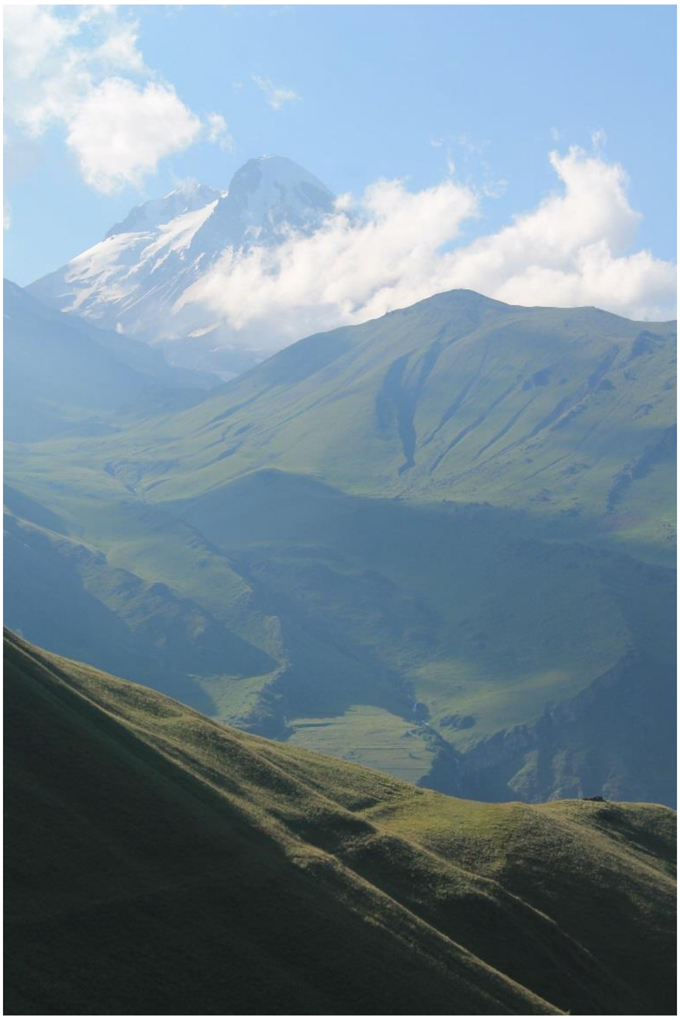
Landscape structure and land use in the Greater and Lesser Caucasus of Georgia:

Impacts of societal change and potentials for sustainable development

Tim Theißen



Division of Landscape Ecology and Landscape Planning

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impacts of societal change and potentials for sustainable development

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List of publications

The thesis 'Landscape structure and land use in the Greater and Lesser Caucasus of Georgia: impacts of societal change and potentials for sustainable development' is based on the following three papers:

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Author´s contribution:

In paper 1 (chapter 5), I did the fieldwork, geo-information-system work, data analysis and writing. The co-authors initiated the study, planned the design and gave valuable comments to the paper.

In paper 2 (chapter 6) again, I did the fieldwork, geo-information-system work, data analysis and writing. The co-authors initiated the study, planned the design and improved the paper with their critical review and remarks.

In paper 3 (chapter 7), the results of the studies from Hanauer, T., Hüller, S., Magiera, A., Shavgulidze R., Tedoradze, G., and me were incorporated. I did the main literature collection, geo-information-system work and writing of the paper. All co-authors helped clarifying controversial points and contributed with valuable ideas and suggestions.

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1. General Introduction

Europe´s mountain area is dominated by forest and grassland land cover, with a high proportion of natural and semi-natural habitats (European Environment Agency, 2002). A large proportion of the habitat types and species that are listed in Annex I, II, and IV of the EU Habitats and Species Directive (European Commission, 1992/1995) occur in mountain areas (European Environment Agency, 2010). The Caucasus, in particular, is one of the 25 biological richest hotspots, hosting highly diverse habitat types and more than 6,300 vascular plant species, with the highest level of endemism in the temperate zone of the northern hemisphere (Akhalkatsi and Tarkhnishvili, 2012; Krever et al., 2001; Myers et al., 2000; Nagy and Grabherr, 2009; Zazanashvili and Mallon, 2009).

The Caucasus, part of the Eurasian Mountain chain, is located in southeast Europe, on the isthmus between the Black Sea and the Caspian Sea. Caucasia can be subdivided in four parts, from north to south: a. Pre-Caucasus plains, b. mountain area of the Greater Caucasus, c. Greater and Lesser Caucasus separating lowlands (also named Transcaucasus), and d. mountain area of the Lesser Caucasus (Walter, 1974). The Caucasian ecoregion ranges over eight latitudes, 24 longitudes and an altitude up to 5,633 m a.s.l. (Mount Elbrus), with diverse landscapes and significant differences in their ecology (Henning, 1970). The main ridges of the Greater and Lesser Caucasus are orientated along a west-east axis. In comparison with the European Alps, both mountain systems have dry inner mountain valleys, whereas the Caucasian climate overall is more continental than the climate of the Alps (Körner and Paulsen, 2017). In this context, several climatic zones along the Caucasian isthmus and the structure of altitudinal zonation determines diverse landscapes, a variety of habitats and a high biological diversity (Georgian Biodiversity and Action Plan, 2005; Nakhutsrishvili, 1999; Tatashidze et al., 2006; Volodicheva, 2002).

Besides Armenia and Azerbaijan, Georgia is one of three states, located centrally in the Caucasus. Several republics of the Russian Federation border the north, with Turkey, Armenia, and Azerbaijan to the south. The Caucasian mountains cover 80 % of Georgia´s land surface with forest (36 %) as the prevailing type of vegetation (EU-FAO, 2013; Nakhutsrishvili, 2013). The republic covers 57,000 km² (without the regions of Abkhazia and South Ossetia) with a population of 3.7 Mio. in 2014 (57 % urban and 43 % rural population; National Statistics Office of Georgia, 2016a). In 1991, Georgia became independent from the Soviet Union.

Followed by the state-owned sovereignty and the collapse of the Soviet Union, the country faced political upheavals and economical transformations. Many countries of Central- and Eastern Europe, i.e. former Soviet Union states, have undergone economic changes from a centralized to a market economy (Kuemmerle et al., 2008). This transformation has had a profound impact on land-use management and food production, ranging from land-use intensification to complete abandonment (Belonovskaya et al., 2016; Gunya, 2017). Changes in administration and land-use management led to environmental problems, like land degradation, erosion and loss of biodiversity, i.e. reduced soil fertility and species loss (Galvánek and Lepš, 2008; Magiera et al., 2016; Tephnadze et al., 2014; Wiesmair et al., 2017). Furthermore, land-use change is a sign for societal changes, like shrinking labor supply, increasing poverty, and population migration (Belonovskaya et al., 2016; Meessen et al., 2015). This is especially true for the Georgian mountainous regions, where due to structural weaknesses like unemployment, poor infrastructure, and the absence of social comfort the youth are leaving and settlements get abandoned (Kohler et al., 2017; Nakhutsrishvili et al., 2009). These societal processes are closely interrelated with environmental problems described above (Tatashidze et al., 2006). These strong interdependencies call for sustainable solutions in land-use science.

Agriculture is the main source of income in Georgia´s mountainous regions, with an employment rate of 47 % (Ministry of Agriculture, 2016). Despite this, agriculture is primarily practiced by smallholders as 'low-input, subsistence and semi-subsistence farming' (Oedl-Wieser et al., 2017). The lack of resources and incentives are seen as the main obstacles for the Georgian farmers to overcome subsistence farming and to establish commercial production (The World Bank, 2009). In the study regions of Kazbegi (Central Greater Caucasus) and Bakuriani (Western Lesser Caucasus), livestock production based on grassland management is currently dominating the mountain farming, with cattle and sheep breeding for milk and meat production (Ministry of Regional Development and Infrastructure of Georgia (MRDI), 2013; Price, 2000; Wheatley, 2009). Transformations in agriculture, which began in the first half of the 20th century – involving a shift from traditional production to intensive livestock breeding and back to a de-intensified farming system upon the demise of the USSR – have greatly affected the land-cover and land-use structure within these agro-pastoral systems (Didebulidze and Plachter, 2002; Haerdle and Bontjer, 2010a). Changes in land use and land cover in these high-mountain landscapes affect the livelihood of the people residing on-site because expanded woody vegetation reduces the productivity of montane and subalpine pastures and hay meadows (Magiera et al., 2013; Tephnadze et al., 2014), which serve as the basis of high-mountain food production. Associated therewith, the rural and cultural uniqueness of this near-natural landscape is endangered. Moreover, the specific habitat types with their endemic-rich and mountain-specific species, especially in the extensive grasslands, correlate with sustainable farming practices (Nakhutsrishvili, 1999). Against a broader background of global change and under the lens of its influence on mountain biodiversity, the importance of biodiversity protection is increasing (Grabherr et al., 1994; Mountain Research Initiative EDW Working Group, 2015; Nikolaishvili and Matchavariani, 2015). Concurringly, mountain areas are especially sensitive to climate change due to the presence of several climatic belts within a relatively small territory (European Environment Agency, 2002). Today, the environmental impact of mountain farming in the study regions is most complex. The patterns and intensities of grazing can simultaneously result in abandonment and overgrazing in separate areas of a topographically diverse region. Land-use abandonment means the disappearance of traditional farming systems, which in turn threatens the local agrobiodiversity by triggering genetic erosion of ancient crop varieties (Akhalkatsi et al., 2010). Overgrazing leads to widespread soil erosion, as it is the case on steep and dry, south-facing slopes in the Kazbegi region (Nakhutsrishvili and Abdaladze, 2017a). However, it is unclear whether the current patterns of grazing causes the erosion features or if they are the consequence of over use during the Soviet period and earlier (Didebulidze and Plachter, 2002). Nevertheless, these problems call for land-use concepts that would avoid uncontrolled management and that support farmers in regions with harsh economic conditions, to foster sustainable mountain farming.

In this respect, agricultural land use plays multiple roles and is therefore in the focus of important concepts, namely the multifunctionality of agriculture, ecosystem services and one health (Huang et al., 2015; Lerner and Berg, 2015). Agriculture guarantees food security and the preservation of biotic and abiotic landscape functions and provides a landscape with rural and cultural uniqueness. In the Swiss Alps, for example, the multifunctionality of agriculture is embedded in the national constitution. Besides the production function, tasks of agriculture are to provide public goods/ services as well as to preserve natural resources and rural livelihood (Stöcklin et al., 2007). This is state-subsidized by agricultural direct payments to the mountain farmers. Multifunctionality is an ‘activity-oriented concept’ which includes multiple functions, referring to production, ecological, and cultural dimensions, and emphasizes the co-benefits from agricultural production processes and their multiple outputs (Galler et al., 2015; Lovell and Taylor, 2013; OECD, 2001). According to the aforementioned role, in order to provide a landscape function with rural and cultural uniqueness, the farmers are crucial for the conservation of landscape and natural resources. In another perspective, but also in the social-ecological context of agriculture, mountain ecosystems provide several essential services (Brunner et al., 2017; Grêt-Regamey et al., 2012; Schirpke et al., 2017). In the concept of ecosystem services the functions of an ecosystem constitute services, and these services are classified/ ranged on a basis of societal choices and values (monetary and non-monetary) (Costanza et al., 1997; Haines-Young and Potschin, 2010). The concept helps in the identification of the benefits of nature or the natural capital to human well-being (TEEB, 2010). In mountainous regions, woodland ecosystems, for example, can provide regulatory services such as the protection against debris flows and avalanches. Furthermore, the extensive mountainous grasslands with agricultural significance provide supply and cultural services, in the form of livestock fodder and a recreational value. One health in this context highlights the linkages, i.e. the interrelationships of ecosystems, humans and animals in a medical framework (Lerner and Berg, 2015). This concept focuses specifically on a multi- and interdisciplinary approach (Schneider et al., 2019). This research approach demonstrates a close linkage between human-, animal-, and ecosystem health, for example in food safety or in emerging infectious diseases (Xie et al., 2017). Ecosystem health in this context means the functioning of an ecosystem expressed by, for example, ecosystem services (Lerner and Berg, 2015). Additionally, research in the control of zoonotic diseases and complex food production systems are focal points (Xie et al., 2017).

Based on the above-introduced problems and challenges with complex interrelations between environmental and societal processes, the focus of this thesis was on the spatial interface of both processes: the agricultural-used mountainous landscape. Accordingly, in two Georgian mountainous study regions, Bakuriani and Kazbegi, the land-use and land-cover patterns were analyzed to evaluate the impacts of both land use and topography on landscape structure. For the Kazbegi region, the context of societal change was considered in the evaluation. In addition and with the aim to foster sustainable development in this remote region, options are given to meet selected *Agenda 2030 Sustainable Development Goals* (SDG´s) (Transforming Our World: The 2030 Agenda for Sustainable Development by the United Nations, 2015). For the Bakuriani region, the societal and natural conditions are quite different compared to the Kazbegi region. The tourism sector is stronger established here, with a stronger engagement of the local population in the sector. Furthermore, the Bakuriani region of the Lesser Caucasus is settled in a lower altitudinal level, directly in the montane to subalpine forest belt, characterized by forest as the main land cover. Therefore, in Bakuriani´s land use forest is an important factor: a silvopastural system with scarcely and densely wooded pastures are important for the local livestock husbandry, while logging and wood processing are further common activities. Even though the region is in a lower altitude with less steep terrain, the topography is strongly influencing the local pattern of different forest types, for example from valley position to lower slope, to upper slope position. The forest types that are affected by agriculture are of value-giving significance for the biodiversity of the Bakuriani region. Nevertheless, in the first half of the 2010s the region also suffered from population decline and agricultural retraction, as it was the case in Kazbegi.

This thesis is based on empirical research in landscape ecology. The scale of the investigations or the spatial frames of the three including studies are from patch to landscape level. This means, the studied 'landscapes' includes the land that belongs to selected mountain settlements, specifically the entire area used for agricultural and forestry purposes from the upper montane to the alpine belt (in Bakuriani from 1,540 m – 2,590 m a.s.l., in Kazbegi from 1,540 m – 2,990 m a.s.l.). In order to clarify how landscape ecology is linked to this thesis, the following two explanations are given:

First, the studied objects are individual aspects of landscape:

- The physical aspects of landscape, i.e. all objects that covers the surface, namely land covers and their spatial reference. Here, remote sensing has been used as the primary tool for classification and mapping. All visible and classifiable objects on aerial and satellite images were mapped. Moreover, the visible and classifiable objects limited the parameters of the studies, respectively.
- The land-use-oriented aspect of landscape, i.e. all the classifiable forms of land use – prevalently agriculture and forestry in these mountainous landscapes.
- Socio-historical aspects of landscape, i.e. the Georgian-Caucasian, societal system of land use. Therefore, the quantifications of land use and land cover were contrasted to agricultural-structural as well as demographic parameters, i.e. amount and type of livestock and local population densities of single settlements. Therefore, landscape transformations from a specific period (1987-2015) have been linked to concurrent changes in population and agriculture at the same time.

Secondly, the term ecology is applied in the sense of the household theory of nature that represent a strict natural science (Remmert and Grieshaber, 1989 cited after Haeckel, 1866). Accordingly, the land cover pattern has been analyzed. This pattern is a complex system that is shaped by anthropogenic activities (to, for example, rural development, agriculture and forestry) as well as by 'activities or forces' of the organic and inorganic nature (Haber, 1996). With regard to the scaling of research, the investigations, as described above, were conducted in the scale of landscape, i.e. a heterogenic complex of related ecosystems (Haber, 1993) located from the montane to the alpine altitudinal belts of the Caucasus.

The thesis is embedded in two international and interdisciplinary research projects, AMIES I (2010-2013) and AMIES II (2014-2019). Both projects were funded by the VolkswagenFoundation and associated to its initiative *Between Europe and the Orient – A Focus on Research and Higher Education in/on Central Asia and the Caucasus*.

2. Objectives

The general aims of this thesis are:

I. to classify the landscape and the forest patterns in the Bakuriani region and to evaluate the impact of land use on the naturalness of vegetation,

II. to analyze and classify land-use and land-cover change contrasted to topography and societal change in Kazbegi, for the identification of land-use trends based on spatial data,

III. to develop sustainable and agricultural land-use scenarios, to foster regional development of the remote, mountainous Kazbegi region.

The results of i – iii characterize two Caucasian landscapes using spatially explicit land-use and land-cover GIS-maps and define their interrelationships to mountain farming and topography. The outcomes are application-oriented and explorative in the context of mountain biodiversity and regional development.

2.1. Landscape Classification in the Lesser Caucasus (chapter 5)

In the first study, I classified and quantified the landscape structure of the Western Lesser Caucasus, in the Bakuriani region to analyze the impact of land use and topography on the pattern of land cover and forest types. Furthermore, I mapped and analyzed the forest pattern in the 223 km² study area. Both the quantification and the mapping were performed via visual interpretation of aerial images (from 2006-2007) in GIS, and a subsequent field validation. For the forest pattern, I inspected forest units according to the dominant tree species in the field. The topographical classification and the land-use distribution were used to evaluate their impacts on the local forest pattern. Moreover, this explored Lesser Caucasian forest pattern was compared to the potential natural vegetation map (PNV) of Europe, by Bohn et al. (Bohn et al., 2004). The mapping and validation showed a locally practiced agroforestry land-use system in the study region. The PNV comparison revealed a near-natural condition of the local forests. However, the land-cover quantification indicated a decline in land use, with associated shrub encroachment.

2.2. Land-Use and Land-Cover Change Relates to Topography and Societal Change in the Central Greater Caucasus (chapter 6)

In the second study, I analyzed the mountainous landscape structure in Kazbegi for 1987 and 2015, to localize and quantify land-use and land-cover changes in that period of Georgia´s transition. Moreover, the study region was spatially classified with respect to topography and distance to settlements. The main variables that defined the spatial units in that classification were aspect and elevation. The combination of the quantification of land-use changes and the spatial classification was the baseline for the exploration of site-specific land-cover change trends. This analysis revealed the dependency of specific land-cover change classes, e.g. pasture to forest or meadow to arable land, on spatial conditions. In the Kazbegi region, the land-use change from 1987 to 2015, initiated and driven by above described transformation processes, was additionally influenced by the topography of this high-mountain landscape with a strong altitudinal gradient.

2.3. Scenario Development in the Central Greater Caucasus (chapter 7)

In the third study, three normative and agricultural land-use scenarios were developed for the Greater Caucasus Kazbegi region that meet selected SDG´s (SDG 8: the promotion of inclusive and sustainable economic growth; SDG 12 on sustainable production and consumption, and SDG 15 to halt land degradation and biodiversity loss). These scenarios are land-use options to foster a sustainable rural land development that achieve the conservation of mountain ecosystems. For this development process, I thoroughly reviewed the existing literature in scenario planning, multifunctional agriculture and ecosystem services. Both latter concepts are important for sustainable agricultural research. The final scenarios were modelled in cooperation with experts in soil science, vegetation ecology as well as agronomy and socio-economy. The results were potential agricultural production outputs with visualized alternative futures. The focus of this study was set on the methodological approach of scenario development, to rather formulate land-use concepts based on interdisciplinary research, than in the exact application of the scenarios.

3. Study Area

Both study regions are located in mountain areas of the republic of Georgia: The Bakuriani region in the Western Lesser Caucasus, central-south Georgia, in the Borjomi district (chapter 5) the Kazbegi region in the Central Greater Caucasus, northeast Georgia, in the administrative unit of the Kazbegi district; (chapter 6 and 7) (Fig. 1).

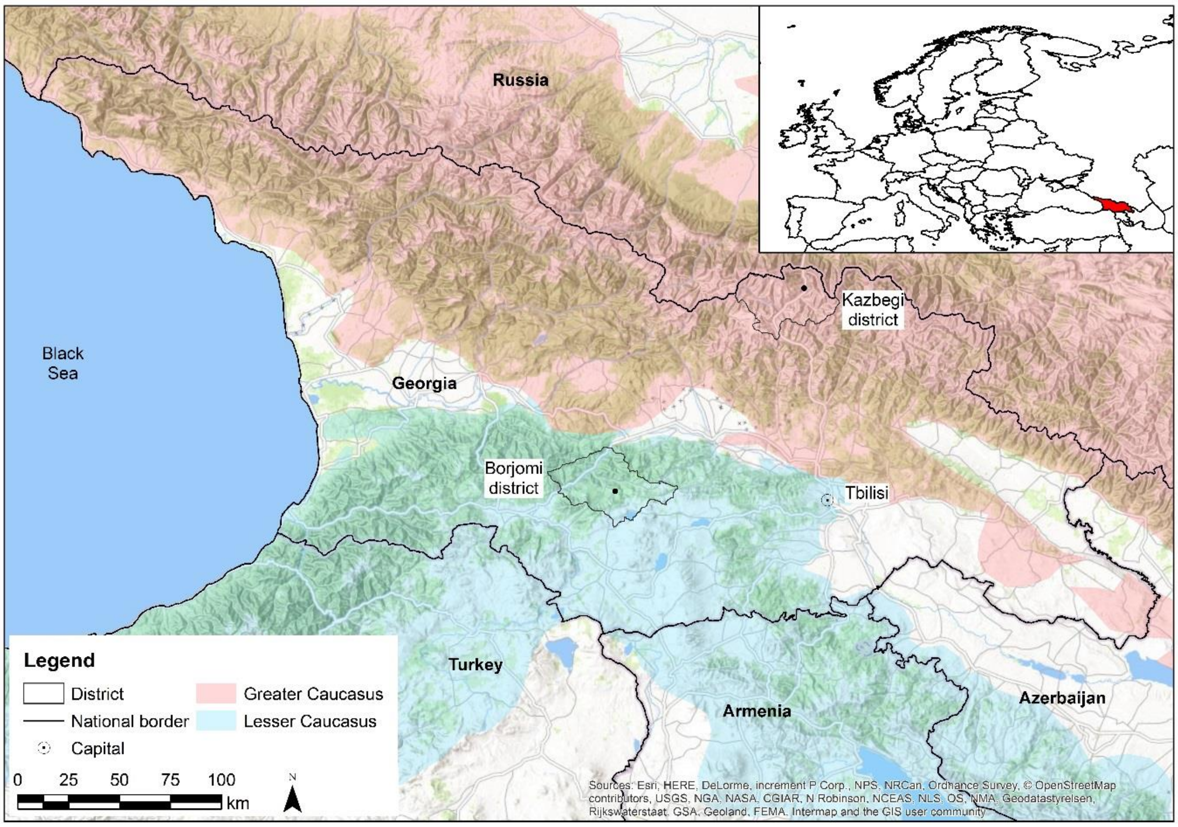

Figure 1: Location of the study areas in the Greater and Lesser Caucasus.

3.1 Geology, Climate and Soil

Geologically, the Greater and Lesser Caucasus originate from the Mesozoic age (252.2 – 145 Ma BP), whereas the uplift of the Greater Caucasus was in the Miocene epoch (23.03 – 5.33 Ma BP) (Philip et al., 1989; Volodicheva, 2002). Besides orogenic processes and the uplift of the mountain-fold structure the Caucasus was shaped by subsequent calc-alkaline volcanism (Koronovsky, 2002). As described in the introduction, the climate in Caucasia is extremely diverse. In general, with rising sea level the thermal budget is decreasing, the solar radiation is getting more intense, the air moisture is decreasing, and the precipitation distribution becomes irregular – thus, high mountain climates are characterized by small-scale and short time variability, which is strongly dependent on topography (Larcher, 1980).

Special features of the Caucasus mountains, especially in comparison to the Alps, are sharp climatic changes within small areas, which is also reflected in vegetation change (Nakhutsrishvili and Abdaladze, 2017b). The Greater Caucasus is forming a climate barrier that limits the penetration of continental, colder air masses from the north, whereas the Lesser Caucasus partially limits the penetration of dry and hot air masses from the south (Urushadze and Ghambashidze, 2013). The Surami mountain range, that connects the Greater and Lesser Caucasus north of the Borjomi district (see Fig. 1), separates the fully humid Rioni depression in Western Georgia (characterized by a warm temperate, sub Mediterranean climate) from the summer-arid/ semi humid Kura depression in Eastern Georgia (with a dry, more continental climate) (Henning, 1970; Kondracki and Bohn, 2004). Complex bioclimatic and different lithological and geomorphological conditions are the reasons for more than 40 different soil types identified in whole Georgia (Urushadze et al., 2000).

