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Assessment of tree mortality and post fire regeneration pattern in Binsar Wildlife Sanctuary, Kumaon Himalaya

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Abstract: After a severe summer forest fires in 1995 in part of Binsar Wildlife Sanctuary, tree mortality was quantified during post monsoon season of 1996 and pre-monsoon of 1998. A total of 100 sampling points were established randomly in severely affected oak forest for vegetation sampling. Tree layer was quantified in 10 m radius circular plots, while seedlings and saplings of various tree species were counted in 3 m radius concentric plots. Out of 1944 individuals of different tree species, 677 (34.8%) individuals were found dead. The mortality was significantly higher than expected in *Viburnum cotinifolium* and *Cornus macrophyla* and significantly less than expected in *Rhododendron arboreum* and *Lyonia ovalifolia* whereas mortality in other species was in proportion to their availability. The mortality was significantly higher than expected in < 50 cm girth class. A total of 184 and 382 saplings were counted during 1996 and 1998 respectively while the corresponding seedling numbers were 465 and 601. The saplings of *Quercus leucotrichophora* and *Lyonia ovalifolia* increased significantly from 1996 to 1998. While among seedlings the number of *Quercus leucotrichophora* and *Viburnum* sp. increased significantly from 1996 to 1998. The post fire species composition at seedling and sapling stage does not indicate any substantial increase in contribution of *Pinus roxburghii* as a consequence of fire. However, change in contribution of other top canopy and understorey species is expected due to differential regeneration pattern of these species.

Resumen: Después de fuegos forestales severos ocurridos en el verano de 1995 en parte del Santuario para la Vida Silvestre de Binsar, la mortalidad de árboles fue cuantificada durante la estación postmonzónica de 1996 y el pre-monzón de 1998. Para el muestreo de la vegetación se estableció aleatoriamente un total de 100 puntos de muestreo en bosque de encino severamente afectado. El estrato arbóreo fue cuantificado en parcelas circulares de 10 m de radio, mientras que las plántulas y los juveniles de varias especies arbóreas fueron contados en parcelas concéntricas de 3 m de radio. De un total de 1944 individuos de diferentes especies arbóreas, 677 (34.8%) fueron hallados muertos. La mortalidad fue significativamente más alta que la esperada al azar en *Viburnum cotinifolium* y *Cornus macrophyla*, y significativamente menor en *Rhododendron arboreum* y *Lyonia ovalifolia*, mientras que la mortalidad en otras especies fue proporcional a su disponibilidad. La mortalidad fue significativamente mayor que la esperada en la clase de perímetro < 50 cm. Un total de 184 y 382 juveniles fueron registrados durante 1996 y 1998, respectivamente, mientras que los números correspondientes de plántulas fueron 465 y 601. Los juveniles de *Quercus leucotrichophora* y *Lyonia ovalifolia* incrementaron significativamente de 1996 a 1998. Las abundancias de las plántulas de *Quercus leucotrichophora* y *Viburnum* sp. aumentaron significativamente de 1996 a 1998. La composición de especies posterior al fuego en las etapas de plántula y juvenil no indica que haya un incremento sustancial en la contribución de *Pinus roxburghii* como consecuencia del fuego. Sin embargo, se espera que haya cambios en la contribución de otras especies del dosel superior y del sotobosque debido al patrón diferencial de regeneración de estas especies.

