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Impact of silvicultural system on natural regeneration in Western Himalayan moist temperate forests of Pakistan

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Abstract: Site conditions (topography, aspect, moisture availability, humus thickness, light exposure, and grazing activities) play a vital role in the germination and regeneration process. The research was conducted in the Himalayan moist temperate forest. The research site was divided based on the silvicultural system (group selection system and single-tree selection system) into 148 plots and 150 plots, respectively. The group selection system was examined on the site of 2 ha which was clear-felled under a project in the 1980's. The present study examined the impact of silvicultural systems on regeneration. The frequency table was used, and relative frequency was calculated for the species and silvicultural system, density per m^2 was also calculated. Diversity indices were calculated through taxa, dominance, Simpson's index, Shannon index, evenness, equitability, and fisher alpha. Ten taxa were found in both silvicultural systems, with individual repetition of 17 and 15 taxa, respectively. Group selection is more compact visibly as compared to the single-tree selection system. The single-tree selection system is more diversified in species composition, stand structure, moisture availability, and less humus availability. The study also highlights future predictions for the conservation of these forests, which are highly sensitive and a hotspot for wildlife and climate change phenomena. Silvicultural practices such as silvicultural system, cleaning, weeding, thinning operations are regularly practiced, which can reduce the negative impact on these productive forests.

Keywords: diversity; mountain forest; stand structure; species composition; watershed

The regeneration gap leads to the forest ecosystem deterioration and degradation of forest stand structure (Barnes et al. 1998). To investigate the life cycle of forest stands, the regeneration process and factors influence the process needs to be identified (Guo et al. 2003). Heterogeneity of forest stands with species composition influences the rate of regeneration (Chen et al. 2007). To maintain the ecosystem of forests, the regeneration process needs to be properly managed through artificial and natural regeneration (Kent, Coker 1992). In the naturally regenerated forest ecosystem plants may die or recruit to the understorey when after the competition they became a part of the overstorey (Barnes et al. 1998). Regeneration methods that were found in woody vegetation are vegetative, viable seed bank, dormant and persistent seed bank, fire-induced opening of cones, widely wind-dispersed seeds, locally dispersed seeds, and persistent juveniles (Grime 1988; Barnes et al. 1998). Seed production in forest crops influences the rate of growth (diameter and height) which affects timber production (Morris 1951; Tappeiner 1969).

Natural regeneration in the high mountains is the only source of growing stock. Almost every forest species is regenerated through seeds except some special broadleaved species (Yadava et al. 2017). On the other hand, vegetative reproduction (layering) of natural regeneration occurs more often than seed production in extreme site and cli-

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matic conditions, such as in mountain areas (Vacek, Hejcman 2012; Vacek et al. 2012; Bulušek et al. 2016). Suitable ground and site conditions are required for the germination and establishment of seedlings. Site conditions like topography, aspect, moisture availability, humus thickness, light exposure, and grazing activities play a vital role in the germination process (Brewer et al. 2012; Vacek et al. 2017a; Gallo et al. 2020). Forest stand structure and density also affect natural regeneration by allowing the required light and availability of enough seed for germination (Rocha et al. 2016; Splawinski et al. 2016). Soil depth and decomposed humus with more nutrients are prone to be ideal space for regeneration. The temperature in the mountainous regions fluctuates during the day (high) and particularly at night time (low) (Chakrabarti 2016). Natural regeneration is threatened by many natural and anthropogenic factors. Natural factors that influence natural regeneration are heavy wind, erosion, heavy rainfall, animals, natural fire, windthrow, air pollution load, and torrents (Vacek et al. 2014, 2017a, b, 2019; Tinya et al. 2019). Whereas grazing practices, tree harvesting activities, roads, and trails are the most important anthropogenic factors which affect the regeneration process in high mountains (dos Santos et al. 2019; Maltoni et al. 2019; Rezende, Vieira 2019).

Most of the forests have mixed species composition and also variation in structure in the mountain region (Pignataro et al. 2017; Dănescu et al. 2018). Shade-tolerant and light-demanding species are common during the early stage of their life. Good seed years also influence the rate of regeneration, and density and other parameters (height, crown, etc.) are also influenced by vegetation cover and microrelief in mountain forests (Vacek et al. 2015). Climatic factors such as snow and heavy rainfall also affect the favourable site for regeneration (Ives 2004). Major and important tree species in the study area which need consideration compared to other plant species are *Pinus wallichiana* A.B. Jackson that is highly shade-tolerant and mostly found with *Picea smithiana* Wall. and *Abies pindrow* Royle. *Cedrus deodara* Roxb. is also dominated by *Abies pindrow* Royle between 1 800 and 2 400 m above sea level, whereas they can be found from 1 500 to 2 800 m a.s.l. *Pinus wallichiana* is a shade-tolerant species along with *Cedrus deodara* and *Picea smithiana*, whereas *Abies pindrow* can grow under all other species (Champion et al. 1965a, b).

Suitable growth conditions in these mountain regions especially with uneven-aged structures are more suitable for sustainable management. According to the past practice in the temperate forests, a shelterwood system was adopted by classifying dry and moist regions. On the dry site, 10–14 m spacing or 51–75 seed bearers were left to provide sufficient seeds to the site, whereas on the moist site 9 m spacing was observed or 123 mother trees stood there as seed factory (Champion et al. 1965 b). Supplementary artificial regeneration practices were also observed if there was a bad seed season or any other natural hazards that were observed in the areas (de Carvalho et al. 2017).

The present study investigated the diversity index under different silvicultural systems, i.e. group selection system (GSS) and single-tree selection system (STSS) in the Himalayan region. The diversity index will assist forest managers and conservationists towards the sustainability and composition of the forest stand. That can help climate change, reducing emissions from deforestation and forest degradation (REDD+), and productivity components and aspects for model development through the best harvesting system.

