PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 12(2): 1-9
https://doi.org/10.14719/pst.3414

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RESEARCH ARTICLE

Ecology, distribution mapping and population structure of *Trichopus zeylanicus* subsp. *travancoricus* (Arogyapacha)

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OPEN ACCESS

ARTICLE HISTORY
Received: 19 February 2024
Accepted: 15 December 2024
Available online
Version 1.0 : 24 February 2025
Version 2.0 : 01 April 2025

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

CITE THIS ARTICLE
Angala M, Anto M, Anilkumar C. Ecology, distribution mapping and population structure of *Trichopus zeylanicus* subsp. *travancoricus* (Arogyapacha). Plant Science Today. 2025; 12(2): 1-9. https://doi.org/10.14719/pst.3414

Abstract

Trichopus zeylanicus subsp. *travancoricus* (Bedd.) Burkill ex K. Narayanan (Arogyapacha) is an ethnomedically important perennial herb with a restricted distribution in the southern Western Ghats, India. Habitat specifications reveal that suitable areas for this species occur at elevations ranging from 100 to 1000 m above sea level. A study was conducted to gain insights into the ecology, distribution mapping and population structure of *T. zeylanicus* subsp. *travancoricus* in the Western Ghats. The spatial distribution of this endemic species showed significant variations among populations. Seven populations were identified, exhibiting large and small distributional patches, even within a single population. Anthropogenic activities and climate-related shifts in ecophysiology have impacted seed dispersal, canopy gap formation and seedling mortality, altering vegetation composition. Observations indicated a disturbed ecological niche, fragmented habitat and patchy occurrence of this species. The vegetation data for *T. zeylanicus* subsp. *travancoricus* showed significant variations among the seven populations. The Kulathupuzha population exhibited higher recruitment rates and density than others. Canopy cover analysis revealed that populations with closed canopies influenced seedling recruitment and density. However, populations with moderately closed canopies displayed variable characteristics, with Kulathupuzha standing out for its higher recruitment rate and reproductive capacity.

Keywords

biosphere reserve; ecological niche; ethnomedicinal; habitat fragmentation; patchy occurrence; spatial distribution

Introduction

The Western Ghats region is renowned for its rich plant diversity and high conservation value (1-3). Over the past few decades, human activities have resulted in widespread habitat destruction and the exploitation of numerous plant species in the Western Ghats. Additionally, climate change is causing global shifts in both the average and variability of temperature and precipitation (4). These climate changes are widely acknowledged as a significant global threat to biodiversity, as temperature and precipitation fundamentally influence the demographic processes determining natural populations' size and long-term viability (5). Consequently, many species now face threats to their survival.

T. zeylanicus subsp. *travancoricus* is a perennial herb belonging to the family Dioscoreaceae, commonly known as "Arogyapacha" for its ethnomedicinal uses (Fig. 1). The Kani tribe, inhabiting the Agasthyar Hills, traditionally uses the fruits of Arogyapacha as a health food for instant stamina, evergreen health and vitality (6). Scientific investigations concerning these tribal claims have revealed that this plant possesses adaptogenic, antifatigue, immunoenhancing, cardioprotective, anticancer, antidiabetic, hepatoprotective, antinociceptive and anti-inflammatory properties. Chemical investigations have also identified the presence of glycolipids, flavonoids, chromones and other compounds in its aerial parts (7).

Fig. 1. Habit of *T. zeylanicus* subsp. *travancoricus.*

This subspecies is primarily found in the Agasthyamala biosphere reserve (ABR) in the southern Western Ghats of India. Small streams are associated with all populations, indicating the riparian nature of the species (8). Within this region, seven distinct populations of Arogyapacha have been identified, existing as tiny, isolated patches. Fragmentation is evident even within individual populations. The spatial distribution of this species shows significant variations across different areas. The habitats of this species are isolated by minor geographical barriers such as rivers, continuous rocks, roads, plantations, barren soils, significant canopy gaps, allelopathic effects of allied species, soil characteristics, climate changes, human settlements and anthropogenic activities. Such factors negatively affect vegetation composition and habitat fragmentation has resulted in the patchy occurrence of this species.

Arogyapacha faces several challenges, including slow growth, limited habitat availability, excessive sunlight and overexploitation for medicinal purposes. These factors collectively categorize it as a vulnerable and rare species. The conservation of Arogyapacha has become a matter of great concern, with efforts aimed at safeguarding this valuable plant from the brink of extinction. To achieve this, gaining a comprehensive understanding of Arogyapachas' habitats is crucial, which is essential for both its conservation and sustainable utilization in traditional medicine and other potential applications. Further research and conservation initiatives are imperative to ensure the preservation of this unique and valuable plant species for the benefit of future generations.

