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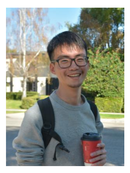
# Changes of community-level leaf traits of terrestrial and epiphytic ferns along an elevation gradient in Northeastern Taiwan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**Aim: How do community-level leaf morphological traits of terrestrial and epiphytic ferns change along elevation and other environmental gradients?**

## Study area

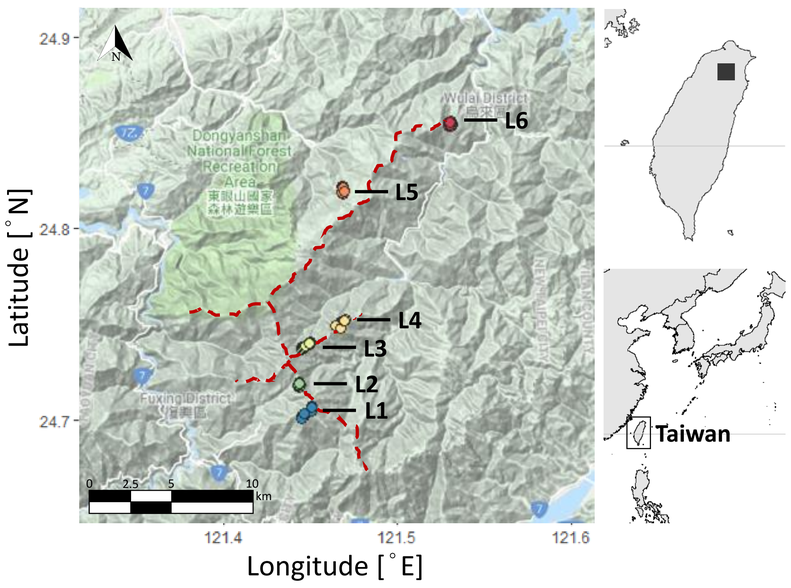



Figure 1. Study area is located in the mountain area in northeastern Taiwan (24.70–24.86°N, 121.44–121.53°E) with subtropical oceanic monsoon climate. Annual mean temperature ranges in 16.1–20.5℃, annual precipitation is 2033–3369 mm (L1–L6). Vegetation types include lowland *Pyrenaria-Machilus* winter monsoon forest, *Quercus* mountane evergreen broad-leaved cloud forest and *Chamaecyparis* mountane mixed cloud forest.

## Sampling design

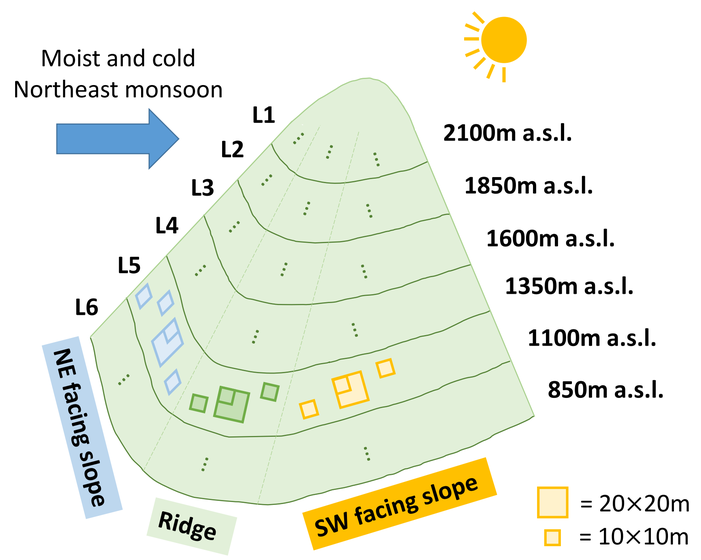



Figure 2. From December 2016 to September 2018, we set up total of 18 20 × 20-m plots and 60 10 × 10-m plots on northeast facing slope, ridge, and southwest facing slope at the elevations of 2100 m (L1), 1850 m (L2), 1600 m (L3), 1350 m (L4), 1100 m (L5), and 850 m (L6). Each elevation zone includes three 20×20-m plots and 10 10×10-m plots. Northeast facing slopes is colder and more humid due to the aspect and winter northeast monsoon, while southwest facing slopes is warmer and drier.

