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The latitudinal distribution patterns of leaf size and florescence properties of Chinese endemic woody seed plants

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ABSTRACT

Background: The spatial patterns of species distribution and their mechanisms have long been the core of ecological research. Plant functional traits influence species distributions directly or indirectly. These functional traits, such as seed size and plant height, also show some regularity along the latitudinal gradient. However, few studies of patterns of leaf size and florescence properties along the latitudinal gradient have looked at the relationship between them.

Question: What are the patterns of leaf size and florescence of Chinese endemic woody seed plant species with latitude? Is there a correlation between leaf size and florescence of these species?

Data: Previously published data on leaf size (leaf length and leaf width), florescence (the first flowering stage, the final flowering stage, and the duration of flowering) of 3497 species, and related species distribution information for Chinese endemic woody seed plants.

Search method: Frequency analysis was used to obtain the basic features of leaf size and florescence of Chinese endemic woody seed plants. Linear regression was then used to examine the patterns of leaf size and florescence of these plants along latitudinal gradients, as well as any correlation between these two traits.

Conclusions: The number of species of Chinese endemic woody seed plants decreases gradually as leaf size and flowering duration increase. The numbers of species of endemic plants for the first and the final flowering stages show unimodal patterns, each peaking in May. Leaf size and flowering duration are negatively correlated with latitude. And there is a positive relationship between leaf length and flowering duration. The distribution patterns of these traits along the latitudinal gradient at a biogeographic scale, and the relationship of patterns of different functional traits, may reflect species ecological strategies.

Keywords: endemic species, plant traits, florescence, leaf size, latitude

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INTRODUCTION

It is essential to explore the relationships between plant functional traits and species distributions. Recently, biological trait-based approaches have attracted more and more attention from ecologists (Gross *et al.*, 2017; Rotter *et al.*, 2018; Lourenço de Moraes *et al.*, 2020). Plant functional traits are an important topic in the study of mechanisms of species distributions (Pollock *et al.*, 2018). In addition, exploring patterns in plant functional traits is considered a useful strategy for biodiversity conservation and management (Saatkamp *et al.*, 2018). The mechanisms that lead to the formation of a species distribution have strong connections with the many important functional traits of plant organs, such as leaf, flower, seed and stem (Bulgarella *et al.*, 2014; Eme *et al.*, 2014; Fry *et al.*, 2014). The shifts in distribution of these traits result mainly from climate change as well as complex species interactions. Competition among species is a vital factor limiting species' realized ranges (Bulgarella *et al.*, 2014; Kisdi and Geritz, 2003).

Some studies have focused on a single trait in plants, such as seed size (Moles *et al.*, 2007), seed mass (Moles *et al.*, 2009b), or plant height (Moles *et al.*, 2009a). On the global scale, there is an abrupt seven-fold fall in seed mass and 2.4-fold drop in plant height at the edge of the tropics. So there may be a major difference in plant strategies between high and low latitudes. Other studies have focused on more than one trait. For instance, Westoby *et al.* (2002) identified four key dimensions to detect plant ecological strategies based on multiple traits. These four dimensions are as follows: leaf mass per area–leaf lifespan, seed mass–seed output, leaf size–twig size, and plant height. Each of these dimensions varies at the scales of climate zones and site types within landscapes. Thus the set of species at a site is a stable mixture of plant strategies.

Leaf traits are some of the most important plant functional traits because photosynthesis occurs in leaves (Wright *et al.*, 2004; Yu *et al.*, 2020). At the regional scale, as elevation increases, area-based leaf nitrogen concentration and stand leaf area increase to their maximum, whereas mass-based leaf nitrogen concentration decreases from its maximum (Luo *et al.*, 2005). At the global scale, leaf nitrogen and phosphorus decline from the magnetic poles to the equator, whereas the nitrogen/phosphorus ratio increases towards the equator. This results from the increase in average temperature and length of the growing season (Reich and Oleksyn, 2004). Worldwide patterns in leaf size show that large-leaved species predominate in wet, hot, tropical environments, while small leaves prevail in colder, high-latitude environments (Wright *et al.*, 2017). At different scales, the distribution patterns of leaf traits are probably related to plant physiology and the geographic pattern of the soil matrix (Aubin *et al.*, 2013).

