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# Effect of Altruistic Surrogacy of Treefall on Herbaceous Flora Colonisation in Subalpine Forest of Khangchendzonga Biosphere Reserve, Eastern Himalaya, Sikkim, India

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***Abstract***: The present study represents the herb species' colonisation on the fallen trees in the subalpine forests in the Khangchendzonga National Park (KNP) West Sikkim, Eastern Himalayas. Around 5 per cent of the forest floor was taken up by fallen logs in various stages of decomposition. The study indicated that there must be no less than 13.50 trees with a diameter of at least 50 cm per 0.25 ha for successful colonization. Seedlings of herbaceous species differed in their probabilities of colonising under fallen logs, pits, and mounds but colonization of most species was substratum-specific. Several species generally colonised on pits, mounds, and logs. Pit colonisation by seedlings appeared to be larger in numbers than on logs and mounds. Most colonisation appeared to be local, from plants within 1 m of the log or pit. Summer species appeared to be superior colonisers and then spring-ephemeral species. Overall, plants with wind-dispersed seeds predominated in the colonisation of pits, and logs. The finding indicates that inclusion of other colonisation sites such as pits, mounds, and tree stumps would further favour the altruistic surrogacy of available colonisation areas. The existence of seasonal herbaceous species may be an indicator of the survival mechanisms of plant species to cope with changing climatic conditions and provide insights into how the species interact with their environment.

***Keywords***: Colonisation, Eastern Himalayas, Khangchendzonga Biosphere Reserve

The Khangchendzonga National Park (KNP) part of the Khangchendzonga Biosphere Reserve (KBR) inscribed to the UNESCO World Heritage site list becoming the first “Mixed heritage site” of India. The region harbors a wealth of biodiversity within its pristine forests and alpine meadows, comprising a wide variety of plant and animal species, many of which are endemic to this locale (Chettri and Sharma 2006). This region exhibits a complex climate with bioclimatic zones ranging from near-tropical to alpine, including subtropical, warm temperate, cold temperate, subalpine, and alpine regions (Kanade and John 2018, Bhutia et al., 2024). Silver fir and Rhododendron trees (*Abies densa* & *Rhododendron* Spp.) are concomitant dominant feature of the subalpine forest of Khangchendzonga Biosphere Reserve in Eastern Himalaya. In these forests, diverse mixtures of *Rhododendron* species are frequently encountered as companion species. In the undisturbed stands, it has been estimated that the frequency of *Rhododendron* spp. would be around 12 to16 individuals in a 10 m x 10 m quadrat. *Abies densa* Griffith ex R. Parker, frequency is low compared to *Rhododendron* species but has higher basal coverage. Lower *Abies* tree-species frequency further reduces complexity in the region, increasing the capacity to understand the role of windthrow across the landscape.

The Himalayan forests are suffering from severe climatic and anthropogenic disturbances (Mittal et al., 2021). These subalpine forests are influenced by many disturbance factors, including fire, wind throw, drought, avalanches, and anthropogenic activities. Various agents of disturbance operate at different temporal and spatial scales, ranging from large-scale disturbances to perturbations affecting individual trees or small groups of trees. To maintain biodiversity, forest management must try to understand the role of natural disturbances in a given ecosystem. In silver fir and *Rhododendron* spp. dominated ecosystems, along with forest fire and other disturbances in pine forests are harmful to the ecosystem (Bhardwaj et al., 2009). Tree falls are a major consequence of windthrow in forests. However, windthrow could also play an important role in silver fir ecosystems (Ruel and Benoit 1999, Leblanc and Belanger 2000) but its general significance has not been quantified. It can occur as a consequence of unusually strong winds (Ruel and Benoit 1999), or by root rots (Whitney 1995). Uprooting exposes mineral soil and creates mixtures of organic and mineral soil (Ulanova 2000) that can be beneficial for seedling establishment. In addition, the fallen trees can become suitable seedbeds for conifer regeneration when they reach an adequate state of decay. However, in such forests as an important component in forests, knowledge of community structure and species diversity for understory herbaceous communities remains scarce (Wang et al., 2021).

