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Natural Regeneration and Population Assessment of *Berberis aristata*: A Endangered High Value Medicinal Shrub of Western Himalayas

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Abstract: The present study was undertaken to assess the natural regeneration and population status of *Berberis aristata* DC. in the Sindh Forest Range of Ganderbal district, Jammu & Kashmir, India. Twelve sampling plots (20 × 20 m), 96 sub-plots (5 × 5 m), and 864 sub-sub plots (1 × 1 m) were randomly established along both north and south aspects of the Sindh River at three elevation ranges: E1 (1500–2000 m AMSL), E2 (2000–2500 m AMSL), and E3 (>2500 m AMSL). The regeneration per cent was highest (16.7%) at mid-altitude (2000–2500 m AMSL). The northern aspect exhibited fair regeneration up to 2500 m AMSL, whereas the southern aspect showed poor regeneration at similar elevations. Population attributes *viz*., mean density (12.9 m²), frequency (14.8%) and basal area (3.51 m²) were highest at mid-altitude on the southern aspect. However, these parameters increased up to mid-altitude and thereafter declined. The study concluded that mean regeneration status of *B. aristata* was very poor (16.7%), indicating that the species faces a high risk of extinction.

Keywords: *Berberis aristata*, Conservation, Kashmir Himalaya, Natural regeneration

There are numerous shrub species which co-exist with other tree and grass-based land use systems (Thakur et al., 2005), contributing towards economics, health wellbeing and environment conservation and carbon sequestration. Among these the genus *Berberis contribute these aforesaid important attributes* (Thakur et al., 2011, Thakur et al., 2017). Globally, this genus comprises of 500 species, of which nearly 60 are reported from the Indian Himalayas (Hashmi et al., 2024). The family Berberidaceae comprises 16 genera, with *Berberis* being the largest, accounting for about 70–80% of total species. Among them, *Berberis aristata* DC., is an important medicinal shrub distributed from the western Himalayas to Sri Lanka, Bhutan, and Nepal, and sporadically in the Nilgiri hills of South India (Sharma et al., 2018). It generally occurs at altitudes of 1800–2800 m AMSL, but in rare and scattered populations (Thakur et al., 2011). Pharmacological studies have confirmed a broad spectrum of properties including antibacterial, antiviral, antifungal, anticancer, and antidiabetic activities, largely attributed to **berberine**, a quaternary is quinoline alkaloid concentrated in the roots and stems (Sharma et al., 2024). Despite its importance, *B. aristata* faces severe threats due to overharvesting of roots for berberine extraction, habitat degradation and lack of propagation protocols. Consequently, it has been listed as an endangered species in the Indian Himalayan Region by the IUCN (Malik et al., 2024). Natural regeneration in this species is poor due to low germination, irregular fruiting and seed predation, resulting in declining wild populations (Malik et al., 2024). Parallel ecological studies have shown that regeneration dynamics of forest species vary markedly along altitudinal gradients (Joshi 2023). *Berberis aristata* and *B. jaeschkeana* attained the highest density in Sangla valley, Northwest Himalayas, reflecting their strong adaptability to extreme climates (Mohapatra 2019). Diversity of *B. lycium* was also higher on drier (southern aspects) along Neeru stream (J&K) (Sharma et al., 2017). Aspect-driven variation in community composition was further confirmed (Sinha and Sinha 2013) in the Balandi watershed, Chhattisgarh, India where species dominance differed significantly between aspects. Despite the ecological and medicinal importance of *B. aristata*, no detailed study on its regeneration status and phytosociology has been reported from Sindh Forest Division, Ganderbal (J&K), or elsewhere in Kashmir Himalaya, particularly across aspects. Therefore, the present study was undertaken to analyze its community structure and regeneration dynamics.

MATERIAL AND METHODS

The regeneration and population assessment of *B. aristata* was conducted during the year 2021 to 2022 in Sindh Forest Range of Ganderbal district (J&K) located at 34°7'0" to 34°28'0"N and 74°42'0" to 74°26'0" E (Fig. 1). The study range was divided into three altitudes *viz*., E1 (1500–2000 m AMSL), E2 (2000–2500 m AMSL), and E3 (>2500 m AMSL) with two aspects *viz*., northern and southern aspects. To assess the population and regeneration status of *Berberis* *aristata*, four sampling plots (20 × 20 m) were established at each of altitudinal range and aspect. Each main plot was subdivided into eight sub-plots (5 × 5 m) for population assessment. However, each sub-plot was further divided into nine quadrats (1 × 1 m) for regeneration survey. In total, 12 main plots, 96 sub-plots and 864 regeneration quadrats were laid along three altitudinal gradients along two aspects of the study area to understand the natural regeneration potential of the species. The occurrence of *B. aristata* was used as an indicator for laying the sampling plots to study its natural population status of the species.

