OPEN ACCESS

COMMENTARY

The Innovation

From primary forests to rubber plantations: A huge ecological loss

Yuxi Wang[1,3] and Lin Zhang[1,2,*]

[1]State Key Laboratory of Tibetan Plateau Earth System, Environment and Resources (TPESER), Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China

[2]Key Laboratory of Biological Resources and Biosafety, Institute of Plateau Biology of Xizang Autonomous Region, Lahsa 850000, China

[3]University of Chinese Academy of Sciences, Beijing 100101, China

*Correspondence: zhanglin@itpcas.ac.cn

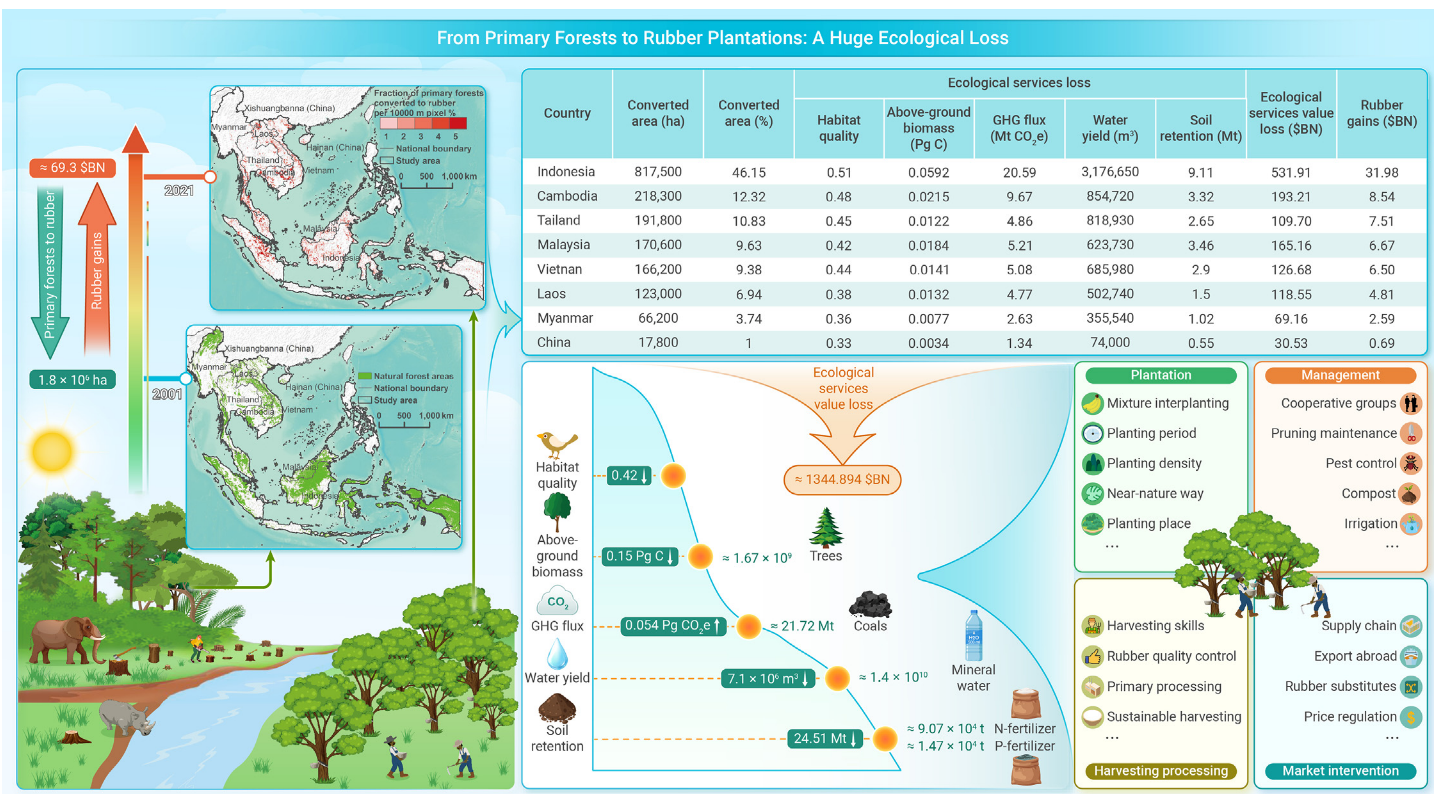
Received: August 7, 2024; Accepted: February 5, 2025; Published Online: February 7, 2025; https://doi.org/10.1016/j.xinn.2025.100836

Citation: Wang Y. and Zhang L. (2025). From primary forests to rubber plantations: A huge ecological loss. The Innovation **6(5)**, 100836.

