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Population Status and Regeneration Pattern of Few Congeneric Species in the Disturbed Sal Forests of Gorakhpur, India

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ABSTRACT

The current study investigates the population structure, inter-ramet distance and regeneration strategies of different congeneric species under varying disturbance levels in the Forest Division of Gorakhpur, UP. The results revealed that *Clerodendrum infortunatum* exhibited the highest density per hectare, with maximum values under moderate disturbance, while *C. viscosum* dominated high disturbance sites. Species such as *Desmodium gangeticum* and *D. pulchellum* were more abundant under high disturbance, whereas *Bridelia retusa* and *B. stipularis* were absent in highly disturbed zones. The study estimated a general trend of declining ramet production and increasing inter-ramet distance with rising disturbance level. Moderate disturbance supported the most balanced population structure and clonal spread, suggesting optimal regeneration conditions. The one-way ANOVA revealed a significant difference in inter ramet distance among different species at different disturbance levels ($F = 6.87$, $p < 0.05$). These adaptive responses indicate that moderate disturbance promotes sustainable clonal expansion and regeneration, while high disturbance limits recruitment and genet stability across most studied congeneric species.

Keywords Age structure, Clonal propagation, Disturbance gradient, Regeneration pattern, Vegetative reproduction.

INTRODUCTION

A population refers to the specific set of individuals of a species inhabiting a defined area. These individuals are generally arranged into small local populations forming scattered patches along the landscape. The population condition of component species within a community can be assessed by their distribution among various girth classes, which reflect their reproductive condition and thus the potential stability and future stability of forest communities (Lehmann *et al.* 1999). Natural regeneration constitutes a central component of tropical forest ecosystems, being vital for the preservation and maintenance of biodiversity (Grubb 1977). As the floristic and structural composition of forests shifts, the competitive ability among

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species and the pattern of regeneration also undergo similar changes (Chazdon *et al.* 2025). Different types of disturbance significantly influence the dominance and composition of seedlings in the forest ecosystem (Benitez-Malvido 1998). Recurrent disturbances, such as fire etc, often lead to habitat fragmentation and consequently produce a clustered distribution of plant species. Recurrent fires and similar disturbances may modify the size, status and/ or regeneration type of individual populations (Bond and Midgley 2001, Keeley *et al.* 2011). The successful regeneration of tree species can be predicted from the overall population structure and the adequate occurrence of seedlings, saplings and tree species (Pandey and Shukla 2003 ; Shrivastava *et al.* 2023). Considerable variation exists among forest species in their sprouting potential ; many are capacity of sprouting at early stages but lose this ability at reaching maturity (Bellingham and Sparrow 2000). Under continuous disturbances, some species compensate for considerably seedling mortality by adopting non-seed regeneration strategies (Saha and Howe 2003). The extent of horizontal ramet spread largely influences the spatial organization of individuals at the genet level (Keeley *et al.* 2011; Pandey and Shukla 2001, 2019). Increasing attention for the sustainable development and management of mixed plantations and natural forests has emphasized the importance of understanding regenerative mechanisms that maintain community structure and ecosystem dynamics (Phillips and Gentry 1994).

Pandey and Shukla (2003) detail studied the composition of species, their regeneration status and conservation pattern of managed forest at Sohagibarwa Wildlife Sanctuary, Gorakhpur. Some information on population status, community pattern and the diversity of *Shorea* forests is available (Pandey and Shukla 2001, Majumdar *et al*. 2012 ; Kushwaha and Nandy 2012 ; Gautam and Devoe 2006 ; Kumar and Sakia 2020 ; Pandey *et al.* 2024, Rai *et al.* 2026) but the information on the status of population status and regeneration potential of congeneric species are of primary importance in the planning of these Sal forest stands. It is important to compare the differences in population status, age structure and regeneration pattern of congeneric plants in plantation forests facing recurrent disturbance.

