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Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors

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In wildlife considerations in planning and managing road corridors little attention has been given to the effects of disturbance by traffic on populations of breeding birds. Recent studies, however, show evidence of strongly reduced densities of many species of woodland and open habitat in broad zones adjacent to busy roads. The density reduction is related to a reduced habitat quality, and traffic noise is probably the most critical factor. Because density can underestimate the habitat quality, the effects on breeding populations are probably larger than have been established. In consequence, species that did not show an effect on the density might still be affected by traffic noise. On the basis of this recent knowledge, methods have been developed that can be used in spatial planning procedures related to main roads, and in road management practice, and some practical points are discussed. An example of application shows that the effects are probably very important in The Netherlands with a dense network of extremely crowded main roads. For 'meadow birds', which are of international importance, the decrease in population in the West of The Netherlands may amount to 16%. Because breeding birds suffer from many other environmental influences there is also a great risk of an important cumulation of effects.

Keywords: traffic; disturbance; noise; breeding bird populations; road planning and management.

Introduction

Wildlife considerations in planning and managing road corridors point out that habitat loss is probably the most important factor that can reduce the population size of breeding birds. Although motorized traffic kills large numbers of birds annually, it is has been concluded repeatedly that road kills do not exert a significant pressure on the population size (e.g. Ellenberg *et al.*, 1981; Leedy and Adams, 1982; Nijland *et al.*, 1982; Bernard *et al.*, 1987; Bennett, 1991). However, little attention has been given to the effect of disturbance by traffic. Recently, evidence was shown that this effect can be very important in affecting breeding bird populations in many species of very different habitat types (Reijnen *et al.*, 1995b, 1996; Reijnen and Foppen, 1995).

The aim of this paper is to stress the importance of considering the 'disturbance' effect in planning and managing road corridors. We discuss the following points:

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1. Evidence illustrating the nature and extent of the disturbance effect in breeding birds.
2. Exploration of the dimensions of the problem in The Netherlands with a dense network of extremely crowded motorways:
3. Possible measures to reduce the effects:
4. General considerations for application.

Bird population response to disturbance by traffic

The effects on breeding density

In earlier studies depressed densities of breeding birds adjacent to roads were found in only a few species belonging to quite different taxonomic groups, such as warblers, waders and tetraonids (Clark and Karr, 1979; Ferris, 1979; Räty, 1979; van der Zande *et al.*, 1980; Adams and Geis, 1981; lllner, 1992a). Since the total number of species investigated in these studies was rather small, it is difficult to interprete whether or not the density-depressing effect of roads is a common phenomenon. However, from the results given in the recent papers of Reijnen *et al.* (1995b, 1996) and Reijnen and Foppen (1995) it can be concluded that the effect is widely spread in breeding birds. Along heavily travelled roads in The Netherlands, 33 of the 45 investigated bird species in woodland showed an effect and 7 of the 12 investigated species in agricultural grassland. The affected species cover almost all taxonomic groups present in these data (Table 1).

Rough estimations of disturbance distances and density reductions over these distances in some of the earlier studies indicate that the effect might also be important quantitativily. For two wader species in open field habitat, van der Zande *et al.* (1980) estimated disturbance distances ranging from to 625 m for a secondary road to 2000 m for a busy highway (van der Zande *et al.*, 1980). Tetraonid species in woodland were disturbed up to a distance of 500 m near relatively quiet highways (Räty, 1979). In both studies the density reduction in the disturbed zone amounted to 50% or more.

