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မြန်မာ့ရွေးချယ်ခုတ်လှဲခြင်းစနစ်၏ သစ်ထုတ်လုပ်ငန်းစဉ်များတွင်ပါဝင်သည့် သစ်ဆွဲလမ်း၊ သစ်တိုင်းဆိပ်၊ သစ်တိုက်ကားလမ်းများတွင် မြေပြင်ထိခိုက်မှုများအား အကဲဖြတ်ခြင်း

စည်သူမင်း၊ လက်ထောက်မန်နေဂျာ၊သစ်ထုတ်ရေးဌာန၊ မြန်မာ့သစ်လုပ်ငန်း
ဒေါက်တာ Nobuya Mizoue၊ ဒေါက်တာTetsuji Ota၊ ကျူးရှုးတက္ကသိုလ်

စာတမ်းအကျဉ်း

ရွေးချယ်ခုတ်လှဲခြင်းစနစ်အား ကျင့်သုံးလျက်ရှိသော သမပိုင်းသစ်တောများတွင် ဂေဟစနစ်ဆိုင်ရာ ပွံ့ပိုးမှုများ တိုးမြင့်လာစေရန်ရည်သန်၍ ပတ်ဝန်းကျင်ထိခိုက်မှုသက်သာ စေသော သစ်ထုတ် နည်းစနစ်ကို ပိုမိုကျင့်သုံးရန် စိတ်ပါဝင်စားမှုတိုးတက်လာချိန်ဖြစ်ပါသည်။ ထို့ကြောင့် အမျိုးမျိုးသော သစ်ထုတ် နည်းစနစ်များကို နှိုင်းယှဉ် အကဲဖြတ်ရန်သည်လည်း အရေးကြီးလာပါသည်။ ၁၉ ရာစုခန့်မှ စတင်ကျင့်သုံးလာသော မြန်မာ့ရွေးချယ်ခုတ်လှဲခြင်းစနစ်၏ ထူးခြား ဝိသေသဖြစ်သည့် ဆင်ကို အသုံးပြု၍ သစ်ဆွဲခြင်းသည် ပတ်ဝန်းကျင်ထိခိုက်မှုသက်သာစေသော သစ်ထုတ်နည်းစနစ်၏ စံစနစ်တချို့နှင့် ကိုက်ညီနိုင်သည်ကြောင်း ယူဆချက်များကိုလဲ တွေ့ရှိရပါသည်။ သို့ရာတွင် ဆင်ကိုအသုံးပြုသော မြန်မာ့ ရွေးချယ်ခုတ်လှဲခြင်း စနစ်နှင့် အခြားနိုင်ငံများ တွင် ကျင့်သုံးလျက်ရှိသော ယန္တရား တစ်မျိုးတည်းသာလျှင် အသုံးပြုသော အခြားနည်း စနစ်များ ၏ ခြားနားချက်မှာ ယခုအချိန်ထိ သေချာစွာသိရှိရခြင်း မရှိသေးသည်ကို တွေ့ရှိရပါသည်။ ယခု သုတေသနသည် သစ်ဆွဲလမ်း၊ သစ်တိုင်းဆိပ်နှင့် သစ်တိုက်လမ်းများ တလျှောက်ရှိ မြေပြင် ထိခိုက်မှုကို သစ်ထုတ်လုပ်ငန်းဆောင်ရွက်လျက်ရှိသော အကွက် ၄ကွက်အတွင်း တိုင်းတာအကဲ ဖြတ်ထားခြင်း ဖြစ်ပါသည်။ ပျမ်းမျှ မြေပြင်ထိခိုက်မှု ရာခိုင်နှုန်းမှာ သစ်တိုက်လမ်းများတွင် ၂.၁ %၊ သစ်တိုင်း ဆိပ်များတွင် ဝ.၄ % ဖြစ်ပြီး ရလဒ်များမှာ အခြား သုတေသနများနှင့် များစွာ ကွာခြား မှုမရှိသည်ကို တွေ့ရှိရပါသည်။ နှိုင်းယှဉ်အကဲဖြတ်သည့် အခြားမိုငြမ်းနှိုင်းယှဉ်သည့်သုတေသန ၂၇ခု၏ သစ်တိုက်လမ်း တလျှောက်ထိခိုက်မှုမှာ၂.၃% ဖြစ်ပြီး၊ အခြားမိုငြမ်းနှိုင်းယှဉ်သည့် သုတေသန၂၁ခု၏ သစ်တိုင်းဆိပ် ပတ်ဝန်းကျင်ထိခိုက်မှုမှာဝ.၇%အသီးသီးဖြစ်ကြပါသည်။ အခြား တဖက်တွင်မူ သစ်ဆွဲလမ်းတလျှောက် ထိခိုက်မှုအနေဖြင့် ဝ.၉% သာလျှင်တွေ့ရှိရပြီး အခြား မိုငြမ်းနှိုင်းယှဉ်သည့် သုတေသနများထက် များစွာ လျော့နည်းနေသည်ကို (၇.၃%၊ အရေအတွက် အားဖြင့်၄၅) တွေ့ရှိရပါသည်။ အဓိကကွာခြားချက်မှာ ဆင်အသုံးပြုရာတွင် သစ်ဆွဲလမ်း အကျယ် မှာ ၁.ဝ မီတာရှိပြီး ယန္တရားအသုံးပြုသည့် သုတေသန ၁၈ ခု၏ သစ်ဆွဲလမ်းအကျယ်မှာ ၅.၄ မီတာ အသီးသီးဖြစ်ကြရာ ဆင်ကိုအသုံးပြု သစ်ဆွဲခြင်းသည် ယန္တရားကို အသုံးပြုခြင်းထက် မြေပြင် ထိခိုက်မှုကို ပိုမိုသက်သာ စေကြောင်း နိဂုံးချုပ်ယူဆရပါသည်။ ယခုသုတေသနအရ သစ်ဆွဲကြိုး အရှည်ကို အသုံးပြု၍ သစ်ဆွဲစက်များကို အသုံးပြုခြင်းသည် သစ်ဆွဲလမ်းတလျှောက် ယန္တရား ရွှေ့လျားမှုကို လျော့နည်း စေပြီးမြေပြင်ထိခိုက်မှုကို သက်သာစေသဖြင့် ပိုမို အသုံးပြု သွားသင့်ပါကြောင်း အကြံပြု အပ်ပါသည်။

Evaluating Ground Disturbance Along Elephant Skid Trails, Along Logging Roads and at Log Landings under the Myanmar Selection System

Sie Thu Minn [a], Nobuya Mizoue [b], Tetsuji Ota [c]

[a] Myanmar Timber Enterprise
[b] Faculty of Agriculture, Kyushu University
[c] Institute of Decision Science for a Sustainable Society, Kyushu University

Abstract

There has been growing interest in the practice of reduced-impact logging to enhance various ecological services of selectively logged tropical forests. It is thus important to evaluate the effectiveness of different logging operations. The Myanmar Selection System (MSS) has a long history, beginning in the 19th century, and is well known for its use of elephants for skidding, which is considered one form of reduced-impact logging. However, the difference in the impacts of logging operations between the MSS using elephants for skidding and machine-only-based operations commonly adopted in other countries is unknown. The present study evaluated ground disturbance along elephant skid trails, along logging roads and at log landings in four compartments logged under the MSS. The average percentages of ground disturbance in the MSS compartments were respectively 2.1% and 0.4% for logging roads and log landings; these values are not significantly different from the average values of 2.3% and 0.7% reported in 27 and 21 references, respectively. In contrast, the disturbed area along elephant skid trails was only 0.9%, which is a much lower percentage than the average (7.3%, n = 45) reported for machine skidding. A large difference in the average width of skid trails was found between elephant skidding (1.0 m) and machinery (5.4 m, n = 18). We conclude that elephant skidding can largely reduce ground disturbance as compared with machine skidding. Our results encourage minimization of the movement of machines in machine skidding through the use of a longer winch cable such that ground disturbance is reduced substantially.

