Websites:
http://www.sciencepub.net/nature
http://www.sciencepub.net

Nature and Science

Emails:
naturesciencej@gmail.com
editor@sciencepub.net

MARSLAND PRESS
Multidisciplinary Academic Journal Publisher

An appraisal of studies on the impact of *Hevea brasiliensis* monocultures on biodiversity in top ten natural rubber producing countries

*Chima, U.D.[1,2], Qi, D.[1], Wu, Z.[1] & Chen, B.[1]

1. Rubber Research Institute, Chinese Academy of Tropical Agricultural Sciences/ Danzhou Investigation & Experiment Station of Tropical Crops, Ministry of Agriculture and Rural Affairs, P. R. China
2. Department of Forestry and Wildlife Management, Faculty of Agriculture, University of Port Harcourt, Nigeria

*Corresponding author: uzoma.chima@uniport.edu.ng

ABSTRACT: Monoculture plantations of natural rubber (*Hevea brasiliensis*) are expanding rapidly in different parts of the world, especially the Southeastern part of Asia, with associated consequences on biodiversity. We evaluated the available literature on the effects of *H. brasiliensis* monocultures on different aspects of biodiversity in the world's top ten producers of natural rubber – Thailand, Indonesia, Malaysia, India, China, Vietnam, Philippines, Cote d'Ivoire, Guatemala, and Brazil. The evaluation was aimed at determining the scope of work done, harnessing the existing knowledge, and identifying gaps for further studies. The relative frequencies of aspects of biodiversity covered in the evaluated studies showed that bacteria/bird (16.66 % each) were the most studied, followed by nematode and earthworm/other annelids (10 % each), ant/archaea/bat/fungi/plant/termite (6.67 % each), and gene (plant)/seed bank (3.33 % each). No studies were found on reptiles, rodents, big mammals, among others. Among the ten largest producers of natural rubber, more studies were conducted in Indonesia (43.48 %), followed by China (30.43 %), Thailand (13.04), Malaysia/India/Brazil (4.35 % each), while none was found for Vietnam, Philippines, Cote d'Ivoire and Guatemala. The number of biodiversity components studied in each country was highest for Indonesia (61.54 % of total), followed by China (53.85 %), Malaysia/Thailand (23.08% each), and Brazil/India (7.69 % each). Almost all aspects of biodiversity studied declined following conversion of natural forests to *H. brasiliensis* monocultures. These findings call for further studies to fill the identified gaps in order to enhance knowledge and practices that will make natural rubber cultivation ecologically more sustainable.

[Chima, U.D., Qi, D., Wu, Z. & Chen, B. Davron Ulmasovich. **An appraisal of studies on the impact of *Hevea brasiliensis* monocultures on biodiversity in top ten natural rubber producing countries**. *Nat Sci* 2021;19(11):8-20]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 2. doi:10.7537/marsnsj191121.02.

Keywords: Forest conversion, natural rubber cultivation, plantation forestry, biodiversity conservation

INTRODUCTION

The origin of the natural rubber tree, *Hevea brasiliensis*, can be traced to the tropical rainforest of the Amazon Basin (Wu *et al.*, 2016), with its natural growth range covering the Brazilian Amazon in addition to other areas in South America including Bolivia, Columbia, Peru, Venezuela, Ecuador, Suriname and Guiana (Moreira, *et al.*, 2009). Presently, *Hevea brasiliensis* is recognized as an economically important tree species all over the world due to its high quality latex which is used for the manufacture of more than forty thousand products including latex gloves, shoe-soles, pipes, belts, condoms, mattress, rubber tyres for over one billion cars that ply on the roads globally, vibration isolators, shock mounts, seals, gaskets, tubes, among others (Mooibroek and Cornish, 2000; Cotter *et al.*, 2009). Despite the recognition of over 2500 plant species that produce rubber, *Hevea brasiliensis* still remains the only commercial source of natural rubber (Hayashi, 2009). It is a major foreign exchange earner for many countries, including Thailand, Indonesia, Vietnam, Malaysia, Cote d'Ivoire, Belgium, Myanmar (Burma), Laos, Guatemala, Liberia, USA, France, Luxemburg, and Philippines, which are the fifteen countries that exported the highest dollar value of natural rubber in 2018 (Workman, 2018).

Although the origin of the natural rubber tree (*H. brasiliensis*) is traced to Brazil, its cultivation and production currently, are not as prominent in Brazil, as it is in the South and Southeastern Asian countries due mainly to the ascomycete fungus - *Microcyclus ulei*, which causes the South American Leaf Blight (SALB) disease that hampers the production of natural rubber in commercial quantities in South and Central America (Guen *et al.*, 2002; Lieberei, 2007; FAO, 2011). The absence of the fungus in Asia, in addition to economic gains, have led to the expansion of monoculture plantations of *H. brasiliensis* in the region/subregion with countries like Thailand, Indonesia, Malaysia, India, China, Vietnam, and Philippines, being among the world's seven largest producers of natural rubber (Lin *et al*., 2013; Jegede, 2019). Southeast Asia alone accounts for more than 90% of the world's natural rubber production (Chen *et al*., 2016; Jegede, 2019), with production volumes having increased from 300,000 to 5,000,000 tons (equivalent to 1500%) from 1961 to 2011, a period of 50 years (FAO, 2013).

The expansion of *H. brasiliensis* monocultures in these countries and some other natural rubber producing countries of the world has been recognized as a major driver of loss of different aspects of biological diversity (Jones *et al*., 2003; Aratrakorn *et al*., 2006; Beukema *et al*, 2007; Zheng *et al*., 2009; Bremnar and Farley, 2010; Phommexay *et al*., 2011; Meng *et al*., 2012; Zhou *et al*., 2012; Li *et al.,* 2013; Thongphak and Kulsa, 2014; Xiao, *et al.,* 2014; Ahrends, *et al* 2015; Ayat and Tata, 2015; Darmawan *et al*., 2015; Schneider *et al.,* 2015; Warren-Thomas *et al*, 2015; He and Martin, 2016; Liu *et al*., 2016; Nurulita *et al.,* 2016; Prabowo *et al*., 2016; Barkelmann *et al*., 2018; Hidayat *et al*., 2018; Singh *et al*., 2019) as their establishment in most cases involves the conversion of forested areas (Xiao *et al*., 2014; Barkelmann *et al*., 2018). In continental Southeast Asia, Ahrends *et al.* (2015) observed that 2500 km^2 and 610 km^2 of natural tree cover and protected areas, respectively, were converted to rubber plantations between 2005 and 2010. There is also a prediction that the areas presently covered by rubber plantations will quadruple by 2050 through the conversion of secondary forests, and areas under swidden agriculture and scrublands (Fox *et al.*, 2012). Natural forest loss due to the expansion of *H. brasiliensis* plantations is not restricted to Southeast Asia alone as it has also been reported for countries like Cote d'Ivoire (Obouayeba *et al*., 2015) and Guatemala (Carlos, 2013) in West Africa and Central America respectively, among others.

