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Regeneration status of tree species and survival of their seedlings in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India

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Abstract: The present investigation aimed to study the regeneration status of tree species and survival of naturally emerged seedlings along an altitudinal gradient in a protected area of Western Himalaya, India. A total of 44 tree species of 36 genera and 25 families were recorded from the study area. Regeneration status of species was determined based on population size of seedlings and saplings while seedling survival was determined by silver foil tagging method. Seedling density and Shannon-Wiener diversity index (H) ranged from 1670 to 7485 ind ha^{-1} and 1.91 to 3.32, respectively, while sapling density and Shannon-Wiener diversity index (H) varied from 1850 to 5600 ind ha^{-1} and 1.23 to 2.57 respectively. Although the majority (27 - 56 %) of species showed good regeneration, a good percentage (19 - 45 %) of tree species showed poor regeneration while fair regeneration was shown by 7 - 30 % of species and new regeneration by 0 - 14 %. Diameter density distribution showed that lower diameter classes have the highest frequency with a gradual decrease in the number of individuals in the higher classes resulting in the formation of an inverse-J curve that is considered to be an indication of good regeneration status. Survival of seedlings in different forests varied from 0 - 88 % (mortality varied from 12 - 100 %). Natural calamities and anthropogenic disturbances are responsible for the high mortality of seedlings. A few species showed discontinuous regeneration due to which it is expected that these tree species although dominant at present may be at risk in future.

Key words: Anthropogenic disturbances, population structure, regeneration status, seedling survival, western Himalaya,.

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Introduction

Regeneration is a key process for the existence of species in a community under varied environmental conditions. Regeneration is a critical part of forest management, because it maintains the desired species composition and stocking after various disturbances (Khumbongmayum *et al.* 2005). The potential regenerative status of tree species often depicts the future composition of forests within a stand in space and time (Henle *et al.* 2004). Regeneration of any species is confined to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographic distribution (Grubb 1977). The successful regeneration of a tree species depends on the ability of its seedlings and saplings to survive and grow (Good & Good 1972). Successful regeneration is perhaps the single most important step towards achieving long term sustainability of

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forests (Saikia & Khan 2013).

The ratio of various age groups in a population determines the reproductive status of the population and indicates its future course (Odum 1971). The population structure characterised by the presence of sufficient number of seedlings, saplings and young trees depicts satisfactory regeneration behaviour, inadequate number of seedlings and saplings of tree species in a forest indicates poor regeneration, while complete absence of seedlings and saplings of tree species in a forest indicates no regeneration (Saxena & Singh 1984). Regeneration of tree species and survival and growth of their seedlings depend upon the interactive influence of biotic and abiotic factors of the forest environment (Khan *et al.* 1986). Tree seedling recruitment is often limited by low and uncertain seed supply and establishment. It is also limited by lack of suitable microsites and factors, which affect early seedling growth and mortality (Clark *et al.* 1999). Micro-environmental factors vary with seasonal changes, which affect the trees growth stage *i.e.* seedling, sapling, coppice and young trees that maintain the population structure (Rahman *et al*. 2011).

Himalayan moist temperate forests represent centres of high species diversity. Lack of sufficient regeneration is a major problem of mountain forests (Krauchii *et al.* 2000). Kedarnath Wildlife Sanctuary (KWLS) is one of the biodiversity-rich sites of the Indian Himalayan Region (IHR), located in Western Himalaya; but unfortunately during the last decade the vegetation of this area has been degraded largely because of human disturbances. An increasing interest in the development and management of the forests gives rise to the need to understand the regeneration process that ensures maintenance of the community structure and ecosystem stability. An understanding of the processes that affect regeneration of forest species is of crucial importance to both ecologists and forest managers (Slik *et al.* 2003). The present study was carried out to investigate the regeneration status of tree species and survival of their naturally emerged seedlings in KWLS and its adjoining areas. This study may provide some insight in the interpretation of future composition of the forests in this part of Western Himalaya.

Materials and methods

Study area

The study area lies in the sub-montane, montane and subalpine zones of Garhwal Himalaya, India. The KWLS is one of the largest protected areas extending to 975 km^2 of districts Chamoli and Rudraprayag of Uttarakhand between 30° 25' - 30° 41' N, 78° 55' - 79° 22' E in the Garhwal region of Greater Himalaya and falls under the IUCN management category IV (Managed Nature Reserve). The sanctuary lies in the upper catchment of the Alaknanda and Mandakini Rivers, two major tributaries of the Ganges. The present study was carried out at three different altitudes of KWLS in Rudraprayag district. After a reconnaissance survey, three sites at different altitudes - lower (Kund, 900 - 1200 m asl), middle (Phata, 1650 - 2000 m asl) and higher (Triyuginarayan, 2250 - 2600 m asl), were selected and from each of these sites two forests (sub-sites) were selected. Hence a total of six forests, two from each altitudinal range, were investigated for studying the regeneration status of tree species in this part of KWLS (Table 1). Forests of higher altitude (Triyuginarayan) form the core zone of KWLS, those of middle altitude (Phata) form its fringe areas, while those at lower altitude (Kund) come under the adjoining areas of KWLS.

The studied forests were named after adjacent villages. The climate in the study areas is divisible into four seasons: summer (May-July), rainy (mid July-September), winter (October-January) and spring (February-April). The rainfall pattern in the region is largely governed by the monsoon rains (July-September), which account for about 60 - 80 % of the total annual rainfall. However, at higher altitudes precipitation is almost a daily routine. The soil types found in the region are podozolic. Soil texture of the study area is predominantly sandy loam and sandy clay loam whereas soil colour varies from dark brown to black. Soils are generally gravelly and large boulders are common in the area (Malik 2014).