Disturbances caused by wind occur in all forested regions, ranging from a single tree's snap-off to uprooting trees over hundreds of hectares. Following a wind event, a dynamic interplay sets up between ecosystem legacies (e.g., surviving trees, deadwood, pit-and mound complexes) and altered environmental conditions (e.g., light, temperature, soil, water regime) while forests are susceptible to subsequent disturbances (Buma 2015, Palm et al., 2024). By mixing upper and lower horizons and creating mound-pit topography, windthrow has important effects on the heterogeneity of soil and the recruitment of plant species (Small et al., 2002). The pit and mound microtopography created by windthrow is a common feature in the subalpine forest.

Many plants respond to windthrow because of increased light and moisture. Ulanova (2000) observed that microsite creation by windthrow may play an important role in the regeneration process of boreal forests where the forest floor is covered by a thick carpet of moss. It influences litter accumulation, water and temperature regimes and could even affect herbivory patterns. Even small-scale disturbance can create regeneration microsites for seed germination and seedling growth. Herbaceous biomass was inversely related to the regeneration aspect, a pattern that seems largely due to reduced nutrients and invasion under closed canopies. This may be due to the relatively open canopy of forests, which allows for extensive growth (Dhakal et al.,2022). However, the extent to which such sites are available in forests and the relative degree to which plant species can colonies these sites are mostly unknown in the subalpine forests of the Eastern Himalaya. Present study addresses questions concerning windthrow and the pattern of herbaceous colonisation in the upper montane forests including colonisation sites in the form of treefalls and probability of summer herb and spring herb colonization related to dispersal types of species.

## MATERIAL AND METHODS

**Study sites:** The KBR, situated in the mountainous regions of India-specifically in the Himalayas-exhibits elevation-associated species richness and diversity patterns (Parker et al., 2015). KBR named after well-known Mt. Khangchendzonga, (8586 meters tall) the third highest peak in the World lies in this region. The KBR lies in between 27º25′ and 22 º55′ N latitudes and 88 º03′ to 88 º38′ E longitudes encompassing one core zone (1784km$^2$) and buffer zones (835.9 km$^2$), with total area of 2619.9 km$^2$(Chettri et al., 2006). The three study areas were located at Phedi-Dungdang in Khangchendzonga Biosphere Reserve, Sikkim in Eastern Himalayas in a 100 ha reserve of old-growth *Abies* (silver fir) *Rhododendron* forests (Chettri et al., 2010). The geocoridinates of the three selected study sites *i.e.*, Dungdang, Lhasosa, and Bikhbari are 22°23′763″ N 88°04′919″ E, 22°23′358″ N 88°05′535″ E and 22°23′715″ N 88°04′695″ E, respectively. The three study areas were at least 1000 m apart. It is in the subalpine region at an elevation of 3000-3500 MSL. Important tree species at study sites are *Abies densa* Griffith ex Parker, *Buddleia colvilei* Thom., *Rhododendron* spp., and *Tsuga dumosa* Eichler, with a maximum canopy height of about 22 m.

Forests covered under the study area are undisturbed primary forests, approachable only by trekking 10 - 20 km distance from the nearest road. The climate of the study area is monsoonal and because of its proximity to the Bay of Bengal with very high rainfall. Three seasons are distinguishable in a year: winter (October-March), summer (March-May) and monsoon (June-September). The average annual rainfall ranges from 3500 to 400 mm, and the annual mean minimum and maximum temperatures of sub-zero in sunb-alpine and alpine areas; and 12 ºC and 16.9 ºC in temperate areas of the BR (Chettri et al., 2006). Since the State is the most humid region in the whole range of Himalayas the Biosphere also experiences a wide range of humidity which may be from 70% in the month of December to 92% in July, the annual means being around 82% (ENVIS). The soils are loose with 50-60% sand and acidic in nature (pH varies from 4.93 to 5.41). The organic carbon, nitrogen, and phosphorus contents of soils are fairly good (Singh and Sundriyal 2005). In each study area, the coverage of fallen trees on the forest floor was calculated by examining five plots per site measuring 50 meters by 50 meters. Each of the three study areas contains a fixed grid, and random sample plots were selected within each grid. The measurement of all fallen logs in each plot, ensuring that only those with a minimum diameter of 50 cm at the midpoint were included in our calculations. Logs lying horizontally on the ground were included; logs partly down but leaning against another tree were excluded. Furthermore, logs that have fallen and are now level with the ground but still visible were omitted.

