Silvicultural Practices in the Management of *Diospyros melanoxylon* (Tendu) Leaf Production: Options and Trade-offs

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Non-timber forest products (NTFPs) are known to provide livelihoods for forest-based communities across the world. While ensuring the sustainability of NTFP harvests is a key challenge, optimizing the production of NTFPs through appropriate silvicultural practices is also critical for forest-based economies. In Central India, the suitability of fire or pruning practices for enhancing the production of leaves of the tendu tree (Diospyros melanoxylon) has been much debated. While villagers commonly adopt annual litter fires, the state Forest Department urges leaf collectors to adopt the more labor-intensive practice of pruning. On the other hand, conservationists recommend completely hands-off management (no fire or pruning). In this study, we compared leaf production from the competing practices of litter fire, pruning, pruning-with-fire, and hands-off management, that are experimented with in community-managed forests. We checked for confounding factors such as tree canopy cover, presence of tendu trees, and inherent differences in forest type. We conducted the study during the pre-harvest season from March to May 2020 in villages in the northern Gadchiroli district of Maharashtra, India. We found that pruning and pruning-with-fire lead to higher root sprout production and, in turn, higher leaf production per unit area when compared to litter fire and the control (no pruning or fire). Fire alone led to a negative impact on leaf production. Implementing pruning instead of litter fire, however, comes with labor costs. Its adoption is therefore linked with the institutional arrangements for tendu management and marketing that shape community perception of costs.

गौण वन उत्पादने जगभरातील वन-आधारित समुदायांसाठी उपजीविका म्हणून महत्त्वाची आहेत. त्यांच्या शाश्वत उपलब्धतेसाठी तसेच त्यांच्यावर अवलंबून आजीविकांच्या दृष्टीने वन उपजाच्या नियोजन पद्धतींचा वनवृक्षशास्त्राच्या दृष्टीने अभ्यास होणे गरजेचे आहे. मध्य भारतातील वन-आधारित समुदाय अनेक वर्ष तेंदू वृक्षाच्या पानांना (म्हणजे बिडी-पत्त्याला) निरनिराळ्या पद्धतीने संकलित करीत आहेत व त्याकरिता निर्रानराळ्या पद्धतीने नियोजन करीत आहेत. झाडाची झुडपी वाढ करून, पाने हाता जवळ वाढवणे हा त्यातील मुख्य उद्देश आहे. यामध्ये झाडाच्या रोपांची मुळाशी छाटणी करणे (खुट/बेल कटाई) किंवा, जंगलातील पाचोळा पेटवणे, किंवा या दोन्ही पद्धती एकत्रित वापरणे ('छाटणी-व-आग') अशा पद्धतींचा समावेश आहे. अलीकडे काही लोक

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तेंदू संवर्धनासाठी झाडाची विना-नियोजन वाद होऊ देतात (म्हणजे विना आग आणि विना खुट कटाईने). यातील कोणत्या पद्धतीने प्रती हेक्टरी सर्वात जास्त तेंदू पाने तयार होतात याचा अभ्यास आम्ही केला. यासाठी आम्ही उत्तर गडचिरोली, महाराष्ट्र येथील काही गावांच्या सामुहिक वन क्षेत्रात मार्च ते मे २०२० मध्ये वेगवेगळ्या नियोजन पद्धतीमध्ये होणाऱ्या तेंदूपत्ता उत्पन्नाचा पद्धतशीर अभ्यास केला. एकूण आम्हाला असे दिसले की, आग वापरण्यापेक्षा तेंदूच्या रोपांची मुळाशी केलेली छाटणी व 'छाटणी-व-आग' या पद्धती अधिक पानांचे उत्पन्न देतात. आम्ही पाहिले की स्थानिक जंगल प्रकार, त्याची दाटी, व तेंदू वृक्षाची निकटता या निकषांमुळे पानांच्या उत्पन्नात नियोजन पद्धतीपेक्षा जास्त परिणाम होत नाही. परंतु यातील कोणतीही पद्धत वापरताना व वन-आधारित उपजीविका सांभाळत, तसेच सामुहिक वन नियोजन करताना काही व्यावहारिक अडचणी आहेत. त्यांचावरही आम्ही या अभ्यासात विचार केला आहे.

Key Words: NTFP, Leaf production, Fire, Pruning, Central India.

Introduction

Non-timber forest product -(NTFP)-based livelihoods are important to local economies worldwide (Wahlén 2017). NTFPs are not only a safety net in lean times but can also be a significant routine source of income if their harvest and marketing are well managed (Shackleton et al. 2011). Simultaneously, they are seen as a more sustainable alternative to timber harvest and more attuned to conservationoriented forestry (Negi et al. 2011; Ruiz-Pérez and Arnold 1995). Over the last few decades, research has therefore concentrated on questions of harvest sustainability, broader ecological dynamics and their drivers (Schmidt et al. 2011; Zuidema et al. 2007). Research has also focused on the economic outcomes of NTFP harvest and the factors affecting them (Wunder et al. 2014). A large body of research has recognized how NTFP harvest has to be optimized within a multiplicity of forest uses (Shahabuddin and Prasad 2004; Ticktin 2004), incorporating ecological feedback (Mandle et al. 2013; Ticktin et al. 2012), and solutions have been sought to ensure harvest sustainability and also to increase returns through improved markets (Shanley et al. 2008).

