

ECOLOGICAL ASSESSMENT OF SPATIO-TEMPORAL CHANGES OF VEGETATION IN RESPONSE TO PIOSPHERE EFFECTS IN SEMI-ARID RANGELANDS OF UZBEKISTAN

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ABSTRACT

Since livestock production in Uzbekistan in arid and semi-arid zones is based on rangeland vegetation, contemporary studies have focused on improvement of low productive grazing lands and rehabilitation of degraded rangelands. Less interest has been given to the driving factors of land degradation and their interaction with other ecosystem components, e.g. response of vegetation to grazing induced disturbances. In recent years, due to poor localized grazing management, rangeland degradation has increased. An understanding of the current trend of vegetation changes due to ecological and anthropogenic factors gives the potential of sustainable management of natural rangelands. The aim of this study was to assess the spatial and temporal vegetation succession of Karnabchul semidesert as a function of piospheric effects in two different range sites. Seasonal measurements of vegetation parameters (biomass, density, vegetative cover) along the apparent grazing gradient were conducted during 2005–2007. A conceptual framework of successive vegetation changes along the grazing gradient was developed by applying State and Transition (S&T) models. Vegetation data were analyzed by applying Non Metric Multidimensional Scaling (NMS) ordination. Seasonal dynamics of the Normalized Difference Vegetation Index (NDVI) derived from Landsat imagery were examined to detect the vegetation changes caused by grazing. The vegetation succession was demonstrated as a presence/absence of unpalatable/palatable species in plant composition as a function of piosphere effects. NMS analysis indicated the evident different processes of vegetation cover of two study sites due to distinct grazing regimes. NDVI analysis showed that Landsat imagery provides relevant information about vegetation changes along the grazing gradient in the Karnabchul semidesert. Such results of multidisciplinary approach of vegetation assessment with combination of ecological models open the way in conception of realistic methods for sustainable rangeland management.

1. INTRODUCTION

The Republic of Uzbekistan is located in the Aral Sea Basin between the Syr-Darya and Amu-Darya rivers. Plains occupy more than 300,000 square km or about 70% of the total land area of the country. The climate is continental, annual precipitation in the plains is less than 250 mm, occurring in autumn, winter and spring, but practically absent in summer (Babushkin, Borovikova & Sitnikova, 2003; Burigin & Markova, 1975).

Around 255,000 km² or 57% of the country are rangelands. They have traditionally been used as common grazing lands for livestock. About 78% of the rangeland cover is desert and semi-desert plains (Gintzburger, Toderich, Mardonov & Mahmudov, 2003). Most of the farming in Uzbekistan's desert rangeland regions is Karakul sheep husbandry, followed by goat, camel and horse husbandry. The total number of head is greater than 10 million (Mahmudov, 2006). More than 2.3 million people are entirely dependent on livestock production for food and economic security (Yusupov, 2003).

The semidesert plains, located in the southwest of Uzbekistan covering 15,000–20,000 km² (Gintzburger *et al.*, 2003) belong to various regions, including Karnabchul, Mubarekchul and Kanimehchul. The term *chul* describes dry areas with sparse vegetation (Zakirov, 1955) and is widely used both by local people and in the scientific literature to describe desert and semi-desert areas. The rangelands of Karnabchul, Mubarekchul and Kanimehchul are some of the largest areas for Karakul sheep breeding in Uzbekistan (Gaevskaya, 1971).

The vegetation of Karnabchul is dominated by various semi shrub-ephemeral plant communities; 238 species of vascular plants belonging to 138 genera and 33 families have been described (Mavlyanov, 1972). The dominant species are *Artemisia diffusa*, *Carex pachystylis*, *Poa bulbosa*, with annual species such as *Bromus tectorum*, *Alyssum desertorum*, *Trigonella Noeana*, *Veronica compylopoda*, *Holosteum umbellatum* and others. This type of desert and semidesert has been commonly described as *Artemisia*-ephemeral rangelands (e.g. Amelin, 1940; Gaevskaya, 1971; Salmanov, 1986).

The *Artemisia*-ephemeral rangelands are commonly used for grazing of small ruminants. Grazing takes place year long but the spring season, when green ephemerals and ephemeroïds are available, and the autumn and winter seasons with *A. diffusa* and dry annual plants dominating, are the most important seasons. *Artemisia*-ephemeral rangelands have low productivity and vegetation biomass with annual production varying from 0.15 to 0.36 t DM/ha⁻¹ (Gaevskaya & Salmanov, 1975; Morozova, 1959) depending on climatic conditions, which vary greatly between seasons and years.

The natural *Artemisia*-ephemeral and ephemeroïdal rangelands are the main grazing lands for sheep and goats, and have been through history. Ninety-five percent of their total diet comes directly from the grazing and the remaining is harvested by the farmers and local herders and

used when no grazing is available. Anthropogenic impact, on top of abiotic disturbances, is thus a part of the disturbance regime this area has been exposed to through the ages. High localized anthropogenic impact often results in rapid land degradation and even desertification, hence altering the native vegetation cover of rangeland areas. The human footprint has increased with the ever-growing human population, as can be seen in the expansion of degraded rangelands in Uzbekistan.

Land degradation of desert and semidesert rangelands throughout the whole Central Asian region has reached an alarming level, calling for prompt action (Nordblom, Shomo & Gintzburger, 1997). It is presently estimated that out of more than 16.4 million hectares of rangelands, 73% are affected by degradation of various origins, including anthropogenic impact and climate fluctuation. The anthropogenic disturbances alone are estimated to affect 7.4 million hectares (UNCCD, 2006). Yusupov (2003) estimated that of all disturbances, overgrazing of livestock was the most serious, accounting for 44% of the total degradation, followed by uprooting and cutting of vital shrubs for fuel (25%). All other disturbances, including all abiotic disturbances such as drought and wind erosion, accounted for only one third of the disturbances.

The effect of grazing is often localized and is ubiquitous around watering points and settlements. Changes in vegetation cover and composition have led to the disappearance of many native fodder species. At the present time the area of degraded desert rangelands continues to grow due to overgrazing. A typical impact covers a radius of 2 to 5 km around watering points, with the most intense degradation occurring closest to the wells. Grazing occurs throughout the year. The animals are kept half of the year in the mountains or other distant regions, but they are brought back to the settlements as winter approaches. It is during this winter grazing seasons that most of the degradation occurs, as grazing pressure is high due to low vegetative production (ICARDA, 2002).

The distribution of livestock is restricted by water availability. This is especially true for the summer season and creates high grazing pressures around the water sources. The grazing pressure diminishes with distance, forming a gradual change in vegetative cover, species composition and soil properties as one moves away from the resource focal point. Such systematic changes have been called “piospheres”. The word piosphere comes from Greek, *pios* meaning to drink and *sphere* meaning round or ball (Lange, 1969). Piospheric effects hence relate to changes in plant community or soil structure along the grazing gradient from a central point of concentration (Andrew, 1988). Gradual reduction in biomass, changes of, for example, species composition from palatable plants into unpalatable, increased trampling and soil compaction as one approaches the focal point are all examples of piosphere effects. Piosphere analysis is recognized as a tool to distinguish between the differences of grazing impact from climatic effects in rangeland degradation (Pickup, Bastin & Chewing, 1994). The situation in Karnabchul is a classical example of piospheres, where the focal points are springs, wells and streams. The grazing-driven dynamics observed within the piospheres in Uzbekistan are

poorly understood. The current knowledge is fragmented at best, as contemporary research has focused on animal husbandry and production, but not on how various ecosystem components interact. A logical first step in any research planning is the accumulation and organizing of available information to enhance our current understanding of a system's behavior under various scenarios of interest. In the case of the Karnabchul rangelands such scenarios would include, for example, grazing-driven disturbances or the effect of extreme climate on plant communities. Westoby, Walker and Noy-Meir (1989) proposed a way to organize and present information, known as the State and Transition models (S&T models). S&T models accommodate discontinuous, reversible and non-reversible vegetation change (Briske, Fuhlendorf & Smeins, 2003) and can be readily constructed for various spatial or temporal scales due to their flexible nature. They thus provide a simple way to classify the current condition of an ecosystem, the *state*, and describe the factors or situations that can cause a state shift, or *transition* (Bestelmeyer, Herrick, Brown, Trujillo & Havstad, 2004). Ecological thresholds are an integral part of state-and-transition models. They differentiate between states of the ecosystem; hence, once crossed, a shift in system properties occurs as it goes through a transition to the next state. Speed of transitions may depend on the type of disturbance and its durability (Stringham, Krueger & Shaver, 2003). It is thus of great importance to understand the nature of thresholds in order to be able to avoid them, i.e. to promote the occurrence of desirable states (Bestelmeyer, Brown, Havstad, Alexander, Chavez & Herrick, 2003). S&T models can provide valuable information in research such as the one presented here where little was initially known. They provide information on the state of knowledge and make it clear where our understanding is lacking, hence where emphasis should be put on further research.

The degradation of the Karnabchul region covers large spatial and temporal scales which are impossible to assess using traditional field data approach. Application of Remote Sensing (RS) data on the other hand, such as the Landsat Enhanced Thematic Mapper Plus (ETM+) and Multispectral Scanner (MSS) imagery, cover both large spatial scales and are available for past decades. RS data can be incorporated into Geographical Information Systems (GIS) for analysis. An RS data approach thus opens up the possibilities to assess changes far beyond what is possible with traditional on-ground data collection, and is especially suitable for areas and problems such as the land degradation currently observed in the Karnabchul region. Remote-sensing-based rangeland assessment is recognized as an effective method due to availability of high spatial and temporal resolutions provided by different sensors and its reasonable cost advantages (Pickup *et al.*, 1994).

Our understanding of the degradation processes currently active in the Karnabchul rangelands is limited as traditional research has focused primarily on optimizing livestock fodder production (e.g. Amelin, 1944; Gaevskaya & Krasnopolin, 1957; Morozov, 1941; Sergeeva, 1951; Shamsutdinov, 1975), although a few published results on biomass changes under different grazing regimes do exist (Gaevskaya & Krasnopolin, 1956; Salmanov, 1986, 1993). There is

an urgent need for multidisciplinary studies of the desert ecosystems to help us understand their properties and processes in order to promote sustainable utilization of natural resources of the Uzbek rangelands.

This project has been an initial effort to use a multidisciplinary approach to enhance our understanding of the Karnabchul rangeland degradation. S&T models were used to identify potential ecological thresholds in the grazing-driven vegetation changes of Karnabchul semi-desert rangelands. The S&T models were then compared to plant community data, collected over a three year period (2005–2007) in the same area. RS analysis of vegetation cover as a function of piospheric effects around settlements and watering wells was also used to assess changes across the temporal and spatial scales that would otherwise be limiting. The RS data were compared to the plant community data. The paper aims to (1) develop assessment of spatial and temporal vegetation succession as a function of piospheric effects; (2) developing and evaluating an S&T model to assess vegetation changes caused by grazing; (3) detect grazing-induced vegetation patterns as apparent by the Normalized Difference Vegetation Index (NDVI) values derived from satellite imagery.

2. MATERIAL AND METHODS

2.1 Study area

The data presented in this paper were collected in two typical rangeland sites of the Karnabchul region: around the Tim village and a watering well, 24 km west of the village. The study areas extend between 39°50'N and 65°55'E. The Tim village is located in the proximity of the Zirabulak Mountains, but the well site sits in the flat rangelands.