The term 'biological diversity' encompasses the totality of the variability of life forms, and can be considered at three different levels: gene, species, and ecosystem. Its importance cannot be overemphasized due to the productive, protective and ecological roles, biological organisms play including in food production, pollination, seed dispersal, prevention and control of erosion, abatement of ecological disasters, climate change mitigation and adaptation, to mention a few. The implications of the expansion of *H. brasiliensis* monocultures for biodiversity conservation are of much concern to the global community of conservation ecologists and environmentalists. This concern has been partly responsible for the available studies and knowledge on the impact of *H. brasiliensis* monocultures on different aspects of biodiversity.

The essence of this review is to appraise these studies in order to harness the existing knowledge on the impact of *H. brasiliensis* monocultures on different aspects of biodiversity in the world's top ten natural rubber producing countries, and to identify the existing gaps in knowledge for future studies. In addition, we examined the distribution of the available studies among the various aspects and components of biodiversity, and also the distribution of the study areas among the top ten producers (countries) of natural rubber, with a view to identifying the extent of work done on each aspect of biodiversity and in each of the natural rubber producing countries as well.

Apart from guiding against making the work unwieldy, our focus on the top ten producers of natural rubber is predicated on the fact that the spate of deforestation and conversion of natural forests and other pristine ecosystems to *H. brasiliensis* monocultures is more critical and alarming in these countries. In addition, it is our utmost belief and hope that the synthesis of the available knowledge on the effects of current trends and practices on different aspects of biodiversity, in these major natural rubber producing countries, will aid comprehensive understanding that may encourage and enhance practices that are in tandem with the principles of sustainability, not only in these countries, but also in other countries where natural rubber is produced.

In this paper, we present the results of our evaluation of published articles, in peer-reviewed journals, on the effect of *H. brasiliensis* monocultures on different aspects/components of biodiversity including genes, seed banks, plants, animals and microorganisms, for the world's ten largest producers of natural rubber. We also identified knowledge gaps regarding aspects of biodiversity that have either not been adequately studied or studied at all, for the various countries.

MATERIALS AND METHODS

Study Area

The study focused on Thailand, Indonesia, Malaysia, India, China, Vietnam, Philippines, Cote d'Ivoire, Guatemala and Brazil, the world's top ten producers of natural rubber (Table 1) according to Jegede (2019). The first seven countries (Thailand, Indonesia, Malaysia, India, China, Vietnam, and Philippines) are in Southern Asia especially the South-eastern part, while Cote d'Ivoire, Guatemala, and Brazil are in Africa, Central America, and South America, respectively (Figure 1).

Table 1: Top ten natural rubber producing countries covered in the study and their production statistics

Country	Location	Region	Annual production (metric tons)	% of the global total	% exported	Ranking
Thailand	Asia	Southeast	4,305,069	35.6	>90	1^{st}
Indonesia	Asia	Southeast	3,088,400	27.3	~90	2^{nd}
Malaysia	Asia	Southeast	996,673	8.8	-	3^{rd}
India	Asia	South	891,344	8.5	-	4^{th}
China	Asia	Southeast	864,806	7.9	-	5^{th}
Vietnam	Asia	Southeast	789,635	7.0	-	6^{th}
Philippines	Asia	Southeast	547,861	-	-	7^{th}
Cote d'Ivoire	Africa	West	411,044	-	-	8^{th}
Guatemala	Central America	-	356,392	-	-	9^{th}
Brazil	South America	East	185,725	-	-	10^{th}

Source: Prepared with information from Jegede (2019)

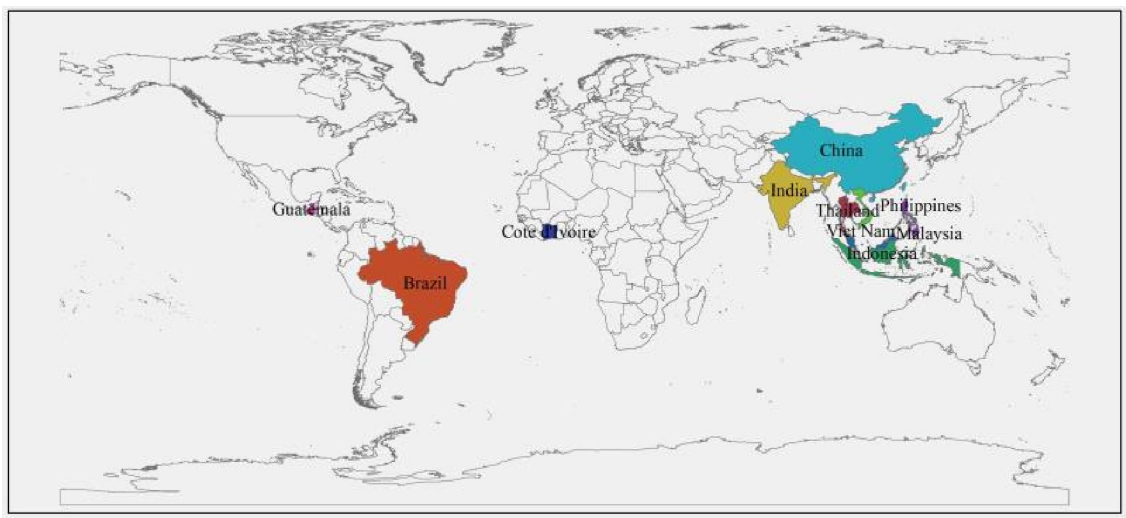

Figure 1: The locations of the world's top ten producers of natural rubber

Data Collection

The publications reviewed in this study were sourced via Google, Google Scholar, Bing, Baidu and ResearchGate. Keywords including Forest conversion, natural rubber cultivation, plantation forestry, biodiversity conservation were first used to search for relevant literature for the study. Subsequently the literature search was expanded using the topics "Biodiversity assessment in *H. brasiliensis* plantations" and "effect of *H. brasiliensis* plantations on biodiversity" specifically for each of the world's top ten producers of natural rubber (Thailand, Indonesia, Malaysia, India, China, Vietnam, Philippines, Cote d'Ivoire, Guatemala and Brazil). Only published articles that were comparative in nature and reported results of empirical studies on the effect of primary and/or natural forest conversion to *H. brasiliensis* plantations on various aspects of biodiversity were considered. Studies that just evaluated aspects of biodiversity in *H. brasiliensis* plantations without any form of comparison with a primary or natural forest or any reference ecosystem within the study area were not appraised.

Data Analysis

Descriptive statistics (frequencies, relative frequencies and percentages) were used to analyse the data extracted from the reviewed articles, to enable relevant abstractions in line with the objectives of the study.

Frequency

First, the number of publications that focused on each of the top ten rubber producing countries was obtained by counting the number of publications on studies conducted in each country, and the relative frequency obtained using formula 1.

$$Rf = \frac{npc}{NPR}\ x\ 100 \text{ -------------------------------(1)}$$

Where: Rf = Relative frequency

npc = Number of studies conducted in a country

NPR = Total number of publications reviewed

Similarly, the frequency of each aspect of biodiversity in the publications was obtained by counting the number of publications in which it was studied and reported. Subsequently, the relative frequency was obtained using formula 2.

$$Rf = \frac{npb}{NPR}\ x\ 100 \text{ -------------------------------(2)}$$

Where: Rf = Relative frequency

npb = Number of publications on a particular aspect of biodiversity

NPR = Total number of publications reviewed

In addition to the computation of frequencies, analysis of distribution of the reviewed studies among the top ten natural rubber producing countries by aspects of biodiversity covered in the studies was also done and presented using a line chart.

