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Vegetation patterns and nature reserve construction in an extremely-arid desert in Anxi, NW China's Gansu Province

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Abstract: Anxi County is located in the northwestern part of the Hexi Corridor in Gansu Province and has the sole national level nature reserve of extremely-arid desert in China. Phytosociological methods (Braun-Blanquet, 1964) are used to classify plant community types in this area. Eleven are distinguished, including six of deserts, four of oases and one transitional type between deserts and oases. Direct gradient analysis (DCA) is employed to correlate the distribution of plant communities to physiogeographic conditions. This study makes clear that water is the most important ecological factor for the distribution of plant species and communities in this area. The effects of water have been demonstrated in different ways. A vegetation gradient from lower altitude to higher altitude in the southern part of the reserve is driven by a precipitation gradient. The effects of the depth of ground water table contribute to the differentiation of vegetation from desert to oasis in the flat area. In a finer scale, the washed gullies have obviously higher species richness and also higher vegetation cover than the surround gobi surfaces, possibly caused by the effects of floods. The vegetation patterns demonstrate that the area of Anxi County is a complete landscape unit. The range of the current nature reserve is not large enough for the purpose of conserving the unique biodiversity in this area.

Keywords: extremely-arid desert; vegetation pattern; nature reserve; Central Asia; gobi

Introduction

The arid land of China occupies an area of about 2.5 million km^2. It can be divided into three subzones: semi-arid desert, arid desert and extremely-arid desert, according to precipitation and vegetation conditions (Chen, 1987a). The extremely-arid subzone is consisted of four parts: Normin Gobi-Juyan Lowland, Tarim Basin, East Xinjiang-Beishan Mountain, northwestern part of Qadam Basin (Chen, 1987b).

The biodiversity in China's extremely-arid desert is quite unique (Chen, 1987b; Anon, 1990). Owing to dry climate and geographical isolation, some species of Tertiary Tethys Sea origin, such as *Gymnocarpa przewalskii*, *Ephedra przewalskii*, *Sympegma regelii*, *Reaumuria soongorica*, *Nitraria sphaerocarpa*, and *Zygophyllum xanthoxylon*, are distributed in this area. This area is also known as the native place of the famous Przewalski Horse (*Equus ferus przewalskii*). 25 animals and 104 birds are recorded in Anxi County, of which 28 are listed as endangered species, for example, *Equus hemionus*, *Panthera uncia*, *Falco chrysaetos daphanea*, and *Gypaetus barbatus hemachalanus*. It is evident that the conservation of biodiversity in this area is very significant. The Anxi Extremely-Arid Desert National Nature Reserve was established in 1986 and is the sole national level reserve to conserve extremely-arid desert ecosystem in China. However, detailed description and analysis of the desert vegetation in this area, which is essential to nature reserve construction, is still lack.

Early in the 1950s, the vegetation of this area has been coarsely surveyed (Chen, 1957). Some typical community types, such as *Haloxylon* spp.-desert (Hu, 1963) and *Populus euphratica*-forest (Qiu, 1985), have been described and analyzed. But the classification of community types was based mainly on some dominant species, and there were sometimes ambiguous in the interpretation of community-environment relationships. In this paper, classification of plant communities is made in a phytosociological way, which is rational to explain the geographical pattern of vegetation in a small scale. Suggestions for

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nature reserve construction are also given based on the vegetation patterns.

1 Study area

Anxi County is located in the northwestern part of Gansu Province, China. The ancient silk-road passes through this area. The geographical coordination of the study area is 39°52′ – 41°53′N, 94°35′ – 97°00′E. The above-mentioned nature reserve is consisted of two separate parts: the northern one and the southern one(Fig.1).

The study area contains three geomorphologic units (Fig.2). The middle of it is the Corridor Plain bestriding the Shule River and forming the oasis. South of it is the front hills of the Qilian-Mountains that belongs to the edge of the Qinghai-Tibet Plateau, while north of it is the Beishan Mountains. To its northeast is the Alxa High Plain, which is a part of the Mongolia Plateau. The highest peak reaches 3547m a.s.l. near the southern boundary of the Anxi County while the lowest site of the county has an elevation of less than 1200m a.s.l.

