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Vegetational Characteristics in Natural Habitat and Population Structure of the Endangered Plant *Tigridiopalma* Genus

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ABSTRACT

This study provides the first comparative community-ecological and demographic assessment of the two extant species of *Tigridiopalma* (Melastomataceae), both of which are classified as Plant Species with Extremely Small Populations (PSEP) and are endangered. Despite sharing similar morphological traits and habitat preferences, *T. magnifica* and *T. exalata* exhibit marked differences in floristic composition, community structure, and population dynamics, reflecting contrasting life-history strategies and degrees of habitat specialization. By integrating analyses of floristic contribution, species associations, and demographic patterns, our findings highlight the importance of habitat context in shaping the persistence of narrowly endemic understory plants. Our results demonstrate that even closely related endangered species can adopt divergent ecological strategies. *Tigridiopalma magnifica* persists through broad biotic associations but appears constrained by seedling establishment, likely due to dense leaf litter or intense understory competition. In contrast, *T. exalata* relies on specific canopy tree associations but shows signs of reproductive limitation within resource-poor niches. Effective in situ conservation therefore requires a shift from a species-centric to an interaction-centric framework, emphasizing the management of community processes rather than target species alone, specifically, facilitative interactions for *T. magnifica* and canopy filtering mechanisms for *T. exalata*.

1 | Introduction

Plant Species with Extremely Small Populations (PSESP) represent a critical conservation category defined by highly restricted distribution ranges (typically $<100\,km^2$) and severely depleted population sizes (typically <5000 mature individuals) (Yang et al. 2020). Unlike widespread taxa, PSESPs are often confined to specific microhabitats, such as ravine understories, karst crevices, or cliff faces, which function as long-term climatic refugia (Harrison and Noss 2017). The persistence of understory herbs in these fragmented habitats is not random but governed by strict environmental filtering (e.g., specific irradiance and moisture requirements) and complex biotic interactions (Kraft et al. 2015). However, conservation assessments for PSESPs frequently rely on census data alone, overlooking the phytosociological context and community assembly rules that sustain these populations in the wild (Volis 2016). Understanding the interplay between community structure and population demography is therefore essential for designing effective in situ conservation strategies.

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The genus *Tigridiopalma* C. Chen (Melastomataceae) serves as an ideal model for examining these ecological constraints. This genus represents a phylogenetically distinct lineage within the tribe Sonerileae, endemic to Guangdong Province, China. Distinguished by exceptionally large basal leaves reaching up to 80 cm in diameter (Chen 1979), the genus comprises two spatially isolated species: the endangered *T. magnifica*, restricted to fragmented subtropical forests in western Guangdong, and the recently described *T. exalata*, endemic to the Nankun Mountains in the east (Zeng et al. 2021). Both species exhibit stenotopic adaptations to the skylight environments of deep ravines, specifically shaded and humid granitic slopes near running water (Tao et al. 2021). Physiological studies indicate that *T. exalata* possesses specialized photosynthetic traits, including a low light compensation point, allowing it to utilize sunflecks in deep shade (Huang et al. 2023). While this specialization facilitates survival in dense forests, it renders the genus highly sensitive to canopy disturbance and hydrological alterations.

Despite its legislative status as a National Class II Protected Wild Plant, *T. magnifica* has undergone severe population decline due to habitat fragmentation. Research indicates that although molecular markers have been developed to monitor its genetic health (Luo 2022), the populations remain severely isolated. Similarly, the newly identified *T. exalata* is restricted to two small localities and faces immediate threats from horticultural over-collection and tourism development (Tao et al. 2021). Although conservative efforts have addressed in ex-situ conservation (Zeng et al. 2008; He et al. 2010), seedling breeding (Li et al. 2006; Zhao 2006), reintroduction (Ren, Zeng, et al. 2012), and genetic diversity (Zhou et al. 2018; Luo 2022), comprehensive studies on their habitat ecology and community associations remain scarce. It is currently unknown whether these species act as competitors or beneficiaries via facilitation within their plant communities and how their distinct life-history stages respond to local environmental filters and community succession.

This study presents the first comprehensive ecological assessment of *Tigridiopalma* across its native distributional range. Integrating phytosociological surveys, interspecific association analysis, and static life-table approaches, we aim to bridge the gap between population demography, community ecology and restoration. We test two specific hypotheses regarding their persistence: Hypothesis 1 (Divergent Community Assembly): Despite shared morphology, *T. magnifica* and *T. exalata* occupy distinct ecological niches driven by different biotic associations, with *T. magnifica* relying on facilitation by understory structural heterogeneity and *T. exalata* dependent on specific canopy structures. Hypothesis 2 (Opposing Demographic Bottlenecks): The persistence of these populations is constrained by specific bottleneck life stages that differ between the two species due to divergent trade-offs between vegetative persistence and reproductive effort. To validate these hypotheses, our specific objectives are to: (1) characterize the floristic composition and vertical structure of the natural habitats; (2) quantify interspecific associations (via r-NCD and correlation matrices) to identify obligate vs. facultative companion species; (3) evaluate survivorship curves and mortality rates (q_x) to pinpoint vulnerable life stages; and (4) translate these ecological baselines into targeted in situ management strategies, shifting from simple replanting to microhabitat reconstruction, and finally derive targeted conservation insights applicable to PSESP management globally.

2 | Methods and Materials

2.1 | Study Site Overview

Flora and vegetation surveys were conducted between June 2020 and December 2024 across potential native habitats of two species of *Tigridiopalma* Historical distribution sites were targeted, including the Yunwu Mountains for *T. magnifica* and the Nankun Mountains for *T. exalata* (Figure 1).

The study area for *T. magnifica* encompassed the Yunwu Mountains (22° 15′–22° 20′ N, 111° 18′–111° 25′ E) in western Guangdong. This northeast-southwest mountain range is deeply dissected by valleys and basins carved by the Moyang and Luoding Rivers. Elevations range from 300 to 800 m, with the highest peak reaching 1704 m. Populations of *T. magnifica* occur across an elevation range of 100–1000 m. The area is underlain by granite/metamorphic bedrock, overlain with acidic lateritic soils. Vegetation is dominated by subtropical evergreen broadleaf forests (500–800 m), transitioning to mixed coniferous-broadleaf communities at higher elevations. The humid subtropical monsoon climate delivers a mean annual temperature of 20.8°C (extremes: −2.1°C–38.5°C) and annual precipitation of 1850 mm. Despite its ecological significance as a biodiversity hotspot, the region faces increasing anthropogenic pressures, particularly from ecotourism-related habitat fragmentation and agricultural encroachment. These threats make the Yunwu Mountains a critical site for understanding the survival prospects of *T. magnifica* in the wild.

The study area for *T. exalata* comprisesd the Nankun Mountains (23°30′–23°45′ N, 113°40′–114°00′ E). This 200-km^2 granitic massif forms the southern extension of the Jiulian Mountain Range. *T. exalata* occurs at altitudes as low as ~100 m. The Nankun River and its tributaries have produced a dendritic river system with numerous gullies and ravines, with 2163 mm annual rainfall. The massif is composed of Mesozoic granite overlain by acidic lateritic soils. Vegetation displays vertical zonation: subtropical evergreen broadleaf forests dominate by Fagaceae and Lauraceae (500–800 m), grading into mixed coniferous-broadleaf forests above 1000 m. The humid subtropical climate is characterized by a mean annual temperature of 20.8°C (extremes −4.4°C to 39.3°C), seasonal flooding (peak rainfall in May: 434.4 mm), and ~80% relative humidity. The Nankun Mountains support 1931 recorded plant species, including 45 threatened endemics such as *T. exalata*, *Paphiopedilum purpuratum*, and *Phlegmariurus austrosinicus*. The persistence of these species depends on fog-enhanced microhabitats, which are increasingly threatened by seasonal flooding and human disturbance.

2.2 | Floral Survey

Given the genus's stenotopic restriction to specific microhabitats (e.g., shaded ravines and granitic slopes), simple random

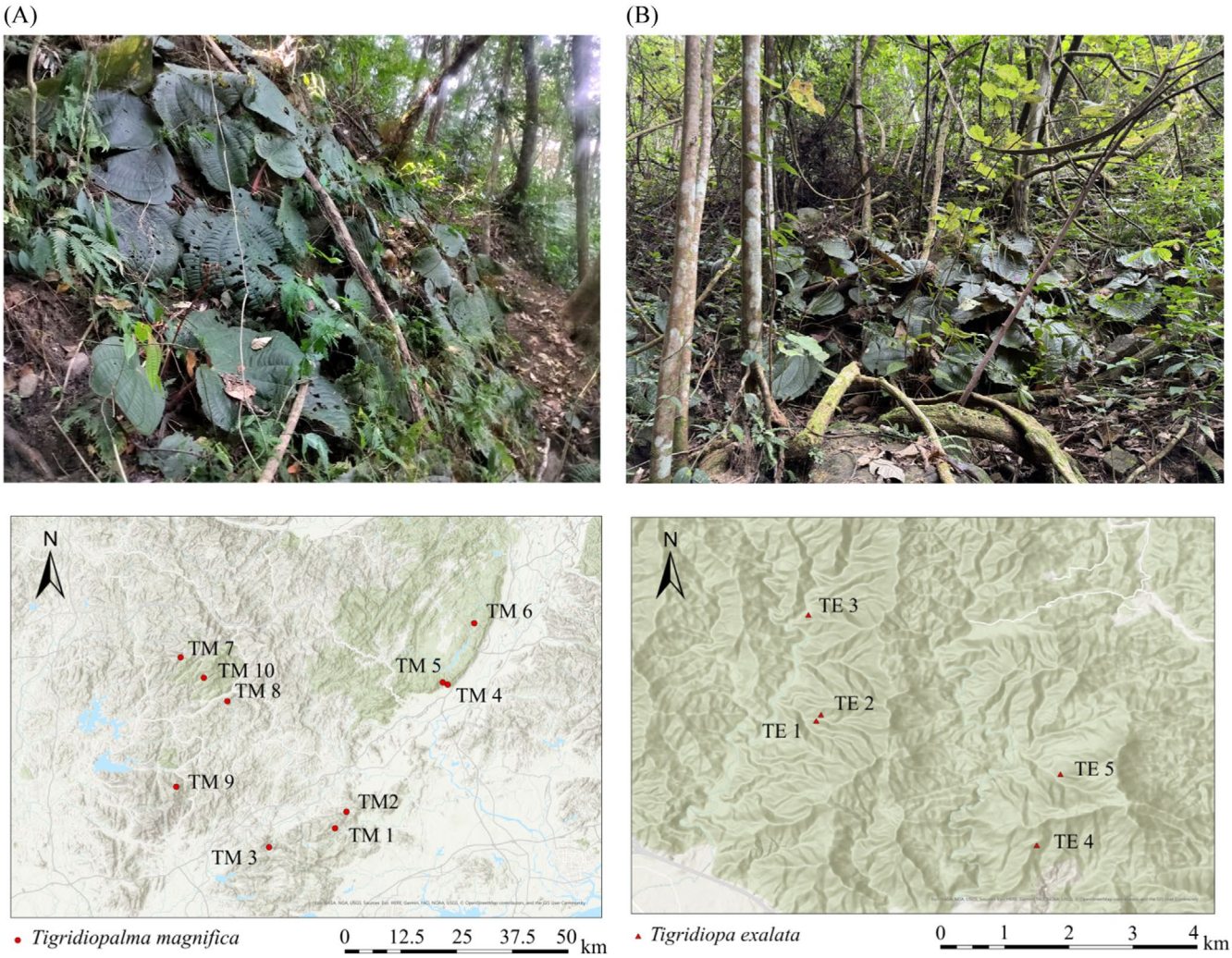


FIGURE 1 | Habitat and survey sites of *Tigridiopalma magnifica* (A) and *Tigridiopalma exalata* (B).

sampling across the entire study area would yield insufficient data density. To effectively characterize the phytosociological context of the patchily distributed *Tigridiopalma* populations, we employed a stratified systematic sampling strategy (Roleček et al. 2007). The sampling procedure followed two steps:

2.2.1 | Stratification and Site Selection

Based on historical records and preliminary field surveys, distinct habitat patches occupied by *T. magnifica* and *T. exalata* were identified as sampling strata. To capture the full range of ecological variation, we selected 10 representative sites for *T. magnifica* (spanning all core habitats among its fragmented range across Yunwu Mountain) and 5 sites for *T. exalata* (near-census of its restrictive endemic range in Nankun Mountain). To avoid spatial autocorrelation and ensure statistical independence, a minimum inter-site distance of 1 km (or distinct hydrological catchments) was maintained. Sampling aimed for exhaustive coverage of all accessible populations rather than a fixed equal sample size. This unequal effort reflects the natural rarity and varying Extent of Occurrence (EOO) of the two species.

