

EFFECT OF ROAD TRAFFIC ON AMPHIBIAN DENSITY

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Abstract

We studied the effect of traffic intensity on local abundance of anurans. We counted dead and live frogs and toads per km and estimated frog and toad local abundances using breeding chorus intensities on similar roads through similar habitats, but with different levels of traffic intensity. After correcting for effects of date, local habitat, time, and region, our analyses demonstrated that (1) the number of dead and live frogs and toads per km decreased with increasing traffic intensity; (2) the proportion of frogs and toads dead increased with increasing traffic intensity; and (3) the frog and toad density, as measured by the chorus intensity, decreased with increasing traffic intensity. Taken together, our results indicate that traffic mortality has a significant negative effect on the local density of anurans. Our results suggest that recent increases in traffic volumes worldwide are probably contributing to declines in amphibian populations, particularly in populated areas.

Keywords: frogs, toads, anurans, amphibians, road mortality, dispersal barrier, population decline.

INTRODUCTION

Recently there has been considerable discussion within the scientific community about declines in amphibian densities and distributions in many regions around the world (Blaustein & Wake, 1990; Wake, 1991; Blaustein *et al.*, 1994). Some suggested causes for declines include habitat destruction by deforestation and drainage, introduction of predators and competitors, pollution from pesticides, mining and logging, acid precipitation, increased levels of ultraviolet radiation, consumption by humans, introduction of exotic species, and climate change (Elmberg, 1993; Blaustein *et al.*, 1994; Pounds & Crump, 1994). An additional potential factor is mortality on roads. Throughout the world, traffic volumes have increased markedly in the past two decades (United Nations, 1992). Many amphibians need to use more than one habitat to meet their needs for forage, breeding and overwinter sites. The juxtaposition of different required habitats in the landscape therefore may necessitate seasonal movements to and from the different habitats (Laan & Verboom, 1990; Reh & Seitz, 1990). When these movements occur across roads, mortality can be substantial (van Gelder, 1973; Oldham & Swan, 1991). For example, as reported in Reh and

Seitz (1990), Kuhn (1987) estimated that 24–40 cars per hour killed 50% of migrating *Bufo bufo* individuals, and Heine (1987) calculated that 26 cars per hour could reduce the survival rate of toads crossing roads to zero. Ehmann and Cogger (1985) estimated conservatively that 5,480,000 reptiles and frogs are killed annually by traffic in Australia. Rosen and Lowe (1994) estimate that tens to hundreds of millions of snakes have been killed by automobiles in the United States.

In and around Ottawa, Canada, we observed that during seasonal movements there appeared to be fewer frogs and toads on more heavily used roads than on less heavily travelled roads. We hypothesized that frog and toad populations near the heavily used roads are smaller, possibly due to mortality associated with automobile traffic. Alternatively, the local frog densities might not differ between roads of differing traffic intensities. In this case, two possible reasons that more frogs and toads might be observed on less heavily travelled roads are that (1) frogs and toads do not attempt to cross heavily used roads or adjust local movement patterns to avoid them, or (2) carcasses do not last as long on heavily travelled roads, giving a false impression of numbers. The goals of the present study were to quantify (1) the numbers of frogs and toads on roads ranging in traffic volume; and (2) the relative densities of frogs and toads near roads ranging in traffic volume to test the above hypothesis.

METHODS

Data collection

We selected road segments in two regions near Ottawa, Canada (Fig. 1) in three categories of traffic intensity — low, medium, and high. The traffic volumes, measured in annual average daily (24 h) two-way traffic flow were, respectively, 500–3500, 5000–6000, and 8500–13,000 (Regional Municipality of Ottawa Carleton Transportation Department, pers. comm.; Ontario Ministry of Transportation Eastern Region Traffic Section, pers. comm.). All roads were two-lane and paved, and the segments selected were similar with respect to the surrounding habitat both within and between regions. The two regions differed in their physiographic characteristics (Chapman & Putnam, 1973). Region 1 consists of drumlin field and clay plain in the north and sand plain in the south. Its soils are imperfectly to poorly drained. Region 2 is a limestone plain and has shallow

