Pakistan J. Zool., pp 1-4, 2023. **DOI**: https://dx.doi.org/10.17582/journal.pjz/20210911090910

Small Mammal Abundance and Forest Structure Changes by Different Post-Fire Silvicultural Practices in Phou Khao Khauy National Protected Area, Lao PDR

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Article Information
Received 11 September 2021
Revised 05 May 2022
Accepted 21 May 2022
Available online 02 June 2023 (early access)

Authors' Contribution
EJL designed the study. BS performed field work. EJL and BS analysed the data. BS wrote the manuscript. EJL and YHL modified the manuscript.

Key words
Forest structure, Primary forest, Rice fields, Rubber plantation stands, Small rodents

ABSTRACT

We examined the abundance of five small rodent species, the chestnut white-bellied rat (*Niviventer fulvescens*), red spiny rat (*Maxomys surifer*), long-tailed giant rat (*Leopoldamys sabanus*), house mouse (*Mus musculus*), and black rat (*Rattus rattus*), and the stand structure of primary and secondary forest stands resulting from two types of post-fire silvicultural management practices in the Phou Khao Khauy National Protected Area (PKKNPA), Lao PDR. Post-fire silvicultural practices contributed to dramatically converting the structure of forests. Coverage of overstory, midstory, and ground vegetation, number of tree stems, woody seedlings, snags, and volume of coarse woody debris all had significant differences among study sites. We captured 456 individual small rodents during the dry and rainy seasons. The mean number of small rodents captured in primary forests was significantly higher than that in two secondary forests. In addition, there were more rodents in burned rice field stands than in burned rubber plantation stands. The value of overstory to understory vegetation coverage and the volume of coarse woody debris were strongly associated with small-mammal abundance in the PKKNPA. Thus, post-fire silvicultural practices should take the differences in small rodent abundance as well as forest structure into account. Long-term experiments may help illuminate the potential effects of management strategies after forest fires in the Lao PDR.

INTRODUCTION

Southeast Asia has the highest annual deforestation, with a rate of 1.9%, compared to the average global rate of 0.2–0.3% (Mattews, 2001). The effect of changing habitat in tropical rainforest ecosystems on wildlife biodiversity is an urgent subject for appropriate forest management and species conservation. Forests in Southeast Asia are utilized for various human purposes, including traditional utility. Thus, both deforestation and anthropogenic uses are dispersed at the landscape level.

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0030-9923/2023/0001-0001 $ 9.00/0

The Lao People's Democratic Republic (Lao PDR) largely comprises hills and plateaus, as well as mountainous terrain that accounts for over 80% of its territory. Approximately 40% of its total land area is forested, with over 10% of its forest classified as primary forest (FAO, 2001). However, previous studies indicate that the characteristics of tropical forests have been highly disturbed, and primaryforest coverage has continued to decrease in recent decades (Angel *et al*., 2009). In addition, Lao PDR has a further 600 million ha of logged-over forests and secondary forests, with an average of more than 9 million ha generated every year (Brown and Lugo, 1990; Emrich *et al*., 2000).

The forest cover of Lao PDR has also declined from 70% in 1943 to 49% in 1982, 47.2% in 1992, 45% in 2002, and 40.3% in 2010 (DoF, 2010). With this rapid rate of deforestation, it is estimated that forest cover is approaching 30% (MAF, 2005). To prevent the rapid loss of forest cover, Lao PDR initiated a reform program in natural resource management in the early 1990s. The loss of forest cover caused major changes in land use, including the development of hydropower, mining, slash-and-burn agriculture and industrial plantations (MAF, 2005).

In addition, Lao PDR is experiencing an extensive and uncontrolled expansion of industrial rubber plantations. This expansion has been motivated by the strong demand for natural rubber in key rubber producing and processing countries, such as China, India, and Vietnam. Several industry experts predict that the existing estimate of 180,000 to 200,000 ha of rubber plantations in Lao PDR will increase to approximately 300,000 ha by 2020 (Hicks *et al*., 2009). Hence, the policies that mandate protecting and conserving the biodiversity of Lao PDR are in conflict with reality.