Resumo: Depois dos severos fogos florestais do verão de 1995 em parte do Santuário de Vida Selvagem de Binsar a mortalidade arbórea foi quantificada durante a estação de pos-monção de 1998 e da pré-monção de 1998. Para amostragem da vegetação foram estabelecidos 100 pontos casualizados na floresta de carvalhos severamente afectada. O estrato arbóreo foi quantificado usando um dispositivo de parcelas circulares de 10 m de raio, enquanto que as plântulas e o nascedio das várias espécies arbóreas foram contadas no interior de parcelas concêntricas de 3 metros de raio. Dos 1944 indivíduos das diferentes espécies arbóreas, 677 (34,8%) encontravam-se mortas. A mortalidade foi significativamente mais elevada do que a esperada para a *Viburnum cotinifolium* e *Cornus macrophyla* e significativamente menor do que a esperada para a *Rhododendron arboreum* e *Lyonia ovalifolia* enquanto a mortalidade das outras eram proporcionais à sua disponibilidade. A mortalidade foi significativamente mais alta do que a esperada na classe de perímetro <50 cm. Um total de 184 e 382 pequenas plantas foram contadas durante 1996 e 1998, respectivamente, enquanto

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os correspondentes números de plântulas foram de 464 e 601. O nascedio de *Quercus leucotrichophora* e *Lyonia ovalifolia* aumentou, significativamente, de 1996 a 1998. Entre as plântulas o número de *Quercus leucotrichophora* e *Viburnum* sp. aumentou significativamente entre 1996 e 1998. A composição das espécies pós-fogo nos estágios de plântulas e nascedio não indicam qualquer aumento substancial na contribuição da *Pinus roxburghii* em consequência do fogo. Contudo, são esperadas mudanças na contribuição de outras espécies dominantes e dominadas devidas ao padrão de regeneração diferencial destas espécies.

Key words: Binsar Wildlife Sanctuary, forest fire, oak forest, tree mortality.

Introduction

Forest fire is one of the important and commonly occurring phenomenon in forested areas of Kumaon Himalaya during the dry months (May–June) of the year. Temperate forests and woodlands, especially south facing grassy slopes in the western Himalayas, are also burnt intentionally by the local people during winter season to promote grass growth. The fire, as such, influences the structure and process of a natural forest ecosystem. The periodicity, spatial coverage and severity of such fires vary temporally and these fires are generally associated with excessive accumulation of pine needles and leaf litter in pine and oak forests in Kumaon (Sharma & Rekhari 1997). Inspite of ample information available on structure and functioning of pine and oak forest ecosystems in Kumaon, very little information is available on impact of repeated fires on pine and oak forests. It is generally believed that disturbance create conducive conditions for chir pine (*Pinus roxburghii* Sarg.) to colonise and grow at the expense of banj oak (*Quercus leucotrichophora* A. Camus) in Kumaon (Rikhari *et al.* 1989).

The widespread forest fires of 1992 caused reduction of crown cover about 4.8% at Binsar Wildlife Sanctuary (BWS) in Kumaon (Rikhari & Palni 1999). Subsequently, the widespread severe forest fires of summer of 1995 throughout the forested areas in Kumaon, caused large-scale destruction of oak forest in the BWS. We considered different burnt patches of oak forest to carry out a preliminary survey of fire-affected areas in post-monsoon 1996. The selected stands were affected with ground fire, and the intensity of fire was so high that it also affected the canopy layer. The survey was carried out to investigate the tree species mortality, and post fire regeneration pattern, which could be used for long term monitoring of changes in species composition of certain key species such as *Quercus* spp. at selected time intervals.

Study area

The Binsar Wildlife Sanctuary–BWS (29° 39′–29° 44′ N lat and 79° 41′–79° 49′ E long) covers an area about 46 km² and is situated 30 km east of Almora town (Fig. 1). Declared as Reserve Forest in 1880, it was upgraded as Wildlife sanctuary in 1988. The rugged terrain and variation in the altitude (1200 to 2440 m above the mean sea level) has resulted into diversified floral composition. While the higher elevation sites are dominated by *Quercus* species, the low altitude sites are dominated by chir pine. In general three different forest types viz. oak-forest, oak mix and chir pine forests are frequent in the sanctuary.