2.2.2 | Plots Establishment

Within each identified habitat patch, sampling plots were established systematically to ensure representativeness of the community structure. Standard plots of 20 m × 20 m were set up in the core distribution area of each population. Minimum inter-plot distance was 20 m. Following the Zürich-Montpellier approach (Braun-Blanquet 1932), each plot was further subdivided into five 5 m × 5 m quadrats (four at the corners and one in the center) for the arboreal layer with nested 2 × 2 m subquadrats for the shrub/herb layer, totaling 50 quadrats for *T. magnifica* and 25 quadrats for *T. exalata*. This approach ensures that the sampled communities are representative of the species' realized niche while maximizing the efficiency of demographic data collection for these extremely small populations (Elzinga et al. 2001).

This hierarchical design ensures that the data reflect the realized niche of these rare species while providing robust inputs for the subsequent r-NCD and interspecific association analyses.

Taxonomic identification was based on regional floras and datasets, including the Flora of China, Flora of Guangdong and other regional illustrated floras and higher plant datasets (Chinese

Academy of Sciences 1993; Compilation Team of the Flora of Guangdong 2011; Song et al. 2023; Song and Chen 2025). The botanical inventory followed Cronquist's classification system (1981), with scientific nomenclature standardized according to the Catalog of Life China (The Biodiversity Committee of Chinese Academy of Sciences and Xu 2024). Ecological attributes, specifically endemicity, phytogeographic indication, conservation status, and invasiveness were verified using relevant national databases and red lists (Wu and Wu 1996; Lin et al. 2022; Ministry of Environmental Protection of China and Chinese Academy of Sciences 2013; Govaerts 2025).

For woody plants (DBH ≥ 1.5 cm and height ≥ 1.5 m), we measured diameter at breast height (DBH), tree height, and crown width. The shrub and herbaceous layers were assessed for height, basal diameter, abundance, and percentage coverage. Alongside a complete inventory of epiphytes and lianas, environmental variables (see Tables 1 and 2) including elevation, slope aspect, crown closure, and soil characteristics were recorded for each plot. Life forms were categorized using a modified Raunkiaer-Numata system adapted for subtropical evergreen forest (Raunkiaer 1934; Numata 1970). This classification focused on three functional dimensions: phenology (phanerophytes vs. cryptophytes), propagation mode (rhizomatous expansion [R3–R5] vs. solitary growth [R1]), and dispersal mechanism (zoochory [D1] vs. barochory [D2]).

2.3 | Community Diversity Index Calculation

To assess species diversity within the study sites, four standard diversity indices were calculated, including the Shannon-Wiener diversity index (H') (Shannon and Weaver 1971), Pielou index (E) (Pielou 1966), Simpson's index of dominance (P) (Simpson 1949) and Gleason index (D') (Gleason 1922) were calculated as formula below via R package OnomasticDiversity v0.1 (Villamayor 2024) and Vegan v 2.7 (Dixon 2003):

Shannon-Wiener Index (Diversity Index, H'):

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Pielou Index (Evenness Index, E):

$$E = \frac{H'}{\ln S}$$

Simpson Index (Dominance Index, P):

$$P = 1 - \sum_{i=1}^{S} p_i^2$$

TABLE 1 | Information of sample sites for investigation of *Tigridiopalma magnifica* communities.

Sample plot	Dominated arbor	Elevation (m)	Slope aspect	Slope gradient (°)	Slope position	Canopy closure (%)	Population size
TM1	*Heptapleurum heptaphyllum*	265	North-east	50	Lower	70%	300
TM2	*Heptapleurum heptaphyllum*	140	North	90	Lower	90%	40
TM3	*Litsea variabilis*	540	North-east	45	Middle	70%	500
TM4	*Heptapleurum heptaphyllum*	278	North	50	Middle	60%	100
TM5	*Heptapleurum heptaphyllum*	298	North	80	Lower	40%	600
TM6	*Heptapleurum heptaphyllum*	81	North	70	Lower	85%	60
TM7	*Phyllostachys edulis*	1077	North	50	Lower	70%	300
TM8	*Bambusa textilis*	325	South-east	10	Lower	60%	15
TM9	*Cryptocarya chinensis*	795	North-west	42	Middle	70%	120
TM10	*Phyllostachys edulis*	631	North-west	22	Middle	50%	80

TABLE 2 | Information of sample sites for investigation of *Tigridiopalma exalata* communities.

Sample plot	Dominated arbor	Elevation (m)	Slope aspect	Slope gradient (°)	Slope position	Canopy closure (%)	Population size
TE1	*Rhododendron moulmainense*	114	North	80	Middle to lower	60	230
TE2	*Castanopsis chinensis*	102	North	70	Lower	30	800
TE3	*Mallotus paniculatus*	149	North	60	Lower	60	400
TE4	*Mallotus paniculatus*	219	North	43	Middle to lower	90	200
TE5	*Castanopsis faberi*	221	South	52	Lower	60	100

Gleason Index (Species Richness Index):

$$D^{`} = \frac{S}{\ln A}$$

where P_i represents the relative importance value of species i; S represents the number of species, N represents the total number of individuals of all plant species in one particular quadrat; A represents the area of the sample plot.

2.4 | Contribution of Each Species Within the Community

To quantify species-specific ecological impacts within the *Tigridiopalma* communities, we calculated the relative Net Contribution Degree (r-NCD). This metric, originally defined by Kim and Manyko (1994) for assessing mixed forest communities, integrates both spatial coverage and occurrence frequency to identify diagnostic species, offering a more sophisticated descriptive value compared to traditional constancy degrees (Classes I–V) or simple summation-based Importance Values (IV). Since r-NCD is a relative metric, it allows for standardized comparisons across different community types. By multiplying the average coverage by the frequency ratio, the index acts as a filter to distinguish species that are both spatially dominant and frequently occurring from those that are accidental or locally abundant but rare elsewhere, which was validated in phytosociological studies of endangered East Asian herbaceous flora (Park et al. 2021).

The computational framework is based on absolute contribution (*NCD*) value, from which the relative contribution of each species was derived according to the following expression:

$$\mathrm{NCD}_i = \sum \frac{C_i}{N} \times \frac{n_i}{N} \left(C_{\min} \le \mathrm{NCD} \le C_{\max}\right)$$

$$r-\mathrm{NCD}_i = \sum \frac{C_i}{\mathrm{NCD}_{\max}} \times 100$$

Where ΣC_i represents Cumulative ground coverage of species i; N represents total sampling plots per community; n_i represents plots containing species i; $\mathrm{NCD}_{\max}$ represents maximum contribution value within the community.

2.5 | Interspecific Association

The Variance ratio (*VR*) test were used to determine whether the community exhibits a non-random assembly (overall positive or negative association) before conducting pairwise correlation analyses (Schluter 1984). VR and W statistic of each layer (tree, shrub & liana, herb) were calculated to quantify the holistic community correlation based on null hypothesis.

Variance Ratio (VR):

$$\mathrm{VR} = \frac{S_T^2}{\delta_T^2} = \frac{\frac{1}{N}\sum_{j=1}^{N}\left(T_j - t\right)^2}{\sum_{i=1}^{S}\left(1 - p_i\right)}$$

where $t = \frac{1}{N}\sum_{j=1}^{N} T_j$ represents average species richness per plot; $p_i = \frac{n_i}{N}$ represents occurrence frequency of species i; N represents total number of plots; S represents total number of species; T_j represents species richness in plot j; S_T^2 represents variance of species richness across plots; δ_T^2 represents pooled sample variance.

The species association was estimated by the extent of VR deviated from 1. A $\mathrm{VR} > 1$ suggests a net positive association (species tend to co-occur more than expected by chance), indicating consistent habitat filtering or facilitation; while a $\mathrm{VR} < 1$ suggests a net negative association (species exclusion), indicative of competition or microhabitat heterogeneity. The significance of this deviation was tested using the statistic W ($W = \mathrm{VR} \times N$). Under the null hypothesis of independence ($\mathrm{VR} = 1$), W follows a Chi-square (χ^2) distribution with N degrees of freedom. Significant deviation is inferred if:

$$\chi^2_{(0.95,\mathrm{N})} < \mathrm{W} < \chi^2_{(0.05,\mathrm{N})}$$

If W falls outside this interval, the null hypothesis is rejected, indicating a significant overall negative or positive association (Gotelli 2000). Similar to previous studies on forest community dynamics of PSEPs (Liu et al. 2017; Zhang et al. 2022), we calculated the VR and W statistic separately for the tree, shrub, and herb layers to quantify holistic community correlations.

Percentage of co-occurrence and Pairwise Pearson or Spearman rank correlations were subsequently calculated to interpret the specific species interactions driving the overall pattern detected by the VR test. R package Hmisc (Harrell and Harrell 2019) was used for significant test.

2.6 | Population Structure and Dynamics

2.6.1 | Demographic Census and Stage Classification

Given the perennial nature of *Tigridiopalma* and the difficulty in determining chronological age for herbaceous plants in the wild, we adopted a stage-based approach for demographic analysis, using space-for-time substitution to infer population dynamics (Cochran and Ellner 1992; Silvertown and Charlesworth 2009).

Due to the conservation status of *Tigridiopalma* as a National Class II Protected Wild Plant, we utilized Diameter of the Largest Leaf (LLD) for vegetative individuals and phenological characteristics for reproductive individuals as non-destructive proxies for developmental stage. Based on field observations of life history traits, the ontogeny of *Tigridiopalma* was divided into eight distinct developmental stages (Table 3). All individuals within the sampling quadrats were censused and assigned to one of these eight stages ($x = 1$–8).

This method is consistent with allometric principles linking linear leaf dimensions to total biomass in herbaceous perennials (Niklas 1994), especially for *Tigridiopalma*, which possess giant leaves. Crucially, vegetative size often outperforms chronological age as a predictor of survival and reproductive fate (Werner 1975; Gross 1981), ensuring our methodology balances demographic precision with conservation ethics. Eight ontogenetic stages were classified, adapted from the standardized ontogenetic classification system proposed by Gatsuk et al. (1980) and applied

TABLE 3 | Definition of developmental stages for *Tigridiopalma* populations.

Stage class	Definition/Morphological criteria	Proxy (LLD/Status)
Seedling	Individuals with cotyledons present; usually 1–2 small true leaves; root system simple.	LLD < 2 cm; Cotyledons present
Juvenile	Established plants; cotyledons absent; leaf morphology distinct from adults (often simpler); rapid vegetative expansion.	2 cm ≤ LLD < 6 cm
Immature	Transitional stage; morphology resembles adults but smaller; no reproductive history; vigorous vegetative growth.	6 cm ≤ LLD < 10 cm
Vegetative Adult	Individuals reaching critical size for reproduction but currently non-flowering; maximum vegetative vigor.	10 cm ≥ LLD; No reproductive organs
Initial Reproductive	Plants flowering for the first time or recent flowering (buds/flowers); typically fewer inflorescences and low reproductive output	Flower buds visible (Early phenology)
Full Reproductive	Individuals at peak reproductive capacity; maximum biomass and seed set; clearly visible capsules or persistent scapes	Fruits/Scapes visible (Late phenology)
Sub-senile	Physiological decline; vegetative point ceases budding; leaves start to withering	LLD variable (often > 10 cm but declining); No flowers/fruits; Leaf tip necrosis
Senile	Post-reproductive survival; residual leaves only; dormancy phase	LLD often decreases (< 10 cm); Severe chlorosis/withered; Living dead state

in endangered herbaceous plants defined by leaf dimension and flowering state (Oostermeijer et al. 1994).

2.6.2 | Compilation of Static Life Table

A static life table was constructed using census data, assuming a stable stage distribution and constant environmental conditions (McCann and Gellner 2020). The standard demographic parameters were calculated as follows (García 2003; Pan et al. 2020; Yu et al. 2024):

x: Developmental stage class (1–8).

a_x: Number of surviving individuals observed at stage x.

l_x: Standardized survivorship at the beginning of stage x, calculated as $l_x = (a_x/a_1) \times 1000$.

d_x: Number of deaths between stage x and $x+1$, calculated as $d_x = l_x - l_{x+1}$.

q_x: Stage-specific mortality rate, calculated as $q_x = d_x/l_x$.

L_x: Average number of individuals alive during the stage interval, $L_x = (l_x + l_{x+1})/2$.

T_x: Total future distinct stage-intervals to be lived by individuals at stage x, $T_x = \sum L_x$.

e_x: Life expectancy (expected number of future stages) for an individual at stage x, $e_x = T_x/l_x$.

2.6.3 | Survivorship Curve Fitting

Survivorship curves were plotted using stage class (x) on the abscissa and the natural logarithm of standardized survivorship ($\ln l_x$) on the ordinate. To quantitatively determine the survivorship type (Deevey I, II, or III), the data were fitted to the mathematical models proposed by Hett and Loucks (1976) using IBM SPSS Statistics 26.0:

- Polynomial Model (Deevey Type I): Used when the curve shows convexity (low early mortality, high late mortality), typically fitted with a quadratic equation $ln(l_x) = a + bx^2$.
- Exponential Model (Deevey Type II): $ln(l_x) = a - bx$ indicating a constant mortality rate regardless of stage.
- Power Function Model (Deevey Type III): $ln(l_x) = a - ln(x)$ indicating high early-stage mortality followed by high survival.