Changes in forest composition after forest destruction (e.g., wildfires, landslides, and logging) have impacts on the populations of diverse wild animals, such as rodents (Dunstan and Fox, 1996; Kelt, 2000), bats (Schulze *et al*., 2000), birds (Sieving and Karr, 1997), and insects (Brown and Hutchings, 1997). In particular, forest destruction by large wildfires may produce substantial changes in the population and structure of small rodent communities (Whelan, 1995). Small rodents contribute to the biodiversity of forest ecosystems and towards functional diversity and species richness (Lee *et al*., 2008). Additionally, they have an important role in forest ecosystems as prey for other wild animals (e.g., reptilians, bird of prey, and mammalian predators) (Lee *et al*., 2012), and also consumers of wild vegetation and invertebrates.

The objective of this study was to investigate the population of small rodents in forest stands with different post-fire management practices and find the implications of our results for forest management, considering the biodiversity in Lao PDR. We lack information on the distribution and ecological characteristics of small rodents inhabiting the forests in Lao PDR. Additionally, though changes in habitats after wildfires affect the population of small rodents (Lee *et al*., 2012; Sullivan *et al*., 1999), how will post-fire management practices associated with habitat conditions change the population of small rodents in Lao PDR remains underexplored. Through understanding the population and characteristics of small mammals in the Phou Khao Khauy National Protected Area (PKKNPA), Lao PDR, this study may contribute to developing suitable forest management practices to maintain its biodiversity and ecological values (Converse *et al*., 2006a).

MATERIALS AND METHODS

Our study was carried out in PKKNPA (18°14′–18°32′ N, 102°38′–102°59′ E), Lao PDR. PKKNPA was declared in 1993 by Prime Minister's Decree 163 (ICEM, 2003), and its protection was placed under the Ministry of Defense's jurisdiction in 1994. This law aims to restore and enhance the biodiversity and ecosystem values of the protected area while maintaining their habitats. PKKNPA has an approximate area of 2000 km^2. The topological characteristics in PKKNPA consist of steep slopes in the low-elevation central portion of the protected area and on the Phou Khao Khauy plateau, where the elevation ranges approximately from 100 to 1700 m above sea level (Lucas *et al*., 2013). Most of PKKNPA is located on rough mountain slopes, cliffs of steep sandstone, flat uplands, or hilly terrain. The steep topography of PKKNPA was created by the exposure and uplifting of underlying sediments (Salter and Phanthavong, 1990).

PKKNPA has a tropical monsoonal climate, similar to the kind experienced in central Laos, with the rainy season starting in May and ending in October, and the dry season progressing from November to April. In the lowland of this site, the average precipitation is approximately 2049 mm, with 92% of rain occurring in May-October. Temperatures are high at the beginning of the rainy season, making April the hottest month with an average temperature of about 39°C, whereas December is the coldest with an average temperature of 10°C (Kitamura *et al*., 2018).

This study was conducted in different forest types. Natural forest stands were original primary forest dominated by *Hopea* spp., *Dipterocarpus* spp., *Vatica dyeri*, and *Anisoptera robusta*, even though selective cuttings for hose or coffin contracture have traditionally happened in limited areas. Post-burned rice field stands were secondary forest at a developmental stage following slash and burn agricultural practices, such as young fallow. Dominant tree species in young fallow (i.e., 4–6 years) were *Cratoxylum cochinchinensis*, *Mesua ferrea, Aporosa villosa*, *Oxytenanthea parviflora*, and *Gigantichloa albociliata*. Post-burned rubber plantation stands, like cultivated agricultural areas, differed from natural communities by including low plant species diversity. Most forest plantations tended to be monocultures, where the dominant tree species was rubber (*Hevea brasiliensis*). Small landholders planted those trees 3–5 years after the abandonment of slash-and-burn agriculture.