Materials and Methods

Study sites

The current study identified seven populations of *T. zeylanicus* subsp. *travancoricus* through a combination of literature review and periodic field expeditions conducted in various forest regions of the Western Ghats. Six of these populations are situated in the Kerala forest areas. At the same time, the remaining one is located in the Tamil Nadu forest regions within the Agasthyamala Biosphere Reserve (ABR) of the Western Ghats. Specifically, the study sites included Aryankavu, Kulathupuzha and Cheenikkala from the Shendurney Wildlife Sanctuary, Bonacaud and Kallar from the Peppara Wildlife Sanctuary, Kottur from the Neyyar Wildlife Sanctuary in Kerala and Poonkulam from the Kalakkad Mundanthurai Tiger Reserve in Tamil Nadu.

Spatial distribution

GPS coordinates of each *T. zeylanicus* subsp. *travancoricus* individual per patch in their respective population was recorded and mapped. In addition, population-associated specific markers like associated plant species, rivers, grasslands, rocks, trek paths and plantations were marked using Garmin e-Trex 30 GPS. A distribution map was prepared using DIVA-GIS (version 7.5).

Population structure and dynamics

Population structure and dynamics were assessed by randomly establishing quadrats in all patches of each population. The number of quadrats placed in each patch was determined based on the total area and density of the candidate species. A total of 829 quadrats were laid out, covering an 829 m^2 area, with each quadrat measuring 1 × 1 m. This methodology followed various reports on population dynamics (9,10,11) and population structure (12, 13).

Canopy cover

A convex spherical densiometer measured the light penetrating the forest canopy (14). Forest canopies were classified based on the percentage of sky obstructed by tree canopies, categorized as open canopy (10-39 %), moderately closed canopy (40-69 %), or closed canopy (70-100 %) (15).

The candidate species and their specific niches were comprehensively analyzed and data were collected on recruitment rate (%), vegetative stage (%), reproductive stage (%), mortality (%) and density for vegetative dynamism analysis from 2019 to 2023. Individual plants were selected, tagged and monitored, with details recorded at regular intervals (15 days). The percentages of vegetative (plant parts without flowers or fruits) and reproductive (plant parts with flowers or fruits) phases of the species per sample plot were noted. Systematic re-censuses were conducted to identify newly recruited and deceased individuals, with recruitment and mortality rates analyzed by counting the number of individuals tagged in previous observations that had died (16). The recruitment rate, mortality rate and density of the species were calculated using standard formulas in Equation 1-3.

$$\text{Recruitment rate (\%)} = \frac{\text{Total number of new recruits in the present year (census)}}{\text{Number of adults in the present year (census)}} \quad \text{(Eqn.1)}$$

$$\text{Mortality rate (\%)} = \frac{\text{Number of dead stems of the species in the present year (census)}}{\text{Total number of living stems in the previous year (census)}} \quad \text{(Eqn. 2)}$$

$$\text{Density} = \frac{\text{Total number of individuals}}{\text{Total number of quadrats studied}} \quad \text{(Eqn. 3)}$$

Results

Spatial distribution

All the populations are located in montane areas at 100-1000 m elevation. The aerial distance from Aryankavu population to Kulathupuzha population is 13.61 km, Kulathupuzha - Cheenikkala - 13.79 km, Cheenikkala to Kallar 7.98 km, Kallar to Bonacaud 5.12 km, Bonacaud to Kottur is 11.60 km and Kottur to Poonkulam is 14.65 Km (Fig. 2). In the Aryankavu population, three distinct patches have been recorded, one of which is a large patch (Fig. 3a). Rivers and rocky areas isolate these patches. Patch 1 (Ph1) showed the maximum recruitment percentage, reproductive potential and density of *T. zeylanicus* subsp. *travancoricus* (Fig. 4a). But plants' vegetative stages were much less compared to other patches. In the case of Ph2 and Ph3, individuals showed similar growth patterns. The candidate species of these patches showed higher reproductive potential. Vegetative stages, recruitment rate and population density were similar in those three patches, with a very low mortality rate. Other dominant plant associates are *Diospyros buxifolia*, *Semecarpus travancorica*, *Artocarpus heterophyllus*, *Hopea parviflora, Myristica beddomei, Knema attenuate*, *Syzygium laetum. Xanthophyllum arnottianum*, *Hydnocarpus pentandrus*, *Psychotria beddomei*, *Baccaurea courtallensis*, *Memecylon malabaricum* and *Ixora nigricans*.

