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Species association in *Xanthoceras sorbifolium* Bunge communities and selection for agroforestry establishment

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Abstract We embraced the "learning from nature and back to nature" paradigm to develop viable agroforestry scenarios through studying species association in 12 wild yellowhorn (*Xanthoceras sorbifolium*: a Chinese endemic oil woody plants) communities. We identified 18 species combinations for their suitability as agroforestry mixes where positive associations were detected and thus economic benefits are anticipated. In each wild yellowhorn community, we use nonmetric multidimensional scaling ordination to assess community structure and composition, and the climatic variables that most likely influenced existing species distributions. Next, pairwise and multiple species associations were evaluated using several multiple species association indices (e.g., χ^2, Jaccard, Ochiai, Dice). Generally, all species association indices were in agreement and were helpful in identifying several high valued medicinal species that showed positive and significant associations with yellowhorn. Finally, we proposed several agroforestry species mixes suitable for yellowhorn.

Keywords *Xanthoceras sorbifolium* · Species association and selection · Agroforestry mixes · Nonmetric multidimensional scaling ordination (NMDS)

Qing Wang and Renbin Zhu have contributed equally to this work.

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Introduction

Plant communities' structure, composition, and environmental covariates represent the three fundamental objects that have received substantial ecological attention for more than a century (Adler and HilleRisLambers 2008). Recent research findings indicate that the on-going climate change has influenced these ecological objects (Malanson 2017) and highlighted the role of species- climate variances relationship and more specifically the identification of which climate variances significantly affect particular species fitness (de Gasper et al. 2015; Šímová et al. 2015). However, plant–plant relationship has also been proven to be effective in shaping community composition through influencing landscape-scale productivity or species relative distribution in a more substantial ways than the climate change's short term effects (Dohn et al. 2013; Riginos 2009).

Evaluating species association could help understanding the various relationships among species (positive or negative) as well as providing insights on community's structure and dynamic under climate change. Species association is usually shaped by the differences in community habitat affecting species' distribution (i.e., the spatial arrangement of a biological taxon) (Greig-Smith 1983). Positive species association may exists when one species relies on another or when both species are affected by the same bioclimatic or no-bioclimatic factors, while negative association is triggered by competition over space, nutrition, allele-chemical interaction, or demand of different environment (shade or light preference). The majority of research on species association has focus on community structure (Masaki et al. 1992; Tokeshi 1993; Wilson et al. 1995); however, the literature lacked its possible role on modern agroforestry establishment (management system that combines trees and crops for the creation of diverse, sustainable, and ecologically sound land use). Modern agroforestry should be designed to minimize interspecific competition and maximize benefits, so it can provide ecosystem services and economic commodities. The Millennium Ecosystem Assessment (Assessment 2005) and the International Assessment of Agricultural Science and Technology for Development (IAASTD) (Kiers et al. 2008) recognized the benefits of modern agroforestry while considering the tradeoff between landowners/farmers and environmental services (Schmidhuber and Tubiello 2007). Deeper understanding of species association may provide a workable model for the development and establishment of new agroforestry assembles through the proper selection of compatible species combinations (Jose 2009; Jose et al. 2004).

Xanthoceras sorbifolium Bunge (yellowhorn), a relic oil woody plants that is endemic to China (Yang et al. 2005). Due to its high oil content and economic importance, yellowhorn has received increased scientific and managerial attention with extensive studies covering its genetics (Bi and Guan 2014), physiology (Zhou et al. 2012; Zhou and Liu 2012), industrial and medicinal uses (Ma et al. 2004). Knowledge on wild yellowhorn communities' structures are very scant and mainly remain unknown. Here, we studied 12 wild yellowhorn communities to: (1) evaluate the species community composition in relation to climatic variables, (2) uncover the understory species associations with special reference to woody and herbaceous species, and (3) develop a yellowhorn agroforestry plantation mixture resembling those present in wild communities.

Materials and methods

Study area

The present study was carried out between July 2014 and June 2015 and covered 12 yellowhorn communities in northern China, representing 12 counties in 6 provinces (Shaanxi, Shanxi, Ningxia, Gansu, Qinghai, and Hebei) (Table 1). The ecology of this region is characterized as arid to semi-arid with 300–600 mm rainfall with 90% occurring between July and September (Kimura et al. 2007; Xin et al. 2011). July and January mean temperatures are 17 °C and − 5 °C, respectively (Maher 2016).