Percentages

The percentage of biodiversity components that has been studied in each country in relation to the total number of components encountered in the review was computed using formula 3.

$$BC(\%) = \frac{nbc}{NBC}\ x\ 100 \text{ -------------------------(3)}$$

Where: BC = Biodiversity component

nbc = Number of biodiversity components studied in a country

NBC = Total number of biodiversity components covered in the review

RESULTS

Distribution of the reviewed studies among the top ten natural rubber producers

The distribution of the reviewed publications on the effect of *H. brasiliensis* monocultures on biodiversity among the top ten natural rubber producing countries is presented in Table 2. Indonesia ranked first with ten publications (43.48%), followed by China with seven publications (30.43%), and Thailand with three publications (13.04%). Malaysia, India and Brazil, had only one publication each (4.35%), while no publication on the subject was found for Vietnam, Philippines, Cote d'Ivoire and Guatemala.

Table 2: Ranking of the top ten natural rubber producers based on frequency of studies on the effect of *H. brasiliensis* monocultures conducted in them

S/No.	Country	Frequency or number of publications	Relative Frequency (%)	Rank	Components of biodiversity studied
1	Thailand	3	13.04	3rd	Ant, Bat & Bird.
2	Indonesia	10	43.48	1st	Archaea, Bacteria, Bird, Earthworm, Fungi, Gene (Plant), Plant & Termite.
3	Malaysia	1	4.35	4th	Bacteria, Fungi & Nematode.
4	India	1	4.35	4th	Earthworm
5	China	7	30.43	2nd	Annelid, Ant, Bacteria, Bird, Nematode, Plant & Seed bank.
6	Vietnam	0	0.00	-	-
7	Philippines	0	0.00	-	-
8	Cote d'Ivoire	0	0.00	-	-
9	Guatemala	0	0.00	-	-
10	Brazil	1	4.35	4th	Bat
Total		**23**	**100**		

Aspects of Biodiversity covered in the studies

Table 3 shows the various aspects of biodiversity covered in the reviewed studies, and the number/relative frequency of publications that reported on each aspect. Bacteria and bird with a relative frequency of 16.66 % each, were the most studied aspects of biodiversity, followed by nematode and Earthworm/other annelids (10.00 % each), ant/archaea/bat//fungi/plant/termite (6.67 % each), and gene (plant)/seed bank (3.33 % each).

Table 3: Frequency of studies on different aspects of biodiversity in the studies reviewed

S/No.	Aspect of Biodiversity	Frequency	Relative Frequency (%)	Study area(s)
1	Ant	2	6.67	Xishuangbanna, China[1*] & Chaiyaphum, Thailand [1]
2	Archaea	2	6.67	Bukit Duabelas/Harapan[1] & Sumatra[1], Indonesia
3	Bacteria	5	16.66	Qiongzhong, China[1]; Sumatra, Indonesia[3]; & Malaysia[1]
4	Bat	2	6.67	Bahia, Brazil[1] and Songkhla/Trang/Phattalung, Thailand[1]
5	Bird	5	16.66	Hainan, China[1]; Sumatra, Indonesia[3] & Krabi, Thailand[1]
6	Earthworm/other Annelids	3	10.00	Xishuangbanna, China[1], Tripura, India[1] & Jambi, Indonesia[1]
7	Fungi	2	6.67	Sumatra, Indonesia[1] & Malaysia[1]
8	Gene (plant)	1	3.33	Sumatra, Indonesia
9	Nematode	3	10.00	Xishuangbanna, China[2] & Malaysia[1]
10	Plant	2	6.67	Danzhou, China[1] & Sumatra, Indinesia[1]
11	Seed bank	1	3.33	Xishuangbanna, China
12	Termite	2	6.67	Melawi[1] & Sumatra[1], Indonesia
Total		**30**	100	

*Superscript numbers on the same row represent ratios for study areas where studies on a particular aspect of biodiversity were conducted in more than one study area

Figure 2 shows the distribution of the reviewed studies among the top ten natural rubber producing countries by aspects of biodiversity studied. The two publications on ant focused on Thailand and China; the two publications on archaea focused only on Indonesia; the five publications on bacteria focused on Indonesia, Malaysia and China in a ratio of 3:1:1; the two publications on bat focused on Thailand and Brazil; the five publications on bird focused on Thailand, Indonesia and China in a ratio of 1:3:1; the three publications on earthworm/other annelids focused on China, Indonesia and India; the two publications on fungi focused on Indonesia and Malaysia; the only study on gene (plant) was reported for Indonesia; the four studies on nematode focused on Malaysia and China in a ratio of 1:3; the two studies on plant species focused on Indonesia and China; the only publication on soil seed bank focused on China; while the two publications on termite focused on Indonesia.

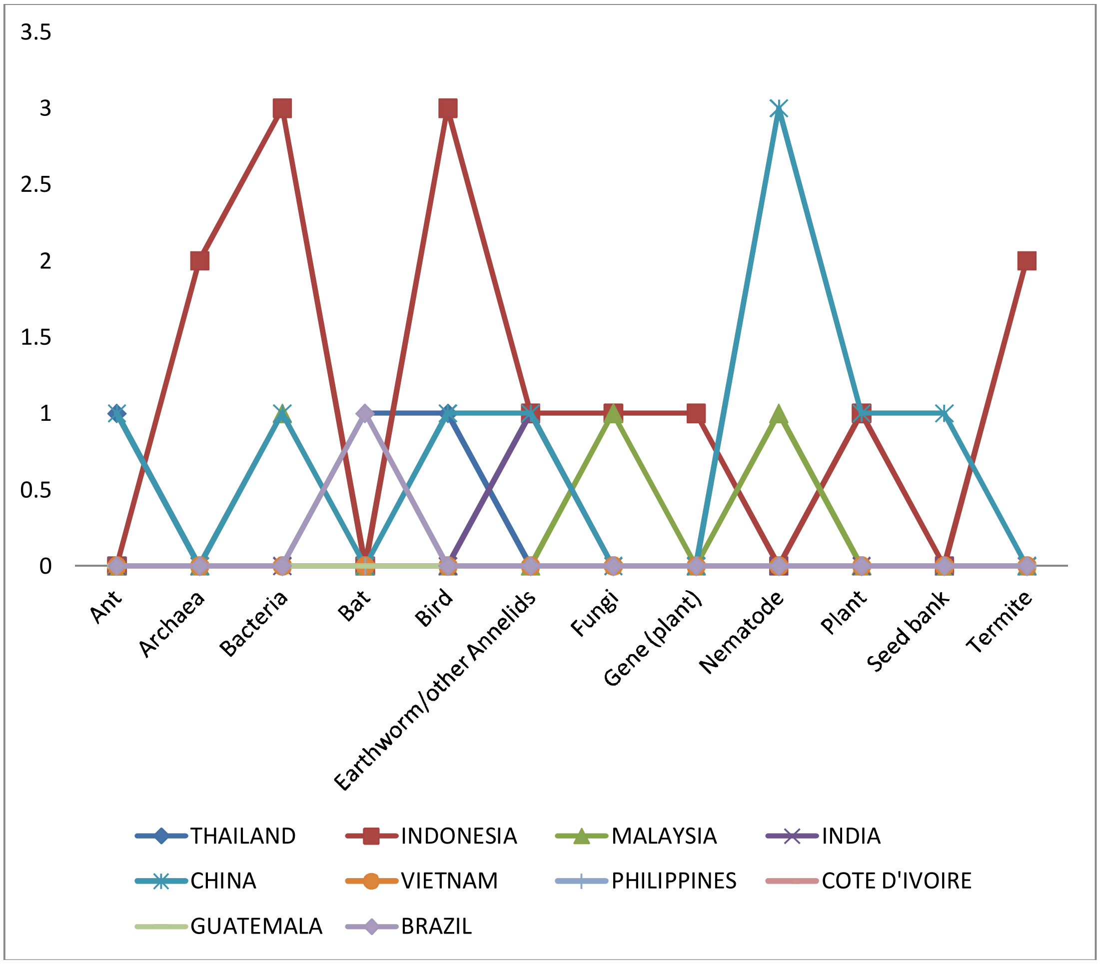

Figure 2: Distribution of the reviewed studies among the top ten rubber producing countries by aspects of biodiversity studied

