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Short communication

Traffic mortality and the role of minor roads

Frank van Langevelde [a,*], Coby van Dooremalen [b], Catharinus F. Jaarsma [c]

[a] *Resource Ecology Group, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands*
[b] *Animal Ecology Group, Vrije Universiteit Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands*
[c] *Land Use Planning Group, Wageningen University, Gen. Foulkesweg 13, 6703 BJ Wageningen, The Netherlands*

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Abstract

Roads have large impacts on wildlife, as they form one of the principal causes of mortality, and disturbance and fragmentation of habitat. These impacts are mainly studied and mitigated on major roads. It is, however, a widespread misconception that most animals are killed on major roads. In this paper, we argue that minor roads have a larger impact on wildlife with respect to habitat destruction, noise load and traffic mortality. We use data on traffic related deaths in badgers (*Meles meles*) in The Netherlands to illustrate that traffic mortality is higher on minor roads. We ask for a more extensive investigation of the environmental impacts of minor roads. Moreover, we argue that the success of mitigation on roads drastically increases when both major and minor roads are integrated in the planning of traffic flows. Therefore, we propose a strategy based on the concept of a ‘‘traffic-calmed area’’. Traffic-calmed areas create opportunities for wildlife by decreasing limitations for animal movement. We ask for further studies to estimate what size traffic-calmed areas should be to maintain minimum viable animal populations.

Keywords: Habitat fragmentation; Mitigation; Road ecology; Traffic and road characteristics; Traffic-calmed area

1. Introduction

Roads have large impacts on wildlife, as there are at least four negative effects of roads and their traffic on wildlife (Van Langevelde and Jaarsma, 2004): destruction or alteration of habitat due to construction, disturbance of habitat along the road (noise, vibrations, car visibility, etc.), barriers created by the road (increased resistance for movement), and barriers by traffic (collision risk during crossing). The barrier and mortality effects of roads may influence animal populations, e.g., insects (Vermeulen, 1994), reptiles and amphibians (Hels and Buchwald, 2001; Aresco, 2005a), birds (Clevenger et al., 2003), and mammals (Lankester et al., 1991; Clarke et al., 1998; Huijser and Bergers, 2000). Collisions with traffic mortality are considered to be among the major causes of death for many of these animals in human-dominated landscapes (Groot Bruinderink and Hazebroek, 1996; Forman and Alexander, 1998; Philcox et al., 1999; Trombulak and Frissell, 2000), and for some species, it is the most likely cause of regional extinction (e.g., badgers, Lankester et al., 1991; Clarke et al., 1998). Notably, these negative effects of roads on wildlife are studied mainly on major roads (e.g., Kanters et al., 1997; Forman et al., 2003). It is, however, a widespread misconception that most animals are killed on major roads (Seiler, 2002). In this paper, we argue that the remaining road network, i.e., minor roads, has a larger impact on wildlife with respect to habitat destruction, noise load and traffic mortality. We use data on traffic related deaths in badgers (*Meles meles*) in The Netherlands to illustrate that traffic mortality is higher on minor roads (example 1).

For reasons of declining biodiversity (Seiler, 2002; Forman et al., 2003) and risks of accidents (Garret and Conway, 1999), mitigation is frequently applied to reduce barriers to animal movement and traffic mortality. These interventions include keeping wildlife off the road (e.g., fences: Romin and Bissonnette, 1996; Putman, 1997; Aresco, 2005b), providing alternative routes (e.g., fauna passages and ecoducts: Keller and Pfister, 1997; Jackson and Griffin, 1998), or reducing the risk of collisions (e.g., highway lighting or mirrors: Romin

* Corresponding author. Tel.: +31 317 484750; fax: +31 317 484845.
E-mail address: frank.vanlangevelde@wur.nl (F. van Langevelde).

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and Bissonnette, 1996; Putman, 1997). Most of these interventions involve technical devices that require alterations to roads. However, other interventions may also reduce barriers to animal movement and traffic mortality, such as reduction of traffic volume or speed, and periodic closing of roads (during the night or for a specific season). Effective mitigation at locations where no passageways or fences can be constructed requires insight into the effects of road and traffic characteristics on both animal movements and traffic mortality (Fahrig et al., 1995; Forman and Alexander, 1998; Jaeger and Fahrig, 2004; Van Langevelde and Jaarsma, 2004). Worldwide, mitigation measures are mainly applied to major roads, whereas minor roads are frequently unmitigated (Kanters et al., 1997; Jaarsma and Willems, 2002; Forman et al., 2003; Van Bohemen, 2005). We argue that the success of interventions that mitigate impacts of roads increases considerably when the minor roads are included in the planning of these interventions. We propose a strategy based on the concept of a ‘‘traffic-calmed area’’ (Jaarsma, 1997), where the effects of minor and major roads are mitigated together. We illustrate this strategy with a case study in The Netherlands (example 2).