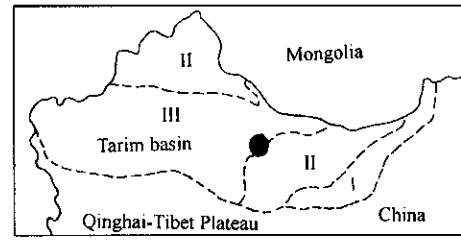

Fig.1 Location of the study area

I, II and III indicate the semi-arid desert subzone, the arid-desert subzone and the extremely-arid desert subzone in China, respectively (Chen, 1987a). The black circle indicate the study area

The climate of the study area is typically continental. The precipitation is low but the evaporation is high and thus the climate is extremely dry. Fig.3 shows the distribution of precipitation on the entire county.

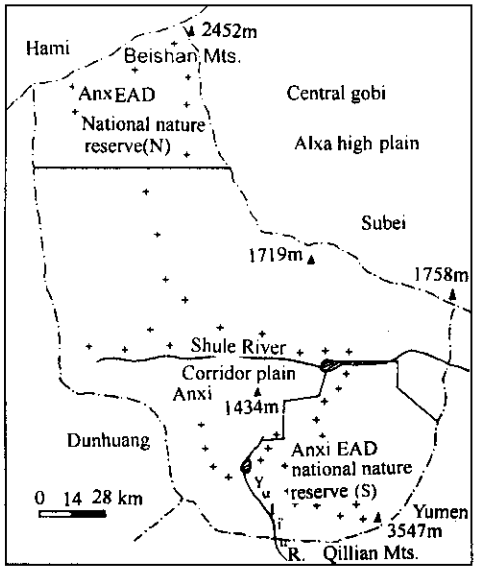

Fig.2 Physiogeographic conditions of the study area

+ represent sites of relevés

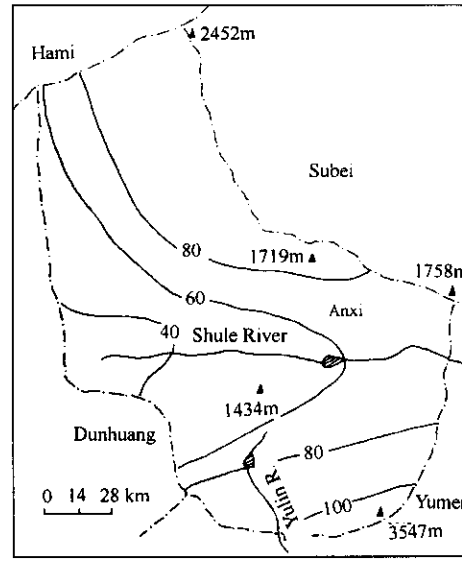

Fig.3 Isohyets of the study area (Anon, 1990)

Two rivers, the Shule River and the Yulin River, pass through the study area. There are good relationship between the ground water table and the elevation(Wu, 1995). In the Corridor Plain, the depth of the ground water table is 3 – 5m, while in the front hills and the mountains, it can reach 5 – 100m or more.

Monotypic genera as well as monotypic families characterize the flora of the study area. More than 60% of the plant species belong to elements of Central Asia.

2 Methods

Vegetation relevés with a size of 10×10 m^2 were conducted on homogeneous and representative sites. At each site the environmental items, including elevation, exposure, topography and soil composition (percentages of gravel, sand, silt and clay), were also recorded.