The Bakuriani region is located in the northwest of the Lesser Caucasus. The Lesser Caucasus is characterized by a number of alternating fold-zones and volcanogenic flysch sediments that are extensively developed (Koronovsky, 2002). The folded structure of the Bakuriani region originated from the Paleogene period (66 Ma – 23.03 Ma BP) and the topography was additional formed by Paleocenic (66 Ma – 56 Ma BP) and Eocenic (56 Ma – 33.9 Ma BP) volcanic layers that mostly consist of andesite tuff breccias (Nakhutsrishvili et al., 2006). The climate is continental influenced because of the bordering arid Armenian-Javakhetian plateau that is characterized by a high degree of continentality (Volodicheva, 2002). In Bakuriani (1,700 m a.s.l.), the main settlement in the region, the climate is humid-maritime to relatively humid-continental, with a mean annual temperature of 4.6° C (winter mean: -4.3° C, summer mean: 13.8°C), and an annual precipitation of 800 mm (Kordzakhia, 1961). May and June are the month with the highest precipitation, 116 days are frost-free, whereas around 100 days are above 10° C, with 170 rainy days (Javakhishvili, 1949). Umbric Leptosols, Eutric and Dystric Cambisols dominate the soil types in the region (WRB, 2014; Urushadze and Ghambashidze, 2013).

The topography of the Kazbegi region is shaped by Paleozoic (443.4 Ma – 252.2 Ma BP) and older granites, Jurassic rocks (201.3 Ma – 145 Ma BP), as well as lava and moraines. The Mount Kazbek (5,047 m a.s.l.) is a Pliocene-Pleistocene volcano (5.33 Ma – 11,700 a BP) that is now dormant and covered by a glacier (Ministry of Environment Protection and Natural Resources (MEPNR), 2010; Volodicheva, 2002). These described substrates altogether are overlain by Quaternary glacial and fluvial deposits (2.58 Ma – postglacial) (Nakhutsrishvili et al., 2005). In Stepantsminda (1,850 m a.s.l.), the main settlement in the Kazbegi region, the mean air temperature is 5.8° C, the mean daily maximum of the warmest month (July) is 19.7° C, the mean daily minimum temperature of the coldest (January) is -9.1° C, and the mean annual precipitation is at 765.2 mm (Tephnadze et al., 2014). The length of the growing season is 180 days, 124 days are frost-free, whereas in 179 days there is the risk of summer frosts (Nakhutsrishvili, 2003). According to the WRB (2006), the dominant soil types in the region are Leptic, Folic, Alumic, Humic Umbrisols.

3.2 Landscape Diversity

As a result of the above described variability of abiotic conditions, the Caucasus shows a wide range of diverse landscapes. In Caucasia, the vegetation distribution is strongly dependent on moisture supply and the botanic-geographic structure (vertical and horizontal) is following the precipitation distribution (Henning, 1970). This Caucasian botanic-geographic structure was described and mapped in detail by A. G. Doluchanow, 1966 (cited in Henning, 1970).

The landscape of Bakuriani is dominated by forest (Fig. 2, left) and can be described along altitudinal belts. Nakhutsrishvili et al. (2006) distinguished Bakuriani´s vegetation as followed:

- Middle mountain forest (800 – 1,500 m a.s.l.)
- Upper mountain forest (1,500 – 1,800 m a.s.l.)
- Vegetation of the subalpine belt (1,800 – 2,400 m a.s.l.)
- Vegetation of the alpine belt (2,400 – 2,600 m a.s.l.)

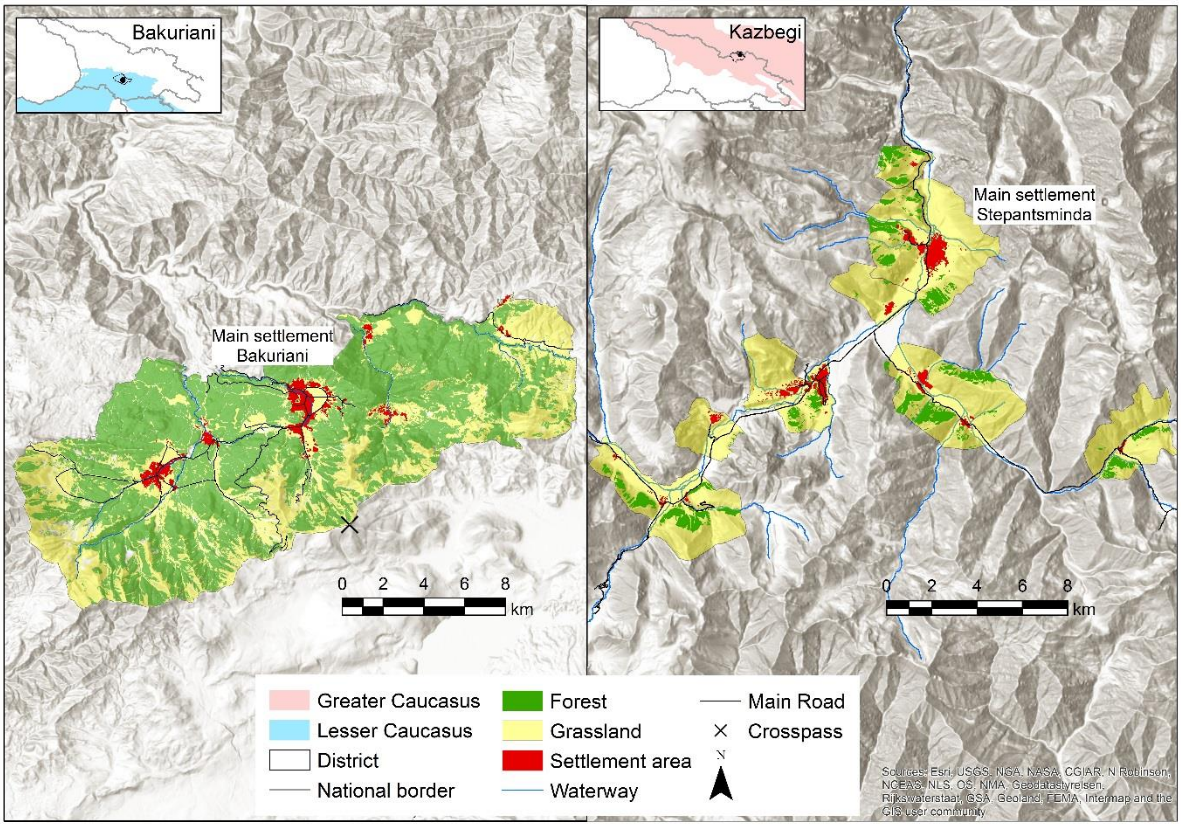

Figure 2: Landscapes of the study areas in Bakuriani (left) and Kazbegi.

According to the Russian soil classification, the forests stock on mountain-forest brown soils – with mountain-meadow soils on open grassland locations in the forest zone – as well as mountain meadow soddy and mountain meadow soddy-peat soils at the tree line and in the alpine belt (Nakhutsrishvili et al., 2006). Along the four above mentioned belts Javakishvili (1949) examined the following vegetation units, that can be used to explain the landscape diversity in Bakuriani more specific:

- Spruce forests,
- Pine forests,
- Beech forests,
- Subalpine vegetation,
- Alpine vegetation,
- 'Postforest meadows' in all above listed forest types (wooded grassland, either used as wooded pasture or wooded meadow).

With a different perspective, William Seifriz (1932) set the focus on the fact that these forests were mostly mixed forests whose distributions are strongly topography related. He divided the forest in Bakuriani in 'Lower mixed forest' and 'Upper forest; deciduous on the north, coniferous on the south' (Seifriz, 1932), whereas north and south designated the slope aspects.

The landscape diversity for the Kazbegi region (Fig. 2, right) from the upper montane (<1,700 m a.s.l.) to the nival belt (>3,500/ 3,600 m a.s.l.) is described in an activity plan on Biosphere Reserves by TJS (Transboundary Joint Secretariat for the Southern Caucasus, 2009):

- Canyon-like gorges with rocky and collapsed vegetation and eroded soils,
- Medium-high mountains covered with aspen and beech, with forest light-gray soils,
- Mountain-valley landscape with forest-meadow (floodplain) vegetation and alluvial soils,
- Subalpine birch sparse and crooked forests, shrubs, high grass, mountain-forest soils,
- Alpine meadows and alpine mats with mountain-meadow soils,
- Subnival landscapes with weakly developed soil and vegetation cover,
- Nival-glacial landscape with permafrost and glaciers.

3.3 Land Use: Past and Present

Agriculture has always played and is still playing an important role in Georgia. At the beginning of the 20th century, agriculture made up the major share of the country´s economy (Bondyrev et al., 2015). During the Soviet era (1921-1991) the agricultural production was specialized in high quality food products like wine, fruits, citrus and tea. (Oedl-Wieser et al., 2017). At the same time, the mountainous regions of the Greater and Lesser Caucasus were used as summer pastures mainly for sheep and goat production in both transhumance and stationary systems (Didebulidze and Plachter, 2002). After the Soviet Union, Georgia´s export oriented food production dropped because of lost sales markets and Russian trade embargos. Furthermore, the livestock production in the mountainous regions decreased and changed. First, without the winter pastures in Northern Caucasus (Dagestan) and Azerbaijan, the sheep and goat production dramatically dropped, by 70 % from the 1980s to 2000s, (National Statistics Office of Georgia, 2013). Second, the focus in livestock production in the mountains shift from sheep to cattle breeding, with slightly but steadily increasing cattle numbers (National Statistics Office of Georgia, 2013). The consequence of the Soviet collapse and subsequent political and economic transitions in Georgia was the establishment of subsistence farming by the Georgian rural population, with 2-3 cows on average per family household (Didebulidze and Plachter, 2002; Haerdle and Bontjer, 2010b; Heiny et al., 2017). In 2015, the agricultural share in Georgian´s GDP was in fourth place at 9.2 %, after trade, industry, and transport and communication (National Statistics Office of Georgia, 2016b). In 1999 the share had been 25 % (EU-FAO, 2013). Compared with the 1980s again, the number of agricultural products in Georgia in 2015 has decreased threefold (Bondyrev et al., 2015).

Currently, in both study regions agriculture and tourism are the main sources of income for the local populations. In Bakuriani, the touristic infrastructure is further developed compared to Kazbegi, especially with ski lifts for winter tourism. Accordingly, one could suggest that summer tourism might play a bigger role in Kazbegi. However, in Kobi, the first settlement after the Jvari cross pass in the Kazbegi region, a large-scale ski lift is currently built to connect the region with Gudauri, south of the cross pass, which is one of the main ski resorts in Georgia. The industry sector, in contrast, is of less importance in both regions but several freshwater sources in Bakurinai and Kazbegi allow the extractions of mineral water. Finally, in Bakuriani there are higher potentials for mining and manufacturing of furniture and wood items (MRDI, 2013; TJS, 2009).

4. Methods

An overview about the methods that are used for the three studies of this synthesis are graphically summarized in Figure 3. Overall, this workflow shows the used input data, the processing steps, and the final output data.

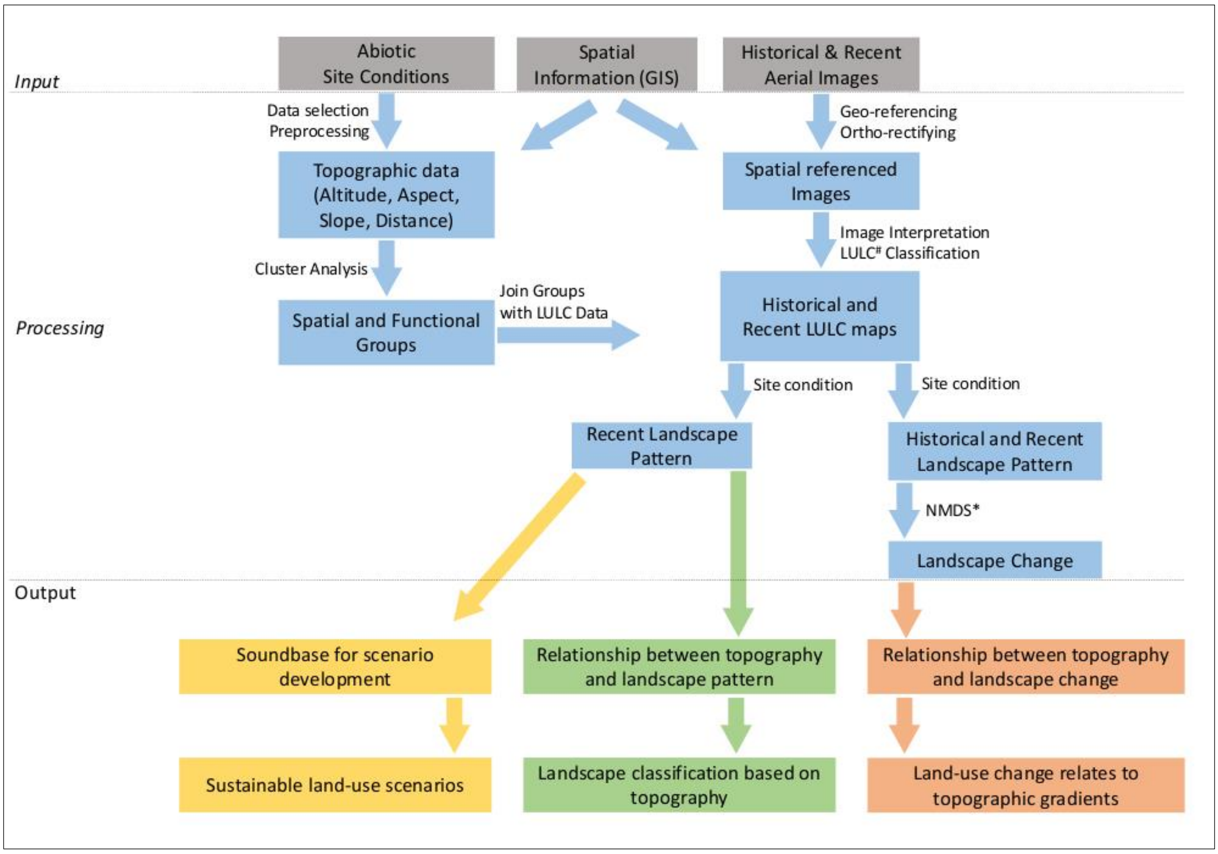

*Figure 3: The methodological workflow of this synthesis with the focus on the used and processed geo-data for the three studies. The grey boxes are the input data. The blue boxes are symbolizing the processing steps, with the blue arrows indicating the hierarchically structure. The yellow (study 3), green (study 1) and red boxes (study 2) are symbolizing the frame and the content of the studies. For the study 'Sustainable land-use scenario' (yellow box) only the data related to landscape ecology is shown. For this interdisciplinary research, also studies in soils science, vegetation ecology and social and agronomic science were necessary. (Abbreviations: #LULC = land use and land cover, *NMDS = the statistical approach of a similarity structure analysis, namely the* ***n****onmetric* ***m****ulti****d****imensional* ***s****caling).*

4.1. Methods of Geo-Referencing and Orthorectifying

To provide image data from the study areas that are useful for the process of visual image interpretation and spatial explicit classification, aerial and satellite images need to be georeferenced and orthorectified (see Fig. 4). Both applications are required to set up the spatial reference for an image or a photograph. In performing the tool *Georeferencing* in the Geographical-Information-System ArcGIS, ArcMap©, a scanned aerial photograph is adjusted to, for example, a topographical map

(1:25.000) with a defined projected coordinate system WGS 84 (World Geodetic System 1984), UTM (Universal Transverse Mercartor) Zone 38N (step A-C in Fig. 4).

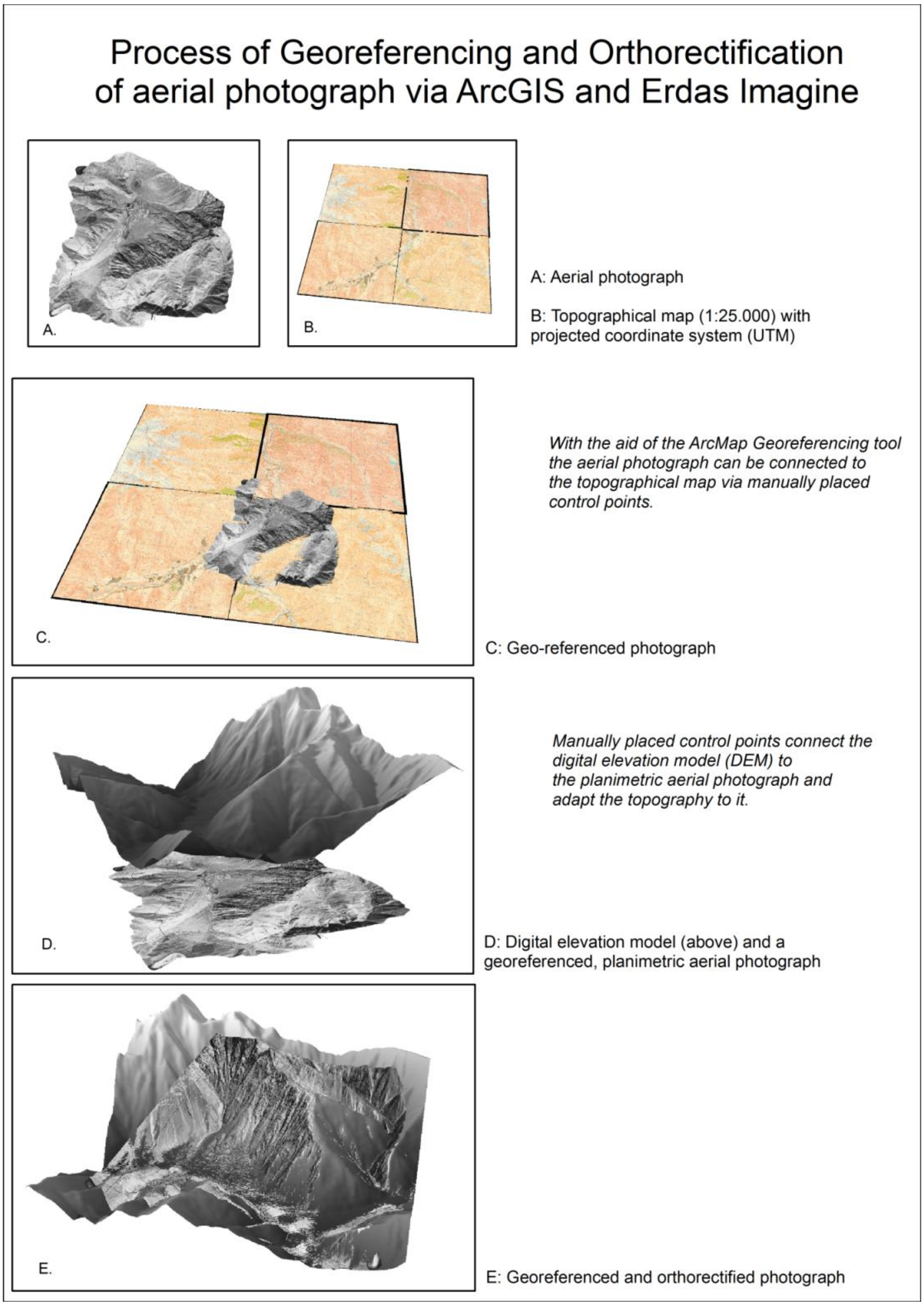

Figure 4: Georeferencing and orthorectification of a digital, historical aerial picture (A-E). From Theissen, 2011 (Masterthesis at the Professorship of Landscape Ecology and Landscape Planning, Justus Liebig University, Giessen) [Theissen, T. (2011): Dynamics and spatial pattern of land cover and land use in a Greater Caucasus Region. – In: Division of Landscape Ecology and Landscape Planning. Justus-Liebig Univ., Gießen. 52 + IX pp.]

The orthorectification of a georeferenced aerial photograph has been conducted with Erdas Imagine© 8.5 (Leica Geosystems, Atlanta, Georgia, USA), a provider of spatial modeling and remote sensing software. This application adjusts the photograph to the locational topography. Aerial or satellite images as raw data are planimetric, this means the images are recorded from a bird´s eye view and according to the recording angle lengths and widths can be stretched or compressed. In the process of topographical correction, the locational altitude (z-value) is included in the recalculation of lengths and widths. Especially in a high-mountain region, this correction is stretching steep slopes (steps D-E in Fig. 4). For this application, a digital elevation model (DEM) is needed. The DEM used in the studies for the orthorectification has a spatial resolution of 20*20 m cell size.

The satellite images used in the studies though has already been georeferenced and orthorectified. The satellite images had been proposed at the RESA project (RapidEye Science Archive©) for images from the RapidEye system. The products (level 3A) are five-band, georeferenced and orthorectified images in GeoTiff format, with a spatial resolution of 5*5 m cell size (16-bit unsigned integers). Temporally, the images cover three-time dates, June, July and August in 2014. Spatially, the study region was covered with seven images, so called tiles in a size covering 25*25 km.

4.2. Methods of Image Interpretation and Classification

The georeferenced and orthorectified images provide the input data for the process of visual interpretation and classification. For this process, a specially created classification key with seven land-use and land-cover (LULC) classes and overall, 26 LULC units was prepared (Fig. 5). In the Central Greater Caucasian study area, the landscape is dominated by cultural, semi-natural and natural mountainous mesophilic grassland, used either as pasture or as meadow. In the Lesser Caucasian study area, the landscape is dominated by mountainous coniferous and deciduous forest. Obviously, the focus of the key is on agricultural used land as well as on forest and woody vegetation. Besides the classes and units, the intention of the key was to depict the sampled land cover and land use in a maximum possible and spatially explicit way. For this purpose, the date of recording of the historic aerial photographs and of the newer satellite images plays a significant role. Both images were recorded between August and September, after haymaking when the haystacks were still on the meadows. According to this visible characteristic, it was possible to distinguish between pasture and meadow and to characterize and quantify grassland managements. Specifically for the Lesser Caucasus study area, different forest types were mapped, i.e. coniferous forest, deciduous forest, and mixed forest, in order to characterize and quantify the forest pattern in Bakuriani.

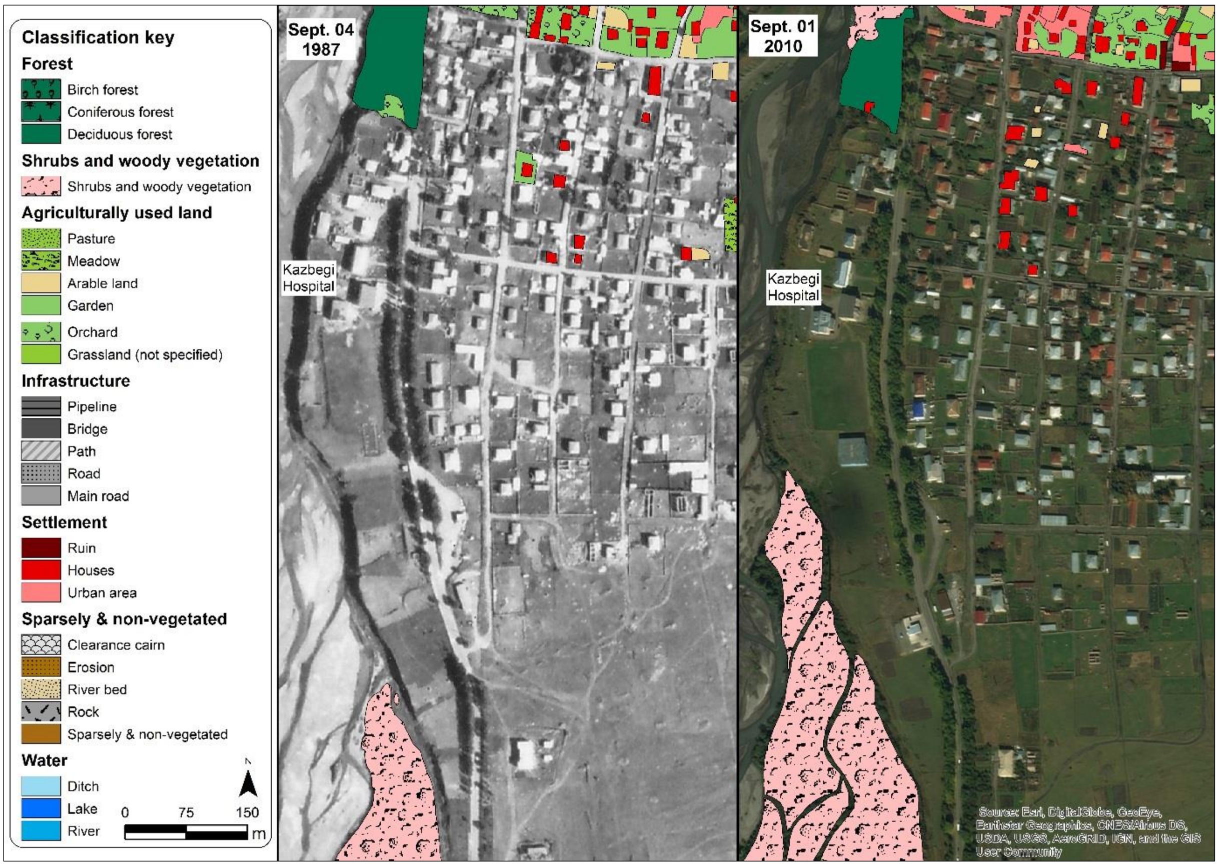

Figure 5: The classification key for land-use and land-cover classification, with 7 classes and 26 units. This key was created and applied for the visual interpretation and classification of b/w aerial photographs (left image) and satellite images (right image), in the context of historic and current, Caucasian-Georgian land use systems. The classification and digitalization lead to demarcated and mapped polygons in accordance to the visible objects in the images. The section selected here show the southwest part of Stepantsminda in Sept. 04, 1987 and in Sept. 01, 2010, in the scale of 1:5,000. Compared to 1987, shrub with Hippophae rhamnoides *spread in 2010 along the Tergi River. Furthermore, the amount of houses and urban area increased as well in 2010.*

Finally, the process of image interpretation and classification resulted in several LULC-maps for the study areas of Kazbegi and Bakuriani. For Kazbegi, LULC-maps were created for 1987 and 2014, with a congruent spatial extension and including 17 settlements (for each year a total area of 93.8 km²). The Bakuriani map depicts the LULC pattern of the year 2007 and includes seven settlements (covering a total area of 223 km²).