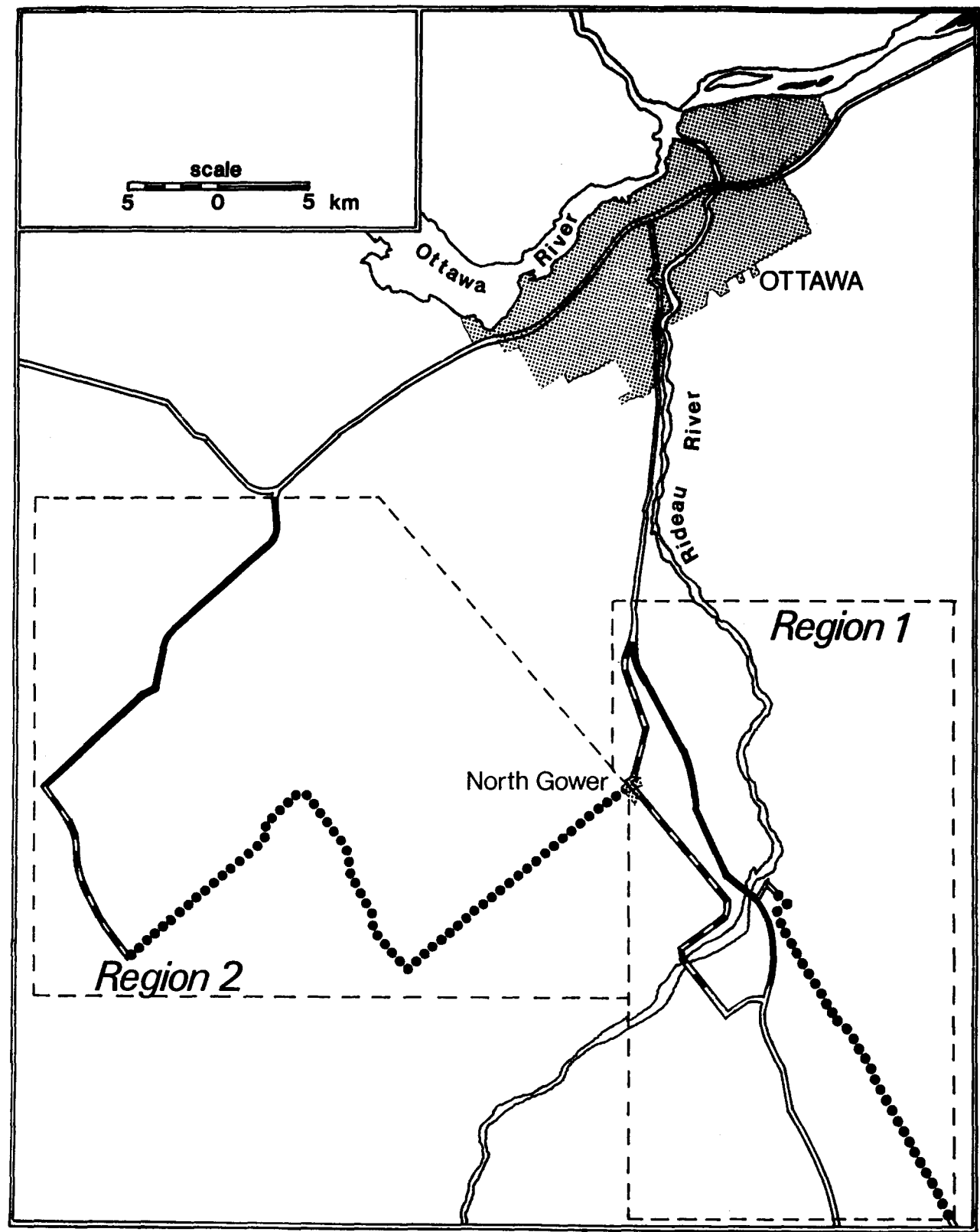


Fig. 1. Map of study area near Ottawa, Canada. Sampled stretches of roads with high (—), medium (---), and low (···) traffic intensity.

