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Evidence-Based Amphibian Conservation: A Case Study on Toad Tunnels

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ABSTRACT: Although the search for the drivers of amphibian declines continues, there is a need to implement conservation actions. Conservation science usually does not deliver clear answers about which conservation actions are most effective and which ones should be implemented. Furthermore, results often cannot be used directly by conservationists. Given that resources are limited, there is a need to know which conservation actions and management interventions are most likely to succeed. The goal of evidence-based conservation is to assess the effectiveness of conservation actions qualitatively and quantitatively, and comparative effectiveness studies are a powerful tool to evaluate different conservation actions. We use a case study on toad tunnels to discuss the benefits and limitations of comparative effectiveness studies. Although we show that wider tunnels are used by a higher proportion of individuals, the strength of evidence for effects of other characteristics of amphibian tunnels on tunnel use was weak. Despite some equivocal results, our case study illustrates that the approach can readily be used to study the effectiveness of conservation actions and to derive recommendations for conservationists and managers that can be used directly to improve future conservation interventions.

Key words: Amphibian tunnels; *Bufo bufo*; Conservation action; Conservation evidence; Mitigation; Population growth; *Rana temporaria*; Road mortality

IN HIS CLASSIC paper "What is Conservation Biology?" Soulé (1985:727) wrote that the goal of conservation biology "is to provide principles and tools for preserving biological diversity." Laurance et al. (2012), however, noted that academic conservation research makes surprisingly few direct contributions to conservation. Likewise, Godet and Devictor (2018) showed that conservation biologists publish papers mostly on principles and very few on tools. In fact, only 3% of the 12,971 papers screened by Godet and Devictor (2018) offered solutions to conservation problems. Fazey et al. (2005) were more optimistic. They found that 20 and 37% of the studies examined had high relevance to policy and management, respectively. However, only 12.6% of the studies tested or reviewed conservation actions (i.e., tools). There are also many papers that describe research on issues relevant to conservation, but where researchers seem to get basic principles wrong or where evidence is weak (Kareiva et al. 2018). A pertinent example is research on habitat fragmentation, where people seem to confound the effects of habitat loss and fragmentation (Fahrig 2019).

It is therefore not surprising that there is a gap between conservation science and practice (Foster and Beebee 2004; Pullin et al. 2004; Arlettaz et al. 2010; Habel et al. 2013). Grant et al. (2019) argued that there was a need to refocus conservation biology because a deeper understanding of a system does not necessarily lead to better conservation. Although knowledge gaps can seriously hamper conservation action, there is no direct link between a deeper understanding of principles and improved conservation action (Grant et al. 2019).

Evidence-based conservation summarizes the knowledge on the effectiveness of conservation interventions. This improves conservation decisions and actions (Sutherland et al. 2004; Walsh et al. 2015). Websites such as conservationevidence.com collate the information from the published literature. However, as Smith et al. (2014) noted, comparative effectiveness studies are particularly useful for conservation practitioners. Comparative effectiveness studies directly compare different conservation interventions for the same threat (Smith et al. 2014). For example, Schmidt et al. (2019) used a comparative effectiveness approach to describe which types of ponds were most likely to be colonized by the target amphibian species. Using this approach, they showed how ponds should be constructed to maximize the likelihood of colonization and the establishment of large, reproducing populations. We stress that others have used a similar approach, either experimental or observational, but did not use the label "comparative effectiveness study" (e.g., Stumpel and van der Voet 1998; Shulse et al. 2010; Buckley et al. 2014; Magnus and Rannap 2019). Population viability analyses might also be regarded as comparative effectiveness studies. However, they predict future outcomes, whereas comparative effectiveness studies are retrospective analyses of conservation actions.

Here, we describe a case study on underpasses for amphibians (toad tunnels) to illustrate the benefits and limits of comparative effectiveness studies, and how they can inform future conservation interventions. Underpasses are an area of conservation where substantial progress was made (Schmidt and Zumbach 2008) but there remains room for improvement (Petrovan and Schmidt 2019). It was noted decades ago (e.g., Fischer 1969; Van Gelder 1973) that many amphibians are killed on roads. Road mortality usually peaks in the spring when adult amphibians undergo seasonal migrations from hibernation sites to breeding sites (Schmidt and Zumbach 2008). There is also road mortality when adults leave the ponds and migrate back to the terrestrial habitat. Juveniles leave ponds weeks or months later after the completion of metamorphosis. Although less often observed, there can be substantial mortality of juveniles on roads (Petrovan and Schmidt 2019). Toad tunnels and associated barrier walls are used to prevent road mortality

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and to mitigate the negative effects of road mortality (Grossenbacher 1985; Glandt et al. 2003; Schmidt and Zumbach 2008; VSS 2010; Beebee 2013).

We evaluated the effectiveness of underpasses by quantifying (1) the effect of physical tunnel characteristics on tunnel use and (2) population size before and after construction of toad tunnel/barrier systems. Ideally, 100% of the amphibians arriving at the tunnel/barrier system would use the tunnel, but the proportion is commonly <100% (Schmidt and Zumbach 2008). Geise et al. (2008) suggested that 75% of the animals should use the tunnels to maintain population viability. We expected positive effects of tunnel width and natural soil types and negative effects of tunnel length and distance between tunnels on the use of the tunnels by amphibians (Smith et al. 2018). The long-term population-level consequences of toad tunnels are poorly known, so we compared population sizes before and after the construction of the underpasses (Matos et al. 2017). Population size prior to tunnel/barrier construction was estimated based on volunteer efforts. Typically, volunteers ("toad patrols") set up temporary drift fences to capture and carry amphibians across the road and to reduce road mortality. The numbers of captured amphibians were carefully collected and stored in the data base of Info Fauna Karch, the Swiss Amphibian and Reptile Conservation Program (Petrovan and Schmidt 2016; Schmidt and Zumbach 2008, 2019). Mitigation measures by volunteers protect only a subset of the population (adults migrating towards the pond); all other migrations (adults on the way back and juveniles) are not protected. Underpasses allow adults and juveniles to cross under the road safely during all seasonal migrations. Therefore, we expected that population size would increase after the construction of functional underpasses because all migrators are protected. Answering these questions can inform the construction of underpasses such that they can be built to be most beneficial to amphibians.

