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Habitat Ecology and Human-Induced Threats to Nardostachys jatamansi in Lingzhi, Western Bhutan

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Abstract

Nardostachys jatamansi (D. Don) DC. belongs to the Valerianaceae is a high-altitude medicinal and aromatic herb whose rhizomes are widely used in traditional medicine and incense. Despite its importance, ecological information from Bhutan remains limited. This study assessed the phytosociology, habitat characteristics, morphometric traits, biomass and anthropogenic threats affecting N. jatamansi in Lingzhi, western Bhutan. Sampling was conducted across three elevation zones (3,500–4,000, 4,001–4,500 and 4,501–5,000 m) using nine vertical belt transects and 270 quadrats of 1 m². Nineteen associated plant species representing 14 families were recorded. Frequency of N. jatamansi increased from 66.67% at 3,871 m to 100% in the highest transects, while density ranged from 1.33 to 22.20 plants m^{-2}, with an overall mean of 11.78 plants m^{-2}. Importance Value Index increased significantly with altitude ($r=0.851$, $p=0.004$). Density was positively associated with soil moisture ($r=0.684$, $p=0.042$), water-holding capacity ($r=0.828$, $p=0.006$) and total nitrogen ($r=0.752$, $p=0.019$). Density was also positively correlated with slope ($r=0.726$, $p=0.027$) and aspect ($r=0.751$, $p=0.020$), with the highest density recorded on a 60° slope. Morphometric and biomass measurements indicated declining plant size and belowground biomass at higher elevation. Grazing and harvesting were important local disturbances; the most intensively grazed plot had the lowest density (1.92 plants m^{-2}), while the plot with the greatest harvesting pressure also had the lowest population density. The findings indicate that N. jatamansi is associated with moist, steep alpine habitats and is vulnerable to rhizome extraction, trampling and grazing. Site-specific monitoring, improved harvesting practices and stronger local conservation measures are recommended. To ensure long-term persistence, we recommend site-specific monitoring, rotational harvesting blocks, nondestructive rhizome slicing practices, and harmonizing local extraction with Bhutan's CITES Non-Detriment Finding (NDF) 25% Allowable Harvest Limit (18 MT/year export quota).

Keywords: alpine medicinal plant; Bhutan; conservation; grazing; habitat; Lingzhi; Nardostachys jatamansi; non-detriment finding

1. INTRODUCTION

Medicinal and aromatic plants (MAPs) represent critical components of Himalayan biodiversity and form the cornerstone of rural highland livelihoods across the Trans-Himalayas. Bhutan supports an exceptional diversity of high-altitude medicinal flora, many species of which inhabit specialized alpine microclimates characterized by environmental extremes (Wangchuk & Tobgay, 2015). Among these high-value species, Nardostachys jatamansi (D. Don) DC. (syn. Nardostachys grandiflora DC., locally known as Pangpoe) is a perennial rhizomatous herb belonging to the family Valerianaceae. It is the sole recognized species within its genus and occurs natively across alpine meadows and rocky scrub habitats in twelve districts of Bhutan, including Thimphu, Haa, Paro, Bumthang, Chukha, Gasa, Samtse, Trashigang, Tashi Yangtse, Wangdue Phodrang, Dagana, and Tsirang (Grierson & Long, 2001).

The highly aromatic woody rhizomes of N. jatamansi contain essential oils (spikenard oil) rich in sesquiterpenes, which are extensively utilized in traditional Bhutanese medicine (Sowa Rigpa), commercial incense manufacturing (sang), and international pharmaceutical and perfumery industries (Singh et al., 2013; Wangchuk et al., 2008). Globally, the species is evaluated as Critically Endangered under Criterion A2cd on the IUCN Red List due to widespread commercial overexploitation, destructive whole-plant harvesting techniques, and habitat degradation across its native range in India, Nepal, China, and Bhutan (Ved et al., 2015). To regulate international trade and prevent population collapse, N. jatamansi was included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1997.