Keywords: Conventional logging; Elephant skidding; Reduced-impact logging; Selective logging

Evaluating Ground Disturbance Along Elephant Skid Trails, Along Logging Roads and at Log Landings under the Myanmar Selection System

1. Introduction

Selective logging, where only large trees of commercial species are selected and harvested, is a common practice of timber production in tropical natural forests. Over 20% of the world's tropical forests have been subjected to selective logging (Bicknell et al., 2014). One global concern is that tropical selective logging may result in forest degradation, and reduced-impact logging (RIL) has thus been suggested and practiced in many countries (FAO, 2004; Poudyal et al., 2018). RIL can be defined as intensively planned and carefully controlled timber harvesting by trained workers, which includes a pre-harvest inventory, marking of trees to be felled, skid trail planning, pre-harvest liana cutting and directional felling (Sist et al., 2003; Khai et al., 2016). In contrast, conventional logging (CON) is conducted by untrained and unsupervised laborers working without the aid of adequate management plans (FAO, 2004). Many studies have evaluated the impacts of CON and RIL on residual stands in terms of residual tree damage and ground disturbance, and RIL has been shown to have great potential in terms of carbon and biodiversity conservation (Bicknell et al., 2014; Miller et al., 2011). Recent articles in the special issue "Reduced-impact logging for climate change mitigation (RIL-C)" have shown that it is crucial for effective adoptions of RIL to evaluate performance of each of different RIL operations, that is, felling, skidding and construction of log landings and logging roads (Ellis et al., 2019a, 2019b; Goodman et al., 2019; Griscom et al., 2019; Umunay et al., 2019). As pointed in the review by Picard et al. (2012), however, many studies focused on damage only from felling and skidding, and differences in residual tree damage and ground disturbance are often not clear among different operations. In addition, studies on the impacts of selective logging are largely biased toward specific countries, such as Brazil, Malaysia and Indonesia, where tropical rainforests are dominant, whereas there have been limited studies for countries such as Myanmar, Cambodia and Vietnam, where tropical seasonal forests are dominant (Poudyal et al., 2018).

Myanmar has one of the world's longest historical records of practicing selective logging, under what is known as the Myanmar Selection System (MSS), beginning in the 19th century (Brunner et al., 1988; Dah, 2004) The major economic species is teak (*Tectona grandis)* while other hardwood species are harvested in five economic groups (Khai et al., 2016). The felling cycle is 30 years, and the minimum exploitable size depends on the species, with the smallest having a diameter at breast height (DBH) of 58 cm (Khai et al., 2016). The logging phases are classified into (I) tree selection, (II) felling and log bucking, (III) elephant skidding (i.e., gathering logs at log landings using elephants), (IV) constructing log landings and logging roads and (V) transporting logs to depots or sawmills. The state-owned enterprise named Myanmar Timber Enterprise (MTE) is mainly responsible for logging operations (Brunner et al., 1988) while all the stages of tree selection, hammering the official legal stumps and transporting the logs are controlled and checked by the Forest Department as the responsible administrative organization.

Even though the MSS has a long history of practice, recent studies indicated that forests selectively logged under the MSS have degraded widely (Mon et al., 2012; Win et al., 2012, 2009). However, it is not well known in Myanmar, as in other countries, which and to what extent logging operations cause forest degradation, relative to other factors such as illegal logging and forest fire. Thus, evaluating the impact of each logging operation is the first step to discovering the drivers of forest degradation and further improving logging operations. Khai et al. (2016) evaluated residual tree damage and ground disturbance caused by felling, elephant skidding and road construction within the MSS and concluded that directional felling toward bamboo and elephant skidding within the MSS are effective RIL practices, causing the least damage to residual trees and the ground among RIL practices. However, their field measurements were limited to only one small rectangular plot of 9 ha within a 740-ha compartment area. No study has investigated the compartment-scale impact of each logging operation in the MSS.

A specific feature of the MSS is that the MSS still uses elephants for skidding, while logging roads and log landings are constructed using machines. Historically, the elephant was largely used in certain Southeast Asian countries, such as Myanmar, India, Laos, Sri Lanka and Thailand (Sessions, 2007), but no county other than Myanmar is currently using elephants for skidding as a part of extensive forestry operations. The number of elephants under MTE's management was reported as 3122 in December, 2018. We may hypothesize that the residual tree damage and ground disturbance by elephant skidding are less than those by machine skidding. However, no study has detected and evaluated the effects of elephant skidding immediately after skidding operations. Khai et al. (2016) tried to evaluate residual tree damage and ground disturbances due to elephant skidding but they failed to detect the impacts of elephant skidding because their measurements were made 3 months after the felling and skidding operations.

2. Objectives

The objective of the present study is to evaluate ground disturbance caused by logging operations at a compartment scale in Myanmar. In this study, ground disturbance is characterized as soil removal. The specific questions to be addressed are as follows.

2.1 Among the three logging operations of the MSS, namely elephant skidding, the construction of log landings and the construction of logging roads, which causes the most ground disturbance?

2.2 Are the impacts of MSS operations larger or smaller than impacts of logging in other countries? In particular, is the impact of elephant skidding under the MSS less than that of machine skidding in other countries?

The present study does not intend to encourage other countries to use elephants and other animals for skidding as in the past. Rather, this study searches to find a way to further improve logging operations in Myanmar and even other countries where elephants will not be used for skidding.

3. Materials and Methods

3.1. Study Sites

We conducted surveys at two sites; a site in Bago, which is the legendary birthplace of the Myanmar Selection System (MSS), and a site in Katha, a famous northern logging concession region (Figure 1). The Bago and Katha sites are respectively located at 17° 40' N, 96° 0' E and 23° 53' N, 95° 58' E. The mean annual rainfalls, temperatures are respectively 3089 and 1532 mm and 26.7 and 25.1 °C. The soil types and elevation ranges which were recorded on the logging roads are respectively fluvisols and lithosols and 70 m to 153 m and 203 to 345 m above the sea level. At each site, we surveyed two compartments (namely 5C and 14C in Bago and 45C and 46C in Katha). The topography of all the compartments is generally mountainous with steep slopes. General information is provided for each compartment in Table 1. The latest logging operations were conducted in two successive logging seasons spanning 2014 to 2016 in 5C and 14C of Bago and in the single 2017–2018 logging season in 45C and 46C of Katha. The recorded history of official logging in the last 10 years was not available for any the compartment before the latest logging. Two governmental extraction agencies, namely Bogo South and Katha East agencies, conducted logging operations in each area.

Trees to be felled were formerly selected by assigned Forest Department officials. The minimum DBH of trees was determined as 58.2 cm (local limit of 6 ft. in girth). Some trees, such as would-be seed trees, trees with defects and non-profitable trees over the DBH limits were not selected or felled. Meanwhile, some trees, such as half-dead trees, fired trees and trees with partial defects but still possessing some economic value were considered for felling. Trees were felled and cut into logs by trained operators using chainsaws. Logs were then collected and dragged to log landings by trained operators using elephants. The log landings and logging roads were constructed using bulldozers (D65). Trucks finally transported the logs to sawmills or more accessible depots.

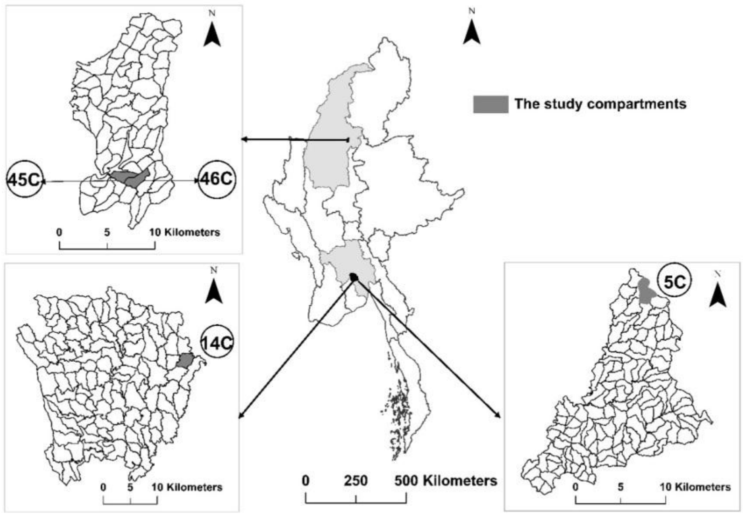

Figure 1. Locations of surveyed compartments; 5C and 14C in two reserved forests of the southern region of Bago and 45C and 46C in one reserved forest of the northern region of Katha in Myanmar.

