

Allometric Relationships for Interspecific Plant Biomass Allocations and Morphological Characteristics

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Research

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Abstract

Background

The allometric relationships of plants and their changes assist with elucidating the adaptive responses of plants to the environment. However, it remains unclear whether different species of the life-form 'shrubs' have consistent or similar allometric relationships between modular characteristics (including morphological characteristics and biomass allocations). Here, we selected eight xerophytic shrubs as samples to investigate the morphological characteristics, biomass allocations and their allometric relationships.

Results

The results showed that there were common allometric scaling exponents (a_{RMA}) between modular characteristics with the exception of crown area (C)-belowground biomass (BGB) and C -plant height (H). Moreover, The BGB -total biomass (TGB) of the eight species accorded with the significant isometric relationships, and the isometric or allometric relationships of different species in aboveground biomass (AGB)- BGB and AGB - TGB were similar, which meant that the belowground biomass mainly determined the total biomass for xerophytic shrubs.

Conclusions

Our results suggested that there were similar trends of collaborative changes between modular characteristics of eight xerophytic shrubs with the exception of C - BGB and C - H , which reflected the convergent adaptation of different species in the life-form 'shrubs' to arid environments.

Introduction

Changes in the morphological characteristics and biomass allocations of plants are the result of the interaction between plant and environment, which reflects the ability of plants to adapt to the environment (Uri et al. 2007, Marfo and Dang 2009, Crane et al. 2017). Allometric relationships are inherent characteristics determined by the genetic attributes of species, which can reveal the internal principles of plant growth. At the same time, there is a power function relationship between certain biological characteristics and plant body size (West et al. 1997, Niklas and Enquist 2001, Niklas 2004). The theoretical predictions based on the metabolic theory and the fractal-like networks show that regardless of whether the plants have secondary tissues or no secondary tissues, the above- and below-ground biomass allocations are in an isometric relationship (i.e., the allometric scaling exponent is 1) (Niklas and Enquist 2001, Enquist and Niklas 2002). In terms of morphological characteristics (e.g. crown area, plant height, and stem diameter) and biomass allocations (e.g. aboveground biomass, belowground biomass, and total biomass), the number of leaves scales as the 3/4-power (i.e., 3/4 scaling exponent) of the total biomass; and the plant body length scales as the 1/4-power of the total biomass (Niklas and Enquist 2001). It can be seen that there are no consistent allometric relationships between different

parameters of the same plant. So, what kind of allometric relationships are there between the modular characteristics (including morphological characteristics and biomass allocations) of xerophytic shrubs?

Shrubs comprise the dominant species of plant communities in arid and semi-arid regions (Gómez-Aparicio et al. 2004, Foronda et al. 2020). Due to shortages of water resources, xerophytic shrubs have developed super-drought resistance (Angert et al. 2007, Zhang et al. 2020). These species are not only an important and unique plant germplasm resource in drought areas, but also have certain edible and medicinal value for livestock (Tuttolomondo et al. 2014). However, the research on allometric relationships of these species has not been reported. Moreover, it remains unclear whether different species of the life-form 'shrubs' have a common or similar allometric relationship between modular characteristics. Considering that the lifestyle is same, we hypothesized that different xerophytic shrubs have convergent adaptation to arid environments.

For this study, eight xerophytic shrubs (*Prunus mongolica* Ricker, *Nitraria tangutorum* Bobr, *Ammopiptanthus mongolicus* Cheng f, *Hedysarum scoparium* Fisch. et Mey, *Caragana korshinskii* Kom, *Zygophyllum xanthoxylum* Bunge, *Artemisia sphaerocephala* Krasch, and *Hedysarum mongolicum* Turcz) were selected as samples. These species are typically employed for ecological restoration projects in the arid regions. With a focus on modular characteristics and their internal relations for xerophytic shrubs in adapting to arid environments, the allometric relationships for plant biomass allocations and morphological characteristics are reported. The allometric relationship is an effective method for estimating plant biomass. This method can not only estimate the above-ground biomass through the allometric relationship between aboveground morphological characteristics and aboveground biomass, but also estimate the belowground biomass non-destructively by using the allometric relationship between the above- and below-ground biomass. Therefore, analyzing the allometric relationships between modular characteristics is helpful toward elucidating the adaptive changes of plants and providing a theoretical basis for the plant protection and utilization.

Material And Methods

Study area

Our experiment was conducted at the Ecological Experimental Station of Lanzhou University (104°09'N, 35°87'E, at an altitude of 1966 m), which is located in the interlaced zone of desert and the Loess Plateau (Li et al. 2014). According to climate data from 1971 to 2000, this area belongs to a typical temperate continental monsoon climate, with an annual mean air temperature and rainfall of 10.3°C and 350 mm, respectively. The rainy season is primarily concentrated from June to September, with approximately 2446 h of sunlight annually, a frost-free period of 180 days, with a Kastanozems soil type (Zhang et al. 2014). In arid and semiarid ecosystem, most of the land-forms are barren gully with a loose soil texture and the effective water resources are seriously insufficient. Planting xerophytic shrubs is benefit to the restoration of aid and semiarid ecosystem (Fig. 1).