The model with the highest coefficient of determination (R^2) and F-statistic was selected to best describe the population dynamics. The resulting curves were classified as Type I (convex), Type II (diagonal), or Type III (concave).

3 | Results

3.1 | Floristic Survey

The floristic composition differed markedly between the habitats of the two species, reflected by differences in family dominance and ecological specialization (Table 4). The *Tigridiopalma magnifica*

TABLE 4 | The number of vascular plants in 11 study sites of *Tigridiopalma magnifica* (TM) and five study sites of *Tigridiopalma exalata* (TE).

	Family		Genus		Species		Subspecies		Variety	
Taxa	**TM**	**TE**	**TM**	**TE**	**TM**	**TE**	**TM**	**TE**	**TM**	**TE**
Pteridophyta	10	6	12	6	13	6	0	0	0	0
Lycopsida	1	1	1	1	3	1	0	0	0	0
Gymnospermae	2	0	2	0	2	0	0	0	0	0
Angiospermae	46	23	71	32	79	34	0	0	0	0
Monocotyledoneae	13	4	18	6	26	6	0	0	0	0
Dicotyledoneae	33	19	53	26	53	28	1	0	1	0
Total	59	30	86	39	97	41	1	0	1	0

habitat supported a richer flora (99 taxa across 59 families) compared to that of *Tigridiopalma exalata* (41 taxa across 30 families) (Table 4). Moraceae and Poaceae were dominant families in *T. magnifica* sites, whereas Euphorbiaceae, Fabaceae, Lamiaceae, and Rubiaceae were the most frequent and speciose families (3 taxa each) in *T. exalata* sites (Tables S1 and S2). Notably, *T. magnifica* habitats harbored a higher proportion of ferns (13 taxa) and regionally endemic species (23 taxa) than *T. exalata* habitats (6 ferns, 2 endemics) (Tables 5 and 6). However, this disparity reflects the broader ecological range sampled for *T. magnifica* ($N=10$) relative to the range of *T. exalata* ($N=5$) due to the restricted distribution of the latter. Thus, direct comparisons of total species richness and family diversity between the two habitats should be interpreted with caution (Gotelli and Colwell 2001).

Regarding conservation status, *T. magnifica* habitats harbored six taxa listed in China's National List of Key Protected Wild Plants (National Forestry and Grassland Administration and Ministry of Agriculture and Rural Affairs 2021) or China Biodiversity Red List Species (Ministry of Environmental Protection of China and Chinese Academy of Sciences 2013), in addition to 23 regional endemic species. In comparison, the *T. exalata* habitat supported one protected taxon and two endemic species that were shared with *T. magnifica* sites.

Eleven indicator species were identified in *T. magnifica* sites, representing distinct environmental characteristics: landforms (e.g., *Rhaphidophora hongkongensis* for karst caves), vegetation-types (e.g., *Alpinia hainanensis* for tropical marginal transition zone vegetation), pedohydrology (e.g., *Selaginella doederleinii* for high-humidity and weakly acidic substrates), and successional-stages (e.g., *Thysanolaena latifolia* for early secondary succession; Table 5). Conversly, only four indicators were recorded in *T. exalata* sites. Notably, all four regional indicator species (*Cibotium barometz*, *Selaginella doederleinii*, *Thysanolaena latifolia*, and *Rhaphidophora decursiva*) and two of ten endemic species recorded in *T. exalata* sites were also present in *T. magnifica* populations (Tables 5 and 6).

Floristic analysis of *Tigridiopalma*'s native habitats revealed a taxonomically diverse flora with broad phylogenetic representation across genera and narrow-range endemics, despite showing limited ecosystem rarity. Nevertheless, these sites demonstrate exceptional conservation significance as a critical refuge for *Tigridiopalma* alongside multiple national protected species, including rare trees and ferns. It is noteworthy that no species listed on the global IUCN Red List or alien plant populations were detected across the surveyed sites.

Raunkiær's life form system has been widely utilized to evaluate interactions between environmental factors and vegetation (Harrison et al. 2010; Marini et al. 2012), and to assess biogeographic patterns in plant communities (Irl et al. 2020). Furthermore, it has been proposed as an proxy for plant trait syndromes linked to persistence strategies (Ottaviani et al. 2020; Conti et al. 2022). The distribution patterns are strongly associated with specific habitat types, defined by the dominance of functional groups (Midolo et al. 2024), thereby offering valuable insights for the conservation of PSESPs.

Analysis of life form spectra for *T. magnifica* and *T. exalata* revealed adaptations consistent with their ecological niche, specifically stable, shaded, and humid forest understories. This is corroborated by the composition of Raunkiaer life forms with their habitats: hemicryptophytes (H) and chamaephytes (CH) collectively dominate (> 60% combined for both species), while therophytes (Th) are nearly absent, confirming the perennial nature of the community (Table 7A).

Propagation strategies in the habitat of both species were characterized by a predominance of non-clonal growth (R4). Disseminule forms were dominated by animal-assisted dispersal (D2) and gravity dispersal (D4), which together accounted for over 60% of observation (Table 7B). Although gravity dispersal (D4) is the primary strategy for *Tigridiopalma* itself, the broader ecosystem stability remains vulnerable to declines in pollinator or disperser populations. Such declines could trigger cascading ecological degradation, threatening the community that sustains *Tigridiopalma*.

Growth-forms analysis demonstrated a convergence of erect (e) and liane (l) structures. These traits facilitate light acquisition in dense understories and enhance interactions with dispersers through vertical positioning of reproductive structures; crucially, they also create shaded microhabitats that serve as shelters for *Tigridiopalma*. The habitats of *Tigridiopalma exalata* exhibit a marginally higher proportion of branched (b) growth and moderate rhizomatous extension (R2), potentially conferring slightly greater resilience in microsites subject to mild disturbance. In contrast, the habitats

TABLE 5 | The list of vascular plants in the study area of *Tigridiopalma magnifica*.

Family name	Scientific name	Note
Acanthaceae	*Strobilanthes cusia* (Nees) Kuntze	
Acoraceae	*Acorus gramineus* Soland.	
Actinidiaceae	*Saurauia tristyla* DC.	
Annonaceae	*Fissistigma oldhamii* (Hemsl.) Merr.	ES
Apocynaceae	*Hoya radicalis* Tsiang & P. T. Li	ES; NT
Araceae	*Pothos chinensis* (Raf.) Merr.	
	Pothos repens (Lour.) Druce	
	Rhaphidophora hongkongensis Schott	i1
Araliaceae	*Eleutherococcus trifoliatus* (L.) S. Y. Hu	
	Heptapleurum heptaphyllum (L.) Y. F. Deng	
Arecaceae	*Calamus rhabdocladus* Burret	i2
	Caryota maxima Blume ex Mart.	
	Pinanga baviensis Becc.	ES, i3
Asparagaceae	*Aspidistra subrotata* Y. Wan & C. C. Huang	ES
Aspleniaceae	*Asplenium normale* Don	
Asteraceae	*Decaneuropsis cumingiana* (Benth.) H. Rob. & Skvarla	
Begoniaceae	*Begonia laciniata* Roxb.	
	Begonia longifolia Blume	
Blechnaceae	*Blechnopsis orientalis* (L.) C. Presl	
Chloranthaceae	*Sarcandra glabra* (Thunb.) Nakai	
Cupressaceae	*Cunninghamia lanceolata* (Lamb.) Hook.	
Curcullinaceae	*Curculigo capitulata* (Lour.) Kuntze	
Cyatheaceae	*Cibotium barometz* (L.) J. Sm.	i3, II
	Alsophila gigantea Wall. ex Hook.	i3, II
	Gahnia tristis Nees	
	Hypolytrum nemorum (Vahl) Spreng.	
Dennstaedtiaceae	*Microlepia hancei* Prantl	
Dilleniaceae	*Tetracera sarmentosa* (L.) Vahl	
Ebenaceae	*Diospyros eriantha* Champion ex Bentham	
Euphorbiaceae	*Macaranga denticulata* (Blume) Müll. Arg.	
Fabaceae	*Archidendron clypearia* (Jack) I. C. Nielsen	i3
	Phanera erythropoda (Hayata) Mackinder & R. Clark	ES
	Castanopsis fissa (Champ. ex Benth.) Rehder & E. H. Wilson	
Gesneriaceae	*Aeschynanthus acuminatus* Wall. ex A. DC.	
	Rhynchotechum ellipticum (Wall. ex D. Dietr.) A. DC.	ES
	Raphiocarpus macrosiphon (Hance) Burtt	ES
Gleicheniaceae	*Dicranopteris pedata* (Houtt.) Nakaike	
Gnetaceae	*Gnetum montanum* Markgr.	i4

(Continues)

TABLE 5 | (Continued)

Family name	Scientific name	Note
Hypericaceae	*Cratoxylum cochinchinense* (Lour.) Blume	
Lamiaceae	*Gomphostemma lucidum* Wall. ex Benth.	NT
	Vitex quinata (Lour.) Will.	
Lauraceae	*Cryptocarya chinensis* (Hance) Hemsl.	ES
	Litsea monopetala (Roxb.) Pers.	
	Lindera nacusua (D. Don) Merr.	
	Litsea variabilis Hemsl.	i2
Malvaceae	*Ayenia grandifolia* (DC.) Christenh. & Byng	
	Sterculia lanceolata Cav.	
Melastomataceae	*Blastus cochinchinensis* Lour.	
	Perilimnastes setotheca (H. L. Li) Ying Liu	ES
	Pseudodissochaeta septentrionalis (W. W. Sm.) M. P. Nayar	
Moraceae	*Ficus esquiroliana* H. Lév.	
	Ficus fistulosa Reinw. ex Blume	
	Ficus sagittata Vahl	
	Ficus hirta Vahl	
	Ficus sarmentosa var. *impressa* (Champ.) Corner	
	Ficus tinctoria subsp. *gibbosa* (Blume) Corner	
Musaceae	*Musa balbisiana* Colla	
	Orchidantha chinensis T. L. Wu	ES, VU, II
Nephrolepidaceae	*Nephrolepis cordifolia* (L.) C. Presl	
Oleaceae	*Jasminum elongatum* (Bergius) Willd.	
Orchidaceae	*Eria corneri* Rchb. F.	
	Liparis viridiflora (Blume) Lindl.	
Osmundaceae	*Plenasium vachellii* (Hook.) C. Presl	
Pandanaceae	*Pandanus austrosinensis* T. L. Wu	ES
Piperaceae	*Piper austrosinense* Y. C. Tseng	ES
Poaceae	*Bambusa chungii* McClure	ES
	Bambusa textilis McClure	ES
	Indocalamus sinicus (Hance) nakai	ES
	Phyllostachys edulis (Carrière) J. Houzeau	
	Pseudosasa cantorii (Munro) P. C. Keng ex S. L. Chen & al	ES
	Schizostachyum funghomii McClure	ES
	Thysanolaena latifolia (Roxb. ex Hornem.) Honda	i4
Polypodiaceae	*Lemmaphyllum microphyllum* C. Presl	
	Leptochilus hemionitideus (Wall. ex Mett.) Noot.	
Primulaceae	*Ardisia quinquegona* Blume	
Rhamnaceae	*Ventilago leiocarpa* Benth.	

(Continues)

TABLE 5 | (Continued)

Family name	Scientific name	Note
Rosaceae	*Rubus reflexus* Ker Gawl.	ES
Rubiaceae	*Mouretia inaequalis* (H. S. Lo) Tange	ES
	Lasianthus japonicus Miq.	
	Psychotria asiatica L.	ES
	Wendlandia uvariifolia Hance	
Rutaceae	*Acronychia pedunculata* (L.) Miq.	
	Tetradium glabrifolium (Champ. ex Benth.) T. G. Hartley	
Sabiaceae	*Sabia limoniacea* Wall. ex Hook. f. & Thomson	
Sapotaceae	*Sarcosperma laurinum* (Benth.) Hook. f.	ES
Selaginellaceae	*Selaginella delicatula* (Desv.) Alston	
	Selaginella doederleinii Hieron.	i3
	Selaginella picta A. Braun ex Baker	
Smilacaceae	*Smilax china* L.	
Symplocaceae	*Symplocos ramosissima* Wall. ex G. Don	
Theaceae	*Camellia sinensis* (L.) Kuntze	VU
Thelypteridaceae	*Pronephrium simplex* (Hook.) Holttum	ES
	Pronephrium triphyllum (Sw.) Holttum	
	Trigonospora ciliata (Benth.) Holttum	
Urticaceae	*Pellionia latifolia* (Blume) Boerl.	
	Pellionia radicans (Siebold & Zucc.) Wedd.	
Vitaceae	*Tetrastigma planicaule* (Hook.) Gagnep.	
Zingiberaceae	*Alpinia hainanensis* K. Schum.	ES, i2
	Amomum villosum Lour.	