Relatively few studies, however, have focused on the silviculture of individual species from the point of increasing the production of NTFPs. Active management for production has not been much discussed, although suggestions have sometimes been made for strategies such as enrichment planting, reducing competition, and cultivation (Ticktin 2004). A study in the Peruvian Amazon shows that smallholders assist the regeneration of shihuahuaco (*Dipteryx* sp.), a timber species, in historically logged areas by planting their seedlings (Putzel et al. 2013). However, studies on silvicultural practices in community-managed systems are rare, although communities have managed forests to maintain or increase NTFP production (Ticktin and Johns 2002; Turner 2001). In one study on Sabal palms (Sabal mexicana Mart. and Sabal yapa C.Wright ex Becc), Martínez-Ballesté et al. (2008) found that across varying intensity and frequency of harvest, the traditional Mayan practice of removing mature leaves led to an increase in young leaf production without adversely impacting plant growth or leaf size. Similarly, a study assessing fruit production in Brazil nut trees found only a weak impact resulting from the Brazil nut collectors' practice of cutting of liana loads (Kainer et al. 2007). In southern India, Rist et al. (2008) compared hand removal or branch cutting of areas infected by parasitic mistletoe (*Taxillus tomentosus* (B.Heyne ex Roth) Tiegh.) from amla (Phyllanthus sp.) and found that branch cutting considerably reduces infection, thereby allowing higher fruit production (Setty 2004). In a rare study, enrichment planting was conducted on Chamaedorea palms in southern Mexico to increase their availability. The focus of the study, however, was the impact of enrichment planting on the composition of the forest community rather than on the production of *Chamaedorea* palms (Trauernicht and Ticktin 2005).

Overall, there seems to be an implicit assumption that it is adequate to limit harvest and reduce other environmental pressures for sustaining natural production and regeneration rates. Forest-dependent communities harvest NTFPs for subsistence and also as an economic and commercial resource. It would, therefore, be necessary to identify practices that increase the production of the resource under use while limiting detrimental impacts on its habitats. This necessity is particularly true with forests coming increasingly under community control through the recognition of customary rights (RRI 2018).

In India, almost 275 million people are forest-dependent (Lynch and Talbott 1995), but the state Forest Department exclusively controlled forests until the last decade (Government of India 2006). Most studies on NTFP management have therefore been done in contexts where these forest-dependent communities had a limited role in regulating forest use. Even fewer studies have been conducted on India's most commercially important species, such as *Diospyros melanoxylon* Roxb. (hereafter, tendu) or mahua (Madhuca longifolia (Roxb.) A.Chev) because these products have historically been under the monopoly control of the Forest Department (Lele et al. 2010). However, tendu and bamboo have recently been deregulated in some Indian states, and rights-holding villages can now actively and independently manage their harvest and sale (RDD 2015). Assessing the production-enhancing silvicultural practices of these important NTFPs in such community-managed areas is critical.

Tendu leaves are used in making beedis, a local cigarette in which the tendu leaves are the wrapping for the tobacco. Tendu leaves remain pliable several months after drying, making them helpful in rolling tobacco. With an estimated annual production of over 450,000 tons of leaves (ICFRE 2011), tendu leaf harvest supports the livelihood of over 12 million people in the beedi-making industry in India (Lal 2012). However, only a limited number of studies have been conducted on the harvest of tendu leaves and the productivity, sustainability, or broader biodiversity impacts of the management practices employed for increasing tendu leaf production across Indian forests (Saha and Howe 2003). Tendu is a deciduous tree and can potentially grow to a height of 12 m and more. The main challenge in managing leaf harvest is maintaining or promoting tender or fresh leaf production at accessible heights, i.e., at ground height or a height scalable by leaf-collectors, including

women. Management practices like burning, pruning, and pollarding trees are commonly used for this purpose (Kumar 2001). These practices, combined with the ability of the tree to propagate easily from root suckers (Rathore 1971), result in the creation of extensive patches of tendu bushes interspersed with a few trees (pers. obs.). Communities choose different leaf production management practices based on their village-level goals and capacity to sustain tradeoffs associated with using these practices.

In this study, we compare the leaf productivity impacts of the three management practices adopted for tendu: fire, pruning, and the conservation-oriented hands-off strategy followed in the last three years in some villages. Further, we study the implications of pruning and fire overlap when communities prefer burning, but the Forest Department also conducts pruning. We specifically focus on leaves that are of commercially collectible quality to describe the livelihood impacts of each practice. We determine which of the four specific practices improves tendu leaf production and discuss the other factors influencing the community's choice of practices.