Table 1. General statistics of the study sites

Region	Bago area		Katha area	
Reserved Forest	Shwelaung Kodukwe	South Zamaye	Pyinde	Pyinde
Compartment	5C	14C	45C	46C
Whole area (ha)	280	622	176	213
Operational area (ha)	280	207	136	213
Felling intensity				
Tree number (treesha^{-1})	1.6	2.1	1.1	1.5
Log volume (m^3ha^{-1})	5.4	4.3	4.9	5

3.2. Field Measurements and Data Analysis

We measured the area of ground disturbance along logging roads, at log landings and along elephant skid trails. As in other studies, we defined ground disturbance as the removal of at least the top soil or A0 layer during operations along skid trails, along logging roads and at log landings. Although soil compaction (Whitman et al., 1997) or degree of soil disturbance (Pinard et al., 2000) is a measure for evaluating ground disturbance, we did not measure them because most of the other studies evaluated only the soil removal. We calculated the ground disturbance percentages (%) of each operation against the operational areas of the compartments. Field measurements were made during the logging seasons of 2014–2016 in Bago and 2017–2018 in Katha.

3.2.1. Logging road

We mapped all the logging roads constructed in all four compartments, from the starting point where a road approached a compartment to the end point. We divided all roads into straight line segments connecting two points that were located in the middle of the road width. In each segment, we measured the length, slope angle and azimuth using a laser instrument (TruPulse 360R™). We measured the width of logging roads every 10 m along eight randomly selected 100-m-long sections in each compartment except 46C, where measurements were made in twelve sections. As a result, a total of the measurement points was 360. Following the definition made by Johns et al. (1996), we measured three different widths (i.e., the road width, berm width and debris width) at each measurement point using fiberglass tape (Figure 2). The areas resulting from dead ends and operator faults were also considered as part of the logging road and measured. Some mechanical movement around log landings was also measured as the logging road. The area of the ground disturbance in each compartment was calculated as the total length of line segments multiplied by the average width of the widest debris parts. The geographical positions of the logging roads were recorded using a Global Positioning System device (Garmin 60CSx®).

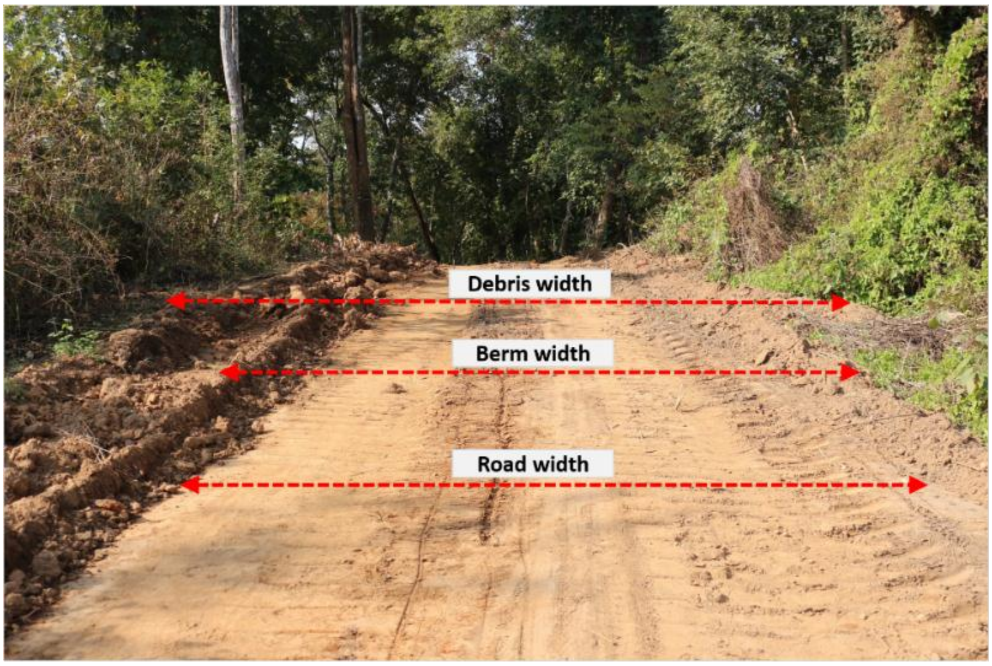

Figure 2. The position for measuring the road width, berm width and debris width.

3.2.2. Log landing

We recorded the geographical position near the center of all the log landings in all four compartments using a Global Positioning System device (Garmin 60CSx®). In compartments 14C, 45C and 46C, we measured the area of ground disturbance at log landings by applying the center-point system (Runkle, 1992) and a laser instrument (TruPulse 360R™). In 5C, we measured only the position and did not measure the area owing to time constraints.

3.2.3. Skid trails

Owing to time constraints, we did not measure all skid trails in four compartments but rather randomly selected 27 and 18 skid trail networks among a total of 53 and 75 that existed in 45C and 46C, respectively. From these sample measurements, we devolved a regression model of the relationship between the number of trees that had been skidded and the areas of ground disturbance for each of a total of 45 skid trail networks to estimate the disturbed area at the compartment scale, as mentioned below.

Each skid trail network comprised one base segment connected to the log-landing and branching segments. For each of a total of 353 segments in 45 skid trail networks, we measured the length (a total of 7,493 m), longitudinal slope angle and azimuth from the starting to ending points. We also measured the width of the disturbed area at starting, middle and ending points of each segment. For the area calculation of each segment, we used the average width at the three points multiplied by the length of each segment. For each segment, we recorded which and how many trees/logs were skidded using elephants.

The total disturbed area for each skid trail network was calculated as a total area for the segments consisting of each network. We summarized data on the relationship between the number of skidded trees (*TN*, trees) and ground disturbance area (*GDA*, m^2) for each skid trail network (n = 45) and applied a linear model without an intercept to formulate this relationship as follows.

GDA (m^2) = α×TN (trees) (1)

In this study, we assumed that this linear relationship at the skid trail network scale can be valid in the 1.0 ha unit area by dividing both sides of Equation (1) by 1.0 ha;

GDA (m^2 ha^{-1}) = α× TN (trees ha^{-1}). (2)

Because TN (trees ha^{-1}) can be regarded as logging intensity LI (trees ha^{-1}), disturbed area percentage against the unit area (GDP, %) is expressed as

GDP (%) = GDA× 10^{-4} ×10^2 = α× 10^{-2}×sLI (trees ha^{-1}). (3)

We used Equation (3) to estimate the disturbed area (%) for each compartment by inputting the logging intensity (trees ha^{-1}) at the compartment scale. We also estimated density (m ha^{-1}) of skid trails for each compartment using the estimated GDP (m^2) and the average width (=1.0 m) of skid trails.

3.2.4. Comparisons with other studies

We compared our results on the ground disturbance (%) along logging roads, at log landings and along skid trails with data from 17 previously published references (Table 2), which included information of the logging intensity for CON and/or RIL operations in other countries. The definition of ground disturbance as soil removal and the measurement methods are almost same among the references. However, some studies classified operations into certified and non-certified operations (and not into CON and RIL operations), and our study regarded these certified and non-certified operations as RIL and CON, respectively, for the ease of comparing data. It is known that ground disturbance (%) depends on the logging intensity, and a generalized linear model (GLM) with a gamma distribution and log-link function was thus used to investigate such dependency as in (Khai et al., 2016). The sample sizes of skid trails, logging roads and log landings for the GLM were respectively 27, 18 and 12 for CON and 18, 9 and 9 for RIL (Table 2). We also compared widths (m) and density (m ha^{-1}) of skid trails and logging loads with data from 17 references listed in Table 3.