## Data and analysis

**R: Plot-environmental data**

- **Spatial factors:** Elevation
- **Microclimate factors:** Temp, $Wet_{freq}$, Heat load
- **Topographical factors:** Slope, Folded aspect
- **Soil factors:** Soil depth, $pH_{H2O}$, $CN_{soil}$, $N_{soil}$
- **Light factors:** Site_open[20], Trans_dir[20]
- **Forest structure factors:** Mean DBH[20]

**L: Plot-species composition data**

- **20×20-m plots:** Species cover data by modified BrBl scales
- **10×10-m plots:** Species presence-absence data

**Q: Species-traits data**

- **47** terrestrial species
- **34** epiphytic species
- Leaf thickness ($L_{th}$)
- Leaf area (LA)
- Specific leaf area (SLA)
- Leaf dry matter content (LDMC)
- Succulence

[20] factors only measured in 20 × 20-m plots

**RLQ** analysis | **Fourth-corner** analysis | **Scatter plot** of CWM traits and environmental factors

Figure 3. Environmental factors and species composition data were recorded in each plots, five leaf morphological traits have been measured on 47 terrestrial and 34 epiphytic species. The plot-environmental data (R), plot-species data (L), and species-traits data (Q) were than analyzed by RLQ analysis and fourth-corner analysis to identify the overall pattern of trait-environment relationships and the individual trait-environment correlations, respectively. The main patterns of the change of the traits with environmental factors on the first two axes of RLQ analysis are presented on Fig. 5 by the weighted regression between CWM of traits and environmental factors.

## Terrestrial ferns

**Figure 4 (left). Overall schema of the correlation between community-level traits and environmental factors identified by RLQ analysis of 20×20-m plots traits data** (see caption bellow)

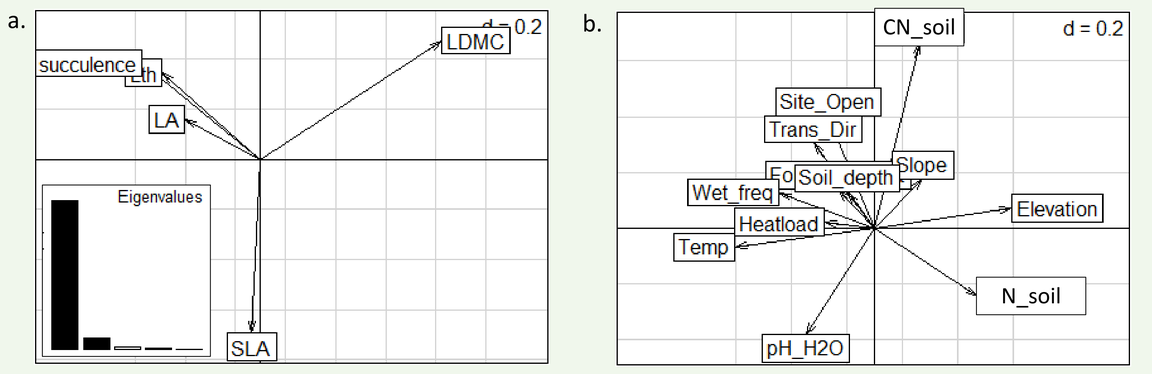
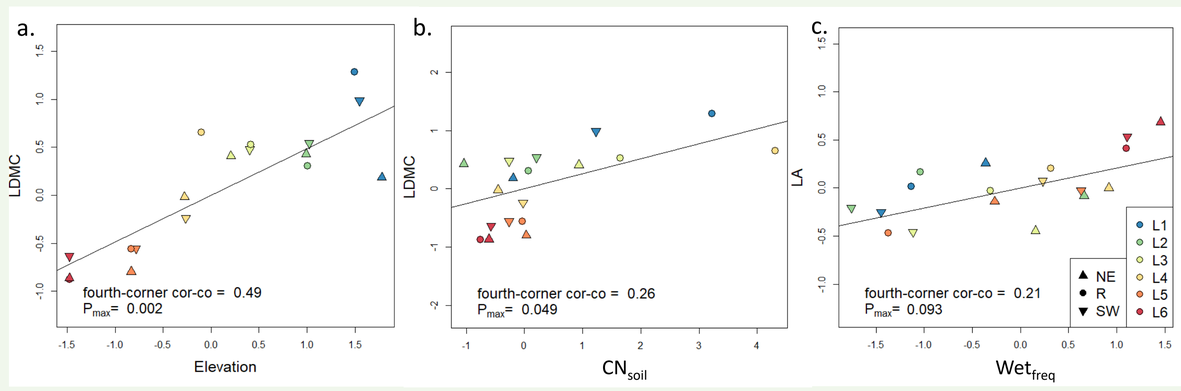



