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Land use affects dung beetle communities and their ecosystem service in forests and grasslands

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ABSTRACT

Dung beetles (Scarabaeidae) are common detritivores, and especially the tunnelling genera *Geotrupes*, *Anoplotrupes* and *Onthophagus* enhance the soil quality and support nutrient cycles by rapid burial of mammalian dung. These functionally important beetles are faced with a wide range of anthropogenic disturbances and changes in environmental conditions due to land use. We thus conducted quantitative surveys of the abundance (converted to total biomass) of dung beetles and their dung removal rates (g per two days) in 150 forest and 150 grassland sites with varying land-use intensity, located in north-east, central and south-west Germany. We used dung from livestock (cow, sheep, horse) and game animals (wild boar, red deer and fox) to provide a characteristic spectrum of dung resources on each site. Most dung beetle species showed habitat preferences: *Anoplotrupes*, *Typhaeus* and several *Aphodius* species almost exclusively occurred in forests, while most *Onthophagus* individuals were found in grasslands. In total we collected 18780 individuals from 33 species. The average dung beetle biomass was 36 times higher in forests than in grasslands, and their effective dung removal rate was 3 times increased. The beetles' total biomass was strongly correlated to their removal rates. In forests, the amount of wood harvesting significantly reduced dung removal rates by 20%, and mowing frequency (−7%) and fertilisation (−4%) had a significant negative effect in grasslands. Dung removal by beetles increased with grazing intensity (+6%), however, and was higher in non-native coniferous forests (+22%). Overall, our study demonstrates negative effects of habitat conversion from forest to grassland, and negative effects of land-use intensity within forests and grasslands on dung beetle activities.

1. Introduction

Fossil evidence suggests that dung beetles exist since the Mesozoic Era (Late Jurassic − Early Cretaceous) thus demonstrating that the usage of dung became an efficient strategy of resource acquisition in a very early stage of fauna evolution (Chin and Gill, 1996; Davis et al., 2002; Nikolajev and Dong, 2010). Furthermore the nearly cosmopolitan superfamily of Scarabaeoidea are the only known invertebrates that store fecal material in tunnels (Vander Wall, 1990).

Despite choosing an unpredictable and patchy occurring resource, dung consumption grants sufficient nutrients for adults and beetle larvae (Philips, 2011). Because of their tunnelling behavior, dung beetles increase the input of nutrients into the soil, benefit the vegetation (Nichols et al., 2008; Wu et al., 2011) and minimize potential breeding grounds of (pathogenic) pests (Fincher, 1973; Ridsdill-Smith and Edwards, 2011). Dung pads would remain much longer without dung beetle activity (Walters, 2008), preventing growth of vegetation and therefore may result in wasted pastures up to two years (Anderson et al., 1984). Additionally burial of dung causes soil aeration and access for water (Bornemissza, 1960; Bang et al., 2005), and it decreases soil compaction (Manning et al., 2016).

Although dung beetles are considered as generalists regarding their resources, various reactions towards their preference for dung types have been shown (Hanski and Cambefort, 1991). Whether it depends on the "host animals" diet (carnivore, herbivore, omnivore) (Halffter and Matthews, 1966; Whipple and Hoback, 2012), nutrients (Whipple and Hoback, 2012), odour intensity (Scholtz et al., 2009) or differences in volatile organic compounds (Schmitt et al., 2004; Dormont et al., 2007) − dung beetles are attracted to a wide range of different dung types, but in variable numbers (Whipple and Hoback, 2012).

In spite of their ubiquitous presence, several dung beetle species are habitat-specific, and forests and grassland communities differ substantially (Roslin and Viljanen, 2011). The beetles' sensitivity to disturbances varies across species, rendering dung beetles as suitable

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biological indicators often considered in monitoring programs, supported by the fact that their sampling is very simple and efficient (Scholtz et al., 2009). Several authors surveyed the diversity of dung beetles in response to land use in tropical ecosystems, where they show their highest diversity in forests and savannas (Hanski and Cambefort, 1991; Estrada and Coates-Estrada, 2002; Feer and Hingrat, 2005; Hanski et al., 2007; Nichols et al., 2007; Barragan et al., 2011). In Europe, anthropogenic influences on the diversity and occurrence of dung beetles have also been monitored (Martín-Piera and Lobo, 1995; Hutton and Giller, 2003; Spector, 2006; Zamora et al., 2007), highlighting changes for certain regions and habitats, such as grasslands and shrubs versus planted forests (Romero-Alcaraz and Avila, 2000; Tocco et al., 2013). However, management activities are particularly diverse in European cultural landscapes, including different silvicultural management types, farm types (conventional versus organic), production systems (cropland, grassland, fertilisation and livestock) and socio-economic conditions (Reidsma et al., 2006). Apart from a differentiation in the type of land use, their quantitative intensities are strongly variable (Herzog et al., 2006). Reviews at the global scale (Newbold et al., 2015) thus highlighted the importance of local-scale studies for suitable characterisation and projection of land use on (local) biodiversity and ecosystem services (Allan et al., 2015; Soliveres et al., 2016). In our study, we thus focused on such local effects of continuous land-use intensity gradients in forests and in grasslands on dung beetle abundance and ecosystem functioning. In addition to land-use gradients within forests or grasslands, we explicitly compared forest versus grassland, representing the two most common habitat types apart from arable fields and reflecting the historical habitat conversion from unmanaged or managed forest, originally covering vast parts of Central Europe, to cultivated grassland. In particular, we assessed (a) the abundance (biomass) of dung beetles, which are potentially involved in removal of various types of dung, and (b) the dung removal rate by these beetles within their habitats. Our goal was to quantify (1) how forests and grasslands differ in dung beetle biomass and their removal activities, (2) how habitat-specific, gradual variation in land-use intensity affects these beetles and their removal rates and (3) to understand which components of land use are responsible for this variation.

