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Article

Impacts of Logging Road Networks on Dung Beetles and Small Mammals in a Malaysian Production Forest: Implications for Biodiversity Safeguards

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Abstract: Various international bodies and non-governmental organizations (NGOs) have proposed guidelines for safeguarding biodiversity. Nevertheless, quantitative criteria for safeguarding biodiversity should first be established to measure the attainment of biodiversity conservation if biodiversity is to be safeguarded effectively. We conducted research on the impact of logging on biodiversity of dung beetles and small mammals in a production forest in Temengor Forest Reserve, Perak, Malaysia. This was done to develop such quantitative criteria for Malaysian production forests while paying special attention to the effects of road networks, such as skid trails, logging roads, and log yards, on biodiversity. Species assemblages of dung beetles as well as small mammals along and adjacent to road networks were significantly different from those in forest interiors. Therefore, minimizing the road network density will contribute to retaining biodiversity; this will allow us to use road network density as a quantitative criterion for safeguarding biodiversity in production forests. Additionally, road network density is easily measurable and verifiable by remote sensing, which enables us to check the implementation of the criteria.

Keywords: biodiversity conservation; dung beetle; REDD+; selective logging; small mammal; tropical rain forest; tropical silviculture

1. Introduction

Southeast Asia is one of the world's hotspots of imperiled biodiversity because of a high rate of forest degradation [1]. Commercial timber extraction is considered as the main driver of forest degradation in this area [2]. Strategies for biodiversity conservation in a production forest are critically important [3] because production forests cover more area than protected forests [4] and most of the remaining forest is designated by forest services for timber production [5,6] and therefore are experiencing selective logging.

Commercial timber companies primarily use selective logging in Southeast Asia [7,8]. Controversy remains related to the conservation values of these selectively logged forests [9,10]. Even selective logging can be a potential cause of species extinction [11], although recent studies show a high conservation value after selective logging [6,12,13].

In general, roads have severe impacts on biodiversity of insects and mammals in any ecosystems [14–17]. In tropical production forests, the major ecological effects of selective logging often result from the construction of road networks including log yards, logging roads and skid trails that cause changes in soil properties, drainage patterns, canopy openness and forest accessibility [18,19]. Selective-logging operations in the tropics often engage in excessive road building without appropriate planning [20,21]. Road networks covered 6–25 percent of a logged area in Bolivia [20], Malaysia [22], and Brazil [23]. Despite the ecological importance of road networks, few research studies have analyzed their impacts on biodiversity in tropical forests.

Non-binding guidelines for safeguarding biodiversity such as social and environmental guidelines and criteria [24], REDD+ social and environmental standards [25], and climate, community, and biodiversity project design standards [26] have been proposed. Nevertheless, concrete and quantitative "criteria" for safeguarding of biodiversity should first be established to measure the attainment of the biodiversity conservation if biodiversity is to be safeguarded effectively.

We conducted research related to the impacts of logging on biodiversity in a production forest in Temengor Forest Reserve, Perak, Malaysia to develop this type of criteria for animals (insects and wild lives) in South-East Asian (at least Malaysian) tropical production forests. Because logging roads have severe ecological impacts on biodiversity [14–16], minimizing logging road density is very likely to contribute to biodiversity conservation. Then, we paid special attention to the effects of logging road networks on biodiversity in this study. Our final goal was to provide quantitative criteria of logging road density to effectively safeguard biodiversity in a Malaysian tropical production forest. There has so far been no quantitative criterion of logging road density for biodiversity safeguarding. However, logging road density is required to be less than or equal to 40 m/ha [27] to protect the soil from erosion during harvesting operations in Malaysia.

To develop quantitative criteria, we focused on dung beetle and small mammal communities in this study. Dung beetles (Scarabaeinae: Scarabaeoinae) can be used as cost-effective bio-indicators in tropical biodiversity surveys [28], because they have a close connection to mammalian fauna. They also play important ecological roles in nutrient cycling, bioturbation, pest control and secondary seed dispersal via moving and burying of mammalian dung piles in soil [29]. Seeds in feces are secondarily dispersed by dung beetles when the beetles move and bury dung piles beneath or away from defecation sites [30]. Secondary seed dispersal by dung beetles is thought to promote seed survival and seedling establishment because it reduces seed predation, provides direct dispersal to favorable microclimates for germination and decreases seed clumping in feces [28]. Many scientists deduced that this is particularly important in tropical forests where defecated seeds often suffer intensive seed predation by rodents [31–37].

The small mammals in this study include species of the Insectivora, Scandentia and Rodentia. The Temengor Forest Reserve has a highly diverse small mammal fauna with 32 recorded species [38], including both ground-dwelling and arboreal taxa. Small mammals serve as an important group in a forest ecosystem providing prey for mammals, reptiles and birds [39]. These mammals are also important seed predators and dispersers; some seeds are endozoochory. In addition, they bury seeds and nuts for use when fruit is not in season and may contribute to seed dispersal when they fail to retrieve them all [40]. Previous studies reported that both dung beetles and small mammals were valuable to road networks [17,41].

