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REGENERATION STATUS OF NATURAL SANDALWOOD POPULATION IN KARNATAKA, INDIA

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ABSTRACT

A study was conducted from 2021 to 2023 to evaluate the regeneration status of natural populations of *Santalum album* in Karnataka. Twenty distinct populations were surveyed across different forest regions. Vegetation was sampled using 20 × 20 m quadrats for mature trees (>30 cm GBH) and 5 × 5 m sub-quadrats for regeneration (seedlings and saplings). Considerable ecological variability was observed among populations. The natural regeneration was restricted, with several historically important sites showing complete absence, while populations at Sandur, Maravagi, J. B. Kaval and Punajanur displayed superior regeneration potential. The occurrence of nitrogen-fixing associates and the adverse influence of invasive species such as *Lantana camara* highlighted the importance of biotic interactions. The study identified priority populations for conservation and stressed the need for integrated measures, including in situ and ex situ conservation, and enrichment planting to conserve genetic diversity and sustain *S. album* populations in Karnataka.
Keywords **:** *Santalum album,* associated species, threats, shrubs, survey.

Introduction

Santalum album L., a long-lived evergreen belonging to the family Santalaceae, attains maturity between 60 and 80 years, typically growing 10 - 15 m in height and 1 - 2.5 m in girth (Ghosh *et al*., 1985). Its natural distribution extends from 30°N to 40°S, ranging from India to the Juan Fernandez Islands, Hawaii, and New Zealand (Srinivasan *et al.* 1992), and it thrives in a wide variety of soils and climatic conditions in India, Sri Lanka, and Indonesia (McComb and Jones, 1998). In India, natural sandalwood populations occupy nearly 9040 km², predominantly in Karnataka (5245 km²) and Tamil Nadu (3040 km²), with smaller populations persisting in Kerala and Andhra Pradesh. Among the 16 hemiparasitic species of Santalum (Ansari *et al.,* 2007), *S. album* is the most economically and culturally significant, valued for its highly aromatic heartwood and essential oil rich in santalol (Radomiljac *et al.,* 1998). Revered as "Queen of Essential Oils," it holds deep religious, cultural, and medicinal importance in India (Rajagopal 1977). The oil is extensively used in perfumery, cosmetics, Ayurveda, allopathy, traditional rituals, and even food products (Burdock and Carabin, 2008). The commercial value of sandalwood has risen steeply, with heartwood prices increasing from Rs. 365 per ton in 1900 to Rs. 7.9-12.5 million per ton at present, while the oil commands Rs. 1,20,000-1,50,000 per kg (Soundararajan *et al.* 2015). Global demand remains high, estimated at 5000 - 6000 tons of heartwood and about 100 tons of oil annually (Joshi and Arun Kumar 2007), with Karnataka historically contributing 70 - 80% of the supply (Rao *et al.,* 2007). However, unsustainable harvesting, poor natural regeneration, habitat degradation, fire, encroachment, weak enforcement, and illegal felling have caused severe population decline and genetic erosion, leading to its classification as "Vulnerable" by the IUCN (2010). Effective conservation, therefore, demands both in situ protection of remaining populations and ex situ measures such as germplasm conservation, clonal plantations, and tree improvement programs (Swaminathan *et al.,* 1998). Ensuring genetically

superior and quality planting stock is critical for sustaining productivity and adaptability. Considering its ecological, cultural, and economic importance, conservation of *S. album* genetic resources has become urgent. Against this backdrop, the present study evaluated the regeneration status of natural populations in Karnataka to provide insights for restoration and long-term sustainable management.

Material and Methods

The study was conducted between 2021 and 2023 across different regions of Karnataka. A reconnaissance survey identified twenty distinct populations of *S. album*, representing diverse geographical zones and environmental conditions. The study sites, located at elevations ranging from 553 m to 1143 m (Table 1; Fig. 1), were selected based on an extensive review of published literature, district floras, Karnataka Forest Department working plans, and previous studies. Final site selection was confirmed through detailed field reconnaissance surveys, undertaken with Karnataka Forest Department officials, to locate naturally occurring *S. album* populations within the designated forest divisions of Karnataka.