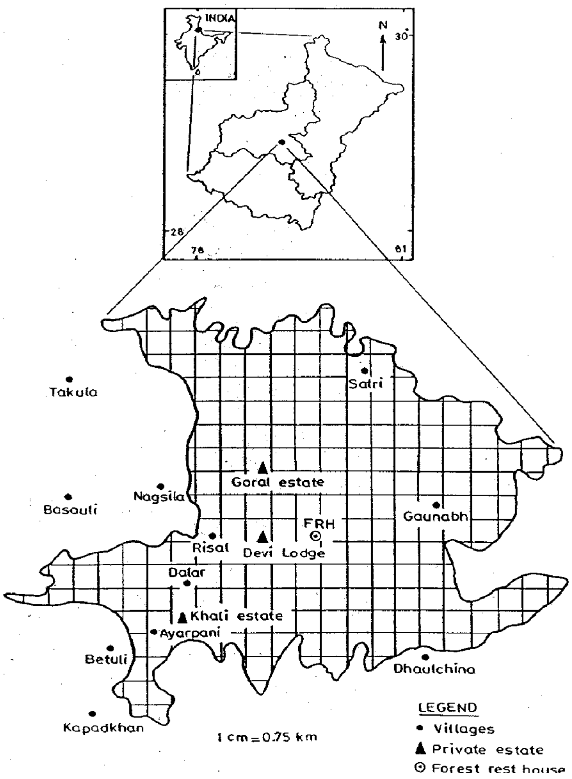

Fig. 1. Map of the Binsar Wildlife Sanctuary.

Methodology

Data collection

To understand the effect of forest fire on woody vegetation, sampling was carried out in a burnt oak patch of BWS and information generated from 100 randomly located sampling points. Sampling was conducted during post-monsoon 1996, further to see changes in regenerating tree species the data were collected during pre-monsoon 1998.

A 10 m radius circular plot was established at each sampling point and trees falling within the plot were enumerated by species. Girth at breast height (GBH) was recorded for each tree. The status (in terms of dead or alive) of each individual tree after the fire was recorded. To understand the effect of forest fire on the regeneration of tree species, sapling and seedlings were also enumerated in a 3 m circular sub-plot laid at the centre of the main plot. Plants up to the height of 0.5 m, including coppice, were classified as seedlings and above 0.5 m in height and less than 30 cm in GBH were considered as saplings.

Data analysis

Percent mortality to the trees caused by fire was calculated among various tree species and girth class categories. Simultaneous 95% Bonferroni confidence intervals was calculated following Byers *et al.* (1984) to find out the significant difference in mortality among various tree species and girth class categories. The formula for calculating 95% Bonferroni confidence interval is as follows:

$$P_{ie}–Z_{\alpha/2k}\sqrt{P_{ie}(1–P_{ie})/n} \leq P_{ie} \leq P_{ie}+ Z_{\alpha/2k}\sqrt{P_{ie}(1–P_{ie})/n}$$

Where, P_{ie} is the observed proportional mortality in each species and $Z_{\alpha/2k}$ is the upper standard normal table value corresponding to a probability tail area of $_{\alpha/2k}$ and n is total number of trees recorded dead. For each species its proportional availability (P_{io}) in the sample was calculated by dividing its total number (n) from that of total number of all individuals (N) sampled for all species (P_{io}= n/∑N). Mortality was significantly greater or less than expected when P_{io} lay out side the 95% confidence limits constructed for proportional mortality (P_{ie}) which was calculated by dividing number of individuals found dead (d) by the total number of dead individuals (D) of all species (P_{ie}= d/∑D).

To find out the regeneration pattern, percentage of saplings and seedlings were calculated for post monsoon 1996 and pre monsoon 1998. The t-test was used to find out significant difference between mean number of seedlings and saplings for each species between 1996 and 1998 in burnt oak patches.

Results

Mortality in tree species

Table 1 provides the data on tree mortality. A total of 1944 trees belonging to 16 species were

Table 1. Proportion available (P_{io}), proportion dead (P_{ie}) and 95% Bonferroni confidence limits for different plant species in Binsar. (0 = Mortality proportional to availability, - = Significantly less mortality. + = Significantly more mortality).

