

Evaluation of teak (*Tectona grandis* Linn. f) stands for establishing seed production areas in West Bengal

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ARTICLE INFO	ABSTRACT
Received : 20 October 2023 Revised : 31 December 2023 Accepted : 04 January 2024 Available online: 01 March 2024 Key Words: Afforestation Conservation QPMs Seed yield Tree improvement	<p>Long-term afforestation programmes are continuously practiced by State Forest Departments (SFDs) to increase forest cover in India. A large quantity of quality seeds is required for producing quality planting materials every year. The development of seed production areas (SPAs) is a method that can be used to obtain genetically improved seeds for immediate planting. Teak (<i>Tectona grandis</i> Linn. f) is one of the species preferred by SFDs in India for plantation purposes due to its high timber value. Previously, the Directorate of Forests, West Bengal, established ten Seed Stands (SSs) of teak in three Silviculture divisions of West Bengal. In the present study, these SSs (five SSs in the Hills Division, four SSs in the North Plains Division and one SS in the South Division) were evaluated by verification on the basis of area, tree density, isolation zone and tree health. SSs were studied thoroughly to recommend culling inferior trees to convert them to SPAs. Trees with poor phenotypic characteristics, such as slow growth, crooked stem form, attack by pest or disease, were recommended for culling. Out of the ten SSs, five (2/TG/BAMON, 3/TG/BAMON, 3/TG/TUKR, 8/TG/REHTI and 9/TG/ATIA) were considered to be SPAs. Cumulatively, 8.86 hectares of land with 829 trees from the hills division and 15 ha of land with 1712 trees from the North Plains division were chosen for inclusion in the SPAs. Phenotypic data estimation revealed that the maximum average height was 8/TG/REHTI (33.19±2.65 m), and the average GBH was 2/TG/BAMON (2.02±0.54 m). The seed production capability of the selected SPAs was also calculated. On the basis of the average seed yield/tree, the 8/TG/REHTI stand produced the highest seed yield of 2.0 (±0.9) kg/tree.</p>

Introduction

West Bengal is the nation's fourth most populous state, with more than 91 million inhabitants (WBPC, 2011) and a total geographical area of 88,752 km². With the Himalayas in the north and the sea in the south and plains and plateaus occupying the

remaining land, the West Bengal boasts vivid biodiversity. In the last ten years, forest cover has increased in western Bengal, which contains 18.96% of the total geographical area of the state (ISFR, 2021). The State Forest Department (SFD) of West

Bengal continuously follows long-term afforestation programs to increase forest cover in the state. This is even more creditable for the SFD because, despite the enormous dependence of tribal people and native people living in forest fringe areas on their livelihood, forest cover has gradually increased over the course of time (Mishra *et al.*, 2021). However, maintaining an upward trend in forest cover requires a large quantity of quality seeds. Using good quality seeds collected from selected superior parent trees ensures improved survival and greater yield and ensures that the resulting plantation will have good form, survival and better resistance under stressed conditions (Ravichand and Gunaga, 2021). Seed stands (SSs) are groups of trees in either natural forests or plantations identified as having superior phenotypical characteristics and managed for seed production (Ingvarsson and Dahlberg, 2019). Nonetheless, SSs seldom exhibit beneficial effects from selective thinning or other management practices intended to improve the quality of seeds produced from stands (Erickson and Halford, 2020). However, the seed production area (SPA) is a natural stand or plantation of phenotypically superior trees that is thinned by removing poor phenotypes, while good trees are left to mate and produce seeds, which are collected for operational forestry programs (Zinnen *et al.*, 2021). SPAs are important and immediate sources of well-adapted and improved seeds. The preconditions for the production of genetically improved seeds are fulfilled in SPAs by the presence of phenotypically superior trees and mating among these trees with minimal selfing and contamination by inferior pollen from outside sources (Varghese *et al.*, 2008). The seeds from SPAs are widely used for the tree species for which improvement programmes have just begun. Moreover, this approach provides an inexpensive supplement to more elaborate and highly technical tree breeding activities. Teak (*Tectona grandis* Linn. f) is one of the most important tropical timber species worldwide due to its exceptional wood quality, distinctive grain and texture, strength, and high level of durability (Mohammad *et al.*, 2023). Teak is indigenous to Asia and generally confined to moist and dry mixed deciduous forest types below 1000 m in elevation in India, Myanmar, Thailand and Laos (Mohammad *et al.*, 2022). The rotation age of teak in forest plantations is typically 40 years,