MATERIAL AND METHODS

Study site. The Western Himalayan moist temperate forest of Pakistan was examined for regeneration under the silvicultural system. Two main silvicultural systems were recorded as GSS and STSS. The group selection system was examined under a project in the 1980s, when a 2-ha area was clear-felled, the present study examined its impact on regeneration. The same site of STSS was also identified by help of the Kaghan Forest Division. The elevation of the site was between 2 100 and 2 200 m a.s.l. (Figure 1). The total area of the Himalayan moist temperate forest is 572 508 ha, i.e. 0.7% of the total forest cover of the country (Bukhari et al. 2012); the experimental area is 4 ha (2 + 2) with quadrat sampling (quadrat size 1 m^2), the sample size is limited due to the area of GSS. The main species of the area are illustrated in Table 1 along with the temperature and ecological conditions. Floristic details of the region are shown in Table 2. Simpson's index (1-D) and Shannon (H) index were calculated as 0.59 and 1.08, respectively, in the group selection system, and 0.61 and 1.24 in the single-tree selection system.

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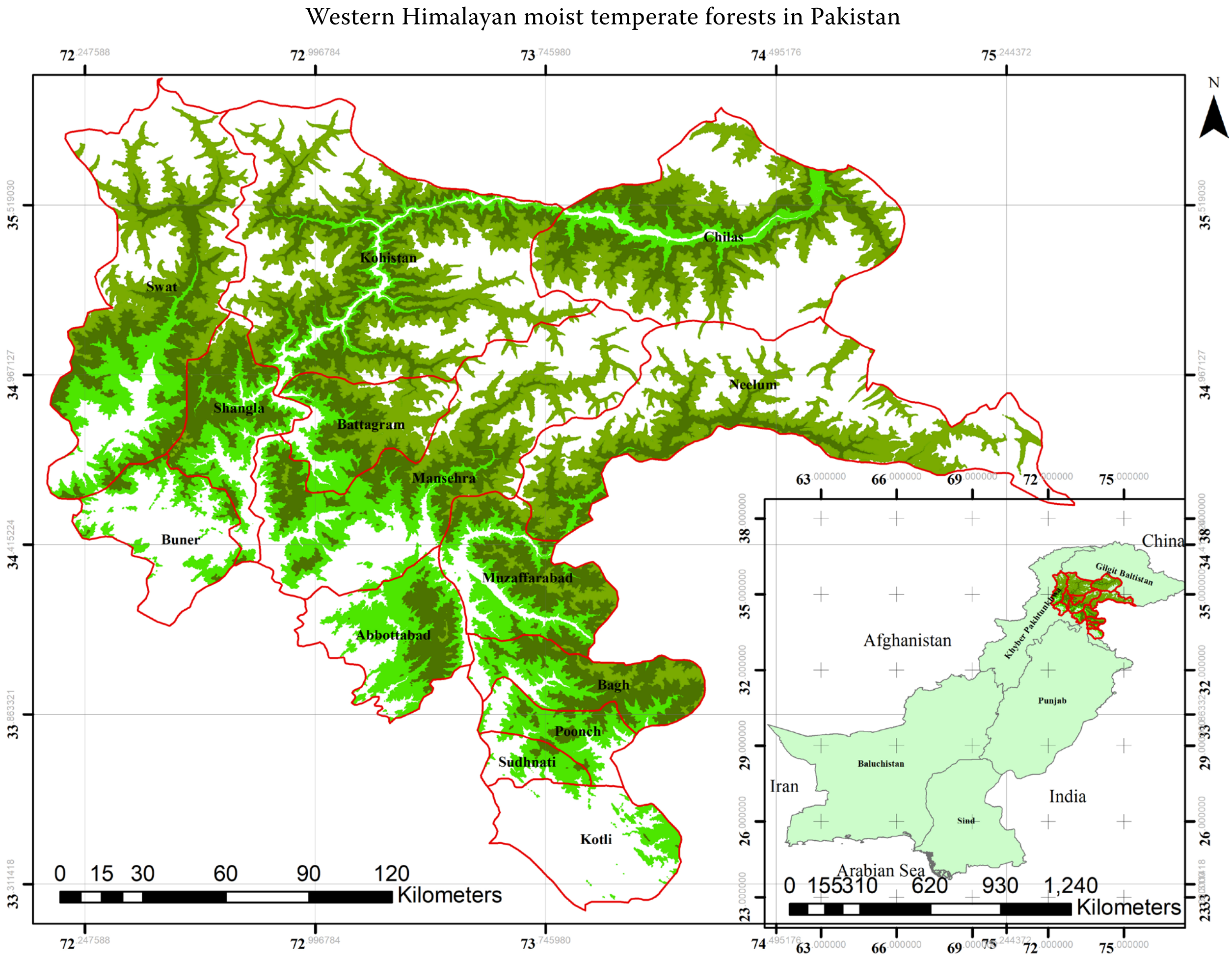

Figure 1. Description and situation of the study area in Western Himalaya (ArcGIS 10.8.1 Academic)

Data collection. The number of individuals (seedlings and saplings) was counted in a quadrat for specific plant species mentioned in Table 1. The sites with two different silvicultural systems (GSS and STSS) were selected to examine and collect the data. Data were collected using a 1 m^2 quadrat, measuring tape, Garmin GPS (eTrex 20x, 2015, USA) was used for coordinate and elevation records. Statistical packages PAST (version 3, 2013) and MS Excel (Office 365, 2019) were used for the analysis. ArcGIS (Ver. 10.8.1, 2020) was used for mapping and site detailed study (Barbour et al. 1987; Hammer et al. 2001).

Data analysis. The area was divided based on the silvicultural system (2 ha). Each site was classified into grids using a fishnet in ArcGIS 10.8.1 Academic with 20/20 girds in the area which turns into 154 quadrats in GSS and 153 in STSS shown in Figure 2.