Methodology

Vegetation analysis

The analysis of woody species was carried out by placing random sampling plots (quadrats) as per Mishra (1968). Trees (≥ 30 cm dbh) were analysed by placing twenty 10 m × 10 m sized quadrats and nested within each such quadrat two plots of 5 m × 5 m were used to enumerate shrubs. Woody vegetation was analysed for species richness, density, diversity and total basal cover at the six forest stands following standard methods (Curtis & Mclntosh 1950; Phillips 1959). Tree

Table 1. Details of studied forests/Sites.

Site/Sub-sites	Elevation (m asl)	Geo-coordinates	Aspect	Slope
Site 1 (Kund), Adjoining area of KWLS	900-1200			
Barmadi Forest (BR)	900-1100	30^{0}30'02.91N, 079^{0}05'22.12E	NWW	30^o ± 10^o
Pathali Forest (PT)	1000-1150	30^{0}30'00.30N,079^{0}05'25.73E	SE	23^o ± 8^o
Site 2 (Phata), Fringe area of KWLS	1650-2000			
Kukrani Band Forest (KB)	1650-1750	30^0 35'07.75N, 079^{0}12'26.85N	SW	15^o ± 8^o
Jamu Forest (JM)	1850-1950	30^{0}34'18.87N, 079^{0}02'10.84E	S	16^o ± 9^o
Site 3 (Triyuginarayan), Core zone of KWLS	2250-2600			
Triyuginarayan Forest 1 (TN1)	2300-2600	30^{0}38'04.02N, 078^{0}58'49.90E	SSW	33^o ± 6^o
Triyuginarayan Forest 2 (TN2)	2250-2400	30^{0}38'47.11N, 078^{0}58'4.75E	WWS	30^o ± 5^o

species diversity was calculated using the Shannon-Wiener index (Shannon & Weaver 1963). Species richness indices were calculated following standard methods *viz.,* Margalef (1958) and Menheink (1964). Concentration of dominance (Cd) was calculated as per Simpson (1949). Species richness (SR) was simply taken as a count of total number of species in a particular forest.

Population structure

Population structure and survival of naturally emerged seedlings of all tree species reported in each forest was studied during 2012 - 2013 using the quadrat method following Khan *et al.* (1986). In each of the selected forests twenty permanent quadrats of 10 m × 10 m size were established. Species were identified and density of all the individuals of seedlings (< 20 cm height), saplings (< 30 cm collar circumference and > 20 cm in height) and trees (≥ 30 cm dbh) were determined. Regeneration status of species was determined based on population size of seedlings and saplings (Khan *et al.* 1987) as:

(i) good regeneration if seedlings > saplings > adults;

(ii) fair regeneration if seedlings > or ≤ saplings ≤ adults;

(iii) poor regeneration if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults).

(iv) no regeneration if a species is present only in adult form.

(v) new regeneration if the species has no adults but only seedlings or saplings.

For studying seedling survival, the available seedlings (a maximum of 50 of each tree) were tagged with aluminium foil (Deb & Sundriyal 2008; Khan *et al.* 1986). The selected seedlings were of uniform growth and healthy in appearance without any evidence of damage or injury. Initially the seedlings were enumerated and tagged in the month of April, 2012. Survival of the tagged seedlings was studied at bimonthly intervals in the selected forests over a period of one year. Hence the census was repeated in July 2012, October 2012, January 2013, and April 2013 to record the survival and mortality of tagged seedlings. Further, the densities of the trees were divided into successive diameter classes *i.e.*, 0 - 30 cm, 31 - 60 cm, 61 - 90 cm, and so on to determine the regeneration status and population structure of a particular forest (and individual tree species). Further, a single tailed Carl-Pearson correlation coefficient was calculated between various regeneration parameters using MS Excel, 2007.

Results

Community composition

The studied forests are composed of different broadleaf tree species and are of vital importance to the local people inhabiting in and around the KWLS. But at the same time these forests are under high anthropogenic pressure due to excessive extraction of forest resources (Table 2). These forests showed differences in terms of some important forest structural attributes like density, diversity, species richness and basal cover (TBC). Forests of the core zone of KWLS (TN1 and TN2) had higher values for these parameters as compared to fringe and adjoining areas (Table 3).

Table 2. Vegetation and resource use pattern in the study area[(a)].

Forest	Main Vegetation[(b)]	Anthropogenic disturbances (Resource use pattern)[(c)]
BR	***Quercus glauca***, *Neolitsea cuipala, Mallotus philippensis, Cinnamomum tamala, Toona hexandra, Bauhinia variegata, Ficus semicardifolia, Ougeinia oogeinensis*	LTL, LG, HSC
PT	***Neolitsea cuipala***, *Toona hexandra, Engelhardtia spicata, Cinnamomum tamala, Mallotus philippensis, Albizia chinensis, Quercus leucotrichophora*	HTL, HSC, HG
KB	***Alnus nepalensis***, *Litsea elongata Lindera pulcherrima, Myrica esculenta, Pinus roxburghii, Pyrus pashia, Quercus leucotrichophora, Lyonia ovalifolia*	HTL, HG, LSC, CNTFP
JM	***Daphniphyllum himalense***, *Betula alnoides, Lyonia ovalifolia, Quercus floribunda. Q. leucotrichophora, Rhododendron arboreum*	HG, LSC, HTL, CNTFP
TN1	***Quercus floribunda***, *Q. semecarpifolia, Q. leucotrichophora, Acer* spp., *Ilex dipyrena, Pyrus pashia, Lyonia ovalifolia, Cotoneaster bacillaris, Taxus baccata, Picea smithiana, Betula utilis*	HG, HTL, CNTFP, HSC
TN2	***Rhododendron arboreum***, *Lyonia ovalifolia, Quercus spp., Ilex dipyrena, Symplocos ramosissima, Taxus baccata, Buxus wallichiana, Juglans regia, Aesculus indica*	HG, LSC, HTL, CNTFP

