Population structure and regeneration status of rhododendrons in temperate mixed broad-leaved forests of western Arunachal Pradesh, India

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ABSTRACT

This study was conducted to investigate the population structure and regeneration status of Rhododendron tree species in temperate mixed broad-leaved forests in Tawang and West Kameng districts of western Arunachal Pradesh, India. Population structure was determined through densities of seedlings, saplings and adults from the sampling quadrats. Based on density of individuals at the seedling, sapling and adult, the regeneration status of the species was determined. Density and basal area of the selected rhododendrons ranged from 16 individuals ha\(^{-1}\) to 1422 individuals ha\(^{-1}\) and 0.24 m\(^2\) ha\(^{-1}\) to 131.30 m\(^2\) ha\(^{-1}\), respectively. Rhododendron species (viz. R. arboreum, R. arboreum ssp. delavayi var. delavayi, R. barbatum and R. kesangiae) exhibited reverse J-shaped distribution with the density of sapling less than seedling and adult population. Density of selected Rhododendron species is found to be higher between the girth classes 10-30 cm to 130-150 cm and decreased with the increase of girth in all the study stands. About, 90% degrees of disturbances recorded due to cooking and space heating purposes. Among the regeneration species, 77% of the species exhibited fair regeneration, 8% species showed good regeneration while 15% of the species exhibited no regeneration. However, 90% of the tree species showed fair regeneration in disturbed stands than the undisturbed stands. Selected Rhododendron species exhibited fair regeneration in their respective stands. Inadequate regeneration status and population structure of tree species, including rhododendrons, are observed as the density of sapling less than seedling and adult population. Anthropogenic disturbances resulted to be declined in populations of Rhododendron and may lead many species to endangered, rare and threatened categories. Therefore, proper conservation and management initiatives with active involvement of local people are urgent need to protect this keystone plant species in their habitat particularly in western Arunachal Himalaya.

Introduction

The population density of seedlings, saplings and adults governed the population structure and status of regeneration of any forest community. Renewal of a tree species in a forest encompasses the production and dispersal of seeds, their germination and subsequent growth and survival of seedlings and saplings until they reach maturity and start producing seeds by themselves (Good & Good, 1972; Rao, 1988). Population structures are very important to know the contrivance of species cohabitation and enduring environmental processes in natural forest (Miura, Manabe, Nishimura, & Yamamoto, 2001). Factors like disturbance, competitive interactions between trees influence the population structure and recruitment patterns of forests (North et al., 2004). Tree species having adequate quantity of seedlings, saplings and young individuals in a forest community points toward successful regeneration, insufficient quantity of seedlings, saplings and young individuals denote poor regeneration, whereas tree species without any seedlings and saplings in a forest signify no regeneration (Khan, Rai, & Tripathi, 1987; Saxena & Singh, 1984). Any species renewal is circumscribed to a particular surroundings of habitat range regulate its geographic distribution (Grubb, 1977). Generally, poor regeneration is the foremost problem in mountainous forests (Krauchii et al., 2000). The forests are experiencing many anthropogenic pressures like tree felling, grazing, trampling, etc., and the regeneration is largely important for those forests (West, Shugart, & Ranney, 1981). Factors of abiotic and biotic interaction of the surroundings significantly influence the structure and regeneration process of forest community (Aksamit & Irving, 1984; Boring, Monk, & Swank, 1981; Khan, Rai, & Tripathi, 1986; Pornon & Doche, 1996; Tripathi & Khan, 2007). Moreover, intensity, magnitude and frequency of disturbance also determine the composition and structure of plant populations in a forest ecosystem (Sprugel & Bormann, 1981; Armeto & Pickett, 1985; Khan et al., 1987; Roxburgh, Shea, & Wilson, 2004; Rüger et al., 2007). In a forest ecosystem, the regeneration of the...
plant is the key ecological process in which seeding and sprouting of woody species are involved (Pratt et al., 2012). Mechanism of forest community dynamics (Dietze & Clark, 2008), regeneration of plant species is very important for succession, stability and restoration of vegetation in a forest ecosystem resulting various disturbances. Regeneration is the most crucial process for the maintenance of natural populations (Grubb, 1977; van der Maarel & Sykes, 1993). Tree species potential regeneration status in a stand with space and time reveals the future composition of the forests (Henle, Lindemayer, Margules, Saunders, & Wissel, 2004). Species diversity, composition, population structure and regeneration of plant communities are influenced by various anthropogenic and natural disturbances (Mishra, Tripathi, Tripathi, & Pandey, 2004; Pandey & Shukla, 2003; Sagar, Raghunathani, & Singh, 2003; Zhu, Mao, Hu, & Zhang, 2007). Both the anthropogenic and natural disturbances alter the ecological circumstances, ecosystem processes, availability of nutrient and interactions of plant to plant (Sheil & Burslem, 2003; Walker, 2012). Furthermore, various physical, climatic and biological disturbances influence the species composition and structure of temperate forests (Oliver, 1980; White, 1979). Although, several workers have studied the population structure of rhododendrons across the world (Thomson, Radford, Norris, & Good, 1993; Naito, Isagi, Kameyama, & Nakagoshi, 1999; Zeng, 2002; Li & Chen, 2005a; 2005b; Jin, Zhou, & Ye, 2006), none of the study have shown disturbance effects on species composition, structure and regeneration prominence of rhododendrons. Besides, studies on population structure and regeneration status of Rhododendron tree species, the prominent group of high altitude vegetation and assemblage of ornamental plants in western Arunachal landscape are still inadequate.