The flowering phenology of plants also varies between different environments (Reeves and Coupland, 2000; Stevenson *et al.*, 2008). The flowering peaks of communities usually match seasonal changes of day length, temperature, and irradiance in subtropical regions (Changyang *et al.*, 2013). Thus closely related species have similar florescence times. However, Boyle and Bronstein (2012) showed that flowering phenology bears little relationship to plant phylogeny, which means that plant flowering time does not reflect obvious phylogenetic conservatism. The trade-off between functional traits is interesting. For example, relatively larger plants tend to flower earlier and have longer flowering duration (Petersen *et al.*, 2010). In addition, research has been conducted on the relationships between seed traits and flowering time. Different seed diffusion modes have different plant flowering times. Plants with larger seeds flower earlier (Bolmgren and Cowan, 2008). Does plant flowering time correlate with some leaf traits? This is worthy of an in-depth study.

The species diversity of plants in China is the largest of any nation in the northern hemisphere. The total number of Chinese seed plant species is 28,684. Altogether, 52.1% of them are endemic seed plants (Huang *et al.*, 2011). Endemic plants are more narrowly geographically distributed than other species (Burke, 2007). Their smaller geographic ranges suggest that endemic plants face a higher risk of extinction. Therefore, endemism has commonly been regarded as an important factor in biodiversity conservation (Lamoreux *et al.*, 2006). So it is crucial to study patterns in the spatial distribution of functional traits in China's endemic species. Studying the distribution of functional traits will help us to understand many pressing ecological issues, such as the spatial distributions of species, variation in functional diversity along different geographical gradients (latitude, longitude or elevation), and balanced strategies of different functional traits. In this paper, we address four functional traits: leaf size and three florescence properties of endemic woody seed plants. We analyse the patterns in their distributions along latitudinal gradients, in the hope of offering them better protection.

MATERIALS AND METHODS

Datasets

From the Chinese endemic seed plants database (Huang *et al.*, 2016), we extracted the scientific names and the distributions of endemic woody seed plant species. Then we updated the distribution data using the *National Spatial Information Infrastructure*, which provides the latest and most comprehensive data for species distributions with the operational geographical unit being the Chinese county [the county has been a relatively stable administrative unit in the history of China (Xu *et al.*, 2018)]. There are 2377 counties with areas ranging from 22.4 km^2 to 208,134 km^2, of which 2215 are less than 10,000 km^2 in size (Huang *et al.*, 2012). We used the latitude and longitude of the centroid of each county as species locations.

We collected the functional traits of 3497 species of Chinese endemic woody seed plants from published monographs, a great many specimens, and three shared datasets. Leaf size traits (cm) included leaf length and leaf width. The florescence properties comprised the first flowering stage (month), the final flowering stage (month), and the duration of flowering (i.e. time from first to last flowering, in months) for each species. The main monographs consulted were *Flora of China* (Wu *et al.*, 1994–2012), *Flora Reipublicae Popularis Sinicae* (Editorial Committee of Flora Reipublicae Popularis Sinicae, 1959–2004), and *Sylva Sinicae* (Zheng, 1983–2004). The shared databases were *Flora of China* (http://www.iplant.cn/frps), *Chinese Natural Museum* (http://www.nature-museum.net/), and *LEDA Traitbase* (http://www.leda-traitbase.org/). We differentiated the growth forms of species (tree, shrub, and liana) according to the standards outlined in *Flora Reipublicae Popularis Sinicae* and *Flora of China* (http://www.iplant.cn/frps). In cases of doubt, we consulted the local taxonomist for final determination.