(a) Courtesy: Malik *et al.* 2014
(b) Species in **bold** are dominant tree species
(c) LTL = Low tree lopping, LG = low grazing, HTL = heavy tree lopping, HG = Heavy grazing, LSC = low stem cutting, HST = heavy stem cutting, CNTFP = collection of non-timber forest products.

Table 3. Structural attributes of KWLS forests.

Forest	Density (ha^{-1})	TBC (m^2 ha^{-1})	SR	H	Cd
		Trees			
BR	280 ± 12	13.67 ± 0.94	12	2.67	0.10
PT	235 ± 9	10.49 ± 0.66	11	2.30	0.10
KB	410 ± 20	20.40 ± 1.24	15	3.02	0.09
JM	465 ± 18	26.79 ± 1.10	18	3.21	0.07
TN1	465 ± 13	31.51 ± 1.86	22	3.53	0.06
TN2	505 ± 21	42.92 ± 2.57	20	3.34	0.08
		Shrubs			
BR	5060 ± 221	0.62 ± 0.047	18	3.78	0.08
PT	6460 ± 277	0.62 ± 0.047	16	3.70	0.09
KB	5660 ± 368	0.36 ± 0.024	16	3.43	0.12
JM	4730 ± 474	0.39 ± 0.046	12	2.74	0.19
TN1	9530 ± 700	0.57 ± 0.045	22	3.48	0.15
TN2	5840 ± 400	0.60 ± 0.047	14	3.19	0.13

Abbreviations: TBC = Total Basal Cover, SR = Species Richness; H = Shannon-Wiener Diversity Index, Cd = Concentration of dominance.

Ecological status of seedlings and saplings

The number of tree species at the seedling/sapling stage varied in different forests (Fig. 1). Various ecological parameters like TBC, density, dominance, equitability, species richness and diversity indices have been measured and/ or calculated for both seedlings as well as saplings (Table 4). Densities of seedlings and saplings varied from species to species and from forest to forest (Table 5).

Overall seedling density ranged between a maximum of 7485 ind ha^{-1} in JM and a minimum of 1670 ind ha^{-1} in PT (Fig. 2), whereas sapling density varied between a maximum of 5690 ind ha^{-1} in JM and a minimum of 1850 in ha^{-1} ind PT (Fig. 2). The highest percentage of seedlings (64 %) was recorded in BR and the lowest (45 %) in PT. The highest percentage of saplings (49 %) was recorded in PT and lowest (32.6 %) in BR, whereas the highest percentage (11 %) of trees was recorded in TN2 and minimum (3.4 %) in BR.

Diameter class distribution and regeneration status

The proportion of different life stages (seedlings, saplings and trees) of different species helps in predicting any possible changes in forest composition. In the present study, all species showed the highest density of individuals in the lower diameter class (i.e., 0 - 30 cm) that included seedlings and saplings and the density decreased progressively as the diameter increased. On the basis of density of seedlings, saplings and trees, different types of regeneration status (i.e. good, fair, poor and new regeneration) were observed in different forests.

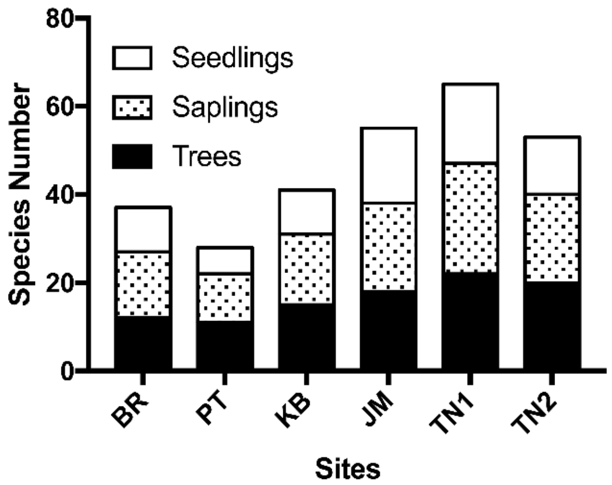

Fig. 1. Species richness of tree, sapling and seedling layers in different forests of KWLS.