The production and consumption of rubber occupy a pivotal position in the global economy, with the manufacture of more than 1 billion tires per year globally now relying on natural rubber.[1] According to the Food and Agriculture Organization of the United Nations (FAO), the world export price of rubber has quintupled from 2001 to 2021. Robust market demand and sharp price inflation have greatly fueled the expansion of rubber plantations. Reports from the Association of Natural Rubber Producing Countries (ANRPC) indicated that global natural rubber production has increased 22-fold during the last 24 years (from 0.68 Mt in 2000 to 15.14 Mt in 2023), with over 90% of this output originating from Southeast Asia, particularly Thailand, Indonesia, and Vietnam.

Recently, Wang et al.[1] used the unique phenological characteristics of rubber plantations to map, for the first time, the distribution of rubber forests across Southeast Asia in 2021. Their findings revealed that the area of deforestation for rubber plantations was at least two to three times greater than current policy data estimates. More alarmingly, over a quarter (approximately 1 million hectares) of rubber plantations were located in key biodiversity areas, which originally possessed exceptionally high ecological value. These data show that the expansion of rubber plantations not only leads to the destruction of primary forests but also results in associated losses of crucial ecosystem services, such as carbon sequestration, soil nutrients, water resources, and biodiversity, which, in turn, generates a cascading effect threatening the ecological balance regionally and globally.[2] Wang et al.[1] noted that rubber has received less attention than other commodities, sparking a widespread debate about its policy controls. There is an urgent need for robust evidence to guide policy actions to prevent rubber from being prematurely excluded from key policies. Wang et al.'s[1] work offers the potential to identify regions where conversion of primary forests to rubber plantations has occurred. However, key questions about "where, how, and how great are the ecological losses" remain unanswered. To this end, we identified the regions where primary forests were transformed into rubber forests between 2001 and 2021, based on the distribution data of primary forests in 2001 and rubber forests in 2021.[1,3] From the perspective of ecosystem services, we quantified the ecological loss caused by this transformation and further explored how to minimize the damage to forest ecosystems and biodiversity hotspots while meeting rubber production demands, thereby achieving synergistic benefits between environmental and production objectives (Figure 1).

In 2001, the area of primary forests in Southeast Asia was 246 million hectares, accounting for 19.26% of the world's total primary forests area.[3] By 2021, 1.8 million hectares of these primary forests had been converted into rubber forest plantations. The results of the pixel-by-pixel evaluations of ecosystem service functions in Southeast Asia based on multi-source remote sensing observations and the integrated valuation of ecosystem services and tradeoffs model found that large-scale forest conversion caused reductions in above-ground biomass, water yield, and soil retention by 0.15 Pg, 7.1 million m^3, and 24.51 Mt in the region, respectively, whereas the net greenhouse gas increased by 0.054 Pg CO_2



Country	Converted area (ha)	Converted area (%)	Ecological services loss					Ecological services value loss ($BN)	Rubber gains ($BN)
			Habitat quality	Above-ground biomass (Pg C)	GHG flux (Mt CO_2e)	Water yield (m^3)	Soil retention (Mt)		
Indonesia	817,500	46.15	0.51	0.0592	20.59	3,176,650	9.11	531.91	31.98
Cambodia	218,300	12.32	0.48	0.0215	9.67	854,720	3.32	193.21	8.54
Tailand	191,800	10.83	0.45	0.0122	4.86	818,930	2.65	109.70	7.51
Malaysia	170,600	9.63	0.42	0.0184	5.21	623,730	3.46	165.16	6.67
Vietnan	166,200	9.38	0.44	0.0141	5.08	685,980	2.9	126.68	6.50
Laos	123,000	6.94	0.38	0.0132	4.77	502,740	1.5	118.55	4.81
Myanmar	66,200	3.74	0.36	0.0077	2.63	355,540	1.02	69.16	2.59
China	17,800	1	0.33	0.0034	1.34	74,000	0.55	30.53	0.69

