, 81.0% (47/58) were recorded based on timed-interval images, while only 19.0% (11/58) triggered motion detectors. In contrast, six images of *A. mavortium*, five of *Anaxyrus boreas*, and 48 of Wandering Garter Snakes (*Thamnophis elegans vagrans*) were all captured through motion detection. At least 26 of the 58 salamanders (44.8%) documented using tunnels with cameras were not captured in exit traps (Table 2). These images were recorded on days when no *A. macrodactylum* were found in corresponding traps or the number of salamanders photographed exceeded the number caught in traps. Given the population estimate for adult *A. macrodactylum* breeding at Linnet Lake of 1372 individuals in 2009 (Pagnucco et al. 2011), traps documented migration of 7.6% of the adult population and cameras documented another 1.9%.

***Speed and diel patterns of tunnel crossings and predation.***—In nine cases where a salamander was photographed multiple times while moving through a tunnel, we were able to calculate travel speed at the tunnel mouth, which averaged 1.1 ± 0.1 m/min (mean ± SE). On four occasions, salamanders were photographed entering and exiting the tunnel with an average speed of crossing as 4.8 ± 1.5 m/min.

Almost all (95%) *A. macrodactylum* tunnel crossings were recorded at night, between 2000 and 0600 (Fig. 4). Four of the six *A. mavortium* used tunnels between 2200 and 0300 and all *Anaxyrys boreas* were photographed 2100–0500. On 48 occasions, *T. elegans vagrans* was photographed using tunnels between 1000 and 1800, whereas only two *A. macrodactylum* (3.4%) used tunnels during this time of day (Fig. 4).

On 27 August 2009, a camera documented two juvenile *A. mavortium* entering a tunnel at 1141 moving towards Linnet Lake. At 1218, the same camera documented a Wandering Garter Snake dragging a juvenile *A. mavortium* by its head out of the same tunnel, moving away from Linnet Lake. Presumably, this was one of the salamanders photographed entering the tunnel 37 min earlier (Fig. 3).

***Camera versus trap data.***—Seasonal patterns of *A. macrodactylum* movement documented by cameras (Fig. 5a) and traps did not differ (KS test statistic = 0.56, $P = 0.92$; Fig. 5b). Daily camera and trap data were highly correlated ($F = 74.0$, $P < 0.001$, $r^2 = 0.67$; Fig. 5c).