In the Cheenikkala population, four patches were recorded, all occupying almost the same Km^2 area (Fig. 3c). Rivers and rocks separate these patches within the population. All four patches showed nearly identical vegetation data. However, patch 4 (Ph4) had the maximum percentage of recruitment, reproductive potential and less percentage of mortality rates of *T. zeylanicus* (Fig. 4c). Compared to other populations, the average density was higher in patch 1 (Ph1). The dominant associated species are *Semecarpus travancorica*, *Artocarpus heterophyllus*, *Hopea parviflora*, *Cullenia exarillata, Palaquium ellipticum*, *Vateria indica*, *Gluta travancorica*, *Myristica beddomei*, *Cinnamomum malabatrum*, *Syzygium laetum, Humboldtia decurrens, Xanthophyllum arnottianum*, *Diospyros buxifolia*, *Baccaurea courtallensis* and *Psychotria beddomei*, *Memecylon malabaricum* and *Quisqualis malabarica*.

In the Kallar population, four distinct patches were recorded and one patch was noted as the largest compared to the other three smaller patches. Rivers, rocks, roads, grasslands and canopy gap formations isolated these patches within the populations (Fig. 3d). The Patch 1 (Ph1) was found to be the largest patch and the Patch 2 (Ph2) was the smallest in this population (Fig. 4d). However, these two patches showed almost identical vegetation data regardless of their size. The percentage density of *T. zeylanicus* in the patch 4 (Ph4) was very low. The dominant plant species associated are *Semecarpus travancorica*, *Artocarpus heterophyllus*, *Hopea parviflora*, *Cullenia exarillata, Palaquium ellipticum*, *Vateria indica*, *Olea dioica*, *Myristica beddomei*, *Cinnamomum malabatrum*, *Syzygium munronii, Syzygium laetum, Xanthophyllum arnottianum*, *Alpinia calcarata, Diospyros buxifolia*, *Baccaurea courtallensis* and *Psychotria beddomei*, *Memecylon malabaricum* and *Quisqualis malabarica* and *Canthium angustifolium*.

In the Bonacaud population, two distinct patches were recorded, out of which one patch was smaller and rounder compared to another larger elongated patch (Fig. 3e). Huge slanting rocks, trek paths, rivers and canopy gap formations isolated these patches within the population. Patch 1 (Ph1) showed a good percentage of recruitment, reproductive capacity and density compared to patch 2 (Ph2) (Fig. 4e). These two patches showed a significant difference in elevation at about 245 m. The mortality rate was slightly higher in the smaller patch (Ph1) at lower elevations compared to a large patch of higher elevations (Ph2). The dominant plant species associated are *Cullenia exarillata, Palaquium ellipticum, Vateria indica*, *Artocarpus heterophyllus*, *Hydnocarpus pentandrus*, *Aglaia bourdillonii*, *Garcinia imberti, Elaeocarpus serratus*, *Olea dioica*, *Syzygium munronii*, *Fagrae aceilanica*, *Cinnamomum sulphuratum, Aporosa indoacuminata*, *Psychotria beddomei*, *Symplocos cochinchinensis*, *Memecylon malabaricum* and *Osbeckia leschenaultiana*.

In Kottur population, three distinct patches were recorded. All of them are random and isolated by rocks, rivers, grasslands and the Neyyar Dam (Fig. 3f). The first two patches showed almost identical vegetation data except for percentage density. Patch 1 (Ph1) showed higher density than the Ph2 and Ph3 (Fig. 4f). An interesting observation was that the largest patch has a very low percentage density of *T. zeylanicus* and the