The produced GIS maps form a sound base for the subsequent field evaluation. In order to provide a ground truth, the maps of 2007 and 2014 were validated in the fields – in Kazbegi in 2014 and 2015, and in Bakuriani in 2012. Starting from the single settlements, the classified LULC units in the maps were inspected to reclassify, update and/or adjust, if necessary. In this evaluation process again, the focus was set on agricultural used land and forest. In the case of Bakuriani, the field evaluation formed the baseline for a subsequent reinterpretation of the forests in the images. Based on selected inspected locations in the field the whole forest in the study area was evaluated afterwards.

Finally, the land-use and land-cover patterns of both regions were quantified and analyzed. To this end, all GIS maps were combined with further spatial information, i.e. topographical data and distances.

4.3. Combine Land-use and Land-cover Data with Spatial Information

In order to intersect the spatially assigned information about land use and land cover with further spatial data, i.e. site conditions, the DEM with 20*20m cell size was used for the terrain analysis. Therefore, appropriate variables were selected: elevation, aspect, slope, and distance. Distance, indicated as the Euclidean Distance in meters, is an important value for a spatial investigation. Moreover, distance can function as an indicator for human impact on the landscape. The main anthropogenic impacts in the study landscapes are agriculture and forestry. It can be assumed that these impacts, and especially the agricultural impact, are the strongest closed to settlements and decrease with increasing distances to the settlements. This assumption is based on the 'von Thünen theory', with distance to town center as a factor that determines strongly management and land-use decisions since accessibility and transportation costs are considered (von Thünen, 1850).

Based on the DEM all four variables can be calculated in a GIS. Euclidean distance, slope inclination, and slope aspect were calculated using the Spatial Analyst Toolbox in ArcGIS 10.2 (ESRI, Redlands, CA, USA). The variable elevation was directly derived from the DEM. To join calculated and derived variables with the land-use and land-cover information, the vector-based LULC maps were converted into point-shapefiles in a grid, based on the spatial resolution of the DEM. These configurations were done again in ArcGIS with the *Conversion Toolbox*. Finally, and spatially consistent, the topographical variables were joined with the point data, by using the tool *multiple values to point* in the *Spatial Analyst Toolbox*. The extracted attribute tables of the created and processed point layers served as input data for subsequent statistical analyses.

4.4. Statistical Analysis and Landscape Classification

According to the processed variables and the spatial linkage in GIS, each single study area of Bakuriani and Kazbegi was classified upon similarity, i.e. landscape segments, here equal sized raster parcels, with more or less equal values in the four variables were aggregated. This was done using a cluster analysis. The cluster analysis is a multivariate statistical method and belongs to the Exploratory Data Analyses and Data Mining Techniques. Clustering is defined as 'the grouping of similar objects' (Hartigan, 1975), it classifies a set of objects into groups, so called clusters. Each study region, converted into a grid-point dataset, was used as input for the clustering. In this process, each grid point functions as an object in the algorithm and 'carries' the information about elevation, aspect, slope, and distance to settlement – the variables that define the clusters.

Preceding to the clustering, a test defines an appropriate number of calculated clusters based on the given input data. This is achieved by the implementation of a previous *v-fold cross validation* to the *k-Means Clustering Algorithm*. The input dataset is repeatedly and randomly portioned into training samples and testing samples. After the portioning, a cluster algorithm computes clusters with the training samples and validates these calculations with the testing samples. This process is applied ten times and each time with different training and testing. The result of these iterative pre-tests is an appropriate number of clusters in accordance with the given input data which is then used for the main clusatering.

Based on the selected variables (dimensions), the *k-Means Clustering Algorithm* divides the objects into the selected number of clusters with a minimized sum of squares (Hartigan and Wong, 1979). In this process, the algorithm computes so-called centroids (means) of each cluster and allocates the objects to the cluster centroids. This is again an iterative process because the objects are repeatedly changed between the clusters to achieve the most significant differences between the clusters. The *k-Means Clustering Algorithm* is a machine-learning method that is defined as artificial intelligence because the algorithm 'learns' from the iteratively recalculation of clusters.

After the completed calculation, the clustered objects of the study regions are re-transferred into a GIS to visualize the landscape classification based on topography and distance. In GIS, the clusters are visualized as contiguous sub-areas of the landscape. Based on this landscape classification the LULC pattern was analyzed.

4.5. Methods to Evaluate Patterns of Land Use and Land Cover

Methodologically, clustering the study area and its implementation in GIS provided the sound base for a landscape analysis in Bakuriani (chapter 5) and in Kazbegi (chapter 6).

LULC Change along a Classified Landscape

In Kazbegi the result of the study area clustering was used to analyze changes in LULC from 1987 to 2015. Therefore, the LULC pattern of 1987 was compared with the pattern of 2014, based on the LULC maps for both years. On settlement-level, the land use and the land cover for each year were quantified. Building upon this, the change was determined by contrasting both quantifications. To localize the changes, the result of the clustering served as a spatial reference. In a last step, an analysis was performed for each settlement with a non-metric multidimensional scaling ordination (NMDS). This final statistical investigation was used to compare the change pattern of each settlement. The result of this change analysis was contrasted and discussed with changes in population and agricultural-structural changes in the same period. For this purpose, data from population and agriculture census (1989, 2002, and 2014) were used.

Land Use and Forest along a Classified Landscape

For Bakuriani the study area was clustered as well, again with the same selection of topographical variables. In this investigation, the landscape classification was used to analyze the spatial pattern of LULC. Moreover, as the Bakuriani study area is richly forested, the spatial classification was used to determine the forest pattern. In a further step, the mapped and validated forest was compared with the map of the potential natural vegetation of Europe. Following the classification, the clusters served as a spatial reference for the comparison of the forest with the potential natural vegetation.

Site-related Potentials for Land-use Scenarios

In this investigation, normative agricultural land-use scenarios in the Kazbegi study region were developed that meet sustainable production goals. To model possible land use and land cover patterns, several site-related information is needed. For this study, the site-related potential was determined by quantitative data of current land-use information, of soil quality and productivity, of grassland productivity, as well as of the agricultural production potential and economic viability. This data was contrasted with qualitative data of current food provision and need of agricultural products by the local population and current tourist volume. The mentioned site-related information was joined to determine locational potentials. Subsequently, and by using normative thresholds, sustainable land-use scenarios were developed on settlement-level. The normative thresholds were used to account for location-adapted land use which considered sustainable high-mountain farming. The GIS model considered the carrying capacity of pasture slopes, the productivity of hay-meadows, as well as the productivity and the erosion susceptibility of arable land locations. To this end, suitable locations for certain agricultural practices were determined to develope land-use patterns with a location-adapted use of normative scenarios.

5. High-mountain Landscape Classification to Analyze Patterns of Land Use and Potential Natural Vegetation

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5.1 Abstract

In Georgia´s Lesser Caucasus extremely species rich wooded grasslands are still used as pasture or meadow. These silvopastoral systems are one of the oldest land-use types in Europe, hosting both light-demanding and shade-tolerant species. However, in Europe silvopastoral systems have decreased over the past centuries.

The aim of this study is to map, quantify and classify the local land use and forest types in comparison to the potential natural vegetation to analyze and evaluate the high-mountain landscape pattern. Therefore, we mapped a 223 km² study area and classified this mountainous terrain by topographical variables in a cluster analysis.

Our results revealed a small-scale pattern of agriculture and forest in the study area, both strongly interlinked. The forest pattern strongly depends on altitude and aspect. The mentioned wooded grassland consists of forests with varying canopy covers connecting the settlement-near pastures and meadows in the montane belt with the natural open grassland in the alpine belts. The forest is in a near-natural condition compared with the potential natural vegetation. However, the quantifications revealed shrub encroachment indicating land-use abandonment.

The compiled GIS-maps and the spatial classification of the landscape can be used to support sustainable management strategies in forestry and agriculture.

Keywords

Landscape structure, Lesser Caucasus, potential natural vegetation, GIS, cluster analysis

5.2 Introduction

Forested mountainous areas dominate the land surface of Georgia. The country is naturally constituted of the Caucasian mountains that cover 80 % of the land surface (EU-FAO, 2013). Forest is the prevailing type of vegetation, covering 36 % of the total area (Nakhutsrishvili, 2013). Forests form a wide altitudinal belt across the Caucasus, with a great variety in forest types, forms, and compositions (Volodicheva, 2002). Beech and oak dominate mountain broad-leaved forests (Walter, 1974). Dark coniferous forests are composed of spruce and fir, partly of pine (Nakhutsrishvili, 2013). Situated in the Western Lesser Caucasus of Georgia, the Bakuriani study region is a richly forested high-mountain landscape, with land-use activity focused in the altitudinal belts of the upper-montane and lower subalpine. Along strong topographical gradients, non-intensive forestry and agriculture are practiced locally. Traditional grassland management dominates the mountain livestock farming. A specific character of this region is the high amount of wooded grassland along all forested altitudinal belts, either used as wooded pasture or wooded meadow. Open and semi-open grassland ecosystems of the Caucasian landscape are characterized by a high biodiversity and a species richness with a high level of endemism, especially in the alpine zone (>1,900 m a.s.l.) (Nagy and Grabherr, 2009; Nakhutsrishvili, 2003). The species-rich Caucasian grassland is a remarkable example of a traditional and sustainable high-mountain land use, with a high ecological and economic value that deserves protection (Millennium Ecosystem Assessment (MEA) 2005). Hence, the Lesser and the Greater Caucasus are biodiversity hotspots and together one of the 25 species-richest regions of the world (Krever et al., 2001; Mittermaier et al., 1999; Myers et al., 2000; Zazanashvili et al., 1999).

The biodiversity in this cultural landscape is threatened by unsustainable and less-systematic management, caused by distinct land fragmentation, uncontrolled production, illegal timber logging and limited assistance by agricultural and forestry services (Ministry of Agriculture, 2016). This leads to habitat degradation, species loss and disruption of ecological processes (Zazanashvili and Mallon, 2009). Mountainous grassland habitats, for example, are vulnerable to land-use change, like the abandonment of regular mowing which directly affects the species richness (Galvánek and Lepš, 2008). At the same time, the biodiversity of mountain grassland was established throughout the traditional cultivation over centuries (Nagy and Grabherr, 2009), and to maintain or re-establish this level it is important to achieve a use that reaches specific elements of the traditional land use practices, like cutting date, carrying capacity or limited fertilization. Furthermore, habitat degradation in Georgia is additionally triggered by effects of social and economic crises after the independence from the Soviet Union, namely a lower living standard in mountain areas, unemployment, migration of population and abandonment of settlements (Akhalkatsi et al., 2010; Nakhutsrishvili et al., 2009). When basic needs are not met, the risk of an unsustainable use of local natural resources increases, like fuel wood consumption, illegal logging or poaching (Zazanashvili and Mallon, 2009). Consequently, this valuable cultural landscape and the multifunctionality of the landscape can be seriously changed.

Furthermore, mountainous regions are most affected by climate change (Kohler et al., 2010). However, the effects of global warming are diverse and the impact on mountainous environments are difficult to predict due to the complex topography and a lack in long-term, high-altitude climatic data (Kohler and Maselli, 2009). Nevertheless, temperature and the snowline have risen in Europe´s mountains between the late 19th and the early 21st centuries, and it is expected that summer precipitation and wind speed will increase in Northern and decrease in Southern Europe (Engler et al., 2011; European Environment Agency, (EEA) 2010). With increasing temperature, the tree line moves upwards as well and the summit vegetation on high mountains will change, because the habitats for cold-adapted organisms will shrink, according to the summit trap phenomenon (EEA, 2002). Although species moved upslope on average, the effects on the biodiversity differed along Europe´s mountain ranges, with an increase and a decrease in species richness (Pauli et al., 2012). However, in a time series data comparison, a range shift by plant communities driven by warming has been demonstrated on several European mountains (Steinbauer et al., 2018). Besides these effects on mountain biodiversity, changing weather patterns affect the resource provision and the production capacity, i.e. yields of grassland and crops (Briner et al., 2012; Gentle and Maraseni, 2012).

Against the background of the high phytodiversity value and the importance of multiple functions of traditional and relative pristine cultural landscapes, the aim of this study is to map, quantify and classify the Lesser Caucasian land-cover and land-use pattern on landscape level in a spatial explicit manner. Furthermore, we want to analyze and point out the local forest composition based on the determination of dominant tree-species and combination-mosaic types. According to the Georgian Forestry Agency, 98 % of Georgia´s forest is natural forest (Ministry of Agriculture, 2016). In order to interpret the pattern and the status of this Lesser Caucasus high-mountain forest, we compared the compiled forest map on landscape level with the map of the potential natural vegetation of Europe, by Bohn et al. (2004). Potentially natural, in this context, means the mosaic of vegetation units that would hypothetically arise without human impact, and based only on inorganic site conditions, i.e. climate and soil conditions (Horvat et al., 1974).

The availability of spatially referenced data in mountainous areas is limited because of difficulties and inaccuracies in the creation, due to the great spatial heterogeneity and complexity. For Eastern Europe, land-use and land-cover quantifications are scarce because agricultural data is missing or inaccurate (Kuemmerle et al., 2008). However, spatially referenced land-use and land-cover data is able to manage trade-offs among uses and resources and can function as a sound base for planning tasks, monitoring systems and assessments (Heinimann et al., 2003; MEA, 2005). Finally, a spatial classification of land use and land cover is useful, since the strong topographical gradients are the main factors for land-use decisions and the spatial pattern of land cover in mountain regions (Pecher et al., 2013; Zimmermann et al., 2010). Based on the described context, our main objective was to analyze if the occurrence of the potential natural vegetation types can be linked to land-use and topographic patterns in the Bakuriani study area. We consequently aim::

- to map the land-use pattern and the local potential natural forest vegetation,
- to quantify and interpret this Lesser Caucasus forest pattern,
- and to classify the mountainous landscape, in order to explain the diverse landscape structure along topographical gradients.

5.3 Study area

5.3.1 Geographical location

This study was carried out in the Borjomi district (1,189 km²), an administrative unit of the Samtskhe Javakheti region, located in the Lesser Caucasus of Georgia (Fig. 6, inset map). Our study was focused on the land cover and land use of the Trialeti Range (southeastern part of the Borjomi district), covering an area from the middle-montane belt (1,144 m a.s.l.) to the alpine belt (2,826 m a.s.l.). The study area included the surrounding land of the settlements Bakuriani (1,661 m a.s.l., with a population of 1,985 in the year 2002), Bakurianis Andeziti (1,600 m a.s.l., 515), Tsikhisjvari (1,650 m a.s.l., 644), Didi Mitarbi (1,300 m a.s.l., 48), Patara Mitarbi (1,540 m a.s.l., 64), Gverdisubani (1,550 m a.s.l., 34) and Tsinubani (1,530 m a.s.l., no population data available) ("Samtskhe Javakheti Region Map," 2002) (Fig. 6).

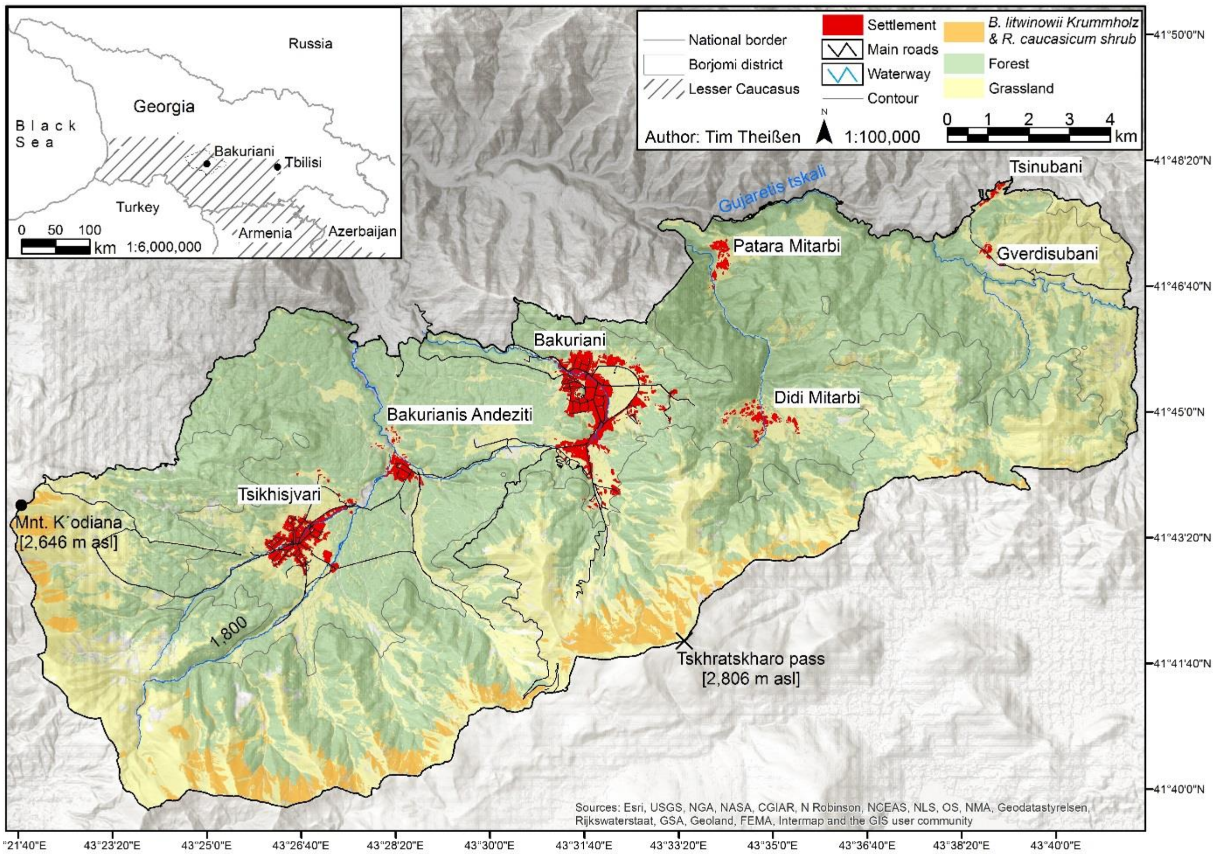

Figure 6: The study area with Bakuriani and neighboring settlements. The land cover of this area in the Lesser Caucasus mostly consists of forest and grassland. The upper limit of wooded vegetation is built by Betula litwinowii Krummholz and Rhododendron caucasicum shrub.

All settlements are located in the upper-montane belt. Nearly all settlements are located within island-like clearings of mixed montane forests, except Didi Mitarbi, which is spread over several hilltops, and Gverdisubani, which is located on an almost forest-free macroslope. Most inhabitants of Gverdisubani (34), leave their homes in the winter to live in towns and cities, e.g. Tbilisi (Metreveli, 2005). Nevertheless, most of them practice agriculture locally, also livestock breeding, since they can keep their livestock at neighboring villages during winter times. The study area border was set by available aerial images, altitude and land-use activity, i.e. accessibility.

5.3.2 Climate, Geology and soil

The climatic conditions of the Tsikhisjvari-Bakuriani basin are humid-maritime to relatively humid-continental, determined by the Mediterranean Western Georgia (Colchis) and by the continental and moderately humid Javakheti Plateau in the south-east. The latter influence is the dominating one because of the humidity-losing eastward drifting air masses form the Black Sea which pass by several mountain ranges (Javakhishvili, 1949). The mean annual temperature in Bakuriani is 4.6 °C and the annual precipitation is 800 mm (Kordzakhia, 1961). The warmest month is August and February is the coldest, with a maximum rainfall in May and June and a minimum at the highest temperature in August. On average, 116 days are frost-free, around 100 days are above +10°C, with 170 rainy days (Javakhishvili, 1949).

Extensive development of volcanic flysch sediments produced by uplift, deformation and erosion of mountains, characterize the main parts of the Lesser Caucasus (Koronovsky, 2002). The study area is part of the Trialeti mountain range, with Tskhratskharo Pass (2,806 m a.s.l., Fig. 6) centrally located at the south-east border of the study area. The range is the north-west border of the Javakheti volcanic plateau which includes many extinct volcanoes and dominates the Lesser Caucasus (Walter, 1974). Paleocenic and Eocenic volcanic layers compose the topography of the study area. Here, mainly Umbric Leptosols, Eutric and Dystric Cambisols dominate (Urushadze and Ghambashidze, 2013). According to the Russian classification, these soils are Brown Forest soils and Mountain Meadow soils (Javakhishvili, 1949).

5.3.3 Land use in the Tsikhisjvari-Bakuriani basin

The altitude in the study area comprises four altitudinal belts: the middle-montane belt, from 1,144-1,500 m a.s.l.; the upper-montane belt, from 1,500-1,800 m a.s.l.; the subalpine belt from 1,800-2,400 m a.s.l.; and the alpine belt from 2,400-2,826 m a.s.l. The latter is located in a thin line along the north-facing and west-facing slopes of the ridges of the Tskhratskharo range in the south (being a part of the Trialeti range), and along the K´odiani range in the west (Fig. 6). Overall, the alpine belt covers 12 km² (5 %) of the whole study region. The main part is in the subalpine and the montane belt with 103 km² (45 %) and 108 km² (50 %), respectively.

The study area is richly forested; forest and woody plants cover 144 km² (63 %). Open landscape covers 85 km². On the one hand, the openness is natural, especially in higher altitudes, with the natural grassland in the subalpine and alpine belts. On the other hand, the open landscapes in the lower altitude are anthropogenic openings for settlement-, infrastructure- and agricultural purposes. Additionally, the forested area is artificially opened in the cases of rolling uplands, debris flow activities, wildfire or windthrow, typical for mountainous regions. As, in the west, the study area is connected to the Banishevi region and, in the east, to the Javakheti region, the vegetation is enriched by Colchis-vegetation and by xeric vegetation of mountain-Armenia (Javakhishvili, 1949).

The major sources of income in the Borjomi district are agriculture, tourism and forestry (Ministry of Regional Development and Infrastructure of Georgia, 2013 (MRDI)). Agriculture is dominated by livestock production. Cattle and sheep breeding are common (Wheatley, 2009). Especially in the high-mountains, most of the agricultural production is managed in family holdings and for self-supply, due to low-productivity and land fragmentation (Ministry of Agriculture, 2016). A population survey (2011) within the framework of the 'amies-project', and based on a standardized questionnaire, showed almost every second household in the study region reared livestock and more than 40 % of the surveyed households kept one to five cows (Heiny, 2017). In a subsistence herding system, the families´ cattle are collectively brought outside the villages by herdsmen in the morning after the milking process (Plachter and Hampicke, 2010). In terms of a rotated grazing system, the herdsmen flock to different locations around the settlement throughout the season in order to uniformly distribute the grazing pressure on common pastures of the villages. In the evening, the cattle move homewards independently or are managed by the herdsmen again (Didebulidze and Plachter, 2002).

Concerning the livelihood in the Borjomi district, tourism has become a significant source of income for the local population with an increasing number of hotels, lodging facilities and visitors (MRDI 2013). Small-scale and community-based mountain adventure tourism is the most frequent form in Georgia (alpine skiing, discovery tours, eco-tourism, mountaineering, trekking and mountain-biking) (Price, 2000). However and despite the fact that the Borjomi district is a traditional resort area, the hotels and guesthouses are often managed independently, i.e. without co-operation, not even to local tourism services (Oedl-Wieser et al., 2017).