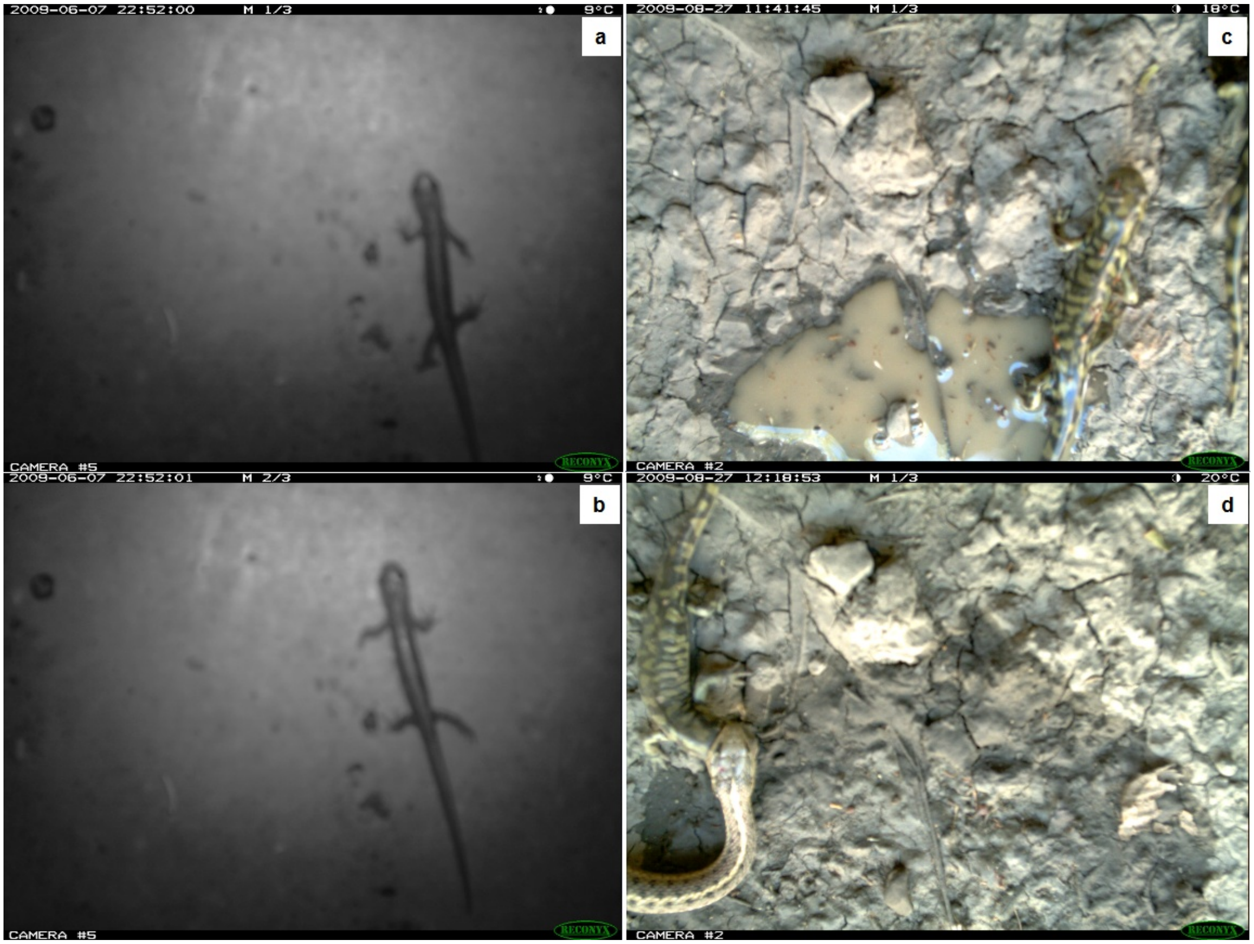

**FIGURE 3.** Motion-triggered images of an *Ambystoma macrodactylum* entering a tunnel at night (a, b), and during the day (c), including a predation event (d). Two juvenile *A. mavortium* enter a tunnel (c), and 37 min later, a *Thamnophis elegans vagrans* drags a juvenile salamander out of the same tunnel (d). Images were time-stamped, making it possible to calculate speed at entrances and crossing speed when an individual was photographed entering and exiting a tunnel.

Of the 58 *A. macrodactylum* photographed using tunnels, we were able to measure salamander SVL from photographs in 36 cases, and TL in 27 cases. Measurements of SVL and TL taken from images did not differ significantly from the same measurements taken by hand for captured Long-toed Salamanders (SVL: females: $t_{92,\ 0.05} = -0.56$, $P = 0.58$; males: $t_{43,\ 0.05} = -0.98$, $P = 0.33$; TL: females: $t_{85,\ 0.05} = -0.93$, $P = 0.35$; males: $t_{41,\ 0.05} = -0.90$, $P = 0.17$). We were able to determine gender from images in 45 cases (78%), which allowed us to determine that sex ratios generated by the two sampling methods did not differ from one another ($\chi^2 = 5.82$, $P = 0.12$).

Most salamanders were photographed in Tunnel 3 (67%), followed by Tunnel 4 (17%), Tunnel 2 (10%), and Tunnel 1 (5%). Although only 15% of *A. macrodactylum* were photographed using either Tunnels 1 or 2, 53% of snake crossings occurred in these two tunnels. Comparable differences in use among the four tunnels was apparent based on camera or trap data ($\chi^2 = 4.22$, $P = 0.24$).

## DISCUSSION

Our results showed that digital cameras and pitfall traps provided complementary information on spatial and temporal patterns of use of wildlife tunnels by an amphibian species. Although we documented 1.79 times as many *A. macrodactylum* moving through tunnels based on trap data, tunnel use determined by digital cameras was strongly correlated with that derived from trapping. In addition, use of digital cameras allowed us to determine diel patterns of tunnel use and crossing speed of *A. macrodactylum*, as well as document potential predators within tunnels, information that pitfall trapping cannot provide without frequent checks.

