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Notes

Dung beetles as indicators for rapid impact assessments: Evaluating best practice forestry in the neotropics

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A B S T R A C T

Dung beetles (Scarabaeidae: Scarabaeinae) are sensitive to habitat perturbations and are easily studied, making them an ideal taxonomic group with which to evaluate the effects of low-intensity anthropogenic disturbances such as Reduced-Impact Logging. Here we examine the effect of a certified Reduced-Impact Logging operation on dung beetles, and demonstrate their suitability for use in rapid ecological impact studies. We sampled dung beetle assemblages, environmental variables and timber extraction rates across four treatment groups in closed canopy and canopy gaps in logged and unlogged forest in Guyana. Community analysis revealed that logged forest supported a more uniform dung beetle assemblage compared to unlogged forest. Differences in assemblage structure were driven by dissimilarity between closed canopy treatments, as plots in artificial and natural canopy gaps supported comparable assemblages. Indicator analyses were conducted across treatments, using a new approach (CLAM) and two well-established methods (IndVal, SIMPER). Two species respectively were classified as indicators of logged (*Hansreia affinis* and *Eurysternus caribaeus*) and unlogged forest (*Canthidium aff. centrale* and *Deltochilum (Calhyboma) carinatum*). BIO-ENV analysis demonstrated that tree extraction intensity, bare ground cover, and ground cover by leaf material were key factors influencing dung beetle assemblages. Despite the relatively low-impact of Reduced-Impact Logging reported by previous studies, we find that dung beetles are sensitive to even small changes in environmental conditions as a result of this form of anthropogenic disturbance. As dung beetles are a highly responsive taxonomic group, we illustrate that they represent a valuable taxon that can be used to critically evaluate best practice forestry operations and other disturbance activities, particularly in time constrained studies (e.g., rapid monitoring and environmental impact assessments). However, we recommend the use of multiple indicator analyses to monitor potential changes in assemblage composition, due to a lack of congruence between methods.

1. Introduction

In the neotropics, the area of degraded forest far exceeds that converted to alternative land-uses (Asner et al., 2005). The primary sources of degradation are selective logging, fragmentation and fire (Barlow et al., 2006; Peres et al., 2010), with 1.2 million ha of the Brazilian Amazon selectively logged each year (Asner et al., 2005). Timber harvesting in tropical forests has negative consequences for forest biodiversity (Barlow et al., 2006; Fimbel et al., 2001; Mason, 1996; Meijaard et al., 2005; Thiollay, 1997), albeit less severe than those arising from either fragmentation or fire (Barlow et al., 2006; Gibson et al., 2011). Given that a further 50 million hectares of the Brazilian Amazon are proposed as timber concessions (Veríssimo et al., 2002), understanding the impacts of selective logging is important for informing forestry policy regarding both biodiversity conservation, and forest regeneration dynamics, as biological communities underpin many essential ecosystem functions (Hooper et al., 2005).

Reduced-Impact Logging (RIL) is a modern system of timber harvesting that endeavours to reduce the collateral damage to forests associated with selective logging (Pinard and Putz, 1996), and attempts to better mimic natural tree-fall dynamics (Felton

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et al., 2006). It typically involves a pre-harvest tree inventory, which is subsequently used to plan the most efficient and least destructive extraction (skid) trail network in a Geographic Information System (GIS). Directional felling and vine cutting are also employed to prevent damage to adjacent trees, and felled timber is winched to skid trails to minimise extraction disturbance and infrastructure (for further details on RIL see: Pinard and Putz, 1996; Vidal et al., 1997; Mason and Putz, 2001). Compared with conventional selective logging, RIL has been shown to reduce tree mortality and total canopy gap fracture by up to 27 percent and 43 percent respectively (Johns et al., 1996; Pinard and Putz, 1996). RIL is expected to improve timber crop sustainability, carbon storage, and the provision of ecosystem services (Miller et al., 2011). Furthermore, it is estimated that implementation of the technique across production forests globally would cut carbon emissions by 160 million tons each year, equivalent to ~10 percent of carbon emissions from deforestation (Putz et al., 2008). Despite this, RIL is not a mandatory component of timber certification schemes and uptake has remained slow, with conventional practices continuing to dominate the industry (Mazzei et al., 2010).

Compared with conventional logging, RIL is also expected to provide benefits for biodiversity, although this is yet to be thoroughly demonstrated (Edwards et al., 2012; Peres et al., 2010). As a result, there is no strong evidence-base to inform conservation management and forestry policy. Of the studies that do exist, most have focused on vertebrates (Azevedo-Ramos et al., 2006; Bicknell and Peres, 2010; Felton et al., 2008; Khanaposhtani et al., 2013; Presley et al., 2008; Wunderle et al., 2006), finding that change in community composition is broadly governed by extraction rate and technique (Fimbel et al., 2001). Little is known about the effects of RIL upon invertebrates, despite the critical role they play in tropical forest ecosystem dynamics (Nichols et al., 2008). It is expected that invertebrates are affected by more fine-scale secondary changes that result from logging, and will therefore provide a complementary perspective on the consequences of best practice forestry operations.

