



Beetle biodiversity in forest habitats in Laos depends on the level of human exploitation

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Received: 16 January 2020 / Accepted: 17 July 2020 / Published online: 31 July 2020
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Abstract

Coleopteran diversity was compared between more and less disturbed lowland evergreen deciduous forests located in Phou Phanang National protected area, Lao PDR. Using window traps and pitfall traps and collecting beetles from March until December 2018, a total of 6243 specimens were obtained. The number of morphospecies found in the less disturbed forest was significantly higher as compared to the more disturbed forest. Slightly more morphospecies were found in the window traps compared to pitfall traps and a significantly higher number of morphospecies were found in the wet season (June and September collections), compared to the dry season (March and December collections). Similarly, more than twice as many specimens were found in the less disturbed forest, compared to the more disturbed forest and also again more were found in the wet season, in particular predators. The data presented here indicate that so far largely undisturbed forests in Lao PDR need to be better protected from human exploitation such as logging.

Keywords Coleoptera · Biodiversity · Deciduous rain forest · Human exploitation · Morphospecies

Introduction

Laos is a landlocked, tropical country in the centre of the Indochinese Peninsula with almost 75% of the country being mountainous and about 40% of its territory still covered with forest. Due to the considerable extension from north to south, a high number of habitat types and exceptionally high biodiversity can be found, making Laos one of the global biodiversity hotspots as designated by Myers et al. (2000). A large proportion of the species occurring in Laos, especially insects, are endemic to the Indochinese subregion within the Indomalayan faunal region, however, a considerable number of endemic species are restricted to

Laos, e.g. in the Annamites and the Khammouan karst area (Geiser and Nagel 2013). To protect biodiversity is a high priority on the agenda globally and also the Lao PDR (Laos) has subscribed to the convention of biodiversity. However, large areas of the Laos landscape have not been thoroughly explored for biodiversity and in particular, the entomofauna has been targeted rarely.

Therefore coleopterans—the most diverse order of insects group on Earth—are also greatly underexplored, despite a number of collections have been conducted during the period of 2000 to 2010 by Swiss taxonomists summarized by Geiser and Nagel (2013). Globally, interests in beetles is increasing due to their stunning biodiversity but also due to their relevance in many ecosystems and last not least also their economic importance (Adamski et al. 2019). Coleopterans have occupied a number of roles and functions, they are e.g. very important pests, biological control agents or act as destruents, being responsible for recycling nutrients in natural settings and thus providing huge benefits for ecological functions. This has been shown in Australia in the 1960s and 70s where a lack of cattle dung consumers became apparent which was resolved by the successful introduction of dung beetles (Nichols et al. 2008). It also seems likely, that beetles are the most species-rich and ecologically diverse group of

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organisms in tropical rainforests because of the very many roles they play in all kinds of ecosystems. Regarding overall species diversity of arthropods, it is widely agreed that there are still vast numbers of unidentified species out there, particularly in tropical rain forests (Basset et al. 2012). Considering the latter, it is unfortunate that few studies have been conducted to characterize beetle communities in tropical forests. As one point of concern, there is a lack of consensus on collection methods, e.g., deciding which trap type to use, and up to date only few studies presented a quantitative comparison of the results generated by standardized methods in tropical beetle communities (Lamarre et al. 2012).

Tropical forests are considered the most ancient, diverse and ecologically complex terrestrial ecosystems, but the destruction, fragmentation and degradation of forests are major threats to the protection of their biodiversity (Myers 1988; Barlow et al. 2007). While occupying only 7% of the land surface, they are estimated to sustain over half of the planet's life forms. Thus, the loss of biodiversity resulting from tropical forest destruction signifies an ecological crisis of global importance (Wilson 1988; Bradshaw et al. 2009). It is widely agreed that the conversion of forest into intensive agriculture inevitably leads to dramatic losses in biodiversity, but a number of other factors may also contribute substantially to this, including deforestation, overexploitation of wildlife, commercial logging, and anthropogenic fire (Sodhi et al. 2004). Clearly, this is of special concern in a region of high species richness and endemism, such as Southeast Asia including Laos. Deforestation and logging were considered as the most urgent threats, with Southeast Asia showing the highest relative rate of lowland forest loss of any tropical region (Sodhi et al. 2004), a trend still valid in more recent years (Estoque et al. 2019). Global climate change may well prove to be another serious threat for tropical trees and associated organisms (Feeley and Silman 2010). Summarizing available evidence, Gibson et al. (2011) clearly pointed out that primary forests are key when it comes to maintaining tropical biodiversity and Watson et al. (2018) recently reported that intact forests are not only contributing significantly to biodiversity when compared to degraded forests but also support globally significant environmental values, including carbon sequestration and storage, water provision or indigenous culture. However, despite several studies have already demonstrated the detrimental effects of heavy wood cutting on diversity for a number of taxonomic groups, conservation biologists are less certain about the conservation value of more structurally complex secondary and planted forests (Wilcove et al. 2013; Giam 2017).