Regeneration assessment: The survey was conducted for counting number of recruits (r), which may be defined as the current year seedlings, established regeneration (u) seedlings other than recruits which has not yet established and with height less than 2 meter and established regeneration (e) plants with more than 2 meter height (Chacko 1965).

$$\text{Recruits= (r)/ha= } 2500 \sum \frac{\text{total number of recruits in each quadrant}}{\text{Total number of recording units (plots or blocks) laid in a stratum}}$$

$$\text{Unestablished regneration=(u)/ha= } 2500 \sum \frac{\text{total no. of un-established plants in each quadrant}}{\text{total number of (plots or blocks) laid in a stratum}}$$

$$\text{Established regeneration=(e)/ha= } 2500 \sum \frac{\text{total number of established plants in each quadrant}}{\text{total number of (plots or blocks) laid in a stratum}}$$

$$\text{Weighted average height (cm)=} \frac{\text{Total height of un-established regeneration + (Number of established plants × establishment height)}}{\text{Total un-established plants + Total established plants}}$$

$$\text{Establishment index (I)=} \frac{\text{Weighted average height}}{\text{Establishment height}}$$

$$\text{Stocking Index (II)=} \frac{1}{2500} \times \frac{\text{(u) regeneration/ha}}{2} + \text{(e) regeneration/ha}$$

Established stocking per cent=100 (Establishment Index × Stocking Index)

Regeneration success (%)=Stocking Index (I) × 100 (Malik et al., 2012).

The regeneration status of *B. aristata* in the area was also evaluated by comparing seedling with sapling and sapling with matured shrub data (Shankar, 2001) in the following categories; G good, fair, poor, none and new regeneration

Population assessment: For population assessment the following quantitative parameters were taken into consideration;

$$\text{Density=} \frac{\text{Total number of individuals of a species in all quadrants}}{\text{Total number of quadrants studied}} \times 100$$

$$\text{Frequency=} \frac{\text{Number of quadrants in which the species occurred}}{\text{Total number of quadrants studied}} \times 100$$

$$\text{Basal area=} \frac{\pi D^2}{4}$$

RESULTS AND DISCUSSION

The maximum mean number of mature shrubs were recorded on the southern aspect at 2000–2500 m AMSL(3.5), while the minimum occurred above 2500 m on the northern aspect (0.5) (Table 1). Mature shrub density increased up to mid-altitude before declining with elevation. Saplings were highest (1.0) at 2000–2500 m AMSL on both aspects, whereas seedlings were maximum (1.5) on the northern aspect at the same elevation, indicating better regeneration potential under northern microclimatic conditions. Regeneration was absent at 1500–2000 m AMSL on both aspects, while above 2500 m AMSL only poor regeneration was observed . Regeneration density and stocking patterns vary significantly with altitude and slope aspect in Himalayan forests, with seedling and sapling densities often peaking at mid-altitudes and differing between northern and southern aspects (Sharma et al., 2018, Negi et al., 2024). Studies in the Garhwal Himalaya revealed that overall regeneration status of forest species was fair to good at mid-altitude zones, correlating with optimal microclimatic conditions and reduced anthropogenic disturbance, while regeneration declined at higher elevations due to harsher climatic constraints (Sharma et al., 2018). Similarly, biological diversity and regeneration in North-Western Himalayan agroforestry varied with altitude, aspect, and habitat. Mid-altitude sites supported greater diversity and regeneration of woody species like *B. aristata*. Replicated, plot-based sampling facilitates accurate assessment of population and regeneration, underscoring the ecological influence on species conservation in Himalayan agroforestry systems (Thakur et al., 2005).

At lower altitude (1500–2000 m AMSL), the maximum number of recruits were recorded on the southern aspect