Abbreviations: ES, endemic species; i1, i2, i2, and i4, floristic indicator plants for landform, vegetation form, pedohydrological form and sessionnal stages form; II, China's National List of Key Protected Wild Plants (Class II); NT, VU, China Biodiversity Red List near threatened (NT), vulnerable (VU) species.

of *T. magnifica* showed greater morphological complexity, including combined forms like branched pseudo-rosettes (b-ps), which were largely broaden niche occupancy across heterogeneous substrates (Table 7C).

3.2 | Community Structure and Species Diversity

Species diversity indices varied according to vertical stratification and dominant arbor species between the two species' habitats (Tables 8 and 9). In *T. magnifica* communities, tree layer diversity ranged from $H' = 0.00$ (monodominant *Phyllostachys edulis*, TM7) to $H' = 1.32$ (mixed *Heptapleurum heptaphyllum*, TM5). The shrub and liana layer maintained consistently high evenness (Pielou's $E > 0.80$ in 9 out of 10 plots) and diversity (Shannon H' mean = 1.48), functioning as a stable buffer even when the tree layer was monodominant (e.g., in bamboo stands like TM7 and TM10). The highest herb layer diversity was observed in the *Bambusa textilis* community (TM8, $H' = 1.92$).

Conversely, *T. exalata* communities exhibited a more simplified structure. While the tree layer diversity was moderate ($H' = 1.04–1.56$), the understory was often impoverished; notably, the shrub/liana layer was completely absent in two communities dominant by *Rhododendron moulmainense* (TE1) and *Mallotus paniculatus* (TE4) respectively. Herb layer diversity in *T. exalata* sites was generally lower than in *T. magnifica* sites (mean Shannon = 0.56 vs. 1.15 in *T. magnifica*), with Shannon values ≤ 0.25 in three out of five plots (TE2, TE3, TE5). Both species occupied sites vulnerable to canopy dominance effects: *Phyllostachys edulis* eliminated subcanopy diversity in *T. magnifica* (TM7), while *T. exalata* communities exhibited frequent shrub/liana layer collapse (TE1, TE4).

Tigridiopalma magnifica communities were classified into five types (A–E) based on the relative Net Contribution Degree (*r-NCD*) of the dominant arbor species, corresponding to three forest physiognomies: evergreen broad-leaved forests (A, B), montane rainforests (C), and bamboo forests (D, E). While *T. magnifica* remained the dominant herb across all plots

TABLE 6 | The list of vascular plants in the study area of *Tigridiopalma exalata*.

Family name	Scientific name	Note
Araceae	*Pothos chinensis* (Raf.) Merr.	
	Rhaphidophora decursiva (Roxb.) Schott	i1
Araliaceae	*Heptapleurum heptaphyllum* (L.) Y. F. Deng	
Asphodelaceae	*Dianella ensifolia* (L.) DC.	
Aspleniaceae	*Asplenium normale* Don	
Balsaminaceae	*Impatiens tubulosa* Hemsley	ES
Blechnaceae	*Blechnopsis orientalis* (L.) C. Presl	
Cannabaceae	*Gironniera subaequalis* Planch.	
Clusiaceae	*Garcinia oblongifolia* Champ. ex Benth.	ES
Commelinaceae	*Amischotolype hispida* (A. Rich.) D. Y. Hong	
Cyatheaceae	*Cibotium barometz* (L.) J. Sm.	i3, II
Ebenaceae	*Diospyros eriantha* Champion ex Bentham	
Ericaceae	*Rhododendron moulmainense* Hook.	
Euphorbiaceae	*Alchornea trewioides* (Benth.) Müll. Arg.	ES
	Macaranga denticulata (Blume) Müll. Arg.	
	Mallotus paniculatus (Lam.) Müll. Arg.	
Fabaceae	*Archidendron clypearia* (Jack) I. C. Nielsen	
	Castanopsis chinensis (Spreng.) Hance	ES
	Castanopsis faberi Hance	ES
Gleicheniaceae	*Sticherus truncatus* (Willd.) Nakai	
Hypericaceae	*Cratoxylum cochinchinense* (Lour.) Blume	
Lamiaceae	*Callicarpa kochiana* Makino	
	Clerodendrum cyrtophyllum Turcz.	
	Gomphostemma chinense Oliv.	ES
Lauraceae	*Machilus grijsii* Hance	ES
Melastomataceae	*Blastus cochinchinensis* Lour.	
Moraceae	*Ficus esquiroliana* H. Lév.	
Oleaceae	*Jasminum pentaneurum* Hand.-Mazz.	
Piperaceae	*Piper sintenense* Hatus.	ES
Poaceae	*Lophatherum gracile* Brongn.	
	Thysanolaena latifolia (Roxb. ex Hornem.) Honda	i4
Polypodiaceae	*Lemmaphyllum microphyllum* C. Presl	
Primulaceae	*Ardisia lindleyana* D. Dietr.	ES
	Ardisia quinquegona Blume	
Pteridaceae	*Pteris semipinnata* L.	
Rubiaceae	*Adina pilulifera* (Lam.) Franch. ex Drake	
	Psychotria asiatica L.	ES
	Wendlandia uvariifolia Hance	

(Continues)

TABLE 6 | (Continued)

Family name	Scientific name	Note
Selaginellaceae	*Selaginella doederleinii* Hieron.	i3
Vitaceae	*Tetrastigma planicaule* (Hook.) Gagnep.	

Abbreviations: ES, endemic species; i1, i2, i2, and i4, floristic indicator plants for landform, vegetation form, pedohydrological form and sessionnal stages form; II, China's National List of Key Protected Wild Plants (Class II); NT, VU, China Biodiversity Red List near threatened (NT), vulnerable (VU) species.

(r-NCD > 50%), the communities exhibited significant structural variation.

In broad-leaved forest associations, Community A (*Heptapleurum heptaphyllum* type) exhibited the most complex floristic composition with 59 recorded species, reflecting both its extensive sampling coverage ($N = 25$) and structural heterogeneity, It featured a complex understory with shurb *Psychotria asiatica* and herb *Pellionia latifolia*. Community B, dominated by the canopy tree *Cryptocarya chinensis*, featured a complex understory where *T. magnifica* co-existed with the fern *Selaginella delicatula* (r-NCD = 38.46) and the shrub *Symplocos ramosissima* (r-NCD = 30.77). In contrast, Community C (*Litsea variabilis* type) represented a dominance-driven, species-poor system. Despite having a similar sampling effort to Communities B and E ($N = 5$), it recorded the lowest richness (only 8 species) and *T. magnifica* coverage (4%). This impoverishment coincided with the absolute dominance of the canopy tree *Litsea variabilis* (r-NCD = 100%), reflecting a strong exclusion effect. In bamboo associations, Communities D and E were defined by *Phyllostachys edulis* and *Bambusa textilis* overstories, respectively, hosting distinct herbaceous layers: Community D featured high coverage of ferns (*Selaginella picta*) and *Blastus cochinchinensis*, whereas Community E was uniquely characterized by hygrophilous herbs, specifically *Pellionia latifolia* (r-NCD 100%) and *Acorus gramineus* (Table 10).

T. exalata communities were classified into four types (F–I), with r-NCD = 100% for the focal species across all plots. All within evergreen broad-leaved forests. Community F, characterized by the tree *Rhododendron moulmainense*, was distinct for its fern-rich understories, dominated significantly by *Selaginella doederleinii* and *Sticherus truncatus*. Communities G, H, and I were structured around *Castanopsis* and *Mallotus* species. Community H displayed the most diverse herbaceous layer among the *T. exalata* sites, supporting significant populations of *Ayenia grandifolia*, *Liparis viridiflora*, and *Gomphostemma chinense*. Conversely, Community I was defined by *Castanopsis faberi* in the canopy and a strong presence of the liana *Rhaphidophora decursiva* in the vertical layer (Table 11).

Both *Tigridiopalma* species demonstrated adaptability to varying canopy closures, yet their phytosociological patterns diverged significantly. *T. magnifica* exhibited greater ecological plasticity, establishing populations across a spectrum of habitats ranging from typical evergreen broad-leaved forests to distinct bamboo thickets (*Phyllostachys edulis* and *Bambusa textilis* stands). However, this broader amplitude came with variable dominance levels: while it maintained high contribution (r-NCD > 87%) in broad-leaved associations (Types A–C), its dominance notably declined in bamboo-dominated communities (r-NCD 54.7%–66.7%; Table 10), showing a tolerance to suboptimal or disturbed habitats.

In contrast, *T. exalata* communities were characterized by high habitat specificity and stability. This species was exclusively associated with mixed evergreen forest structures (e.g., *Castanopsis* and *Mallotus* canopies) lacking bamboo dominance. Remarkably, within this narrower niche, *T. exalata* consistently maintained maximum dominance (*r-NCD* = 100% across all Types F–I; Table 11), reflecting a highly specialized and competitive status within its restricted range.

Principal Coordinate Analysis (PCoA) based on species composition revealed distinct spatial patterns for the two target species. For *T. magnifica* (Figure 2A), the first two principal coordinates explained 51.6% of the total variance, with PCoA1 accounting for 34.8% and PCoA2 for 16.8%. The sampling plots exhibited a diffuse distribution across the ordination space. The 95% confidence ellipses for the three broad-leaved forest communities (A, B, and C) showed extensive overlap near the center of the plot. In contrast, the two bamboo-dominated communities were spatially distinct: plots associated with *Phyllostachys edulis* (Community D) and *Bambusa textilis* (Community E) were separated from the broad-leaved cluster and from each other along the first axis.

For *T. exalata* (Figure 2B), the first two axes cumulatively explained 54.4% of the variation (PCoA1: 31.6%; PCoA2: 22.8%). Unlike *T. magnifica*, the ordination plot for *T. exalata* displayed four discrete clusters with less or no overlap. Each cluster corresponded to a specific community type (F, G, H, and I) and was tightly grouped. The communities were segregated across different quadrants of the ordination plane, with Community I (*Castanopsis faberi* dominated) and Community G (*Castanopsis chinensis* dominated) showing the greatest separation along PCoA Axis 1.

3.3 | Interspecific Associations

The analysis of interspecific associations is instrumental in elucidating the successional trajectory of the community. To test overall community association, Variance ratio (VR) and W statistic of each layer (tree, shrub & liana, herb) were calculated based on null hypothesis. Among the quadrats of *T. magnifica*, 21 species were observed in the arbor layer, and the VR value for the arbor layer was 1.09, with a test statistic $W = 54.70$. With $N = 50$, the critical values for the Chi-square distribution are $\chi^2_{0.95} = 34.76$ and $\chi^2_{0.05} = 67.50$ (Schluter 1984). The calculated W fell within this acceptance interval ($34.76 < 54.70 < 67.50$), supporting no significant overall association among arbor

TABLE 7 | Life form spectra in the habitat of *Tigridiopalma*.

A. Dormancy form

		CH	H	N	HH	MM	Th
T. magnifica	Species	25	30	20	1	8	0
	%	29.8%	35.7%	23.8%	1.2%	9.5%	0%
T. exalata	Species	12	11	10	0	6	1
	%	29.3%	26.8%	24.4%	0%	14.6%	2.4%

B. Propagation form

		Radicoid form								Disseminule form					
		R1	R2	R3	R4	R(v)	R(s)	R1,2	R2,3	D1	D2	D3	D4	D5	D1,4
T. magnifica	Species	8	8	5	32	5	7	1	1	16	30	9	34	8	3
	%	8%	8%	5%	32%	5%	7%	1%	1%	16%	30%	9%	34%	8%	3%
T. exalata	Species	4	5	3	21	4	1	1	1	6	16	4	12	1	2
	%	9.8%	12.2%	7.3%	51.2%	9.8%	2.4%	2.4%	2.4%	14.6%	39.0%	9.8%	29.3%	2.4%	4.9%

C. Growth form

		e	b	l	e,b	b-l	t	r	ps	pr	p	t–p	b-ps	p-bs
T. magnifica	Species	18	12	15	10	8	9	7	6	4	5	3	2	1
	%	18%	12%	15%	10%	8%	9%	7%	6%	4%	5%	3%	2%	1%
T. exalata	Species	8	6	7	5	3	4	3	2	1	1	1	0	0
	%	19.5%	14.6%	17.1%	12.2%	7.3%	9.8%	7.3%	4.9%	2.4%	2.4%	2.4%	0%	0%

Note: (A) CH, Chamaiphytes; H, Hemicryptophytes; HH, Helophytes; MM, Mesophanerophytes; N, Nanophanerophytes; Th, Therophytes. (B) R1: Widest extent of rhizomatous growth, R2: Moderate extent of rhizomatous growth, R3: narrowest extent of rhizomatous growth, R4: Non-clonal growth monophyte, R1,2 or R2,3: plant with rhizomatous mutation of R1 and R2 or R2 and R3; R(s): Succulent type; R(v): Vertical type; D1: disseminated widely by wind or water, D2: disseminated attaching with or eaten by animals and man, D3: disseminated by mechanical propulsion of dehiscence of fruits, D4: having no special modification for dissemination, D5: not producing seeds, D1,4: plant with D1 and D4. (C) b: branched form; e: erect form; p: procumbent form; pr: partial-rosette form; ps: pseudo-rosette form; r: rosette form; t: tussock form; l: liane form; e,b: erect or branched form; b-l: b form with liane form; b-p: b form with procumbent stem; b-ps: b form with pseudo-rosette; p-ps: p form with pseudo-rosette; t–p: t form with procumbent stem.