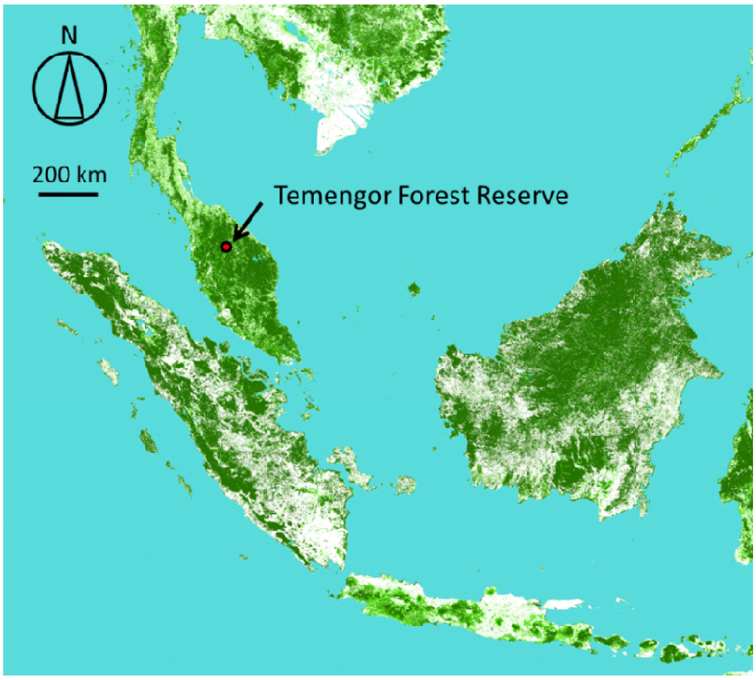
2. Methods

2.1. Study Site

We conducted this study in the Temengor Forest Reserve in Perak, Peninsular Malaysia (5°24′–5°34′N, 101°33′–101°39′E, at 400–1000 m above sea level, Figure 1). The reserve is part of the 266,000 ha Belum-Temengor Forest Complex [42]. Of the 148,870 ha reserve, 9000 ha in 30 blocks have been managed by a state-owned company and selectively logged since 2001, using Sustainable Forest Management with a moderate intensity of timber harvesting (39–55 $m^3 \cdot ha^{-1}$) [43]. The forest consists primarily of hill dipterocarp forests with some bamboo-dominated patches [43].

Fieldwork was conducted in a 200-ha part of Block 5 in August 2011 and August 2012 after 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 when trees were selectively logged in 2010–2011 [44]. The unpaved but graded logging roads were used by timber trucks to transport timber and are maintained for permanent use [44]. The skid trails, which were used by bulldozers and other heavy machinery to extract and move timber from logging sites to the log yards adjoining the logging roads, were unpaved, ungraded and plowed after logging to mitigate soil compaction [43]. The densities of logging roads and skid trails were 39.4 m/ha and 75.6 m/ha, respectively (Forest Research Institute Malaysia, unpublished data).

Figure 1. Map showing the location of the study site (●) in the Temengor Forest Reserve in northern Perak State, Malaysia, generated from the Global Map from the Geospatial Information Authority of Japan (GSI). The greener parts have the higher percent of tree covers. Our study site (the Temengor Forest Reserve) is indicated by an arrow.



2.2. Field Methods

We used pitfall traps to sample dung beetles. The pitfall traps were made of 10 cm diameter, 9 cm deep plastic containers containing 250 mL of detergent solution and were buried flush with the ground. We used human dung in this study because no option like livestock dung was available. Fresh human dung (50 g) wrapped with fine mesh net was hung on a wire over the middle of the trap. An umbrella (90 cm diameter) shielded the traps to protect them from rain and direct sunlight. The traps were set at least 50 m apart to avoid interference among them [45]. We set 95 pitfall traps at eight different sites in the study area with 10–15 traps in each of the following habitats (Figure 2A). We set 15 traps in three sites, log yards ("Yard"), logging roads ("Road"), and skid trails ("Trail"). Ten traps were placed in each of five sites: forests at 10 m, 30 m, and 60 m from logging roads ("10 L", "30 L", and "Forest", respectively), and forests at 10 m and 30 m from skid trails ("10 S" and "30 S", respectively). All the traps were set from 10:00 h to 11:00 h on the first day. Dung beetles were collected at 24 h intervals for two days and stored in 70% ethanol for later identification. True species richness including unsampled species was estimated by the Jack 1 estimator [46] using EstimateS ver 8.2.0 [47]. This resulted in our sampled dung beetle species covering 77% of the estimated true species richness in the sites, suggesting that we sampled the dung beetle species assemblage quite well.

We used camera traps to quantify the species composition of small mammals [48,49]. The cameras (Fieldnote DS2, Marif Co. Ltd., Yamaguchi, Japan) have a sensor that detects the infrared radiation (IR) from an animal's body. A few seconds after the sensor detects IR, the camera takes a picture, creating a few seconds of delay between the detection of IR and the camera being triggered. We used peanuts and bananas as baits to encourage animals to remain in the field of view to compensate for the time lag.

Thirty motion sensitive cameras were set in a grid system for 10 days in a logged forest in August 2011 and in a nearby intact (unlogged) forest in August 2012 (Figure 2B). Figure 2 shows the camera locations. The nearest distance of a camera from the logging road varied from 0 m to 250 m in the logged forest and always exceeded 300 m in the unlogged forest. We counted a series of conspecific appearances within 30 min as a single appearance following Yasuda [50]. Photographic identification of small mammals to the correct species was sometimes impossible because the key characteristics needed for identification were not always visible. Then, we identified some animals to only the genus level. Note that all genera of *Maxomys*, *Rattus*, and *Sundasciurus* included two species each (Table 1) but these species in the same genus share similar life histories and occupy similar ecological niches [51]. For the other genera, only one species in each genus was observed in our study (Table 1).

