Short Communication

Litter loss in Cambodian evergreen forests is mainly caused by soil macrofauna feeding

ITO Eriko[1,*] & TITH Bora[2]

[1] Kansai Research Center, Forestry and Forest Products Research Institute, 68 Nagaikyutaroh, Momoyama, Fushimi, Kyoto, 612-0855 Japan.

[2] Institute of Forest and Wildlife Research and Development, Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia, 120806.

* Corresponding author. Email iter@ffpri.affrc.go.jp

Paper submitted 31 January 2023, revised manuscript accepted 23 April 2023.

Deforestation and forest degradation are ongoing issues in Cambodia (MoE *et al*., 2020). In lowland dry evergreen forests in Kampong Thom Province, many large-diameter trees of Dipterocarpaceae species e.g., *Dipterocarpus costatus* C.F.Gaertn. (*chhoeuteal bankouy* in Khmer) and *Anisoptera costata* Korth. (*phdiek*), have been felled (Ito *et al*., 2010). Selective logging results in microsites with different degrees of disturbance. We examined the weight loss of leaf litter to verify whether the decomposition rate of leaf litter differs among microsites at selective logging sites.

Our study was conducted in lowland dry evergreen forests in Kampong Thom Province in central Cambodia (Fig. 1). These forests developed on sandy alluvial plains, where soils are deep (Ito *et al*., 2021). Mean annual precipitation and temperature are 1,625.8 mm and 27 °C (Kabeya *et al*., 2021), respectively. The monthly average temperature range is 24–29 °C (Chann *et al*., 2011). The seasonal tropical climate, which is governed by monsoons, has been described in detail elsewhere (Ito *et al*., 2021; Kabeya *et al*., 2021).

Experiments were conducted on 12 plots located within a rectangle of approximately 2 km (east–west) × 4 km (north–south). Each plot was set up on the site of a dipterocarp tree logging area that was cut during the 2007–2008 dry season. The plots were established in June 2018; thus, approximately ten years had passed from logging to plot establishment. Each plot comprised five subplots: control, stump, timber, unused trunk and crown

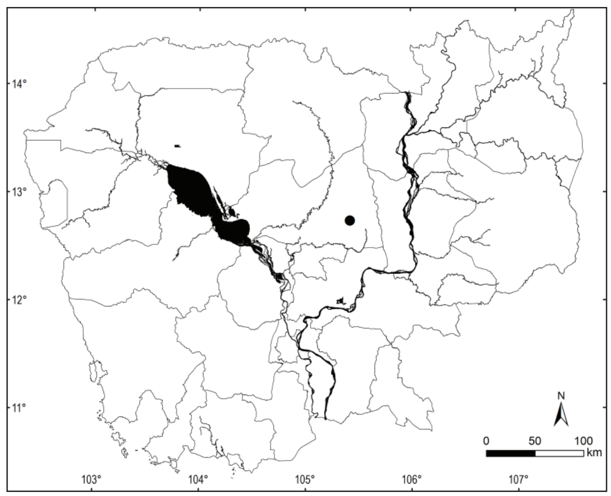

Fig. 1 Location of the study site (solid circle) in Cambodia.

(Fig. 2). The control was selected in a direction opposite to that of logging and in an area with little human disturbance. In the stump subplot, sawing operations were conducted after felling. The lumber was removed from the forest, leaving a large amount of sawdust at the site (Fig. 3). The sawdust had disappeared from the forest by the time of the survey, although decaying wood blocks remained from the sawmilling operations (Fig. 4). Logging roads for lumber removal often passed near the stump and timber subplots (Fig. 5). The quantity of litter on the forest floor was examined near locations where

CITATION: Ito E. & Tith B. (2023) Litter loss in Cambodian evergreen forests is mainly caused by soil macrofauna feeding. *Cambodian Journal of Natural History*, **2023**, 1–7.