Accurate quantitative data of many species from the recent studies of Reijnen *et al.* (1995b, 1996) and Reijnen and Foppen (1995) show, that such large disturbance distances and high-density reductions are not exceptional. They quantified the relationship between traffic load and density with regression by using a threshold model with traffic noise (in dB(A)) as the explanatory variable (see for explanation Reijnen *et al.*, 1995b; Fig. 1). Disturbance distances were derived from these equations by transforming the threshold value in dB(A) into distance from the road (m). To compare the results of these studies we converted values for 5000 vehicles a day to 10 000 vehicles a day (grassland) and values for 60 000 vehicles a day to 50 000 vehicles a day (woodland). Estimated disturbance distances of grassland breeding birds vary from 30 to 2180 m at 10 000 vehicles per day and from 75 to 3530 m at 50 000 vehicles per day. Woodland breeding birds have a similar range of disturbance distances, from 30 to 1500 m and from 60 to 2800 m, respectively. For the density of all species combined, the estimated disturbance distance in open grassland is 190 m at 10 000 vehicles a day and 560 m at 50 000 vehicles a day (based on one data set), in woodland 50–1500 m and 100–2800 m respectively (based on three data sets).

However, it was pointed out that the very large disturbance distances might be unrealistic because they are based on regressions in which a threshold is absent (lowest noise level was taken as the threshold). If we disregard these regressions, estimated disturbance distances remain very large but they do not exceed 1000 m any more (Table 2). Also, the

Table 1. Number of species affected by traffic in different taxonomic groups

Taxonomic group[a]	Number of species investigated in woodland		Number of species investigated in agricultural grassland	
	Total	Affected	Total	Affected
Anatidae	1	0	4	1
Accipitridae	1	1	–	–
Phasianidae	1	1	–	–
Rallidae	–[b]	–	1	1
Haematopodidae	–	–	1	1
Charadriidae	–	–	1	1
Scolopacidae	1	1	2	1
Columbidae	3	2	–	–
Cuculidae	1	1	–	–
Picidae	3	2	–	–
Alaudidae	–	–	1	1
Motacillidae	1	1	2	1
Troglodytidae	1	1	–	–
Prunellidae	1	0	–	–
Turdidae	4	3	–	–
Sylviidae	8	8	–	–
Muscicapidae	2	1	–	–
Aegithalidae	1	0	–	–
Paridae	6	4	–	–
Sittidae	1	0	–	–
Certhidae	1	1	–	–
Oriolidae	1	1	–	–
Corvidae	3	2	–	–
Sturnidae	1	0	–	–
Fringillidae	2	2	–	–
Emberizidae	1	1	–	–
Total	45	33	12	7

[a]Nomenclature follows Voous (1973, 1977).
[b]No species present.
Source: Reijnen *et al*. (1995b, 1996), Reijnen and Foppen (1995).

range of threshold values in dB(A) for species and for all species combined now becomes very similar in both types of habitat (Table 3).

The reduction of the density over the disturbance distances varies greatly between species, but is never smaller than 30%. In both types of habitat several species even show a density reduction of almost 100%. This means that dense traffic, in particular, can cause an important loss of numbers of species. Because many species are affected, there is also a significant reduction of the total density: in open agricultural grassland 39%, and in woodland 35%.

In some previous studies higher densities of breeding birds close to roads were also found (Clark and Karr, 1979; Ferris, 1979; Adams and Geis, 1981). However, this can be explained by habitat conditions being much more favourable close to roads than farther

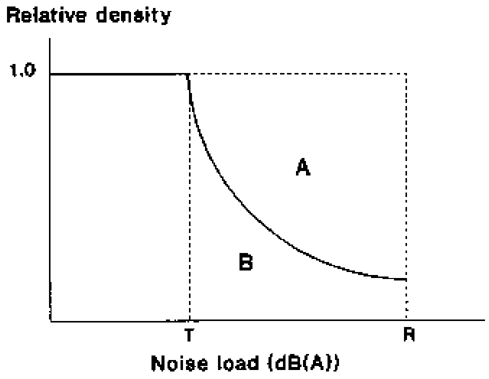

Figure 1. Threshold model for relative breeding density of birds plotted against traffic noise, where T is the threshold value and R the value at the roadside. The decrease factor of the density = area of A/(area of A + B). Source: Reijnen *et al.* (1995b).

