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Does the effect of forest roads extend a few meters or more into the adjacent forest? A study on understory plant diversity in managed oak stands

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ABSTRACT

Roads are recognised as having different ecological roles such as barrier, corridor or habitat, but the spatial extent of road effects on plant communities in forests remains unclear. We studied the effect of forest road distance on plant understory diversity at 20 sites in young and adult oak stands in a French lowland forest with a long history of management and road construction. All vascular and bryophyte species were collected at five distances ranging from the road verge to 100 m into the adjacent forest stand. We analysed species composition, individual species response, a priori life-history traits response – life form, habitat preference and dispersal mode – and environmental indicator values in relation to road distance and stand age. Plant composition strongly differed between road verge and forest interior habitats. The main road effect extended less than 5 m into the forest stand. A third habitat was detected at the forest-road edge resulting from the road effect on light and soil conditions, and from edge-specific topography. Non-forest species were almost absent from the forest interior. In contrast, many bryophytes and several vascular plants kept away from the road. We identified a posteriori six species groups that better explained the variability of plant response profiles than a priori life-history traits. Plant response to road distance was also dependent on stand age: some species colonised from the road into the forest interior in young stands following regeneration cutting, while other species displayed the reverse pattern in adult stands once canopy closed above the forest road. Even if the depth of forest road effect measured in lowland managed stands was narrow, building of a new forest road has non-negligible effects on plant population dynamics. Forest managers should take into account the impacts of roads on biodiversity, since the expected intensification of silviculture in response to global changes is set to accentuate the effect of forest roads. We recommend further study on the role of dispersal by vehicles (i.e. agestochory) in road effects.

1. Introduction

Road density and road use have continued to increase over the last few decades (see UNEP-DEWA-GRID-Europe, 2007). This increase has also been observed in managed forests in France, where roads have long served for timber harvesting and silvicultural management. Indeed, forest surface area 500 m away from logging roads declined by 5% between 1985 and 1998 (according to French National Forest Inventory figures). Roads are liable to have multiple impacts on animals, plants and ecosystem functioning, and are now being recognised as important landscape elements (Spellerberg, 1998; Trombulak and Frissell, 2000; Forman et al., 2003). Roads change forest spatial patterns by slicing the forest into pieces (Reed et al., 1996; Tinker et al., 1998), but they also establish new habitats within the forest matrix.

The impact of forest roads on plant biodiversity has generally been studied in the immediate proximity of the road (Ullmann et al., 1998; Parendes and Jones, 2000; Mullen et al., 2003; Pauchard and Alaback, 2006), but few studies have investigated road effect further into the adjacent stand (Honu and Gibson, 2006; Belinchon et al., 2007), with 150 m being the maximum distance studied (Watkins et al., 2003; Hansen and Clevenger, 2005). However, even if road effect mainly occurs within the first few meters, it can also extend further for some species. Moreover, research has mainly focused on exotic or invasive plants (Parendes and Jones, 2000; Pauchard and Alaback, 2004; Flory and Clay, 2006; Honu and Gibson, 2006) paying less attention to community-level response (Ullmann et al., 1998; Watkins et al., 2003). Furthermore, the majority of European forests have been managed for centuries now, meaning that the ecological effects of forest roads on plant communities have a long history, contrary to the other temperate forests studied in the references cited above

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which have a shorter management history. Consequently, there is a need to investigate road effects on the whole plant community, at large distance and in a context of long management history, which is the case of French lowland forests.

Roads can favour the introduction of exotic species from more human-affected areas into the forest, by serving as both a habitat to grow in and a conduit along which they may disperse by wind or by vehicles (Forman et al., 2003; Gelbard and Belnap, 2003). On the roadside, the high level of disturbance together with specific site conditions such as frequent mowing, soil disturbance, exposure to light, or nutrient-rich and moister soils are favourable to exotic species (Parendes and Jones, 2000; Watkins et al., 2003; Flory and Clay, 2006) but also non-forest species (sensu Honnay et al., 2002). Forest roads could also provide a substitute habitat for disturbance-tolerant forest species that would take refuge near the road after canopy closure in the forest stand forces them out.

Conversely, since environmental conditions near the roadside are unsuitable for the presence of certain species, thus keeping them away, roads can act as a dispersal filter. When considering edge effects, the spatial influence of roads is often wider than their actual area implies (Reed et al., 1996; Forman, 2000; Watkins et al., 2003). Hence, roads do not just disrupt continuous habitats but can also drastically reduce patch size and core area. This can lead to a change in community composition by removing less competitive species or species that are dependent on particular interior habitat conditions (Belinchon et al., 2007). Habitat fragmentation can also lead to the reduction of genetic variation of forest plant species (Van Rossum et al., 2002).

