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Studies on Natural Regeneration of Dollar Earning Parasite (*Santalum album* Linn.) in Himachal Pradesh

Sachin Verma, Aditi Sharma and Vimal Chauhan[1]

Department of Biodiversity and Climate Change, Indian Council of Forestry Research and Education Dehradun-248 006, India
[1]Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan-173 230, India
E-mail: sachinsilvi@gmail.com

***Abstract*:** The present investigation was conducted in two different sites *viz.,* Jawalaji (Kangra) and Dholra (Bilaspur) during 2020-2022. Seeds of *Santalum album* L. are dormant due to the presence of hard seed coat which results in poor natural regeneration and slow growth rate. The *Santalum album* L. was found to be the dominant tree species in selected sites and co-dominated species were *Dalbergia sissoo, Acacia catechu* or *Lannea coromendelica*. The dominant shrub species were *Lantana camara* and *Carrisa carandus*. *Cymbopogon martini* and *Chrysopogon montanus* were dominant herbaceous vegetation of Jawalaji (Kangra) and Dholra (Bilaspur) site. The maximum successful regeneration (8.50%) was recorded at Dholra (Bilaspur) site.

***Keywords*:** Regeneration, Sandalwood, Dominant, Parasite

Santalum album L. belongs to family *Santalaceae*, family consists of 29 genera with more than 400 species, out of which 19 species are useful for oil aromatic purpose. One species *Santalum fernandezianum* has been reported to be extinct (Harbaugh 2007, Harbaugh and Baldwin 2007, Harbaugh et al 2010, Butaud, 2015). The global distribution of the sandalwood is between 30˚N and 40˚S from Indonesia in West to Juan Fernandez Island in the north to New Zealand in the South. The species is mainly found in India, Indonesia and Australia. In India, its distribution is mostly in the deciduous forests of the Deccan region of Peninsular India and mainly growing naturally in the states of Karnataka and Tamil Nadu. In Himachal Pradesh, the sandalwood is found growing naturally in districts of Kangra, Bilaspur and Sirmour. There were 3,000 fully grown sandalwood trees on a forest land near Jwalamukhi temple by the end of 2011 and the number touched 3,998 by December 2018.

The main reason for the economic and cultural value of sandalwood is the oil contained mainly in the heartwood. Heartwood oil content varies, widely between species and even within species. The Indian sandalwood is valued for its oil, which is highly rated for its sweetness, fragrance, persistent aroma and the fixative property and demanded by the perfumery industry. Heartwood oil priced at 22,000 Indian rupees per kg (Jain et al 2003). Being a root hemi-parasite, sandalwood depends upon host plants for nutrients and water for survival and growth. Host plants with the nitrogen-fixing ability and light shade appear to be the most suitable for good sandalwood growth (Silva et al 2016). Production of *Santalum album* L. has been decreased due to mismanagement (over-exploitation) in the past, inadequate plantation and establishment techniques and lack of support of the local community in planting and maintaining sandalwood trees. Stringent legal control and centralized authority on sandalwood resource, management, utilization and trade are the factors which have resulted in the low interest of the private sector towards investing in sandalwood plantation (Butar et al 2007).

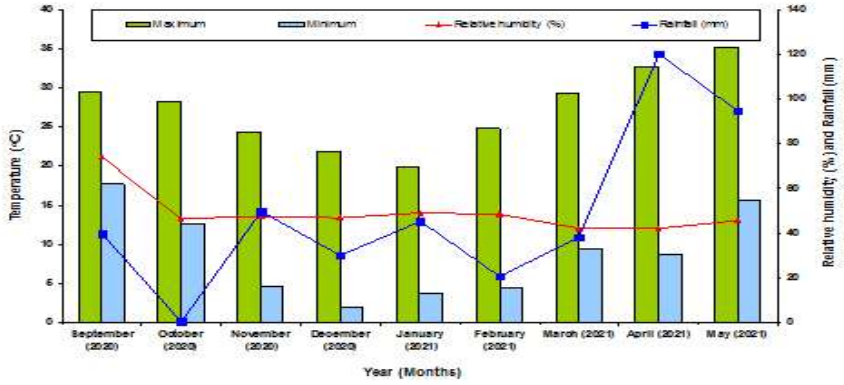
The tree is now on the verge of extinction due to over exploitation, though much of work has been done by the government to protect the tree plantation by applying strict laws. But, still the use of new techniques and biotechnological methods like that of rapid mass propagation such as *in-vivo, in-vitro* and micro grafting are required. In addition to that, proper storage of seeds is also an important factor because large number of seeds fails to develop due to improper storage and poor cultivation methods (Solanki et al 2015). The major constraints in raising large-scale plantations of sandalwood are the poor germination rate, prolonged seed germination period and slow rate of field establishment (Anandalakshmi et al 2019). Das and Tah (2013) reported physical dormancy due to hard seed coat which results in poor germination of sandalwood. Therefore keeping in view, the above facts, the present investigation has been carried out to study on natural regeneration of *Santalum album* L. in low hills of Himachal Pradesh.