(<1 m), poorly drained soils. Both regions are low-lying and wet. Snell (1987) estimated that in 1890 45.8% of the Ottawa area (including both our regions) was covered in wetland. By 1967 this had been reduced through drainage to about 12.8% and by 1982 to 12.6%; drainage ditches currently criss-cross the area. Follow-

ing snowmelt in the spring, fields remain wet and most forest is in standing water until mid to late May. On six evenings, between 2030 and 2230 h, during the spring breeding season between 25 April and 24 May 1993, we traversed the road segments and counted all dead and live frogs and toads along contiguous

1 km sections of the roads (Fig. 1). Shaffer and Juterbock (1994) provide a discussion of this sampling method. Every 2 or 4 km, depending on the number of vehicles involved in the sampling, we stopped to listen to frog and toad choruses. We waited for substantial gaps in the traffic (to eliminate confounding effects of traffic noise) and listened for a total of 30 s at each stop. Choruses were identified to species and each species' chorus was given an intensity rating of 1, 2, or 3 as a rough indication of the number of individuals calling — 1, 1 individual, 2, distinguishable individuals; and 3, many indistinguishable individuals calling. Chorus ratings were summed over species to give a relative index of anuran density at each sample point. Note that this chorus index is a relative measure of densities only.

Although the habitat around all road segments was similar, we also quantified habitat attributes along roads, to control for habitat differences in statistical models. We recorded the presence or absence of forest and wetland or standing water within 100 m of each 1 km section.

Data analyses

In all analyses, any effects of habitat differences within and among road segments were corrected for by including in the models the habitat variables (forest and wetland or standing water), and a class variable for the two regions. Differences in frog and toad activity between nights, probably due mainly to differences in weather conditions, were corrected for by including date as a class variable in the models. Effects of time of evening on frog and toad activity were corrected for by including a variable giving the time of sampling. In all analyses, the effect of traffic intensity on frog and toad counts or the chorus index was determined *after* the variation in the data due to these other effects (habitat, region, date, and time) was removed.

To determine whether the proportion of dead frogs and toads observed changed with traffic intensity, we conducted logistic regression analysis using a generalized linear model in Splus (StatSci, 1991). The proportion of all frogs dead in each 1 km segment was used as the dependent variable. Habitat, region, date, time and traffic intensity, and the two-way interaction between region and traffic intensity, were fitted as independent variables. The effect of traffic intensity was assessed after accounting for all other effects.

To determine whether the number of anurans observed on roads, and the local density of anurans, were related to traffic intensity, we fitted Analysis of Variance models (GLM; SAS Institute Inc., 1990) with (1) the total number of frogs and toads (dead plus live) for each 1 km segment and (2) the breeding chorus index at each stopping point as the dependent variables, respectively, and the same set of independent variables as in the previous analysis. Again, the effect of traffic intensity was assessed after accounting for all other effects.

RESULTS

The habitat measures confirmed our initial impression that the frog habitat near the different road segments was similar (Table 1). In total, there were 1856 dead and 591 live frogs for a total of 506 km travelled. There were significant effects ($\alpha = 0.05$) of date, region and traffic intensity on the number of frogs and toads (live and dead) observed per km of road (Table 2, Fig. 2(a)). There were more frogs and toads on the roads in region 1 than in region 2. The effect of traffic intensity was negative, that is, the number of frogs and toads decreased with increasing traffic intensity. Although there was a significant difference between regions in the number of frogs, the pattern was the same for both regions since there was no significant interaction between region and intensity.

Table 1. Habitat near low, medium, and high traffic intensity roads

Percent forest (or wetland/water, or forest and/or wetland/water) is percent of all 1 km sections with forest (or wetland/water, or forest and/or wetland/water) with 100 m of the road.

Traffic intensity	Total km	% forest	% wetland/water	% forest and/or wetland/water
Low	61	74	75	87
Medium	37	76	78	89
High	42	83	79	95

Table 2. Analysis of variance of the number of frogs and toads per 1 km section
Number of observations = 506; model R² = 0.31.