**Colonisation:** In June 2020, a thorough examination was conducted on the colonisation of logs, pits, and mounds for summer herbs. In addition to that, in April 2021, a comprehensive study was carried out on the colonisation of these areas by spring herbs (Fig. 1).

The spring herbs are those that appear aboveground in early spring and flower mostly in March, April and May. During the monsoon season, a variety of summer herbs make their appearance. For all the groups, 150 logs, 150 pits and 150 mounds (70 in Dungdang, 40 in Lhasosha and 40 in Bikhbari) were randomly chosen along transects in each study area. The same tree was not sampled for the study of the colonisation of logs, pits and mounds. All herbaceous species within 1 m of the edge of the log or pit were recorded to determine the availability of potential colonists nearby. Species were recorded if the individuals had overcome the cotyledon stage. For the colonisation of logs, individuals were recorded if rooted within the log itself. Colonisation of pits was divided into the far slope, the near slope and the centre. The far slope included all the slope of the pit excluding that at the base of the tree itself. The near slope, then, was just below the root mass at the base of the tree. The centre was the deepest area of the pit. For the colonisation of mounds, individuals were recorded if rooted in the exposed portion of the mound and colonisation of the upper portion of the mound was not considered because it may often contain a mosaic of buried old seed pools. The purpose of these divisions was to determine if these sites were differently colonised by plant species.

**Statistical analysis**: For statistical analysis, nonmetric multidimensional scaling (NMDS; Kruskal 1964), Community Analysis Package, version 4.1.3 (PISCES Conservation Ltd. 2007), Community Analysis Package, version 4.1.3 (PISCES Conservation Ltd. 2007) was used. Bray–Curtis similarity based on the species-specific abundance was used as a distance metric for NMDS and ANOSIM. Non-parametric Permutational Multivariate Analysis of Variance (PERMANOVA) post hoc test using Bray-Curtis dissimilarity is performed with the function of the "vegan" library.

## RESULTS AND DISCUSSION

**Treefalls:** The mean percentage of the forest floor under fallen logs was 5.1 per cent. The sample areas averaged 13.5 logs of ≥ 50 cm diameter per 0.25 ha and were similar for all three study areas (Table 1). Not all logs included had a humus build-up on the surface that could support herbs at present. Inclusions of other colonisation sites such as pits, mounds and tree stumps would further increase the estimate of available colonisation areas.

**Colonisation:** The mean number of species recorded at a log, pit or mound were similar for all three study areas in both spring and summer, although the Bikhbari study area had a lower mean number of species in spring (Table 2). Logs were generally colonised by several species, averaging about two species from the summer flora and one species from the spring flora. As a group, the summer herbs were better colonisers of logs than the spring herbs, with a large majority of species found near the edge of a log colonising the logs.

However, even in spring flora, an average of 36-40% of the species at a site managed to colonise the log. Only a small percentage (0-18%) of the species found on the logs did not occur within 1 m of the logs. Therefore, colonisation appeared to be primarily from the nearby herbaceous contingent. The general pattern for the colonisation of pits and mounds was similar (Tables 3, 4). The percentage of species colonising pits and mounds during summer was also somewhat higher than the percentage colonising logs. The higher percentage of the summer flora than of spring flora