MATERIALS AND METHODS

Study Sites

We selected 17 sites for this study. A site is defined as a stretch of road with toad tunnels and a barrier wall system and seasonal amphibian migrations across the road (see Fig. 1A). We used data from Info Fauna Karch (Schmidt and Zumbach 2019) and the following criteria to select sites: (1) Volunteers used drift fences and collected data on the number of amphibians (primarily Common Frogs, *Rana temporaria*, and Common Toads, *Bufo bufo*) captured prior to any construction of tunnels and barrier walls and archived the data at Info Fauna Karch (see http://lepus.unine.ch/zsdb; mean number of years = 7.8, range = 1–23); (2) toad tunnels and barrier walls were at least 10 yr old. These criteria are important because we wanted sufficient time before and after the construction of the tunnels to quantify population sizes, and thus identify the demographic response to the conservation action (construction of tunnels)

At all sites, volunteers had collected data prior to tunnel/barrier wall construction. They set up temporary drift fences with buckets to capture amphibians. Buckets were usually emptied daily, once in the morning and once in the evening. Amphibians were carried across the road and released either at the edge of the road or at the pond. Temporary drift fences had very low trespassing rates (i.e., few amphibians climbed over the fence). Volunteers would notice trespassing amphibians because many would be killed on the road and volunteers could detect the carcasses. Volunteers improved fences when they noted trespassing amphibians. Fences were set up well before the breeding season and were taken down after the seasonal migration towards the pond had ended. We are therefore confident that the counts of migrating amphibians are a reliable index of breeding population size (total adult population size, which includes nonbreeders, may be larger).

As an example, Fig. 1 shows a map of one of the study sites (near Bleienbach, Switzerland; for additional photos see Figs. S1–S9 in the Supplemental Material available online). The breeding site (pond) is located in an open agricultural landscape of mostly arable fields. At that site, amphibians primarily use the adjacent forested hill south of the pond as terrestrial habitat. Some amphibians may also use the small woodlot close to the pond or the forested hills located north of the pond. A road separates the breeding site and the terrestrial habitat south of the pond. Ten toad tunnels were built at that site. A permanent barrier wall system was built on the southeastern side of the road. There is no barrier wall system on the side facing towards the breeding site.

Field Work

To collect new data on tunnel use and population sizes comparable to the volunteer data, we set up a drift fence system as described by Geise et al. (2008) at every site. We placed a temporary drift fence made of plastic a few meters away from the permanent barrier wall. The drift fence was parallel to the permanent barrier wall. The distance between the drift fence and the barrier wall depended on the site and local topography and vegetation. At the ends of the barrier walls and the drift fence we also put a fence such that barrier wall and drift fence formed an enclosure. We buried buckets on the outer side of the fence to capture amphibians. These temporary drift fences were set up and buckets dug into the ground shortly after snow melt but before the start of the spring migration of amphibians. The drift fence allowed us to determine the number of amphibians that arrived at the site (i.e., the number of frogs and toads migrating towards the breeding site, which was our index of population size in that particular year). All amphibians that were captured were released on the other side of the fence such that they could continue their migration towards the pond and potentially use the tunnels. We placed drift fences and buckets at the exit of the tunnels. This allowed us to capture all toads that used the tunnels (i.e., they were exiting the tunnel at the other side). The number of animals that successfully used the tunnels (i.e., were captured at the exits), divided by the number of animals captured at the drift fence, was our estimate of the proportion of the population that successfully used the tunnels.

Common Frogs, *Rana temporaria*, and Common Toads, *Bufo bufo*, were the most common species at the study sites. We also observed newts (primarily *Ichthyosaura alpestris* and *Lissotriton helveticus*) and other frogs (*Pelophylax* sp.). Amphibian tunnels are commonly built to protect Common Frogs and Common Toads (Glandt et al. 2003; Schmidt and Zumbach 2008).