Under the family Ericaceae, Rhododendron L. is the largest genus with more than 1000 species distributed throughout Asia, Europe, North America and Australia (Chamberlain, Hyam, Argent, Fairweather, & Walter, 1996; Fang et al., 2005; Gibbs, Chamberlain, & Argent, 2011). It ranges from tiny mat-like (2.5 cm) to giant trees up to 40 m height consisting of evergreen, semi-deciduous or deciduous (Hora, 1981; Mao, Dash, & Singh, 2017) and grow well in loose, open, well-aerated, acidic soil (de Milleville, 2002; Ross, 1998). A total of 132 taxa (80 species, 25 subspecies and 27 varieties) of rhododendrons have been reported from India, among which 129 taxa distributed in North East India and 119 taxa (74 species, 21 subspecies and 24 varieties) in Arunachal Pradesh. Arunachal accounted about 90% of the total rhododendrons diversity of India (Mao, Dash, & Singh, 2017), distributed in the higher elevation with ecological significant and economic importance. Literature revealed that habitat of rhododendrons ranges from subtropical forests (800 m) to alpine scrubs (6500 m). Rhododendrons are terrestrial and epiphytic in nature. The genus is characterized by variation in morphological features, among the species (Mao, Dash, & Singh, 2017).

Rhododendron forests of high altitude areas in and around Tawang and West Kameng districts of western Arunachal Pradesh experience varying degrees of anthropogenic disturbances like unsustainable extraction for fuel wood, clear felling, logging, forest clearance for settlement, agriculture and developmental activities (Paul, Khan, Arunachalam, & Arunachalam, 2005). Understanding the population structure and regeneration processes of rhododendrons including associated tree species in the Rhododendron forests is the key for better management of these forests. The principal aim of this study is to provide information on population structure and regeneration status of Rhododendron tree species, particularly, which are facing pressure on the high altitude forest ecosystem. Besides, until today, no in-depth studies are carried out on regeneration status and population structure of Rhododendron species, especially in Arunachal Himalaya. Hence, the present study conducted in the temperate mixed broad-leaved Rhododendron forests of Tawang and West Kameng districts of western Arunachal Pradesh. The main objectives of the present study include (i) to determine the tree species composition of Rhododendron forests and (ii) to determine the population structure and regeneration status of selected Rhododendron L. species [namely, R. arboreum Sm., R. arboreum ssp. delavayi var. delavayi (Franch.) D. F. Chamb., R. barbatum Wallich ex G. Don and R. kesangiae D.G. Long & Rushforth] as well as associated tree species in their natural habitat.

Material and methods

Study area

The study sites are located in temperate regions of Tawang and West Kameng districts of western Arunachal Pradesh. Geographic locations, area, forest cover, climate of both the districts are presented in Table 1. Six Rhododendron forest stands are selected for the present study based on land use history and disturbance regime. Out of which, four were undisturbed stands, having no anthropogenic disturbances like extraction of fuel wood, clear felling, logging etc., having closed canopy, while two were disturbed stands with open canopy and having high intensity of above-mentioned disturbances. Study sites are located at Paipraw (Jang circle), Fallockchar (Mukto circle) of Tawang district and Sangpasa of Dirang circle and Wangu of Bomdila circle in West Kameng district (Figure 1). The study sites fall under temperate mixed broad-leaved forests having Rhododendron as the main dominant evergreen tree species. The Paipraw
undisturbed stand is a primary forest dominated by *Rhododendron arboreum* while Falockchar undisturbed stand is a mixed primary forest dominated by *Rhododendron arboreum*, *Rhododendron barbatum* and *Rhododendron kesangiae*. The other two undisturbed stands (Sangpasa and Wangu) are the primary forests, mainly composed of *Rhododendron arboreum* ssp. *delavayi* var. *delavayi*, while both the Paipraw and Falockchar disturbed stands are dominated by *Rhododendron arboreum*. Cut stumps were recorded from both the disturbed stands, whereas no cut stumps were observed in undisturbed stands. Species like *Lyonia ovalifolia*, *Michelia* sp., *Pinus wallichiana*, *Quercus griffithii*, *Quercus semecarpifolia* etc. were other co-dominant species of the study area. *Rhododendron* species associate with other broad-leaved trees like *Acer caudatum*, *Acer pectinatum*, *Alnus nepalensis*, *Betula alnoides*, *Betula utilis*, *Castanopsis tribuloides*, *Cornus capitata*, *Exbucklandia populnea*, *Ilex dipyrena*, *Juglans regia*, etc. (*Table 2*). The study stands are very old-aged and in climax stage. Sandy to loamy sand soils with coarse textured having acidic pH ranged between 3.24 and 4.89.