The frequency Table was used in MS Excel and relative frequency was calculated for the species and silvicultural system, density per m^2 was also calculated by density. Diversity indices were calculated through taxa (S), dominance (1-Simpson index), Simpson's index (1-dominance), Shannon index (H), evenness (e), equitability (E_H) and Fisher's alpha (α) were calculated using the PAST software (Fisher et al. 1943; Magurran 1988; Roth et al. 1994; Rosenzweig 1995; Begon et al. 1996; Mulder et al. 2004). Formulas used in the calculations are as follows:

$$\text{Density} = \frac{\text{Total number of individuals}}{\text{Total number of sample plots}} \qquad (1)$$

$$\text{Shannon Index}\,(H) = -\sum_{i=1}^{s} p_i \ln p_i \qquad (2)$$

where:

S – species richness

p_i – relative abundance of species i

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Table 1. Details of the study area and site conditions

		Silvicultural systems	
		GSS	STSS
Area (ha)		2.00	2.00
Number of quadrates (1 m^2)		154	153
Coordinates (dd)	left	73.527799	73.495787
	right	73.530780	73.498911
	top	34.717508	34.649902
	bottom	34.715882	34.648226
Altitude range (m)		2 100–2 160	2 130–2 170
Temperature MAT (°C)		3.2	3.2
Precipetation MAR (mm)		635–1 524	635–1 524
Soil		Podzol	Podzol
Plant species			
	site	*Pinus wallichiana*, *Cedrus deodara*, *Picea smithiana*, *Abies pindrow*	*Pinus wallichiana*, *Quercus dilatata* Royle, *Cedrus deodara*, *Picea smithiana*, *Abies pindrow*, *Aesculus indica* Wall., *Alnus nitida (Spach)* Endl.Gen., *Pinus roxburghii* Sargent, *Robina pseudoacacia* L. *Ailanthus altissimus* (Mill.) Swingle
	surrounding	*Aesculus indica* Wall., *Populus ciliata* Wall., *Juglans regia* L. *Quercus dilatata* Royle, *Robina pseudoacacia* L. *Fraxinus hookeri* Wenzig in Engler	*Populus ciliata* Wall., *Juglans regia* L. *Fraxinus hookeri* Wenzig in Engler

GSS – group selection system; STSS – single-tree selection system; MAT – mean annual temperature; MAR – mean annual rainfall; dd – decimal degree

$$\text{Simpson's Index}(D) = \frac{1}{\sum_{i=1}^{s} p_i^2} \quad (3)$$

$$\text{Equitability}(E_H) = \frac{H}{H_{\max}} \quad (4)$$

where:
$H_{\max}$ – Shannon Index maximum

$$\text{Evenness } (e) = \frac{e^H}{S} \quad (5)$$

Fisher's alpha (α) is calculated as

$$S = \alpha \times \ln(1 + \frac{n}{\alpha}) \quad (6)$$

where:
n – total number of individuals

RESULTS

Regeneration diversity. During the data collection, vegetation diversity was examined, whereas only the species which were found in the sample plot and in the surrounding area were listed in Table 3. Regeneration diversity in the study site is focused on main forest crop which includes *Pinus wallichiana* (PW), *Cedrus deodara* (CD), *Picea smithiana* (PS), *Abies pindrow* (AP), *Quercus dilatata* (QD), *Aesculus indica* (AI), *Alnus nitida* (AN), *Pinus roxburghii* (PR), *Robinia pseudoacacia* (RP), *Ailanthus altissima* (AA) and some other species which are rarely found in the regeneration plots. The number of taxa found in both silvicultural systems (group selection system and single-tree selection system) is 10, with individual repetition of 17 and 15 taxa, respectively, calculated and analysed by diversity indices.

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Table 2. Scientific names of plant species found during the research activities in two sites (Kamalbad and Malkandi Forest); family and altitude of the species are also mentioned below