while the rotation length in commercial teak plantations is predicted to be significantly shorter for early returns (Shukla and Viswanath, 2021). Nevertheless, several studies have indicated that a rotation duration of 20 to 30 years is the best cycle for achieving equilibrium amid revenue generation and the production of high-quality timber (Krishnapillay, 2000; Chundamannil, 2000; Shukla and Viswanath, 2014; Sasidharan and Ramasamy, 2021). Despite its fairly long rotation age, teak is one of the most important species in plantation programs in various states in India because of its multidimensional use and high market price. Every year, approximately 50000 hectares of land are planted with teak in India (Subramanian *et al.*, 2000), which accumulates approximately 43% of the total teak plantations worldwide (Mohapatra *et al.*, 2020). Shahapurmath *et al.* (2016) reported that teak has a mean productivity of 0.865 cumper tree in block plantations. It is estimated that an additional revenue of Rs. 15 lakh/ha can be fetched by the marginal farmers from selling the timber within 25 years by adopting agroforestry models based on teak on their farms or fields. In India, most teak plantations are raised from seeds from unselected sources, leading to low productivity. The recommendations of Kedharnath and Mathews (1962) have been the basis for teak improvement in the country. This has paved the way for developing seed production areas and seed orchards of teak in India. The amount of genetic gain (higher productivity) in plantations raised from the seeds of SPAs is expected to be small but greater than that in plantations raised from the seeds of an unimproved source and seed stand (Mulawarman *et al.*, 2003). The first step toward improving the genetic quality of the seed is setting apart a few excellent plots as SPAs. Such SPAs are highly relevant for long rotation crops such as teak since they assure the immediate availability of adequate quantities of seeds at modest cost (Ferrerias and Galetto, 2010). Considering its ever-growing value, the Directorate of Forests, West Bengal, established 10 SSs of teak in three Silviculture divisions of West Bengal. Nevertheless, many of these SSs have reproduced excessively, and their production capacity seems to have fallen. Therefore, it was necessary to evaluate the health of the stands and their seed production capacity for converting them into SPAs. These SSs

were evaluated during 2018-2021 by the ICFRE – IFP, Ranchi under the West Bengal Forest and Biodiversity Conservation Project (WBFBCP) funded by the Japan International Cooperation Agency (JICA).

Material and Methods

Study area: Evaluations were carried out on 10 teak seed stands (SSs) established in three silviculture divisions, viz., Hills, North Plains and South Bengal, by the Directorate of Forests, West Bengal.

Mapping of SSs: Several geo-coordinate points along the boundary of the SSs were taken for mapping with the handheld GPS Garmin eTrex30. These GPS points were subsequently exported to Comma Separated Value files (CSV) through Microsoft Excel. These points were subsequently saved in KML format with Google Earth Pro. Shape files were created in ArcGIS 10.4 and exported in JPG format.

Evaluation of SSs: Evaluation of seed stands was carried out by verification on the basis of area, tree density, isolation zone and tree health. SPAs that recorded more tree density were studied thoroughly to recommend culling of inferior trees. Trees with poor phenotypic characteristics, such as slow growth, crooked stem form, attack by pest or disease, were recommended for culling.

Assessment of the seed production capacity of selected SPAs: Estimation of the seed production capacity of the selected SPAs was carried out following the procedure described by Bila *et al.* (1999). For each tree, primary, secondary, tertiary and fourth-order branches were counted. Samples of fourth-order branches were cut, and the number of fruits was counted. However, the order of the branches to be cut was decided according to the situation for the species. All counts were extrapolated to estimate the total number of fruits per tree. After the fruits were harvested, the seeds were extracted and dried. The seed yield was subsequently calculated via the following formula:

$$\text{Seed yield (kg/ha): } S = (F \times S_n) \times S_w \times T_n$$

where S = total seed yield of the SPA; F = number of fruits on the tree; S_n = number of seeds per fruit; S_w = average seed weight; and T_n = number of trees bearing fruits per ha of SPA.

