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Air-pressure waves generated by vehicles do not imperil road-crossing amphibians

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Although everyone would agree that management of imperilled fauna should be evidence-based, the reality is different. Many regulations are based on tradition, intuition or uncritical acceptance of speculation (Pullin & Knight 2001), often because empirical data collection is difficult (Brook et al. 2003). In this paper, we describe an example of a management practice (speed limits on roads during amphibian migration periods) based on predictions from a mathematical model (on air-pressure waves generated by moving vehicles) that appears never to have been tested empirically.

Over the last three decades, amphibians have experienced high rates of population decline and extinction (Gibbons et al. 2000, Stuart et al. 2004, Hayes et al. 2010). The causes of these declines are diverse, and include disease (Berger et al. 1998, 1999), introduced species (Kats & Ferrer 2003), habitat destruction (Gibbons et al. 2000), pesticides (Davidson et al. 2002), and possibly climate change (Carey & Alexander 2003). Roadkill can also be a major source of amphibian mortality (Hels & Buchwald 2001, Glista et al. 2008), particularly in heavily populated areas with high road densities (Vos & Chardon 1998, Gibbs & Shriver 2005). Even in relatively natural areas, roads are common features of the landscape (Mustard et al. 2012), influencing amphibian populations by creating barriers to movement and gene flow, pollution (light, chemical, noise, etc.), and direct mortality due to road kill. Collectively, the combined environmental effects of roads have come to be known as the "road-effect zone" (Forman & Deblinger 2000). Direct vehicular mortality is particularly important for migratory species, often runover when attempting to cross roads at certain times of the year (e.g. Hels & Buchwald 2001).

Hummel (2001) used mathematical modelling to predict that amphibian mortality may be higher than expected simply from the numbers of animals that are flattened by vehicle tyres. His calculations suggested that amphibians also will be killed by rapid changes in air-pressure caused by a vehicle passing over them at high speed, causing collapse of the amphibian's lungs (termed 'barotrauma'; Hummel 2001). Often cited in the conservation and management literature, this suggested mechanism of impact has influenced proposed methods for assessing road impacts on amphibian populations (e.g. Holden 2002, Jaeger & Fahrig 2003, Schmidt & Zumbach 2008, Coelho et al. 2012). For example, the air-pressure risk posed by fast-moving vehicles has led to speed limits on roads in Germany; a speed limit of 30 km/h has been suggested (https://www.nabu.de/tiere-und-pflanzen/amphibien-und-reptilien/amphibien/06359.html) and implemented (e.g. http://www.goettinger-tageblatt.de/Goettingen/Uebersicht/Kroetenwandern-wieder/Strassensperrungen-und-Beeintraechtigungen-im-Landkreis) on many roads during the migration period of anurans. Similarly, a speed limit to reduce the risk of vehicular pressure-induced mortality has also been suggested by conservation organizations in Austria (http://www.noe-naturschutzbund.at/PDF/AmphibienschutzStrassenFolder_HP.pdf). Despite the inclusion of this putative threat in conservation plans, the validity of this mechanism appears never to have been tested.

During fieldwork on reptiles in northern Queensland (under University of Sydney animal ethics committee approval L04/3-2013/3/5969), we accidentally drove over thousands of anurans (mostly invasive cane toads, *Rhinella marina* (Linnaeus, 1758), in the past also called *Bufo marinus*) without hitting them with the car tyres. We never noticed any negative effects of the air-pressure due to the cars' movement, so we became sceptical of the predictions by Hummel (2001). In February 2016, we gathered detailed data in the course of our usual fieldwork in northern Queensland, Australia, using a Ford Falcon XR6. The front of the car was 15 cm above the ground, the rear was 25 cm above the ground, and the lowest point was 9 cm above the ground. Based on Hummel's model, such a car should generate air-pressure waves intense enough to kill toads when we were driving > 60 km/h (Hummel 2001). We drove at night (between 22:00 and 23:30 h) on a tarmac road as part of our normal survey studies. Cane toads commonly use the road (e.g. Brown et al. 2006), and thus we often inadvertently drove over toads (there being no room to stop or decelerate), aiming not to hit them with the car tyres. As part of our survey design, we drove at four different speeds: 50, 80, 100, and 110 km/h. After we drove over a toad, we stopped the car, returned to the toad, collected it, scored its condition (not injured, light injuries, heavy injuries, dead), and determined the animal's sex, mass and snout to vent length (SVL) in four categories: large (≥ 100 mm), medium (≥ 50 and < 100 mm), small (≥ 20 and < 50 mm), and metamorph (< 20 mm). We kept the toads overnight in moist cloth bags, and recorded whether or not they were still alive the next day. All live animals were released the following night, as part of our ecological study.

We drove over 97 cane toads ranging in size from 12.5 to 151.5 mm (mean ± SD 59.8 ± 46.0 mm, median 30.5 mm, Table 1) and in mass from < 1 g to 454 g (mean ± SD 60.7 ± 91.1 g, median 3 g). None of the anurans died after the car drove over them (Table 1). Twenty-four hours after being subjected to the air-pressure wave from the vehicle, all of the cane toads were alive and none showed any visible signs of barotrauma, injury or distress.

We failed to find any evidence for the hypothesis that the wave of air pressure from a rapidly-moving vehicle is lethal to anurans. The model of Hummel (2001) either overestimated the negative effects of a sudden air-pressure increase on amphibians, or overestimated the pressure increase itself. We cannot exclude the possibility of air-pressure-induced internal injuries (e.g., internal bleeding). For example, there is evidence that bats died from lung damage due to barotrauma induced by wind turbines (Baerwald et al. 2008). Vulnerability of an anuran species also might depend on body size, but the range of body sizes in the toads we studied is similar to those of many anuran species of conservation concern. However, other species might be more sensitive to air-pressure waves compared to cane toads, and thus, our results might not be applicable to all amphibian species. Our field trials provide a cautionary tale about basing conservation and management plans on unverified hypotheses. The original paper predicting this mortality mechanism (Hummel 2001) has been cited in numerous papers and conservation texts, and has informed management practices for more than a decade.

Although we have no evidence that road traffic induces barotrauma in amphibians, speed limits might nevertheless enable drivers to avoid running over amphibians on the road. However, experimental studies indicate that most drivers are unaware of small animals, especially at night (Beckmann & Shine 2012). Generally, scarce resources for conservation should be allocated wisely, based on empirical evidence (Bottrill et al. 2008). In this case, reliance on untested hypotheses may have led managers to the conclusion that speed limits themselves are a sufficient tool for anuran conservation. Resources should rather be spent on other mitigation methods, such as fencing, culverts or the construction of new breeding ponds, which were shown to reduce amphibian mortalities (Linck 2000, Jolivet et al. 2008).

Our study emphasises the need for evidence-based management for conservation. Although overly conservative regulations in conservation, management and animal welfare are better than excessively loose regulations, conservation should be based on rigorous testing whenever possible rather than theoretical models and untested hypotheses.

Table 1. Body sizes and survival of 97 cane toads (*Rhinella marina*) that we drove over with a car in February 2016 in northern Queensland, Australia, showing the car speed, number of toads, snout–vent length (SVL) in mm (mean ± SD, followed by range in parentheses), and survival rates.

Car speed (km/h)	Number of toads	SVL	Survived (%)
50	18	68.0 ± 47.0 (17–141)	100
80	17	75.1 ± 50.2 (15–151)	100
100	21	61.7 ± 47.4 (13–138)	100
110	41	49.0 ± 41.8 (14–143)	100
Total	97	59.8 ± 46.0 (13–151)	100

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