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Culverts alone do not reduce road mortality in anurans [1]

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Abstract: Roads are linked to population declines in amphibians, primarily due to road mortality. Culvert-type ecopassages, along with fencing to direct animals to the passage, have been used to mitigate these impacts. However, the effectiveness of the ecopassage itself, independent of the associated mitigation fencing, is largely untested. In regions with heavy snowfall, long-term maintenance of amphibian-proof fencing is extremely costly. Therefore, it is important to know whether ecopassages alone (without fencing) mitigate amphibian mortality. We used a Before-After-Control-Impact design to experimentally test the hypothesis that pre-existing drainage culverts of the type typically used to mitigate road effects on herptiles mitigate anuran road mortality. Grates were installed at both ends of 6 culverts to exclude anurans from the culverts. At an additional 4 sites fencing was installed on either side of culverts on both sides of the road, to keep anurans off the road. Ten control culverts were left un-manipulated. Roadkill surveys were conducted 1 y before treatments were installed and in each of 2 y after. We predicted that, if culverts alone mitigate mortality, road kill should increase following installation of the grates. If fencing is effective for mitigation, road kill should decrease following installation of fences. We found no evidence for the first prediction: culverts alone did not mitigate road kill effects. In contrast, there was a large decrease in mortality at fenced sites, relative to control sites, indicating that fencing is effective at mitigating road mortality. These results suggest that culverts alone do not reduce anuran mortality; to reduce mortality, animals must be excluded from the road surface.
Keywords: amphibian, BACI, ecopassage, fragmentation, mitigation, roadkill.

Résumé : Les routes sont associées à des déclins de populations d'amphibiens, principalement en raison de la mortalité des animaux sur la route. Les corridors écologiques de type ponceau combinés à l'installation de clôtures pour diriger les animaux vers les points de passage sont utilisés pour atténuer ces impacts. Cependant, l'efficacité du corridor écologique en soi, indépendamment de la clôture qui l'accompagne, demeure peu étudiée. Dans les régions qui reçoivent d'importantes quantités de neige, le maintien à long terme d'une clôture empêchant le passage d'amphibiens est extrêmement coûteux. Il est donc important de savoir si les corridors écologiques seuls (sans clôtures) réduisent la mortalité des amphibiens. Nous avons utilisé un plan d'échantillonnage de type « comparaison avant-après avec témoin » (BACI en anglais) afin d'évaluer l'hypothèse que les ponceaux de drainage préexistants, comme ceux généralement utilisés pour atténuer les impacts des routes sur l'herpétofaune, réduisent la mortalité des anoures. Des grilles ont été installées aux 2 bouts de 6 ponceaux pour en exclure les anoures. Des clôtures ont été installées dans 4 autres sites de chaque côté des ponceaux des 2 côtés de la route pour empêcher les anoures d'aller sur la route. Dix ponceaux témoins ont été laissés tels quels. Des relevés de mortalité sur la route ont été effectués 1 an avant l'installation des traitements et au cours des 2 années suivantes. Notre première hypothèse était que si les ponceaux seuls atténuent les impacts de la route, la mortalité devrait augmenter à la suite de l'installation des grilles. La deuxième était que si la clôture est efficace pour atténuer les impacts de la route, la mortalité devrait diminuer à la suite de l'installation des clôtures. Nous n'avons trouvé aucune preuve supportant la première hypothèse; les ponceaux seuls n'ont pas réduit la mortalité sur la route. À l'opposé, nous avons observé une forte diminution de la mortalité aux sites clôturés en comparaison avec les sites témoins, indiquant que la clôture est efficace pour réduire la mortalité sur la route. Ces résultats suggèrent que les ponceaux seuls ne diminuent pas la mortalité des anoures; pour cela, on doit empêcher les animaux d'aller sur la route.
Mots-clés : amphibien, atténuation des impacts, BACI, corridor écologique, fragmentation, mortalité sur la route.

Nomenclature: Roskov *et al*., 2014.

Introduction

Studies of the effects of roads on wildlife abundance have documented negative effects on large mammals, birds, reptiles, amphibians, and invertebrates (Fahrig & Rytwinski, 2009 and references therein). Road effects on wildlife can result from direct mortality (Ashley & Robinson, 1996; Romin & Bissonette, 1996; Trombulak & Frissell, 2000; Clevenger *et al.*, 2001; Clevenger *et al.*, 2003; Gibbs & Shriver, 2005; Glista *et al.*, 2008), habitat loss and degradation (Gibbs, 1998; Underhill & Angold, 1999), and isolation of populations (Lode, 2000; van der Ree *et al.*, 2009; Eigenbrod, Hecnar & Fahrig, 2008; Shepard *et al.*, 2008; Corlatti, Hacklander & Frey-Roos, 2009). These effects have been linked to reductions in wildlife populations.