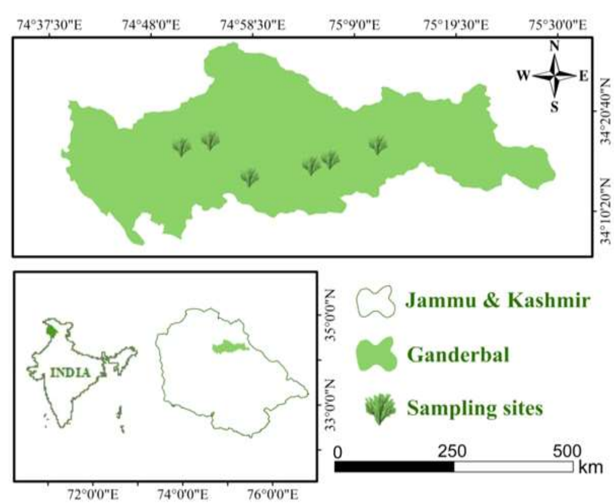

Fig. 1. Ganderbal district distribution zone of *B. aristata*

(414.66 recruits ha⁻¹), whereas the minimum (277.77 recruits ha⁻¹) on the northern aspect. In contrast, un-established regeneration peaked at mid-altitude (2000–2500 m AMSL) on the northern aspect (555.56 ha⁻¹) and was lowest (138.89 ha⁻¹) at higher altitude (>2500 m AMSL) on the same aspect. Established regeneration followed a similar trend, with the highest value (277.78 ha⁻¹) observed at mid-altitude on the southern aspect and the lowest (138.89 ha⁻¹) at both lower and higher altitudes of the southern aspect and at higher altitudes of the northern aspect. The stocking index (I_1) also varied across altitudes and aspects, with the highest at mid-altitude (2000–2500 m AMSL) (0.167) on the northern aspect, followed by 0.112 on the southern aspect, while the lowest (0.083) occurred at lower altitude on the southern aspect. Shrub species diversity in the Indian Himalayas generally shows a hump-shaped pattern along elevation, with peak diversity at mid-altitudes and decline at higher elevations due to colder temperatures and harsher conditions (Boscutti et al., 2018). Aspect influences shrub distribution, as southern slopes often support higher species diversity owing to greater sunlight exposure, while northern slopes tend to support moisture-retentive but less diverse shrub communities (Wani et al., 2023). These vegetation patterns reflect strong altitudinal and aspect-driven ecological gradients documented in cold desert and temperate Himalayan zones, underscoring their importance in biodiversity conservation planning (Negi et al., 2024). Regeneration per cent exhibited marked variation across altitudes and aspects (Fig. 3). The highest regeneration per cent (16.7%) was at mid-altitude (2000-2500m AMSL) on the northern aspect, followed by 11.2% at lower altitude (1500-2000m AMSL) on the northern aspect and 2.78% (the lowest figure) at higher elevation on the southern aspect . According to the methodology of Chacko (1965), the overall maximum regeneration potential (recruits: 277.78 ha⁻¹, un-established: 555.56 ha⁻¹, established: 277.77 ha⁻¹, establishment stocking: 7.47%) was also concentrated at mid-altitude on the northern aspect.– These findings clearly indicate that regeneration of *B. aristata* is more successful on the northern aspect, particularly at mid-altitudes, where favorable

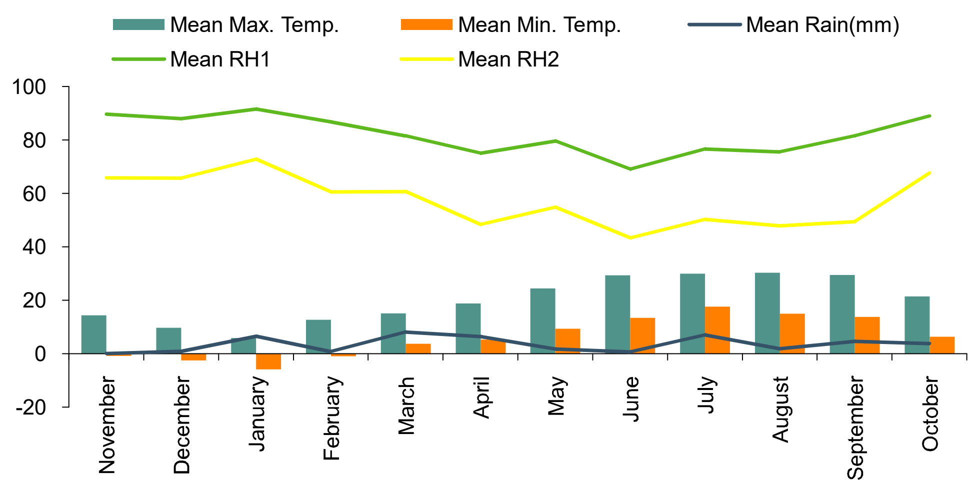

Fig. 2. Meteorological data of Sindh forest range (November 2021 to October 2022)

Table 1. Regeneration status of *B. aristata* along the altitudinal gradient and aspect in Sindh Forest range of district Ganderbal