Results and Discussion

Among the 10 SSs evaluated, 5 are situated in the Hills Division, 4 are situated in the North Plains Division, and only 1 is situated in the South Division (Figure 1). The total area of the SSs and the year of plantation were sourced from the working plans of the respective divisions. The number of trees in the SSs was counted as the total number of trees, excluding the inferior teak trees existing in the SSs. The birth at breast height (GBH) of the numerated trees was taken 1.37 m from the ground, and height was measured with a digital hypsometer. Tree density and regeneration status in the SPAs were also estimated. Furthermore, the boundary maps of the evaluated SPAs are shown in Figure 2.

Evaluation of the SSs in the Hills division: The results from the evaluation of the 5 SSs in the Hills division are detailed in Table 1. No isolation zone was found around any of the five SSs of teak in this division. Plantation of teak was also observed outside of all the designated SSs. All nonnumerated inferior teak trees inside the SSs were recommended for culling. Seed-stand 1/TG/SANG, established in 1943, spans 3 hectares and hosts 60 trees with an average GBH of 2.02 ± 0.3 m and an average height of 22.65 ± 1.9 m. 2/TG/BAMON and 3/TG/BAMON, planted in 1942 and 1952, respectively; cover 4.60 hectares and 4.26 hectares, with 403 and 426 trees, respectively. The average GBH (2.02 ± 0.54 m and 1.82 ± 0.36 m) and average height (24.4 ± 1.18 m and 21.62 ± 1.58 m) were similar. Stand No. 4/TG/KHUM, established in 1941 on 0.40 hectares, contained 38 trees with an average GBH of 1.29 ± 0.21 m and an average height of 19.1 ± 0.93 m. However, 6/TG/KHUM, planted in 1966 on 1 hectare, consisted of 32 trees with an average GBH of 1.52 ± 0.52 m and an average height of 23.98 ± 1.03 m. Tree density varied across stands, with 2/TG/BAMON exhibiting the highest density at 87.6 trees/ha. Tree health was generally good in the 2/TG/BAMON and



Figure 1: Evaluated teak seed stands for recommending SPAs

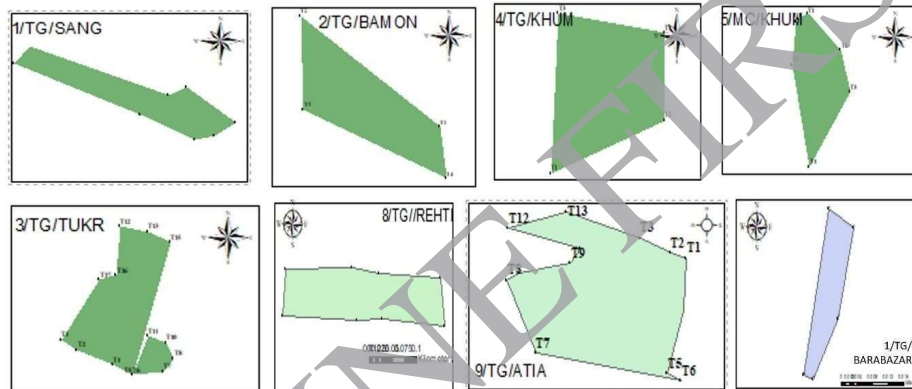


Figure 2: Boundary maps of the evaluated teak seed stands

Table 1: Evaluation of Hills in Seed Standings

Division	Hills Division				
Stand No.	1/TG/SANG	2/TG/BAMO N	3/TG/BAMO N	4/TG/KHU M	6/TG/KHU M
Range	Kalimpong	Bamonpokhri	Bamonpokhri	Jaldhaka	Jaldhaka
Location	Sangser-5	Bamonpokhri	Bamonpokhri	Khumani -5	Khumani -5
GPS Coordinate (Realized Middle Point of SPAs)	27.1328°N, 88.5077°E	26.8292°N, 88.2773°E	26.8267 °N, 88.2798°E	26.9735°N, 88.8648°E	26.9934°N, 88.8657°E
Total Area	3 ha	4.60 ha	4.26ha	0.40ha	1 ha
Year of plantation	1943	1942	1952	1941	1966
Number of trees	60	403	426	38	32
Average GBH (in m)	2.02±0.3	2.02±0.54	1.82±0.36	1.29±0.21	1.52±0.52
Average Height (in m)	22.65±1.9	24.4±1.18	21.62±1.58	19.1±0.93	23.98±1.03
Tree Density (No. of trees/ha)	20	87.6	100	N/A as < 1 ha	32
Tree Health	Moderate	Good	Good	Inferior	Inferior
Regeneration status	Good	Fair	Fair	Very less	Moderate