### Population structure of tree species

Stratified quadrat method used to study the population structure of all the tree species occurring in each forest stand including rhododendrons. In each study site, 50 quadrats (10 m x 10 m) were laid randomly for trees and saplings. Within the same quadrat, another 50 quadrats (1 m x 1m) were also laid down randomly for seedlings. Species were identified and densities of seedlings (≤20 cm height), saplings (<30 cm, collar circumference at the base and >20 cm height) and adults (≥10 cm girth at breast height i.e., 1.37 m height from the ground) were determined. Specimens of various associate plant species including rhododendrons were collected and herbarium of each species were prepared following the methods outlined by Jain and Rao (1977) and preserved for further study. Identification of *Rhododendron* species and other plant species were done consulting available flora references like *The Rhododendrons of Sikkim-Himalaya* (Hooker, 1849), *Sikkim-Himalayan Rhododendrons* (Pradhan & Lachungpa, 1990), *Encyclopedia of Rhododendron Species* (Cox & Cox, 1997), *The Rhododendrons of Nepal* (de Milleville, 2002), *Flowers of the Himalaya* (Polunin & Stainton, 2006), *Materials for the Flora of Arunachal Pradesh* (Chowdhery, Giri, Pal, Pramanik, & Das, 1996, 2008, 2009), *Contribution to the Flora of Namdapha, Arunachal Pradesh* (Chauhan, Singh, & Singh, 1996), *Flora of Assam* (Kanjilal et al., 1934-1940) and *Flowers of the Himalaya – A Supplement* (Stainton, 2007). Several herbaria, like the State Forest Research Institute (SFRI) Itanagar, Botanical Survey of India (BSI) Itanagar, and Shillong and Central National
Herbarium (CNH) Kolkata, were also consulted for validation of identifications and further validation was done by consultation with *Rhododendron* taxonomists Mr Kenneth Cox (Managing Director, Glendoick Gardens Ltd., Perth, Scotland), Dr Ashiho Asosii Mao (Scientist E/Incharge, Botanical Survey of India, Eastern Regional Centre, Shillong, India) and Dr Debjyoti Bhattacharyya (Department of Life Science and Bioinformatics, Assam University, Silchar, India). *Rhododendron* species (viz., *R. arboreum*, *R. arboreum* ssp. *delavayi* var. *delavayi*, *R. barbatum* and *R. kesangiae*), the main dominant evergreen tree species were selected from the six stands for studying their detailed population structure and regeneration status. Relative proportion (%) of the different groups to the density of a given species or to the total density of tree species in a stand was also calculated. Densities of seedlings, saplings and adults were worked out following the methodologies as outlined by Misra (1968) and Mueller-Dombois and Ellenberg (1974). Girth at breast height (GBH) of adult individuals of selected *Rhododendron* species was measured at 1.37 m above the ground level and categorized into eleven girth classes (namely, 10 – 30, 30 – 50, 50 – 70, 70 – 90, 90 – 110, 110 – 130, 130 – 150, 150 – 170, 170 – 190, 190 – 210, > 210 cm). The basal area of each adult individual was determined by using the formula $g^2/4\pi$.

**Species richness**

Tree species richness or “S” was determined following Whittaker (1972) by tabulating the total number of
species distributed in the respective Rhododendron forest stands representing the species richness for each stand.

**Disturbance index**

The disturbance index of each of the study stand was calculated following Rao, Barik, Pandey, and Tripathi (1990) as DI = Total number cut stumps/Total number of individuals of all species including cut stumps x 100.

**Regeneration status of tree species**

Based on the density of individuals at the seedling, sapling and adult, the regeneration status of all the tree species was determined following Uma Shankar (2001) as good (seedlings > saplings > adults), fair (seedlings > or = saplings ≤ adults), and poor (species exists only in sapling stage, but no seedlings, saplings may be <, > or = adults). Species present only in adult form and is considered as not regenerating. Species present only in seedlings or saplings form and no adult is considered as “new”.

**Results**

**Tree species composition**

Altogether, 26 tree species were noted from the six study stands. The number of tree species was recorded highest (14 species) in Paipraw undisturbed stand followed by Wangu undisturbed stand (10 species), Falockchar undisturbed stand (eight species) and Sangpasa undisturbed stand (seven species), while Paipraw disturbed stand had seven species and Falockchar disturbed stand had six species (Table 2). *Rhododendron arboreum* was dominant in both the undisturbed and disturbed stands of Paipraw. *R. arboreum* ssp. *delavayi* var. *delavayi* was common in undisturbed stands of Sangpasa and Wangu. *R. arboreum, R. barbatum* and *R. kesangiae* were dominant in the Falockchar undisturbed stand. Whereas in the Falockchar disturbed stand, the main dominant tree species was *R. arboreum*. Total density (individuals ha\(^{-1}\)) of all seedlings, saplings and adults were recorded highest in Falockchar undisturbed stand (6790) and lowest in Paipraw disturbed stand (1894) (Table 2).

**Population structure of tree species**

The proportion of seedlings, saplings and adults of tree species varied from stand to stand (Figure 2). Relative proportions of seedlings recorded highest in Falockchar and Paipraw disturbed stands as compared to undisturbed stands. Among undisturbed stands, Wangu contributed highest proportion followed by Falockchar and lowest by Paipraw. Sapling populations recorded scanty in all study stands than adults. The highest percentage of sapling was recorded in Wangu undisturbed stand followed by the Sangpasa undisturbed stand and lowest in the Paipraw disturbed stand while in case of disturbed stands, Paipraw contributed highest sapling population than the Falockchar. The percentages of adults were recorded highest in undisturbed stands of

### Table 2. Density (individuals ha\(^{-1}\)) of different tree species occurring in the Rhododendron forest stands.

| Name of species                  | Density (individuals ha\(^{-1}\)) (seedling+ sapling+ adult) |
|----------------------------------|--------------------------------------------------------------|
|                                  | PUD  | PD   | FUD  | FD   | WUD  | SUD  |
| Acer caudatum Wallich            | 14   | -    | -    | -    | -    | -    |
| Acer pectinatum Wall. ex G. Nicholson | 152  | 100  | 116  | -    | -    | -    |
| Alnus nepalensis D. Don          | -    | -    | -    | -    | 206  | 122  |
| Betula alnoides Buch.-Ham. ex D. Don | 172  | 134  | 104  | 186  | 158  | -    |
| Betula utilis D. Don             | -    | -    | -    | 68   | -    | -    |
| Castanopsis trifloraides (Smith) A. DC. | 74   | -    | -    | -    | -    | -    |
| Cornus capitata Wallich         | -    | -    | 172  | -    | -    | 168  |
| Ebucklandia populnea (R. Br. ex Griffith) R. W. Brown | -    | -    | -    | -    | -    | -    |
| Ilex dipryrena Wallich          | 14   | -    | -    | -    | -    | -    |
| Juglans regia L.                | -    | 24   | -    | -    | -    | -    |
| Lyonia ovalifolia (Wallich) Drude | 496  | 440  | 378  | 372  | 692  | 738  |
| Michelia sp.                     | 22   | 16   | -    | -    | -    | -    |
| Pinus wallichiana A. B. Jackson  | -    | -    | -    | -    | 342  | 422  |
| Prunus cerasoides Buch.-Ham. ex D. Don | 20   | -    | -    | -    | -    | -    |
| Pyrus pashia Buch.-Ham. ex D. Don | 104  | -    | -    | -    | -    | -    |
| Quercus griffithi Hook.f. & Thomson ex Miq. | -    | -    | -    | -    | 552  | 650  |
| Quercus lanata Smith             | -    | -    | -    | -    | 232  | -    |
| Quercus semecarpofolia Smith     | 104  | -    | -    | -    | 150  | -    |
| Rhododendron arboreum Sm.        | 3058 | 900  | 874  | 560  | -    | -    |
| Rhododendron arboreum Sm. ssp. delavayi var. delavayi (Franch.) D. F. Chamb. | -    | -    | -    | -    | 2872 | 3562 |
| Rhododendron barbatum Wallich ex G. Don | 214  | 200  | 1910 | 524  | -    | -    |
| Rhododendron kesangiae D.G. Long and Rushforth | 198  | -    | 3182 | 368  | -    | -    |
| Rhododendron falconeri Hook. f.  | 94   | -    | -    | -    | -    | -    |
| Rhododendron keyii Nutt.         | 118  | -    | 202  | -    | -    | -    |
| Rhododendron neriiflorum (Franch.) ssp. phaedropum (Balf. f. and Forrest) Tagg | -    | -    | -    | 130  | -    |
| Schima khasiana Dyer             | -    | -    | -    | -    | 168  | -    |
| **Total**                        | 4750 | 1894 | 6790 | 2022 | 5572 | 5820 |