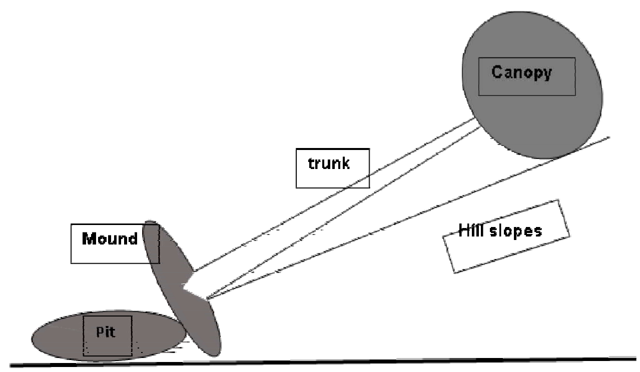


**Fig. 1**. Characteristics features of tree fall and demarcation of pit, mound and trunk for the sampling of herbaceous flora

**Table 1**. Percentage of forest floor area in fallen logs (Mean ± SD)

| Study areas | Forest floor percentage under fallen logs | No. logs |
|---|---|---|
| Dungdang | 6.60 ± 1.69 | 16.00 ± 2.73 |
| Lhasosha | 4.50 ± 1.25 | 12.80 ± 2.28 |
| Bikhbari | 4.10 ± 0.75 | 11.80 ± 1.78 |
| Mean | 5.10 ± 1.65 | 13.50 ± 2.28 |

**Table 2**. Number of species on a log and overall probability for colonisation of logs by spring and summer herbs (Mean ± SD)

| Species colonisation | Season | Dungdang | Lhasosha | Bikhbari |
|---|---|---|---|---|
| Mean no. of spp. per site (edge and on a log) | Spring | 2.90 ± 1.19 | 2.70 ± 0.99 | 2.00 ± 1.08 |
| | Summer | 4.30 ± 1.66 | 3.40 ± 1.53 | 3.30 ± 1.46 |
| Mean no. of species on the log | Spring | 1.20 ± 0.91 | 1.00 ± 0.78 | 1.00 ± 0.78 |
| | Summer | 2.70 ± 1.24 | 2.30 ± 1.12 | 1.90 ± 1.07 |
| Per cent spp. on log edge | Spring | 40.00 ± 1.12 | 40.10 ± 1.17 | 36.60 ± 1.83 |

Edge refers to the area of forest floor within 1 m periphery of the fallen log colonised the pits from distances > 1 m (33-37 vs. 27-30%). The percentage of summer flora on an exposed surface of the mound was also higher than the percentage colonising during spring (47-51 vs. 41-48%).

Individual species varied greatly in their frequency of occurrence at sites and in their probability of colonising either logs or pits (Table 5, 6). Spring ephemeral species, such as *Juncus grisebachii* and summer species such as fern were highly successful in colonising the logs. In contrast, *Abies* and *Rhododendron* seedlings were much more successful at colonising pits than logs. This applies, however, to the percentage of pits and logs colonised and not the abundance of individuals, which were not analyzed in this study. The probability of colonising a pit or log from a distance > 1 m was highest in some of the summer species. However, plants of this group had no single, specific type of seed. Out of 14 species under 17 genera encountered in pits and logs but not within the surrounding 1 m of the forest floor, *Poa annua*, *Polygonum tortuosum*, and *Polygonum polystachya* have hooks which may have attached to fur or feathers; *Hemiphragma heterophyllum* have fleshy fruits ingested by birds or mammals; *Selinum* spp., have ballistic mechanism; *Rhododendron* seeds have no obvious mechanism for dispersal in space but the minute seeds probably remain viable in the soil over longer periods, hence, disperse in time. *Abies* seeds have wings and are dispersed by wind to new microsites like exposed mounds and pits. As a group, wind-dispersed seeds tended to predominate in the colonisation of pits and logs from > 1 m.

Colonisation from distances > 1 m was not uncommon, especially in the summer species. In the summer species, colonisation from > 1 m accounted for 44.4% of the occurrences of species in logs and 62.3% of the occurrences on pits; in the spring species and this colonisation accounted for 53.3% on logs and 54.5% in pits. Thus, species that were not necessarily established in the nearby neighbourhood in the recent past are accumulated by treefalls and the holes that accompany them.