Figure 3 shows the number of biodiversity components studied in each of the top ten natural rubber producing countries and their percentages. The highest number of biodiversity components was found to have been studied in Indonesia (61.54 % of total), followed by China (53.85%), Malaysia/Thailand (23.08 % each), Brazil/India (7.69 % each), while Vietnam, Philippines, Cote d'Ivoire, and Guatemala had 0 % each, indicating non-availability of studies on the impact of *H. brasiliensis* monocultures on any aspect of biodiversity.

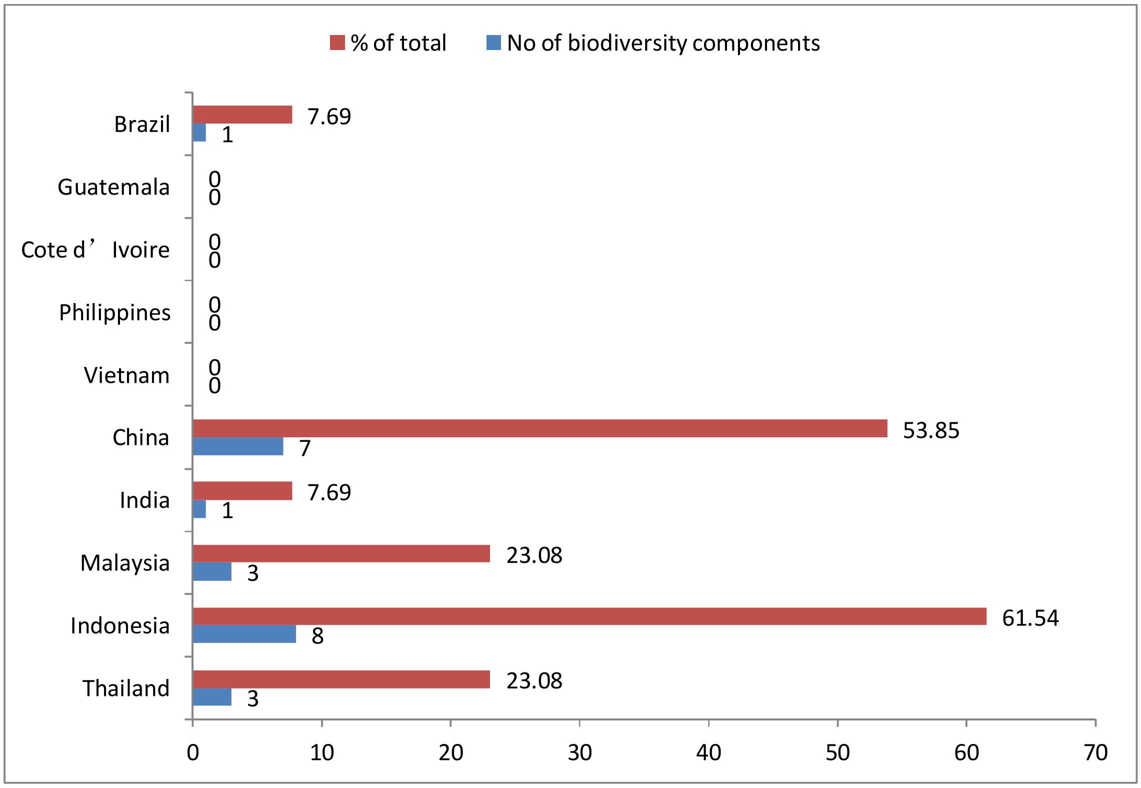

Figure 3: Number of biodiversity components studied in the top ten rubber producing countries and their percentages of the total number covered in the review

Information on the study sites (Table 3) show that all the studies on the impact of *H. brasiliensis* monocultures on different aspects of biodiversity in Indonesia were conducted at four areas/locations (Duabelas, Harapan, Sumatra & Jambi) with Sumatra being the most studied area. In China, the studies were conducted at Xishuangbanna, Qiongzhou, Danzhou/Hainan with Xishuangbanna being the most studied area. In Thailand, the studies were conducted at five sites (Chaiyaphum, Songkhla, Trang, Phattalung, & Krabi) with one of the studies spanning across three sites (Songkhla, Trang, Phattalung). The studies conducted in Brazil and India, were conducted at Bahia and Tripura, respectively.

Effects of *H. brasiliensis* monocultures on biodiversity in the top ten largest producers of natural rubber

Effect on genetic diversity

The only available study on the effect of *H. brasiliensis* monocultures on plant genetic diversity was conducted in Sumatra, Indonesia by Breidenbach *et al.* (2018). The authors evaluated the genetic diversity of 112 dominant plant species in old growth tropical lowland rainforest, jungle rubber, *H. brasiliensis* (natural rubber) and *Elaeis guineensis* (oil palm) monocultures. Their results showed lower genetic diversity in *H. brasiliensis* and *Elaeis guineensis* monocultures than in the natural forest and the jungle rubber forest.

Effect on seed bank diversity

Chen *et al* (2013) evaluated the soil seed bank in plantations (including *H. brasileinsis*) and tropical seasonal rainforests in Xishuangbanna, in Southwestern part of China. This was the only available study that investigated the effect of natural rubber monoculture plantations on soil seed bank in our review for the world's top ten producers of natural rubber. They found that conversion of the natural forest into rubber plantations exhausted seeds of tree species in the seed bank and increased the density of exotic herbs, leading to paucity of seeds for forest regeneration and restoration.

Effect on plant species diversity

Two studies were found on the effect of natural rubber (*H. brasiliensis*) monocultures on plant species diversity; one conducted in Sumatra, Indonesia by Beukema *et al*. (2007) and another in China by Lan *et al.* (2017). Considering all categories of plant species (epiphytic pteridophytes, trees, and vascular plants) covered in their study, Beukema *et al*. (2007) found that the natural forest compared better in plant species diversity than both the jungle forest and monoculture rubber plantations while the jungle rubber also compared better than the rubber monoculture. However, Lan *et al*, (2017) compared plant species richness between a modified management system which they termed 'Naturally Managed System' and the conventional monoculture system. The 'Naturally Managed System' to some extent mimics the 'jungle rubber' considering that other species of plants are also allowed to grow together with the rubber trees. In addition, there is no slashing of undergrowth and the application of herbicides and fertilizers as is the case with conventional management system of rubber monocultures. Species richness was found to be higher in the naturally managed system than in the conventional system, and also compared favourably with results obtained for some natural forests within the study area.