MATERIALS AND METHODS

Three stands of sal forests in Gorakhpur forest division were identified by different disturbance area within in regional forests facing low disturbance, moderate disturbance and high disturbances. The average age of these stands was 65 ± 5 years, and they showed the characteristic conditions of their respective disturbance levels in terms of species composition and community structure. Disturbance intensity was quantified using the Disturbance Index (DI) following Pandey and Shukla (1999). A DI of > 60 denoted high disturbance, DI of < 60 denoted moderate disturbance and that of < 30 as low disturbance. In each of the three stands, one-hectare (100 m × 100 m) plots were marked on the basis of average ground vegetation. Different congeneric species were identified and the number of their trees (> 30 cm. gbh.), other genets and sprouts/ ramets was counted and the basal diameter was measured. The individuals with separate identity at the soil surface were treated as genet while the plants arising from suckers on subterranean root-stock of the genet were treated as *ramets.*

Age structure

The percent number of individuals falling under girth-class (in case of trees) or age classes (in case of non-tree woody species) were arranged in the form of vertical bars to show the age structure of the plant populations (Pandey and Shukla 2018). The non-tree individuals (< 30 cm gbh) were arranged according to their age from 1 yr to >5 yr. The age of woody shrubs was determined on the account of growth features (Halle *et al.* 1978 ; Shukla and Ramakrishnan 1986) and the number and vigor of respective sprouts. The individuals of 2 yr to >5 yr of age were excavated their ramets were traced by digging out the surface soil. The mean inter ramet distance was based on 5 multiples. Normally, the most sporous and old shoot of the complex was treated as genet and all other shoots as ramets. The number of ramet/genet and inter ramet distance (IRD) of a species at the different level of disturbances were compared and the significance differences were statistically tested. It represents the average number of ramets (vegetatively produced clones) per genet

(genetic individual) along with the standard deviation, indicating the variability in ramet production.

RESULTS

Population studies

In the Sal forest of Gorakhpur *Clerodendrum infortunatum* had the highest number of individuals/ hectare with maximum count in moderate disturbance. *C. viscousum*, had highest density at high disturbance. *C. viscousum* shows the highest number of individuals per hectare facing high disturbance. *Desmodium gangeticum* and *D. pulchellum* were more prevalent in high disturbance areas, with total counts of 916.2±6. 57 and 465.99 ± 24.66 individuals per hectare, respectively. *Bridelia retusa* and *B. stipularis* were absent in high disturbance areas, with maximum counts in low and moderate disturbances *Flacourtia indica* and *F. zangomos* had a lower number of individuals, with the highest count being 200 and 135 respectively. *Leea alata* and *L. aspera* show moderate presence across all disturbance levels, with the highest count for *L. alata* being 739.32 ± 106.77 individuals in moderate disturbance. *L. alata* and *L. aspera* show moderate presence across all disturbance levels, with the highest count for *L. alata* being 739.32± 106.77 individuals in moderate disturbance. *Moghania chappar* and *M. bracteata exhibit* higher numbers in moderate disturbances, with *M. chappar* had a total of 9709.66 ± 148.71 individuals per hectare. *M. lineate* had a low presence overall, with a maximum of 67.33 ± 5.73 individuals in high disturbance (Table 1).

The PCA diagram demonstrates a exact separation of species along the disturbance, with the first principal component (PC1) explaining 64.8% of the total variance and representing increasing disturbance intensity, while the second component (PC2) accounts for 17.8% of the variance, reflecting species-specific variability. The separation of clusters is statistically supported by significant variation among disturbance levels ($F = 8.76$, $p < 0.01$), indicating that the observed distribution is not random (Fig. 1).