Table 2. Maximum size of the disturbed zone adjacent to main roads (in metres) that has a reduced density of breeding birds, when probable unrealistic values are not considered

	Species		All species combined	
Habitat	10 000 Vehicles per day	50 000 Vehicles per day	10 000 Vehicles per day	50 000 Vehicles per day
Open grassland	365	930	190	560
Woodland	305	810	125	365

Based on Reijnen *et al.* (1995b, 1996) and Reijnen and Foppen (1995).

away and therefore should not be interpreted as a positive effect of traffic (see Reijnen *et al.*, 1995b). There are no indications that species might be favoured because of competition (increase of density if there is an effect on related species) or better feeding conditions due to the presence of road victims (Reijnen *et al.*, 1995b). This is in accordance with the fact that total bird density is also reduced.

Possible causes and mechanisms

Reijnen *et al.* (1995b) found almost no effects on species along roads when the noise load due to traffic was relatively low. This indicates that the presence of a road *per se* is not very important in affecting densities of breeding birds. Also, it is not probable that mortality

Table 3. Range of threshold values for traffic noise (dB(A)) of breeding birds (probable unrealistic values are shown in parentheses); below the threshold the density is not affected

Habitat	Species	All species combined
Woodland	(23)36–58	(23)42–52
Open grassland	(27)43–60	47

Source: Reijnen *et al.* (1995b, 1996) and Reijnen and Foppen (1995).

due to collisions is an important causal factor. Although the numbers of road victims can be rather large (e.g. Hodson and Snow, 1965; Adams and Geis, 1981; Füllhaas *et al.*, 1989; van den Tempel, 1993), it was assumed that they are, in general, not sufficient to cause a significant increase of the total mortality of species (Ellenberg *et al.,* 1981; Leedy and Adams, 1982; Reijnen *et al.*, 1995b). Support for this assumption is given by Reijnen and Foppen (1994), who observed equal survival rates of male willow warblers (*Phylloscopus trochilus*) close to a busy highway and in areas at a distance of several hundred metres. Only for owls, in particular barn owl, *Tyto alba*, road mortality might influence population size significantly (Joveniaux, 1985; Illner, 1992b; van den Tempel, 1993). This implies that possible causes will rather be related to emission of matter and energy by road traffic, such as pollution, visual stimuli and noise (van der Zande *et al.*, 1980; Ellenberg *et al.*, 1981; Leedy and Adams, 1982). Reijnen *et al.* (1995b) show evidence that, in woodland, noise is probably the most critical factor in causing reduced densities close to roads. In regression analysis using noise and visibility of vehicles as response variables, noise appeared to be the best and, in many species, also the only predictor of observed depressed densities close to the road. A reduction of the total density could be explained only by noise. Furthermore, they argued that other possible causes, such as pollution and visual stimuli, are not very important, because they operate at a very short distance from the road and have in all probability a limited effect. In open landscape, however, an effect of especially visual stimuli cannot be excluded for certain. Here, visual stimuli reach much further than in wooded areas, and breeding birds might respond differently (Reijnen *et al.*, 1996). On the other hand, a study of Illner (1992a) showed that, even in the absence of visual stimuli (road bordered by hedgerows), grey partridge (*Perdix perdix*) densities in open arable farmland were still heavily depressed up to several hundred metres from busy highways. Also, breeding birds of open grassland and woodland respond very similarly to disturbance by traffic (Table 3). This indicates that noise is also the most critical factor in open landscape.

Very little is known about how noise could cause reduced densities of breeding birds. For the willow warbler it has been shown that, close to a highway, many males experience difficulties in attracting or keeping a female and because of the lack of reproductive success move out of the road zone in the following year (Reijnen and Foppen, 1994; Foppen and Reijnen, 1994). This could point to distortion of the song of males as a possible mechanism (cf. Reijnen and Foppen, 1994). However, there is some evidence that disturbance of the vocal communication between birds is probably not a general mechanism in causing reduced densities (Reijnen *et al.*, 1995b). An alternative, or more likely a supplementary explanation is that birds avoid areas close to roads because of stress (Illner, 1992a; Reijnen *et al.*, 1995b).

Figure 2 summarizes the probable relationship between traffic and density of breeding birds.