Data collection

The 12 yellowhorn communities were investigated by line transects. In each location, a randomly located plot of 3000 m × 10 m was studied (36 ha in total). The minimum distance separating any two sampling plots was 11.5 km. All woody and herbaceous species within each plot were recorded, and included 52 woody and 97 herbaceous species; however, 100

Table 1 Summary of the twelve locations along with their locations (Lat., Long., Elev.), canopy coverage, soil texture, and slope

	Location	Latitude (°N)	Longitude (°E)	Elevation (m)	Canopy coverage (%)	Soil texture	Slope (°)
1	Xifeng District, Qingyang City, Gansu Province	35°40′35.39″	107°29′37.96″	1120	5	Typical loess	40
2	Heshui County, Qingyang City, Gansu Province	36°04′56.54″	108°19′42.22″	1360	20	Typical loess	20
3	Yu County, Zhangjiakou City, Hebei Province	40°05′41.69″	115°03′24.57″	1186	10	Typical loess	15
4	Pingluo County, Shizuishan City, Ningxia Province	38°53′24.75″	106°07′15.11″	1461	5	Sierozem soil	35
5	Xunhua County, Haidong City, Qinghai Province	35°49′47.87″	102°41′34.39″	1961	10	Typical loess	30
6	Fangshan County, Luliang City, Shanxi Province	37°52′44.03″	111°14′46.00″	1219	20	Typical loess	25
7	Ji County, Lingfen City, Shanxi Province	36°09′31.26″	110°41′14.53″	1086	40	Typical loess	40
8	Shilou County, Luliang City, Shanxi Province	37°01′16.96″	110°44′51.40″	1085	10	Typical loess	15
9	Tianlong Mountain, Taiyuan City, Shanxi Province	37°42′33.83″	112°23′38.66″	973	50	Clayey loess	25
10	Fanzhi County, Yizhou City, Shanxi Province	39°13′24.83″	113°17′13.29″	1026	5	Sandy loess	15
11	Ganquan County, Yan'an City, Shaanxi Province	36°14′51.45″	109°20′49.65″	1060	20	Typical loess	20
12	Feng County, Baoji City, Shaanxi Province	34°03′44.94″	106°41′39.70″	1123	60	Clayey loess	25

species were removed from the analysis (see below) (Table S1). For each plot, a total of 188 climatic variables representing the prevailing climatic conditions present during the surveys were generated by estimating climate norms from geographic coordinates using the software package Climate AP (Wang et al. 2016).

Data analysis

For species association analyses, 100 of the 149 species occurred only in a single plot (i.e., singletons), and were excluded, thus the subsequent analyses were based on the remaining 49 species (5 annual or biennial forb, 25 perennial forb, and 19 woody species, Table S1). Additionally, we compared the species' lists between the May and September/October surveys and did not detect any incidence of presence/absence across the 12 studied plots, indicating that life-history differences (seasonal effects) did not play a role in the observed species.

Ordination analysis between species and climate variance

The Nonmetric Multidimensional Scaling (NMDS) technique which is known to be effective with ordination when compared to other multivariate techniques in handling ecological data (Bettinetti et al. 2000; Kenkel and Orlóci 1986) was used and implemented in R "Vegan" package to interpret the relationship between species (dependent variables) and climatic variables (Oksanen et al. 2013).

Multi-species associations

Multi-species associations were carried out in R "spaa" package (Griffith et al. 2016). We first consider measures of species association (SA) based on records of presence or absence only.

Variance of species relative frequency

$$\sigma_T^2 = \sum_{i=1}^{S} P_i(1 - P_i) \quad (1)$$

where P_i is species frequency, then variance of species number was estimated as:

$$S_T^2 = (1/N)\sum_{j=1}^{N}(T_j - t)^2 \quad (2)$$

where N is the number of plots (12), S is number of species (49), T_j is the total number of species for each plot, and t is the variance of species relative frequency.

Species relative frequency was determined as:

$$P_i = \frac{n_i}{N} \quad (3)$$

where n_i is the total number of species for plot i.

Variance ratio (VR) is expressed as:

$$VR = \frac{S_T^2}{\sigma_T^2} \quad (4)$$

where positively and negatively associated species produce VR values of > 1 and < 1, respectively.

The value W is equivalent to Chi-square (χ^2) with n degrees of freedom:

$$W = VR * N \quad (5)$$

If $\chi^2_{0.05}(N) > W > \chi^2_{0.95}(N)$, species were independent.