**Table 1 (left). Individual trait-environment correlation identified by fourth-corner analysis** (see caption bellow)

| Trait | elevation | temp | $wet_{freq}$ | folded aspect | $pH_{H2O}$ | $CN_{soil}$ | $N_{soil}$ | slope | soil depth | heat load | site open | trans dir |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LDMC | | 20 | 20 | 10 | | 20 | | 10 | | 10 | | |
| succulence | 10 | 20 | 20 | | 10 | 10 | | 10 | | | | |
| $L_{th}$ | 10 | | | | 10 | | 10 | | | | | 20 |
| LA | | | 20 | | | | | | | | | |
| SLA | | | | | | | | | | | | |

**Figure 5 (left). Scatter plots of CWM trait and environmental factors** (see caption bellow)




## Epiphytic ferns

**Figure 4 (right). Overall schema of the correlation between community-level traits and environmental factors identified by RLQ analysis of 20×20-m plots traits data** (see caption bellow)

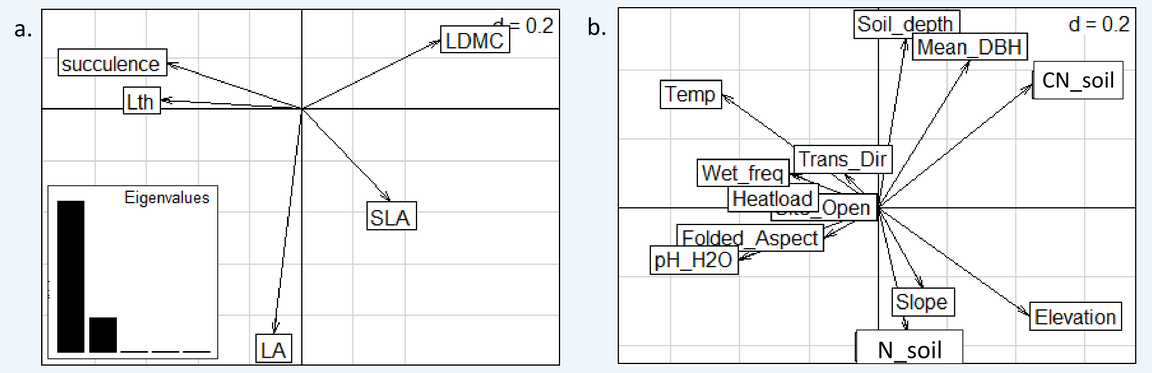



**Table 1 (right). Individual trait-environment correlation identified by fourth-corner analysis** (see caption bellow)

| Trait | elevation | temp | $wet_{freq}$ | folded aspect | $pH_{H2O}$ | $CN_{soil}$ | $N_{soil}$ | slope | soil depth | heat load | site open | trans dir | mean DBH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LDMC | | | | 10 | | | | | | 10 | | | 20 |
| succulence | 20 | 20 | 20 | 10 | | | | | | | | | |
| $L_{th}$ | 20 | 20 | | 10 | | | | | | 10 | | | |
| LA | | | | | | 20 | | | 20 | | | | 20 |
| SLA | | | | | | | | | | | | | |