MATERIAL AND METHODS

Climate and Location: The study area falls under sub-tropical sub montane low hill zone with 31.8756˚N latitude and 76.3243˚E longitude, which receives about 518mm precipitation annually and the major part of which is received during July and August (monsoon period). Jawalaji (Kangra) is situated at 650m amsl, April to June are the hottest months with temperature ranges up to 38˚C, whereas mid-November to mid-March are the coldest with temperature sometimes reaching to freezing point (Fig. 1). The sandalwood trees were grown naturally near the Jawalaji temple and in the private lands. The soils of the location were shallow, embedded with stones. Bilaspur district has a hilly terrain. The district is situated in the Shivalik range of the lower Himalayas. Dholra is situated, along the left bank of river Govind Sagar Lake. The study area falls under sub-tropical sub montane low hill zone, with 31.3330˚N latitude and 76.7584˚E longitude with an elevation of 600m amsl, which experiences warm summers and cool winters but is protected from the temperature extremes of the surrounding mountains and its situation in valley. The monsoons are received from July to September. The highest temperature months are May and June when the temperature reaches upto 38˚C and sometimes exceeding up to 40˚C (Fig. 1).

Floristic composition and phytosociological analysis of vegetation: Floristic and phytosociological analysis of the existing vegetation was carried out at two sites *viz.* Jawalaji (Kangra) and Dholra (Bilaspur). At each site, five quadrates each of 31.62m×31.62m for trees, 5m×5m for shrubs and 1m×1m for herbaceous components were randomly laid out. Percent frequency, density, basal area, relative frequency, relative density, relative dominance and important value index were calculated for each species (Raunkiaer 1934, Mishra 1968, Menon and Balsubramanyan 1985).

Regeneration studies: The regeneration survey of two sites was carried out in all the major sample plots. Within each sample plot (31.62m×31.62m) three sub-quadrat per plot of size (2m×2m) for regeneration studies were laid down. To express satisfactory regeneration 2500 established plant per hectare were desired. The quadrate was considered fully stocked when it contained on established plant (Chacko 1965). The regeneration survey was conducted from recruits (r) which may be defined as current years seedlings, unestablished regeneration (u) seedlings other than recruits



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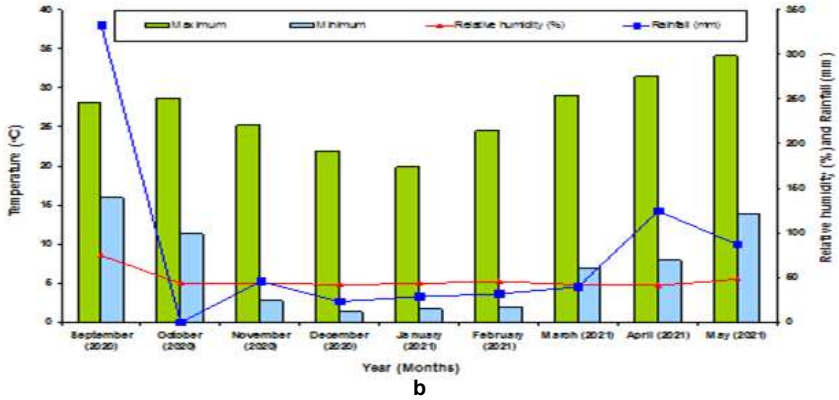

b

Fig. 1. Meteorological data of a) Jawalaji (Kangra) b) Dholra (Bilaspur) site on monthly basis during period of study (September 2020 - May 2021)

which has not established and whose height was less than 2 m, here four established plants were taken equivalent to one established plant and established regeneration (e) having height more than 2 m.

RESULTS AND DISCUSSION

Floristic composition and phytosociology: The maximum number (9) of tree species were observed in Dholra (Bilaspur) site and the minimum number (7) of species were in Jawalaji (Kangra) site (Table 1). The maximum number (7) of shrubs species were recorded in Jawalaji (Kangra) site and the minimum number (6) of shrubs species in Dholra (Bilaspur) site. The maximum numbers (7) of herbaceous species were in Jawalaji (Kangra) site and minimum numbers (6) of species were in Dholra (Bilaspur) site.