2. Major and minor roads

The suitability of mitigation efforts to prevent negative impacts of roads differs between types of roads. In Table 1, a summary of some network, road, and traffic characteristics of major and minor roads outside built-up areas in The Netherlands is given. We will show that these characteristics are important both to study and mitigate environmental impacts of roads.

Table 1
Characteristics of minor and major roads outside built-up areas in The Netherlands (Jaarsma and Beunen, 2005)

Scale of road network	Minor roads		Major roads	
	Local		Regional	National
Road type	Access road	Collector road	Arterial highway	Motorway
Network characteristics				
Length (paved) (km)	47,652[a]		7508[b]	2291
Road density[c] (km km^{-2})	1.55		0.24	0.07
Mesh width[c] (km)	1.3		8.2	26.8
Road characteristics[d]				
Cross-section width (m)	5.5–9.5	6.5 to >10	±20	±40–60[e]
Pavement width (m)	2.5–4.5	4.5–6.2	±7.5	2×(12–21)[e]
Number of carriageways	1	1	1	2
Number of traffic lanes	1	1 or 2[f]	2	4, 6, 8
Traffic characteristics				
Traffic volume (×1000 vehicles day^{-1})	0.1–1	0.5–5	2–25	20–200
Legal speed limit (km h^{-1})	60	60/80[g]	80/100	100/120

[a] Road statistics do not allow for a specification of the local network by road type.
[b] Including 868 km arterial highway belonging to principal national routes (non-motorways).
[c] Based on 30,682 km^2 land outside built-up areas. See text for explanation.
[d] Profiles based on the Dutch concept of sustainable traffic safety.
[e] Based on a 2 × 2 and a 2 × 4 motorway, respectively, total width including two verges of 5 m.
[f] For 2 lanes, a minimum pavement width of 5.5 m is required.
[g] Both limits are still in use. The limit used to be 80 km h^{-1} since 1974 and this is still the official limit, unless 60 is signposted. Today, the latter is the case for already half of the Dutch network of rural minor roads.

In The Netherlands, it is possible to distinguish between local roads, regional roads and national roads. Local roads are managed by municipalities and can be divided into local access roads and local collector roads, which differ in pavement width and, consequently, in traffic volume. Local roads give direct access to adjacent houses, farms and businesses, etc. The regional road network is managed by the provincial authorities and consists of arterial highways. Arterial highways open up regions by giving access to these regions. The national network consists of motorways, which have mainly a flow function in that they provide a fast and easy route for through traffic on long distances. Motorways and local roads can clearly be categorised as major and minor roads, respectively, for the regional network such an assignment is less clear. However, on the basis of traffic volumes (between 2000 and 25,000 vehicles day^{-1} and typically between 5000 and 15,000) and their function in providing fast flows for through traffic rather than direct access to adjacent land, we will classify them as major roads for the purpose of this paper.

One major difference between major and minor roads is their length. The total length of minor roads in The Netherlands is 47,652 km, which is nearly 5 times that of the major roads (9799 km). Road lengths can be used as a crude measure of landscape fragmentation with the statistic road density, D (Forman et al., 2003). D is the quotient of the total road length (km) in an area and the size of this area (km^2). The calculated road density for rural areas in The Netherlands is about 1.87 km^{-2}, which is mainly determined by the length of minor roads (see Table 1). The mesh width, L, is calculated by laying out the total road length in an area in a regular square grid, as in a rope netting, and is related to the road density as $L = 2/D$ (Jaarsma and Willems, 2002). The mesh width is relevant to habitat fragmentation because it indicates how far an animal can move through the landscape in a straight line before it encounters a road. The overall mesh width in The Netherlands is 1.07 km (= 2/1.87 km), a figure determined almost completely by minor roads, i.e., animals meet a minor road on average every 1.3 km (Table 1). The small mesh width of minor roads illustrates that these roads are present all over the rural area in The Netherlands. A similar pattern can be found in other industrialized countries with a high human population density, such as Germany, Belgium, and the UK.

Within the rope netting, the average area enclosed by roads has an extent of L^2, which is here called the mesh size (Jaarsma and Willems, 2002). It indicates the average extent of an area within which an animal can travel through the landscape without encountering a road on its way. In contrast to the ‘‘effective mesh size’’ (Jaeger, 2000), which denotes the size of the areas when a region is subdivided by roads, the mesh size only yields the average in a region. The average mesh size for the Netherlands is 1.14 km^2. It is impossible to calculate an ‘‘effective mesh size’’ on this national scale because of lacking data.