Amphibian and reptile populations are often reduced near roads (Fahrig & Rytwinski, 2009; Rytwinski & Fahrig, 2012). For these species, the main cause of population

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declines near roads is likely road mortality. Results of previous studies suggest that amphibians and reptiles experience higher levels of road mortality than other taxa (Ashley & Robinson, 1996; Smith & Dodd, 2003; Glista, DeVault & DeWoody, 2009). The ectothermic nature of reptiles and amphibians may cause them to be attracted to increased temperatures associated with road surfaces for thermoregulation, which increases the likelihood of individuals being killed by traffic (Dodd, Enge & Stuart, 1989; Rosen & Lowe, 1994). In addition, Mazerolle (2004) found that frogs traversing roadways stop moving in response to oncoming traffic. This behaviour may increase the vulnerability of frogs to wildlife–vehicle collisions as it increases the time spent on the road (Andrews, Gibbons & Jochimsen, 2008). Finally, amphibians are often found on roads during mass migration events (Forman & Deblinger, 2000; Jochimsen *et al.*, 2004; Andrews, Gibbons & Jochimsen, 2008; Glista, DeVault & DeWoody, 2009), which often take place at night, making detection of individuals by motorists difficult.

The most common proposed solution to road impacts is the construction of ecopassages, also known as wildlife crossings, to allow animals to cross safely above or below the road surface (Aresco, 2003; Clevenger & Waltho, 2005; Cramer & Bissonette, 2006; Glista, DeVault & DeWoody, 2009; Balmori & Skelly, 2012; van der Grift *et al.*, 2013). Use of ecopassages has been demonstrated for several taxa. For example, Clevenger *et al.* (2001a) found that mammals' use of culvert-type ecopassages increased in response to traffic volume. In a cross-taxa comparison of ecopassage use, Mata *et al.* (2008) found that larger-bodied animals favoured more open passages, while small mammals and herpetofauna favoured culvert-type structures (Mata *et al.*, 2008). Culvert-type ecopassages designed for amphibians and reptiles have been installed in numerous locations across North America (Jackson & Griffin, 1996; Jackson, 1999; Dodd, Barichivich & Smith, 2004; Aresco, 2005a; Cramer & Bissonette, 2006), Europe (Puky, 2003; Lesbarrères, Lode & Merila, 2004; Mata *et al.*, 2005; 2008), and Australia (Norman, Lean & Finegan, 1998; Taylor & Goldingay, 2003; 2010). In most cases, fencing accompanies the ecopassage to direct the animals to the culvert (Clevenger *et al.*, 2001a,b; Dodd, Barichivich & Smith, 2004; Aresco, 2005b).

Several studies have shown that amphibians and reptiles use culverts. In Spain, pre-existing drainage culverts under a railway line were used by snakes and lizards (Rodriguez, Crema & Delibes, 1996). Also in Spain, Yanes, Velasco, and Suárez (1995) found that amphibians and reptiles used sub-road crossing structures of less than 1.2 m in height. Use of structures by amphibians appears to be tied directly to the environmental conditions within the culvert, with preference for structures with high moisture content and natural substrates (Lesbarrères, Lode & Merila, 2004; Mazerolle & Desrochers, 2005). Therefore, road mitigation sites for amphibians often coincide with sites where drainage culverts would be needed under the road to allow passage of small streams. Recommendations for mitigation usually involve installation of large, flat-bottomed drainage culverts, as these are thought to be more likely to allow animal passage than the more typical round metal culverts (Dexel, 1989; Dodd, Barichivich & Smith, 2004; Ontario Ministry of Transportation, 2006; Merrow, 2007).

However, the mere fact that animals use ecopassages such as culverts does not demonstrate that these passages effectively mitigate the impact of the road on the population. In the case of amphibians and reptiles, where road mortality is the main impact of concern, effective mitigation would require that the culverts actually reduce mortality rates; it is not sufficient to show that animals are in the culverts. Several studies show that culverts combined with fencing or barrier walls to keep animals off the road and direct them to the culverts reduce road mortality. Schmidt and Zumbach (2008) found that barrier walls were critical for use of culverts by amphibians. Aresco (2005b) found that drift fencing in conjunction with drainage culverts significantly reduced turtle road mortality. Clevenger *et al.* (2001b) observed decreases in ungulate mortality in response to the installation of exclusion fencing and wildlife crossing structures. Dodd, Barichivich, and Smith (2004) found reduced mortality in amphibians, reptiles, and mammals following the installation of a 2.5-km barrier wall and 8 culverts. Finally, a review of road mitigation studies on amphibians found high variation in culvert use among studies (Smith & Sutherland, 2014), possibly linked to variation in the presence, type, or length of fences or barrier walls.