Source	d.f.	Type III SS	F value	Pr. type I error
Date	5	9503.8	25.55	0.0001
Forest	1	100.1	1.35	0.2459
Wetland/water	1	248.4	3.34	0.0682
Time	1	182.0	2.45	0.1184
Region	1	885.7	11.91	0.0006
Reg*intensity	1	1.0	0.01	0.9058
Traffic intensity	1	1716.1	23.07	0.0001

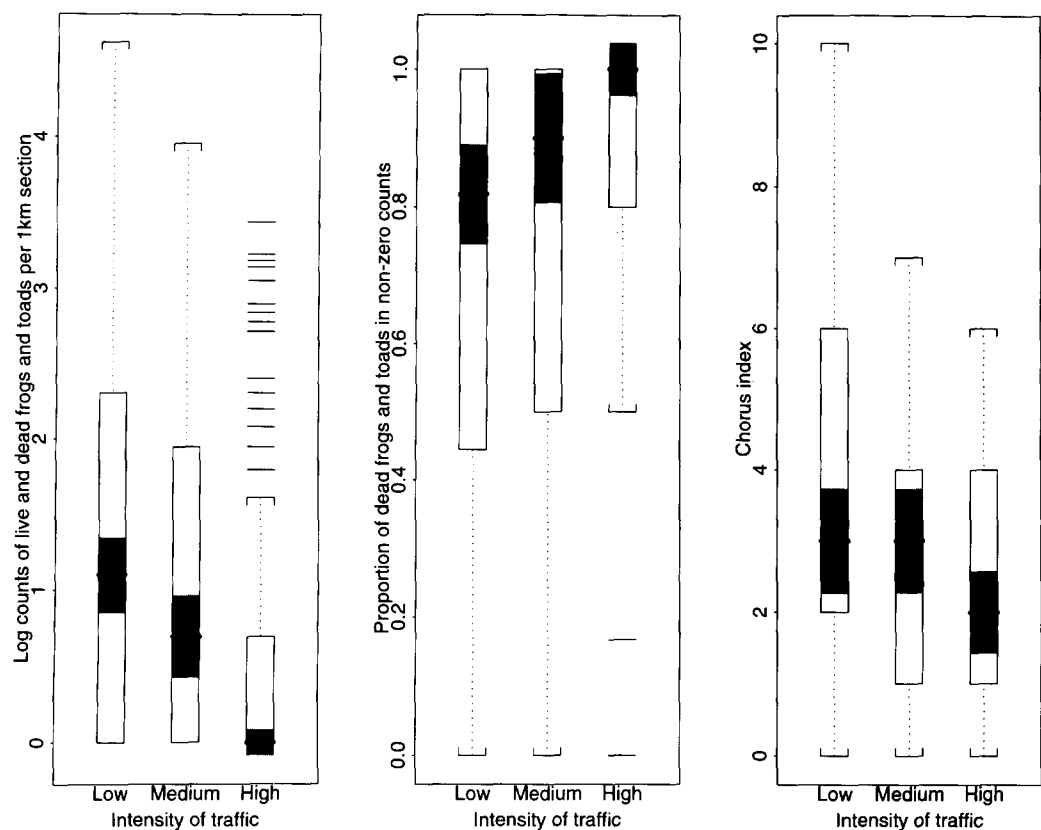


Fig. 2. Box plots (StatSci, 1991) of (a) log (counts of frogs and toads), (b) proportion of frogs and toads dead in non-zero counts and (c) the chorus index (see text), each by level of traffic intensity. Thick black bar is median, shaded area is approximate 95% confidence interval for the median, box is inter-quartile distance (central 50% of the data), and brackets show range of observations except for thin bars which are outliers.

Table 3. Analysis of deviance from logistic regression analysis of the proportion of frogs and toads found dead in 1 km sections
Number of 1 km road sections with non-zero observations = 276. Total number of dead frogs and toads observed = 1856, total number of live frogs and toads observed = 591.

Variable	d.f.	Deviance	Pr.type I error
Null model		203.5	
Date	5	14.5	0.0130
Forest	1	0.1	0.7510
Wetland/water	1	2.5	0.1093
Time	1	17.6	<0.0001
Region	1	1.7	0.1940
Reg*intensity	1	1.8	0.1755
Traffic intensity	1	15.3	<0.0001

Table 4. Analysis of variance of the index of frog and toad choruses (see Methods)
Number of observations = 182; model R² = 0.36.