**Figure 5 (right). Scatter plots of CWM trait and environmental factors** (see caption bellow)

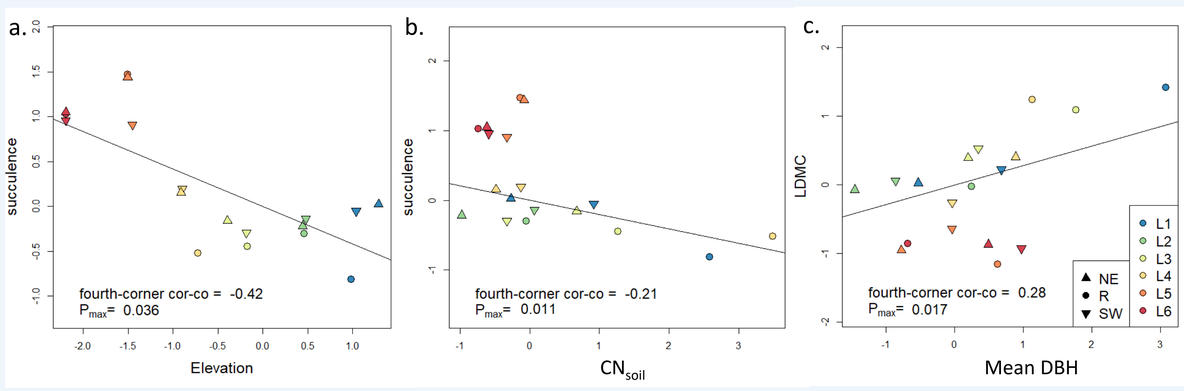



**Figure 4. Overall schema of trait-environment correlation.** Results of the first two axes of the RLQ analysis of 20x20-m plots terrestrial (left) and epiphytic (right) species traits and environmental factors. Ordination for a) traits (the insert shows eigenvalues, with the first two axes in black), and b) environmental variables. To read the diagrams, panels a and b should be overlapped, trait arrows and environmental factor arrows go with the same direction indicate the positive correlations, otherwise indicate negative correlation, angle between two arrows more close to 90° indicate weaker correlation.

**Table 1. Individual trait-environment correlation.** Results of the fourth-corner analysis of community-level traits and environmental factors (left: terrestrial; right: epiphyte). The cells with red background indicate significant ($P < 0.05$) positive correlation tested by max test, with blue background indicate significant negative correlation tested by max test, light red/light blue background indicate the marginally significant correlation ($P < 0.1$). The number 20 and 10 in the box indicates significant result of analysis on only 20x20-m and 10x10-m plots, respectively.

**Figure 5. Scatter plots of CWM traits and environmental factors.** Results of the weighted linear regression between community-weighted mean (CWM) of traits and environmental factors of terrestrial (left) and epiphytic (right) species. The slope of the weighted regression line equals to the fourth-corner correlation coefficient. The plots were all drawn based on 20x20-m plots data, each elevation zone was distinguished by different colors, and the aspect was identified by the shapes of the point. NE: northeast facing plots; R: ridge; SW: southwest facing plots; $CN_{soil}$: soil C:N ratio; $Wet_{freq}$: monthly wet event frequency (frequency of RH records > 95%); Mean DBH: mean tree DBH of the plots.

## Conclusions

- **In terrestrial fern species, LDMC strongly increased with elevation, and decreased with mean temperature; LDMC also increased with soil C:N ratio, which is often related to soil nutrient availability; leaf area weakly increased with wet event frequency and decreased with elevation.**
- **In epiphytic fern species, succulence and leaf thickness decreased with elevation and increased with mean temperature; the negative correlation of succulence and leaf thickness with soil C:N ratio, and the positive correlation of LDMC with mean DBH were possibly due to the correlation of large *Chamaecyparis* trees with soil properties and epiphytic fern community composition.**
- **Elevation, microclimate and soil properties all affected terrestrial and epiphytic ferns' traits directly or indirectly.**

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