While the studies above demonstrate mitigation effectiveness, they do not demonstrate an effect of the culvert itself, rather than the mitigation fencing or barrier walls, on mortality. In every case, fencing or a barrier wall, which not only led the animals to the culverts but also kept them off the road, accompanied the culverts. It is possible that the fencing or wall was entirely responsible for the reduced mortality observed in these studies and that the culvert did not play a role in the documented reduction. In parts of the world experiencing heavy snowfall, long-term maintenance of amphibian-proof mitigation fencing is very costly. Such fencing, being near the road, is easily damaged by the weight of direct snow accumulation and snow cleared from the road. Therefore, it is important to know whether culverts alone, without mitigation fencing, reduce anuran road mortality. To test this, we took advantage of an existing set of large, flat-bottomed drainage culverts typical of the design used for amphibian road mitigation. To some of these we added screens to block access to the culverts by anurans. For others, fencing was added along the road on each side of the culvert on both sides of the road. We predicted that if culverts alone reduce road kill, then road kill should increase at sites where anuran access to culverts has been blocked by screens. In contrast, if the apparent effect of culverts found in previous studies is due partly or even entirely to the fencing, then road kill should decrease at sites where fencing is added.

Methods

The overall design of our experiment was to compare the number of road-killed anurans, before and after experimental manipulation with control sites (Before-After-Control-Impact experiment), on road sections within

100 m of each of 20 pre-existing concrete box drainage culverts (hereafter culverts) along a 24-km stretch of paved highway with a 60–80 km/h speed limit. The experimental manipulation consisted of installing grating at both ends of 6 of the culverts, to keep anurans out of the culverts (GRATE, Figure 1a), and installing 90 m of drift fencing on either side of the culvert, along both sides of the road, at 4 other culverts, to keep anurans off the road and potentially direct them to the culvert openings (FENCE, Figure 1b,c). We left the remaining 10 culverts in their original (CONTROL) state (no grates or fencing, Figure 1d). We predicted that if the culverts alone mitigate road mortality, the number of road-killed anurans should increase at the GRATE sites (in comparison to CONTROLs) following installation of the grates, and if fencing is important for mitigation, then the number of road-killed anurans should decrease at the FENCE sites (in comparison to CONTROLs) after installation of the fencing.

The Thousand Islands Parkway ("the Parkway", Figure 2) is a 37-km long, 2-lane portion of Provincial Highway 2 that begins approximately 12 km west of Brockville, Ontario and extends to the eastern edge of Gananoque, Ontario. Prior to the construction of Highway 401 (MacDonald-Cartier Freeway), Provincial Highway 2, including the Parkway, was the primary transportation corridor between Kingston and Brockville. Currently, it provides access to National Park facilities (St. Lawrence Islands National Park) as well as numerous privately owned parcels of land. Our study area comprised a 24-km subset of the Parkway extending from the Thousand Islands Bridge, a United States–Canada border crossing to US Interstate Highway 81, east to the intersection with Highway 401. Along this 24-km portion of the Parkway, the speed limit is 80 km/h, with the exception of a 1-km section where the speed limit is 60 km/h (Figure 2).

The twenty concrete box culverts were selected to be as similar to each other as possible, to avoid confounding factors. To identify culverts for the study, in 2008 the locations of all 140 drainage culverts along the 24-km section of the Parkway (Figure 2) were recorded. We then applied a sequence of selection criteria to identify the culverts that were most likely to be used by anurans and were most similar to each other in size, shape, and site. The 140 culverts ranged in diameter from 25 to 200 cm and were either circular or rectangular. We first narrowed our selection to rectangular culverts of 100–200 cm diameter (n = 41), as anurans are known to preferentially use crossing structures with larger openings (Yanes, Velasco & Suárez, 1995; Aresco, 2005a; Woltz, Gibbs & Ducey, 2008). Woltz, Gibbs, & Ducey (2008) suggest that dry culverts may be avoided

FIGURE 1. Examples of GRATE (a), FENCE (b,c), and CONTROL (d) sites.

