Effects of roads on the abundance of birds in Swedish forest and farmland

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Abstract

We studied birds in forest and farmland adjacent to roads; primarily to test a model to determine the width of the "effect zone", the area along a road in which breeding bird density is reduced because of traffic noise (M. Reijnen et al., 1995. 'Predicting the effects of motorway traffic on breeding bird populations'. DLO-Institute for Forestry and Nature Research, The Netherlands). Birds were counted in spring, along transects perpendicular to larger roads in South-Central Sweden in 1998-1999. In farmland, a lower abundance of birds within the road effect zone was observed, both for some target species and for all species combined. Data were however not consistent in this respect. In forest, no general difference in bird abundance with distance to road could be established. We found a tendency for lower abundance proximate to roads in six species, but the opposite tendency in four. This pattern could be explained by the different habitat requirements of the species. Accordingly, the predictions derived from the model were only partly correct, and we conclude that the model may not be directly applicable under the present conditions. We suggest that habitat changes as a consequence of road construction under some circumstances can override the negative effects of traffic noise on the surroundings, and argue that also the potential positive effects of roads should be considered in road management.

Introduction

Ecological effects of roads and car traffic on wildlife are at present receiving a growing concern. Roads create barriers, open up forest habitat and introduce artificial edges in the landscape; vehicle traffic causes mortality and produces noise; road maintenance and traffic lead to the emission of dust, toxins, fertiliser nutrients and other pollutants (reviews in Bennett, 1991; Forman and Alexander, 1998; Forman et al., 2002; Seiler, 2002). The effects on the density of birds in surrounding habitats have previously been addressed by a number of authors (Clark and Karr 1979; Ferris 1979; Räty 1979; Van der Zande et al., 1980; M. Reijnen and Thissen, 1987; Illner, 1992; Rich et al., 1994; Foppen and Reijnen 1994; R. Reijnen et al., 1995; 1996; Junker-Bornholdt et al., 1998; Kuitunen et al., 1998; Forman and Deblinger 2000), and reduced densities have been explained mainly by the noise load (R. Reijnen et al., 1995; Forman et al., 2002).

Although ecologists and road planners are generally aware of the ecological problems caused by roads and traffic (e.g. Canters et al., 1997; Pierre-Le Pense and Carsignol, 1999), methods and criteria for ecological impact assessments are rarely applied. A recent approach that has received much attention by road administrations in several countries is to calculate the width of the zone along a road where a reduced breeding bird density due to traffic noise could be expected (the "effect zone").

The model for this calculation (M. Reijnen et al., 1995) was developed from a comprehensive study in the Netherlands, where an overall reduction of breeding bird density in agricultural grassland and in coniferous woodland in proximity to main roads was found (R. Reijnen et al., 1995, 1996). In grassland, the effect was strong, and a majority of species was affected, while in coniferous woodland the effect was weaker and attributed mainly to a small number of species. The effect zone extended up to several km from the road for the most sensitive species in that study.