Figure 1. Schematic of ecological losses from primary forest conversion to rubber plantations in 2001–2021 and strategies for optimal management of rubber plantations The framework shows where the conversion from primary forest to rubber plantations did occur in Southeast Asia and how much area has been converted, the total amount of ecosystem services and their value loss from the conversion from primary forest to rubber plantations and the differences in individual countries in Southeast Asia, and a framework for the optimal management of rubber plantations.

equivalent. Furthermore, the region's average habitat quality index decreased by 47.7% (from 0.88 to 0.46), resulting in a substantial decline in the populations of birds, invertebrates, plants, and fungi dependent on primary forests and, consequently, a significant loss in biodiversity.[4] Through economic valuation by the market value method, involving direct market prices and proxies for non-market ecosystem services, we found that the total economic value of the lost ecosystem services resulting from these conversions amounted to a staggering $1,344.894 billion.

Among the Southeast Asian countries, Indonesia experienced the most significant conversion, accounting for 46.15% of the total and causing up to $531.91 billion in economic loss. This conversion not only originated from Indonesia's long-standing rubber cultivation history and the farmers' enthusiasm for the substantial demand in the rubber market but also can be tracked with the Proyek Inti Rakyat (PIR) project started in the 1970s. The PIR project promoted extensive rubber cultivation in Sumatra, Kalimantan, and Java, leading to great expansion. Despite agricultural policies adjustments in the early 21st century, the PIR's core principles have been continued in new initiatives. In Cambodia, natural forest conversion accounted for about 12.32% of primary forest, second only to Indonesia. A key driver is the country's Economic Land Concessions policy, allowing foreign investors to lease land for up to 70 years, thereby facilitating large-scale land development and profit generation. Inclusive Development International reported that the Vietnamese company Hoang Anh Gia Lai acquired over 20,000 ha of land in Ratanakiri Province in northeastern Cambodia for rubber cultivation, with more than 40% of the area directly linked to deforestation, sparking social and environmental conflicts over land acquisition, environmental damage, and labor rights. Notably, although Thailand's land conversion (0.192 Mha) surpassed that of Malaysia (0.171 Mha), its total ecosystem service economic loss was only 2/3 of that of Malaysia's. This is due to more sustainable agricultural management in some regions. For example, farmers in Songkhla province in southern Thailand have implemented an agroforestry system combining rubber with durian and wood beans, which reduced soil erosion and increased farmers' incomes by up to 30% compared to traditional monoculture cropping patterns. This system is being promoted in other regions, such as Nakhon Ratchasima and Surat Thani, with projections to cover more plantations within 5 years. Furthermore, deforestation due to rubber cultivation in Myanmar and China's Xishuangbanna and Hainan regions was comparatively minimal, accounting for 3.74% and 1% of the conversion area, respectively.

It is undeniable that the converted rubber plantations also yielded considerable economic benefits. According to the FAO, in 2021, the average production of natural rubber in Southeast Asia was 1.4 t/ha with an export price of about $1,300/t. Assuming that the 1.8 million hectares of converted rubber plantations began harvesting in 2001, the direct economic benefits over this period amounted to $69.3 billion. Although these benefits represented only 1/19 of the ecosystem services value lost, as long as rubber remains profitable, the expansion of rubber plantations will be an inevitable consequence. Therefore, for this price-driven plantation sector, we must explore alternative cultivation and management models to safeguard environmental health in Southeast Asia and other regions.

Encouragingly, rubber has been included under the purview of the European Union Deforestation Regulation in 2023. According to this regulation, rubber products destined for the EU market must ensure that their supply chains do not involve any deforestation. Additionally, numerous efforts have been made by various countries for the sustainable development of the rubber industry, including India's Rubber Act, Malaysia's Rubber Production Incentive Scheme since 2015, and Thailand's Rubber Farmers Income Guarantee Program launched in 2019. However, challenges remain unresolved, such as ensuring that farmers receive adequate economic returns under eco-friendly cultivation practices. Therefore, regarding the identified issues, we discuss the relevant measures in detail below.