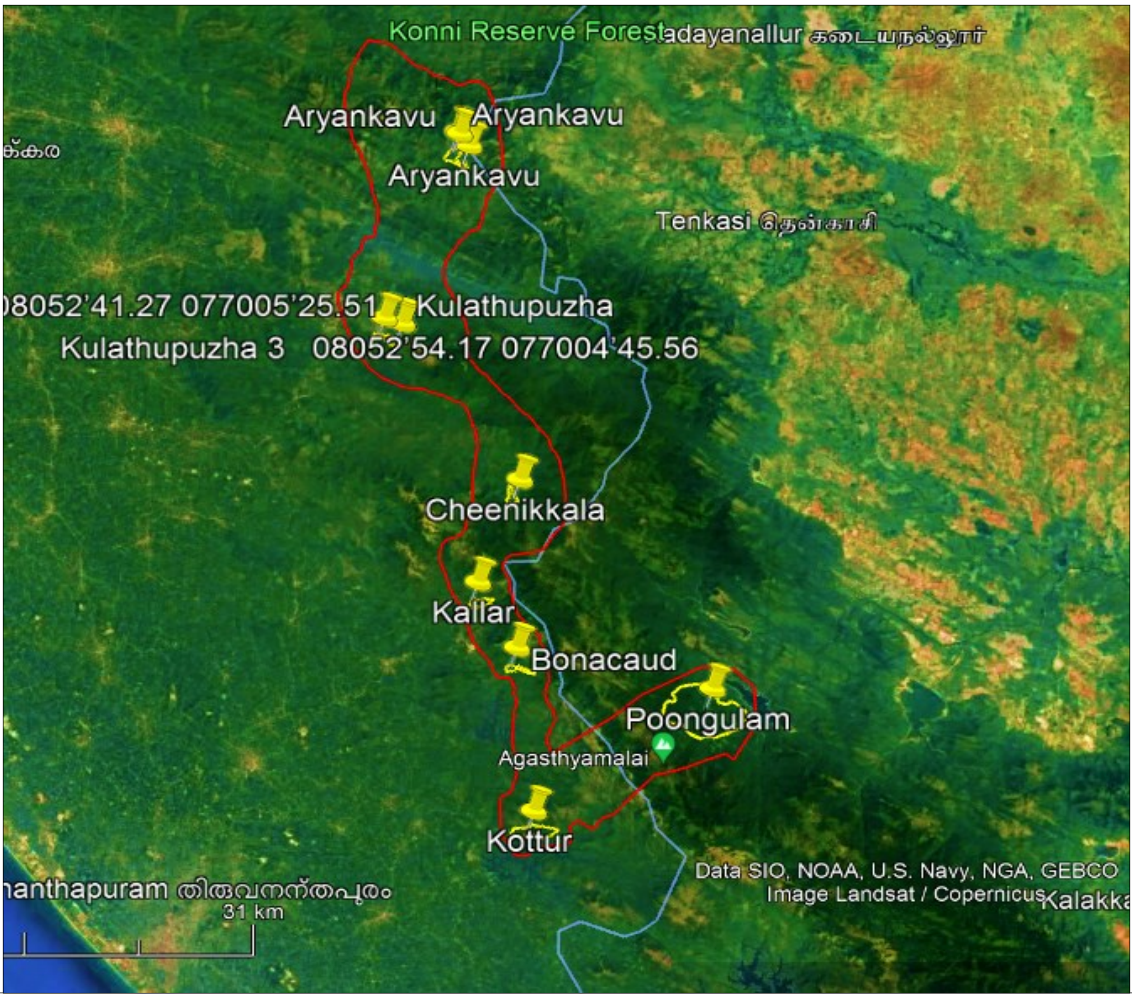

Fig. 2. The vegetation map shows the study area and sites at Agasthyamala Biosphere Reserve. Red and yellow lines indicated the area of occupancy and occurrence of *T. zeylanicus* subsp. *travancoricus* respectively (Source: google map).

smallest patch has a higher percentage density. The dominant associated species are *Gluta travancorica*, *Artocarpus heterophyllus*, *Palaquium ellipticum*, *Cullenia exarillata, Myristica beddomei, Olea dioica*, *Hydnocarpus pentandrus*, *Polyalthia coffeoides*, *Elaeocarpus serratus*, *Cinnamomu msulphuratum, Casearia rubescens, Vernonia travancorica* and *Symplocos oligandra*

In Poonkulam population, two distinct patches were noted which are randomly isolated rocks, rivers grasslands and canopy gap formations (Fig. 3g). Vegetation data changed significantly with these patches since higher percentage of reproductive potential, recruitment rate and density of the Patch 2 (Ph2) and lower mortality rate compared to the Patch 1 (Ph1) (Fig. 4g). The dominant plant species associated are *Hopea parviflora*, *Diospyros buxifolia, Artocarpus heterophyllus*, *Vateria indica, Myristica beddome, Mesua ferrea, Cinnamomum malabatrum, Xanthophyllum arnottianum, Symplocos cochinchinensis, Baccaurea courtallensis*, *Humboldtia decurrens, Syzygium zeylanicum*, *Psychotria beddomei*, *Ixora nigricans*.

populations studied (Fig. 4h). The recruitment rate and percentage density were very high in the Kulathupuzha population. In contrast, the recruitment rate was low in the Kottur and Cheenikkala populations. Poonkulam and Kottur populations have significantly higher and lower reproductive capacities, respectively. Additionally, mortality rates were high in the Cheenikkala and Kottur populations.