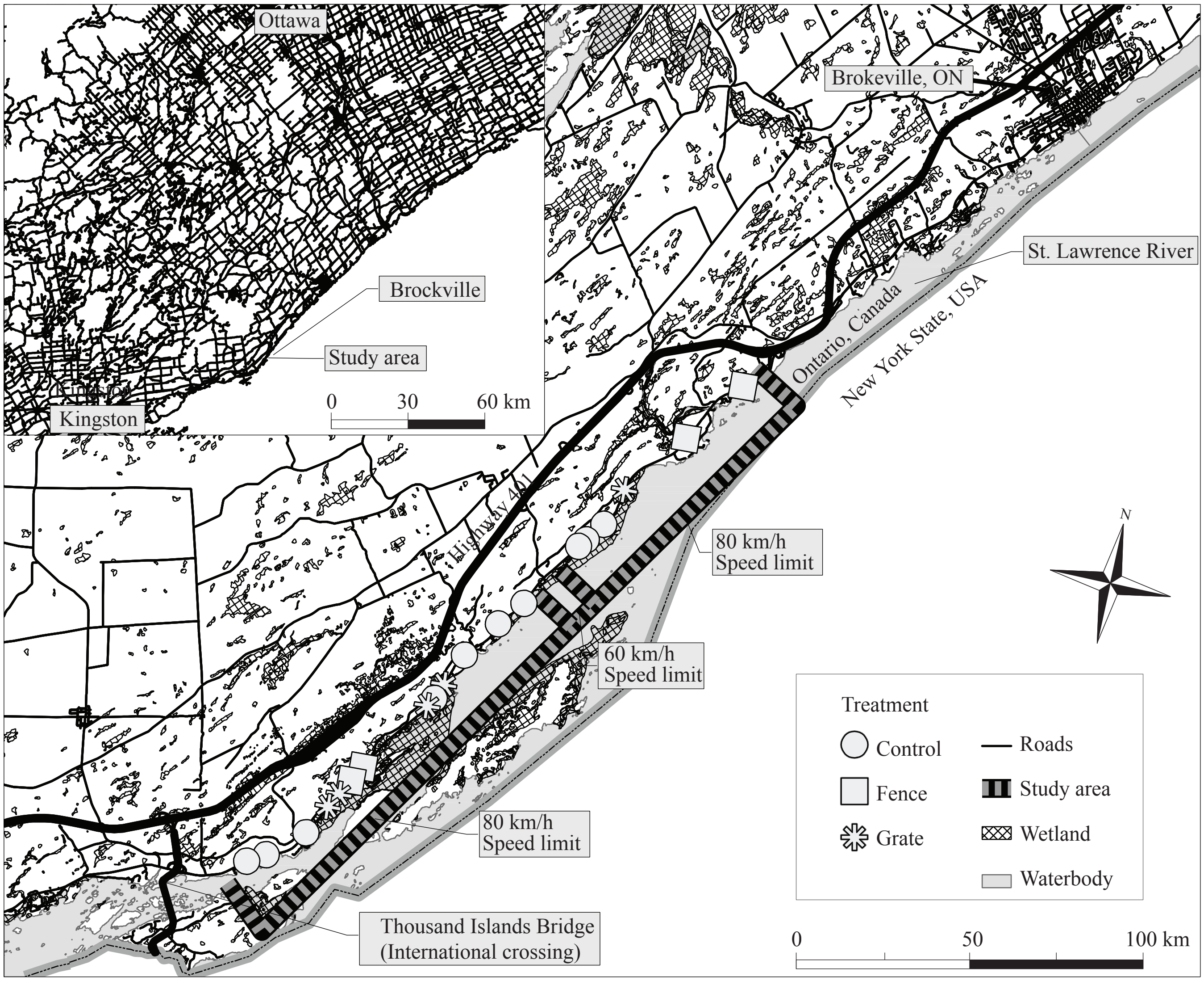

Figure 2. Locations of FENCE, GRATE, and CONTROL sites along a 24-km section of the Thousand Islands Parkway, Ontario.

by anurans, so we further reduced our culvert selection to only those that contained water throughout the survey period (n = 30). Finally, we selected 20 culverts that were not within 200 m of any other culvert, driveways, or intersecting roadways, to reduce or avoid inter-site variation that could have confounded our results (Figure 2). The mean distances from the culverts to the closest wetlands were 56 m, 42 m, and 64 m for the GRATE, FENCE, and CONTROL treatments respectively. We were unable to determine if any of the culverts had been replaced since the road was constructed in the late 1930s. A number of the culverts were marked with the inscription “The King’s Highway 1938”; we assumed they were all the same age.

In the summers of 2009 and 2010, 6 of the 20 culverts were randomly selected, and both openings of each culvert were covered with hardware cloth (6 mm mesh size) stretched across wooden frames (GRATE). These grates allowed water to pass through but blocked anurans from accessing the culvert (Figure 1a). Also in the summers of 2009 and 2010, at each of 4 randomly selected culverts we installed 0.9-m-high plastic silt fencing (FENCE), extending 90 m from either side of the culvert opening, on both sides of the road (Figure 1b,c). The fencing height was based on Woltz, Gibbs, and Ducey (2008), who found that barriers 0.9 m in height excluded 99% of anurans. The final 10 culverts were left unaltered as control sites (CONTROL; Figure 1d). Treatments were installed at the same locations in 2009 and 2010. Treatments were in place by the last week in June 2009, removed in mid-October 2009, reinstalled in the third week in May 2010, and removed in mid-October 2010. They were not in place over winter to avoid damage from ice and snow; in any case, anurans in our area are not active during winter.