Karnabchul is a sagebrush-annuals semidesert rangeland situated around the Karnab settlement in West Uzbekistan at the foothills of the Zirabulak mountain range. The elevation ranges from 240–500 m a.s.l. (Chalbash, 1963). The total area of the Karnabchul region is about 5,000 km² (Gaevskaia, 1971; Chalbash, 1963; Shamsutdinov, 1975). Prevailing types of Karnabchul soil are light sierozem and transitional types from light sierozem to gray-brown (Roza'nov, 1958; Lobova, 1960). The soils are rich in gypsum and water soluble salts (chlorides and sulphates) with a low content of organic matter (<1.0%) and basic nutrient elements. The soil texture varies from heavy clays to loamy sands (Gintzburger *et al.*, 2003). The ground water table is at 18–40 m and is generally unavailable to the dominating vegetation (Shamsutdinov, 1975).

The climate of Karnabchul is characterized by high inter- and intra-annual fluctuations of both daily and seasonal temperatures and belongs to cold arid desert climates according to the Köppen-Geiger climate classification (Kottek *et al.*, 2006). Bailey (1998) classifies this area as a Temperate Desert Division of the Dry Ecoregion. Summers are hot and dry and winters

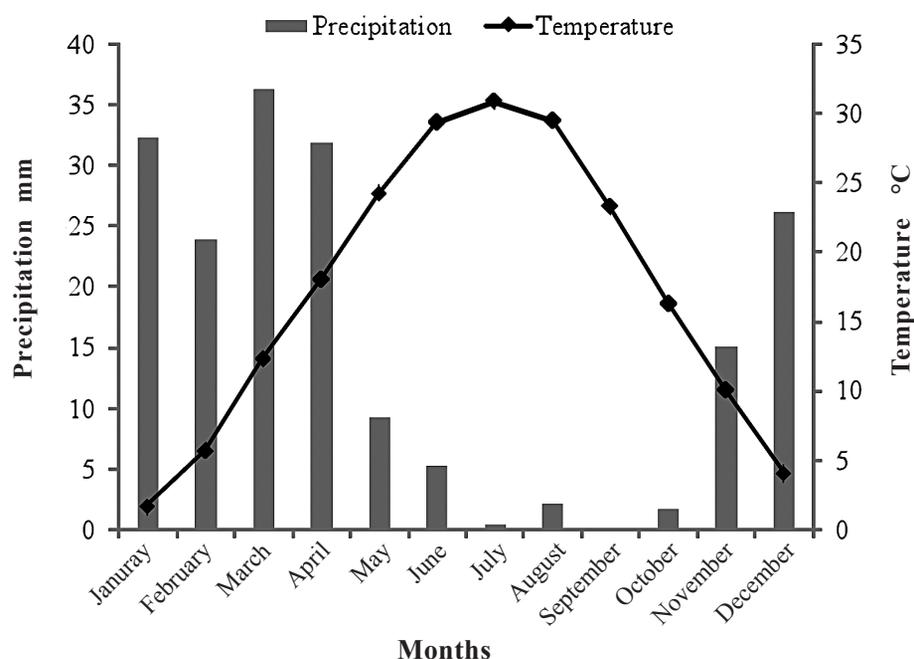


Fig. 1. Mean monthly precipitation and mean monthly temperature of Karnabchul semidesert for 2002–2007. Data from Mubarek weather station.

cold. The drought period lasts from June to November. Mean Annual Temperature (MAT) is 17°C. Rainfall is characterized by small non-uniformly distributed events. Mean Annual Precipitation (MAP) is 182.6 mm but the variability is high. The greatest precipitation falls during the cold period - in winter and early spring. Roughly 62% or 113.1 mm of total rainfall occurs at a temperature below 12°C from November to March. Only about 27% of the rainfall falls within the growing season (Fig. 1). The aridity can be assessed by calculating an Aridity Indicator (AI) from MAP, MAT and Potential Evapotranspiration (PE) (Gintzburger *et al.*, 2003). It shows the extreme climatic condition of the region (Table 1).

Table 1. Aridity Indicator (AI) of Karnabchul semidesert derived from Mean Annual Temperature (MAT), Mean Annual Precipitation (MAP) and evaluated Potential Evapotranspiration (PE). PE equals approximately 70xMAT and AI equals MAP divided by PE.

Year	MAT, °C	MAP, mm	PE, mm	AI
2002	16.7	223	1170	0.19
2003	16.2	257	1140	0.23
2004	18.2	216	1277	0.17
2005	16.9	176	1189	0.15
2006	17.6	116	1235	0.09
2007	17.3	177	1212	0.15
2008	16.2	112	1136	0.10

2.2 State & Transition modeling

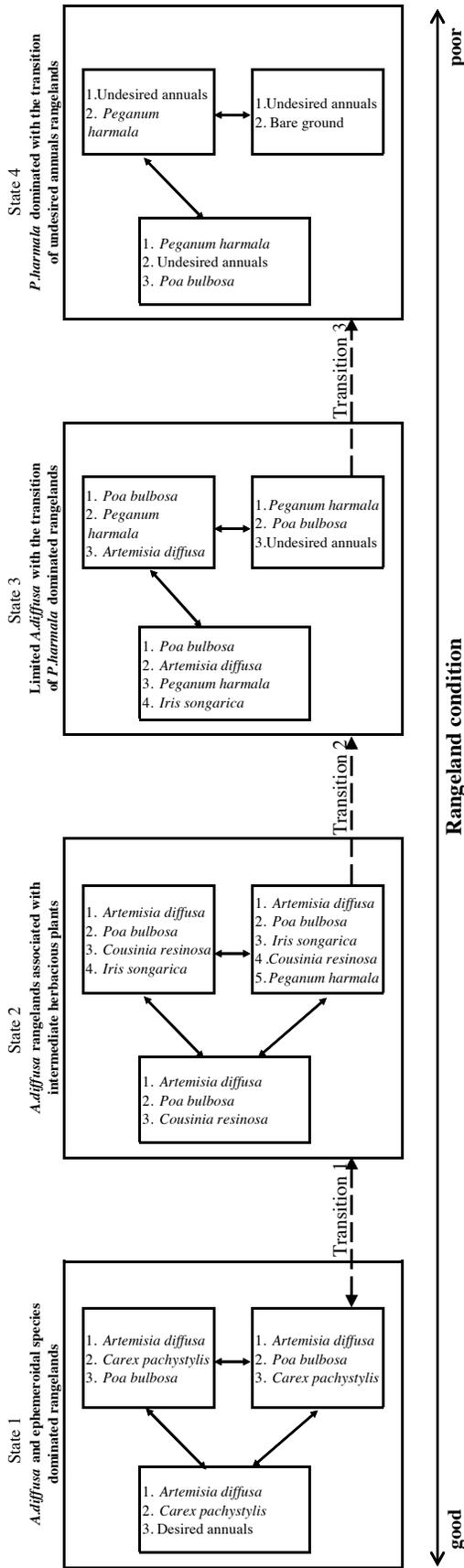
Based on field observations and data collected from 2005–2007 I developed a conceptual State and Transition (S&T) model of vegetation succession for the village and well study sites. As their name implies, S&T models consist of two basic elements: *states* or plant communities that are discrete and distinguished by differences in structure and rates of ecological processes; and the *transitions* between them. The transitions are pathways of community change, and qualitative assessments of the resilience and resistance of the states. States are the product of interaction of two components – the soil properties and vegetation structure (Stringham *et al.*, 2003). In the proposed S&T model for the Tim village and the well site, pristine states are represented by sagebrush-ephemeral and ephemeroïdal plant communities. Various edaphic conditions and distinctive grazing patterns of the sites are reflected in different spatial and temporal behavior within the S&T model. Four states are used to represent the current dynamics of the Tim village site, while the well site dynamics require 3 states (Fig. 2 and 3).

2.2.1 Tim village

A sagebrush vegetation community associated with ephemeroïds and desired annuals is a reference site for the current equilibrium condition of Karnabchul rangelands, and is presented here as State 1 (S1) (Fig. 2). The seral stages within S1 consist of *A. diffusa*, *C. pachystylis*, and desired annuals such as *T. Noeana*, *H. umbellatum* and *V. compylopoda*. *P. bulbosa* can be found at these seral stages, but becomes more abundant within State 2 (S2). The appearance of herbaceous plants (*C. resinosa* and *I. songarica*) in S2 is a sign of increased grazing pressure. At this state, *A. diffusa* remains as a dominant species in S2 with the combination of herbaceous plants. Ephemeroïdal plant communities start to dominate as *P. bulbosa* increases relative to the abundance of *C. pachystylis*. The presence of *P. harmala* can be observed in the last seral stage of S2. Under continuous grazing, the system moves to State 3 (S3), which is represented by the disappearing of palatable species and appearance of unpalatable species. In this state, *A. diffusa* is replaced by *P. harmala*, and herbaceous species are omitted from the species composition. *P. bulbosa* remains as a dominant ephemeroïdal species, but in the meantime undesired annual plants start appearing in the community. In the last state, State 4 (S4), *P. harmala* remains as a dominant perennial plant but it disappears from the vegetation composition due to trampling. *P. bulbosa* will be also affected by heavy trampling and is expected to disappear at the last seral stage of S4. The appearance of undesired annuals with low palatability (e.g. *Leptaleum filifolium*, *Ceratocephalus falcatus*) is the expected in the final seral stage within S4 under heavy grazing pressure.

2.2.2 Well site

Unlike the Tim village site, the vegetation succession at the well site is considered to be simpler and consists in its current configuration of three states (Fig. 3). Radial symmetry of the



- State 1** Pristine sagebrush-ephemeral rangelands. Vegetation community is represented by *Artemisia diffusa* from perennials. Grass layer is dominated by *Carex pachystylis* and less by *Poa bulbosa*. Desired annuals are abundant in species composition.
- State 2** *Artemisia diffusa* remains as a dominant plant. Intermediate herbaceous species (*Cousinia resinosa* and *Iris songarica*) appear in the vegetation composition. *Carex pachystylis* and *Poa bulbosa* have almost equal proportion. *Peganum harmala* appears in last seral stages.
- State 3** *Artemisia diffusa* and herbaceous perennial species become less abundant in the first seral stages and disappears in the last stage. *Peganum harmala* has a trend to be dominant in the vegetation composition. *Poa bulbosa* takes dominance over *Carex pachystylis*. Desired annual plants will be replaced by undesired species.
- State 4** Vegetation composition is represented by full dominance of *Peganum harmala* and undesired annuals in the beginning seral stages. *Peganum harmala* disappears followed by *Poa bulbosa*. Undesired annuals remain before shifting to bare ground.
- Transition 1** Pristine vegetation community is shifted to communities with mixture of intermediate herbaceous plants due to continuous grazing. Reversible transition is possible by improved management.
- Transition 2** If grazing continuous or increases invaders and undesired annuals start appearing causing a shift from State 2 to State 3. Reverse process requires intense vegetation manipulation and improved grazing management, but is considered unlikely under the current grazing regime.
- Transition 3** Continuous intense grazing causes full dominance of unpalatable species resulting in transition from State 3 to State 4. Reverse process requires significant addition of resources and energy, but is considered impossible under the current grazing regime.

Fig. 2. Schematic illustration of a conceptual State and Transition model and its description for vegetation changes under current grazing regime for the Tim village site. Numeral order of species refers to relative dominance within each seral stage.