Two different sites had varied floristic composition of trees, shrubs and herbaceous indicating common species. Generally common species for trees found in both the sites were *Santalum album, Acacia catechu, Mallotus philipensis, Leucaena Leucocephala, Dalbergia sissoo* and *Cassia*

Table 1. Floristic composition of Jawalaji (Kangra) and Dholra (Bilaspur) sites in Himachal Pradesh

Name of species	Family	Jawalaji (Kangra)	Dholra (Bilaspur)	Total
Trees				
Santalum album	Santalaceae	+	+	2
Acacia catechu	Legumeaceae	+	+	2
Mallotus philipensis	Spurgeaceae	+	+	2
Bombax ceiba	Bombacaeae	+	-	1
Albizzia lebbeck	Legumeaceae	-	+	1
Lannea coromandelica	Anacardiaceae	-	+	1
Leucaena Leucocephala	Legumeaceae	+	+	2
Dalbergia sissoo	Legumeaceae	+	+	2
Cassia fistula	Legumeaceae	+	+	2
Grewia optiva	Malvaceae	-	+	1
Total		7	9	16
Shrubs				
Lantana camara	Verbenaceae	+	+	2
Murraya koengii	Rutaceae	+	-	1
Justacia adhatoda	Acanthaceae	+	+	2
Carissa carandas	Apocynaceae	+	+	2
Zizyphus numularia	Rhamnaceae	+	+	2
Asparagus adscendens	Asparagaceae	-	+	1
Dodonea viscosa	Sapindaceae	+	+	2
Agave Americana	Asparagaceae	+	-	1
Total		7	6	13
Herbaceous				
Ageratum conyziodes	Asteraceae	+	+	2
Bidens pilosa	Asteraceae	+	+	2
Eupatorium adenophorum	Asteraceae	+	+	2
Achyranthus aspera	Amaranthaceae	-	+	1
Ageratum houstonianum	Asteraceae	+	-	1
Chrysopogon montanus	Poaceae	+	+	2
Cymbopogon martini	Poaceae	+	-	1
Heteropogon contortus	Poaceae	+	-	1
Dicanthium anulatum	Poaceae	-	+	1
Total		7	6	13

+ = present; - = not present

fistula. Common species of shrubs were *Lantana camara, Justacia adhatoda, Carissa carandas, Zizyphus numularia* and *Dodonea viscosa.* In herbaceous, the common species consisted of *Ageratum conyziodes, Bidens pilosa, Eupatorium adenophorum* and *Chrysopogon montanus.* In the present investigation, species diversity in tree component was recorded highest in Dholra (Bilaspur) site. The species diversity of shrubs and herbaceous component was observed highest in Jawalaji (Kangra) site. Seven species of trees, seven species of shrubs and seven species of herbaceous in which four species of herbs and three species of grasses were in Jawalaji (Kangra) site (Table 2). The tree species in all reported a total density of 294.00 no. ha^{-1}, percent frequency 280.00, basal area of 12.71 $cm^2 ha^{-1}$ and IVI of 300. Maximum density (212.00 no. ha^{-1}), per cent frequency (100.00), basal area (10.14 $cm^2 ha^{-1}$) and IVI (187.58) in case of trees were in *S. album* and minimum density (2.00 no. ha^{-1}), percent frequency (20.00), basal area (0.08 $cm^2 ha^{-1}$) and IVI (8.42) were recorded in *Bombax cieba* whereas *L. leucocephala* (0.03 $cm^2 ha^{-1}$) showed minimum basal area (0.05 $cm^2 ha^{-1}$) followed by *C. fistula* . The shrub species in all reported a total density of 2416.00 no. ha^{-1}, percent frequency 304.00, basal area of 23046.00 $cm^2 ha^{-1}$ and IVI of 300 . Maximum density (736.00 no. ha^{-1}), percent frequency (72.00) were in *Murraya koengii* whereas, maximum basal area (5726.07 $cm^2 ha^{-1}$) and IVI (64.43) were recorded in *Lantana camara*. Minimum density (80.00 no. ha^{-1}) and IVI (25.17) were in *Agave Americana*. Minimum percent frequency (16.00) was observed in *Carrisa carandas* while minimum basal area (987.42 $cm^2 ha^{-1}$) was in *J. adhatoda.*

