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The Opportunity Costs of Conserving Pasture Resources for Mobile Pastoralists in the Greater Caucasus

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ABSTRACT *Ecological damage caused by unadjusted and raised stocking rates are persistent problems in grazed mountain areas in developing countries, including in post-Soviet Asia. An assessment of this degradation is difficult due to site heterogeneity and insufficient knowledge about the grazing systems. We present an integrated appraisal of the potential stocking rates of sites based on physical site properties. We combine these ecological and agrarian analyses with the economic calculation of opportunity costs in scenarios. We apply this approach to a high mountain region in the eastern Greater Caucasus in Azerbaijan, which provides valuable ecosystem services and is heavily used as summer pasture by mobile pastoralists. Hence, an impact assessment of reducing the legal prescriptions of stocking rates or the calculation of payments for ecosystem services is possible. Our results show that stocking rates on many pastures are spatially unadjusted and destocking measures need to be implemented in order to preserve ecosystem services. We also discuss different distribution possibilities of the opportunity costs.*

KEY WORDS: Azerbaijan, landscape ecological research, grazing impact, erosion reduction

Introduction

Spatially unadjusted and excessive grazing can cause degradation in fragile environments like mountain areas. It is a threat for the provision of valuable ecosystem services, when, for example, water and sediment retention, soil formation and hence also carbon storage, and habitat functions are disturbed, due to the loss of vegetation and soil cover (Conant & Paustian, 2002; Costanza *et al.*, 1997; Farber *et al.*, 2002). With 'spatially unadjusted grazing', we term grazing practices that do not sufficiently consider different physical site properties and their consequences for

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pasture productivity and quality. While in developed countries the abandonment of high mountain pastures is a major cause for habitat and biodiversity loss (e.g. Kleinebecker *et al*., 2011; Lasanta-Martinez *et al*., 2005; Niedrist *et al*., 2009), in developing countries overgrazing and its negative effects is more relevant (e.g. Geray & Özden, 2003; Zunckel, 2003). In post-Soviet transition countries overgrazing problems have become relevant in recent years, as livestock numbers have risen strongly after a sharp decline directly after the breakdown of the Soviet Union (Akhmadov *et al*., 2006; Borchardt *et al*., 2011; Mamedov, 2003).

In Azerbaijan livestock numbers are currently growing to levels never reached during Soviet times (State Statistical Committee of Azerbaijan, 2008). Therefore, the correct assessment of the stocking potential of pastures becomes relevant in order to minimise ecological damage (TJS, 2008). Mitigation of ecological problems should be based on grazing management measures and the adjustment of stocking rates, which would affect the economic performance of agricultural farms. In order to quantify these economic effects, the calculation of opportunity costs is a common approach. A great body of literature is devoted to cost-effective planning of protected areas, which in most cases involves the complete abandonment of land uses (e.g. Chomitz *et al*., 2005; Ferraro, 2002; Naidoo & Iwamura, 2007). In contrast, the integration of conservation measures into existing land uses, for example, for the design of payments for ecosystem services, requires more detailed knowledge on the production systems. In European countries livestock grazing and its effects on nature conservation have been studied comparably well (e.g. Nilsson, 2009; Plachter & Hampicke, 2010; van Teeffelen *et al*., 2008). Our study tackles similar questions in a cultural landscape, which is situated in the macroeconomic environment of a post-Soviet transition country. Besides some adjustments in methodology, this also has consequences for the potential implementation of grazing management recommendations. The success crucially depends on the integration into the existing administrative framework and the traditional knowledge of herders. This knowledge encompasses information on site characteristics and appropriate grazing management. However, these traditions might need an 'update' against the background of the enormously increased livestock numbers.

In this paper we integrate ecological, agrarian and economic data for a high mountain region in Azerbaijan, an approach that, to our knowledge, is new in the literature on Caucasian grasslands. We want to answer the following questions:

- Considering site heterogeneity in mountain areas, what are the most decisive factors influencing phytomass production on grasslands and what are the expressions of overgrazing?
- What are appropriate stocking rates taking into account site heterogeneity?
- What are the herders' opportunity costs for achieving adjusted stocking rates and what are the distributional consequences of an implementation?

We combine an ecological analysis of the pasture vegetation with an economic assessment of pastoral farms. We estimate fodder supply and demand in order to assess appropriate stocking rates and their impact on ecosystem services. We use scenario-calculations to evaluate the effect of different stocking rate prescriptions on the economic performance of pastoral farms. However, the paper cannot provide a full cost–benefit analysis of destocking measures, since we calculate only the farms' opportunity costs and do not value environmental benefits that are enjoyed by other members of the society. Nevertheless, our analysis gives an important estimation of farmers' opportunity costs of destocking, which may serve as a basis for the design of a payment system for ecosystem services.

Materials and Methods

Study Area and Economic Background

The study area is located in the northern part of Azerbaijan (approximately 50 000 ha above 1800 m a.s.l. in Quba and Qusar district) in the Eastern Greater Caucasus near the border to Dagestan (Russian Federation) (See Figure 1). This area is considered a biodiversity hotspot, delivers valuable hydrological services for the semi-arid lowlands and is popular for its landscape beauty (Elliott, 2004; Foster-Turley & Sultanov, 2010; Gadžiev, 1970). It predominantly consists of high mountain grasslands and is in close vicinity to the recently established Shahdag National Park, which comprises mostly forest ecosystems and unused rock areas, but hardly any pasture areas (MENR, 2010). Data collection took place predominantly in 2007 and 2008.

Our study area represents the most extensive summer pasture region in Azerbaijan for mobile pastoralists, since as consequence of the conflict with Armenia only approximately 370 000 ha (of once approximately 600 000 ha) of the total summer pasture territory is nowadays available (after Mamedov, 2003). In the vicinity of the summer pastures for mobile herds a few villages exist. The land around these villages is used as hay meadows or common pasture for stationary livestock. In contrast to the village livestock, the mobile pastoralists' herds from our study area spend the winter months in the steppe foothills of the Greater Caucasus west of Baku (Absheron and Qobustan district) with semi-arid and more variable climate conditions, while on the summer pastures humid and more balanced conditions occur (Aliev *et al*., 1965; Hongkong Observatory, 2008; Kottek *et al*., 2006; Madatzade & Šichlinskij, 1968; MENR, 2008; UNESCO, 1979).