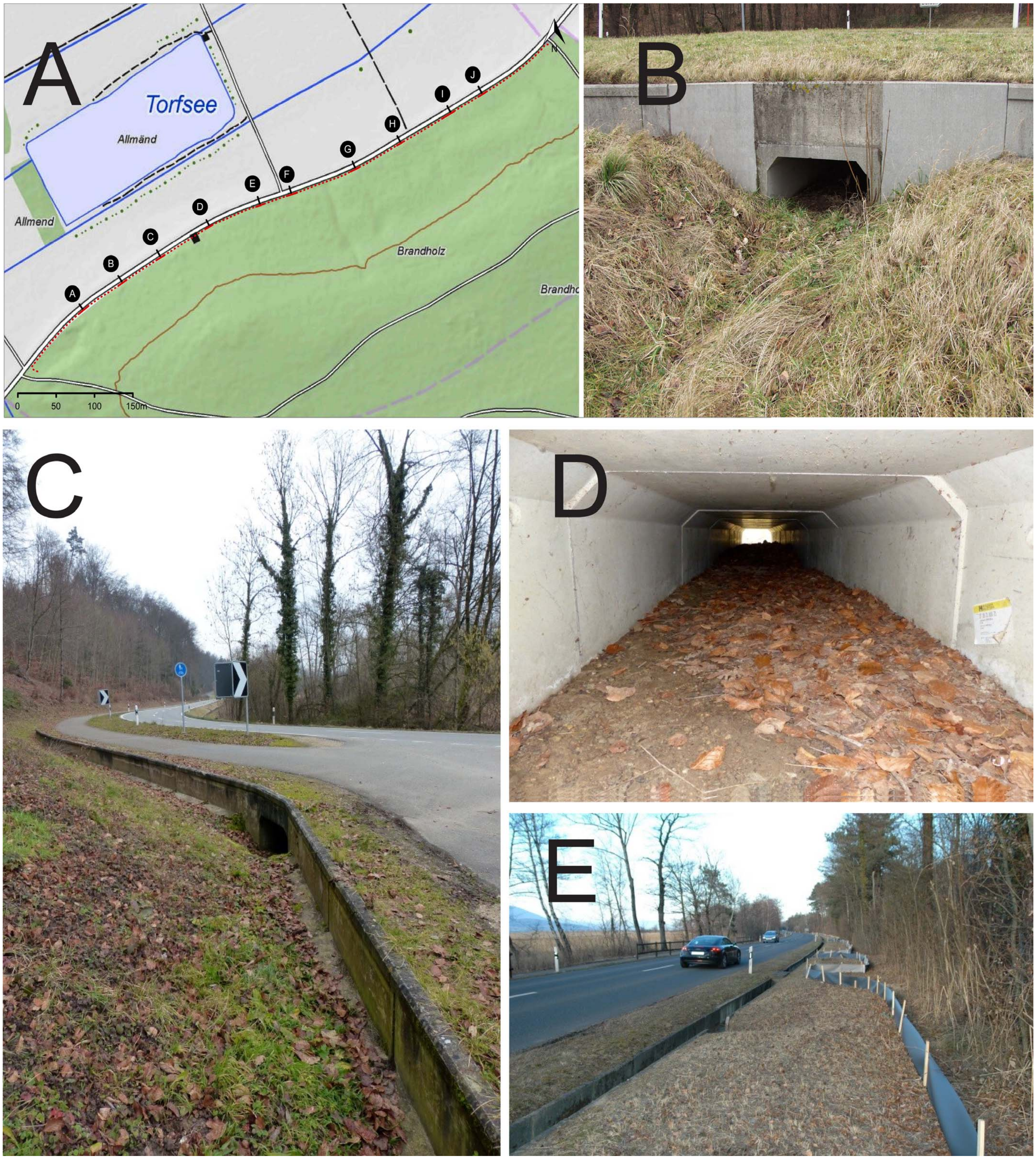

FIG. 1.—Study sites, amphibian tunnel/barrier wall systems, and temporary drift fences. (A) Map of the study site Bleienbach; black dots with letters show the location of the amphibian tunnels. (B, C) Examples of amphibian tunnel/barrier wall systems. (D) Photograph of the inside of a tunnel. (E) Permanent barrier wall and the temporary drift fences. A color version of this figure is available online.

Amphibian populations fluctuate widely in size (Meyer et al. 1998; Green 2003), so we collected data at 16 sites during two spring seasons (at 1 site during one season). Field work was labor intensive, so only a subset of sites was surveyed each year. Field work was done from 2011 to 2014. Field work began when the first amphibians started to migrate and ended when amphibian migration towards the breeding site ended. Thus, effort was comparable to volunteer collection effort. Drift fences and buckets were checked daily, except during cold weather when no amphibians were migrating. In

TABLE 1.—Description of study sites with tunnel/barrier wall systems (– indicates that no population size data were available; * indicates populations which were removed from the analysis of changes in population size; see text for details).

Site	Tunnel type	Construction year	Study years	Number of years during which volunteers collected data	Mean *Bufo bufo* population size before tunnel construction	Mean *B. bufo* population size during study	Mean *Rana temporaria* population size before tunnel construction	Mean *R. temporaria* population size during study
Balzenwil	Rectangular culvert	2000	2012, 2013	8	1*	9	667	98
Bleienbach	ACO tunnel	1994	2011, 2012	23	2062	8538	356	817
Cossonay	Round tunnel	1978	2011, 2012	13	1714	87	238	168
Dättnau	Rectangular culvert	1992	2011, 2012	5	2699	7790	456	810
Hochfelden	Rectangular culvert	1993	2012, 2013	2	1937	170	1188	2616
Kirchberg	Rectangular culvert	2002	2011, 2012	4	122	345	590	1207
Kottwil	Corrugated steel (half-round)	2003	2011, 2012	16	2816	8550	244	143
Felsenau	Rectangular culvert	2000	2011, 2012	15	1103	1021	514	249
Menznau	Rectangular culvert	NA	2011, 2012	8	143	1412	900	428
Magdenau	Rectangular culvert	1994	2011, 2012	3	9042	6616	690	1282
Niederuster	Rectangular culvert	1998	2012, 2013	1	682	250	290	459
Oberuzwil	Rectangular culvert	1994	2011, 2012	5	702	3099	15*	136
Payerne	Round tunnel	1996	2012, 2013	1	–	35	–	5
Stansstad	Round tunnel	1988	2012, 2013	2	355	38	245	13
St. Blaise	Round tunnel	1994	2010, 2011	15	3857	597	3*	21
Yvonand	Round tunnel	1988	2013	1	–	29	–	67
Zofingen	Rectangular culvert	1999	2011, 2012	11	432	302	38	6

the statistical analysis, we used the sum of the daily counts as our response variable (i.e., population size index).

Statistical Analyses

To quantify how characteristics of the tunnel affected the proportion of amphibians that used the tunnels, we used linear regression with normal errors. The mean proportion of individuals using the tunnels during our 2 yr of sampling was the response variable. In some cases, the number of amphibians at the exits of the tunnels was larger than the number captured at the drift fence, leading to tunnel use rates greater than 100%. Amphibians may have trespassed the drift fences or they may have been hibernating in the area in between the barrier wall and the drift fence. In these cases, we fixed tunnel use rates at 1. The proportions were arcsine square root transformed prior to analysis (Crawley 2007). Preliminary analyses suggested that different types of analysis (logit transformation of proportions, Warton and Hui 2011; beta regression, Douma and Weedon 2019) yield qualitatively similar results. Explanatory variables were not transformed or scaled. We fitted three candidate models to the data: (1) tunnel width and tunnel length, (2) tunnel width and distance between tunnels, and (3) tunnel width and soil type (concrete vs. natural). Correlations among the three explanatory variables were less than $|0.46|$.

To quantify the effect of tunnel characteristics on the change in population size, we used linear regression with normal errors. The change in population size was defined as $\log(N_2/N_1)$ where N_1 was the mean size before tunnel construction and N_2 was the mean of the two population size counts during this study (Table 1). For this analysis we removed populations (two for *Rana temporaria*, one for *Bufo bufo*) where recorded population size prior to tunnel construction was less than 20. We did so because such small population sizes could create very large relative changes in size. For example, if a population increased from 10 to 20 individuals, then this would be analyzed as a doubling of population size even though only 10 individuals were added. We fitted two models to the data. In the first model, we used the mean proportion of individuals that used the tunnels as the explanatory variable. In the second model, we used the two explanatory variables from the best-supported model in our first analysis.