Elevation (m AMSL)	Average no. of mature shrubs		Average no. of saplings		Average no. of seedlings		Regeneration status	
	NA	SA	NA	SA	NA	SA	NA	SA
E_1	1.0	2.0	-	-	-	-	N	N
E_2	1.50	3.50	1.0	1.0	1.50	-	F	P
E_3	0.50	1.0	0.50	0.50	-	-	P	P
Mean	1.0	2.10	0.50	0.50	0.50	-		
CV (%)	50.0	59.50	100.0	100.0	172.0			
C.I.	U.L	2.35	5.11	1.37	1.37	1.66		
	L.L	1.56	3.11	0.58	0.58	0.29		

NA-north aspect; SA- south aspect; E1= (1500-2000); E2= (2000-2500); E3= (Above 2500); N-no regeneration, F-fair regeneration, P-poor regeneration, C.I-Confidence interval, UL-upper limit, LL-lower limit moisture regimes, nutrient availability and reduced anthropogenic disturbances likely create optimal conditions for establishment. The trend is consistent with previous studies, where higher regeneration on northern aspects was reported for *Pinus gerardiana* (Malik et al., 2012), *Pinus ponderosa* (Busse et al., 1996), and fir–spruce communities in Shimla (Yashpal, 2006). The overall regeneration status indicated fair regeneration on the northern aspect at mid-altitude and poor regeneration on the southern aspect, while both aspects lacked regeneration at lower elevations.

Phytosociological parameters also followed a mid-altitude dominance trend. The maximum density (22.22 m^2/ha), basal area (6.93 m^2), and frequency (22.22%) were at 2000–2500 m AMSL on the southern aspect (Table 3). In

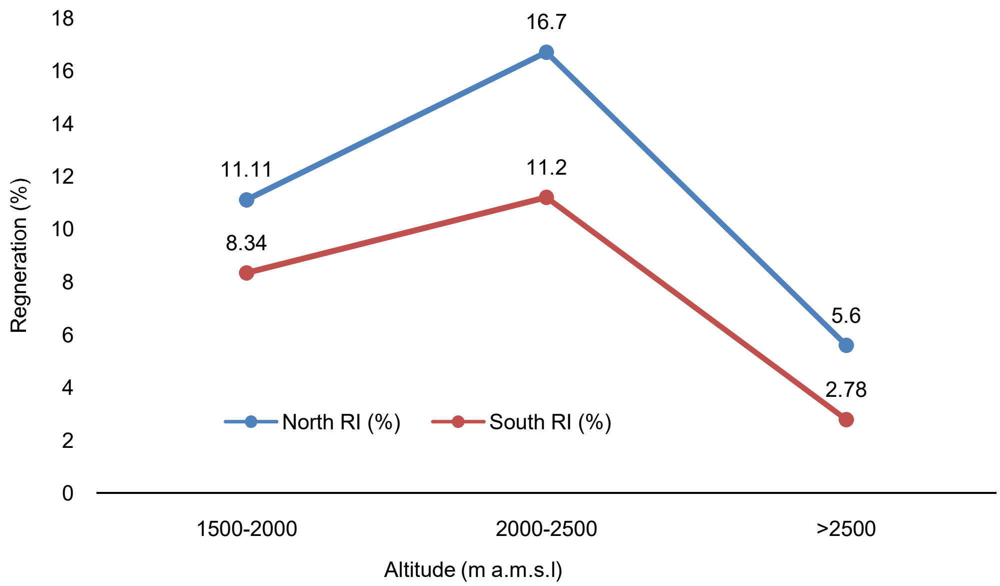

Fig. 3. Regeneration index (%) of *B. aristata* across altitudinal gradients under north and south aspects in the Sindh Forest Range

Table 2. Natural regeneration status of *B. aristata* at different elevations and aspects of Sindh forest range of district Ganderbal

Aspect	E	RC/ha	U/ha	Ht. U (cm)	Est./ha	WAH (cm)	EI (I_1)	SI (I_2)	ES (%)
North aspect	E_1	277.77	555.55	155.00	0.00	0.38	0.19	0.11	2.14
	E_2	277.78	555.56	150.00	277.77	0.89	0.44	0.16	7.47
	E_3	0.00	138.89	190.00	138.89	1.95	0.97	0.05	5.46
South aspect	E_1	414.66	277.78	160.00	138.89	1.05	0.52	0.08	4.37
	E_2	0.00	277.78	155.00	277.78	1.18	0.53	0.11	6.64
	E_3	0.00	0.00	0.00	138.89	1.70	0.85	0.02	2.36

See Table 2 for treatments details

Table 3. Phytosociology of *B. aristata* along altitudinal gradient and aspects in Sindh Forest Range of district Ganderbal