Materials and Methods

STUDY AREA

We conducted the study in the Gadchiroli district (19.4969° N, 80.2767° E) of Maharashtra state in India (Fig. 1). Maharashtra is the only state in India where tendu has been deregulated, although only in specific "Scheduled Areas," i.e., areas dominated by indigenous communities. Maharashtra state reports a collection of more than 0.176 million standard bags (1 standard bag consists of 70,000 leaves) (DES GoM 2021). Gadchiroli district is the main contributor of tendu leaves harvested in the state. Over 1400 g sabhas (village councils) in this district have received "community forest resource rights," enabling and empowering forest dwellers to themselves manage forests and trade in forest produce. Attracted by the high income from tendu leaves, forest-dwelling communities have started forming institutions for forest conservation and improved marketing of forest products.





Forests in Gadchiroli belong to Southern Tropical Dry Deciduous to Southern Tropical Moist Deciduous types (Champion and Seth 1968; FD GoM 2012). The forests, especially in the study area, are dominated by deciduous species such as Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr., Terminalia alata Wall., Schleicheria oleosa Merr., Lagerstroemia parviflora Roxb., and tendu. The forests also have the Dendrocalamus strictus Nees. and other species of bamboo. The region experiences hot summers (March to June), with mean maximum temperatures of ~42°C, recorded in May, and moderately cold winters (November to February) mean minimum of ~11 °C. The region has an average rainfall of 1479 mm, falling mainly between June and September. Most tree species are deciduous and are typically leafless in early April; new leaves appear from late April to early May (FD 2012). Large tracts of these forests

have been community-managed since 2011, and tendu trade under community control has started functioning since 2016.

DIOSPYROS MELANOXYLON AND MANAGEMENT PRACTICES

Tendu (Diospyros melanoxylon, a member of the Ebenaceae family) is a deciduous tree found in mixed deciduous forests across India (Ghosh et al. 1976) (see Fig. 2A). There are over 11 species belonging to the *Diospyros* genus in India (Kumar 2001), of which two, *Diospyros* kaki L.f. (widely cultivated for its fruit) and Diospyros melanoxylon (for its wild harvested leaves), are commercially important. Historically, forest-dwellers in India have used tendu fruit as a food source. However, around 1915, tendu leaves started being used for beedi production and acquired commercial importance (Kumar 2001), with tendu leaves becoming more important than the fruit as an NTFP. Today it is probably one of the highest labor-generating NTFPs in the country (Lal and Wilson 2012; Lal 2012) (see Fig. 2E, F).

Tendu propagates by seeds and vegetatively through root suckers (Troup 1921). Clonal sprouts emerge from these root suckers several meters away from the parent tree (Rathore 1971). The trees are fire resistant, and the ability to produce root suckers and root sprouts after disturbance (including fire) gives the species the ability to sustain itself in areas of frequent fire (Ghosh et al. 1976). A further advantage for the species is that it is rarely browsed (Troup 1921).

Given that *beedi*-rolling requires young leaves and that tendu propagates through root suckers, silvicultural management is focused on using multiple techniques meant to encourage the sprouting of fresh tendu leaves. Tendu leaves are shed from February to March, and new leaves emerge around April-end or early May (Singh and Kushwaha 2006) (see Fig. 2D). Silvicultural management takes advantage of the natural leaf shedding and regeneration seasons and seeks to enhance new leaf production through pruning, pollarding, or the setting of fire at the onset of summer (Fig. 2B, C). Usually, management practices are initiated in early March, with the expectation that leaves will sprout by mid-April and be ready for harvest in May.

When fires are used for inducing leaf production, leaf-collectors set litter fire in early March to top-kill tendu seedlings and saplings. Fires are set from the periphery of forests and allowed to spread inside the main forest area but may also be started from patches within the forest area. Litter fires kill existing stems shorter than 1 m, and fire-induced damage is expected to lead to copious production of new sprouts. Fire rarely impacts the stems of tendu saplings more than 1 m in height, even though most leaves get scorched. The use of litter fire is considered a low-cost management practice with little labor required to "manage" (burn) large forest areas. Given a large number of fire-tolerant species in Central India, fires have likely been a part of the complex dynamics of these forests (Saha and Howe 2006; Ray et al. 2020). The use of fire, however, is deemed illegal by the Forest Department because it is considered damaging to forests. Setting fire in forests comes at the cost of legal action, including payment of fines and arrests of persons involved (GoI 1927). Studies on forests in India frequently criticize tendu-oriented burning for causing damage to other species in forests (Agarwala et al. 2016; Boaz 2004; Jaiswal et al. 2002; Saha and Howe 2006).

Instead of fire, the state Forest Department has been promoting the use of pollarding of bigger trees followed by pruning of the bushes for tendu leaf management for several years (Ghosh



Fig. 2. Tendu under various management practices. **A.** Tendu trees, **B.** Litter fire in the forest, **C.** Pruning of tendu root sprouts by lopping at the base, **D.** Regenerated root sprout in bush form <1m in height, **E.** Tendu leaf collection from root sprouts, **F.** Tendu leaf bundling, **G.** Drying tendu leaves for further processing.

et al. 1976). Pruning mimics the impact of fire in terms of the top-kill of existing sprouts. Pruning consists of lopping tendu saplings and root sprouts at the base, at the soil level. It leads to coppice regrowth, and successive pruning can create dense patches of tendu bushes with uniform, accessible height. Communities can selectively prune tendu with little damage to other species (pers. comm). However, communities typically limit pruning to small patches of forests adjacent to agricultural lands because of the time and labor involved.