Canopy cover is the critical factor for reaching sunlight on the forest floor. The canopy cover analysis indicated that two populations of Cheenikkala and Kottur have closed canopy cover compared to others with moderately closed canopy cover (Fig. 3h and Table 1). Those populations of closed canopy showed significantly less seedling recruitment and density of the candidate species. With closed canopy cover, individuals showed a prominent vegetative stage other than the reproductive stage, indicating the significance of sunlight for the transition from the vegetative stage to the reproductive stage.

Populations like Aryankavu, Kulathupuzha, Kallar, Bonacaud and Poonkulam showed moderately closed canopy cover. The vegetational data analysis indicated that the candidate species' recruitment rate and percentage density were very high in the Kulathupuzha and Poonkulam populations, with a good percentage of reproductively abled plants. Nevertheless, Cheenikkala and Kottur populations showed closed canopy cover with high mortality rates and a low percentage of reproductively abled plants. The overall vegetational analysis indicated that the Kulathupuzha population with moderate canopy cover supported the recruitment and establishment around the year and protected new recruits from death (mortality), indicating the reproductive capacity supported by suitable niche characteristics of the Kulathupuzha population.

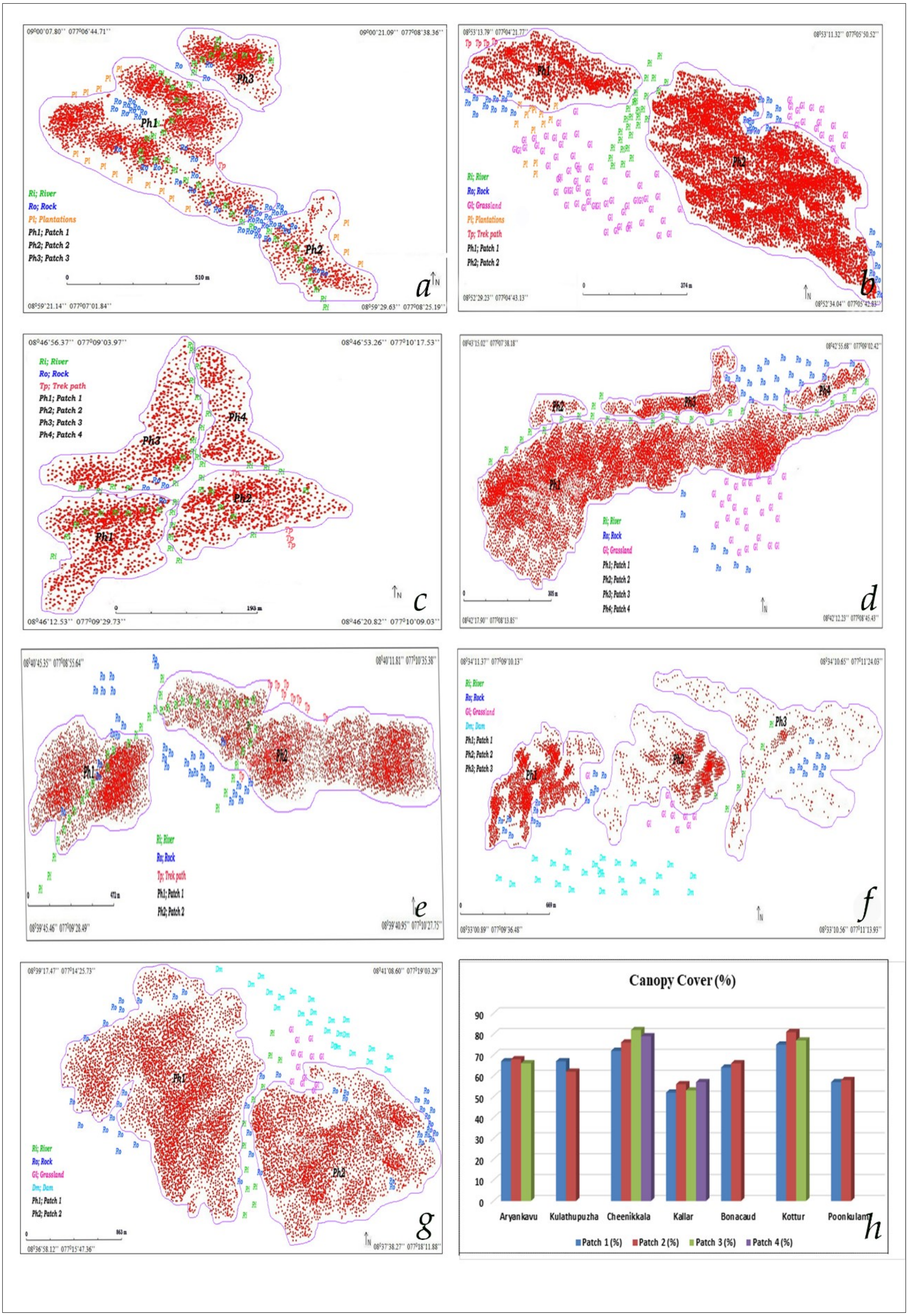

Fig. 3. Spatial distribution of *T. zeylanicus* subsp. *travancoricus* at different populations: a. Aryankavu; b. Kulathupuzha; c. Cheenikkala; d. Kallar; e. Bonacaud; f. Kottur; g. Poonkulam; h. Percentage of canopy cover at different populations.