Scientific name	Family	Altitude (m)
Acer caesium Wall. ex Brandis	Aceraceae	2 000–3 500
Acer pictum auct.	Aceraceae	2 000–3 500
Pistacia integerrima J. L. Stewart	Anacardiaceae	450–2 000
Hedera nepalensis K. Koch	Araliaceae	1 000–3 000
Berberis lycium Royle in Trans.	Berberidaceae	
Alnus nitida (Spach) Endl.Gen.	Betulaceae	1 000–2 900
Betula utilis D.Don	Betulaceae	3 000–4 500
Sarcococca saligna (D.Don) Muell.-Arg.	Buxaceae	Up to 3 000
Lonicera webbiana Wall.	Caprifoliaceae	2 000–4 000
Viburnum grandiflorum Wall. ex DC.	Caprifoliaceae	1 500–3 000
Viburnum nervosum D. Don	Caprifoliaceae	1 500–3 000
Cornus macrophylla Wall.	Cornaceae	1 500–2 700
Corylus colurna L.	Corylaceae	1 600–3 300
Diospyros lotus L.	Ebenaceae	± 1 500
Rhododendron arboreum Sm.	Ericaceae	1 500–2 500
Euphorbia wallichii Hook. f.	Euphorbiaceae	2 400–3 400
Quercus dilatata Royle	Fagaceae	1 600–2 900
Quercus glauca Thunb.	Fagaceae	700–2 000
Quercus ilex L.	Fagaceae	1 800–3 000
Quercus incana Roxb.	Fagaceae	1 000–2 700
Quercus semecarpifolia Smith in Rees	Fagaceae	
Ribes himalense Decne.	Grossulariaceae	2 000–3 400
Parrotia persica (DC.) C.A.Mey.	Hamamelidaceae	
Aesculus indica Wall.	Hippocastanaceae	1 200–3 300
Juglans regia L.	Juglandaceae	1 000–3 300
Plectranthus barbatus Andrews	Labiatae	
Ficus palmata Forssk.	Moraceae	2 500
Olea glandulifera Wall.	Oleaceae	600–1 800
Paeonia emodi Wall.	Paeoniaceae	3 200
Indigofera heterantha Wall.	Papilionaceae	
Abies pindrow Royle	Pinaceae	2 500–3 500
Cedrus deodara Roxb.	Pinaceae	2 000–3 000
Picea smithiana Wall.	Pinaceae	2 500–3 300
Pinus roxburghii Sargent	Pinaceae	600–1 800
Pinus wallichiana A.B. Jackson	Pinaceae	1 800–3 500
Actaea spicata L,	Ranunculaceae	2 000–3 300
Anemone obtusiloba D. Don	Ranunculaceae	
Clematis montana Buch.-Ham.	Ranunculaceae	2 000–3 000
Rhamnus virgata Roxb.	Rhamnaceae	
Cotoneaster humilis Dunn	Rosaceae	
Fragaria nubicola (Hook.f.) Lindl.	Rosaceae	1 500–3 600
Prunus cornuta Wall. ex Royle	Rosaceae	
Prunus cornuta Wall.	Rosaceae	
Prunus padas L.	Rosaceae	
Pyrus pashia Buch.-Ham.	Rosaceae	
Rosa macrophylla Lindl.	Rosaceae	1 800–2 800
Rosa moschata Herrm.	Rosaceae	1 000–2 500
Rosa webbiana Wall.	Rosaceae	1 000–2 500
Rubus armeniacus Focke.	Rosaceae	
Sorbus aucuparia L.	Rosaceae	
Populus alba L.	Salicaceae	
Populus ciliata Wall.	Salicaceae	2 000–3 000
Salix flabellaris Andersson in Kung.	Salicaceae	Up to 4 000
Taxus baccata L.	Taxaceae	1 800–3 000
Ulmus wallichiana Planch.	Ulmaceae	2 200–3 000
Viola kashmiriana W. Becker	Violaceae	2 000–2 700

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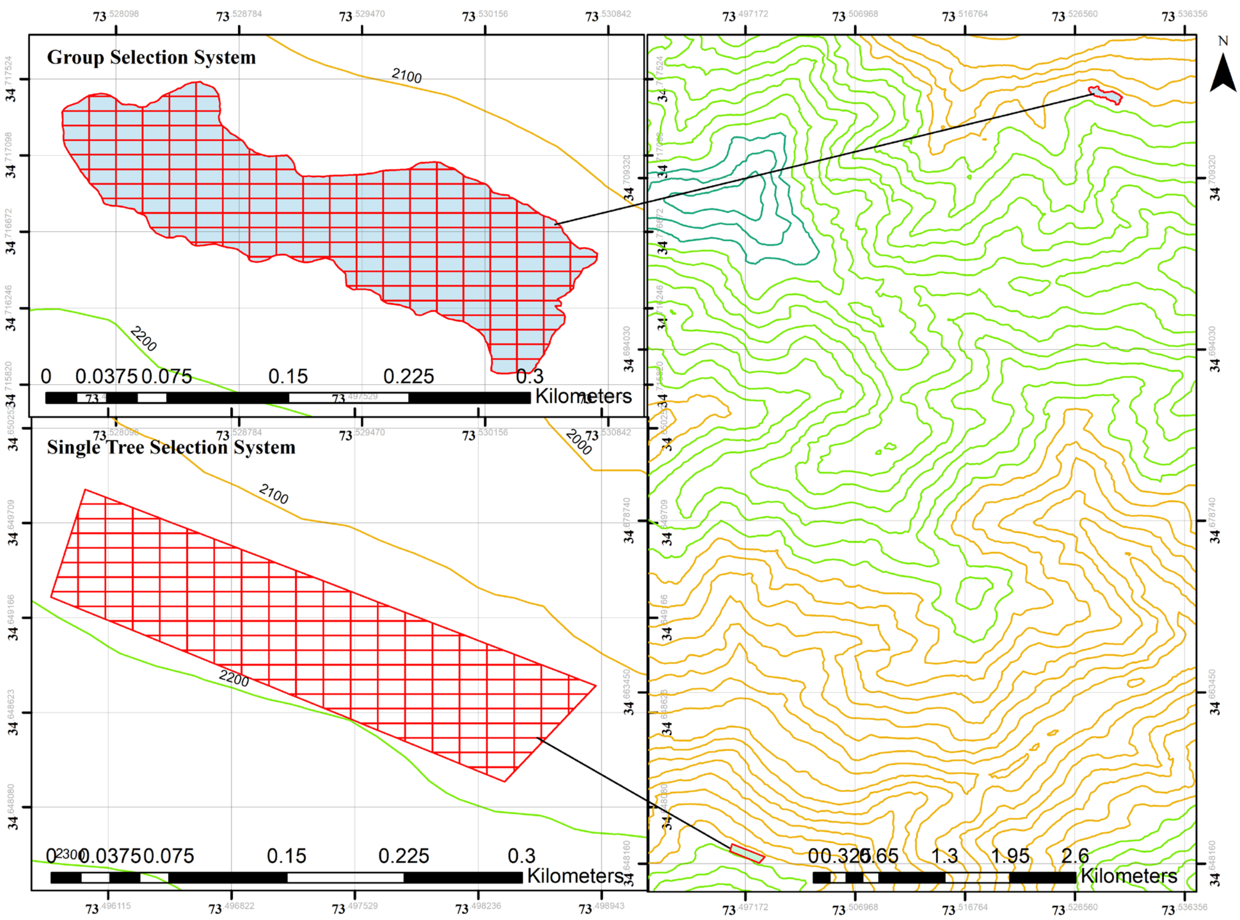

Figure 2. Detailed description and location of the study site (ArcGIS 10.8.1 Academic)

