

Unpredictable Reproductive Behavior of *Cedrus deodara* (Roxb.) G. Don

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Abstract

The long lived iteroparous conifers produce male and female gametophyte for hundreds of years once they reach the reproductive stage, however, the production of seed is not frequent. This phenomenon of infrequent seed production in conifers is yet to be understood. An attempt to study this change in cone production in *Cedrus deodara* of Western Himalayas - a species reported to be mainly monoecious and rarely dioecious has been made. The observations recorded on selected trees of flowering/fruitlet stage for four years at four different locations have shown the species to be dioecious with higher percentage of female trees during good seed year but with no definite or predictable pattern of reproduction in the trees. A decline in production of female trees was witnessed at all but one location immediately year after reaching the maximum (good seed year). The phenomenon of seed production has been observed to be cyclic and site specific. A change in the sexual behavior of the trees from male to female or vice-versa, male or female turning monoecious or vegetative and vegetative coming to reproductive was unpredictable.

Key Words: iteroparous, conifers, dioecious, monoecious, reproductive, neutral

Introduction

The long lived trees are the main carrier species of complex forest ecosystems compared to other ecologically or economically significant species. The long life of the tree species exposes them to a much greater environmental heterogeneity and thus results in display of differences in individuals or populations in one or more traits for the species generally spread over a wide geographical range. The environmental conditions of trees, unlike agricultural crops, cannot be manipulated efficiently by means of fertilization or pest control. Thus many forest tree populations can still be considered wild with very particular strategies of adaptation and survival. These wild populations are the potential reservoirs of genetic variation-a fundamental component of

survival and stability of forest ecosystems.

Conifers, amongst the tree species, are the most abundant, oldest and long lived iteroparous plants with 620+ species, 71 genera and 7 families (Williams 2009). About 11 genera and 24 species are native to India of which *Pinus*, *Cedrus*, *Abies* and *Picea* are the main forest forming genera predominant in the subtropical and temperate regions of N-W Himalayas.

The genus *Cedrus* is represented by four species *Cedrus atlantica*, *Cedrus libani*, *Cedrus brevifolia* and *Cedrus deodara* (Debazac 1964; Vidakovic 1991). Of these four species, *Cedrus deodara* (deodar), is the most important temperate timber species of Western Himalayas found growing from Afghanistan to Garhwal up to the Valley of Dhaul River below Niti pass (Tewari 1994). The species covers an

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area of about 0.2 million hectares in three north Indian hilly states of Himachal Pradesh, Jammu & Kashmir and Uttarakhand. The altitudinal range of deodar is usually higher on the southern than on the northern slopes and the trees grows best and reaches its largest dimensions in cool situations on northern aspect in moist temperate regions (50 m high and approximately 3 m in diameter). The growth remains stunted in dry temperate regions.

The species is reported to be predominantly monoecious with male and female cones occurring on separate branches and rarely dioecious (Troup 1921; Maheshwari and Biswas 1970; Tewari 1994). The differentiation of male and female trees based on morphometric traits is not possible till the cones start appearing on the trees. The small, inconspicuous cones appear in August and pollination takes place from the middle of September to the middle of October and become full sized by the end of June or July, bluish when young and chocolate brown when ripe from the end of September to the middle or end of November. Thus the time period occupied from the first appearance to the ripening of the cone is about 12 ½ to 13 ½ months (Raizada and Sahni 1960; Sahni 1990). The male cones appear in June and shed their pollens during the autumn (September-October).

Good seed year in conifers generally occurs once in three to four years with *Cedrus deodara* being no exception. However, this pattern is not uniform as a good proportion of trees in one population bear cones (seed) in a good seed year, the other populations may not follow suit. Also, the complete absence of cones throughout the distribution zone of the species has not been observed. This phenomenon of uncertain or infrequent seeding in conifers still remains to be understood. Preliminary information from different forest divisions in the state of Himachal Pradesh where plantations of deodar was taken up regularly revealed that the seed collection year and the sources were different. Since, there was no available data or report on reproductive behavior of

the species an attempt was made to study the phenomenon of seeding in deodar.