Forest structure data were gathered at each trap station in December 2015. We used the circle method following Lee *et al*. (2008) to survey environmental factors. We measured forest conditions at each trap station (108 stations/stand) within a circle of 2.5 m in radius. The stand characteristics within each circle were recorded, including species, number of shrubs, snags, woody seedlings, diameter at breast height (DBH) for each tree, and volume of down coarse woody debris (CWD). We divided vertical layers within the circles into overstory (20–50 m), sub-overstory (8–20 m), mid-story (2–8 m) and ground (0–2 m). Coverage was classified into four categories on the basis of coverage rates in each vertical layer within the circle, as per the method proposed by Rhim and Lee (2001): 0 (percent coverage = 0%), 1 (1–33%), 2 (34–66%), and 3 (67–100%).

To avoid pseudo-replication, each plot was located at least 300 m from other plots. We used three hectares representing each type of forests, designated as natural forest stands, post-burned rice field stands, and post-burned rubber plantation stands. Each of the three hectares was divided into three subplots, and each subplot was separated into a grid pattern consisting of a 20×20 m array for trapping and investigating habitats.

We trapped small rodents over 10 consecutive nights per season using Sherman live traps (7.5 × 9.2 × 29.2 cm) baited with peanuts, in August 2015 (rainy season) and December 2015 to January 2016 (dry season) (Lee *et al*., 2012). The traps were placed in six lines in each plot, each line consisting of six traps at 20 m intervals at each station. The three-hectare trapping grids had 108 trap stations (20× 20 arrays at 20 m intervals) with live traps in each forest type. The data recorded for all captured small mammals in this study were sex, maturity, body mass, trap location, whether the specimen was new or recaptured, and release conditions (Lee *et al*., 2012). For individual identification, each small mammal captured was given an ear tag number and was released at the point of capture immediately (Rhim and Lee, 2001; Lee *et al*., 2008).

For the analysis of stand structures, each subplot of three different forest stands was analyzed through randomized-block analysis of variance (ANOVA) to compare forest coverage, number of tree stems, number of shrubs, number of snags, number of woody seedlings, and volume of downed CWD among stands (Zar, 1984). We used two-way ANOVA to compare the differences in small mammal abundance by stand and season. Also, we utilized step-wise multiple regression models for determining which environmental factors accounted for the biggest portion of variation in the abundance of small rodents. A step-wise multiple regression helps identify which variable explains the greatest variability of species abundance, as well as which variables belong to the regression model (Lee *et al*., 2008). Variables can be eliminated when variables are strongly correlated. Variables were selected for the regression model if the p value was smaller than 0.10. After utilizing the step wise process to identity important and statistically significant variables, we analyzed the overall models through regression. The significance level was $p < 0.05$ for all analyses. All variables are presented as mean ± standard error (Table I).

RESULTS

We found significant differences in forest structure among forest stands. Overstory vegetation coverage (simple one-way ANOVA, F = 134.721, $p < 0.001$) and sub-overstory vegetation coverage (F = 52.112, $p < 0.001$) were the highest in the natural forest stand but had no coverage in the post-burned rice field stand or post-burned rubber plantation stand, while mid-story (F = 60.677, $p < 0.001$) vegetation coverage was the highest in the post-fire rubber plantation stand and lowest in the natural forest stand (Table I). However, ground vegetation coverage was higher in the post-burned rice field stand than that in the other forest types (F = 159.518, $p < 0.001$). Additionally, the number of tree stems (F = 288.142, $p < 0.001$) and volume of downed CWD (F = 11.615 $p < 0.001$) were the highest in the natural forest stand, whereas the number of woody seedlings (F = 2.779, $p = 0.064$) did not show significant differences between the natural forest stand, post-burned rice field stand, and post-burned rubber plantation stand. There were more snags in the natural forest stand than in the other types of forests, which is statistically significant (F = 13.795, $p < 0.001$).

Table I. Differences in forest variables with results of ANOVAs that are nature forest and secondary forest with different post-fire management practices at PKKNPA.