Table 2. Felling intensity (trees ha^{-1}) and ground disturbance (%) reported in 17 references

No.	References	Conventional logging (CON)				Reduced-impact logging (RIL)			
		Felling intensity (trees ha^{-1})	Ground disturbance (%)			Felling intensity (trees ha^{-1})	Ground disturbance (%)		
			Skid trail	Logging road	Log landing		Skid trail	Loggin g road	Log landing
1	Asner et al., 2004a	3.7	6.8	1.2	0.9	3.0	3.6	0.6	0.6
		6.4	7.3	2.0	1.9	3.5	2.9	1.0	0.7
		2.6	8.8	1.1	0.6	3.8	6.5	1.7	0.4
		3.1	12.2	1.5	1.6	2.9	3.7	1.1	0.4
2	Feldpausch et al., 2005	2.6	5.6	2.0	0.2				
		1.1	4.2	2.5	0.2				
3	Gullison and Hardner, 1993	0.1	2.3	2.6					
4	Hendrison, 1990	5.2	14.5			6.5	7.3		
		6.1	16.0			5.7	7.2		
						7.3	7.0		
						7.4	6.8		
						4.7	5.4		
						3.4	5.7		

5	Jackson et al., 2002	4.4	19.8	2.1	0.1				
6	Johns et al., 1996	5.6	10.1	3.4	1.5	4.5	5.1	2.0	0.6
						4.5	6.9	2.0	0.6
7	Jonkers, 1987	3.5	6.0						
		6.1	9.8						
		11.7	16.7						
8	Medjibe et al., 2011					0.8	5.4		
9	Medjibe et al., 2013	0.8	4.5	5.4	0.1	0.4	1.6	1.5	0.1
10	Neba et al., 2014	0.8		1.8	0.1				
11	Pereira Jr. et al., 2002	3.7	6.8	1.2	0.9	3.0	3.6	0.6	0.6
		6.4	7.3	2.0	1.9	3.5	2.9	1.0	0.7
12	Uhl and Vieira, 1989	4.3	4.0	4.0					
13	Van der Hout, 1999	8.0	12.9			4.0	5.0		
		16.0	20.7			8.0	8.0		
						16.0	8.8		
14	Veríssimo et al., 1995	0.3	2.3	2.6					
		0.5	2.3	3.0					
		2.1	5.2	5.7					
15	Webb, 1997	6.3	4.0						
16	White, 1994	2.0	5.0	6.4					
17	Whitman et al., 1997	0.5	10.1						
	Average	4.2	8.7	2.8	0.8	4.9	5.4	1.3	0.5

Table 3. Widths and density of skid trails and logging roads reported in 17 studies

		Conventional Logging (CON)		Reduced Impact Logging (RIL)		Conventional Logging (CON)		Reduced Impact Logging (RIL)	
No.	References	Width (m)	Density (m ha^{-1})	Width (m)	Density (mha^{-1})	Width (m)	Density (mha^{-1})	Width (m)	Density (mha^{-1})
1	Bryan et al., 2016							39.3	
2	Feldpausch et al., 2005	4		4		10.6		10.6	21.5
3	Griscom et al., 2014	10.6	156.3	7.7	116.1	31.8		32.8	
4	Gullison and Hardner, 1993	13.2				24.7			
5	Iskandar et al., 2006		48				28.6		
6	Jackson et al., 2002	3.6				16.7			
7	Johns et al., 1996	3.9		3.3			27.3	10.7	22.6
8	Karsten et al., 2014	4				8			
9	Medjibe et al., 2011	4.1			69				

10	Medjibe et al., 2013	5.3	28.7	3.8	15.2	66.6	8.1	18.9	5.5
11	Neba et al., 2014					20	10		
12	Pinard et al., 2000	5.1	199		66.5				
13	Sist et al., 2003	7.7	70.9	5.9	65.9				
14	Uhl and Vieira, 1989	2.6	145.4			12.5	32.1		
15	van der Hoeven et al., 2009					17			
16	Webb, 1997	4							
17	Whitman et al., 1997	3.6							
	Average	5.5	108.1	4.9	66.5	23.1	21.2	22.4	16.5

4. Results

4.1. Logging Roads

The ground disturbance along logging roads under the MSS was 2.1% on average and similar (ranging from 1.6% and 2.9%) among the four compartments (Table 4). Average values are not significantly different among CON (2.8%), RIL (1.3%) and the MSS (2.1%) (analysis of variance (ANOVA), $p = 0.065$, Figure 3). The GLM analysis confirmed that ground disturbance (%) along logging roads did not depend on the logging intensity for all of CON, RIL and the MSS (Figure 4.). Taking the example of CON, the inclusion of the logging intensity as an explanatory variable (Akaike information criterion (AIC) of 57.2 was not statistically significant (chi-squared, $p = 0.44$) as compared with a constant-only model (AIC of 56.1), and similar results were obtained for RIL and the MSS.

The average width of logging roads was 6.4 m for the MSS (Table 4), which is significantly lower than values for CON (23.1 m, $n = 9$) and RIL (22.4 m, $n = 5$) (t-test, $p < 0.0001$, Table 3). The average density of logging roads was 30.5 m ha^{-1} for the MSS, which is not significantly different from values for CON (21.2 m ha^{-1}, $n = 5$, t-test, $p = 0.170$) and RIL (16.5 m ha^{-1}, $n = 3$, t-test, $p = 0.106$) (Table 3).

Table 4. The results on size and ground disturbance logging road, log landing and skid trail

Compartment	5C	14C	45C	46C	Average
Logging road					
Area of ground disturbance (%)	2.0	1.6	1.8	2.9	2.1
Average width(m)	8.6	6.0	6.4	6.6	6.9
Density(m^2ha^{-1})	24.0	26.9	27.7	43.5	30.5
Log landing					
Number in the compartment	24	26	21	32	25.8
Area of ground disturbance(%)	n.a.	0.4	0.5	0.4	0.4
Skid trail					
Area of ground disturbance(%)	0.9	1.2	0.6	0.8	0.9
Average width(m)	n.a.	n.a.	1.0	1.0	1.0
Density(m^2ha^{-1})	89.8	117.8	61.7	84.2	88.4

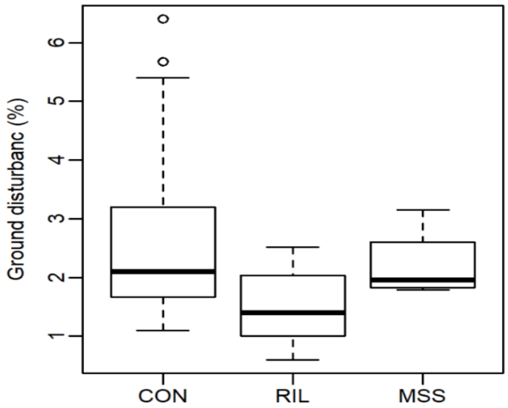

Figure 3. Ground disturbance (%) along logging roads for CON (n = 18), RIL (n = 9) and the MSS (n = 4). The boxplots indicate minimum, first quartile, median (bold line), third quartile (Q3), maximum and outliers (open circles).

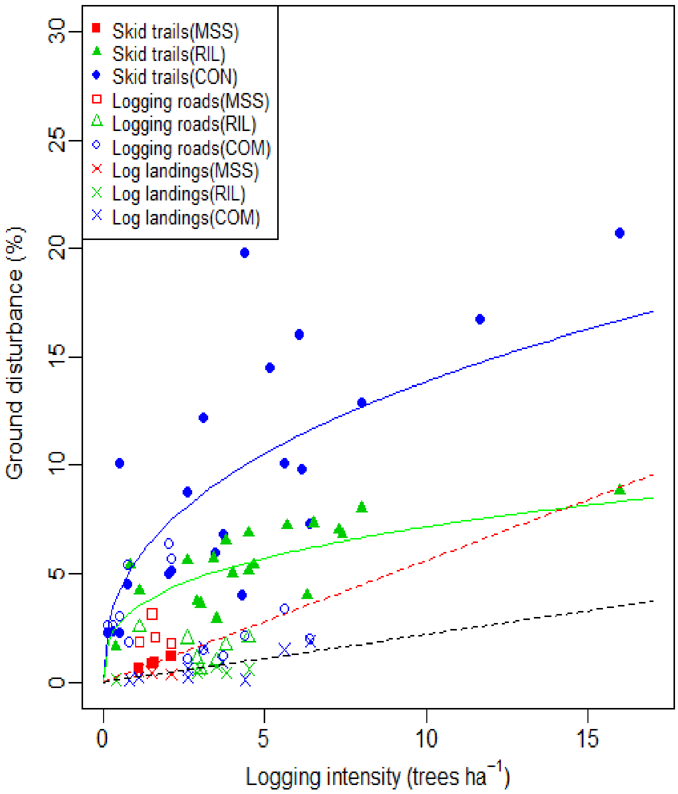

Figure 4. Relations between logging intensity (*LI*, trees ha^{-1}) and ground disturbance (*GDP*, %) along skid trails, logging roads and log landings for CON, RIL and the MSS using data given in Tables 2 and 4. In the case of skid trails, equations fitted using GLMs with a gamma distribution and log-link were $GDP = 5.569434LI^{0.3957903}$ for COM (blue line) and $GDP = 3.395392LI^{0.3238609}$ for RIL (green line). Equation (3) $GDP = 0.5611198LI$ (red dashed line) for the MSS was based on the relation between the number of skidded trees and area of ground disturbance (m^2) for each of 45 elephant skid trail networks, as shown in Figure 6. For log landings, the liner equation fitted by pooling all data from CON, RIL and the MSS was $GDP = 0.219795LI$ (black dashed line).