Table 1 : Location details of natural populations of *S. album* in Karnataka, India

Sl. No.	Population	Forest division	Elevation (m)	Latitude (N)	Longitude (E)
1.	Belasuru	Yellapur	552.87	14° 56' 44"	74° 44' 48"
2.	Chanagiri	Bhadravathi	682.59	14° 1' 28"	75° 55' 40"
3.	Chikkamngalur	Chikkamangalur	919.77	13° 27' 31"	75° 51' 58"
4.	Dharwad	Dharwad	741.46	15° 27' 46"	74° 59' 51"
5.	Haliyal	Haliyal	586.3	15° 19' 51"	74° 46' 8"
6.	Hoogyam	M. M. Hills WL	727.77	11° 51' 36"	77° 24' 2"
7.	Hulekal	Sirsi	557	14° 38' 24"	74° 44' 22"
8.	IWST	Bengaluru urban	874	13° 0' 45"	77° 34' 14"
9.	J.B. Kaval	Bengaluru urban	941.61	13° 03' 53"	77° 32' 25"
10.	Katur	Mundagod	615.2	14° 49' 0"	75° 4' 16"
11.	Kollegal	M. M. Hills WL	694.29	12° 9' 1"	77° 6' 47"
12.	Lokanahalli	BRT	1142.11	11° 59' 52"	77° 13' 19"
13.	M.M. Hills	M. M. Hills WL	1028	12° 2' 10"	77° 33' 48"
14.	Maravagi	Bhadravathi	715.55	14° 0' 14"	75° 56' 46"
15.	Murkawada	Haliyal	558.12	15° 16' 15"	74° 50' 56"
16.	Nrupathunga	Dharwad	734.48	15° 22' 33"	75° 7' 45"
17.	Punajanur	Chamarajanagar	879.72	11° 49' 8"	77° 6' 28"
18.	Sandur	Ballari	675.27	15° 1' 41"	76° 34' 8"
19.	Shantisagar	Bhadravathi	678.18	14° 01' 01"	75° 50' 19"
20.	Tangli	Chikkamangalur	745.32	13° 32' 17"	76° 3' 40"

Observations on regeneration status were made in a quadrat size of 20 m × 20 m for mature trees (>30 cm GBH) and in each quadrat, a sub-quadrat of 5 m × 5 m for saplings (10 - 30 cm GBH height ≥ 1.3 m), seedlings (<10 cm circumference and height ≤ 1.3 m).

Regeneration was classified into five categories (Hanief *et al.,* 2016):

1. Good regeneration: number of seedlings (NOS) > saplings (NOSA) > mature tree (NOM).
2. Fair regeneration: number of seedlings (NOS) > or < saplings (NOSA) < mature tree (NOM).
3. Poor regeneration: species present only as saplings, with no seedlings (number of saplings may be more, less or equal to that of adults).
4. No regeneration: individuals of the species are present only as adults.
5. New regeneration: individuals of the species are present only as seedlings or saplings with no adults.

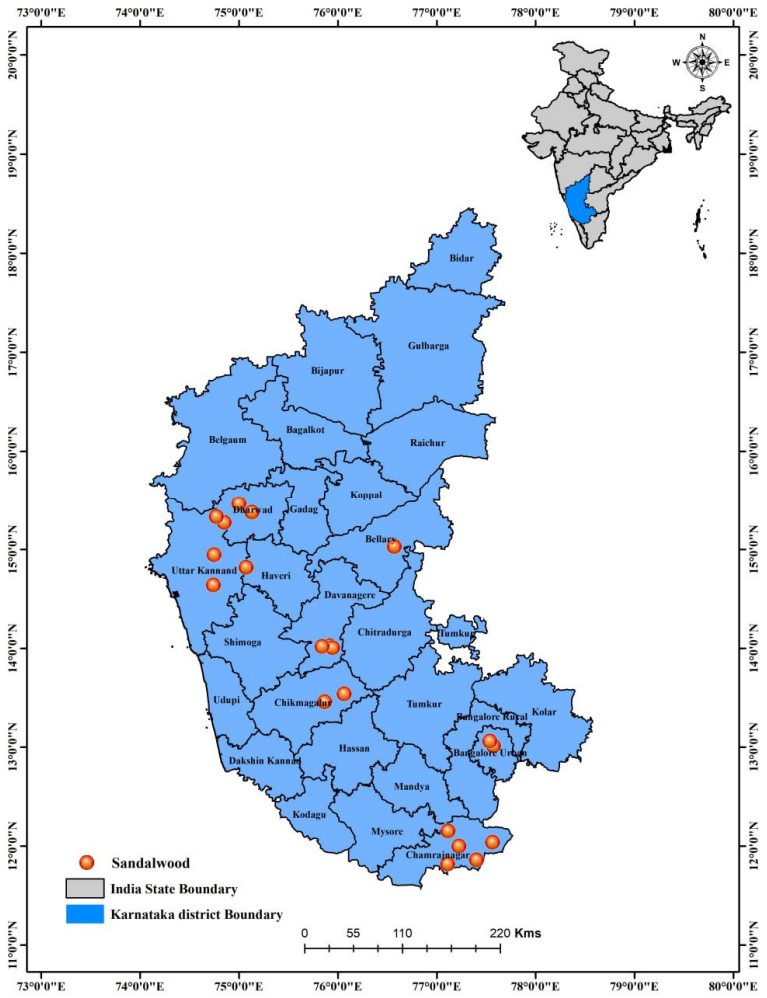

Fig. 1 : Geographical distribution of natural populations of *S. album* in Karnataka, India

Statistical analysis

The recorded data were analysed using Microsoft Office Excel 2021, and descriptive statistics were applied to quantify the measured parameters.