A total of 65 relevés are included in this analysis. Braun-Blanquet methods (Braun-Blanquet, 1964; Dierschke, 1994) are used for the classification of community types and direct gradient analysis (Mueller-Dombois, 1974) is used to interpret the relationship between community distribution and physiogeographical conditions. For the purpose of describing communities, cover values are assumed for each degree: $r = 0.1\% - 0.5\%$, $+ = 0.5\% - 1\%$, $1 = 1\% - 5\%$, $2 = 5\% - 25\%$, $3 = 25\% - 50\%$, $4 = 50\% - 75\%$, $5 = 75\% - 100\%$. The value 2 is subdivided to 2a, 2b and 2m according to Dierssen (Dierssen, 1990). The constancy levels are assumed as: $r = 1\% - 5\%$, $+ = 5\% - 10\%$, $I = 10\% - 20\%$, $II = 20\% - 40\%$, $III = 40\% - 60\%$, $IV = 60\% - 80\%$, $V = 80\% - 100\%$ (Dierschke, 1994).

This is the first time to classify the desert vegetation in a phytocoenological way in the study area and no former research can be used for a comparison. We only use differential species to distinguish community types. Further research works in a larger area are still needed for the name, the character species and hierarchical order of the communities. Hilbig (Hilbig, 1995) described the desert vegetation of Mongolia in a phytosociological way, to which we refer for a regional comparison.

3 Results

3.1 Plant communities

The results of the vegetation classification have been presented in a synoptic table (Table 1). Eleven community types can be recognized. The community types are distinguished obviously among the deserts, the oases and the transitional zones between them. Table 1 follows more or less the gradient of water supply.

3.1.1 Desert communities

The desert communities are dominated by shrub or semi-shrub species, such as *Reaumuria soongorica*, *Nitraria sphaerocarpa*, *Ephedra przewalskii*, *Sympegma regelii* and *Salsola passerina*. According to differential species, six plant community types can be distinguished.

3.1.1.1 *Nitraria sphaerocarpa*-desert

Nitraria sphaerocarpa is most frequently distributed in the desert of the study area. As a monodominant or even single-species community, it occurs when the precipitation is less than 50 mm, matching the elevation of less than 1500m. When precipitation increases, *Nitraria sphaerocarpa* is mixed with other shrub species. This distribution pattern is similar to that in the western part of Inner Mongolia (Anon, 1985).

Nitraria sphaerocarpa usually forms mound on the alluvial fan (gobi). Sands are deposited near the mound when they are blown by winds.

3.1.1.2 *Reaumuria soongorica*-desert

Reaumuria soongorica is another frequently distributed species in the study area. The *Reaumuria soongorica*-desert is distributed between 1500 – 2500m a.s.l. *Reaumuria soongorica* and *Nitraria sphaerocarpa* can both act as dominant species. Other species, such as *Salsola passerina*, *Ephedra przewalskii*, are sparsely present.

3.1.1.3 *Sympegma regelii*-desert

This community type is distributed at an elevation of 1800 – 2200m a.s.l. The species richness is higher than other desert communities in the study area. *Nitraria sphaerocarpa*, *Reaumuria soongorica*, *Salsola passerina*, *Zygophyllum xanthoxylon*, *Ephedra equisetina*, *Gymnocarpus przewalskii* and

Asterothamnus centrali-asiaticus occur with high frequencies. In contrast, the *Sympegma regelii*-desert only hosts *Anabasis brevifolia* as a fairly constant species in Mongolia (Hilbig, 1995).

Table 1 Synoptic table of vegetation types in Anxi. The left figure in a cell indicates the constancy class; the superscript in the right gives the cover class when the species is present