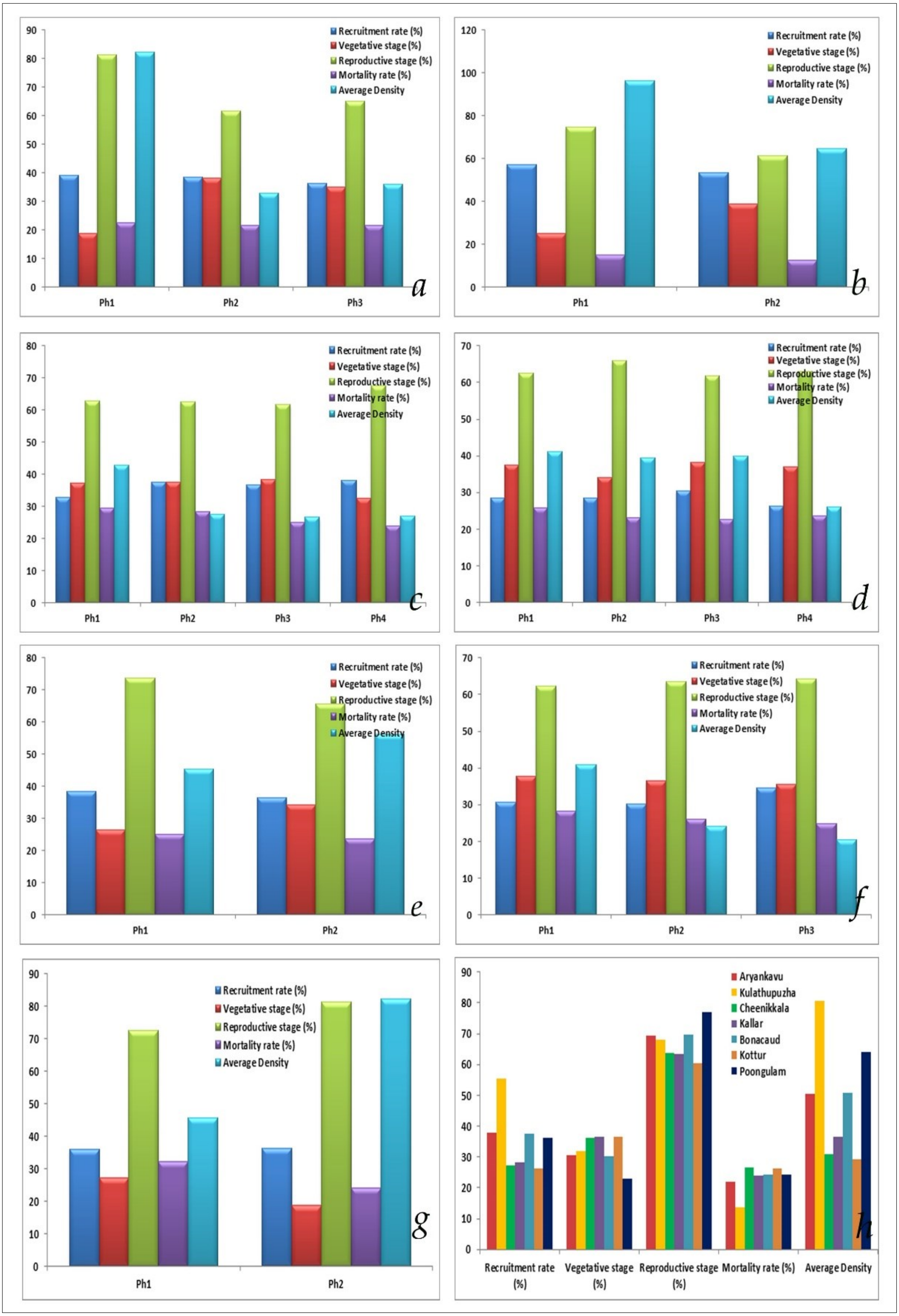

Fig. 4. Population dynamics of *T. zeylanicus* subsp. *travancoricus* at different populations (Average for 2019-2023; ph1-Patch 1, ph2-Patch 2 like that): a. Aryankavu; b. Kulathupuzha; c. Cheenikkala; d. Kallar; e. Bonacaud; f. Kottur; g. Poonkulam; h. Population dynamics of *T. zeylanicus* subsp. *travancoricus* in all patches per population (Average for 2019-2023).

Table. 1. Ecophysiological characters of *T. zeylanicus* subsp. *travancoricus* habitat

Parameters	Ar	Ku	Ch	Ka	Bo	Ko	Po
Altitude (m amsl)	240-330	260-360	240-320	120-280	320-480	130–240	570- 710
Atmospheric temperature (°C)	21 ± 2	20 ± 3	24 ± 2	22 ± 3	20 ± 4	21 ± 3	22 ± 2
Soil temperature (°C)	23 ± 3	21 ± 2	23 ± 2	19 ± 3	22 ± 3	18 ± 4	22 ± 3
Atmospheric humidity (%)	67 ± 3	69 ± 2	68 ± 3	70 ± 3	67 ± 4	69 ± 3	71 ± 2
Soil moisture (%)	62 ± 4	61 ± 2	71 ± 4	69 ± 3	78 ± 3	73 ± 4	67 ± 3
Light intensity (Lux)	840-1140	850-1250	910-1080	930- 1290	860- 1090	870-1040	890-1270
Canopy cover	Moderately closed	Moderately closed	Closed	Moderately closed	Moderately closed	Closed	Moderately closed

Ar:Aryankavu, Ku: Kulathupuzha; Ch: Cheenikkala; Ka:Kallar; Bo: Bonacaud; Ko:Kottur; Po: Poonku; m amsl: meter above mean sea level

Discussion

Exceptional and valuable, *T. zeylanicus* subsp. *travancoricus is a medicinal herb* encountering relentless and uncontrolled exploitation, leading to its rapid decline in the Agasthyamala Biosphere Reserve. Habitat degradation due to encroachment for agriculture, human settlements, deforestation leading to large canopy gap formations all contributed environmental changes. These activities exposed the native habitats of these species