Table 2. Phytosociological parameters of vegetation in sandalwood forest at Jawalaji (Kangra) site in Himachal Pradesh

Name of species	Density (No. ha^{-1})	Frequency (%)	Basal area ($m^2/cm^2 ha^{-1}$)	RD	RF	RBA	IVI
Trees							
Santalum album	212.00	100.00	10.14	72.11	35.71	79.76	187.58
Acacia catechu	18.00	40.00	1.08	6.12	14.29	8.51	28.92
Mallotus philipensis	24.00	40.00	0.12	8.16	14.29	0.92	23.37
Bombax ceiba	2.00	20.00	0.08	0.68	7.14	0.60	8.42
Leucaena Leucocephala	10.00	20.00	0.03	3.40	7.14	0.21	10.75
Dalbergia sissoo	20.00	40.00	1.22	6.80	14.29	9.61	30.70
Cassia fistula	8.00	20.00	0.05	2.72	7.14	0.40	10.26
Total	294.00	280.00	12.71	100.00	100.00	100.00	300.00
Shrubs							
Lantana camara	416.00	68.00	5726.07	17.22	22.37	24.85	64.43
Murraya koengii	736.00	72.00	1037.79	30.46	23.68	4.50	58.65
Justacia adhatoda	608.00	60.00	987.42	25.17	19.74	4.28	49.19
Zizyphus numularia	208.00	44.00	2159.72	8.61	14.47	9.37	32.45
Carissa carandas	160.00	16.00	7160.88	6.62	5.26	31.07	42.96
Dodonea viscosa	208.00	24.00	2452.29	8.61	7.89	10.64	27.14
Agave Americana	80.00	20.00	3522.16	3.31	6.58	15.28	25.17
Total	2416.00	304.00	23046.34	100.00	100.00	100.00	300.00
Herbaceous							
Ageratum conyziodes	8000.00	63.20	2930.82	3.86	18.99	5.62	28.46
Bidens pilosa	6160.00	28.00	3626.98	2.97	8.41	6.95	18.33
Eupatorium adenophorum	8400.00	57.60	3949.98	4.05	17.31	7.57	28.92
Ageratum houstonianum	5280.00	42.40	2039.22	2.54	12.74	3.91	19.19
Chrysopogon montanus	67040.00	61.60	10680.98	32.31	18.51	20.46	71.28
Cymbopogon martini	67280.00	39.20	19800.09	32.42	11.78	37.94	82.14
Heteropogon contortus	45360.00	40.80	9163.53	21.86	12.26	17.56	51.68
Total	207520.00	332.80	52191.60	100.00	100.00	100.00	300.00

*m^2= Basal area (trees)
*cm^2= Basal area (shrubs and herbaceous component)

The herbaceous vegetation reported a total density of 207520.00 no. ha^{-1}, percent frequency 332.80, basal area of 52191.60 cm^2ha^{-1} and IVI of 300. Maximum density (8400.00 no. ha^{-1}), basal area (3949.98 cm^2 ha^{-1}) and IVI (28.92) in f herbs were observed in *Eupatorium adenophorum* whereas, maximum percent frequency (63.20.00) were in *Ageratum conziodes* and minimum density (5280.00 no. ha^{-1}), basal area (2039.22 cm^2 ha^{-1}) were observed in *Ageratum houstanianum* whereas minimum percent frequency (28.00) and IVI (18.33) were recorded in *Bidens pilosa.* In case of grasses maximum density (67280.00 no. ha^{-1}), basal area (19800.00 cm^2 ha^{-1}) and IVI (82.14) were observed in *Cymbopogon martinii* whereas, percent frequency (61.60) were observed in *C. montanus* and minimum density (45360.00 no. ha^{-1}), basal area (9163.53 cm^2 ha^{-1}) and IVI (51.68) were recorded in *Heteropogon contatus* whereas minimum percent frequency (39.32) were observed in *C. martini.*

Trees species (9), shrubs (6) and herbaceous (6) were found in Dholra (Bilaspur) site. The tree species reported a total density of 272.00 no. ha^{-1}, percent frequency 400.00, basal area of 7.51 cm^2ha^{-1} and IVI of 300 (Table 3). Maximum density (148.00 no. ha^{-1}), percent frequency (100.00), basal area (5.97 cm^2 ha^{-1}) and IVI (158.94) in *S. album.* The minimum density (6.00 no. ha^{-1}), percent frequency (20.00), basal area (0.01 cm^2 ha^{-1}) and IVI (7.23) were recorded in *Grewia optiva.* The shrub species reported a total density of 6160.00 no. ha^{-1}, percent frequency 192.00, basal area of 80522.08 cm^2ha^{-1} and IVI of 300 (Table 3). Maximum density (1760.00 no. ha^{-1}), percent frequency (68.00), basal area