Effects on habitat quality in relation to density

There is much evidence that the reduction of the density is related to a reduction of the habitat quality (Reijnen and Foppen, 1994, 1995). On the other hand, it is known that density is not always a good indicator of habitat quality and might even be misleading (Fretwell, 1972; van Horne, 1983). In several territorial bird species it has been shown that, when overall density is high, less-preferred habitat is more strongly occupied than when overall density is low (Kluyver and Tinbergen, 1953; Glas, 1962; O'Connor and Fuller, 1985). Similar relation-

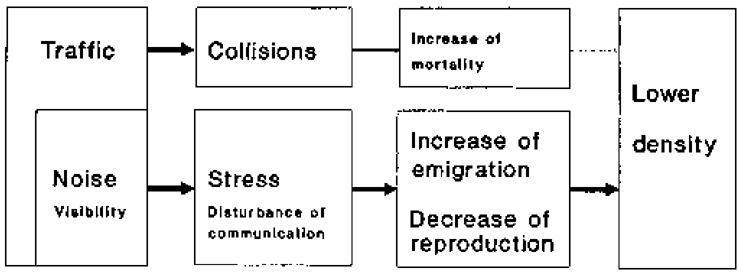

Figure 2. Probable relationship between traffic and density of breeding birds.

ships were found between habitats close to roads and habitats further away (Reijnen and Foppen, 1995). This means that the size of zones adjacent to roads that have a lower quality due to disturbance by traffic can easily be underestimated when it is based on density data (Fig. 3). The study of Reijnen and Foppen (1995) indicates that in woodland birds such underestimation can be substantial, since many species only had a depressed density in years when there was a relatively low overall density. As a consequence, species that did not show an effect on the density still might be affected by traffic.

Consequences for breeding populations

To understand the consequences of the effect of disturbance by traffic on breeding bird populations the reduction of the habitat quality is probably the most important. There are many indications that the size and persistence of breeding populations depend mainly on areas with a high quality (Wiens and Rotenberry, 1981; Bernstein *et al.*, 1991). In consequence, the largest effects on the overall population size can be expected when disturbance causes a major loss of high-quality areas. Also, a further degradation of habitats with a low quality can have some effect, because they may contribute significantly to the overall population size (Howe *et al.*, 1991). This is supported by the study of Foppen and Reijnen (1994), who found that there is a quantitatively important breeding dispersal flow of male willow warblers from highway-induced low-quality habitat to high-quality habitat nearby.

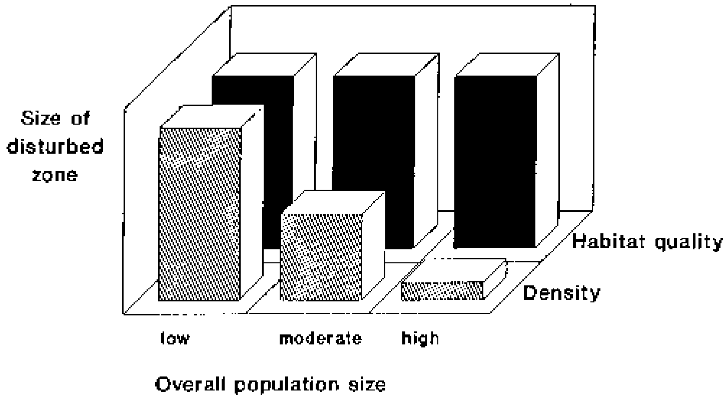

Figure 3. Schematic representation of the effect of disturbance by traffic on habitat quality (solid) and density (hatched) of breeding birds in relation to overall population size.

Finally, one should also consider possible risks of cumulation of effects. Breeding birds in The Netherlands, for example, suffer from many other environmental influences, of which eutrophication of ground water and surface water, ammonium deposition from agricultural emmissions, lowering of the water table, and habitat fragmentation are considered of greatest importance (e.g. Canters and De Snoo, 1993; Vos and Zonneveld, 1993; Bink *et al.*, 1994) and this increases the risk of an important cumulation of effects. The first three factors cause a decline of the habitat quality (or even a loss of habitat), which may affect the size of local populations. If the population size becomes very small there will be an increased risk of extinction due to demographic chance processess (Goodman, 1987; Shaffer, 1987). Habitat fragmentation can reinforce this process. It increases the risk of extinction due to demographic chance processes and it may reduce the chance that dispersers rescue small local populations from extinction; eventually, this will affect whole network populations (e.g. Opdam *et al.*, 1993; Verboom *et al.*, 1993). Evidence for these effects have been shown in several studies (see Opdam, 1991; Opdam *et al.*, 1993, 1995).