Experimental procedure

For this experiment, we employed eight xerophytic shrubs, which included *P. mongolica*, *N. tangutorum*, *A. mongolicus*, *H. scoparium*, *C. korshinskii*, *Z. xanthoxylum*, *A. sphaerocephala*, and *H. mongolicum* (Table 1). All seeds for these species were obtained from the Psammophyte Garden in Gansu Province.

In May 2014, shrub seeds of uniform size were placed in a Petri dish containing moist filter paper and observed for germination in a growth cabinet for one week at 25°C with a 12 h photo-period. Following germination, the seedlings were planted in the botanical garden at the Ecological Experimental Station of Lanzhou University. In this experiment, there is a randomized block design (total of five blocks), and each block with four similarly sized plots that contained all eight species with 40 seedlings per plant species in each plot, and the plant-cluster spacing was 75 cm. Five harvests were carried out during the vegetative growth period, with intervals of three months. The timing for all the species was as follows: harvest 1 (initial) on September 2014; harvest 2 on the end of November 2014; harvest 3 on March 2015; harvest 4 on June 2015; harvest 5 on September 2015. That is, a total of five harvests lasting about one years.

Measurements

During the survey, three plants with uniform growth were selected for each species in each plot, after which the plant height (H), plant body length (L) and width (W) were measured. Subsequently, each plant was carefully excavated with a shovel at a depth of 60 cm, and the soil at the roots was washed away. The leaves, stems, and roots were collected, dried, and weighed. Data from the four plots of each block were pooled together ($n = 12$), recorded as one repetition (that is, the number of repetitions is the number of blocks, $N = 5$), and included in a statistical analysis.

Computation

The area formula of ellipse

$$L \times W \times \frac{\pi}{4}$$

was employed to calculate the crown area (C).

$Y = \beta X^a$ is the allometric equation, where Y is a biological characteristic or function, β is a standardized constant, and X is the plant body size. When $a = 1$, it is an isometric relationship, that is, the dependent variable and independent variable change uniformly or proportionally; when $a \neq 1$, it is an allometric relationship, that is, the changes of dependent variable and independent variable are not uniform or proportional. When determining allometric parameters, the power function must be converted to the form of

$$\log Y = \log \beta + \alpha_{\text{RMA}} \cdot \log X$$

, where a_{RMA} is the slope of linear regression following the logarithmization of the power function, and $\log\beta$ is the intercept of the linear regression. The reduced major axis regression (RMA) method is used to calculate the parameters of regression model (e.g. $\log\beta$ and a_{RMA}), 95% confidence interval (CI), and Pearson correlation coefficient (R^2) (Niklas and Enquist 2001, Niklas 2004).

Statistical analysis

All statistical analyses were run using SPSS software (v. 22.0, Chicago, USA). The analysis of the allometric relationship was performed using the RMA (reduced major axis) regression method of the SMATR software package. All data were converted using a logarithm of base-10, and following conversion, linear fitting was performed to analyze the allometric relationships between modular characteristics of the eight xerophytic shrubs. The significance level was set at $P < 0.05$ for all tests, and all data were expressed by mean \pm SE.

Results

Allometric relationships between morphological characteristics

The biomass allocations or growth-related morphological characteristics of different xerophytic shrubs were different (Appendix S1) and had an interaction between time and species (Appendix S2). With the exception of the crown area (C)-plant height (H) of *H. Mongolicum*, *H. scoparium* and *Z. xanthoxylum*, and the stem diameter (D)- C of *A. sphaerocephala*, *H. Mongolicum*, *H. scoparium* and *Z. xanthoxylum*, there were significant allometric relationships between morphological characteristics for the other species (Table 2). The D - H of *H. Mongolicum* and *H. scoparium* accorded with the significant isometric relationships (95% CI included 1). The D - H of *A. sphaerocephala* showed an allometric relationship with allometric scaling exponents (a_{RMA}) significantly greater than 1 (95% $CI > 1$), while that of the other five species (*A. mongolicus*, *C. korshinskii*, *N. tangutorum*, *P. mongolica*, and *Z. xanthoxylum*) showed an allometric relationship with a_{RMA} significantly less than 1 (95% $CI < 1$) in which the D of *A. mongolicus*, *C. korshinskii* and *Z. xanthoxylum* scaled as the 3/4-power of the H (95% CI included 3/4). The C - H and D - C of *A. mongolicus*, *C. korshinskii* and *N. tangutorum* accorded with the significant isometric relationships, while those of the *P. mongolica* were allometric relationships with a_{RMA} significantly less than 1.