Road kill surveys along the Parkway were conducted by bicycle and on foot 3 to 4 mornings weekly in each of 2008 (the year before the experimental manipulations), 2009, and 2010. Surveys were completed on the same dates each year to avoid potential confounding effects of season and weather with our treatments. During each survey, the location of each anuran found dead on the paved road surface or gravel shoulder (hereafter road) was recorded with a differentially corrected Global Positioning System (GPS) receiver (Trimble Nomad, Trimble Navigation Ltd., Sunnyvale, California, USA; mean accuracy 3–5 m) with a mobile GIS (ESRI ArcPad, version 7.1, Environmental Systems Research Institute, Redlands, California, USA), and then removed from the road. The gravel shoulder was included in the survey area to include individuals thrown from the road by the impact with a vehicle. While it was often possible to determine the species of anuran killed, the condition of most made it impossible to determine size, age, or sex. We assumed that all anurans found dead on the road were killed by vehicular traffic. As some injured or killed individuals may have been removed from the road by scavengers (Smith & Dodd, 2003; Row, Blouin-Demers & Weatherhead, 2007), counts of the number of dead anurans were considered conservative estimates of road mortality. We assumed that the probability of removal by scavengers was unrelated to treatment (GRATE, FENCE, and CONTROL).

The total number of road-killed anurans within 100 m of each study culvert per year was the response variable in analyses. The fencing used in the 4 fenced sites extended 90 m from each side of the culvert opening, so the road kill surveys included 10 m of road beyond the ends of the fence. This was to ensure that we included the possibility of elevated road mortality at the fence ends in case anurans followed the fencing to the end and then attempted to cross the road. Road kill values were summed for each sampling site (n = 20) in a given year and then log transformed to improve homogeneity of variance. We used generalized linear mixed models (GLMM) using the restricted maximum likelihood method (REML) as recommended by McDonald, Erickson, and McDonald (2000). We conducted 2 analyses: one comparing road kill numbers at GRATE *versus* CONTROL sites and the other comparing road kill numbers at FENCE *versus* CONTROL sites. Predictors were treatment (GRATE *versus* CONTROL or FENCE *versus* CONTROL), year (2008 [Before], 2009, and 2010 [After]), and the interaction between year and treatment as fixed effects. The interaction effect between treatment and year in each analysis is the effect of interest to us, since it tests our predictions that mortality should increase following installation of grates and decrease following installation of fencing. In the GRATE *versus* CONTROL analysis we predicted an increase in mortality from Before (2008) to After (2009, 2010) at the GRATE sites relative to the changes over these same years at the CONTROL sites. In the FENCE *versus* CONTROL analysis we predicted a decrease in mortality from Before (2008) to After (2009, 2010) at the FENCE sites relative to the changes over these same years at the CONTROL sites. Finally, we tested for spatial autocorrelation of the residuals using Moran's I to ensure that it was valid to treat each site as an independent sample.

Results

Altogether, we identified 1761 dead anurans (726 in 2008, 454 in 2009, 581 in 2010). Roadkill anurans identified included bullfrog (*Lithobates catesbeianus*), northern leopard frog (*Lithobates pipiens*), northern green frog (*Lithobates clamitans melanota*), eastern American toad (*Anaxyrus americanus americanus*), gray treefrog (*Hyla versicolor*), mink frog (*Lithobates septentrionalis*), and wood frog (*Lithobates sylvaticus*). These are all the anuran species common to the survey area (G. M. Cunnington, unpubl. data), with the exception of the spring peeper (*Pseudacris crucifer*), which may have been present but is likely very difficult to detect due to its small size. Anuran roadkills occurred throughout the survey period, with an apparent peak in July (Appendix I).

Roadkill numbers did not vary significantly between years at the CONTROL ($F_{2, 27}$ = 1.981, P = 0.157) and GRATE ($F_{2, 15}$ = 0.758, P = 0.486) sites; however, there was a significant difference between years in the number of dead anurans at FENCE sites ($F_{2, 9}$ = 4.55, P = 0.043). In the GRATE *versus* CONTROL analysis, there was no significant interaction effect between treatment and year, indicating no significant effect of the GRATE treatment on anuran road mortality (Table I; Figure 3). In contrast, in the FENCE *versus* CONTROL analysis, there was a significant interaction between treatment and year (Table I; Figure 3), indicating that the effect of FENCE relative to CONTROL (*i.e.*, treatment) depended on year. In particular, relative to the CONTROL sites, the number of dead anurans was reduced by about 40% at the FENCE sites after the fencing was in place (2009, 2010) than before (2008) (Figure 3; coefficients in Table I). Residual road kill numbers were not spatially autocorrelated (Moran's I = 0.001, z = 0.68, P = 0.495), suggesting that the sites could be considered independent samples.