The second major difference between major and minor roads is traffic volume (Table 1). On roads in the urbanised regions of the western part of The Netherlands, traffic volumes can be up to 200,000 vehicles day^{-1}. For the majority of the minor roads, traffic volumes are on average between some tens to a few thousands vehicles day^{-1}, depending on the location of the road in the network. These differences in traffic volume go together with the differences in pavement width and cross-sections: the cross-section width of a motorway of 2×2 lanes is at least 40 m (including the verges), while this is below 10 m for most minor roads.

The third difference between major and minor roads is the legal maximum speed. In The Netherlands, the maximum speed limit on rural minor roads used to be 80 km h^{-1} as the general limit for all rural roads except motorways. Since the introduction of the program ''Sustainable Traffic Safety'', the maximum speed limit on most rural minor roads has decreased to 60 km h^{-1}. The maximum speed on major roads is 100 or 120 km h^{-1} (Table 1). The speed limit of 80 km h^{-1} on minor roads is often violated. In The Netherlands, De Wilde (1997) reports for 22 minor roads (17,076 vehicles) that on average 17% of the vehicles exceed the speed limit (91 km h^{-1} on average). Oei (1989) found even on minor roads 38–43% of vehicles exceeding the 80 km h^{-1}. One might expect a higher number of offenders in a 60 km h^{-1} zone. As is illustrated by Van den Berg et al. (2005) for six roads (5448 vehicles), only 21% of the vehicles respect this limit, whereas 50% of the vehicles travelled at speeds of 60–80 km h^{-1} and 28% even exceeded the 80 km h^{-1} limit, with one vehicle travelling up to 130 km h^{-1}.

It is not only the traffic volume that differs greatly between the road types, but also the traffic composition (Fig. 1). Buses and motorcycles constitute only a small proportion of the vehicles on major roads and hardly appear on minor roads, whereas cars are dominant on both minor and major roads. On minor roads, besides cars and trucks, bicycles and agricultural vehicles are found, with their proportions differing between local access roads and local collector roads.

3. Roads and habitat fragmentation

3.1. Effects of different types of roads

Estimates of destruction or alteration of habitat due to road construction can be made using the area that roads occupy. The area of major and minor roads can be tentatively calculated by multiplying the length of the roads by their pavement width (with the average of the lower and upper values indicated in Table 1). For motorways, the area occupied is estimated at 7500 ha compared to 5600 ha for arterial highways. For rural minor roads, the ''asphalted'' area is estimated at not less than 20,700 ha. Due to their length, the minor roads thus have the largest contribution to the direct loss of habitat (61% of the total). An alternative way to estimate habitat loss is by means of the right-of-way, i.e., the whole cross-section of the road including its verges. Then, the average of the minimum and maximum estimated area becomes 63,500 ha, of which 37,000 ha (58%) is due to minor roads.

Disturbance along infrastructure is often measured by noise load. This noise load is mainly determined by traffic volume, speed, and composition. As noise load by traffic is logarithmically related to traffic volume, the disturbed area surrounding a busy road is less than the area surrounding two roads with half of the volume. Therefore, a road network of busy major roads with a large mesh size may disturb a smaller area than a network of minor roads with lower traffic volume and smaller mesh size. Moreover, major roads may cause a continuous disturbance, even during the night, as there is less variation in traffic volume and composition and thus in noise load (Ministry of the Environment, 1977). As traffic on minor roads differs greatly in volume and composition (Fig. 1), these roads show relatively large fluctuations in noise load. These irregularities might have a greater disturbing effect on animals than the louder, but constant noise load from major roads (Forman et al., 2003).

When encountering a road, individuals decide either not to cross and follow another route, or attempt to cross with the