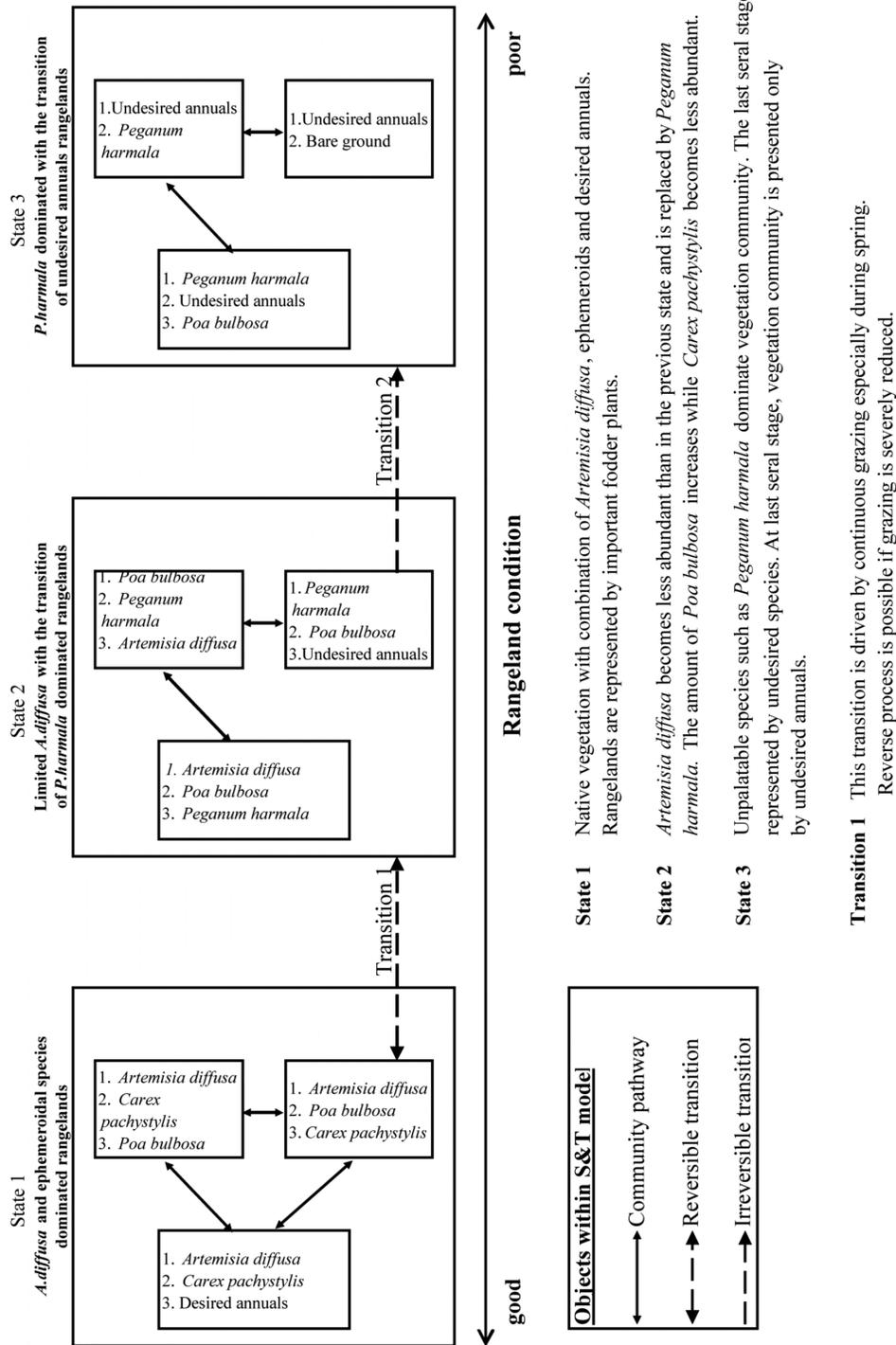


Fig. 3. Schematic illustration of a conceptual State and Transition model and its description for vegetation changes under current grazing regime for the watering well site. Numeral order of species refers to relative dominance within each seral stage.

grazing pattern and edaphic properties are more pronounced than around the village. The first state (S1) is identical to the village site in term of species composition and vegetation structure. Under continuous grazing, the vegetation structure will change and enter State 2 (S2). At S2 *P. harmala*, a typical invader plant, increases in abundance and replaces *A. diffusa* in the last seral state. The ratio of ephemeroïdal species is characterized by domination of *C. pachystylis* over *P. bulbosa*. Continued heavy grazing and subsequent invasion of exotic species cause a further shift towards unpalatable and undesired dominating plant communities including *P. harmala*, *Hordeum leporinum* and some unpalatable *Bromus* species. This is represented by State 3 (S3). In this last state, increased heavy grazing and trampling lead to a further decrease in *C. pachystylis* and *P. bulbosa*, resulting in the domination of *P. harmala* and other undesired annuals. Furthermore, trampling causes *P. harmala* to disappear closest to the well. This area is dominated by *H. leporinum* and unpalatable *Bromus* species can be found.

2.3 Plant community data

The two sites were established west of the Tim village (39°40'N; 65°46'E, 460 m a.s.l.) and at a watering well (39°38'N; 65°31'E, 334 m a.s.l.) (Fig. 4). Each site was divided radially into subplots along a grazing gradient with the focal point in the village or watering well. The

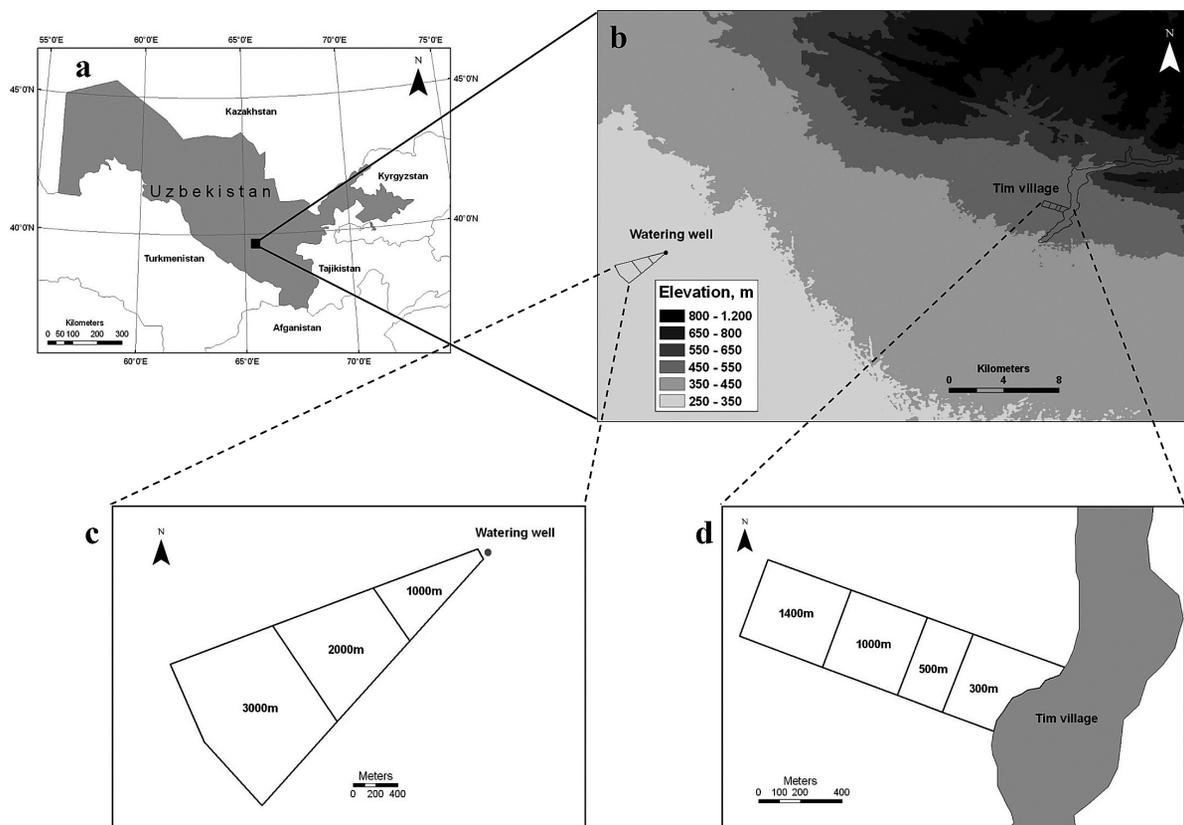


Fig. 4. Location of the study area in Uzbekistan (a), digital elevation model (DEM) (b), schematic illustration of the measurement transects laid out perpendicular to the well (c), and village (d). DEM was obtained from Earth Remote Sensing Data Analysis Center (ERSDAC, 2009). Please notice the different spatial scales on the images.

subplots were located successively at a distance of 300 m, 500 m, 1000 m and 1400 m from the Tim village and 1000 m, 2000 m and 3000 m from the well, and their location recorded using a handheld GPS unit (Garmin 12; Garmin Ltd., Kansas) with a maximum accuracy of 3 m (Fig. 4).

Vegetation data were collected within the spring, summer and autumn seasons for three years, 2005–2007. The subplot measurements included perennial plant composition, biomass, cover and density, biomass of annuals, both above ground and below ground, woody part biomass, and the dead part of plants. Description of the vegetation cover and determination of the plant biomass was done according to Granitov (1980) using 2 m x 50 m transects (3 replications per subplot). The total numbers of shrubs of each species within the 100 m² area were counted and separated into 3 size classes (big, medium, small) based on plant size: height and diameter. For each species within every size class, 3 representative plants were clipped at a height of 1.0 cm for determination of standing biomass (woody, green and dead tissue) in the laboratory. A total biomass for each subplot was then calculated using the density data and species biomass. The cover of individual shrub species was determined along a 100 m line intercept of the 2 m x 50 m transect. Biomass production of ephemerals and ephemeroïds was identified within 50 x 10 cm frame quadrates, randomly distributed with 5 replications.

The vegetation data similarities and trends were analyzed by applying Non Metric Multidimensional Scaling (NMS) ordination (McCune & Mefford, 1999). The NMS ordination is well suited for data that is non-normal or on arbitrary or discontinuous scales (McCune, Grace & Urban, 2002).

2.4 Satellite Data Set

Altogether 12 satellite images of the study area were obtained from different Landsat satellites for calculation of the Normalized Difference Vegetation Index (NDVI) values (Table 2). They covered the research period from 2005–2007, and additional data from 1987 for spring, summer and autumn seasons were used to evaluate long-term trends in the area. The year 1987 was selected because three seasons were available.

NDVI is the ratio of the amounts of reflectance in the near infrared (NIR) and red (RED) portions of the electromagnetic spectrum ranges 0.72–1.10 µm and 0.58–0.68 µm, respectively. NDVI is based on the reflectance of vegetation - high in infrared and low in red radiation. NDVI is calculated using the equation:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

Nowadays availability of remote sensing data with high spatial and temporal resolution allows conducting research on monitoring and assessing the current condition and changes of the land surface. Using NDVI values derived from satellite data, seasonal and annual changes of vegetation cover, additionally trends of degradation processes can be analyzed.

Table 2. Some characteristics of Landsat satellite images used for NDVI calculation of the study areas.