**Species association and significance testing:** The clear separation of the communities along the first two axes, indicates that NMDS produced a two-dimensional solution (stress = 0.10) with three plant associations that could be clearly recognized (Fig. 2). The NMDS revealed significant variation in substrate types, with some species groups having a stronger association with particular habitat types than others. Closely spaced plots suggest that their species compositions are comparable. There is a constant fluctuation in species composition among substrates, as seen by the species distribution in ordination space. The seedling of *Abies* and *Rhododendron* that are grouped at the right side of the biplot are substrate specific and show better colonisation for pits and mound habitat. A substantial compositional difference between communities is described by the *post hoc* PERMANOVA.

The projected result of increasing spatial heterogeneity is the formation of mixed stands of *Rhododendron* and *Abies* following windthrow. Pandey et al. (2018) conducted a study

**Table 3**. Number of species in pits and overall probability for colonisation of pits by spring and summer herbs (Mean ± SD)

| Species colonisation | Season | Dungdang | Lhasosha | Bikhbari |
|---|---|---|---|---|
| Mean no. of spp. per site (edge and on pit) | Spring | 3.60 ± 1.05 | 3.70 ± 0.95 | 3.40 ± 0.91 |
| | Summer | 4.30 ± 1.59 | 4.90 ± 1.25 | 3.70 ± 1.22 |
| Mean no. of species on pit | Spring | 2.20 ± 0.77 | 2.30 ± 0.71 | 2.02 ± 0.71 |
| | Summer | 2.70 ± 1.07 | 2.90 ± 0.92 | 2.60 ± 0.98 |
| Per cent spp. on edge also on pit | Spring | 45.60 ± 3.12 | 48.40 ± 3.34 | 47.90 ± 3.06 |
| | Summer | 54.40 ± 2.91 | 51.60 ± 3.71 | 52.10 ± 3.31 |
| Per cent species on pit only | Spring | 27.50 ± 3.31 | 30.70 ± 4.96 | 28.900 ± 4.12 |
| | Summer | 33.90 ± 3.15 | 37.90 ± 3.94 | 37.5 ± 3.35 |

**Table 4**. Number of species on the exposed portion of mounds and overall probability for colonisation of mounds by spring and summer herbs (Mean ± SD)

| Species colonisation | Season | Dungdang | Lhasosha | Bikhbari |
|---|---|---|---|---|
| Mean no. of species on the mound | Spring | 2.40 ± 0.96 | 2.00 ± 0.92 | 2.00 ± 0.94 |
| | Summer | 2.50 ± 1.14 | 2.20 ± 1.03 | 1.90 ± 1.13 |
| Per cent species on the mound only | Spring | 46.30 ± 4.33 | 41.90 ± 4.10 | 48.20 ± 3.82 |
| | Summer | 47.10 ± 3.82 | 47.80 ± 3.90 | 51.90 ± 3.35 |

on timberline structure and woody taxa regeneration towards tree line along atitudinal gradients in Khangchendzonga National Park, Sikkim and revealed that humus, elevation and slope. The predominant species of the herb, small tree and shrub genera varies with the effect of microclimatic conditions (Moran et al., 2023). The forest floor was rapidly colonised by the typical plant life that develops on fallen trees, pits, and mounds. It can be accomplished through *Rhododendron* and *Abies* species seedling establishment or vegetative growth. When tree falls, pits and mounds are formed, the tree's root system may weaken and eventually collapse, exposing mineral soils. The growth of seedlings got more favourable conditions in shallow pits formed by uprooted silver fir *(Abies densa)* than in deeper pits as per the