Tree species	Total	P_{io}	Dead trees	P_{ie} trees	% dead trees	Relative for P_{ie}	%Confidence limits	Mortality ratings
Quercus leucotrichophora	853	0.438	329	0.485	38.5	16.9	0.43≤p≤0.54	0
Rhododendron arboreum	515	0.244	100	0.147	19.4	5.1	0.11≤p≤0.19	-
Lyonia ovalifolia	342	0.175	118	0.277	34.5	6.0	-0.0029≤p≤0.0123	-
Pinus roxburghii	78	0.04	30	0.044	38.4	1.5	0.0361≤p≤0.05188	0
Viburnum cotinifolium	62	0.03	50	0.073	80.6	2.5	0.04401≤p≤0.10199	+
Quercus floribunda	26	0.013	10	0.014	38.4	0.5	0.001≤p≤0.027	0
Swida oblonga	18	0.009	15	0.022	83.3	0.7	0.0057≤p≤0.0383	0
Alnus nepalensis	15	0.007	6	0.008	40.0	0.30	-0.0016≤p≤0.0192	0
Stranvaesia nussia	13	0.006	8	0.011	61.5	0.41	-0.0004≤p≤0.0238	0
Myrica esculenta	9	0.004	3	0.004	33.3	0.15	0.00303≤p≤0.011034	0
Cedrus deodara	6	0.003	6	0.008	100	0.30	-0.0019≤p≤0.0179	0
Cornus macrophyla	2	0.001	1	0.0047	50	0.50	0.2272≤p≤0.3268	+
Pyrus pashia	2	0.001	1	0.004	50	0.05	0.00292≤p≤0.01232	0
Toona ciliata	1	0.005	0	0	0	0	0	
Symplocos theifolia	1	0.005	0	0	0	0	0	
Euonymus tingens	1	0.0005	0	0	0	0	0	
Total	1944		677					

sampled, of which 677 (34.8%) trees were found dead due to fire. Percent tree mortality was highest in *Cedrus deodara* Roxb. (100%), *Swida oblonga* Wallich. (83.3%), *Viburnum cotinifolium* (80.6%) and *Stranvaesia nussia* D. Don (61.5%). The relative percent mortality was, however, highest in *Quercus leucotrichophora* (16.9%), followed by *Lyoina ovalifolia* Wallich (6.0%), *Rhododendron arboreum* Smith (5.1%) and *V. cotinifolium* (2.5%). The individual tree mortality differed among species and it was significantly higher than expected in *Viburnum cotinifolium* and *Cornus macrophyla* Wallich. On the contrary, it was significantly less than expected in *Rhododendron arboreum* and *Lyonia ovalifolia.* The mortality in rest of the species was in proportion to their availability. The overall tree mortality differed significantly between different girth classes (Fig. 2). It was maximum (21.35%) in girth class ≤50 cm, which was significantly more than expected. The mortality was significantly less than the expected in girth classes ranging between 51 and 200 cm while no mortality was recorded in >200 cm girth class.

Table 2 provides mortality ratings among various girth classes in seven selected species. The mortality was significantly more than expected in *Q. leucotrichophora* in girth classes ≤ 50 cm and 151–200 cm, while it was less than expected in girth class 101–150 cm. Mortality in *R. arboreum* was significantly more than expected in girth class ≤ 50 cm while it was significantly less than expected in girth classes 101–150 cm and 151–200 cm. In case of *L. ovalifolia,* mortality was more than expected in girth classes ≤50 cm and 151–200 cm whereas it was less than expected in 51–100 cm. Tree mortality in various girth classes of *S. oblonga, V. cotinifolium, P. roxburghii* and *Q. floribunda* was in proportion to the availability.