Data analyses

We used frequency diagrams to analyse leaf size and florescence. We divided leaf length (1–10, 10–20, 20–100 cm) and leaf width (1–5, 5–10, 10–60 cm) into three size groups each (where 1–10 cm indicates a leaf length $\leq$ 10 cm, and 10–20 cm indicates a leaf length $>$ 10 cm but $\leq$ 20 cm). We determined whether these groups differed significantly using the Kruskal-Wallis test (Hollander and Wolfe, 1973). We also grouped the first flowering stage, final flowering stage, and flowering duration by calendar month. Then we used a contingency table to test the significance of their differences (Kateri, 2014).

We transformed plant traits to the $\log_{10}$ scale before regression analysis. We assessed the patterns of leaf size and florescence along latitudinal gradients, and examined the correlations between functional traits and latitude with linear regression (Wilkinson and Rogers, 1973). We also tested whether there was a linear relationship between leaf size and florescence. We performed all statistical analyses in R v.3.6.3 (R Core Team, 2019).

RESULTS

Features of leaf size and florescence properties of Chinese endemic woody seed plants

Leaf size of Chinese endemic woody seed plants varies greatly (Fig. 1, Tables 1, 2). The number of species decreases as leaf length increases. The number of species also decreases as leaf width increases. Species with a leaf length ≤ 10 cm are most common, followed by species with a leaf length of 10–20 cm, and finally 20–100 cm leaf length (Fig. 1A). There is a similar relationship of leaf width to number of species; wider leaves are associated with fewer species (Fig. 1B). The

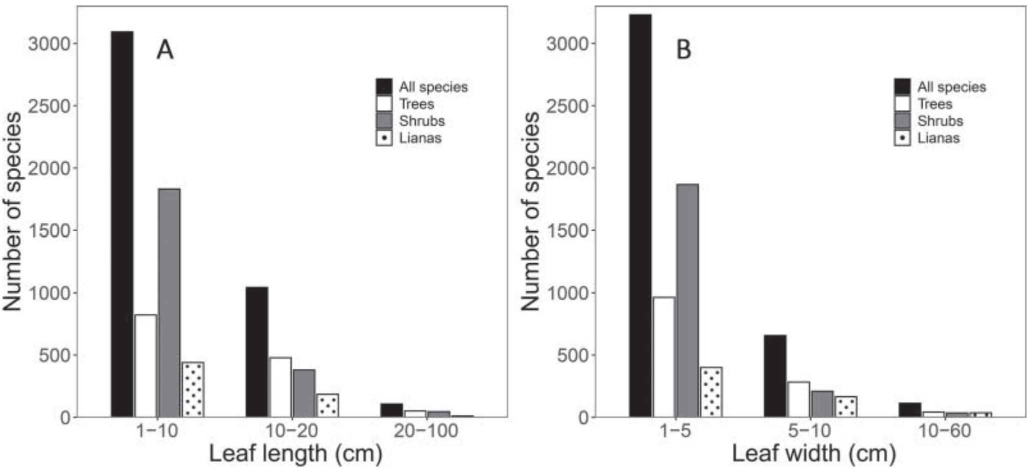

Fig. 1. Leaf length (A) and leaf width (B) of Chinese endemic woody seed plants.

Table 1. Results of Kruskal-Wallis tests for different leaf lengths of Chinese endemic woody seed plants

Species	Leaf length (cm)	Means	SE	SD	Rank
All species	1–10	5.63	0.05	2.74	a
	10–20	13.27	0.08	2.51	b
	20–100	28.96	1.32	13.65	c
Trees	1–10	6.70	0.08	2.43	a
	10–20	13.37	0.12	2.60	b
	20–100	30.29	2.42	17.26	c
Shrubs	1–10	4.90	0.06	2.73	a
	10–20	13.39	0.13	2.55	b
	20–100	27.03	1.30	8.74	c
Lianas	1–10	6.71	0.11	2.29	a
	10–20	12.79	0.16	2.13	b
	20–100	30.68	3.31	10.99	c

Note: SE = standard error, SD = standard deviation. Significantly different contrasts are indicated by different lower-case letters. All $P < 0.01$.