Figure 2. (**A**) Locations of pitfall traps at block five of the Temengor Forest Reserve. Thick and thin red lines indicate logging roads and skid trails, respectively. In the figure, "Yard," "Road, and Trail" indicate pitfall traps at log-yards, logging roads, and at skid trails, respectively. 10 L, 30 L, 10 S, 30 S and Forest represent forests at 10 m or 30 m from logging roads, forests at 10 m or 30 m from skid trails and forests at 60 m from logging roads, respectively. The locations of plots for camera traps are also shown; A, plot in a logged forest; B, plot in an unlogged forest; (**B**) Camera grid system pattern set in forests in the Temengor Forest Reserve.

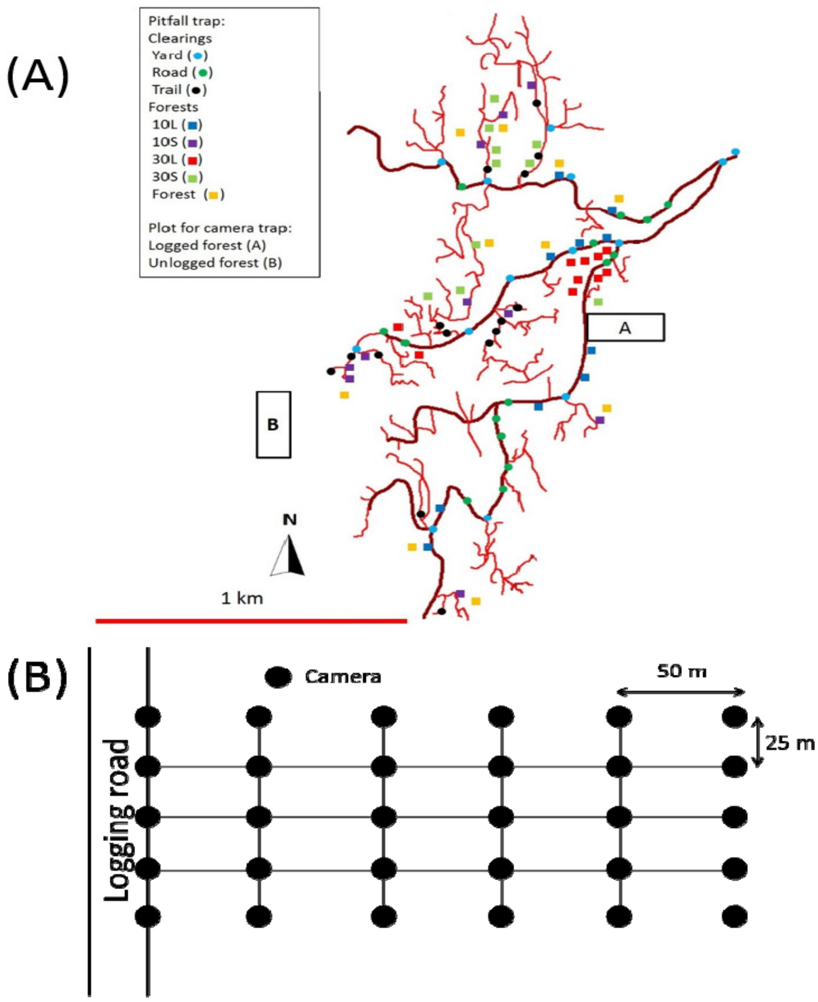


Table 1. Small mammal species documented in the block 5 of Temengor Forest Reserve, Perak, Malaysia. Open and closed circles denote the presence and absence of small mammal species in logged and unlogged forest.

Family	Scientific Name	Presence or Absence	
		Logged Forest	**Unlogged Forest**
Erinaceidae	*Hylomys suillus*	○	●
Soricidae	*Crocidura fuliginosa*	○	○
Tupaiidae	*Tupaia glis*	○	○
Sciuridae	*Sundasciurus lowii; Sundasciurus tenius*	○	○
	Lariscus insignis	○	○
Muridae	*Rattus rattus*; *Rattus tiomanicus*	○	●
	Sundamys muelleri	○	●
	Berylmys bowersi	○	●
	Niviventer cremoriventer	○	○
	Leopoldamys sabanus	○	○
	Maxomys surifer; Maxomys whiteheadi	○	○

2.3. Analysis

All analyses were carried out using R 2.15.1 [52]. Differences in abundance and species richness for dung beetles among the eight sites with pitfall traps as well as the difference in dung remaining among four sites was tested by Mann-Whitney U-test and post-hoc multiple comparison of Pairwise Wilcoxon Test with Holm protection [53], because the criteria of normality was not satisfied.