PUD – Paipraw Undisturbed, PD – Paipraw Disturbed, FUD – Falockchar Undisturbed, FD – Falockchar Disturbed, WUD – Wangu Undisturbed, SUD – Sangpasa Undisturbed
Paipraw followed by Sangpasa and lowest in Wangu. On the other hand, in case of disturbed stands, Paipraw contributed the highest percentage of adults than the Falockchar (Figure 2).

Good population structure with seedlings, saplings and adults exhibited by the selected rhododendrons in all the study stands. Variations in density (individuals ha$^{-1}$) of seedlings, saplings and adults were observed in the selected study stands. *Rhododendron arboreum* shows a steady decline in seedlings, saplings and adults density (individuals ha$^{-1}$) from Paipraw undisturbed to Falockchar disturbed stand (Figure 3). *Rhododendron arboreum* ssp. *delavayi* vari. *delavayi* exhibited highest seedlings and adults density (individuals ha$^{-1}$) in the Sangpasa undisturbed stand while samplings were highest in Wangu undisturbed stand. *Rhododendron barbatum* showed highest seedlings, saplings and adult density (individuals ha$^{-1}$) in the Falockchar undisturbed stand compared with other stands. In contrast, *Rhododendron kesangiae* exhibited highest density (individuals ha$^{-1}$) of seedlings, saplings and adults in the Falockchar undisturbed stand than the other stands (Figure 3). Despite the variation in density of seedlings, saplings and adults, population structure of selected *Rhododendron* tree species (namely, *R. arboreum*, *R. arboreum* ssp. *delavayi*, *R. barbatum* and *R. kesangiae*) showed a reverse J-shaped distribution with a population density of sapling less than seedling and adult population in all stands (Figure 4). The main dominant rhododendrons contributed more than 50% stand density (individuals ha$^{-1}$) and basal area (m$^2$ ha$^{-1}$) in the respective study stands (Table 3). *Rhododendron arboreum* contributed highest density (1422 individuals ha$^{-1}$) and basal area (131.30 m$^2$ ha$^{-1}$) followed by *Rhododendron arboreum* ssp. *delavayi* vari. *delavayi* (1236 individuals ha$^{-1}$) with basal area (39.92 m$^2$ ha$^{-1}$) and *Rhododendron kesangiae* (1152 individuals ha$^{-1}$) with basal area (54.48 m$^2$ ha$^{-1}$) and lowest by *Rhododendron kesangiae* (16 individuals ha$^{-1}$) having basal area (0.72 m$^2$ ha$^{-1}$), although the lowest basal area (0.24 m$^2$ ha$^{-1}$) was contributed by *Rhododendron barbatum* (Table 3). The density (individuals ha$^{-1}$) of *R. arboreum* was recorded maximum between the girth classes 30–50 cm to 130–150 cm and lowest between 190–210 cm to > 200 cm in the Paipraw undisturbed stand. Whereas, the number of individuals was highest in lower girth class 10–30 cm and lowest in higher girth class 170 – 190 cm in the Paipraw disturbed stand. However, highest number of individuals of *R. arboreum* was recorded in the Falockchar undisturbed stand between the girth classes 30–50 cm to 70–90 cm and lowest in higher girth class 150–170 cm. The density of *R. barbatum* was highest in 30–50 cm and lowest between 110–130 cm to 130–150 cm. While, *R. kesangiae* was found highest between the girth classes 30–50 cm to 90–110 cm and lowest in 150–170 cm. In Falockchar disturbed stand the density of *R. arboreum* was recorded maximum between the girth classes 10–30 cm to 90–110 cm and minimum in 110–130 cm girth class. Highest number of individuals of *R. arboreum* ssp. *delavayi* vari. *delavayi* was recorded between the girth classes 10–30 cm to 70–90 cm and lowest in 130–150 cm in Wangu.

**Figure 2.** Population structure of tree species in *Rhododendron* forest stands. Total density of a particular stand is shown at the top of the corresponding bar. PUD – Paipraw Undisturbed, PD – Paipraw Disturbed, FUD – Falockchar Undisturbed, FD – Falockchar Disturbed, WUD – Wangu Undisturbed and SUD – Sangpasa Undisturbed.
undisturbed stand. Whereas, in Sangpasa undisturbed stand the highest density of *R. arboreum* ssp. *delavayi* var. *delavayi* was found between the girth classes 30–50 cm to 70–90 cm and lowest in 130–150 cm (Figure 5).