First, rigorous planning for rubber cultivation is essential, designating high-value ecosystem areas as exclusion zones to prevent uncontrolled expansion and landscape fragmentation. Second, research indicates that "jungle-like rubber forests" can reduce soil erosion by over 30% and enhance microbial diversity by 20% compared to monocultures.[5] Integrating rubber trees with other economically valuable crops can also provide farmers supplementary income during the initial 6–7 unproductive years. However, planting densities must be carefully managed to avoid competition between rubber trees and intercropped species. The successful precedents established by Thailand and China can serve as an example; however, it is essential to tailor the selection of appropriate intercrops to local climatic conditions and market demand and to explore diversification patterns. For existing rubber plantations, measures such as eco-friendly pest control, compost recycling, and optimized irrigation can significantly increase rubber yields while reducing environmental stress. To address the supply-demand imbalance of natural rubber, promoting alternative rubber sources (including synthetic, bio-based, chemically modified natural rubber) and rubber reuse is critical to reduce overdependence on natural rubber and market risks. Meanwhile, cooperatives can also combat labor shortages faced by small-scale farmers and enhance the efficiency and yield of natural rubber production by centralizing and optimizing production processes, particularly in the forest management, harvesting, and subsequent processing stages. Equally important, countries must optimize agricultural policies in time; particularly, Cambodia should consider revising lease durations or enhancing foreign investor scrutiny to meet environmental standards. Simultaneously, implementing unified land use planning is a transformative solution but requires balancing economic pressures, historical land tenure complexities, and ecological priorities, with benefits likely unfolding over decades.

We emphasize the huge ecological losses incurred by converting primary forests to rubber plantations and propose an optimization framework for rubber plantation management to inform decision-making and promote sustainable production. However, rubber plantations may extend ecological impacts through edge effects upon adjacent primary vegetation or secondary forests, potentially causing losses beyond our estimates. Notably, apart from rubber forests, "about 90% of tropical deforestation is linked to the production of global commodities like oil palm, tea, coffee, and cocoa,"[1] requiring greater attention to the ecological losses from these crops to support global sustainability and ecosystem conservation.

REFERENCES

1. Wang, Y., Hollingsworth, P.M., Zhai, D. et al. (2023). High-resolution maps show that rubber causes substantial deforestation. *Nature* **623**:340–346. DOI:https://doi.org/10.1038/s41586-023-06642-z.
2. Grass, I., Kubitza, C., Krishna, V.V. et al. (2020). Trade-offs between multifunctionality and profit in tropical smallholder landscapes. *Nat. Commun.* **11**:1186. DOI:https://doi.org/10.1038/s41467-020-15013-5.
3. Turubanova, S., Potapov, P.V., Tyukavina, A. et al. (2018). Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia. *Environ. Res. Lett.* **13**:074028. DOI:https://doi.org/10.1088/1748-9326/aacd1c.
4. Ewers, R.M., Orme, C.D.L., Pearse, W.D. et al. (2024). Thresholds for adding degraded tropical forest to the conservation estate. *Nature* **631**:808–813. DOI:https://doi.org/10.1038/s41586-024-07657-w.
5. Chen, C., Liu, W., Wu, J. et al. (2019). Can intercropping with the cash crop help improve the soil physico-chemical properties of rubber plantations? *Geoderma* **335**:149–160. DOI:https://doi.org/10.1016/j.geoderma.2018.08.023.

ACKNOWLEDGMENTS

This work was supported by grants from the Base & Talent Project in Science and Technology of Xizang Autonomous Region (XZ202401JD0025). We also thank Prof Francisco I. Pugnaire from the Estación Experimental de Zonas Áridas, Consejo Superior de Investigaciones 3 Científicas, Almería, Spain, for helping us to improve the language quality of this commentary.

DECLARATION OF INTERESTS

The authors declare no competing interests.