to both non-living (abiotic) and living (biotic) disturbances. Spatial distribution of *T. zeylanicus* subsp. *travancoricus* showed significant variations in all populations; even within a single population, there were multiple instances of both small and large patches noted. The distribution pattern of *Arabidopsis thaliana* similarly exhibited patches of varying sizes and densities (17). The heterogeneity of soil patches within a population significantly influences individual plant growth, community structure and ecosystem functioning (18, 19). In the case of *T. zeylanicus* subsp. *travancoricus* was observed that geographical barriers and factors such as river, continuous rocks and roads, human settlements and anthropogenic activities, plantations, barren soils, large canopy gaps, soil characters and water holding capacity and climate changes isolate the habitats.

In the present study, some populations like Aryankavu, Kallar and Kulathupuzha also had notable anthropogenic activities by invasive species, particularly in plantations and tourism. These human activities have had detrimental effects on the composition of vegetation and the fragmentation of natural habitats for wild species. The boundary between the human settlement and species ecological niche is the beginning point of exotic invasions into natural localities (20-22). *T. zeylanicus* subsp. *travancoricus* displayed distinct phenotypic traits under specific conditions of low atmospheric and soil temperature, high atmospheric humidity, soil moisture and low sunlight intensity. It was also observed that soil and root mycorrhizal associations are critical in its habitat specificity (23).