The a_{RMA} of D - H of different species ranged from 0.547 to 1.676 (Table 2, Fig. 2), with a common a_{RMA} being 0.818 ($Y = D$, $X = H$) (Fig. 2); the a_{RMA} of C - H of different species ranged from -1.926 to 1.084, and there was no common a_{RMA} ($Y = C$, $X = H$); the a_{RMA} of D - C of different species ranged from -0.341 to 1.011, with a common a_{RMA} being 0.868 ($Y = D$, $X = C$). Although the eight species had differences in isometric and allometric relationships, with the exception of C - H , the double logarithm fitting curve between morphological characteristics (i.e., D - H or D - C) was similar (Fig. 3), with a common a_{RMA} (Fig. 2) and Pearson correlation coefficient (Fig. 3).

Allometric relationships between morphological characteristics and biomass allocations

With the exception of the *C*-aboveground biomass (*AGB*) and *C*-belowground biomass (*BGB*) of the *H. Mongolicum*, *H. scoparium* and *Z. xanthoxylum*, and *C-BGB* of the *A. mongolicus*, there were significant allometric relationships between morphological characteristics and biomass allocation for the other species (Table 3). The a_{RMA} of those allometric relationships was all less than 1, among which 10 pairs were 1/4 scaling exponent (95% CI included 1/4) and 4 pairs were 3/4 scaling exponent (i.e., *C-AGB* and *C-BGB* of *N. tangutorum*, *D-BGB* of *H. Mongolicum*, and *H-BGB* of *P. mongolica*). Moreover, with the exception of the individual parameters of individual species, there were significant allometric relationships between total biomass (*TGB*) or root/shoot ratio (*R/S*) and morphological characteristics for other species, and the a_{RMA} of those allometric relationships was all less than 1 (Appendix S3, S4). The double logarithm fitting curves between morphological characteristics and biomass allocations were similar with the exception of the *C-BGB* (Fig. 3), with a common a_{RMA} (Fig. 2) and Pearson correlation coefficient (Fig. 3).

The a_{RMA} of *D-AGB* of different species ranged from 0.224 to 0.420 (Table 3, Fig. 2), with a common a_{RMA} being 0.341 ($Y = D$, $X = AGB$) (Fig. 2); the a_{RMA} of *H-AGB* of different species ranged from 0.251 to 0.518, with a common a_{RMA} being 0.416 ($Y = H$, $X = AGB$); the a_{RMA} of *C-AGB* of different species ranged from -0.901 to 0.561, with a common a_{RMA} being 0.453 ($Y = C$, $X = AGB$); the a_{RMA} of *D-BGB* of different species ranged from 0.312 to 0.586, with a common a_{RMA} being 0.430 ($Y = D$, $X = BGB$); the a_{RMA} of *H-BGB* of different species ranged from 0.254 to 0.674, with a common a_{RMA} being 0.526 ($Y = H$, $X = BGB$); the a_{RMA} of *C-BGB* of different species ranged from -0.961 to 0.535, and there was no common a_{RMA} ($Y = C$, $X = BGB$).

Allometric relationships between biomass allocations

There were significant allometric relationships between biomass allocations of the eight species (Table 4). The *AGB-BGB* and *AGB-TGB* of *A. mongolicus*, *A. sphaerocephala* and *C. korshinskii* accorded with the significant isometric relationships, while those of the other five species (*H. Mongolicum*, *H. scoparium*, *N. tangutorum*, *P. mongolica*, and *Z. xanthoxylum*) were allometric relationships with a_{RMA} significantly greater than 1. The *BGB-TGB* of the eight species accorded with the significant isometric relationships. Although the eight species had differences in isometric and allometric relationships, the double logarithm fitting curves between biomass allocations were similar (Fig. 3). For example, the a_{RMA}

of $AGB-BGB$ of the eight species all fluctuated near 1, with a common a_{RMA} ($a_{RMA} = 1.264$) (Fig. 2) and Pearson correlation coefficient ($R^2 = 0.70$) (Fig. 3, 4).

The a_{RMA} of $AGB-BGB$ of different species ranged from 0.974 to 1.848, with a common a_{RMA} being 1.264 ($Y = AGB$, $X = BGB$) (Fig. 2); the a_{RMA} of $AGB-TGB$ of different species ranged from 1.015 to 1.736, with a common a_{RMA} being 1.150 ($Y = AGB$, $X = TGB$); the a_{RMA} of $BGB-TGB$ of different species ranged from 0.809 to 1.047, with a common a_{RMA} being 0.910 ($Y = BGB$, $X = TGB$).