Vegetation type	1	2	3	4	5	6	7	8	9	10	11
Number of relevés	5	16	10	4	3	3	10	5	3	3	3
Nitraria sphaerocarpa	V^{2a-2b}	V^{+-2m}	IV^{r-1}	V^{1-2m}	V^{1-2a}	V^{r-1}	I^{+-1}	–	–	–	–
Reaumuria soongorica	–	V^{r-2m}	IV^{r-1}	V^{r-1}	V^{1-2a}	V^{r-1}	–	–	–	–	–
Sympegma regelii	–	I^{r-1}	V^{1-2a}	III^{r-+}	–	–	–	–	–	–	–
Salsola passerina	–	I^{1}	III^{1-2a}	I^{1}	–	–	–	–	–	–	–
Gymnocarpa przewalskii	I^{1}	–	III^{1-2a}	–	–	–	–	–	–	–	–
Zygophyllum xanthoxylon	–	I^{r}	III^{+-1}	I^{r}	I^{1}	I^{1}	–	–	–	–	–
Haloxylon ammodendron	–	–	–	V^{r-2m}	–	–	–	–	–	–	–
Salsola arbuscula	I^{+}	I^{+-1}	I^{1}	III^{r-2a}	I^{+}	I^{r}	–	–	–	–	–
Anabasis brevifolia	–	–	–	I^{r}	V^{1}	I^{r}	–	–	–	–	–
Stipa glareosa	–	–	–	–	V^{+-2a}	II^{2a}	–	–	–	–	–
Salsola adrotanides	–	–	–	–	–	V^{+-2a}	–	–	–	–	–
Alhagi maurorum var. *sparsifolium*	–	–	–	–	–	–	V^{1-3}	I^{1}	–	–	–
Nitraria sibirica	–	$+^{r}$	I^{r}	–	–	–	IV^{r-3}	I^{+}	–	–	–
Tamarix karelinii	–	–	–	–	–	–	I^{r}	V^{2a}	–	I^{1}	–
Tamarix remosissima	–	–	–	–	–	–	I^{r}	V^{2a-4}	–	II^{1-3}	–
Glycyrrhiza inflata	–	–	–	–	–	–	–	I^{1}	V^{2}	V^{+}	II^{1-2a}
Agropyron desertorum	–	–	–	–	–	–	I^{1}	–	V^{2}	V^{+}	–
Populus euphratica	–	–	–	–	–	–	–	–	–	V^{3}	–
Apocynum venetum	–	–	–	–	–	–	II^{+-2a}	–	–	V^{+}	–
Sophora alopecuroides	–	–	–	–	–	–	I^{1}	I^{r}	–	V^{+}	II^{+-1}
Achnatherum splendens	–	–	–	–	–	–	–	–	–	–	V^{2b-3}
Phragmites communis	–	–	–	–	–	–	II^{1-3}	–	–	–	IV^{1-3}

Notes: 1. *Nitraria sphaerocarpa*-desert; 2. *Reaumuria soongorica*-desert; 3. *Sympegma regelii*-desert; 4. *Haloxylon ammodendron*-desert; 5. *Anabasis brevifolia*-desert; 6. *Salsola adrotanides*-desert; 7. *Alhagi maurorum* var. *sparsifolium-Nitraria sibirica*-shrubland; 8. *Tamarix* spp.-shrubland; 9. *Glycyrrhiza inflata*-grassland; 10. *Populus euphratica*-forest; 11. *Achnatherum splendens*-grassland. Community presence of other species: *Ajania fruticulosa* (5,6 *), *Allium mongolicum* (5), *Anabasis aphylla* (6), *Arnebia guttata* (3), *Artemisia arenaria* (1,5), *Artemisia sphaerocephala* (2), *Artemisia xerophytica* (1 - 6), *Asterothamnus centrali-asiaticus* (1,3,4,6), *Astragalus hamiensis* (6), *Astragalus* sp. (3,5), *Atraphaxis pungens* (3), *Calligonum mongolicum* (1,2,3), *Caragana leucophloea* (5), *Caryopteris mongolica* (1), *Clematis camescens* (3), *Convolvulus gortschakovii* (6), *Cynomorium songaricum* (8), *Ephedra equisetina* (1,2,3,6), *Ephedra przewalskii* (3,4), *Halogeton glomeratus* (2), *Halostachys caspica* (6), *Kalidium foliatum* (8), *Kalidium gracile* (5), *Hydesarum multijugum* (3), *Leymus secalinus* (11), *Limonium maritima* (3), *Lycium ruthenicum* (7,8), *Nitraria roborowskii* (7,8), *Oxytropis glabra* (2), *Saussurea salsa* (11), *Scorzonera pseudodivaricata* (3), *Scorzonera divaricata* (3), *Rheum nanum* (4), *Zygophyllum rosovii* (5). * code of plant commuunity types

