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Vegetation Patterns and Options for Ecological Restoration in the Central Loess Plateau of Shaanxi Province, PR China

- Ulrich Schmitt, Anton Fischer, Clemens Abs, München

Yang Pinghu, Chen Cungen, Yangling -

Abstract

Large-scale forest restoration is an important ecological option for reducing soil erosion and preventing further land degradation in the Central China Loess Plateau Region. As demonstrated for the area of Yan'An Prefecture in Shaanxi Province, remnant forest patches in largely deforested and degraded areas still include significant information on the composition of locally adapted natural plant communities as well as the underlying ecological factors that shape their local distribution. Vegetation surveys and the analysis of vegetation data can promote ecological reforestation when results of such surveys are compiled and formulated in terms of operational guidelines for local decision makers, which do not have such information readily available. For the region of Yan'An, exposition and local topography can serve the major ecological selection criteria for appropriate tree and shrub species out of a large local species pool. The option of utilizing local and economically exploitable species is thus one important element in reforestation programmes. However, to ensure the long-term sustainability of such ecological restoration efforts, socio-economic surveys as well as land-use planning need to supplement such research in order to ensure sound spatial priority setting as well as to find acceptance in economically underdeveloped regions as there still are on the Chinese Loess Plateau.

Zusammenfassung

Großräumige Wiederaufforstungen im zentralchinesischen Lössplateau sind wichtige ökologische Maßnahmen der Erosionsminderung und der Verringerung von fortschreitender Degradation. Am Beispiel von vegetationskundlichen Untersuchungen in der Region Yan'An in der Provinz Shaanxi wird gezeigt, dass Reste der ursprünglichen Waldvegetation in weitgehend entwaldeten und degradierten Bereichen heute noch relevante Informationen über die Zusammensetzung der lokal angepassten Vegetation sowie über die ökologischen Standortparameter enthalten, die die räumlichen Verteilung der Vegetation bestimmen. Die Analyse von vegetationskundlichen Datensätzen kann daher wichtige Hilfestellungen für Aufforstungen mit heimischen Arten liefern, wenn die Ergebnisse vegetationskundlicher Arbeiten in Form von operationalen Richtlinien lokalen Entscheidungsträgern zur Verfügung gestellt werden, die über Kenntnisse heimischer Arten nicht oder nur ungenügend verfügen. Für die Region Yan'An können die Standortfaktoren Exposition und Topographie als wichtigste Kriterien für die Auswahl von heimischen Baum- und Straucharten aus einem großen lokalen Artenspektrum angesehen werden. Die Möglichkeit, auf heimische und wirtschaftlich nutzbare Arten zurückzugreifen, ist ein wichtiges Element im Rahmen von Wiederaufforstungen. Um die Nachhaltigkeit von Renaturierungsmaßnahmen sicherzustellen, sind sozioökonomische

Untersuchungen sowie integrierte Landnutzungsplanungen ebenfalls von Bedeutung. Mit einer Verknüpfung dieser drei Teilaspekte können ausgewogene räumliche Pritäten für Wiederaufforstungsmaßnahmen definiert werden. Besonders in unterentwickelten Regionen wie dem chinesischen Lössplateau ist die Akzeptanz durch die ländliche Bevölkerung entscheidend für einen Erfolg von Vorschläge zur Verbesserung des Landschaftshaushaltes.

1. Introduction

The Central Loess Plateau of Northwest China comprises the world's largest geological deposits of wind-blown loess and today is characterized by massive soil erosion and the most serious land degradation in China (HUANG 2000). Annual erosion rates in Central Shaanxi Province amount to 4,300 tons/km^2 under farmland and up to 6,100 tons/km^2 in heavily degraded locations (LUO 1995). In addition, the Loess Plateau Region is considered to be one of the least developed and poorest regions in China. The impoverished population largely depends on agriculture and cannot afford the continued loss of fertile soil surfaces (VEECK et al. 1995). In this context, the Chinese Government has long given high priority to broad soil erosion prevention measures and the improvement of farming techniques such as wide-level terrace agriculture and the development of fruit tree plantations (WORLD BANK 2000). However, in addition to mainly production oriented soil erosion prevention measures ecological restoration and reforestation is an important option to mitigate land degradation and to reduce current erosion rates.

Vegetation surveys in natural forests can serve as useful guidance for ecological restoration efforts of deforested and degraded areas. This is especially true if ecological and managerial knowledge of local species and plant diversity is not available to or properly developed by local decision makers and reforestation planners. Depending on the grade of degradation remnant forest patches in largely deforested areas can still assemble major components of the site-specific natural plant communities and be seen as valuable information source to provide insights into general vegetation composition, species occurrences and vegetation distribution along ecological gradients in these particular areas. In order to efficiently and adequately utilize such vegetation-related information derived from remnant forests special attention has to be paid to the underlying ecological site factors, which might vary with on very small spatial scales and also change along medium and large-scale ecological traits.