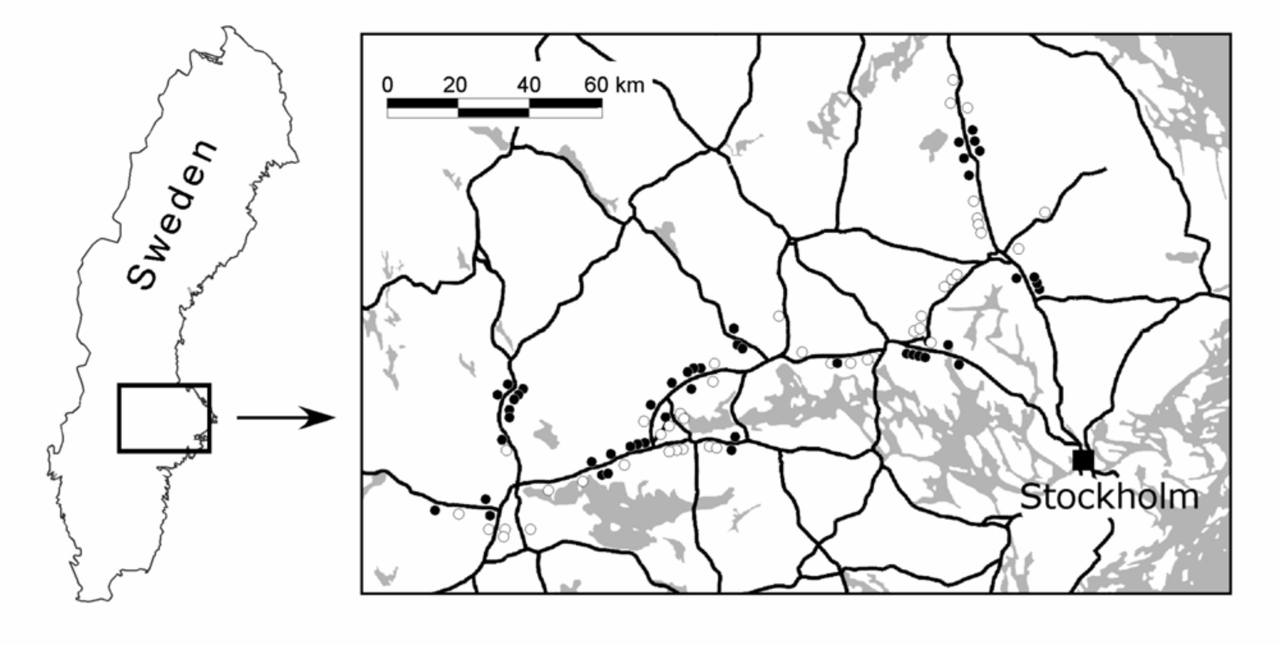
The propagation of traffic noise depends on both vehicle weight and speed, road characteristics, and on several environmental factors such as topography, vegetation and climate (Larsson, 1994; Anonymous, 1999). Furthermore, since the sensitivity to traffic noise vary among species (e.g. R. Reijnen et al., 1995), the overall effect of roads should also depend on the local species pool. The model derived from the Netherlands may thus not be universally applicable. Other studies have implied no effect of roads, or even higher densities of some species near roads (Ferris, 1979; Clark and Karr, 1979; Adams and Geis, 1981). Accordingly, Forman and Alexander (1998) called for studies that could clarify the significance of the results of R. Reijnen and co-workers.

The primary aim of our study was to test the applicability of "the Dutch model" (M. Reijnen et al., 1995) under Swedish conditions. We predicted lower density of some focal species (see Methods), and of all species combined, within a given effect zone. As an alternative, we also analyzed the data for any trend in bird abundance with distance from road. This was done to detect both positive and negative effects on distances other than the ones predicted by the model. Two standardized habitats were included comparable to those in the studies of R. Reijnen et al. (1995, 1996), i.e. open farmland and coniferous forest.

Methods

The study was conducted in 1998-1999 in South-Central Sweden (Fig. 1), in the geographic region Mälardalen, characterized by a relatively flat landscape relief below 100 m above sea level, with a mix of farmland and forest (roughly 50% each). By Swedish standards, the area is densely populated (on average 70 inhabitants/km^2; Öberg and Springfeldt, 1991), with numerous towns interlinked by major roads.

Fig. 1. Major roads in mid-Sweden and location of transects in forest (black dots) and farmland (open dots), along which birds were counted in spring 1998-1999.



Birds were censused along 90 transects (Fig. 1) perpendicular to major roads of 4,600-25,000 (mean 10,400) cars/day and car speed limit 90-110 km/h. Transects were placed adjacent to the road corridor in either homogenous, mature (=60 yrs) coniferous forest (n = 47) or homogenous, open farmland (n = 43). Minimum distances between transects on the same side of the road were set to 1000 m, for transects on opposite sides 500 m.

We used slightly different sampling methods in the two habitat types, both mainly suitable for passerine birds (Bibby et al., 2000). In forest, birds were counted at points at 100 m interval along the transect line. At a count, all birds observed during five minutes was noted. To avoid double counts, only birds within a radius of 50 m from the point were included. The distances from road corridor to nearest point were distributed at 10m intervals from 0 to 90 m. The length of forest transects varied from 300 to 600 m. In farmland, birds were counted along a strip, 100 m on each side, while walking at standardized speed (ca 2 km/h) along the transect line. For all birds observed, distance from road corridor (at 10 m accuracy) was noted. Length of farmland transects varied from 500 to 1000 m. Transect length was limited by habitat characteristics, but set so that at least half the transect was outside the predicted effect zone.