Acquisition date	Landsat Scanner and number	Spatial Resolution (m)	Spectral bands used for NDVI calculation*
05/21/2005	ETM+ 7 SLC-off	30	3. 4
08/09/2005	ETM+ 7 SLC-off	30	3. 4
10/12/2005	ETM+ 7 SLC-off	30	3. 4
04/06/2006	ETM+ 7 SLC-off	30	3. 4
08/28/2006	ETM+ 7 SLC-off	30	3. 4
10/15/2006	ETM+ 7 SLC-off	30	3. 4
05/27/2007	ETM+ 7 SLC-off	30	3. 4
08/31/2007	ETM+ 7 SLC-off	30	3. 4
10/02/2007	ETM+ 7 SLC-off	30	3. 4
05/12/1987	MSS 5	60	2. 3
08/16/1987	MSS 5	60	2. 3
10/19/1987	MSS 5	60	2. 3
10/19/1987	MSS 5	60	2. 3

*Spectral bands 3 and 4 of Enhanced Thematic Mapper Plus (ETM+) and bands 2 and 3 of Multispectral Scanner (MSS) design red and near infrared reflectance, respectively.

Selection of acquisition date of images was based on dates when ground truth data were collected and additional images were obtained in order to assess the long-term rangeland vegetation dynamics of the study area.

2.4.1 Image processing

Satellite images were clipped to the areas of interest using the Corridor Design Evaluation Tool ArcGIS extension (Majka, Jenness & Beier, 2007) and then processed using ArcGIS 9.3 (ESRI, 2008). The subplots along the grazing gradient were clipped separately and divided into single polygons for each year (Fig. 4). NDVI values were then calculated for each separate polygon along the grazing gradient.

The Landsat 7 ETM+ Scan Line Corrector (SLC) failed in May 31, 2003, producing images with the zigzag pattern line with resulting data gaps (USGS Fact Sheet, 2005; ERSDAC, 2009). Since this research period (2005–2007) started after 2003, the images have SLC data gaps. The watering well site was not affected by the erroneous zigzag pattern lines, but lines with data gaps were found around the village area for the whole study period (Fig. 5) and covered some of the subplots. The SLC error also caused erroneous NDVI values along the line edges with high (+1.0) values. These were eliminated from the calculation.

The relationship between selected vegetation properties and NDVI was evaluated by calculating linear regression using the Excel 2007 spreadsheet program (Microsoft Inc.).

3. RESULTS

3.1 Species composition and density

3.1.1 Tim village

Artemisia diffusa is a permanent component of vegetation communities of the Karnabchul semi-desert, and is also common around the Tim village, despite high grazing intensities closest to the village. Its proportional distribution shows well the piosphere effect created by the grazing, as the *A. diffusa* proportion increases with increased distance from the village (Fig. 6). Likewise, *Cousinia resinosa* and *Iris songarica* were found near the village. The presence of these species can be taken as indicators of grazing-driven rangeland degradation. These herbaceous

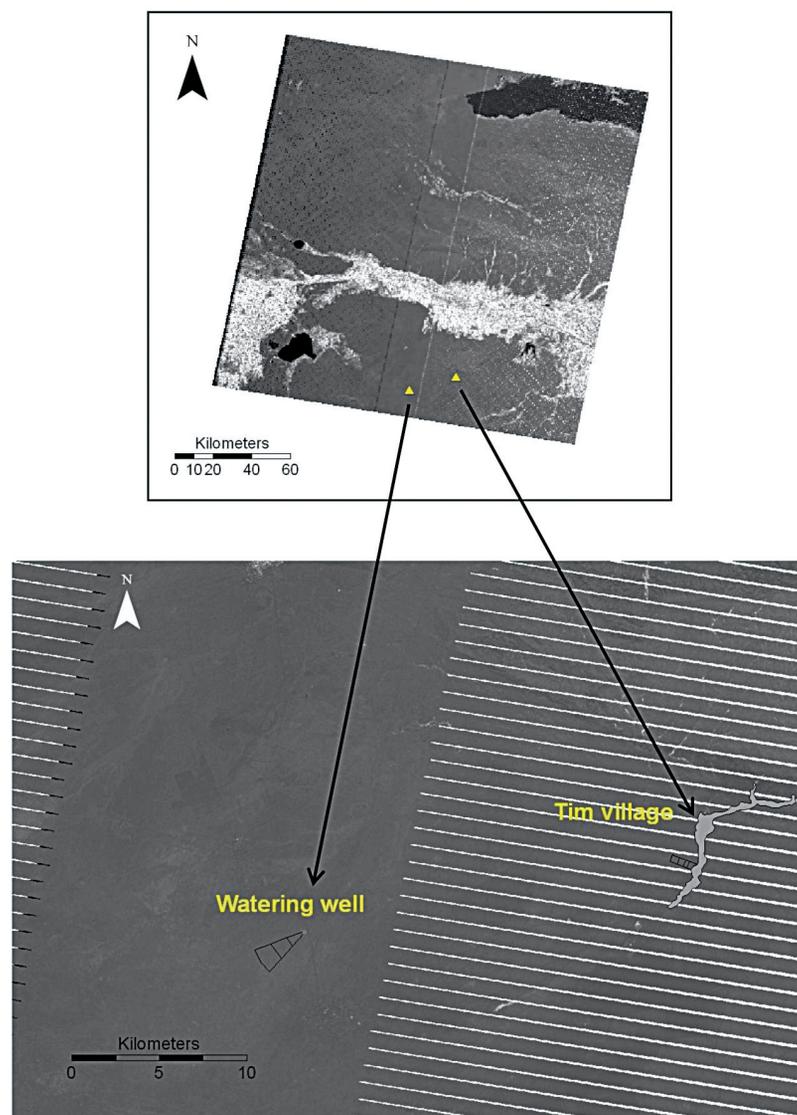


Fig. 5. Illustration showing data gaps on the Landsat scene. Study area around village is affected by the zigzag pattern of data gaps while the watering well is located in a section having no missing data. Please notice different spatial scales on images.

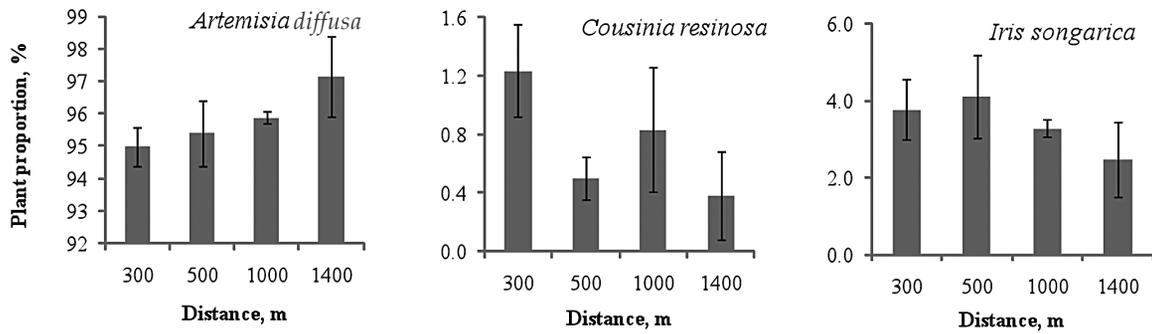


Fig. 6. Proportion of individual species in spring season in vegetation community as a distance away from the village site, 2005–2007. Note that the y-axes are different for each species. Vertical bars represent \pm SE.

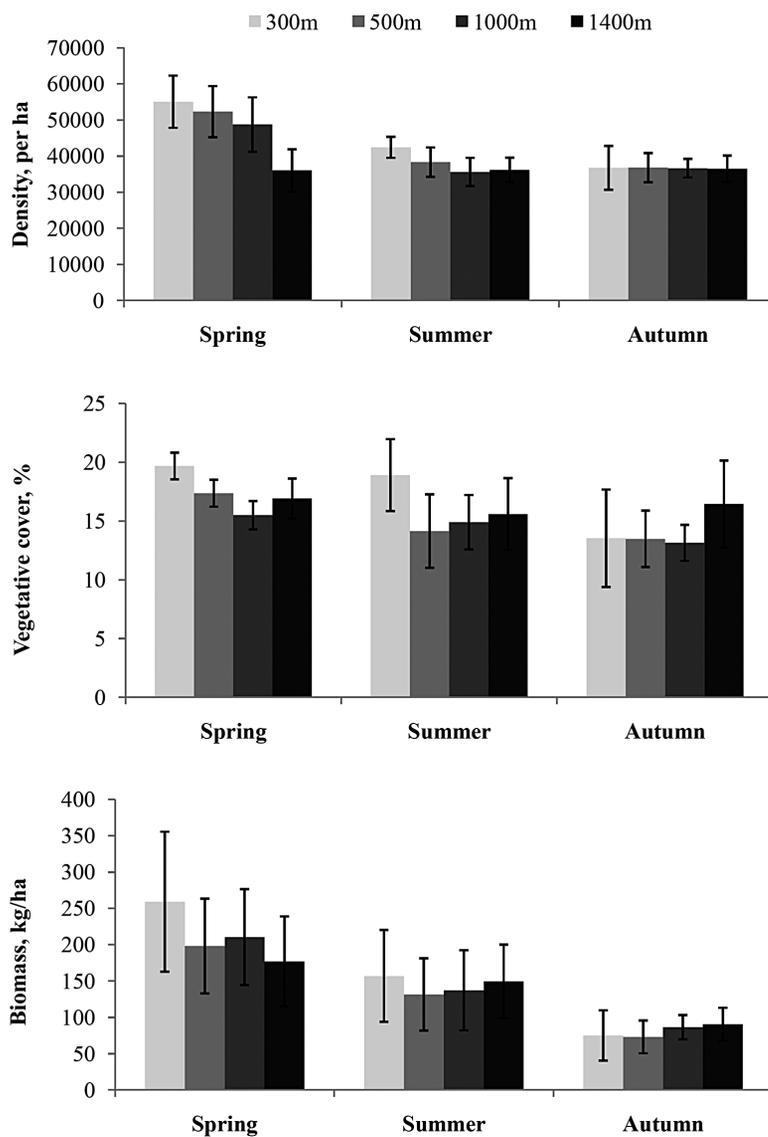


Fig. 7. Seasonal dynamics of density, vegetative cover and biomass of *Artemisia diffusa* along the grazing gradient, village site, 2005–2007. Note different y-axes on the graphs. Vertical bars represent \pm SE.