In some villages, fear of legal action against the use of fire and a perceived reduction in tendu fruiting from continuous pollarding of big trees has led communities to choose a hands-off strategy where neither pruning nor fire is used. Therefore, the change in the volume of collectible leaves and incomes under such a hands-off practice needs to be studied further.

RESEARCH DESIGN AND FIELD METHODS

We focus on leaf production in tendu bushes, the predominant morphological form in which tendu leaf collection takes place in India. We compare plots subjected to fire, pruning, or neither ("control" or hands-off management) to look for differences in useful leaf production. At times, areas under pruning may also burn leading to the fourth management practice, "pruning-with-fire."

Since the Forest Department did not permit controlled experiments of our own, we used a "natural experiment" (i.e., a non-manipulative, observational experiment) method by identifying villages that followed different tendu management practices in their villages and were willing to be part of such a comparative study. The study was conducted in four villages across Korchi and Kurkheda blocks (sub-districts) in northern Gadchiroli (Fig. 1), over 1700 ha. Forests of these four villages had a history of annual fire setting for stimulating tendu production. Two villages in Korchi block have suppressed fire (approx. 900 ha) for the last three years, while the two in Kurkheda block continue to use fire for tendu production (approx. 800 ha).

Wherever permitted, we conducted participant observation of the silvicultural practices. Pruning could be easily observed and documented; however, communities rarely disclose how fires are set and often allude to their "natural origin" as the practice is deemed illegal, and hence we only observed the area after the fire had subsided.

The current study was conducted in the tendu leaf collection season of 2020, covering the months from March to May. The study was conducted during COVID-19 pandemic-induced restrictions on mobility, which hampered field data collection, and its consequences are explained in the section on plot-based assessment of tendu leaf production.

Plot-Based Assessment of Commercially Collectible Tendu Leaf Production

We marked the boundaries of the four villages' community forest areas by walking the perimeter using a GPS device. We identified forest patches that were consistently managed with fire, those managed only with pruning, and patches of pruning-with-fire and control (nofire-no-pruning) patches within these boundaries, based on discussions with local community members.

We laid a 500 m \times 500 m grid over the forest area. We tagged the midpoint of each cell in the grid by the management practice prevailing in that cell. In each area typically treated with a particular management practice, 16 cells were randomly selected per management type. In the Korchi block, where there was only a single patch of unburned and unpruned forest that could act as a control, the grid size was reduced to 250 m \times 250 m, and 16 cells in this grid were randomly selected from the area. A total of 64 cells (16 points per management practice, including control) were thus identified.

At the center of each of the selected cells, a 10 $m \times 20$ m plot was laid. All tendu root sprouts (defined as single stems <1.5 m in height) were counted in each plot. In addition, tendu trees (i.e., stems >1.5 m in height) were also enumerated, and their height, diameter at breast height, the status of flowering/fruiting, and the signs of any management practice (coppice, pollarding, girdling) were noted.

Counting all the leaves on all the sprouts in a $10 \text{ m} \times 20 \text{ m}$ plot was not possible. So, we

estimated total leaf production in a plot as the product of the total number of root sprouts per plot and the average number of leaves per root sprout. Estimation of average leaves per sprout was conducted using three sub-plots of 2 m \times 2 m laid in each 10 m \times 20 m plot. Two subplots were located at diagonally opposing corners of the plot and one in the center. The corner sub-plots were laid one meter inside the plot's boundary to avoid any edge effects. Within the three subplots, leaves of "commercially collectible quality" were counted for all root sprouts. Tendu leaf quality is termed "commercially collectible" if the leaves are fresh, soft, and flexible (especially the midrib) and are around 10-30 cm long. The commercially collectible leaves must also be free of damages such as large holes or tears. Leaves too large (>30 cm) or too small (<10 cm) in length were spared by leaf-collectors and so were not counted in the study.

We hoped to complete the surveys within a week to 10 days. The start of the COVID-19 pandemic and mobility restrictions led to a 19-day gap between the first and last days of the survey. The time difference is significant for leaf production and leaf length growth. To account for this, we used slightly different length cutoffs in defining "collectible leaves" based on leafcollectors' knowledge: in the plots surveyed in the first week, we counted leaves between 4 and 20 cm in length, and in the last week, we counted leaves between 7 and 30 cm length. Leaf-collectors suggested that leaves smaller than 4 cm will not grow to commercial length during the harvest season, and those larger than 20 cm prior to the collection season will grow larger than 30 cm and will not be collected.