Pairwise species associations

Numerous methods of expressing the degree of association between species have been proposed and used. In fact the data represent a simple 2×2 contingency table, and the association measure of such tables has been used to address completely different contexts (Li et al. 2008). For any two species, these measures may be expressed in the form where the total number of samples M, is partitioned into those with: both species present (a), both species absent (d), and only one of the two species present (b and c). Pairwise species associations were implemented in R "spaa" package (Griffith et al. 2016; Zhang 2013).

The value V is used to determine if any pair of species are positively or negatively associated:

$$V = \frac{(a + b) - (b + c)}{a + b + c + d} \quad (6)$$

where a, b, c, and d represent the two species possible scenarios (above) and values of > 0.0 or < 0.0 represent positive and negative associations, respectively.

The Chi-square (Yate's correction) is used to determine the two species association significance level:

$$\chi^2 = \frac{(|ad - bc| - 0.5N)^2 N}{(a + b)(a + c)(b + d)(c + d)} \quad (7)$$

with $\chi^2 \geq 3.841 (0.01 < P < 0.05)$ and $\chi^2 \geq 6.635 (P < 0.01)$ indicating, significant and highly significant pairwise association between the two species means.

The following three indices were also used for assessing species association:

1. The Jaccard index (*JI*) (Hubalek 1982). It is a presence-absence metric, which indicates quantitative species abundance, and contains important information about species–species interactions (Jost 2007):

$$JI = \frac{a}{a + b + c} \quad (8)$$

2. To evaluate the species association in a given region is best using the Ochiai index (*OI*), as it can be split into the phi coefficient of association and species regional diagnostic value (De Cáceres et al. 2008). *OI* is very strongly correlated with the Dice index (Hubalek 1982).

$$OI = \frac{a}{\sqrt{(a + b)(a + c)}} \quad (9)$$

3. Dice (1945) (Dice index; *DI*) developed coincidence index from a simpler metric (Dice 1945), which is 'association index', and conceptually equivalent to measuring the 'degree of faunal resemblance' between continental biotas developed by George G. Simpson (Arita 2017; Simpson 1943).

$$DI = \frac{2a}{2a + b + c} \tag{10}$$

The *JI*, *OI*, and *DI* indices show the percentage of co-occurrence and its associated level, when a = 0.0, *JI*, *OI*, and *DI* yield a value of zero indicating that the two species never co-occurred and when a = 1 indicate the two species co-occurred.

Association Coefficient (*AC*):

$$\text{If } ab \geq bc, \text{ then } AC = \frac{ad - bc}{(a + b)(b + d)} \tag{11}$$

$$\text{If } bc > ad \text{ and } d \geq a, \text{ then } AC = \frac{ad - bc}{(a + b)(a + c)} \tag{12}$$

$$\text{If } bc > ad \text{ and } d < a, \text{ then } AC = \frac{ad - bc}{(b + d)(d + c)} \tag{13}$$

AC ranges from 1 (in the case of perfect positive association) to 0.0 or -1 (in the case of perfect negative association). When *AC* = 0.0, species were independent. The same applied for point correlation coefficient (PCC) and Pearson correlation.

Point correlation coefficient (PCC):

$$PCC = \frac{ad - bc}{(a + b)(a + c)(c + d)(b + d)} \tag{14}$$

Pearson correlation:

$$r_p = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2 \sum_{i=1}^{N}(y_i - \bar{y})^2}} \tag{15}$$

where x_i and y_i represent the species number of *x* and *y* in plot *i*; and $\bar{x}$, $\bar{y}$ represent the average species number in all plots.

Results

Communities' component and ordination

A total of 49 species (5 annual or biennial forb, 25 perennial forb, and 19 woody species) belonging to 41 genera in 24 families were recorded in the studied 12 plots (Table S1). The species with the most occurrence belonged to four families; namely, Asteraceae (11 species), Poaceae (5 species), Fabaceae (3 species), and Rosaceae (3 species) (Table S1).

The nonmetric multidimensional scaling technique (NMDS) showed that MAP (mean annual precipitation (mm) (r^2 = 0.72, *P* = 0.004)), AHM (annual heat: moisture index (MAT + 10)/(MAP/1000)) (r^2 = 0.85, *P* = 0.001)), CMD (Hargreaves climatic moisture deficit (r^2 = 85, *P* = 0.001)), PPT09 (September precipitation (r^2 = 0.45, *P* = 0.001)), and TD (temperature difference between MWMT and MCMT, or continentally (°C) (r^2 = 0.48, *DI* = 0.050)) were significantly affected the distribution of herbaceous plants (Fig. 1a). While EMT (extreme minimum temperature over 30 years (r^2 = 0.57, *P* = 0.028)), Tmin_DJF (winter mean minimum temperature (°C) (r^2 = 0.68, *P* = 0.009)), DD_0_MAM (spring degree-days below 0 °C (r^2 = 0.82, *P* = 0.001)), PAS_SON (autumn precipitation as snow (r^2 = 0.62, *P* = 0.004)) and PAS11 (November precipitation as snow (r^2 = 0.63, *P* = 0.003)) significantly affected the distribution of woody plants (Fig. 1b).