**Disturbance index**

Degree of disturbance (i.e., disturbance index) in both Paipraw and Falockchar disturbed stands exhibited almost same (89%). However, undisturbed stands exhibited zero percentage of disturbances (Figure 6).

**Regeneration status of tree species**

Disturbed stands exhibited better regeneration than undisturbed stands. About 90% (9) of the total regenerating species in disturbed stands showed fair...
regeneration as compared to undisturbed stands. Undisturbed stands exhibited lower percentage of tree regeneration than disturbed stands through seeds. Only 9% (2) of the species exhibited good regeneration, 74% (17) of the species showed fair regeneration while 17% (4) exhibited no regeneration (Figure 7).

Regeneration status of tree species expressed based on the relative proportion of individuals at seedling, sapling and adult stage. Overall, about 77% of the species showed fair regeneration, 8% species showed good regeneration while 15% of the species exhibited no regeneration (Table 4). Out of the 14 species recorded in Paipraw undisturbed stand, 11 species showed fair regeneration and three species did not show any regeneration. On the Paipraw disturbed stand, out of seven species, six species exhibited fair and one species exhibited no regeneration (Figure 8). Among the eight species in the Falockchar undisturbed stand, seven species showed fair and one species exhibited no regeneration. However, in Falockchar disturbed stand and Wangu undisturbed stand, all species exhibited fair regeneration, whereas in Sangpasa undisturbed stand among seven species, five species showed fair and two species showed good regeneration (Figure 8, Table 4). Conversely, selected Rhododendron species (viz. R. arboreum, R. arboreum ssp. delavayi var. delavayi, R. barbatum and R. kesangiae) revealed fair regeneration in their respective stands, with higher seedlings compared with the adults and saplings (Table 4).

Table 3. Density and basal area of dominant Rhododendron tree species in different Rhododendron forest stands.

| Study sites | Scientific name | Local name | Density (ha⁻¹) | Basal area (m² ha⁻¹) |
|------------|----------------|------------|----------------|---------------------|
| Paipraw UD | Rhododendron arboreum | Udongsheng | 1422 | 131.30 |
| Paipraw D  | Rhododendron barbatum  | Tamasheng | 22  | 0.24  |
|            | Rhododendron kesangiae | Latasheng | 18  | 0.52  |
| Falockchar UD | Rhododendron arboreum | Udongsheng | 182 | 8.05  |
|            | Rhododendron barbatum  | Tamasheng | 398 | 7.36  |
|            | Rhododendron kesangiae | Latasheng | 1152 | 54.48 |
| Falockchar D | Rhododendron arboreum | Udongsheng | 112 | 7.98  |
|            | Rhododendron barbatum  | Tamasheng | 28  | 0.33  |
|            | Rhododendron kesangiae | Latasheng | 16  | 0.72  |
| Wangu UD   | Rhododendron arboreum ssp. delavayi var. delavayi | Gidangsheng | 938 | 34.91 |
| Sangpasa UD | Rhododendron arboreum ssp. delavayi var. delavayi | Gidangsheng | 1236 | 39.92 |

UD – Undisturbed and D – Disturbed

Figure 5. Density (individuals ha⁻¹) of selected Rhododendron species in different girth classes of six study stands. PUD – Paipraw Undisturbed, PD – Paipraw Disturbed, FUD – Falockchar Undisturbed, FD – Falockchar Disturbed.
Discussion

Relative proportion of growth form in the total population could provide the regeneration status and structure of population of all the species in a forest community. The population of seedlings was higher than adults and saplings in the total population in all the selected stands. The ratio of growth form (seedlings, saplings and adults) varied from stand to stand. Interactions of biotic and abiotic elements prevailing in the respective study stands might be influencing the variation of this growth form. However, Ashton and Hall (1992) and Davies, Palmiotto, Ashton, Lee, and Lafrankie (1998) reported that habit variation relay on the differences in forest composition and structure. Anthropogenic disturbances like deforestation, fuel wood extraction, logging, grazing, etc. also influence the variation of life forms. Koirala (2004) reported similar findings from Tinjure to Milke region of east Nepal. The stand age, site quality, local climatic conditions and anthropogenic activities wedged the present composition and structure of tree species also reported by Nlungu-Kweta, Leduc, and Bergeron (2017). Conversely, Jensen (1998) reported that floristic similarity often decreases during the succession of vegetation in temperate regions. Furthermore, Mishra, Tripathi, Tripathi, and Pandey (2003) reported that population structure of species namely, Casearia vareca, Eurya japonica, Psychotria symplacifolia and Rhododendron arboreum exhibited decreases in population density in seedling and adult stage. On the contrary, Duchok, Kent, Devi, Paul, and Khan (2005) observed the dominance of adult individuals of Illicium griffithii in different

Figure 6. Degree of disturbance in Rhododendron forest stands. PUD – Paipraw Undisturbed, PD – Paipraw Disturbed, FUD – Falockchar Undisturbed, FD – Falockchar Disturbed, WUD – Wangu Undisturbed and SUD – Sangpasa Undisturbed.