TABLE 8 | Species diversity index at three layers in 10 of *Tigridiopalma magnifica* communities.

Sampling	Dominated arbor	Layer	Shannon Wiener (H')	Pielou (E)	Simpson (P)	Gleason (D')
TM1	*Heptapleurum heptaphyllum*	Tree	0.6616	0.9544	0.4688	0.4343
		Shrub and liana	1.5403	0.8597	0.7273	1.3029
		Herb	1.4737	0.6400	0.6312	2.1715
TM2	*Heptapleurum heptaphyllum*	Tree	1.0549	0.9602	0.6400	0.6514
		Shrub and liana	1.7479	0.9755	0.8163	1.3029
		Herb	1.1202	0.6960	0.5860	1.0857
TM3	*Litsea variabilis*	Tree	0.3622	0.5226	0.2076	0.4343
		Shrub and liana	0.8760	0.7974	0.5408	0.6514
		Herb	0.7917	0.5711	0.4987	0.8686
TM4	*Heptapleurum heptaphyllum*	Tree	0.6829	0.9852	0.4898	0.4343
		Shrub and liana	1.5677	0.8057	0.7188	1.5200
		Herb	1.0376	0.7485	0.5970	0.8686
TM5	*Heptapleurum heptaphyllum*	Tree	1.3209	0.9528	0.7188	0.8686
		Shrub and liana	0.9503	0.8650	0.5600	0.6514
		Herb	0.5917	0.3302	0.2631	1.3029
TM6	*Heptapleurum heptaphyllum*	Tree	1.0549	0.9602	0.6400	0.6514
		Shrub and liana	1.5346	0.9535	0.7675	1.0857
		Herb	1.4770	0.7103	0.6750	1.7372
TM7	*Phyllostachys edulis*	Tree	0.0000	0.0000	0.0000	0.0000
		Shrub and liana	0.0000	0.0000	0.0000	0.2171
		Herb	1.4702	0.9135	0.7497	1.0857
TM8	*Bambusa textilis*	Tree	0.8223	0.5931	0.4141	0.8686
		Shrub and liana	1.3108	0.9455	0.7160	0.8686
		Herb	1.9222	0.8748	0.8244	1.9543
TM9	*Cryptocarya chinensis*	Tree	1.7219	0.8281	0.7650	1.7372
		Shrub and liana	1.2742	0.7917	0.6688	1.0857
		Herb	0.8003	0.5773	0.4391	0.8686
TM10	*Phyllostachys edulis*	Tree	0.5004	0.7219	0.3200	0.4343
		Shrub and liana	2.2333	0.9699	0.8850	2.1715
		Herb	1.7690	0.8051	0.7941	1.9543

species. Similarly, the shrub (VR = 0.99) and herb (VR = 0.83) layers showed non-significant holistic associations. This independent distribution pattern showed the consistency of the populations in the community on habitat requirements, pointing to a loose community structure where species interactions have not yet intensified to shape spatial patterns or biotic couplings. It is typical of pioneer or early successional stages with limited structural maturity or dynamic equilibrium.

For *T. exalata*, the arbor layer VR was 0.29, yielding a test statistic $W = 7.33$. This value fell below the lower critical threshold ($\chi^2_{0.95} = 14.61$), indicating a statistically significant negative

TABLE 9 | Species diversity index at three layers in 10 of *Tigridiopalma exalata* communities.

Sampling	Dominated arbor	Layer	Shannon Wiener (*H′*)	Pielou (*E*)	Simpson (*P*)	Gleason (*D′*)
TE1	*Rhododendron moulmainense*	Tree	1.5403	0.8597	0.7273	1.3029
		Shrub and liana	0.0000	0.0000	0.0000	0.2171
		Herb	1.2390	0.6915	0.6509	1.3029
TE2	*Castanopsis chinensis*	Tree	1.2425	0.8962	0.6667	0.8686
		Shrub and liana	1.4127	0.8778	0.7219	1.0857
		Herb	0.2473	0.1380	0.0863	1.3029
TE3	*Mallotus paniculatus*	Tree	1.5596	0.9690	0.7812	1.0857
		Shrub and liana	1.5124	0.9397	0.7644	1.0857
		Herb	0.2479	0.3576	0.1264	0.4343
TE4	*Mallotus paniculatus*	Tree	1.0362	0.9432	0.6281	0.6514
		Shrub and liana	0.0000	0.0000	0.0000	0.2171
		Herb	0.9533	0.6877	0.5312	0.8686
TE5	*Castanopsis faberi*	Tree	1.0790	0.9821	0.6531	0.6514
		Shrub and liana	0.6616	0.9544	0.4688	0.4343
		Herb	0.1242	0.1131	0.0447	0.6514

overall association among tree species. The shrub (VR = 0.97) and herb (VR = 0.6) layers did not deviate significantly from independence. Specifically, a competitive exclusion relationship existed in arbor layer, which mean utilization of overstory environmental resources had not reached optimum.

Interspecific associations were analyzed using the Percentage of Co-occurrence (PC) based on presence/absence matrices in all of the quadrats (*T. magnifica*: 50; *T. exalata*: 25; Figure 3). For *T. magnifica*, the heatmap revealed a predominantly loose community structure. PC values for most species pairs remained low (0%–40%), reflecting weak interspecific dependence consistent with the unstable composition of early successional stages. Notable positive linkages were observed with *Heptapleurum heptaphyllum* (PC = 60%) among the *T. magnifica* pairwises (Figure 3A).

T. exalata exhibited stronger and more integrated network of associations (Figure 3B). High PC values (reaching 100%) was frequently observed, particularly in understory layer (10.5% in herb layer vs. 5.8% in *T. magnifica*, 30.0% in shrub and liana layer vs. 5.3% in *T. magnifica*, and 4.4% in abor layer vs. 4.8% in *T. magnifica*), reflecting a high degree of ecological niche overlap within its habitats. While the arbor layer presented similar low connectivity for both species, *T. exalata* showed distinct microhabitat preferences through robust co-occurrence with specific partners such as *Mallotus paniculatus* and *Ficus esquiroliana*, reflecting that *T. exalata* resides in a structured community with established interspecific interactions (Figure 3B).

As PC value takes account for Bernoulli distribution which can only manifest positive linkage, Pearson coefficient and Spearman rank coefficient were further applied to reveal specific species-pair intensities of positive or negative correlation. In *T. magnifica* habitats, statistically significant positive or negative correlations were shown across all vegetation layers (Figure 4). In the arbor layer, strong positive associations ($r = 1$, $p < 0.001$) were shown between the focal species and three tree species, *Castanopsis fissa*, *Cratoxylum cochinchinense*, and *Sterculia lanceolata*. Likewise, seven strong positive associations ($p < 0.001$) were observed primarily with understory shrub, liana and herbs (e.g., *Decaneuropsis cumingiana*, *Pseudosasa cantorii*, and *Rubus reflexus* in shrub layer; *Blechnopsis orientalis*, *Selaginella doederleinii*, *Dicranopteris pedata*, and *Thysanolaena latifolia* in herb layer). Only two weak negative correlation pairs between the focal species were recorded (with *Ardisia quinquegona* in shrub layer and with *Musa balbisiana* in herb layer, $r < -0.5$, $p < 0.05$).

In contrast, in *T. exalata* habitats, positive correlations were frequently observed across all vertical strata (Figure 5). *T. exalata* showed moderate positive associations ($r > 0.6$, $p < 0.01$) with three arbor species (*Castanopsis chinensis*, *Cratoxylum cochinchinense* and *Heptapleurum heptaphyllum*), five shrubs (*Adina pilulifera*, *Alchornea trewioides*, *Ardisia lindleyana*, *Clerodendrum cyrtophyllum*, and *Wendlandia uvariifolia*), and three herb (*Lophatherum gracile*, *Pteris semipinnata*, and *Thysanolaena latifolia*). No statistically significant negative pairwise correlations were detected for *T. exalata* in the sampled plots.

3.4 | Population Structure and Dynamics

Static life tables based on ontogenetic stages revealed distinct survivorship patterns (Table 12). Regression analysis of the standardized survivors (lnl_x) against age class indicated that both species

TABLE 10 | Synopsis of plant communities in habitats of *Tigridiopalma magnifica* by *r-NCD* value.

Community type	Total	A (TM1, TM2, TM4-6)	B (TM9)	C (TM3)	D (TM7, TM10)	E (TM8)
Number of plots	50	25	5	5	10	5
Total number of occurring species	99	59	17	8	24	17
Mean Coverage of *T. magnifica*	/	9.6%	10%	4%	15%	1%
Character species of community	**Form**			***r-NCD* (%)**		
Tigridiopalma magnifica	H	100	100	87.49	54.67	66.67
A. *Heptapleurum heptaphyllum*	T	20.13	—	—	—	—
B. *Cryptocarya chinensis*	T	—	23.08	—	—	—
C. *Litsea variabilis*	T	—	—	100	—	—
D. *Phyllostachys edulis*	T	—	—	—	55.99	—
E. Bambusa textilis	S	—	—	—	—	50
Companions	**Form**			***r-NCD* (%)**		
Acronychia pedunculata	T	3.84	—	—	—	—
Alsophila gigantea	T	—	15.38	—	—	66.66
Archidendron clypearia	T	2.84	—	—	—	—
Caryota maxima	T	—	—	—	—	16.66
Castanopsis fissa	T	1.17	—	—	—	—
Cratoxylum cochinchinense	T	1.17	—	—	—	—
Cunninghamia lanceolata	T	—	—	—	—	16.66
Ficus esquiroliana	T	1.48	7.69	—	—	16.67
Ficus fistulosa	T	2.84	7.69	—	—	—
Ficus tinctoria subsp. *gibbosa*	T	—	—	—	4.79	—
Lindera nacusua	T	—	7.69	—	—	—
Litsea monopetala	T	1.48	—	—	—	—
Macaranga denticulata	T	5.08	—	—	—	—
Sarcosperma laurinum	T	—	7.69	—	2.4	—
Sterculia lanceolata	T	1.17	—	—	—	—
Tetradium glabrifolium	T	—	15.38	—	—	—
Vitex quinata	T	—	7.69	—	—	—
Ardisia quinquegona	S	8.73	—	—	—	33.33
Bambusa chungii	S	2.96	—	—	—	—
Blastus cochinchinensis	S	4.44	—	37.51	21.12	—
Calamus rhabdocladus	S	7.85	—	—	—	—
Camellia sinensis	S	1.92	—	—	—	—
Eleutherococcus trifoliatus	S	—	—	—	2.4	—

(Continues)

TABLE 10 | (Continued)

Community type	Total	A (TM1, TM2, TM4-6)	B (TM9)	C (TM3)	D (TM7, TM10)	E (TM8)
Ficus hirta	S	—	7.69	—	—	—
Ficus sarmentosa var. *impressa*	S	—	—	—	2.4	—
Gomphostemma lucidum	S	—	—	—	2.4	—
Jasminum elongatum	S	—	7.69	—	—	—
Lasianthus japonicus	S	—	15.38	—	—	—
Pinanga baviensis	S	5.08	—	—	—	—
Pseudodissochaeta septentrionalis	S	3.84	—	—	—	—
Pseudosasa cantorii	S	2.33	—	—	—	—
Psychotria asiatica	S	15.37	—	50.21	4.79	—
Sarcandra glabra	S	—	15.38	—	2.4	—
Saurauia tristyla	S	5.81	—	—	2.4	—
Schizostachyum funghomii	S	—	—	—	—	33.33
Smilax china	S	3.84	—	—	2.4	—
Symplocos ramosissima	S	—	30.77	—	—	—
Wendlandia uvariifolia	S	—	—	—	2.4	—
Ayenia grandifolia	L	—	—	12.48	—	—
Decaneuropsis cumingiana	L	1.17	—	—	—	—
Ficus sagittata	L	4.54	—	—	—	—
Fissistigma oldhamii	L	1.69	—	—	—	—
Gnetum montanum	L	1.92	—	—	—	—
Hoya radicalis	L	2.84	—	—	—	—
Phanera erythropoda	L	2.84	—	—	—	—
Piper austrosinense	L	—	—	—	2.4	16.67
Pothos chinensis	L	—	—	12.48	2.4	—
Pothos repens	L	2.84	—	—	—	—
Rhaphidophora hongkongensis	L	3.39	—	—	—	—
Rubus reflexus	L	1.17	—	—	—	—
Sabia limoniacea	L	1.69	—	—	—	—
Tetracera sarmentosa	L	1.69	—	—	—	—
Tetrastigma planicaule	L	1.69	—	—	—	—
Ventilago leiocarpa	L	2.84	—	—	—	—
Acorus gramineus	H	—	—	—	—	66.67
Aeschynanthus acuminatus	H	—	7.69	12.48	—	—
Alpinia hainanensis	H	2.84	—	—	—	—