In the transition period from 1994 to 2000 pastoral farms were privatised and restructured, which was at first accompanied by a decrease in livestock numbers, but then followed by a strong increase. Farms still struggle for economic viability and stability while bearing huge cultural value (Lerman & Sedik, 2010; Neudert & Allahverdiyeva, 2009). Pasture access was restructured to a state property system, in which pastures are leased by herders in individualised contracts of 15 years on average. A cadastre with a spatially clear definition of pasture plot boundaries, which are also enforced in practice, guarantees the security of property rights against the state and other herders. As a consequence, pastures are parcelled up into individual holdings. This facilitates our analysis but also hinders movements of livestock from overgrazed to undergrazed pasture areas. The economic results of farms are also influenced by the macroeconomic environment in Azerbaijan, which boasts a rapid economic growth due to the exploitation of oil and gas reserves. Nevertheless, some institutional deficits, especially concerning the quality of the business environment indicate that the transition process is not fully completed yet (Lerman & Sedik, 2010).

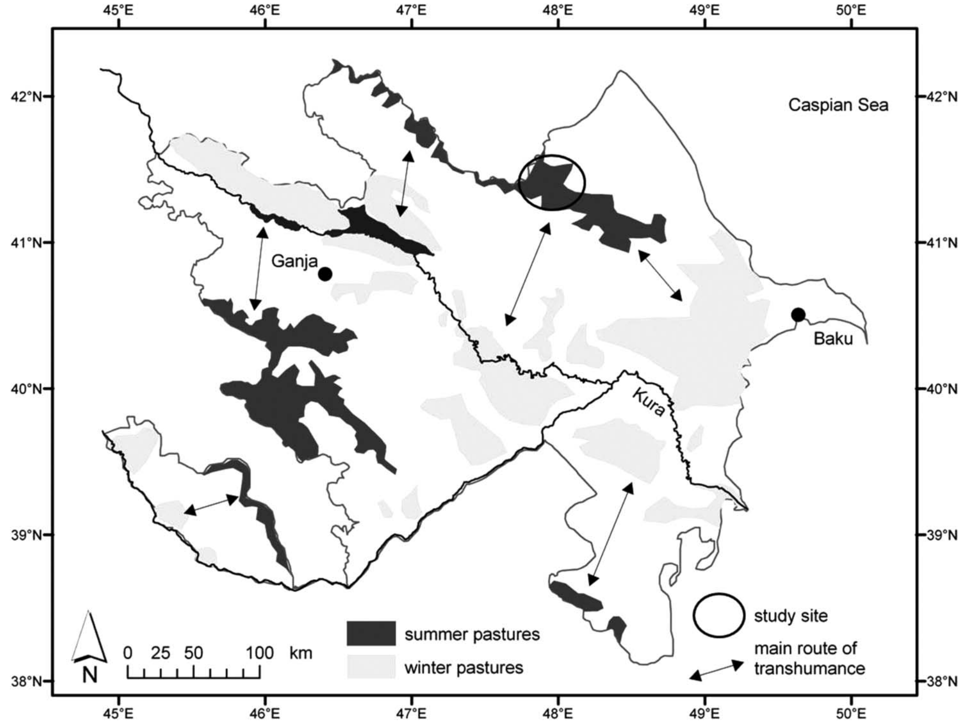

Figure 1. Study area (encircled) in Azerbaijan (after Aliev *et al*., 1965, adapted from Peper, 2010).

Landscape Ecology Methods

For the plot-based vegetation analysis we applied a stratified random sampling design after Traxler (1997) and similar to Peper *et al*. (2010). The lower and upper boundaries were set at 1800 and 3500 m a.s.l. respectively, reflecting more or less the present timber line in the region and the upper limits of grasslands and hence the area available for pasturing (Aliev *et al*., 1965; Gadžiev, 1970). In a further step, areas with very low or no vegetation cover were excluded, using the NDVI (Normalized-Difference-Vegetation-Index) of a Landsat 7 ETM+-image. With the help of a digital terrain model (SRTM data, USGS, 2006), these grasslands were subdivided into 16 strata: one subalpine (1800–2500 m a.s.l.) and one alpine belt (2500–3500 m a.s.l., after Gadžiev, 1970); two classes of inclination (0–20° and >20°; according to Ruff (2005) above this threshold there is strong susceptibility to erosion) and four aspect classes (NNE, SSW, WNW, ESE). For each stratum we randomly selected sampling plots, which met criteria of minimum extent and homogeneity regarding the NDVI.

Species taxonomy follows the reference list of the former Soviet states (Czerepanov, 1995). Endemism to the Caucasus or the Eastern Caucasus region was assigned by combining the information from Czerepanov (1995) and Karjagin (1950–61) and in some cases by cross-checking with Holubec and Krivka (2006).

Each plot was assigned to one of the three prevailing types of parent material in the study area: Upper Jurassic limestone, Middle Jurassic black shales (after the geological map of Alizade, 2008) and the transition zone of both, where limestone material is found on shale bedrock.

We measured position, altitude, and distance to the next summer camp with a Garmin GPS device and slope inclination and aspect with a combined clinometer and compass device. The latter was transformed to an aspect index (0–20, after Parker, 1982).

Soil depth above bedrock was estimated in six classes (in cm: no soil layer, 1–10, 11–20, 21–30, 31–40, >40) and root density in six classes following AG Boden (1994). We estimated the cover of vascular plants, litter, moss layer, bare soil and stones in percentage. The cover area of erosion tracks was defined as a combination of cover of bare soil/bare gravel and visible erosion processes (excluding bigger, i.e. immobile stones). Hence, we determined soil erosion impact of plots visually by estimating the percentage of the soil surface with clear traces of erosion. This is not identical with the percentage of bare soil not covered by vegetation but depends on other factors like actual grazing intensity, slope inclination, slope position and resistance of the soil substrate against erosion. The cover of cattle tracks, and the tracks of browsing (after Klötzli, 1965) served as indicators for grazing intensity. On each plot we took a composite soil sample of 200 cm^3 from the upper soil layer and measured the content of organic matter as loss on ignition.

We harvested aboveground phytomass (standing crop of living and dead plant material) on a representative sampling scheme on 10 m^2 and dried the samples until weight constancy. Additionally, we estimated productivity on sites without livestock impact, such as exclosures and hay meadows. Nutritional values such as metabolisable energy were analysed for composite samples (based on vegetation units, see Etzold *et al.*, 2010).