***Size to trigger motion detectors.***—The lack of studies using cameras to monitor use of crossing structures by amphibians may stem from concerns that amphibians are too small to trigger motion detectors found in most wildlife cameras (Jackson 1999; Fitzgibbon 2001). In

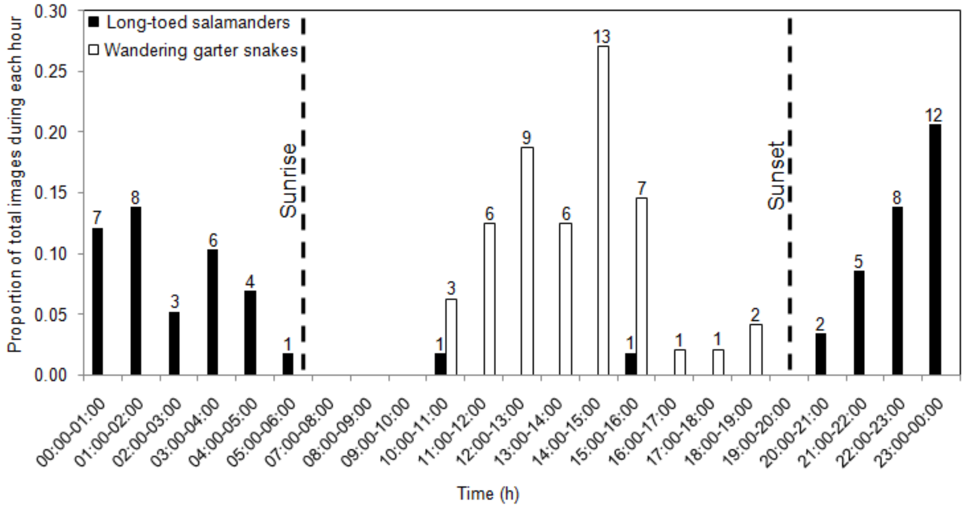

**FIGURE 4.** Proportion of *Ambystoma macrodactylum* (n = 58) and *Thamnophis elegans vagrans* (n = 48) photographed entering or exiting tunnels at different hours of the day from 3 May – 14 Oct 2009. Sunrise and sunset are indicated by dashed lines. Sample sizes for each species during each hour given above bars.

the case of *A. macrodactylum*, this concern is valid because 81.0% of all crossings were photographed during timed intervals when motion detectors were not triggered. However, not all amphibians failed to trigger motion detectors: all records of adult *Anaxyrus boreas* and *Ambystoma mavortium* were captured by motion-triggered images. Although five juvenile *A. boreas* were captured in exit traps, camera images did not document any of them using tunnels, suggesting that small toads did not trigger motion detectors. In cases where the target species is of equal or smaller size than *Ambystoma macrodactylum*, it would be advisable to use timed-interval images. If the number and resolution of images precludes taking exceedingly large numbers of images, cameras could be programmed to be active during the time of day when animals are moving. Alternatively, motion detectors could be augmented by either the installation of sensitive weight triggers or laser beam sensors, or by increasing the interval or field of view of images. For larger amphibians, programming cameras to capture images when motion sensors are triggered may be sufficient to document tunnel use.

The main disadvantage to using timed-interval images is the large number of empty images generated. High numbers of images result in shortened battery life and require large capacity memory cards, creating the need for more frequent maintenance of camera systems, as well as increased amounts of time required to assess images (e.g., in this study, an experienced researcher could review 1875 images/h). However, despite having cameras set to capture an image every minute from 2100–0600, batteries only needed to be changed on a weekly basis in this study, and memory cards emptied on a monthly basis.