This paper presents results of vegetation research carried out in the Central Loess Plateau Region of Northern Shaanxi Province (P.R. China). Within the framework of a Sino-German research project titled „Erosion Control in Shaanxi Province“ fieldwork for vegetation research was mainly carried out by the Chair of Geobotany (TUM-Germany) with support from the North-western Science and Technology University of Agriculture and Forestry in Yangling/Shaanxi (P.R. China). Specific research objectives of this particular project component were to survey the remains of natural forest vegetation in the northern part of Yan'An Prefecture, to derive major natural forest vegetation types, and to identify the determining ecological site factors. Further objectives were to investigate secondary vegetation in heavily degraded areas and to identify ecological site factors, which determine species composition and distribution. In order to analyse the potential transferability of forest vegetation types to degraded areas vegetation relevés of degraded areas were compared among different sites to isolate ecological factors from human factors assumed to be influential on the current vegetation distribution. Finally, a first attempt was made to assess the economic cost that would be associated with large-scale land-use changes through reforestation and to evaluate potential socio-economic impacts of large-scale reforestation campaigns as a major effort to reduce soil erosion.

In addition to vegetation research, the above Sino-German Research cooperation includes two more components, which are not covered in this article. By using remote sensing technologies the project seeks to identify erosion hotspots in selected areas by comparing sets of satellite images from different periods and to prioritise areas where erosion prevention measures are most needed. Furthermore, the project aims at spatially relating data on ecological, land-use and socio-economic characteristics in a geographical information system and to develop an integrated land use plan including local plant species and socio-economic characteristics. This research project is thus a timely reference to several ecological programmes, which were initiated by the Central Chinese Government in recent years. The two most related among them are the Three-North Shelterbelt Programme (duration from 1978 to 2050) - an integrated rural development program with the general purpose of increasing vegetation cover rates in China's Northern regions - and the campaign „Returning Farmland to the Forests" (initiated in 1999) with the major objective of reducing agriculture on erosion-prone slope lands in the middle and upper watersheds of Yellow and Yangtze Rivers.

2. Material and Methods

2.1 Study Area

Yan'An Prefecture of Shaanxi Province (city district of Yan'An at 109°18' - 110°15' E / 36°05' - 37°05' N) is located in the middle reaches of the Yellow River and part of the Central Loess Plateau (chin: Huangtu Gaoyuan), a distinct geo-morphological unit in Northwest China (fig. 1).

With a total area of 37,000 square kilometres Yan'An is the second largest administrative district in Shaanxi. As part of the Central Loess Plateau it belongs to a transition zone between the Southeast-Asian monsoon climate and the Siberian-Mongolian continental climate. Distinct features of the regional climate are warm and rainy periods during the summer months June to September and cold and dry periods during the wintertime.

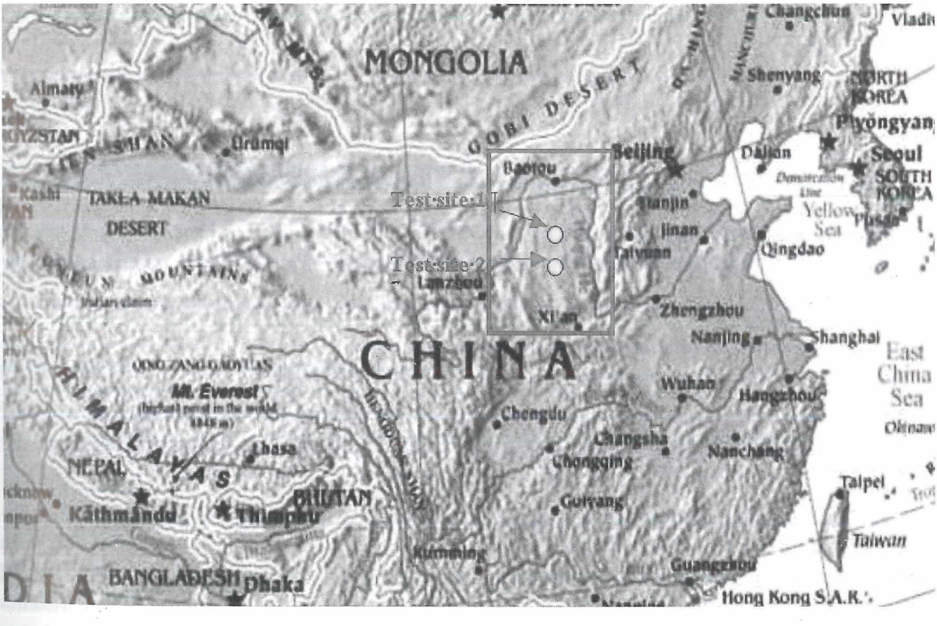

Figure 1: Geographical location of research area and test sites on the Loess Plateau.