Variables	Forest type			df	F	P value
	Nature forest stand (n=108)	Post-burned rice field stand (n=108)	Post-burned rubber plantation stand (n=108)			
Coverage of over story vegetation	1.43± 1.277[a]	-	-	2	134.721	<0.0001
Coverage of sub-over story vegetation	0.72 ± 1.040	-	-	2	52.112	<0.0001
Coverage of mid-story vegetation	0.66 ± 0.888	1.57 ± 0.919[a]	1.90 ± 0.760[a]	2	60.677	<0.0001
Coverage of ground vegetation	-	1.46 ± 0.766	0.68 ± 0.708	2	159.518	<0.0001
Number of tree stems/survey point	6.24 ± 2.055	0.98 ± 3.66	0.48 ± 0.502	2	288.142	<0.0001
Number of shrub stems/survey point	5.17 ± 2.578	14.83 ± 5.138	2.02 ± 3.840	2	302.319	<0.0001
Number of woody seedlings/survey point	5.50 ± 4.045	4.35 ± 3.624	4.56 ± 3.710	2	2.779	0.064
Number of snags/survey point	0.16 ± 0.366	0.03 ± 0.165	-	2	11.424	<0.0001
Volume of downed CWD (m3/ha)	1.189 ± 3.502	0.106 ± 0.455	0.022 ± 0.127	2	11.615	<0.0001

Coverage indices are 0 (coverage percentage= 0%); 1 (1–33%); 2 (34–66%); and 3 (67–100%); CWD, Coarse Woody Debris; [a]Mean ± S.E.

Table II. Number of small mammals captured by the capture-mark and release method among nature forest stand, post-burned rice field stand and post-burn rubber plantation stand in rainy season and dry season.

Season	species	Forest types			Total
		Nature forest stand	Post-burned rice field stand	Post-burned rubber plantation stand	
Rainy	N.f	89(35.54)a	22(7.15)	-	104(43.69)
	M.m	49(25.24)	60(25.35)	35(18.17)	144(68.76)
	R.r	61(37.24)	57(21.36)	23(12.11)	141(70.71)
	M.s	53(26.27)	27(10.17)	-	80(36.44)
	Total	253(123.120)	166(63.103)	58(30.28)	469(217.260)
Dry	N.f	249(104.145)	31(15.16)	-	279(119.160)
	M.m	23(10.13)	48(16.32)	15(9.6)	86(35.51)
	R.r	35(18.17)	28(12.16)	5(2.3)	68(32.36)
	M.s	61(33.28)	30(11.19)	-	91(44.47)
	L.s	19(10.9)	-	-	19(10.9)
	Total	387(175.212)	137(54.83)	20(11.9)	543(240.303)

Abbreviation of species, N.f, *Niviventer fulvescens*; M.m, *Mus musculus*; R.r, *Rattus rattus*; M.s, *Maxomys surifer*; L.s, *Leopoldamys sabanus*. [a]No. of time that small mammal was captured (No. of captured individuals, No. of times recaptured).

During the study period, we captured 456 individuals (1020 captures in total) in nine study stands belonging to five species, including *Niviventer fulvescens*, *Maxomys surifer*, *Leopoldamys sabanus*, *Mus musculus*) and *Rattus rattus* (Table II). In the rainy season, 216 individuals belonging to four small mammal species (excluding *L. sabanus*) were captured for a total of 476 times. In the dry season, 240 individuals comprising these five species were captured a total of 544 times. The abundances of *R. rattus* and *N. fulvescens* were the highest in the rainy and dry season, respectively. No *L. sabanus* were captured in the rainy season. The total number of captured small rodents in the natural forest stand was more than that of other forest types, whereas rodent abundance was lower in the post-burned rubber plantation stand in both seasons relative to other forest types. In addition, the abundance of all rodent species captured in the rainy season, and the four rodent species (except *M. surifer*) captured in the dry season were the highest in the natural forest stand and the lowest in the post-burned rubber plantation stand. The total abundance and abundance of each rodent species differed significantly between stands, seasons, and stands *seasons (Table III). Additionally, small rodent community composition significantly differed among stands (ANOSIM; R= 0.53, $p = 0.03$).