Table 3. Diversity indices (the diversity was calculated, and the data were examined by Simpson's index and Shannon index)

	Group selection system			Single-tree selection system		
	mean value	lower	upper	mean value	lower	upper
Taxa (*S*)	4	3	4	10	3	6
Individuals	17	17	17	15	15	15
Dominance (*D*)	0.4061	0.247	0.5083	0.3859	0.2034	0.4968
Simpson (1-*D*)	0.5939	0.4917	0.753	0.6141	0.5032	0.7966
Shannon (*H*)	1.08	0.7036	1.252	1.244	0.6682	1.413
Evenness (e^H/S)	0.736	0.5594	0.8861	0.347	0.5775	0.9051
Brillouin	0.6035	0.4882	0.9436	0.5554	0.4168	0.9752
Menhinick	0.9234	0.6925	0.9234	2.403	0.7209	1.442
Margalef	1.059	0.7059	1.059	3.323	0.7385	1.846
Equitability (*J*)	0.7789	0.581	0.9095	0.5403	0.6082	0.9093
Fisher's alpha	1.557	1.057	1.649	9.867	1.128	3.706
Berger-Parker	0.5329	0.373	0.6927	0.5197	0.3465	0.6929
Chao-1	4	3	5	10	3	9

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Table 4. Quadrat measurement (calculate variation among the species and also between the two silvicultural systems)

Species	Group selection system			Single-tree selection system		
	density·m^{-2}	total No. of seedlings·ha^{-1}	relative frequency (%)	density·m^{-2}	total No. of seedlings·ha^{-1}	relative frequency (%)
Pinus wallichiana	10.584	105 844.156	56.401	9.279	92 792.208	53.581
Cedrus deodara	5.032	50 324.675	26.817	5.240	52 402.597	30.259
Picea smithiana	2.162	21 623.377	11.522	1.266	12 662.338	7.312
Abies pindrow	0.987	9 870.130	5.260	0.636	6 363.636	3.675
Quercus dilatata	–	–	–	0.273	2 727.273	1.575
Aesculus indica	–	–	–	0.221	2 207.792	1.275
Alnus nitida	–	–	–	0.065	649.351	0.375
Pinus roxburghii	–	–	–	0.019	194.805	0.112
Robina pseudoacacia	–	–	–	0.188	1 883.117	1.087
Ailanthus altissima	–	–	–	0.130	1 298.701	0.750

The details of the silvicultural systems are below.

Group selection system. The group selection system was used in the KamalBan forest of the Kaghan forest division. Four major species were found along with other species that occurred in the sample plot. The density of the main forest species per square meter was ± 10.58 PW, ± 5.03 CD, ± 2.16 PS, and ± 0.99 AP; details are given in Table 4; through quadrate measurement in the study area. Quadrate measurements show a high level of influence in the group selection system compared to the single tree selection system with the number of seedlings/ha. Many taxa and species were high in the single-tree selection system, compare to the group selection system. Therefore, both of the systems are highly rich in density and diversity. Diversity indices were also shown diversity in Table 3; the dominance of (0.41) both on the upper and lower level of dominance. The Simpson and Shannon diversity were also calculated in Table 3 (± 0.59 and ± 1.1 respectively), whereas the maximum values are ± 1.39 in the group selection system. The equitability and evenness are high also the data record (± 0.78 and ± 0.74 respectively), which shows the excellent mixed crop for sustainable forest management practices. Statistical summary of the data is also shown in Table 5; a std.error of ± 2.14 and variance of ± 18.32 along with the stand.dev of ± 4.28, this data has shown significant value (≤0.05) in the data. Diversity t-test variance is ± 0.029 as compared to the statistical summary, which is ± 18.32, which shows in Table 6; with less difference on diversity level for the Shannon index. Whereas the Simpson index for diversity t-tests variance is highly significant that is ± 0.01. The equal variance test for group selection system values on (P = 0.05) is 5.08, whereas the system's F-values are 1.92 shown in Table 7.

Two sample t-test was also examined to analyse the values in both the silvicultural systems. This shows the critical values of 2.18 under P = 0.05, as the t value is 1.46 under the unequal variation of t-test 1.26.

Table 5. Summary statistics (comparison between two different systems)

	Group selection system	Single-tree selection system
N	4	10
Min	0.987013	0.0194805
Max	10.58442	9.279221
Sum	18.76623	17.31818
Mean	4.691558	1.731818
SE	2.140144	0.9761641
Variance	18.32087	9.528964
SD	4.280288	3.086902
Median	3.597403	0.2467532
25 percentil	1.280844	0.1136364
75 percentil	9.196429	2.25974
Skewness	1.170253	2.113901
Kurtosis	0.7522905	3.919991
Geom. mean	3.265304	0.3857658
CV	91.23382	178.2463

SE – standard error; SD – standard deviation; CV – coefficient of variance

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Table 6. Diversity t-test (additional analysis for mature forest stand comparison and evaluation of the data)

	Group selection system	Single-tree selection system
Shannon index		
H	1.0798	1.2441
Variance	0.029714	0.077317
t	–0.50215	
df	29.206	
P	0.61932	
Simpson index		
D	0.40607	0.38595
Variance	0.0085853	0.0088374
t	0.15245	
df	35.977	
P	0.87969	

Table 7. F-test (comparison with Table 7 for the authenticity of the results)

	Tests for equal variances	
	group selection system	single-tree selection system
N	4	10
Variance	18.321	9.529
F	1.9227	P = 0.39295
Critical F value (P = 0.05)	5.0781	
Monte Carlo permutation	P	0.7531
Exact permutation	P	0.76324