4.2. Log Landings

The ground disturbance at log landings of the MSS was 0.4% on average, ranging from 0.4% to 0.5% among three compartments (Table 4). The average did not differ among CON (0.8%), RIL (0.5%) and the MSS (0.4%) (ANOVA, $p = 0.33$, Figure 5). Figure 4 shows a linear relation between ground disturbance (%) and logging intensity when pooling all data from CON, RIL and the MSS ($r^2 = 0.82$, $p < 0.0001$). There may not be a large difference in relationships between ground disturbance (%) and logging intensity among the MSS, RIL and CON, although this cannot be statistically confirmed owing to the small sample size for each of CON, RIL and the MSS.

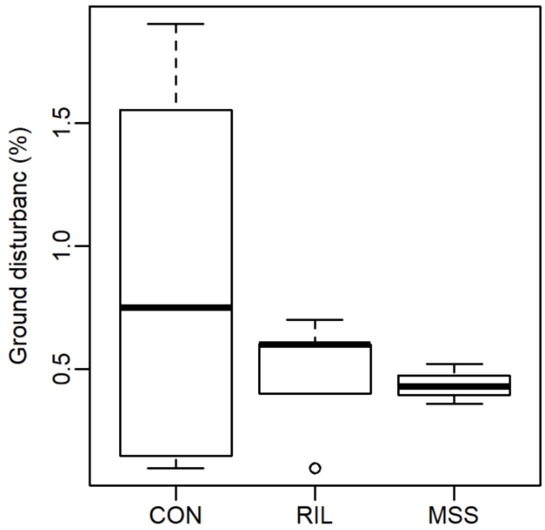

Figure 5. Ground disturbance (%) at log landings for CON (n =12), RIL (n = 9) and the MSS (n = 3).

4.3. Skid Trails

There was a linear relation between the number of trees skidded and ground disturbance (m^2) for each skid trail network (Figure 6, $r^2 = 0.88$, $p < 0.0001$). Assuming that this linear relation can be applied to a relation between logging intensity (trees ha^{-1}) and ground disturbance per ha (m^2 ha^{-1}), we estimated ground disturbance of 0.9% on average (ranging from 0.6 to 1.2%) under a logging intensity ranging from 1.1 to 2.1 trees ha^{-1} for the four compartments, as shown in Figure 4 and Table 4.

The averages of ground disturbance were significantly different among CON (8.5 %), RIL (5.4%) and the MSS (0.9%) (ANOVA, $p < 0.0001$, Figure 7). The inclusion of the logging intensity as an explanatory variable of the GLM for CON (AIC = 125.9) and RIL (AIC = 83.4) was statistically significant (chi-squared, $p < 0.0001$ for CON and RIL) as compared with a constant-only model for CON (AIC = 141.7) and RIL (AIC = 94.4), indicating that ground disturbance (%) along skid trails increased with increasing logging intensity for both CON and RIL (Figure 4).

The average width of skid trails was 1.0 m for the MSS (Table 4) , which is significantly lower than that for CON (5.5 m, n = 13) and that for RIL (4.9 m, n = 5) (t-test, $p < 0.0001$, Table 3). The average density of skid trails estimated for each compartment was 88.4 m ha^{-1} (n = 4) for the MSS, which is not significantly different from values for CONs (108.1 m ha^{-1}, n = 6, t-test, $p = 0.536$) and RIL (66.5 m ha^{-1}, n = 5, t-test, $p = 0.305$) (Table 3).

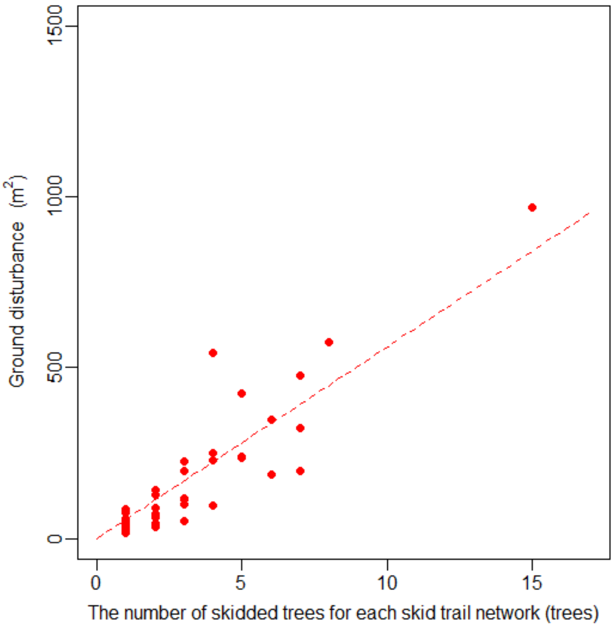

Figure 6. Relations between the number of skidded trees (*TN*) and ground disturbance area (*GDA* m^2) for each of 45 elephant skid trail networks, where Equation (1) was *GDA*=56.11198*TN*.

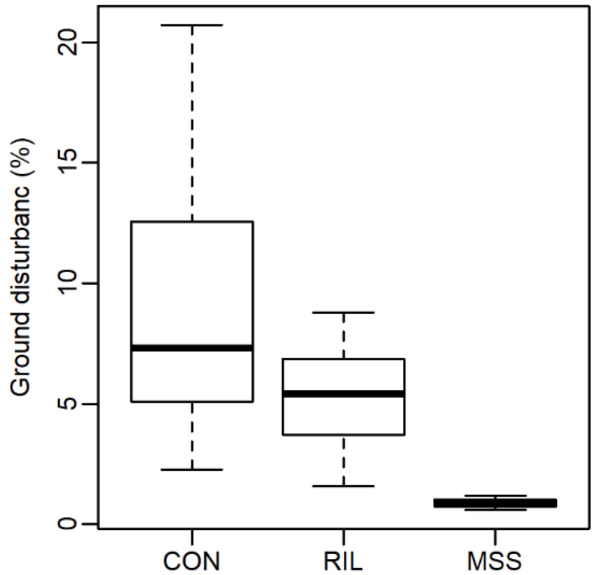

Figure 7. Ground disturbance (%) along skid trails for CON (n =27), RIL (n = 18) and the MSS (n = 4).

5. Discussion

The present study investigated how impacts from MSS operations using elephants for skidding are different from those of machine-only-based operations. Our results show large differences in ground disturbance between MSS skidding operations and other skidding operations while the results for logging roads and log landings do not differ between the MSS and other systems.