When focusing on beetles, not much data is available for the above question. Dung beetles have been considered as indicator species and a meta-analysis on the consequences of landscape change for tropical forest dung beetles showed that, while clear-felling and intensive agriculture led to

significant reductions in diversity, land uses that maintained a high degree of forest cover and relatively high vegetation complexity (such as secondary forests) held species-rich dung beetle communities similar to those found in intact areas (Nichols et al. 2007). It is agreed that the rapid expansion of secondary and plantation forests, and generally in human-affected landscapes across the tropics, asks for more biodiversity research and we thus aim here to increase our understanding of the effect of forest degradation on beetle diversity in Laos. Specifically, the objective of this study was to assess the number of beetle morphospecies and the composition of beetle feeding guilds in more and less disturbed forests in Phou Phanang National protected area in Laos.

Material and methods

Study site

Beetle collections were done in lowland evergreen deciduous forests located in Phou Phanang National protected area (NPA). The site is located 20–40 km to the North-West of Vientiane and includes 152,500 ha land at an elevation level of 200 m–700 m. The average yearly temperature is 25.1 °C and average annual rainfall in the region is approximately 2000 mm. The rainy season usually starts in late April or May and finishes in October while the dry season lasts from November to April. While most of the NPA is covered with partly degraded forest, there is also a small area of semi-evergreen forest in mostly natural shape. While the NPA is close to Vientiane and thus easily accessible in general, this special area of evergreen forest had a relatively bad accessibility until recently, when a new road was built a few years ago. Thus, this special part of this NPA measuring about 50 ha was not much exploited by humans and was considered the less disturbed site in our study. It is a primary forest covered with hardwoods of numerous species (e.g. *Hopea ferrea*, *Gmelia arborea*, *Irvingia cambodiana*, *Sandoricum indicum*, *Pentace burmanica*, *Bombax anceps*, *Dialium indum* and *Hoppea odorata*). In particular on the steeper areas only minor signs of human activities could be observed, such as looking for food and hunting. Logging, which generally is considered the most relevant human activity affecting biodiversity, was not observed in this area (18°5'48.14"N and 102°23'23.13"E). It showed dense canopy cover and all age classes of trees, a substantial number of understory trees with considerable amount of dead wood as well.

As more disturbed forest habitat, a site without slope was chosen about 2–4 km away, where the forest comprised mostly of teak trees planted (*Tectona crandis*) 25–30 years ago, mixed with additional, mostly smaller, trees (18°5'23.41"N and 102°24'52.87"E). This forest

canopy showed some gaps, due to logging activities of village people living in or near the NPA.

Design

At each of the two habitats described above, beetle collections were done at six sites (separated from each other by a minimum of 150 m) based on window traps (flight interception traps) and pitfall traps, which both are well established methods for beetle collections. Both trap types selectively capture mobile species, but at different height within a habitat. Thus, the two methods chosen do not provide a complete picture of the beetle assemblages in the habitats chosen, but they will be able to collect a majority of beetle species and allow for a relative comparison of the beetle assemblages between the two habitats. Traps were established four times, i.e. on 20 March, 20 June, 20 September and 13 December 2018 and exposed for 96 h each. At each site two window traps and six pitfall traps were established which always were separated from each other by a minimum of 4 m. The window traps consisted of a common plastic sheet with a panel size of 100 × 80 cm established between small trees with the lower end fixed at about 30–60 cm above the ground level. Underneath, a collection container made of plastic measuring 90 × 20 × 16 cm (length × width × depth) was fixed as well which was filled with 1 l of 70% alcohol. During the two collections done during the rainy season (June and September), a roof was provided to protect the window traps from rain. Pitfall traps consisted of plastic cups (300 cm³) with a diameter of 8 cm at the top, buried in the ground so that the top rim was flush with the soil surface. Traps were filled with about 50 ml of 70% alcohol and had a cover for rain protection during the two collections done during the rainy season (June, September). Samples were taken separately for each trap and brought back to the Plant Protection Unit, National University of Laos in Vientiane for processing.