Single-tree selection system. The single-tree selection system was observed in the Malkandi forest by help of and suggested by the forest department for data collection in comparison with the Kamal-Ban forest with group selection system. The total area of the research site for data collection was two ha, with 10 major species and surrounded by *Populus ciliata*, which was rare for data inventory and was not included in the data. Density per square meter of the major species was ± 9.28 PW, ± 5.24 CD, ± 1.27 PS, ± 0.64 AP, ± 0.27 QD, ± 0.22 AI, ± 0.07 AN, ± 0.019 PR, ± 0.19 RP, ± 0.13 AA; for further details see Table 4. For the diversity indices, statistical packages were used and the results are shown in Table 3, mean dominance of 0.39 with a lower level of 0.20 and upper level of 0.50 of dominance. Table 3 also shows the values of ± 0.61 and ± 1.24 related to Simpson and Shannon diversity, respectively, whereas the maximum value of ± 2.30 was calculated for the single-tree selection system. Summary statistics of the research data (Table 5) show the standard error of ± 0.98 and the standard deviation of 3.09 for the single-tree selection system. The two-sample tests (t-test) are shown in Table 8.

The single-tree selection system shows variance of ± 9.53, P-values of 0.05. The single-tree selection system gives high variation in species composition, but the number of individuals in this silvicultural system is low.

Table 8. Two-sample test (t-test) (variance and confidence level were examined in the table)

	Tests for equal means			
	group selection system		single-tree selection system	
N	4		10	
Mean	4.6916		1.7318	
95% conf.	–2.1193 to 11.502		–0.47641 to 3.94	
Variance	18.321		9.529	
Difference between means			2.9597	
95% conf. interval (parametric)			–1.4544 to 7.3739	
95% conf. interval (bootstrap)			–1.2455 to 6.7591	
t	1.4609	P (same mean)	0.16972	Critical t value (P = 0.05), 2.1788
Uneq. var. t	1.2583	P (same mean)	0.27207	
Monte Carlo permutation	P (same mean)	0.1635		
Exact permutation	P (same mean)	0.16484		

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DISCUSSION

From the regeneration diversity, it was a clear indication that the forest stand is highly diversified, diversification leads the forest to the maximum productivity (yield productivity) (Rosenzweig 1995; Suratman 2012; Barlow et al. 2016; Felton et al. 2016). *Pinus wallichiana* and *Cedrus deodara* are abundantly available in the region which have a high market value both for locals and urban markets.

The number of taxa is highly important for the diversity of forest stands, the group selection system and single-tree selection system have the same number, whereas the species variation is large in GSS compared to STSS. This relation of the silvicultural system and management activities has a strong relation between the ecology and management, as the silvicultural system contributes to the health with management treatment and practices (Ames et al. 2015; de Sousa et al. 2015; Egnell, Ulvcrona 2015). The diversity in both research sites shows excellent diversity due to the functions of these forests because these forests are managed for the production of timber and also have a protective role of the watershed area. *Cedrus deodara* is the main timber productive species in the mountainous regions, whereas species like *Pinus wallichiana* are considered as firewood in the high altitude region (Maltoni et al. 2019). Both at the low and high altitude *Quercus* species are among the main and easily accessible tree species for the firewood with high calorific value.

Forest regeneration is also under competition with other undergrowth, which causes a high threat to future regeneration (Vopravil et al. 2014; Novák et al. 2015). But, due to the favourable conditions for the growth the soil health is also in a very good condition on a moderate slope area, which can help the regeneration (Marques et al. 2010). Regeneration diversity is of great importance for future conservation, climate change, forest degradation, and deforestation activities (Sulaiman et al. 2017). Group selection is more compact visibly as compared to the single-tree selection system, whereas the single-tree selection system is more diversified in species composition, stand structure, moisture availability, less humus most of the litter is decomposed (Achat et al. 2015).

The regeneration was highly influenced by the first regeneration felling which retained seed bearers which need to be 10–14 m apart in deodar regeneration sites (Champion et al. 1965 b). Fir and spruce regeneration sites are treated with the shelterwood system where these species are highly associated with broadleaved species (Champion et al. 1965 b; Vauhkonen, Pukkala 2016). These two species have different growth requirements in the early stage of their life. Weed growth is also highly significant for the interception and disturbance during the growth season of these natural regeneration areas (Yamashita et al. 2016). Unfavourable growth conditions, bad seed years, competition due to weeds and/or other unwanted plant species lead foresters to treat the regeneration with artificial supplementation if it is necessary (Tappeiner 1969).

CONCLUSION

Stand structure. Stand structure of both group selection system and single-tree selection was different due to the silvicultural system. Compared to the group selection system litter is partially decomposed due to low moisture and lower exposure to sunlight. Diameter and height data were also collected but due to being out of focus in the present study they were not included here. Whereas visibly there is homogeneity in diameters and heights of the main stand crop, only partial differences were observed on the edges due to low competition in the group selection system compared to the single-tree selection system.

Stand composition. Forest stands are highly diversified in the single-tree selection system, along with the undergrowth, but the number of individuals is high in the group selection system. Single-tree stand composition gives a high value to the watershed and also plays a vital role in livestock management, wildlife conservation, and as the source of fuelwood. Due to the nature of these mountain areas, the stand composition is very important. The present study also highlights the future prediction for the conservation of these forests, which are highly sensitive and a hotspot for wildlife and climate change phenomena. The carbon sequestration ability of these mountain forests has great importance after calculating the regeneration growth and rate of success.

Future management. These valuable forests need critical care and proper silvicultural, scientific, and economic management practices to be addressed

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for the policy of mountain forest. The mountain forests are highly threatened throughout the globe. Silvicultural practices such as silvicultural system, cleaning, weeding, thinning operations are regular practices that can reduce the negative impact on these productive forests, and also they give space to reduce the emission of carbon and other gases. The numbers of taxa have multiple uses and functions in ecological sustainability, they are productive, protective, and suitable niche for the wildlife of the mountain region.

REFERENCES

Achat D.L., Fortin M., Landmann G., Ringeval B., Augusto L. (2015): Forest soil carbon is threatened by intensive biomass harvesting. Scientific Reports, 5: 15991.