and 3/TG/BAMON groups, with 1/TG/SANG indicating moderate health, while 4/TG/KHUM and 6/TG/KHUM indicated inferior health. Regeneration status was found to be especially good in 1/TG/SANG and fair in 2/TG/BAMON and 3/TG/BAMON. Stands 4/TG/KHUM and 6/TG/KHUM, on the other hand, showed very little and moderate regeneration, respectively. Considering the results obtained from the evaluation, the 1/TG/SANG stand was not considered to be SPA because there were many teak trees outside the perimeter, and the tree density was found to be very low. Similar results were observed for stands 4/TG/KHUM and 6/TG/KHUM, where the overall tree density of healthy trees was very low and the area of stands was found to be very low enough to be considered SPA. If the original seed source forms a large genetic base, better gain can be expected due to cross-pollination and mutual transfer of genes. A decrease in the area of the tree population influences gene flow and the genetic structure of seed stands and affects the future viability of the population due to a high level of inbreeding and random genetic drift. Therefore, these stands were not considered SPAs. Among these 5 stands of teak evaluated under Hills Division, two stands of Bamonpokhri (2/TG/BAMON and

3/TG/BAMON) were found to be comparatively better in terms of area, tree density and tree health. Nonetheless, these two stands were found to be adjacent; hence, it was recommended that these two stands be merged into one SPA. In addition, the lack of proper isolation of these two stands also poses a significant problem because there were a large number of teak trees outside the perimeter. Therefore, it was suggested that these nonnumerated teak trees might be converted into a buffer zone for the SPA. The inferior trees inside the SPA were also recommended to be culled out to inhibit the mixture of pollens from inferior trees during cross-pollination.

Evaluation of SSs in the North Plains and South Plains: Table 2 summarizes the findings from the assessment of four SSs in the North Plains division and one SS in the South division. No isolation zone was observed surrounding these SSs. In addition to these declared SSs, teak plantations were also observed. Stand 3/TG/TUKR, established in 1974 on a 5-hectare plot, encompassed 385 trees characterized by an average GBH of 1.4 ± 0.17 m and an average height of 19.7 ± 1.68 m. In contrast, in 1975, 6/TG/TUKR, which was planted over a larger 10-hectare area, contained 2645 trees with an average GBH of 0.9 ± 0.2 m and an average height of

Table 2: Evaluation of seed stands in the Silviculture North plains and South plains

Division	North Plains Division				South Division
Stand No.	3/TG/TUKR	6/TG/TUKR	8/TG/REHTI	9/TG/ATIA	1/TG/Barabazar
Range	Tukriajhar	Tukriajhar	Banarhat	Cooch Behar Territorial	Bara bazar
Location	Tukriajhar	Tukriajhar	Reti-1	Atiamochor	Bara bazar
GPS Coordinate (Realized Middle Point of SPAs)	26.6513°N, 88.1875°E	26.6510°N, 88.1883°E	26.47444°N, 89.06598°E	26.26479°N, 89.44142°E	23.02468°N, 86.37140°E
Year of plantation	1974	1975	1965	1961	1972
Area	5 ha	10 ha	5 ha	5 ha	0.75 ha
Number of trees	385	2645	542	785	63
Average GBH (in m)	1.4 ± 0.17	0.9 ± 0.2	1.9 ± 0.50	1.19 ± 0.23	1.43 ± 0.41
Average Height (in m)	19.7 ± 1.68	11.1 ± 1.3	33.19 ± 2.65	14.84 ± 0.75	21.27 ± 0.84
Tree Density (No. of trees/ha)	77	264.5	108.4	157	N/A as < 1 ha
Tree Health	Good	Inferior	Good	Excellent	Good
Regeneration status	Good	Very Less	Good	Excellent	Moderate