(Continues)

TABLE 10 | (Continued)

Community type	Total	A (TM1, TM2, TM4-6)	B (TM9)	C (TM3)	D (TM7, TM10)	E (TM8)
Amomum villosum	H	—	—	—	—	50
Aspidistra subrotata	H	5.69	—	—	—	—
Asplenium normale	H	9.61	—	—	—	—
Begonia laciniata	H	—	—	—	4.23	—
Begonia longifolia	H	—	—	—	—	33.33
Blechnopsis orientalis	H	2.32	—	—	4.79	—
Cibotium barometz	H	4.43	—	—	—	—
Curculigo capitulata	H	2.96	—	—	—	—
Dicranopteris pedata	H	3.5	—	—	—	—
Diospyros eriantha	H	3.17	—	—	—	—
Eria corneri	H	5.69	—	—	7.19	—
Gahnia tristis	H	1.92	—	—	—	—
Hypolytrum nemorum	H	3.39	—	—	—	—
Indocalamus sinicus	H	11.38	—	—	—	—
Lemmaphyllum microphyllum	H	—	—	—	2.4	—
Leptochilus hemionitideus	H	—	—	—	21.12	—
Liparis viridiflora	H	—	—	—	31.15	—
Microlepia hancei	H	1.92	—	—	—	—
Mouretia inaequalis	H	7.41	—	—	—	—
Musa balbisiana	H	2.96	—	—	—	16.67
Nephrolepis cordifolia	H	—	—	—	4.79	—
Orchidantha chinensis	H	3.39	—	—	—	—
Pandanus austrosinensis	H	—	7.69	—	—	—
Pellionia latifolia	H	17.78	—	—	—	100
Perilimnastes setotheca	H	5.08	—	—	—	—
Plenasium vachellii	H	1.69	—	—	—	—
Pronephrium simplex	H	6.67	—	—	—	—
Pronephrium triphyllum	H	5.93	—	—	—	—
Raphiocarpus macrosiphon	H	5.08	—	—	—	—
Rhynchotechum ellipticum	H	—	—	—	—	33.33
Selaginella delicatula	H	—	38.46	—	—	—
Selaginella doederleinii	H	5.83	—	—	—	—
Selaginella picta	H	—	—	62.53	24.09	—
Strobilanthes cusia	H	—	—	—	—	83.33
Thysanolaena latifolia	H	1.17	—	—	—	—
Trigonospora ciliata	H	—	—	—	—	33.33

Note: Form: H, herb; L, liana; S, shurb; T, tree.

TABLE 11 | Synopsis of plant communities in the habitats of *Tigridiopalma exalata* by *r-NCD* value.

Community type	**Total**	**F (TE1)**	**G (TE2)**	**H (TE3-4)**	**I (TE5)**
Number of plots	25	5	5	10	5
Total number of occurring species	41	13	15	17	8
Mean Coverage of *T. exalata*	/	9.6%	10%	4%	15%
Character species of community	**Form**		***r-NCD* (%)**		
Tigridiopalma exalata	H	100	100	100	100
F. *Rhododendron moulmainense*	T	16.67	—	—	—
G. *Castanopsis chinensis*	T	—	1.45	1.87	—
H. *Mallotus paniculatus*	T	3.33	0.72	7.6	—
I. *Castanopsis faberi*	T	—	—	—	17.65
Companions	Form		*r-NCD* (%)		
Archidendron clypearia	T	—	—	4.73	—
Cratoxylum cochinchinense	T	—	0.72	—	—
Diospyros eriantha	T	3.33	—	—	11.76
Ficus esquiroliana	T	3.33	—	1.87	5.88
Garcinia oblongifolia	T	—	—	3.75	—
Gironniera subaequalis	T	3.33	—	—	—
Heptapleurum heptaphyllum	T	—	0.72	—	—
Macaranga denticulata	T	—	—	8.59	—
Machilus grijsii	T	3.33	—	—	—
Alchornea trewioides	S	—	2.89	—	—
Ardisia lindleyana	S	—	0.72	—	17.65
Ardisia quinquegona	S	—	—	—	—
Blastus cochinchinensis	S	—	—	5.62	—
Callicarpa kochiana	S	—	—	3.75	—
Clerodendrum cyrtophyllum	S	—	0.72	—	—
Psychotria asiatica	S	—	—	7.49	—
Wendlandia uvariifolia	S	—	0.72	—	—
Jasminum pentaneurum	L	—	—	2.86	—
Piper sintenense	L	—	—	3.75	—
Pothos chinensis	L	—	—	1.87	—
Rhaphidophora decursiva	L	3.33	—	—	23.53
Adina pilulifera	H	—	2.17	—	—
Amischotolype hispida	H	—	—	9.37	—
Ayenia grandifolia	H	—	—	22.89	—
Blechnopsis orientalis	H	6.67	2.17	—	—
Cibotium barometz	H	3.33	—	—	—
Dianella ensifolia	H	13.33	1.45	—	—
Gomphostemma chinense	H	—	—	17.17	—

(Continues)

TABLE 11 | (Continued)

Community type	Total	F (TE1)	G (TE2)	H (TE3-4)	I (TE5)
Impatiens tubulosa	H	—	—	—	5.88
Lemmaphyllum microphyllum	H	—	—	—	5.88
Lophatherum gracile	H	—	5.8	—	—
Pteris semipinnata	H	—	2.9	—	—
Selaginella doederleinii	H	50	—	—	—
Sticherus truncatus	H	46.67	—	—	—
Tetrastigma planicaule	H	—	—	2.86	—
Thysanolaena latifolia	H	—	0.72	—	—

Note: Form: H, herb; L, liana; S, shurb; T, tree.

conform to the Deevey Type I survivorship pattern (Figure 6). This pattern is mathematically characterized by a quadratic equation ($lnl_x = a + bx^2$), representing a convex curve where the mortality rate is not constant but increases progressively with age.

For *T. magnifica*, the survivorship was best described by the model $ln(l_x) = 6.423 - 0.029x^2$ ($adj\text{-}R^2 = 0.849$, AIC = 5.6866, $F = 40.3$, $p < 0.001$; Figure 6A). Survivorship declines most sharply at the earliest ontogenetic transition from Seedling (Stage 1) to Juvenile (Stage 2) with a mortality rate of $q_1 = 0.45$. Although this species experienced a substantial demographic filter at the early stage, the population maintained a Type I (convex) classification due to the marked stabilization of survival in subsequent vegetative stages. Specifically, mortality dropped precipitously to its lowest levels in the Immature ($q_3 = 0.08$) and Vegetative Adult ($q_4 = 0.12$) stages. This prolonged period of high mid-life survivorship effectively buffered the initial seedling loss, creating the characteristic convex arch before mortality rose again to $q_7 = 0.32$ at the Subsenile stage.

In contrast, *T. exalata* followed a distinct quadratic trajectory characterized by $ln(l_x) = 6.807 - 0.048x^2$ ($adj\text{-}R^2 = 0.9898$, AIC = −8.9362, $F = 680.1$, $p < 0.001$), driven by late-stage attrition (Figure 6B). Initial mortality rate was comparatively lower ($q_1 = 0.30$), reflecting more effective early establishment. However, the population faced a severe bottleneck during the transition from Full Reproductive ($q_6 = 0.53$) to Sub-senile ($q_7 = 0.56$) stages.

The dynamic index (V_{pi}) was 0.315 for *T. magnifica* and 0.303 for *T. exalata*. The relative number of individuals in each size class is structurally close to the theoretical stable distribution reflected by the disturbance response index (V_{pi}') approached zero for both species (0.002 and 0.003, respectively; Table 12).

4 | Discussion

4.1 | Niche Differentiation and Vegetational Characteristics

Our findings support Hypothesis 1, confirming that although *T. magnifica* and *T. exalata* share superficial similarities as understory herbs in subtropical evergreen forests, they occupy distinct realized niches governed by divergent community assembly rules. In this study, *Tigridiopalma magnifica* displays considerable ecological plasticity rather than functioning as a strict habitat generalist. As evidenced by the PCoA ordination (Figure 2A), its sampling plots exhibit a diffuse distribution with extensive overlap among broad-leaved forest types (Communities A, B, and C). This continuum suggests that species composition is not rigidly constrained by specific arbor dominance but is likely structured by multi-dimensional environmental filtering, such as soil moisture availability and light penetration, that cuts across different forest physiognomies. Crucially, while *T. magnifica* maintains absolute dominance (r-NCD = 100%) in optimal broad-leaved forests (Table 10), it also persists in biologically distinct bamboo thickets (*Phyllostachys edulis* and *Bambusa textilis*). However, this broader amplitude involves a trade-off: its dominance notably declines in these bamboo-dominated habitats (r-NCD dropped to 54.67%–66.67%; Table 10), indicating tolerance to sub-optimal structural filters rather than optimal proliferation. The high species richness in these sites (e.g., 59 taxa in Community A) implies that *T. magnifica* benefits from facilitative interactions, specifically the nurse plant effect provided by diverse canopy and understory neighbors (Callaway 2007), while simultaneously navigating competition, as reflected by the weak negative correlations with understory species such as *Ardisia quinquegona* and *Musa balbisiana* (Figure 3A).

Conversely, *T. exalata* exhibits traits of a stenotopic specialist with high phytosociological fidelity to specific canopies. Its ordination pattern is defined by four discrete clusters with less or non-overlap (Figure 2B), where each cluster corresponds strictly to a dominant arbor species (e.g., *Castanopsis* or *Mallotus*). Unlike the plastic response of its congener, *T. exalata* was absent from bamboo-dominated ecotones. However, within its restricted niche, it consistently maintained maximum community contribution (r-NCD = 100% across all communities F–I; Table 11). This structural rigidity indicates that the community is governed by strong biotic filtering, where the identity of the canopy tree determines the suitability of the understory microsite (Kraft et al. 2015). The strict dependence on specific woody associations (e.g., *Castanopsis faberi* in Community I) suggests that *T. exalata* occupies a narrow steno-endemic niche, rendering it highly vulnerable to the loss of specific keystone trees that define its habitat (Keddy 1992). Consequently, conservation strategies must acknowledge this dichotomy: while *T. magnifica*

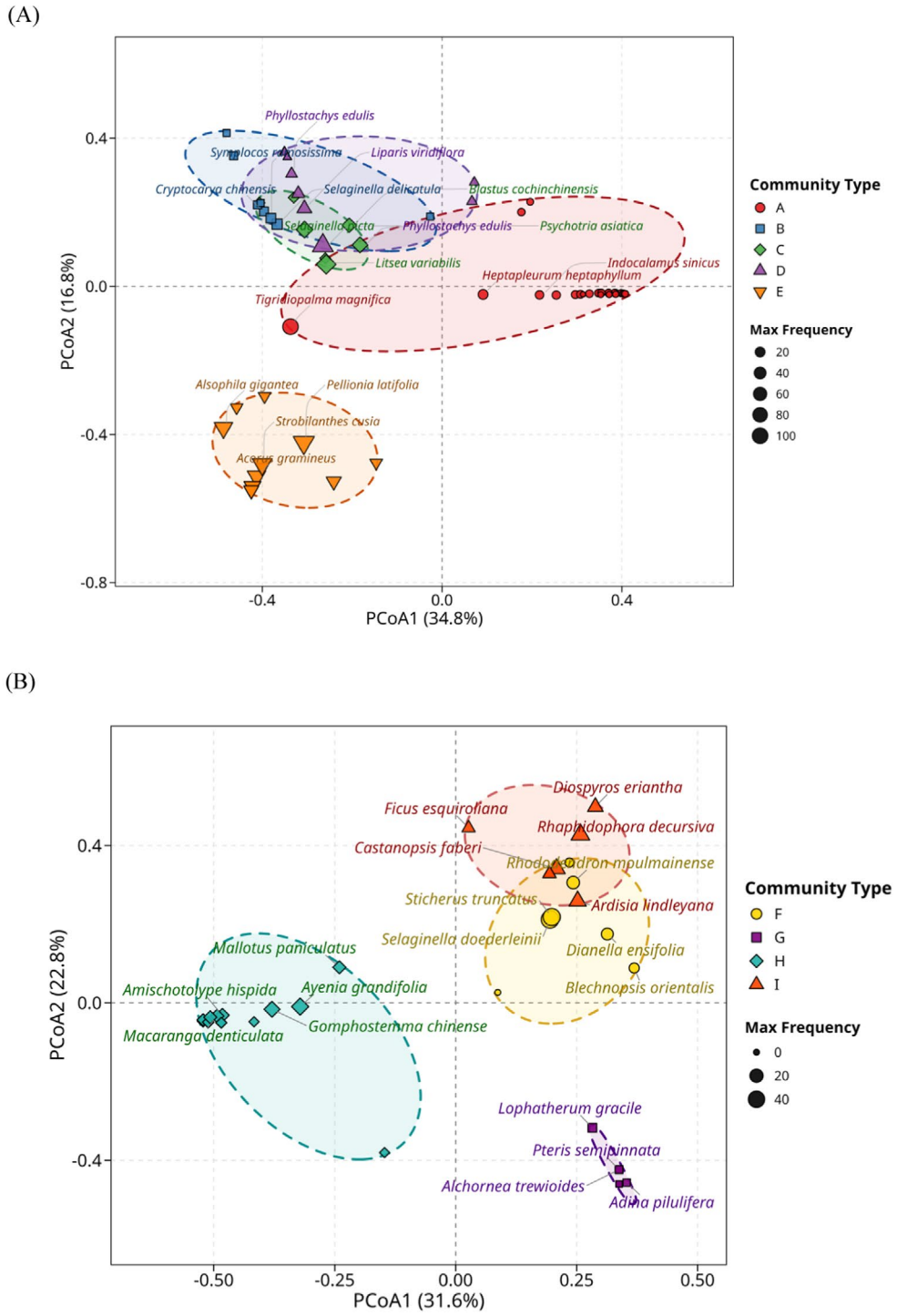


FIGURE 2 | PCoA plot of vegetation of the survey area of *Tigridiopalma magnifica* (A) and *T. exalata* (B).

requires the maintenance of structural heterogeneity and understory complexity to facilitate recruitment, *T. exalata* requires the strict preservation of specific canopy-subcanopy associations to maintain the biotic filters essential for its persistence.