Spring and autumn are short transition periods, where spring is especially dry and characterized by sudden temperature declines with negative impacts on vegetation and agricultural production. In autumn, temperatures decline rapidly and mark a sharp end of the vegetation period. In general, large seasonal and daily temperature amplitudes dominate the regional climate.

Mean annual precipitation in Yan'An region ranges from 450 to 550 mm of which the majority falls during July to September. The average daily temperature is 9.3 °C, while average maximum temperatures in July generally exceed 22 °C and minimum temperatures are generally below -6 °C in January. The frost-free period is 150 to 170 days (ZOU 1996). Reflecting the climatic transition from semi-humid to semi-arid conditions the common classification systems of vegetation zonation of the Central Loess Plateau describe the region of Yan'An as forest grassland zone, which at its northern borders gradually transits into the zone of typical grasslands (MENZIES 1994).

Loess layers in this area can reach up to 200 meters, whereby the upper layers are mainly comprised of Malan Loess and New Loess from more recent depositions. Both types of loess are characterized as of block structure, easy to disperse when wet and of poor erosion resistance (ZOU 1996).

Yan'An prefecture itself is divided into two geo-morphological and microclimatic sub-regions, whose characteristics can be observed in the differing land use structures. The northern sub-region belongs to a larger region known as Shanbei („mountainous north") comprising the northern parts of Shaanxi and Shanxi provinces. Shanbei region forms the so-called loess uplands (loess highlands). This northern sub-region - about one half of the total land area of Yan'An - accounts for 31% of the agricultural land of the prefecture, for 73% of grassland and for 17% of the total forestry land. Agricultural land is mainly on slopelands and in general of low productivity. Slightly less precipitation and a general lack of natural vegetation cover in this area is widely acknowledged (ANONYMOUS 2000).

The southern sub-region of Yan'An district accounts for about 69% of all available farmland, 83% of land for forestry and for about 27% of the grasslands of the district. Geo-morphologically, the southern sub-region mainly centres around the counties of Luochuan and Huangling with the typical loess tablelands and plateaus dissected by steep gullies (chin: Gaoyuan Qu).

The regional forest vegetation includes oak (*Quercus liaotungensis*), Arbor vitae (*Platycladus orientalis*), maple (*Acer ginnala, Acer stenolobum*) and a number of other broadleaved tree and shrub species (e.g. *Ulmus pumila, Pyrus betulafolia, Betula platyphylla, Lonicera hispida, Lonicera maackii*). Major agricultural crops of Yan'An are apple, walnut, chestnut, Chinese pepper (*Xanthoxylum bungeanum*), pear, Chinese date (*Ziziphus jujuba*), tobacco, apricot, peach and grape (ANONYMOUS 2000).

Initially, three locations within test site 1 in the northern sub-region of Yan'An district were selected for vegetation surveys, which are covered in this article (fig. 1). These locations represent typical features of the remaining natural forest vegetation as well as degraded secondary vegetation in close proximity to intensively used agricultural areas:

(1) Within the state forest farm of Nan Niwan (109°31'36" - 109°49'58"E / 36°10'36" - 36°25'05"N) forest vegetation was surveyed. (2) In the adjacent community lands of the Liu Linzhen Township surveys were carried out to investigate vegetation patterns of degraded secondary steppes. (3) The same was done in the community lands of He Zhuangping Township (about 40 km further north to (2)).

Elevation in the survey area range from about 1,100 to 1,400 m a.s.l. in Nan Niwan and Liu Linzhen and from 800 to about 1,100 m a.s.l. in He Zhuangping. Characteristic for all three sites are homogenous light loessial soils of little or no soil development.

2.2 Field Surveys

Field surveys were carried out during the summer months June to September of 2000 and 2001. Sample plots were stratified to equally cover all expositions as anticipated major ecological factor on the homogeneous loessial soils. Sample units were placed to examine natural and degraded vegetation patterns but did not cover agricultural areas and farming systems.

Vegetation was recorded on 10 m x 10 m marked out sample plots widely distributed in each of the three survey areas. Within each plot, all vascular plant species were recorded according to the following three height classes: ground vegetation (0-1 m), shrub vegetation (1-3 m), tree vegetation (>3 m). Cover degrees of plant species as well as total vegetation cover were estimated according to a modified Braun-Blanquet cover-abundance scale (tab. 1) (FISCHER 1995).

Table 1: Cover-abundance scale.

Cover value	+	1a	1b	2a	2b	3	4	5
Coverage %	< 1	1 - 3	3 - 5	5 – 12.5	12.5 - 25	25 - 50	50 - 75	75 - 100
Mean Coverage %	0.5	2	4	8.75	18.75	37.5	62.5	87.5

Ecological parameters recorded for each plot included altitude, exposition and slope degree. Further were recorded the occurrence of organic litter, existence and depth of an organic mineral horizon, and the $CaCO_3$ - content measured in 20 cm soil depth. Finally, grazing intensity as well as recent events of timber cutting and other human activities were visually assessed and recorded to complete the general description of each plot.