Changes in Inter -Ramet Distance

The species like *B. retusa* showed peak ramet production under moderate disturbance while *C. infortunatum* exhibits sharp declines in ramet numbers under high disturbance. *B. retusa* showed the highest ramet count under moderate disturbance (3.5) but decreases significantly under high disturbance (1.4), with inter- ramet distance increasing as disturbance increase. *C. infortunatum* has high ramet numbers under low and moderate disturbance (20) but drops drastically under high disturbance (2.6), with inter-ramet distances increasing as disturbance increases. *F. indica* and *Moghania* species exhibit similar trends of decreasing ramet numbers with increasing disturbance. *M. chappar* and *M. lineata* shows via sharp decline in ramet numbers in disturbances particularly for *M. lineata* which drops from 16.0 to 1.3. The *C. viscousum* had a relatively stable ramet count across different disturbance levels with moderate variation in inter-ramet distances (Table 2). The one-way ANOVA revealed a significant difference in species abundance among disturbance levels ($F = 6.87$, $p < 0.05$). The mean number of individuals was highest in the low disturbance condition (12.5), followed by moderate disturbance (7.12), and lowest in high disturbance (2.30). This indicates that increasing disturbance significantly reduces species abundance (Table 3).

Among the 5-year-old plants, *B. stipularis* was more abundant, while *B. retusa* was less so. In contrast, 4-year-old *B. retusa* plants outnumbered those of *B. stipularis*. The number of 3-year-old *B. stipularis* plants was higher compared to *B. retusa*. Similarly, 2-year-old *B. stipularis* plants were more abundant than *B. retusa*. Under moderate disturbance, the number of *B. stipularis* individuals older than 5 years was higher, while *B. retusa* had fewer individuals in this age category. The total number of individuals of 5 yrs was also higher in *C. infortunatum*, while it was lower in *C. viscousum*. Additionally, the number of plant species aged 4 years was fewer in *C. viscousum* compared to *C. infortunatum*. However, the number of individuals aged 3 years was higher in *C. viscousum* than in *C. infortunatum*. The maximum number of individuals aged 2 years was lower in *C. infortunatum* but higher in *C. viscousum*. The number of individuals aged 5 and 4 years was also greater in *C. infortunatum* but fewer in *C. viscousum*. At low disturbance *F. indica* had 28 individuals pe 0.01 Ha,

Table 1. Number of Individuals/ 0.10 ha in different disturbance level.

Species name	Low Disturbance	Moderate Disturbance	High Disturbance
Desmodium gangeticum	164 ±7.78	307± 8.8	445.6±9.9
Desmodium pulchellum	7.66±2.05	136± 5.37	322.33±17.2
Clerodendron infortunatum	4126±90	11631±24.85	6774±22.82
Clerodendron viscousum	1420±76.48	2285±18.70	6651±76.63
Moghania chappar	2220±74.83	4135±49.66	3354.66± 24
Moghania bracteata	120.33±4.49	293±14.45	10.33±1.03
Moghanialineata	43.33±7.40	31.66±4.13	67.33±5.73
Bridelia retusa	24.33±3.29	34.33±3.68	0
Bridelia stipularis	18.6±2.8	24.33±3.29	0
Flocourtia indicia	43.33±7.40	130±1.73	43.33±7.40
Flocourtia zangomos	34.33±3.68	90.33± 9.48	24.33±3.29
Leea alata	58.66±2.86	4 70±37.41	210.66±6.59
Leea aspera	43.33±7.40	34.33±3.68	34.33±3.68

whereas *F. zangomos* had 34 individuals overall. The individuals of five-yr-old plants was higher in *F. indica* but lower in *F. zangomos*. The maximum number of two-yr-old individuals was lower in *F. indica* and higher in *F. zangomos*. However, the number of one-yr individuals was greater in *F. indica* and lower in *F. zangomos*. Under moderate disturbance, the number of 5-yr individuals was higher in *F. indica* but lower in *F. zangomos*. Additionally, the number of one-year-old individuals was greater in *F. indica* and lower in *F. zangomos*. The percentage of four-year-old plants of *L. alata* was also less than that of *Leea aspera*. The three-year old were also more prevalent in *L. alata* and *L. aspera*, *L. alata* and *L. aspera* were lower and more isolated respectively with a maximum age of two years. In *L. aspera* what was more frequent than *Leea alata* was one and three-year old. Of two years also, there were more in the *L. alata* and less in the *L.*