Of the total five small mammal species analyzed, all species showed two or more significant correlations with forest variables according to the step-wise approach (Table IV). *L. sabanus* was excluded in the analysis of correlations due to lack of data. The volume of downed CWD was the most influential variable for these four species. *N. fulvescens* and *M. surifer* were also sensitive to overstory coverage, and *M. musculus* and *R. rattus* exhibited positive associations with mid-story coverage (Bonferroni test: $p = 0.001$).

Table III. Comparison of small mammal communities and, result from the Univariate Analysis of Variance (two-way ANOVA) among nature forest stand, post-burned rice field stand, and post-burned rubber plantation stand during rainy season and dry season.

Species	Description	df	F	P value
R. rattus	Forest	2	75.55	0.01
	Season	1	16.64	0.01
	Forest*season	2	4.36	0.03
M. musculus	Forest	2	3.82	0.05
	Season	1	48.69	0.01
	Forest*season	2	1.65	0.23
N. fulvescens	Forest	2	48.09	0.01
	Season	1	0.19	0.67
	Forest*season	2	0.79	0.48
M. surifer	Forest	2	59.53	0.01
	Season	1	15.74	0.01
	Forest*season	2	4.15	0.04
L. sabanus	Forest	2	100	0.01
	Season	1	100	0.01
	Forest*season	2	100	0.01
Total	Forest	2	51.73	0.01
	Season	1	40.93	0.01
	Forest*season	2	2.59	0.12

Table IV. Relationship between small mammal species and forest available, results multiple regression analysis showing to compete models with associated habitat variables that influenced small mammal abundance.

	N. fulvescens	*M. musculus*	*R. rattus*	*M. surifer*
First variable	Overstory coverage	Midstory coverage	Volume of downed CWD	Sub-overstory coverage
Coefficient	0.01	0.01	0.01	0.01
Partial r^2	0.78	0.82	0.71	0.79
Second variable	Volume of downed CWD	Volume of downed CWD	Mid-story coverage	Volume of downed CWD
Coefficient	0.03	0.04	0.03	0.03
Partial r^2	0.67	0.64	0.64	0.66
Third variable	Sub-over story coverage	Ground coverage		
Coefficient	0.10	0.05		
Partial r^2	0.47	0.61		
Model r^2	0.89	0.79	0.81	0.74
Model P	0.01	0.01	0.01	0.01

DISCUSSION

The structural characteristics of forest stands are the major determinant of habitats for small mammals such as small rodents (Monamy and Fox, 2010). Changes in forest structure resulting from wildfires thus influence changes in small mammal communities (Wilson and Carey, 2000; Converse *et al*., 2006b). Wildfire and post-fire management practices dramatically changed the forest structure of our study area. Vegetation coverage, number of tree stems, number of shrubs, number of snags, and volume of downed coarse woody debris were significantly different among the three different forest types of our study area. Only the number of woody seedlings was not significantly different in the study areas. Wildfire and post-fire management can create new habitats and microhabitats that represent a function of time following the fire (plant secondary succession) and are preferentially selected by different mammalian species (Fox, 1982). In addition, forest canopies become open because of the management practice of removing damaged trees after a wildfire. Thus, we found that forest variables showed significant differences among natural forest stands, post-burned rice field stands, and post-burned rubber plantation stands. Our results support that forest structure differs among primary forest and secondary forests subjected to different post-fire management practices.