Diversity of small mammals was quantified by the rarefaction index [54]. The rarefaction index measures the expected number of genera in random subsamples with a fixed number of appearances (five from a community sample of appearances in this study), with the standard errors of sampling defined by Heck *et al*. [55]. *Rattus* species do not occur naturally in undisturbed tropical forests and represent locally invasive species in forests [56]. Because we are interested in diversity of small mammals living in the forest, we excluded *Rattus* species from community vectors for the rarefaction index. We calculated species diversity for each camera based on a community vector of appearances. Then, the cameras were grouped into three distance classes based on the distance from logging road to a focal camera, D; near ($D < 100$ m, $n = 10$), intermediate ($100 \text{ m} \leq D < 200$ m, $n = 10$), and far ($D \geq 200$ m, $n = 10$). Finally, we compared appearances of each species and species diversity among the three distance classes using the Mann-Whitney U-test and *post-hoc* multiple comparison of Pairwise Wilcoxon Test with Holm protection [53] because the criteria of normality was not satisfied. In the analysis of the relationship between appearances and D, we included only the appearances of genera having more than 200 appearances to ensure enough sample size in this study; as a result, five genera were examined: *Lepoldamys*, *Maxomys*, *Niviventer*, *Rattus*, and *Tupaia*.

3. Results

3.1. Dung Beetles

In total, 1271 dung beetles of 41 species in 10 genera were collected (Table 2). Abundance and species richness of dung beetles per pitfall trap were significantly higher in forest than all types of clearings, except for 10 L (Figures 3 and 4). In clearings, abundance and species richness were highest at skid trails and lowest at log yards. When looking at forest interior, again, the numbers of individuals and species found were even lower in forests within 10 m of logging roads (10 L) than in more interior forest locations and they were similar with those in clearings.

Table 2. Dung beetle species trapped in block 5 of Temengor Forest Reserve, Perak, Malaysia. Dung beetle species which appeared in eight sites are denoted by open circles and those which did not appear are by closed circles in the presence or absence columns. "Yard," "Road, and Trail" indicate pitfall traps at log-yards, logging roads, and at skid trails, respectively. 10 L, 30 L, 10 S, 30 S and Forest represent forests at 10 m or 30 m from logging roads, forest at 10 m or 30 m from skid trails and forests at 60 m from logging roads and skid trails, respectively.

Species	Presence or Absence							
	Yard	Road	Trail	10 L	10 S	30 L	30 S	Forest
Caccobius bawangensis	●	●	●	●	●	●	○	●
Caccobius unicornis	●	●	●	●	●	○	○	○
Catharsius renaudpauliani	○	○	○	○	○	○	○	○
Copris agnus	●	●	○	○	○	○	○	○
Copris spinator	●	●	●	●	○	○	○	●
Microcopris doriae	●	●	○	○	○	○	○	●
Microcopris hidakai	●	●	●	●	○	●	●	●
Ochicanthon peninsularis	●	○	○	○	○	○	○	●
O. sp.A	●	○	●	●	○	●	○	●
O. sp.B	●	○	●	○	○	○	○	●
Onthophagus aphodioides	●	●	○	●	●	●	●	●
Onthophagus deliensis	●	○	○	○	○	○	●	●
Onthophagus falculatus	●	●	●	○	●	●	●	●
Onthophagus kawaharai	●	●	●	○	●	●	●	●
Onthophagus leusermontis	●	○	○	○	○	○	○	○
Onthophagus liliputanus	○	○	○	●	●	●	●	●
Onthophagus mentaveiensis	●	●	●	●	○	●	●	●
Onthophagus nigriobscurior	●	●	●	●	○	●	●	●
Onthophagus obscurior	●	○	○	○	○	○	○	●
Onthophagus orientalis	●	○	●	●	●	●	●	●
Onthophagus roralius	●	●	●	●	●	○	○	●
Onthophagus roubali	●	○	●	●	●	●	●	●
Onthophagus rudis	●	●	○	○	●	○	○	●
Onthophagus rugicollis	●	○	●	●	●	○	●	●
Onthophagus rutilans	●	●	●	○	○	○	○	●

Table 2. *Cont.*

Species	Presence or Absence							
	Yard	Road	Trail	10 L	10 S	30 L	30 S	Forest
Onthophagus semifex	●	●	●	●	●	○	●	●
Onthophagus sepilokensis	●	○	○	○	●	●	●	○
Onthophagus ulugombakensis	●	○	●	●	○	○	●	●
Onthophagus tsubakii	●	●	○	●	●	○	●	●
Onthophagus vethi	●	●	○	●	●	●	●	●
Onthophagus viridicervicapra	●	●	○	●	○	●	○	●
Onthophagus vulpes	●	○	○	○	○	○	○	○
O. sp. A	●	●	○	●	○	●	●	●
O. sp. B	●	○	○	●	●	○	○	●
Paracopris ramosiceps	●	●	●	●	●	○	○	○
Paragymnopleurus maurus	●	●	●	●	○	○	○	●
Paragymnopleurus striatus	○	○	○	○	○	○	○	○
Sisyphus thoracicus	○	○	○	○	○	○	○	○
Synapsis ritsemae	●	●	●	●	○	○	○	○
Synapsis roslihashimi	●	●	●	●	○	●	○	●

Figure 3. Number of dung beetle individuals (abundance) collected with baited pit-fall traps; Yard, log yards; Road, logging roads; Trail, skid trails; 10 L, 30 L, 10 S, 30 S and Forest represent forests at 10 m or 30 m from logging roads, forest at 10 m or 30 m from skid trails and forests at 60 m from logging roads or skid trails, respectively. Data are shown with a median value (thick black line), 25th and 75th percentiles (upper and lower boundary of box) and maximum and minimum values (whiskers). Boxes labeled with different letters differ significantly among sites ($p < 0.05$, Pairwise Wilcoxon Test with Holm protection).