All plot-based vegetation and site data are stored in a Turboveg database in the version 2.89 (Hennekens & Schaminée, 2001). The database is registered in the Global Index of Vegetation-Plot Databases (Dengler *et al.*, 2011) with the ID EU-AZ-001 ('region Greater Caucasus Azerbaijan'). Data were processed with Microsoft Excel 2007 and the statistical environment R 2.9.0 (R Development Core Team, 2008).

In our analysis, we use 105 plots from areas under the management of mobile pastoralists with a minimum distance of 100 meters to summer camps.

To determine the major drivers of phytomass production in mountainous areas, we tested our data set with the robust regression tree models (R-package 'tree'), which cope with different data qualities that highlight also non-linear correlations (Breiman *et al.*, 1998; De'ath & Fabricius, 2000; Hothorn *et al.*, 2006; McCune & Grace, 2002).

We used phytomass as response variable and the stable and easily accessible variables aspect, inclination, altitude and bedrock as explanatory variables. Please note here that we use 'standing crop' data, which are a minimum estimation of phytomass available for grazing, since an unknown part of the phytomass had already been consumed.

Since aspect had the highest explanatory value (Nagy & Grabherr, 2009), we split the plots into two aspect groups (56 plots with northern aspect: 1–116° and 289–360° and 49 plots with southern aspect: 117–288°, following Parker, 1982). The significance of difference in site parameters between the two aspect groups was tested with a Mann-Whitney test (see Table 1).

In order to analyse the correlation between livestock induced degradation and phytomass production, we first identified the variable 'cover erosion tracks' as the best proxy for site degradation. Our assumption was that almost all observed traces of erosion are caused by livestock impact, besides only a few negligible 'naturally' eroded steep scree areas.

In a further step, we tested within both aspect groups the most and least eroded plot sites (upper and lowest quartiles) against each other (Mann-Whitney test) for differences in site and vegetation parameters (see Table 2).

Economic Investigations

Socio-economic data comprised qualitative interviews and a quantitative data set. Qualitative data gathering on randomly selected farms in the study area covered the present economic situation, management and prospects of pastoral farms. The quantitative data set comprises information about 49 summer pasture camps (farms) which cover around one quarter of the studied summer pasture area. We recorded the location of each camp using a Garmin GPS device and collected information about farm organisation, location of the winter pastures, livestock possessions and summer pasture size. Sheep constitute the great majority of livestock (more than 80% of total livestock), while only few goats and cattle are kept. Data on sheep numbers were collected using the number of female animals as they represent the core productive assets. We use a herd model based on qualitative field data to include the number of offspring and males in the analysis: 1 sheep unit (SU) consisting of 1 ewe, 0.04 and 0.8 shares of males and lambs, respectively. We convert the SU to tropical livestock units (1 SU = 0.532 TLU) according to FAO (1999). The stocking rate is calculated as SU/ha and TLU/ha for the pasture area of one farm and applies to one summer pasture period, which is three months (June, July, August). Statistics were calculated with PASW Statistics 18.

The entrepreneurial profit, that is, profit minus the salaries for non-paid workers from the entrepreneur's household and the cost for interest on owner's capital, is used to assess the profitability of pastoral farms (Kuhlmann, 2003; Mußhoff & Hirschauer, 2011). Detailed cost-revenue calculations for sheep production were already conducted for another region in Azerbaijan (Neudert & Allahverdiyeva, 2009). These calculations were fitted to the conditions in Shahdag region according to qualitative information in order to calculate the entrepreneurial profit for each farm of the quantitative data set. The currency of calculation is AZN (New Azeri Manat, 1 AZN = 0.83€, August 2008). As the pastoral production is mainly market-oriented, products can be directly valued with market prices. We assume that all farms use the same production methods and achieve the same physical yields and market prices. The economic results vary only with livestock number and pasture area. This assumption of only small variation in the production system is justified according to qualitative information from herders. As sheep constitute the main income source of pastoral farms, we did not include cost–revenue calculations for goats and cattle.

Model of Fodder Supply and Demand

We compared fodder supply and demand using a simple deterministic model of vegetation growth and energy demand of livestock. The carrying capacity concept is applicable in the study area as the precipitation (>550 mm) is relatively high and stable enough to ensure a comparable fodder production every year (see Ellis, 1994). Furthermore, the clear-cut delimitation of pasture areas for each farm through lease contracts enables the specification of stocking rates. However, our data contain only the pasture size in hectares, but no spatial specification of pasture boundaries.

The calculation of fodder supply is based on phytomass data harvested in six north- and six south-oriented exclosures and hay meadows at the peak of the vegetation period. The one-time harvest can only approximate the phytomass produced under constant grazing as compensatory growth occurs (as shown by unpublished results from own experiments). However, more accurate measurements are rare in literature due to the low practicability of more extensive measurements. We compared the data with literature data from different sites of the Caucasus (see Table 4) obtained with the same method.

Furthermore, we used standing crop and energy content data of the 105 pasture plots in combination with literature data to estimate the production potential of different altitudinal belts.

The calculation of fodder demand by livestock is based on sheep units. For females, males and offspring we calculated monthly energy requirements according to their reproductive/growth status. Data on energy requirements for each species are based on Dahl and Hjort (1976), Jeroch *et al.* (1999) and KTBL (2005) and is fitted to the local production system according to qualitative interview data from the study area. We arrive at energy requirements for one sheep unit (one female and shares of offspring and males) in MJ ME (megajoule metabolisable energy) for the three summer months, June to August.

Based on fodder supply data and the energy demand per sheep unit we calculate the potential stocking rate of a site under the following assumptions: 1) only living biomass is grazed and 2) 35% of the living biomass is left over on continuously grazed sites at the end of the grazing period (Bornard & Dubost, 1992; Mayer *et al.*, 2005).

GIS Application

For all spatial calculations georeferenced, 1:100 000 topographic maps (Berkeley Library, 2003) and SRTM data with 90 m spatial resolution (USGS, 2006) were used and processed in the software ArcMap 9.3. To obtain a representative pasture area for each summer camp a circle of 500 m radius (~ 80 ha) was created and placed encircling the camp. The circle's position was adjusted based on our on-site knowledge and with respect to the relief. On the basis of the SRTM data, we derived values for slope, aspect and altitude within each of the circles. We calculated the following parameters: mean altitude, the share of the area with $\leq 20°$ and $>20°$ inclination (Ruff, 2005) and the share of the area with northern (1–116° and 289–360°) and southern (117–288°) aspect (following Parker, 1982). The bedrock type (see above) was assigned to each camp according to the geological map from Alizade (2008).

