Biological Conservation 164 (2013) 22–29

Contents lists available at SciVerse ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

The habitat-specific effects of highway proximity on ground-dwelling arthropods: Implications for biodiversity conservation

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ARTICLE INFO

Article history:
Received 22 September 2012
Received in revised form 8 April 2013
Accepted 15 April 2013

Keywords:
Dispersal corridor
Edge effect
Habitat fragmentation
Migration barrier
Road ecology
Roadside verges

ABSTRACT

The total length of highways worldwide has increased continuously over recent decades. Highways and their roadside verges may substantially affect species dispersal, and the ecological effects of highways often extend to neighbouring areas. This study investigated the effects of highways on assemblages of ground-dwelling arthropods in neighbouring forest and open habitats. In total, 24 sites within five highway segments situated in the Czech Republic were sampled using transects of pitfall traps placed at increasing distances (0, 50 and 100 m) from the edge of highway verges. The total catch size and species richness of ground-dwelling spiders and beetles varied more strongly with distance from the highway edge in forest habitats than in open habitats. Species composition of both spiders and beetles was significantly affected by distance from the highway edge in open habitats as well as in forest habitats. In general, the species richness of forest specialist beetles (but not of spiders) was negatively affected by highway proximity in forested sites, whereas habitat generalists and open habitat specialists (both spiders and beetles) benefited from proximity to a highway in both forest and open habitats. Our results indicate that highway verges may potentially enhance local assemblages of ground dwelling spiders and beetles because they provide suitable sites (in intensively managed open landscapes) or dispersal corridors (in forested landscapes) for habitat generalists and open habitat specialist species. However, negative effects on forest specialists must also be considered, especially in landscapes with little forest. The landscape context should be given substantial consideration in future decisions about highway location because possible threats to forest specialists and benefits for other species must be recognised and balanced.

1. Introduction

The total length of paved roads and highways worldwide has increased continuously over recent decades to satisfy the increasing demands of society for transportation and additional highways will be needed in the future (Forman et al., 2003). For example, the current highway network in the Czech Republic is 1192 km long and the construction of an additional 988 km is planned by the year 2030 (Czech Motorways, 2012). In the European Union (EU-27), the total length of highways increased from 41,885 km in 1990 to 66,700 km in 2008 (Eurostat, 2011). As a result, paved roads and highways have become important landscape features and have recently merited the attention of ecologists and nature conservationists, and a specialised scientific field termed "road ecology" has been established (Coffin, 2007; Fahrig and Rytwinski, 2009; Forman et al., 2003; Jackson and Fahrig, 2011; Koivula and Vermeulen, 2005; Trombulak and Frissell, 2000).

The negative effects of roads on certain groups of organisms are well known (Balkenhol and Waits, 2009; Coffin, 2007; Trombulak and Frissell, 2000). Organisms can be directly threatened by road construction, which completely destroys or seriously alters their habitats (Trombulak and Frissell, 2000). Mobile animals suffer from collisions with vehicles (Neumann et al., 2012). Roads present substantial barriers to the movement of many animal species (Clark et al., 2010; Koivula and Vermeulen, 2005), including

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http://dx.doi.org/10.1016/j.biocon.2013.04.012

invertebrates, and such barriers may limit gene flow and reduce effective population sizes (Balkenhol and Waits, 2009; Holderegger and Di Giulio, 2010). At the same time, roads can serve as corridors that enhance the dispersal of invasive species (Joly et al., 2011; Kalwij et al., 2008). Traffic and management actions (e.g., road salting in winter) can substantially affect the chemical and physical environmental characteristics of adjacent habitats, and these changes can be harmful to sensitive organisms (Coffin, 2007).

On the other hand, roadside verges may also represent areas of high conservation value for insects (Noordijk et al., 2008; Ries et al., 2001; Saarinen et al., 2005). These areas may be especially important in intensively managed agricultural landscapes, where natural and semi-natural habitats have become rare (Hopwood, 2008). Thus, if properly managed, verges can serve as dispersal corridors not only for invasive species but also for native and endangered species (Noordijk et al., 2011; Ries et al., 2001; Vermeulen and Opdam, 1995).

To date, most studies investigating the ecological effects of roads on arthropods have focused on individual species, whereas effects on the characteristics of entire assemblages (e.g., total abundance, species richness and species composition) have rarely been studied (Coffin, 2007; Fahrig and Rytwinski, 2009). There is a need for the study of ground-dwelling arthropods, focusing on the effects of highways on entire assemblages (but see Melis et al., 2010 for the effects of small roads). Ground-dwelling beetles and spiders include many species with limited dispersal abilities (unable to fly nor disperse passively by wind) and strict habitat preferences, which makes these groups potentially suitable for modelling biological responses (Koivula, 2011; Marc et al., 1999). Moreover, studies on the ecological effects of roads are usually performed in a single habitat type. This approach, however, prevents the comparison and generalisation of road effects on assemblages across habitats.