**Table 5**. Probabilities for colonisation of logs by spring and summer herbs

| Taxon | species letter codes | Dispersal of seeds | $N_e$ | % $N_e$ on log | % $N_{max}$ on log only |
|---|---|---|---|---|---|
| Spring | | | | | |
| *Cirsium falconeri* (Hook. F.) Petr. | Cfal | Hooks/burs | 132 | 12.0 | 0.0 |
| *Elsholtzia flava* Benth. | Efla | Insects | 134 | 10.7 | 4.4 |
| *Fragaria daltoniana* J. Gay | Fves | Birds | 129 | 14.0 | 0.0 |
| *Gaultheria trichophylla* Royle | Gtri | Wind | 137 | 08.7 | 3.6 |
| *Hemiphragma heterophyllum* Wall. | Hhet | Birds | 118 | 21.3 | 8.8 |
| *Juncus grisebachii* Buchenau | Jgri | Water | 143 | 04.7 | 1.9 |
| *Megacodon stylophorus* (Clarke) Sm. | Msty | Wind | 137 | 08.7 | 0.0 |
| *Panax bipinnatifidus* Seem. | Pbip | Birds | 136 | 09.3 | 0.0 |
| *Panax sikkimensis* R. N. Banerjee | Psik | Birds | 130 | 13.3 | 0.0 |
| *Parsenecio quinquelobus* (Wall. ex D.C.) Y.L. Chen | Pqui | Wind | 123 | 18.0 | 0.0 |
| *Polygonum tortuosum* D. Don | Ptor | Hooks/burs | 104 | 30.7 | 12.6 |
| *Primula calderiana* Balf. f. & R.E. Cooper | Pcal | Water | 113 | 24.7 | 0.0 |
| *Saxifraga* spp. | Sax | Water | 123 | 18.0 | 0.0 |
| *Senecio raphanifolius* Wall. Ex. DC. | Srap | Wind | 110 | 26.7 | 0.0 |
| *Stellaria sikkimensis* Hook. f. | Ssik | Water | 116 | 22.7 | 9.3 |
| Summer | | | | | |
| *Anaphalis margaritacea* (L.) Benth. & Hook. f. | Amar | Wind | 121 | 19.3 | 0.0 |
| *Anaphalis triplinervis* (Sims) C.B. Clarke | Atri | Wind | 103 | 31.3 | 0.0 |
| *Buplerum longifolium* L. | Blon | Ballistic | 122 | 18.7 | 0.0 |
| *Chrysanthemum atkinsonii* C. B. Clarke | Catk | Wind | 121 | 19.3 | 0.0 |
| *Clintonia udensis* Trautv. & C.A. Mey. | Cude | Ant | 131 | 12.7 | 0.0 |
| *Cremanthodium reniforme* (DC.) Benth. | Cren | Wind | 117 | 22.0 | 0.0 |
| *Dubyaea hispida* DC. | Dhis | Wind | 128 | 14.7 | 0.0 |
| *Fern* spp. | Fspp | Wind | 140 | 06.7 | 1.8 |
| *Gaultheria pyroloides* Hook. f. &Thom. Ex Miq. | Gpyr | Wind | 103 | 31.3 | 8.3 |
| *Halenia elliptica* D. Don | Hell | Wind | 130 | 13.3 | 3.5 |
| *Juncus clarkei* Buchenau | Jclar | Water | 131 | 12.7 | 3.4 |
| *Juncus khasiensis* Buchenau | Jkha | Water | 134 | 10.7 | 2.8 |
| *Ligularia fischeri* (Ledeb.) Turcz. | Lfis | Wind | 128 | 14.7 | 0.0 |
| *Pilea* spp. | Pspp | Ant | 101 | 32.7 | 8.7 |
| *Poa annua* L. | Pann | Hooks/burs | 121 | 19.3 | 5.1 |
| *Polygonum polystachya* T.M. Schust. & Reveal | Ppol | Hooks/burs | 107 | 28.7 | 7.6 |
| *Potentilla peduncularis* D. Don | Pped | Wind | 104 | 30.7 | 8.1 |
| *Selinum* spp. | Sspp | Ballistic | 93 | 38.0 | 10.1 |