Figure 7. Regeneration status of tree species in the disturbed and undisturbed forest stands (Values inside the figures are percent of total species).
Table 4. Regeneration status of different tree species in *Rhododendron* forest stands of western Arunachal Pradesh.

| Name of species                                      | Pairpaw UD | Pairpaw D | Falockchar UD | Falockchar D | Wangu UD | Sangpasa UD |
|------------------------------------------------------|------------|-----------|---------------|--------------|----------|-------------|
|                                                      | SE  | SA | AD | St | SE  | SA | AD | St | SE  | SA | AD | St | SE  | SA | AD | St | SE  | SA | AD | St | SE  | SA | AD | St |
| Acer caudatum Wallich                               | -   | 14 | Nn | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Acer pectinatum Wall. ex G. Nicholson               | 140 | 12 | F  | 80 | 20 | 100 | 16 | F  | 180 | 10 | 16 | F  | 100 | 14 | 8  | G  | -   | -  | -  | -  | -   | -  | -  | -  |
| Alnus nepalensis D. Don                             | -   | -  | -  | -  | 120| 14 | F  | 70 | 24 | -  | -   | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Betula alnoides Buch.-Ham. ex D. Don                | 160 | 12 | F  | 80 | 24 | 100 | 16 | F  | 160 | 10 | 16 | F  | 140 | 8  | 10 | F  | -   | -  | -  | -  | -   | -  | -  | -  |
| Betula utilis D. Don                                 | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Castanopsis trifoliata (Smith) A. DC.               | 60  | 14 | F  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Cornus capitata Wallich                             | -   | 16 | F  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Exbucklandia populnea (R. Br. ex Griffith) R. W. Brown | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Ilex diphylla Wallich                                | 160 | 14 | Nn | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Juglans regia L.                                    | -   | -  | -  | -  | -  | 24 | Nn | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Lyonia ovalifolia (Wallich) Drude                   | 420 | 28 | 48 | F  | 380 | 24 | 36 | F  | 320 | 30 | 28 | G  | 340 | 14 | 18 | F  | 460 | 68 | 164 | F  | 460 | 54 | 224 | F  |
| Michelia sp.                                         | -   | 22 | Nn | -  | 16  | Nn | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Pinus wallichiana A. B. Jackson                      | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Prunus cerasoides Buch.-Ham. ex D. Don               | -   | 20 | Nn | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Pyrus pashia Buch.-Ham. ex D. Don                    | -   | -  | -  | -  | 80  | 24 | F  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Quercus grifithii Hook.f. & Thomson ex Miq           | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Quercus lanata Smith                                 | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Quercus semecarpifolia Smith                         | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Rhododendron arboresum Sm.                           | 1580| 56 | 142 | F  | 780 | 28 | 92 | F  | 660 | 32 | 182 | F  | 420 | 28 | 112 | F  | 1820| 114 | 938 | F  | 2260| 66 | 1236 | F  |
| Rhododendron barbatum Wallich ex G. Don              | 180 | 12 | 22 | F  | 160 | 18 | 22 | F  | 1420| 92 | 398 | F  | 480 | 16 | 28 | F  | -   | -  | -  | -  | -   | -  | -  | -  |
| Rhododendron kesangiae D.G. Long and Rushforth      | 180 | 12 | F  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Rhododendron falconeri Hook. f.                     | 80  | 14 | F  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Rhododendron keysii Nutt.                           | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Rhododendron nerviflorum (Franch.) ssp. phaedropum   | 100 | 18 | F  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |
| Schima khasiana Dyer                                 | -   | -  | -  | -  | -  | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  | -   | -  | -  | -  |

SE – Seedlings (ha⁻¹), AD – Adults (ha⁻¹), St – Status, F – Fair regeneration, G – Good regeneration, Nn – No regeneration, UD – Undisturbed, D – Disturbed
stands and disturbances bear an impact on the natural regeneration of the species.

Climatic and edaphic factors may be ascribed to the difference in the population density of seedlings, saplings and adults of the studied *Rhododendron* species in the respective study stands. Variation of growth form distribution among the dominant species also reported by Gairola, Rawal, Todaria, and Bhatt (2014) from the western Himalaya. In all the study stands, the selected *Rhododendron* tree species exhibit a reverse J-shaped distribution even though the differences among the density of seedlings, saplings and adults. The findings of Liao, Chou, and Wu (2003) and Shrestha, Ghimire, Lekhak, and Jha (2007) concur with the present results who also recorded reverse J-shaped distribution of Taiwan Yellow False Cypress (*Chamaecyparis obtusa* var. *formosana*) in Yuanyang Lake Nature Reserve, Taiwan and tree line birch (*Betula utilis* D. Don) forest in a trans-Himalayan dry valley in Manag (central Nepal), respectively. Moreover, Miyadokoro, Nishimura, and Yamamoto (2003) also found reverse J-shaped distribution of plant species in the old-growth coniferous forest of the sub-alpine region of the Ontake Forest Reserve of Central Japan. Unimodal, sporadic and reverse J-shaped population structure was reported by Wangda and Ohsawa (2006) because of species dominance with the elevation in slopes of dry valley of Bhutan Himalaya. *Larix chinensis* population in the Qinling Mountains of China is investigated by Duan et al. (2009) and reported a closed bell-shaped population distribution at lower elevation mainly dominated by adults. However, reverse J-shaped distribution in the middle elevation and multi-modal age distribution in higher elevation was recorded owing to lack of seedlings and saplings. Furthermore, Zegeye, Teketay, and Kelbessa (2011) recorded reverse J-shaped population structure of woody species in Tara Gedam and Abebaye forests, northwestern Ethiopia. Reverse J-shaped distribution of population is a sign of steady population having equitably of status of good regeneration (Teketay, 1997; Tesfaye, Teketay, & Fetene, 2002; Tesfaye, Teketay, Fetene, & Beck, 2010). However, many authors recorded an inverse J-shaped population distribution signifying stable populations with good regeneration (Malik & Bhatt, 2016; Sop, Oldeland, Schmiedel, Ouedraogo, & Thiombiano, 2011). Among the studied *Rhododendron* species, variations in population structure might be due to their habitat differences and existing micro-environmental conditions also reported by Zhang, Wang, Kang, and Liu (2004). Number of individuals selected *Rhododendron* species decreased with the increased of girth may be due to the competition of resources and between species also recorded by many researchers around the world (Zeng, 2002; Li & Chen, 2005a; Jin, Zhou, & Ye, 2006). Moreover, the selected *Rhododendron* species were recorded higher large girth class range, indicating the forest is an old one. The girth class distribution attributed to the regeneration and future population stability in forest communities (Pande, 1999; Robertson, 1978; Schmelz & Lindsey, 1965), while the variation in population structure of