Saplings

Table 3 presents number of saplings and seedlings of different species, their percentage and diversity values during 1996 and 1998. A total of 155 saplings of different tree species were recorded during 1996, which increased to 382 in 1998. Correspondingly the diversity of saplings also increased marginally from 0.59 in 1996 to 0.65 in 1998. Only *S. oblonga, L. ovalifolia* and *Q. leucotrichophora* had more than 10 individuals. There were changes in the proportion of saplings of various tree species between 1996 and 1998. There was a significant increase in the proportion of saplings of *L. ovalifolia* from 23.8% to 30.6% (t=4.7, d.f.=198, p<0.001) and *Q. leucotrichophora* from 7.09% to 16.4% (t=3.3, df=198, p<0.001). On the contrary, there was a significant reduction in the proportion of *S. oblonga* from 60% to 40% (t=2.2, d.f=198, p<0.025). Changes in the proportion of saplings of other species were not significant.

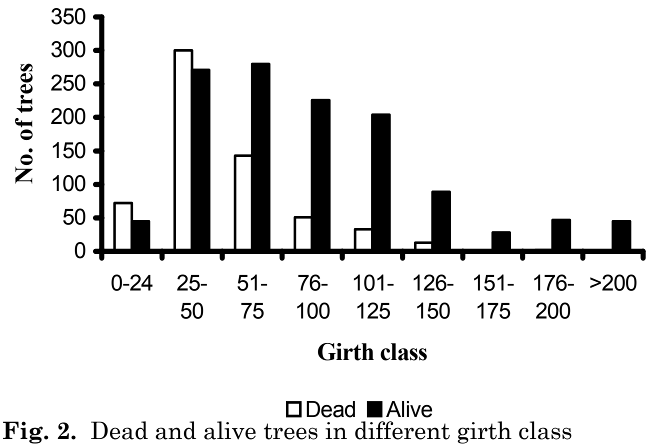

Fig. 2. Dead and alive trees in different girth class during post monsoon 1996.

Seedlings

A total of 465 seedlings belonging to 17 tree species and 601 seedlings belonging to 13 tree species were recorded during 1996 and 1998 (Table 3). 30.7% of seedlings belonged to *S. oblonga*, followed by *Q. leucotrichophora* (28.6%), *R. arboreum* (10.75%) and *L. ovalifolia* (9.03%) during 1996, while during 1998 maximum number of seedlings found were of *Q. leucotrichophora* (36.1%), followed by *S. oblonga* (21.6%), *R. arboreum* (11.14%) and *V. cotinifolium* (8.32%). *Q. leucotrichophora* and Q. *floribunda* showed increase in their proportion from 1996 to 1998, but the increase was significant for *Q. leucotrichophora* only (t=3.152, d.f. = 198 p<0.002). Similarly proportions of *R. arboreum* and *V. mullah* increased from 1996 to 1998 but the increase was significant for *V. mullah* only (t= –3.710, d.f. =198, p<0.001). The proportion *of S. oblonga, L. ovalifolia* and *P. roxburghii* decreased from 1996 to 1998 but the differences were not significant statistically (P>0.05).

Discussion

The fire in Binsar caused mortality upto 34% in mature trees. This suggests the high intensity of fire. In a mountainous terrain trees on slopes are more susceptible, as fire sweeping through slopes can burn a tree at different canopy position and elevations, specially the fire which starts from the lower end of the slope and goes towards higher end. Smaller trees on slopes usually get engulfed even by low surface fire and have little chances of survival. The chances of survival also

Table 2. Proportion available (P_{io}) proportion dead (P_{ie}) and 95% Bonferroni confidence limits for six dominant tree species in different girth classes during post-monsoon 1996. (0= Mortality proportional to availability,= Significantly less mortality.+= Significantly more mortality).