Identifying appropriate indicators of ecosystem health has become increasingly important in conservation biology, with many taxonomic groups used to assess tropical forest disturbance, including both vertebrates (e.g. Banks-Leite et al., 2013) and invertebrates (e.g. Lachat et al., 2006). Dung beetles (Scarabaeidae: Scarabaeinae) are regarded as excellent bioindicators. They are particularly suitable for examining subtle effects of low-intensity habitat modifications such as RIL, because they are stenotopic and thus intrinsically sensitive to alterations in environmental conditions (Davis et al., 2001; Feer and Hingrat, 2005; Nichols and Gardner, 2011; Scheffler, 2005). Furthermore, they are diverse and taxonomically well characterised, sampling methods are inexpensive, community turnover occurs rapidly (Nichols and Gardner, 2011), they provide key ecosystem services important to forest dynamics (such as decomposition, secondary seed dispersal, nutrient cycling and parasite control; Davis et al., 2001; Feer and Hingrat, 2005; Nichols et al., 2008; Ponce-Santizo et al., 2006; Scheffler, 2005; Shahabuddin et al., 2005; Shepherd and Chapman, 1998; Vulinec, 2002), and they have been shown to be reliable indicators of tropical forest disturbance (Aguilar-Amuchastegui and Henebry, 2007; Barlow et al., 2010; Gardner et al., 2008a, 2008b; Lachat et al., 2006; Nichols and Gardner, 2011). They are also often considered a proxy for the wildlife communities (primarily large mammals) that provide the faeces upon which they feed (Hanski and Cambefort, 1991; Nichols et al., 2009), making their value as indicators disproportionally high (Nichols and Gardner, 2011).

In this study we aimed to: (i) assess the effects of RIL on a neotropical dung beetle assemblage in order to inform production forest management policies and (ii) demonstrate the use of dung beetles as forest impact indicators, and as a highly effective tool for evaluating levels of forest disturbance in rapid and easily replicated monitoring programmes. As part of our study, we use a consensus approach of three analytical techniques to identify indicator species, in order to ensure that we identified all indicators from our rapid assessment dataset. The research was undertaken at an experimental timber operation in the Iwokrama Forest, Guyana, enabling us to sample in logged (RIL) and unlogged areas and to test for differences in natural (tree-fall) and artificial (logged) canopy gaps. We use community analyses to quantify variation in dung beetle assemblage composition in each of the treatments, and examine whether this is associated with changes in local environmental conditions and/or RIL extraction rates.

2. Methods

2.1. Study area

The Iwokrama Forest in central Guyana is a 3,710 km^2 area of tropical forest managed by the Iwokrama International Centre for Rainforest Conservation and Development (IIC) (Fig. 1). Lying between 4° and 5° N, and 58° and 59° W, the study system is characterised by *terra firme* tropical rainforest, dominated by timber species that include *Chlorocardium rodiei* (Schomb), *Eperua falcate* (Aubl.), *Dicorynia guianensis* (Amsh), *Mora excelsa* (Benth) and *Swartzia leiocalycina* (Benth). Rainfall averages 3000 mm/yr, with a rainy season from April to July. Temperatures range from a mean minimum of 22 °C at night during July, to a maximum of 36 °C during October.

Timber operations in the Iwokrama Forest are certified by the Forestry Stewardship Council, and every stage of the extraction process is conducted with environmental sustainability in mind. Harvesting methods go beyond RIL guidelines, with extraction road densities ~25 percent lower than current recommendations (GFC, 2002). Research into growth rates also permit accurate Annual Allowable Cuts (the annual harvest rate and interval period at which sustainability can be maintained) for primary timber species to be calculated, coupled with a 60 year polycyclic felling rotation. RIL within the logged sites used in this study was completed 12 months prior to field surveys. Logging intensity ranged between 1.2 and 5.1 trees/ha (mean = 3.7; S.D. = 1.3), while the volume equivalent varied from 4.8 to 24.0 m^3/ha (mean = 14.7; S.D. = 5.4).

2.2. Experimental design

To quantify the effects of RIL on dung beetle assemblages, 20 plots were sampled, five in each of four treatment groups: (1) canopy gaps in RIL forest; (2) closed canopy in RIL forest; (3) canopy gaps in unlogged (control) forest, and; (4) closed canopy in unlogged (control) forest. In RIL forest, the canopy gaps were artificially created by logging operations, where a timber tree had been felled and extracted. In unlogged forest, canopy gaps were natural tree-fall openings. All sample plots were positioned more than 500 m apart and greater than 200 m from forestry block boundaries to minimise potential edge effects and assemblage spill-over.

To best mimic the conditions of a rapid biological monitoring assessment, but also to account for bias caused by seasonal effects independent from RIL, the sampling of treatments was conducted on a rotational basis (Andresen, 2008b) over a single season in April and May 2009. Elsewhere in north-eastern Amazonia (French Guiana and northern Brazil), studies have demonstrated that dung beetle abundance and assemblage composition does not vary between seasons (Barlow et al., 2010; Feer and Pincebourde, 2005; Gardner et al., 2008b), and so our sampling procedure should generate findings that are representative of other times of the year.