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Effects of logging road networks on the ecological functions of dung beetles in Peninsular Malaysia

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ABSTRACT

The loss of forest biodiversity via anthropogenic disturbance is severe in tropical countries and its consequences to ecological functions are of global concern. Selective logging is one of the main causes of tropical forest degradation, and its ecological impacts often result from the construction of road networks such as skid trails, logging roads and log yards. However, the effects of such narrow road clearings on forest-dependent species and associated ecological functions have rarely been studied. The present study therefore aimed to assess the impacts of such clearings on dung burial and secondary seed dispersal by dung beetles. The abundance of all functional guilds and the total biomass of dung beetles were drastically low at road clearings, but guild composition was only significantly different between the forest interior and log yards. Dung burial rates decreased with canopy openness, where 40% of dung remained unburied at logging roads and log yards. However, beads (seed mimics) in the dung piles were buried deeper and more frequently in log yards than the forest interior. In contrast, horizontal seed-removal distance was longer in the forest interior than at all road clearing sites. Reduced dung burial rates, and deeper but shorter, seed removal in clearings implies a negative effect of road clearings on the efficiency of secondary seed dispersal and other ecological functions of dung beetles. The imposition of limits on the number and size of logging road networks would be effective for retaining the ecological functions performed by the diverse forest-dependent species after logging.

1. Introduction

Human impacts on the diversity and composition of biological communities are most pronounced in the tropics, where human populations are growing and developing rapidly (Lewis, 2009). The conservation value of logged forests in the tropics has been highlighted in recent years, as these forests cover more area than protected forests and retain many forest-dependent species even after logging, unlike more intensive land uses such as cattle pastures and oil palm plantations (Edwards et al., 2014; Gibson et al., 2011). However, for forest specialists, the habitat quality of logged forests depends on the intensity of disturbance (Sekercioglu, 2002; Slade et al., 2011). Biodiversity is both inherently and for its contributions to ecosystem services (Reid et al., 2005), so strategies for minimizing impacts on biodiversity are essential for sustainable forest management (IUCN, 2006).

The major ecological impacts of selective logging often result from the construction of road networks such as logging roads, skid trails and log yards for extraction and transportation of timber (Gullison and Hardner, 1993; Malcolm and Ray, 2000). Canopy openings and soil compaction that result from road construction substantially alter microclimates, soil properties, drainage patterns and forest accessibility (Laurance et al., 2009; Malcolm and Ray, 2000). Typically, 6–25% of a logged area is damaged by road networks (Jackson et al., 2002; Pinard et al., 2000; Uhl and Vieira, 1989), yet most selective-logging operations in the tropics still engage in excessive road building without appropriate planning (Jackson et al., 2002; Putz et al., 2008).

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The effects of narrow clearings, often less than 10 m in width (Jackson et al., 2002; Malcolm and Ray, 2000; Pinard et al., 2000; Ziegler et al., 2007), on tropical biodiversity have rarely been quantified. Our previous study, however, demonstrated that these road networks negatively affect on dung beetle community in terms of abundance, species richness and species composition (T. Hosaka, unpublished data). Two critical questions have arisen: how narrow clearings affect the functional aspects of biological communities and how the ecological functions of these communities change in consequence.

Dung beetles (Scarabaeidae: Scarabaeinae) are both cost-effective bio-indicators in tropical biodiversity surveys (Gardner et al., 2008) and performers of important ecological functions such as nutrient cycling, bioturbation, pest control and secondary seed dispersal via aggressive moving and burying of mammalian dung piles in soil (Nichols et al., 2008). Secondary seed dispersal occurs when dung beetles move and bury dung piles and the seeds they contain beneath or away from the defecated site (Andresen and Feer, 2005). Secondary seed dispersal by dung beetles is thought to facilitate seed survival and seedling establishment by reducing seed predation, providing direct dispersal to favorable microclimates for germination and decreasing seed clumping in faeces (Nichols et al., 2008). This seems particularly important in tropical forests, where seeds of most woody plants are dispersed by frugivorous animals (Jordano, 2000), and seeds in faeces are more likely to suffer intensive seed predation by animals (often 50–100% by rodents) unless they are quickly buried by dung beetles (Andresen, 1999, 2001; Andresen and Levey, 2004; Beaune et al., 2012; Estrada and Coates-Estrada, 1991; Shepherd and Chapman, 1998).

Some studies have shown that forest disturbance leads to changes in the functional guild composition of dung beetles, specifically causing a loss of large-sized species (Edwards et al., 2014), which leads to lower dung and seed removal rates (Andresen, 2003; Braga et al., 2013; Santos-Heredia et al., 2011; Slade et al., 2011). Therefore, we anticipate that the construction of logging road networks will change the functional guild composition of dung beetles and result in a loss of large-sized species, which will make dung removal and seed dispersal less active. We thus examined whether road networks affect (1) functional aspects of dung beetle communities (i.e. total biomass, abundance and relative abundance of each functional guild) and influence (2) dung removal and secondary seed dispersal (i.e. dung removal rates, seed removal rates, seed removal distance and seed burial depth) in a tropical rainforest in Peninsular Malaysia. Our study provides the first quantitative data on seed-burial depth and horizontal seed-removal distance by dung beetles in South-East Asia.