It is known that in tropical forestry operations there is much more ground disturbance along skid trails than along logging roads and at log landings. Feldpausch et al. (2005), for example, found in the study of RIL operations in southern Amazonia that skid trails created when dragging logs to log landings accounted for much of the damage to the forest, disturbing on average an area 4% greater than the area disturbed by building roads. Asner et al. (2004b) investigated sites in the eastern Amazon across wide ranges of the harvested area (14–158 ha) and logging intensity (2.6–6.4 trees/ha). They showed that skid trails were consistently the largest contributor to the overall ground disturbance in CON (7.0–12 %) and RIL (3.0–6.5 %) treatments, whereas log landing and logging roads were small components of the ground damage, usually accounting for less than 1% and 2% of the ground damage respectively. In contrast, our results for Myanmar show that ground disturbance associated with elephant skid trails (0.9%) was much smaller than that associated with logging roads under the MSS (2.1%) and was lower than disturbances reported in other studies (Figure 4, Figure 7). One reason for such low-level disturbance from elephant skidding is that the skid trails are much narrower for elephant skidding (mean width of 1.0 m) than for machine skidding (mean width of 5.4 m), while the density of elephant skid trails (mean of 88.4 m ha^{-1}) is not different from machine skid trails (mean of 89.2 m ha^{-1}) (Table 3). Bulldozers or wheeled skidders that are usually used for machine skidding easily disturb soils for at least 3.0–4.0 m machine widths during skidding (Johns et al., 1996). Meanwhile, we observed during our field survey that soil disturbance due to elephant footprints was almost negligible, and disturbed areas during elephant skidding arose not from the elephant movement itself but from the logs that were dragged by the elephants. Therefore, widths of elephant skid trails are affected mainly by the size of logs, which are mostly less than 100 cm in diameter. We also found that the logging roads were significantly narrower for the MSS (mean width of 6.4 m) than for the other countries (mean width of 22.9 m), even though the MSS also used a bulldozer as in the other countries. This difference in the road widths may be because most logging road construction involves much wider corridors than just the road track itself due to traffic safety reasons and in order to let the sun dry the road surface after rain (Kleinschroth et al., 2016), while such road construction is not common for the MSS, which is operated mostly in mountainous regions.

Increasing attention has been paid to RIL, which has the potential to enhance various ecosystem services, such as the conservation of biodiversity (Runting et al., 2019), carbon (Sist et al., 2003) and water (Miller et al., 2011), in selectively logged tropical forests. It is thus important to quantify the effectiveness of each RIL operation. Our study indicated that the effectiveness in reducing ground disturbance did not differ among CON, RIL and the MSS for logging roads and log landings but was largely different for skid trails. The MSS had the lowest level of ground disturbance along skid trails, followed by RIL and then CON

(Figure 4). Pinard et al. (2000) indicated that ground disturbance in RIL was one-third that in CON whereas the logging road area was similar for the two treatments. At their study sites, RIL involved the restricted use of bulldozer blades and the encouraged use of winch cables, whereas CON did neither. Similarly, Asner et al. (2004a) showed that ground disturbance from skid trails in CON was twice that in RIL, but there was no difference in the road area between CON and RIL. Griscom et al. (2014) indicated that the effectiveness of RIL in terms of reducing biomass carbon emissions was greater for skidding than for logging roads. Their RIL practices included skid trail planning, directional felling and long-line winching where logs were skidded using a ca. 100 m winch cable drawn by an 18 horsepower diesel engine welded to a narrow metal sled anchored to a tree (Griscom et al., 2014) . When the skidder stops while logs are dragged by winching a long cable, the situation of ground disturbance may be somewhat similar to that during elephant skidding; ground disturbance arises only from logs that are being dragged and not from movements of the skidder machines or elephants. The results of our study encourage the use of a longer line winch when machine skidding in other countries so as to minimize the movement of the machines and thus further reduce the ground disturbance. On this other hand, we also should consider that damage to residual trees (not to ground) may increase when using a longer cable, but we can improve winching using a snatch block for changing the pulling direction to prevent residual tree damage (Picchio et al., 2012).

It is also known that ground disturbance tends to increase with increasing logging intensity (Khai et al., 2016; Pereira Jr. et al., 2002). However, the cited studies did not distinguish components of ground disturbance, such as skid trails, logging roads and log landings. Our study showed that there was a dependency of ground disturbance on logging intensity for skid trails and log landings but not for logging roads (Figure 4). Gullison and Hardner (1993) presented simulation results where the ground disturbance (%) was constant with increasing logging intensity for logging roads but increased with increasing logging intensity for skid trails. These results demonstrate that the logging intensity should be considered when evaluating the ground disturbance along skid trails. Our results in Figure 4 confirm that ground disturbance along skid trails is lowest for the MSS, at least under a lower logging intensity of <5 trees/ha, followed by RIL and then CON. Our study used the linear relation between the number of dragged trees and ground disturbance (m^2) for skid trail networks (Figure. 6) to estimate the ground disturbance rate (%) by inputting the logging intensity (trees ha^{-1}). It is cautioned that this linear relation was obtained from data for the range of low logging intensity from 1.1 to 2.1 trees ha^{-1}. The extrapolation of this relation to higher logging intensity may therefore result in overestimation of the ground disturbance because there would be increasing probabilities of using the same skid trails for different trees under the condition of higher logging intensity. In addition, the ground disturbance along skid trails may be influenced by various site condition such as microtopography, terrain slope and soil types. Thus, further research under different logging intensity and site condition is needed to generalize the estimation of ground disturbance along elephant skid trails.

6. Conclusion

Our study evaluated ground disturbance under the operation of traditional tropical forestry in Myanmar, the so-called MSS, using elephants for skidding as compared with machine-only-based operations conducted in other countries. The following conclusions are drawn from the results of the study.

6.1 Among three logging operations of the MSS, ground disturbance is greatest along logging roads (2.1%), followed by elephant skid trails (0.9%) and then log landings (0.4%).

6.2 As compared with cases in other countries, the ground disturbance of the MSS is least along skid trails, but not different along logging roads and at log landings.

The lowest level of disturbance along elephant skid trails resulted from widths (mean of 1.0 m) much narrower than those of machine skidding (mean = 5.4 m). Such narrow disturbance arises from the logs that are dragged by elephants, whereas elephant movement itself does not cause ground disturbance distinctly. Our results encourage the use of long winch cables in machine skidding to minimize the movement of machines and thus reduce the ground disturbance substantially to levels closer to those for elephant skidding.

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Evaluating Ground Disturbance along Elephant Skid Trails, along Logging Roads and at Log Landings under the Myanmar Selection System

[1]Sie Thu Minn,[2]Nobuya Mizoue,[2]Tetsuji Ota.[1]Extraction Department, Myanma Timber Enterprise, [2] Faculty of Agriculture, Kyushu University