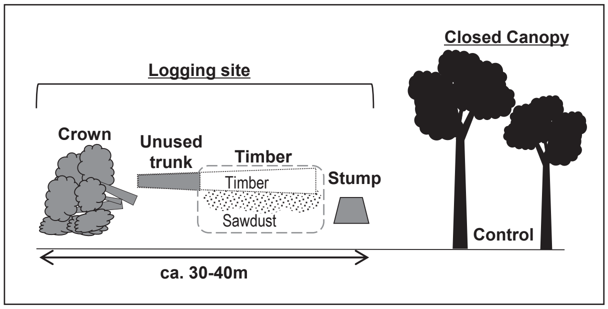

Fig. 2 Schematic diagram of the five subplots: control, stump, timber, unused trunk, and crown. Timber and sawdust may have been deposited in the timber plot during logging operations, but were not present during the survey.

Fig. 3 A) Sawing operations and B) sawdust deposited at the logging site.

Fig. 4 Study site ten years after logging. No sawdust remained, although decaying wood blocks from the sawmilling operation were still present.

Fig. 5 Logging roads near the stump and timber subplots were maintained even ten years after logging.

leaf litter bags (described below) were placed. Organic matter was collected from within a 50 × 50 cm frame and dry weights were measured. The survey dates were 6–13 December 2018 and 7–10 December 2019, depending on the survey plot. The total dry weight of fallen leaves and dry branches did not differ among subplots, whereas the dry weights of bark and wood blocks were significantly higher in the timber subplot than in the unused trunk and control subplots (Table 1).

Leaf litter bags used for leaf decomposition experiments were made of vinylon cheesecloth (polyvinyl alcohol fiber, #500; UNITIKA, Japan), with an opening size of 1.0 mm. Each litter bag was stapled with 0.2 mm thick cold-resistant vinyl numbered tape and packed with fallen dipterocarp leaves weighing approximately 5 g (air-dry weight). Air-dry weight was converted to oven-dry weight using a preliminary sample. Leaves were identified as *D. costatus*, *A. costata*, *Vatica odorata* and *Hopea recopei*. Further details on leaf litter collection are provided in Table 2 and Fig. 6a.

Collected leaves were sorted into leaves and bags and their oven-dry weights were measured. Collection bags installed for the dry season (2.5 months, Table 1) remained white until the time of collection, whereas those collected after the rainy season (at 9.5 and 12 months) had microscopic amounts of soil trapped in the gaps between the fibers (Fig. 6b). Consequently, some bags increased in weight during the collection period (Fig. 7).

Unexpectedly, nearly all bags were damaged (605 of 610) and many were partially lost (Figs 7, 8, 9a). The underside of bags in contact with the ground were more prone to extensive damage and loss (Figs 8, 9b) and when a large part of a bag was lost, its upper and lower sides were often equally damaged (Fig. 8). Number tapes were frequently also partially lost; some remaining number tapes had semi-circular gouges with a radius of approximately 2 mm, which were presumed to be bite marks (Fig. 9c). Thus, we infer that soil macrofauna with a bite width of approximately 2 mm had foraged on the litter bags and surrounding leaves. We also observed sand corridors or clusters at or near the undersides of the damaged nets (Fig. 9d). These observations may imply that the bag damage and loss were caused by wood- and/or litter-eating termites.

During the field surveys, we did not observe termites or any other soil animals foraging on litter bags installed at the site. However, termite mounds were found, especially near stumps (Fig. 9e) and termites were observed feeding on timber in the same forest as the study site (Fig. 9f). Termites are major ecosystem engineers responsible for decomposing wood and leaf litter (Abe *et al*., 2000; Ohkuma, 2003). Termites have been reported in the seasonal tropics of the Indochina Peninsula (Harris, 1968), including in some ecological studies of forest (Vietnam: Vu *et al*., 2007; Thailand: Takematsu

Table 1 Dry weight (Mg ha^{-1}) of litter on the forest floor according to study subplots. Data are means ± standard deviation (range). Different letters among columns indicate significant differences according to analysis of variance (ANOVA: p<0.05).