For the local population, the forest plays a significant role, not only for the provision of touristic services, like recreation or aesthetic values. Using the forests for firewood collection and for agricultural, silvopastoral systems has a long history in the Caucasus (Heiselmayer and Zazanashvili, 2004). In Georgia, woodland grazing is still widespread nowadays (Plachter and Hampicke, 2010). This traditional and rare land-use type provides a high biodiversity, because a diverse vegetation combines light-demanding and shade-tolerant species from grassland and forest habitats in continuous transition (Hübl et al., 2010). Javakhishvili (1949) reported that, in the Bakuriani region, 'postforest' grassland was used by the local population as meadow or pasture throughout the middle of the 20th century, harvesting 60 70 % of the whole hay biomass. In consequence of timber logging and the following forest grazing or haymaking, a well-developed grass and herbage layer in the understorey established in the ‘postforest’ meadow and pasture sites. Flat or gentle slopes of former pine stands with mesophilic site conditions have been the most productive ‘postforest’ grassland (Javakhishvili, 1949).

5.3.4 Agriculture and forestry during and after the Soviet period

In the context of the region´s land-use development, the intensity of land use has varied since the last century until today in the Borjomi district. During the Soviet era the Caucasian states (Armenia, Azerbaijan, Georgia and Russia) established an extensive livestock transhumance system with subalpine and alpine summer pastures in the Greater and Lesser Caucasus mountains and winter pastures in the bordering plains (Didebulidze and Plachter, 2002). The livestock production in the Soviet Union was intensified starting in the mid 20th century with increasing sheep and cattle stocking rates, up to several million heads in total, followed by pasture depression and local erosion as well, in consequence of the increased grazing pressure (Nakhutsrishvili et al., 2009; Robinson et al., 2003). During that time, the agricultural production was partly practiced with disregard for the environment (Price, 2000).

After the official declaration of independence from the Soviet Union in April 1991 (Curtis, 1994), the borders to the neighboring states in the Caucasus were closed and thus the transhumance system was minimized significantly, with a loss of winter pastures and decreasing numbers of livestock. Furthermore, after the independence the young republic faced a period of internal conflicts (Didebulidze and Urushadze, 2009) as well as political, economic and social restructuring (Abbott et al., 2011). In the 90s of the 20th century, several agricultural structural reforms entered into force, e.g. the Law of Privatization of Agricultural Land (1993) and the Land Registration Law (1996) (Salukvadze, 1999). For instance, a decree permitted a maximum of 1.25 ha of the former state-owned land free for cultivation per homestead in rural regions (Lohm, 2006). However, especially in rural regions the decentralization of economic management and use of product markets rather than planning (Fischer and Gelb, 1991) resulted in disadvantages for its economic development, reflected in a lower living standard compared to urban centers in the country (Kötschau et al., 2009). Loss of sales markets, distribution systems (including high quality seeds, concentrated feed, fertilizers and pesticides) and machinery after the breakdown forced a restructuring and retraction of agriculture production, especially in marginal regions in the mountains with frequently inadequate infrastructure (Lohm, 2007). In addition, differences in agro-climatic conditions plus the dominated small-sized farm structure led to regional differences in agricultural production, and thus in the income of the farmsteads, today, as described above, mostly operated in family holdings (Lohm, 2007; The World Bank, 2009). After 1989, the population in the Borjomi district strongly decreased, like in other rural areas of Georgia (Population Census, 2002; Rowland, 2006).

Tending, protection, restoration, and usage of the National Forest Fund are formalized in the Georgian Forest Code. Regional offices of forestry on a district level are responsible for the forest, which, nationwide, is almost completely publicly owned (Metreveli, 2005). The use of the forest by the local population, except for free agricultural use, is managed by short-term or long-term licenses, confirmed by a ten-year management plan, developed by the State Forest Fund Cadaster. Mowing, pastoralism as well as the establishment of arable land within the forest are permitted. In terms of extent transhumance systems, the local population is given priority in agricultural use of the forest (Ministry of Environment and Natural Resources, 1999). After Georgia´s independence, wood import from Russia almost stopped completely, with the consequence of increased unsustainable and uncontrolled harvesting of national timber resources (Didebulidze and Urushadze, 2009). Almost 60 % of the annual forest harvest in 2005 was for fuelwood, primarily for rural households, additionally affected by the decreased energy subsidies for fossil fuels. Coppice forests have been most affected (Metreveli, 2005). In 2009, agricultural farms and communities managed 20 percent of Georgia´s forested land (The World Bank, 2009).

5.4 Material and Methods

5.4.1 Land-cover and land use mapping

The land cover and land use (lclu) of the study area was mapped in two steps: first, in an aerial image digitalization and classification and second in an on-site evaluation of the classified map in the field.

Official spatial and ortho-rectified aerial images in high resolution (cell-size 0.5 x 0.5 m) of 2006 and 2007 from the Borjomi district were interpreted via object-based classification. The interpretation was performed by a consistent hierarchical classification, primarily at a working scale of 1:5,000, resulting in a cartographical visualization of the study region´s land use and habitat pattern (Waldhardt et al., 2011). Concerning the forest structure, visual homogeneous canopies were combined to separate coniferous, deciduous, and mixed forest stands and were distinguished in three cover ratios: closed forest with total canopy cover, dense forest with a canopy cover of 30 – 75 %, and open forest with 10 – 30 % cover. In this process, the wooded meadows and pastures were localized. We assumed that closed forests were negligible as areas used for grazing livestock. Areas with single trees or groups of trees with a canopy cover ratio less than ten percent were not treated as forests. Furthermore, we assumed that infrastructure, including roads and paths, and rivers are fragmenting polygons, whereas ditches are not.

During a one-month field work in 2012, the lclu map was updated and evaluated with a focus on the villages´ agricultural land use and on the forest classes. The small-sized farmstead´s arable fields were localized and mapped beside the mowed gardens and orchards. Uncertain aerial image grassland classifications were inspected and primarily identified as meadow or pasture. In terms of the wooded meadows and pastures, the cover ratio was evaluated, and the dominant tree species determined. Concerning the closed forest, selected forest polygons of the map were inspected, and the dominant tree species were determined as well. Ten percent of the study area´s closed forest was evaluated, and these identified polygons were further used as reference data to re-determine the whole forest again. This last step was applied to object-based aerial image classification again to assign all forest polygons to specific forest classes, based on the field work´s dominant tree species identification.

5.4.2 Data processing

An essential aspect of the study´s analysis was to differentiate the study area according to descriptive spatial indicators. Afterwards and by an argumentum e contrario, this classification served as a descriptor of the local land use and the highly structured and diverse forest pattern. The explanatory variables for the analysis were elevation, aspect, slope and distance to a settlement. Despite the topographical variables, distances to settlements was selected to explain the anthropogenic influence, assuming long distances define less influence, i.e. pronounced naturalness, respectively. The variables were derived from a 20x20-m resolution digital elevation model (DEM).

The DEM included the grid-cell information elevation and was further the basic data for the calculation of the other variables in the same resolution. Applying the raster calculation of ESRI´s ArcGIS© the inclinations in degree have been calculated. To include aspect in the analysis as a continuous rather than a categorical variable, the eastness and northness were calculated for each grid-cell. Both parameters range from -1 to 1. Values close to 1 represent the aspect east, and north, respectively. -1 reflect western and southern aspects. Both parameters can be calculated by trigonometric functions (Roberts, 1986), for eastness the sinus transform of the product of aspect and pi, and for northness the cosine transform of the same term, both via applying the raster calculator. The distances to settlements have been calculated with the Network Analyst toolbox of ArcGIS© for the vector-level and based on the study area´s infrastructure. Further, and after the transformation into grid-cells, the Euclidean distance of each cell to the neighboring road or path has been determined. The sum of both, infrastructure length and distance to infrastructure was the distance of each grid-cell to a center-midpoint in the settlements. Finally, for 572,320 grid-cells we extracted and calculated the explanatory variables to cover the whole study area. This information was further combined in a vector-point-layer. The layer-points served as input data in the follow-up cluster analysis, treated as cases there.

5.4.3 Data analysis

In this study, we applied the k-Means cluster analysis, combined with a previous v-fold cross validation. During the clustering algorithm, the involved cases were grouped together or separated from each other by distances between them. Therefore, the Euclidean distance has been set, operating as a geometric distance in a multidimensional space, while the variables are reflecting the dimensions of the space (here, Euclidean distance as a statistical measure in the statistic software, not the one calculated in GIS, which is used as an explanatory variable in the analysis). For the analysis, the included variables were standardized to exclude scale effects, in terms of variations in value scattering (Bahrenberg et al., 2008).

The prior v-fold cross validation is a calculation to find a suitable number of clusters by a defined data, the whole dataset in our case. The dataset was randomly portioned into ten parts, of which nine parts were used as training samples and one as a testing sample. The clustering algorithm computes the cluster with the training samples; the testing sample validates the cluster calculation by assigning the test samples to the built-up clusters. This is repeated ten times, every time with different testing samples. Finally, an averaged classification error is calculated. This whole procedure is done starting with two clusters, up to 25. To find the accurate number of clusters, not only the smallest averaged classification error is taken into account, also low cluster numbers are preferred (Sherrod, 2014). In the following k-Means clustering the number of clusters defined by the v-fold cross validation had been set. Then, all cases of the dataset were assigned to the clusters by the clustering algorithm. During this classification, the similarity within the cluster will be maximized and minimized between the clusters. Cases are repeatedly changed between the clusters in order to receive the most significant differences between the clusters. This is corresponding to an `ANOVA in reverse` (StatSoft, 2013).

5.5 Results

5.5.1 Quantification of the local land-use pattern

The output of the object-based classification of ortho-rectified aerial images (2006-2007) and the field evaluation in 2012 was a land-use and land-cover map of 2012 for Bakuriani and its neighboring villages (Fig. 7).

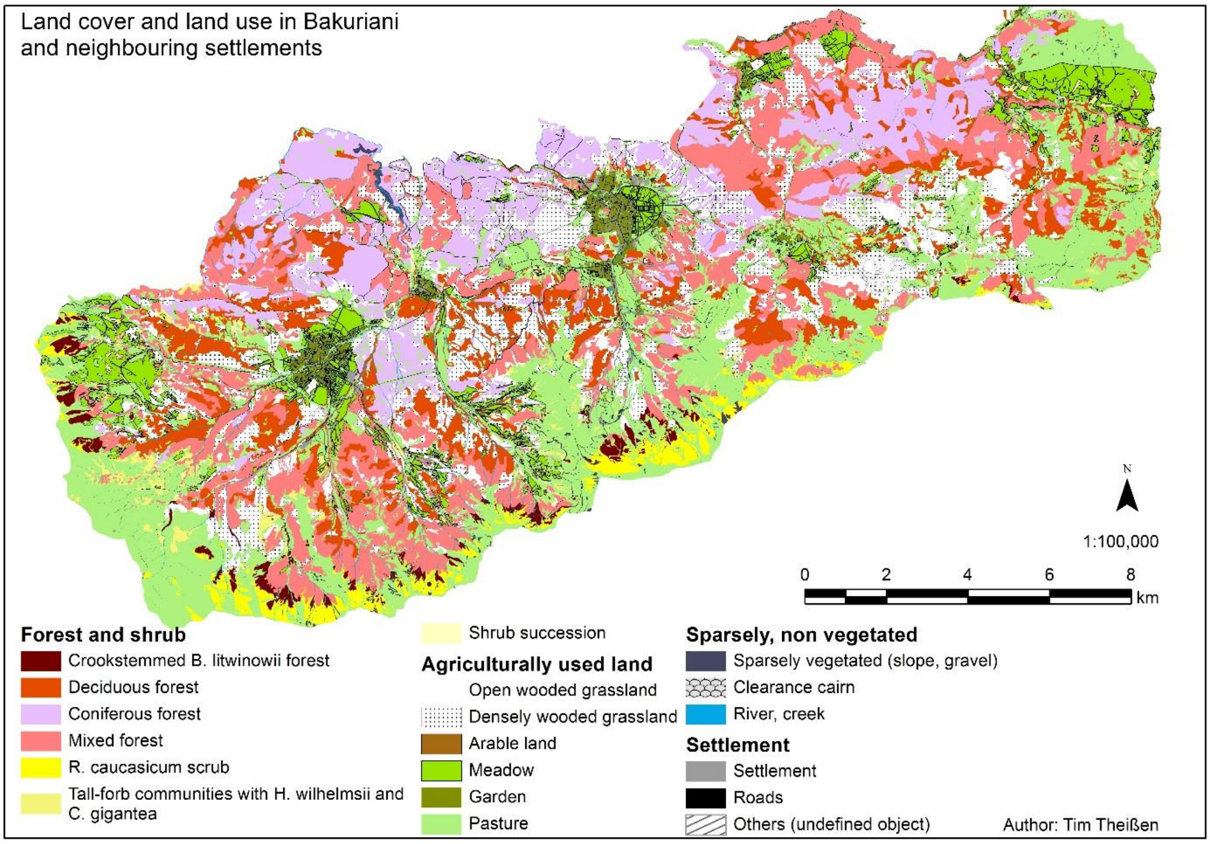

Figure 7: Land-cover and land-use pattern of Bakuriani and neighboring settlements based on aerial imagery mapping (with images from 2006-2007) and field validation in 2012.

The urban area of all six settlements and the local infrastructure cover 800 ha, 3.5 % of the study area. Small-sized cultivated arable fields (22 ha, 0.1 %) are mostly within the settlements, situated in house-gardens or orchards (239 ha, 1 %). However, the fieldwork demonstrated that fenced cultivated parcels, sparsely located and arranged as allotments, are outside but near the villages. Infrastructure alone, including roads, paths, and trails cover 347 ha (1.5 %) and are distributed all over the study area, connecting the settlements with peripheral agricultural areas but are also used by tourists for mountaineering, hiking and horse trekking.

Typical for mountainous regions, agriculture is dominated by grassland management for livestock farming, as is the case in the Bakuriani study area. The total open grassland is used as pasture (5,787 ha, 25 %) and meadow (1,531 ha, 7 %). Above the timberline, in the subalpine and alpine belt, natural open grassland provides additional pasture area for the local livestock and serves as upland pastures for flocks of sheep from nationwide nomadic pastoralists.

Most of the study area is covered by closed forest (9,505 ha, 42 %). Caucasian deciduous, coniferous and mixed forests make up the forest belt from the montane to the subalpine belt. The timberline and the tree line are mostly formed by the birch species Betula litwinowii, whereas the trees are in a crookstemmed, ‘krummholz’ habit in the upper timberline. The forest is used by the local population for forestry and agricultural purposes. Small-scale and mostly private timber logging is practiced for fuel wood and constructional timber. As mentioned above, a particular and remarkable characteristic of this region are the wooded grassland locations. According to the local agriculture, the local forest is strongly affected by agro-silvopastoral use (agroforestry). Forests are grazed by the local cattle throughout warmer periods and in the late summer, and parts of the wooded grassland are mowed. We classified these species-rich habitats as open wooded grassland (1,117 ha, 5 %) and dense wooded grassland (2,471 ha, 11 %), according to the tree layer cover.

Shrub vegetation covered 1,325 ha (6 %) of the total area and was classified as Rhododendron caucasicum shrub, tall-forb communities (dominated by Heracleum wilhelmsii and Cephalaria gigantea) and shrub succession.

Further landscape structure elements were defined as clearance cairn and sparsely vegetated areas (93 ha, 1 %). The latter are bare soils, erosion sites, avalanche tracks, scree slopes, gravel, rock fissures, outcropping bedrocks and riverbeds. These natural elements were distinctive landmarks, typical for a high mountain landscape, and sparsely but entirely spread. Rivers, ditches and lakes covered 265 ha, 1 %.

5.5.2 Interpretation and quantification of the local forest

Forest, shrubs and wooded grassland covered together 144 km² of the study region, i.e. 63 % of the total study area. Comparing the compiled and evaluated forest map with the Map of the Natural Vegetation of Europe of the German federal office ‘Bundesamt für Naturschutz ‘, (freely available in the scale of 1: 2,500,000) a high accordance is revealed. The distribution of dominant tree species in the study region (Fig. 8) corresponds strongly with the distribution of the BfN-mapping units (inset map of Fig. 8).

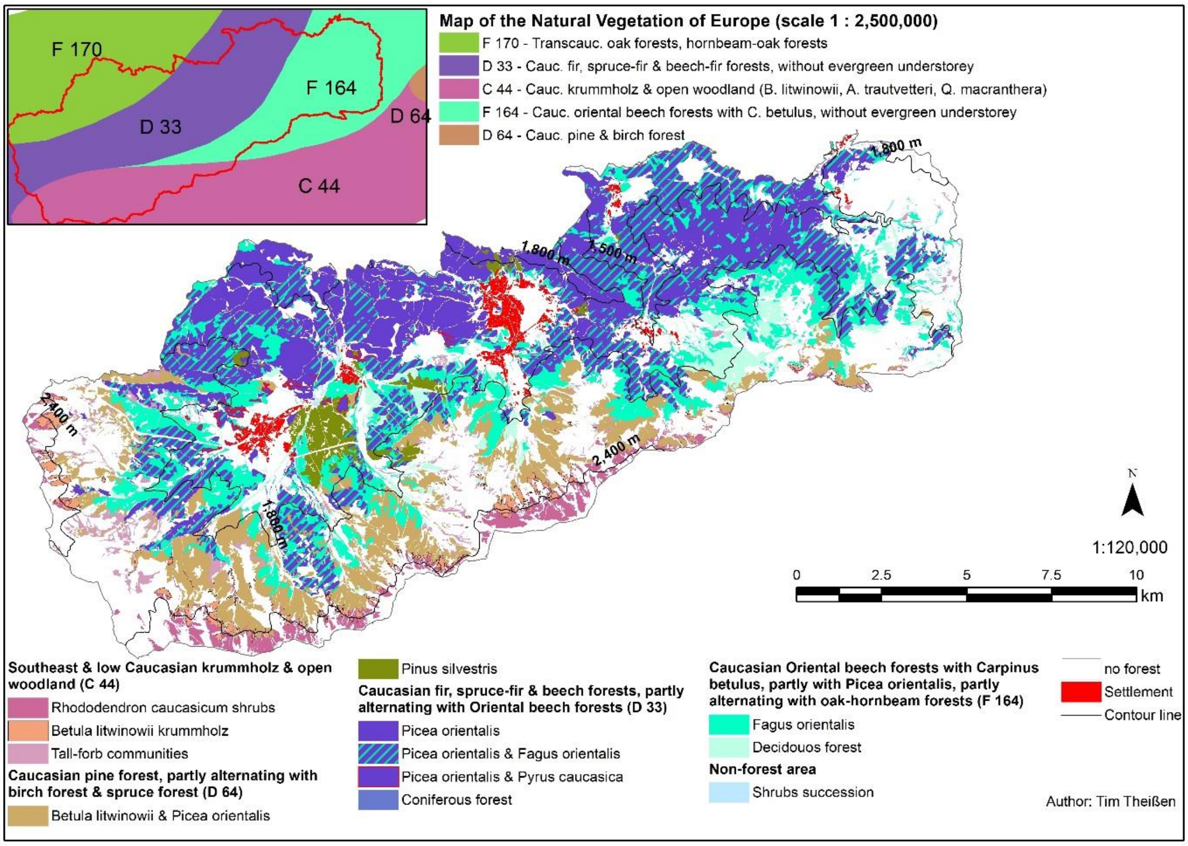

Figure 8: Forest structure of the study area based on the Map of the Natural Vegetation of Europe and field validation.

This suggests that the local forests exist in a near natural composition, in the sense of the BfN-map. According to this potential natural vegetation map, the study region is subdivided in four forest types:

- Caucasian fir, spruce-fir and beech-fir forests (*Abies nordmanniana, Picea orientalis, Fagus sylvatica subsp. orientalis*) without evergreen understorey, partly alternating with Oriental beech forests (*Fagus sylvatica subsp. orientalis*) (BfN-mapping unit D 33)
- Transcaucasian oak forests (*Quercus iberica*), hornbeam-oak forests (*Quercus iberica, Carpinus betulus*) and Oriental hornbeam-oak forests (*Quercus iberica, Carpinus orientalis*), with *Acer cappadocicum, Sorbus torminalis*, partly in combination with shibliak communities (scrub) (F 170)
- Caucasian Oriental beech forests (*Fagus sylvatica subsp. orientalis*) with *Carpinus betulus*, partly with *Picea orientalis*, without evergreen understorey, partly alternating with oak-hornbeam forests (*Carpinus betulus, Quercus iberica*) (F 164)

- Southeast and Low Caucasian krummholz and open woodlands (*Betula litwinowii, Acer trautvetteri, Quercus macranthera*), scrub (*Rhododendron caucasicum*), tall-forb communities (*Heracleum sosnowskyi, Aconitum orientale*) and grasslands (*Festuca woronowii, Calamagrostis arundinacea, Geranium ibericum*) (C 44)

However, the field work in 2012 revealed two mismatches of the current status of the local forest and the potential vegetation map: first, the distribution of the Transcaucasian oak forests (BfN-mapping unit F 170) in the north-west of the study region was considerably reduced. The reduction of this strongly xerophytic oak forests is the consequence of long-standing effects of anthropogenic impact (Dolukhanov and Bohn, 2004). In our opinion, these forests are replaced by oriental beech forests, spruce forests and mixed spruce-beech forests. Second, an increase in the extent of mixed pine, spruce and birch forest can be described within the study region, on the north-facing slopes leading up to the Tskhratskharo Pass. These forests can be described as:

- Caucasian pine forests (*Pinus kochiana*), partly alternating with birch forests (*Betula litwinowii, B. raddeana*) and spruce forests (*Picea orientalis*) (mapping unit D 64)

These forests also belong to the mesophytic and hygromesophytic Caucasian coniferous and mixed broad-leaved-coniferous forests like the spruce and spruce-beech forests.

Comparing the forest types, 7,136 ha (31 % of the total study area) were covered by mapping unit D 33, whereas the fieldwork revealed that spruce is more frequent than fir in the study area. F 164 covered 3,429 ha (15 %). The Unit C 44 covered 1,258 ha (6 %) and D 64 2,532 ha (11 %). Considering the altitude in the forest pattern, 80 % of the coniferous forest existed in the middle-montane and upper-montane belt, i.e. lower than 1,800 m a.s.l. The mixed forests and broad-leafed forests were mainly located above, in the subalpine belt. Here, in the lower-subalpine belt, the lower boundary of the timberline occurred, partly formed by *Fagus orientalis* forest, preferring north-western slopes. In places, the *Betula litwinowii* and *Picea orientalis* forest made up the upper boundary of the timberline, for example on the exposed northern slopes leading up to the Tskhratskharo Pass. *Betula litwinowii* krummholz formed the tree line in the study area on northern slopes. Nearly the whole shrub vegetation (90 %) occurred above 1,800 m a.s.l., consisting of *Rhododendron caucasicum* shrub, Tall-forb communities and shrub succession. The endemic *R. caucasicum* shrub grows in the natural grassland above 2,400 m a.s.l. in the alpine belt.

5.5.3 Landscape classification along topography

The k-Means clustering landscape analysis calculates six clusters with a classification error of 0.315 for the testing sample. The classification error of seven clusters is even smaller (0.300). However, the decline of the error from six to seven clusters is smaller than the decline from five to six. Thus, at six clusters the classification error curve has been saturated and the cluster numbers been set, including the fact that a lower cluster number is desirable.

The output of the analysis is a classification of the study region in six classes (domains) according to explanatory variables as spatial indicators (see chapter 3.3). The classification is relatively homogeneous due to the spatial expansion of the domains (minimum 13 %, 31 km² of the study area, maximum 20 %, 45 km²). Aspect (Northness and Eastness) was the variable with strong differentiation of the domains (Fig. 9).