We used program R and JAGS called from R using the R package jagsUI to fit the models to the data in a Bayesian format (Plummer 2003; Kéry 2010; R Core Team 2014; Kellner 2016). We modified code available in Kéry (2010) for our models. The JAGS code is shown in the Supplemental Material (available online). We used uninformative normal priors (with a mean of 0 and a precision of 0.001) for the regression coefficients and uninformative uniform priors in the interval (0, 1000) for the standard deviation of the residual variance. For each model, we ran three Markov chains with 20,000 iterations and removed the first 2000 as burn-in. Chains were not thinned. Convergence was assessed using the $\hat{R}$ statistic (Brooks and Gelman 1998) and visual inspection of the Markov chains. To select from among competing models, we used the deviance information criterion (DIC; Spiegelhalter et al. 2002) to rank models. We report the mean and the 95% credible interval of the posterior distribution of all parameters. We also report the proportion of the posterior that had the same sign as the mean (f). This can be interpreted as the probability that the effect is positive or negative (Wade 2000).

RESULTS

Tunnel Use

On average across all sites and both years, 77% of Common Frogs and 68% of Common Toads used the tunnels but there was substantial variation among sites and years (Fig. 2). Mean proportions of amphibians using the tunnels were weakly correlated between the two species among sites ($r = 0.44$; Fig. 3).

The best supported models for tunnel use differed between species. For Common Frogs, the best supported model included the explanatory variables tunnel width and distance between tunnels. Tunnel width had a positive effect, whereas distance between tunnels had a negative effect (Table 2; Fig. 4). For Common Toads, the best supported model included the explanatory variables tunnel width and tunnel length. Tunnel

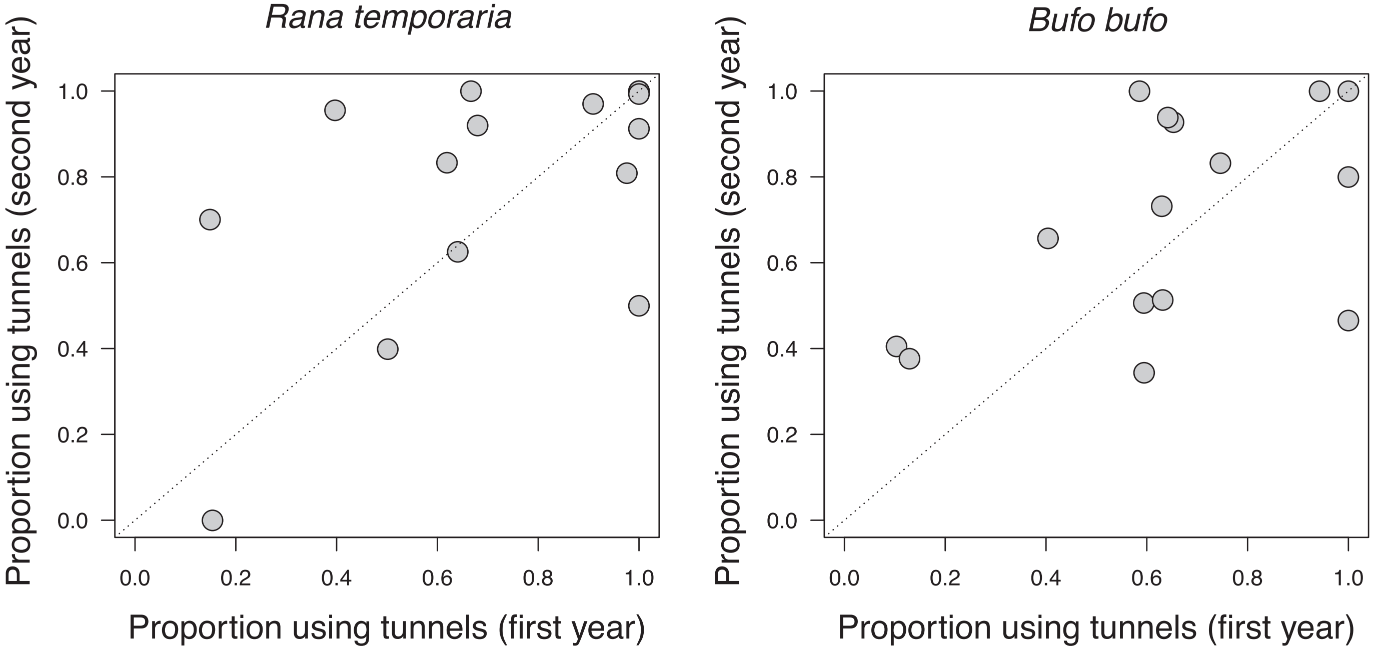

FIG. 2.—Year-specific proportions of Common Frogs (*Rana temporaria*) and Common Toads (*Bufo bufo*) using the tunnels. Each point represents a site. The diagonal dotted line shows the 1:1 relationship. A point below the 1:1 line indicates that a higher proportion of individuals used the tunnels in Year 1 than in Year 2.

width had a positive effect on the proportion of amphibians using the tunnel, whereas tunnel length had a negative effect (Table 2; Fig. 4). The 95% credible intervals of the regression coefficients for all explanatory variables overlapped zero, but in the best model, the proportion of the posterior with the same sign as the mean (f) was greater than 0.948 for all coefficients, suggesting support for an effect. For both species, the estimates for the effect of soil type were positive, as expected, but the models that included soil type were not well supported by the data (Table 2).

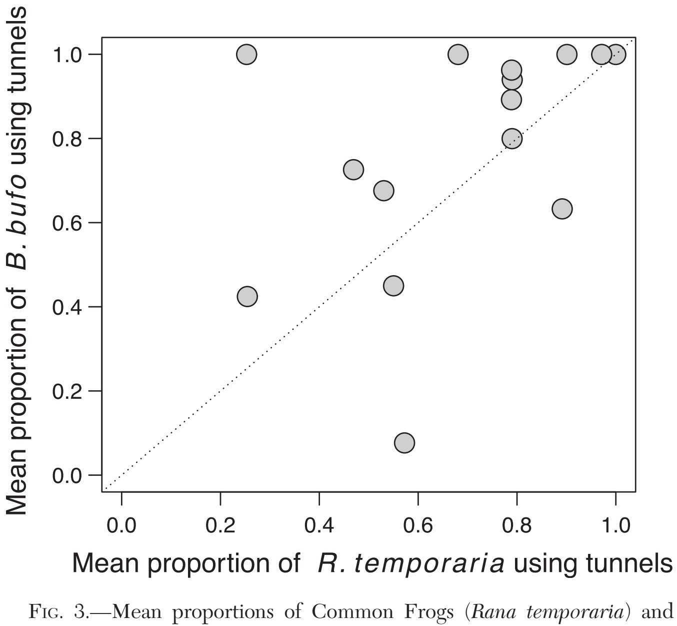

FIG. 3.—Mean proportions of Common Frogs (*Rana temporaria*) and Common Toads (*Bufo bufo*) using the tunnels (the mean is the average of both years). Each point represents a site. The correlation coefficient is $r = 0.44$. The diagonal dotted line shows the 1:1 relationship.