Species association among the 49 species

The variance ratio (*VR*) of herbaceous multi-species association for the 12 plots was equal to 1.784, a value > 1 with *W* = 21.407 ($\chi^2_{0.995}(49) = 27.249$), indicating that they were positively correlated. The pairwise species associations produced a total of 1176 pairwise associations involving 49 pairwise herbaceous species with 18 significant ($\chi^2 > 3.841$) (Table 2). The 18 significant pairwise associations were *Androsace longifolia* and *Artemisia frigida*, *Androsace longifolia* and *Scutellaria viscidula*, *Androsace longifolia* and *Ephedra sinica, Androsace longifolia* and *Ulmus macrocarpa, Artemisia capillaris* and *Cymbaria mongolica*, *Artemisia frigida* and *Ephedra sinica*, *Artemisia frigida* and *Scutellaria viscidula*, *Artemisia frigida* and *Ulmus macrocarpa*, *Convolvulus ammannii* and *Cynanchum thesioides*, *Convolvulus ammannii* and *Ulmus glaucescens*, *Cynanchum thesioides* and *Ulmus glaucescens*, *Ephedra sinica* and *Scutellaria viscidula*, *Ephedra sinica* and *Ulmus macrocarpa*, *Leymus secalinus* and *Thermopsis lanceolata*, *Lonicera ferdinandi* and *Rosa xanthina f. normalis*, *Saussurea japonica* and *Sophora davidii*, *Scutellaria viscidula* and *Ulmus macrocarpa*, and *Stipa bungeana* and