Source	d.f.	Type III SS	F value	Pr. type I error
Date	5	107.7	6.34	0.0001
Forest	1	58.2	17.13	0.0001
Wetland/water	1	0.3	0.10	0.7532
Time	1	0.0	0.01	0.9315
Region	1	6.0	1.76	0.1862
Reg*intensity	1	1.9	0.56	0.4557
Traffic intensity	1	63.3	18.62	0.0001

There were significant effects ($\alpha = 0.05$) of date, time, and traffic intensity on the proportion of frogs and toads dead (Table 3, Fig. 2(b)). The proportion of frogs and toads dead increased with time in the evening, probably due to accumulation of carcasses. The effect of traffic intensity on the proportion of frogs and toads dead was positive, that is, an increase with increasing traffic intensity.

Frog and/or toad chorus(es) were heard at 152 of the 182 stops made (83.5%). There were significant effects ($\alpha = 0.05$) of date, presence of forest (positive effect) and traffic intensity on the chorus index of frog and toad relative density (Table 4, Fig. 2(c)). The effect of traffic intensity on local frog and toad choruses was negative; that is, the frog and toad density decreased with increasing traffic intensity.

DISCUSSION

Our results provide evidence that traffic exerts a negative effect on anuran populations. Roads have been shown to affect movement of a variety of species (e.g. Mader, 1984; Merriam *et al.*, 1989, and references therein). However, very few studies have shown an effect of roads on population density (but see Rosen & Lowe, 1994, for snakes). The fact that there was a higher proportion of dead frogs and toads on the high-intensity roads suggests that differential road mortality contributes to the observed differences in abundance. Other road-related factors, such as pollutants in road run-off (oil, salt), exhaust emissions, vibrations, and noise, may also affect anuran densities either by causing direct mortality or interrupting anuran behaviour (Buchanan, 1993).

Two factors that may contribute to the larger number of frogs and toads on the roads in region 1 than in region 2 are (1) the road with high traffic intensity in region 2 is much older than the high-intensity road in region 1, resulting in a longer period of negative effect of the road on anuran densities in region 2; and (2) the soil is generally deeper in region 1, which is important for overwintering survival (Pinder *et al.*, 1992).

The lack of significant habitat effects (forest and water) in most analyses was probably due to the fact that habitat did not vary greatly within and between road segments (Table 1). There was forest and/or water within 100 m of most 1 km sections; 77% had forest, 77% had water, and 90% had either forest, water, or both.

There are two major approaches to studying the effects of human impacts on natural populations. First, one may study a population (or several populations) over time during the course of the impact. Second, one may study the organism(s) over a wide area experiencing differing levels of the impact; in this approach one essentially substitutes space for time. We used the second method in this study. We suggest that this approach is particularly useful for studies of environmental effects on amphibians, due to the high natural variability over time in amphibian populations. This variability obscures effects of human impacts which means that long-term studies are necessary to differentiate natural variation

from a change due to the impact (Pechmann *et al.*, 1991; Blaustein *et al.*, 1994). Such long-term studies are often impractical for conservation studies in which answers are needed quickly. In such cases it may be more profitable to study many areas in a range of impacts rather than a few areas over a long time.

Amphibian populations around the world may be declining (Blaustein & Wake, 1990; Blaustein *et al.*, 1994). Our data suggest that, particularly in urban areas, road mortality may be a factor contributing to these declines. Since 1970 the number of passenger cars in the world has more than doubled; in Canada there has been an increase from 6.4 million in 1969 to 12.8 million in 1989 (United Nations, 1992). Road density is strongly correlated with population density (Glover & Simon, 1992), which continues to increase exponentially. Over the past two decades, the distance driven in the United States has far outpaced population growth (US Department of Commerce, 1992).

There are at least two means by which road mortality of frogs and toads could be reduced. Barriers, in conjunction with underpasses, would separate cars and frogs while still allowing free movement. Underpasses have been used in Europe (van Leeuwen, 1982; Langton, 1989) and may be feasible in North America (Tynning, 1989). One cause for concern with this approach is that predation may be facilitated by the funnelling of prey through the underpass. If this is the case, the mortality due to traffic will be shifted to predation and little will be gained. This question needs to be addressed. Another possibility would be to increase traffic volume on a few already existing roads rather than building new ones. In this way the negative effects would be concentrated in a few areas. This approach, combined with underpasses and barriers, would probably minimize road-related effects on amphibian populations.

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