Table 2. Results of Kruskal-Wallis tests for different leaf widths of Chinese endemic woody seed plants

Species	Leaf width (cm)	Means	SE	SD	Rank
All species	1–5	2.54	0.02	1.29	a
	5–10	6.76	0.05	1.31	b
	10–60	14.05	0.57	6.03	c
Trees	1–5	3.00	0.04	1.18	a
	5–10	6.73	0.08	1.29	b
	10–60	16.34	1.36	8.84	c
Shrubs	1–5	2.17	0.03	1.25	a
	5–10	6.85	0.09	1.35	b
	10–60	12.99	0.56	3.30	b
Lianas	1–5	3.14	0.06	1.13	a
	5–10	6.71	0.10	1.29	b
	10–60	12.40	0.33	1.98	c

Note: SE = standard error, SD = standard deviation. Significantly different contrasts are indicated by different lowercase letters. All $P < 0.01$.

number of species of the three growth forms also differs. For plants with leaf length 1–10 cm and leaf width 1–5 cm, the number of shrub species is greater than that of both trees and lianas. However, trees outnumber shrubs and lianas for leaf length 10–20 cm and leaf width 5–10 cm.

Plant florescence properties are seasonal (Fig. 2). The total number of species in the first flowering stages shows a unimodal pattern along the time axis (Fig. 2A, B) with a peak in May. The same is true of the total number of species flowering for the last time in the year. Shrubs and lianas peaked in May, the same month as all species. But more tree species initiated flowering in April. The final flowering stage was also concentrated in May for all species but varied among different growth forms. The final flowering times of trees peaked in May, while shrubs peaked in June. The final month of flowering in liana species showed a tendency to concentrate in a single month; results for May, June and July were all similar. Similarly, the duration of flowering is not concentrated in one month but two (Fig. 2C). Regardless of growth form, most species flowered for one or two months; very few for four or more months.

Latitudinal patterns of leaf size and florescence properties

The leaf lengths and leaf widths of Chinese endemic woody seed plants both decrease significantly as latitude increases (Fig. 3). For all species, there is a six-fold decline in leaf length and an eight-fold decline in leaf width from 16°N to 52°N (Fig. 3, Table 3).

At higher latitudes, Chinese endemic woody seed plants have significantly shorter flowering durations (Fig. 4). Similar to leaf length, there is a six-fold decline in flowering duration between the maximum and minimum for all species (Table 3). The pattern in leaf lengths and leaf widths is similar.

However, the flowering duration of lianas is an exception. The maximum flowering duration of lianas is only twice that of its minimum. And flowering durations of lianas show no significant latitudinal gradient (Fig. 4; $P > 0.05$).