4.2 | Demographic Strategies and Survivorship Patterns

The demographic analysis suggests that established *Tigridiopalma* populations exhibit characteristics of Deevey Type I survivorship, a pattern often associated with species inhabiting stable environments where external mortality risks (e.g., predation, extreme weather) are low for mature individuals (Deevey Jr 1947; Begon et al. 2006). The quadratic decay observed in our models signifies that mortality is largely senescence-driven. Ecologically, this aligns with the habitat preference of *Tigridiopalma* species: shaded, humid granitic slopes under dense canopies. These microhabitats buffer mid-stage individuals (Juvenile to Immature) from environmental fluctuations, facilitating higher survival rates compared to the vulnerable seedling stage or the physiologically declining senescent stage.

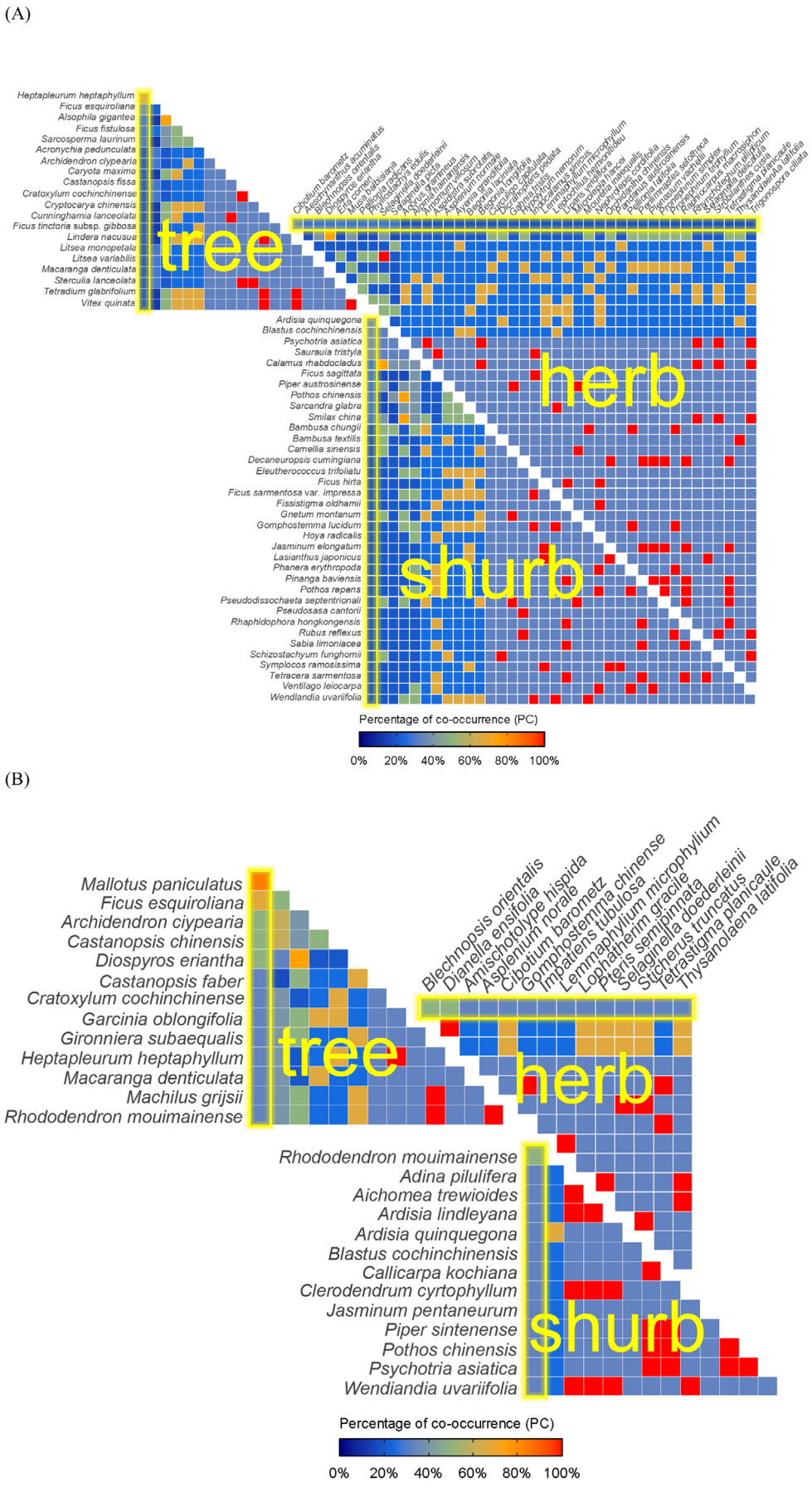


FIGURE 3 | Percentage of co-occurrence (PC) of *T. magnifica* (A) and *T. exalata* (B). The columns highlighted were *T. magnifica* or *T. exalata* involved pairwise.

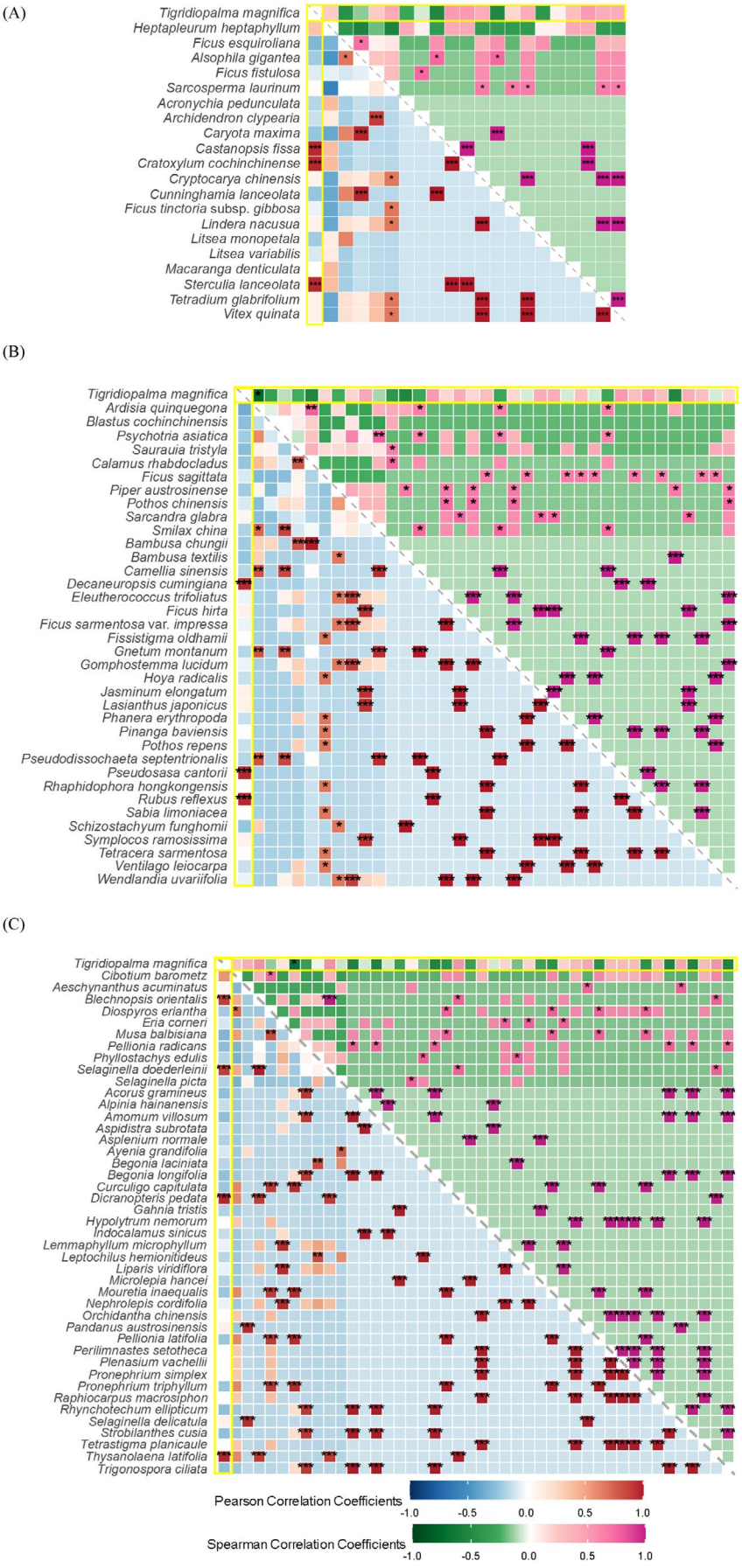


FIGURE 4 | Pearson Correlation Coefficients and Spearman Correlation Coefficients of *T. magnifica* with species in (A) abor layer, (B) shrub and liana layer, and (C) herb layer. The columns or rows highlighted were *T. magnifica* involved pairwises. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

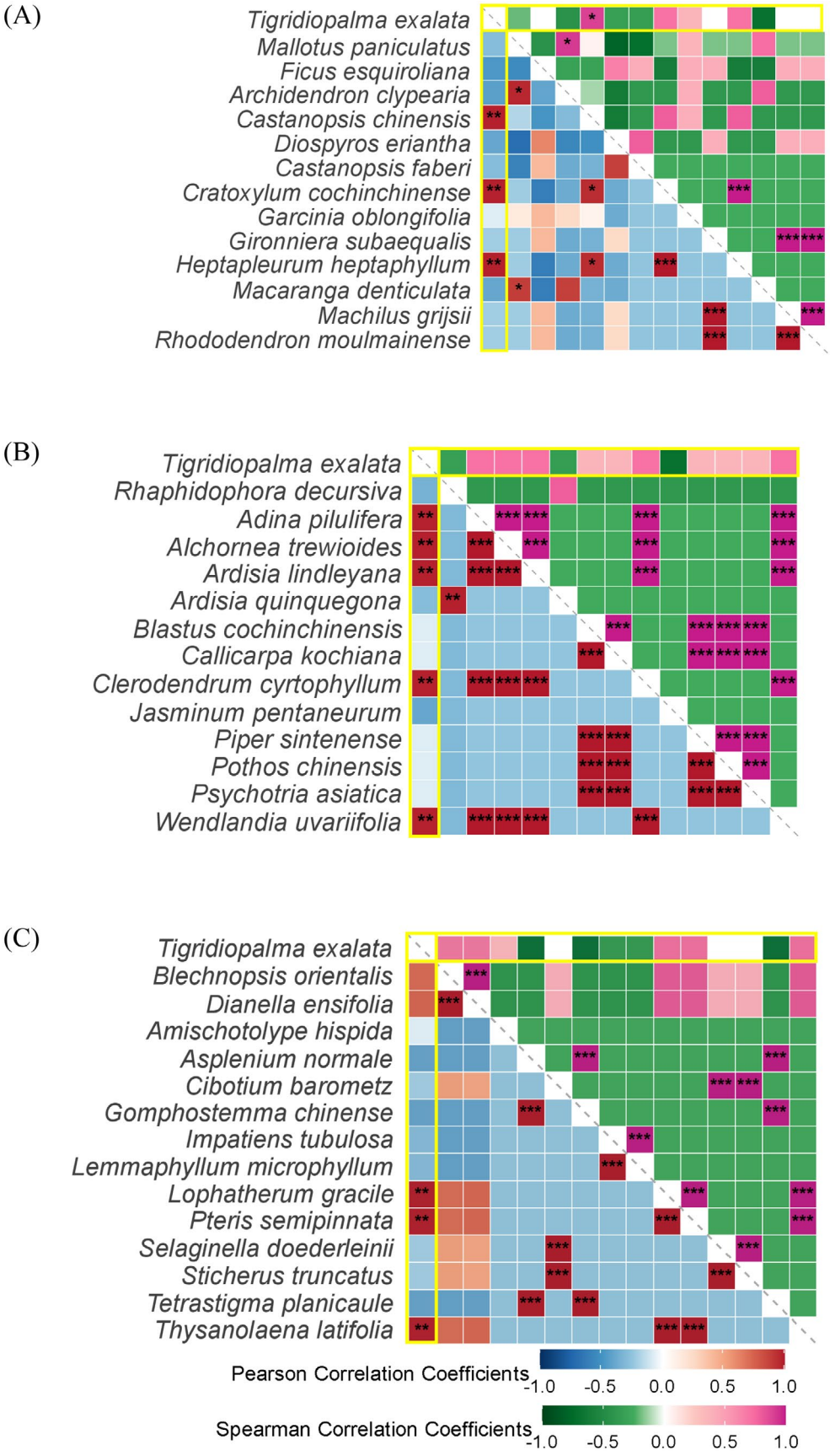


FIGURE 5 | Pearson correlation Coefficients and Spearman correlation coefficients of *T. exalata* with species in (A) abor layer, (B) shrub and liana layer, and (C) herb layer. The columns or rows highlighted were *T. exalata* involved pairwises. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