Discussion

The allometric relationships between the modular characteristics of plants were confirmed by a fractal-like network, metabolism theory and other methods (Enquist and Niklas 2002, Niklas 2004, Pretzsch and Dieler 2012), and verified by a large quantity of measured data. It is predicted that there are isometric relationships between the biomass allocations of plants, while the relationships between other modular characteristics are mainly allometric (Niklas 2004, 2005). In this study, with the exception of the individual parameters of individual species, there were significant allometric relationships between most of the morphological characteristics for eight xerophytic shrubs, and between the morphological characteristics and biomass allocations, which was consistent with the theoretical prediction. However, there were also allometric relationships between belowground biomass (BGB) or total biomass (TGB) and aboveground biomass (AGB) for *H. Mongolicum*, *H. scoparium*, *N. tangutorum*, *P. mongolica* and *Z. xanthoxylum*, which didn't conform to the theoretical prediction. This difference might be caused by the ability of the above five shrubs to store additional resources in root organs to ensure that plants can germinate and grow again in the coming year. This study also found that the $BGB-TGB$ of the eight species accorded with the significant isometric relationships, which conformed to the theoretical prediction and supported the above view.

There was no common a_{RMA} between plant height (H) or BGB and crown area (C), which was mainly caused by the differences in the activity of plant body length (L) and width (W) of different xerophytic shrubs in order to adapt to the drought environment. The results indicated that there was no consistent rule of synergetic change between H or BGB and C for xerophytic shrubs. Niklas (2004) analyzed the allometric relationships between the morphological characteristics and biomass allocations for two ferns and one dicotyledonous plant. The results revealed that although the growth rate was non-isometric, the morphological characteristics of the three species and the allocation of organic biomass had a consistent rule of synergetic change. The difference between the result of Niklas and our result might be caused by species, life forms, and even environmental factors.

This study showed that the a_{RMA} of $C-H$ fluctuated most between morphological characteristics of different species, as well as the *A. mongolicus* and *P. mongolica* had the largest ($a_{RMA} = 1.084$) and smallest a_{RMA} ($a_{RMA} = -1.926$), respectively. The a_{RMA} of $C-BGB$ fluctuated most between morphological characteristics and biomass allocations of different species, as well as the *N. tangutorum* and *P.*

mongolica had the largest ($a_{RMA} = 0.535$) and smallest a_{RMA} ($a_{RMA} = -0.961$), respectively. From the above results, it could be seen that the species with the largest a_{RMA} was different for *C-H* and *C-BGB*, which might be caused by individual plant development. The allometric relationships between plant attributes are influenced by individual plant development, whereas the allometric relationships between modular characteristics of different species have variable trends with individual plant development, which are species-specific.

The allocation of biomass reflects the adaptation strategies of plants to align with the availability of resources (Liu et al. 2010, Gutiérrez-Girón and Gavilán 2012). The above- and below-ground growth of plants is a unified whole. The acquisition of water and nutrients is primarily contingent on strong roots, while the acquisition of light and the loss of water are more related to leaves (Poorter and Pothmann 1992, Andrade et al. 2014). During the process of plant growth, with changes in available resources, their various organs will develop harmoniously, and modify their existing resource utilization strategies to maintain their own growth and development requirements (Hara 1994). In this study, the double logarithm fitting curves between above- and belowground biomass were similar and the a_{RMA} of the eight species all fluctuated near 1. This result signified that although the eight species had differences in isometric and allometric relationships, there was a relatively consistent trend of collaborative change in the biomass allocation pattern of above- and below-ground (Li et al. 2017). Moreover, the common a_{RMA} and Pearson correlation coefficient (R^2) between biomass allocations of different species in this study also confirmed the conclusion that the allometric relationship between biomass allocations has nothing to do with species. This result was similar to that of Enquist and Niklas (2002) regarding the patterns of biomass partitioning in seed plants.

Abbreviations

a_{RMA} : Allometric scaling exponents

C: Crown area

D: Stem diameter

H: Plant height

L: Plant body length

W: Plant body width

AGB: Aboveground biomass

BGB: Belowground biomass

TGB: Total biomass

R/S: Root/shoot ratio

RMA: Reduced major axis regression

CI: 95% confidence interval

R²: Pearson correlation coefficient

Declarations

Competing interests

The authors declare they have no competing interests.

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Author contributions

CZ and DN conducted the experiments, data analysis and article writing; DN and HF provided valuable suggestions and made modifications; LZ and XL supervised development of this work. All authors contributed to the writing of this article.

Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

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Author contributions

CZ and DN conducted the experiments, data analysis and article writing; DN and HF provided valuable suggestions and made modifications; LZ and XL supervised development of this work. All authors contributed to the writing of this article.