Materials and Methods

The material to study the seeding behavior of deodar comprised of trees of flowering/fruitlet stage selected at four sites. These sites represent pure crops of deodar distantly located from each other and at different altitudes (Table 1). The trees were randomly selected depending on the area of the population, and accordingly 34, 47, 42 and 39 trees were selected at Site 1, Site 2, Site 3 and Site 4, respectively. The selected trees of every location were numbered and marked according to their seeding behavior as male (M), female (F) or Monoecious (M/F) at the time of selection during the year 2011. The reproductive behavior of these selected trees was recorded continuously for four years i.e. 2011 to 2014.

Results

The available literature defines the species mainly as monoecious and rarely dioecious. The male and female trees do not bear any marked differences for morphometric traits such as bark pattern, needle colour or crown form. The trees become distinguished at the time of cone production to be recognized as male and female. As a result the observations on the selected trees were recorded for their reproductive behaviour and trees were marked as dioecious and monoecious. Under dioecious condition trees were marked as Male (bearing male cones only) and Female (bearing female cones only). The trees bearing both male and female cones were marked as Monoecious (Table 2).

Site 1: Conifer campus, Shimla

Of the 34 trees marked during the year 2011, 12 were

Table 1. Experimental site details

Sites	Locations	Latitude	Longitude	Altitude (msl)	Forest area	Trees selected
1	Conifer Campus, Shimla forest	31° 04.022' N	77° 10.208' E	1893	6.0 ha	34
2	Nankhari forest	31° 03.400' N	77° 18.933' E	2412	25 ha	47
3	Sarain forest	30° 54.078' N	77° 31.791' E	2308	20 ha	42
4	Kandyali forest	31° 18.120' N	77° 35.167' E	2520	22 ha	39

Table 2. Data of reproductive behaviour of selected trees at four sites for 4 years