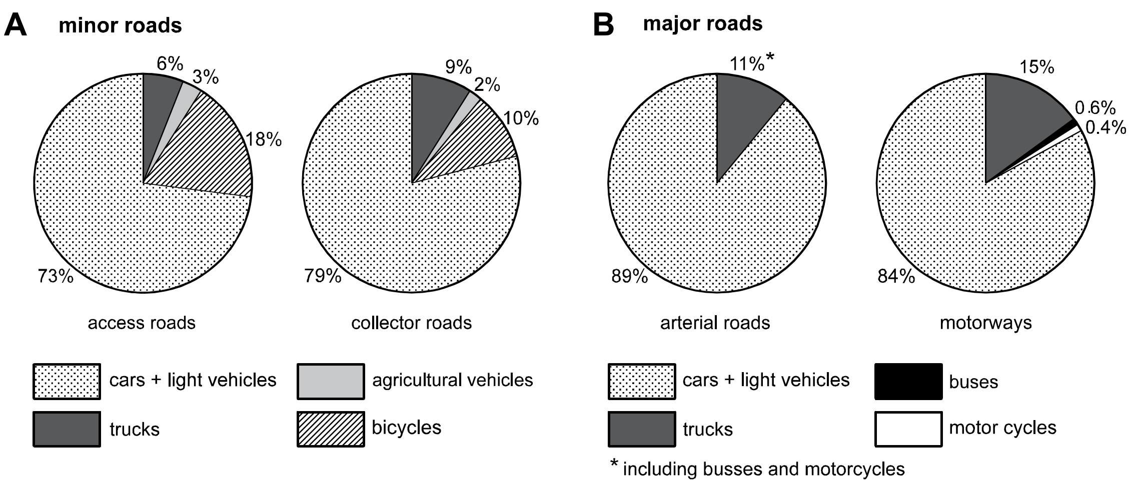

Fig. 1. Traffic composition in The Netherlands on (A) minor and (B) major roads.

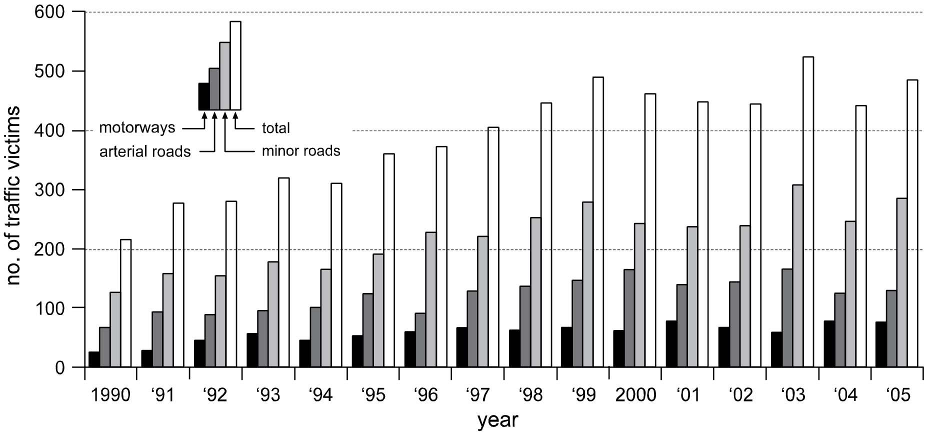

Fig. 2. Traffic kills for badgers (*Meles meles*) in The Netherlands by type of road (see Table 1) (Das&Boom, unpublished data).

risk of a collision. When animals cross a road with high traffic volumes, they experience high collision probability because the intervals to cross between the vehicles are small (Van Langevelde and Jaarsma, 2004; Aresco, 2005b; Jaarsma et al., 2006). Furthermore, crossing a road with vehicles travelling at high speed increases the collision probability (Jaarsma et al., 2006). When the roads are wider and traffic volume is higher, the barrier effect also increases (Jaeger and Fahrig, 2004). For small mammals, reptiles, amphibians and many ground-dwelling insect species, arterial highways and motorways are an absolute barrier, whereas they might cross minor roads (Vermeulen, 1994; Fahrig et al., 1995; Lodé, 2000; Rondinini and Doncaster, 2002). Moreover, major roads are, in contrast to minor roads, frequently fenced to prevent crossing by larger animals thereby optimising human safety. For larger animals, these major roads are thus also absolute barriers. On both minor and major roads, traffic victims are found. Using traffic victim data for badgers in The Netherlands, and more specifically data of Central Limburg in the south of The Netherlands, we illustrate the difference between traffic mortality on minor and major roads.

3.2. Example 1: Badgers in Central Limburg

For The Netherlands, data on road mortality per road type were collected during the period 1990–2005 (Fig. 2) by the Dutch NGO "Das&Boom". The increase in traffic mortality is assumed to be caused by the increase in traffic volume and in badger population size (Das&Boom, unpublished data). For Central Limburg, the exact locations of road kills were recorded on maps during 1990–1995. In this period, the population of the badger is considered to be stable in Central Limburg, and traffic volumes grew with circa 7%. Based on these maps, we made a classification for road type and number of victims (Fig. 3). We identified road sections, which were bounded by two crossroads and had a maximum length of 1 km (for longer distances between crossings, more sections were distinguished: on average, the road sections were about 500 m). We counted the number of badgers that were killed by traffic in these sections. Deaths occurring at 250 m or less were considered to be one location; otherwise, we distinguished more locations in the road section. The measure of 250 m is arbitrary, however with one exception (see below) a shortening to 100 m would give a same result.