Ames G.M., Vineyard D.L., Anderson S.M., Wright J.P. (2015): Annual growth in longleaf (*Pinus palustris*) and pond pine (*P. serotina*) in the Sandhills of North Carolina is driven by interactions between fire and climate. Forest Ecology and Management, 340: 1–8.

Barbour M.G., Burk J.H., Pitts W.D. (1987): Terrestrial Plant Ecology. Michigan, Benjamin/Cummings Publishing Company: 604.

Barlow J., Lennox G.D., Ferreira J., Berenguer E., Lees A.C., Nally R.M. *et al.* (2016): Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. Nature, 535: 144–147.

Barnes B.V., Zak D.R., Denton S.R., Spurr S.H. (1998): Forest Ecology. 4th Ed. New York, John Wiley & Sons, Inc.: 774.

Begon M., Harper J.L., Townsend C.R. (1996): Ecology: Individuals, Populations and Communities. Oxford, Blackwell Science: 1068.

Brewer J.S., Bertz C.A., Cannon J.B., Chesser J.D., Maynard E.E. (2012): Do natural disturbances or the forestry practices that follow them convert forests to early-successional communities? Ecological Applications, 22: 442–458.

Bukhari S.S.B., Haider A., Laeeq M.T. (2012): Landcover Atlas of Pakistan. Peshawar, Pakistan Forest Institute, Peshawar: 220.

Bulušek D., Vacek Z., Vacek S., Král J., Bílek L., Králíček I. (2016): Spatial pattern of relict beech (*Fagus sylvatica* L.) forests in the Sudetes of the Czech Republic and Poland. Journal of Forest Science, 62: 293–305.

Chakrabarti B.K. (2016): Geology of the Himalayan Belt. Amsterdam, Elsevier: 264.

Champion S.H.G., Seth S.K., Khattak G.M. (1965a): Forests Types of Pakistan. Peshawar, Pakistan Forest Institute, Peshawar: 238.

Champion S.H.G., Seth S.K., Khattak G.M. (1965 b): Manual of Silviculture for Pakistan. Peshawar, Pakistan Forest Institute, Peshawar: 547.

Chen J., Yamamura Y., Hori Y., Shiyomi M., Yasuda T., Zhou H.-K., Li Y.-N., Tang Y.-H. (2007): Small-scale species richness and its spatial variation in an alpine meadow on the Qinghai-Tibet Plateau. Ecological Research, 23: 657–663.

Dănescu A., Kohnle U., Bauhus J., Weiskittel A., Albrecht A.T. (2018): Long-term development of natural regeneration in irregular, mixed stands of silver fir and Norway spruce. Forest Ecology and Management, 430: 105–116.

de Carvalho A.L., d'Oliveira M.V.N., Putz F.E., de Oliveira L.C. (2017): Natural regeneration of trees in selectively logged forest in western Amazonia. Forest Ecology and Management, 392: 36–44.

de Sousa K.F.D., Detlefsen G., de Melo Virginio Filho E., Tobar D., Casanoves F. (2015): Timber yield from smallholder agroforestry systems in Nicaragua and Honduras. Agroforestry Systems, 90: 207–218.

dos Santos J.F.C., Gleriani J.M., Velloso S.G.S., de Souza G.S.A., do Amaral C.H., Torres F.T.P., Medeiros N.D.G, dos Reis M. (2019): Wildfires as a major challenge for natural regeneration in Atlantic Forest. Science of the Total Environment, 650: 809–821.

Egnell G., Ulvcrona K.A. (2015): Stand productivity following whole-tree harvesting in early thinning of Scots pine stands in Sweden. Forest Ecology and Management, 340: 40–45.

Felton A., Hedwall P.O., Lindbladh M., Nyberg T., Felton A.M., Holmström E., Wallin I., Löf M., Brunet J. (2016): The biodiversity contribution of wood plantations: Contrasting the bird communities of Sweden's protected and production oak forests. Forest Ecology and Management, 365: 51–60.

Fisher R.A., Corbet A.S., Williams C.B. (1943): The relation between the number of species and the number of individuals in a random sample of an animal population. Journal of Animal Ecology, 12: 42–58.

Gallo J., Vacek Z., Baláš M., Vacek S. (2020): Germinative capacity and energy of critically endangered Ojców birch (*Betula oycoviensis* Besser) in the Czech Republic. Journal of Forest Science, 66: 227–235.

Grime J.P. (1988): The CSR Model of Primary Plant Strategies – Origins, Implications and Tests. In: Gottlieb L.D., Jain S. K. (eds): Plant Evolutionary Biology. Dordrecht, Springer: 371–393.

Guo Q., Kato M., Ricklefs R.E. (2003): Life history, diversity and distribution: A study of Japanese pteridophytes. Ecography, 26: 129–138.

Hammer O., Harper D., Ryan P. (2001): PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4: 1–9.

https://doi.org/10.17221/124/2020-JFS

Ives J.D. (2004): Himalayan Perceptions: Environmental Change and the Well-being of Mountain Peoples. Abingdon, Routledge Taylor & Francis Group: 271.

Kent M., Coker P. (1992): Vegetation Description and Analysis. A Practical Approach. London, Belhaven Press: 363.

Magurran A.E. (1988): Ecological Diversity and its Measurement. London (UK), Chapman & Hall: 179.

Maltoni A., Mariotti B., Tani A., Martini S., Jacobs D.F., Tognetti R. (2019): Natural regeneration of *Pinus pinaster* facilitates *Quercus ilex* survival and growth under severe deer browsing pressure. Forest Ecology and Management, 432: 356–364.

Marques M.C.M., Swaine M.D., Liebsch D. (2010): Diversity distribution and floristic differentiation of the coastal lowland vegetation: Implications for the conservation of the Brazilian Atlantic Forest. Biodiversity and Conservation, 20: 153–168.