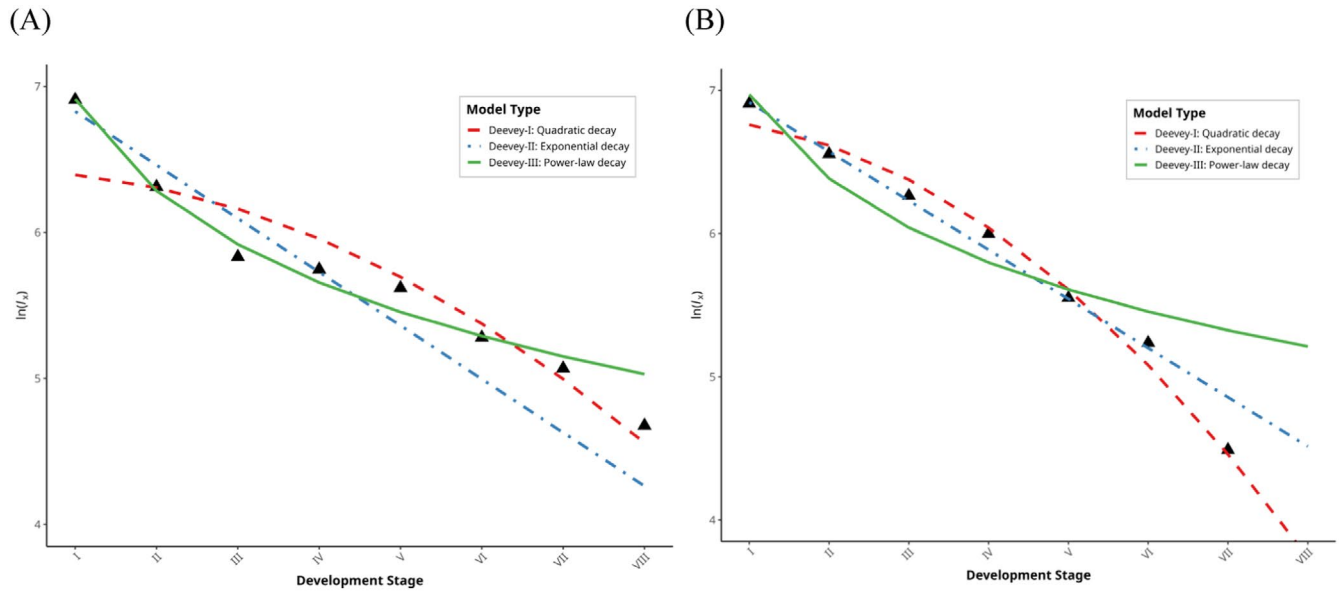


FIGURE 6 | Population survival curve and fitting curve of *Tigridiopalma magnifica* (A) and *Tigridiopalma exalata* (B).

The contrast between the two species is notable. *Tigridiopalma exalata* shows a more dramatic decline at the fruiting onset ($q_6 = 0.53$). This pattern indicates a high physiological cost of reproduction, likely exacerbated by the resource limitations in its narrower ecological niche of rocky ravine habitats. The steep decline in life expectancy at maturity suggests that *T. exalata* may exhaust its resource reserves during flowering and fruiting, making adult persistence the key vulnerability (Obeso 2002; Silvertown and Charlesworth 2009). Conversely, *T. magnifica* displays a more gradual senescence, indicating a strategy that spreads mortality risk over a longer reproductive lifespan. The primary bottleneck of *T. magnifica* occurs at the seedling-to-juvenile transition ($q_1 = 0.45$). This high early-stage mortality is typical of K-strategist microsite limitation in saturated understories, where dense leaf litter or competition from the robust herb layer limits the photobiotic seedling recruitment in this species (Gadgil and Solbrig 1972; Münzbergová and Herben 2005; Li et al. 2009). However, once established, individuals show high longevity (e_x peaks at 3.58), suggesting a strategy of vegetative persistence to secure space in the community.

It is essential to interpret these survivorship patterns within the constraints of static life table analysis. Our method derives demographic parameters from a cross-sectional survey of size classes, which relies on the critical assumptions of stable age distribution and constant recruitment over time (Caughley 1977). In fact, the anthropogenic disturbances and habitat fragmentation observed in the *Tigridiopalma* ranges may have caused historical fluctuations in recruitment. For instance, a past year of low seedling establishment could result in a gap in the current age structure, which a static life table might erroneously interpret as a period of high mortality. Therefore, the calculated mortality rates (q_x) should be viewed as a snapshot of the current population structure. While the quadratic models provide a statistically significant fit to the current data, long-term monitoring of cohorts would be required to definitively separate age-specific mortality from environmental stochasticity.

4.3 | Conservation Implications and Management Strategies

Effective conservation for PSESPs must transcend simple population reinforcement (e.g., outplanting) to address the specific demographic bottlenecks and community assembly rules identified in this study (Ren, Zhang, et al. 2012; Volis 2016). Our data reveal that *T. magnifica* and *T. exalata* require divergent management regimes dictated by their contrasting life-history trade-offs and habitat dependencies.

For *T. magnifica*, conservation actions should focus on microsite amelioration to break this recruitment bottleneck. Thick leaf litter in late-successional forests often acts as a mechanical barrier to seedling emergence. We recommend manual reduction of litter thickness immediately prior to seed rain (typically spring) in dense patches, a technique successfully applied to enhance recruitment in other endangered understory herbs like *Primula* spp. (Brys et al. 2004). However, complete removal should be avoided to maintain soil moisture critical for this hygrophilous species. Restoration programs must avoid planting in unsuitable bamboo-dominated monocultures (e.g., Community Types D/E), where dominance and fitness were observed to decline. Instead, we propose a multi-species reintroduction model based on the positive associations identified in correlation matrices (Figures 3–5). Reintroduction sites should be structured around nurse plants, specifically *Heptapleurum heptaphyllum* and *Castanopsis fissa* in overstory and ferns in understory, which appear to provide the optimal canopy density and community heterogeneity, facilitating microclimate for *T. magnifica* persistence (Callaway 2007).

In contrast, *T. exalata* faces a reproduction-induced mortality crisis ($q_6 = 0.53$), compounded by its obligate dependence on specific canopy structures. The extremely high co-occurrence (r-NCD = 100%) and positive associations with *Mallotus paniculatus* and *Castanopsis* species (Figure 3B) indicate that *T. exalata* cannot survive canopy opening. Conservation strategies

TABLE 12 | Static life and population dynamic change index of *Tigridiopalma magnifica* and *T. exalata*.

Age class (x)	Developmental stage	Actual survivors (a_x)	Standardized survival (l_x)	Deaths (d_x)	Mortality rate (q_x)	Average survivors (L_x)	Total survivors (T_x)	Life expectancy (e_x)	Disappearance rate (K_x)	Dynamic index (V_x)
Tigridiopalma magnifica										
1	Seedling	214	1000.00	448.60	0.4486	775.70	2443.93	2.44	0.5957	44.86%
2	Juvenile	118	551.40	210.28	0.3814	446.26	1668.23	3.03	0.4802	38.14%
3	Immature	73	341.12	28.04	0.0822	327.10	1221.97	3.58	0.0857	8.22%
4	Vegetative Adult	67	313.08	37.38	0.1194	294.39	894.87	2.86	0.1267	11.94%
5	Initial Reproductive	59	275.70	79.44	0.2881	235.98	600.48	2.18	0.3397	28.81%
6	Full Reproductive	42	196.26	37.38	0.1905	177.57	364.50	1.86	0.2114	19.05%
7	Sub-senile	34	158.88	51.40	0.3235	133.18	186.92	1.18	0.3911	32.35%
8	Senile	23	107.48	107.48	1.0000	53.74	53.74	0.50	—	—
									V_{pi}	0.315
									V_{pi}'	0.002
Tigridiopalma exalata										
1	Seedling	303	1000.00	297.03	0.2970	851.49	2704.65	2.70	0.35	29.70%
2	Juvenile	213	702.97	178.22	0.2535	613.86	1853.16	2.64	0.29	25.35%
3	Immature	159	524.75	122.11	0.2327	463.70	1239.30	2.36	0.26	23.27%
4	Vegetative Adult	122	402.64	145.21	0.3606	330.04	775.60	1.93	0.45	36.07%
5	Initial Reproductive	78	257.43	69.31	0.2692	222.78	445.56	1.73	0.31	26.92%
6	Full Reproductive	57	188.12	99.01	0.5263	138.62	222.78	1.18	0.75	52.63%
7	Sub-senile	27	89.11	49.51	0.5556	64.36	84.16	0.94	0.81	55.56%
8	Senile	12	39.60	39.60	1.0000	19.80	19.80	0.50	—	—
									V_{pi}	0.303
									V_{pi}'	0.003

must shift from targeting the herb alone to establishing Plant Micro-Reserves (PMRs) that legally protect the specific canopy patches. Any silvicultural thinning that disrupts this canopy filter will likely lead to population collapse due to photoinhibition or moisture loss, similar to the extinction dynamics observed in shade-obligate orchids (Swarts and Dixon 2009). To mitigate the physiological exhaustion observed during the reproductive stage (Figure 6B), resource supplementation is recommended for key breeding individuals. Targeted application of slow-release phosphorus/potassium fertilizers or mycotrophy during the flower budding stage could compensate for the nutrient-poor granitic substrates, potentially extending adult longevity and iteroparity. Furthermore, given the potential for Allee effects in these small, disjunct populations, artificial pollination between the clustered subpopulations (Types F and I) should be conducted to maximize seed set and genetic exchange, ensuring that the high reproductive effort translates into viable offspring.

4.4 | Broader Implications for PSESP Conservation

Our comparative study underscores that even closely related PSESPs can exhibit fundamentally different ecological requirements and demographic vulnerabilities. The contrast between the understory-facilitated *T. magnifica* and the canopy-dependent *T. exalata* challenges the one-size-fits-all approach often applied in rescue plans. Effective in situ conservation for understory herbs requires a shift from species-centric view (focusing solely on population size) to an interaction-centric framework (focusing on biotic persistence), where maintaining the specific community assembly rules: whether they be facilitative networks or strict canopy associations is as critical as protecting the target species itself. The failure of many reintroduction programs often stems from creating living dead populations: individuals planted in abiotically suitable but biotically deficient habitats (e.g., lack of nurse plants or pollinators) (Volis 2016; Ren, Zhang, et al. 2012). Future PHVA (Population and Habitat Viability Assessment) models for PSESPs should explicitly incorporate these phytosociological parameters to improve the accuracy of extinction risk predictions.

Author Contributions

Peishan Zou: investigation (supporting), methodology (equal), software (lead), visualization (supporting), writing – original draft (lead). **Xirong Zheng:** investigation (lead), visualization (lead), writing – original draft (supporting). **Shiou Yih Lee:** writing – review and editing (lead). **Chunzhi Liu:** investigation (supporting). **Zhijun Xie:** investigation (supporting). **Ke Zheng:** investigation (supporting). **Guofeng Liu:** conceptualization (supporting). **Seping Dai:** conceptualization (lead), project administration (lead), writing – review and editing (supporting).

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in Data S1.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** The number of individuals of the 99 plant species recorded in the 10 surveyed locations within the current range of *Tigridiopalma magnifica* (TM1-10). **Table S2:** The number of individuals of the 41 plant species recorded in the 5 surveyed locations within the current range of *Tigridiopalma exalata* (TE1-5).