In Bhutan, Nardostachys jatamansi occurs across fragile alpine microhabitats between 3,000 and 5,000 m above mean sea level (Airi et al., 2000; Shah, 2007). Habitat-specific population structure and slow regeneration make the species particularly sensitive to disturbance and destructive harvesting (Airi et al., 2000; Ghimire et al., 2005). Previous preliminary surveys in Lingzhi (Thimphu District) noted localized distributions, high-altitude habitat specialization, and acute vulnerabilities associated with unmanaged grazing and commercial extraction (Dorji, 2008; Lakey & Dorji, 2016). Because commercial harvesting requires uprooting the entire plant to extract the underground rhizome, collection directly eliminates mature, seed-producing individuals and disrupts clonal vegetative propagation. Simultaneously, heavy yak and horse grazing in alpine pasturelands induces physical trampling and soil compaction.

Despite its ecological and economic importance, robust quantitative empirical data connecting N. jatamansi population density, phytosociological structure, and morphometric attributes with soil physical-chemical properties and human disturbance metrics in Bhutan remain remarkably scarce. Furthermore, there is an urgent imperative to contextualize local community extraction against national conservation frameworks. According to Bhutan's national CITES Non-Detriment Finding (NDF) assessment, the total national wild growing stock of N. jatamansi is estimated at 497 Metric Tons (MT) across an Extent of Occurrence (EOO) of 27.97 km² (DoFPS, 2022). Crucially, Jigme Dorji National Park (JDNP) within which Lingzhi Gewog is situated, holds 82.5% (410.07 MT across 17.12 km²) of the entire national growing stock.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Lingzhi Gewog, Thimphu District, western Bhutan, within Jigme Dorji National Park (Figure 1). More importantly, Lingzhi is an important high-altitude habitat for Nardostachys jatamansi, a threatened medicinal plant subject to harvesting and habitat pressures. Lingzhi covers approximately 386 km² and is located at about 27°51′15″N and 89°25′35″E. Elevation within the Gewog ranges from approximately 3,445 to 6,782 m. The landscape features rugged Trans-Himalayan topography, alpine pasture meadows, moist Rhododendron-Juniper scrub, and rocky scree slopes. Transhumant pastoralism centered on yak and horse herding constitutes the primary land-use activity across alpine pastures during summer months.

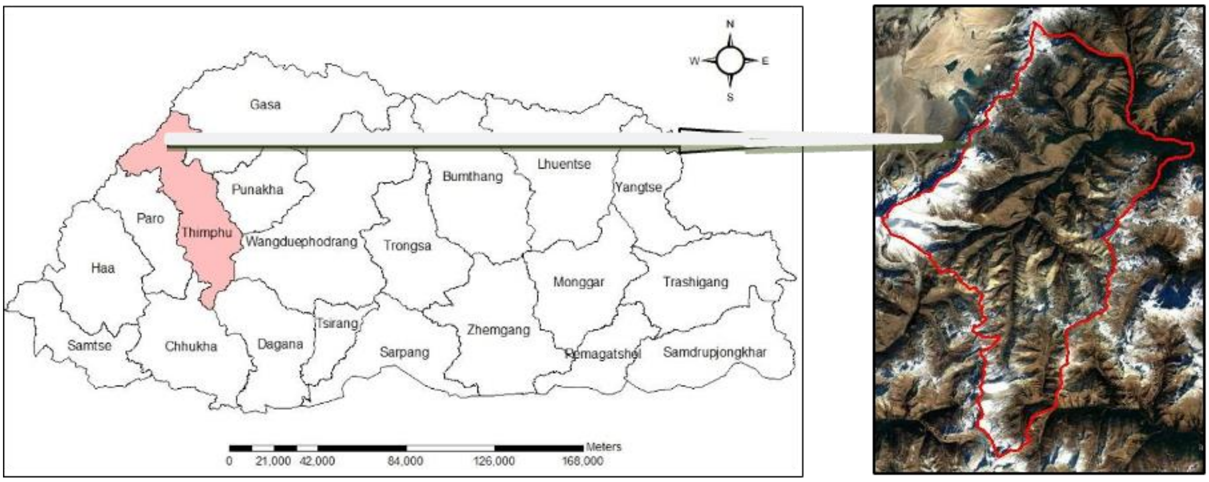

Figure 1: Map of Bhutan highlighting the study area of Lingzhi

In Bhutan, besides the present study area of Lingzhi in Thimphu, N. jatamansi is distributed in Haa, Paro, Bumthang, Chukha, Gasa, Samtse, Trashigang, Tashiyantse, Wangdue and Tsirang districts at 4,000- 4,500 m.a.s.l. (Ngawang, 2006). In Lingzhi, it is mainly found in areas of open grassland but also among sparse Rhododendron scrub (Dorji, 2008).