2. Materials and methods

2.1. Study site

Our study site was in the Temengor Forest Reserve in Perak, Peninsular Malaysia (5°24′ N–5°34′ N, 101°33′ E–101°39′ E, 400–1000 m a.s.l.). The forest consists primarily of lowland and hill dipterocarp forests with some bamboo-dominated patches. The reserve is part of the 266000 ha Belum–Temengor Forest Complex, the second largest contiguous rainforest in Peninsular Malaysia (Kaur et al., 2011). Of the 148870 ha of the reserve, 9000 ha in 30 blocks have been managed by a state-owned company and selectively logged since 2001, using the Sustainable Forest Management with a moderate intensity of timber harvesting (39–55 m^3 ha^{-1}; PITC, 2010).

Fieldwork was conducted in a 200-ha part of Block 5 in August 2012, where trees had been selectively logged in 2010–2011. Logging roads (5–8 m wide) were constructed in 2009, while skid trails (4–5 m wide) and log yards (~0.2 ha) were built during 2010–2011. The logging roads were used by wheeled trucks to transport timber to a log station adjoining a paved highway, and were unpaved but graded and maintained for permanent use. The skid trails were used by bulldozers and other heavy machinery to extract and move timber from logging sites to the log yards adjoining the logging roads. The skid trails were unpaved, ungraded and plowed after logging (PITC, 2010). Canopy openness measured with hemispherical photographs, the best parameter to predict dung beetle richness (T. Hosaka unpublished data), was significantly different among sites [Kruskal–Wallis test, $P < 0.001$: mean ± SD, 16 ± 6.2% (skid trails, $n = 15$); 33 ± 6.4% (logging roads, $n = 15$); 46 ± 6.1% (log yards, $n = 15$); 7.7 ± 2.2% (interior forests, $n = 40$)] (T. Hosaka unpublished data).

2.2. Dung beetle survey

Dung beetles were sampled using baited pitfall traps made of plastic containers buried flush with the ground. The containers, 10 cm in diameter by 9 cm deep, contained 250 ml of detergent solution. Fifty grams of fresh human dung wrapped with a fine mesh net was hung on a wire over the center of each trap. Human dung is known to be effective bait for attracting a wide range of dung beetles feeding on both primate, herbivore and omnivore dung (Nichols et al., 2013b). An umbrella, 90 cm in diameter, was placed 20 cm above each pitfall trap for protection from rain and direct sunlight.

In total, 85 baited pitfall traps were set: 40 in forest interior, 15 on skid trails, 15 on logging roads and 15 in log yards. The traps were placed apart at least 50 m apart to avoid interference (Larsen and Forsyth, 2005). Traps in the forest interior were placed at least 30 m away from log yards and logging roads, and 10 m away from skid trails, to avoid edge effects of those road clearings (M. Niino, unpublished data). The traps were left at each site for 2 days without bait renewal. Dung beetles were collected from traps every day and stored in 70% ethanol for later identification.

Since nesting strategy (tunnellers or rollers) and body size (large or small) are key factors affecting the magnitude of dung burial and seed dispersal (Larsen et al., 2005; Nichols et al., 2013b; Slade et al., 2007), we classified dung beetle species into four guilds: large tunnellers, large rollers, small tunnellers and small rollers. Tunnellers bury brood dung balls in vertical chambers in close proximity to the original deposition site, while rollers transport balls some horizontal distance away before burial beneath the soil surface (Cambefort and Hanski, 1991). The nesting strategy of each genus was determined following Slade et al. (2011), Edwards et al. (2014) and personal observations. Ten air-dried, haphazardly selected individuals of each species were weighed using an electronic balance to the nearest 0.1 mg (Sartorius CP224S). For species with fewer than 10 individuals, the masses of all individuals were weighed. Species that weighed less than 0.1 g were classified as "small" and those that weighed more than 0.1 g were classified as "large", following Nichols et al. (2013b).

2.3. Dung removal and seed dispersal

We assessed dung removal and secondary seed dispersal by dung beetles in the forest interior ($n = 17$ plots), on skid trails ($n = 14$) and logging roads ($n = 15$) and in log yards ($n = 15$) in the Block 5. The plots were at least 30 m apart and did not necessarily overlap with those used for the dung beetle survey. Three piles of fresh human dung (10 g each) were placed on the ground at each plot (1 m apart); similar studies in the Neotropics were used as references when determining the amount of dung (Andresen, 2003;