Processing of samples

All specimens collected in window- and pitfall traps were carefully examined under a microscope and beetles separated from other species and any debris. Thereafter, all beetles were identified to the level of morphospecies. This technique separates taxa by morphological differences that are obvious to the identifier and may be used as surrogates for species to estimate richness (Beattie and Oliver 1994). Pooling was done for the two window traps and the 6 pitfall traps established at each collection site for statistical analysis.

In addition, all specimens were identified to family or subfamily level with the aim to assign them to a feeding guild (predator, herbivore, fungivore, detritivore (i.e. saprophagous)). For this, the knowledge of the authors together

with published information was used. Specimens we could not identify down to family/subfamily level were discarded from the analysis of functional groups and so were specimens which were identified but where published information indicated a diverse range of feeding niches in that group.

Statistical analysis

The effect of three independent factors (habitat, trap type and collection date) on the number of morphospecies as well as the number of beetle specimens were analyzed using a 3-way ANOVAs with Tukeys HSD tests for post-hoc analysis of the four collection dates. Similarly, the effect of habitat, trap type and collection date on the number of specimens belonging to different beetle functional feeding guilds were analysed with 3-way ANOVA, again with Tukeys HSD tests for post-hoc analysis of the four collection dates. For each of the six sampling sites per habitat, data from the two window traps and for the six pitfall traps were pooled respectively. Data were log-transformed to meet the assumptions for ANOVAs.

Results

In total, 6243 beetle specimens were collected during the survey in Phou Phanang National protected area presented here. These belonged to 30 different coleopteran families and Staphylinidae and Curculionidae were found to be most dominant, accounting for 36.3% and 33.8% of all specimens collected respectively. Most importantly, significantly more morphospecies were found in the less disturbed forest, as compared to the more disturbed forest ($F_{1,80}=41.4$, $P<0.001$, Fig. 1). Significantly more morphospecies were also found in the window traps as compared to pitfall traps ($F_{1,80}=7.41$, $P=0.008$) and significant differences were observed among the four different sampling dates ($F_{3,80}=51.1$, $P<0.001$). Specifically, a significantly higher number of morphospecies was found in the wet season, i.e. in June and September compared to the dry season, i.e. in March and December ($P<0.05$, Fig. 1).

A significant interaction was found between trap type and date ($F_{3,80}=8.44$, $P<0.001$), mostly due to a higher number of morphospecies found in the rainy season especially for the window traps (Fig. 1). Significant interaction was further found between habitat type and trap type ($F_{1,80}=4.64$, $P=0.034$), due to more morphospecies found in the less disturbed habitat especially in the window traps. Finally, significant interaction was found also among trap type, habitat type and date ($F_{3,80}=3.09$, $P=0.032$), possibly because of the low number of morphospecies found in window traps in more disturbed habitats during the collection done in September.

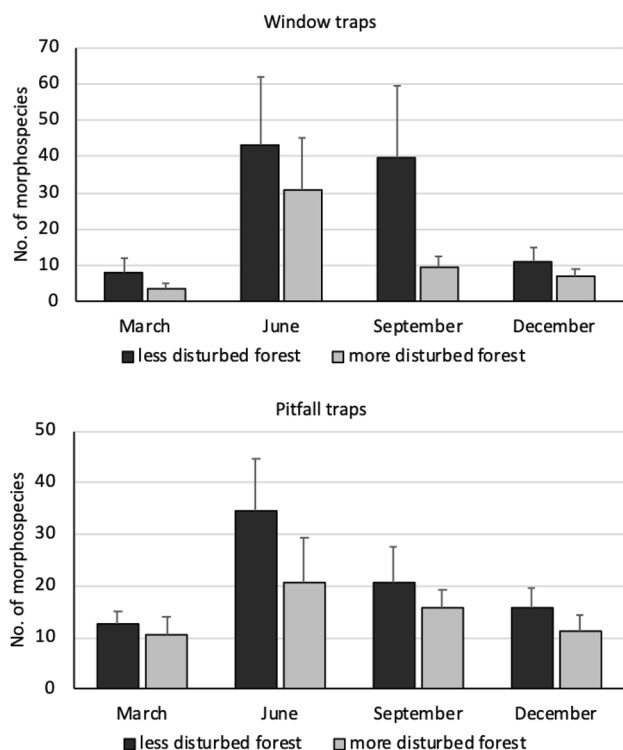


Fig. 1 Mean (+SD) number of coleopteran morphospecies found in less or more disturbed lowland deciduous forest during field collections done in Phou Phanang National protected area in Laos during 2018 for window traps (top) and pitfall traps (bottom)