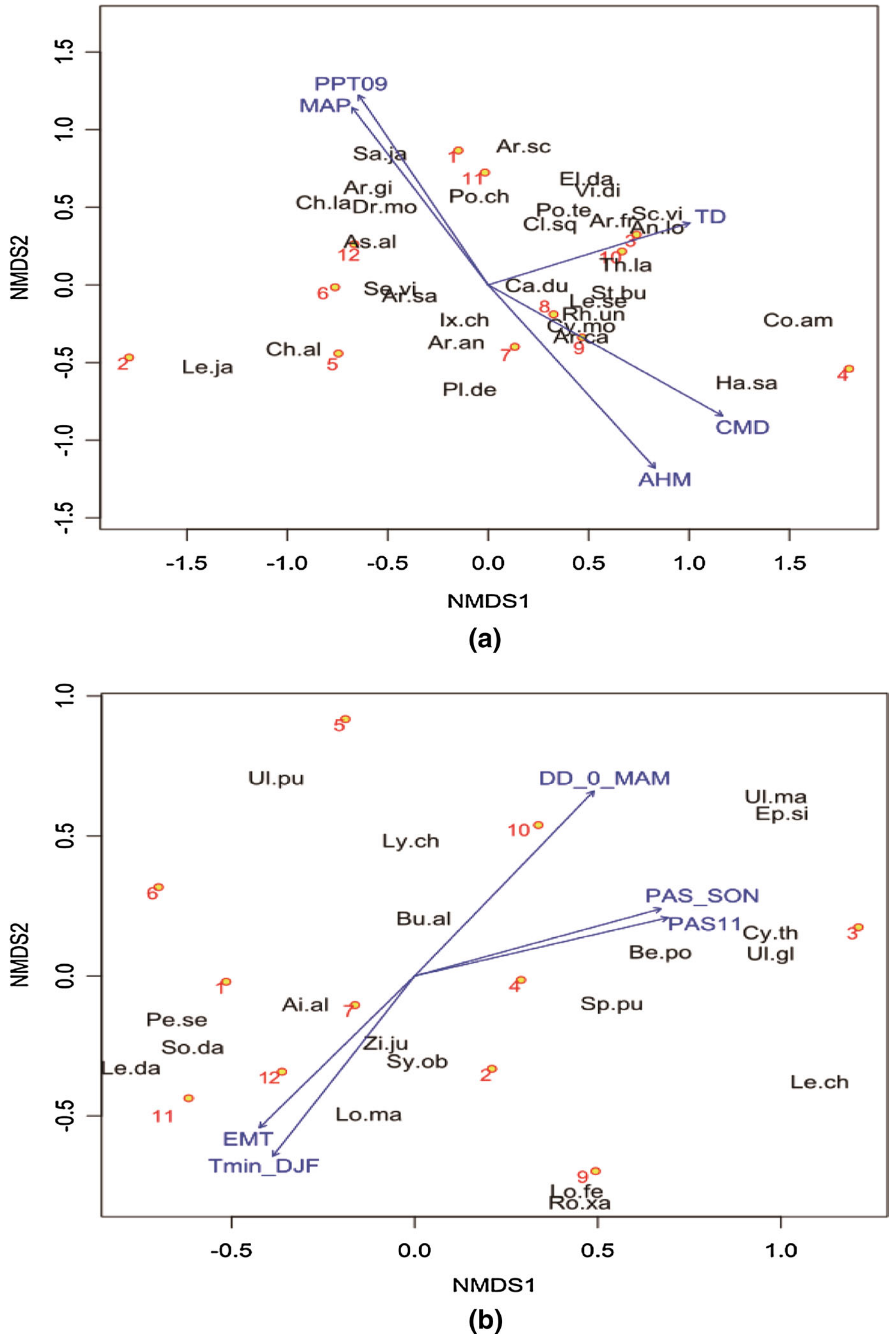

Fig. 1 Nonmetric multidimensional scaling (NMDS) ordination of herbaceous (**a**) and woody (**b**) species based on the Bray–Curtis dissimilarity of community composition (stress (herbaceous) = 0.080, stress (woody) = 0.008). Stress values of ≤ 0.1 and ≤ 0.05 are considered fair and good fit, respectively) represented the best ordination space fit (R^2 (herbaceous) = 0.970, R^2 (woody) = 0.974). The circles and numbers indicate the 12 communities and the arrows show the direction at which the climatic vectors fit the best (using envfit. function) onto the NMDS ordination space. Only climatic factors reach significant levels ($P < 0.05$) are represent

Thermopsis lanceolata. The *V* value was used to determine if these pairwise were positively or negatively associated and yielded 896 (76.19%) and 113 (9.61%) pairwise positive and negative associations, respectively. The other pairwise association indices produced a slight progression of a declining values with $OI > DI > JI$ and all were consistent and produced supporting results (Fig. 2, Table 2 and Table S2). Ochiai index (*OI*) produced 47 strong positively pairwise associations ($OI > 0.8$, Fig. 2, Table 2 and Table S2). Similarly, the point correlation coefficient (*PCC*), Pearson correlation, and *AC* were mostly similar, supporting the results obtained from the *OI*, *DI*, and *JI* indexes (Table 2).

Table 2 Summary of the eight association indices for the observed 18 significant species pairwise associations

Species pairwise association[†]	Chi-square[§]	V	Ochiai	Dice	Jaccard	Pearson	Spearman	PCC	AC
Artemisia capillaris-Cymbaria mongolica	7.92**	1	1	1	1	1	1	0.03	1
Androsace longifolia-Artemisia frigida	5.88*	1	1	1	1	1	1	0.05	1
Androsace longifolia-Ephedra sinica	5.88*	1	1	1	1	1	1	0.05	1
Androsace longifolia-Scutellaria viscidula	5.88*	1	1	1	1	1	1	0.05	1
Androsace longifolia-Ulmus macrocarpa	5.88*	1	1	1	1	1	1	0.05	1
Artemisia frigida-Ephedra sinica	5.88*	1	1	1	1	1	1	0.05	1
Artemisia frigida-Scutellaria viscidula	5.88*	1	1	1	1	1	1	0.05	1
Artemisia frigida-Ulmus macrocarpa	5.88*	1	1	1	1	1	1	0.05	1
Convolvulus ammannii-Cynanchum thesioides	5.88*	1	1	1	1	1	1	0.05	1
Convolvulus ammannii-Ulmus glaucescens	5.88*	1	1	1	1	1	1	0.05	1
Cynanchum thesioides-Ulmus glaucescens	5.88*	1	1	1	1	1	1	0.05	1
Ephedra sinica-Scutellaria viscidula	5.88*	1	1	1	1	1	1	0.05	1
Ephedra sinica-Ulmus macrocarpa	5.88*	1	1	1	1	1	1	0.05	1
Lonicera ferdinandi-Rosa xanthina	5.88*	1	1	1	1	1	1	0.05	1
Saussurea japonica-Sophora davidii	5.88*	1	1	1	1	1	1	0.05	1
Scutellaria viscidula-Ulmus macrocarpa	5.88*	1	1	1	1	1	1	0.05	1
Leymus secalinus-Thermopsis lanceolata	4.50*	0.83	0.87	0.86	0.75	0.82	0.82	0.03	1
Stipa bungeana-Thermopsis lanceolata	4.50*	0.83	0.87	0.86	0.75	0.82	0.82	0.03	1