Species, which could not be identified in the field, were collected for later identification based at the Sci-Tech University of Agriculture and Forestry in Yangling. The nomenclature of vascular plants is according to the FLORA LOESS PLATEAU SINICA (1992ff.)

2.3 Data Analysis

Vegetation relevés were compiled separately for forest vegetation and degraded secondary vegetation. Two data sets - (1) forest vegetation and (2) secondary shrub vegetation, each of about 120 samplings - were then tabulated and prepared for further statistical evaluation. For the sake of clarity species occurring only once in the data set were eliminated for the numerical analysis. Since they don't provide information on redundancy patterns in the data multivariate methods cannot handle them satisfactorily (GAUCH 1982).

In a first step, cluster analysis using Sorensen (Bray & Curtis) Distance Measure (HILL et al. 1980; GAUCH 1982) was applied to both sets of relevés (PC-ORD for Windows). A first approximation of groups of sample plots on the third level of division was derived for forest vegetation as well as for shrub vegetation for further interpretation. Groups derived from forest vegetation samples were then manually reorganized and named after the most abundant tree species. Similarly, groups derived from shrub vegetation samples were manually reorganized according to the most frequent shrub species or ground vegetation species if shrubs (>1 m) did not occur in this particular group. The reorganization of vegetation samples and the identification of the most abundant species within each group resulted in a small set of plant communities for forest vegetation and for shrub vegetation respectively. These groups could also be visually identified and confirmed in the field.

In a second step, detrended correspondence analysis (PC-ORD for Windows; DCA, HILL et al. 1980) was used to detect correlations between these approximated groups and recorded environmental parameters. Vegetation relevés were then presented in an ordination diagram to illustrate their distribution in a two-dimensional ecological space along three anticipated environmental gradients, namely exposition, altitude and slope.

In a final step, two factors of direct human influence (grazing regime, timber cutting) and 3 indicators of indirect human disturbance (occurrence and abundance of farm weeds, life-form groups, introduced species) were evaluated to allow for conclusions regarding land use and disturbance history. The results of this latter step are not covered in this article.

3. Results

3.1 Forest Vegetation

The results of the cluster analysis revealed that forest vegetation samples appeared to describe a rather continuous community variation. Samples thus could not sharply be separated into distinct groups but instead diverged only gradually into several clusters. Six larger groups suggested by the hierarchy tree were identified within the third cluster level and further sorted according to dominant species in the tree layer. These groups and their dominating tree species as well as their expositional distribution are presented in table 2.

The ordination diagram below (fig. 2) arranged sample plots along ordination Axes 1 and 2 in a two-dimensional coordinate system. Again, as already observed from the results of the clustering above, sample plots along Axes 1 and 2 could not be clearly segregated into distinct units but instead showed a tendency of continuously transiting from *Quercus lioatungensis* dominated samples (Group 1) restricted to the left-hand side of the scatter plot to *Acer stenolobum* dominated sample groups (Group 2 and 3), and finally to *Platycladus orientalis* dominated samples (Group 4) on the far right of the diagram. Group 5 (*Quercus liaotungensis* - mixed deciduous communities) was located below Axis 1 and to the left of Axis 2, while a small cluster of *Koelreuteria paniculata* dominated plots (Group 6) could only be found in the area below Axis 1 and to the right of Group 5.

From the recorded environmental factors exposition could be found supportive in explaining these compositional patterns of the vegetation samples along Axis 1. In addition, slope degree and elevation were also identified as two additional ecological vectors along Axis 1

Table 2: Groups of vegetation samples – natural forest vegetation.

	Group Name Dominating Tree Species	Co-dominant Tree Species	Exposition/Site Conditions
Group 1	*Quercus liaotungensis*	*Acer stenolobum* *Acer ginnala*	N / NE / NW
Group 2	*Acer stenolobum*	*Euonymus verrucosoides* *Quercus liaotungensis*	N / NE/ NW Hill tops and upper slopes
Group 3	*Acer stenolobum*	*Amygdalus davidiana* *Xanthoceras sorbifolia*	SW / W; E / SE
Group 4	*Platycladus orienatalis* *(Thuja orientalis)*	*Sophora davidii*	S /SW Slopes > 35°
Group 5	*Quercus liaotungensis*	*Malus baccata, Ulmus pumila* *Populus davidiana etc.*	Valleys and lower slopes
Group 6	*Koelreuteria paniculata*	-	SW – exposed lower slopes and valleys