In BR, the highest density was recorded for seedlings (5330 ind ha^{-1}), followed by saplings (2685 ind ha^{-1}) and trees (280 ind ha^{-1}). As far as the regeneration status is concerned in this forest, most (50 %) tree species showed good regeneration and the other tree species showed fair (7.1 %), poor (28.6 %) or new (14.3 %) regeneration (Fig. 3). In PT, the highest density was recorded for saplings (1850 ind ha^{-1}), followed by seedlings (1670 ind ha^{-1}) and trees (235 ind ha^{-1}). Most (45 %) tree species showed poor regeneration, while others showed eithergood (27 %) or fair (27 %) regeneration (Fig. 3). In KB, the highest density was recorded for seedlings (4535 ind ha^{-1}), followed by saplings (2950 ind ha^{-1}) and trees (410 ind/ ha). Most of the tree species in KB showed either good or poor regeneration (41 % each) while the remaining ones (5.9 % and 11.8 %) showed fair and new regeneration respectively (Fig. 3). In JM, the highest density was recorded for seedlings (7485 ind ha^{-1}), followed by saplings (5690 ind ha^{-1}) and trees (465 ind/ ha). Most species (52.4 %) showed good regeneration and other tree species showed fair (14.3 %), poor (19.0 %) or new (14.3 %) regeneration (Fig. 3). In TN1, the highest density was recorded for seedlings (4740 ind ha^{-1}), followed by saplings (3200 ind/ ha) and trees (465 ind ha^{-1}). Most species (56 %) showed good regeneration and the remaining ones showed fair (8 %), poor (24 %) or new (12 %) regeneration (Fig. 3). In TN2, the highest density was recorded for seedlings (2100 ind ha^{-1}), followed by saplings (1965 ind ha^{-1}) and trees (505 ind ha^{-1}). Most tree species showed either good or poor regeneration (35 % each) while the remaining ones (30 %) showed fair regeneration (Fig. 3).

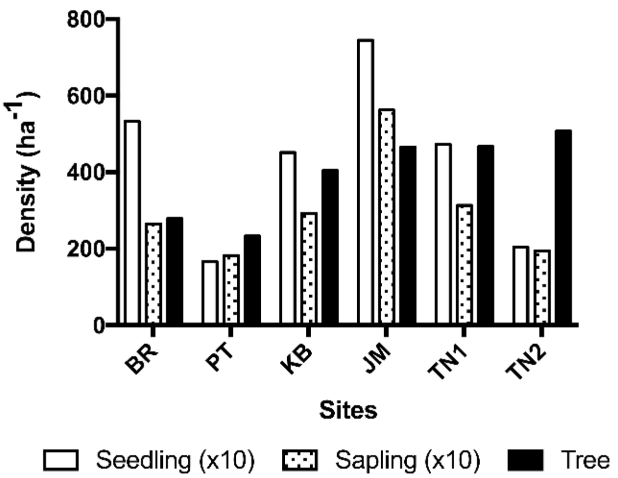

Fig. 2. Seedling, sapling and tree density in different forests of KWLS. Based on the overall density-diameter class distribution, all forests showed an inverse-J (i-J) curve (Table 6). The i-J type population structure is formed when lower diameter classes have the highest frequency with a gradual decrease in the number of individuals in the higher classes, which is due to initially high mortality of juvenile tree in

Table 4. Consolidated inventory of regenerating tree species in KWLS.

Forest	Density (ha^{-1})	TBC (m^2 ha^{-1})	H´	Cd	Eq.	SR*	MI	MeI	ß-Div
				Seedlings					
BR	5330	0.021	2.64	0.21	1.14	10	2.18	0.3	3.63
PT	1670	0.0078	1.91	0.37	1.06	6	0.86	0.32	4.44
KB	4535	0.0423	2.41	0.31	1.04	10	1.32	0.33	3.38
JM	7485	0.0504	3.31	0.15	1.16	17	2.18	0.43	3.65
TN 1	4740	0.0572	3.32	0.11	1.19	18	2.48	0.58	3.91
TN 2	2100	0.0201	3.2	0.11	1.24	13	1.98	0.63	4.12
				Saplings					
BR	2685	1.73	2.56	0.21	0.97	14	2.06	0.6	4.51
PT	1850	1.23	2.07	0.24	0.86	11	2.02	0.57	5.49
KB	2950	1.97	3.15	0.13	1.11	17	2.5	0.69	6.06
JM	5690	2.57	3.15	0.11	1.03	21	2.84	0.62	4.16
TN 1	3200	2.25	3.59	0.07	1.11	25	3.71	0.98	5.31
TN 2	1965	1.90	3.38	0.07	1.12	20	3.18	1	5.06

TBC = Total Basal Cover; H´ = Shannon-Wiener Diversity Index; Cd = Simpson Concentration of Dominance; Eq = Pielou Equitability; SR = Species Richness; MI = Margalef Index of Species Richness; MeI = Menheink's Index of Species Richness; ß-Div = Beta Diversity.

Table 5. Seedlings **(Sapling)** density (ind ha^{-1}) of various tree species in different forest types.

Species	BR	PT	KB	JM	TN1	TN2
Abies pindrow	-	-	-	-	35 **(35)**	-
Acer caesium	-	-	-	-	400 **(170)**	60 **(40)**
Acer cappadocicum	-	-	-	-	110 **(50)**	0 **(20)**
Acer oblongum	25 **(25)**	-	-		-	
Aesculus indica	-	-	-	170 **(55)**	0 **(20)**	140 **(100)**
Albizia chinensis		55 **(90)**	-		-	-
Alnus nepalensis	300 **(165)**	-	600 **(270)**	370 (**190**)	-	-
Bauhinia variegate	45 **(65)**	-	-	-	-	-
Betula alnoides	-	-	235 (**130**)	460 **(315)**	-	-
Betula utilis	-	-	-	-	0 **(30)**	-
Buxus wallichiana	-	-	-	-	220 **(500)**	0 **(50)**
Carpinus faginea	-	-	115 **(60)**	-	0 **(30)**	-
Cinnamomum tamala	950 (270)	110 (115)	0 **(40)**	-	-	-
Daphniphyllum himalense	-	-	-	1700 **(1850)**	-	-
Engelhardtia spicata	0 **(150)**	0 (135)	-	-	-	-
Euonymous pendulus	-	-	-	255 (**550**)	800 (**450**)	340 **(285)**
Ficus auriculata	270 **(80)**	0 **(35)**	-		-	0
Ficus glaberima	-	-	-	360 **(150)**	-	-
Ficus semicardifolia	550 **(185)**	-	-	-	-	-
Fraxinus micrantha	-	-	210 **(85)**	210 (**165**)	30 **(20)**	0 **(40)**
Ilex dipyrena	-	-	-	270 **(150)**	200 **(90)**	90 **(100)**

Contd...