Each transect was visited twice to cover the seasonal peak in singing activity for most bird species; once in late April - early May, once in late May - early June. At the two visits, transects were walked in different directions (except in a few cases were this was not possible). All counts were made in early mornings, and most on weekends, when traffic was relatively low. Habitat characteristics were recorded along the transects. In forest, tree species composition was measured (to the nearest 10 %) and shrub density estimated (on a 3-level scale; none, sparse, dense) at the counting points. In farmland, farm crop (pasture, ploughed field, tender crop, or stubble-field) and occurrence of ditches and shrubs were recorded in 100-m intervals.

The "effect distance" (width of the effect zone measured from the road) was calculated based on a combination of traffic density (cars/day), car speed and woodland fraction near the road, using tables in M. Reijnen et al. (1995, pp. 50-53). The predicted effect distances varied from 98 to 245 m at forest transects and from 66 to 285 m at farmland transects.

In analyses, obvious non-breeding birds (large flocks, apparently migrating birds, birds passing by at high altitudes) were excluded. For all analyses on single species, only the visit with most individuals observed of that species was used. Species for which a negative effect of traffic was found by R. Reijnen et al. (1995; 1996), and which also occurred in our study, were selected as "focal species". These included wood pigeon (*Columba palumbus*), great spotted woodpecker (*Dendrocopos major*), willow warbler (*Phylloscopus trochilus*), goldcrest (*Regulus regulus*), and coal tit (*Parus ater*) in woodland; lapwing (*Vanellus vanellus*), skylark (*Alauda arvensis*), and meadow pipit (*Anthus pratensis*) in farmland. Because of difficulty in field identification of common crossbill (*Loxia curvirostra*) and parrot crossbill (*L. pytyopsittacus*), these species were combined as crossbill species (*Loxia spp.*)

Statistical analyses

The data set was analyzed in two ways. In a first step, lower abundance of birds within the effect zone was tested with a paired Wilcoxon signed-rank test (1-tailed). A relative bird density estimate was produced by dividing the number of birds observed with the number of points (in forest) or distance (in farmland) censused within and outside the effect zone.

The test was conducted separately on all species observed at ≥ 4 transects, and on all species combined. The standard significance level was set to P = 0.10, but in the analyses of single species (focal species excluded) we applied a Bonferroni correction (Rice 1989):

$$P(crit.) = a / k, \qquad \text{(eqn 1)}$$

where P(crit.) is the corrected significance level, a is the standard significance level and k is the number of tests, resulting in P(crit.) = 0.10/26 = 0.004 for forest and P(crit.) = 0.10/9 = 0.011 for farmland. As Bonferroni correction can be criticized as being too conservative, we chose to acknowledge results of $P < 0.10$ as tendencies in the data.

In a second step, trends (negative as well as positive) in occurrence of birds in 100-m intervals of transects was tested against distance from road, habitat characteristics, traffic density, and car speed, using multiple logistic regression (Wald test; 2-tailed) with Bonferroni correction P(crit.) = 0.10/34 = 0.003 for forest and P(crit.) = 0.10/13 = 0.008 for farmland. This test was conducted separately on all species observed at ≥ 3 transects. Correlations between distance from road and other independent variables were tested for, and not found (n = 254-304, r = -0.11-0.08, P = 0.07-0.96). Differences in abundance of birds (all species combined) and number of bird species among 100-m intervals were tested with one-way ANOVA (2-tailed). In the latter analysis, only the five intervals most proximate to the road was used, for reasons of sample size.

Results

Test of lower bird abundance in the effect zone

Among the five focal forest species, lower densities within the effect zone could be proven only for great spotted woodpecker and goldcrest (Table 1). Significantly lower density could not be established for any of the other 26 testable species. However, there was a tendency for such in song thrush (*Turdus philomelos*), willow tit (*Parus montanus*), crested tit (*Parus cristatus*), crossbill (*Loxia spp.*), and bullfinch (*Pyrrhula pyrrhula*). All three farmland focal species occurred at lower density within the effect zone (Table 2), and of the other nine testable species, hooded crow (*Corvus corone*), starling (*Sturnus vulgaris*), and reed bunting (*Emberiza schoeniclus*) showed a tendency for lower density. When all species were pooled, only in farmland, and only during one of the two visits, a significantly lower bird density was noted within the effect zone (Tables 1 and 2, column A).

Table 1. Bird species observed in roadside coniferous forest, number of individuals observed, and results from statistical analyses of difference in abundance relative to road proximity. Column A: test of lower bird abundance within the "effect zone" (Wilcoxon signed-rank, 1-tailed P-values). Focal species are in bold text. Column B: test of effect of distance to road, corrected for effects of habitat characteristics, traffic density, and car speed (multiple logistic regression/Wald test, 2-tailed P-values). Species are ordered following Voous (1973; 1977).