Changes in Population Size

Population sizes of both species changed after the construction of the toad tunnels. About half of the populations decreased in size, whereas the other half increased in size. Across sites, there was no correlation between the changes in population size of two species ($r = 0.03$; Fig. 5), suggesting that it was not the tunnel system per se that influenced population size.

The change in population size was not explained by tunnel characteristics for either species, given the wide 95% credible intervals. However, despite wide 95% credible intervals, there was support ($f = 0.979$) for an effect of the proportion of Common Toads using the tunnels on the change in population size (Table 3; Fig. 6). A similar effect was less supported in Common Frogs ($f = 0.750$; Table 3; Fig. 6). However, given the width of the credible intervals, it is preferable to restrict the conclusion to a qualitative result that there was a positive effect. Although effects of tunnel length and distance between tunnels were not well supported by the data (as judged by f values smaller than 0.685), there was substantial evidence ($f > 0.91$) for an effect of tunnel width of the magnitude of the change in population size. The effect of tunnel width on change in population size should be described as positive because there is substantial uncertainty about the true value (Table 3; Fig. 6).

DISCUSSION

To improve the conservation of amphibians, it is necessary to know which conservation actions work and which do not. Our case study on comparative effectiveness shows how the type of tunnel/barrier wall systems affects tunnel use and population size. Our results are in line with previous information and support current guidelines for road engineers (e.g., VSS 2010; Smith et al. 2018). Wider tunnels

TABLE 2.—Model selection results and parameter estimates for the analysis of the relationship between explanatory variables and the mean proportion using the tunnels. Models had two explanatory variables. Deviance information criterion (DIC) indicates support for each model, with smaller values indicating higher support. For each explanatory variable, entries indicate (1) regression coefficient (the mean of the posterior distribution), (2) 95% credible interval in parentheses, and (3) the proportion of the posterior distribution (f) that has the same sign as the regression coefficient. Soil type is a categorical variable with two levels (natural soil, concrete soil). A positive regression coefficient suggests that natural soil is associated with a higher proportion of individuals using the tunnels.

Species	Model	DIC	Explanatory variable			
			Tunnel width	Tunnel length	Distance between tunnels	Soil type
Rana temporaria	1	19.043	1.116 (0.025, 2.198) ($f = 0.977$)	−0.020 (−0.099, 0.058) ($f = 0.704$)	–	–
	2	15.683	0.796 (−0.087, 1.684) ($f = 0.963$)	–	−0.007 (−0.016, 0.002) ($f = 0.948$)	–
	3	18.998	0.883 (−0.147, 1.917) ($f = 0.956$)	–	–	0.133 (−0.342, 0.603) ($f = 0.724$)
Bufo bufo	1	10.534	0.713 (−0.102, 1.524) ($f = 0.960$)	−0.053 (−0.112, 0.006) ($f = 0.962$)	–	–
	2	15.185	0.333 (−0.527, 1.194) ($f = 0.792$)	–	−0.002 (−0.010, 0.007) ($f = 0.648$)	–
	3	14.688	0.322 (−0.561, 1.214) ($f = 0.777$)	–	–	0.065 (−0.342, 0.473) ($f = 0.637$)

were better because a larger proportion of the individuals used them. There was also some evidence that wider tunnels led to increases in population size. Despite some uncertainty in our model estimates, our case study provides clear recommendations for conservationists.

Amphibian Tunnels

Amphibians use tunnels, but a large proportion of individuals do not (Fig. 2). Our results align with the results of previous studies. For example, Beebee (2013) reported that the median percentage of individuals using tunnels was 42.5% (range 4–100%). Our results also support the idea that poorly constructed (e.g., tunnels that are too narrow and likely poor maintenance of tunnels and barrier walls) amphibian tunnels can hinder rather than facilitate amphibian migration towards the breeding site (Matos et al. 2017). To maintain amphibian population viability it may not be necessary that 100% of the individuals use the tunnels. For example, a population may be able to compensate for the reduction of the size of the breeding population that is caused by the fact that some individuals that would have bred but were stopped at the tunnel/barrier wall system and did not arrive at the pond. The proportion of individuals using the tunnels that leads to viable populations has not yet been determined. Based on experience with toad tunnels in Germany, Austria, and Switzerland, Geise et al. (2008) argued that 75% should use the tunnels, but a more formal analysis of a range of population models seems worthwhile. Whether tunnels facilitate or hinder migration depends on the proportion of individuals that use the tunnels. The proportion that should use the tunnels depends on the effects of the tunnel-induced reduction in population size. The proportion of individuals that is necessary to maintain population viability is likely to depend on the life history of the species (fast vs. slow; Healy et al. 2019) and type of population regulation (Ryser 1988), most importantly the strength of density dependence and environmental stochasticity (e.g., pond drying; Bjørnstad and Grenfell 2001).

The use of tunnels by amphibians depends on the characteristics of the tunnels (Dexel 1989; Lesbarrères et al. 2004; Woltz et al. 2008; Beebee 2013; see Smith et al. 2018 for a review on the variability in the magnitude and direction of effects among studies). Independent of effect sizes and strength of evidence, the direction of the effects (positive, negative) in our case study were as expected (positive effects for tunnel width, distance between tunnels and soil type; negative effects for tunnel length). Wider tunnels were used by higher proportions of individuals. This is important, because tunnel width is actionable, as road engineers can choose the tunnel width when they build a new tunnel/barrier wall system. The same is the case for the distance between tunnels, which affected tunnel use by Common Toads. A recent study from the Netherlands showed that a tunnel/barrier wall system failed because there were too few tunnels and toads had to travel several hundred meters to reach a tunnel entrance (Ottburg and van der Grift 2019). Tunnel length, in contrast, had negative effects, but is not actionable because it depends on the width of the road.