2.2 Reconnaissance, Participatory Mapping and Questionnaire Survey

A reconnaissance survey was conducted to identify areas where N. jatamansi occurred and to determine accessible sites for field sampling. Fifty knowledgeable participants, including forest personnel, officials from related institutions, local collectors and herbal practitioners, contributed to focused group discussions. Purposive sampling was used to identify participants with knowledge of the species' distribution and harvesting. Structured and open-ended questionnaires were subsequently used to document use, harvesting patterns, perceived population trends and views on sustainable use.

2.3 Sampling Design

The study area was divided into three elevation zones: 3,500–4,000 m, 4,001–4,500 m and 4,501–5,000 m. One 100 × 100 m sampling plot was established within each zone at locations identified through the reconnaissance survey. Three vertical belt transects measuring approximately 60 × 30 m were established within each plot. Three 10 × 10 m stands were selected within each transect, and ten 1 × 1 m quadrats were sampled within each stand. A total of 270 quadrats across nine transects were assessed.

2.4 Phytosociological Assessment

All plant individuals occurring within quadrats were recorded and plant cover was assessed. Frequency, density, abundance, relative frequency, relative density, relative dominance and Importance Value Index (IVI) were calculated using standard phytosociological procedures (Curtis & McIntosh, 1950; Kershaw, 1973; Philips, 1959). Species diversity was assessed using Simpson's Diversity Index. Voucher specimens of unidentified associated species were collected non-destructively and identified using available botanical literature and the Flora of Bhutan, with confirmation from the herbarium.

2.5 Soil Assessment

Composite soil samples of approximately 250 g were collected from the rooting zone to a depth of 25 cm for each transect. Soil moisture content, water-holding capacity and texture were assessed following established procedures. Soil pH, soil organic carbon, total nitrogen, were determined using laboratory methods described in the thesis, including the Walkley–Black method for soil organic carbon and Kjeldahl analysis for total nitrogen.

2.6 Morphometric and Biomass Assessment

Morphometric measurements were taken from mature individual plants selected from the sampled stands. Plant height, number of leaves, number of branches or ramets, number of flowers per ramet and rhizome length were measured using rulers and vernier calipers. Aboveground and belowground biomass were measured from 27 selected plants, with one plant sampled from each stand.

2.7 Habitat Assessment

Altitude and geographic coordinates were recorded using GPS. Slope was measured using a clinometer and aspect using a magnetic compass. Vegetation type was recorded for each transect. Habitat variables were subsequently compared with N. jatamansi density and frequency.

2.8 Grazing and Harvesting Assessment

Grazing intensity was assessed using grass and bare-soil cover, livestock numbers, grazing livestock units, duration of grazing and the number of N. jatamansi shoots browsed. Harvesting pressure was assessed through interviews with local collectors and by comparing the quantity and frequency of harvest among the three plots. The number of collectors and harvest frequency were related to observed N. jatamansi density.

2.9 Data Analysis

Data were compiled and analysed using Excel and SPSS. Pearson correlation was used to examine relationships among N. jatamansi density, altitude, habitat variables, soil properties, morphometric traits and biomass. Statistical significance was interpreted at $p<0.05$ and $p<0.01$, as reported in the original analysis.

3. RESULTS AND DISCUSSION

3.1 Floristic Association and Distribution

Nineteen plant species associated with N. jatamansi were recorded across the nine transects, representing 14 families. Sixteen species were herbs and three were shrubs. Ericaceae was the most represented family, followed by Asteraceae, Dipsacaceae and Rosaceae. Frequently recorded associates included Bistorta macrophylla, Cassiope fastigiata, Cotoneaster microphyllus, Gentiana urnula, Morina nepalensis, Potentilla flagellaris, Rhododendron anthopogon, R. setosum and Saxifraga moorcroftiana. The associated flora differed among elevation zones, with species richness generally declining at higher elevation.