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Tables

Table 1. The family, leaf longevity, root system and species of eight xerophytic shrubs.

| Family | Leaf longevity | Species |
|----------------|----------------|----------------------------------|
| Compositae | deciduous | <i>Artemisia sphaerocephala</i> |
| Chenopodiaceae | deciduous | <i>Zygophyllum xanthoxylum</i> |
| | deciduous | <i>Nitraria tangutorum</i> |
| Leguminosae | deciduous | <i>Caragana korshinskii</i> |
| | deciduous | <i>Hedysarum scoparium</i> |
| | evergreen | <i>Ammopiptanthus mongolicus</i> |
| | deciduous | <i>Hedysarum mongolicum</i> |
| Rosaceae | deciduous | <i>Prunus mongolica</i> |

Table 2. Allometric relationships between morphological characteristics for the eight xerophytic shrubs.

| Family | Leaf longevity | Species |
|----------------|----------------|----------------------------------|
| Compositae | deciduous | <i>Artemisia sphaerocephala</i> |
| Chenopodiaceae | deciduous | <i>Zygophyllum xanthoxylum</i> |
| | deciduous | <i>Nitraria tangutorum</i> |
| Leguminosae | deciduous | <i>Caragana korshinskii</i> |
| | deciduous | <i>Hedysarum scoparium</i> |
| | evergreen | <i>Ammopiptanthus mongolicus</i> |
| | deciduous | <i>Hedysarum mongolicum</i> |
| Rosaceae | deciduous | <i>Prunus mongolica</i> |

Note: "-" represents no allometric relationship between the two parameters ($P_{aRMA} > 0.05$), and $P < 0.05$ indicates that the isometric relationship is significant. The same below.

Table 3. Allometric relationships between morphological characteristics and biomass allocations for the eight xerophytic shrubs.

| Family | Leaf longevity | Species |
|----------------|----------------|----------------------------------|
| Compositae | deciduous | <i>Artemisia sphaerocephala</i> |
| Chenopodiaceae | deciduous | <i>Zygophyllum xanthoxylum</i> |
| | deciduous | <i>Nitraria tangutorum</i> |
| Leguminosae | deciduous | <i>Caragana korshinskii</i> |
| | deciduous | <i>Hedysarum scoparium</i> |
| | evergreen | <i>Ammopiptanthus mongolicus</i> |
| | deciduous | <i>Hedysarum mongolicum</i> |
| Rosaceae | deciduous | <i>Prunus mongolica</i> |

Table 4. Allometric relationship between biomass allocations for the eight xerophytic shrubs.

| Parameter | Species | R^2 | $P_{\alpha_{RMA}}$ | α_{RMA} | $\log\beta$ | α_{RMA} 95% CI | $\log\beta$ 95% CI | F | P |
|-----------|---------------|-------|--------------------|----------------|-------------|--------------------------|-----------------------|--------|-------|
| $Y = AGB$ | <i>A. mon</i> | 0.826 | 0.000 | 0.974 | 0.346 | 0.814 ~ 1.165 | 0.252 ~ 0.441 | 0.094 | 0.000 |
| $X = BGB$ | <i>A. sph</i> | 0.863 | 0.000 | 1.012 | 0.646 | 0.863 ~ 1.186 | 0.477 ~ 0.815 | 0.024 | 0.000 |
| | <i>C. kor</i> | 0.679 | 0.000 | 1.118 | 0.183 | 0.878 ~ 1.424 | 0.019 ~ 0.347 | 0.901 | 0.000 |
| | <i>H. mon</i> | 0.188 | 0.031 | 1.848 | -0.544 | 1.264 ~ 2.701 | -0.941 ~ -0.148 | 12.090 | 0.000 |
| | <i>H. sco</i> | 0.420 | 0.000 | 1.611 | -0.189 | 1.167 ~ 2.225 | -0.483 ~ 0.105 | 9.725 | 0.000 |
| | <i>N. tan</i> | 0.862 | 0.000 | 1.326 | 0.550 | 1.130 ~ 1.556 | 0.275 ~ 0.825 | 13.575 | 0.003 |
| | <i>P. mon</i> | 0.644 | 0.000 | 1.529 | -0.032 | 1.185 ~ 1.973 | -0.257 ~ 0.192 | 12.374 | 0.000 |
| | <i>Z. xan</i> | 0.797 | 0.000 | 1.310 | 0.308 | 1.080 ~ 1.589 | 0.171 ~ 0.445 | 8.460 | 0.000 |
| $Y = AGB$ | <i>A. mon</i> | 0.983 | 0.000 | 1.020 | -0.171 | 0.964 ~ 1.079 | -0.197 ~ -0.145 | 0.511 | 0.000 |
| $X = TGB$ | <i>A. sph</i> | 0.994 | 0.000 | 1.015 | -0.121 | 0.982 ~ 1.049 | -0.178 ~ -0.065 | 0.838 | 0.000 |
| | <i>C. kor</i> | 0.938 | 0.000 | 1.114 | -0.313 | 1.000 ~ 1.240 | -0.408 ~ -0.217 | 4.370 | 0.000 |
| | <i>H. mon</i> | 0.631 | 0.000 | 1.736 | -0.989 | 1.339 ~ 2.249 | -1.309 ~ -0.669 | 20.944 | 0.000 |
| | <i>H. sco</i> | 0.793 | 0.000 | 1.469 | -0.636 | 1.209 ~ 1.784 | -0.817 ~ -0.455 | 17.262 | 0.000 |
| | <i>N. tan</i> | 0.980 | 0.000 | 1.133 | -0.153 | 1.066 ~ 1.204 | -0.222 ~ -0.084 | 17.986 | 0.000 |
| | <i>P. mon</i> | 0.949 | 0.000 | 1.237 | -0.459 | 1.123 ~ 1.363 | -0.573 ~ -0.345 | 20.799 | 0.000 |
| | <i>Z. xan</i> | 0.979 | 0.000 | 1.122 | -0.257 | 1.054 ~ 1.196 | -0.309 ~ -0.206 | 14.367 | 0.000 |
| $Y = BGB$ | <i>A. mon</i> | 0.912 | 0.000 | 1.047 | -0.531 | 0.814 ~ 1.165 | -0.592 ~ -0.470 | 0.561 | 0.000 |
| $X = TGB$ | <i>A. sph</i> | 0.911 | 0.000 | 1.003 | -0.758 | 0.882 ~ 1.140 | -0.976 ~ -0.540 | 0.002 | 0.000 |
| | <i>C. kor</i> | 0.878 | 0.000 | 0.996 | -0.443 | 0.858 ~ | -0.564 ~ | 0.003 | 0.000 |