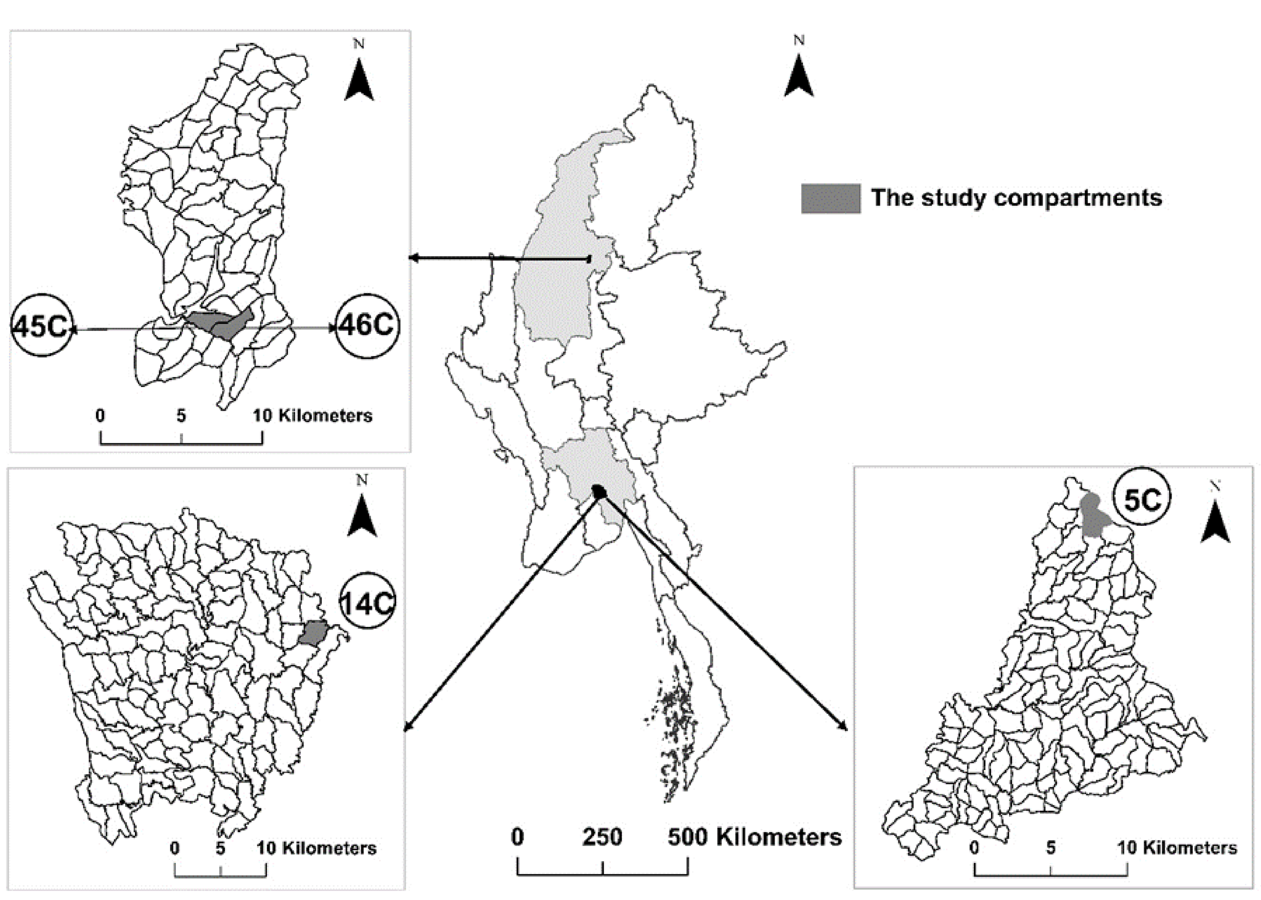
Introduction

•Over 20% of the world's tropical forests have been subjected to selective logging(Bicknell et al., 2014).
•Compared to conventional logging (CON), reduced impact logging (RIL) has been suggested as more effective and practiced in many countries(FAO, 2004; Poudyal et al., 2018).
•Many studies have evaluated the impacts of CON and RIL on residual stands in terms of residual tree damage and ground disturbance
•In Myanmar, traditionally practiced selective system (MSS) is considered to have potentials to be integrated as RIL but empirical evidence on evaluation of logging impacts is still rare.

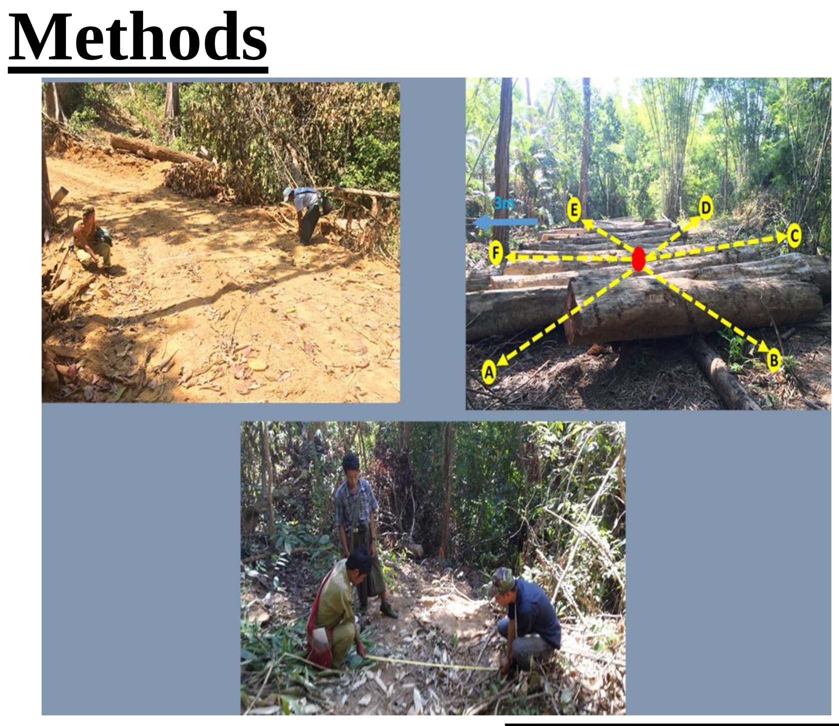
Objectives

• to evaluate ground disturbance caused by logging operations at a compartment scale in Myanmar
1) Among the three logging operations of the MSS, namely elephant skidding, the construction of log landings and the construction of logging roads, which causes the most ground disturbance?
2) Are the impacts of MSS operations larger or smaller than impacts of logging in other countries? In particular, is the impact of elephant skidding under the MSS less than that of machine skidding in other countries?