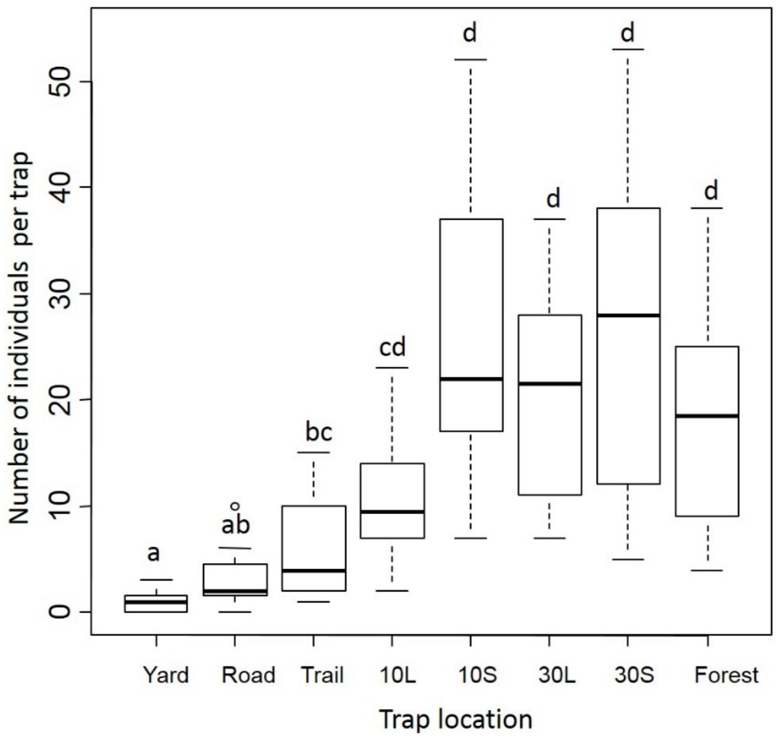
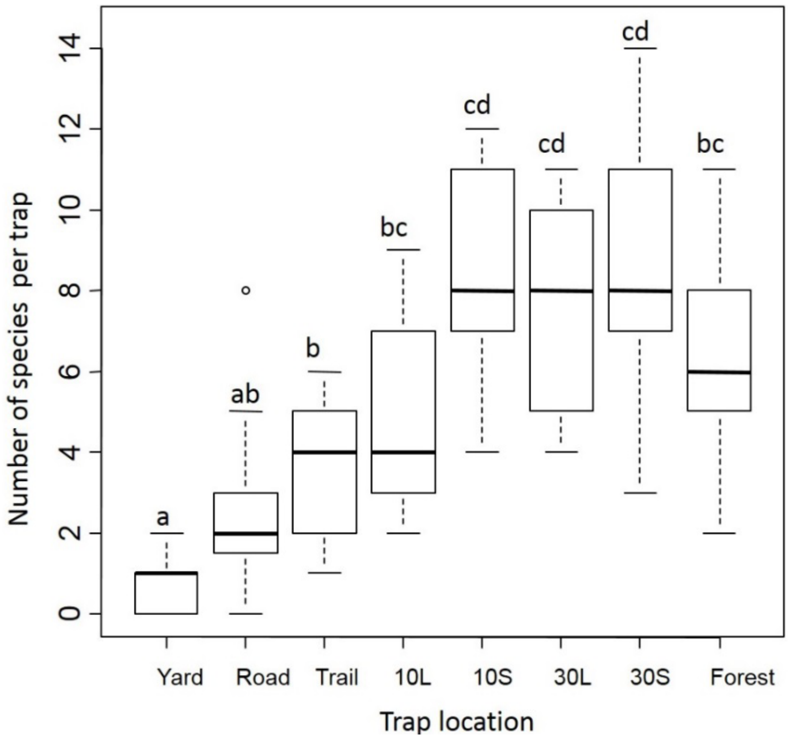


Figure 4. Number of dung beetle species collected with baited pit-fall traps; Yard, log yards; Road, logging roads; Trail, skid trails; 10 L, 30 L, 10 S, 30 S and Forest represent forests at 10 m or 30 m from logging roads, forest at 10 m or 30 m from skid trails and forests at 60 m from logging roads or skid trails, respectively. Data are shown with a median value (thick black line), 25th and 75th percentiles (upper and lower boundary of box) and maximum and minimum values (whiskers). Boxes labeled with different letters differ significantly among sites ($p < 0.05$, Pairwise Wilcoxon Test with Holm protection).