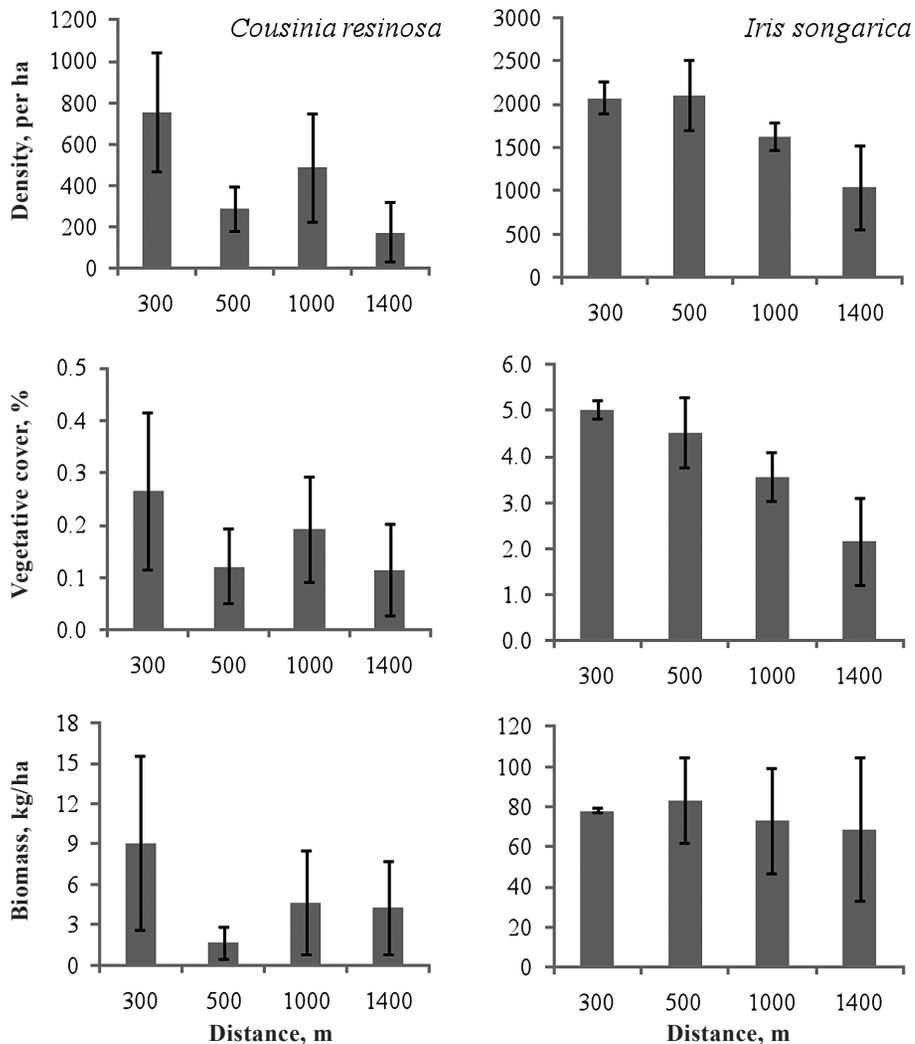


Fig. 8. Vegetation parameters of *Cousinia resinosa* and *Iris songarica* in spring season as a distance away from the village site, 2005–2007. Note that the y-axis is different for each species. Vertical bars represent $\pm SE$.

plants appear during the spring season but disappear through summer due to livestock grazing and harvesting for winter feed. *Peganum harmala* was found closest to the focal point, but was not present within the measurement plots. In general, during spring 95.7% of the plant composition of the village site is comprised of *A. diffusa*. Only 3.3% belongs to *I. songarica* and 1% to *C. resinosa* (Fig. 6). The general trend of the species percentage ratio shows a slight increase in *A. diffusa* and decline of *I. songarica* and *C. resinosa* with increased distance from the piosphere center, but great variability was found, probably due to selective livestock grazing. The density of *A. diffusa* declined with distance from the village during the spring season (Fig. 7). The density of herbaceous species was highest in the plot closest to the village and lowest in the area distant from the village (Fig. 8)

Perennial plant composition during the dry seasons (summer and autumn) is dominated by *A. diffusa*. Fig. 7 shows the difference in plant density between grazing gradients in spring and

autumn. Density appears to decrease between these two seasons up to a distance of 1000 m from the village, but beyond that distance it stays similar (Fig. 7).

3.1.2 Well site

The grazing gradients are better defined around the well site than the Tim village due to the fact that there is only a single well site, whereas the livestock has a greater spread around the village due to wider water access (Fig. 4). This leads to clearer trends of vegetation changes around the well site. The area up to 1000 m from the well is dominated by *Peganum harmala*

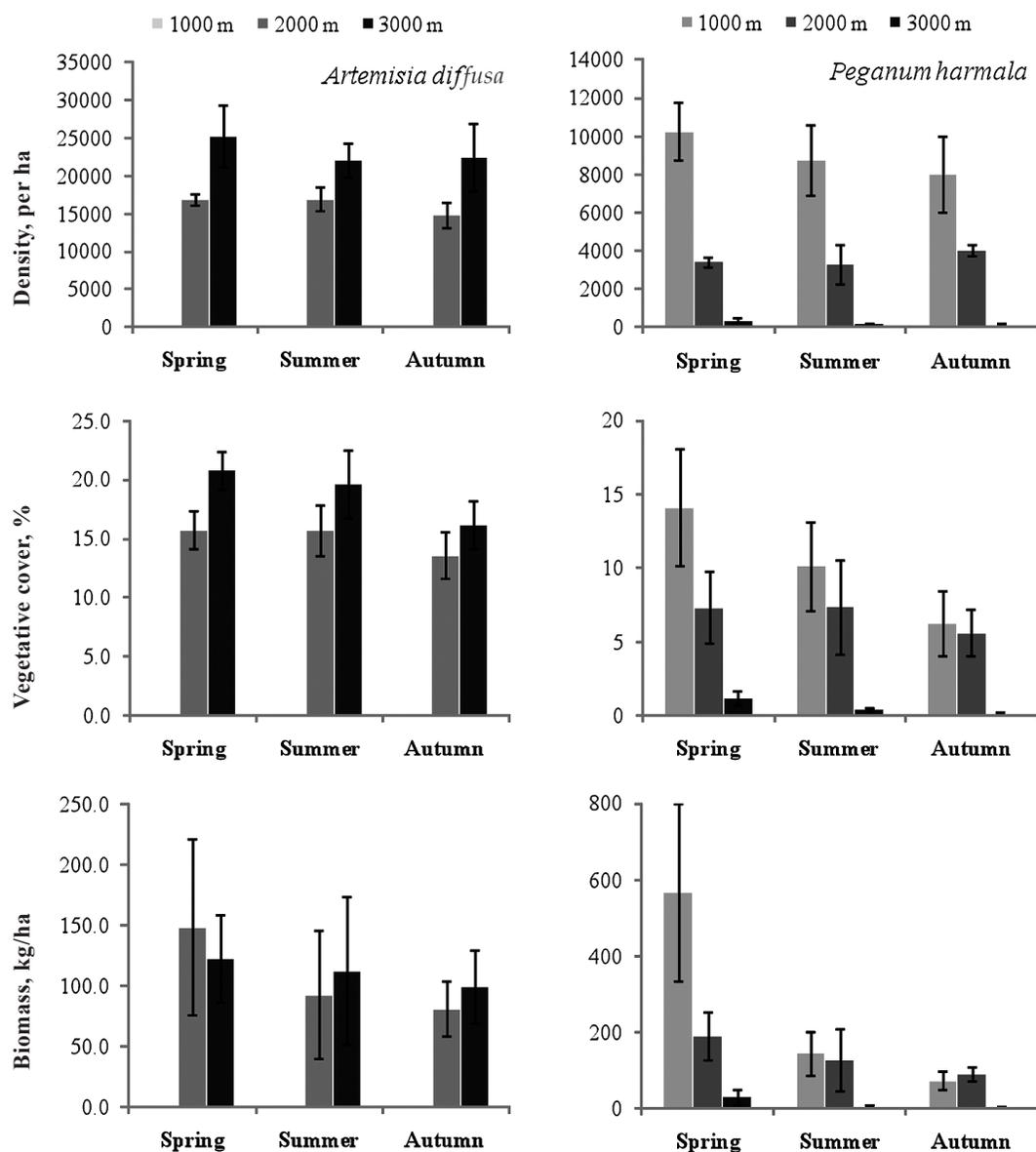


Fig. 9. Density, cover and biomass of *Artemisia diffusa* and *Peganum harmala* at the well site, 2005–2007. Note that the y-axis is different for each species. Vertical bars represent \pm SE.

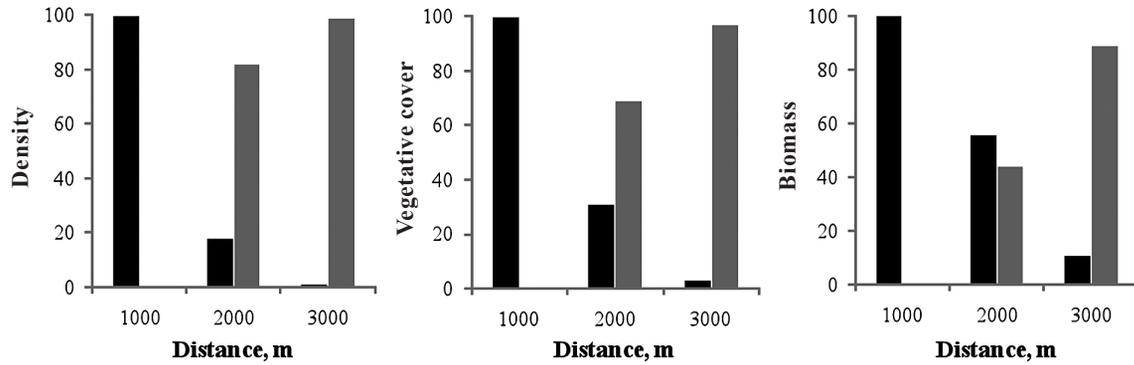


Fig. 10. Proportional distribution of density, vegetative cover and biomass of *Artemisia diffusa* (in grey columns) and *Peganum harmala* (in black columns) as distance from the well site, 2005–2007.

(Rajabov, Mardonov, Pittroff & Bobojanov, 2007, 2008). *A. diffusa* was observed in this area, but was not detected within the transects (Fig. 9). Species composition of the area beyond 1000 m consisted of both species. *A. diffusa* increases gradually, replacing *P. harmala*. At 3000 m from the well *A. diffusa* dominates over *P. harmala* (Fig.9). The proportional distribution of density in vegetation composition was decreased for *P. harmala* and increased for *A. diffusa* as a result of decreased grazing pressure further from the watering well (Fig. 10).

3.2 Vegetative cover and biomass

3.2.1 Tim village

Cover values of the plant communities had trends similar to those observed for density. In general, 21.4% of ground at a 1400 m radius around the site was covered with perennial plants during the spring season. The proportion of *C. resinosa*, and *I. songarica* was small, or 0.2% and 3.8%, respectively (Fig. 8). *A. diffusa* dominated the vegetation community with 17.4% cover in the spring season. A reduction in cover of each species was observed according to the distance from the village, in accordance with the expected piosphere effect (Fig. 7 and 8). During other seasons, *A. diffuse* remained the only perennial plant in the vegetation community.

Fifty-six percent of the above-ground biomass of grass layer was represented by ephemeroïds. In the spring season, the biomass of *C. pachystylis* was 43.9 kg/ha or 23.5% of the total herbaceous biomass, while *P. bulbosa* was 57.7 kg/ha or 33.1% of the total. The biomass decreased generally for *P. bulbosa* but increased for *C. pachystylis* with increased distance from the piosphere center, but some exceptions were observed, especially with the greatest proximity to the village (Fig. 11).