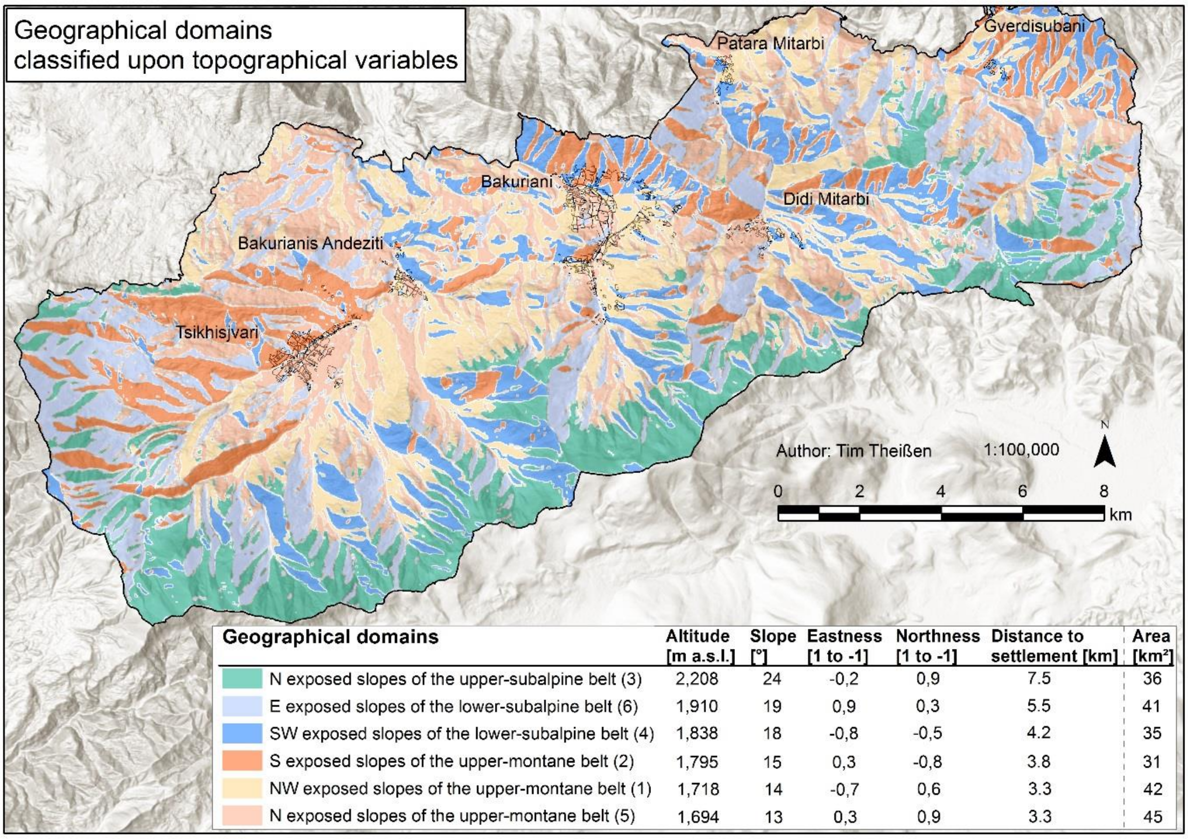

Figure 9: Landscape classification of the study area with a k-means cluster anaylsis and based on topographical variables, with six domains seperated mainly by altitude and aspect (northness and eastness).

The total study area reaches from the montane (minimum 1,144 m a.s.l.) to the alpine belt (maximum 2,826 m a.s.l.). According to the altitudinal belts, three geographical domains cover the upper-montane belt, north exposed slopes showed the lowest altitude (a mean of 1,694 m a.s.l.) and the flattest terrain (mean = 13°) of the study area. This domain is close to the settlements (with a mean distance of 3.3 km). NW exposed slopes of this belt showed a marginally higher altitude, with a mean of 1,718 m a.s.l. and 14° steepness, but the same proximity to settlements as the first domain. South exposed slopes, with 1,795 m a.s.l., reach the border to the subalpine belt. These slopes are on average 15° steep, with 3.5 km distance to villages. With a higher altitude the steepness and the distance to the settlements are increasing. This is true for the three domains in the subalpine belt. South-west exposed slopes of the lower-subalpine are at 1,838 m with 18° inclination and 4.2 km distance. East exposed slopes here reach 1,910 m, 19° and 5.5 km. Finally, in the upper-subalpine, where north-exposed slopes dominate, the area is on average 2,208 m a.s.l., the slopes are 24° steep and the next settlement is 7.5 km away. These slopes belong to the macroslopes of the Trialeti range, located in the south, and are the highest locations of the study area.

Further the output of the cluster analysis served as a grouping variable for an analysis of the pattern of land use and of forest habitats (Fig. 10).

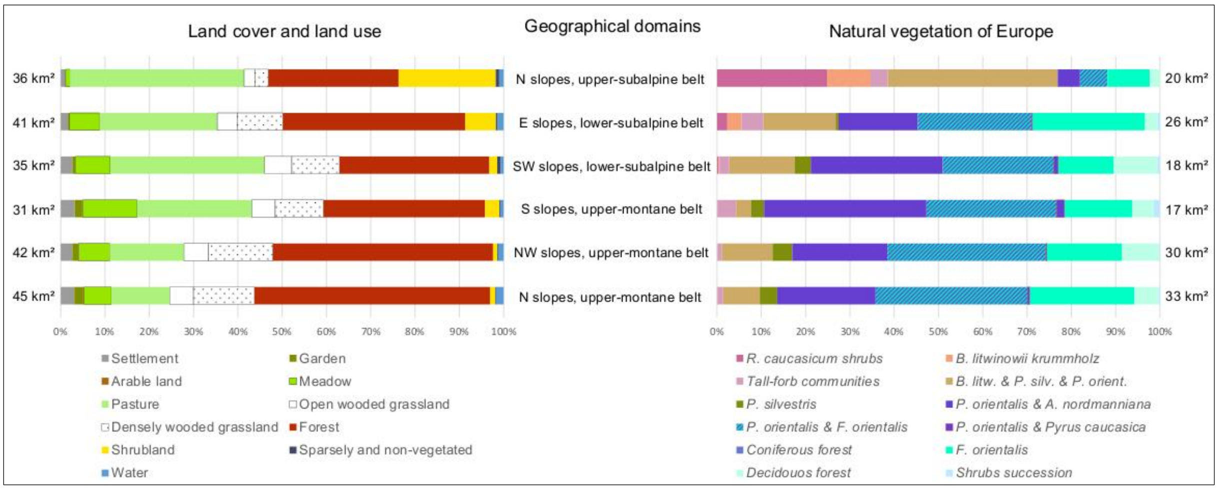

Figure 10: The pattern of land use and forest along six geographical domains, seperated mainly by altitude and aspect. The forest pattern (right) is the detailed description and interpretation of the forest and wooded parts on the left (the yellow, red, hatching and white parts of the bars).

Settlements show a strong distribution on relatively flat northern slopes in the upper-montane belt. Thus, also gardens, orchards and arable land are mainly in this domain. Open grassland is less distributed. In contrast, open and dense wooded grassland are most frequently spread in this domain. As the forest consists mostly of *P. orientalis* with *A. nordmanniana* and *P. orientalis* with *F. orientalis* here (both mapping unit D 33), the wooded grassland is characterized by these species as well. However, the conifers dominate in densely wooded grassland, and the broad-leafed trees in the open wooded grassland. *F. orientalis* and *B. litwinowii* are spread here as well, but to a minor extent (F 164 and C 44).

At the NW exposed slopes, there are less settlements and forests. The open landscape, i.e. meadow and pasture grassland, increases slightly. The forest distribution is quite equal to the N domain.

However, *B. litwinowii* and *P. sylvatica* are more frequent here and the open wooded grassland consisted of more conifers.

At the S exposed slopes, we found the most open landscape of the montane belt, i.e. grassland habitats. Compared to the northern exposed slopes, the shrub amount is also higher on southern slopes. Of the 17 km² south exposed montane forests, the coniferous species *P. orientalis* and *A. nordmannian*a are dominant. Additionally, we found the species *Pyrus caucasica* quite frequently, here. *F. orientalis* and deciduous forest exist to a clearly lesser extent. The shrubs consisted primarily of tall-forb communities.

On SW exposed slopes of the lower-subalpine belt grassland is dominant as well, but with a lesser amount of meadows, because the distance to the settlements and the inclination increase. Overall, settlement areas in the subalpine belt decrease. Furthermore, with increasing altitude, the forest pattern changes: *P. orientalis* with *A. nordmanniana* decreased, whereas *B. litwinowii* and *Pinus slivatica* increased. *P. orientalis* also belongs to this formation but with increasing altitude less frequently than beech and pine. As is the case in the NW domain of the montane belt, the wooded grassland consisted mostly of the conifers and the open of broad-leafed trees.

In the domain ‘E slopes of the lower-subalpine belt’, which covers, in total, more area than the ‘SW exposed slopes of the lower-subalpine’, the proportion of meadow and pasture habitats are less, whereas forest and shrub land increased. In the forest, the amount of *F. orientalis* increases strongly. On these slopes as well, birch and pine were more frequent. Accordingly, as *F. orientalis* is dominating, the wooded grassland consisted mostly of beech. However, both types, dense and open, were also found in the formation *B. litwinowii* and *P. silvestris* with partly *P. orientalis*. In the shrub land, we found a succession of shrubbery and the first *R. caucasicum* individuals. Besides and sparsely spread, crookstemmed *B. litwinowii* were located here.

In the highest domain of the study area, the ‘N slopes of the upper-subalpine belt’, we found subalpine and alpine pastures and meadows, with less occurrence of the latter. However, in this domain with the least forest, the mentioned birch, pine and spruce formation is predominant, followed by pure beech forest. Dense and open wooded grasslands were located in these forests. On these northern slopes of the upper-subalpine belt the crookstemmed birch was most widely spread. In contrast to the least existent forest, this domain showed the most amount of shrub land, made up of *R. caucasicum* and tall-forb communities. According to our data set, the timberline in the study area ran at 2,054 m a.s.l. with a deviation of ± 147 m, and a maximum at 2,517 m a.s.l. This timberline was mostly formed by the dense mixed forest of *B. litwinowii, P. silvestris* and *P. orientalis*. Furthermore, the treeline, which was formed by the crookstemmed birch, showed a mean of 2,324 m a.s.l., with a deviation of ± 124 m and a maximum at 2,606 m a.s.l.

5.6 Discussion

5.6.1 Land-use distribution

The Caucasus Mountains are characterized by natural contrasts with strong topographical gradients. Changeful geographical and climate conditions strongly influence the land cover and vegetation pattern (Zazanashvili et al., 2000). There is a distinct horizontal and vertical vegetation structure in Caucasia, depending on both temperature and moisture distribution (Henning, 1970). Besides these physical features, the land cover in Europe´s mountains is affected by the activities of the people living in the mountains, establishing a cultural landscape which, in the past, was made up of traditional mountain farming (EEA, 2010). Since the 70s of the 20th century, traditional management of the mountainous cultural landscape became more and more abandoned in Central and Western Europe, due to the preference and intensification of productive farmland and under-utilization of less productive or hard to access locations (EEA, 2002). However, in the former Soviet states of Eastern Europe, the agricultural production shifted from a collectively and centrally planned to a market oriented and price liberalized economy as of the 1990s, after the demise of the Soviet Union. This economic transition further faced post-socialist land reform strategies and rural population outmigration (Kuemmerle et al., 2008). In mountainous regions, this led to farmland abandonment and subsequent land-cover changes as consequences (Belonovskaya et al., 2016; Lieskovský et al., 2015). Still, the Lesser Caucasian land-cover and land-use pattern is quite similar to other mountainous regions of Europe, with dominating forest followed by grassland, cultivated and barren land (EEA, 2010). In 2012, most of the land-use activity in the study area was concentrated in Bakuriani and Tsikhisjvari, the largest settlements. Since most of the hotels and guesthouses are located in Bakuriani, touristic activity is focused here. In comparison, agricultural production dominated in the western part, in and around Tsikhisjvari, considering the area of meadow, garden, orchard, arable land, and scattered orchard meadows with Pyrus caucasica (Fig. 7 and 8, chapter 5.5.1). Along with a high amount of uninhabited houses and ruins, we localized less grassland and home-gardening management in the remote settlements of Bakurianis Andeziti, Didi Mitarbi, Patara Mitarbi and the Gverdisubani villages. This is in accord with Kohler et al. (2017), who described the strongest population decrease, even total settlement abandonment, after 1989 in remote settlements as well, e.g. in the Oni district in the central Greater Caucasus of Georgia. The field work showed that grassland and home gardening were managed in a traditional way, an extensive, low-input production mainly for self-supply. We found that the whole unfenced open grassland was used as pasture, with a decreasing grazing pressure with increasing distance to the settlements. The fenced meadows are cut once a year in August. Additionally, flocks of sheep from supra-regional nomadic pastoralists used the upper grasslands. Although the Borjomi district is rich in natural resources, like forests, biodiversity-rich meadows and pastures as ell as water, these ecosystems are vulnerable to degradation induced by mismanagement or illegal logging of timber (Oedl-Wieser et al., 2017).

Across the entire study area, we found wooded grassland of a dense or open type, used either as pasture or as meadow. Silvopastoral systems are one of the oldest land-use types in Europe, a prehistoric form that dates back to Neolithic times (Hartel et al., 2013; Luick, 2008). In Europe, the number of actually used wooded grassland decreased over the past century and can be found mainly in south and southeast of the continent, today (Bergmeier and Roellig, 2014). The quantification of our data revealed that grazing in wooded grassland is dominating. Not surprisingly, and in accordance with the preference of a minimized workload, the fewer wooded meadows were mostly located near the settlements. The densely type occurred mostly in the upper-montane belt, whereas the open type existed in the lower subalpine. Thus, the amount of deciduous forest is higher in open wooded grassland, as this forest became dominant with increasing altitude. We conclude this vegetation pattern based on quantifications on landscape level and an one-time field evaluation alone, despite the fact that for example grazing pressure, feeding preferences, livestock selectivity, dung deposition or cutting regimes strongly influence the vegetation and species composition and especially affect the forest rejuvenation in this land-use type (Mayer et al., 2005). With light grazing pressure by cattle, for example, forbs and small species benefit, because cattle prefer grasses and tall species, with finally an increase in plant species diversity, as Mayer and Houvinen (2007) demonstrated for the Alps. This ecotone, i.e. a dynamic mosaic of forest and grassland with continuous gradients, that is not used intensively, is characterized by a high biodiversity (Buttler et al., 2014; Gillet et al., 2010). However, wooded pastures and wooded meadows are fragile ecosystems, with a shift either to forest or to grassland if the land-use intensity changes and follows alterations in the landscape mosaic and vegetation heterogeneity (Gillet, 2008; Hartel and Plieninger, 2014). Furthermore, the uncontrolled use of wooded ecosystems in the study area, by unchecked cuttings and unregulated use of wooded pastures, is seen critical with presumed negative impacts on the forest ecosystem, like the spreading of diseases and pests (MRDI 2013). Nevertheless, in our opinion, uncontrolled and illegal timber logging negatively affects or even degrades the forest ecosystem stronger than the use of wooded grassland. Further, an ongoing, non-intensified use can be a valuable management tool to maintain or even increase biodiversity (Mayer and Huovinen, 2007).

5.6.2 Forest distribution

Most of the studied forest is covered by mesophytic and hygomesophytic Caucasian coniferous and mixed broad-leafed-coniferous forests (following the mapping unit D 33 of the Map of the Natural Vegetation of Europe). The spruce *Picea orientalis* and the beech *Fagus orientalis* are the dominant tree species, both also making up pure stands but to a lower extent than the mixture, and mainly by *P. orientalis*, which prefers deep to shallow soils that are coarse to fine-textured, with a broad range in nutrient availability (Matuszkiewiez, 2004). The Caucasian fir, spruce-fir and beech-fir forests show a vertical distribution between 850 (1,000) and 2,000 m a.s.l., whereas the dominance of the spruce increases with increasing altitude (Vasilevic et al., 2004). The shade-tolerant spruce is the most widely spread coniferous species in the study area. It has a relatively broad temperature tolerance, is not vulnerable to winter frosts but late frosts in spring, and is susceptible to too much moisture (Javakhishvili, 1949). The fir *Abies nordmanniana* is rarely found in the forests here, since it is more frequent in lower altitudes (Hübl et al., 2010; Seifriz, 1932). The Caucasian coniferous forests are quite different from those of Western Europe, where one can find more taiga (boreal) species, like the larch, and even boreal species of spruce and fir (Nakhutsrishvili, 1999).

The pine *Pinus silvestris var. hamata* (assigned to D 64) occurs in the study area but to minor extent than the spruce. This pine is described as a dry tolerant, light preferring and non-competitive tree (Seifriz, 1932). It is a pioneer species which can develop quickly (e.g. on windthrow-sites, here it forms secondary pioneer woodland), also on nutrient-poor locations, but prefers open and flat places (Javakhishvili, 1949). In the study region, as well as in the whole Caucasus, *Pinus silvestris var. hamata*-forests do not form a continuous altitude layer, they are distributed as islands (Vasilevic et al., 2004). According to Javakishvili (1949) this pine is naturally distributed in the region, whereas on the Map of the Natural Vegetation of Europe this pine is naturally distributed on or directly at the Javakheti Plateau (Bohn et al., 2004), i.e. south and east of the study area. However, this pine was planted around the settlements Bakuriani and Tsikhisjvari in the past, with the aim of harvesting the pine tree resin for paint manufacture.

Naturally, the oak occurs in the study area, but is strongly reduced. Oak forests are absent in the humid western parts of Georgia, but mesophilous forms occur in the Lesser Caucasus (like mapping unit F 170), preferring north-exposed slopes (Heiselmayer and Zazanashvili, 2004). In the study region, two oak species are rare. One is *Quercus iberica*, showing a potential altitude distribution from 1,000- 1,700 m a.s.l. Above 1,400 m a.s.l. it is replaced by the Caucasus endemic oak species *Quercus macranthera*. The oak never occurs in closed stands together with *F. orientalis* because the shade intolerant oak cannot compete with the oriental beech. This is unlike the sessile oak in Central Europe, which can stand the competition in closed stands with the beech. Even *Quercus macranthera* cannot compete and is therefore mostly replaced by the oriental beech as well or by the subalpine krummholz vegetation with increasing altitude (Dolukhanov and Bohn, 2004). Additionally, human impact strongly affected oak forests, especially in the study area, because favorable oak forest locations, which are base-rich cambisols and chromic luvisols, have been clear-cut for the purposes of agricultural land use

(Dolukhanov and Bohn, 2004). This is why there is an urgent need to conserve the oak remnants in Caucasia, an issue that should be focused on with special attention (Zazanashvili, 2005).

The most widely spread broad-leaved species in the study area is the beech *Fagus orientalis* (in this study assigned to the mapping unit F 164). Beech forests occur in temperate climates with a continuously positive precipitation budget, while an oceanity or continentality gradient influences the regional classification of deciduous forests (Matuszkiewiez, 2004). In the study area, the continental climate is pronounced due to the bordering Javahketi Plateau. For the region, it is described that soil and inclination are main factors for the distribution of the beech: soil moisture is important for the beech development, but persistently or periodically wet soils are unfavorable (Matuszkiewiez, 2004); flat and windy terrain inhibit the tree development because frosts are damage the young beech shoots (Javakhishvili, 1949). The upper limit of the beech depends on the temperature regime and the amount of precipitation during winter, because snow protects young trees from frost. When the climate conditions are more continental, the vertical limit of the beech is at 2,200 m a.s.l. (Nakhutsrishvili, 1999). The beech prefers skeletal, moderately acidic to neutral cambisols, and when the canopy cover is open, beech forests represent a well-developed understorey rich in light-demanding gramineous and herbage plants (Dolukhanov and Bohn, 2004). On such openings, the re-growth of F. orientalis is strongly affected by browsing through forest grazing (Hübl et al., 2010; Javakhishvili, 1949).

The low Caucasian krummholz and open woodlands (C 44) consist mainly of the birch *Betula litwinowii*, a Caucasian emdemic species. The krummholz-forests and open woodlands are a transition area between the downhill closed forests and the open alpine heaths, meadows and grasslands; and the open woodlands form the climatically determined tree line (Heiselmayer and Zazanashvili, 2004). The vegetation is a mixture of typical subalpine and forest vegetation (Hübl et al., 2010). According to Javakhishvili (1949) the upper limit of the timberline reached 1,800-1,900 m a.s.l. in the Bakuriani region, with open woodland above, thinning out at higher altitude; subalpine grassland formations began at 2,000-2,100 m a.s.l. up to the alpine belt at 2,400 m a.s.l. Open woodlands mostly stock on cambisol, rarely on leptosol or rendzic leptosol, which is commonly covered by dwarf-scrub- and scrub-formations (Heiselmayer and Zazanashvili, 2004). Box et al. (2000) determined the tree line in the Bakuriani region at about 2,300 m a.s.l.

5.6.3 Land-use and forest pattern along topographical gradients

In order to characterize the spatial land use and vegetation pattern, we classified the study area with regard to its sub-areas, i.e. geographical domains. The strong topographical gradients (altitude, slope and aspect) in the study area provided relevant indicators for this spatial classification. It is appropriate to use topography in a mountain landscape typology, since the vegetation and land use pattern is strongly influenced by altitudinal zonal characteristics (Ogureeva, 2005). Even in broader scales, like the regional or country level, mountain landscape classifications are necessarily based on spatial aspects (Pecher et al., 2013; Udvardy, 1975).

The montane belt, covering approx. 50 % of the study area, is rich in forest, whereas coniferous species dominate. On northern and northwestern slopes of the montane belt, we found a dominance of mixed spruce-beech-forests, what is in accordance with the description of Matuszkiewiez (2004). The beech is a shade preferring tree with a local affinity to north exposed slopes. This is in accordance with Hübl et al. (2010) who described F. orientalis as a species with the highest demand on soil condition and the lowest on light. The oriental spruce stocks more or less on all aspects, but with a west slope affinity (Seifriz, 1932). When the soils are moister the spruce can compete, even outcompete the pine on southern slopes. This is the case on southern slopes near the Bakuriani settlement, described by Javakhishvili (1949), where P. orientalis is the dominant tree species nowadays after predominance of pine-stands before. Hübl et al. (2010) suggested that the spruce might be supported by human impact. Around Bakuriani and Tsikhisjvari the wild form of a pomaceous tree Pyrus caucasica occurs. Additionally, fruit trees were planted near the settlements for fruit cultivation (Seifriz, 1932). Most of the cultivated montane grassland is located near the settlements, i.e. in short distance and comparatively well accessible. On southern slopes, the amount is higher than on other expositions, because here are the favorable sun-exposed locations. However, shrub succession with tall-forb communities indicate the abandonment of former land-use activity and were found in the whole study area but mainly in the montane belt - a fact that underpins the decline of land-use activity in the study area.

In the subalpine belt, the patterns are different: with increasing altitude, the beech is replaced by the maple Acer trautvetteri and by the birch Betula litwinowii. This Caucasian birch has a clear affinity to higher altitude and northern aspects. In the study area, B. litwinowii predominantly makes up the treeline on northern slopes, together with Sorbus aucuparia, and with pine on the western slopes (Seifriz, 1932). Land-use activity and distinct climatic conditions form the huge amount of open landscape in the subalpine belt. Each restrict forest establishment, or above the treeline even tree growth (Holtmeier, 2009), and both co-form both the semi-natural and natural grassland.

The forest identification, which is based on dominance and combination-mosaic types, provided the possibility to classify the local forest and build the sound base for our forest-pattern evaluation. The comparison with the potential natural vegetation revealed a near-natural forest pattern. The naturalness of the vegetation, considered as a biological indicator, is an important ecological characteristic of a location that is used for various nature impact assessments (Schlüter, 2005). However, a livestock farming system, as an impact on naturalness, provides a high biodiversity at multiple scales (Plachter and Hampicke, 2010), and in the study area especially through the agricultural use of the forests. Agriculture and forestry are highly relevant for managing the landscape and the provision of ecosystem services, like water purification, erosion control, habitat provision and carbon sequestration (Toscani and Sekot, 2017). In accordance with Schlüter (2005), we classified the studied forest as a near-natural, less-managed forest, with non-intensive pasture and meadow in near-natural grassland and wooded grassland. For the benefit of the multifunctionality of this cultural landscape it is vital to understand the current agriculture and forest resources, to foster a systematic approach for sustainable development that is able to mitigate and adapt threats like rural poverty and global change (FAO, 2016; Gratzer and Keeton, 2017).

5.7 Conclusion

The Bakuriani region in the Lesser Caucasus of Georgia provided a good opportunity to analyze traditionally managed land use and a near-natural forest. However, the mapping and quantification of the land use and land cover of the 223-km² study area was time consuming and revealed certain difficulties, like the exact determination of grassland management and forest-type classification or rather explicit differentiation among the types. The wide-spread wooded grasslands that represent the transition between agriculture and forestry - systematically and spatially - defined the major challenge for spatial-explicit GIS-based mapping. Nevertheless, our results indicate a great diversity of habitat types, whereby the mentioned wooded grassland plays a significant role in providing habitats for both light-demanding and shade-tolerant species. Further, the land-cover and land-use quantifications pointed out that shrub encroachment took place in the entire study area, indicating a decline in land use because of population outmigration. In our opinion, the studied forest is near natural and less managed, and demonstrated a high accordance with the potential natural vegetation (PNV). However, two differences to the PNV were localized: strongly reduced oak stands and an increased amount of pine. Both might be caused by anthropogenic influence in the past. Besides already existing studies about the current forest vegetation by, for example, Nakhutsrishvili (2013; 2006), Hübl (2010), and Box (2000), further studies could emphasize the valuable biodiversity that is worth protecting of these Lesser Caucasian forests. Finally, the georeferenced and orthorectified dataset from plot to landscape level can be useful for planning tasks, monitoring systems and assessments. The combination of land-use information and land-cover composition make it especially valuable for ecological monitoring and nature conservation. In respect of the multifunctionality of this cultural landscape, the compiled GIS-maps can function as a sound base for sustainable management plans in forestry and agriculture.