Results and Discussion

The survey across 20 natural populations of *S. album* revealed substantial variation in regeneration status. Among the sites, 13 populations showed fair regeneration, four (Sandur, Maravagi, J. B. Kaval and Punajanur) were rated as good, while three (Belasuru, Chanagiri, and Haliyal) exhibited no regeneration. Seedling density was highest at Sandur (450.75/ha), followed by Maravagi (368.75/ha), whereas Belasuru, Chanagiri, Dharwad, Haliyal, Kollegal, and IWST showed complete absence. Saplings were most abundant in Sandur (257/ha), Shantisagar (250/ha), Lokanahalli (193.75/ha), Punajanur (175/ha) and Maravagi (143.75/ha) but were entirely lacking at Belasuru, Chanagiri, Haliyal, and Hulekal. Mature trees were concentrated in Punajanur (42.25/ha) and Hulekal (34.50/ha).

Punajanur displayed the most balanced stand structure, with individuals represented in all growth stages, indicating a sustainable regeneration cycle. Sandur, Maravagi and J. B. Kaval also showed strong regeneration, mainly through seedlings and saplings, favoured by red loam and red sandy loam soils and reduced biotic stress. In contrast, the complete absence of regeneration in several sites reflected severe ecological degradation and intense anthropogenic disturbance.

The major threats recorded across populations were poaching, recurrent fires, livestock grazing, trampling, and wildlife damage. Wild boars damaged fragile seedlings, while deer and elephants browsed seedlings, saplings, and bark in areas such as M.M. Hills, and Punajanur. Seedling suppression due to insufficient light further hindered establishment and contributed to early mortality. Overall, regeneration of *S. album* was highly site-specific, shaped by ecological and anthropogenic pressures. While Sandur and Maravagi showed high regeneration potential,

populations like Belasuru, Chanagiri, and Haliyal appeared critically endangered, with Punajanur standing out as a model site for in situ conservation (Table 2).

Table 2 : Regeneration status of *S. album* in natural populations of Karnataka, India

Sl. No.	Populations	Soil Texture	Seedlings /ha	Saplings /ha	Trees /ha	Status	Major threats
1.	Belasuru	Red gravelly	0	0	28.25	No	Trampling by nearby villagers, grazing by cattle and theft
2.	Chanagiri	Red sandy loam	0	0	20.25	No	Trampling
3.	Chikkamngalur	Red clay loam	37.5	50	18.75	Fair	Trampling by nearby villagers, forest fire and theft
4.	Dharwad	Red gravelly	0	35.45	28.15	Fair	Trampling
5.	Haliyal	Red gravelly	0	0	20.05	No	Trampling and theft
6.	Hoogyam	Black	200	13.25	15.75	Fair	Grazing by cattle and deer and theft
7.	Hulekal	Red loam	93.75	0	34.5	Fair	Wild boar eats root suckers
8.	IWST	Red	0	50	15.45	Fair	
9.	J. B. Kaval	Red	163.75	162.5	15.55	Good	Theft
10.	Katur	Red sandy loam	80	150	18.25	Fair	Theft
11.	Kollegal	Red	0	41.25	26.5	Fair	Theft
12.	Lokanahalli	Red sandy loam	118.75	193.75	20.15	Fair	Theft
13.	M.M. Hills	Red sandy loam	212.5	18.75	20.25	Fair	Wild borers consume *S. album* fruits, while fragile seedlings and saplings are eaten by deer and theft
14.	Maravagi	Red loam	368.75	143.75	15.75	Good	Forest fire and theft
15.	Murkawada	Red sandy loam	43.75	56.25	15.55	Fair	Theft
16.	Nrupathunga	Red gravelly	33.75	56.25	15.65	Fair	Trampling and theft
17.	Punajanur	Red brown	200	175	42.25	Good	Wild borers consume *S. album* fruits, deer eat fragile seedlings and saplings and elephants consume the bark and theft
18.	Sandur	Red sandy loam	450.75	257	18.75	Good	Theft
19.	Shantisagar	Red sandy loam	200	250	20.15	Fair	Theft
20.	Tangli	Red sandy loam	62.5	87.5	20.25	Fair	Theft