Furthermore, the physiognomy of the edge can influence the edge effect (Cadenasso and Pickett, 2001). The road edges of most managed lowland forests in France have a specific topographic profile, with an earth embankment arising from road ditch management. This specific edge topography can also shape the edge effect on plant communities: in particular, some bryophytes can be favoured by the persistence of bareground. Consequently, it is important to take into account the life-history traits of species in the response of plant communities.

Disturbance and environmental conditions change along the forest cycle. In the early stages of regeneration, non-forest species are favoured by previous canopy removal and soil disturbances (Brunet et al., 1996; Gondard and Deconchat, 2003; Bergès, 2004). Considering the road as a permanent source of non-forest or forest-edge species, there could be a long-term cumulative effect of periodic cuttings on the penetration of these species into forest stands. This could lead to a shift in forest plant communities and a decline in forest species. However, the penetration of non-forest species into stands can be strongly limited by canopy closure after stand regeneration: while many non-forest species have a persistent seed bank, the long phase of canopy closure specific to current oak silvicultural treatment can deplete the seed bank (Van Calster et al., 2008). Disturbance and environmental factors can also change on the road verge. Taken together, these facts suggest that plant response patterns to road distance can vary with stand age, as recently tested by Flory and Clay (2006).

This study aimed to quantify the effect of distance to gravelled roads – the dominant road type in French state forests – on plant diversity in a managed, lowland deciduous forest of two successional ages. Our study case was Montargis forest, which has a well-documented history of forest management stretching back to 1670. We specifically addressed the following two questions:

(1) Does road effect penetrate far into the forest interior or simply result in a shift at the road-forest edge, and how many habitats can be identified along the road-forest gradient?
(2) Is road effect dependent on stand age?

2. Materials and methods

2.1. Study sites

Our study area was located in the ancient state forest of Montargis (48°01′N, 2°48′E, Loiret, France) managed by the French National Forestry Office (ONF). It covers 4090 ha and altitude ranges from 95 to 132 m. The climate is oceanic with a weak continental influence, mean annual precipitation is 650 mm, and mean annual temperature is 10.9 °C. Forest management was historically coppice-with-standards with sessile oak (*Quercus petraea* Liebl.) as standards and hornbeam (*Carpinus betulus* L.) as coppice, until 1857 when a conversion was initiated into an even-aged high forest system. Our sample sites were mainly located in even-aged high forest stands derived from natural regeneration, and some were under coppice-with-standards still in conversion. Nevertheless, all stands showed a very similar aspect and composition, with dominant sessile oak mixed with hornbeam and beech (*Fagus sylvatica* L.). Sample sites were selected on homogeneous soil conditions. Soils were luvisol according to FAO classification (IUSS-Working-Group-WRB, 2006), with a variable depth of high clay content. All forest stands selected were bordered by gravelled roads closed to public traffic and only used for stand management and recreational activities such as hunting. Road width averaged 12.1 ± 1.2 m. These roads were managed with some limestone amendments when the native gravel (flint) was not sufficient, plus more or less frequent clearings of vegetation from the road verge to the top of the adjacent earth embankment (referred to hereafter as "embankment", see Fig. 1). In addition, there has been moderate to severe soil disturbance and compaction on road verges every 6–12 years during thinning and every 200 years during regeneration phase.

2.2. Sampling design and data collection

We sampled 20 oak sites from June to the beginning of August 2007 using the ONF forest management map. Even-aged high forests were classified as "young stands" if they had an average age of 20 ($n = 5$) to 40 ($n = 6$) years. Both coppices-with-standards in conversion ($n = 4$) and even-aged high forests at least 90 years old ($n = 5$) were classified as "adult stands". At each site, a transect was set up perpendicular to the road, and extended from the roadside to 100 m into the forest interior (see Fig. 1), a distance rarely investigated. Distance was measured from the top of embankment. We selected transect location in order to avoid confounding relationships such as multiple edge effects. Managed forests are entirely gridded by forest roads, leading to the reduction of stand size and thus the potential area for setting up transects. More precisely, transects were set up at least 300 m away from forest/non-forest boundary, and at least 150 m away from any contrasted intra-forest edges ("hard" edges), i.e. edges with clearings, clearcuts and other roads. In addition, transects were kept at least 60 m away from non-contrasted intra-forest edges, i.e. boundaries sharing similar stand type but separated by a narrow dirt road. Likewise, the type of stand at the opposite side of the road had to be similar to the sampled site. Finally, we also controlled for homogeneous stand conditions and soil type within a 60 m buffer zone surrounding the transect.

Along each of the 20 transects, we established 2 m × 50 m plots parallel to the road at five locations: on the road verge, at the top of the embankment, and at 5, 30 and 100 m (Fig. 1). In contrast with previous published studies that used an almost continuous sampling scheme (Watkins et al., 2003; Honu and Gibson, 2006), we only sampled 5 selected distances in order to determine whether the road effect penetrated far into the forest interior (30 and 100 m) or stopped just after the edge (5 m). At each of these