The number of specimens also differed significantly between the two habitats sampled, with altogether 4241 specimens found in the less disturbed habitat, thus more than twice as many as compared to the more disturbed habitat (2002 specimens, $F_{1,80} = 29.1$, $P < 0.001$). While more morphospecies were found in the window traps, significantly more specimens were obtained from the pitfall traps as compared to the window traps ($F_{1,80} = 12.4$, $P = 0.001$). Significant differences were finally also found among the four different dates sampled ($F_{3,80} = 31.0$, $P < 0.001$, Fig. 1). Significantly more specimens were found in the rainy season and in fact, all sampling dates differed from each other at $P < 0.05$, except for the two collections done in March and December, i.e. during the dry season. A significant interaction was found between habitat types and sampling date ($F_{3,80} = 5.1$, $P = 0.003$).

Focusing on functional feeding guilds, there were significantly more predatory beetles found in the less disturbed forest ($F_{1,80} = 14.6$, $P < 0.001$, Fig. 2), and significantly more collected by the pitfall traps, ($F_{1,80} = 19.1$, $P < 0.001$), mainly due to high numbers of Staphylinidae in the latter. Predators were at least tenfold more common in the rainy season compared to the dry season ($F_{3,80} = 105.6$, $P < 0.001$). A higher number of herbivores was found in the less disturbed habitat

when compared to the more disturbed forest ($F_{1,80} = 18.3$, $P < 0.001$), and more herbivores were also found in the pitfall traps when compared to window traps ($F_{1,80} = 7.2$, $P = 0.009$). Herbivores were also more commonly found during the rainy season as compared to the dry season ($F_{1,80} = 196.0$, $P < 0.001$, Fig. 2). Differences between less and more disturbed habitats ($F_{1,80} = 6.0$, $P = 0.014$) as well as between traps ($F_{1,80} = 5.4$, $P = 0.028$) were smaller for fungivores but still significant. Due to fungivores, mainly Scolytinae, predominantly being found in the March collection (dry season), their numbers were highly significantly different among dates ($F_{3,80} = 173.3$, $P < 0.001$). As for the saprophages, higher numbers were found in the less disturbed habitat ($F_{1,80} = 8.9$, $P = 0.004$) as well as in the pitfall traps when compared to window traps ($F_{1,80} = 50.7$, $P < 0.001$) and higher numbers were found in the rainy season when compared to the dry season ($F_{3,80} = 7.1$, $P < 0.001$, Fig. 2).

Discussion

The present study is the first assessing the negative effects of forest degradation on beetle diversity in Laos and there are generally also not many studies on this subject that were conducted in South East Asia, in particular few that included the coleopteran fauna as a whole. Despite the fact that the less disturbed forest was rather small in size, surrounded by more disturbed forest and with agricultural areas in less than 10 km distance, it was clearly more species rich when compared to the more disturbed forest. It may be expected that the difference between the two sampled habitats would have even been more pronounced, in case of connection of the relatively small area of less disturbed habitat to a much larger similar area, as it is known that species richness increases generally with the size of the sampled area (Azovsky 2011). Furthermore, in the study presented here, the less and more disturbed habitats were only a few km apart, thus it is possible that the diversity of beetles in the more disturbed habitat slightly profited from the neighbourhood to the less disturbed habitat and diversity might have been lower without it.

This key finding of the present study of higher species richness in less disturbed lowland deciduous forests from Laos agrees with other studies of the subject. For instance, Sakchoowong et al. (2008) found that teak plantations and secondary forest had substantially fewer individuals and species of pselaphine beetles in a study conducted in eastern Thailand. Another study showed that abundance, species richness and guild structure of saproxylic beetles were not maintained in a logged and regrowth forest in Queensland, Australia (Grove 2002). Furthermore, it was found for dung beetles in the neotropical landscape, that their diversity in