Girth Class	Total trees	P_{io}	Dead trees	P_{ie}	Confidence limits for P_{ie}	Mortality ratings
Quercus leucotrichophora						
< 50	302	0.35	185	0.56	0.512≤P≤0.607	+
51-100	372	0.43	112	0.34	0.275≤P≤0.465	0
101-150	145	0.16	30	0.09	0.051≤P≤0.129	-
151-200	23	0.026	2	0.06	0.027≤P≤0.090	+
> 200	11	0.01	0	0.00	0	0
Rhododendron arboretum						
< 50	127	0.24	56	0.56	0.436≤P≤0.684	+
51-100	174	0.30	38	0.38	0.258≤P≤0.501	0
101-150	145	0.25	5	0.05	0.004≤P≤0.104	-
151-200	41	0.07	1	0.01	0.014≤P≤ 0.0337	-
> 200	28	0.04	0	0.00	0	0
Swida oblonga						
<50	15	0.83	12	0.80	-0.625≤P≤0.975	0
51-100	2	0.11	2	0.13	-0.087≤P≤.0.347	0
101-150	1	0.05	1	0.06	-0.093≤P≤0.213	0
151-200	0	0.00	0	0	0	0
> 200	0	0.00	0	0	0	0
Lyonia ovalifolia						
< 50	234	0.68	99	0.83	0.743≤P≤0.916	+
51-100	96	0.28	15	0.127	0.051≤P≤0.203	-
101-150	11	0.032	3	0.025	-0.010≤P≤0.060	0
151-200	1	0.0029	1	0.084	0.020≤P≤0.147	+
> 200	0	0	0	0	0	0
Viburnum cotinifolium						
<50	47	0.75	32	0.74	0.585≤P≤0.895	0
51-100	13	0.209	12	0.24	0.090≤P≤0.390	0
101-150	2	0.032	1	0.02	-0.029≤P≤ 0.069	0
151-200	0	0	0	0.00	0	0
>200	0	0	0	0.00	0	0
Pinus roxburghii						
< 50	20	0.26	12	0.40	0.180≤P≤0.62	
51-100	30	0.39	13	0.43	0.205≤P≤0.655	0
101-150	19	0.25	03	0.16	-0.007≤P≤0.377	0
151-200	7	0.09	0	0.00	0	0
> 200	0	0	0	0.00	0	0
Quercus floribunda						
< 50	9	0.346	5	0.5	0.341≤P≤0.658	0
51-100	16	0.615	5	0.5	0.341≤P≤0.658	0
101-150	1	0.038	0	0.0	0	0
151-200	0	0.00	0	0.0	0	0
> 200	0	0.00	0	0.0	0	0

depend on the resistance of trees to fire which varies greatly among species, depending upon tree size, physiological condition, site quality and season of burning (Kalabokidis & Wakimoto 1992). The features such as thickness and moisture contents of the bark are considered as the attributes that best characterise a species adaptation to fire (Martin 1989). It follows that smaller individuals are at greater risk of mortality due to their thin bark as compared to larger individuals. This was the case in present study where a significantly more mortality in < 50 cm girth class was recorded. *V. cotinifolium* and *S. oblonga* suffered high level of mortality (> 80%) since majority of individuals were in < 50 cm girth class. *L. ovalifolia* which had > 68% individuals in < 50 cm girth class had significantly more mortality. While the girth class 51–100, however, suffered significantly lower mortality than expected, there were 96 individuals out of which 15 were dead. *R. arboreum* which suffered only 19% mortality

Table 3. Number of tree species saplings, seedlings during 1996 and 1998.

Tree species	Sapling		Seedlings	
	1996	1998	1996	1998
	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon
Swida oblonga	93	155	143	130
Lyonia ovalifolia	37	117	42	37
Quercus leucotrichophora	11	63	133	217
Alnus nepalensis	4	2	3	0
Euonymus tingens	4	2	0	0
Lindera pulcherima	2	1	7	4
Myrica esculenta	2	6	10	5
Pyrus pashia	1	9	0	17
Viburnum mullah	1	16	7	50
Litsea umbrossa	0	5	1	11
Rhododendron arboreum	0	6	50	67
Pinus roxburghii	0	0	39	28
Euonymus sp.	0	0	13	0
Stravessia nussia	0	0	5	0
Quercus floribunda	0	0	4	16
Toona ciliata	0	0	3	0
Persia duthi	0	0	2	0
Albizia chinensis	0	0	2	0
Acer sp.	0	0	1	0
Pyrus sp.	0	0	0	18
Viburnum cotinifolium	0	0	0	1
Total	155	282	465	601
Diversity	0.597	0.653	0.835	0.836