Changes in various ecological factors are responsible for fluctuations in *T. zeylanicus* subsp. *travancoricus* population, which exhibits unique phenotypic characteristics under specific environmental conditions. The local abundance and regional distribution of species are contingent upon the availability of their particular niche requirements. The distinctive characteristics of a species' niche determine its lower abundance and limited distribution (24, 25). The population growth rates of the species are influenced by various abiotic environmental factors such as light availability, nutrient concentrations as highlighted, flooding and the historical occurrence of calamitous events (26-29). Population growth rate is determined by assessing population dynamics through survival, fertility, or individual growth rate (30).

The population growth rate of niche-specific plants is determined by factors within the surrounding environment and intra-specific densities (31). Formation of canopy openings can also limit *T. zeylanicus* subsp. *travancoricus* distribution in various locations. Large trees with broad leaves create closed canopies, further limiting understory species' growth. Seed dispersal only to a limited distance may also contribute to its sporadic presence in certain areas (23). The competitions between understory plant species and trees for soil nutrients and moisture make it difficult for herbaceous plants beneath canopies to be healthy and productive, which results in a loss of herbaceous plant cover (32). In the present study, two populations like Cheenikkala and Kottur with closed canopy cover compared to others with moderately closed canopy cover. *T. zeylanicus* subsp. *travancoricus* individuals of this population with only prominent vegetative stages rather than reproductive stages indicate the significance of sunlight for the transition from the vegetative stage to the reproductive stage. The close canopy cover permits low insulation on the forest floor, which decreases herbs' density (33). The amount of litter and moisture combined with the lack of light may cause this decrease in herbaceous plant germination and growth (32).

Furthermore, the formation of broad canopy gaps reduces both atmospheric and soil relative humidity and exposes native habitats to intense sunlight, which negatively impacts their populations. The presence of grazing and trampling by animals, as noted in Cheenikkala and Kottur populations and landslides, has also been observed to contribute to species mortality. The distribution and abundance of a species can also be constrained by biotic interactions, such as herbivory and the accelerated growth of associated plant populations (34). These activities not only reduce the size of mature individuals but also lead to diminished seed production and disruptions in their life cycles. Herbivory leads to reductions in plant biomass and the reproductive output of perennial herbs (35).

Herb density is governed by the required sunlight, accelerating their recruitment, growth and development (36). *T. zeylanicus* subsp. *travancoricus* populations of Aryankavu, Kulathupuzha, Kallar, Bonacaud and Poonkulam are under moderately closed canopy cover. The vegetational data analysis indicated that the candidate species' recruitment rate and percentage density are very high in the Kulathupuzha population. Compared to the reproductively abled plants in the Poonkulam population, Cheenikkala and Kottur populations under much-closed canopy cover showed very high mortality rates and low percentages of reproductively abled plants. Partial canopy opening favours herbaceous plants to acclimate to the changing conditions and competition with other species (37, 38). The results indicated that the Kulathupuzha population recruited more sound seedlings annually with low mortality rates, indicating suitable niche characteristics.

Conclusion

T. zeylanicus subsp. *travancoricus (Arogyapacha)* is an ethnomedically valuable herb in montane forests at 100–1000 m elevations. Populations vary significantly, separated by distances up to 14.65 km. Human activities, limited seed dispersal, canopy gaps and variable ecophysiology impact seedling survival, leading to patchy distribution. Vegetation data reveal that Kulathupuzha has the highest recruitment rates and density among the seven studied populations, while Kottur and Cheenikkala suffer from lower recruitment and higher mortality. Canopy analysis shows that closed canopies, especially in Cheenikkala and Kottur, restrict sunlight, lowering recruitment rates and existence. Moderately closed canopies at Aryankavu, Kulathupuzha, Kallar, Bonacaud and Poonkulam support variability, with Kulathupuzha excelling in reproductive success. Future research should focus on adaptive management, such as selective canopy thinning, to improve recruitment and support population sustainability across diverse habitats, especially in vulnerable areas.

Acknowledgements

We wish to acknowledge the Director, Jawaharlal Nehru Tropical Botanic Garden and Research Institute, for the facilities provided and Kerala and Tamil Nadu Forest Departments for forest entry permit. The first author is also thankful to the Department of Science and Technology for financial assistance and Kannur University for approving the PhD programme on *T. zeylanicus* subsp. *travancoricus*

Authors' contributions

AM[1] and AM[2] designed the objectives and work plan and analysed the population and vegetational data. AM[1] carried out the distribution mapping of the species. AC participated in the result analysis, interpretation and manuscript correction. All authors read and approved the final manuscript [AM[1] stands for Angala Mathew and AM[2] stands for Anto Mathew].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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