11.1±1.3 m. Stand 8/TG/REHTI, established in 1965 on 5 hectares, showed a distinct profile with 542 trees, an average GBH of 1.9±0.50 m, and an impressive average height of 33.19±2.65 m, which was the highest among all the SSs evaluated. Stand 9/TG/ATIA, dating back to 1961 on a 5-hectare expanse with 785 trees, showed an average GBH of 1.19±0.23 m and an average height of 14.84±0.75 m. 1/TG/Barabazar, planted in 1972 on a smaller 0.75-hectare parcel, comprised 63 trees, featuring an average GBH of 1.43±0.41 m and an average height of 21.27±0.84 m. Variations in tree density were evident among the analyzed stands, with 6/TG/TUKR displaying the highest density at 264.5 trees per hectare. While overall tree health is deemed satisfactory across the stands, a notable exception was observed in 6/TG/TUKR, where tree health was characterized as inferior. Regarding regeneration status, stands 3/TG/TUKR, 8/TG/REHTI and 9/TG/ATIA demonstrated notably good regeneration prospects. Conversely, 6/TG/TUKR and stand 1/TG/Barabazar displayed a moderate level of regeneration. Considering the findings from the assessment of these teak stands, only three stands, i.e., 3/TG/TUKR, 8/TG/REHTI and 9/TG/ATIA, were considered to be SPA. Despite the fact that the trees in both stands of Tukarijhar were the same age, the growth of teak in the 6/TG/TUKR stands was substantially worse than that in the 3/TG/TUKR stands. Despite having 10 ha of area and an abundance of teak trees inside the seed stand exhibiting high tree density, the 6/TG/TUKR treatment had very limited potential for seed production. Additionally, the health of the trees was exceptionally poor, and very little regeneration was observed. As a result, stand 6/TG/TUKR did not qualify for SPA. Nonetheless, prior to designating the three chosen stands as SPAs, it was suggested that any subpar teak trees be removed from the area. It was advised to cut down 20 inferior trees from stands 3/TG/TUKR, 87 from stands 8/TG/REHTI, and 73 from stands 9/TG/ATIA. Along with removing the inferior trees from within the stand, it was additionally recommended that the inferior trees in the surrounding areas be removed. Due to its limited area (< 1 ha), the 1/TG/Barabazar stand was ultimately disregarded as an SPA. Additionally, four times as many teak trees were found beyond the perimeter as within the seed stand. There were 210

teak trees of the same age group adjacent to the stand that the forest officials had designated as the sample plot. Furthermore, on the east side of the seed stand, there were approximately 20 unlabeled teak trees. On the other hand, there were many teak trees in the vicinity of the Range Office buildings, which are next to this stand. As a result, there was a considerable likelihood that the stand would become contaminated by stray pollen.

Evaluation of the seed production capacity of selected SPAs: The estimation of seed production capacity was carried out on selected seed stands, which were designated as SPAs. These selected seed stands were revisited for this estimation work. Only trees from the core zone were taken into consideration when estimating the overall seed production of a seed stand, while no isolation zone was maintained. Table 3 shows the seed production capacity of the selected SPAs. Overall, stands 2/TG/BAMON and 3/TG/BAMON in the Hills division exhibited an average seed yield of 1.6±1.1 kg/tree, with 350 seed-bearing trees, leading to an estimated overall availability of 560 kg of seeds. In the North Plains Division, 3/TG/TUKR presented an average seed yield of 1.8±0.8 kg/tree, with 160 seed-bearing trees contributing to an anticipated availability of 288 kg of seeds. Furthermore, 8/TG/RETI displayed a higher average seed yield of 2.0±0.9 kg/tree, with an anticipated availability of 400 kg of seeds from 200 seed-bearing trees. Similarly, stand 9/TG/ATIA exhibited an average seed yield of 1.9±1.1 kg/tree, with 200 seed-bearing trees contributing to an anticipated availability of 380 kg of seeds. Similarly, stand 9/TG/ATIA had an average seed output of 1.9±1.1 kg/tree, with 200 seed-bearing trees contributing to 380 kg of seed availability. Globally, the extensive loss of forest cover due to deforestation underscores the critical need for afforestation activities to restore and improve forest cover. Nevertheless, the traditional approach of relying on wild-collected seeds to supply the expanding need for afforestation is no longer viable, and to solve this issue, the establishment of dedicated SPAs has become essential (Nevill *et al.*, 2016). The development and maintenance of SPAs is a science-based technique that ensures seed production under controlled conditions, hence contributing to successful genetic gains in afforestation initiatives.