Nardostachys jatamansi was strongly represented in the selected habitats. Its frequency increased from 66.67% in the first transect at 3,871 m to 100% in transects 6–9. Density ranged from 1.33 plants m^{-2} in transect 1 to 22.20 plants m^{-2} in transect 6. The mean density across the nine transects was 11.78 plants m^{-2}. The highest densities occurred mainly between 4,001 and 4,500 m, while density declined at the

highest sampled elevation. This pattern suggests that occurrence alone increased with elevation, whereas maximum abundance was concentrated within an intermediate portion of the elevation gradient.
The IVI of N. jatamansi increased from 47.09 in transect 1 to 124.92 in transect 9 and was positively correlated with altitude ($r=0.851$, $p=0.004$). Simpson's Diversity Index showed a strong negative relationship with IVI ($r=-0.980$, $p<0.01$), reflecting increasing dominance of N. jatamansi as the number and abundance of associated species declined at higher elevations. The pattern is consistent with the restricted ecological niche reported for the species in other Himalayan studies (Airi et al., 2000; Shah, 2007), although the exact associated flora differed between regions.

Table 1. Phytosociological attributes of Nardostachys jatamansi across the nine transects.

Transect	Altitude (m)	Frequency (%)	Density (plants m^{-2})	Abundance	IVI
1	3,871	66.67	1.33	2.00	47.09
2	3,912	70.00	1.66	2.38	48.10
3	3,955	76.67	2.77	3.61	55.83
4	4,167	40.00	13.00	32.50	99.91
5	4,175	66.66	19.70	29.55	100.54
6	4,190	100.00	22.20	22.20	119.36
7	4,547	100.00	19.37	19.37	116.51
8	4,685	100.00	17.47	17.47	121.59
9	4,864	100.00	8.53	8.53	124.92

3.2 Soil Characteristics and Habitat Relationships

Nardostachys jatamansi occurred in soils with moisture content ranging from 33.54 to 39.95%, water-holding capacity from 35.45 to 43.56%, pH from 4.96 to 6.33 and soil organic carbon from 7.90 to 13.30%. The soil texture was mainly sandy loam, with one loam site. Density was positively correlated with soil moisture ($r=0.684$, $p=0.042$), water-holding capacity ($r=0.828$, $p=0.006$) and total nitrogen ($r=0.752$, $p=0.019$). These relationships indicate that moisture availability and nitrogen-rich soils were important characteristics of occupied sites. The association with moist soils agrees with observations from the western Himalaya that N. jatamansi favours moist habitats and moisture-retaining substrates (Airi et al., 2000).
The sampled habitats occurred between 3,871 and 4,864 m and had slopes ranging from 40° to 68°. Nardostachys jatamansi occurred mainly in moist alpine shrubland and grassland, alpine grassland and grassland with sparse shrub. Density was significantly correlated with slope ($r=0.726$, $p=0.027$) and aspect ($r=0.751$, $p=0.020$). The maximum recorded density of 22.20 plants m^{-2} occurred on a 60° slope. These results indicate a preference for steep, relatively moist alpine habitats, although the relationship with altitude was not statistically significant for density alone ($r=0.478$).
The aspect pattern differed from earlier observations in Lingzhi that emphasized north-east-facing slopes (Dorji, 2008) and from studies elsewhere in the western Himalaya that reported higher abundance on

western aspects (Airi et al., 2000). In the present study, the mean habitat aspect category was associated most strongly with south-east-facing sites. Such differences may reflect local variation in moisture, exposure, slope and vegetation structure. Therefore, habitat characterization at local scale is important when identifying conservation sites for N. jatamansi.

Table 2. Selected environmental variables and their relationships with Nardostachys jatamansi density. *p<0.05; **p<0.01.