Scenario Calculation

The stocking rates assumed in the scenarios build on our own assessment of fodder demand and supply as well as supplementary literature data. We also include field experience from elaborating an application-oriented monitoring manual for high mountain ranges in Azerbaijan, which involved the assessment of stocking rates (Etzold & Neudert, 2010). The results obtained from the farm-specific economic models form the basis for the calculation of opportunity costs in a farm economic sense. They comprise the net costs of a given action for an economic unit that is affected by this action. We calculated the opportunity costs assuming a complete abolishment of total livestock and rejected other measures for the following reasons: a shifting of livestock to other summer pastures is unlikely, as all summer pastures are leased out according to information from the responsible administrations. We also rejected the possibility of shifting herding days to the winter pastures, since winter pastures are scarce as well. To stay with the herds on the winter pastures all year would involve high fodder and water costs and decreased livestock productivity resulting from climatic hardships which all is undesirable from the herders' point of view. Furthermore, if applied on large scales, the consequence is a mere shifting of the ecological problems from summer to winter pastures, which additionally damages the cultural values associated with mobile livestock keeping.

We did not include herd productivity increases as benefits of destocking measures in the scenario calculation, as according to qualitative information from herders in Azerbaijan the number of lambs born and raised more strongly depends on the conditions in winter pastures. Therefore, significant increases in productivity could not be attributed to destocking measures on summer pastures.

In order to calculate for each scenario a farm-specific maximum number of sheep units, we used for each farm our scenario prescriptions in combination with the site characteristics obtained from the GIS application. If the current sheep number exceeded the maximum number of sheep units in the scenario, we recalculated the economic performance with the latter number. From this performance the current economic result of the farm was subtracted, which yields the herder's opportunity costs. Figure 2 summarises the described steps of scenario definition and calulation.

Current Condition of the Pastoral System

Current State of Pastures

The regression tree (Figure 3) with standing crop as response variable shows that the whole data set of 105 plots on summer pastures of mobile pastoralists is first split into a southern, less productive group of 43 plots (to the left, aspect index < 8.5) and a northern, more productive group (62 plots). It underlines that aspect is the strongest factor for differentiation in terms of phytomass production.

In the southern group, less standing crop was harvested on sites with the bedrock limestone compared to sites on shale. The northern group is further separated by elevation (threshold 2750 m a.s.l.), with significantly less standing crop at higher sites compared to sites below that elevation limit. Here, on slopes steeper than 20°, less standing crop was recorded. Follow the branches for further partitioning.

Table 1 shows the results of the comparison between the 'northern' and the 'southern' groups for physical site properties, vegetation data and grazing indicators. Both groups do not differ significantly in physical site conditions like inclination and altitude and in the indicator variables for grazing intensity (camp distance and

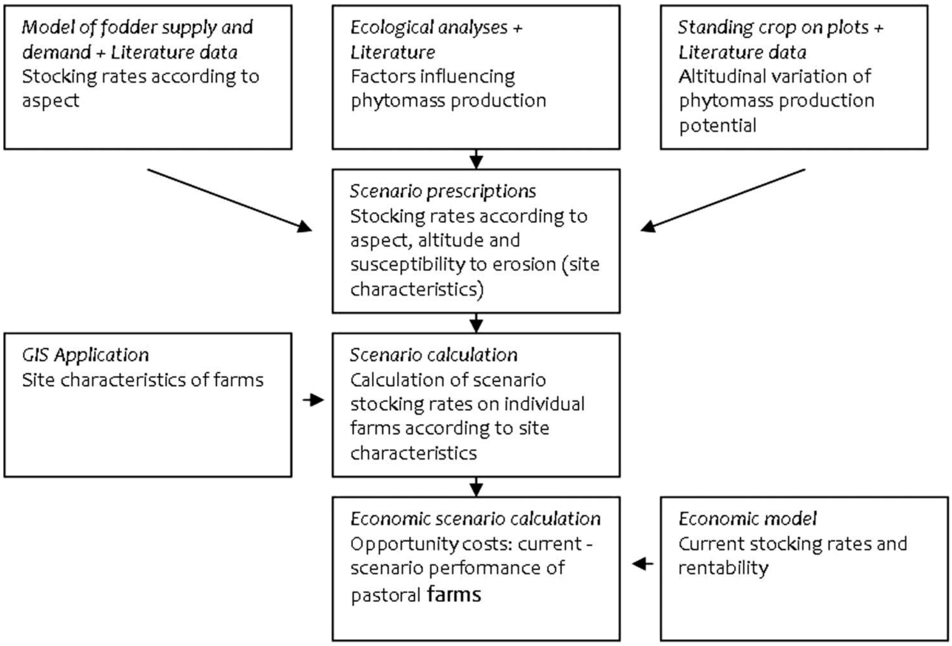

Figure 2. Steps of scenario definition and calculation.

browsing tracks). Confirming the regression tree, they differ significantly in standing crop. Other variables like total plant cover, erosion tracks, soil organic matter or soil depth are also significantly different. Note that also the total plant species number is significantly higher on northern slopes.

In order to analyse the correlation between livestock induced degradation and phytomass production, we compared the lower and upper quartiles regarding cover erosion tracks within the 'northern' and 'southern' data set (see Table 2).

The data show that inclination and altitude are important topographic factors responsible for a high susceptibility to erosion, although the latter is less important on southern slopes. The depicted components of erosion point out the long-term damage of the soil cover. The correlation between erosion tracks and cattle tracks also supports the assumption of livestock induced erosion.

Differences in standing crop yield are significant on northern slopes, while on the southern slopes the least and most eroded sites are only slightly different. The same pattern occurs when comparing plant species numbers. As well, the concentration of metabolisable energy (in MJ/kg dry mass) is lower on the eroded sites, even significantly on the southern slopes. These results indicate a double loss of overall pasture quality on eroded sites due to declining quantity (measured in standing crop) as well as lower quality of forage (measured in concentration of metabolisable energy).