Figs. 2 and 3 show that most traffic deaths in badgers occur on minor roads. Although the road kills per km road were lower for minor roads than for major roads because of their larger total length, 64% of the victims in Central Limburg were found on minor roads vs. 36% on arterial highways or motorways. On all minor roads with a length of about 35 km, 97 badgers became traffic victims at 74 locations with on average 1.3 victims per location. This average was influenced by one location with 8 victims, which were evenly distributed along a road section of 1 km (the average was 1.22 badgers per location on minor roads without this outlier). On about 12 km of major roads, 55 badgers were killed at 25 locations (on average 2.2 badgers per location). Both groups from Fig. 3 were compared for deviations with the Wilcoxon rank-sum test. We first tested whether the number of locations for a specific number of victims would be higher on major than on minor roads, for example, are there more locations with 5 victims on major than on minor roads? Indeed there is

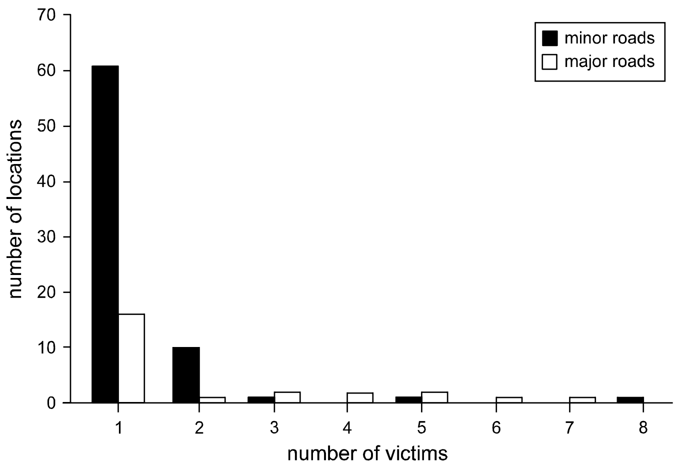

Fig. 3. Number of locations of badgers (*Meles meles*) as traffic victims per road section in Central Limburg, The Netherlands, from 1990 to 1995 (Das&Boom, unpublished data).

a significant difference between the groups. Although some number of victims can be found more often on minor than on major roads (for example, locations with 1 victim), the general pattern is the reverse ($T = 2.48$, $p = 0.007$). We also found that the average number of victims per location is higher on major roads ($T = 3.99$, $p < 0.0001$). On major roads, road kills are thus concentrated on a few locations with a high number of victims, whereas a more diffuse road kill pattern was found for the minor roads (many locations with 1 victim).

4. Mitigation and minor roads

4.1. Differences between minor and major roads

Based on the differences between major and minor roads, we argue that the negative impacts of minor roads on wildlife cannot be neglected. Our calculations show that minor roads caused greater habitat destruction than major roads, and a larger area is disturbed by noise. Moreover, we illustrated for badgers in Central Limburg that in absolute numbers more animals were killed on minor roads than on major roads.

The selection of locations on minor roads to mitigate traffic mortality is problematic, however, as locations with high victim numbers are generally the first to be nominated for mitigation. Example 1 shows that minor roads have a more diffuse road kill pattern than major roads, i.e., many locations with only a few accidents. Therefore, locations for mitigation are more difficult to determine and prioritise. Moreover, interventions on major roads such as fences in combination with wildlife underpasses and overpasses are primarily directed towards reducing the barrier effect (without increasing the mortality effect), whereas mitigation on minor roads should primarily reduce the number of road kills (without increasing the barrier effect).

In contrast to major roads, minor roads often have an access function for houses, farms and businesses. Therefore, fences together with wildlife underpasses and overpasses would not be effective as many interruptions to local access would be required. Furthermore, the length of the minor road network sets financial and practical bounds to the construction of fences and underpasses and overpasses. On the other hand, increasing the probability of safely crossing the roads themselves would be more effective and feasible for minor than for major roads. Measures to reduce traffic volume or speed and/or even a temporary closing to traffic may result in a reduction of road kills on minor roads. What alternative planning approach could introduce such measures to mitigate the negative impacts of minor roads?

4.2. Arguments for an integrated strategy

Interventions to mitigate negative environmental impacts of roads can only be really successful when minor roads are taken into account. We therefore recommend a strategy in which the environmental impacts of both major and minor roads in a region are considered together. Such an integrated strategy is needed as unintended effects on traffic flows can occur elsewhere as soon as mitigation is implemented on a certain road section of the road network. For example, temporary closing of one specific road section will lead to increased traffic volumes at other road sections in the network. From the point of view of traffic, implementing road design or road closing interventions for a certain road section is only possible when alternatives are offered to through traffic. The planning concept ‘‘traffic-calmed rural areas’’ (Jaarsma, 1997) is based on such a regional network approach. This concept was originally developed to promote traffic safety and to tackle rat-run traffic in rural areas. We argue here that this concept can also be applied to mitigate environmental impacts of roads.