Elevation (m AMSL)		Density/plot (m^2)		Frequency (%)		Basal area (m^2)	
		North aspect	South aspect	North aspect	South aspect	North aspect	South aspect
E_1		6.25	11.11	5.60	11.11	2.0	2.20
E_2		9.37	22.22	16.70	22.22	3.20	6.93
E_3		3.12	5.60	5.60	11.11	1.10	1.40
Mean		6.24	12.90	9.30	14.80	2.10	3.51
CV (%)		67.60	65.11	68.8	43.30	48.0	82.6
CI	UL	9.87	19.64	16.76	19.93	2.90	5.83
	LL	3.12	6.15	1.83	9.66	1.29	1.18

See Table 2 for treatments details

contrast, the northern aspect reported lower density (6.24 m²/ha) and basal area (2.1 m²). Bhandari et al. (2000) observed highest density of shrubs on southern aspect may be related to the lower density and less developed canopy of trees, which may have allowed enough light to reach the ground and encouraged the growth of shrubs. In contrast, the deep, well-developed canopy in the northern aspect prevents enough sunlight from reaching the shrub vegetation to support it. The basal area is directly correlated with density of the species. Similar trends were observed in Kashmir Valley agroforestry systems, where shrub and herb densities declined with increasing canopy cover, highlighting the role of light availability in understory growth (Rather et al., 2025). Rawat and Chandra (2014) also reported that while trees and herbs attained maximum diversity, richness, and density along moist stream banks in Garhwal Himalayas, shrubs thrived better on drier sites—supporting the present observation of *B. aristata* exhibiting higher density on southern (drier) aspects and better regeneration on northern (moister) aspects. Sharma et al. (2017) observed higher density and diversity of *B. lycium* in drier zones (Z-II) on both banks of Neeru stream (J&K). Sharma et al. (2014) documented the highest density of *B. aristata* and *B. jaeschkeana* in Sangla Valley, attributing this to their strong adaptive capacity to extreme Western Himalayan climates. The phytosociological study in Gomarda Wildlife Sanctuary, Chhattisgarh, recorded 66 herb species across 52 genera and 25 families, reflecting moderate to high herbaceous diversity linked to habitat heterogeneity and microenvironmental variation indicated by IVI differences among sites (Patel et al., 2024). The present findings also align with Kumar (2017) indicating higher density and basal area of shrubs on southern aspects, likely due to increased solar radiation. Bhardwaj et al. (2021) reported that the community characters differ among aspect, slope, and altitude even in the same vegetation type. These findings are consistent with reports indicating that shrub diversity attains its peak on drier sites, reflecting niche differentiation driven by microhabitat conditions.

The population structure, characterized by low seedling and sapling density, indicates regeneration challenges, largely attributed to anthropogenic pressure, fuelwood collection, and poor agricultural practices of *B. aristata* (Srivastava et al., 2006; Ali et al., 2008). Given the species' endangered status (Amira, 2021), these findings provide baseline data essential for its conservation and sustainable management.

CONCLUSION

Maximum regeneration percentage of *B. aristata* occurred at mid-altitudes (2000-2500 m AMSL) across northern and southern aspects, with the northern aspect exhibiting relatively better regeneration compared to the southern aspect. The overall regeneration status of the species was extremely poor, with only 16.7% regeneration and 7.4 % establishment stocking, indicating the poor natural regeneration in the study area. This poor regeneration can be attributed to multiple anthrogenic pressures such as overharvesting, intensive grazing and habitat disturbance, coupled with species biological constraints. Given that *B. aristata* has already been categorized as "endangered" by the IUCN, the observed regeneration failure underscores the urgent need for immediate protection measures. For the implementation of successful conservation strategies and for understanding the status of *B. aristata* in the area, this information is crucial for further ex-situ and in-situ conservation of the species.

AUTHOR'S CONTRIBUTION

Nisha Tariq: Conceptualization, field investigation, data collection, data analysis and manuscript writing (original draft preparation) ,A.R. Malik: Conceptualization, Supervision, study design, project administration and critical manuscript review and editing, S.A. Gangoo: Methodology development and guidance on experimental design, P. A. Sofi: Data analysis, interpretation and statistical validation, Tahir Mushtaq: Assistance in field sampling and data compilation, Amerjeet Singh: Support in data management and preparation of figures/ tables, Peerzada Ishtiyak Ahmad: Review and editing of the manuscript, Mehvish Mushtaq: Literature survey and preparation of reference materials, N. A. Pala: Assistance in data interpretation and manuscript editing, S. N. Zafar: Administrative support and coordination with field authorities.

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