$N_e$ = number of sites in which the species occurred on the soil surface within 1 m of the edge of a log; $N_{max}$ = 150 sites report of Vodde et al. (2010). The dispersal of seeds to these sites results partly from the relationships between treefalls and wind that act as dispersal agents of the forest herbs. one-third of the plant species that colonised logs and pits are wind-dispersed. The study area is affected by strong wind currents. Due to the direction of the wind, seeds that are dispersed by the wind would end up in fallen logs, pits, and mounds Wind direction, and its variability, is important for determining the area over which seeds are dispersed (Augspurger 2024). Medium-sized gaps were the most suitable for seed germination and radicle growth as they promote the regeneration of endangered species in the natural forest (Zhu et al., 2021). In light gaps, fallen logs are a common landing spot for plant seeds such as *Primula calderiana, Juncus* spp., and *Stellaria sikkimensis*. The rain from hill slopes often washes these logs down, leading to the accumulation of seeds. A key factor in the evolution of dispersal methods among the herbs of the upper montane forest is the orientation of animal-dispersed seeds toward possible colonisation sites, such as treefalls. For these forests to thrive, animal-dispersed seeds must be able to discern parent plants and locate optimal areas for growth and development. The ant-dispersal is a strategic advantage as it facilitates relocation to a secure germination site. Although fallen logs may only cover 5% of the forest floor in the study areas, their impact on the total area available for seed colonisation cannot be overlooked. This percentage could still have significant consequences that demand attention. The disturbance of soil caused by windthrow creates a suitable environment for the growth and maturation of silver fir and *Rhododendron* species by exposing mineral soils or a mixture of organic minerals favourable for germination and survival. This may be just one of the mechanisms involved (Ruel and Pineau 2002). Out of every species that was found,

**Table 6.** Probabilities for colonisation of pits by spring and summer herbs

| Taxon | Dispersal type | $N_e$ | % $N_e$ on pit | % $N_{max}$ on pit only |
|---|---|---|---|---|
| Spring | | | | |
| *Abies* seedling | Wind | 129 | 86.0 | 24.0 |
| *Fragaria vesca* | Birds | 29 | 19.3 | 0.0 |
| *Gaultheria trichophylla* | Wind | 31 | 20.7 | 5.8 |
| *Hemiphragma heterophyllum* | Birds | 35 | 23.3 | 6.5 |
| *Panax bipinnatifidus* | Birds | 8 | 5.3 | 0.0 |
| *Panax sikkimensis* | Birds | 28 | 18.7 | 0.0 |
| *Polygonum tortuosum* | Hooks/burs | 51 | 34.0 | 0.0 |
| *Primula calderiana* | Water | 45 | 30.0 | 0.0 |
| *Rhododendron* seedling | Wind | 104 | 69.3 | 19.3 |
| *Senecio raphanifolius* | Wind | 49 | 32.7 | 0.0 |
| *Stellaria sikkimensis* | Water | 29 | 19.3 | 5.4 |
| Summer | | | | |
| *Abies* seedling | Wind | 130 | 86.7 | 21.6 |
| *Anaphalis margaritacea* | Wind | 19 | 12.7 | 0.0 |
| *Anaphalis triplinervis* | Wind | 21 | 14.0 | 0.0 |
| *Buplerum longifolium* | Ballistic | 21 | 14.0 | 0.0 |
| *Chrysanthemum atkinsonii* | Wind | 35 | 23.3 | 0.0 |
| *Clintonia udensis* | Ant | 26 | 17.3 | 0.0 |
| *Cremanthodium reniforme* | Wind | 30 | 20.0 | 0.0 |
| *Dubyaea hispida* | Wind | 19 | 12.7 | 0.0 |
| *Ligularia fischeri* | Wind | 22 | 14.7 | 0.0 |
| *Pilea* spp. | Ant | 57 | 38.0 | 9.5 |
| *Polygonum polystachya* | Hooks/burs | 47 | 31.3 | 7.8 |
| *Rhododendron* seedling | Wind | 114 | 76.0 | 18.9 |
| *Selinum* spp. | Ballistic | 61 | 40.7 | 10.1 |