Exploration of the dimensions of the problem in The Netherlands

Estimation of the total disturbed area

The Netherlands has a dense network of main roads (ca 0.3 km per 100 ha, total ca 3000 km) (Anonymous, 1993a) with high traffic densities varying from 10 000 to more than 140 000 vehicles per day (Anonymous, 1988, 1993b) (Fig. 4). This network of main roads adsorbs the majority of the traffic volume on all paved roads outside the urbanized areas (Anonymous, 1992), and therefore it accounts for most of the effects of traffic on breeding bird populations.

To obtain a rough indication of the consequences for breeding bird populations we made an estimation of the total disturbed area along the network of main roads. Since the distribution pattern of habitats was not available we used either the disturbance distances of woodland birds or the disturbance distances of grassland birds. It has been assumed that these distances also cover the range of distances in other habitats. We focused on the disturbance distances for all species combined and for the most sensitive species. The analysis was carried out for the situation in 1986 and for a scenario in 2010 (Anonymous, 1988), which is based mainly on an ongoing increase of the traffic density. Calculations were made by using the computer program SILENCE (Anonymous, 1991).

In 1986 the estimated size of the disturbed zone based on all species combined covered more than 8% of the land area of The Netherlands, and based on the most sensitive species more than 15% (Table 4). In 2010 these values could be 30–40% higher (Table 4). Although it was not possible to show which part of actual habitats is affected, it is very likely that such a large disturbed area should have important consequences for breeding bird populations of many species, in particular the more sensitive ones.

Exploration of consequences for meadow bird populations

To support the assumption that disturbance by traffic has important consequences for breeding populations of species, we made a rough analysis for birds of moist and wet grasslands. Many of these grasslands, in particular in the North and West of The Netherlands, are well known for their rich communities of so-called ‘meadow birds’, which are of international importance (Beintema, 1986). The most typical species is the

Figure 4. Pattern of main roads in The Netherlands in 1986. The traffic density varies from 10 000 to > 100 000 vehicles per day. The thickness of the lines reflects the area that has a noise load of > 50 dB(A). Source: Anonymous (1991).

Table 4. Estimated size of area disturbed by traffic along main roads in The Netherlands in 1986 and for a scenario in 2010, which is based on an ongoing increase of the traffic density

	Disturbed area (size × 100 ha[a])		Total land area in The Netherlands (%)[b]	
Estimate	1986	2010	1986	2010
All species combined[c]	2786–3901	3965–5377	8.2–11.5	11.7–15.9
Most sensitive species[c]	5324–5872	7114–7776	15.8–17.4	21.1–23.0

[a]Area of pavement and verges excluded.
[b]Total land area is ca 33 800 km^2.
[c]Lowest value is based on woodland birds, highest value on grassland birds.

black-tailed godwit (*Limosa limosa*) of which 80–90% of the European population nests in these grasslands (van Dijk *et al.*, 1989).

For practical reasons the survey was restricted to the West of The Netherlands, which has the highest density of main roads (Fig. 5). Data on the distribution of moist and wet