Species		# ind.	A z	A P	B P
Snipe	*Gallinago gallinago*	1			
Green sandpiper	*Tringa ochropus*	6	1.10	0.14	0.74
Woodpigeon	***Columba palumbus***	9	1.12	>0.50	0.30
Black woodpecker	*Dryocopus martius*	2			
Great spotted woodp.	***Dendrocopos major***	5	1.84	0.03*	0.04(*)
Woodlark	*Lullula arborea*	1			
Tree pipit	*Anthus trivialis*	48	0.24	0.40	0.17
Meadow pipit	*Anthus pratensis*	4	1.07	>0.50	0.17
White wagtail	*Motacilla alba*	3			0.18
Wren	*Troglodytes troglodytes*	9	0.68	0.25	0.51
Hedge sparrow	*Prunella modularis*	16	0.88	0.19	1
Robin	*Erithacus rubecula*	127	0.03	0.49	0.90
Redstart	*Phoenicurus phoenicurus*	2			
Blackbird	*Turdus merula*	27	0.02	0.49	0.76
Fieldfare	*Turdus pilaris*	6	0.97	0.16	0.52
Song thrush	*Turdus philomelos*	55	1.74	0.04(*)	0.80
Redwing	*Turdus iliacus*	15	0.14	0.44	0.96
Mistle thrush	*Turdus viscivorus*	5	0.73	>0.50	0.51
Garden warbler	*Sylvia borin*	2			
Blackcap	*Sylvia atricapilla*	3			0.44
Chiffchaff	*Phylloscopus collybita*	1			
Willow warbler	***Phylloscopus trochilus***	89	1.55	>0.50	0.01(+)
Goldcrest	***Regulus regulus***	129	2.03	0.02*	0.75
Spotted flycatcher	*Muscicapa striata*	6	0.10	0.46	0.60
Pied flycatcher	*Ficedula hypoleuca*	1			
Long-tailed tit	*Aegithalos caudatus*	2			
Willow tit	*Parus montanus*	11	1.68	0.05(*)	0.19
Crested tit	*Parus cristatus*	32	1.78	0.04(*)	0.33
Coal tit	***Parus ater***	24	0.24	0.40	0.81
Blue tit	*Parus caeruleus*	2			
Great tit	*Parus major*	41	0.77	0.22	0.01(+)
Nuthatch	*Sitta europaea*	3			0.71
Treecreeper	*Certhia familiaris*	30	0.34	0.36	0.80
Jay	*Garrulus glandarius*	7	0.36	0.36	0.83
Jackdaw	*Corvus monedula*	5	0.82	>0.50	0.15
Hooded crow	*Corvus corone*	8	1.76	>0.50	0.02(+)
Raven	*Corvus corax*	1			
Chaffinch	*Fringilla coelebs*	306	0.54	0.30	0.82
Brambling	*Fringilla montifringilla*	8	0.94	>0.50	0.91
Greenfinch	*Carduelis chloris*	19	0	0.50	0.07(+)
Goldfinch	*Carduelis carduelis*	1			
Siskin	*Carduelis spinus*	169	0.91	0.18	0.04(*)
Crossbill	*Loxia* spp.	30	1.34	0.09(*)	0.05(*)
Bullfinch	*Pyrrhula pyrrhula*	7	1.84	0.03(*)	0.05(*)
Hawfinch	*Coccothraustes coccothraustes*	1			
Yellowhammer	*Emberiza citrinella*	8	1.48	>0.50	0.01(+)
All species					
1st visit		1107	1.25	0.11	
2nd visit		928	0.27	>0.50	

*** significantly lower abundance proximate to road, (*) tendency for lower abundance proximate to road, (+) tendency for higher abundance proximate to road**

Table 2. Bird species observed in roadside farmland, number of individuals, and results from statistical analyses of difference in abundance relative to road proximity. Column A: test of lower bird abundance within the "effect zone" (Wilcoxon signed-rank, 1-tailed P-values). Focal species are in bold text. Column B: test of effect of distance to road, corrected for effects of habitat characteristics, traffic density, and car speed (multiple logistic regression/Wald test, 2-tailed P-values).