Item	Control	Stump	Timber	Unused Trunk	Crown	*p*
Total	4.2 ± 2.2 (1.8–9.2)	4.6 ± 3.6 (1.8–15.4)	6.8 ± 6.7 (1.7–23.9)	3.5 ± 1.3 (1.7–6.1)	3.6 ± 1.0 (2.0–5.3)	0.1361
Leaves	2.0 ± 0.8 (1.0–3.5)	1.4 ± 0.6 (0.7–2.8)	1.6 ± 1.7 (0.6–6.8)	1.4 ± 0.6 (0.9–2.5)	1.5 ± 0.7 (0.7–3.3)	0.6879
Branches	1.5 ± 1.5 (0.2–5.5)	0.7 ± 0.5 (0.1–1.9)	0.8 ± 0.5 (0.2–2.0)	1.7 ± 1.5 (0.5–5.1)	1.1 ± 0.8 (0.1–2.9)	0.1037
Bark & wood blocks	0.4 ± 0.7^{b} (0.0–1.8)	2.4 ± 4.0^{ab} (0.0–14.0)	4.4 ± 6.9^{a} (0.0–22.3)	0.4 ± 0.8^{b} (0.0–2.1)	0.9 ± 1.0^{ab} (0.0–3.3)	0.0244

Table 2 Duration of leaf litter bag installation.

Duration (months)	Installation Date	Collection Date	Period (days)	Season	*n*
2.5	13 December 2018	2 March 2019	79–80	Rainy	10
9.5	2–3 March 2019	7–11 December 2019	280–284	Rainy, briefly dry	300
12	2–3 March 2019	26–27 February 2020	360–362	Rainy and dry	300

Fig. 6 Leaf decomposition experiments using leaf litter bags. A) Installation and B) collection of leaf litter bags at the same site.

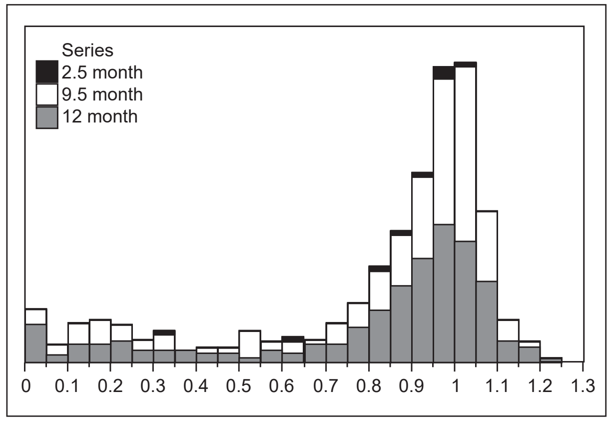

Fig. 7 Histogram of weight ratios of litter bags before and after installation (after/before).

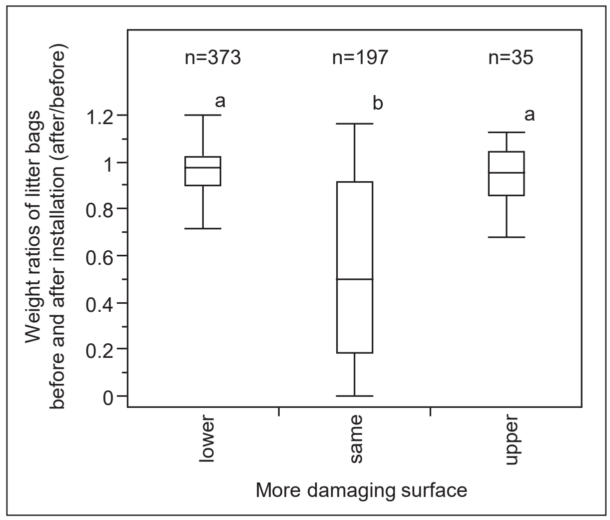

Fig. 8 Relationship between litter bag damage and installation position, and between weight ratios before and after installation. Plots show the median, 25% and 75% quartiles, and range of the data. Different letters among columns indicate significant differences according to analysis of variance (ANOVA: $p<0.05$).