[†]Significant pairwise associations, other non-significant pairwise associations are listed in supplemental Table S2

[§]Significant level: $*P < 0.05$; $**P < 0.01$

Discussion

Species component and response to different climatic variables

Climatic variables have significant effect on plant species communities by directly changing species interactions leading to communities' structure changes (Malanson et al. 2017; Tilman et al. 2001). The present study indicated that herbaceous species response to annual climatic variables (TD, MAP, AHM, CMD, PPT09) was stronger than woody species, especially annuals and biannual (mostly herbaceous species) (Dwyer et al. 2015; Koerner and Collins 2014). Our results is in agreement with previously published on herbaceous plants sensitivity to water resources (e.g., *Microlaenastipoides Labil*, *Cymbopogon refractus*: Pathare et al. 2017) and temperature (e.g., *Aciphylla glacialis*: Briceño et al. 2014). The observed difference between woody and herbaceous species could be due to the former slower migration rate as compared to the latter, thus creating a climate change response lag for woody species (Adler and HilleRisLambers 2008; Lenoir and Svenning 2015; Yamori et al. 2014). It is noteworthy to mention that the climate change impact is long-term in nature and the apparent contemporary ability of some woody species to withstand drought (e.g., *Pseudotsuga menziesii*: Bansal et al. 2015); yellowhorn: Ruan et al. 2017) or tolerance to low temperature (e.g., white spruce: Liu et al. 2015) is bound to climatic variables. Based on the NMDS analysis, the fact that herbaceous and woody species response differently to climatic variables hints to the ability of herbaceous–herbaceous species relationship to explain the short-term community composition changes associated with climatic variables variation while woody–woody species relationship explain those changes associated with long-term effects of climatic variables (i.e., changes in plant communities structure and composition are indicators of climatic variables). Thus, the major crop mix with woody species should consider the prevailing climatic variables as long-term plan (mapping the suitable area for the selected woody species), while mix plantation with herbaceous should be consider climatic variables to selected