Discussion

Results of our study indicate that culverts alone do not reduce anuran mortality. Placing grates over the openings of culverts to block anuran entry did not result in an increase in mortality of anurans on the roads. This suggests that the presence of a culvert does not reduce the likelihood that anurans attempt to cross over the road, and that anurans attempting to cross the road near a culvert do not detect the presence of the culvert and direct their movements towards it. This implies that culverts, at least concrete box culverts such as those we studied, should not be viewed as a means to mitigate road mortality on anurans.

On the other hand, the installation of fencing along both sides of the road did reduce anuran mortality. Because there was no effect of culverts alone on anuran mortality, we cannot conclude that the effectiveness of the fencing was in any way related to the fact that the fencing was associated with culverts. It would not be accurate to infer that adding fencing makes culverts effective; the same reduction in mortality might have been observed if we had installed the same length of fencing along road sections where no culvert was present. This result suggests that reducing anuran mortality on roads requires fencing (or some other means) to keep the anurans off the road. This result is consistent with predictions of a recent simulation study (Ascensão *et al.*, 2013).

Note that we detected a significant effect of the FENCE treatment even though this treatment had the smallest

TABLE I. Generalized Linear Mixed Model (GLMM) analyses using the Restricted Maximum Likelihood (RML) method on a Before-After-Control-Impact (BACI) study of the effects of GRATE and FENCE treatments on anuran mortality. Treatments were GRATE sites (n = 6), where grates were placed over culvert entrances such that anurans could not enter them, and FENCE sites (n = 4), where 90 m of fencing was placed along the road on either side of both culvert entrances. CONTROL sites (n = 10) were culvert sites where no grates or fencing were installed. Road kill surveys were conducted at all sites in 2008 before grates and fencing were in place and again in 2009 and 2010 after grates and fencing were in place.

Comparison	Variable	β	*F*	*P*-value
GRATE *versus* CONTROL	Treatment		0.065	0.799
	CONTROL	0		0.923
	GRATE	0.013		
	Year		0.475	0.627
	2008	0		
	2009	–0.187		0.063
	2010	0.069		0.513
	Treatment·Year		2.612	0.088
	CONTROL·2008	0		
	GRATE·2008	0		
	CONTROL·2009	0.222		0.170
	GRATE·2009	0		
	CONTROL·2010	0		
	GRATE·2010	–0.194		0.306
FENCE *versus* CONTROL	Treatment		0.512	0.479
	CONTROL	0		
	FENCE	0.404		0.052
	Year		10.551	<0.001
	2008	0		
	2009	–0.187		0.112
	2010	0.093		0.461
	Treatment·Year		10.166	<0.001
	CONTROL·2008	0		
	FENCE·2008	0		
	CONTROL·2009	–0.438		0.051
	FENCE·2009	0		
	CONTROL·2010	0		
	FENCE·2010	–1.086		<0.001

number of replicates (4). This indicates that our study had sufficient power to detect a treatment effect despite our relatively small sample sizes. We had 6 replicates of the GRATE treatment but did not detect any effect. It remains possible that culverts have a small impact on mortality that we missed due to our low sample size. However, our results do indicate that if there is an effect of the culverts, it is a very small effect, especially relative to the effect of the fencing.

Our results have important implications for mitigation of road effects on amphibians. Most mitigation efforts currently assume that the primary focus should be on improving permeability of roads to animal movements; for that reason, the focus is on ecopassages such as culverts (Beebee, 2013). This assumption may be valid in some situations, such as when road mortality is low (*e.g.*, because the animals are able to avoid oncoming vehicles) and migration across the road is required for the animal to complete its life cycle (Jaeger *et al.*, 2005). However, simulation studies suggest that road mortality usually has a much stronger impact than the movement barrier effect on both population persistence and genetic diversity (Jaeger & Fahrig, 2004; Jackson & Fahrig, 2011). Because our results suggest that fencing is much more effective than ecopassages at reducing road mortality in anurans, a group of species vulnerable to road mortality, we conclude that the first priority for mitigation