Species		# ind.	z	A P	B P
Lapwing	***Vanellus vanellus***	33	2.27	0.01*	0.01(*)
Curlew	*Numenius arquata*	8	0	0.50	0.84
Stock dove	*Columba oenas*	1			
Wood pigeon	*Columba palumbus*	3			
Skylark	***Alauda arvensis***	352	1.99	0.03*	0.58
Meadow pipit	***Anthus pratensis***	52	2.31	0.01*	0.24
Yellow wagtail	*Motacilla flava*	1			
White wagtail	*Motacilla alba*	17	1.07	0.14	0.70
Whinchat	*Saxicola rubetra*	17	0.18	0.43	0.104
Wheatear	*Oenanthe oenanthe*	3			
Fieldfare	*Turdus pilaris*	2			
Song thrush	*Turdus philomelos*	1			
Reed warbler	*Acrocephalus scirpaceus*	5			
Whitethroat	*Sylvia communis*	5	6.68	0.25	0.21
Garden warbler	*Sylvia borin*	1			
Willow warbler	*Phylloscopus trochilus*	1			
Blue tit	*Parus caeruleus*	1			
Magpie	*Pica pica*	4			0.13
Jackdaw	*Corvus monedula*	36	1.60	>0.50	0.20
Rook	*Corvus frugilegus*	2			
Hooded crow	*Corvus corone*	15	1.96	0.02(*)	0.81
Raven	*Corvus corax*	5			
Starling	*Sturnus vulgaris*	15	1.40	0.08(*)	0.57
Tree sparrow	*Passer montanus*	3			
Chaffinch	*Fringilla coelebs*	2			
Greenfinch	*Carduelis chloris*	4			
Linnet	*Acanthis cannabina*	2			
Common rosefinch	*Carpodacus erythrinus*	2			
Yellowhammer	*Emberiza citrinella*	20	0.45	0.32	0.13
Reed bunting	*Emberiza schoeniclus*	14	1.60	0.05(*)	0.12
All species					
1st visit		634		0.13	
2nd visit		526		0.02*	

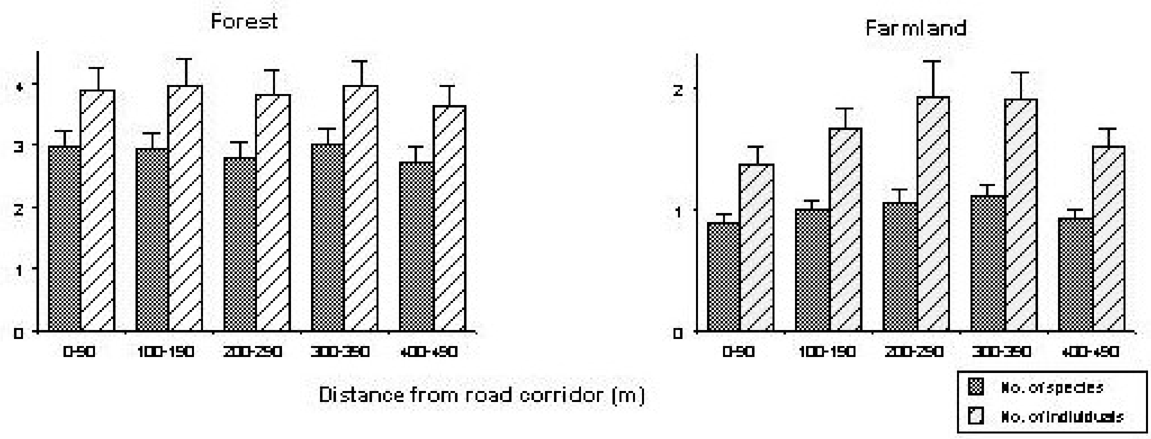
* significantly lower abundance proximate to road, (*) tendency for lower abundance proximate to road, (+) tendency for higher abundance proximate to road

Analyses for any trend in bird abundance with distance from road

No significant trend in the number of bird species or individuals (all species combined) observed in relation to distance from road corridor could be found (repeated ANOVA; forest: F = 0.42-0.55, df = 32, P = 0.70-0.79, farmland: F = 1.51-1.67, df = 42, P = 0.17-0.20). Although not significant, there was an indication of fewer species and individuals near roads in farmland (Fig. 2).