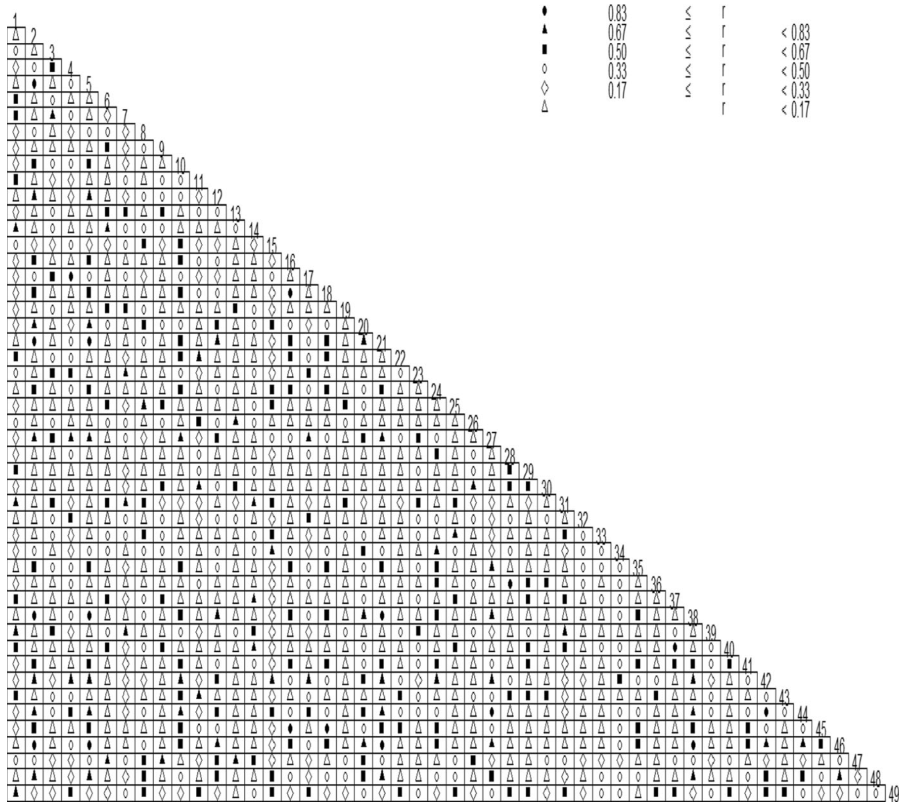

Fig. 2 Lower semi matrix of the Ochiai index (OI) showing 1176 pairwise species relationship. Filled circle, filled triangle, filled square, open circle, open square, and open diamond represent OI values of > 0.83, 0.67–0.83, 0.50–0.67, 0.33–0.50, 0.17–0.33, and < 0.17, respectively. Filled circle is the only pairwise maybe considered for yellowhorn agroforestry (see Table S1 for species number)

suitable species in different locations (i.e., species have drought tolerance may be selected for dry area).

Species association and species combination selection in yellowhorn communities

Positive species relationship plays an important role in their communities composition no matter if it is highly variable (Dullinger et al. 2007) or even non-significant (Mitchell et al. 2009). Research found that the growth rates of woody plants were highly relative to their conspecific versus heterospecific neighbors (Dohn et al. 2017). Our results indicated that both woody and herbaceous species showed multi-species positive associations in yellowhorn communities as all pairwise species association indexes (χ^2, V, AC, PCC, Jaccard (JI), Ochiai (OI), and Dice (DI)) were in agreement and supported each other and significant positive associations among economically valuable species were observed (e.g., *Artemisia capillaris*, *Artemisia frigida*, *Scutellaria viscidula, Thermopsis lanceolate, Ephedra sinica*, and *Rosa xanthina*) in the studied yellowhorn wild communities (Table 2). These positive associations could be considered for species combination selection in yellowhorn's agroforestry mixes.

Recently evidence of positive beneficial species interactions in plant communities has been recognized and reported (Kuebbing and Nuñez 2015). Such beneficial interactions could be facilitated through improving nutrient availability to a species' contemporary associates or elevating stress in harsh environments such as salt marches, and deserts and arctic regions (Blaser et al. 2013; Callaway et al. 1991; Chapin et al. 1994; Franco and Nobel 1989). For example, a reciprocal beneficial relationship was observed for an agroforestry mix consisting of planting the leguminous shrub *Retama sphaerocarpa* with the *Marrubium vulgare* understory (Pugnaire et al. 1996). Furthermore, this observed beneficial relationship was not realized if *Retama sphaerocarpa* and *Marrubium vulgare* were individually planted (Pugnaire et al. 1996). Nitrogen has a significant positive effect on yellowhorn root, stem, and leaf development and most importantly improving seeds production (Wei et al. 2010). Members of the Fabaceae family are known for their biological nitrogen fixation. *Sophora davidii* and *Thermopsis lanceolata* are members of the Fabaceae family and have shown positive association in the studied 12 yellowhorn communities. In addition to *Sophora davidii* and *Thermopsis lanceolata* nitrogen fixing abilities, which is beneficial to yellowhorn, they have proven medicinal values (Ciğerci et al. 2016; Sheela et al. 2006), representing an ideal agroforestry mix. The combinations of *Sophora davidii* or *Thermopsis lanceolata* and yellowhorn represent promising agroforestry scenarios. It is well known that *Artemisia capillaris*, *Leymus secalinus* and *Stipa bungeana* are widely distributed on the Loess Plateau (Guo et al. 2006), a situation that make *Sophora davidii* and *Thermopsis lanceolata* readily adapted to the environment. *Sophora davidii* has been successfully cultivated in Nei-Meng-gu region of China for many years (Guo et al. 2014), thus it should be consider as a feasible understory species with yellowhorn in agroforestry plantations.

Tree and shrub/herb mixes (e.g., multi-species agroforestry) are among the most common agroforestry combinations as they take full use of their spatial environment, including access to sunlight. For example, root crops, legumes, sweet sorghum, and other biofuels crops are successfully used as the intercrop with mango (*Mangifera indica*) and cassava (*Manihot esculenta*) (Harrison 2005; Harrison and Harrison 2016; Harrison et al. 2009)). Additional herbaceous and small shrub species such as *Scutellaria viscidula*, *Ephedra sinica*, and *Rosa xanthine* are well-known for their medicinal (traditional Chinese medicine, Table 3) (Efferth and Kaina 2011; Ekor 2013), and nutritional and perfume extracts values (De Padua et al. 1999). Yellowhorn agroforestry understory species could consider combining *Scutellaria viscidula* and *Ephedra sinica* or *Rosa xanthine*, which maximize the full use of the available resources. However, *Ephedra sinica* and *Rosa xanthine* were negitively associated, thus their co-planting should be avioded. The combination of *Lonicera ferdinandi* and *Rosa xanthine* is also recommended as they are positively associated pair (Fig. 2, Table 2 and Table S2).