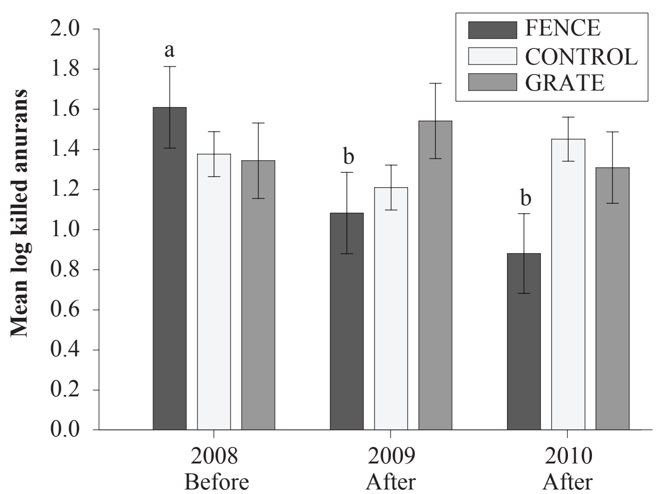

FIGURE 3. Mean log number of dead anurans at FENCE, CONTROL, and GRATE sites before and after the treatments were applied. Error bars represent standard errors. Letters indicate significant differences (α = 0.05) between groups.

should normally be installation of fencing or other structures that keep animals off the roads, thereby keeping them from being killed. This is critical for designing effective road mitigation in situations where choices must be made due to limited mitigation funds. For example, if a road runs for 2 km through a wetland where anuran populations have declined due to road kill, a limited mitigation budget would likely be better spent on fencing the entire 2 km to keep frogs off the road rather than spending most of the money on a few crossing structures with only limited fencing, thus leaving most of the road unfenced. If the road blocks access to a resource needed for the species to complete its life cycle, *e.g.*, breeding habitat is on one side of the road while overwintering habitat is on the other side, then 1 or more ecopassages will need to be included along with the fencing. On the other hand, in some situations it may be feasible and less costly to create or enhance habitat such that both required habitat types exist on the same side of the road.

Our results are particularly challenging in regions experiencing heavy snowfall, where long-term maintenance of amphibian-proof fencing is very costly. If fencing is susceptible to damage over the winter, it may be preferable to erect temporary fencing each spring and dismantle it each fall, so that the fencing itself can be re-used. However, this is also very costly, particularly because the fencing needs to be buried to keep small animals from passing underneath. If a permanent solution to the road mortality is preferred, our results imply that development of new engineering solutions for keeping amphibians off roads should be a high priority. One notable example is the reconstruction of Highway 441, Florida, USA, which passes through a 3.2-km section of prairie habitat. In response to concern over the extremely high road kill numbers (Smith & Dodd, 2003) on this section of road, the road was rebuilt such that the road bed was raised and walls were installed along the sides of the roadbed (below the road surface). The walls have a lip along the top so that most animals cannot climb onto the road. Since reconstruction of this section of road, mortality has been reduced by over 90% (excluding birds; Barichivich & Dodd, 2002). There may also be other ways to keep animals from being killed on roads, besides installation of fencing or other barriers. Closures of roads at specific times of year when large numbers of individuals attempt to cross the road can be effective. In Burlington, Ontario, Canada, a stretch of municipal roadway is closed for 3 weeks each spring to allow the annual migration of Jefferson salamanders (*Ambystoma jeffersonianum*), an endangered species. In addition to closing existing roads during periods when species are most likely to migrate across them, the mortality imposed by new roads could be reduced by building them far from natural habitats such as wetlands. However, as impacts of roads on anurans extend as far as 1 km from the road (Eigenbrod, Hecnar & Fahrig, 2009), this strategy will be limited in many regions.

Our finding that culverts alone do not reduce mortality of anurans cannot necessarily be extrapolated to other species or species groups. In particular, it may not apply to animals that avoid moving onto the road surface, as road mortality in such species will be very low. Several studies have shown that small mammals avoid moving onto the road surface (Garland & Bradley, 1984; Ford & Fahrig, 2008; McGregor, Bender & Fahrig, 2008; Brehme *et al.*, 2013), and work by Clevenger *et al.* (2001a) suggests that culverts are often used by small mammals to cross roads. This implies that small mammals may move along the road edge searching for a means to cross without going over the road surface. Ecopassages may thus further reduce road mortality in these species. On the other hand, because roads appear to have little effect on small mammal abundances (Fahrig & Rytwinski, 2009; Rytwinski & Fahrig, 2012), it is questionable whether ecopassages are needed for them. In contrast to small mammal behaviour, amphibians attempt to cross the road where their paths intersect it (Bouchard *et al.*, 2009). Without the aid of fencing, amphibians would not locate a culvert unless it occured directly in their path.

Our findings suggest that we should not assume that the occurrence of animals in or on ecopassages actually demonstrates their effectiveness at mitigating the effect of the road. More Before-After-Control-Impact (BACI) studies like the one presented here are required to determine effectiveness of these structures. Future studies would benefit from the inclusion of population level monitoring to determine the efficacy of ecopassages at mitigating the impacts of roads on wildlife populations. Given the cost of installing ecopassages, standard practice for monitoring their effectiveness should follow a BACI design (van der Grift *et al.*, 2013). This would include measurements of road mortality, movement rate, and/or population size taken before the structures are installed, at both the structure site and at control sites, and then these measurements should be repeated after the structures are installed.