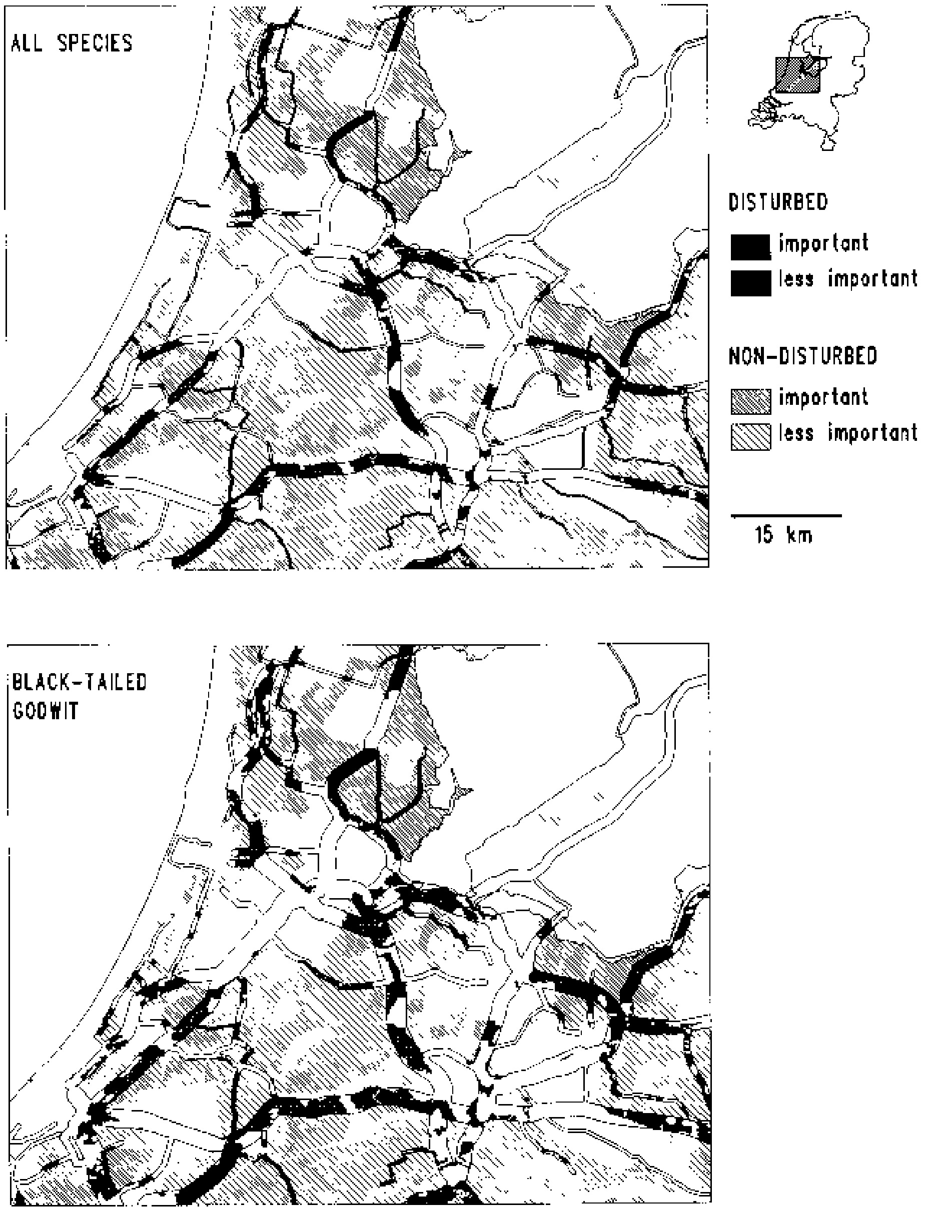

Figure 5. Disturbed area for grassland breeding birds by traffic on roads with > 10 000 vehicles a day in the West of The Netherlands in 1986 (see also Table 5).

grasslands were taken from Bakker *et al.* (1989), which reflect the pattern of 1986. To indicate differences in habitat quality of the grasslands we used general data on the distribution of grassland birds based on Bakker *et al.* (1989) and van Dijk *et al.* (1989). Two categories were distinguished:

- important, many species and high densities;
- less important, few species and low densities.

It is not likely that the effects of roads are already reflected by these categories. The densities of the grassland species in the 'important' habitat are, on average, five times higher than in the 'less important habitat' (Vogelwerkgroep Avifauna West-Nederland, 1981), which is much more than the reduction of the density by traffic. For the black-tailed godwit, the most abundant species, the number of breeding pairs between 1979 and 1987 in this region was, on average, 20 000 (van Dijk *et al.*, 1989).