Economic Profitability of Pastoral Farms

On average a pastoral farm in the study area keeps 985 ewes and has 266 ha summer pasture (Table 3). Livestock varies from 350 to 2000 ewes and the summer pasture

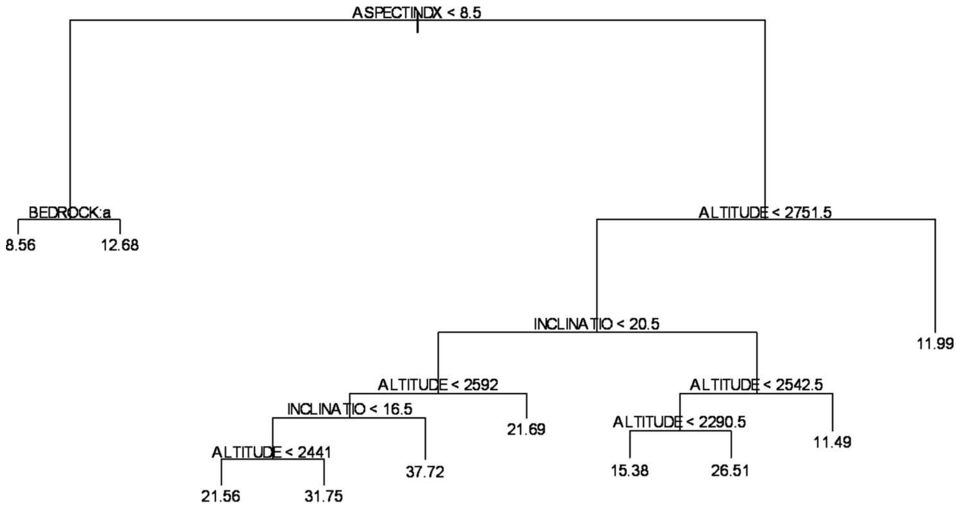

Figure 3. Regression tree, with standing crop as response variable (values at end of branches in dt ha^{-1}). The four explanatory variables ASPECTINDX: index of aspect after Parker (1982) from south (0) to north (20); BEDROCK (three classes) Limestone: a (here to left), shale: b, mixed case: c; ALTITUDE (m a.s.l.) and INCLINATIO: inclination (°).

size from 80 to 800 ha. The economic indicators (lines 4–7 of Table 3) are outputs of the economic model.

The results in Table 3 show that the majority of farms are profitable and earn a high entrepreneurial profit. The high revenue in sheep production is mainly based on the marketing of six-month-old lambs for 70 AZN/pc. The huge differences in entrepreneurial profits (line 4 in Table 3) are caused by strong economies of scale. Because the majority of fixed costs (like transport, labour, interest) do not directly depend on the ewe number kept on a farm, the fixed costs per ewe decrease with increasing livestock numbers. Thus, the farms with the least livestock numbers also have the lowest profits. Our calculations indicate that only farms with more than approximately 500 ewes are profitable, which is confirmed by qualitative information from herders. Smaller farms can exist under insufficient remuneration of capital or low family labour costs. A statistical analysis confirmed the strong positive relationship between entrepreneurial profit and stocking rate, while the correlation between pasture size and entrepreneurial profit was less strong. We also tested for relationships between stocking rate and location within the study area, which would verify spatial differences in farm management. None of the parameters showed a significant result.

Potential and Actual Stocking Rates

Table 4 depicts the results from own studies (hay meadows and one-year exclosures) and literature data (protected areas with long-term grazing exclusion) pertaining to annual phytomass production of subalpine and alpine vegetation in the Greater Caucasus.

The low share of nekromass in our data can be explained by the sampling on hay meadows with regular harvest or grazing in the previous year, while the literature

Table 1. Mean values (minimum to maximum in brackets) of those variables that differ significantly between both groups (*p*-values from Mann-Whitney-Test) and also of selected non-significant (n.s.) variables. For variables with ordinal scale the median is given; their classes are as follows: root density: 1–6; soil depth: 1–6; browsing tracks: 0–4

Grouping	Data set Variables	Northern ($n = 56$)	Southern ($n = 49$)	*p*-value
Plant cover reaction	Total plant cover (%)	84.6 (10–100)	70.2 (30–98)	<0.001
	Cover mosses (%)	10.2 (0–78)	2.2 (0–60)	<0.001
	Cover litter (%)	10.7 (0–40)	4.0 (0–30)	<0.01
	Classes of root density	6.0 (1.5–6)	4.3 (2–6)	<0.001
	Standing crop (dt ha^{-1})	19.4 (2.5–62.7)	12.2 (2.6–49.7)	<0.001
	Species number (100 m^2)	51.2 (19–81)	42.6 (22–63)	<0.001
Components of erosion	Cover erosion tracks (%)	13.9 (0–50)	21.2 (0–70)	<0.01
	Cover of cattle tracks (%)	12.5 (0–50)	19.8 (0–45)	<0.01
	Cover bare soil (%)	7.2 (0–35)	13.1 (0–35)	<0.001
	Cover stones (%)	8.1 (0–85)	16.9 (0–70)	<0.001
	Loss on ignition (%)	20.3 (4.4–40.4)	14.2 (4.8–34.1)	<0.001
	Classes of soil depth	3.0 (1–6)	2.0 (1–4)	<0.01
Topographic variables	Inclination (°)	21.4 (3–44)	22.3 (5–40)	n.s.
	Altitude (m)	2563.8 (1861–3274)	2631.7 (1810–3182)	n.s.
Indicators for grazing intensity	Camp distance (m)	826.6 (135–2615)	821.2 (160–2150)	n.s.
	Classes of browsing tracks	4.0 (1–4)	4.0 (1–4)	n.s.

data are from protected areas that exclude grazing or hay making, where nekromass is accumulated over the years.

Our results are similar to data obtained in other regions in the Greater Caucasus. As our study area receives less precipitation (>550 mm, MENR, 2008) than the regions in the Central or Western Caucasus (regionally >2500 mm, e.g. Henning, 1972; Prilipko, 1954; Walter, 1974), our data likely show the upper limit of the production potential of sites in the Eastern Caucasus.

Table 5 depicts the results of standing crop measurements according to altitude. The maximum yields are obtained on north oriented sites from 2250 to 2500 m and on south oriented slopes in the belt 2500–2750 m. The data are consistent with the results from exclosure measurements (Table 4). On high altitude sites the production is lowest due to shorter vegetation periods (see also Table 4, line 6). Precipitation patterns in the Greater Caucasus (increases up to 2500 m a.s.l. and decreases above, after Meessen, 1992; Walter, 1974) contribute to the phytomass distribution.