| | | | | | | | | |
|---------------|-------|-------|-------|--------|---------------|-----------------|-------|-------|
| | | | | | 1.157 | -0.323 | | |
| <i>H. mon</i> | 0.786 | 0.000 | 0.939 | -0.240 | 0.770 ~ 1.145 | -0.371 ~ -0.110 | 0.422 | 0.000 |
| <i>H. sco</i> | 0.844 | 0.000 | 0.912 | -0.278 | 0.769 ~ 1.080 | -0.375 ~ -0.181 | 1.268 | 0.000 |
| <i>N. tan</i> | 0.941 | 0.000 | 0.854 | -0.530 | 0.770 ~ 1.004 | -0.619 ~ -0.441 | 9.773 | 0.000 |
| <i>P. mon</i> | 0.838 | 0.000 | 0.809 | -0.279 | 0.681 ~ 1.062 | -0.413 ~ -0.145 | 6.470 | 0.000 |
| <i>Z. xan</i> | 0.896 | 0.000 | 0.857 | -0.432 | 0.746 ~ 1.085 | -0.519 ~ -0.345 | 5.281 | 0.000 |

Figures

Restoration process of arid and semiarid ecosystem



Figure 1

The restoration process of arid and semiarid ecosystem.

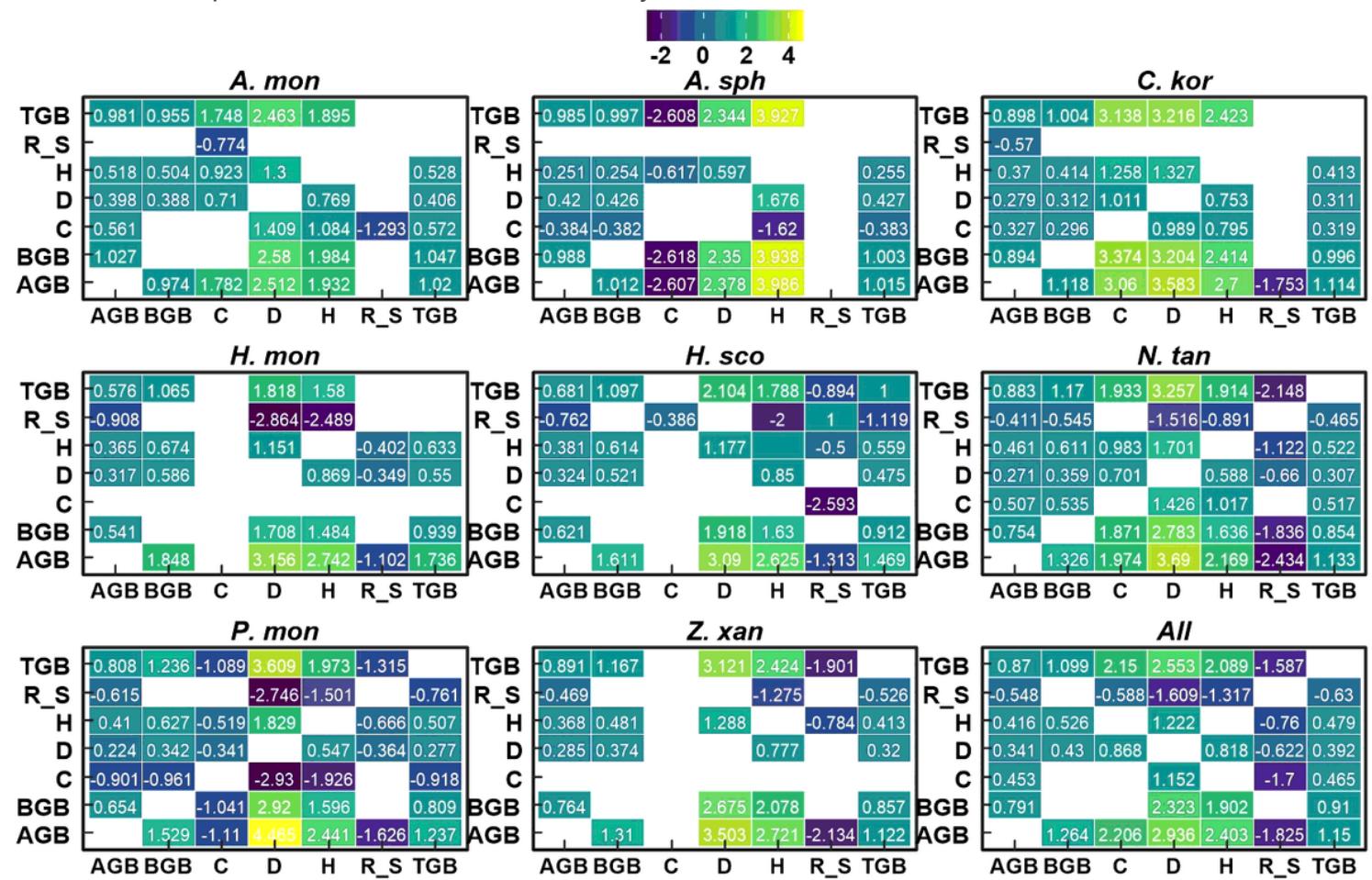


Figure 2

The allometric scaling exponents (αRMA) between morphological characteristics and biomass allocations for the eight xerophytic shrubs.