Fires are usually set in early March. However, in 2020, the month of March saw some spells of unseasonal rains due to cyclones in the Bay of Bengal, with Kurkheda recording 36.5 mm of rainfall (23.3 mm above normal) and Korchi recording 26.9 mm (20.9 mm above normal) rainfall (DoA GoM 2020). Villagers attempted to adapt to this phenomenon by delaying the fire set to early April. Unfortunately, that is when the COVID-19-induced lockdown occurred, and increased police presence in forests further reduced areas set on fire by people. This led to an unbalanced sample, with only 7 plots impacted by fire, 7 plots impacted by pruningwith-fire, 25 plots under pruning, and 25 control plots. We could not survey additional areas due to tight schedules and COVID-19-related restrictions on mobility.

In addition to the possible effects of the treatments, we hypothesized that tree canopy cover, adult tendu trees (influencing root stock), and eco-climatic conditions are co-variates that could influence tendu leaf production. Data on tendu trees were collected in the plot surveys as described above. (Ideally, we would have enumerated the pre-treatment root sprout density as a measure of pre-existing root stock; this was not possible due to resource and time limitations). Overall tree canopy cover was recorded with a spherical densiometer at the center of each plot to check for its possible impacts.

We used tree vegetation structure as a proxy to check for possible differences in eco-climatic conditions across study sites. The survey was conducted across the forest areas using six belt transects (three in each block) (500 m \times 5m each) and all single-stemmed individuals >1.5 m in height in each transect were identified and their diameter at breath height (DBH) was also measured. The similarity in the tree vegetation across these two blocks was assessed as described below.

Data Analysis

Total root sprout production and average leaf production per root sprout were compared among the four different management practices using non-parametric Kruskal-Wallis and posthoc Dunn tests. Similarly, differences in the estimated total leaf production across management practices were analyzed using non-parametric Kruskal-Wallis and post-hoc Dunn tests. As the *H* static of the Kruskal-Wallis test approximates a Chi-squared distribution for sample sizes more than 5, the Chi-squared values have been used here.

Vegetation transect data within each of the two forest blocks were pooled (i.e., the site that is typically burnt and the site where fires are not set) and were quantitatively analyzed for the relative abundance of different species at the two sites. Vegetation data for the two sites were compared using the dissimilarity index (Chao et al. 2005). The influence of canopy cover on leaf production across management practices was checked using Spearman's rank correlation test and Kruskal-Wallis Test. Similarly, the influence of tendu tree presence through on leaf production was checked using Spearman's rank correlation test.

All data analysis was conducted using R Software, version 4.0.3, and packages FSA (Ogle et al. 2021) and CommEcol (Oksanen et al. 2002).

Results

MANAGEMENT PRACTICES AND THEIR IMPACTS ON LEAF PRODUCTION

We found that root sprout production ranged between 11 and 787 sprouts per 200 m² plot (Fig. 3). It also differed significantly across the various management practices (Chi-squared = 22.28, df = 3, p < 0.05). Post-hoc Dunn tests showed that pruning led to significantly higher root sprout production (n = 25, $\mu = 366 \pm 194$ (hereafter, μ represents averages with standard deviation) when compared with root sprout production in control plots (n = 25, $\mu = 171 \pm 126$) (Dunn; p = 0.0007) and in fire-only plots (n = 7, $\mu = 79 \pm 76$) (Dunn; p = 0.0005). Pruningwith-fire (n = 7, $\mu = 307 \pm 201$) also led to significantly higher production of root sprouts as compared with fire-only plots (Dunn; p = 0.02), but not as compared to pruning-only plots (p = 0.46). Root sprout production in control plots and fire-only plots did not differ significantly (p = 0.16).

Unlike root sprout production per plot, the number of leaves per sprout did not differ significantly across management practices (Chi-squared = 5.2, df = 3, p = 0.15) (Fig. 4). While leaf production per sprout ranged between 0 and 37 leaves, the average was ~4 leaves per sprout (standard deviation (s.d.) = 5.8)

Consequently, the variation in total leaf production (estimated as the product of the number of root sprouts in a plot and the average number of leaves per sprout estimated from the sub-plots) followed the pattern of the number of sprouts but was tempered by the added variability in leaves per sprout. The total leaf production ranged from 0 in some



Fig. 3. Variation in root sprout production across management practices (Chi-squared = 22.28, df = 3, p < 0.05). Plot shows medians, 25th, and 75th percentile, and numbers refer to sample sizes. Letters a, b, and c denote significant differences across management practices.



Fig. 4. Variation in average leaf production per root sprout across management practices (Chi-squared = 5.2, df = 3, p = 0.15). The plot shows medians, 25th, and 75th percentile, and outliers (shown as points). Sample sizes are noted as numbers in the plot.