Effect on animal species diversity

The effect of *H. brasiliensis* monoculture plantations on animal diversity has been investigated in some of the top ten natural rubber producing countries. However, the studies mainly concentrated on some small and intermediate members of the animal Kingdom like ants, bats, birds, earthworm, and termite.

Liu *et al.* (2016) in their study in Xishuangbanna, Southwest of China, investigated the impact of forest conversion to *Hevea brasiliensis* plantation on taxonomic, functional and phylogenetic diversities of leaf-litter ant at both within-community (alpha) and between- community (beta) levels. Their results showed a sharp reduction in ant species richness when compared with that of the nearby forest, and a low beta diversity which was indicative of spatial homogeneity of species in rubber plantations. They equally observed patterns of both alpha and beta diversities that pointed to the evolution of functionally distinct ant communities in the rubber plantation in relation to the forest. In another study conducted in Chaiyaphum Province in Northeastern Thailand, Thongphak and Kulsa (2014), evaluated and compared the diversity and species composition of ant communities among a mixed deciduous forest, pine forest and para rubber (*H. brasiliensis*) plantation. Among the three land use types, they found that both ant species diversity and similarity in species composition were lowest and highest in the mixed deciduous forest and the monoculture rubber plantation, respectively.

The effect of natural rubber plantations on the diversity of bats has been investigated in Bahia, Northeastern Brazil and in two wildlife sanctuaries in Southern Thailand by Heer *et al*. (2015) and Phommexay *et al*. (2011), respectively. Specifically, Heer *et al.* (2015) investigated the extent to which the species richness and abundance of Neotropical bats differed among forest fragments and rubber plantations under different management systems. Their results show that the abundance and diversity of open-space bats were equal among the land use types while the species richness of the phyllostomid and aerial insectivorous forest bat species differed significantly among land use types with the species richness being higher in the forest fragments. In addition, they recorded high bat abundance and diversity in an intensively managed rubber-cocao plantation and opined that bats do not see plantations as an adverse environment but most likely exploit them as links between secondary vegetation and forest fragments, and that rubber plantations might help to preserve highly diverse bat assemblages. However, Phommexay *et al*. (2011) reported a significant decline in the diversity, activities, and biomass of insectivorous bats in rubber plantations when compared with the forest.

Beukema *et al.* (2007), Ayat and Tata (2015) and Prabowo *et al.* (2016) have evaluated the impact of natural forest conversion to monoculture rubber plantations on birds at three different locations in Sumatra, Indonesia. Their results showed a paucity of forest bird species in rubber plantations (Beukema *et al.* 2007); similar abundance but lower species richness between the rubber monoculture and the lowland rainforest (Prabowo *et al.*, 2016); and 23.68 % higher bird diversity index in the natural forest than the rubber plantation (Ayat and Tata, 2015). In a separate study conducted in Thailand, Aratrakon *et al.* (2006) reported a 60 % reduction in avifauna species richness in the rubber plantation compared to the lowland forest, with a greater detrimental impact on species that feed on fruits and insects than the omnivores. In addition, they observed that 94 % of the globally threatened or near-threatened species encountered in the study were exclusively found in the forest. In Hainan, Southern China, Li *et al*. (2013) investigated the impact of natural forest conversion to monoculture rubber plantation on bird communities and found higher species richness in the natural forest with marked variation in the species composition of birds between the natural forest and the natural rubber monoculture. They also reported the absence of many forest species in the rubber monoculture including the Grey Laughingthrush (*Garrulax maesi*) which is endemic to Hainan.

In West Tripura, India, Chaudhuri *et al.* (2013) have evaluated the impact of age of *H. brasiliensis* plantation on earthworm communities. Their results showed that an increase in the age of natural rubber plantation decreased the species richness, diversity and evenness of earthworm communities but increased their density, dominance and biomass, with *Pontoscolex corethrurus* accounting for over 60 % biomass and 70 % density of the earthworm communities. In another study in Jambi Province, Sumatra, Indonesia, Darmawan *et al.* (2015) reported that *P. corethrurus* (a non-native species) was the only species of earthworm found in a natural rubber monoculture and other land use types including oil palm plantation, jungle rubber and a secondary forest with its populations not varying significantly among the four land use types. The authors attributed the colonisation and dominance of *P. corethrurus* in modified and introduced land use types to its better tolerance than the native species of earthworm. Another study conducted in Xishuangbann, China by Singh *et al.* (2019) also reported a decline in alpha and beta diversity of some meso- and micro- fauna including annelids, nematodes and arthropods following natural forest conversion to rubber plantation, although, annelids were found to be more abundant in the rubber plantation than nematodes and arthropods.

Hidayat *et al.* (2018) in their study conducted in Melawi, West Kilamantan, Indonesia, attempted to ascertain the long term effect of *H. brasiliensis* monocultures on termite assemblages by evaluating and comparing termite communities in a primary forest with those of a newly opened rubber forest site and an unproductive/old rubber forest. They found a higher reduction in the species richness between the primary forest and the old rubber forest (62.5 %), and a slight difference in species richness between the primary forest and the newly opened rubber forest site. In another study conducted in Jambi Province, Central Sumatra, Indonesia, Jones *et al.* (2003) reported a decline in termite species richness and relative abundance along a land use intensification gradient including a mature rubber plantation.

Effect on the diversity of microorganisms

The effect of natural rubber monocultures on the diversity and activities of active soil microbial communities has been reported in studies conducted by Xiao *et al*. (2014), Zhou *et al.* (2017) and Singh *et al.* (2019) in China; Schneider *et al.* (2015), Nurulita *et al.* (2016) and Barkelmann *et al.* (2018) in Indonesia; and Kerfahi *et al*. (2016) in Malaysia. Zhou *et al*. (2017) reported that the diversity and composition of soil bacteria changed across chronosequences of natural rubber plantations, representing different stages of succession, with those of 10, 13 and 18 years having the highest diversity, followed by that of 30 years old while those of 5 and 25 years old had the lowest bacterial diversity. The authors posited that the bacterial diversity and composition in all the chronosequences were driven mainly by soil pH and vegetation, among other factors like soil nutrients and altitude. Other studies (Xiao *et al.* 2014; Nurulita *et al.* 2016; Barkelmann *et al.* 2018) posited that natural forest conversion to rubber monocultures significantly affects soil microbial communities including archaea, bacteria, fungi and nematodes. However, Kerfahi *et al.* (2016) reported that the conversion of a rainforest forest to rubber plantation did not result to consistent difference in alpha and beta diversity of soil biota including bacteria, fungi and nematodes but had a significant difference in their species composition; while Schneider *et al.* (2018) reported higher alpha and beta diversity of prokaryotic communities (including archaea and bacteria) in managed land use systems than in a rainforest. Singh *et al.* (2019) also reported that the conversion of the tropical forest to rubber plantation in Southern Yunnan, China, did not significantly affect both the alpha and beta diversity of nematodes, although they observed that total beta diversity for nematodes was marginally higher in the forest.