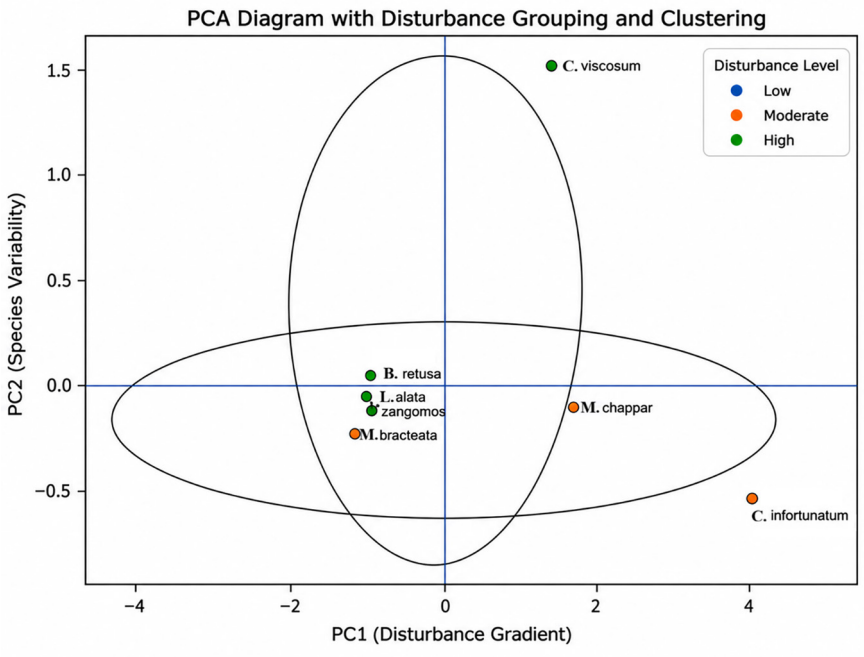

Fig. 1. Principal Component Analysis (PCA) ordination showing species distribution at three disturbance level.

Table 2. The number of ramets/ genet complex and the inter-ramet distances in cms (mean ± SD) for various ramet-producing species in stands having low, moderate or high level of disturbance.

Species	Low disturbance	Moderate disturbance	High disturbance
Bridelia retusa Hook. f	2.8 ± 0.6 (12.8 ± 2.86)	3.5 ±1.43 (10.6 ±2.37)	1.4 ± 0.70 (21.1 ± 3.64)
Clerodendron. infortunatum Gaerin	20.2 ± 8.11 (14.8 ± 5.94)	19.7 ±6.60 (16.8 ± 6.73)	2.6 ± 0.87 (29.1 ± 8.2)
Clerodendron viscousum	15.5 ±2.80 (3.9 ±1.0)	3.7 ±0.95 (12.8 ±3.88)	4.5 ± 1.3 (14.1 ± 2.77)
Flacourtia. indica (Burm. F.) Merr	4.5 ± 1.3 (14.1 ± 2.77)	2.6 ±0.52 (2.0 ±0.82)	1.6 ± 0.8 (21.1 ± 5.59)
Moghania chappar	16.0 ± 3.0 (1.2 ± 0.42)	9.3 ±2.31 (13.4 ±4.27)	2.4 ± 1.35 (1.6 ± 0.52)
Moghania. Lineata (L.) Ktze	16.0 ± 3.0 (1.2 ± 0.42)	3.9 ±1.0 (15.5 ±2.80)	1.3±0 .48 (8.5±2.6)

aspera. At high disturbance total of the individuals of those species of *L. aspera* whose age was more than five years old was higher than that of *L. alata*, there were also more five and four-year olds that were found in *L. alata* than in *L. aspera* five-year old there were also less, however, and more in *L. alata*. (Fig. 2). At recurrent disturbance in *C. infortunatum*, the earliest stage of development, the genet initiates primary ramets that emerge from the root stock. These primary ramets provide the first framework for underground organization and act as starting points for subsequent branching. It consists of multiple orders of ramets (primary, secondary, tertiary), adventitious root suckers, and strong anchor roots (Fig. 3).