***Comparisons of metrics of tunnel use.***—Our study showed that camera data and exit trap data produced equivalent patterns in several metrics, including descriptions of: (1) seasonal patterns in tunnel use; (2) body size and proportion of males and female *A. macrodactylum* immigrating to and emigrating from Linnet Lake; and (3) spatial variation related to the use of the four tunnels. Information on spatio-temporal variation in tunnel use will inform Parks Canada as to when and where tunnels should be monitored to maximize information obtained. Information on body size and sex ratios of *A. macrodactylum* moving through tunnels may be used to extrapolate whether certain components of populations are more or less likely to cross tunnels. For instance, bias towards only smaller, non-reproductive *A. macrodactylum* using tunnels could result in decreased reproduction and recruitment, which could lead to population declines.

When comparing the ratio of images of salamanders to trap captures across sampling days, cameras documented about half as many crossings as did traps. By obtaining this detection probability (Mackenzie et al. 2005), future monitoring of these tunnels could use camera data to extrapolate how many salamanders actually crossed through tunnels, as well as a measure of relative abundance. However, this estimate assumes that all salamanders using tunnels are trapped, which was not true as 26 of the *A. macrodactylum* that were photographed using tunnels were not subsequently captured in exit traps. Possibly, these 26 salamanders entered tunnels but turned back and were not photographed exiting the same way they entered; thus, trap efficiency could still be 100%. Visual observation of tunnel exits during periods of peak migration would allow calibration

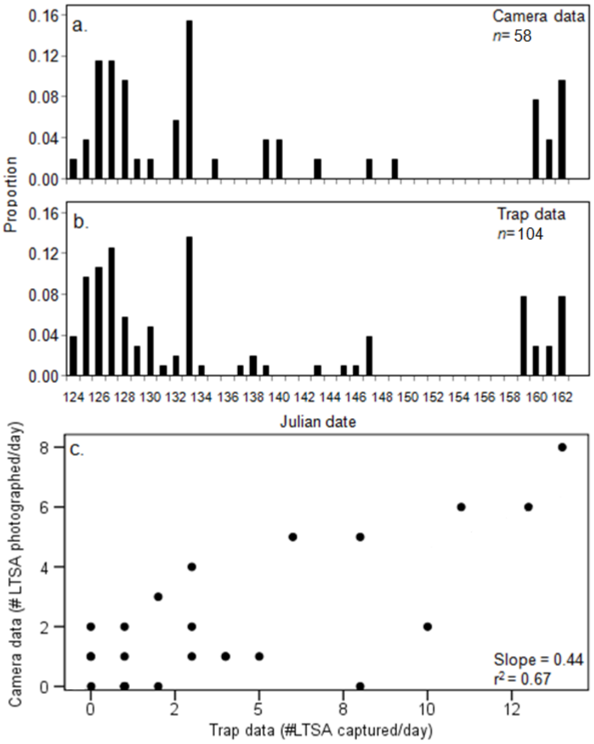

**FIGURE 5.** Comparison of proportions of Long-toed Salamanders (*Ambystoma macrodactylum*) crossing tunnels in 2009 documented with cameras (a) and exit pitfall traps (b). Capture data of Long-toed Salamanders (*Ambystoma macrodactylum*; LTSA) derived using cameras and by trapping are highly correlated (c). Data are restricted to the peak period of migration to and from Linnet Lake (3 May – 10 June).

between the absolute number of salamanders crossing tunnels and the numbers detected by traps and by cameras.

***Diel patterns and crossing speed.***—In contrast to manual trapping, cameras provide information on crossing speeds, exact time of day of crossings, and the occurrence of predation within tunnels. *Ambystoma macrodactylum* moved four times slower at tunnel entrances than their average crossing speed, indicating that *A. macrodactylum* may hesitate at tunnel mouths. Salamanders may have moved slowly along the bare concrete at tunnel mouths, but at increased speeds inside the sand-lined tunnel; thus, the addition of substrate at tunnel mouths may increase use by amphibians.