All roads that had traffic densities of more than 10 000 vehicles per day were considered. Traffic data of 1986 were available in reports of the national and provincial authorities. Calculation of disturbance distances was carried out according to Reijnen *et al.* (1996), and the size of the disturbed area was estimated by using overlay-techniques in a GIS system (ARCINFO). This was done for all species combined and for the black-tailed godwit and for the two habitat categories separately.

It appeared that, in 1986, a substantial proportion of both 'important' and 'less important' areas for meadow birds was disturbed by traffic (Table 5 and Fig. 5). If we take into account observed reductions of the density in the disturbed zone (39% for all species combined and 47% for black-tailed godwit; Reijnen *et al.*, 1996) and densities in the 'important' habitat being five times higher than in the 'less important' habitat (Vogelwerkgroep Avifauna West-Nederland, 1981), this points to a loss of population that amounts to 12% for all species combined and to 16% for the black-tailed godwit (approximately 3200 breeding pairs). Because of the ongoing strong increase of traffic densities (Anonymous, 1990), the effects will only become more important. Based on a scenario for 2010 (see Anonymous, 1991), this could lead to an expected population loss of approximately 30%.

So, in grassland birds, there is strong evidence that disturbance by traffic has a significant impact on the size of breeding populations in the West of The Netherlands. In combination with the probably larger effect of poor management (Beintema, 1991), this causes a serious threat for grassland bird populations. In nature conservation strategies this should get much more attention.

Table 5. Estimated size of area disturbed by traffic on roads with > 10 000 vehicles a day for grassland breeding birds in the West of The Netherlands in 1986 (see also Fig. 5)

	Disturbance of important area		Disturbance of less important area	
Estimate	Size (ha)	Total (%)[a]	Size (ha)	Total (%)[b]
All species combined	6 800	11	30 200	21
Black-tailed godwit	12 000	19	44 700	32

[a]Total size 62 000 ha, area of pavement and verges excluded.
[b]Total size 140 700 ha, area of pavement and verges excluded.

Possible measures to reduce the effects

Because noise is probably the most critical factor, one can expect that a reduction of the noise load will reduce the effects on the density. Although further experimental evidence is needed, there are probably no important restrictions to apply this knowledge. Measurements that reduce the noise load, such as the construction of walls of earth or concrete materials, will also reduce or eliminate the other traffic-related factors.

A reduced density adjacent to roads can also be compensated for by developing new favourable habitats outside the disturbed zone. Improvement of the habitat quality within this zone, in general, will have a limited effect, since the observed density reductions were very large. However, since the reduction of the density decreases with increasing distance from the road it might have some effect in the part of the disturbed zone far from the road.

Reducing effects along existing roads

A sufficient reduction of the noise load along roads in order to reduce the effects of traffic on breeding-bird populations can be achieved only by constructing noise barriers. However, to obtain a substantial reduction, the length of these barriers should be very large and their height rather high. Moreover, in open areas, such barriers may also act as a source of disturbance themselves, because many birds of open grassland avoid the vicinity of hedgerows, wooded banks and dykes up to several hundred metres (e.g. Klomp, 1954; van der Zande *et al.*, 1980; Altenburg and Wymenga, 1991). So, application seems appropriate only for major problems (large disturbance distances in important areas for breeding birds). However, in constructing noise barriers for birds, one should take into account that they can hamper movements of other animal species. This might give fewer problems if under- or overpasses for wildlife are present. Openings in noise barriers at the ground level are probably not very effective, since, in particular, for small animals, the barrier effect of the road itself seems much more important (e.g. Oxley, 1974; Mader, 1984; Mader *et al.*, 1990). On the other hand, they might be useful for animals to escape from the road area.

Compensation for loss of population along roads by creating new habitats outside the disturbed zone has the disadvantage that, in general, it will take many years before the habitat is fully developed. Moreover, in The Netherlands, with a dense human population, application is probably limited. At present, re-allotment plans afford the best opportunity, in particular with respect to birds of agricultural grasslands. Extensification of agricultural management in areas outside the disturbed zone (which improves the habitat quality), can be compensated for by intensifying the agricultural management close to roads (cf. Reijnen *et al.*, 1996). One should take care that such measurements do not cause loss of other natural values in the disturbed zone, such as interesting plant communities.