Table 5. Continued.

Species	**BR**	**PT**	KB	JM	TN1	TN2
Juglans regia	-	-	0 **(20)**	0 **(35)**	0 **(30)**	0 **(60)**
Lindera pulcherima	-	-	240 **(260)**	360 **(95)**	320 **(300)**	60 **(70)**
Litsea elongate	-	-	2360 **(1210)**	2150 **(1200)**	1070 **(550)**	500 **(300)**
Lyonia ovalifolia	-	0 **(60)**	0**(85)**	0 **(25)**	100 **(50)**	175 **(130)**
Mallotus philippensis	235 **(120)**	0 **(35)**	-	-	-	-
Myrica esculenta	-	-	70 **(50)**	-	-	-
Neolitsea cuipala	2085 **(1150)**	960 **(850)**	-	-	-	-
Olea glandulifera	0 **(45)**	-	-	-	-	-
Ougeinia oogeinensis	0 **(135)**	-	-	-	-	-
Persea odoratissima	-	-	-	135 **(55)**	115 **(75)**	0 **(120)**
Picea smithiana	-	-	-	-	0 **(30)**	-
Pinus roxburghii	-	0 **(60)**	135 **(45)**	-	-	-
Prunus cerasoides	-	-	0 **(20)**	-	-	-
Prunus venosa	-	-	-	0 **(10)**	-	-
Pyrus pashia	-	-	0**(115)**	210 **(180)**	0 **(55)**	0 **(40)**
Quercus glauca	460 **(95)**	-	0**(85)**	-	-	0 **(60)**
Q. floribunda	-	-	-	410 **(285)**	400 **(180)**	50 **(75)**
Q. leucotrichophora	-	170 **(110)**	0 **(195)**	60 **(220)**	150 **(85)**	185 **(210)**
Q. semecarpifolia	-	-	-	-	40 **(50)**	40 **(30)**
Rhamnus virgatus	-	-	-	125 **(45)**	250 **(155)**	-
Rhododendron arboreum	-	140 **(150)**	270 **(210)**	125 **(35)**	100 **(35)**	215 **(235)**
R. campanulatum	-	-	-	-	0 **(50)**	-
Sapium insinge	0 **(115)**	-	-	-	-	-
Swida macrophylla	-	-	-	0 **(35)**	-	-
Symplocos racemosa	-	-	300 **(70)**	115 **(45)**	-	-
S. ramosissima	-	-	-	-	150 **(60)**	85 **(30)**
Taxus baccata	-	-	-	-	250 **(100)**	160 **(70)**
Toona hexandra	410 **(85)**	235 **(210)**	-	-	-	-
Total	5330 **(2685)**	1670 **(1850)**	4535 **(2950)**	7485 **(5690)**	4740 **(3200)**	2100 **(1965)**

Table 6. Density in different diameter classes in KWLS forests.

	Density in Diameter (cm) classes							
Forest	0 - 30	31 - 60	61 - 90	91 - 120	121 - 150	151 - 180	181 - 210	> 211
BR	8015	130	95	40	10	10	0	0
PT	3522	90	100	20	15	0	0	5
KB	7485	175	165	45	10	0	5	10
JM	13175	190	135	95	40	0	0	5
TN1	7870	240	115	65	15	5	0	25
TN2	4065	165	160	100	30	15	20	15

the smallest size class. The number of individuals reduced sharply with the increase of diameter.

Survival of seedlings

The survival percentage of naturally emerged seedlings varied in different forests. In BR, seedlings of only 8 out of 10 tree species survived throughout the year. Seedlings of *Acer oblongum* and *Bauhinia variegata* showed 100 % mortality within the first three months of tagging. Minimum mortality (64 %) was recorded for the seedlings of *Cinnamomum tamala* (Table 7). In PT, minimum (19 %) and maximum (64 %) mortality were recorded in the seedlings of *Albizia chinensis* and *Rhododendron arboretum*, respectively (Table 7). In KB, tagged seedlings of all the 8 tree species survived throughout the year. Minimum (12 %)

Table 7. Survival of tagged seedlings in KWLS during different seasons.