We suggest it may be time to reconsider the appropriateness of the current road mitigation emphasis on crossing structures, at least for amphibians. Amphibian and reptile populations are known to be particularly vulnerable to the effects of roads, with road mortality likely the main mechanism (Fahrig & Rytwinski, 2009; Rytwinski & Fahrig, 2012). Because our results suggest fencing is much more effective than ecopassages at reducing mortality, we suggest that a realignment of road mitigation for amphibians (and possibly reptiles) towards fencing and other measures aimed at keeping animals off roads would be appropriate.

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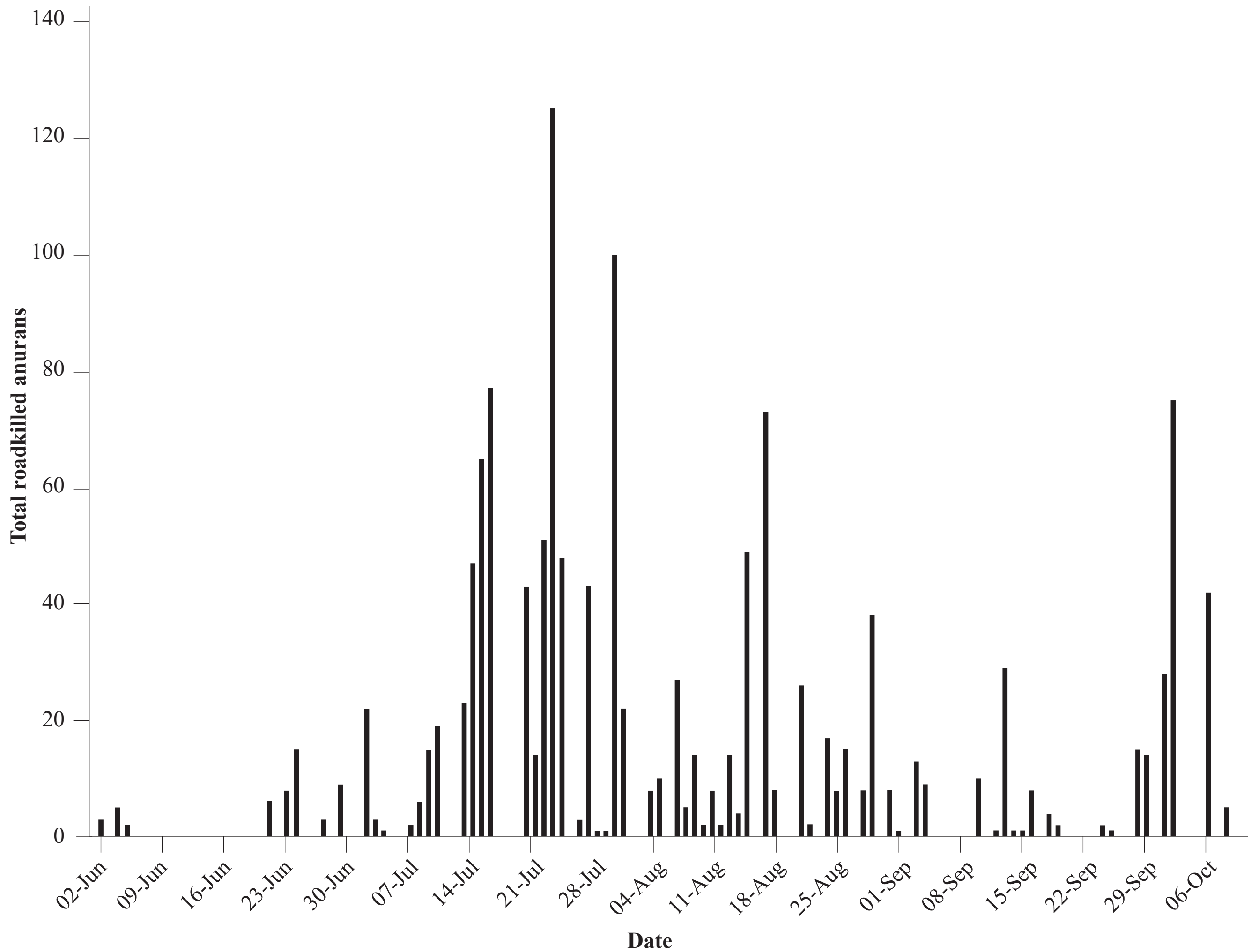
Appendix I



APPENDIX I, FIGURE 1. Summary of roadkilled anurans throughout the survey period. Data presented represent combined counts from all 3 y of survey (2008–2010) at all sites.