Earlier studies emphasized the dual regeneration pathways in sandalwood, vegetative (root suckers, coppicing) and sexual reproduction mediated by bird dispersal (Venkatesan *et al.* 1995). However, despite good germination capacity, survival in forest tracts has historically been poor due to fires, grazing, and poaching (Jain *et al.,* 2003; Venkatesan *et al.,* 1995). More recent studies (Divakara and Tewari, 2021; Arun Kumar, 2022) documented better regeneration under protected conditions. A striking divergence is evident between past and present observations. Earlier surveys reported relatively widespread regeneration across Karnataka (Ballari, Chamarajanagar, Chikkamagaluru, Kolar, Mandya), whereas the current study shows regeneration confined to a few pockets. This decline likely reflects cumulative impacts of illegal felling, overexploitation, recurrent disturbance, and selective removal of superior genotypes (Venkatesan *et al.,* 1995), resulting in demographic contraction and genetic erosion. Natural regeneration of *S. album* in Karnataka is restricted and uneven, with several key populations lacking recruitment. Only Punajanur, Maravagi, Sandur and J. B. Kaval show good regeneration and should be prioritized for conservation. Site-specific strategies, such as anti-poaching, controlled grazing, fire prevention, and enrichment planting, are essential. Without urgent action, the sustainability and genetic diversity of sandalwood may be severely compromised.

Associated species: *S. album* regeneration is found to be better in the presence of associated species. The survey of 20 sandalwood populations revealed a wide range of associated 22 tree and seven shrub species. Among tree associates, *Acacia nilotica, Acacia*

catechu, Eucalyptus spp., Dalbergia sissoo, Pongamia pinnata, and *Diospyros melanoxylon* were frequently observed. Other common associates included *Delonix regia, Pterocarpus marsupium*, *Anacardium occidentale, Syzygium cumini, Artocarpus heterophyllus, Albizia amara, Dalbergia paniculata, Melia dubia, Syzygium cumini, Anogeissus latifolia, Terminalia elliptica, Phoenix sylvestris, Butea frondose* and *Terminalia arjuna*. Shrub associations were dominated by *Lantana camara, Dodonaea viscosa, Zanthoxylum asiaticum, Cassia auriculata, Bambusa bambos*, *Gliricidia sepium* and *Ziziphus oenopolia*. Notably, *Lantana camara* was present in more than 50% of the surveyed sites, and *Acacia nilotica, Acacia catechu* in 30% and 25% respectively, suggesting its widespread co-occurrence with sandalwood (Table 3).

Table 3 : Associated species in natural populations of *S. album* in different populations

Sl. No.	Name of the population	Associated species	
		Trees	**Shrubs**
1	Belasuru	*Anacardium occidentale, Syzygium cumini, Artocarpus heterophyllus*	*Cassia auriculata*
2	Chanagiri	*Pongamia pinnata*	-
3	Chikkamngalur	*Acacia nilotica, Acacia catechu, Albizia amara*	*Lantana camara, Zanthoxylum asiaticum, Dodonaea viscosa,*
4	Dharwad	*Pongamia pinnata*	-
5	Haliyal	*Diospyros melanoxylon, Dalbergia paniculata*	-
6	Hoogyam	*Acacia nilotica, Acacia catechu,*	*Lantana camara, Dodonaea viscosa,*
7	Hulekal	*Eucalypus spp., Anacardium occidentale*	*Lantana camara, Bambusa bambos*
8	IWST	*Pongamia pinnata*	-
9	J. B. Kaval	*Eucalyptus spp., Melia dubia*	*Bambusa bambos, Lantana camara,*
10	Katur	*Acacia nilotica, Acacia catechu,*	*Gliricidia sepium,*
11	Kollegal	*Delonix regia, Syzygium cumini*	*Bambusa bambos*
12	Lokanahalli	*Anogeissus latifolia, Terminalia elliptica,*	*Ziziphus oenopolia, Lantana camara, Dodonaea viscosa, Zanthoxylum asiaticum,*
13	M.M. Hills	*Phoenix sylvestris, Anogeissus latifolia,*	*Lantana camara, Ziziphus oenopolia, Dodonaea viscosa,*
14	Maravagi	*Eucalyptus spp., Delonix regia*	*Lantana camara*
15	Murkawada	*Diospyros melanoxylon, Pterocorpus marsupium, Dalbergia latifolia*	-
16	Nrupathunga	*Diospyros melanoxylon, Pterocorpus marsupium*	-
17	Punajanur	*Terminalia arjuna, Pterocarpus marsupium,*	*Lantana camara*
18	Sandur	*Acacia nilotica, Acacia catechu,*	*Dodonaea viscosa, Lantana camara,*
19	Shantisagar	*Acacia nilotica, Acacia catechu,*	*Lantana camara, Zanthoxylum asiaticum, Dodonaea viscosa*
20	Tangli	*Acacia nilotica, Butea frondose, Eucalyptus spp.*	-