Based on our own data (lines 1 and 2 in Table 4) we calculated the potential stocking rate according to the herd model and compared it with the actual stocking rates (see Table 6). The comparison shows that the mean actual stocking rate is below

Table 2. Mean values (minimum to maximum in brackets) of those variables that differ significantly between lower and upper quartiles (regarding cover erosion tracks) within the 'northern' and 'southern' data sets (p-values from Mann-Whitney Test) and also of selected non-significant (n.s.) variables. For variables with ordinal scale the median is given; their classes are as follows: root density: 1–6; soil depth: 1–6; browsing tracks: 0–4

	Data set	Northern (n = 56)			Southern (n = 49)		
Grouping	Quartiles (regarding cover erosion tracks) Variables	Lower (n = 14)	Upper (n = 14)	p-value	Lower (n = 12)	Upper (n = 12)	p-value
Separation variable	Cover erosion tracks (%)	1.5 (0–3)	35.6 (20–50)	<0.001	5.8 (0–10)	44.6 (30–70)	<0.001
Topographic variables	Inclination (°)	16.0 (3–34)	25.4 (9–39)	<0.05	16.4 (5–16)	26.0 (12–40)	<0.01
	Altitude (m)	2466.8 (2003–2825)	2724.1 (2035–3274)	<0.05	2552.5 (2204–3182)	2684.4 (2028–3059)	n.s.
Components of erosion	Cover of cattle tracks (%)	7.3 (0–35)	19.0 (1–50)	<0.05	8.2 (1–30)	25.4 (0–45)	<0.01
	Cover bare soil (%)	2.9 (0–10)	9.4 (0–35)	n.s.	10.3 (2–30)	11.8 (0–25)	n.s.
	Cover stones (%)	1.1 (0–5)	24.9 (0–85)	<0.05	5.6 (0–25)	34.8 (0–70	<0.01
	Loss on ignition (%)	23.7 (7.8–36.4)	14.6 (4.4–39.5)	<0.05	17.6 (7.7–34.1)	9.7 (4.8–15.3)	<0.01
	Classes of soil depth	3.0 (3–6)	3.0 (1–4)	n.s.	3.0 (2–4)	2.0 (1–4)	n.s.
Plant cover reaction	Total plant cover (%)	95.7 (90–99)	65.4 (10–100)	<0.01	83.3 (55–98)	54.7 (30–85)	<0.05
	Cover litter (%)	16.1 (0–40)	5.9 (0–25)	<0.05	5.6 (0–30)	2.1 (0–5)	n.s.
	Classes of root density	6.0 (4–6)	5.0 (1.5–6)	<0.05	5.0 (3–6)	4.3 (2–5)	<0.001
	Standing crop (dt ha^{-1})	26.1 (3.5–45.2)	17.2 (2.5–62.7)	<0.05	9.6 (3.1–20.2)	9.0 (2.6–23.7)	n.s.
	Metabolisable energy (MJ/kg dry mass)	7.6 (6.3–9.0)	7.3 (6.3–7.9)	n.s.	7.9 (6.4–9.3)	7.5 (6.4–8.3)	<0.05
	Species number (100 m^{-2})	57.7 (29–77)	44.0 (19–59)	<0.05	44.6 (35–61)	40.3 (22–53)	n.s.
Indicators for grazing intensity	Camp distance (m)	663.2 (135–1295)	963.6 (200–2330)	n.s.	645.4 (200–1300)	1051.3 (200–2150)	n.s.
	Classes of browsing tracks	4.0 (1–4)	3.0 (1–4)	n.s.	4.0 (3–4)	4.0 (0–4)	n.s.

Table 3. Characteristics of pastoral farms ($n = 49$) (SU: sheep units; TLU: tropical livestock units)

No.	Variable	Unit	Min.	Mean	Max.
1	Ewes	heads	350	985	2000
2	Summer pasture	ha	80	266	800
3	Stocking rate	SU/ha (TLU/ha)	1 (0.45)	4.62 (2.10)	14 (6.34)
4	Entrepreneurial profit	AZN/farm	−6529	22 311	68 243
5	Entrepreneurial profit per ewe	AZN/SU	−18.66	18.45	34.12
6	Entrep. profit per ha summer pasture	AZN/ha	−38.47	97.34	412.95
7	Interest rate on owner's capital		0.01	0.26	0.39

the mean potential stocking rate on northern slopes while on southern slopes the useable phytomass is nearly fully used. However, the maximum actual stocking rates are above the stocking potential on the most productive sites. Furthermore, the results confirm that the legally prescribed stocking rate of 8 sheep/ha is feasible on most north-oriented slopes but is set too high for the majority of south-oriented slopes.

Opportunity Costs of Reduced Stocking Rates

The central measure to achieve nature conservation goals is the adjustment of stocking rates. We recalculated the economic indicators of pastoral farms under the following scenarios:

(1) *Compliance with legal prescriptions* (LEGAL): Legal regulations for pasture use prescribe a maximum of 8 sheep per hectare for all summer pasture sites (Azerbaijan Republic, 2000). If a farm does exceed this figure, we recalculate the entrepreneurial profit with the maximum number of sheep units allowed on this pasture.

(2) *Ambitious general reduction of stocking rate* (REDUCT): As our results in Table 6 showed, a stocking rate of 8 sheep/ha would overuse pastures on most southerly oriented slopes. Therefore, a reduction of the legally prescribed stocking rate seems appropriate. In this scenario, we assume a maximum stocking rate of 5 sheep units/ha for all pastures.

(3) *Spatially adjusted stocking rates* (ADJUST): Given the heterogeneity of phytomass production on northern and southern slopes, a differentiation of stocking rates would allow a better exploitation of pasture resources while still preventing an overexploitation of vulnerable sites. For this scenario we specified the stocking rates according to altitude classes and aspect index based on own data (Tables 5, 6 and 7).