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6. Land-use change related to topography and societal drivers in high-mountains – a case study in the upper watershed of the Tergi (Kazbegi region), Greater Caucasus

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6.1 Abstract

High mountain ecosystems, with strong topographic and climatic gradients, are fragile and particularly sensitive to changes in land use. The abandonment of historic cultural landscapes has often lead to changes in the pattern of land cover and thus to a shift in the functions of high mountain landscapes, like fresh water supply, productivity or erosion control.

In order to understand the effects of land-use change on the land-cover pattern at the local and regional scale, we analyzed and classified the mountainous landscape structure in the Kazbegi region in Georgia, located in the Central Greater Caucasus. For 13 settlements, we determined the land cover as present in 1987 and 2015 and quantified the changes over time to detect land-cover development trends for each settlement. Using a cluster analysis, the study area was analyzed regarding to topography (altitude, aspect, slope) and distance to settlements at the regional scale to gain six groups with separating conditions. Furthermore, each settlement was classified according to topography and land-cover change to obtain site-specific, comparative development trends.

Our results show that this Caucasian high-mountain landscape is characterized by open grassland (67 %) used as pasture and hay meadow, and natural birch forests (7 %) in patches in the upper half of the subalpine belt. Within the settlements but also in their surroundings, field vegetables are cultivated in home gardens (1 %). Land-cover change during the observation period mainly affected the cultural grassland with hay meadow abandonment. Moreover, shrubbery and forest expanded considerably on abandoned pastures. We further detected a strong relationship to topography that considerably varied between settlements resulting in specific trends in land-use change. Hay-making and arable land cultivation are focused today on sun-exposed and gentle slopes near the settlements. Shrub encroachment and reforestations were localized on farer distances and mostly on north-exposed slopes.

Besides providing basic information about the historic and current land-use and land-cover patterns, our results quantify the landscape change during almost 30 years. A spatio-temporal analysis revealed an understanding of how land-use decisions influence the landscape pattern. In the context of societal development, regional socio-economic processes, like shifts in the agricultural structure and population outmigration, seem to be societal drivers of changes. Our findings reveal linkages and interrelationships between natural, human-induced environmental and socio-economic processes within high-mountain socio-ecological systems. Moreover, we suggest that sustainable land-use strategies for spatial development on sub-regional level, especially in marginal high-mountain regions, should consider topography and its influence on land-use change.

Key words:

Landscape structure; GIS; Land-use change; Remote sensing; Georgia; Caucasus

6.2 Introduction

Mountainous regions provide important landscape functions for biomass productivity, regulation and cultural purposes. Heterogeneous mountain landscapes serve as a source for local food production and the supply with freshwater, even for lowlands far away. Forested mountains regulate the climate and water circles, and reduce the risk of gravitational natural hazards, like downslope mass movement (Grêt-Regamey et al., 2012). Today, they are also main areas for tourism and recreation offering scenic beauty (Zoderer et al., 2016). Further, mountain landscapes often possess a high habitat and species richness within small territories (Becker et al., 2007; Nakhutsrishvili, 1999).

Mountains have been shaped by humans since ancient times. The impact of land use, i.e. mostly by livestock grazing, has led to the development of cultural landscapes with large, un-fragmented habitats that are characterized by high biodiversity and an aesthetical appeal. As a result, they have a significant conservational and historical value (Körner et al., 2006). Human use of the landscape through agriculture and forestry caused the establishment of the typical landscape appearance visible today – a mosaic of open grassland and wooded areas along a diverse topography with a strong altitudinal gradient. The effects of long-lasting impacts of land use adapted to heterogenic site conditions thus have formed a specific diversity of land-cover types.

Land-use and land-cover changes, often induced by either political and/or climate changes, severely affect landscape functioning in high mountain landscapes, like for example the productivity, the biodiversity or the landscape´s appearance with related habitat types (Hietel et al., 2004; Körner, 2000). At present, land-cover changes in cultural high-mountain landscapes can be observed from over- or under-utilization in contrast to prior use (Spehn et al., 2006). In European mountainous regions, the use of fertile agricultural land has been intensified whereas remote areas that are difficult to access and to manage have been abandoned (MacDonald et al., 2000; Niedrist et al., 2009; Török et al., 2016). Land-use change can lead to the loss of high mountain biodiversity, especially species richness, in addition to affected productivity and system integrity and, therefore, can affect the livelihood of the local population (Körner, 2004; Poschlod et al., 2005; Tasser and Tappeiner, 2002).

Georgia´s Greater Caucasus is facing severe changes in land use since the soviet time (1922 – 1991) until today (Wiesmair et al., 2016). Nevertheless, this mountain range with an east-west extension of

1,500 km (Walter, 1974) in the distant southeast of Europe is one of the global biodiversity hotspots, characterized by an exceptional species richness and outstanding number of endemics especially in the subalpine belt (Myers et al., 2000; Nagy and Grabherr, 2009). The plant species diversity within the subalpine grassland is a result of the macro-relief (aspect), the micro-relief (convex and concave landforms) and the land-use intensity, such as the long-term and extensive grazing pressure (Lichtenegger et al., 2006; Pyšek and Šrůtek, 1989). The land-use intensity was driven by society changes: from the middle of the 20th century until 2014, there had been substantial transitions in population development and agriculture in the Kazbegi region (National Statistics Office of Georgia, 2014 and 2015). Former traditional alpine farming had been replaced by intensive livestock husbandry and afterwards, after the breakdown of the Soviet Union, by de-intensified agriculture. These transitions have been reflected in the land-cover structure of this agro-pastoral system. The upper watershed of the Tergi River with its tributaries in the Central Greater Caucasus is considered to be prone to current and future land-use change affecting the diversity, productivity and integrity of the grassland ecosystems (Magiera et al., 2013; Tephnadze et al., 2014). Consequently, concepts of sustainable, agricultural land use considering site-specific carrying capacity as well as profitability of land use are urgently needed to maintain the valuable cultural landscape and to strengthen the rural development of remote areas. Spatial-explicit land-cover and land-use maps in high resolution provide a sound base for the development of concepts for integrated and sustainable land-use. Based on landscape analysis findings, i.e. with the knowledge about the environmental conditions and the landscape´s multifunctionality, such concepts provide the opportunity to balance the three dimensions of sustainable development: the economic, social and environment, as stated in the Agenda 2030 (United Nations 2015).

Our study aims at the observation of the landscape structure for several settlements as illustrated in GIS-based land-use and land-cover maps. Further, and based on a two-date comparison, we identified spatio-temporal trends in land-use and land-cover patterns on landscape and regional scale. Changes in land cover often demonstrate a small-scale variability, depending on different physical site conditions, like topography and climate, and on socio-economic and structural conditions (Lueker-Jans et al., 2016). Accordingly, typifications of the patterns of change on a small-scale and precise landscape level are useful. Therefore, the objectives of our study are:

i) to analyze the landscape patterns in 2015 and in 1987 at high resolution, and to quantify the changes in land use and land cover during that period,

ii) to identify development trends in land-use changes on settlement level and along a classified study area.

Based on these objectives, the interrelations between topography, societal change, and land-use change in the high-mountain Kazbegi region are analyzed and discussed.

6.3 Study area:

The study was carried out in the Kazbegi district of the Mtskheta-Mtianeti municipality, north of the Jvari cross pass, in the eastern part of the Central Greater Caucasus of Georgia, in the upper watershed of the Tergi and its tributary, the Snotskali (Fig. 11). The geomorphology of this region, embedded in the northern macroslope of the Greater Caucasus, is highly complex with high elevations and steep slopes (Nakhutsrishvili, 1999). The highest peak in the study region is the extinct volcano Mount Kazbek (5,047 m a. s. l.) (Ketskhoveli et al., 1975). The bedrocks of the study region consist of Jurassic sedimentary rocks. Besides volcanic rocks (andesite and dacite) with pyroclastic products, glacial and fluvial sediments from the quaternary period characterize the soil. On these materials Leptosols, Skeletic Regosols, Skeletic Cambisols and Umbrisols are prevailing soil types (Hanauer et al., 2017).

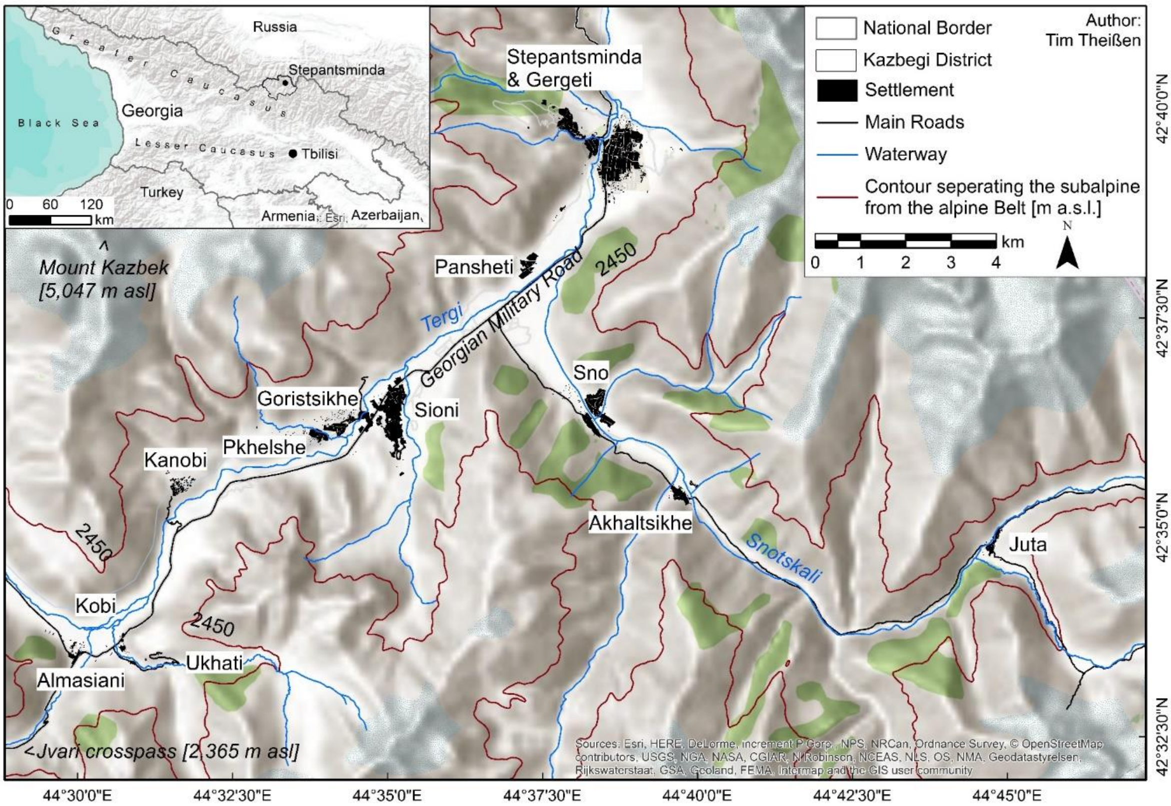

Figure 11: Location of the study area within the Kazbegi district embedded in the eastern part of the Central Greater Caucasus, in Georgia. The 13 study settlements are settled along the rivers Tergi and Snotskali, in the subalpine altitudinal belt.

The climate of the study region belongs to the sub-continental climate and is moderately humid, with dry and cold winters and cool summers (Nakhutsrishvili, 1990; Togonidze and Akhalkatsi, 2015). Rain events occur mainly in the growing season, with only a mean annual precipitation of 806 mm (Lichtenegger et al., 2006). July is the warmest month (mean temperature 14.3 °C) and January the coldest (mean temperature -5.2 °C), whereas the mean annual temperature is 4.9 °C (Lichtenegger et al., 2006; Togonidze and Akhalkatsi, 2015). As located in the northern macroslope of the Greater Caucasus, the mean annual precipitation in the Tergi valley decreases from south to north: from 1,192 mm in the village Kobi, near the Jvari cross pass, to 806 mm in Stepantsminda, the main settlement in this region (Walter, 1974). Simultaneously, the mean annual temperature increases from 3.0 to 4.1 °C (Hijmans et al., 2005).

In the Caucasus, sheep and goat grazing is a long-standing tradition and has been the predominant pasturage activity for centuries (Heiselmayer and Zazanashvili, 2004). In Georgia, a centralized agricultural program replaced sustainable agricultural management practices during the Soviet period (Körner, 1980; Nakhutsrishvili et al., 2009). Up to Georgia´s independence (1991), the grassland was intensively used by a transhumance sheep grazing system with flocks originating from the bordering countries of Azerbaijan and Dagestan (Didebulidze and Plachter, 2002; Nakhutsrishvili et al., 2009). Along the military road – a North to South traverse through the mountain chain – intensive grazing by large herds of sheep caused pasture degradation, slope erosion and the reduction of subalpine forest vegetation (Cernusca and Nakhutsrishvili, 1981). However, the alpine belt was less grazed. Mass-wasting events seriously threatened the local settlements (Körner, 1980). Following Georgia´s independence and several internal political conflicts, subsistence agriculture has become predominant in rural areas of the country (Didebulidze and Urushadze, 2009). This self-sufficient agriculture is now characterized by less sheep grazing but increasing cattle husbandry (Haerdle and Bontjer, 2010). Both, cattle (up to 2,300 m a.s.l.) and sheep grazing (up to 3,000 m a.s.l.) are concentrated in high altitude. Today, the dominant land-use form in the Kazbegi region is still high-mountain grassland management as pasture and meadow, serving mainly the local demands (Haerdle and Bontjer, 2010; Lichtenegger et al., 2006). Due to Georgia´s political and economic transformation, the population of the Mtskheta-Mtianeti municipality was declining enormously since the country´s independence (Didebulidze and Plachter, 2002) (Tab. 1), resulting in a decrease of approx. 18 % from 1989 to 2002 in the Kazbegi district. In the period from 2002 to 2014, the population of the district decreased by approx. 28 %, with the settlements of Kobi and Ukhati being completely abandoned. However, in larger settlements (Stepantsminda and Gergeti, Sno and Sioni) the relative decline was smaller.

For our study, we chose 13 out of 25 populated settlements in the Tergi and Snotskali valleys (Tab. 1 and Fig. 11), based on available data for both years, 1987 and 2015.

As situated along the Tergi and Snotskali valley, settlements are located along varying aspects and altitudes. The borders of the altitudinal belts run different in northern and southern slopes. According to climatic differences, on southern slopes the belts ascends negligibly higher than on northern slopes (Otte et al., 2011). Therefore, besides altitude, the slope exposition determines the allocation of the settlements to the altitudinal belts, as it is the case for the settlement Goristsikhe (Tab.1).

Table 1: Altitude and population development of the study settlements and the Kazbegi district. The border between the lower-subalpine and the middle-subalpine belts varies on northern and southern slopes; brackets show the altitudinal borders at the southern slopes. Population data are composed from National Statistics Office of Georgia (2002, 2014). Data for the year 1989 were only available on district level. '-' indicates 'no data available'.

Settlement, district	Altitude [m a.s.l.]	Altitudinal belt [m a.s.l.]	Population 1989	2002	2014
Stepantsminda & Gergeti	1,765	Lower-subalpine belt		1.783	1.326
Pansheti	1,770			-	54
Sno	1,770	1,700 - 1,850 (1,930)		418	263
Akhaltsikhe	1,780			129	35
Goristsikhe	1,870			283	187
Sioni	1,875	Middle-subalpine belt		384	324
Pkhelshe	1,930			-	167
Almasiani	1,950			13	22
Kanobi	1,985	1,850 (1,930) - 2,200 (2,300)		182	86
Kobi	2,010			25	0
Juta	2,160			62	26
Ukhati	2,190			9	0
Kazbegi district	1,230 - 5,047	Montane - nival belt	**6.377**	**5.261**	**3.795**

According the location, many settlements, and the most populated ones in particular, like Goristsikhe, Sioni and Stepantsminda, got direct contact to the region´s main road, the former military road. This road is the main transportation corridor in the region connecting the highland with the lowland, for example Tbilisi beyond the Jvari cross pass, and along with several connecting-nodes to tributary valleys. In contrast, other settlements are peripheral located, i.e. with limited connectivity to the market, characterized by long distance to the main road, unpaved and unsecured roads or bridges, like the disadvantaged settlements of Ukhati, Juta, Kanobi, Pkhelshe and Akhaltsikhe. The more isolated a settlement is, the more limited is the supply with goods and services.

6.4 Materials and methods

6.4.1 Data and data processing

In order to map the current and historic land cover of the Kazbegi region, we used satellite images and black and white aerial-photographs from 1987. And we used five-band (blue, green, red, red edge and near infrared), high-resolution (5 m x 5 m), orthorectified (radiometric, sensor and geometrically corrected) RapidEye sensor images from 2014. Six tiles covering approx. 3,750 km² were recorded for June, July and August. We produced a false color composite that increased the distinction between land-cover types (Shalaby and Tateishi, 2007).

The aerial photographs were recorded (on photographic paper) by the Soviet Union military on September 4, 1987 and were provided by the institute of Geography at Ivane Javakishvili, Tbilisi State University (TSU) Georgia. The aerial photographs with a resolution of approx. 0.8 x 0.8 m were scanned, georeferenced and orthorectified using Erdas Imaging 8.5 (Leica Geosystems, Atlanta, Georgia, USA). We derived the topographic variables altitude, eastness, northness, inclination and distance to settlements from a digital elevation model (DEM, 20 m x 20 m) using the Spatial Analyst Toolbox in ArcGIS 10.2 (ESRI, Redlands, CA, USA). We used distance to town center as our fifth variable. According to the von Thünen theory, distance to town center is important for management/land-use decisions and therefore land-cover distribution – since the pattern of land use is strongly dependent on settlement-distance, considering accessibility and transportation costs (von Thünen, 1850).

Additionally, we included two topographic (1: 25,000 and 1: 50,000) and one historic land-use map (1:25,000) to improve the digitization. The topographic maps originated from the Department of the Army of the Soviet Union in 1958 and the land-use map, dated from 1963, was produced by the Land Use Project Institute of Georgian Soviet Republic.

6.4.2 Land-cover mapping and joining of spatial information

The 13 study settlements were visually interpreted and digitized along with their surrounding agricultural land for 1987 and 2015. The study area boundaries were set by altitude (3,000 m a.s.l.). During the digitization, polygons were generated at the scale of 1: 5,000. The land-cover and land-use classes of the applied classification key (Fig. 12) were developed in advance and proved in the field.

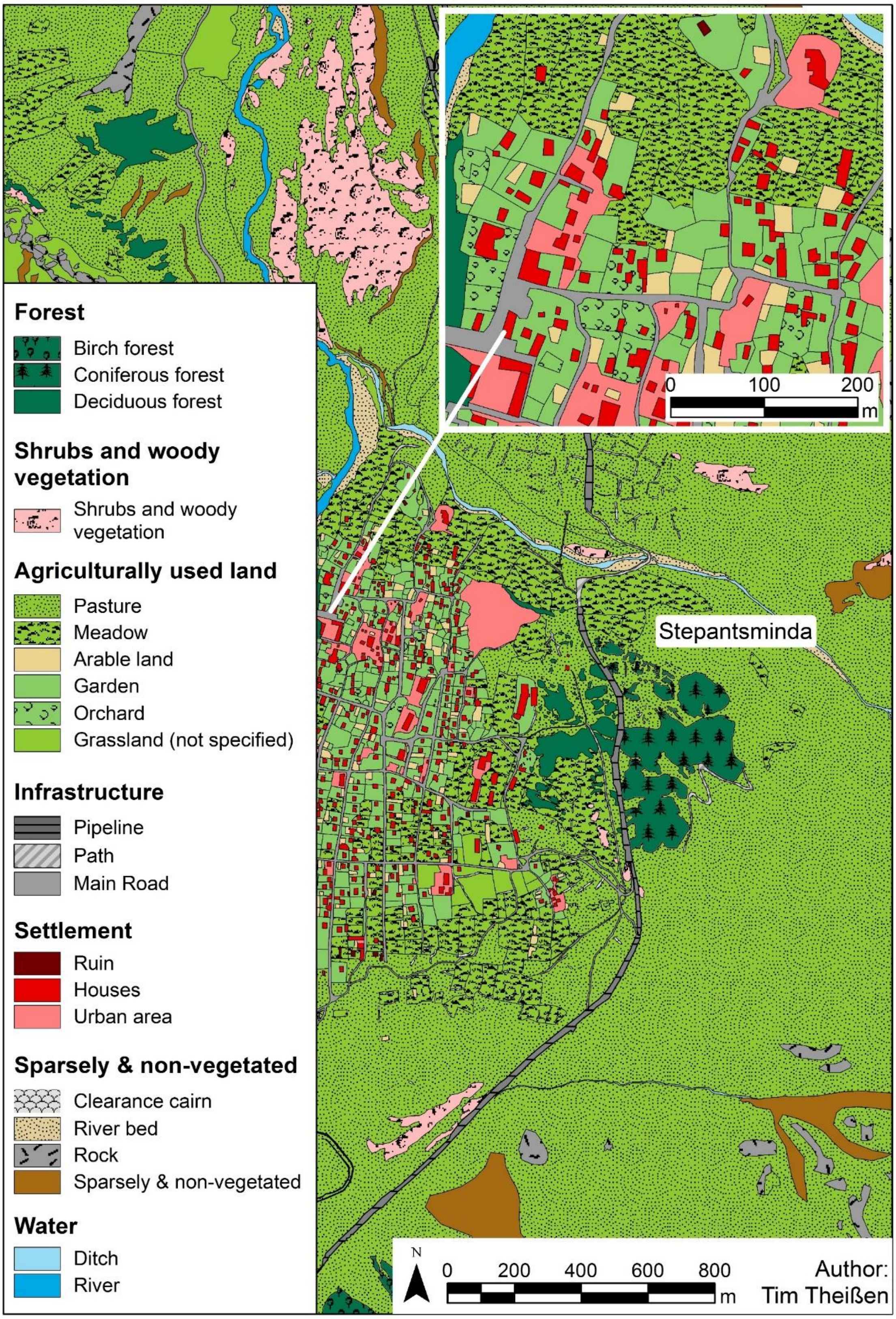

Figure 12: Land-cover and land-use pattern of the eastern part of Stepantsminda as well as the surrounding area (1987) in a zoomed-in, detail view. The legend is hierarchically structured with seven land-cover and land-use categories and 26 classes, used for all study settlements and both dates (not

visible here are the classes Road, Bridge, Lake, and Erosion). On the inset map (upper right corner), the settled area is mapped in detail, highlighting the distribution of arable land.

Overall, 26 maps were digitized. The size of the maps varies from 6.4 km² (Pansheti) to 22.5 km² (Stepantsminda plus Gergeti), the total digitized area amounts to 90 km². In-situ validation was required to correct possible misclassification due to the coarser 5 x 5 m resolution and shadowing during the visual interpretation and classification of the 2014 satellite images. In July and August 2014 and 2015, the digitized land-cover maps from 2014 were updated and validated in the field. Special attention was paid to the small-scale arable fields in home gardens and allotments, which were spatially explicitly mapped during the aerial image interpretation and in the GPS supported field validation. The digized land-use maps of Stepantsminda and Gergeti are moreover based on a prior digitalization of a Quickbird image (Digital Globe©, with a resolution of 2x2 m) in 2011 (Waldhardt et al., 2011, based on Theissen 2011). This digitization was compared to the Rapid Eye imagery and consequently updated to the state of 2014/15 and validated during fieldwork. The river course and water level, especially in the Stepantsminda floodplain is rather unstable during and within years. It was thus decided after visual comparison with the Rapid Eye imagery and field validation to keep the shape of the river course from 2011 (see Fig. 13). The river courses in all other maps were defined by an average water level based on field validations in 2014 and 2015 (see appendix, map A.2.-A.8.). Further, we defined scree slopes, steep stony areas and gorges as sparsely or non-vegetated areas.

The vector-based land-cover maps of 1987 and 2015 were transformed into grid-based point-layer data sets at the same resolution and spatial extent as the altitude, eastness, northness, inclination and distance to settlements topographic raster data. The land-cover information of both years and the topographic variables were combined to a single point-layer in GIS. Finally, for each point (221,683 points in total) the land-cover change was determined by describing the transition of land cover from 1987 to 2015 (e.g. from pasture land cover in 1987 to shrub land cover in 2015).