Our estimate of the mean speed of *A. macrodactylum* crossing tunnels (4.8 m/min) was about five times higher than those reported for Marbled Salamanders (*Ambystoma opacum*; mean = 0.9 m/min; Charney et al. 2009). This result is surprising given that *A. opacum* are similar in size to *A. macrodactylum* (Scott 1994), and the running speeds of adult ambystomid salamanders are positively correlated with body size (Bennett et al. 1989). Travel speeds of *A. macrodactylum* are closer to burst speeds of the larger California Tiger Salamander (*A. californiense*; body mass range, 7.3–30.3 g; mean burst speed ± SE, 8.7 ± 0.5 m/min; Austin and Shaffer 1992). *Ambystoma macrodactylum* may have increased their speed to minimize the time spent in tunnels, which represent unfamiliar routes or areas of unsuitable substrate. The high alkalinity of concrete has been shown to deter other amphibian species from using crossing structures (Mougey 1996 as cited by Glista et al. 2009).

***Tunnels as predator "traps."***—Several previous studies have expressed concern that crossing structures could be used by mammalian predators to capture prey, as structures reduce the ability of prey species to avoid detection or escape (Little et al. 2002; Taylor and Goldingay 2003; Clevenger and Waltho 2005). However, ours is one of few studies that has actually documented a predation event occurring in a crossing structure. Predation by *T. elegans vagrans* on *A. mavortium* happened in late morning, when snakes were typically active. All other crossings by *A. mavortium* occurred at night. Similar to *A. macrodactylum*, *A. mavortium* are typically nocturnal (Madison and Farrand 1998); thus, the cameras recorded what was likely a rare predatory occurrence.

Overall, the tunnels considered in this study are not likely to act as significant predator traps for *A. macrodactylum*, because tunnel use by salamanders and garter snakes was separated temporally (seasonal and diel separation) and spatially. In terms of seasonal patterns of tunnel use, all *T. elegans vagrans* were photographed in the late summer (from 24 June – 18 September 2009; see also Yanes et al. 1995) when most *A. macrodactylum* had finished migrating across the road from Linnet Lake; only one *A. macrodactylum* was documented crossing a tunnel during this period (on 10 July). Only two *A. macrodactylum* (3.4%) used tunnels between 1000–1800, whereas all 48 *T. elegans vagrans* were photographed during this time period. Diel separation between the two species may have been exaggerated by the activation period of timed-interval image capture (2100–0600), which was responsible for most records of tunnel use by salamanders but not by snakes.

In addition, although only 15% of *A. macrodactylum* were photographed using either Tunnel 1 or 2, 53% of snake crossings occurred in these tunnels. Most salamanders photographed used Tunnel 3 (67%). Soil moisture content was highest in the habitats surrounding the entrances of Tunnel 3 (Pagnucco 2010), which may explain higher use of this tunnel.

*Ambystoma macrodactylum* crossed tunnels primarily at night when potential mammalian predators, such as shrews, skunks, and raccoons, were also documented using tunnels. However, in the 2,000 crossing events documented by cameras, none showed a mammal preying upon *A. macrodactylum* or other amphibians. We also found no evidence of mammals feeding on salamanders confined in pitfall traps.

Appreciable overlap exists in the types of information provided by traps and cameras regarding amphibian tunnel use. In addition, cameras provide additional information not available through trapping. Therefore, coupled with validation using direct observation of tunnel exits, cameras represent a valuable new tool for amphibian monitoring. In addition to being less invasive, the use of cameras to monitor tunnels is less labour intensive than trapping. Each pitfall trap took 1 h to install. Checking traps and measuring captured individuals took 1–5 h daily during our study. Alternatively, it took 1 h to install all eight cameras. Changing camera batteries on a weekly basis took 30 min, and exchanging memory cards on a monthly basis required an additional 5 min. Although cameras are relatively expensive (~$450–$750 US each, depending on make and model), they are more cost effective in the long term than pitfall trapping as a means of monitoring tunnels, especially if coupled with customized image analysis software. However, it must be cautioned that motion detection was not a reliable method of monitoring tunnel use by animals the size of *Ambystoma macrodactylum*. Therefore, when the target species are similar in size or smaller than *A. macrodactylum*, we advise managers to either augment motion detectors by: (1) installing sensitive weight triggers or laser beam sensors; (2) increasing the interval or field of view of images, or (3) also using timed-interval images to maximize the probability of documenting tunnel use.