Fig. 5. Variation in total (estimated) leaf production across management practices (Chi-squared = 13.68, df = 3, p < 0.05). The graph shows medians, 25th, 75th percentile, and outliers (shown as points). Sample sizes are noted as numbers in the plot. Letters a, and b denote significant differences across management practices.

fire-only plots to more than 6000 leaves in pruned plots (Fig. 5), with the medians ranging from 48 in fire, 468 in control, 1022 in pruning, and to 1338 in pruning-with-fire. The total leaf production across management practices showed a significant difference (Chi-squared = 13.68, df = 3, p = 0.003), and a post-hoc Dunn test showed that there was a significantly higher leaf production in plots under pruning-with-fire as compared to control plots (Dunn; p = 0.02) and those with only fire (Dunn; p = 0.04). There was no significant difference between pruning-with-fire plots compared with plots under pruning (Dunn, p = 0.48). We found no significant difference in leaf production between control plots and those under fire (Dunn, p = 0.37).

CO-VARIATES THAT COULD INFLUENCE LEAF PRODUCTION

To examine the influence of co-variates, we first checked for variations in vegetation composition (as a proxy for variation in eco-climatic conditions) across the two blocks. We then also checked for potential co-variates across all plots. These included variation in canopy cover and variation in the presence of tendu trees >1.5 m in height (their height, DBH, and whether they were flowering or fruiting).

Overall, tree composition was similar between the two blocks, with a Dissimilarity Index of only 0.17, even though the total tree species richness was higher in the Korchi block (57 species) compared with that in the Kurkheda block (39 species). Both the sites were dominated by *Anogeissus latifolia*, *Cleistanthus collinus* (Roxb.) Benth. ex Hook.f., *Terminalia elliptica* (Willd.), and *Lagerstroemia parviflora*, indicating an abundance of fire-tolerant species.

Regarding canopy cover, we found large variations across plots and within management types ranging from 0 to 99%. However, we found no significant correlation between canopy cover and leaf production based on the Spearman rank correlation and their p-values (control ($\rho = 0.17$, p = 0.39), fire ($\rho = 0.37$, p = 0.40), pruning ($\rho = 0.13$, p = 0.51)), pruning-with-fire ($\rho = -0.53$, p = 0.23)).

Across all plots, we recorded 21 tendu trees with a DBH higher than 10 cm with a potential to influence root stock. Of the 21 trees, we saw 14 trees in control plots, 6 in pruning, and 1 in fire only. No tendu trees were recorded in plots under pruning-with-fire. Root sprout production was not significantly correlated with the presence of tendu trees based on Spearman rank correlation in the case of pruning ($\rho = 0.34$, p = -0.19). However, it was positively correlated in the case of control ($\rho = 0.37$, p = 0.06). Although there is a bias in the distribution of trees vis-à-vis the management practices, it does not confound our result in terms of leaf production, as root sprout production was higher in plots with lower tree presence.

Discussion

The Impact of the Management Practices on Leaf Production

We find that management practices impact root sprout production from the rootstock but do not directly impact the production of leaves per sprout. We find that root sprout production and total leaf production increase significantly under pruning and pruning-with-fire compared with fire-only and control plots. Our findings on pruning are similar to those of Ghosh et al. (1976), who showed that leaf production increases in tendu by pruning at the ground twice with a month-long interval. However, their study did not describe whether this increase in leaf production resulted from increased numbers of root sprouts or increased numbers of leaves per sprout; neither did the study describe the impacts of pruning-with-fire and fire-only.

We further confirmed that differences in leaf production across management practices could not be attributed to differences in eco-climatic conditions, canopy cover, or pre-existing adult tendu trees. We find that there is a bias in the presence of tendu trees (>10 DBH) impacting root stock in control plots, but this bias does not confound the results. We find that there was significantly higher root sprout production in areas managed with pruning and pruning-with-fire despite the presence of a comparatively lower number of trees through the management of existing root stock.

A couple of limitations of our study may be noted. Our study was conducted during the COVID-19 lockdown, affecting our planned sample size, specifically in areas under fire-only management and pruning-with-fire. The smaller sample size limits our understanding of whether the increase in leaf production in pruning-withfire results from pruning alone or a compounded impact of pruning and fire. The dependence on a natural experiment method and the complex history of these forests in terms of pruning and fire also led to a smaller sample size for the fire-only and pruning-with-fire treatment. So, although the statistically significant differences may hold, the magnitude of the differences may need to be treated with some caution.

Similarly, this assessment of leaf production under different treatments is from a single season. Our comparison of rainfall data for March and April 2020 with normal rainfall in Korchi and Kurkheda suggested that March was unusually wetter. However, villagers adapted to the wetter March by setting fire later than usual. Thus, we do not believe that unusual weather would account for the differences observed, although the delay in fire setting may have impacted our observations. Nevertheless, repeat studies would help confirm our findings. The main constraint in adopting pruning is its labor cost, which we discuss later.