Table 3: Seed production capacity of the selected SPAs

Sl. No.	Division	Stand No. (Selected as SPA)	Average seed yield/Tree (in kg)	Number of seed-bearing trees	Anticipated availability of seeds from SPA (in kg)
1	Hills	2/TG/BAMON and 3/TG/BAMON (Combined)	1.6±1.1	350	560
2	North Plains	3/TG/TUKR	1.8±0.8	160	288
3		8/TG/RETI	2.0±0.9	200	400
4		9/TG/ATIA	1.9±1.1	200	380

These SPAs play an important role in sustainable forestry practices, ensuring the availability of high-quality seeds to support global afforestation goals and prevent the ongoing loss of forest ecosystems. Since the 1950 s, India has performed systematic genetic improvement programs for teak and established vegetative propagation procedures, and has also produced genome-level data (Warrier *et al.*, 2022). Teak tree improvement, however, is still heavily reliant on traditional approaches such as the development of SPAs (Sinha and Prasad, 2003). Compared to seeds produced via genetic improvement programs, the projected genetic gain from seeds of SPA is minimal (Mandal *et al.*, 1998). The achievable gain through thinning has been reported to be 2-3%, which is half of the gain achievable in seed orchards (Rosvall *et al.*, 2001). SPAs provide a stable source of well-adopted seeds at a low cost, notwithstanding their limited genetic gain (Shahapurmath *et al.*, 2016). Poor quality stock in teak stands is a common phenomenon. In Orissa and other North-East Indian states, as well as in teak stands analyzed in West Bengal, similar substandard teak stocks were found in the seed stands (Nayak *et al.*, 2017). Therefore, all low-quality stocks should be removed to maximize genetic gain in an SPA. According to Sivakumar *et al.* (2011), genuine genetic gains for seed weight (32.1%), percentage of seed germination (51.9%), and seedling dry weight (22.9%) can be made by culling 39% of inferior trees from the SPA of *Acacia auriculiformis*. For the purpose of producing improved seeds, Varghese *et al.* (2000) critically discussed expanding teak seedling seeds orchards (SSOs). Such SSOs can be established from the selected SPAs in the near future. According to Mishra *et al.* (2017), the transformation of such SPAs into SSOs significantly improved germination

potential and seed weight, increasing yield.

Conclusion

According to the National Forest Policy, forest cover in India must reach 33% of the country's geographical area while simultaneously addressing forest productivity issues in India, which is low in comparison to the global average. Forest productivity can be increased by cultivating high-quality forest plantations. Plantations perform an important part of the forest industry by producing timber, pulpwood, and wood-based panels. To establish high-quality forest plantations, quality seeds capable of producing plants that can thrive in planted areas are needed. The provision of dedicated forest areas for seed production purposes, where such production may be carried out economically and efficiently, is required for the production of high-quality forest tree seeds in large quantities. A superior stand is made up of vigorously healthy trees that have been improved by thinning to remove weaker genotypes and managed to generate copious seed output. Despite the commendable work performed on improving the roots of a large number of tree species, unimproved seeds of various tree species are still being used for plantation purposes. The fundamental cause for this is the scarcity of high-quality seeds in adequate quantities. Numerous research facilities and institutions across the nation are working to improve the genetics of teak through selection vis-à-vis progeny trials to choose better parents for inclusion in breeding programs. The selection of Plus trees (PTs) is crucial for tree improvement. For the silviculture divisions of West Bengal, a number of teak trees were chosen as PTs. Since PTs are chosen based on their phenotype, it is crucial to establish progeny trials so that their breeding potential can

can be understood. Therefore, progeny trials involving conversion to SSOs, made up of descendants of PTs, should be set up immediately in West Bengal to promote teak improvement practices. To the extent that such SSOs do not produce sufficient quantities of high-quality seeds, seeds may nevertheless be obtained from these selected SPAs for use in plantation programs. This study provides essential insight into the structural variations in these stands, helping to characterize forest dynamics more comprehensively. The expected seed availability elucidates the seed production capacity of the selected stands, providing critical insights for the development of efficient seed management and conservation strategies. However, further research and ongoing monitoring are needed to analyze the long-term trends and dynamics of these stands, assuring sustainable seed harvesting as

well as the health and resilience of forest ecosystems.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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