4.3. Planning concept ‘‘traffic-calmed areas’’

During the 1970s, the concept of urban residential traffic-calmed areas was developed. Traffic-calmed areas are within built-up areas with restricted access for motorised traffic and a specific design forcing low speeds. This concept has already served as an international model (Macpherson, 1993). The concept of ‘‘traffic-calmed rural areas’’ uses the same ideas derived from built-up areas, and transfers them to the rural area (Jaarsma, 1997). The underlying idea is a clear separation between living space for inhabitants as well as wildlife, and space for traffic flows. Roads in traffic-calmed areas are designed to allow access rather than for through traffic. Traffic-calmed areas will be accessible by means of minor roads which are designed for low speeds and low traffic volume. Around the traffic-calmed area, a network of major roads offers fast routes for through traffic. On these roads, a concentration of former diffuse traffic flows appears. Along the major roads a number of ‘‘entrances’’ is situated, connecting this network with the network of minor roads within the traffic-calmed area. Only locally bound traffic will use the minor roads, allowing for a moderate technical design for low volumes and speeds. At the entrances a legal speed limit of 60 km h^{-1} for this area is indicated. To achieve this limit, in practice further speed-reducing measures on the minor roads are necessary, for example, speed humps and raised level crossings (Jaarsma, 1997).

The reduction of traffic speed and volume in the traffic-calmed areas is expected to have a positive impact on traffic safety and to reduce the barrier and mortality effect for wildlife (Jaarsma and Van Langevelde, 1997; Jaarsma and Willems, 2002). Large reductions in road noise can be expected along traffic-calmed roads. The most important disadvantage of the traffic-calmed areas is the increase in vehicle kilometers travelled because the route along minor roads is often shorter in both length and time than the route along major roads. In time, however, calculated differences are mostly very small (Jaarsma, 1997; Jaarsma and Willems, 2002). To illustrate the traffic-calming, we applied the concept in the region of Ooststellingwerf in the south-eastern part of Friesland, one of the northern provinces of The Netherlands.

4.4. Example 2: Traffic-calming in Ooststellingwerf

The region of Ooststellingwerf is part of the forest complex Fries-Drentse Wouden. It is designated as a core nature area with wet and dry corridor zones in the National Ecological Network (Fig. 4A). Several minor roads act as barriers in the corridor zones: Kruisweg (KW), Leidijk (LEI), Dorpsstraat and Bovenweg (DBW), Haulerdiek (HAU), and the major road N381. The barriers and conflict points for wildlife movement are indicated in Fig. 4A. For larger animals in particular, such as roe deer *Capreolus capreolus*, red fox *Vulpes vulpes* and mustelids (pine marten *Martes martes*, beech marten *Martes foina*, stoat *Mustela erminea* and weasel *Mustela nivalis*), these roads act as barriers (Streekplan Friesland, 1994). A population of pine marten exists in the Fries-Drentse Wouden. Traffic collisions are the major cause for mortality of pine martens in this area (G. Müskens, unpublished data). The area is considered to be important for the pine marten as a corridor zone between populations in the forests of Beetsterzwaag, Duurswoude and Appelscha. In addition, nature restoration plans intend to reintroduce the badger and the otter *Lutra lutra* in the Fries-Drentse Wouden. These populations will certainly be affected by traffic in the region Ooststellingwerf. The barrier and mortality effects are mainly caused by