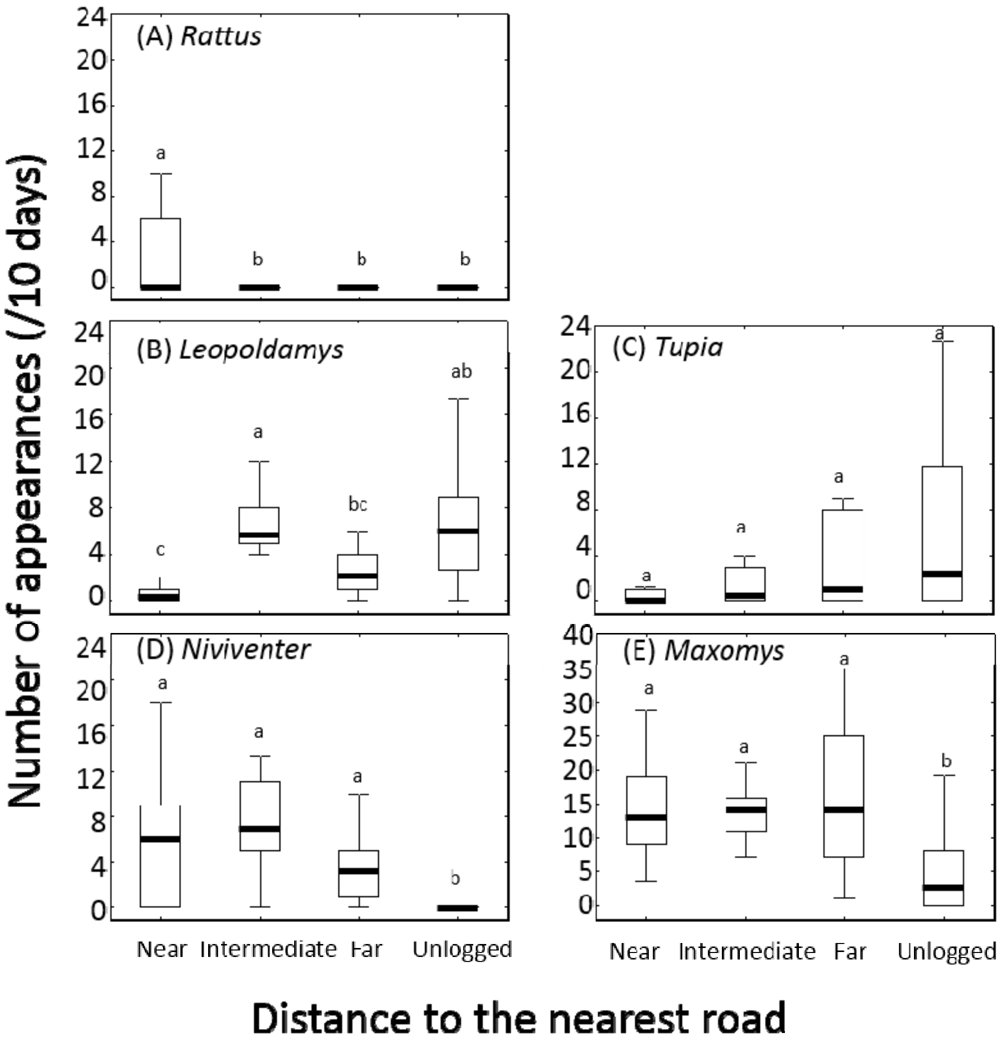
3.2. Small Mammals

We recorded 2330 appearances of small mammals including 14 species in 11 genera belonging to five families in three orders (Table 2). Of the 14 species, nine species were common in both logged and unlogged forests, five species were found only in the logged forest, and no species were found only in the unlogged forest. Diversity of small mammals in the logged forest (median value = 2.32) was comparable to that in the unlogged forest (median value = 2.28, Pairwise Wilcoxon Test, $p = 0.31$).

Species in different genera responded to road networks differently. *Rattus* species, (including *R. rattus* and *R. tiomanicus*) locally invading species, appeared only in the vicinity of logging roads ($D < 100$ m, Figure 5A). *Leopoldamys sabanus* were more abundant at the intermediate distance (from 100 m to 200 m from a logging road, Figure 5B). The appearances of *L. sabanus* in vicinity of logging roads were significantly lower than that in the unlogged forest. *Tupia glis* appeared more frequently with increased distance from logging roads (Figure 5C). Nevertheless, for *Tupia glis* we could not find statistical differences among distance classes and the unlogged forest possibly because of a small sample size of this species. *Niviventer cremoriventer* and *Maxomys* species (including two species each) appeared abundantly everywhere regardless of the distance from a logging road (Figure 5D,E).

Appearances of both *N. cremoriventer* and *Maxomys* species in logged forest were significantly higher than the unlogged forest irrespective of distance from a logging road.