Tr No.	Shimla				Nankhari				Sarain				Kandyali			
	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014
1	F	F	F	M/F	M	M	M/F	M	F	F	F	F	F	F	F	F
2	M/F	M/F	M/F	F	M/F	M/F	F	M/F	F	F	F	N	M/F	M/F	F	M/F
3	M	M/F	M	F	F	F	F	F	F	F	F	F	M	M	M/F	M/F
4	M/F	M/F	F	M	M	N	M	N	F	N	F	N	M	M	M	M
5	M/F	M/F	M/F	F	M	M	M/F	M/F	F	M/F	M/F	M/F	M	M/F	F	M/F
6	F	F	M/F	M	M	M	M	M	F	M/F	F	M/F	M/F	M/F	M/F	F
7	M	M	M/F	F	M/F	N	M/F	N	F	F	F	F	M/F	M/F	M/F	F
8	M	M	M	F	F	F	F	N	M/F	M	M/F	M	M	N	M/F	F
9	M/F	M/F	N	F	M/F	F	F	M/F	M	M	M	M/F	M/F	M/F	M/F	M/F
10	M/F	M/F	M	F	M/F	M/F	F	M/F	M/F	M/F	F	M/F	M	M/F	F	F
11	F	F	N	F	M	M	M/F	M	F	M/F	F	M/F	M/F	M/F	M/F	F
12	M	M	N	N	F	F	F	F	F	F	F	F	F	F	F	M/F
13	M/F	M/F	M	M	M/F	M/F	F	M/F	M/F	M/F	F	M/F	M/F	M/F	M/F	F
14	F	F	M	F	M	M	M/F	M/F	M	M	N	M	M	M/F	M	F
15	M/F	M/F	M/F	M	M	M	M	M	F	F	F	N	M/F	M/F	F	M
16	M	M	M/F	M	M	M/F	F	M/F	M/F	M/F	F	M/F	M/F	M/F	M/F	F
17	F	M/F	N	F	M/F	M/F	M/F	N	F	F	F	M/F	M/F	M/F	F	F
18	M/F	M/F	M/F	N	F	M/F	F	M/F	F	F	M/F	M/F	M/F	M/F	F	F
19	M	N	M/F	F	F	F	F	F	M	M/F	M	M/F	M	M/F	F	F
20	M/F	M/F	M/F	M/F	M/F	F	F	M/F	F	F	F	N	F	F	F	F
21	M	M/F	F	F	F	N	F	N	F	F	M/F	M/F	M/F	M/F	F	F
22	M/F	M/F	M/F	M/F	M	M	N	M	M/F	F	F	M/F	M	M/F	N	F
23	F	F	F	N	F	M/F	F	M/F	M	M	M	M/F	F	F	F	F
24	M	M/F	F	M/F	F	F	F	M/F	M/F	F	F	M/F	F	M/F	F	M/F
25	M	M	M	F	M	M	N	M	M/F	M	M/F	M	F	F	F	F
26	M	M	F	F	F	F	F	M/F	F	F	F	F	F	F	F	F
27	M/F	M/F	F	F	F	F	F	F	F	M/F	M/F	M/F	F	M/F	M/F	M/F
28	F	F	M	F	M/F	F	F	M/F	M	M	M/F	M	F	F	F	M/F
29	M/F	M/F	F	F	M	N	M/F	M	M/F	M/F	F	M/F	M	M	M	M/F
30	M/F	M/F	F	F	M/F	F	F	M/F	M/F	M/F	F	M/F	M	N	M	M/F
31	M	M/F	F	F	F	F	F	F	F	M/F	F	F	F	F	F	F
32	F	F	F	F	F	F	F	F	M	M/F	M	M	F	M/F	F	M/F
33	M/F	M/F	F	M/F	M/F	M/F	F	M/F	M/F	M/F	F	M/F	M/F	F	F	F
34	M	M/F	N	M/F	M	M/F	M	M	F	F	F	N	M	M	M/F	M/F
35					F	F	F	F	M/F	M/F	F	M/F	M/F	M/F	F	F
36					M/F	M/F	F	F	M	M	M	M	F	F	F	F
37					F	F	F	M/F	F	M/F	F	M/F	M/F	M/F	F	M/F
38					M	M	M	M/F	M/F	M	M/F	M/F	M	M	M/F	M/F
39					M	N	M	N	M	M/F	M	M	M	M	M	M
40					F	F	F	F	M/F	M/F	F	M/F				
41					F	F	F	M/F	M	M/F	M/F	M/F				
42					M/F	F	F	F	M/F	F	F	F				
43					M	M	M/F	M/F								
44					M/F	F	F	F								
45					M/F	F	F	M/F								
46					F	F	F	F								
47					M	M/F	M/F	M								

M, Male; F, Female; M/F, Monoecious; N, Neutral.

male, 8 female and 14 monoecious. The observations of the year 2012 recorded 6 male, 7 female, 20 monoecious and one tree recorded as male during 2011 did not produce any cones and was recorded as neutral i.e. vegetative. The observations of 2013 recorded 7 male, 12 female, 10 monoecious and 5 trees were recorded as neutral or vegetative. The year 2014 produced interesting results with 5 trees recorded as male, 20 female, 6 monoecious and 3 neutral (Table 3).

The summary of the results of site 1 showed change in the reproductive behavior of the species as of the 34 trees 7 changed their behavior (5 M→M/F, 1F→M/F and 1M→N) during 2012. In 2013, 23 trees changed their sex (3M/F→M, 8M/F→F, 2F→M, 1F→M/F, 1M→F, 2M→M/F, 3M/F→N, 1F→N, 1M→N, 1N→M/F) and 11 trees remained unchanged. In the 4th year i.e., 2014, 23 changed their sex (3F→M/F, 1F→M, 1F→N, 4M/F→F, 3M/F→M, 1M/F→N, 6M→F, 3N→F, 1N→M/F) and 11 trees did not show any change in their reproductive behavior (Table 2).