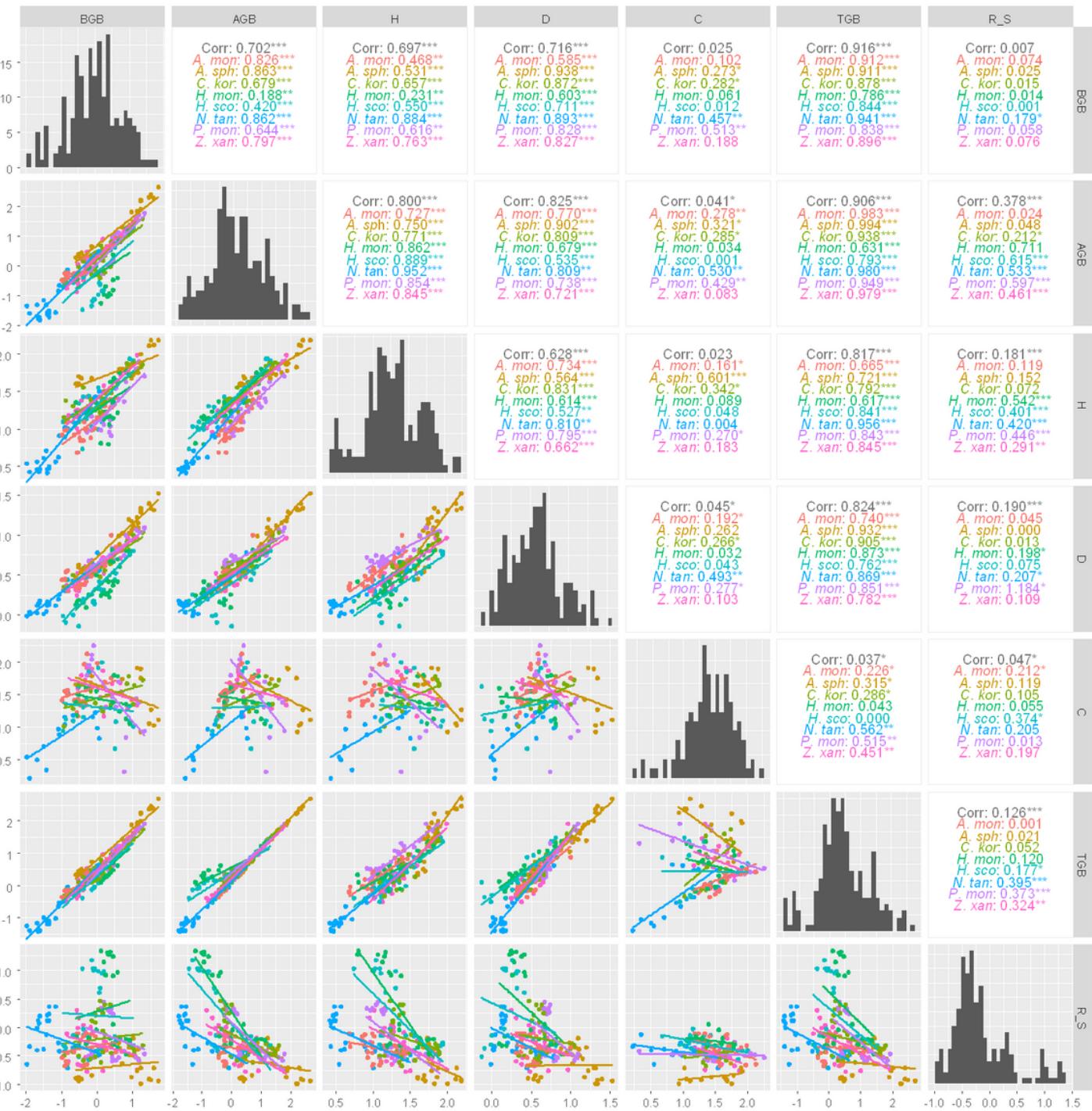


Figure 3

The log10-log10 linear regression plot between morphological characteristics and biomass allocations for the eight xerophytic shrubs. Black Corr represents common Pearson correlation coefficient (R^2) of different species.