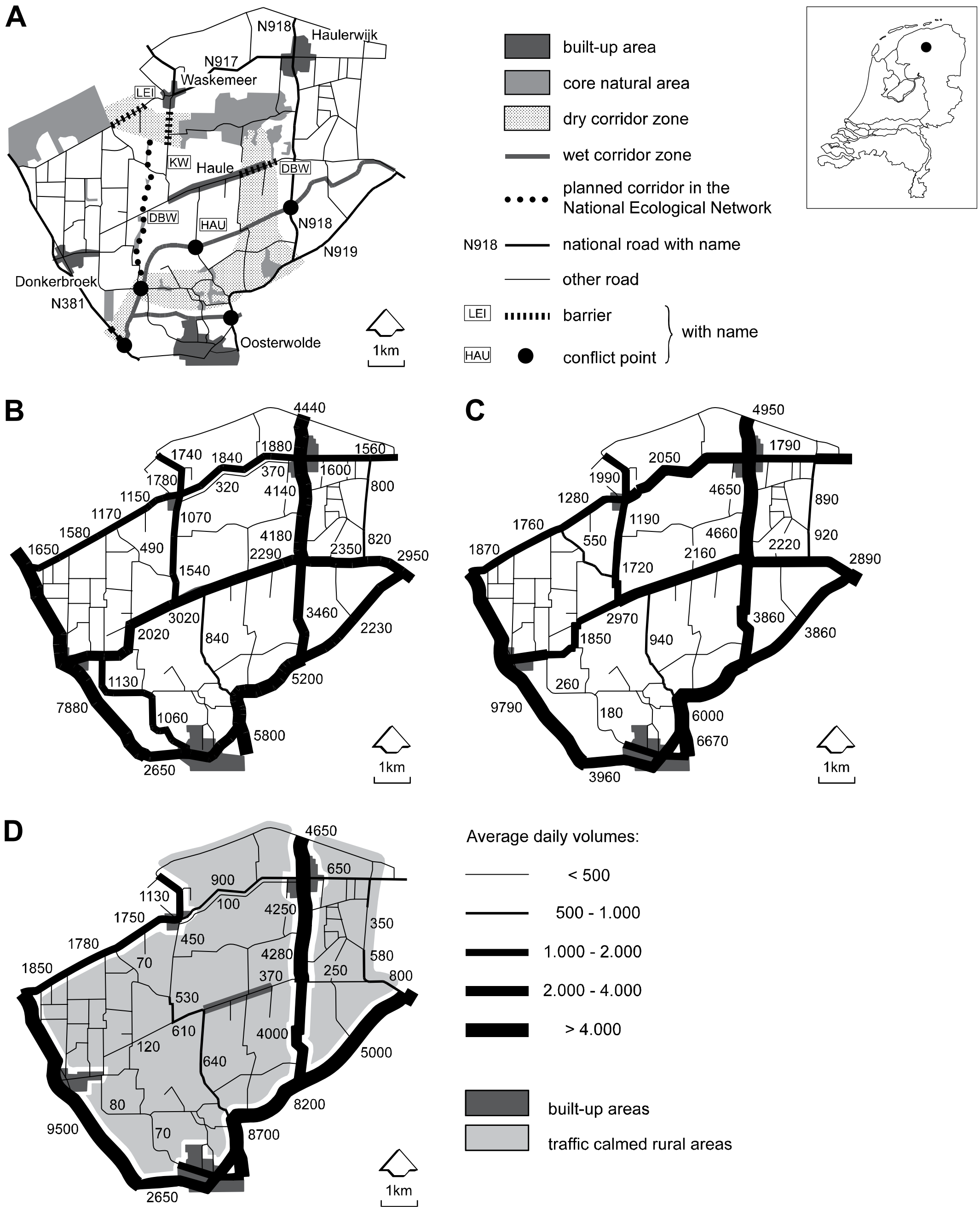

Fig. 4. (A) Core nature areas with dry and wet corridors in the region Ooststellingwerf, The Netherlands, and barriers and conflict points for wildlife movement (Streekplan Friesland, 1994). (B) The present diffuse traffic flows, and the predicted traffic volumes in (C) the development within 10 years without traffic-calming and (D) when applying the concept of traffic-calmed areas. The development within 10 years is calculated based on the expected trend of increasing volume of 1% per year.

the high traffic volumes and high (legal) speeds (Jaarsma and Van Langevelde, 1997).

The changes in traffic flows and resulting traffic mortality in roe deer can be illustrated when the concept of traffic-calmed areas is applied. Roe deer occurs throughout the Ooststellingwerf region. The results for the other large mammalian species did not yield qualitatively different results. First, the present diffuse traffic flows are shown in Fig. 4B. The effects of concentration of traffic flows on a few major roads are illustrated in Fig. 4C and D, in which the results of a traditional transportation model for traffic predictions are shown (Jaarsma and Willems, 2002). The transportation model is a so-called sequential aggregated model, with a distribution of traffic flows based on the gravity principle. Distances in the model are expressed in travel time and the assignment of traffic flows to the road network considers the shortest and second shortest routes in the network. The figure shows the difference between areas with diffuse traffic flows in the development within 10 years without traffic-calming (Fig. 4C) and concentrated traffic flows when a traffic-calmed area is implemented (Fig. 4D). The development within 10 years is calculated based on the expected trend of increasing volume of 1% per year. In the traffic-calmed area, the N381 and Leidijk are assigned with a traffic flow function. The remaining roads of interest are classified as access roads with smaller pavement width, resulting in lower traffic volumes (Fig. 5A). Concentration also reduces the traffic noise load in the traffic-calmed areas.