Morris R.F. (1951): The effects of flowering on the foliage production and growth of balsam fir. The Forestry Chronicle, 27: 40–57.

Mulder C.P.H., Bazeley-White E., Dimitrakopoulos P.G., Hector A., Scherer-Lorenzen M., Schmid B. (2004): Species evenness and productivity in experimental plant communities. Oikos, 107: 50–63.

Novák J., Dušek D., Slodičák M. (2015): Thinning in artificially regenerated young beech stands. Lesnícky časopis – Forestry Journal, 61: 232–239.

Pignataro A.G., Levy-Tacher S.I., Aguirre-Rivera J.R., Nahed-Toral J., González-Espinosa M., González-Arzac A., Biganzoli F. (2017): Natural regeneration of tree species in pastures on peasant land in Chiapas, Mexico. Agriculture, Ecosystems & Environment, 249: 137–143.

Rezende G.M., Vieira D.L.M. (2019): Forest restoration in southern Amazonia: Soil preparation triggers natural regeneration. Forest Ecology and Management, 433: 93–104.

Rocha G.P.E., Vieira D.L.M., Simon M.F. (2016): Fast natural regeneration in abandoned pastures in southern Amazonia. Forest Ecology and Management, 370: 93–101.

Rosenzweig M.L. (1995): Species Diversity in Space and Time. Cambridge, Cambridge University Press: 436.

Roth D.S., Perfecto I., Rathcke B. (1994): The effects of management systems on ground-foraging ant diversity in Costa Rica. Ecological Applications, 4: 423–436.

Splawinski T.B., Gauthier S., Bergeron Y., Greene D.F., Valeria O. (2016): A landscape-level tool for assessing natural regeneration density of *Picea mariana* and *Pinus banksiana* following fire and salvage logging. Forest Ecology and Management, 373: 189–202.

Sulaiman C., Abdul-Rahim A.S., Mohd-Shahwahid H.O., Chin L. (2017): Wood fuel consumption, institutional quality, and forest degradation in sub-Saharan Africa: Evidence from a dynamic panel framework. Ecological Indicators, 74: 414–419.

Suratman M.N. (2012): Tree Species Diversity and Forest Stand Structure of Pahang National Park, Malaysia. In: Gbolagade A. L. (ed.): Biodiversity Enrichment in a Diverse World. London, InTech: 473–492.

Tappeiner J.C.II. (1969): Effect of cone production on branch, needle, and xylem ring growth of Sierra Nevada Douglas-fir. Forest Science, 15: 171–174.

Tinya F., Márialigeti S., Bidló A., Ódor P. (2019): Environmental drivers of the forest regeneration in temperate mixed forests. Forest Ecology and Management, 433: 720–728.

Vacek Z., Vacek S., Podrázský V., Bílek L., Štefančík I., Moser W.K., Bulušek D., Král J., Remeš J., Králíček I. (2015): Effect of tree layer and microsite on the variability of natural regeneration in autochthonous beech forests. Polish Journal of Ecology, 63: 233–246.

Vacek S., Hejcman M. (2012): Natural layering, foliation, fertility and plant species composition of a *Fagus sylvatica* stand above the alpine timberline in the Giant (Krkonoše) Mts., Czech Republic. European Journal of Forest Research, 131: 799–810.

Vacek S., Hejcmanová P., Hejcman M. (2012): Vegetative reproduction of *Picea abies* by artificial layering at the ecotone of the alpine timberline in the Giant (Krkonoše) Mountains, Czech Republic. Forest Ecology and Management, 263: 199–207.

Vacek Z., Vacek S., Bílek L., Král J., Remeš J., Bulušek D., Králíček I. (2014): Ungulate impact on natural regeneration in spruce-beech-fir stands in Černý důl Nature Reserve in the Orlické Hory Mountains, case study from Central Sudetes. Forests, 5: 2929–2946.

Vacek S., Vacek Z., Kalousková I., Cukor J., Bílek L., Moser W.K., Bulušek D., Podrázský V., Řeháček D. (2017a): Sycamore maple (*Acer pseudoplatanus* L.) stands on former agricultural land in the Sudetes – evaluation of ecological value and production potential. Dendrobiology, 79: 61–76.

Vacek S., Černý T., Vacek Z., Podrázský V., Mikeska M., Králíček I. (2017 b): Long-term changes in vegetation and site conditions in beech and spruce forests of lower mountain ranges of Central Europe. Forest Ecology and Management, 398: 75–90.

Vacek S., Prokůpková A., Vacek Z., Bulušek D., Šimůnek V., Králíček I., Prausová R., Hájek V. (2019): Growth response of mixed beech forests to climate change, various management and game pressure in Central Europe. Journal of Forest Science, 65: 331–345.

Vauhkonen J., Pukkala T. (2016): Selecting the trees to be harvested based on the relative value growth of the remaining trees. European Journal of Forest Research, 135: 581–592.

https://doi.org/10.17221/124/2020-JFS

Vopravil J., Podrázský V., Khel T., Holubík O., Vacek S. (2014): Effect of afforestation of agricultural soils and tree species composition on soil physical characteristics changes. Ekológia, 33: 67–80.

Yadava A.K., Sharma Y.K., Dubey B., Singh J., Singh V., Bhutiyani M.R., Yadav R.R., Misra K.G. (2017): Altitudinal treeline dynamics of Himalayan pine in western Himalaya, India. Quaternary International, 444: 44–52.

Yamashita N., Okuda S., Suwa R., Lei T.T., Tobita H., Utsugi H., Kajimoto T. (2016): Impact of leaf removal on initial survival and growth of container-grown and bare-root seedlings of Hinoki cypress (*Chamaecyparis obtusa*). Forest Ecology and Management, 370: 76–82.

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