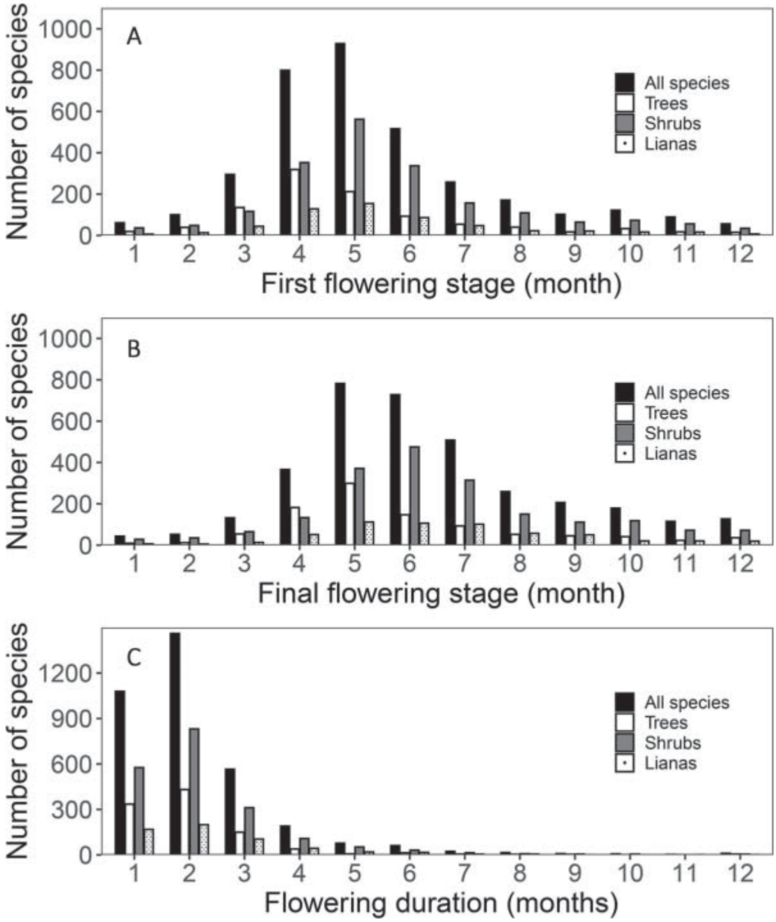

Fig. 2. Florescence properties of Chinese endemic woody seed plants: (A) first flowering, (B) final flowering, (C) flowering duration. Contrasts of differences of 12 groups for each florescence property were significant (see contingency tables in Appendix Tables S1–S3). All $P < 0.05$.

Correlations between leaf size and florescence properties

We found no significant correlation between leaf width and flowering duration of Chinese endemic woody seed plants (Fig. S1; see evolutionary-ecology.com/data/3206Appendix.pdf). However, a very significant positive relationship was observed between leaf length and flowering duration of endemic plants (Fig. 5). For all species, for trees and for shrubs, leaf length increases significantly with an increase in flowering duration. Although the leaf length of lianas does not vary significantly with flowering duration, there may be some positive relationships when flowering duration is 2 or 3 months (Fig. S2).

DISCUSSION

Leaf size reflects the adaptation of plants to their environment. Leaf size directly affects the ability of plants to obtain light, which varies widely from habitat to habitat. The more arid and colder the habitat, the smaller the leaf size (Geng *et al.*, 2012; Wright *et al.*, 2017).

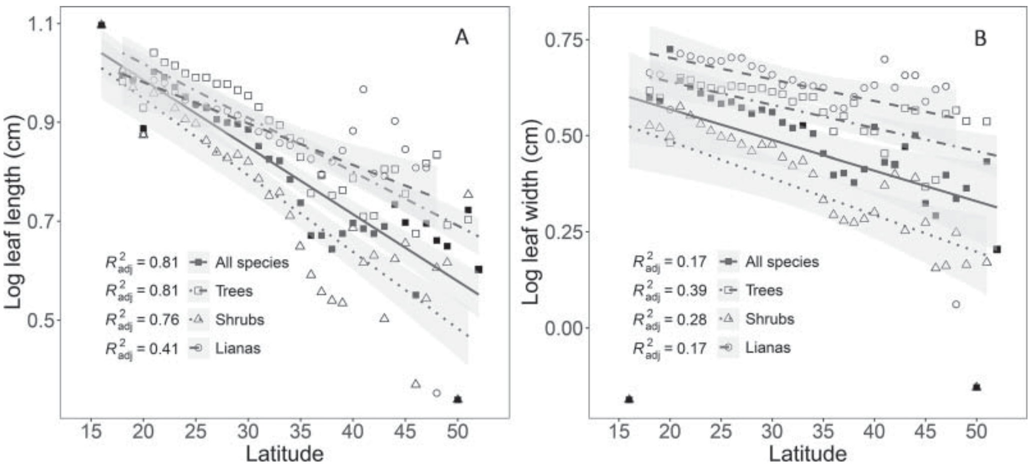

Fig. 3. Patterns of leaf size among Chinese endemic woody seed plants along a latitudinal gradient: (A) leaf length, (B) leaf width. The grey area represents the 95% confidence interval. All $P < 0.05$.