DISCUSSION

In the forests of Gorakhpur, India, we studied 13 similar plant species to understand how they grow and survive in areas with different types of disturbance. These disturbances were caused by things like human activity, cattle grazing, firewood collection, and natural changes. Some species like *C. infortunatum* grew best in areas with moderate disturbance. Moderate disturbance seems to help this plant grow better, possibly because there is enough light and space for new growth without too much damage. This matches findings from tropical forests elsewhere, where a small amount of disturbance can actually help forests regenerate and increase plant diversity (Kumar and Sakia 2020 ; Chazdon *et al.* 2025). On the other hand, *C. viscousum* grew more in areas with high disturbance. This shows that it is more tolerant of disturbance and can survive in harsh conditions. Its strong root system and fast growth help it spread quickly even when the forest is damaged. Similar results were found in other studies, where fast-growing shrubs increased in disturbed areas (Veldman *et al.* 2015). Some plants did not survive well in disturbed areas. For example, *B. retusa* and *B. stipularis* were not found at all in highly disturbed zones. They grew better in places with low or moder-

Table 3. One-way ANOVA table showing ramet number/ genet across different disturbance levels.

Source of Variation	SS	df	MS	F
Between Groups (level of disturbance)	319.78	2	159.89	6.87*
Within Groups (among the congeneric species)	348.84	15	23.26	
Total	668.62	17		