We evaluated the effects on traffic mortality in roe deer using the model presented by Van Langevelde and Jaarsma (2004). This model estimates the probability of a successful road crossing for individual animals related to characteristics of the species (the animal's length and traversing speed), the pavement width, and the traffic volume (deciding for the appearance of gaps in the traffic flow). Assumptions in this model are (1) a prompt crossing of a road by an animal at a constant speed, and (2) a kill of the animal in a collision if the appearing gap in the traffic flow at the start of the crossing is too small. Due to lower volumes and smaller pavement width, a substantial decrease of traffic mortality for roe deer is predicted. Fig. 5B shows the predicted relative change in their traffic mortality in the current situation and the development with traffic-calming related to the development without traffic-calming. For the barriers in the corridor zone KW, DBW and HAU, a positive change can be expected for the planned traffic-calmed area.

5. Proposal for an integrated strategy

In this paper, we discuss the relevant, but not always distinguished, effects of minor roads and their traffic on wildlife. Originally, the road network "was built in an era when transportation planners focused on providing safe and efficient transport with little regard for wildlife. That is changing [the regard for wildlife]…the call for new knowledge and skills is stronger than ever" (Forman et al., 2003; p xiii). As the majority of the attention was given to major roads, we ask now for a more extensive investigation of the environmental impacts of minor roads. We argue that the fragmentation effects of both major and minor roads can only be properly mitigated in an integrated strategy. The concept of traffic-calmed areas may contribute to balance the need to make areas accessible and protect wildlife. The Ooststellingwerf example shows that reduction of traffic volume in combination with smaller pavement width will substantially contribute to mitigating fragmentation effects by roads. Traffic-calmed areas create opportunities for wildlife by decreasing limitations for animal movement. We ask for further studies, particularly to estimate what area should be traffic-calmed to maintain minimum viable populations of certain species.

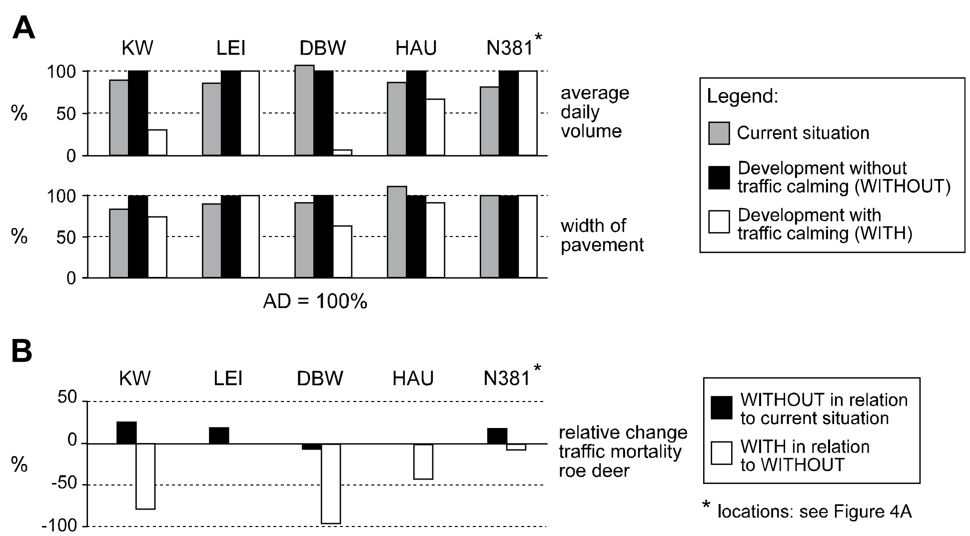

Fig. 5. Impacts of traffic-calming in the region Ooststellingwerf, The Netherlands. (A) Relative changes in traffic volume and pavement width in the actual situation, the development within 10 years without traffic-calming, and the development with traffic-calming (see Fig. 4). The development without traffic-calming is set at 100%. (B) The predicted changes in traffic mortality for roe deer (development without traffic-calming compared with actual situation and the development with traffic-calming).

6. Conclusions

We conclude that minor roads and their traffic can have a substantial role in traffic mortality in wildlife. The badger example in Central Limburg shows that a more diffuse road kill pattern was found for minor roads than for major roads. To mitigate the mortality of minor roads as well as minimise the risks to vehicles by collisions with wildlife, we propose an integrated strategy considering regional networks of both major and minor roads. With this strategy, positive effects of mitigation efforts at one location will not be nullified by unintended effects elsewhere. Above all, it means that transportation planners will design infrastructure that will reduce wildlife mortality and the barrier effect and increase traffic safety.

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