		Surviving tagged seedlings						Surviving tagged seedlings			
Forest/ Tree species	Number of Tagged seedlings	July, 2012	Oct, 2012	Jan, 2013	April, 2013	Tree species	Number of Tagged seedlings	July, 2012	Oct, 2012	Jan, 2013	April, 2013
BR						**JM (contd....**					
Acer oblongum*	5	5	0	0	0	*Pyrus pashia*	40	32	27	22	18
Alnus nepalensis	50	45	18	12	10	*Q. floribunda*	50	39	35	35	26
Bauhinia variegata	9	7	0	0	0	*Q. leucotrichophora*	12	9	9	9	5
Cinnamomum tamala	50	50	21	18	18	*Rhamnus virgatus*	25	25	18	11	8
Ficus auriculata	40	32	8	8	8	*Rhododendron arboreum*	25	21	21	17	11
Ficus semicardifolia	50	44	13	10	8	***Symplocos racemosa***	23	17	17	11	8
Mallotus philippensis	40	31	9	9	9	**TN1**					
Neolitsea cuipala	50	46	17	17	17	***Abies pindrow***	7	7	5	5	2
Quercus glauca	50	42	13	9	9	*Acer caesium*	50	40	40	32	26
Toona hexandra	50	39	12	8	8	*Acer cappadocicum*	22	18	18	11	5
PT						*Buxus wallichiana*	40	40	34	27	22
Albizia chinensis	11	11	9	9	9	*Euonymus pendulus*	50	50	50	43	37
Cinnamomum tamala	22	22	20	18	14	***Fraxinus micrantha***	6	6	4	4	0
Neolitsea cuipala	50	50	42	42	38	*Ilex dipyrena*	40	40	33	33	23
Q. leucotrichophora	30	30	21	19	13	*Lindera pulcherrima*	50	43	43	38	38
R. arboreum	25	25	17	17	9	*Lyonia ovalifolia*	20	11	0	0	0
Toona hexandra	40	37	34	34	22	*Litsea elongata*	50	43	43	37	37
KB						*Persea odoratissima*	23	17	9	7	7
Alnus nepalensis	50	50	43	40	35	*Quercus floribunda*	50	41	41	40	29
Betula alnoides	45	40	40	34	30	*Q. leucotrichophora*	30	30	30	30	14
Carpinus faginea	23	23	9	9	7	*Q. semicarpifolia*	8	8	8	7	4
Fraxinus micrantha	40	28	23	20	17	*Rhamnus virgatus*	50	39	31	31	18
Lindera pulcherrima	45	45	42	38	31	*Rhododendron arboreum*	20	20	19	19	15
Litsea elongata	50	50	50	46	44	*Symplocos ramosissima*	30	30	27	23	16
Myrica esculenta	14	11	8	5	2	*Taxus baccata*	50	48	48	38	23
Pinus roxburghii	27	21	17	10	5	**TN2**					
R. arboreum	50	41	35	31	20	*Acer caesium*	12	9	9	9	5
Symplocos racemosa	50	43	40	33	22	*Aesculus indica*	28	21	21	17	9
JM						*Euonymous pendulus*	50	43	43	43	37
Aesculus indica	34	30	25	22	16	*Ilex dipyrena*	18	18	18	15	10

Contd...

Table 7. Continued.

Forest/ Tree species	Number of Tagged seedlings	Surviving tagged seedlings July, 2012	Oct, 2012	Jan, 2013	April, 2013	Tree species	Number of Tagged seedlings	Surviving tagged seedlings July, 2012	Oct, 2012	Jan, 2013	April, 2013
Alnus nepalensis	50	41	36	29	22	*Lindera pulcherrima*	12	12	8	8	8
Betula alnoides	50	38	38	30	23	*Litsea elongata*	50	47	47	41	38
D. himalense	50	50	50	44	38	*Lyonia ovalifolia*	35	29	14	14	5
Euonymous pendulus	50	45	45	40	29	*Quercus floribunda*	10	10	10	10	5
Ficus glaberima	50	44	38	29	18	*Q. leucotrichophora*	37	37	31	31	27
Fraxinus micrantha	40	34	34	29	21	*Q. semicarpifolia*	8	8	8	6	4
Ilex dipyrena	50	43	36	36	30	*R. arboreum*	43	40	38	38	38
Lindera pulcherrima	50	50	50	35	27	*Symplocos ramosissima*	17	11	11	9	6
Litsea elongata	50	45	45	40	36	*Taxus baccata*	32	25	18	18	13
Persea odoratissima	27	23	20	17	11						

***Species in bold** showed "new regeneration".

Table 8. Carl-Pearson's correlation coefficients between various regeneration parameters.

	SED	SESR	SETBC	SEDH̄	SAD	SASR	SATBC	SAPH̄	TOR	TD	TTBC	SD	STBC	TSR
SESR	0.6													
SETBC	0.71	0.83**												
SEDH̄	0.49	0.94*	0.65											
SAD	0.91*	0.65	0.71	0.53										
SASR	0.38	0.95	0.77	0.92*	0.40									
SATBC	0.91*	0.66	0.87*	0.44	0.87**	0.48								
SAPH̄	0.32	0.83**	0.76	0.84**	0.33	0.92*	0.40							
TOR	0.99*	0.63	0.72	0.52	0.96*	0.39	0.91*	0.33						
TD	0.27	0.80	0.65	0.85**	0.40	0.84**	0.30	0.94*	0.32					
TTBC	-0.04	0.67	0.35	0.80	0.09	0.78	-0.03	0.84**	0.01	0.91*				
SD	-0.24	0.35	0.36	0.20	-0.23	0.52	0.09	0.36	-0.24	0.17	0.23			
STBC	-0.46	-0.1	-0.48	0.06	-0.60	0.04	-0.56	-0.15	-0.53	-0.53	0.12	0.31		
TSR	0.19	0.88*	0.67	0.88**	0.30	0.96*	0.31	0.93*	0.24	0.92*	0.89**	0.50	0.014	
SSR	-0.10	0.11	0.22	-0.004	-0.34	0.28	0.10	0.13	-0.19	-0.16	-0.12	0.82**	0.457	0.149

*Correlation is significant at 0.01 significance level;** Correlation is significant at 0.05 significance level.