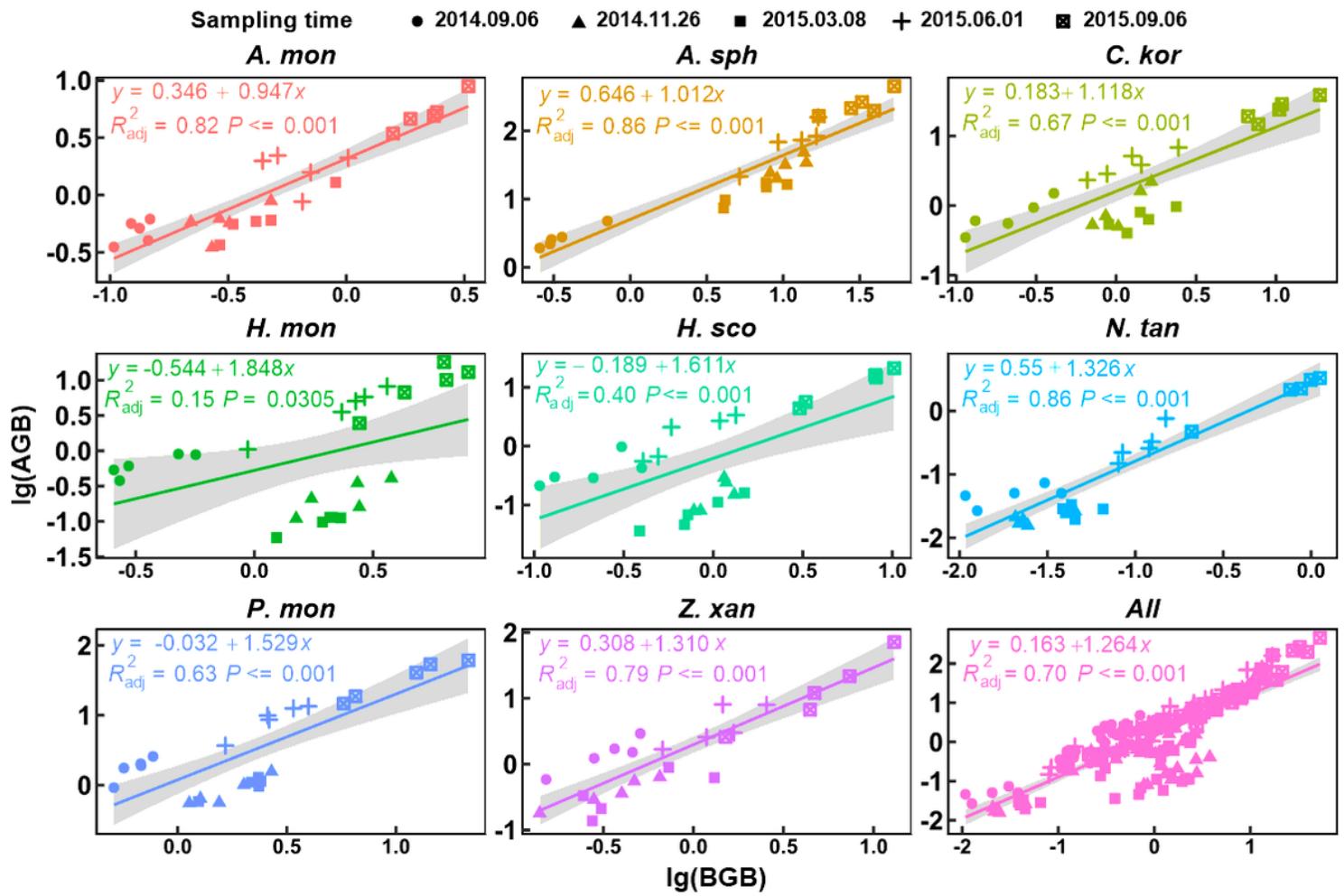


Figure 4

The log10-log10 linear regression plot between AGB and BGB for the eight xerophytic shrubs.

Supplementary Files

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- SupportingInformation.docx