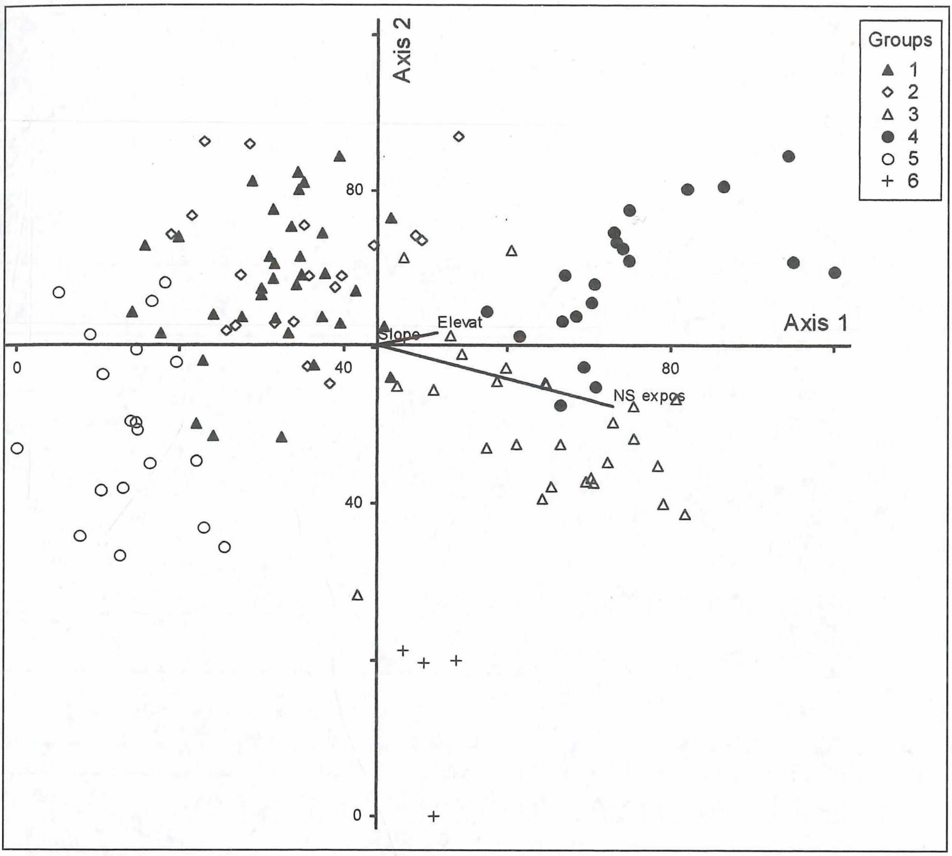

Figure 2: DCA ordination diagram – natural forest vegetation in the ecological space (Yan'An Prefecture). Group number according to Table 2

but were much less pronounced than exposition. Because of the very small range of elevations in this particular area of only about 300 meters, the elevation gradient is more accurately interpreted as a topographic gradient, where higher elevations simultaneously describe hilltops and upper slopes while lower elevations simultaneously mark lower slopes and valleys.

The conclusion of the above analysis and an interpretation of the spatial distribution patterns of the current forest vegetation in the northern sub-region of Yan'An district can be offered as follows: In an environment of rather homogenous soil and nutrient conditions local forest plant communities appear to be mainly shaped by site-specific humidity conditions. So far, these humidity or aridity conditions seem to be dominated by the exposition of each particular site.

On northern, northeastern and eastern slopes of higher humidity oak (*Quercus liaotungensis*) dominates forest communities. Oaks (*Quercus liaotungensis*) are gradually replaced by *Acer stenolobum* communities, followed by *Acer stenolobum, Pyrus betulafolia* and *Amygdalus davidiana* communities to xerothermal tree species (e.g. *Xanthoceras sorbifolia* etc.) as one moves to more drier sites on north-western, western, south-western slopes. Apparently, only *Platycladus orientalis* can cope with the driest conditions on southern facing slopes of the survey area.

Though much less pronounced, local topography, as expressed in elevation and slope degree, can also be interpreted as a humidity-aridity gradient parallel to exposition. Again, *Quercus liaotungensis*, *Malus baccata, Ulmus pumila, Acer ginnala*, and several poplar species mainly dominate valleys and lower slopes of better water availability, while *Acer stenolobum, Pyrus betulafolia* and *Amygdalus davidiana* follow on middle and upper slopes of medium slope degrees. *Platycladus orientalis* forests again characterize the relatively driest sites with slope degrees above 40° or exposed upper slopes.

As a more general conclusion concerning future reforestation and restoration activities, it has been found that the northern part of Yan'An District still contains a diverse natural forest vegetation, even though the region has long been under intensive agricultural use and many areas are heavily degraded.