Site II: Nankhari forest

The site Nankhari located at 2412 m elevation in Rampur Forest Division is a pure stand of *Cedrus deodara* spread over 25 ha. Following same criterion of selection, 47 trees were marked during 2011 of which, 16 were male, 17 female and 14 monoecious. The observations of the year 2012, recorded 10 male, 21 female, 11 monoecious and 5 trees remained vegetative and hence recorded as neutral. During the year 2013, the observations showed 6 male, 30 female, 9 monoecious and 2 neutral. The 4th year (2014) of the study recorded 9 male, 12 female, 20 monoecious and 6 neutral trees (Table 3).

The summary of the results of site 2 showed change in the reproductive behavior of the species as of the 47 trees, 17 changed their behavior (3M→M/F, 2F→M/F, 3M→N, 1F→N, 1M/F→N and 7M/F→F) during 2012. In 2013, 21 trees changed their sex (5M→M/F, 2M→N, 2N→M, 2N→M/F, 1N→F, 1M/F→M, 8M/F→F) and 26 trees remained unchanged. In 4th year i.e., 2014, 29 trees changed their reproductive behaviour (1M→M/F, 2M→N, 4M/F→M, 2M/F→N, 16F→M/F, 2N→M and 2F→N) and 18 trees did not show any change (Table 2).

Site III: Sarain forest

The Sarain forest under Chopal Forest Division in the inner Himalayas spread over 20 ha represents pure crop of deodar. Of the total 42 trees marked during 2011, 9 were male, 19 female and 14 monoecious. The observations recorded during the year 2012, revealed 8 male, 15 female, 18 monoecious and 1 neutral. The year 2013 recorded 6 male, 26 female, 9 monoecious and 1 neutral. The year 2014 recorded 7 each male and female, 23 monoecious and 5 neutral (Table 3).

Out of 42 trees selected during the year 2011 for reproductive/seeding behavior 17 changed their behavior during 2012 (6F→M/F, 3M/F→M, 3M/F→F, 4M→M/F and 1F→N). In 2013, 23 changed their sex (1N→F, 12M/F→F, 3M/F→M, 4M→M/F, 1M→N and 2F→M/F). In the 4th year (2014) of observation, 26 changed their behavior (5F→N, 14F→M/F, 3MF→M, 3M→M/F and 1N→M) and 16 remained unchanged (Table 2).

For Site IV: Kandyali forest

The Kandyali forest at 2520 m elevation under Kotgarh Forest division covering 22 ha area consists of pure crop of

Table 3. Year wise changes observed in reproductive behavior of trees at 4 sites

Location	Shimla				Nankhari				Sarain				Kandyali			
	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014
M	12	6	7	5	16	10	6	9	9	8	6	7	13	6	5	3
F	8	7	12	20	17	21	30	12	19	15	26	7	12	10	22	22
M/F	14	20	10	6	14	11	9	20	14	18	9	23	14	21	11	14
N	0	1	5	3	0	5	2	6	0	1	1	5	0	2	1	0
T	34	34	34	34	47	47	47	47	42	42	42	42	39	39	39	39

M, Male; F, Female; M/F, Monoecious; N, Neutral; T, Total trees.

deodar. In the population 39 trees were selected during 2011, of which 13 were male, 12 female and 14 monoecious. The observations on reproductive behavior during 2012, recorded 6 male, 10 female, 21 monoecious and 2 neutral trees. In the 3rd year (2013), 5 male, 22 female, 11 monoecious and 1 neutral tree were recorded. In 2014, 3 male, 22 female and 14 monoecious were recorded (Table 3).