Not even at species level (when effects of habitat characteristics, traffic density, and car speed were accounted for) did our analysis reveal any general difference with distance to road (Tables 1 and 2, column B). In forest, 4 species (great spotted woodpecker, siskin *Carduelis spinus*, crossbill, and bullfinch) showed a tendency for a lower abundance proximate to the road, whereas five species (willow warbler, great tit *Parus major*, hooded crow, greenfinch *Carduelis chloris*, and yellowhammer *Emberiza citrinella*) showed the opposite tendency. In farmland, only lapwing showed a tendency for a lower abundance proximate to the road.

Fig. 2. Mean number of bird species (grey bars) and individuals (hatched bars) observed in forest and farmland adjacent to main roads in mid-Sweden, spring 1998-1999.



Discussion

The results implied that the model presented by M. Reijnen et al. (1995) may not be directly applicable under all conditions, because the predictions derived from it were only partly correct. Only in farmland a lower total abundance of birds within the effect zone could be observed, and still not consistently. Of the focal species (for which a negative effect of traffic was shown by R. Reijnen et al., 1995; 1996), all three in farmland, and two of five in forest, had a lower density in the effect zone. However, when corrected for habitat characteristics, traffic density, and car speed, the trend for lower density near the road was consistent only for two of these species (great spotted woodpecker and lapwing). Willow warbler, pointed out as one of the most sensitive forest birds by previous authors (R. Reijnen et al., 1995; Kuitunen et al., 1998), did actually show a tendency for increased abundance proximate to roads in our study.

In forest, the total abundance of birds appeared unaffected by the road. The four small passerines showing a positive tendency with proximity to roads in forest habitat (willow warbler, great tit, greenfinch, and yellowhammer) all prefer edges or areas with scattered trees and bushes, whereas the six species showing the opposite tendency (song thrush, willow tit, crested tit, siskin, crossbill, and bullfinch) are all woodland species (based on descriptions in Heinzel et al., 1974). Similarly, Ferris (1979) studied breeding birds in forest adjacent to a highway, and found no change in total numbers of birds, but a change in species composition, with edge species being more abundant within 100 m from the highway corridor. Adams and Geis (1981) presented similar results. This pattern is likely best explained by differences in forest structure close to the road corridor (R. Reijnen et al., 1995). As opposed to these results, in a comparable study Kuitunen et al. (1998) could not find forest edge species at higher density close to roads, and concluded that edge effects did not control bird densities in roadside habitats.

Obviously, we cannot exclude the possibility that roads still have general negative effects on forest birds. There may be negative effects on species other than those covered by our census method (e.g. forest grouse: Hjort, 1977; Räty, 1979). The chance of finding significant effects could be greater at higher traffic densities. Although the roads in our study were among the largest in Sweden, average traffic density was only *ca* 10,000 cars/day, which is one third of that in the studies by R. Reijnen et al. (1995; 1996). A study in Massachusetts suggested significant reduction in bird breeding only at traffic densities above 8,000 cars/day (Forman and Deblinger, 2000). Furthermore, spring bird density may not reflect habitat quality, for two reasons. First, the road-forest edge may appear attractive for some species but yet involve an elevated mortality or decreased breeding success, thus acting as an "ecological trap" (Van Horne, 1983; Reijnen and Foppen, 1994). Second, in years of high overall population size, surplus birds may accumulate in marginal habitats (e.g. Van Horne, 1983; Reijnen and Foppen, 1995). The years of the present study could however not be characterized as years of particularly high population size of any of the forest species in question (Svensson, 2000). Nevertheless, the method we used could underestimate the reduction in habitat quality for some species.

Conclusions

Our results suggest that caution is needed when applying the road effect zone model presented by M. Reijnen et al. (1995) under conditions different from those the model was developed for. It is likely that habitat edge effects introduced by road construction may override the adverse effects of traffic noise on adjacent bird populations and lead to increased or decreased width of the road effect zone. Whether edge effects cause enrichment or deprivation of bird communities near roads may also depend on the type of landscape or habitat surrounding the road. In woodland, open grassy road verges may introduce more diversity into surrounding habitat than it would do in an open landscape, in addition to the larger subdue of the traffic noise. In a forested landscape, like that in boreal Sweden, busy roads could be localized to woodland areas (as long as it does not violate other conservation concerns). In an open landscape on the other hand, fragmentation effects of roads may be less important.
Irrespective of the surrounding habitat, mitigation measures may be taken to further increase the positive components of the habitat changes. These measures could include allowing development of natural vegetation (Bennett, 1991; Warner, 1992), or construction of other elements in short supply in the surrounding landscape (e.g. Roach and Kirkpatrick, 1985).

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