stands out as the most fire resistant species as compared to *Quercus* spp. (38% mortality in each species) and *P. roxburghii* (38%) the latter species being regarded as most fire resistant.

The fire changes the environment of forest floor from litter layer to clear soil, rich in readily available minerals. It also changes vertical structure of forest due to opening up of canopy allowing more solar radiation to penetrate the forest floor and thereby increasing soil temperature. Such conditions promote establishment and growth of tree seedlings (Chapin *et al.* 1988). The combined density of seedlings and saplings in burnt patch was 2295 and 3477 individuals ha^{-1} during 1996 and 1998 respectively. The density in burnt oak patch, even after two years, is less than the density in unburnt oak patch (4639 individuals ha^{-1}) of Binsar (Ilyas 2001). This suggests that fire did not enhance the regeneration of seedlings and saplings in Binsar as one would expect. Interestingly 7 species at seedling stage has disappeared after 1996, but two new species have appeared in sampling layer, also 3 in seedling stage.

The tree layer composition in sampled stand is numerically dominated by *Q. leucotrichophora* (44%), *R. arboreum* (24%) and *L. ovalifolia* (17%). Other species which have >1% contribution in tree layer are *P. roxburghii* (4%), *V. cotinifolium* (3%) and *Q. floribunda* (1.3%). The postfire regeneration pattern of these species, though numerically not same as in tree layer, does not indicate any major change in species composition as there were 36% seedlings of *Q. leucotrichophora*, 11.1% seedlings of *R. arboreum*, 6.15% seedlings of *L. ovalifolia,* 8.3% seedlings of *V. cotinifolium* and 2.6% seedlings of *Q.floribunda* as compared to 4.6% seedlings of *P. roxburghii*. The immediate post fire regeneration pattern of different species, therefore, do not provide any substantial evidence that *P. roxburghii* has any better regeneration after fire in comparison to other species. In fact except for *L. ovalifolia*, seedlings of other species have shown definite increase from 1996 to 1998. On the contrary the contribution of *P. roxburghii* has decreased although not statistically. The other interesting species is *S. oblonga*, which has shown remarkable regeneration capacity after the fire, as there were 21% seedlings in 1998 despite the fact that its overall contribution in tree layer is only 0.9%. The species composition at sapling stage shows dominance of *S. oblonga* (40%), *L. ovalifolia* (31%), *Q. leucotrichophora* (16%) and *V. cotinifolium* (4.1%). Though the composition is not as per the tree layer or seedling layer in terms of contribution of *Quercus* species, there is complete absence of *P. roxburghii* and a very low contribution of *R. arboreum* (1.5%). It is, therefore, clear that after fire, *P. roxburghii* has not shown vigorous regeneration to pose a major threat to *Quercus* spp. which have substantial representation in seedling and sapling stage. However, in the long run *R. arboreum* is expected to loose its dominance in tree layer due to poor representation at sapling stage and moderate regeneration (11%) after fire. *L. ovalifolia* and *Q. leucotrichophora* having 17% and 43% (respectively) contribution in tree layer may maintain its dominance due to high abundance at sapling stage. Among small tree *S. oblanga* is expected to gain in medium canopy due to its excellent regeneration as well as very high representation at sapling stage.

Many of the observations pertaining to seedling and sapling layers may require a reassessment after suitable time interval (5–10 years). It is essential that changes in this particular oak stand in Binsar be tracked in future vis-à-vis survival of regenerating *P. roxburghii* seedlings.

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