Abbreviations: SED = Seedling Density; SESR = Seedling Species Richness; SETBC = Seedling Total Basal Cover; SEDH̄ = Seedling Shannon-Wiener Diversity Index; SAD = Sapling Density; SASR = Sapling Species Richness; SATBC = Sapling Total Basal Cover; SAPH̄ = Sapling Shannon-Wiener Diversity Index; TOR = Total Regeneration (Seedlings + Saplings); TD = Tree Density; TTBC = Tree Total Basal Cover. SD = Shrub Density; STBC = Shrub Total Basal Cover; TSR = Tree Species Richness; SSR = Shrub Species Richness.

and maximum (86 %) mortality were recorded in the seedlings of *Litsea elongata* and *Myrica esculenta* respectively (Table 7). In JM, minimum (24 %) and maximum (68 %) mortality were recorded in the seedlings of *Daphniphyllum himalense* and *Rhamnus virgatus* respectively (Table 7). In TN1, minimum (26 %) and maximum (78 %) mortality were recorded in the seedlings of *Litsea elongate* and *Acer cappadocicum*, respectively (Table 7). Seedlings of *Fraxinus micrantha* and *Lyonia ovalifolia* showed 100 % mortality within a few months of tagging (Table 7). In case of TN2, minimum (12 %) and maximum (86 %) mortality were recorded in the seedlings of *Rhododendron arboretum* and *Lyonia ovalifolia*, respectively (Table 7).

A one-tailed Carl-Pearson Correlation coefficient was calculated between various regeneration parameters (Table 8). Sapling density was significantly and positively correlated with seedling density (r = 0.91), sapling total basal cover (0.87) and total regeneration (0.96) whereas it was negatively correlated with shrub density (r = -0.23), shrub total basal cover (-0.60) and shrub species richness (-0.34).

Discussion

The forest wealth depends on the potential regenerative status of species composing the forest stand in space and time (Jones *et al.* 1994). The regeneration of a forest is a vital process in which old trees die and are replaced by young ones in perpetuity. In this study, an attempt was made to study the tree regeneration status and survival of their seedlings at three altitudes in KWLS and its adjoining areas in Western Himalaya, India. The overall regeneration status was fairly high in the study area. Being a protected forest, there is a restriction to some extent on human activities like tree felling, and collection of fuelwood and litter. This ultimately favoured the regeneration of a maximal number of tree species. In addition, high rainfall, moderate temperature and wide variation in altitude and soil characteristics provided a favourable environment for the luxuriant growth of many tree species.

In the present study, seedling density ranged from 1670 ind ha^{-1} (PT) to 7485 ind/ ha (JM) while sapling density varied from a minimum of 1850 ind ha^{-1} (PT) to a maximum of 5600 ind ha^{-1} (JM). The variation in seedling density among the forests and/or species along the altitudinal gradient may be due to change in climatic conditions which could restrict the distribution of some species via the germination and establishment of seedlings (Vera 1997). Seedling mortality in different species varied from 12 - 100 % in the study area. The highest mortality (64 - 100 %) was shown by the species of BR forest. The reason for this high mortality is the natural calamity that hit the Ukhimath region of this area in September 2012. A series of cloudbursts struck more than 20 villages in Ukhimath Block of District Rudraprayag on the night of 13th September, 2012 triggering land-slides and flash floods. That natural calamity adversely affected the vegetation of Barmadi Forest. The intensity of destruction can be imagined by the fact that half of the permanently marked 20 quadrats were completely washed away along with the tagged seedlings. Anthropogenic disturbances like fuelwood and litter collection and grazing are the most important factors affecting regeneration in the study area. The repeated lopping of trees for leaf-fodder and fuelwood results in the reduction of canopy cover. The reduced canopy cover has a direct effect on seed production, but it may also indirectly affect regeneration through changes in the understorey vegetation and soil properties (Vetaas 2000). There are 2.94 - 5.85 cattle per household in the study area (Malik *et al.* 2014). A major part of their fodder is extracted from forests (tree, shrub, leaves and herbaceous ground flora). In times of scarcity of leaf fodder, cattle feed on the ground flora including the seedlings and saplings. Overgrazing by livestock harms the ground flora and impedes regeneration of dominant tree species in this area (Malik *et al.* 2014). According to Saxena & Singh (1984) grazing and trampling by cattle also affect the soil structure by compacting it; the highly compacted soil shows, in general, a lower moisture content because of lower permeability and higher run-off. All these conditions may alter the habitat and make it less suitable for the establishment of seedlings.

Construction of hydroelectric power projects may be one of the important reasons for the highest mortality in BR (64 - 100 %) and KB (12 - 86 %). Singoli Bhatwari HEP (99 MW) and Phata Byung HEP (76 MW) are being constructed in the vicinity of BR and KB, respectively. For these projects, tunnels (6 - 12 km long) have been constructed that run all along beneath these forests. Because of this the trees do not get sufficient support and hence are uprooted easily even with slight wind blows, resulting in removal of the upper soil layer along with seedlings and saplings.