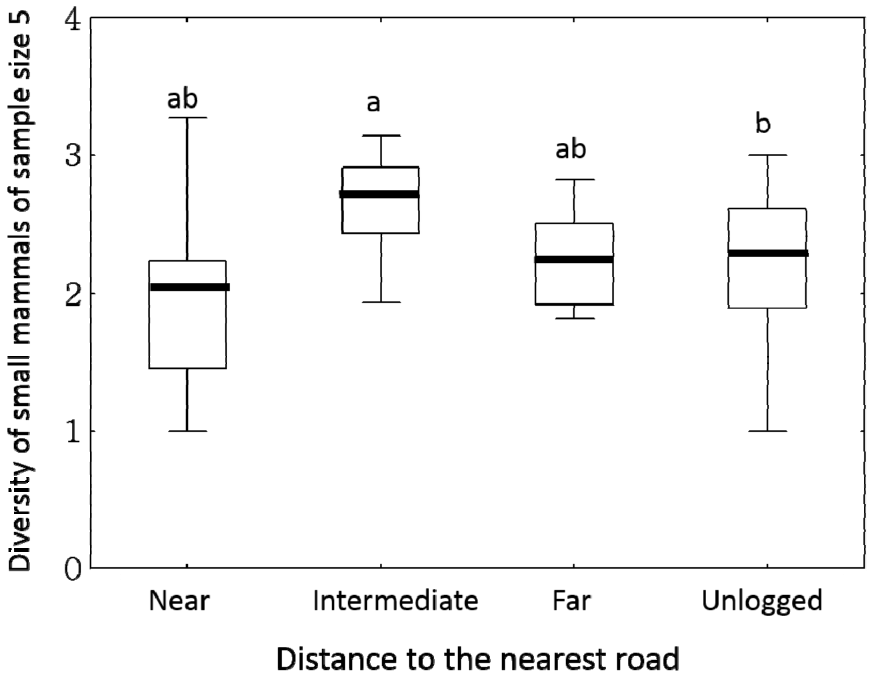
Figure 5. The appearances of small mammals in three distance classes, near (distance from logging road, $D < 100$ m), intermediate (100 m $\leq D <$ 200 m), and far ($D \geq 200$ m) from the logging road in the logged forest in Temengor Forest Reserve for (**A**) *Rattus* species; (**B**) *Leopoldamys sabanus*; (**C**) *Tupia glis*; (**D**) *Niviventer cremoriventer*; and (**E**) *Maxomys* species. The appearances of small mammals in unlogged forest are also shown (unlogged). We counted a series of conspecific appearances in 30 minutes as a single appearance. The number of appearances indicates the total number of appearances for a genus over 10 days per camera. Data are shown with a median value (thick black line), 25th and 75th percentiles (upper and lower boundary of box) and maximum and minimum values (whiskers) of appearances for a genus at 10 cameras within a distance class from the logging road (see Figure 2B). Boxes labeled with different letters differ significantly among sites ($p < 0.05$, Pairwise Wilcoxon Test with Holm protection).



Because most species avoided the vicinity of logging roads, the diversity of small mammals near logging roads was lower than those in other distance classes as well as that in the unlogged forest

(Figure 6), although they were not statistically distinguishable. The diversity in the intermediate distance class from 100 to 200 m was significantly higher than that in the unlogged forest.

Figure 6. Diversity measured by rarefaction index for small mammals trapped by cameras for distance classes, near (distance from logging road (D) < 100 m), intermediate (100 m ≤ D < 200 m), and far (D ≥ 200 m) from the logging road in the logged forest in the Temengor Forest Reserve. The diversity of small mammals in unlogged forest is also shown (unlogged). Data are shown with a median value (thick black line), 25th and 75th percentiles (upper and lower boundary of box) and maximum and minimum values (whiskers). Boxes labeled with different letters differ significantly among sites (p < 0.05, Pairwise Wilcoxon Test with Holm protection).



4. Discussion

4.1. Impacts of Logging Roads on Dung Beetles and Small Mammals

Our pitfall trap surveys demonstrated that even narrow or small clearings for skid trails, logging roads, and log yards affect local distributions of dung beetles, suggesting that any clearings created for road construction largely degrade the quality of dung beetle habitat. Other studies have shown that dung beetle abundance and species richness are the most strongly affected by canopy openness [56]. The increase in canopy openness by road clearings results in the penetration of sunlight and in turn greater temperature and desiccation [57]. Such changes in microhabitat critically affect many forest-dependent species [57]. Tropical dung beetle species have been suggested to be generally unable to exploit modified, high-temperature habitats [58,59].

Perhaps, the change in community structure of dung beetle may affect ecological function of dung beetle [60]. Hosaka *et al*. [44] showed that dung decomposition rates decreased from the forest interior to clearings. Because dung decomposition is directly related to the many ecological functions of dung beetles, for example nutrient cycling, bioturbation, pest control and secondary seed dispersal [29], a decline in dung removal rates should lessen these ecological functions of dung beetles. Actually, a field experiment analyzing secondary seed dispersal by dung beetles suggested that seeds were not often dispersed in clearings while they were dispersed effectively in forest interiors [44]. The construction of road networks in tropical forests alters not only the diversity of forest fauna but also ecological functions provided by them.

Logging has the potential to cause terrestrial mammals to either increase [19] or decrease [61] in abundance. Logging may cause animals that require undisturbed primary forest to abandon an area, which obviously decreases mammalian species diversity. Additionally, these same activities may create a heterogeneous vegetative structure that can enhance mammalian species diversity [[19]. Therefore, the consequences of these activities on species diversity of terrestrial mammals may depend on the intensity and extent of the logging and construction of logging roads. In our analysis of small mammals, on average, our logged forest had comparable biodiversity to the unlogged forest. Additionally, all species that appeared to be using the unlogged forest did appear in the logged forest. All these findings suggest a high conservation value of our logged forest for small mammal diversity in general. Recent meta-analyses also showed similar results compared to ours; 85%–100% of species in a study of biodiversity were maintained after selective logging in a tropical forest [13].

On the other hand, other studies showed that the direct impacts of logging on biodiversity pale in comparison to the impact of logging roads [10]. When looking at the relationships between logging roads and appearance of small mammals, as we expected, logging roads had severe impacts on the local distributions of small mammals. For example, *Rattus* species were found only adjacent to logging roads. They occurred in the vicinity of human settlements or in disturbed areas and rarely inhabit undisturbed primary forest [62]. These species may increase in abundance in areas where selective logging has created severe disturbance such as near logging roads. A recent study suggested that these rat species drive catastrophic extinctions of other small mammals in disturbed forests [62]. Therefore, logging roads that allows *Rattus* species to invade into forests must be minimized if the biodiversity of small mammals is to remain secure.