We expected that tunnel characteristics would determine the proportion of individuals that use the tunnels. Unexpectedly, we found that tunnel use varied among years (Fig. 2). We do not know why there was among-year variation. It

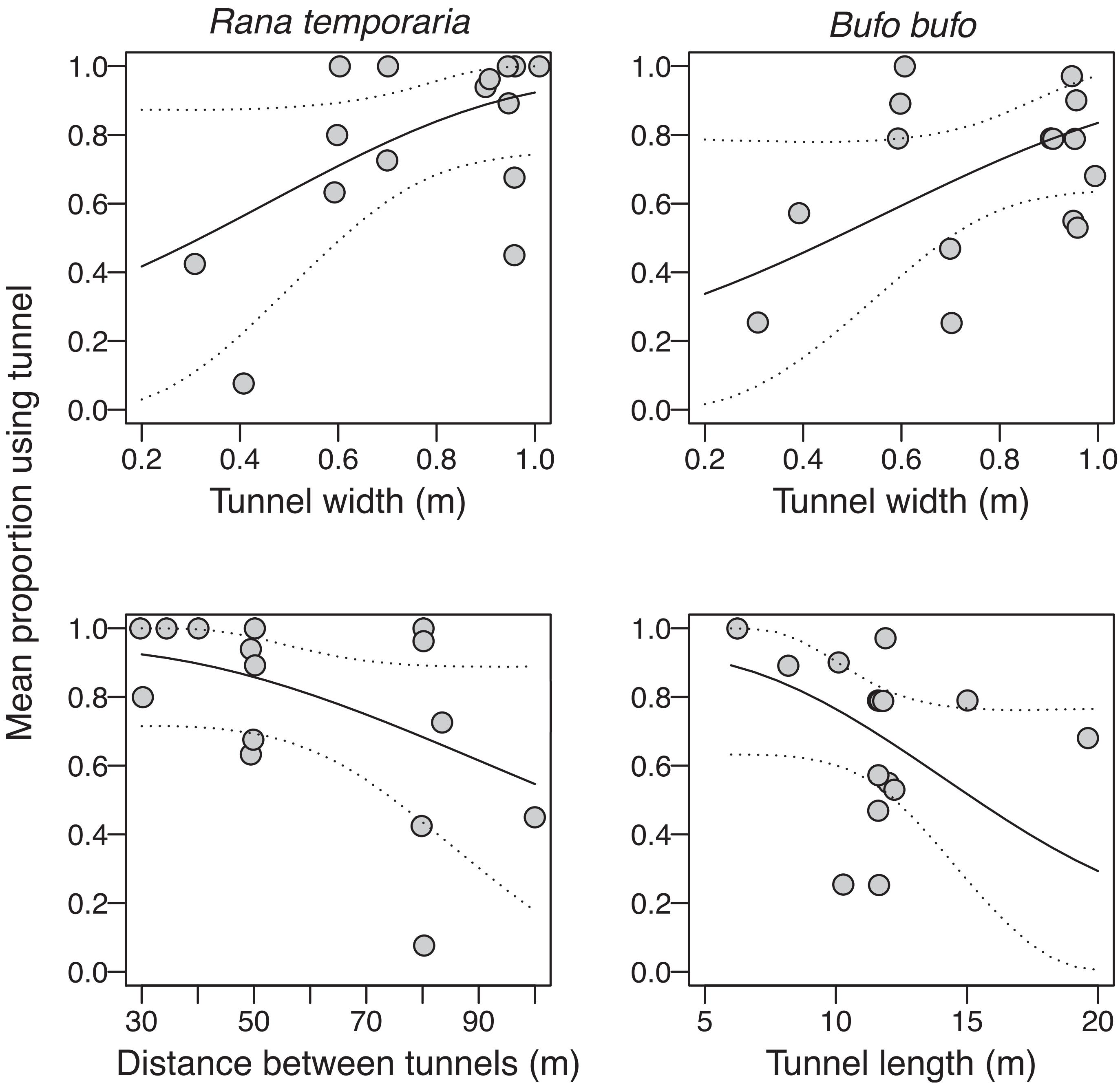

FIG. 4.—The relationship between the proportion of individuals using the tunnels and explanatory variables for Common Toads (*Bufo bufo*) and Common Frogs (*Rana temporaria*). The dependent variable was the mean proportion of individuals using the tunnels, over 2 yr. Each point represents a site. Solid lines are regression lines based on the posterior mean of the parameter estimates and dotted lines represent 95% credible intervals. Jittering was used to increase visibility of individual data points along the *x*-axis.

may be related to weather conditions, density, methodology, or unknown factors. It would be worthwhile to study the factors that determine among-year variation because this may lead to better amphibian tunnels.

Population Size

We expected that population size would increase after the construction of tunnels and when they are used by a large proportion of the migrating individuals. Contrary to our expectation, populations did not increase in size at all sites after the construction of the tunnels. We expected such an increase because volunteer conservation action prevents road mortality of adults on their way to the breeding sites. In contrast, amphibian tunnels protect amphibians against road mortality during all migrations to and from the pond, that is, adults during seasonal migrations and juveniles after metamorphosis. Our expectation was additionally supported by previous work indicating that a reduction of road mortality in juveniles leads to population growth (Hels and Nachman 2002; Petrovan and Schmidt 2019). On the other hand, there are several reasons why an increase in population size may not occur after the construction of

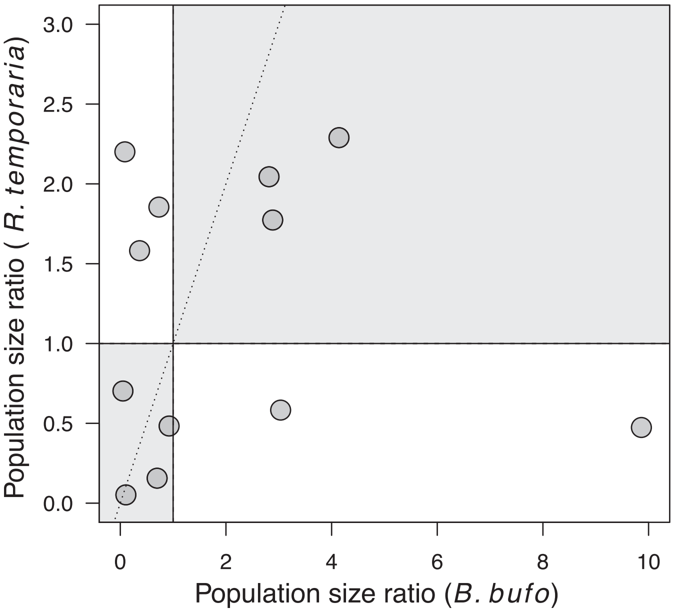

FIG. 5.—The ratio of population size after the construction of tunnels divided by the population size before the construction of tunnels for each species. Each point represents a site; only sites where both species occur are shown. A value of 1 means that population size did not change whereas values greater than 1 or smaller than 1 mean that populations became larger or smaller, respectively. Shading is used where the populations of both species changed in the same direction. The correlation coefficient is r = 0.03. The dotted line shows the 1:1 relationship (i.e., where the magnitude of change is the same for both species).