Seedling survival and mortality over shorter time spans could provide important clues for the future composition of a forest stand (Deb & Sundriyal 2008); and results of the present study indicated important differences among seedling groups. In the present investigation, of the total number of individuals (seedling + sapling + tree), a total of 64, 32.6 and 3.4 % individuals at BR; 45, 49, and 6 % at PT; 57, 37 and 5 % at KB; 55, 42 and 3.4 % at JM; 56, 38 and 5.5 % TN1 Forest; and 46, 43 and 11 % individuals at TN2 forest were recorded in respective stages. The study recorded a net loss of about 3 - 32 % seedlings during the developmental stage from seedling to sapling, and a further loss of 30 - 43 % individuals in the developmental stage from sapling to tree stage. The individual mortality rate from seedling to sapling to tree stratum also varied for different species. The i-J diameter distribution of stem density, as shown by most tree species, indicates that a small fraction of the seedling and sapling classes survived to the larger tree classes. Kennedy and Swaine (1991) reported two phases of mortality. The initial mortality that occurs during the early (seedling/sapling) stages of development is high and caused by microsite effects and small terrestrial animals. During later (juvenile/adult) mortality, competition with each other and other plants plays an important role. Increased mortality is usually attributed to gap size and light availability, physical damage, soil dryness and herbivore attack (Nunez-Farfan & Dirzo 1989). Seedling survival is also greatly affected by the ambient environment, biotic and abiotic factors (Harper 1977). Maximum seedling mortality occurred during the winter season which could be attributed to the prevailing low soil moisture and low temperature conditions. The importance of soil moisture in influencing tree seedling survival and growth in forests has been well reported (Deb & Sundriyal 2008; Schulte & Marshall 1983). Seedlings are generally vulne-rable to cool and dry climatic conditions prevailing during the winter season and a large number of seedlings die in both understorey and gaps (Khumbongmayum *et al.* 2005). Cierjack *et al.* (2008) also stated that plant regeneration is generally limited in harsh environments.

The values of various parameters of seedling and sapling like density, TBC and diversity had lower values in forests of lower altitude (900 - 1200 m asl) *i.e.* BR and PT (Table 4). The reason is that these two forests are adjacent to KWLS and are not protected. Human interference is not restricted and anthropogenic disturbance in the form of grazing by domestic animals, lopping, fodder, fuel and litter collection is very high in these forests as compared to mid and high altitudinal sites. Ballabha *et al.* (2013) pointed out some of the anthropogenic disturbances like forest fires, overgrazing and lopping affect both plant diversity and regeneration in Garhwal Himalaya.

Regeneration showed a negative correlation with shrub density (-0.24), shrub TBC (-0.53) and shrub species richness (-0.19) and this is because of increased competition for resources and space. According to Moktan *et al*. (2009), the presence of abundant shrubs and herbs impedes seedling establishment of both shade-tolerant and intolerant species. Crow (1988) also found that shrubs and herbaceous vegetation inhibit growth of seedlings and saplings of trees. The seedlings are more prone to competition from herb and shrubs than saplings (Gairola *et al.* 2012). Regeneration showed a positive correlation with seedling SR (0.63), sapling SR (0.38) and tree SR (0.24). It means increased diversity increases regeneration (*i.e.*, survival) of forests. The requirements of tree species differ for nutrition and other resources, and hence these trees are specialized to exploit all the available resources in their surroundings. Accor-ding to McNaughton (1977), a diverse ecosystem is more resistant to environmental disturbances, and is likely to contain species that would thrive through natural or imposed perturbations in the ecosystem and compensate for the loss of other members (Stapanian *et al.* 1997).

The density-diameter (d-d) distribution of stems has been used to represent the population structure of forests (UNESCO/UNEP/FAO, 1978; Khan *et al.* 1987). The population structure of a species in a forest conveys its regeneration behaviour and a population structure characterized by sufficient seedlings, saplings and adults, indicates successful regeneration. In the present study, most species showed highest density in the lower diameter classes and density decreased progressively as diameter classes increased. Variation in the number of individuals in different diameter classes among the six forests may be ascribed to the prevailing environmental factors and degree of disturbance. If a species shows an i-J shaped distribution with higher number of individuals in the seedling stage and the number gradually decreasing in saplings, small trees, and old trees categories, such distribution shows that these species are in the most dominant form in the stand at present. An i-J distribution is considered to indicate good regeneration status (Getachew *et al.* 2002; Pala *et al.* 2013; Tesfaye *et al.* 2010). The 'J' shaped distribution depicts pioneer status while i-J expresses successional status of the species. The J shaped distribution is when the density of lower diameter classes is low as compared to the higher classes. The dominance of tree individuals in medium to lower diameter classes suggests that the forest is still in aevolving stage (Campbell *et al.* 1992). The i-J diameter distribution shows that a small fraction of the individuals in seedling and sapling classes survived up to the larger tree classes. In any forest, if the greatest number of individuals of any species is represented in higher diameter classes, the population structure of that species should be considered on the verge of extinction (Benton & Werner 1976). The presence of a sufficient number of seedlings, saplings, young trees (pole) and mature trees in a given population indicates successful regeneration (Khan *et al.* 1987). The tree species that are represented by all diameter classes constitute continuous regeneration while those species that are not represented by some diameter classes constitute discontinuous regeneration. In a forest stand generally the most dominant species are represented by all diameter classes (Khan *et al.* 1987). In the present study, there were a few tree species at each site that showed discontinuous regeneration. These tree species although dominant at present may be at risk in future. The reason for discontinuous regeneration and deviation from the i-J curve is anthropogenic disturbance and/or sometimes natural calamities.

A shift from i-J shaped to any other type (unimodal, sporadic *etc.*) distribution is the result of substantial changes in the state and pattern of forest regeneration, suggesting that the forest is in trouble (Ghimire *et al.* 2010). A bell-shaped class distribution has been attributed to the disturbed forest in which regeneration is hampered (Saxena *et al.* 1984). In the present investigation most tree species showed an i-J shaped population structure having many small tree individuals, a considerable number of medium sized individuals and very few large tree individuals. Some other species devoid of regeneration showed poor status, while a few were represented in the seedling and sapling stages only and such species seem to be new intruders in the studied stands which may form sub-canopy in the future.

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