See Table 5 for details

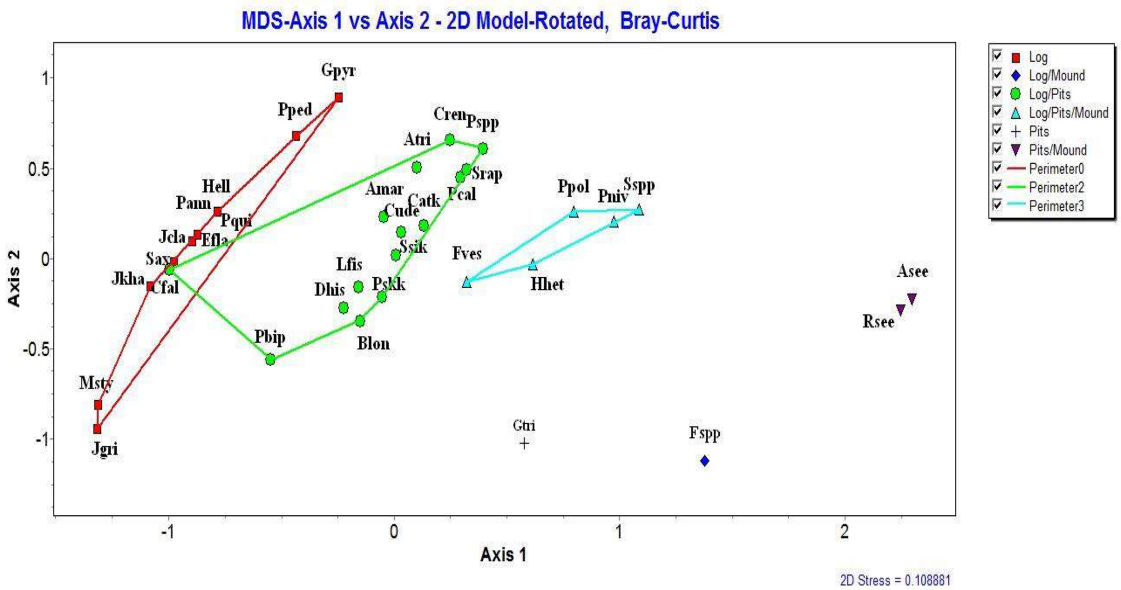


**Fig. 2**. Non-metric multidimensional ordination (NMDS) of plant community in present study (Refer Table 5 column 2 for scientific names of the species letter code used in this figure; The four-letter code represents the name of the plant species, with first letter corresponding to the genus name and the subsequent letters being initials of species name)

43 percent grew in the log and pits, 34 percent grew in the log substrate, 5 per cent grew in the log, pits, and mound substrate combined, and the other species, such as *Rhododendron* and *Abies* (seedlings), preferred growing in both pits and mound substrate.

## CONCLUSION

This research, conducted in the subalpine forest of Khangchendzonga Biosphere Reserve, marks the inaugural documentation and represents the initial exploration into the herb species colonisation of fallen trees. The colonisation of seasonal herbaceous species in the studied forests may facilitate indicators of plant survival mechanisms in response to changing climatic conditions, shedding light on the intricate interactions between these species and their environment. It plays a pivotal role in the preservation of biodiversity by conserving fallen trees in subalpine forest ecosystems. Through a comprehensive analysis, the study identifies promising harmonious assembly of herbs in various substrates such as fallen logs, pits, and mounds. Around 5 per cent of the forest floor comprises fallen logs in different stages of decomposition, emphasizing the significance of these elements for potential altruistic surrogacy in colonisation. Colonisation patterns vary, with substratum-specific preferences, and pits demonstrate higher seedling colonisation than logs and mounds. Localized colonisation is prevalent, particularly within 1m of the log or pit. Summer species are identified as superior colonisers, exhibiting better long-distance dispersal capabilities than spring-ephemeral species. Wind-dispersed seeds emerge as the predominant factor in colonisation dynamics. The study emphasizes the importance of considering various colonisation sites, such as pits, mounds, and logs, in afforestation planning to favour altruistic surrogacy. The conservative estimate provided by the study offers insights into the forest cover available for colonisation in the recent past, present, or near future. Furthermore, the presence of seasonal herbaceous species serves as an indicator of plant survival mechanisms in response to changing climatic conditions, providing valuable insights into species-environment interactions.

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## AUTHOR'S CONTRIBUTION

Arun Chettri, Arun Kumar Rai, Sailendra Dewan and Srijana Mangar have contributed in conceptualisation, methodology writing, data collection, drafting, analysis and interpretation. They have also reviewed and approved the final manuscript.

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