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## LITERATURE CITED

Allaback, M.L., and D.M. Laabs. 2003. Effectiveness of road tunnels for the Santa Cruz Long-toed Salamander. Transactions of the Western Section of The Wildlife Society 38/39:5–8.

Ascensão, F., and A. Mira. 2007. Factors affecting culvert use by vertebrates along two stretches of road in southern Portugal. Ecological Research 22:57–66.

Austin, C.C., and H.B. Shaffer. 1992. Short-, medium-, and long-term repeatability of locomotor performance in the tiger salamanders *Ambystoma californiense*. Functional Ecology 6:145–153.

Bennett, A.F., T. Garland Jr., and P.L. Else. 1989. Individual correlation of morphology, muscle mechanics, and locomotion in a salamander. American Journal of Physiology 256:1200–1208.

Brehm, K. 1989. The acceptance of 0.2 m tunnels by amphibians during their migration to the breeding site. Pp. 29–42 *In* Amphibians and Roads, Proceedings of the Toad Tunnel Conference. Langton, T.E.S. (Ed.). ACO Polymer Products, Shefford, United Kingdom.

Cain, A.T., V.R. Tuovila, D.G. Hewitt, and M.E. Tewes. 2003. Effects of a highway and mitigation projects on Bobcats in Southern Texas. Biological Conservation 114:189–197.

Charney, N.D., B.H. Letcher, A. Haro, and P.S. Warren. 2009. Terrestrial passive integrated transponder antennae for tracking small animal movements. Journal of Wildlife Management 73:1245–1250.

Clevenger, A.P. 2005. Conservation value of wildlife crossings: measures of performance and research directions. GAIA 14:124–129.

Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121:453–464.

Cornwall, M.C., E.F. MacNichol Jr., and A. Fein. 1984. Absorptance and spectral sensitivity measurements of rod photoreceptors of the tiger salamander, *Ambystoma tigrinum*. Vision Research 24:1651-1659.

Dodd, C.K., Jr., W.J. Barichivich, and L.L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily travelled highway in Florida. Biological Conservation 118:619–631.

Dodd, N.L., J.W. Gagnon, A.L. Manzo, and R.E. Schweinsburg. 2007. Video surveillance to assess highway underpass use by elk in Arizona. Journal of Wildlife Management 71:637–645.

Fahrig, L., J.H. Pedlar, S.E. Pope, P.D. Taylor, and J.F. Wegner. 1995. Effect of road traffic on amphibian density. Biological Conservation 73:177–182.

Fitzgibbon, K.R. 2001. An evaluation of corrugated steel culverts as transit corridors for amphibians and small mammals at two Vancouver Island wetlands and comparative culvert trials. M.A. Thesis, Royal Roads University, Vancouver, British Columbia, Canada. 71 p.

Ford, A.T., A.P. Clevenger, and A. Bennett. 2009. Comparison of methods of monitoring wildlife crossing-structures on highways. Journal of Wildlife Management 73:1213–1222.

Forman, R.T.T., D. Sperling, J. Bissonette, A. Clevenger, C. Cutshall, V. Dale, L. Fahrig, R. France, C. Goldman,

K. Heanue, J. Jones, F. Swanson, T. Turrentine, and T. Winter. 2003. Road Ecology: Science and Solutions. Island Press, Washington, D.C., USA.

Fukumoto, J. 1995. Long-toed Salamander (*Ambystoma macrodactylum*) ecology and management in Waterton Lakes National Park. M.E.Des. Thesis, University of Calgary, Calgary, Alberta, Canada. 126 p.

Gartshore, R.G., M. Purchase, R.I. Rook, and L. Scott. 2006. Bayview Avenue extension, Richmond Hill, Ontario, Canada habitat creation and wildlife crossings in a contentious climatic setting: a case study. Pp. 55–76 *In* Proceedings of the 2005 International Conference on Ecology and Transportation. Irwin, C.L., P. Garrett, and K.P. McDermott (Eds.). Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Glista, D.J., T.L. DeVault, and J.A. DeWoody. 2009. A review of mitigation measures for reducing wildlife mortality on roadways. Landscape and Urban Planning 91:1–7.