Table 3. Changes in leaf size and flowering duration of Chinese endemic woody seed plants along the latitudinal gradient 16°N–52°N

Trait	Species	Maximum	Minimum	Ratio
Leaf length (cm)	All species	12.5	2.2	6
	Trees	11.0	4.0	3
	Shrubs	12.5	2.2	6
	Lianas	10.1	2.3	4
Leaf width (cm)	All species	5.3	0.7	8
	Trees	4.5	1.6	3
	Shrubs	3.8	0.7	6
	Lianas	5.2	1.2	4
Flowering duration (months)	All species	6	1	6
	Trees	5	1	5
	Shrubs	6	1	6
	Lianas	4	2	2

Leaf size at the community scale is directly related to precipitation and temperature (Sugden, 2017) also. When environmental conditions improve, the leaves of plants can increase in size, and vice versa (Wang and Wang, 2015). Yates *et al.* (2010) attribute this relationship to the fact that having a small leaf size reduces the damage caused by high transpiration in hot and arid environments. This probably accounts for the fact that relatively few species of Chinese endemic woody seed plants have large leaf sizes.

The florescence properties of Chinese endemic woody seed plants show seasonal patterns. The total number of species in their first and final flowering stages both had a single peak in May, which is consistent with other research showing that the majority of sub-alpine plants bloom in mid-spring (CaraDonna *et al.*, 2014).

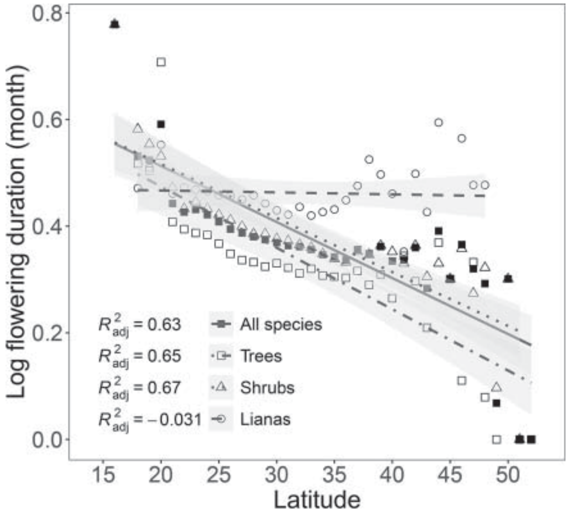

Fig. 4. Patterns of flowering duration among Chinese endemic woody seed plants along a latitudinal gradient. The grey area represents the 95% confidence interval. All $P < 0.05$ except lianas (see text).

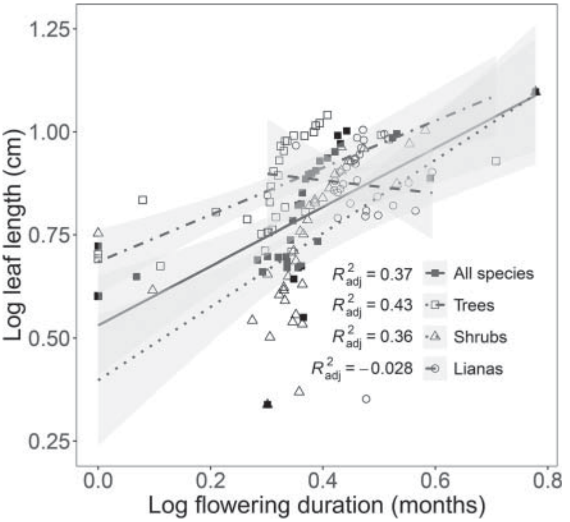

Fig. 5. Correlations between leaf length and flowering duration of Chinese endemic woody seed plants. The grey area represents the 95% confidence interval. All $P < 0.05$ except lianas (see text).