Table 3. Phytosociological parameters of vegetation in sandalwood forest at Dholra (Bilaspur) site in Himachal Pradesh

Name of species	Density (No. ha^{-1})	Frequency (%)	Basal area (m^2/cm^2 ha^{-1})	RD	RF	RBA	IVI
Trees							
Santalum album	148.00	100.00	5.97	54.41	25.00	79.52	158.94
Acacia catechu	10.00	40.00	0.09	3.68	10.00	1.26	14.94
Mallotus philipensis	18.00	60.00	0.03	6.62	15.00	0.43	22.05
Albizzia lebbeck	16.00	40.00	0.04	5.88	10.00	0.59	16.47
Lannea coromandelica	28.00	40.00	0.44	10.29	10.00	5.88	26.17
Leucaena leucocephala	18.00	40.00	0.03	6.62	10.00	0.36	16.97
Cassia fistula	8.00	20.00	0.06	2.94	5.00	0.80	8.74
Dalbergia sissoo	20.00	40.00	0.84	7.35	10.00	11.14	28.49
Grewia optiva	6.00	20.00	0.01	2.21	5.00	0.02	7.23
Total	272.00	400.00	7.51	100.00	100.00	100.00	300.00
Shrubs							
Lantana camara	960.00	40.00	18179.16	15.58	20.83	22.58	58.99
Carissa carandas	1760.00	68.00	42807.50	28.57	35.42	53.16	117.15
Justacia adhatoda	1360.00	32.00	1916.81	22.08	16.67	2.38	41.13
Zizyphus numularia	400.00	12.00	6725.14	6.49	6.25	8.35	21.10
Asparagus adscendens	720.00	24.00	593.16	11.69	12.50	0.74	24.92
Dodonea viscosa	960.00	16.00	10300.30	15.58	8.33	12.79	36.71
Total	6160.00	192.00	80522.08	100.00	100.00	100.00	300.00
Herbaceous							
Ageratum conyziodes	4200.00	35.20	812.63	2.18	13.71	1.23	17.12
Bidens pilosa	2933.33	17.60	1647.31	1.52	6.85	2.50	10.88
Eupatorium adenophorum	4733.33	44.00	2051.50	2.45	17.13	3.12	22.70
Achyranthus aspera	4266.67	40.00	892.50	2.21	15.58	1.36	19.14
Chrysopogon montanus	133360.00	76.00	59478.17	69.14	29.60	90.36	189.10
Dicanthium anulatum	43401.60	44.00	938.17	22.50	17.13	1.43	41.06
Total	192894.93	256.80	65820.28	100.00	100.00	100.00	300.00

*m^2= Basal area (trees)
*cm^2= Basal area (shrubs and herbaceous component)

(42807.50 $cm^2 ha^{-1}$) and IVI (117.15) in shrubs were observed in *C. carandus*. The minimum density (400.00 no. ha^{-1}), percent frequency (12.00) and IVI (21.10) were in *Z. numularia* and the minimum basal area (593.16 cm^2 ha^{-1}) were observed in *Asparagus adscendens.* The herbaceous species in all reported a total density of 192894.93 no. ha^{-1}, frequency 256.80 per cent, basal area of 65820.28 cm^2 ha^{-1} and IVI of 300 (Table 3). Maximum density (4733.00 no. ha^{-1}), percent frequency (44.00), basal area (2051.50 $cm^2 ha^{-1}$) and IVI (22.70) in case of herbs were observed in *Eupatorium adenophorum* and minimum density (2933.33 no. ha^{-1}), percent frequency (17.60) and IVI (10.88) were in *B. pilosa* whereas *A. conyziodes* showed minimum basal area (812.63 $cm^2 ha^{-1}$). In case of grasses maximum density (133360.00 no. ha^{-1}), percent frequency (76.00), basal area (59478.17 $cm^2 ha^{-1}$) and IVI (189.10) were observed in *C. montanus* and minimum density (43401.60 no. ha^{-1}), percent frequency (44.00), basal area (938.17 $cm^2 ha^{-1}$) and IVI (41.06) were in *Dicanthium anulatum.*

Dutt et al (2021) also revealed that the Jawalamukhi site showed maximum dominance of *S. album* L. Maximum IVI for *S. album* L. is attributed to its higher frequency, basal area and density. Among shrubs, *C. carandus* dominated the site. *C. montanus* was found to be the most dominant grass with an IVI (186.04) which is due to its high frequency and basal area.