Out of 39 trees selected in the year 2011, 11 changed their behavior (5M →M/F, 2M→N, 3F→M/F and 1M/F→F). In 2013, 19 changed their behavior (12M/F →F, 3M→M/F, 1N→M/F, 1N→M, 1M/F→M and 1M/F→N) and 20 remained unchanged. In 4th year (2014) 18 changed their behavior (7F→M/F, 6M/F→F, 1M→F, 1F→M, 1N→F and 2M→M/F) and 21 remained unchanged (Table 2).

Year wise per cent distribution of sexual behavior

The perusal of Table 4 showed a constant decline for the percentage of male trees at Site 4 whereas for Site 2 and Site 3 the percentage of male trees decreased from 2011 to 2013 and then increased. At site 1 the male trees showed decline and increase during alternate years.

The percentage of monoecious trees was comparatively higher at Site 1 during 2011 which further increased to 58.82 per cent during 2012 after which it recorded a decline for the next two years. At Site 2 the monoecious trees decreased consistently for three years and increased and reached 42.6 per cent during 2014. At Site 3 the monoecious trees recorded increase for all the years except for the year 2013 in which the percentage of monoecious trees dropped down to 21.4 % from 42.9 per cent recorded during 2012. The percentage of monoecious tree was equal

(35.9%) during 2011 and 2014 which increased to 53.8 % during 2012 and declined to 28.2 per cent during 2013.

The percentage of female trees at Site 1 recorded a decline during 2012 but increased substantially during next two years with maximum (64.7%) recorded during 2014. Site 2 recorded a constant increase in the percentage of female trees for consecutive two years with maximum (63.8%) recorded during 2013 followed by a decline (25.5%) during 2014. The Site 3 recorded maximum percentage (61.9%) during 2013 followed by a decline (16.7 %) during 2013. Site 4 recorded a decline in the percentage of female trees during 2012 and produced maximum number of female trees (56.4%) consecutively during 2013 and 2014.

As the trees remaining or becoming vegetative after reproduction was known at the time marking of trees during 2011, hence the trees in vegetative state could only be record from 2012 onwards. During 2012 at Site 1 only 2.94 percent were recorded as neutral which increased to 14.7 per cent during 2013 and declines during the observations recorded during 2014 to 8.82 per cent. At Site 2 the percentage of neutral trees was recorded as 10.6, 4.25 and 12.8 per cent for the years 2012, 2013 and 2014 respectively. No change in the percentage of neutral trees (2.38%) was recorded for the year 2012 and 2013 which increased to 11.9 per cent during 2014 at Site 3. At Site 4 the percentage of neutral trees recorded as 5.12 % during 2012 decreased to 2.56 % during 2013. In the year 2014 no tree was recorded to be in vegetative state as all trees produced either male or female cones.

Year and site wise percentage of female trees

The year wise distribution pattern of the sexual behavior of the species at four different sites given in Fig. 1 indicates good seed year of a particular forest. It is evident from the

Table 4. Year wise percent distribution of reproductive behavior at four sites

Location	Shimla				Nankhari				Sarain				Kandyali			
	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014
% M	35.29	17.64	20.6	14.7	34	21.3	12.8	19.1	21.4	19.04	14.3	16.7	33.3	15.4	12.8	7.69
% F	23.52	20.58	35.3	64.7	36.2	44.7	63.8	25.5	45.2	35.7	61.9	16.7	30.8	25.6	56.4	56.4
% M/F	41.17	58.82	29.4	11.8	29.8	23.4	19.1	42.6	33.3	42.9	21.4	54.8	35.9	53.8	28.2	35.9
% N	0	2.94	14.7	8.82	0	10.6	4.25	12.8	0	2.38	2.38	11.9	0	5.12	2.56	0

M, Male; F, Female; M/F, Monoecious; N, Neutral.