Variable	Minimum	Maximum	Mean/ range	Relationship with density
Altitude (m)	3,871	4,864	4,262.89 ± 356.01	r=0.478
Slope (°)	40	68	55.78 ± 9.46	r=0.726*
Soil moisture (%)	33.54	39.95	—	r=0.684*
Water-holding capacity (%)	35.45	43.56	—	r=0.828**
Soil pH	4.96	6.33	—	r=0.394
Soil organic carbon (%)	7.90	13.30	—	r=0.627
Total N (%)	0.09	0.88	—	r=0.752*

3.3 Morphometric Traits and Biomass

Morphometric measurements showed marked variation among elevation plots. Mean plant height was 27.1 cm in Plot 1, 26.7 cm in Plot 2 and 11.1 cm in Plot 3. Mean rhizome length was 19.6, 23.6 and 6.2 cm, respectively. The number of leaves and flowers also generally declined at the highest elevation, while the number of branches or ramets varied among plots. Plant height was significantly associated with rhizome length (paired test, $t=6.097$, $p<0.001$) and number of branches ($t=11.619$, $p<0.001$).

The belowground biomass was positively correlated with plant height ($r=0.680$, $p=0.044$) and aboveground biomass ($r=0.837$, $p=0.005$). It was negatively correlated with elevation ($r=-0.812$, $p=0.008$), indicating a reduction in belowground biomass towards the highest sampled sites. Total biomass declined from 4.50 g plant^{-1} in the first biomass sample to 2.63 g plant^{-1} in the highest-elevation samples. The observed decline in plant size and biomass at high elevation is consistent with the shorter growing conditions expected in alpine environments, although the present study cannot distinguish the effects of elevation from associated changes in habitat and disturbance.

Table 3. Summary of morphometric variation among the three study plots.

Plot and elevation	Mean plant height (cm)	Mean rhizome length (cm)	General biomass pattern
1 (3500-4000 m.a.s.l)	27.1	19.6	Higher biomass

2 (4001- 4500 m.a.s.l)	26.7	23.6	Highest rhizome development
3 (4501- 5000 m.a.s.l)	11.1	6.2	Lowest plant size and biomass

3.4 Grazing Pressure

Grazing pressure differed substantially among plots. Plot 1 had the highest grazing intensity, with 60% grass cover, 40% bare-soil cover, 187 browsed shoots and an assigned grazing-intensity score of 3. Plot 2 had moderate grazing intensity, whereas Plot 3 had the lowest intensity. The number of grazed shoots per grazing animal was 2.26 in Plot 1, 2.17 in Plot 2 and 1.23 in Plot 3.

The most intensively grazed plot also had the lowest mean density of N. jatamansi (1.92 plants m^{-2}), compared with 18.30 plants m^{-2} in Plot 2 and 15.12 plants m^{-2} in Plot 3 as shown in Table 4. Plot 1 was therefore classified as heavily impacted. However, the relationship was not strictly linear across all plots, suggesting that grazing pressure interacted with habitat conditions and other disturbances. Trampling may be particularly important because the species grows in exposed alpine habitats and whole plants may be damaged even where direct browsing is limited.

Table 4. Grazing indicators and observed Nardostachys jatamansi density.

Plot and elevation)	Grass cover (%)	Bare soil (%)	Browsed shoots	Grazing intensity	Mean density (plants m^{-2})	Impact
1. 3500-4000 m.a.s.l	60	40	187	3	1.92	Heavy
2. 4001- 4500 m.a.s.l	82	18	152	2	18.30	Moderate
3. 4501- 5000 m.a.s.l	90	10	99	1	15.12	Low

3.5 Harvesting Pressure

Harvesting was most pronounced in Plot 1 and least pronounced in Plot 3. Local collectors reported harvesting rhizomes, with typical quantities of approximately 5–10 kg per collection and higher quantities of up to 20 kg associated with incense manufacturers. The collection process involved digging and removing the whole plant. Plot 1 had the greatest number and frequency of collectors and simultaneously exhibited the lowest average density of N. jatamansi.

Average density was negatively correlated with the number of collectors (r=-0.549) and harvest frequency (r=-0.829), while the number of collectors was strongly positively correlated with harvest frequency (r=0.923). These relationships support the interpretation that repeated rhizome extraction contributed to reduced local abundance. Similar concerns have been reported for Nardostachys populations elsewhere in the Himalaya, where destructive rhizome collection can remove reproductive individuals and disturb fragile alpine soils (Ghimire et al., 2005; Larsen & Hall, 2008).