3.1.1.4 *Haloxylon ammodendron*-desert

As the only tree species in the deserts of the study area, the distribution of *Haloxylon ammodendron* is confined to some plots. In the *Haloxylon ammodendron*-desert, *Haloxylon ammodendron* occupies the

tree layer with cover values from less than 1% to over 10%. The shrub layer is dominated by *Reaumuria soongorica* and *Nitraria sphaerocarpa*. Herbaceous species, such as *Stipa glareosa*, also occur in some cases. According to the classification of Hilbig (Hilbig, 1995) in Mongolia, our relevés can be included into the *Reaumuria soongorica* variant and the *Nitraria* variant of the *Haloxylon* desert respectively.

3.1.1.5 *Anabasis brevifolia*-desert

This desert type has obviously two layers: the shrub layer and the herb layer. It is distributed only in the northern part of the reserve. The shrub layer is dominated by *Nitraria sphaerocarpa* and *Reaumuria soongorica* while the herbaceous layer is dominated by *Stipa glareosa*, showing a transition between the arid desert (also named true desert) and the extremely-arid desert.

3.1.1.6 *Salsola adrotanides*-desert

The species composition and structure of this community type is similar to the *Anabasis brevifolia* community. It is distributed mostly in those sites with more clay and silt than sand and gravel.

3.1.2 Oasis communities

3.1.2.1 *Populus euphratica*-forest

As a riverine community, the *Poplus euphratica*-forest is distributed near the Shule River and the Yulin River. *Populus euphratica* is the sole species in the tree layer. Understory species are dominated by *Tamarix* spp., *Glycyrrhiza eurycarpa*, *Agropyron* spp., *Sophora alopecuroides* and *Apecynum venetum*. The species composition is similar to its typical distribution in the Tarim Basin(Wu, 1980).

3.1.2.2 *Tamarix* spp.-shrubland

This community type is widely distributed in the oasis. Eight *Tamarix* species were recorded. Two of them, *T. karelinii* and *T. remosissima* usually dominate. The cover of the shrub layer is usually over 10%, and sometimes reach 60%. The herbaceous layer is dominated by such species as *Glycyrrhiza inflata*, *Sophora alopecuroides* and *Kalidium foliatum* with low cover values.

3.1.2.3 *Glycyrrhiza inflata*-grassland

Three *Glycyrrhiza* species were recorded in the study area. *Glycyrrhiza inflata*-grassland is most frequently distributed on sandy soils in the study area. *Agropyron desertorum*, *Sophora alopecuroides* and *Apocynum venetum* also occur in this community type.

3.1.2.4 *Achnatherum splendens*-grassland

The *Achnatherum splendens*-grassland occurs usually in salinized soils. Its upper sub-layer is dominated by *Achnatherum splendens* with a height of over 1m. In the lower sub-layer, *Sophora alopecuroides*, *Glycyrrhiza* spp. and *Alhagi maurorum* var. *sparsifolium* and others occur.

3.1.3 Oasis-desert transitional zones

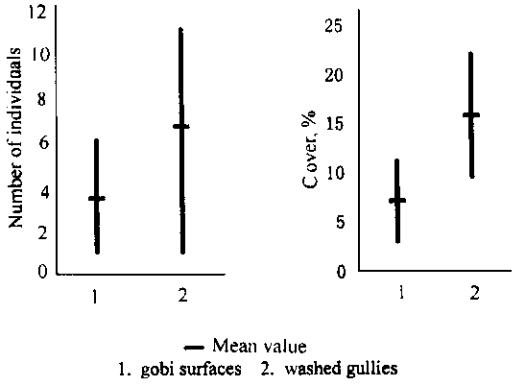

Fig.4 Differences between the washed gullies and the surrounding gobi surfaces

The oasis-desert transitional zones are characterized by *Alhagi maurorum* var. *sparsifolium*-*Nitraria sibirica*-shrubland. A gradient from desert to oasis will be discussed in the following part.