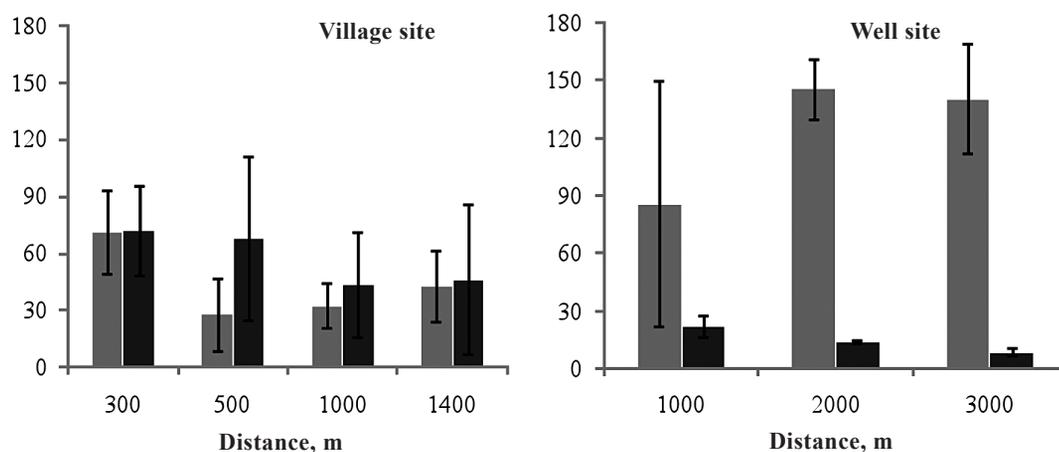


Fig. 11. Biomass of *Carex pachystylis* (in grey columns) and *Poa bulbosa* (in black columns) as distance from the village and well sites, 2005–2007. Vertical bars represent \pm SE.

3.2.2 Well site

P. harmala had the highest cover values closest to the well in the spring season and radially decreased along the decreasing grazing gradient (Fig. 10). A similar trend was observed for the summer and autumn seasons. The cover of *A. diffusa* showed a different trend as it increased along the grazing gradient but decreased slightly between seasons (Fig. 9). In general, as is expected from piosphere effects, the cover of *P. harmala* decreased while *A. diffusa* cover increased. The biomass of *P. harmala* had a considerable spatial and temporal variability in the vegetation community. High biomass values were observed during the spring season, but declined up to 87% in the autumn season (Fig. 9). *A. diffusa* was not found within a 1000 m radius around the well site. The data showed seasonal variability for both the *A. diffusa* and *P. harmala* biomass. Both show reduction, but much greater for *P. harmala* than *A. diffusa*.

Above-ground biomass of the herbaceous layer was dominated by *C. pachystylis* representing 71% of the total biomass, while *P. bulbosa* accounted for only 9.3% of the total. The trend for these two dominating species was opposite, where *C. pachystylis* increased but *P. bulbosa* decrease with increased distance from the well. The biomass of *C. pachystylis* ranged from 86 kg/ha to 140.6 kg/ha for the 1000 m and 3000 m distance intervals, respectively, whereas the biomass of *P. bulbosa* ranged from 22 kg/ha to 8.7 kg/ha for the same distance intervals. Results for the above-ground biomass of *C. pachystylis* showed that it dominated over *P. bulbosa* along all three grazing gradients (Fig. 11). However, the results of the below-ground data for these species showed relatively increased root biomass of *P. bulbosa* over *C. pachystylis* at a distance of 1000 m from the well. The percentage ratio of the below-ground biomass of *P. bulbosa* and *C. pachystylis* were 58.6% and 40.5%, respectively.

3.3 Plant community data ordination

The preliminary NMS data ordination revealed distinct patterns in the data. There were more similarities within the village and well site data than between those two sites (Fig. 12). However, there seemed to be more dissimilarities within the well site data than within the village site data.

3.4 NDVI values

3.4.1 Tim village

Calculation of time series from Landsat imagery resulted in negative NDVI values during the research period and positive values in 1987. Presence of positive values of long-term NDVI data can be confirmed by the favorable vegetation condition during 1987 according to the Salmanov (1993) research conducted in Karnabchul. The NDVI values showed considerable differences between grazing gradients during the research period 2005–2007. NDVI values showed a decreasing trend as a function of increased distance from the village. Seasonal variations were observed between wet (spring) and dry seasons (summer and autumn), but little difference was seen between summer and autumn (Fig. 13). However, NDVI values for the image from 1987 showed positive values for spring and autumn seasons and negative for the

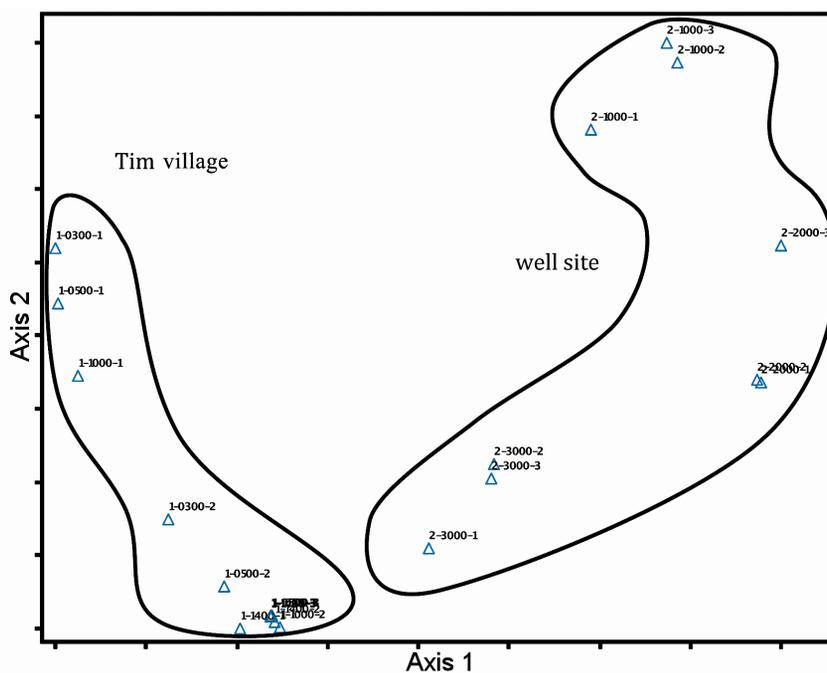


Fig. 12. NMS ordination plot of selected plant community properties averaged over three years, 2005–2007: species density, cover, biomass, height and diameter for *Artemisia diffusa*, *Cousinia resinosa*, *Iris songarica* and *Peganum harmala*. Point legends consist of “site-distance zone-season”, where the village is site 1, well is site 2, season 1 is spring and season 3 is autumn: 1-0300-1 thus represents the 300 m village site in spring.

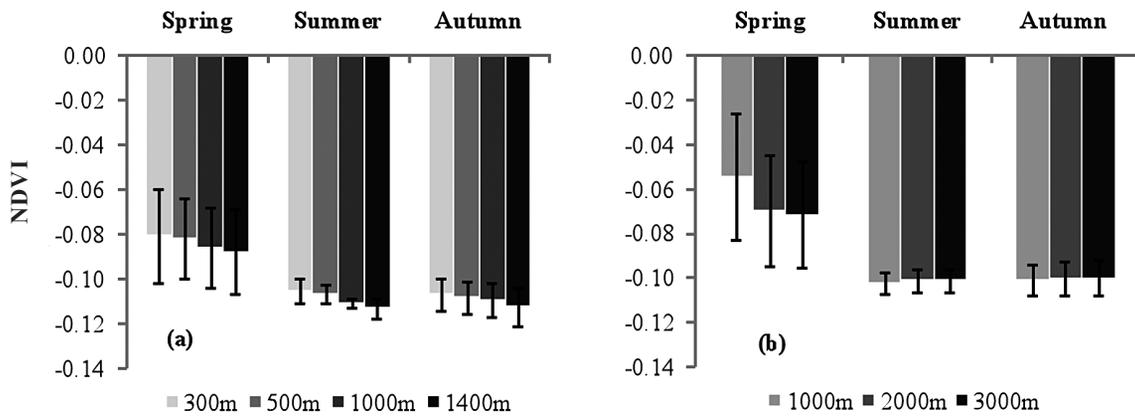


Fig. 13. Average NDVI values of vegetation communities of (a) the village site and (b) the watering well during 2005–2007. Vertical bars represent $\pm SE$.

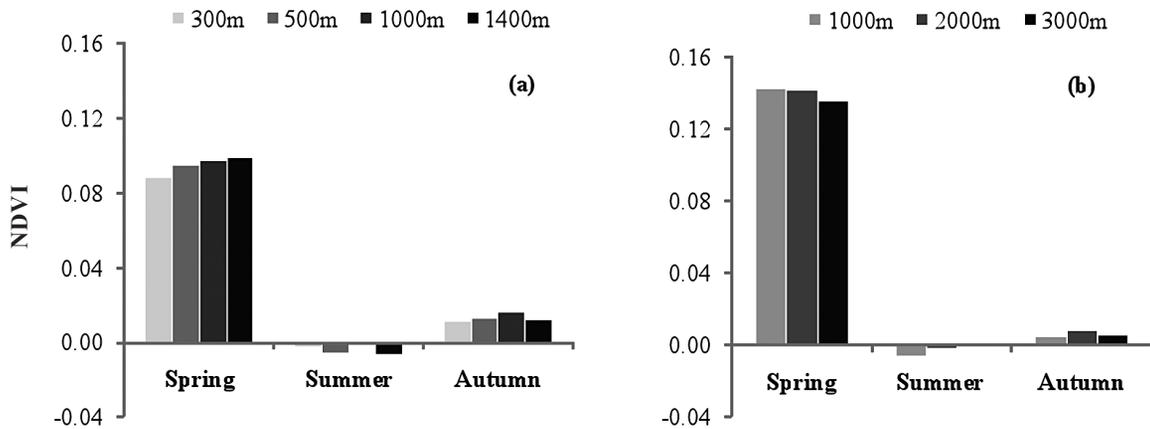


Fig. 14. Long-term NDVI values of vegetation communities of (a) village site and (b) watering well in 1987.

summer seasons (Fig. 14). During spring the NDVI values increased along the grazing gradient, in contrast to the summer season when there were no directional changes across the grazing gradient. The NDVI values increased in the autumn with increased distance from the village except for the 1400 m distance interval (Fig. 14).