Respondents also perceived a reduction in species availability compared with approximately ten years earlier, although they reported that quantities harvested had remained similar. No current cultivation was reported by respondents. These observations indicate that harvesting pressure and local availability may be diverging: continued extraction in areas of declining availability can increase the risk of localized depletion.

3.6 Integration with National CITES NDF Policy Context

A critical contribution of this study is bridging local field data in Lingzhi with Bhutan's national CITES Non-Detriment Finding (NDF) policy baseline. At the national level, the Department of Forests and Park Services (DoFPS) estimates Bhutan's total wild growing stock of N. jatamansi at 497 Metric Tons (MT) across an Extent of Occurrence (EOO) of 27.97 km^2 (DoFPS, 2022). Jigme Dorji National Park (JDNP) represents the single most vital conservation reservoir in Bhutan, containing 410.07 MT (82.5% of national stock) across 17.12 km^2 with an average stock density of 23.95 kg km^{-2}. Our observed mean density in Lingzhi (11.78 plants m^{-2}, peaking at 22.20 plants m^{-2}) confirms that JDNP supports exceptionally robust wild populations. However, the strong negative correlation between harvest frequency and plant density ($r = -0.829$) highlights acute localized depletion risks around settlements. To reconcile community commercial trade with CITES Appendix II obligations, extraction in Lingzhi must strictly align with the national Allowable Harvest Limit (AHL) of 25% over a 7-year generation length, which fixes Bhutan's annual national export quota at 18 MT/year (DoFPS, 2022). Enforcing rotational 5-to-7-year harvesting blocks and adopting non-destructive rhizome slicing (leaving 25–30% of basal rootstock intact) will safeguard reproductive clones while maintaining highland livelihoods.

3.7 Conservation Implications and Study Limitations

The results identify moist, steep alpine habitats as important sites for N. jatamansi in Lingzhi and highlight the need to manage both direct extraction and livestock disturbance. Conservation measures should include periodic population monitoring, mapping of occupied habitat, regulation of collection intensity, training in less destructive harvesting practices, and assessment of regeneration following harvest. Where feasible, cultivation or propagation could reduce dependence on wild populations, while in situ conservation should focus on maintaining occupied alpine habitats.

This study focused on sampled occupied alpine habitats within Lingzhi Gewog; findings describe localized phytosociological relationships and should not be extrapolated as a nationwide inventory. The study also used a limited number of plots and transects, and grazing and harvesting pressure were assessed partly through plot-level indicators and respondent information. Relationships among environmental variables should therefore be interpreted as associations rather than evidence of causation.

4. CONCLUSION & RECOMMENDATIONS

Nardostachys jatamansi is an ecologically dominant yet vulnerable alpine medicinal herb in Lingzhi, western Bhutan. Population density peaks at intermediate alpine elevations (4,001–4,500 m) on steep, moist, nitrogen-rich 60° slopes facing south-east. While species occurrence increases with altitude, plant height and belowground biomass exhibit severe phenotypic reduction above 4,500 m. Unmanaged whole-rhizome harvesting represents the primary driver of localized population depletion ($r = -0.829$).

To ensure ecological sustainability and CITES compliance, we recommend the following strategic actions:

- Rotational Harvest Blocks: Establish 5 to 7 year rotational collection blocks across Lingzhi subcatchments to allow rhizome recovery and vegetative ramet expansion.
- Non-Destructive Harvesting Protocols: Mandate traditional partial rhizome slicing (leaving 25–30% of rootstock intact in situ) rather than total uprooting.
- Enforcement of CITES Quotas: Cap local commercial collection permits in harmony with Bhutan's national 18 MT/year export quota (25% AHL).
- Grazing Management: Establish seasonal exclosures around heavily degraded sites (such as Plot 1) to mitigate livestock trampling during seed germination (May–June).
- Permanent Plot Monitoring: Institute long-term biodiversity monitoring plots managed by JDNP field rangers to track climate change impacts and population recovery dynamics.

2. DECLARATIONS & ACKNOWLEDGMENTS

Conflict of Interest

The authors declare that there are no known competing financial or personal relationships that could have influenced the work reported in this manuscript.

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