3.2 Spatial pattern of vegetation distribution

3.2.1 Topographic conditions and vegetation complex

On the Gobi deserts, the land surfaces are not homogeneous. Gullies washed by floods have more silt and clay than surrounding gobi surfaces. The water supplies are also more sufficient in washed gullies than on the gobi surface during the rainy season. A vegetation complex can be detected.

Differences of species richness and vegetation cover between gullies and surrounding gobi surfaces are shown in Fig.4. It is found that gullies have generally more species than the gobi surfaces. But species richness has also relations with plant community types. For example, the *Nitraria sphaerocarpa*-desert has only one species in both gullies and gobi surfaces. The vegetation cover usually exceeds 10% in gullies but below 10% in the surrounding gobi surfaces.

The differences between gobi surfaces and washed gullies might be affected by both soil conditions and water supplies. Some species, for example *Calligonum mongolicum* and *Gymnocarpus przewalskii*, are usually confined in gullies. These species have been demonstrated to tolerate drought stress worse than *Nitraria sphaerocarpa*, *Reaumuria soongorica* and *Sympegma regelii* (Lou, 1985; Wu, 1995). Therefore, we speculate that plants in gullies can obtain more water than on gobi surfaces when floods pass through.

3.2.2 Elevation and community continuum

Fig.5 shows the change of the cover values of different desert species along the elevation in the southern part of the reserve. With the increase of the elevation, the cover of *Nitraria sphaerocarpa* declines while that of *Reaumuria soongorica* and *Sympegma regelii* rises up. A good example of community continuum can be detected.

The change of plant species along the elevation matches the change of precipitation in the southern part of the reserve. Laboratory experiments show that *Nitraria sphaerocarpa* tolerates water loses better than other species (Lou, 1985; Wu, 1995). The above-mentioned pattern of species distribution also in consist with this result.

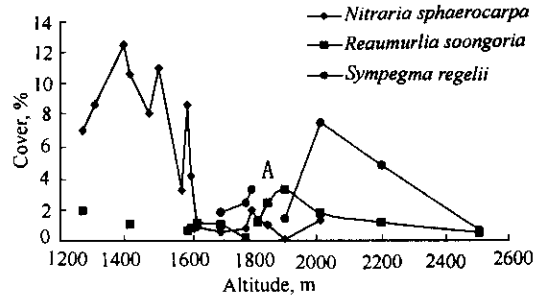

Fig.5 Changes of species coverage along the altitude in the southern part of the reserve

When the elevation exceeds 2500m, the vegetation is changed to steppe dominated by species of *Artemisia*, such as *A. frigida*, *A. macrocephala* and *A. scoparia*. When it reaches 2900m, subalpine species, such as *Potentilla parvifolia* var. *hypoleuca*, dominate.

3.2.3 Vegetation gradient of the desert-oasis transitional zone

Ten relevés along a topographical gradient from desert to oasis are set near the Shule River to show the vegetation gradient. An obvious decline of vegetation cover and number of individuals in per unit area is found along the gradient from oasis to desert. The change of species composition is shown in Fig.6. The boundaries between different community types are easy to detect. *Alhagi maurorum* var. *sparsifolium*-*Nitraria sibirica*-shrubland is strictly confined to the desert-oasis transitional zone and thus serves as its indicator in the study area.