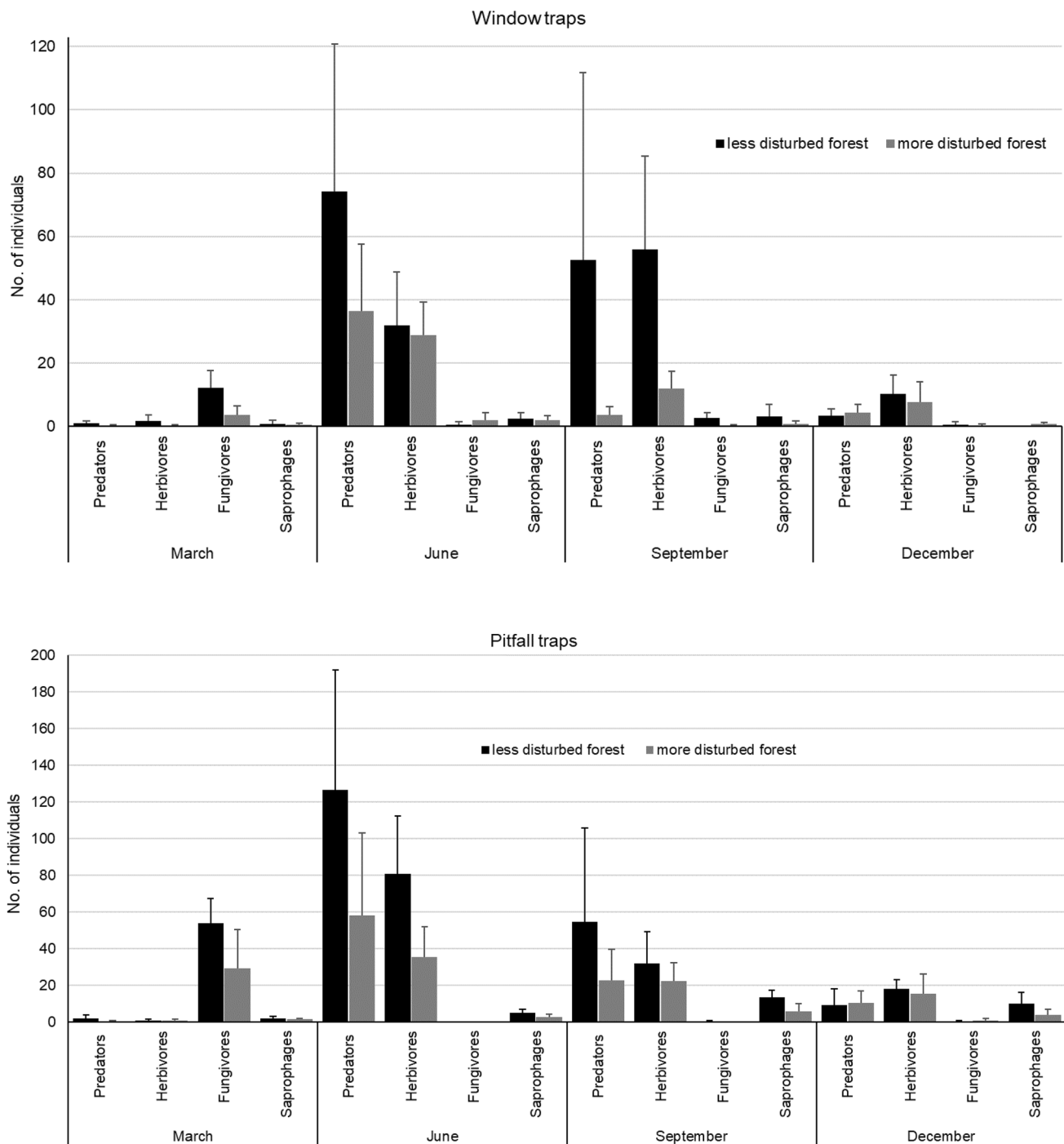


Fig. 2 Mean (\pm SD) number of beetles belonging to four functional trophic groups in less or more disturbed lowland deciduous forest during field collections done in Phou Phanang National protected area in Laos during 2018 for window traps (top) and pitfall traps (bottom)

secondary and plantation forests was substantially decreased (Gardner et al. 2008). In a more general approach testing the effect of deforestation on the diversity of trees and 10 groups of animals, it was found that the disturbed habitats (still containing some forests) had significantly reduced species diversity, when compared to the undisturbed forests (Alroy

2017). In that study, about 41% of the tree and animal species found in total, were absent from disturbed habitats. The effect of deforestation on beetle diversity observed in the present study cannot be easily generalized as the situation might differ between different types of forests which may be characterized by different soil parameters, tree diversity etc.

We also clearly have only collected a fraction of all species occurring in the sampled forests, however, sampling efforts between the main types of habitats sampled were the same, thereby avoiding a pitfall identified by Gotelli and Colwell (2001). Thus, the work presented here provides a novel piece of evidence that still largely undisturbed forests need to be protected carefully, which should be seen within the current context of a high level of deforestation ongoing in the region (Estoque et al. 2019).