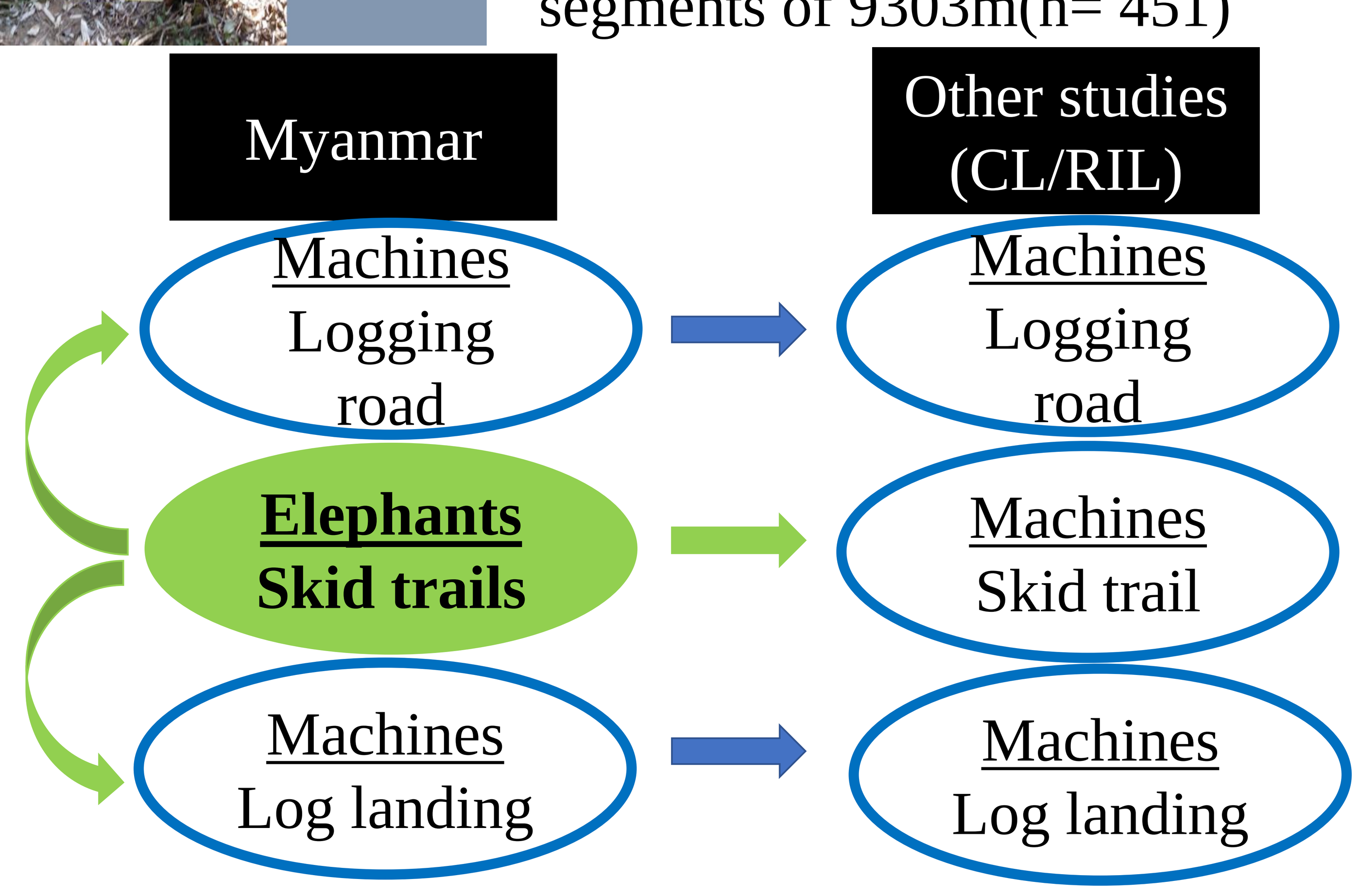
Study Area



Methods



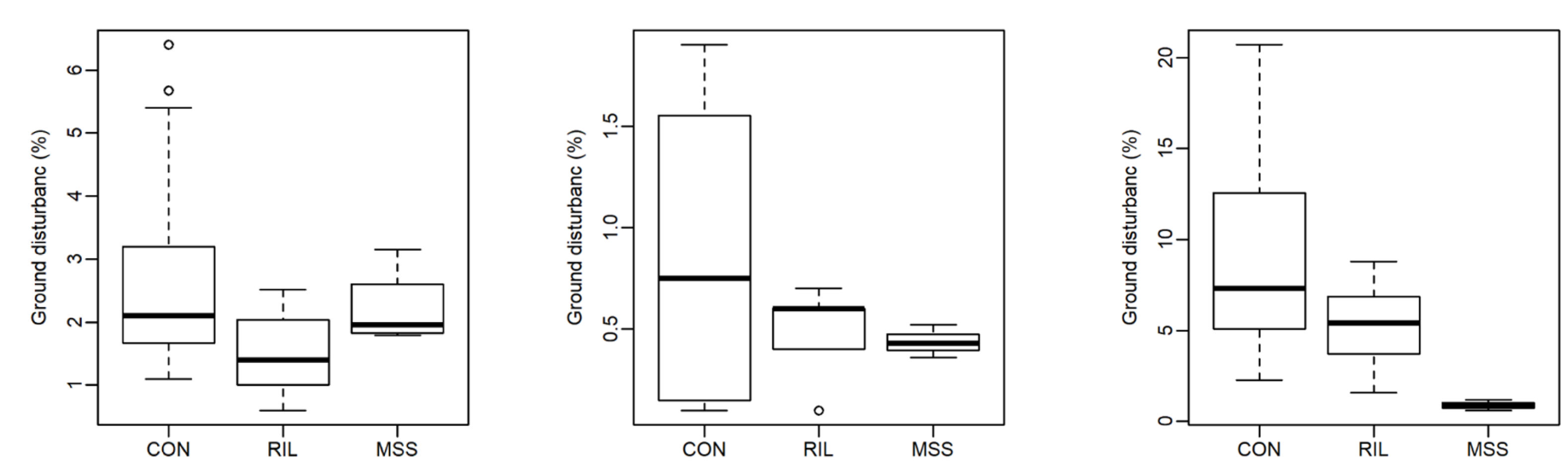
Road
Length: total length
Width: 10 sections in 100m (n=36)
Log Landing
Area: Center Point System(Runkle 1992)(n=79)
Skid Trail
Length and width samples in segments of 9303m(n= 451)



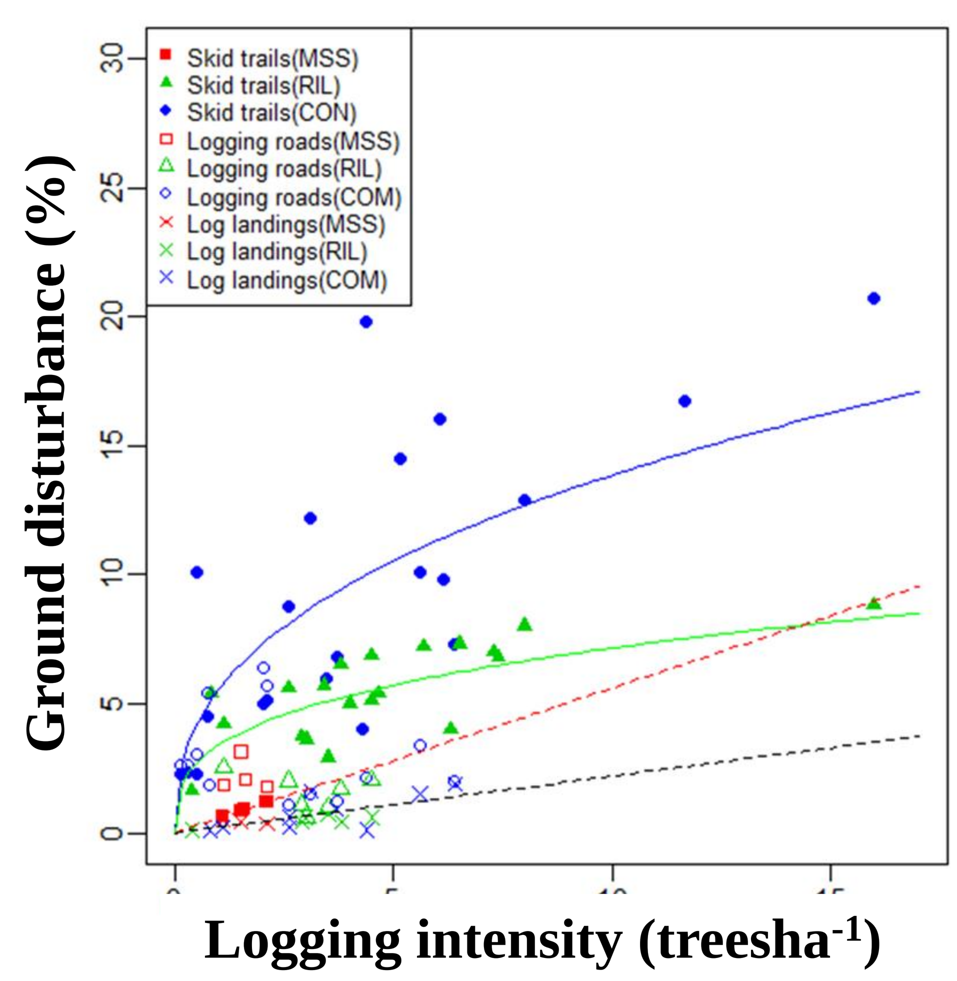
Results

Compartment	5C	14C	45C	46C	Average
Logging road					
Area of ground disturbance(%)	2.0	1.6	1.8	2.9	2.1
Average width(m)	8.6	6.0	6.4	6.6	6.9
Density(m^2ha^{-1})	24.0	26.9	27.7	43.5	30.5
Log landing					
Number in the compartment	24	26	21	32	25.8
Area of ground disturbance(%)	n.a.	0.4	0.5	0.4	0.4
Skid trail					
Area of ground disturbance(%)	0.9	1.2	0.6	0.8	0.9
Average width(m)	n.a.	n.a.	1.0	1.0	1.0
Density(m^2ha^{-1})	89.8	117.8	61.7	84.2	88.4

Results



Logging road **Log landing** **Skid trail**



Discussion

•This study indicated that the effectiveness in reducing ground disturbance did not differ among CON, RIL and the MSS for logging roads and log landings but was largely different for skid trails because that of CON is 3 times higher than RIL reported by Pinard et al. (2000) and twice reported by Asner et al. (2004).
• Use of longer line winch is encouraged which is similar to elephant movement because most of the disturbance is elephant skid trail comes from the skidded logs while the footprints by elephants in terms disturbance is almost negligible.

Conclusion

- Among three logging operations of the MSS, ground disturbance is greatest along logging roads (2.1%), followed by elephant skid trails (0.9%) and then log landings (0.4%).
- As compared with cases in other countries, the ground disturbance of the MSS is least along skid trails, but not different along logging roads and at log landings.

Curriculum Vitae

Name	- Sie Thu Minn
Occupation	- Assistant Manager (Extraction) Extraction Department, Myanma Timber Enterprise
Educational Status	- PhD Candidate, Kyushu University, Japan
Work Experience	- 2007 to 2013, Senior Timber Ranger 2013 to now, Assistant Manager
Paper publication	-
Research Paper Title	- Evaluating Ground Disturbance along Elephant Skid trails, along Logging Roads and at Log Landings under the Myanmar Selection System