3.4.2 Well site

Seasonal fluctuations of NDVI values were observed at 1000 m from the well. The highest values were detected in spring for the 1000 m interval, but the 2000 m and 3000 m intervals showed similar values during the summer and autumn seasons (Fig. 13). The values of the 1987 image showed positive values in both spring and autumn seasons, whereas the summer

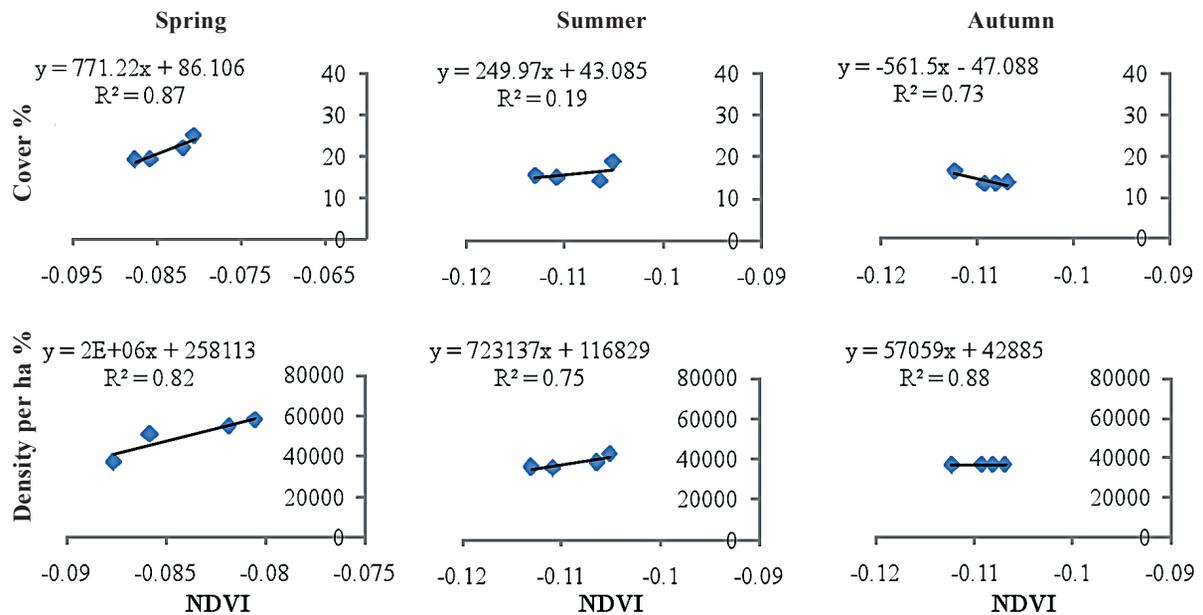


Fig. 15. Correlation values between averaged NDVI and vegetation parameters (vegetative cover and density) in village site, 2005–2007. Note different x- and y-axes.

season showed negative values. NDVI values along the grazing gradient decreased in the spring and increased in dry seasons (Fig. 14).

3.5 Correlation between NDVI and vegetation parameters

3.5.1 Tim village

NDVI data were correlated with vegetation parameters (density, vegetative cover and standing biomass) to evaluate if there was a directional relationship between remotely sensed data and vegetation variables. The results were not conclusive as there was little variability in the NDVI values. However, a relatively high correlation was observed for the village site compared to the well site since the vegetation structure at the village site had not been invaded with unpalatable species such as *P. harmala*. I suggest that the correlation was relatively high for NDVI and vegetation data (Fig. 15) due to dominance of *A. diffusa* and the small amount of intermediate invader species (Fig. 6) in the vegetation composition of the village site. According to my analysis, there was a high correlation between NDVI and density of plants during the spring, summer and autumn seasons, $R^2 = 0.82$, $R^2 = 0.75$, $R^2 = 0.88$, respectively (Fig. 15). High correlation values of vegetative cover were observed only in the spring season ($R^2 = 0.87$), for summer there were very low values ($R^2 = 0.19$), and the autumn season gave a negative correlation with a greater value ($R^2 = 0.73$). Green biomass demonstrated low correlation values with NDVI during the spring ($R^2 = 0.14$) and summer seasons ($R^2 = 0.004$), and negative values for autumn ($R^2 = 0.77$). As high correlation values with density were found

within all seasons, the woody part of plants was included with green biomass to test whether the correlation would become higher than only with green biomass. Inclusion of the woody parts increased the correlation values for all seasons but it gave a relatively higher value only for the spring season ($R^2 = 0.44$). Based on this comparison, I assume that density is a suitable vegetation variable to compare with NDVI values in *Artemisia*-ephemeral rangelands.

3.5.2 Well site

Presence of unpalatable invader species led to strong changes in correlation between NDVI and vegetation data. The results suggest that there is a high variability of vegetation community between wet (spring) and dry (summer and autumn) seasons at the well site. Green biomass had high correlation values with NDVI in spring ($R^2 = 0.87$). The value for summer was low ($R^2 = 0.07$) whereas the correlation coefficient for autumn was higher ($R^2 = 0.52$). Density was not as strongly correlated with NDVI values as in the village site. Inclusion of the woody part of plants decreased the correlation coefficient in spring ($R^2 = 0.22$), but increased in the summer and autumn with very low distribution. I assume that the presence of the invader herbaceous plant, *P. harmala* and its lack of woody parts provided low correlation values for the spring season. The biomass of *P. harmala* does not contain green tissues during the dry seasons.

4. DISCUSSION

4.1 Spatio-temporal vegetation changes along the grazing gradient

Considerable changes in vegetation structure were observed at both study sites. The spatial variability that was observed showed gradients, similar to predicted piosphere effects, and were probably derived from intense grazing around water sources at the village and well site. Grazing-driven changes in perennial and annual species composition in the closest areas and intermediate distances from the focal points were demonstrated as presence/absence of unpalatable/palatable species in plant composition. The common-grazing rangeland around the Tim village had a more complex vegetation utilization pattern by livestock animals. In spring, most household flocks with a relatively large number of animals (200–300 head) will be sent to rangelands in the neighboring foothills. The remaining flocks with only a small number of animals (30–100 head) are kept permanently at the village and grazed from 300 m up to 2500 m around it. Despite the relatively small numbers, they cause significant changes in vegetation pattern. Grazing pressure maximizes when animals are returned from the grazing foothill areas in October, with corresponding changes in vegetative cover around the village (Fig. 6 and 7).

A relatively high spatial variability of density, vegetative cover and biomass of *A. diffusa* was observed along the grazing gradient in the spring season while the variability decreased in

autumn as a result of the high grazing impact. I suggest that the apparently opposite directional vegetation dynamics along the grazing gradient during different seasons (Fig. 7) is because of the non-uniform spatial and temporal distribution of the livestock. A greater density of *A. diffusa* occurred in areas closest to the village as a result of overgrazing and resulted in increased cover and biomass in the spring season. Increased grazing in the autumn season resulted in a reduction of all vegetation parameters close to the village. Lower grazing intensities further away from the village resulted in little observed changes in vegetation parameters (Fig. 7).

Consumption of *A. diffusa* was less in the spring than in other seasons due to growth of ephemeral and ephemeroïdal species. However, young stems of *A. diffusa* can be eaten early in spring, albeit in very small amounts, but is avoided in late spring and summer due to secondary compounds that accumulate through their maturity (Gaevskaya, 1971). This property of the plant also resulted in a greater biomass production in the spring season around the village site. During the spring season, the vegetation biomass was dominated by three ediphicator species (*A. diffusa*, *C. resinosa* and *I. songarica*). The proportion of each species depended on the distance from the village (Fig. 6). Nevertheless, the complex grazing regime with scattered distribution of livestock around the village site did not represent a linear dynamics biomass increment along the grazing gradient. However, a general reduction of biomass was observed along the grazing gradient in spring. Considerable variability in biomass production of *A. diffusa* was observed during all seasons (Fig. 7).

The intense grazing disturbance closest to the village was reflected in the appearance of invader species such as *C. resinosa* and *I. songarica* (Fig. 6 and 8). Based on the literature, I assume that presence of these intermediate plants in the study area was also related to edaphic variability, such as the gypseous gravelly and loamy soils in the semidesert foothills (Gaevskaya & Salmanov, 1975; Gintzburger *et al*, 2003). These herbaceous plants were more abundant close to the village, and density, cover and biomass declined as a function of distance from the village area. Considerable high grazing caused the appearance of *P. harmala* at the closest location to the village. Presence of this invader plant in the vegetation community showed the beginning of severe changes in the rangelands under grazing. The community structure of the herbaceous layer also changed as a result of the piosphere effects. *P. bulbosa* and *C. pachystylis* are strong competitors under intense grazing (Sinkovskiy, 1959). A clear example of this competitive advantage was observed along the grazing gradient, as these species gradually increased with decreased distance from the village site, eventually dominating the immediate surroundings (Fig. 11).

Vegetative cover around the watering well showed high variability, both in time and space (Fig. 9). Radial attenuation of stocking and grazing pressure from the watering point resulted in changes in perennial and annual species composition (Lange, 1969; Andrew, 1988). Vegetation was usually absent around the well within the radius of 60–80 meters. This zone was

characterized by a highly compacted, flat surface of black or brown color called “tirlo” (Morozova, 1946) or “sacrifice zone” (Valentine, 1947, cited in James, Landsberg & Morton, 1999) as a result of intense trampling. At the next 1000 m from the well, throughout the 40 years since the well was established, *A. diffusa* had been constantly overgrazed and trampled by livestock and finally replaced by the pastoral invader plant *P. harmala*. This plant is recognized as an indicator of overexploited-overgrazed rangelands by scientists and the local people (Morozova, 1946; Sinkovskiy, 1959; Gintzburger *et al.*, 2003). *P. harmala* is not touched by livestock because of its toxicity, strong characteristic smell and high content of alkaloid in green leaves and seeds (Gintzburger *et al.*, 2003). *P. harmala* thus dominates the first 1000 m from the well. The shift towards dominance of unpalatable plants in vegetation composition resulted in a very low quality of grazing rangelands in term of fodder value of plants. As a function of increased distance away from the watering point, available grazing area for animals increases and stocking pressure on this area decreases (Andrew & Lange, 1986). This is reflected in the appearance of *A. diffusa* in the area 2000 m from the well (Fig. 9). Relatively high grazing pressure promoted *P. harmala* to remain in the vegetative cover, consisting of 31% of total vegetative cover and 18.1% of the density in plant composition. In contrast, 56% of the total perennial biomass of the vegetative community at a distance of 2000 m consisted of *P. harmala* (Fig. 10). Beyond 2000 m, *A. diffusa* became more abundant and at a distance of 3000 m it dominated *P. harmala*. The vegetation structure of ephemeral and ephemeroïdal species is influenced by the heavy grazing. As observed at the village site, competition existed between *P. bulbosa* and *C. pachystylis* under the heavy grazing pressure around the watering well. In comparison, at the village site *P. bulbosa* had less above-ground biomass than *C. pachystylis* along all grazing gradients from the well. I suggest that the greater abundancy of *C. pachystylis* around the watering well than around the village area is related to edaphic factors. The sandy loamy soils of the watering well are more preferable for *C. pachystylis* than the gravelly-gypsous soils in the village area. The well site might thus be better suited for plant growth. As a piosphere response, the two species had opposite directional changes along the grazing gradient; *C. pachystylis* increased with distance and *P. bulbosa* decreased with distance from the watering point (Fig. 11). However, despite the favorable soil condition for *C. pachystylis*, the below-ground biomass declined under the heavy grazing at the 1000 m zone, where *P. bulbosa* dominated.

4.2 Vegetation succession in the frame of a State and Transition model

The S&T approach for vegetation assessment of sagebrush-ephemeroïdal Karnabchul semi-desert promoted a better description of major processes occurring in rangelands under the ecological (drought) and anthropogenic factors such as grazing. The S&T model highlights the expected changes of vegetative structure and soil conditions under the impact of disturbance along the piosphere gradients. The characteristic pattern of grazing with the combination of edaphic factors created various trends of vegetation successions in the framework of the S&T

model. The constructed S&T model, based on current field observations and publications, distinguished between the different trends of vegetation succession of *Artemisia*-ephemeroidal rangelands depending on grazing or ecological factors. Many studies have contributed to a greater understanding of complexities of vegetation succession of sagebrush and sagebrush-ephemeroidal rangelands in local ecological conditions of desert and semidesert zones. Initial observation on interaction of sagebrush and ephemerals was conducted by Zakirov (1939) in the foothill zones of Southern Uzbekistan (Nishon foothills). Based on the investigations, he detected strong competition between *Artemisia* species and ephemerals (*C. pachystylis* and *P. bulbosa*) during development of the vegetation community. He concluded that *Artemisia* species will be replaced by ephemeroidal plants at the last stages of development. Dominance of ephemerals over *Artemisia* species is explained by a strong sod-forming root system of ephemerals which captures atmospheric moisture by compacting the soil surface and deteriorates moisture supply for roots of sagebrush plants. As a result Zakirov (1955) states that the competition between *Artemisia* plants and ephemeroidal species will lead to a “victory” of *C. pachystylis*. There are less conclusive studies on the interaction between *C. pachystylis* and *P. bulbosa* and their comparative relation in the ecological condition and particularly under the impact of grazing. A number of primary studies on vegetation changes along grazing gradients were published by Morozov (1941) and Morozova (1946), followed by studies of Sinkovskiy (1959) on vegetation changes of sagebrush-ephemeral rangelands under varying grazing intensities in the Kashkadarya district, Uzbekistan. They found that palatable species gave way to unpalatable species under the grazing regime.