& Vongkaluang, 2012). Termite research in Cambodia is primarily concerned with damage to buildings (e.g., Megna & Liotta, 2015). Only a few studies have examined the ecology of forest termites, either as food consumed by jackals (Kamler *et al*., 2021) or in relation to a new beetle species (Maruyama, 2012). Although not conducted in our study, comparison of termite species composition, population density, and ecological traits between the logging site and surrounding undisturbed sites would contribute to clarifying the roles of termites in Cambodian forest ecology. Further research on termite ecology in Cambodian forests is needed.

The residual weight ratio of leaves i.e., the ratio of leaf litter weight in bags after installation compared to before installation, was clearly related to bag disappearance (Fig. 10). As the degree of bag residuals decreased, the degree of leaf litter residuals decreased exponentially. Thus, we infer that wood/litter-eating termites entered the bags through holes made by chewing and preferentially foraged on the trapped leaves. This suggests that litter loss in Cambodian evergreen forests is mainly caused by soil macrofauna feeding, but it is also possible that soil organisms with body sizes that can pass through a mesh size of 1 mm (microfauna and mesofauna) could be contributing to the reduction in leaf weight. However, it is not possible to quantify the relative contributions of micro- vs. meso- vs. macrofauna to leaf weight reduction with our data. This should be clarified through leaf litter

Fig. 9 A) Damaged litter bags and number tapes at study site, B) Underside of a severely damaged bag that was in contact with ground surface, C) Semi-circular gouge in a damaged number tape, D) Soil clusters, likely derived from soil animals, were found on ground surface after litter bags were collected, E) Termite mounds near stumps, F) Termites feeding on rotten timber.

decomposition tests with graded mesh sizes using robust materials that are not damaged by soil animals.

We developed generalized linear models to predict the weight ratios of litter bags and leaves before and after installation using subplots and installation period as independent variables and plot as a random effect. All statistical analyses were performed using JMP v10.0 statistical software (SAS Institute Inc., USA). Due to the limited number of samples collected at 2.5 months, we used only the data from samples collected at 9.5 and 12 months. Subplots significantly predicted the weight ratios of litter bags (p<0.0001), whereas installation period had no significant effect. Timber subplots showed

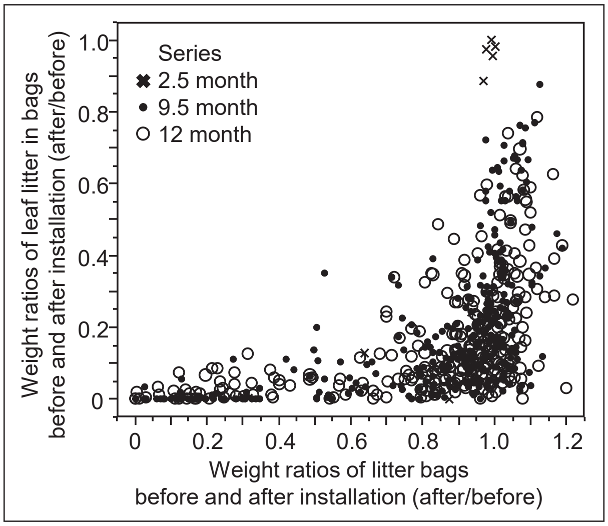

Fig. 10 Relationship between residual weight ratios of litter bags and leaves in bags.