DISCUSSION

The appraised studies generally show significant decline in the diversity and species richness of different aspects of biodiversity in natural rubber (*H. brasiliensis*) monocultures compared with the primary or natural forests except for Schneider *et al.* (2015) who reported higher alpha and beta diversity of prokaryotic communities (including archaea and bacteria) in managed land use systems (including natural rubber monoculture) than in a rainforest, and Singh *et al.* (2019) who despite observing a consistent decrease in soil micro- and meso-faunal community generally, following tropical rainforest conversion to rubber plantation, also noted that nematodes were not significantly affected when the organisms were considered separately. Even in the case of nematodes, an earlier study in the same area (Xishuangbanna) by Xiao *et al.* (2014) had reported a higher nematode abundance and species richness in a natural forest with the species richness in the rubber monoculture being reduced by as high as 33 % after 15 to 20 years. Lower plant diversity (Singh *et al*., 2019), changes in soil properties induced by rainforest conversion and management practices like fertiliser application (Schneider *et al*., 2015; Berkelmann *et al*., 2018), and frequent anthropogenic perturbation (Hossain and Sugiyama, 2011; Lin *et al*., 2012), are among the possible reasons for lower biodiversity, including soil animal diversity, in monoculture rubber plantations. Philpott *et al.* (2008) also observed that a decline in species richness of many taxa usually occurs following the conversion of forests to agricultural systems, including rubber plantations (Meng *et al*., 2012).

The decline in the diversity, species richness and changes in species composition of communities of different aspects of biodiversity in monoculture rubber plantations may have negative consequences on ecosystem/ecological processes and functions that are driven and maintained by different components of biodiversity like the biogeochemical processes, pollination, biological pest control, seed dispersal, population regulation through competition and predation, among others. In order to enhance the sustainability of the rubber plantation ecosystems, some authors like Ziegler *et al*. (2009) and He and Martin (2015) have advocated the use of integrated land use systems that will combine rubber trees with other crops. The better performance of some integrated land use systems including the Jungle rubber and rubber-tea mixed plantation than the natural rubber monoculture, in terms of abundance, species richness and diversity of different aspects of biodiversity, as reported by Jones *et al.* (2003), Xiao *et al.* (2014), Ayat & Tata (2015), and Prabowo *et al.* (2016), lends credence to that advocacy.

Indonesia, China, and Thailand accounted for 86.95 % of the available studies on the impact of *H. brasiliensis* monocultures on biodiversity in the world's top ten natural rubber producing countries. This indicates poor spread of research/studies on the subject among these countries. It should be noted that Indonesia, China, and Thailand are countries in South/East Asia; a region that accounts for over 90 % of the world's natural rubber production (Chen *et al*., 2016; Jegede, 2019). Hence, a higher percentage of studies in South/East Asia, is indicative of some level of consciousness on the need to ascertain the ecological implications of the rapidly expanding natural rubber monocultures in the region. However, the majority of the studies in Indonesia concentrated in Sumatra while those conducted in China concentrated mainly in Hainan and Xishuangbanna. The lop-sidedness of the studies could most probably be as result of higher concentration of rubber plantations and experimental stations in those areas. In China for instance, Hainan was among the first areas rubber was planted and a major planting area for that matter (He and Huang, 1987). Xishuangbanna (in Yunnan Province) is also a major planting area for natural rubber in China (Chen *et al.,* 2013).

However, in countries like Guatemala, Cote d'Ivoire, India, Vietnam, Brazil, Philippines and Malaysia, there appears to be paucity of available scientific information on the impact of *H. brasiliensis* monocultures on biodiversity. For instance, only one study each was reported for Brazil on the effect of *H. brasiliensis* monocultures on bat by Heer *et al.* (2015), Malaysia on bacteria/fungi/nematodes by Kerfahi *et al*. (2016), and India on earthworm by Chaudhuri *at al.* (2013). None at all was reported for Vietnam, Philippines, Cote d'Ivoire and Guatemala. In Malaysia for example, our observations show that studies on the effects of monoculture plantations on biodiversity focused more on oil palm (*Eleais guineensis*) plantations. Although, Malaysia produces about 20% of the world's natural rubber and is currently the third largest producer, there are expectations that production will reduce due to fallen prices and as land use decisions give priority to oil palm plantations (Shimonski, 2015). In Cote d'Ivoire and Guatemala, available information online, dwell more on growth and economic projections of natural rubber production and the rubber industry.

The observations on countries like Cote d'Ivoire and Guatemala are not encouraging especially with respect to biodiversity conservation. Cote d'Ivoire for instance is the largest producer of natural rubber in the whole of the African continent; accounting for 60% of the Continent's natural rubber output (Koffi, 2018). Although Cote d'Ivoire's current annual production output of natural rubber is estimated at 411,044 tonnes (Jegede, 2019) probably due to fallen prices, predicted output was 720,000 tonnes in 2018 from 468,000 and 603,000 tonnes in 2016 and 2017, respectively (Koffi, 2018). There is the need for these phenomenal growth and expansion projections to be accompanied with measures that will ensure environmental and ecological sustainability. The efficacy of such measures to a large extent will depend on reliable findings from empirical studies especially within the respective localities as differences in climate and inherent variations in edaphic factors across regions and geographic zones may make species and populations of various aspects of biodiversity respond differently to the effects of *H. brasiliensis* monocultures.

CONCLUSION

Our appraisal generally shows that the conversion of primary or natural forests to *H. brasiliensis* (natural rubber) monocultures leads to decline in the species richness and diversity of different aspects of biodiversity. Among the world's ten largest producers of natural rubber, studies conducted in Indonesia, China, and Thailand, account for 86.95 % of the total number of publications found on the subject, and the three countries also rank first, second, and third, respectively, in terms of the number of aspects of biodiversity studied per country. However, despite the encouraging number of aspects biodiversity that have been covered by studies conducted in these countries, our observations reveal that 38.46, 46.15 and 76.92 % of the total number of biodiversity aspects recorded from all the appraised studies, have not been studied in Indonesia, China, and Thailand, respectively. One study each was reported for Brazil, Malaysia, and India, while none was found for Vietnam, Philippines, Cote d'Ivoire, and Guatemala. There was only one study each on the effect of natural rubber monocultures on plant genetic diversity and the soil seed bank, conducted in Indonesia and China, respectively. This implies that the impact of natural rubber monocultures on these aspects of biodiversity may not have been investigated in 90 % of the top natural rubber producing countries. In addition, the effect of natural rubber monocultures on some important aspects of biodiversity like ant, archaea, bat, fungi, plant and termite, have also not been adequately studied as available records show that they have been studied just in one or two of the top ten natural rubber producing countries. There were no available studies on some other important aspects of biodiversity like the big mammals, rodents, reptiles, among others, in the ten countries. These findings call for further studies to fill the identified knowledge gaps in order to enhance practices that will make natural rubber production more sustainable in terms of biodiversity conservation.

AKNOWLEDGEMENTS

The authors are grateful to the Science and Technology Exchange Centre of the Ministry of Science and Technology, People's Republic of China, for funding Dr Uzoma Darlington Chima's research fellowship at the Rubber Research Institute, Chinese Academy of Tropical Agricultural Sciences (RRI-CATAS), under the auspices of the Talented Young Scientists' Programme (TYSP-Nigeria-18-002). Dr Uzoma Darlington Chima is also grateful to the Management of the RRI-CATAS for providing a good work environment for him during the research period.