*Significant at $p < 0.05$

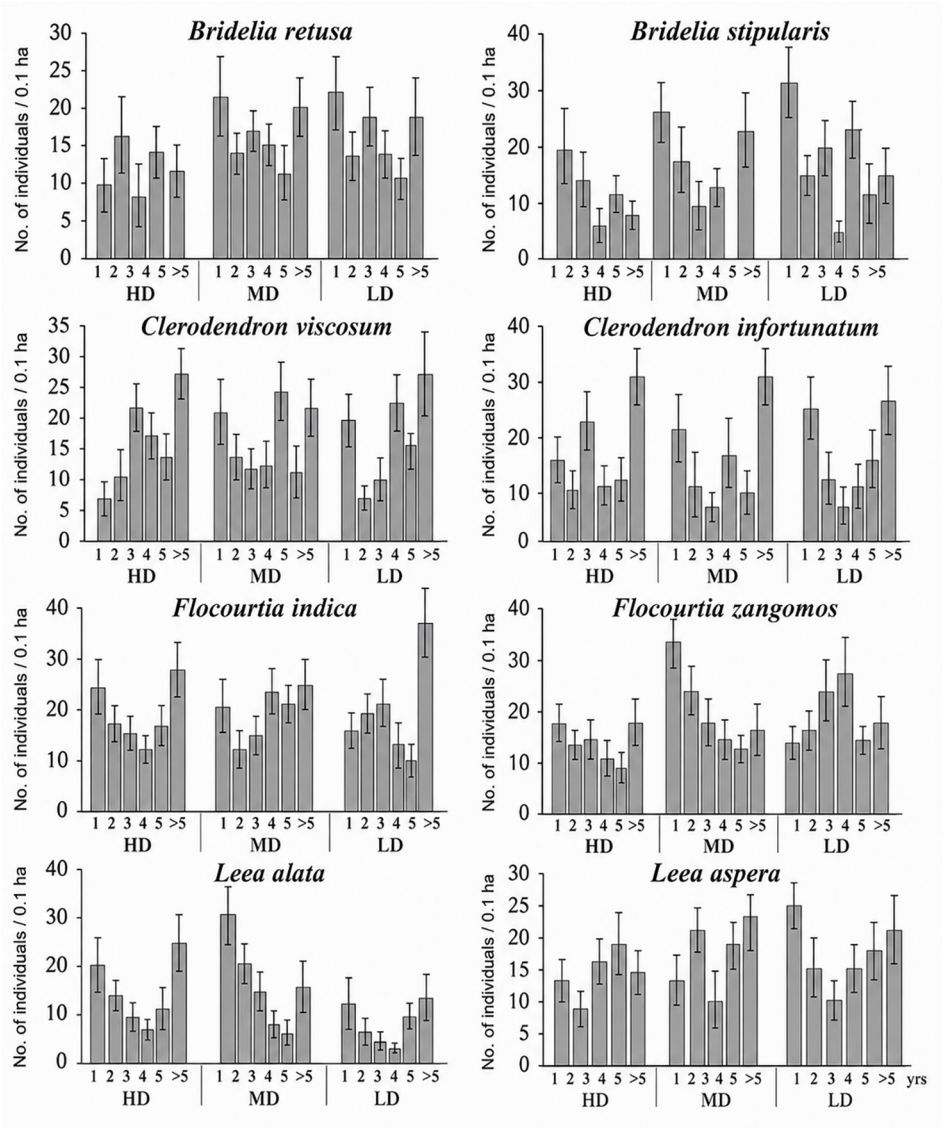

Fig. 2. Population status of four different congeneric species across low (LD), moderate (MD) and high (HD) level of disturbances along the age series (year).

ate disturbance. These plants are more sensitive and may need more stable conditions to survive. When disturbance is too high, older trees are often cut down or damaged, and sensitive species lose their habitat. Other researchers have found that such species are often lost from heavily disturbed forests (Pandey and Shukla 2001 ; Keeley *et al.* 2011). We found that most of ramet producers made more ramets in low and moderately disturbed areas. In areas with high disturbance, they made fewer ramets. This means high disturbance stops the plant from spreading naturally (Phillips and Gentry 1994 ; Saha S. and Howe 2003 ; Maurent *et al.* 2023). We also measured the distance between these clones (inter-ramet distance). In low disturbance areas, clones were close together. In high disturbance areas, they were spread out. This might be because the plants are trying to grow away from damaged areas or are under stress. A study by

Fig. 3. Spatial organization of subterranean structures showing ramet positions and inter-ramet distance (IRD) along the root-stock of a *Clerodendrum infortunatum*..

de Kroon and Hutchings (1995) showed that clonal plants often grow this way to survive difficult conditions. Species associated with low disturbance (e.g., *Bridelia* and *Leea* spp.) are positioned on the negative side of PC1, whereas high-disturbance-tolerant species such as *C. infortunatum*, *C. viscosum* and *Desmodium* spp. are clustered on the positive side, indicating strong ecological adaptation to disturbed habitats. Moderate-disturbance species occupy intermediate positions, forming a transitional group. The high cumulative variance explained by the first two components (82.6%) confirms that disturbance intensity is the primary driver of species composition, and the distinct clustering pattern reflects a significant ecological gradient influencing thicket community structure. The variation of IRD was substantially greater within different species, confirming that disturbance intensity has a strong effect of disturbance on species distribution patterns.

In high disturbance areas, there were more young plants, this could be because old plants were destroyed, and only new plants were growing back. *B. stipularis*, *C. infortunatum*, and *D. gangeticum* showed this trend clearly. *B. stipularis* had older individuals in low disturbance zones. Species like *M. chappar* and *M. bracteata* had more ramets in low and moderately disturbed areas. This sharp decline shows that this plant is very sensitive and may need protection in disturbed forests (Pandey *et al.* 2024). *L. alata* was more common in moderate disturbance areas, while *L. aspera* was found more in high disturbance zones. This may be due to their different ways of surviving. Similarly, *F. indica* and *F. zeylanica* had low numbers overall and were more limited in their presence. Some plants grow better with light disturbance because it opens space and brings lighter. Others suffer when the forest is disturbed too much. But high disturbance harms their ability to grow more ramets and survive long-term (Pandey and Shukla 2001, 2003). Meanwhile, moderate disturbance may support fast-growing species and increase variety. Our results show that managing disturbance levels carefully is key to preserving the wide range of plant life in tropical forests like those in Gorakhpur.