6.4.3 Data analysis

6.4.3.1 Spatial structuring of the study region using cluster analysis

A k-Means clustering (Hartigan and Wong, 1979; MacQueen, 1967) combined with a previous v-fold cross validation was applied (Lueker-Jans et al., 2016) to classify the study region according to topography and distance to settlements into classes with approx. equal conditions along the variables using STATISTICA 12 (StatSoft Inc., 1984 – 2014, Tulsa, OK, USA). The included variables were standardized and tested by Pearson´s coefficient of correlation for spatial autocorrelation prior to the analysis (Leyer and Wesche, 2008). Euclidean distance was chosen as a distance measure. The v-fold cross validation is a calculation to find a suitable number of clusters in a given data set. During the classification, the similarity within each cluster is maximized and minimized between the clusters. Cases are repeatedly changed between the clusters in order to receive the most significant differences between the clusters. This corresponds to an 'ANOVA in reverse' (StatSoft, 2013). In our study, the analysis resulted in clusters (sub-areas of the study region) with almost equal topographic conditions within the cluster.

6.4.3.2 Spatial structure and land-cover change in the region

In order to show similarities and differences among the settlements based on land-cover change and topography, we used NMDS (non-metric multidimensional scaling)-ordination. The NMDS is an ordination technique to graphically display the similarity of data. Therefore, a distance measure is calculated which is placed stepwise into a multidimensional space to keep the original distance. The quality of ordination is indicated by the level of stress (Shepard, 1962). In our study, the NMDS was calculated with the percentages of each k-means cluster per settlement from the prior k-Means cluster analysis and the percentages of the respective land-cover changes. We used the metaMDS function of the 'Vegan' package for 'R 3.1.2 (Oksanen, 2013; R Core Team, 2016) to calculate a three-dimensional NMDS. After 20 tries, two convergent solutions with minimum stress were found in the iterative analysis. For assigning the new axis one to the direction of the largest variance, principal component (PC-) rotation was applied (Clarke, 1993).

6.5 Results

6.5.1 The landscape pattern in 2015

In 2015, the landscape in the upper watershed of the Tergi River was dominated by subalpine to alpine open grassland (Fig. 13 with Stepantsminda and Gergeti; see Appendix for all maps). The region was either managed as pasture (59 % of the study area) or as meadow (8 %). Meadows were located in close vicinity to the settlements and were often fenced off from free-ranging cattle. Sparsely or non-vegetated areas, e.g. gorges and scree slopes, typical in high-mountain regions, were quite frequent (14 %). Only a comparatively small area was covered by forest (7 %). At high altitudes on steep north-facing slopes, the natural forest is dominated by Betula litwinowii and to a lesser extent by Salix caprea and Sorbus caucasigena. Coniferous (Pinus sylvestris) and deciduous forests (Populus tremula), planted as reforestation for firewood, occur at lower altitudes in near vicinity to the settlements. Beside the forests, different types of shrub vegetation (5 %) were found in the study region. Shrub vegetation mainly comprises three species: Elaeagnus rhamnoides, which frequently occurs on Regosols of the floodplains and steep rocky slopes mixed with Berberis vulgaris, and Rhododendron caucasicum in the transition zone between the upper subalpine to the alpine belt, indicating the upper border of the tree-line ecotone. Small-cultivated arable land (1 %) with an average field size of 290 m² was located in home gardens and orchards or even allotments outside but not far away from the settlements, often within fenced meadows. These family allotments were mainly used for subsistence potato and field vegetable cultivation. Settlements defined as 'urban area' covered 0.66 km², i.e. 1 % of the study region. Along a gas-pipeline through the valleys and within the studied settlements of Stepantsminda, Gergeti, Pansheti, Sioni, Sno, Akhaltsikhe, Pkhelshe and Goristsikhe, greenhouses were built during the Soviet period. Their functioning depended on Russian gas, which was discontinued in the early twenty-first century. We found 96 greenhouses of which 60 have been damaged but are partly still in use for cultivation. In 64 greenhouses, cultivation of mainly potatoes, cucumbers, tomatoes and lettuce is practiced.

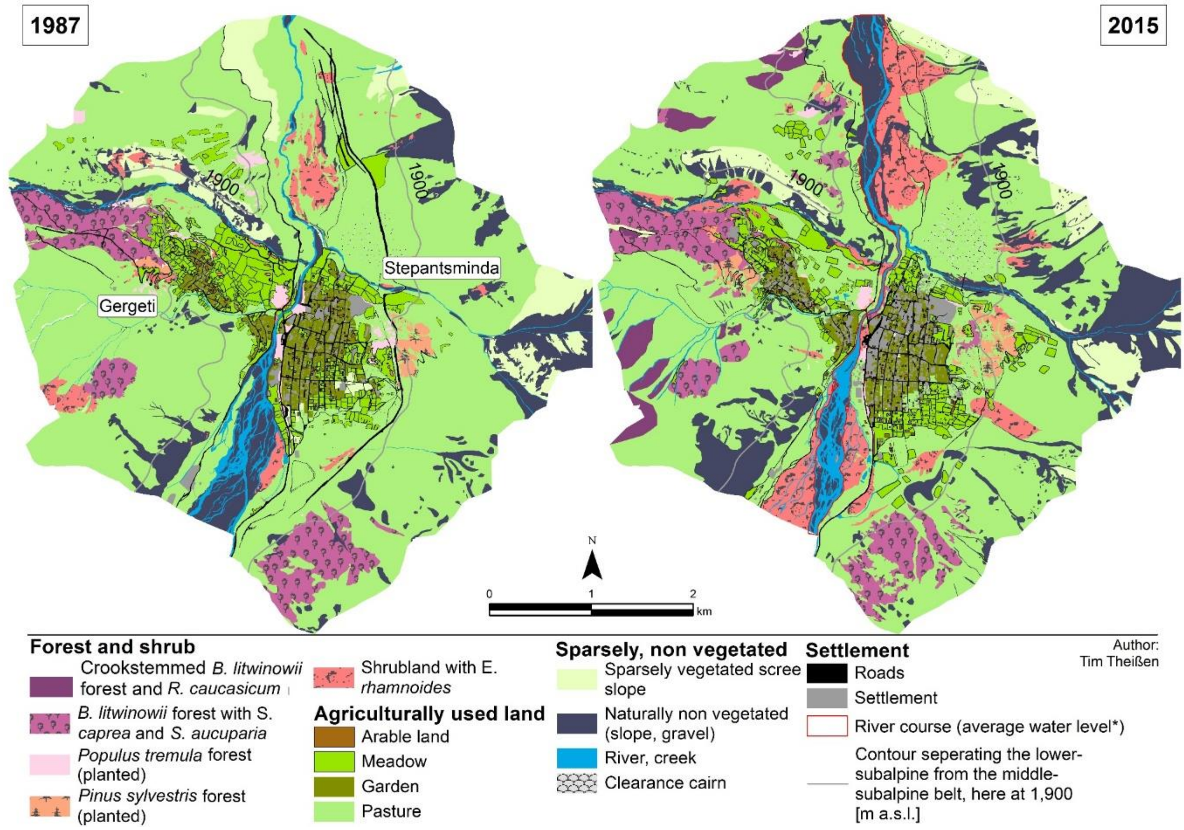

*Figure 13: Land-cover and land-use pattern of Stepantsminda and Gergeti in the years 1987 and 2015 (land-cover classes partly grouped). The 2015 map is from Theissen et al. (2019). *The water level of the Tergi River was validated in the field in 2011, 2014, and 2015.*

6.5.2 The landscape pattern in 1987 and land-cover change between 1987 and 2015

In 1987, the landscape pattern was characterized by less forest- and shrub cover, and by a lesser extent of urban area. Settlements (comprising the land-cover classes urban area, houses, ruins, garden, orchard and arable land) covered around 2 km², in total, in 1987. In 2015, the study settlements cover 2.4 km², with 0.7 km² accounting for the main settlement Stepantsminda. During the study period, the settlements have developed differently with small villages spatially decreasing and larger ones expanding. The expansion of settlement area mostly took place on former (1987) garden land and meadows. However, Juta, a small and remote village with a size of 0.1 km² showed a different development: its settlement area nearly doubled from 1987 to 2015. The population decreased in all settlements except Almasiani, and to an even greater extent in remote villages. Ukhati, for example, located offside the military road and hidden in the mountains, was completely abandoned. Nevertheless, in 2015, its former arable land was re-cultivated with potatoes and managed by farmers from Stepantsminda, because the soil properties are convenient for cultivation (in particular physical structures like deep soils with fine and loamy material, in plateau location). Arable fields expanded in most of the settlements, either from pasture or from garden land in 1987. In Almasiani, the largest area of potatoes was cultivated in 2015 (0.2 km²), but in the closed-by settlement Kobi arable land in home gardens almost vanished. The land-cover type characterized by the greatest changes was grassland. 6 % (around 5.3 km²) changed from pasture in 1987 to sparsely and non-vegetated area in 2015 and 3 % from pasture to meadow (around 2.5 km²). However, the grassland changes performed different among the settlements. Sno and Juta showed the highest proportion and the highest increase of meadows (> 1 km²). Especially the remote Juta had the strongest meadow increase (0.4 km² in 1987 to 1 km² in 2015). The settlements Sioni, Stepantsminda, Gergeti and Juta as well experienced a decrease in pasture combined with an increase in woody vegetation (shrubs, forests), especially in Gergeti where shrubs increased strongly, from 0.2 km² up to 0.9 km². In contrast, pasture area increased in Almasiani, Goristsikhe, Sno and Pansheti, whereas meadow area decreased, together a decline of approx. 0.6 km² (Tab. 2).

Table 2: Land-cover sizes (ha) of the 13 study settlements from 1987 and 2015 and land-cover change in percent within this period. 'Trend' indicates an increase or decrease in land-cover sizes in each settlement.

Settlement	Total	**Settlement area**				**Arable fields**				**Meadow**				**Pasture**				**Shrub**				**Forest**				**Sparsely, non-vegetated**			
		1987	2014	Change	Trend	1987	2014	Change	Trend	1987	2014	Change	Trend	1987	2014	Change	Trend	1987	2014	Change	Trend	1987	2014	Change	Trend	1987	2014	Change	Trend
	[ha]	[ha]	[ha]	[%]		[ha]	[ha]	[%]		[ha]	[ha]	[%]		[ha]	[ha]	[%]		[ha]	[ha]	[%]		[ha]	[ha]	[%]		[ha]	[ha]	[%]	
Akhaltsikhe	**779**	7	8	25	↗	1	1	-	→	34	27	-22	↘	487	480	-1	↘	5	1	-80	↘	41	41	-	→	185	202	9	↗
Almasiani	**566**	9	6	-33	↘	6	16	165	↗	58	29	-50	↘	261	337	29	↗	37	40	7	↗	30	26	-10	↘	132	89	-33	↘
Gergeti	**995**	18	26	47	↗	2	4	58	↗	83	53	-36	↘	674	574	-15	↘	21	92	347	↗	81	99	21	↗	82	106	29	↗
Goristsikhe	**407**	9	13	45	↗	1	2	84	↗	54	41	-24	↘	292	339	16	↗	-	-	-	→	-	1	100	↗	46	10	-78	↘
Juta	**1032**	3	5	92	↗	1	1	-	→	42	103	144	↗	841	718	-15	↘	38	64	70	↗	61	64	5	↗	29	62	113	↗
Kanobi	**503**	5	5	-10	↘	2	4	73	↗	101	92	-9	↘	312	302	-3	↘	1	-	-100	↘	-	7	100	↗	62	74	19	↗
Kobi	**859**	5	3	-36	↘	2	< 0.5	-81	↘	16	16	4	↗	366	565	54	↗	126	79	-37	↘	99	105	6	↗	188	77	-59	↘
Pansheti	**516**	9	11	19	↗	1	1	-	→	23	20	-11	↘	325	348	7	↗	-	2	100	↗	-	-	-	→	124	120	-3	↘
Pkhelshe	**229**	7	7	5	↗	2	3	55	↗	64	71	11	↗	85	75	-12	↘	2	4	100	↗	-	10	100	↗	52	41	-21	↘
Sioni	**454**	49	54	9	↗	1	4	206	↗	76	91	19	↗	222	188	-15	↘	-	14	100	↗	21	29	37	↗	52	53	2	↗
Sno	**1021**	19	26	41	↗	3	3	21	↗	123	111	-9	↘	413	475	15	↗	38	17	-55	↘	207	179	-14	↘	183	167	-9	↘
Stepantsm.	**1267**	64	70	11	↗	5	5	11	↗	64	61	-5	↘	779	642	-18	↘	39	100	155	↗	80	75	-6	↘	172	230	34	↗
Ukhati	**206**	2	1	-26	↘	2	1	-	→	15	24	59	↗	158	162	3	↗	-	4	100	↗	10	9	-7	↘	15	3	-80	↘

Sparsely or non-vegetated localities covered large areas, although the patterns varied considerably between the settlements, where these sites occur either on steep, mostly high-elevated or unaccessible locations and on flat river bed terrain which is varying in extent due to seasonal flooding. In Akhaltsikhe and Stepantsminda approx. 2 km² were sparsely or non-vegetated in 1987, and this area increased in both localities from 1987 to 2015, in contrast to Ukhati where the area decreased.

6.5.3 Land-cover change trends along environmental conditions

Based on all compiled land-cover and land-use maps of the 13 studied settlements, the cluster analysis divided the whole study area into sub-areas with similar spatial structure regarding topography and distance to settlements. The k-means cluster algorithm revealed the six clusters with characteristic properties (see Fig. 14 and Tab. 3):

- North-west exposed slopes of the upper-subalpine belt,
- East exposed slopes of the upper-subalpine belt,
- South-west exposed slopes of the upper-subalpine belt,
- South-east exposed slopes of the middle-subalpine belt,
- North-east exposed slopes of the lower-subalpine belt,
- West exposed slopes of the upper-montane belt.

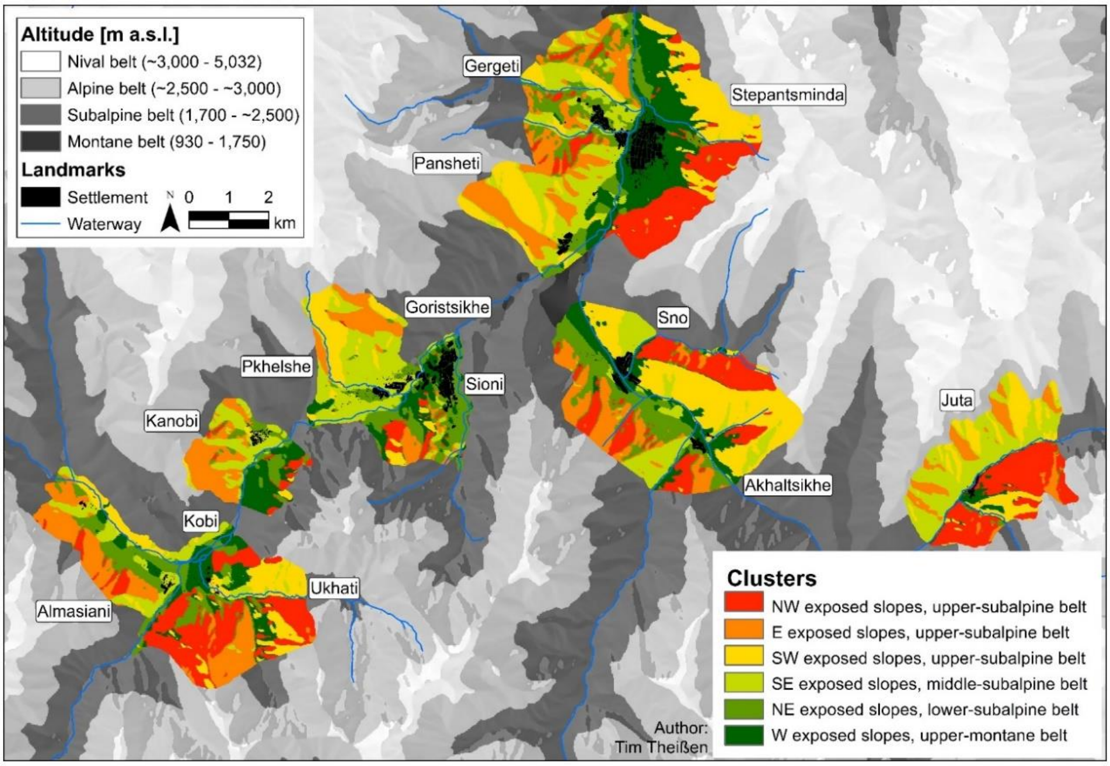

Figure 14: Spatial pattern of the k-means cluster analysis based on topography and distance to settlements (calculated for the 13 study settlements).

Table 3: Properties of the clusters, with the centroids (means) of the variables included in the k-means cluster analysis; Northness indicates slope position between north (value =1) and south direction (value = -1), and Eastness between east direction (value 1) and west direction (value -1).

	North-west exposed slopes of the upper-subalpine belt	East exposed slopes of the upper-subalpine belt	South-west exposed slopes of the upper-subalpine belt	South-east exposed slopes of the middle-subalpine belt	North-east exposed slopes of the lower-subalpine belt	West exposed slopes of the upper-montane belt
Altitude [m a.s.l.]	2,276	2,242	2,278	2,117	1,920	1,878
Slope [degree]	32	32	32	24	14	12
Eastness [1 to -1]	-0.4	0.9	-0.6	0.6	0.4	-0.9
Northness [1 to -1]	0.8	0.3	-0.7	-0.7	0.8	0.2
Distance to settlements [km]	1.6	1.8	1.8	1.3	1.1	1.1
Area [km²]	15.5	14.4	15.5	17.3	12.5	13.5
Percentage	17%	16%	17%	20%	14%	15%

The area sizes of the clusters (Tab. 3) were relatively balanced. Northness and Eastness, i.e. the aspect, showed the strongest variable differentiation. The area of the cluster 'NW exposed slopes of the upper-subalpine belt' is characterized by upper slope positions with steep slopes of 32° average inclination. In contrast, 'NE exposed slopes of the lower-subalpine belt' were less steep and closer to settlements. South facing slopes can be differentiated by altitude and the east-west axis as well: the clusters 'SW exposed slopes of the upper-subalpine belt' and 'SE exposed slopes of the middle-subalpine belt'. The upper south-west facing slopes are characterized by high altitudes, steepness and greater distances to settlements. South-east facing slopes include favorable sun-exposed areas, which are less steep and closer to settlements. Two further clusters ('E exposed slopes of the upper-subalpine belt' and 'W exposed slopes of the upper-montane belt`) can be distinguished by clear east-west separation. High altitudes, steep inclination and large distances to settlements characterize these east facing slopes. In contrast, the west-exposed low slopes represent the lowest and flattest terrain of the whole study region (around 1,880 m a.s.l., with an averaged inclination of 12°, Tab. 3). Stepantsminda – the largest settlement in the study region – is located on these gentle slopes.

The settlements were grouped by their topographic and land-cover change similarity in an NMDS ordination (Fig. 15). Land-cover changes and k-means cluster affiliation were fitted as vectors against NMDS ordination and the most significant ones ($p \leq 0.1$) are shown in the ordination graph, whereas non-significant vectors are left out. The graph shows the settlements with more similar properties closer to each other, like Stepantsminda and Akhaltsikhe, and the lesser similar ones in a greater distance to each other, like Pkhelshe and Ukhati.

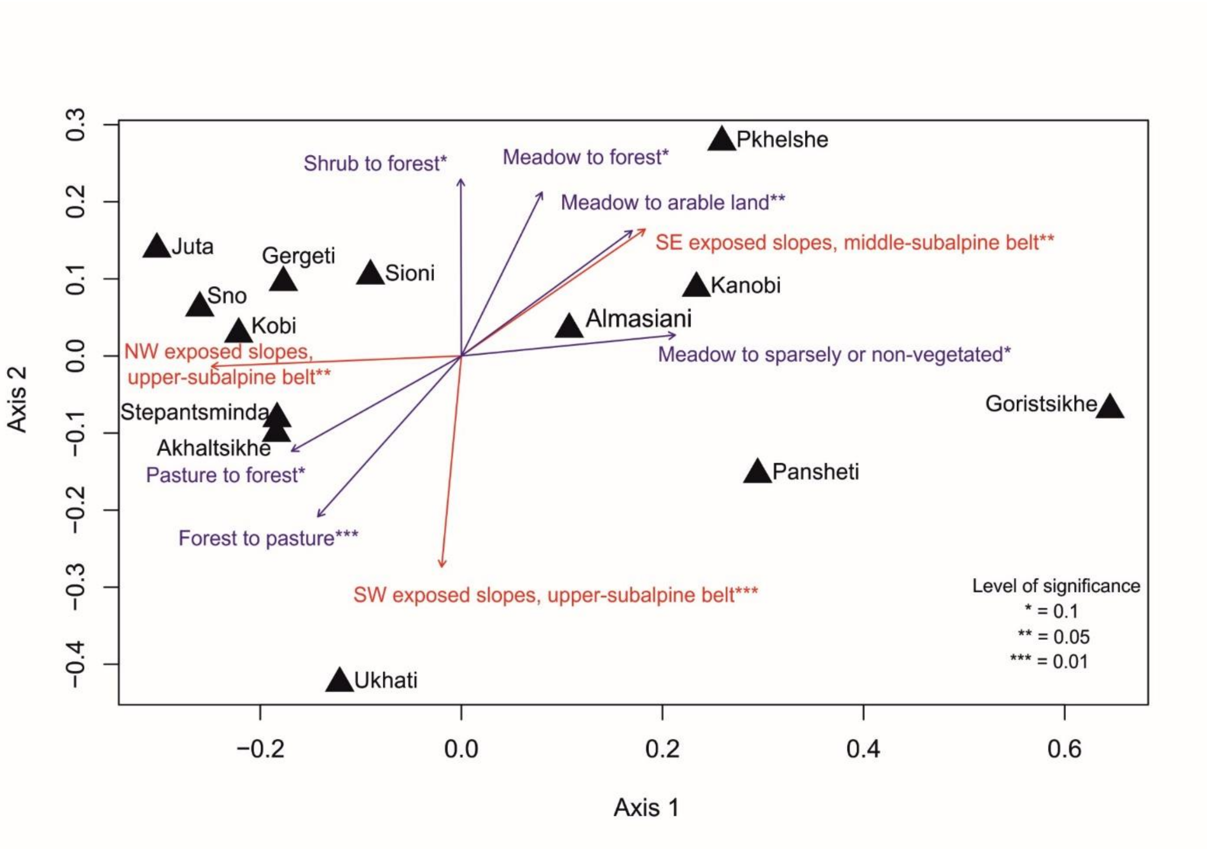

Figure 15: NMDS-Ordination of the study settlements (n = 13). The settlements were sorted by their k-means cluster affiliation and land-cover change. Arrows indicate significant linear correlations for clusters (red) as well as for the land-cover change classes (blue), with $p \leq 0.1$ (*), $p \leq 0.05$ (**) or $p \leq 0.01$ (***).

The first NMDS axis displays a strong gradient of north-west facing areas, whereas the second axis represents a strong gradient of south-west facing areas.

The NMDS ordination shows that Juta, Sno, Kobi, Gergeti and Sioni as well as Stepantsminda and Akhaltsikhe are characterized by a high number of steep northern slopes, up to high altitudes ('NW exposed slopes of the upper-subalpine belt'). In this cluster, grassland reduction and forest expansion is prevailing: grass- and scrubland of 1987 has changed to forest in 2015. Ukhati, as decribed above, is correlated to south-west expositions. The distinct ordination position of Ukhati suggests an increased amount of pasture and a decreased amount of forest (with a highly significant land-cover change class 'Forest to pasture'), which can be confirmed by the land-cover map of Ukhati (see appendix). Ukhati and its surrounding (2.200 – 2.500 m a.s.l.) is located near the climatic limit for cultivation (short growing season, frequent late frosts), i.e. rather adverse conditions for cultivation, but provided with deep, fertile soils and favorable topography. Almasiani, Kanobi and Pkhelshe can be described by favorable climatic conditions on sun-exposed area, marked by 'SE exposed slopes of the middle-subalpine belt' and therefore by increasing arable fields which are indicated by a land-cover change from meadow to arable land. This cluster combines locations at lower altitudes and close to settlements. However, in the middle-subalpine belt, sparsely or non-vegetated sites, i.e. agriculture-unfavorable locations, increased from 1987 to 2015, and, this is remarkable, meadow sites decreased. Pansheti and Goristsikhe are, therefore, located between the clusters 'SE exposed slopes of the middle-subalpine belt' and 'SW exposed slopes of the upper-subalpine belt', which explains their correlation to southern expositions as well. These settlements show the lowest proportion of forest and shrub (see Tab. 2).

