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Effects of forest roads on oak trees via cervid habitat use and browsing

Karen Marie Mathisen[a,*], Adam Wójcicki[b], Zbigniew Borowski[b]

[a] Inland Norway University of Applied Sciences, Faculty of Applied Ecology and Agricultural Sciences, Department of Forestry and Wildlife Management, Postboks 400, 2418 Elverum, Norway

[b] Department of Forest Ecology, Forest Research Institute, Braci Leśnej Str. 3, Sękocin Stary, 05-090 Raszyn, Poland

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ABSTRACT

Roads can affect animals in several ways, by affecting movement, space use, foraging behavior and mortality. As roads often have a negative effect on populations of birds and mammals, their effects are important for wildlife management. However, the effect of roads differ between different types of roads, and most studies of road ecology have focused on major roads with high traffic intensity, whilst effects of smaller unpaved forest roads in northern ecosystems are less known. We investigated the effects of forest roads in a mixed conifer forest in central Europe on cervid habitat use and browsing impact on forest regeneration during the winter season. We found that hunted cervid species avoided forest roads, and that browsing pressure was higher within the core of forest areas rather than close to roads. This led to an increased density of undamaged trees (by browsing) close to forest roads, whilst browsing damages were relatively high in the interior. Hunters often use these forest roads in the hunting season. We suggest that human disturbance creates corridors of fear along forest roads, and that cervids alter their habitat and browse use to avoid humans. This in turn has implications for forest and cervid management. This is the first study to document that gravel roads can affect oak trees through modifying cervid behavior. Future studies should use experiments to explore this question further and separate different effects of forest roads to understand the mechanisms; edge effects on vegetation, traffic, effects on natural predators and human disturbance.

1. Introduction

Roads can affect animals in numerous ways. Roads lead to fragmentation of habitat, and major roads can create movement barriers (Bartzke et al., 2015). Major roads can also cause direct mortality by traffic accidents, as well as indirect effects through creating disturbance and affecting animal behavior (Leblond et al., 2013). On the other hand, roads can also increase movement by facilitating more energy-efficient travel and access to new areas (Bruggeman et al., 2007). The effect of roads is important for wildlife conservation, as both birds and mammals often show either avoidance or reduced population density close to human infrastructure and roads (Fahrig and Rytwinski, 2009; Benitez-Lopez et al., 2010). Especially densities of hunted wildlife species are often negatively related to the density of roads, or positively with the distance to roads (Coffin, 2007). The effect of roads varies with road type and traffic intensity, and avoidance of roads by large mammals generally increases with increasing disturbance intensity (road width, traffic density, human disturbance) (Eldegard et al., 2012; Leblond et al., 2013; D'Amico et al., 2016). However, roads with low traffic intensity may also influence animal behavior (Ciuti et al., 2012; D'Amico et al., 2016). The majority of studies on the effects of roads on wildlife have focused on roads with high traffic intensity, traffic accidents and barrier effects. The effect of forest gravel roads with low traffic intensity on ungulates is less known.

The road edge environment may differ from the surroundings, as roads create gaps in forested environments, increasing light and nutrient availability and creating soil disturbance, which can lead to changes in the vegetation (Coffin, 2007). These edge effects on vegetation can also affect herbivores in different ways which may have cascading effects on vegetation, potentially important for forest management (Cadenasso and Picett, 2000). The effect on the road-edge environment is different among road types and road surfaces, as high traffic levels on paved roads may cause local pollution, but on gravel or dirt roads, dust may spread from the road onto the vegetation nearby. Several studies have investigated effects of logging roads in tropical forest, particularly in the Amazon, which increase human access to forest areas (including effects of disturbance but also poaching) see review in Coffin (2007). Few studies have been carried out on forest roads in northern and temperate forests.

Changes in ungulate habitat selection and movement, or changes in

* Corresponding author.
E-mail addresses: karen.mathisen@inn.no (M. Karen Marie), WojcickA@ibles.waw.pl (W. Adam), Z.Borowski@ibles.waw.pl (B. Zbigniew).

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roadside vegetation, may in turn have both positive and negative effects on ungulate browsing, and affect browsing damage on commercial forests. Aggregations of moose (*Alces alces*) due to barrier effects of major roads on migration, led to increased moose browsing on pine within 3 km from major highways (Ball and Dahlgren, 2002). Moose have also been observed to avoid major roads with high traffic intensity, and select for browse far from the road (Eldegard et al., 2012). However, according to our knowledge, how forest roads with low traffic intensity affect ungulate browsing, is unknown.

Roads affect predation risk from hunters and natural predators, which often use roads for transport and access to new areas (Coffin, 2007; Lone et al., 2014; Zimmermann et al., 2014). However, if natural predators also tend to avoid roads, prey may benefit from predator free areas close to human disturbance (Berger, 2007; Muhly et al., 2011). The effects of roads on predation risk may also differ with disturbance intensity. Large predators may avoid roads with high traffic intensity (Muhly et al., 2011), but are known to use forest roads with low human disturbance for travel and scent marking (Barja et al., 2004; Zimmermann et al., 2014). As forest roads can be used by both hunters and natural predators, the risk of encountering a predator is higher close to forest roads, and roads may affect ungulates indirectly by creating a "landscape of fear" (Brown et al., 1999) in the near vicinity of roads. The presence of predators may affect ungulate browsing on plants either through density-mediated effects (McLaren and Peterson, 1994; Beyer et al., 2007), or by indirect non-lethal effects. Predators can affect ungulate spatio-temporal distribution, by avoiding risky habitats or risky periods (Edwards, 1983; Fortin et al., 2005; Lone et al., 2017). Predators may change ungulate behavior, such as increased vigilance or increased group size (Laundre et al., 2001). Earlier studies have shown that group vigilance in elk increased close to roads, with reduced foraging time (shorter feeding bouts, less total time feeding) (Ciuti et al., 2012). Both avoidance of high risk areas and behavioral changes can mediate browsing pressure on plants growing in these areas (Ripple et al., 2001). The effects of predators on prey behavior may also change with vegetation type, as predation risk from humans may be higher in open landscapes, whilst predation risk from lynx is higher in dense understory (Ciuti et al., 2012; Lone et al., 2014).