As discussed earlier, improvement of habitat quality of disturbed areas near the road will not be of great value since the reduction in the density of many species is very marked. Moreover, it can increase the number of road kills (van den Tempel, 1993). In view of this, one should also have low expectations of positive effects of roadside management for breeding birds in general. This does not mean that roadside management to maintain or improve natural qualities is not effective from a conservation point of view. In particular, when roadside habitat comprises remnants of natural vegetations, it can be valuable for many plant species and animals, such as small mammals, butterflies, carabids and other invertebrates (e.g. Bennett, 1991; Hochstenbach, 1993; Sykora *et al.*, 1993). If roadsides connect other habitat patches, they also can function as a corridor, which might have positive effects on the size and persistence of the overall population (see e.g. studies on carabids, Vermeulen, 1993, 1994). In large agricultural areas, the occurrence of many species, including birds, may depend on roadside habitat (see e.g. Bennett, 1991).

Although it is now rather well established that the development of new natural areas for breeding birds should not be close to main roads, in The Netherlands this still sometimes happens. Recently, in the re-allotment plan for the 'Eempolders', a nature reserve for meadow birds was situated adjacent to a highway. This resulted in discussions about how to reduce the effects of disturbance!

Minimizing effects in planning roads

The best way to minimize the effects of new roads is to avoid disturbance of important areas for breeding birds. This can be achieved by using knowledge on disturbance distances in the first phase of the EIA-procedure, to which all plans for main roads are subjected. In exploring possible solutions for transportation routes, one should take into account a sufficient distance from these areas, based on expected traffic densities. In general, 1000 m on both sides of the road seems an adequate distance.

When effects are inevitable, one should consider measurements to compensate for or to reduce effects. As discussed earlier, development of natural areas in or adjacent to roadsides are, in general, not a useful strategy with respect to breeding birds.

General considerations for application

In applying the recent knowledge on the relationship between traffic and breeding bird populations in spatial planning procedures we distinguish between (1) assessment of the size of the problem and (2) selection of effective measurements that reduce the effects.

The use of noise to quantify the traffic load has the advantage of describing the relationship between traffic and density in a rather universal way. Noise takes into account many characteristics of traffic that might be important in affecting breeding birds (such as number and size of vehicles, speed) and, as mentioned before, noise is probably also the most critical factor. Furthermore, there are appropriate mathematical models to calculate the noise load along roads (Moerkerken and Middendorp, 1981; Huisman, 1990; see also Reijnen *et al.*, 1995b) and basic data are readily available or can be easily measured.

The available data give adequate information to establish the effects of traffic on main roads in woodland (deciduous and coniferous) and open agricultural grassland. Sampling plots were distributed all over The Netherlands, and the range of traffic densities involved was rather large (3000–75 000 vehicles per day). Furthermore, application of the results to other types of habitat seems allowable. The species studied are representative for the whole group of breeding-bird species in The Netherlands and many of them can also be found breeding outside woodland and open agricultural grassland. It is likely that the results are also applicable in areas outside The Netherlands that have a similar bird fauna. However, in hilly areas the established relationships between noise and density might not be valid. In that case and in all other very different situations additional investigations are needed.

Effect curves in which a threshold was absent resulted in very large and probable unrealistic disturbance distances and it is better not to use them. On the other hand, evidence was shown that the available data can underestimate the size of the disturbed zone considerably. To reduce this risk, for the remaining effect curves one can concentrate on the largest effect found for the total density and the effect for the most sensitive species. These effect curves also have relatively narrow confidence limits. A side-advantage of this approach is that it makes extrapolation to other types of habitat more easy.

To assist in the application of the present knowledge to the effects of traffic on breeding bird populations in spatial planning procedures related to main roads, such as EIA and in road management practice, we compiled a manual that makes application easier (Reijnen *et al*., 1995a).

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