The comparatively large species pool (altogether about 40 tree and shrub species) offers a variety of options to move away from previously practised mono-species afforestations (mainly *Robinia pseudoacacia, Pinus tabulaeformis*) towards natural forest restoration. For reforestation tasks in this particular region, exposition and topography (as a second indicator of local humidity conditions) should serve as major ecological decision criteria for the selection of appropriate tree and shrub species.

3.2 Degraded Shrub Vegetation

The classification attempt of degraded secondary shrubs in the Yan'An region again revealed a continuous variation in vegetation patterns rather than discrete and clearly definable vegetation structures. For the reason of conceptualising degraded vegetation patterns, four larger groups of plant communities were identified for further interpretation as summarized in table 3.

Table 3: Groups of vegetation samples – degraded shrub and steppe vegetation.

	Group Name Dominating Species	Co-dominant Species	Exposition/Site Conditions
Group 1	*Artemisia mongolica*	*Stipa bungeana Bothriochloa ischaemum*	N / NO / O
Group 2	*Artemisia mongolica*	*Stipa bungeana, Lespedeza juncea, Sophora davidii*	NO / SO / W / SW
Group 3	*Artemisia mongolia*	*Carex lanceolata, Lonicera hispida, Cotoneaster div. spec.*	N / NO / O / NW / W
Group 4	*Sophora davidii*	*Ziziphus jujuba*	S / SW

The analysis shows, that *Artemisia mongolica* communities and other *Artemisia* species together with species typically found in steppe vegetation types of the region by and large dominate secondary shrub vegetation. Group 3 also included several species, which had been found in the forest plant communities of Nan Niwan, while Group 4 - separated already on the first division level of the cluster analysis - is characterized mainly by *Sophora davidii* shrubs.

Placed in the ordination diagram (fig. 3) together with the aforementioned ecological vectors exposition, elevation and slope degree, vegetation samples showed a continuous transition from *Artemisia mongolica* dominated communities on the left and central part of the ordination diagram to *Sophora davidii* communities gathering in the far right of the diagram. Similarly to forest vegetation, exposition appeared as most significant ecological gradient along Axis 1 again.

This result well corresponds with the earlier observation that *Sophora davidii* shrubs occurred most frequently on southern exposed slopes of less humidity. However, in contrast to three parallel ecological traits along Axis 1 of above, sample plots of secondary shrub vegetation showed an additional differentiation along Axis 2 associated with elevation, though a differentiation along Axis 2 is of much less explanatory power.

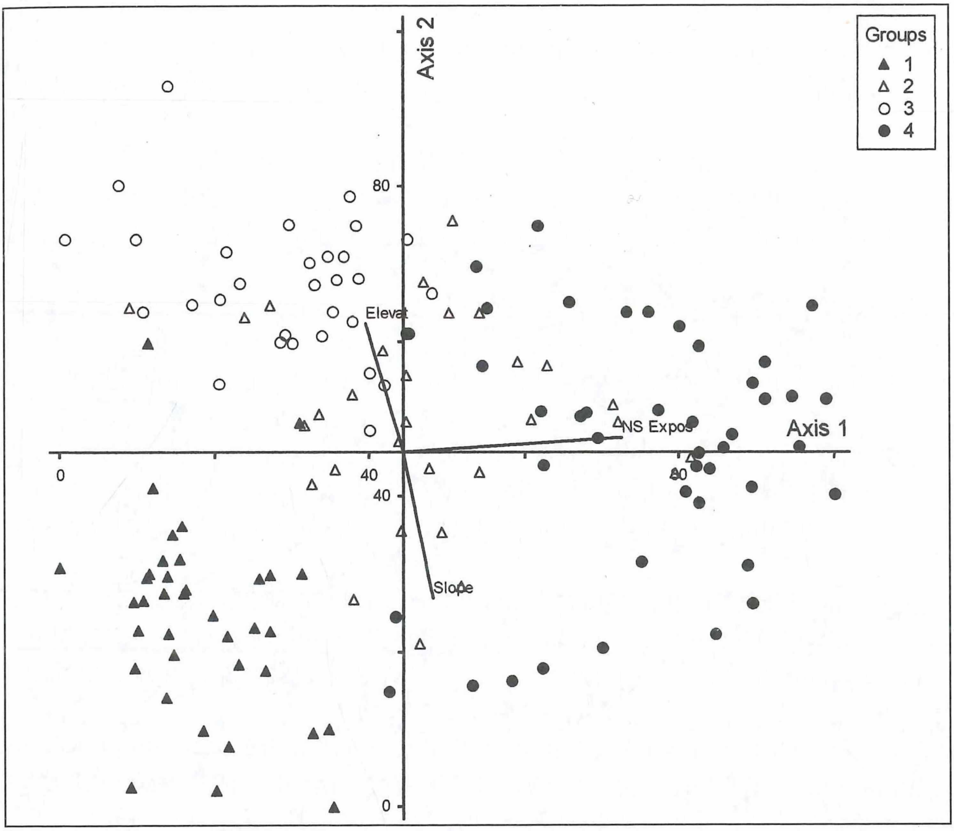

Figure 3: DCA ordination diagram – degraded secondary steppe vegetation in the ecological space (Yan'An Prefecture). Group number according to Table 3.