The occurrence of diverse associated tree species indicates that sandalwood is capable of establishing itself under varied ecological conditions and in association with both native and exotic species. The frequent presence of nitrogen-fixing trees such as *Acacia, Pongamia* and *Albizia* highlights their potential role as supportive hosts that improve soil fertility and enhance sandalwood growth. Conversely, invasive shrub species such as *Lantana camara* and *Dodonaea viscosa* exhibited dominance across several sites, indicating a facilitative role in sandalwood regeneration by providing protective cover that mitigates browsing pressure on vulnerable seedlings. The repeated occurrence of *Eucalyptus* spp. in some populations suggests its adaptability as a secondary host, though its allelopathic effects may influence sandalwood establishment in the long term. These results are in line with earlier studies reporting sandalwood's adaptability to both moist and dry deciduous habitats, but also highlight threats from invasive species that may negatively impact natural regeneration. Effective management of invasive

species and promotion of beneficial host trees (e.g., Acacia, Pongamia, Dalbergia, Terminalia) are crucial for maintaining healthy sandalwood populations. Hence, host selection and control of invasive flora should be prioritized in conservation and plantation programs to ensure sustainable growth and heartwood development of sandalwood.

Previous studies have similarly highlighted the diverse host and associate preferences of sandalwood. Nurochman *et al*. (2018) reported strong associations with *Syzygium cumini* and *Ziziphus oenopolia* in Indonesia, while Thinley *et al*. (2020) observed co-dominance of *Mallotus philippensis* and *Albizia sikkimensis* in Bhutan, with *Chromolaena odorata* and *Desmodium sp.* supporting seedling establishment. The present study partially corroborates these findings, as *Ziziphus* and *Albizia* species were recorded, though at lower frequencies compared to *Acacia* and *Dalbergia* in Karnataka. Durairaj and Kamaraj (2013) in Tamil Nadu, and Ankush *et al*. (2022) in Himachal Pradesh, emphasised the presence of *Lantana camara* as a support of natural sandalwood regeneration. This observation is strongly reinforced by the present findings, where *Lantana* was among the most widespread associates. Similarly, *Dodonaea viscosa* was frequently recorded, confirming its consistency as a natural associate, though with positive implications for regeneration success.

Unlike earlier reports, the present study also documented associations with exotic plantation species such as *Eucalyptus spp.* and *Gliricidia sepium.* Their occurrence likely reflects plantation-driven ecological shifts in Karnataka. While Gliricidia, being a nitrogen fixer, may act as a supportive host, Eucalyptus poses uncertainties due to potential allelopathic effects, marking an important distinction from previous findings that largely emphasized native associates.

The present study confirms the broad ecological adaptability of *S. album* while expanding earlier knowledge by demonstrating its dual interaction with beneficial hosts and invasive competitors across contrasting agroclimatic zones of Karnataka. The recurrence of nitrogen-fixing tree associates across regions highlights their positive role in sandalwood establishment, while the dominance of invasive shrubs underscores the need for active management interventions. Compared to previous studies from Tamil Nadu, Himachal Pradesh, Indonesia, and Bhutan, the present findings emphasize the unique context of Karnataka where traditional native associates coexist with exotic plantation species, thereby shaping population structure and regeneration dynamics.

Conclusion

Natural regeneration of *S. album* in Karnataka is highly restricted and uneven, with complete absence in several populations. Only a few sites (Punajanur, Maravagi, Sandur and J. B. Kaval) show good regeneration and should be prioritized for conservation and genetic improvement. Regeneration success is strongly influenced by soil fertility, host diversity, and disturbance pressures. Nitrogen-fixing and compatible hosts (*Acacia*, *Albizia*, *Pongamia*, *Dalbergia*, *Terminalia*, *Syzygium*) enhance growth, while invasive shrubs (*Lantana*, *Dodonaea*) provide protection. Sustainable management requires site-specific interventions including fire and grazing control, anti-poaching measures, invasive management, soil enrichment, and assisted regeneration. *S. album* regeneration is best supported in mixed-species ecosystems, highlighting its ecological adaptability and scope for conservation and agroforestry-based cultivation.

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