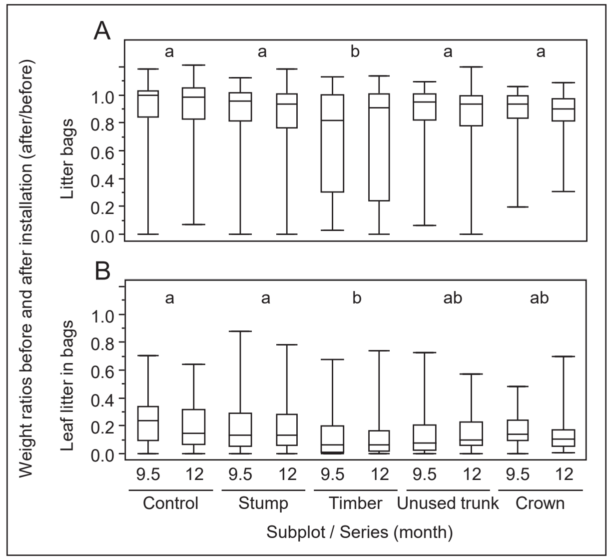

Fig. 11 Residual weight ratios of A) litter bags and B) leaves in bags according to subplot and sampling duration. Plots show the median, 25% and 75% quartiles, and range of the data. Different letters among columns indicate significant differences according to analysis of variance (generalized linear model: $p<0.05$).

significantly lower ratios than the other subplots (Fig. 11a). Subplots significantly predicted the weight ratios of leaves (p=0.0003) and installation period was also significant (p=0.0423). The timber subplots had significantly lower ratios than the control and stump subplots (Fig. 11b). Weight ratios were significantly lower for leaves collected at 12 months (least-squares mean=0.16) than for those collected at 9.5 months (0.19). Significantly greater bag and leaf sample losses in the timber subplots may have been caused by termite density. Wood-feeding termites were found to be more abundant in recently logged areas in Amazonia (Azevedo *et al*., 2021). It is possible that the large amount of sawdust left at the timber subplot in the past attracted termites, leading to higher termite density at that plot.

There were no differences in litter accumulation such as fallen leaves and branches on the forest floor between subplots (Table 1). Variability in the degree of leaf litter loss from the bags was lower among subplots than among bags (Fig. 11). The scale of the logging site was several tens of meters (Fig. 2). The distance from some termite nests to feeding areas was on a similar or greater scale (Abe, 1979; Hoare & Jones, 1998), which suggests that termites move through the forest floor to forage for fallen leaves. Although logging of large-diameter trees causes significant heterogeneity in the forest floor environment, the material cycle originating from plant litter supplied to the forest floor by termites or other leaf litter foragers migrating across the forest floor is likely to be relatively uniform. Selective logging may have a lower long-term impact on nutrient cycling and decomposition than other anthropogenic disturbances (Azevedo *et al*., 2021). Our results are consistent with this finding.

Acknowledgements

The authors are deeply indebted to H.E. Dr. Keo Omaliss, Director-General of Forestry Administration, and three former Director-Generals of the Forestry Administration, H.E. Dr. Ty Sokhun, H.E. Dr. Chheng Kimsun and H.E. Mr. Ung Sam Ath, for their support of the Changes of Water Cycle in Mekong River Basin (CWCM) project. We are grateful to Dr. Sokh Heng, Director of the Institute of Forest and Wildlife Research and Development within the Forestry Administration for permission to undertake field research. We would like to sincerely thank our former CWCM project coordinator, Mr. Chann Sophal for all his hard work over the years. We thank Prof. Motohiro Hasegawa for providing valuable insights into termites in the tropics and we also thank Ms. Reiko Takeuchi, Ms. Kimiko Awaji and Ms. Yukari Yamamoto for supporting our litter bag experiment. This work was supported by JSPS KAKENHI Grant Number 18K06437.

References

Abe, T. (1979) Studies on the distribution and ecological role of termites in a lowland rain forest of west Malaysia (2), food and feeding habits of termites in Pasoh Forest Reserve. *Japanese Journal of Ecology*, **29**, 121–135.