Our vegetation surveys showed a dominance of fire-tolerant species in the forests where communities collect tendu leaves across the two sites we studied. This domination of fire-tolerant species can be observed across Central India, where fires are used frequently for not only tendu leaf management but for the collection of a few other NTFPs such as mahua (Neeraja et al. 2021; Ray et al. 2020; Saha and Howe 2003). Even in the villages that have recently controlled the use of fire after receiving community forest rights, the forests show evidence of a history of frequent fires based on species composition, as also reported by communities. It remains to be seen whether pruning in areas with longer periods of fire-control could potentially yield even higher leaf production or whether fire-control will allow non-fire tolerant species to grow and lead to shading and suppression of the tendu bushes. We expect that fire-control over more extended periods could also impact commercial leaf production in areas not managed with either pruning or fire. During the study, we saw that control plots had a higher frequency of tall root sprouts, just short of 1.5 m in height, compared to pruned or fire-only plots. These taller but still accessible, root sprouts may result from growth after the recent fire control process. As the saplings

grow into trees with time, we expect accessible leaf production in control areas to decrease.

In light of the above, we recommend adopting pruning as a management practice as it is not only highly productive but also a selective process with little harm to other species in the forest. Our recommendation to adopt pruning is based on the assessment of leaf production in a single season, and there may be variations owing to other temporal factors; long-term studies would therefore be helpful to confirm our findings. Pruning-based management has been studied across several other species. Pruning of branches is a commonly used productionoriented management strategy in woody species used for charcoal or firewood production (Moyo et al. 2015; Neke et al. 2006; Syampungani et al. 2017). Pruning has also been shown to be an important "fire-proxy" strategy for California hazelnut (Marks-Block et al. 2019); this is also the case in the current study. In a recent study, pruning with fertilization was also reported to lead to higher leaf area in tendu (Jain et al. 2020), although fertilization over large forest areas seems impractical and may have impacts on overall species composition. There is more control in pruning as a management practice than fire in terms of timing, coverage, and selectively sparing tendu saplings and other species.

The use of fire may not be recommended for increasing tendu leaf production based on our findings, although the delayed fire setting in 2020 may have led to some anomalous results. Fire can have adverse impacts on vegetation community composition, favoring species that can produce root suckers and resprouts at the expense of species that propagate with epicormic sprouts or exclusively through seeds (Kammesheidt 1999; Saha and Howe 2003; Vanderlei et al. 2021) and species that favor forest-edge like conditions (Balch et al. 2013). Our observations on the use of fire are, however, limited by the sample size and clustering of plots. Fire is a very widespread management practice in the study area, and additional studies will be necessary to unpack our findings. Furthermore, the impact of fire on tendu itself may vary with intensity and frequency. In a study specific to dry tropical forests, Ray et al. (2020) show that tendu seedlings and saplings showed a decreasing trend over increasing fire frequencies, though tendu trees were found to peak in

areas with a five-year return interval. In other species, too, the use of high-frequency fires can lead to a decrease in population growth, but on a longer time frame, fire return may be necessary for propagation for certain species (Sinha and Brault 2005; Souza et al. 2018; Varghese et al. 2015). Further, fire restrictions, especially in dry deciduous forests, may lead to litter buildup and increase fuel load over time (Verma and Jayakumar 2015). Fires at intervals may also be necessary to promote regeneration. For example, "no fire" areas in the moist deciduous forests of Chhattisgarh show that litter build-up may inhibit regeneration (Kittur et al. 2014). Longterm assessments on varying fire intervals may therefore be necessary to understand further the role of fire on tendu resprouting.

ECONOMIC CONSIDERATIONS IN THE ADOPTION OF MANAGEMENT PRACTICES BY VILLAGES

If we use the median leaf production estimates from our study, fire-only management will produce only 2400 commercially collectible tendu leaves per hectare, while almost 23,400 leaves ha⁻¹ can be collected under the control treatment (no-pruning, no-fire). In areas under pruning and pruning-with-fire, the leaf collection increases to about 51,100 leaves ha^{-1} and 66,900 leaves ha^{-1} , respectively. At current prices, even ignoring the strangely low productivity in the fire-only treatment, the difference between 23,000 leaves ha⁻¹ in control areas and 51,000 leaves ha⁻¹ in pruned areas translates to a difference of at least INR 3,000 ha⁻¹ of forest (2022, approx. USD 37). Given, in addition, the Forest Department's opposition to fire, it seems like the villages should obviously adopt pruning as the management practice, given how much it increases leaf production and hence income from leaves.

In the study region, however, of the 260 villages in Korchi and Kurkheda blocks, less than 20 villages have shifted from using fire to pruning. The fire remains a dominant practice for tendu management. In our discussions with them, those villages that shifted to pruning-only attributed the decision to the perceived conservation benefits or the Forest Department's opposition to fire rather than the perceived benefits for tendu production itself. What makes the use of fire a more widespread practice for tendu leaf productivity than pruning, and what might be the possible incentive mechanisms for promoting pruning?