REFERENCES

[1] Ahrends A., Hollingsworth P.M., Ziegler A.D., Fox J.M., Chen H., Su Y. & Xu J. 2015. Current trends of rubber plantation expansion may threaten biodiversity and livelihoods. *Global Environmental Change*, 34, 48-58.

[2] Aratrakorn S., Thunhikorn S. & Donald P.F., 2006. Changes in bird communities following conversion of lowland forest to oil palm and rubber plantations in southern Thailand. *Bird Conservation International* 16, 71 - 82.

[3] Ayat A. & Tata H.L. 2015. Diversity of birds across land use and habitat gradients in forests, rubber agroforests and rubber plantations of North Sumatra. *Indonesian Journal of Forestry Reasearch* 2(2), 103 – 120.

[4] Berkelmann D., Schneider D., Engelhaupt, M., Heinemann, M. Christel, S., Wijayanti, M., Meryandini, A. & Daniel, R. 2018.How rainforest conversion to agricultural systems in Sumatra (Indonesia) affects active soil bacterial communities. *Frontiers in Microbiology* 9, 2381. doi:103389/fmich.2018.02381

[5] Beukema, H., Danielsen, F., Vincent, G., Hardiwinoto, S. & Andel, J.V. 2007. Plant and bird diversity in rubber agroforests in the lowland Smatra, Indonesia. *Agroforestry Systems* 70, 217 – 242.

[6] Breidenbach, N., Rahayu, S., Siregar, I.Z. Siregar, U.J., Hamzah, Finkeldey, R. 2018. Genetic diversity of dominant plant species in Tropicalland use systems in Sumatra, Indonesia. *Tropical Conservation Science* 11, 1 -14. Doi: 10.1177/1940082918813908.

[7] Bremer, L.L. & Farley, K.A. 2010. Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effect of land use transitions on plant species richness. *Biodiversity Conservation,* 19, 3893 – 3915. Doi: 10.1007/s10531-010-9936-4

[8] Carlos, S. 2013. Guatemala: The silent advance of industrial rubber tree plantations. World Rainforest Movement (WRM) Bulletin 193. Available at wrm.org.uy/articles-from-the-wrm-belletin/section 1/Guatemala. Accessed 2nd September, 2019.

[9] Chaudhuri, P.S., Bhattacharjee, S., Dey. A., Chattopadhyay, S. & Bhattacharya, D. 2013. Impact of age of rubber (*Heavea brasiliensis*) plantation on Earthworm communities of West Tripura (India). *Journal of environmental Biology* 34, 59 – 65.

[10] Chen, H., Cao, M. & Tang, Y. 2013. Soil seed banks in plantations and tropical seasonal rainforests of Xishuangbanna, Southwest, China. *Journal of Tropical Forest Science* 25(3), 375 – 386.

[11] Chen, H., Yi, Z.F., Schmidt-Vogt, D. Ahrends, A., Beckschafer, P., Kleinn, C, Ranjitkar S. & Xu, J. 2016. Pushing the limits: The pattern and dynamics of rubber monoculture expansion in Xishuangbanna, SW China. *PLoS One* 11(2), e0150062.

[12] Cotter, M., Martin, K. & Sauerborn, J. 2009. How Do 'renewable products' impact biodiversity and ecosystem services – The example of natural rubber in China. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 110(1), 9–22

[13] Darmawan, A., Atmowidi, T., Manalu, W. & Suryobroto, B. 2015. *Pontoscolex corethrurus* (Muller, 1857) (Oligochaeta Glossoscolecidae) in forest transformation system in Bungku Village, Jambi, Indonesia. *Biodiversity Journal* 6(2), 505 - 512

[14] Food and Agriculture Organization (FAO), 2011. Protection against South American leaf blight of rubber in Asia and the Pacific region. FAO RAP Publication, 2011. Available from http://www.fao.org/3/i2157e/i2157e00.pdf

[15] Food and Agriculture Organization (FAO), 2013. Statistical Division (FAOSTAT). FAO Statistical Databases 2013. Available from: URL: http://faostat.fao.org/

[16] Fox, J. Vogler, J.B., Sen, O.L., Giambelluca, T.W., Ziegler, A.D. 2012. Simulating land-cover change in montane mainland southeast Asia. *Environmental Management* 49, 968–979.

[17] Guen, V.L., Garcia, D., Mattos, C.R.R. & Clément-Demange, A. 2002. Evaluation of field resistance to Microcyclus ulei of a collection of Amazonian rubber tree (*Hevea brasiliensis*) germplasm. Crop *Breeding and Applied Biotechnology*, 2(1), 141-148

[18] Hayashi, Y. 2009. Production of natural rubber from Para rubber tree. *Plant Biotechnology* 26, 67–70.

[19] He, K. & Huang, Z.D. 1987. *Rubber Culture in the Northern Part of the Tropical Area.* Guangzhou: Guanglong Science and Technology Press.

[20] He, P. & Martin, K. 2015. Effect of rubber cultivation on biodiversity in the Mekong Region. *CAB Reviews* 44., 1 – 6.

[21] Heer, K., Helbig-Bonitz, M., Fernandes, R.G., Mello, M.A.R. & Kalko, E.K.V. 2015. Effects of land use on bird diversity in a complex plantation – forest landscape in Northeastern Brazil. *Journal of Mammalogy,* 94(6), 720 – 731. Doi: 10.1093/jmammal/gyv068.

[22] Hidayat, M.R., Endris, W.M. & Dwiyanti, Y. 2018. Effect of a rubber plantation on termite diversity in Melawi, West Kalimantan, Indonesia. *Agriculture & Natural Resources* 52, 439 – 444.

[23] Hossain, Z. & Sugiyama, S. 2011. Geographical structure of soil microbial communities in northern Japan: effect of distance, land use type and soil properties. *European Journal of Soil Biology*, 47, 88 – 97. Doi: 10.1016/j.ejsobi.2010.11.007

[24] Jegede, A. 2019. Top ten largest rubber producing countries in the world. Available at www.thedailyrecords.com/2018-2019-2020-2021/world-famous-top-ten-list/. Retrieved 18th July, 2019.

[25] Jones, D.T., Sucilo, F.X. Bignell, D.E., Hardiwinotos, S., Gillison, A.N. & Eggleton, P. 2003. Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia. *Journal of Applied Ecology* 40, 380 -391.

[26] Kerfahi, D., Tripathi, B.M., Dong, K., Go R. & Adams, J.M. 2016. Rainforest conversion to rubber plantation may not result in lower soil diversity of bacteria, fungi and nematodes. *Microbial Ecology* 72(2), 359 – 371.

[27] Koffi, C. 2018. In Ivory Coast, global rubber glut erases profits. Available at http://www.phys,org/news/2018-08-ivorycoast-global-rubber-glut.html. Reterieved 24th September, 2019.

[28] Lan, G., Wu, Z., Chen, B. & Xie, G. 2017. Species diversity in a naturally managed rubber plantation in Hainan Island, South China. *Tropical Conservation Science* 10, 1 – 7. Doi:10.1177/1940082917712427.