In this study, we focused on the effect of the presence of highways on assemblages of ground-dwelling spiders and beetles in neighbouring habitats, either forests or open habitats (fields or meadows). We investigated how various assemblage characteristics (total catch size, species richness and species composition) varied with distance from the highway body, and how this effect differs between forest and open habitats. Highway verges neighbouring sampled sites were typically represented by open, treeless habitat, which resulted in higher habitat contrast with bordering sites in forested landscape compare to landscape with prevailing open habitats. Consequently, the effect of highway proximity on arthropod assemblages may differ between the two habitat types. Moreover, species could vary in their response on highway proximity in dependence on their habitat specialisation. We therefore separately analysed diversity and abundance patterns within groups of species specialised on particular habitat types (open habitat specialists, habitat generalists and forest specialists).

In particular, we hypothesise that (1) in forests, forest specialists will increase and open habitat specialists will decrease in abundance further from highway whereas in open habitats abundance of both groups will be relatively unaffected by distance from highway; (2) total species richness will increase in highway proximity in both habitat types, but from different reasons. In open habitats, highway verges will serve as refuges for species avoiding intensively managed arable fields and meadows. In forests, open habitat specialists inhabiting highway verge will penetrate into neighbouring forest site, resulting in enhanced species richness closer to highway. To our knowledge, this is the first study investigating such effects on ground-dwelling arthropods in two contrasting habitat types at the same time.

2. Materials and methods

2.1. Data collection

The study was conducted between 2005 and 2008. Five highway segments (Fig. 1) that varied in age (time since highway construction) and climatic conditions were selected (for details see Supplementary material Table A1). Five sampling sites representing the most common habitat types for particular segments were chosen within each highway segment, except for the D11 highway, where only four sites could be sampled. Two sites (only one in case of D11) represented open habitats (typically arable fields and managed meadows), and three represented forest habitats. Forest sites varied in tree species composition (see Table A1). Individual sites were selected to maximise the homogeneity in vegetation cover within area of at least 0.16 km^2 (400×400 m) in order to minimise possible effects of surrounding landscape on sampled assemblages of ground-dwelling arthropods. Within each of the 24 sites, ground-dwelling arthropods were sampled using pitfall traps at three distances (0, 50 and 100 m) from the edge of the highway body (Fig. 1). Traps closest to the highway (distance 0 m) were placed at the boundary between the highway verge and neighbouring habitat, which was ca. 10–30 m away from the asphalt edge. At each distance, a line of three traps spaced 50 m apart was placed parallel to the highway body.

The pitfall traps used in the study were 0.5 l transparent plastic cups (round opening, 8.5 cm in diameter) filled with a 50% aqueous solution of ethylene glycol as a preservative fluid. The traps were covered by a non-transparent plastic roof to protect the trap contents against flooding, and the roof was covered with branches to protect the traps against destruction by large mammals, e.g., roe deer (*Capreolus capreolus* L.) and wild boar (*Sus scrofa* L.). The traps were operated from early May to September, and samples were collected monthly. Sampling over such a long period should account for species-specific seasonal variation in abundance and result in most species to be trapped. However, it is important to note that pitfall traps are not able to record all ground-dwelling species occurring at the site and their efficiency could depend on the trap design (Knapp and Růžička, 2012; Koivula, 2011; Riecken, 1999).

In the laboratory, the pitfall samples were sorted and spiders (Araneae), ground beetles (Coleoptera: Carabidae) and large rove beetles (Coleoptera: Staphylinidae: Staphylinina) were identified to species. Juvenile specimens of spiders were excluded from the dataset because the majority of these juveniles were impossible to identify to species. The nomenclature of spiders follows that of Platnick (2012), of ground beetles that of Löbl and Smetana (2003) and of large rove beetles that of Löbl and Smetana (2004). Voucher specimens of spiders were deposited in the collection of the National Museum, Prague. Those of beetles were deposited partly in the collection of the North Bohemian Museum, Liberec, and partly in the private collections of P. Moravec (Litoměřice) and P. Vonička (Liberec).

The species were classified by their habitat preferences based on the existing literature from the area of the study (Buchar and Růžička, 2002; Hůrka, 1996; Smetana, 1958). The referred literature contain list of habitats where each species commonly occurs. Species commonly occurring only in forest habitats were classified as forest specialists, species commonly occurring only in open habitats were classified as open habitat specialists and species that do not show clear preference, i.e. commonly occurring in both open and forest habitats were classified as habitat generalists. For the list of all species sampled in the present study, including their habitat classification, see Supplementary material Tables A2 and A3.