tunnels. First, volunteers already prevented road mortality of adult amphibians before the tunnels were built. Thus, populations may have fluctuated around the carrying capacity. If this is the case, one would not expect an increase in population size after the construction of toad tunnels. Second, other factors may limit population size. For example, the construction of tunnels may not help much if the pond is infested with nonnative fish (e.g., goldfish, Meyer et al. 1998). Third, the amphibians using the tunnels may represent only a subpopulation. Depending on landscape structure, only a subpopulation of the population may have to cross a road during seasonal migrations. If this is the case, then only this subpopulation is affected by the road and the tunnels (and only this subpopulation was counted in this study). The dynamics of the subpopulation that is unaffected by the road may be more important to the dynamics of the total population than the subpopulation that has to cross the road.

Comparative Effectiveness Studies

Comparative effectiveness studies produce evidence that can be used to improve conservation action and management (Smith et al. 2014; Schmidt et al. 2019). Although the benefit of such studies is obvious, there are also limitations. Even if the hypotheses are clear and the study design simple, data analysis is not necessarily straightforward. For example, we had to make decisions regarding whether we should use year-specific proportions of individuals using the tunnels or the mean of 2 yr; we opted for the simpler model. Furthermore, explanatory variables can be correlated and correlations can complicate the analysis and interpretation of

TABLE 3.—Parameter estimates for the analysis of the relationship between explanatory variables and the change in population size ($\log[N_2/N_1]$; see main text). Deviance information criterion (DIC) indicates support for each model, with smaller values indicating higher support. For each explanatory variable, entries indicate (1) regression coefficient (the mean of the posterior distribution), (2) 95% credible interval in parentheses, and (3) the proportion of the posterior distribution (f) that has the same sign as the regression coefficient.

Species	Model	DIC	Explanatory variable			
			Proportion using tunnels	Tunnel width	Tunnel length	Distance between tunnels
Rana temporaria	1	46.016	0.920 (−2.020, 3.855) ($f = 0.750$)	–	–	–
	2	45.903	–	2.819 (−0.707, 6.317) ($f = 0.948$)	–	0.006 (−0.030, 0.043) ($f = 0.647$)
Bufo bufo	1	52.228	4.558 (0.202, 8.906) ($f = 0.979$)	–	–	–
	2	58.702	–	3.143 (−1.547, 7.813) ($f = 0.918$)	0.090 (−0.494, 0.313) ($f = 0.685$)	–