(4) *Erosion reduction* (EROSION): A serious threat to the mountainous ecosystems is erosion caused by excessive grazing on vulnerable sites. Sites above 20° inclination and where the bedrock is rather soft (slate vs. limestone) are

Table 4. Annual phytomass production (in kg dry mass (DM)/ha) in the Greater Caucasus (GC; AZ = Azerbaijan, GEO = Georgia, RF = Russian Federation)

No.	Author	Region	*n*	Slope	Altitude (m a.s.l.) Mean	Nekromass (%) Mean	Living phytomass/ annual production (kg DM/ha) Min.	Mean	Max.
1	Own data	Shahdag region, Eastern GC, AZ	6	Southern	2252	7.3	824	2314	3724
2	Own data	Shahdag region, Eastern GC, AZ	6	Northern	2390	6.2	2192	3240	3843
3	Efendiyev (1969)	Zakatala, Eastern GC, AZ	4	S, S, N, W	2518	32.7	2040	3379	4080
4	Nakhutsrishvili *et al*. (1980)	Kasbegi, Central GC, GEO	5	W-S	1940	52.6	1600	2644	3448
5	Onipchenko (2004), Onipchenko *et al*. (2009)	NW-GC, RF	4	S-SW	2750	48.3	1500	3375	5500
6	Nakhutsrishvili *et al*. (1980)	Kasbegi, Central GC, GEO	4	Not specified	3088	54.9	164	1200	2530

Table 5. Mean standing crop (minimum to maximum in brackets) in kg dry mass (DM)/ha of vegetation plots ($n = 105$) in five altitudinal belts

	North		South	
Altitude (m asl)	n	Phytomass (kg DM/ha)	n	Phytomass (kg DM/ha)
<2250	10	2288 (430–6270)	5	526 (263–912)
2250–2500	8	2818 (1491–3910)	6	1030 (563–2078)
2500–2750	22	2008 (304–4523)	24	1550 (389–4971)
2750–3000	10	1396 (250–2507)	9	833 (568–1332)
>3000	6	872 (308–1333)	5	1220 (673–2368)

Table 6. Potential and actual stocking rates

	Living phytomass kg DM/ha	Useable phytomass (65 %) kg DM/ha	Energy content[a] MJ ME/ha	Potential stocking rate[b]		Actual stocking rate Sheep units/ha (TLU/ha)
				sheep units/ha	TLU/ha	
South						
Min.	824	535	4553	2.12	0.95	1 (0.45)
Mean	2314	1504	12 786	5.95	2.67	4.62 (2.10)
Max.	3724	2420	20 575	9.58	4.29	14 (6.34)
North						
Min.	2191	1424	12 108	5.64	2.53	1 (0.45)
Mean	3239	2105	17 898	8.33	3.74	4.62 (2.10)
Max.	3842	2497	21 230	9.88	4.43	14 (6.34)

[a]Energy content: 8.5 MJ ME/kg DM.
[b]Energy requirement: 2148 MJ ME/sheep unit, 4791 MJ ME/TLU.

significantly more susceptible to erosion (own results not shown, confirmed by Ruff, 2005). To minimise erosion on the endangered sites we calculate an index based on the share of the area of one farm with $>20^\circ$ inclination and the prevailing bedrock. The bedrock is weighted half as important as the area of inclination. The more a site is susceptible to erosion according to the index, the more we reduce the stocking rates used in scenario ADJUST, but maximally by 50% (Table 7).

The results of the scenario-calculations are shown in Table 8. Under the baseline scenario in total 48 300 sheep units are kept on the studied farms, which generate an entrepreneurial profit of 1 093 248 AZN on a total area of 13 024 ha. According to the four scenarios, different shares of the total 49 farms are affected by a reduction of their sheep numbers. For these farms the average opportunity cost is calculated, which yields for some farms a negative entrepreneurial profit. The amount of the total opportunity costs depends on the number of farms affected and their farm-specific opportunity cost and ranges from 69 157 to 470 075 AZN. The opportunity costs of the last scenario sum up to nearly half of the entrepreneurial profits generated by the study farms in the baseline scenario.

Table 7. Stocking rates (sheep units/ha) in scenarios ADJUST and EROSION

	ADJUST		EROSION	
Altitude	North	South	North	South
< 2250	7	4	7–3.5	4–2
2250–2500	8	5	8–4	5–2.5
2500–2750	7	6	7–3.5	6–3
2750–3000	5	4	5–2.5	4–2
> 3000	3	3	3–1.5	3–1.5

Discussion

Ecological Analyses

Due to the heterogeneous topography in mountains a great variety of different conditions for plant growth occur and hence a multitude of grassland types can be found. With our stratified random sampling design we tried to cover as much variation as possible.

In our results it became clear that although the stocking rates exceed their stocking potential only on some pastures (see maximum values in Table 6), on the majority of pastures grazing is spatially unadjusted. This is shown by strong signs of degradation, that is, the loss of vegetation and soil cover, which implies a reduced ability to provide ecological services. With less vegetation cover and changes in species composition the productivity and fodder quality of the sites diminish, which also decreases the value of the pasture from the herders' point of view.

To maintain the production potential of the pastures, erosion reduction by means of destocking and changed herding regimes is advisable. Our results in Table 2 show that the most eroded sites have significantly less vegetation cover, root density, and soil organic matter and consequently less standing crop yield with less energy content, which are expressions of decreased soil fertility and productivity (Huang *et al*., 2007; Pei *et al*., 2008; Podwojewski *et al*., 2002; Pohl *et al*., 2009; Tasser *et al*., 2003; Zuazo & Pleguezuelo, 2009). When erosion is reduced, phytomass yield would increase, especially on northern slopes, while energy content is likely to increase as well, especially on the southern slopes.

Plant species numbers are significantly higher on less eroded sites, which is in agreement with other observations (Huang *et al*., 2007; Juying *et al*., 2009; Pei *et al*., 2008; Pohl *et al*., 2009; Zuazo & Pleguezuelo, 2009). Especially on the more species rich northern slopes, erosion reduction by the measures mentioned is likely to lead to an increase of α-diversity. In our study area we found a wide range of disturbance levels with different species numbers, complying with the Intermediate Disturbance Hypothesis, which postulates highest species richness in an ecosystem at medium levels of disturbance (Connell, 1978; Grime, 1973; Loucks, 1970). We found the absolutely highest species numbers on hay meadows (mown once per year and afterwards moderately grazed) and on a few only very slightly grazed sites. We assume here peak diversity at a medium level of disturbance. Hence, our 105 pasture plots used in this analysis are found between medium and high levels of disturbance. A reduction of the frequency of disturbances (grazing livestock) is likely to result in

Table 8. Results of economic scenario calculations

No.	Variable	Unit	BASELINE	LEGAL	REDUCT	ADJUST	EROSION
1	Maximum allowed stocking rate	Sheep units/ha	N/A	8	5	8–4	8–2
2	Spatial differentiation?		N/A	No	No	Yes	Yes
3	Farms affected (of 49)	No.	N/A	4	16	17	27
4	Average stocking rate	Sheep units/ha	4.62	4.37	3.79	3.65	3.22
5	Average opportunity cost per farm affected	AZN/farm	N/A	−11 635	−13 765	−12 133	−17 421
6	Stocking potential on all farms	Sheep units	N/A	104 192	78 144	64 584	52 569
7	Total sheep number	Sheep units	48 300	46 768	43 235	41 527	37 887
8	Difference in total sheep number	Sheep units	N/A	−1532	−5065	−6773	−10 413
9	Difference in total sheep number	%	N/A	−3	−10	−14	−22
10	Total entrepreneurial profit of all farms	AZN	1 093 248	1 024 090	864 604	787 514	623 173
11	Total opportunity cost of all farms	AZN	N/A	−69 157	−228 644	−305 734	−470 075
12	Total opportunity cost per 1000 ha	AZN/1000 ha	N/A	−5310	−17 556	−23 475	−36 092

more species. Referring to species composition, many of the endemic species, but also of the valuable fodder plant species (results not shown) would also profit from such measures (Akhmadov *et al.*, 2006).