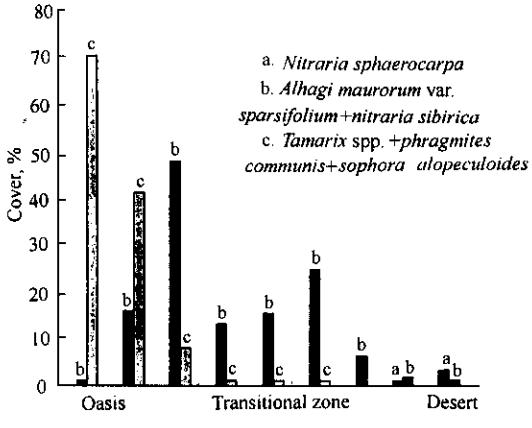

Fig.6 Vegetation transition from desert to oasis

4 Discussion

4.1 Vegetation differentiation in the study area

The landscape of Anxi County consists of three parts, the southern Gobi, the northern Gobi and the Shule River basin. From the distribution of plant species and communities, the vegetational characteristics of them are quite different, the

southern Gobi is different from the northern one by the lacking of herbaceous layer in the communities. The former one also has an evident vertical gradient of vegetation distribution. From lower altitude to higher altitude, the community types are changed from *Nitraria sphaerocarpa*-desert to *Reaumuria soongoria*-desert and followed by *Sympegma regelii*-desert. In the northern Gobi, *Haloxylon ammodendron*-desert, *Anabasis brevifolia*-desert and *Salsola adrotanides*-desert are typical. Between the northern Gobi and the southern Gobi, the oasis is formed near the Shule River. Transitional zone between oasis and desert maintains plant species that occurs neither in the desert nor in the oasis.

Based on vegetation pattern, the landscape in Anxi County can be regarded as a complete unit. Water is the driving factor for the distribution of plant species and communities. Spatial distribution of precipitation and ground water table determines the heterogeneity of this landscape unit, which is the basis for biodiversity in the study area.

4.2 Improvement of the current nature reserve

The shrub species-dominated extremely arid desert in Central Asia(northwestern China and western Mongolia) is quite different from the desert in other part of the world(Yong, 1990). Although species richness is relatively poor, most of them are endemic species. In Anxi where extremely arid desert is the zonal vegetation, endemics act as dominants, such as in the *Nitraria sphaerocarpa*-desert and *Sympegma regelii*-desert. *Gymnocarpa prezwalskii*, *Salsola passerina* and *Zygophyllum xanthoxylon*, characteristic species of the *Reaumuria soongorica*-desert, are also endemics in Central Asia.

The current nature reserve consists of two part, one in the north and the other in the south (Fig.2). For the purpose of biodiversity conservation, the follow shortcomings arise: (1) Water is the controlling factor for plant community distribution. The distribution of some tree species, such as *Populus euphratica*, is confined to the river banks. They are unprotected and suffering the risk of extinction in Anxi due to over-use of surface water by the humans. (2) The desert-oasis ecotone has relative high species richness. Due to human cultivation, some of the ecotone have been destroyed and direct contact between desert and oasis thus occurs. (3) Some animals need a large area for their growth and breeding, for example, some species living in the desert may come to the river to drink water. But large part of the river was not included into the reserve and animal movement was threatened by human disturbance. (4) The range of the present reserve is too small to protect the typical elements of the extremely arid desert, for example, the most part of the *Nitraria sphaerocarpa* desert was excluded from the reserve.

On the basis of vegetational pattern, it is suggested that current reserve should be enlarged to contain the whole landscape unit, that is to say the whole range of Anxi County.

5 Conclusions

From above discussions, following conclusions can be made:

The desert communities of the study area are generally species poor but unique, most of them are shrub or semi-shrub species, which is typical in Central Asia (Wu, 1980; Anon, 1985; Yong, 1992; Hilbig, 1995).

Water is most important for the distribution of species and communities in the study area. The effects of water are demonstrated in different ways. Inside the Gobi desert, washed gullies and surrounding Gobi surfaces have different water supply during the rainy seasons and thus have different plant species composition and covers. The transitional zone from desert to oasis shows the effects of different depth of ground water table on the differentiation of vegetation. In the southern part of the reserve, precipitation along the elevation controls the distributions of species and communities.

On the basis of the evaluation of the present nature reserve, it is suggested that the whole county should be included into the range of the reserve in order to protect a complete landscape unit.

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