On the other hand, roads may be attractive habitats for wildlife. In road-edge habitats, increased light availability, disturbance and nutrients, may favor growth of early successional, fast-growing plants, usually preferred by herbivores (Price, 1991; Månsson et al., 2009). Management of road-edge vegetation may also affect browse availability and palatability (Rea et al., 2010). However, spreading of dust from gravel roads may render plants less palatable (Forman and Alexander (1998); Ndibalema et al., 2008). In addition, herbivores may also use roads for the ease of transport, similar to predators. In areas with snow where roads are plowed during wintertime, animals may prefer to travel on roads (Bruggeman et al., 2007). Use of forest roads may therefore represent a trade –off for ungulates, between the risk of encountering predators or vehicles, and the benefits of foraging on edge vegetation and efficient travelling (Eldegard et al., 2012). If predation is temporally predictable, e.g., human hunters are usually active in the daytime, this trade-off can be solved by temporal allocation of use of roads. A study of roe deer in France showed that roe deer use of open habitats increased with distance to roads and during the night, whilst use of forest increased during daytime, most likely to avoid humans (Bonnot et al., 2013).

This study focuses on the effects of unpaved forest roads with low traffic intensity on cervid habitat use and browsing in Central Europe, to our knowledge, an area previously little investigated. We studied the effect of distance to forest roads at a small spatial scale (20–400 m) on cervid habitat use and browsing impact during winter in a commercial mixed conifer forest dominated by Scots pine (*Pinus sylvestris*) and oak (*Quercus robur*) in North-East Poland, where roe deer, red deer and moose are present. In this area, humans are the most important predator; hence, we expect that cervids would avoid forest roads during the hunting season. We also expected that avoidance of forest roads would lead to reduced browsing pressure on the vegetation near forest roads, with impacts for commercial forestry. In Poland, roe deer and red deer are hunted, whilst moose is a protected species, hence roe and red deer would be expected to avoid roads more than moose. In addition, cervids have to handle the trade-off between being vigilant and foraging. In habitats with high forage availability, we expect less avoidance of roads than in habitats with low forage availability, where the cost of avoiding roads is less in terms of missed foraging opportunities.

We therefore predict that:

1. Habitat use by cervids will increase with increasing distance from forest roads.
2. Hunted species (roe deer and red deer) show stronger avoidance of roads than non-hunted species (moose).
3. Avoidance of roads will be strongest in habitats with low forage availability.
4. Browsing pressure will increase far from road.
5. Density of commercial trees undamaged by browsing will decrease with increasing distance to forest roads.

2. Materials and methods

2.1. Study area

The study was carried out in the state forest district of Czarna Białostocka with an estimated area of 26 066 ha in northeastern Poland (from 53°13′ to 53°43′ N and from 22°56′ to 23°44′ E). This forest district is part of a larger forest complex called the Knyszyńska Forest (62 319 ha) which is located near the Polish-Belarussian border. The forest stand is dominated by Scots pine (up to 50% cover) and oak (up to 20%), the average age of the forest is 64 years. Other major species include birch (*Betula* spp.), Norway spruce (*Picea abies*), alder (*Alnus* spp.), hornbeam (*Carpinus betulus*), larch (*Larix* spp.), ash (*Fraxinus excelsior*) and maple (*Acer* spp.). Most tree stands of the forest district were regenerated by planting. The region is characterized with a continental climate. The coldest month is January with average temperature −3.4 °C and the warmest month is July with average temperature 17.2 °C. The average number of days with snow cover between December and March between years 2014 and 2017 is approximately 51, but average snow depth rarely exceeds 16 cm. The growing season lasts 122 days, starting in May and ending in September. The area is flat, and its elevation ranges between 125 and 157 m.a.s.l. Seasons were defined based on phenological patterns as follows: spring 16 March-15 June, summer 16 June-15 September, autumn 16 September-15 December, winter 16 December-15 March.

There were three deer species present in the study area: red deer (3 ind./km^2), roe deer (5.8 ind./km^2) and moose (1 ind./km^2). Density of deer populations were estimated based on drive counts (Borkowski et al., 2011) by hunting associations and foresters in the study area. Previous tracking studies in the area showed that wolves were present at low densities (1–5 individuals) in the area, but lynx were not (Borowik and Schmidt, 2013). Human hunting pressure therefore represented the largest predation risk for ungulates in this area. The hunting season for red deer stags starts 21. August, whilst for hinds and calves it starts at 1.October. For stags and calves, the hunting season ends the last day in February, but for hinds the end of the hunting season is 15 January. For roe deer, the hunting season is similar to red deer for females and calves, but the hunting season for bucks is 11 May–30 August. For red deer, the hunting quota in the area during the winter 2015–2016 was for 231 animals, and 62% were shot. For roe deer, the hunting quota was for 449 animals, and 85% were shot. During the hunting season 2015–2016, 144 red deer and 380 roe deer were registered shot in the study area. Red and roe deer are hunted individually, usually from high seats or hunting towers, for a few hours at dawn and dusk. Hunters use forest roads and paths for transport, and