Erosion reduction would be advantageous in the long run for a sustainable land use as well as for nature conservation.

Socio-economic Analyses

The pastoral farms in Azerbaijan are larger and more market-oriented than farms in comparable pastoral regions in Central and Middle Asia (Behnke *et al.*, 2005; Kerven, 2006; Kerven *et al.*, 2006; Ludi, 2003). This is related to the rapid economic development in the Azerbaijani economy in recent years, though it might only anticipate future developments in other post-Soviet countries. However, economic results can be negatively affected by climatic variations on the winter pastures (Huseynov & Malikov, 2009), which may lead to lower survival rates of lambs and the death of ewes. Despite this risk, most entrepreneurs perceive sheep farming as a profitable economic activity.

In the LEGAL scenario, the opportunity costs represent the additional profit farms generate by not complying with the legal regulations. As farmers do not possess the property rights to these additional profits (Bromley, 1989), they can be subtracted from the opportunity costs calculated in other scenarios. The REDUCT scenario calculates a decreased stocking rate to 5 sheep/ha, which would already eliminate many overstocking problems. However, under this scenario phytomass on the most productive pastures would not be properly used, while on the contrary, on pastures with lower phytomass production the capacity is exceeded.

Both the ADJUST and EROSION scenarios take into account the spatial heterogeneity of pastures as indicated by topographic characteristics. In the former scenario the stocking rates were adjusted to the phytomass production of sites, while the latter additionally takes into account the susceptibility to erosion. The results of the EROSION scenario match the appraisal of the current situation by experienced herders that the majority of pastures are grazed to the limit of their carrying capacity, while phytomass is still available on others.

However, if such a scenario is implemented, the distribution of opportunity costs among the farms should be considered (Adams *et al.*, 2010). Without touching the current distribution of pasture land, eight out of 49 study farms become unprofitable under the EROSION scenario and have to give up sooner or later. Others have to bear opportunity costs (i.e. destock) but are still profitable, while for the third group nothing changes. Under this regulation, no incentive is set for the individual farmers to comply with the new stocking rate prescriptions. Furthermore, a distribution of opportunity costs that is viewed as unequal may seriously undermine the motivation of farmers to comply with the new regulations (Fehr & Falk, 2002). In this way even the slightest chance to tackle the overgrazing problems may be lost.

Another possibility would involve the redistribution of pasture area. As the stocking potential of all study farms' pastures under the most restrictive scenario is still higher than the current total sheep number (see Table 8: 52 569 versus 48 300 sheep), a redistribution of pasture area would reduce destocking needs and thus opportunity costs. This seems possible as due to the limited duration of lease contracts (usually 15 years) a fluctuation in utilisation rights already exists. However, as rights to pasture have been frequently altered in the transition period, the security of the property rights may further decrease in the perception of herders (Sjaastad & Bromley, 2000). Essential would be an anticipatory lease policy of the administration, which takes into account adjusted stocking rates and economically reasonable pasture sizes.

The distribution of opportunity costs between different herders could be also facilitated by compensating farmers for destocking measures. It would even have a beneficial effect on the opportunity costs, if owners of currently unprofitable farms were compensated and provided with alternative income opportunities.

Regarding the calculation method, other ecological services, for example, biodiversity, could be included within the framework of a payment system for ecological services as long as the basic relationships between the service and topographical characteristics are known.

Our calculation could also be carefully extrapolated to the whole summer pasture area of Azerbaijan, as for summer pastures in the western part of Azerbaijan (Ganja-Qazakh region) the economic results as well as stocking rates are similar (Allahverdiyeva, 2009; Neudert & Allahverdiyeva, 2009). Given the currently available total summer pasture territory of 370 000 ha in Azerbaijan, the opportunity costs under the EROSION scenario sum up to approximately 13.5 million AZN. However, as in some areas the grazing pressure might be lower than in our study area, this extrapolation rather represents the maximum opportunity costs.

Our approach could be transferred with limited research efforts to other mountain ecosystems as well. As quantitative data included in our model are either commonly recorded in administrative statistics (pasture area and livestock numbers) or freely available topographic data (SRTM), a practical application within pasture administrations is feasible and would involve only low implementation costs.

Concluding Remarks

We showed that a reduction of grazing intensity in our study area would have a positive impact on soil and vegetation cover, pasture productivity and biodiversity. These consequences would be beneficial for the direct land users, the pastoralists, as well. For a future implementation the acceptance of adjusted stocking rate regulations could be enhanced by taking into account the traditional knowledge of experienced herders in grazing management. It might be advantageous to link our scientifically derived recommendations of stocking rates to these traditional concepts describing pasture characteristics. For example, our partition in north- and south-oriented pastures resembles the local concept of *güney* (southern and eastern slopes) and *kusey* (northern and western). The terms do not only name the aspects, but include information about different plant species, pasture value and needs for herding.

In addition, our study showed the heterogeneous production potential and carrying capacity of the pastures and a large extent of unadjusted stocking rates. Therefore, we recommend a pasture/vegetation monitoring system which leads to spatially differentiated recommendations of stocking rates (e.g. like Etzold &

Neudert, 2010). This would be beneficial for all pastures in Azerbaijan in order to enhance the compatibility of nature conservation and production goals.

Our study area delivers valuable ecosystem services, like water retention, biodiversity and landscape beauty, which are crucially influenced by the intensity of land use. Therefore, an appropriate solution could be a payment system for ecosystem services, which compensates local land users for safeguarding these services. The opportunity costs calculated in this paper are a first hint to the amount of payments involved. However, as the institutional framework in Azerbaijan is generally weak, regulations need to be carefully designed and adapted to the local situation.

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