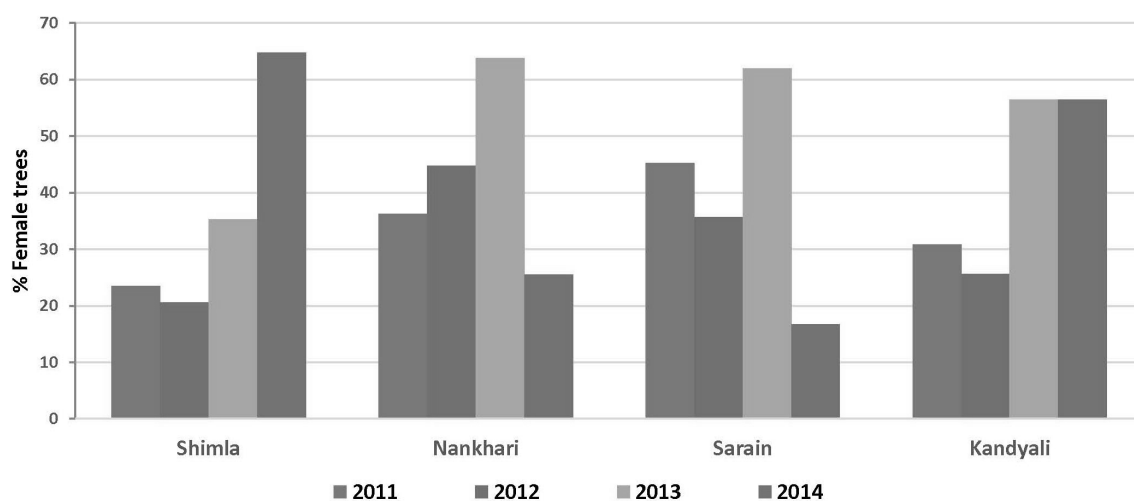


Fig. 1. Year and sitewise changes in the % of female trees. The total number of female trees changed every year at all locations except Kandyali for the years 2013 and 2014. All sites showed a declining trend in production of female cones after reaching maximum and the production of female cones (seed year) is cyc.

Fig. 1 that the number of female trees at Site 1 recorded a decline (20.58%) during 2012 and then increased from 35.3% during 2013 to 64.7% in 2014. However, a constant increase from the year 2011 to 2013 was recorded at Site 2 with maximum (63.8%) recorded during 2013 which was followed by a decline (25.5%) during 2014. The Site 3 recorded maximum number of female trees (61.9%) during 2013 followed by a decline (16.7%) during 2014. An interesting trend was observed at Site 4 where two consecutive years (2013 and 2014) recorded maximum (56.4%) number of female trees. As the change in the sexual behaviour of the trees was not known in the base year of the study, hence observations on neutrality was not recorded. The percentage of neutral trees was observed during all the remaining three years except for Site 4 where during 2014 all trees produced cones.

Discussion

In order to confirm the change observed for the trees marked as 'Seed Bearers' in Seed Production Areas (SPAs), trees of flowering/fruitlet stage were observed for four years at four different sites. As elucidated in the results, the species have been found to change its reproductive behavior at all four sites. The results of the study showed that the reproductive behavior of the trees was not definite as trees changed their cone producing nature while some retained it

for longer duration and it remained unpredictable what sexual behavior any tree will show in the year ahead?

It is evident from the results of the four sites that the good seed year for the sites varied. It was found to be cyclic wherein the number of trees producing female cones increased in the population in a particular year and then changed their sexual behaviour in the next year. This cyclic movement has been found to decide the seed year of any forest. The lean years may produce large number of pollens which may be the part of wind dispersal for avoiding inbreeding depressions in other nearby forests.

The observations recorded on 162 trees at four different sites for four years in *Cedrus deodara* made it evident that the reproductive behavior in the species is not definite and is influenced either by the seed cycle of the forest or the environment or may have the possibility of genetic control over the reproductive capacity.

Conclusion

Cedrus deodara does not have any definite pattern of change/retention of sex characters and requires further investigations as to what triggers the change or to predict the behavior of trees.

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