The number of small mammals captured was high in the natural forest stand, which had a higher coverage of overstory and sub-overstory vegetation, a higher number of snags, and a higher volume of downed coarse woody debris than both secondary forest stands. This result is likely due to the fact that CWD is necessary to maintain small mammal populations; it thus had been recommended as a key factor of forest stands (Fuller, 2004; Lee *et al*., 2012). As microhabitat characteristics, including the number of tree stems, shrubs, snags, the volume of woody debris and forest coverage, play an important role in determining small mammal abundance and diversity (Dueser and Shugart, 1978), downed woody material can also provide a habitat for invertebrates, escape cover from predators (Hayes and Cross, 1987; Lee *et al*., 2012), and a growing surface for fungi (Hagan and Grove, 1999), and create a microclimate by maintaining moisture (Fraver *et al*., 2002). Forest management and forest structure influence small mammal abundance, each of the above variables can be managed by forest managers through post-fire management practices. The results of our study indicate that forest components, such as overstory and sub-overstory vegetation coverage, the number of downed trees, and the volume of coarse woody debris, have a strong influence on small mammal communities (Lee *et al*., 2008).

The richness of overall small mammal species was low in post-burned rubber plantation stands and high in the natural forest and post-burned rice field stands. Additionally, the species composition and dominant species changed with forest type. The natural forest stand contributed to the highest value of species diversity and species richness in these forest types. *M. musculus* and *R. rattus* were the most common species captured in each of the forest types in the rainy season and dry season, respectively. Different small mammal species were dominant in different forest types. For example, *N. fulvescens* was most abundant in natural forest stands and *M. surifur* was most abundant in post-burned rice fields. Interestingly, *L. sabanus* was found only in the natural forest stand during the dry season.

The number of small mammals captured during the rainy and dry seasons was the highest in the natural forest stand and the lowest in the post-burned rice field stand and post-burned rubber plantation stand, respectively. Because the natural forest stand was not disturbed by fire, the number of individuals captured in the natural forest stand was higher than other secondary forest stands (Lee *et al*., 2008). Additionally, a high number of individuals in natural forest stands may reflect the abundance of food resources, such as fruits and insects, that are more plentiful than in other forest types (Nakashizuka *et al*., 2006). However, the post-burned rubber plantation, where the lowest number of small mammals was captured, and which had the lowest species richness, may have an intermediate microhabitat structure that is not attractive to some small mammal species. Alternatively, post-fire silviculture could have impacted wildlife and changed the vegetation structure, causing spatial variability in microhabitats and resources (Homyack *et al*., 2004), increased predation pressure due to decreased vegetation cover, and reduced food availability. Fires also negatively impact wildlife habitats and food sources (Gordon, 1996).

In this study, we utilized a rubber tree plantation that had been abandoned for >5 years since the practice of slash and burn agriculture and plantations. Future studies on older rubber tree plantations may be useful for determining the appropriateness of rubber plantations for recuperating the community of small mammals. The artificial plantation of rubber trees affects small mammal societies, in particular increasing the populations of some species, because the oil-rich seeds and leaves of rubber trees tend to be preferred by those mammals (Smallwood and Peters, 1986; Ikwuagwu *et al*., 2000). Widespread forest deforestation causing negative effects on biodiversity is expected to occur in Southeast Asia. There is a need to carefully assess the ecological effect of wildfires and post-fire rubber plantations over longer time periods.

CONCLUSIONS

Since 2000, more than 3.5 million square kilometers of global forest areas were lost or degraded in tropical rainforests, including in the Lao PDR. This massive deforestation may lead to the decline of biodiversity. Our study found that post-fire management practices affect stand structure and small mammal societies, which should be considered when evaluating post-fire management approaches in burned stands. Agriculture and artificial plantation after wildfires may have negative impacts on small mammal societies relative to natural forest stands. It would be prudent to examine the response of other wildlife communities, e.g., birds, large mammals, amphibians, and reptiles, to post-fire management practices. Additionally, there is a need to evaluate the ecological effect of post-fire management practices over longer time periods in order to reduce the impact of high temporal variation on the estimation of treatment effects. The consistent long-term study of wildfires and disturbances of wildlife communities may provide a better sense of the long-term impacts of wildfire and forest management.

ACKNOWLEDGMENT

We would appreciate the valuable comments and suggestions of anonymous reviewers.

Funding

This work was not supported by any institute.

Statement of conflict of interest

The authors have declared no conflict of interest.

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