[29] Li, H.M., Ma, Y.X., Liu, W.J. & Liu, W.J. 2012. Soil changes induced by rubber and tea plantations in comparison with tropical rainforest soil in Xishuangbanna, SW China. *Environmental Management,* 50, 837 – 848. Doi: 10.1007/s00267-012-9942-2

[30] Li, S., Zou, F. Zhang, Q. and Sheldon, F.H. 2013. Species richness and guild composition in rubber plantations compared to secondary forest in Hainan Island, China. *Agroforestry Systems* 87(5), 1117 – 1128.

[31] Lieberei, R. 2007. South American Leaf Blight of the rubber tree (*Hevea* spp.): New steps in plant domestication using physiological features and molecular markers. *Annals of Botany* 100(6), 1125–1142. doi: 10.1093/aob/mcm133

[32] Lin Q, Li H, Luo W, Lin Z. & Li B G. 2013. Optimal soil-sampling design for rubber tree management based on fuzzy clustering. *Forest Ecol Manag*. 308: 214–222.

[33] Liu, C., Guenard, B., Blanchard, B., Peng, Y., & Economo, E.P. 2016. Reorganisation of taxonomic, functional, and phylogenetic ant biodiversity after conversion to rubber plantation. *Ecological Monographs* 86(2), 215 – 227.

[34] Meng, L.Z., Martin, K.,Weigel,A., Liu, J.X., 2012. Impact of rubber plantation on carabid beetle communities and species distribution in a changing tropical landscape (southern Yunnan, China). *Journal of Insect Conservation* 16, 423-432.

[35] Mooibroek, H., and Cornish, K. 2000. Alternative sources of natural rubber. *Applied Microbiology & Biotechnoogy.* 53, 355–365. doi: 10.1007/s002530051627

[36] Moreira, A., Moraes, L.A.C. & Fageria, N.K. 2009. Potential of rubber plantations for environmental conservation in the Amazon Region. *Bioremediation, Biodiversity & Bioavailability*, 3(1), 1 – 5.

[37] Nurulita, Y., Adetutu, E.M., Kadali, K.K., Shahsavari, E., Zul D., Taha, M. & Ball, A.S. 2016. Assessment of the influence of oil palm and rubber plantations in Tropical Peat Swamp soils using microbial diversity and activity analysis. *Journal of Agricultural Chemistry and Environment* 5, 53 – 65. http://dx.doi.org/10.4236/jacen.2016.52006.

[38] Obouayeba, S., Boko, A.M.C.K., Soumahin, E.F., Elabo, A.A.E.E., Dea, G.B., N'guessan, B.E.A., Kouame, C., Zehi. B. & Keli, Z.J. 2015. Natural rubber-based intercropping systems in Cote d'Ivoire: A review of forty years work, *Rubber Science,* 28(3), 211 – 226.

[39] Philpott, S.M., Arendt, W.J., Armbrecht, I., Bichier P., Diestch, T.V., Gordon C., Greenberg R., Perfecto I., Reynoso-Santos R., Soto-Pinto L., Tejeda-Cruz, C., Williams-Linera G., Valenzuela, J., Zolotoff J.M. 2008. Biodiversity loss in Latin America coffee landscapes: a review of the evidence on ants, birds and trees. *Conservation Biology*, 22, 1093-1105.

[40] Phommexay, P., Satasook, C., Bates, P., Pearch, M., Bumrungsri, S., 2011. The impact of rubber plantations on the diversity and activity of understorey insectivorous bats in southern

Thailand. *Biodiversity & Conservation* 20, 1441 - 1456.

[41] Prabowo, W.E., Darras, K., Clough, Y., Toledo-Hernandez, M. Arletazz, R., Mulyani, Y.A. & Tscharntke, T. 2016. Bird responses to lowland rainforest conversion in Sumatran smallholder landscapes, Indonesia. *PLoS ONE* 11(5), e0154876. doi.10.1371/journal.pone.0154871

[42] Schneider, D., Engelhaupt, M., Allen, K., Kumiawan, S., Krashevska, V., Heinemann, M., Ncke, H., Wijayanti, M., Meryandini, A. Corre, M.D., Scheu, S., & Daniel, R. 2015. Impact of lowland rainforest transformation on diversity and composition of soil prokaryotic communities in Sumatra (Indonesia). *Frontiers in Microbiology* 6, 1339. Doi:10.3389/fmich.2015.01339

[43] Shimonski, J. 2015. "A Brief History on Rubber Tapping in Malaysia," *Malaysia Flora*, www.malaysiaflora.com/index.php?option=com_content&view=article&id=5:a-brief-history-on-rubber-tapping-in-malaysia&catid=13&Itemid=104. Accessed 22nd September, 2019.

[44] Singh, D., Slik, J.W.F., Jeon, Y., Tomlinson, K.W. Yang, X., Wang, J., Kerfahi, D., Porazinska, D.L., & Adams, J.M. 2019. Tropical forest conversion to rubber plantation affects soil micro- and mesofaunal community and diversity. *Scientific Reports* 9, 5893. https://doi.org/10.1038/s41598-019-42333-4

[45] Thongphak, D. & Kulsa, C. 2014. Diversity and community composition of ants in the mixed deciduous forest, pine forest and the Para rubber plantation at Chulaborn Dam, Chaiyaphum Province, the Northeastern Thiland. *International Journal of Environmental and Rural Development* 5(1), 72 – 76.

[46] Warren-Thomas, E., Dolman, P.M., & Edwards, D.P., 2015. Increasing demand for natural rubber necessitates a robust sustainability initiative to mitigate impacts on tropical biodiversity. *Conservation. Letters* 8(4), 230 – 241. http://dx.doi.org/10.1111/conl.12170.

[47] Workman, D. 2018. Natural rubber export by country. http://www.worldstopexports.com/natural-rubber-exports-country/. Retrieved 20th August, 2019.

[48] Wu, J., Liu, W. & Chen, C. 2016. Can intercropping with the world's three major beverage plants help improve the water use of rubber trees? *Journal of Applied Ecology*, 53, 1787–1799. doi: 10.1111/1365-2664.12730

[49] Xiao, H.F., Tian, Y.H., Zhou, H.P., Ai, X.S., Yang, X.D. & Schaefer, D.A. 2014. Intensive rubber cultivation degrades soil nematode communities in Xishuangbanna, Southwest China. *Soil Biology & Biochemistry* 76, 161 – 169.

[50] Ziegler A.D., Fox J.M. & Zu J. 2009. The rubber juggernaut: The demise of swidden agriculture in Southeast Asia may have devastating environmental consequences. *Science* 324, 1024 – 1025.

[51] Zheng, G., Yang, X.D., Li, S.Q., 2009. Biodiversity of ground-dwelling spider in six forest types in Xishuangbanna, S. W. China. *Acta Entomologica Sinica* 52, 875 - 884.

[52] Zhou, H.P., Ai, X.S., Zhang, H.D., Zhang, L.Q., Wei, L.P., 2012. Species diversity of understorey vegetation in rubber plantations in Xishuangbanna. *Chinese Journal of Tropical Crops* 33, 1444 - 1449.

[53] Zhou, Y., Li, J., Friedman, C.R. & Wang, H. 2017. Variations of soil bacterial communities in a chronosequence of rubber tree (*Hevea brasiliensis*) plantations. *Frontiers in Plant Science* 8, 849. Doi:103389/fpls.2017.00849.

11/12/2021