2. Material and methods

2.1. Study site

We conducted our study within the framework of the Biodiversity Exploratories project, comprising a large number of representative forest and grassland sites in three regions (north-east, central and south-west Germany) (Fischer et al., 2010). These sites varied continuously in land-use intensity, which was quantified based on farmer interviews and forest surveys. The three regions are: (1) Biosphere Reserve Schorfheide-Chorin (SCH; in North-East Germany, ~13.000 km², 3–140 m a.s.l., 13°23′27″–14°08′53″ E/52°47′25″–53°13′26″ N), (2) Hainich National Park and surroundings (HAI; in Central Germany, ~13.000 km², 285–550 m a.s.l., 10°10′24″–10°46′45″ E/50°56′14″–51°22′43″ N) and (3) Biosphere Reserve Schwäbische Alb (ALB; in South-West Germany, ~422 km², 460–860 m a.s.l., 09°10′49″–09°35′54″ E/48°20′28″– 48°32′02″N). Using a grid of 100 × 100 m placed over the entire area within each region, experimental plots (hereafter: sites) were chosen at random. Sites with inhomogeneous land cover or partial overlap with settlements, agricultural fields, water bodies and sites intersected by roads were discarded. In each region, 100 square-shaped sites were selected, 50 sites in forests (each 100 × 100 m) and 50 in grasslands (50 × 50 m), which are representative for the regional variation in land-use and management intensities. All sites are surrounded by a larger area of the same land use, i.e. the squares are usually only a small part of the forest or grassland with a specific management.

Our studies are based on two approaches:

- Comprehensive survey: a survey of all 300 experimental sites during summer 2014 was conducted once to maximize spatial replication.
- Intensive survey: on a subset of 54 of these sites (9 forests and 9 grasslands per region), we repeatedly surveyed the dung beetles and their activity to account for temporal variation across seasons and years. Since the comprehensive survey includes these 54 sites, we additionally used this subset from summer 2014 (a) in the analyses of temporal variation.

For the comprehensive survey we sampled the 100 sites per region in 20 days (SCH – June, HAI – July, ALB – August) (10.06.14–04.07.14; 07.07.14–01.08.14; 04.08.14–29.08.14). For the intensive survey we sampled each region (starting in SCH, followed by HAI and then ALB) for 5 days each in May 2014, December 2014, April 2015 and July 2015 (05.05.–23.05.14; 01.12.–12.12.14, 06.04.–24.04.15; 29.06.–17.07.15). Days of sampling were constrained by field permissions (weekends excluded) and logistics (9–12 sites per day).

As we did not discover any beetles in December and registered no removal at all, we excluded the December survey from further analysis and results.

In each site we monitored the dung beetle abundance and dung removal simultaneously for 48 h. To assess dung beetle abundance, we used dung-baited pitfall traps. To account for the beetles characteristic spectrum of dung resources available, we used six different dung baits consisting of three livestock and three game species, namely: cow (*Bos taurus* L., 1758), horse (*Equus caballus* L., 1758), sheep (*Ovis aries* L., 1758), red deer (*Cervus elaphus* L., 1758), wild boar (*Sus scrofa* L., 1758) and fox (*Vulpes vulpes* L., 1758). For removal rate experiments we used the same dung types (due to very low quantities of fox dung we were only able to use it for pitfall traps during the intensive survey). For both, pitfall traps and removal experiments, dung samples were collected from the same sources. Livestock dung was collected at the farm 'Oberfeld' in Darmstadt (cow and horse) and at a sheep farm in Darmstadt (sheep); all livestock animals were grazing in pastures for at least part of the day, cows were additionally provided hay. Game species dung has been collected in the wildlife park 'Alte Fasanerie' in Hanau (fox, wild boar and red deer) and at the zoo 'Opel-Zoo' in Kronberg (additional fox). Diets for the animals were as follows: cow: grazing on pasture, hay; horse and sheep: grazing on pasture; red deer: grass, hay, maize, fodder beet, lucerne pellets, apples, carrots; wild boar: pig food (Raiffeisen), bread, maize, fruit, vegetables, lucerne pellets, meat of cattle, fallow deer and red deer; fox: 60% meat (chicken, mice, rats, cattle), fruits, vegetables. Veterinarian medication (e.g. Ivermectin) can influence the treated animal's dung and is known to have negative effects on dung beetle performance (Lumaret et al., 2012; Verdu et al., 2015). According to farmers and animal keepers, however, all animals involved in this study have not faced any veterinarian treatment for several weeks before dung collection. Therefore, we do not expect adverse reactions during removal activity.

After collecting samples in a sufficient amount, the dung was prepared in a lab either by filling dung in a tea bag and transferring the bait in a freezer bag or by filling freezer bags directly with dung for removal experiments. Afterwards the freezer bags where hermetically sealed, weighed and labelled. They were stored in a freezer at −20 °C until use, in order to prevent microbial decomposition, moulding or possible dung beetle activity (if small dung beetles had been accidentally collected in the dung).

2.2. Experimental design

Pitfall traps and removal rate experiments were placed on each site. Six pitfall traps (six dung types) were placed in a transect along the site margin, and in parallel five dung samples for removal assessment on the