Oil uses agroforestry demonstration sites including *Paeibua suffruticosa* and yellowhorn have been recently established in Shandong Provence China (PY, personal observation). However, yellowhorn multi-species agroforestry still needs further exploration as basic questions such as understory species selection, timing of different species planting, and intercrop distance have not fully investigated (Dick et al. 2011).

Sustainable management and mix agroforestry in yellowhorn communities

The increasing demand for forest products, including biofuel, has caused a rapid exploitation of forests resulting in substantial loss of biodiversity (Amigun et al. 2011). The development of innovative management systems that balance environmental and economic concerns while maintaining the sustainable use of the resources, especially for private and small landowners, are of substantial values. Agroforestry offers an opportunity for optimum forest utilization while maintaining biodiversity through the efficient use of underutilized resources existing in major forest tree stands/populations (Tamang et al. 2014). Yellowhorn has been recognize as one of the next-generation biofuel species in China (Zhang et al. 2010), thus it's over exploitation is of concern. The sustainable management of yellowhorn in its "close to nature" communities is a favorable scenario to forest owners and ecologist. The development of viable yellowhorn agroforestry mixes that capitalizes on the positive and significant species associations is urgently needed; however, this "new concept" is costly, not commonly practiced, and more importantly without demonstrable economic success. The present study has identified several yellowhorn and herbaceous and small shrub species positive and significant associations that could be translated to agroforestry mixes. These selections represent a "learning from nature and back to nature" paradigm, with species selections that is adapted to local climatic or bioclimatic variables as well as a prerequisite for designing conservational practices. In our opinion, future agroforestry practices should consider combining of community ecology, species associations, species distributions, climate change, and economic benefits.

Conclusions and future of work

Species screening for agroforestry is often time- and resources-dependent. Species association analyses are widely used in ecological studies and may provide an

Table 3 Species with medical use for the selected for yellowhorn agroforestry

Species	Medical values	References
Artemisia capillaris	Remedy liver diseases such as hepatitis, jaundice and fatty liver in traditional oriental medicine	Yeo et al. (2018)
Artemisia frigida	Pharmacological functions of stanch and detumescence	Liu et al. (2013) and Yang et al. (2006)
Cymbaria mongolica	Compounds exhibit significant antitumor and antibacterial activity	Dai et al. (2002) and Wang et al. (2012)
Cynanchum thesioides	Used for lungs; relive pain	Tan (2012)
Ephedra sinica	Reduce obesity and hyperglycemia	Song et al. (2012) and Zhao et al. (2009)
Leymus secalinus	Stop bleeding, chilblain and asthma relive	Jiang et al. (2015)
Rosa xanthina f. normalis	Effective for qi stagnation, blood stasis	Yu et al. (2007)
Saussurea japonica	Gingivitis treatment, chills, blood circulation, stasis analgesia, rheumatism, bruises, leprosy, cold headache, lower back pain	Toda et al. (2017)
Scutellaria viscidula	Roots are source of Huang Qin which is used as a remedy for hepatitis, diarrhea, and inflammation	Wang et al. (2003)
Sophora davidii	Root: cooling blood to stop bleeding stoppage; Fruit: anti-cancer; Leaves: cooling, detoxification and as insecticide	Ohyama et al. (1999)
Thermopsis lanceolata	Relive cough and asthma	Gao et al. (1998)
Ulmus macrocarpa	Chronic treatment with RBUM exerts antihypertensive effects in SHRs, and its direct vasorelaxant and antioxidant properties may contribute to reduce elevated blood pressure, treatment of inflammation, ulcers, cancers, and parasites	Oh et al. (2008) and Kwon et al. (2011)

efficient species screening method that could rescue information from nature. In the present study, vegetation surveys have been conducted in a total area of 36 ha across 12 sites and was effective in identifying nine species association that could be used in an agroforestry setting. Ideally, multiple replications per site are needed for assessing vegetation surveys; however, the large size of the studied plots (10 m × 3000 m) precluded the use of replications. In future studied, we recommend the inclusion of soil and terrain descriptive variable to improve the derived associations resolution. Finally, we advocate the potential of species screening as a first step in designing agroforestry systems that mimics natural settings.

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