**Figure 8.** Regeneration status of trees in *Rhododendron* forest stands. PUD – Paipraw Undisturbed, PD – Paipraw Disturbed, FUD – Falockchar Undisturbed, FD – Falockchar Disturbed, WUD – Wangu Undisturbed and SUD – Sangpasa Undisturbed.
different species may also ascribe adapted to local climate (Behera, Kushwaha, & Roy, 2001). Uncontrolled and indiscriminate harvesting of rhododendrons for fuel wood mainly for the purpose of cooking and room heating attributed 90% (i.e., disturbance index) degree of disturbance in both Paipraw and Falockchar disturbed stands. The present results support the findings of Pandey and Shukla (2003) who recorded 90% degree of disturbance due to anthropogenic disturbances. On the contrary, protection made by the local community for future, attributed zero degree of disturbances in the undisturbed stands.

Extraction of fuel wood, clear felling, etc. created the suitable microsites, which attributed to the higher proportion of seedlings in the disturbed stands (Figure 9a, b). Present result confirms with the findings of Koirala (2004) who also reported higher seedling density in degraded forest than an undisturbed forest in Tinjure-Milke region, east Nepal. Pollmann and Veblen (2004)

also observed abundant regeneration of Nothofagus species in disturbed stands while rare or lacking in undisturbed stands in old-growth high-elevation forests of central Chile. While, Spracklen, Lane, Spracklen, Williams, and Kunin (2013) recorded better regeneration in clear-cut areas owing to dearth of ground flora in conifer plantations in upland Britan. On the other hand, Sundriyal and Sharma (1996) reported that the majority of the canopy species showed poor regeneration in Mambil watershed temperate forest of Sikkim and only 39 were found regenerated among the 81 tree species. Similarly, Zu, Chen, Wang, and Nie (2006) reported that the population structure of Taxus cuspidata was not balanced because of anthropogenic disturbances in Muling region of Heilongjiang Province, China. Iszkulo, Boratynski, Didukh, Romaschenko, and Pryazhko (2005) also reported that population of Taxus buccata inclined toward aging in Western Ukraine. Various kinds of anthropogenic disturbances could be the reasons in change in plant population structure in the study stands.
also reported by many researchers from different parts of the world (Chettri, Sharma, Deb, & Sundriyal, 2002; Elu & Obua, 2005; Foster, 1980; Halpern & Spies, 1995; Heinselman, 1973; Khan et al., 1987; Lorimer, 1989; Nlungu-Kweta et al., 2017; Primack, Ashton, Chai, & Lee, 1985; Saxena, Singh, & Singh, 1984; Sundriyal & Sharma, 1996). The less proportion of seedling population in the undisturbed stands might be due to the dense canopy and thick litter layer barrier for seedling emergence. Grime (1979) also reported similar results. It could also be due to allelopathic effects of leaf litter that affect the growth and survival of seedlings. Many researchers have reported such kind of allelochemicals influence of litter layer on survival of seedlings (Blaschke, 1979; Del Moral & Cates, 1971; Fisher, 1980; Rice, 1974; Wills, 1980). Conversely, Rhododendron metternichii var. hon-doense seedlings were greatly reliant to canopy cover and ground conditions in Mt. Kamakuraji of Hiroshima Prefecture, Japan (Kameyama, Nakagoshi, & Nehira, 1999). On the contrary, many authors have reported that the seedling densities are lower in higher altitude than the lower altitude (Bruggink, 1993; Hititmana, Kiyiapi, & Njunge, 2004; Maruta, 1983, 1994; Vera, 1997). The seedling densities decrease close to the parent tree in temperate forests because of density-dependent mortality (Lambers & Clark, 2003). Very less proportion of sapling population including Rhododendron species was recorded in all the study stands, which might be due to mortality of seedlings in early stage and also intricacy in establishment in a forest environment during the sapling stage. Similar results are reported by Koirala (2004) in mature and undisturbed forest with closed canopy in Tinjure-Milke region, east Nepal. Findings of Mejias, Arroyo, and Ojeda (2002) confirm the results of present study who found dearth of seedlings and saplings (two juveniles out of 2489 adults) of Rhododendron ponticum in southern Spain. The intensity of fuel wood extraction, logging, grazing and environmental factors attributed to the less population of saplings in the disturbed stands. Our result corroborates with the findings of Noguchi and Yoshida (2004) who reported low density of seedling and sapling in stands having heavy logging intensity in hardwood mixed forests of northern Japan.