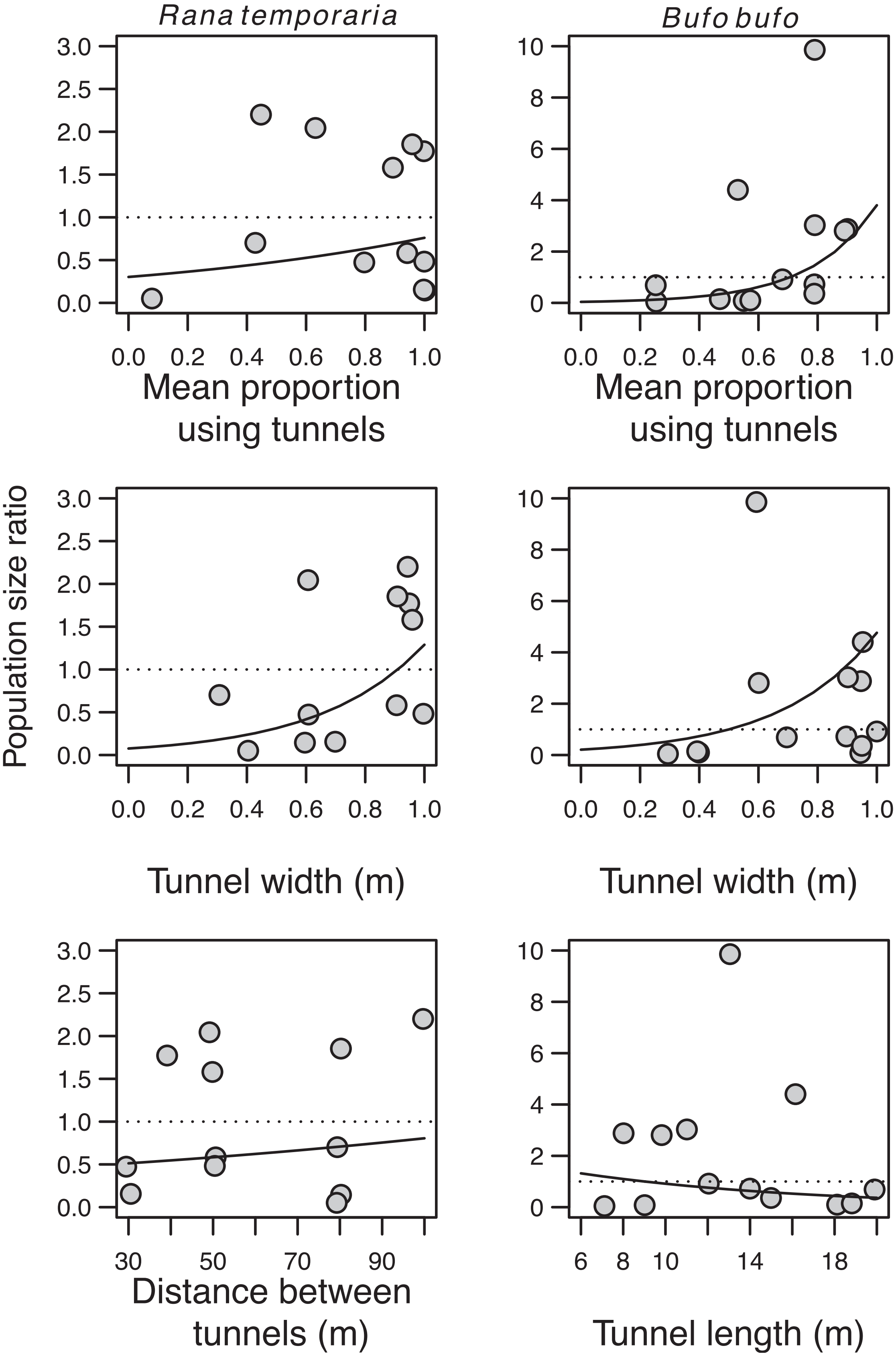

FIG. 6.—The relationship between the change in population size and explanatory variables for Common Frogs (*Rana temporaria*) and Common Toads (*Bufo bufo*). The ratio of population size after the construction of tunnels divided by the population size before the construction of tunnels is displayed on the *y*-axis. Points represent sites. A value of 1 means that population size did not change (horizontal dotted line) whereas values greater than 1 or smaller than 1 mean that populations became larger or smaller, respectively. Ninety-five percent credible intervals were too wide to be displayed. Jittering was used to increase visibility of individual data points along the *x*-axis.

results. For example, longer tunnels were wider tunnels and shorter tunnels were narrower. There were not short and wide or long and narrow tunnels. This means that the effect of width is always partially confounded with length. Last, sample size ($n = 17$ sites) is small in relation to a large list of candidate explanatory variables, even though the manpower necessary to collect the data was very large. This means that it is not possible to test the influence of all variables (including year effects, nonlinear, and interactive effects) and small, tapering effects cannot be detected (sensu Burnham and Anderson 2002; see Schmidt et al. 2019 for discussion). We note, however, that simpler models can be better for management purposes than more complicated ones (Hilborn and Mangel 1997). Even though we acknowledged this and purposefully kept our models simple, the strength of evidence was weak for some explanatory variables. Such limitations are common in conservation efforts (Hilborn and Mangel 1997), partly because the manpower necessary to collect such data is considerable and logistically challenging. We suggest that these problems can be partially solved if one develops clear expectations based on prior knowledge (Franklin et al. 2001; Anderson 2008). Prior knowledge can lead to meaningful candidate models and allows evaluating the plausibility of the results. Our results largely corroborate the evidence presented on the conservationevidence.com website, as this compilation of many case studies shows similar effects of tunnel characteristics (Smith et al. 2018).

We used an observational approach in our case study, but experiments are also possible. For example, Shulse et al. (2012) created experimental ponds to test for effects of slope, fish presence, and plants. Semlitsch et al. (2009) used large replicated experiments to test how timber harvest treatments affect amphibians. Whenever possible, experiments should be embedded into an adaptive management framework (Canessa et al. 2019). Experiments are worthwhile because correlations among explanatory variables are not an issue and because cause–effect relationships are clear. Thus, there is less uncertainty regarding the effect of an explanatory variable on a response variable. The limited number of factors that can be tested in an experiment can be seen as a drawback but, as discussed above, the number of explanatory variables is likely to be low in many comparative effectiveness studies. Experimental studies can have additional drawbacks. Although an observational study builds on conservation action, experiments have to be set up. It thus takes time until results are available and long-term effects cannot be assessed. Furthermore, experimental conditions may not be realistic. For example, the tunnels used by Woltz et al. (2008) were put on grass and not dug into the ground. Thus, microclimatic conditions may be quite different from real amphibian tunnels. If amphibians respond to microclimate, then this may affect results.

Improving the Efficiency of Conservation

Amphibians have been declining in population size and distribution for decades (Houlahan et al. 2000; Grant et al. 2016; Leung et al. 2017; Falaschi et al. 2019). Evidence that can be used to improve conservation action and management interventions is sorely needed. Amphibian conservation biologists should strive for results that can directly be used by conservationists (Grant et al. 2019). There are many ways in which science can contribute to better conservation practice, but the conservation evidence approach (Sutherland et al. 2004) seems particularly promising to provide the necessary information. One may either collate results from individual studies (as done in Smith et al. 2018) or one may actively initiate studies to obtain the required knowledge (Smith et al. 2014; Schmidt et al. 2019).

Many authors have commented on the gap between conservation science and practice (Foster and Beebee 2004; Pullin et al. 2004; Arlettaz et al. 2010; Habel et al. 2013). We argue that there is not one gap between conservation science and practice but multiple gaps. The link between conservation science and practice can be seen as a three-step process. The first step is basic science, which may, or may not, inform conservation practice. For example, research may show how landscape structure, including human infrastructure, affects amphibian populations, but not how to mitigate the effects. The second step is applied research, which, for example, may identify populations that are most at risk from infrastructure such as roads, but not how to mitigate the risk. Improved knowledge does not translate directly into better management (Grant et al. 2019). Development is the necessary third step. Once we know what the risk is and which populations are at risk, we need to know how to mitigate the problem. This needs to go far beyond the usual management implications in scientific articles. Development should deliver ready-to-use solutions. Nonscientists must be able to implement conservation actions, sometimes under the supervision of a conservationist. In the case of toad tunnels, clear instructions on how toad tunnels are to be built are available (VSS 2010). Without this final step, conservation action will not happen or will be delayed until the solutions are available. Unfortunately, the third development step is usually absent and is likely the main reason for the gap between conservation science and practice (Arlettaz et al. 2010; Habel et al. 2013). Conservation evidence studies do not suffer from this problem, or experience it to a lesser extent. They do not assess novel conservation actions but rather assess the effectiveness of conservation actions that were already implemented (Schmidt et al. 2019). Conservation evidence assessments build on the fact that the development step has already happened and that conservationists already know how to implement conservation action. In the case of amphibian tunnels, our conservation evidence assessment indicates that we can simply recommend wider tunnels. The tunnels are already available on the market.

Thus, comparative effectiveness studies, and conservation evidence in general, allow conservationists to improve conservation action without delay. To reduce the delay further, it is important that the results are disseminated to the people who need to know the results. To this end, we published the key conclusions of the amphibian tunnel assessment in two outreach articles in two languages well before this scientific article will be published (Schmidt et al. 2017a,b). Evidence matters, but only in the hands of the people who can make a difference.

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Supplemental Material

Supplemental material associated with this article can be found online at https://www.doi.org/10.1655/Herpetologica-D-19-00052.S1.

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