Like leaf size, plant florescence properties also depend significantly on environmental factors, such as temperature, precipitation and solar radiation (Zimmerman *et al.*, 2007; Stevenson *et al.*, 2008). In temperate regions, gradually increasing temperatures in spring can induce plant flowering (Neil and Wu, 2006). However, a reduction in temperature can induce flowering in tropical regions (Ashton *et al.*, 1988). And in seasonally dry forests, plant flowering usually peaks at the convergence of the dry and wet seasons (Zimmerman *et al.*, 2007). The effect of precipitation on flowering mainly manifests in plant germination and flowering (Tyagi, 2004). Many Chinese endemic woody seed plants flower for 2 months. This is in line with a previous study (Changyang *et al.*, 2013). In subtropical and temperate forests, shorter growing seasons and strong environmental changes between seasons may limit the flowering duration of plants. In comparison, many plants in tropical forests grow throughout the year, which perhaps is why they have longer flowering durations (Pau *et al.*, 2018).

The leaf size and flowering duration of Chinese endemic woody seed plants were both negatively correlated with latitude. A similar pattern was seen in many functional traits, including leaf area, seed mass, and plant height (Moles *et al.*, 2007, 2009a; Wright *et al.*, 2017). For example, the leaf area of plants that are widespread throughout the northern hemisphere also decreases with increasing latitude (Wright *et al.*, 2017). Variations in the distributions of functional traits lead to the different functional properties of communities (Liu and Ma, 2015). Differences in climate (temperature, precipitation, and light) and soil along the latitudinal gradient are responsible for variations in plant functional traits, resulting in different growth forms and functional groups (Meng *et al.*, 2007). This change may indicate that the distribution of functional traits is a reflection of the geographical distribution of species.

The variation in functional traits along the latitudinal gradient occurred at different rates. For all species, we found a six-fold decline in flowering duration, a six-fold decline in leaf length, and an eight-fold decline in leaf width between 16°N and 52°N.

Other research has shown that seed mass and plant height also experience such significant declines between the equator and polar regions (Moles *et al.*, 2007, 2009a). At the edge of the tropics, there is a sudden seven-fold drop in seed mass and a two-fold reduction in plant height. Moreover, the height of plants growing near the equator is 29 times that of species between 60°N and 75°N, and 31 times that of species between 45°S and 60°S (Moles *et al.*, 2009a). In the present study, we found both leaf size and flowering duration to show significant variation with changing latitude. Thus there may be a switch in plant strategies between different regions (Smith and Sibly, 2008). The rates at which leaf size and flowering duration change along the latitudinal gradient differed between the three growth forms. The trees and shrubs had similar slopes but the flowering durations of the lianas were not significantly correlated with latitude.

Lianas depend on other plants for support, which results in special adaptive traits, such as thin stems, wide vessels, deep root systems, and a relatively high leaf-area/basal-area ratio (Van Der Heijden and Phillips, 2009). Therefore, the growth and distribution of lianas in different environments may change in ways that ecology has not yet predicted, as well as ways that differ from what we see in other growth forms.

A correlation between plant functional traits is common in plant ecology. It is based on links between plant developmental mechanisms and stable physiological function. In this study, we found that leaf length of Chinese endemic woody seed plants had a positive relationship with flowering duration. This phenomenon probably reflects trade-offs between functional traits (Wright *et al.*, 2006; Smith and Sibly, 2008). Such balanced relationships would seem to be the result of natural selection after the formation of trait combinations (Westoby *et al.*, 2002).

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