In the present study, tree species showed inadequate regeneration status in Rhododendron forest of western Arunachal Himalaya. Among the total recorded tree species, only 8% showed good regeneration, 77% showed fair regeneration, while 15% of the species exhibited no regeneration. Malik and Bhatt (2016) recorded 27–56% of the tree species under good regeneration, 19–45% poor regeneration and 7–30% fair regeneration in the western Himalaya. Tree species regeneration was found to be better in the disturbed stands compared to undisturbed stands could be due to availability of enough light through open canopy, nutrient availability and ecological circumstance. The present result commemorate with the findings of Koirala (2004) who found seedling, sapling and regeneration potential higher in disturbed forest due to the open canopy. Zhu, Lu, and Zhang (2014) reported that forest gaps augment the regeneration of woody plant species. Besides, local factors, soil and stand conditions play substantial role in regeneration dynamics (Gao et al., 2017). Tree species having no regeneration may be due to the availability of enough moisture content of the soil for the germination of seeds also reported by Tiwari, Rana, Krishan, Sharma, and Bhandari (2018). The ericaceous plants at large, especially Rhododendron species, compete with other associated species and sometimes entirely obstruct canopy tree regeneration in temperate forest ecosystems all over the northern hemisphere (Baker & Van Lear, 1998; Clinton & Vose, 1996; Lei, Semones, Walker, Clinton, & Nilsen, 2002; Mallik, 1996; Messier & Kimmins, 1991; Nilsen et al., 2001, 1999). While, Nilsen et al. (2001) reported that in northern red oak (Quercus rubra) forests, recruitment of canopy trees were impedes by Rhododendron maximum, whereas densities of seedling and sapling in forest floor are not steady, somewhat vigorous in nature and may vary with the species (Bazzaz, 1991). Mortality may be attributed to the change in density, light, drought, herbivore, disease or competition (Augspurger & Kelly, 1984). Any species can be categorized under successful regeneration only when enough space is available for seedlings growth, survival and their subsequent establishment (Klinka, Carter, & Feller, 1990). Pokhriyal, Uniyal, Chauhan, and Todaria (2010) also reported fair regeneration having higher proportion of trees in the watersheds of Phakot and Pathri Rao in Garhwal Himalaya. However, Rawat et al. (2018) recorded good regeneration status of trees in the Neora Valley National Park. On the contrary, Tiwari, Pananjay, Tadele, Aramde, and Tiwari (2010) and Singh, Malik, and Sharma (2016) found about 82% and 80% of total recorded that tree species have good regeneration status from Garhwal Himalaya. Conversely, Chauhan et al. (2008) based on their study recorded 33% good regeneration out of the total 126 listed species from natural and planted forest of Katarniaghat Wildlife Sanctuary. Poor regeneration status of plant species in temperate forest of north eastern Ethiopia was also observed by Zegeye et al. (2011) and stressed on priority conservation of those species. Decline in structure, abridged regeneration pattern was recorded by Shaheen, Ullah, Khan, and Harper (2012) in temperate forests of Kashmir and strained immediate attention for the forest planners.

All the selected Rhododendron species exhibited fair regeneration having a greater seedling density compared with adults and saplings in their respective
stands. This could be the availability of suitable niches for the *Rhododendron* species present in the selected stands and also existing micro-environmental factors. No adequate numbers of seedlings and saplings of *Rhododendron* species are observed in their respective stands. Therefore, species are represented by more adults than the young. Many other workers (Bormann & Likens, 1979; Sundriyal & Sharma, 1996) have reported similar results. Stable climax *Rhododendron* forest and very old age, having a close canopy, might be one of the main reasons for low saplings and seedling density in the present study stands. Koirala (2004) also reported similar observations in the *Rhododendron* forest community in Nepal. Moreover, it has been reported that seed germination of *Rhododendron* in nature is also very poor (Singh, Rai, & Gurung, 2009). In spite of occurrence of seedlings and adults, low sapling population observed in all the stands might be because of harsh impact of ecological conditions prevailing for the period of the sapling development. Thus, resulting in death of saplings stage before reaches the canopy level. Shrestha (2003) also recorded such results for *Quercus semecarpifolia* in the Himalayan region. Semwal, Nautiyal, and Bhatt (2008) reported that transformation of sapling to tree is most vital for good regeneration of forests. Furthermore, inadequate light intensity, closed canopy and thick litter layer (Facelli & Pickett, 1991) on the forest floor might reduce the establishment of seedlings and saplings of *Rhododendron*. Kameyama et al. (1999) reported that *Rhododendron metternichii* var. *hondoense* seedlings were greatly dependent on the canopy cover and ground circumstances for their growth and survival. Moreover, low light intensity on the ground surface in a mature and closed canopy forest is the major constraint for the seedling establishment. Thus, the adult stage represented well not by sapling stage, while seedlings need suitable light conditions (Bormann & Likens, 1979; Sundriyal & Sharma, 1996). Conversely, it has been observed that the seedlings of *Rhododendron* species were very scanty within the canopy in all the stands, whereas seedlings were abundant in the periphery, openings and forest margins. Light could be the one of the possible reasons, which attributed to very less density of seedlings beneath the canopy. Many authors (Arocha, Blazich, Warren, Thetford, & Berry, 1999; Blazich, Warren, Acedo, & Reece, 1991; Blazich, Warren, Starrett, & Acedo, 1993; Cho, Jung, & Yeam, 1981; Hebert, Blazich, & LeBube, 2010; LeBude, Blazich, Walker, & Robinson, 2008; Malek, Blazich, Warren, & Shelton, 1989a, 1989b; Rowe, Blazich, Warren, & Ranney, 1994) reported that light is an outright necessity for *Rhododendron* seeds germination. Moreover, it has also been observed that seedlings of *Rhododendron* species growing well on moist rocks, decay logs and soils are covered by bryophyte mats. This reason may be owing to these specific sites, where moisture, temperature and light were suitable for seeds for better germination and effective recruitment. Similar results were reported by Cross (1981) in the case of *Rhododendron ponticum* from south-west Ireland. It signifies that present study species have good regeneration, but could not reach to the sapling stage that may be because of the allelopathic effect of leaf or litter layer and other environmental condition. Other possible reasons could be the wind dispersal mechanisms of the species attributed to the low seedling density beneath the canopy. On the other hand, the extraction of *Rhododendron* trees before the reproductive phenophases attributed to the low regeneration of the species in the disturbed stands. Our results support the findings of Maren and Vetaas (2007) who reported low regeneration of evergreen oaks due to human interference in Central Himalaya.

The overall findings of the present study indicate that *Rhododendron* tree species have a good population structure with seedlings, saplings and adults. However, the density of saplings is very less compared with seedlings and adults. The selected *Rhododendron* species have fair regeneration status as exhibited by low density of saplings compared with the seedlings and adults. Besides, regeneration efficacy from seedling to sapling stage is very poor and also very slow growing in nature. Anthropogenic disturbances have influenced the variation in species population structure and regeneration status among the study stands. Moreover, over harvesting or harvesting during the reproductive stage affects the natural regeneration of rhododendrons, which have resulted in the declined populations of *Rhododendron*. In addition, it has led many species to shift into the endangered, rare and threatened categories.

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