The vertical differentiation can be explained that some of the plots of secondary shrub vegetation were located near to forest sites where elevations in general were around 300 meters higher than in other parts of the survey area. Ecologically interpreted, this differentiation might caused by the fact that *Artemisia*-shrubs located in close proximity to the forest included many species of the neighbouring forest communities such as *Cotoneaster ambiguus, Acer stenolobum, Lonicera hispida* etc., which could not be found in *Artemisia*-shrubs far away from the forests.

The differences in species composition within the group of *Artemisia*-shrubs are thus attributable to differences in land use history and current land use regimes within the survey area rather than to profound climatic differences and precipitation or humidity regimes. While forests still have some influence on the species composition of nearby degraded shrubs through natural species propagation as well as human utilization of forests, these effects do not occur in completely deforested areas.

Frequent encroachment and temporary management of forest lands for agricultural and grazing purposes at the edges of the forest districts can be assumed to be responsible for the occurrence of species in degraded shrubs, which were identified as typical forest species.

As a second example of the potential influence of human factors on vegetation characteristics, it was observed that *Sophora* shrubs on southern slopes frequently coincide with villagers' grazing areas. Grazing areas are mostly located on southern slopes because of the higher daily temperatures during the cold winter months. Higher daily temperatures make these locations preferable to goats throughout most of the year. At the same time, northern exposed slopes are not used for grazing but rather for cutting fodder for cattle and goats held inside or close to the farmhouses. Such land use patterns might thus have an significant influence on species composition and partly enforce the vegetation differentiation along natural traits.

By and large, secondary degraded shrub communities appear to be very homogenous throughout the whole survey area. Although small differences in species composition can be observed within these communities, which are associated with elevation, these differences are also characteristic for differences in current and historic land use. The great similarity of degraded shrub vegetation communities over a region of broadly homogenous site conditions is therefore taken as a strong indication that the current small forest coverage in this particular region is largely historically determined and the survey area is at large suited for forest vegetation. Therefore the forests of Nan Niwan have to be interpreted as remainders resulting by human use and not ecologically conditioned islands of woodland.

4. Conclusions and Outlook

Vegetation analysis and the evaluation of ecological gradients in the geo-morphologically and climatically well-defined area of Yan'An revealed that plant communities of both natural forest vegetation and secondary degraded shrub vegetation are largely determined by the ecological site factors exposition and local topography. Because of the homogeneity of other site conditions, especially soil types, exposition and local topography can thus be seen as most important ecological decision criteria, if certain tree or shrub species or even combinations of different species are to be selected for restoration projects.

Vegetation data from three different sites were first classified by cluster analysis for the purpose of obtaining an overview of local vegetation patterns and then analysed by detrended correspondence analysis seen to be more suitable to interpret continuous community variation. However, both approaches to vegetation analysis are rather complementary especially in the context of defining a more operational set of plant groups for specific reforestation activities.

Although, a very limited number of ecological factors seems to be responsible for local vegetation differentiation it is important to note that human influence has greatly shaped the overall environment of the area of Yan'An for many centuries.

In order to develop an overall concept for sustainable land use the above results need to be qualified and to be accommodated to the specific socio-economic situation of the local population of the region. A complete reconstruction of the natural forest cover solely for erosion reduction purposes would imply a general change in land use from agriculture to forestry and is rather unrealistic because of the general cost involved.

Until today, rural population in this area largely depends on farming and thus local incomes depend on the availability of farming land and other production factors (e.g. labour, access to capital etc.). An assessment of the economic importance of farmland to the rural household seems thus suitable to assess economic implications of large-scale reforestation in an agricultural area and to decide on land management priorities for particular sites.

Based on an initial random sample of about 70 household surveys conducted by the author in summer 2000 and 2001 in Yan'An district general information on current land use practices and the importance of different land use categories and economic activities was obtained for the northern sub-region of Yan'An.

Fig. 4 illustrates the current situation as follows: While roughly 50% of household incomes are obtained from off-farm employment opportunities such as seasonal construction work, employment in rural service industries etc. ca. 50% of rural income are obtained from agricultural activities, mainly conventional farming, animal husbandry and fruit plantations. It can also be seen that incomes in forested areas (dark bars) are in generally slightly lower than in farming areas (light bars) with the exception of animal husbandry. Obviously, communities closer to forest areas are able to utilize forest as grazing grounds and thus can receive slightly higher incomes here.