We found that regeneration potential varied significantly among species and across disturbance levels. In areas with low and moderate disturbance, many species showed robust regeneration, with a balanced presence of seedlings, saplings, and mature individuals. This indicates that light or moderate disturbance may help stimulate regeneration by opening the canopy, allowing lighter and space for young plants

to grow, without causing too much damage to the existing vegetation. Such conditions often promote a healthy age structure and greater biodiversity (Grubb 1977 ; Chazdon *et al.* 2025). The *C. viscousum* was most abundant in highly disturbed zones, suggesting that it is a disturbance-tolerant species with fast growth and a high regeneration potential even under stressful conditions. Its fibrous root system and ability to produce suckers may help it rapidly colonize disturbed sites. Species such as *B. retusa* and *B. stipularis* were absent in high disturbance areas, showing limited regeneration under harsh conditions (Pandey *et al.* 2024). These species may be sensitive to environmental changes and depend on long-lived adult plants to contribute seeds and maintain the population structure. This pattern matches observations in other studies where high disturbance negatively affected the regeneration of sensitive forest species (Pandey and Shukla 2001; Keeley *et al*. 2011). In addition to seed-based regeneration, clonal propagation played a vital role in population maintenance. Species such as *B. retusa*, *C. infortunatum* and *M. lineata* reproduced vegetatively through ramets. Clonal reproduction allows species to maintain themselves even when seedling survival is low. This suggests that stressed environments, plants may spread their clones more sparsely, possibly as a strategy to reduce intra-clonal competition or to escape unfavorable microsites. Similar patterns were observed in clonal plant species elsewhere, where fragmentation led to wider spacing between ramets (de Kroon and Hutchings 1995).

The age structure of plant populations also provided insights into regeneration dynamics. In low disturbance areas, species exhibited a full range of age classes, including many older individuals. This implies successful long-term regeneration and minimal disruption to life cycles. In contrast, high disturbance areas had more young individuals and few older plants, indicating that mature individuals were removed or destroyed and regeneration was recent and potentially unstable. These differences emphasize the need to consider species-specific traits and reproductive strategies when evaluating regeneration potential (Pandey and Shukla 2019). Species like *L. alata* and *L. aspera* showed differing regeneration patterns under similar conditions. *L. alata* was more abundant in moderate disturbance, while *L. aspera* appeared more frequently in high disturbance areas. These patterns may be due to differences in seed dispersal, growth rates or tolerance to environmental stress. *F. indica* and *F. zangomos* had limited distribution and low regeneration rates, suggesting that they are habitat specialists requiring specific conditions not met in disturbed environments. Moderate disturbance can promote regeneration for many species by creating favorable conditions for both seedling establishment and clonal spread. However, excessive disturbance reduces regeneration capacity, especially in species that rely on clonal reproduction or require stable habitats for seedling survival (Bellingham and Sparrow 2000 ; Saha and Howe 2003 ; Pandey and Shukla 2019 ; Chazdon *et al.* 2025). The genet serves as a long-lived unit, while the ramets act as short-lived but continuously renewing modules. Together, they form a resilient clonal network that can survive damage, regenerate rapidly, and ensure population persistence even in degraded or disturbed environments the overall strategy of *C. infortunatum* demonstrates a strong reliance on clonal propagation rather than seedling recruitment. While the species does produce seeds, its underground system ensures continuous regeneration even under stress conditions. This makes it an excellent example of a clonal shrub adapted to disturbance-prone habitats. Its capacity to produce successive orders of ramets, root suckers, and deep anchor roots reflects an evolutionary adaptation for survival, colonization, and dominance in variable environments.

CONCLUSION

To protect plant diversity in the regional forests, we need to consider how each species reacts to disturbance. Some need least disturbed environments, while others can survive in changing conditions. Forest managers can use this information to plan better conservation methods. The spatial arrangement of ramets and subterranean spacers in different species illustrates an adaptive mechanism where short inter-ramet distances allow clumped growth, while the development of root suckers provides opportunities for colonization of nearby patches. Over time, this growth pattern enhances the ability of the species to persist under pressure, thereby contributing to the stability of the ecosystem. Forest management strategies

must therefore aim to maintain a balance—protecting moderate disturbance patches to preserve sensitive and long-lived species while allowing controlled disturbance in other areas to support dynamic species and enhance biodiversity. It underscores the need for disturbance-sensitive forest management practices to ensure long-timespan conservation and sustainable use of biodiversity in sal forest ecosystems.

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