In Bilaspur *S. album* dominated the vegetation with maximum IVI (87.51) which is attributed to its higher frequency, basal area and density. The most dominant shrub at Bilaspur site was *L. camara* (IVI 51.99). *C. montanus* (IVI 145.49) dominated the different grass species, owing to its high density, frequency and basal area. Sreejith et al (2016) studied the flora in Marappalam forest in Kerala and reported that the forest includes a total of 20 species in which sandalwood excels all other species, indicating 100 per cent frequency of distribution, total density more than 38 per cent, total basal area more than 36 per cent with 31 per cent of importance value index (IVI). Huish et al (2015) reported the population densities of *Santalum. yasi* ranging from 19 to 63 trees ha^{-1} in Fiji and Tonga. Bahadur, (2019) reported that sandalwood showed maximum relative density (21.67%) and relative frequency (16.67%).

Regeneration status: In Jawalaji (Kangra) site, *S. album* maximum number of recruits ha^{-1} (150.00), unestablished ha^{-1} (250.00), established ha^{-1} (50.00), establishment stocking percent (3.32%) and successful regeneration (4.50%) (Table 4). *L. leucocephala* showed number of unestablished ha^{-1} (100.00) and successful regeneration (1.00%) whereas recruit's ha^{-1}, established ha^{-1} and establishment stocking percent were found absent in *L. leucocephala.* In Dholra (Bilaspur) site *S. album* showed maximum number of recruits ha^{-1} (450.00), unestablished ha^{-1} (450.00), established ha^{-1} (100.00), establishment stocking percent (4.59%) and regeneration successful (8.50%) as compared to other species followed by *L. leucocephala,* which showed unestablished ha^{-1} (250.00), established ha^{-1} (100.00), establishment stocking percent (4.93%) and regeneration successful (6.50%). *A. lebbeck* showed recruits ha^{-1} (250.00), unestablished ha^{-1} (200.00), established ha^{-1} (50.00), establishment stocking percent (2.28%) and regeneration successful (4.00%). *M. phillipensis* showed recruits ha^{-1} (200.00), established ha^{-1} (50.00), establishment stocking percent (2.00%) and regeneration successful (2.00%) whereas recruit's ha^{-1} in *L. leucocephala* and unestablished ha^{-1} in *M. phillipensis* were found absent. The maximum recruits ha^{-1} (900.00), unestablished ha^{-1} (900.00), established ha^{-1} (300.00), establishment stocking percent (13.81%) and regeneration successful (21.00%) were recorded in Dholra (Bilaspur) site and minimum recruits ha^{-1} (150.00), unestablished ha^{-1}

Table 4. Regeneration status at Jawalaji (Kangra) and Dholra (Bilaspur) site in Himachal Pradesh

Name of species	Recruits (ha^{-1})	Unestablished (ha^{-1})	Established (ha^{-1})	Establishment stocking percent (%)	Regeneration successful (%)
Jawalaji (Kangra)					
Santalum album	150.00	250.00	50.00	3.32	4.50
Leucaena leucocephala	-	100.00	-	-	1.00
Total	150.00	350.00	50.00	3.32	5.50
Dholra (Bilaspur)					
Santalum album	450.00	450.00	100.00	4.59	8.50
Leucaena leucocephala	-	250.00	100.00	4.93	6.50
Mallotus phillipensis	200.00	-	50.00	2.00	2.00
Albizzia lebbeck	250.00	200.00	50.00	2.28	4.00
Total	900.00	900.00	300.00	13.81	21.00

(350.00), established ha^{-1} (50.00), establishment stocking percent (3.32%) and regeneration successful (5.50%) in Jawalaji (Kangra) site.

CONCLUSION

Santalum album was dominant tree species in selected sites and co-dominated species were *Dalbergia sissoo*, *Acacia catechu and Lannea coromandelica*. The dominant shrub species were *Lantana camara* and *Carrisa carandus*. *Cymbopogon martini* and *Chrysopogon montanus* were dominant herbaceous vegetation in Jawalaji (Kangra) and Dholra (Bilaspur) site. The regeneration of sandalwood was found maximum in Dholra (Bilaspur) site as compared to the minimum regeneration observed at Jawalaji (Kangra) site.

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