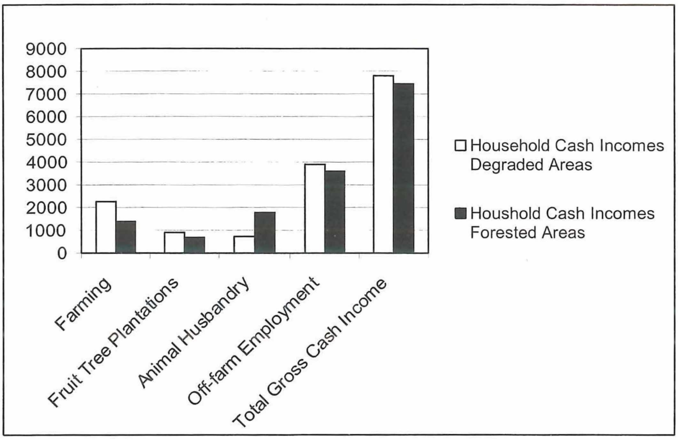

Figure 4: Current income structure of rural communities in Yan'An Region (figures in Chinese Yuan) - Data based on author's survey of ca. 70 households in northern Yan'An District.

Because of the dependence on farmland, land use changes from agriculture to forestry involve major opportunity cost for rural communities caused by the loss of farming opportunities. Opportunity cost imply foregoing an economically and socially valued land use - as for example agriculture - in order to pursue an alternative, e.g. protection forest (MAGRATH et al.1996). Reducing soil erosion through ecological restoration is thus an economic proposition, which goes beyond simple investment analysis of afforestation planning. This is especially true in areas of subsistence agriculture and in circumstances where economic benefits of forest can only be expected in the long term and do not materialize immediately to replace former income sources.

Since difficulties of cost and benefit estimation of long-term investments as afforestation (e.g. decision on interest rates, harvesting projections etc.) are well documented as well as the complexity of integrating different spatial levels, such as cost incurring at the reforestation site and immediate economic benefits occurring far away downstream in the form of prevented siltation and sedimentation, following an opportunity cost evaluation seems to be an appropriate starting at this level of analysis.

Fig. 5 gives a first rough estimation on how much a scenario of 100% reforestation would influence current money incomes of rural households. With current money incomes slightly above the levels of international and national poverty standards (in money terms: World Bank: ca. US$1 / day/ capita; P.R. China: ca. US$0.6 / day/ capita) such an ecological reforestation would probably push incomes of the rural population below such standards.

These conclusion correspond well with recent case studies on forest protection and land conversion programs conducted in China, which found that restrictions in the accessibility to

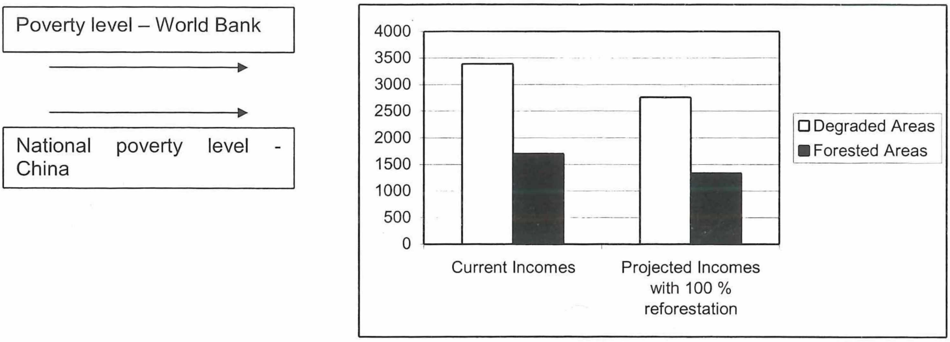

Figure 5: Income reduction (opportunity cost) of reforestation and implications for local living stan dards.

natural resources and economic opportunities resulted in poverty or a return to poverty in some communities (ANONYMOUS 2002).

Within the scope of combining land use and erosion protection the opportunity of using exploitable, site adjusted, native tree species consists one essential element in reforestation program.

It is obvious from a political as well as humanitarian perspective that such exclusively ecological reforestation program are simply unfeasible. This result is of great importance and demonstrates that with growing human needs and increasing demands on the environment the reconstruction of natural forests has to be judged from multiple perspectives and be seen as only one component of a larger approach to sustainability.

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Authors' addresses:
Dipl.-Forest Ulrich Schmitt, Prof. Dr. Anton Fischer, PD Dr. Clemens Abs, Geobotany, Department of Ecology, Center of Life Sciences, Technische Universität München, Am Hochanger 13, D-85354 Freising
e-mail: uschmitt@public.bta.net.cn, a.fischer@wzw.tum.de, abs@wzw.tum.de

Prof. Yang Pinghu, Prof. Dr. Chen Cungen, Northwest Sci-Tech University of Agriculture and Forestry, 712100 Yangling, Shaanxi, P.R. of China
e-mail: chencg@pub.xa.online.com