There were species which were less influenced by logging roads. *Niviventer cremoriventer*, a species that is mainly arboreal, prefers forest edges and lightly wooded areas more than primary, old-growth forests [51]. This trait may result in fewer species occurring in the unlogged forest than in logged forest. Although *N. cremoriventer* appeared in forest edge habitat by logging roads, it completely avoided areas without trees; treeless areas often occur along and adjacent to logging roads. *Maxomys* species showed a similar pattern with *N. cremoriventer*, which had no correlation with distance from logging road, suggesting they exploit a wide variety of habitats. In contrast, *Leopoldamys sabanus* avoided road sides. *Leopoldamys sabanus* is not arboreal, but does climb trees frequently [51]. This trait allows this species to avoid treeless logging roads and their appearance often occurred at an intermediate distance from logging roads.

As mentioned above, species in different genera responded to logging roads differently; some avoided them and others exploited them. As a result, species diversity showed a conservative change with distance from logging roads.

4.2. A Guideline to Safeguarding Biodiversity in Malaysian Production Forests

As expected, our study clearly showed that small clearings by logging road networks ruin habitat quality, resulting in a decrease in dung beetles in small clearings. However, the effects of road networks on dung beetle abundance and species richness were spatially limited. Dung beetle diversity decreased only in forests within 10 m from the logging roads and it rapidly recovered in more interior forest locations. A similar limited impact of logging road on dung beetles was reported by Carpio *et al*. [41].

Although the impacts of logging roads on dung beetle diversity was spatially limited within 10 m from logging roads, a considerable area of a production forest will be damaged by logging roads. For example, in Block 5, the spatial area occupied by the combination of logging roads and log yards was only 12.3 ha of the total of about 200 ha, occupying only 6% of Block 5. However, the areas within 10 m from roads covered 27.4 ha when added to log yard areas, occupying 14% of the study area; that is, a considerable portion of Block 5 had been turned into low quality habitat for dung beetles. Clearly, minimizing logging road density will contribute to retaining forest biodiversity.

To prevent logging road networks from negatively impacting the population size of most sensitive small mammals, such as *L. sabanus*, as a result of habitat degradation, our study suggests that neighboring logging roads should be separated by more than 150 m (the midpoint of the intermediate distance class from 100 m to 200 m). To secure this road interval, the logging road density needs to be less than 66.7 m/ha. Nevertheless, refereeing the Malaysian Standard of Performance in a way that protects the soil from compaction by harvesting machinery and to protect the soil from erosion during harvesting operations, logging road density is required to be less than or equal to 40 m/ha [27], which is stricter than 66.7 m/ha. Another study reported a longer penetration distance of the edge effect for a butterfly species [63]. Therefore, as a precautionary measure for other animals that have a longer distance of edge effect than *L. sabanus*, we tentatively propose a logging road density of less than or equal to 40 m/ha as a quantitative criterion for safeguarding biodiversity in Malaysian production forests. However, to propose more robust criteria, we apparently need more studies including many more species than dung beetles and small mammals.

We examined the effects of logging roads on biodiversity in about 200 ha of Block 5. However, on the other hand, at the same time, the effects may need to be examined in the context of larger areas, because many more species have a much lower tolerance to road distance than small mammals, dung beetles and butterflies [17]. Plus, logging road makes hunters accessible to deeper forests and the hunting pressure may give additional impact on biodiversity [64] and this effect must appear on a larger spatial scale.

Based on dung beetle species assemblages, skid trails also have impacts on biodiversity, although the impact is less than the impact of logging roads. Therefore, minimizing skid trail density will also contribute to retaining forest biodiversity. Again, referring to Malaysian standards of performances for soil compaction and soil erosion, these guidelines require the skid trail density to be less than or equal to 300 m/ha in peninsular Malaysia [27]. When looking at Block 5 where logging roads and skid trails were well planned prior to logging, skid trail density was very moderate, only 75.6 m/ha (Forest Research Institute Malaysia, unpublished data). This density may be reduced further by using various RIL (reduced impact logging) harvesting techniques [65–67]. Obviously, a quantitative criterion for skid trail density for biodiversity safeguard is necessary, but we need additional studies before it is proposed.

The use of road network density as a quantitative criterion for safeguarding biodiversity takes advantage of the requirements of MRV (Measurement, Reporting and Verification) [68]. Any kind of quantitative criteria may be required for the MRV process to check the implementation of a project. The road network density may be detectable by remote sensing techniques [69,70]. Furthermore, if we apply an airborne LiDAR technique [71–73], we can clearly see road networks on a large spatial scale [74] and this technique makes them easily measurable and verifiable. This aspect of road networks provides powerful and feasible criteria for implementing biodiversity safeguards.

5. Conclusions

We need to have quantitative criteria for safeguarding of biodiversity if biodiversity is to be safeguarded effectively. The criteria of logging road network density proposed by this study is an example of such quantitative criteria for Malaysian production forests. Needless to say, we have to have many other quantitative criteria to safeguard biodiversity effectively for Malaysian production forests as well as other land use types.

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Author Contributions

Toshihiro Yamada and Toshinori Okuda developed the study design, collected field data and performed the analysis. Toshihiro Yamada wrote the manuscript. Tetsuro Hosaka and Masahiro Niino studied dung beetles and Toshihiro Yamada and Satoru Yoshida studied small mammals.

Conflicts of Interest

The authors declare no conflicts of interest.

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