Firstly, we find that leaf-collectors have limited clarity about the difference in the impacts of pruning as compared to fire (pers. comm.); they consider fire and pruning as having similar productivity impacts. In such a situation, they find the laborious process of pruning to be unwarranted unless the costs are covered by someone else. Based on field discussions, we estimate that the cost of conducting pruning is approximately INR 30 – INR 50 ha⁻¹ (2022, USD 0.37–USD 0.61), estimated using minimum wage rates. The cost of pruning a forest with an area of 400 ha (based on average forest areas in study villages) is around INR 12,000 to INR 15,000 (2022, USD 147–USD 180). However, the Forest Department or the tendu traders currently pay a lumpsum amount of around INR 3000-INR 4000 (2022, USD 0.37–USD 0.48) to villages, irrespective of the leaf production potential, the forest area, or the labor involved. If villagers and traders are convinced about the significant increase in tendu productivity through pruning, higher payments might get negotiated.

Secondly, there are uncertainties in tendu leaf sale contracting that lead to limited incentives for adopting pruning. Tendu leaf markets often experience volatility (Agarwal 2018; Moudgil 2017). Traditionally, the Forest Department bore the pruning costs. Even though these expenses would eventually come out of the revenue the department gets from tendu leaf auctions (and therefore affect the "bonus" payments to the collectors), the collectors do not see this cost and think they are being separately paid for their pruning labor. When, on the other hand, communities have management rights to tendu, it seems to the community that they themselves are paying for this labor. Moreover, as communities do not have financial reserves to pay for the labor upfront, they seek to get the trader to pay for pruning. However, delays in tendu leaf sale contracts between traders and villages lead to either delay or evasion of payment of tendu pruning wages. Such uncertainty in compensation leads to skipping pruning and ultimately using fire as a production management practice.

In other words, encouraging pruning will require robustly demonstrating its productivity benefits and the state providing working capital to the villages. These measures will ensure early completion of the tendu leaf contracting process and prevent traders from reneging on their contracts. The state must thus provide financial and regulatory support to the newly decentralized forest management institutions. Unfortunately, as we have pointed out elsewhere (Date and Lele 2022), the state still appears to be blowing hot and cold regarding such support. Sustained efforts at co-producing ecological knowledge will have to be accompanied by similar efforts to build the financial and organizational capacities of the villages to manage their tendu leaf resource effectively.

Conclusions

Tendu leaves are a highly valuable NTFP for communities in the forested regions of Central India. We showed that there is improved production of leaves using pruning compared to the use of fire, and this can potentially increase incomes despite the higher labor cost involved. Avoiding fire potentially has the added advantage of reducing the collateral damage to the forest's biodiversity. Conversely, following a hand-off strategy and avoiding pruning will not be recommended as our study finds limited leaf production in control areas compared to pruning or pruning-with-fire. Further research is, however, required to confirm the findings under changing weather conditions and different fire cycles, and to understand the long-term genetic impact of annual management of tendu in the form of bushes for leaf harvest.

Despite its obvious economic benefits, pruning will remain a less preferred strategy to fire because of financial and contractual bottlenecks or non-transparency. Promoting pruning will, therefore, require demonstrating the ecological implications and finding ways to ease the financial and contractual risks of incurring pruning costs upfront. Payments by the Forest Department, based on more accurate per-hectare leaf production estimates for each village, may be the first step. Further, providing working capital to villages from state governments for pruning and allied support in tendering/contracting will protect villages from the exploitative practices of traders and reduce the risk.

Tendu is one example of resource use under community-based management for an economic goal. It brings to light the complexity of the ecological aspects of management and the economic questions of fair compensation for sustainabilityand production-oriented practices. There is enormous potential to study several other NTFP species in Central India that are critical to the local economy, including bamboo species, mahua, and chironji (*Buchanania lanzan* Spreng.), in terms of their production practices and sustainability of harvest.

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Author Contribution

Anuja Anil Date, Dr. Ankila J. Hiremath, and Dr. Sharachchandra Lele contributed to the conceptualization of the research. Dr. Ankila J. Hiremath and Dr. Atul A. Joshi contributed to designing the research methodology. Anuja Anil Date conducted the data collection, curation, and analysis. Anuja Anil Date wrote the first complete draft of the manuscript, while all authors contributed to its revisions. This research is part of the doctoral dissertation of Anuja Anil Date under the supervision of Dr. Sharachchandra Lele.

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Data Availability

Data that support the findings of this research are not openly available as it contains sensitive data with location details and is available from the corresponding author upon request.

Declarations

Ethics Approval

The research protocol has been approved by an Institutional Review Board at Ashoka Trust for Research in Ecology and the Environment (ATREE, Bangalore). The IRB approval code for the research is IRB/ACA/0008/AD/02/2019. The research questions emerged from the ongoing work with communities on the rights of forest dwellers. The authors sought prior consent from the Gram Sabhas (village councils) for conducting the study. Villagers were interested in the study and joined in the fieldwork whenever possible. Further permissions were sought when the study had to resume during the COVD-19 pandemic. Restrictions on movement within forests with minimal visits to settlement areas were respected. As the study involves the assessment of the use of fire that is deemed illegal, details on village names, names of informants, and specific locations of plots have been kept confidential. All photos have been taken with prior consent. Results from the study were discussed with the villagers, and inputs were sought on the correctness of our interpretations.

Competing Interests

The authors declare no competing interests.

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