Abe, T., Bignell, D.E. & Higashi, M. (2000) *Termites: Evolution, Sociality, Symbiosis, Ecology*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Azevedo, R., Santos, Q., Fluck, I., Rodrigues, D., Battirola, L. & Dambros, C. (2021) Selective logging does not alter termite response to soil gradients in Amazonia. *Journal of Tropical Ecology*, **37**, 43–49.

Chann S., Keth N., Nobuhiro T., Araki M., Tamai K., Shimizu T., Kabeya N., Iida S. & Shimizu A. (2011) Interannual variation in the evapotranspiration of an evergreen forest in Kampong Thom, central Cambodia. In *Proceedings of International Workshop on Forest Research in Cambodia, November 2011* (eds Shimizu A., Chann S., Sawada H., Ohnuki Y. & Tamai K.), pp. 21–24. Forestry and Forest Products Research Institute, Japan and Forestry Administration, Cambodia.

Harris, W.V. (1968) Isoptera from Vietnam, Cambodia and Thailand. *Opuscula Entomologica*, **33**, 143–154.

Hoare, A. & Jones, D.T. (1998) Notes on the foraging behaviour and taxonomy of the southeast Asian termite *Longipeditermes longipes* (Termitidae: Nasutitermitinae). *Journal of Natural History*, **32**, 1357–1366.

Ito E., Furuya N., Tith B., Keth S., Chandararity L., Chann S., Kanzaki M., Awaya Y., Niiyama K., Ohnuki Y., Araki M., Sato T., Matsumoto M. & Kiyono Y. (2010) Estimating diameter at breast height from measurements of illegally logged stumps in Cambodian lowland dry evergreen forest. *Japan Agricultural Research Quarterly*, **44**, 435–446.

Ito E., Tith B., Keth S., Chann S., Iida S., Shimizu T., Tamai K., Araki M., Kabeya N. & Shimizu A. (2021) Bimodal leaf fall in a lowland dry evergreen forest in Cambodia. *Cambodian Journal of Natural History*, **2021**, 21–39.

Kabeya N., Shimizu A., Shimizu T., Iida S., Tamai K., Miyamoto A., Chann S., Araki M. & Ohnuki Y. (2021) Long-term hydrological observations in a lowland dry evergreen forest catchment area of the lower Mekong river, Cambodia. *Japan Agricultural Research Quarterly*, **55**, 177–190.

Kamler, J.F., Minge, C., Rostro-García, S., Gharajehdaghipour, T., Crouthers, R., In V., Pay C., Pin C., Sovanna P. & Macdonald, D.W. (2021) Home range, habitat selection, density, and diet of golden jackals in the Eastern Plains Landscape, Cambodia. *Journal of Mammalogy*, **102**, 636–650.

Maruyama M. (2012) A new genus and species of flightless, microphthalmic *Corythoderini* (Coleoptera: Scarabaeidae: Aphodiinae) from Cambodia, associated with *Macrotermes* termites. *Zootaxa*, **3555**, 83–88.

Megna, B. & Liotta, G. (2015) Biodeterioration of the wooden roof of the Phnom Penh national museum. *Conservation Science in Cultural Heritage*, **15**, 73–83.

MoE, UNDP, FAO, JICA & FFPRI (2020) *Cambodia Forest Cover 2018*. Https://data.opendevelopmentcambodia.net/library_record/cambodia-forest-cover-2018 [accessed 31 May 2022].

Ohkuma M. (2003) Termite symbiotic systems: efficient bio-recycling of lignocellulose. *Applied Microbiology and Biotechnology*, **61**, 1–9.

Takematsu Y. & Vongkaluang C. (2012) A taxonomic review of the Rhinotermitidae (Isoptera) of Thailand. *Journal of Natural History*, **46**, 1079–1109.

Vu Q.M., Nguyen H.H. & Smith, R.L. (2007) The termites (Isoptera) of Xuan Son National Park, northern Vietnam. *The Pan-Pacific Entomologist*, **83**, 85–94.