Our studies confirm the identical trend of vegetation changes of previous studies along the grazing gradient. Grazing caused the appearance of intermediate herbaceous species in the vegetation composition of the village area. Increased grazing pressure shifted to the formation of another vegetation state with an abundance of intermediate plants. The density and other parameters of intermediate plants decreased as a function of distance away from the village. As a result of high grazing disturbance, the grass layer was completely dominated by *P. bulbosa*. Gravelly-gypsous soils associated with the grazing pressure in the village area prevented the successful growth of *C. pachystylis* (Fig. 11). *A. diffusa* was more common in the more distant area than in the area closest to the village. Radially increased grazing pressure was demonstrated by strong vegetation changes around the watering well compared to the village site. Early succession states of the vegetation communities were dominated by sagebrush and *C. pachystylis* with the combination of desired annuals. This was replaced by domination of *P. harmala* with undesired annuals in the last states of succession. *C. pachystylis* had stronger growth ability in sandy loamy soils than other soil types (Gintzburger *et al.*, 2003) such as gravelly-gypsous soils (Fig. 11). In comparison with village area, the sandy loamy soil by the watering well promoted the dominance of *C. pachystylis* over *P. bulbosa* at the beginning and at intermediate states of vegetation succession. With the radially increased grazing pressure in the closest area of the well, *P. bulbosa* became more abundant than *C. pachystylis* in

the last states of vegetation change. Loss of *A. diffusa* from the vegetation composition was related to heavy grazing pressure along the gradient from one side and the dense root system of ephemeroïds. At the same time, increased grazing led to expansion of ephemeroïds in the vegetation community. Trampling was a more disturbing factor than grazing in the location closest to the watering well. In the last states of vegetation succession, *P. bulbosa* disappeared from the vegetation community because of high trampling by livestock animals, but not because of overgrazing. *P. harmala* totally disappeared as a result of heavy trampling of animals. Only undesired annuals could tolerate heavy trampling in the near distance around focal points, but they were also not found elsewhere. Primary vegetation states had a longer spatial variability than the last states. With increased frequency and pressure of disturbances, the spatial variability of the last states could increase with shifting of the primary states.

Different zones of the village and well sites resembled the constructed S&T model. All intervals of the village site were similar to S2, but represented different seral stages. The 300 m interval of the village site could be ranked to last seral stages of S2. The next 500 m and 1000 m zones were more similar to the intermediate seral stage and the 1400 m zone was similar to the primary seral stage of S2. It is likely that the current grazing regime will shift the vegetation status of the village sites from S2 to S3 in the future. The vegetation succession of the three zones at the well site, the 1000 m, 2000 m, and 3000 m intervals, ranked as S3, S2 and S1, respectively. However, at 3000 m distance from the well, there was a sign of a shift in the system from S1 to S2 under the current grazing regime.

NMS ordination was conducted to evaluate the two sites, the village site and the well site (Fig. 12). The results, although preliminary, suggest that the observed changes and different behavior between the two sites, is supported by the vegetation data. More similarities seemed to exist within the village site data and the well site data than between them. Different distance zones at the village site were also more similar in time than at the well site, the latter having more similarities between distance zones than time of year. The grazing gradient around the well was expected to be more uniformly distributed, but this was not expected for the village site due to its larger spatial extent. The grazing gradients, if present, would thus be buffered out by seasonal variability, hence emphasizing time clustering, as shown in Figure 12. This suggests that different underlying processes were governing the vegetation responses, as predicted in the S&T model, but more studies and further analysis are required before any definitive conclusions can be drawn. If these preliminary findings can be supported, then grazing appears to have had a greater overall impact on the well site than at the village site; the latter appears to have been under more influence from the climate.

4.3 Vegetation dynamics from the NDVI time series

NDVI derived from remotely sensed data are recognized as a capable tool for classification of vegetation communities and estimation of spatial and temporal variations of standing biomass

in different ecological zones (Jensen, 1980; Luus & Kelly, 2008; Martinez & Gilabert, 2009; Senay & Elliot, 2000). NDVI values of seasonal and annual vegetation dynamics of the two study sites showed a high potential for utilization of remote sensing data for monitoring of rangeland conditions in Karnabchul semidesert. Ecological and climatic conditions maintained various seasonal NDVI values of vegetation cover between growing seasons, being greater in spring than in the summer and autumn months. Vegetation patterns under the impact of livestock grazing showed significant variability of NDVI values along the grazing gradient (Blanco, Aguilera, Paruelo & Biurrun, 2008; Pickup *et al.*, 1994; Washington-Allen, Van Niel, Ramsey & West, 2004). Directional trends of NDVI values under the effect of grazing were observed at the village site during all seasons. As a function of distance away from the village, NDVI values decreased with distance along the grazing gradient (Fig. 13). I suggest that this non-equilibrium trend of NDVI values was related to plant density, being high in the areas closest to the central point and low number in areas distant from the village under grazing intensity, and thus reflected the dominance of unpalatable species in close proximity to the water source. I assume density to be a suitable vegetation variable to be compared with NDVI values in *Artemisia*-ephemeral rangelands (Fig. 15). During spring, the higher NDVI values of the vegetation community in areas closest to the village can be explained by the appearance of intermediate herbaceous species. As is known from the literature, (e.g. Alimukhamedova & Li, 1983; Gaevskaya, 1971) *A. diffusa* will stop growing during the summer months as a defense mechanism against drought. During the temporary growth stoppage, the green leaves of *A. diffusa* may fall off. This adaptation of the plant resulted in the reduction of NDVI values in the summer season. The biomass growth of *A. diffusa* in autumn was also detected by the NDVI signal. Increased NDVI values in autumn were observed in the areas distant from the village while close areas showed lower values in response to heavy grazing (Fig. 13).

Strong changes in vegetation composition associated with invader plants around the well site showed non-directional seasonal changes of NDVI values along the grazing gradient. NDVI values significantly decreased in spring and increased slightly in summer and autumn along the grazing gradient. The greater spring season values of NDVI can be explained by the presence of *P. harmala* and ephemeral and ephemeroïdal species in the vegetation composition. *P. harmala* is green in spring but becomes dry as summer approaches. The typical morphological character and dominance of this plant was reflected in high NDVI values in the closest (1000 m) location at the watering well. The lower abundance of *P. harmala* in the areas distant from the well resulted in lower values. The dry condition of the plant in summer and autumn is recognized as an important factor in decreasing NDVI values. The results suggest that there was a high variability of vegetation community between wet (spring) and dry (summer and autumn) seasons.

The long-term NDVI time series showed considerable difference between current and past conditions of rangelands in the Karnabchul study area (Fig. 14). NDVI values for the spring

season were found to be an important indicator in distinguishing the long-term changes in the vegetation community under the effect of grazing associated with climatic conditions. However, when current NDVI values were compared to values obtained from the 1987 data, the village site showed the opposite trend along the grazing gradient during the spring compared to the contemporary data. I assume that the occurrence of this trend indicates a better condition of vegetation cover around the village site during 1987 in terms of green biomass. It seems that non-uniformly distributed grazing pressure existed at that time around the village and resulted in non-directional changes of NDVI values during all seasons. The dynamics of the 1987 NDVI values showed a similar trend as the 2005–2007 data for the well site. However, the variation between gradients was small compared to the variation in the present state of vegetation. As the watering well was established approximately 40 years ago, the unpalatable plants could have appeared in the vegetation community during that time, particularly closest to the well. The high values of NDVI in spring and low values in summer and autumn at the 1000 m distance indicates the presence of *P. harmala* in the vegetation community. I suppose that the small variability in NDVI values along the grazing gradient was related to less abundance of unpalatable plants than at the present time around the well. The seasonal dynamics of NDVI values were identical for the village site.

The considerable NDVI value difference between 1987 and the present leaves us with the question: what was the vegetation productivity of *A. diffusa* dominated rangelands during 1987? To answer to this, my results can be compared with the long-term data (1971–1989) of vegetation dynamics carried out by Salmanov (1993) in the Karnabchul semidesert. According to his observations, the biomass of *A. diffusa* amounted to 403 kg/ha in the 1987 spring season. However, my averaged data for the research period showed low biomass values at both sites, 211.1 kg/ha in the village area and 135.9 kg/ha around the watering well. Based on the evidence of biomass and NDVI values of the study area we can conclude that the vegetation status during 1987 in the Karnabchul semidesert was better in terms of biomass. Over time, grazing-induced degradation with the combination of climatic variables seems to have caused a decline in the vegetation cover.

5. CONCLUSION

Considerable vegetation changes have occurred in the *Artemisia*-ephemeral rangelands of Karnabchul semidesert due to grazing. Palatable species have given way to unpalatable species, and signs of land degradation were apparent where the most intense grazing has taken place. An S&T model framework of vegetation succession as piosphere effects was developed to help get a better overview of both the status of the area, and the changes it is going through or might go through under the current management regime. The proposed model was based on current knowledge and available field data, and seems to correspond to the system behavior, as suggested by NMS data ordination. It hence appears to reflect the dynamics of the area.

The results of this study show the potential of using Landsat remote sensing imagery for detecting and characterizing spatial and temporal vegetation variability in semi-arid rangelands. Remote sensing based rangeland assessment can be carried out using both broad and local scales. However, remotely sensed data can not detect the changes in the level of species composition. Analysis of long term NDVI values suggests that the rangelands are in decline, but the temporal resolution is too small for any definitive conclusions to be drawn. The changes since 1987, however, are clear.

The present vegetation cover of the two study sites has been strongly affected by livestock grazing, especially the well site. Spatial and temporal vegetation changes under the grazing intensity are demonstrated as the presence/absence of unpalatable/palatable species in the vegetation community. *C. resinosa* and *I. songarica* were found as an intermediate invader species in the gypsous-gravelly soils of foothills. *C. pachystylis* has more potential to grow in sandy loamy soils such as are found around the watering well. Increased grazing-driven disturbance has resulted in replacement of ephemerooids by undesired annuals. The radial symmetry of grazing pressure around the well has resulted in more rapid changes in vegetation structure than around the village where the grazing intensity is distributed around the elongated village area. Different edaphic factors played a key role in the formation of vegetation structure. Such vegetation changes of rangelands under the impact of grazing are distinctively described by integration of the S&T model. Piosphere analyses helped to identify states and transitions of vegetation communities and their shifts over time under grazing-induced disturbances. Application of such ecological concepts in range assessment helps to understand the driving factors of vegetation changes and to provide a framework for solution of degradation problems and sustainable management of natural resources.

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