However, in line with other studies on the subject (e.g. Edwards et al. 2011), also the more disturbed forest harboured a considerable number of coleopteran species. In the present study the focus was put on diversity rather than individual species, but it may be hypothesized that secondary forests, such as the more disturbed forest studied here, may have limited value for habitat specialists as has recently been demonstrated for a flagship European saproxylic beetle (Bełcik et al. 2019). In general, the still considerable diversity is suggesting that the rate of deforestation of such exploited forests, which is even going on at higher speed compared to that of natural forests (Wilcove et al. 2013), should also be of concern. When forests are finally turned to agricultural land, biodiversity loss has been shown several times to be massive (Sodhi et al. 2004). In addition, there is increasing evidence that important ecoservices such as e.g. the removal of dung are still provided by logged forests but not when forest ecosystems are converted to agriculture (Edwards et al. 2014). Even if major parts of the forest have been logged, Salomão et al. (2018) showed the importance of forest fragments embedded in such unfavourable landscapes for the maintenance of beetle biodiversity.

It was clearly observed that a larger diversity and more specimens occurs in the rainy season. Seasonality of beetle diversity is not well studied but a very similar picture, i.e. a higher species richness and abundance was recorded in the rainy season in a study conducted in India (Arya and Tamta 2016). A distinct peak in abundance during the summer wet-season was also found by Wardhaugh et al. (2018) even though the authors found that temperature was the best predictor of abundance and species richness in their study from Northern Australia, while rainfall had little influence. An interesting finding of the present study was further that the observed increase in species diversity in the less disturbed forest was more pronounced in the window traps, suggesting that beetles with larger flight movements are profiting more from the less disturbed forest than others such as those mostly walking on the ground. This is somewhat in contrast to Lassau et al. (2005) who found that composition and species richness of flight-intercept-trapped beetles were similar in high and low complexity sites. It may be hypothesized that less actively flying beetles have more problems to colonize/recolonize such relatively small areas of less disturbed forest.

In terms of functional groups, predators and herbivores were dominating the samples, and this was observed for both habitats as well as for both trap types. Predators may generally be considered a very active group of beetles while they are looking for prey and thus are expected to be found more often than based on their absolute abundance. Among these, the Staphylinidae which are generally free-living predators (Lawrence and Britton 1994) were dominating the samples. In contrast, it may be expected that beetles from groups that have a very hidden lifestyle such as many saprophages and fungivores were underrepresented in our samples. A relative high number of fungivores was found in the March sample as compared to very few in all other samples but so far, we are not aware of any factor that could explain this observation. Altogether, there seem to be no clear effect of habitat exploitation on the composition of functional groups.

Biodiversity in Laos is believed to be very rich but few studies have been undertaken to systematically study it (Lazarus et al. 2006). Recent studies on coleopterans have increased our taxonomic understanding on several groups of beetles (Brancucci et al. 2016) while the study here is in particular pointing towards differences in beetle assemblages between forest habitats and the need to better protect less disturbed forests from human exploitation. Logging and generally habitat degradation are major drivers of declines in biodiversity in tropical biodiversity hotspots such as Laos, while unsustainable hunting is increasingly emerging as a major threat especially larger wildlife (Alroy 2017, Tilker et al., 2020). Compared to other countries in the region, Laos has 21% and thus a large area under protection, however, resources of the government to implement this are limited and more international efforts to support this seem warranted.

Acknowledgements The help of staff at the Phou Phanang NPA who facilitated access to the forest was greatly appreciated. We would also like to thank Mr. Souphaphone Rattanalasy and students of the Plant Protection unit at NUoL for their help with field collections and working on the specimens in the laboratory. This study was funded by the Brancucci foundation. We further acknowledge with thanks the support of the CABI Development Fund. CABI is an international intergovernmental organisation and we gratefully acknowledge the core financial support from our member countries (and lead agencies) including the United Kingdom (Department for International Development), China (Chinese Ministry of Agriculture), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), Netherlands (Directorate-General for International Cooperation), and Switzerland (Swiss Agency for Development and Cooperation). See <https://www.cabi.org/about-cabi/who-we-work-with/key-donors/> for details.

Data availability The data that support the findings of this study are openly available in [repository name] at [https://doi.org/\[doi\]](https://doi.org/[doi]), reference number [reference number].

Compliance with ethical standards

Conflict of interest The corresponding author confirms on behalf of all authors that there have been no involvements that might raise the question of bias in the work reported or in the conclusions, implications, or opinions stated.

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