Jackson, S.D. 1999. Overview of transportation related wildlife problems. Pp. 1–4 *In* Proceedings of the International Conference on Wildlife Ecology and Transportation. Florida Department of Transportation, Tallahassee, Florida, USA.

Jackson, S.D., and T.F. Tyning. 1989. Effectiveness of drift fences and tunnels for moving Spotted Salamanders *Ambystoma maculatum* under roads. Pp. 93–99 *In* Amphibians and Roads, Proceedings of the Toad Tunnel Conference. Langton, T.E.S. (Ed.) ACO Polymer Products, Shefford, United Kingdom.

Jaeger, J.A., and L. Fahrig. 2004. Effects of road fencing on population persistence. Conservation Biology 18:1651–1657.

Little, S.J., R.G. Harcourt, and A.P. Clevenger. 2002. Do wildlife passages act as prey-traps? Biological Conservation 107:135–145.

Mackenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2005. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Elsevier, San Diego, California, USA.

Madison, D.M., and L. Farrand III. 1998. Habitat use during breeding and emigration in radio-implanted Tiger Salamanders, *Ambystoma tigrinum*. Copeia 1998:402–410.

Mata, C., I. Hervás, J. Herranz, F. Suárez, and J.E. Malo. 2005. Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. Biological Conservation 124:397–405.

Mougey, T. 1996. Des tunnels pour batraciens. Le Courrier de la Nature 155:22–28.

Pagnucco, K.S. 2010. Using under-road tunnels to protect a declining population of Long-toed Salamanders (*Ambystoma macrodactylum*) in Waterton Lakes National Park. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada. 127 p.

Pagnucco, K.S., C.A. Paszkowski, and G.J. Scrimgeour. 2011. Wolf in sheep's clothing: Effects of predation by small-bodied fish on survival and behaviour of salamander larvae. Écoscience 18:70–78.

Paton, P.W., and W.B. Crouch III. 2002. Using the phenology of pond-breeding amphibians to develop conservation strategies. Conservation Biology 16:194–204.

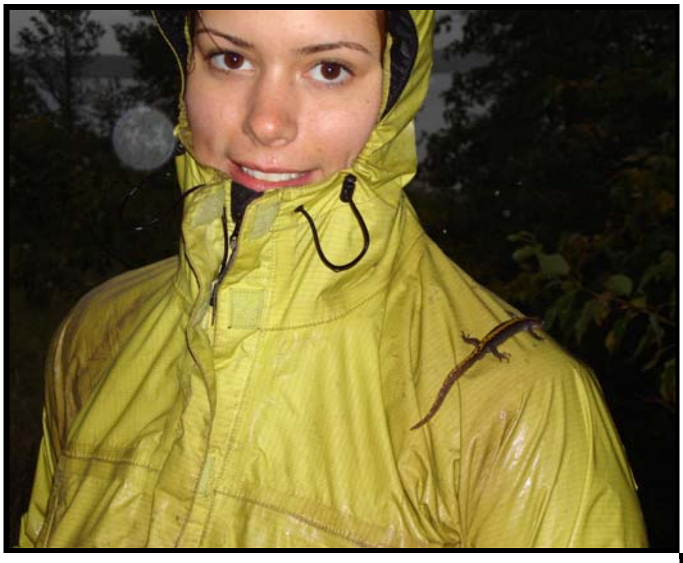
Scott, D.E. 1994. The effect of larval density on adult demographic traits in *Ambystoma opacum*. Ecology 1383–1396.

Smith, C., K. Pagnucco, B. Johnston, C. Paszkowski, and G. Scrimgeour. 2010. Using specialized tunnels to reduce highway mortality of amphibians. Pp. 583–591 *In* Proceedings of the 2009 International Conference on Ecology and Transportation. Wager, P.J., D. Nelson, and E. Murray (Eds.). Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Spellerberg, I.F. 2002. Ecological Effects of Roads. Science Publisher Inc., Plymouth, United Kingdom.

Taylor, B.D., and R.L. Goldingay. 2003. Cutting the carnage: wildlife usage of road culverts in north-eastern New South Wales. Wildlife Research 30:529–537.

Yanes, M., J. Velasco, and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71:217–222.



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