6.6 Discussion

6.6.1 Landscape pattern in 2015

In Georgia 43 % of the total population lives in rural and mainly mountainous areas (National Statistics Office of Georgia, 2015). Usual and appropriate for mountainous regions, its population and most of the human activity is focused on flat valley locations, as it is the case in the upper watershed of the Tergi River and its tributaries, in the Central Greater Caucasus. A specific character of this Caucasian high-mountain landscape, in comparison to other European mountainous regions, is the relatively small amount of forest along the valley slopes, i.e. the high proportion of open grassland. Thus, below the timberline, in the upper montane and subalpine belts, most of the slopes in the region are unforested and used as cultural grassland, as either pasture or meadow. On the contrary, in Europe´s Mountains overall, forest covers 41 % of the total massif´s area and is the main land-cover type (European Environment Agency, 2010). As described above, forest vegetation was strongly reduced throughout former mountain grazing (Cernusca and Nakhutsrishvili, 1981; Körner, 1980; Lichtenegger et al., 2006), which established extensive subalpine grasslands, with a mixture of forest and alpine species (Grossheim, 1936). Still today, agriculture is a major source of income and employment in Georgia´s rural areas (Ministry of Agriculture, 2016), and is mostly practiced as low-input, subsistence or semi-subsistence farming (EU-FAO, 2013; Oedl-Wieser et al., 2017). In the study region, livestock farming with cattle is practiced in family structures with 2-3 cows per family to produce milk, yoghurt and cheese (Haerdle and Bontjer, 2010; Heiny et al., 2017). Nearly every household is cultivating a home garden to produce field vegetables, mostly for own consumption, and is mowing grassland-parcels once a year – manually, without machinery – in peripheral location to the settlements, to harvest winter fodder for the cattle. This agricultural land-use system is true for all 13 study settlements, but with varying extent dependent on population density. This system harbors a high biodiversity on the landscape level (a diverse pattern of ecosystems in the region) and the local level (species richness in pastures, meadows and arable fields) (Plachter and Hampicke, 2010). This cultural landscape reflects traditional, sustainable land use with a high biotic richness that strongly contributes to the status of the Caucasus as one of the species-richest ecoregion globally and because of its endemism a biodiversity hotspot (Millennium Ecosystem Assessment, 2005; Mittermaier et al., 1999; Myers et al., 2000). Besides ecological effects, and considering the critical income situation in rural areas, this land-use system is functioning as an important safety net for the rural population (EU-FAO, 2013; Kötschau et al., 2009). However, the land-use situation today is basically a consequence of the nationwide land privatization process, beginning in 1992, high costs of agricultural inputs, a lack of machinery and a lack of access to markets that leads to a low level of production efficiency (Didebulidze and Plachter, 2002). Additionally, a Russian trade embargo negatively influence the Georgian agricultural production and its development (EU-FAO, 2013), and furthermore leads to an one way direction for the Kazbegi region with regard to access to sales markets, transportation, and trade out of the region. Accordingly, farmers in Kazbegi are relatively isolated and act independently in a high degree whereas most of them, as mentioned above, for self-supply. It can be assumed that subsistence farming in the region will remain as long as these above-described factors are stable. However, Shavgulidze et al. (2017) determined that labor input, commercialization of agricultural activities, and proper management practices are significant factors of the local production efficiency. Thus, applicable enhancements in the agricultural production can be seen as local measures to possibly overcome subsistence farming. Moreover, based on the natural productivity of the local extensive grassland, there is potential to optimize and increase the region´s livestock production even with the consideration of measures to protect soil fertility and biodiversity (Theissen et al., 2019) In contrast, increased livestock production means changes in the regional landscape pattern, as more area is needed for the agricultural production. Nevertheless, managed appropriate, a higher agricultural impact can lead to a more diverse landscape (Theissen et al., 2019).

6.6.2 Historic landscape pattern and change from 1987 to 2015

Before the today´s stationary cattle husbandry, the grassland of the Kazbegi region was used as mountainous summer pastures for large flocks of sheep in a local-driven and transhumance system, based on a traditional Caucasian pasturage system (Didebulidze and Plachter, 2002; Onipchenko, 2004). The two-year comparison shows a greater area in both, pasture and meadow, as well as a smaller area in shrub and forest land cover in the 1987 landscape pattern. Agriculture was more intensively practiced in 1987 than it was in 2015, with strong landscape structure-forming effects, like extensive cultural grassland and reduced woody vegetation. Since the breakdown of the Soviet Union, the de-intensification of land use became evident and, in turn, the change affected the actual landscape pattern, characterized by abandoned cultural grassland, re-forestation and shrub-encroachment (Hansen et al., 2018). Changes in high-mountain land use can have major effects on land cover and are often driven by agricultural suitability (UNEP (United Nations Environment

Program), 2002) like intensification and abandonment affected the landscapes of Europe´s mountain regions (Drexler et al., 2016). In the Alps, fertile valley floors and slope terraces experienced agricultural intensification over the last 200 years, whereas marginal locations often got abandonment (Egarter Vigl et al., 2017). A worsening of socio-economic conditions in high-mountain agriculture (Tasser et al., 2007) had aggravated this land-use abandonment in the alps. Cultivating sloping areas is time-consuming with heavy workloads and thus means higher production costs (Zimmermann et al., 2010). In post-soviet, high-mountain countries the situation is quite similar, with land-use intensification and abandonment being dependent of geophysical factors as well, like slope steepness and fertility (Alix-Garcia et al., 2012; Lieskovský et al., 2015). However, in post-socialist countries land-use change was additionally affected by land reforms and market-price liberalizations after the breakdown of the USSR (Gunya, 2017; Kuemmerle et al., 2008). In southern and eastern mountains of Europe, agriculture is still particular important but with land-use abandonment in areas far away from settlements and intensification nearby (European Environment Agency, 2010). This is especially true for the Kazbegi region, where the grazing by cattle became more concentrated near settlements in the lower and middle-subalpine belt, whereas grazing by sheep at higher altitudes strongly decreased. With the independence, the agricultural management shifted, since the supply of the Georgian population with basic foods became the main priority (Haerdle and Bontjer, 2010). Similar effects, with a shift from transhumance to stationary grazing systems, were observed in many other former Soviet Union states and Asian countries (Food and Agriculture Organization of the United Nations, 2003). Besides livestock grazing, private farming on small scale, household plots played an important role in Georgia with the highest share of production during the Soviet period, compared to other Union states, and with increased importance after the Union´s disintegration and subsequent reformations (Kegel, 2003). This high affinity for self-supply production is still the situation in 2015 and clearly visible in the region. In 1987, nearly all settlements show a smaller area than in 2015, although the population mainly decreased from 1989 to 2014 (see Tab. 1). There might be two reasons to explain these opposing trends. First, settlements in favorable position, i.e. located in the flat valley and close to the main road, can benefit from further sources of income, like tourism. For instance, the involvement of the local population in tourism or the development of tourism infrastructure, like new constructed guesthouses and service offering, are higher in Stepantsminda than in remote located settlements, like Kanobi and Juta (Heiny et al., 2017; Hüller et al., 2017). Second, remote settlements, like Pkhelshe with limited accessibility, focuses on agriculture because there are less further sources of income. Consequently, agricultural used area close by, like meadows, arable land as well as garden and orchard, increased there. Nevertheless, the population decrease is more obvious in the remote settlements than in those close to the main road, as it is the case in other Greater Caucasus regions of Georgia

(Kohler et al., 2017). The impacts just described are indicating an increasing importance of tourism for most of the region´s population.

6.6.3 Landscape change trends along environmental conditions

Spatial classification based on topographical variables is highly applicable (Hoechstetter et al., 2008) especially in mountain landscapes (Maurer et al., 2006; Sebastiá, 2004; Zimmermann et al., 2010). In our study, different development trends of the settlements have been spatially characterized and compared. Categorizing the whole study area into six clusters along environmental conditions revealed that the trends followed a clear pattern. The urban area of the settlements is mostly located within the clusters 'north-east exposed slopes of the lower-subalpine belt', 'south-east exposed slopes of the middle-subalpine belt' and 'west exposed slopes of the upper-montane belt', i.e. at lower altitudes and on relatively flat terrain. Accordingly, and besides the urban area, these clusters are characterized by a high amount of arable land, greenhouses and meadows and, although below the timberline, less of forest. In particular, these above-mentioned lower slopes with east exposition showed a high dynamic in grassland management. We found old hay meadows that were used in 1987 but fallow land in 2015. Simultaneously, on eastern slopes at a different location, hay meadows had been established in 2015. Furthermore, the increased area of arable fields in 2015 supports the fact that subsistence agriculture is still dominant in remote areas in Georgia after the independence (Didebulidze and Urushadze, 2009). The surrounding land of the settlements Pkhelshe, Sioni and Juta are representatives for settlements situated on lower eastern slopes, with favorable conditions for agriculture. On the opposite, 'West exposed slopes of the upper-montane belt' can be described by decreasing pasture area combined with shrub-encroachment and increasing sparsely or non-vegetated area. Reduced grazing in the valley bottom and in settlement-near locations results in the succession of woody vegetation as well and leads to a loss of montane grassland habitats (Barcella et al., 2016). In favorable locations for agricultural use, shrub (Elaeagnus rhamnoides) is expanding and will further expand when pastures stay abandoned (Magiera et al., 2016; Waldhardt et al., 2011). North of Stepantsminda, in the floodplain of the Tergi river a huge area of fallow land was totally covered by shrub in 2015 (see Fig. 13). Natural birch forests mostly grow on steep 'north-west exposed slopes of the upper-subalpine belt' and to a minor extent on 'north-east exposed slopes of the lower-subalpine belt' at lower altitudes closer to settlements. Nakhutsrishvili (1999) explained the exclusive distribution of birch forests on northern exposures with favorable moist conditions protected by a longer snow cover during the winter – avoiding forest desiccation. The land-cover change from grassland into scrubland and forest mainly occurred on the northern slopes. The clusters 'east exposed slopes of the upper-subalpine belt' and 'south-west exposed slopes of the upper-subalpine belt' showed a high proportion of sparsely or non-vegetated area. Slope movements occur quite frequently on steep mountain flanks consisting of loose glacial sediments (Lichtenegger et al., 2006). In accordance with Kreeb and Nakhutsrishvili (1990), rocky outcrops and scree slopes scattered with tragacanth vegetation can be found mostly on southern slopes.

6.6.4 High mountain systems – evaluation and development

High mountain regions are large coherent natural environments with a high level of diversity among natural and semi-natural habitats, and they provide several valuable ecosystem services, like agricultural products, water yield, slope stability or recreational value (Körner, 2000). Historical practices in agriculture and forestry often associated with heavy workloads, formed region-characteristic high-mountain cultural landscapes (Maurer et al., 2006; Plachter and Hampicke, 2010). Moreover, several landscape functions are closely related to land use and the evolved cultural landscape structure (Farina, 2000; Fleskens et al., 2009; Varotto and Lodatti, 2014). In Georgia´s Greater Caucasus, land-use abandonment and, thus, land-cover change are caused by complex interactions of socio-economic processes such as rural impoverishment and migration with changes in agricultural practices and natural processes. Changes in land use due to political, economic and societal transformation processes are evident, as described above, for marginal regions of post-soviet countries in Eastern Europe (Didebulidze and Urushadze, 2009; Fischer and Gelb, 1991; Tölgyesi et al., 2015) and especially in rural mountainous regions (Pedashenko et al., 2015). In our study region, in particular the small and remote settlements experienced changes in land use (see Tab. 2) and depopulation, even total abandonment (see Tab. 1). Population out-migration, in this context, also signify the loss of local knowledge with concern to agroecosystems and various habitats, their characteristics, and the presence and usage of certain plants (Vogl and Vogl-Lukasser, 2015). However, to maintain cultural landscapes and to protect related habitat types with unique species, national and supranational subsidies are offered to increase profitability of low-intensive land utilization in the mountainous countryside in Central and Western Europe (Fleskens et al., 2009; Pôças et al., 2011). Sustainable management preserves the rural and cultural uniqueness and the diversity in habitat types and species. In that respect, the development of land-use strategies is important (Török et al., 2016). Concepts of land use include agricultural potential considerations and reflect the regional economy (Norton, 2016). Furthermore, they can assess the multifunctionality of the landscape in order to establish sustainable usage forms. Those integrated land-use concepts provide possibilities to support a sustainable spatial development in marginal mountainous regions and, at the same time, conserve the mountain ecosystems, as stated in the United Nations´ 2030 Agenda. However, our results suggest that there is an urgent need to locally adapt those concepts - since even within the study region land-use change affected the landscape in different ways.

6.7 Conclusion

This study is based on empirical landscape ecological research in a Caucasian high-mountain cultural landscape. Within an observation period from 1987 to 2015, land-use change in the grassland-dominated landscape is closely related to topography and thus shows different trends on settlement development. These trends are additionally affected by socio-economic processes during that period, as changes in population and the regional agrarian structure indicate. In order to show linkages between the spatial structure of a high-mountain landscape and changes in land use, the combination of geophysical factors with socio-economic parameters seems reasonable. This study quantitatively defines changes in land cover and puts this in relation to location-based factors and societal development. Thus, this approach can help to highlight interrelationships in socio-ecological systems in high-mountain regions. Moreover, it demonstrated how socio-economic transformations affect land-use decisions and the pattern of a cultural landscape. Maps of historical and current land-cover pattern and consequently the knowledge of the genesis and development of the local landscape structure offers an important orientation for future sustainable land use. In this context, the typification and topographic differentiation of landscape areas can be an appropriate tool to enhance the localization of site-adapted land use, especially in high-mountain regions with high environmental variability. The methodological approach of a spatio-temporal comparison combined with a GIS-based landscape analysis revealed an understanding of how land-use decisions influence the landscape pattern. Building on this approach, predictions can be made upon agricultural productivity, landscape diversity and services. This approach is transferable to other marginal or high-mountain regions, whereas the study outcomes can be compared or can serve as a sound base for landscape planning aiming to ensure good agricultural and environmental conditions of mountain land use. The understanding of case specific land-cover development trends can further be helpful to indicate future changes as well as regional development strategies.

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7. Environmental and socio-economic resources at the landscape level – Potentials for sustainable land use in the Georgian Greater Caucasus

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7.1 Abstract

Mountain regions cover one quarter of the Earth´s terrestrial surface and are both valuable and vulnerable areas with complex human-environmental interrelationships. In this coupled system, land-use changes induced by political or socio-economic transformations generate consequences for ecological landscape functions like soil productivity and species richness, and integrative land-use concepts provide the potential of a sustainable land development. In the Kazbegi region in the central Greater Caucasus of Georgia, these transformations further lead to landscape-structure change and population marginalization. Hence, we developed three agricultural land-use scenarios that meet Agenda 2030 Sustainable Development Goals to ensure a sustainable rural land development and the conservation of mountain ecosystems. Our normative scenario approach integrates quantitative and qualitative findings of empirical research in landscape ecology, soil science, vegetation ecology as well as agronomics and socio-economics. According to the examined environmental and socio-economic resources, we defined various scenario logics and normative assumptions that combine optimized livestock production (in dairy cow keeping and cattle fattening) with ecological limitations to maintain the functioning of mountain ecosystems. The rule-based scenarios achieved measurably increased outputs in biomass yields, livestock production and related revenues at the regional scale. Further, GIS generated scenario maps demonstrate the related land-use patterns spatially explicit and in high resolution and visualize the alternative future from local to the regional scale. In conclusion, scenario development helps to determine region-specific and integrated land-use options to provide a sound base for land users and decision makers. Based on research on multiple landscape functions, this approach can assist sustainable land development in a mountain region.

Keywords

Agricultural land-use options; Hay yields; Integrative scenario development; Muencheberg soil quality rating; Multifunctionality

7.2 Introduction

Worldwide, millions of people are dependent on the integrity of the functioning of mountain ecosystems (Körner, 2000; Messerli et al., 2004). Mountain ecosystems are highly multifunctional; they provide many provisioning, regulating, and cultural services, which are of increasing importance, particularly with regard to water regulation, protection against natural hazards, tourism, recreation, and forests (European Environmental Agency (EEA), 2010a). However, mountain ecosystems are fragile and vulnerable against changes in land use, economic conditions, and climate, leading to losses in biodiversity and system integrity as well as alterations in the ability of ecosystems to provide critical goods and services (Drexler et al., 2016; EEA, 2010b; Jodha, 2000; Körner, 2004; Price et al., 2016). Livestock grazing plays a major role for food production in mountainous regions of the northern hemisphere. Grassland management has thus shaped the biodiversity and floristic composition in those cultural landscapes for centuries. Land-use change, due to structural changes in agriculture or by shifts in socio-economic conditions, often leads to changes in ecosystem functioning and the related landscape pattern (Cernusca et al., 1996; Tasser et al., 2007), and can thus cause a loss in productivity (Tasser and Tappeiner, 2002). As a result, the sustainable development of human and natural resources is of utmost importance for rural mountainous regions.

Land use in the Greater Caucasus has changed in a long-term view (Belonovskaya et al., 2016), and dramatically since the Soviet era, considering the socio-economic adaption as a consequence of the disintegration of the former Soviet production and distribution systems and the establishment of subsistence agriculture (Didebulidze and Urushadze, 2009; Gunya, 2017). Livestock grazing in the Kazbegi district, a region located in the republic of Georgia and in the eastern part of the central Greater Caucasus, shifted from collective farming and intensive sheep transhumance during the USSR (1922 – 1991) to small-scale, stationary cattle husbandry to accomplish self-sufficiency for an increasingly impoverished rural population (Haerdle and Bontjer, 2010). Even more than two decades after the country´s independence (1991), poverty and population decline are still severe problems in rural regions of Georgia, where subsistence farming is a major source of livelihood and significantly contributes to food security (EU-FAO, 2013). Especially in the mountain areas, covering 87 % of the country´s surface, these problems lead to land-use abandonment (Nakhutsrishvili et al., 2009).

The diverse mountainous parts of the Caucasus are well-known for their rich multi-ethnic cultural heritage (Khardzeishvili, 2009; Nikolaishvili et al., 2012) and are commonly acknowledged hot spots of biodiversity at the Eurasian and global scale (Myers et al., 2000; Nakhutsrishvili, 2013; Pauli et al., 2012). Both, cultural and natural heritage are seen as assets to enhance the economic development of the country by tourism (European Commission, 2006). In this respect, agricultural land use plays the essential role for food security, income generation for the local inhabitants, the preservation of biotic and abiotic landscape functions, and the maintenance of the characteristic cultural landscape.

In the Kazbegi region, the abandonment of agricultural practices became highly visible through fallow arable fields and birch succession on grasslands (Hansen et al., 2018; Magiera et al., 2016; Tephnadze et al., 2014; Togonidze and Akhalkatsi, 2015). In order to sustain the agricultural land use and with respect to the numerous functions and services of this cultural landscape, the interdisciplinary AMIES II-project (Scenario development for sustainable land use in the Greater Caucasus, Georgia; funded by Volkswagen Foundation 2014-2018) focuses on the development of sustainable agricultural land-use scenarios for the rural development of the marginal Kazbegi region.

In the social-ecological context of agriculture, two prominent research concepts focus on human-nature interrelationships, considering the implications of human activity and its benefits in a comprehensive way. Both multifunctionality and ecosystem services have been promoted by international programs and are formative for sustainable agriculture research and policy-making (Huang et al., 2015). Different sets of landscape functions are included in the land-user-centered concept of multifunctionality with respect to production, cultural, or ecological dimensions (Galler et al., 2015; Huang et al., 2015; Lovell and Taylor, 2013; OECD, 2001). Multifunctionality plays a significant role in mountain research (e.g. Bernués et al., 2015; Fleskens et al., 2009; Hopkins and Holz, 2006; López-i-Gelats et al., 2015; Soliva et al., 2008; Wyder, 2001). While addressing the same dimensions, the concept of ecosystem services is focused on ecosystems and their services to human wellbeing, while ecosystem functions are valuated as ecosystem services, also by including economic valuation and incentives (Costanza et al., 1997; Haines-Young and Potschin, 2010; Huang et al., 2015; MEA, 2005a; TEEB, 2010). In mountain research, the ecosystem service concept is a vital element as well (e.g. Brunner et al., 2017; Egarter Vigl et al., 2017; Grêt-Regamey et al., 2012; Lamarque et al., 2011; Schirpke et al., 2017). Interdisciplinary research in socio-ecological systems tries to fill the gaps between the traditional, individual disciplines of social science and ecological research, and explain human-environment interactions, by considering human impact and ecological effects (Liu et al., 2007).

Scenario development can be a tool to analyze human-environment interactions. It has been a commonly acknowledged method in science for decades, with a wide range of methodical approaches and structures (van Notten et al., 2003). Scenario development can be differentiated by approach: for instance, scenario developments mostly based on expert knowledge (e.g. Rounsevell et al., 2012; Santelmann et al., 2004) or participatory scenario planning (e.g. Oteros-Rozas et al., 2015; Pfeifer et al., 2012; Hanspach et al., 2014). Synonyms for these approaches are ‘normative or exploratory’ and ‘top-down or bottom-up’ (Sarkki et al., 2017; van Notten et al., 2003). Furthermore, spatial scale can be a distinctive feature in scenario development: with observations at the patch/ field and local scale (e.g. Kohler et al., 2017; Schirpke et al., 2017), on landscape and regional scale (e.g. Nassauer and Corry, 2004; Vervoort et al., 2014; Waldhardt et al., 2010), or on global scale (e.g. IPCC, 2000; MEA, 2005b; Sala, 2005).

In our approach and in the context of high-mountain agriculture, we developed location-based and normative land use scenarios from the local to regional level. Normative scenarios for socio-ecological systems can combine quantitative and qualitative information (Peterson et al., 2003; Sarkki et al. 2017; van Notten et al., 2003) and finally evaluate (ex-ante) possible land use, allowing decision-makers to anticipate the effects of different strategies (Biggs et al., 2010; Nassauer and Corry, 2004). Thus, in our scenarios, we integrate diverse disciplinary knowledge (qualitative and quantitative) to analyze and evaluate possible future study landscapes. Besides this interdisciplinary effective approach of data integration, i.e. combining and spatial representation of numerical data, there are alternative approaches, like using an algebraic method for evaluation (see Papadimitriou (2012b), and Brüggemann and Voigt (1995) who applied the lattice theory) or methods of artificial intelligence for data analyzing (Goulart et al., 2013; Papadimitriou 2012a; Salles and Bredeweg, 2006).

In the first phase of our study, ecological, agronomic and socio-economic field research was applied with respect to sustainable development to carry out an interdisciplinary landscape analysis. This analysis combined soil quality assessment and yield potential (Hanauer et al., 2017) with a grassland productivity model to indicate hay yields (Magiera et al., 2017) and the spatially explicit distribution pattern of land-cover and land-use types. The information on spatial potential was further contrasted with agronomical and socio-economical findings about the food production and consumption needs of the population and the tourists in the region. These findings were ascertained through quantitative farmer surveys (Shavgulidze et al., 2017) as well as qualitative expert interviews, and focus group discussions (Hüller et al., 2017). At stage two, this analysis offers the opportunity to develop integrative and normative land-use scenarios on increased income generation in comparison to the status quo, respecting the ecological limits of the studied landscape. Thus, these scenarios contribute to the Sustainable Development Goal (SDG) 8, the promotion of inclusive and sustainable economic growth, SDG 12 on sustainable production and consumption, and SDG 15 to halt land degradation and biodiversity loss (United Nations 2015).

Our study aims to answer the following research questions:

i) How does the landscape and the fodder production change under the different scenarios?

ii) How much additional cattle can the landscape bear and how does this affect regional food production and revenues?

Although multifunctionality and ecosystem services as a whole define ecological, economic, and societal perspectives of a landscape, likewise landscape sustainability (Otte et al., 2007), a single research investigation is mostly focused on selected, specific landscape functions, considering the setting of the studied landscape and the participating research disciplines. However, in the evaluation of the three scenarios we highlight their effects on multifunctionality and the provision of ecosystem services induced by the scenario logics. Our scenario results are based on the region-specific project findings and are not transferable to other regions. Nevertheless, as we try to clarify the methodical approach of integrative and normative land-use scenarios development, it may help to stimulate research to support sustainable development in other rural regions. Our approach combines ecological science with socio-economic research to meet the comprehensive requirements of sustainable development.

7.3 Study region

The study region is part of the Kazbegi district (1,070 km², GeoStat, 2011) in the Mtskheta-Mtianeti region, located in the eastern part of the central Greater Caucasus. The district (population in 2014 approx. 3,800, Census 2014, GeoStat 2016), as an administrative unit, is situated in the northern slopes of the Great Caucasian Ridge, between the Jvari crosspass and the Russian border. The study area is embedded in the upper catchment of the river Tergi, which originates in the glacier area of the Mount Kazbek and drains to the north in the Caspian Sea. Selected settlements and their surrounding land located along the Tergi and Snotskali valley are the focus of this study (Fig. 16.), with Stepantsminda (2014 pop. approx. 1,300) being the main town in the district.

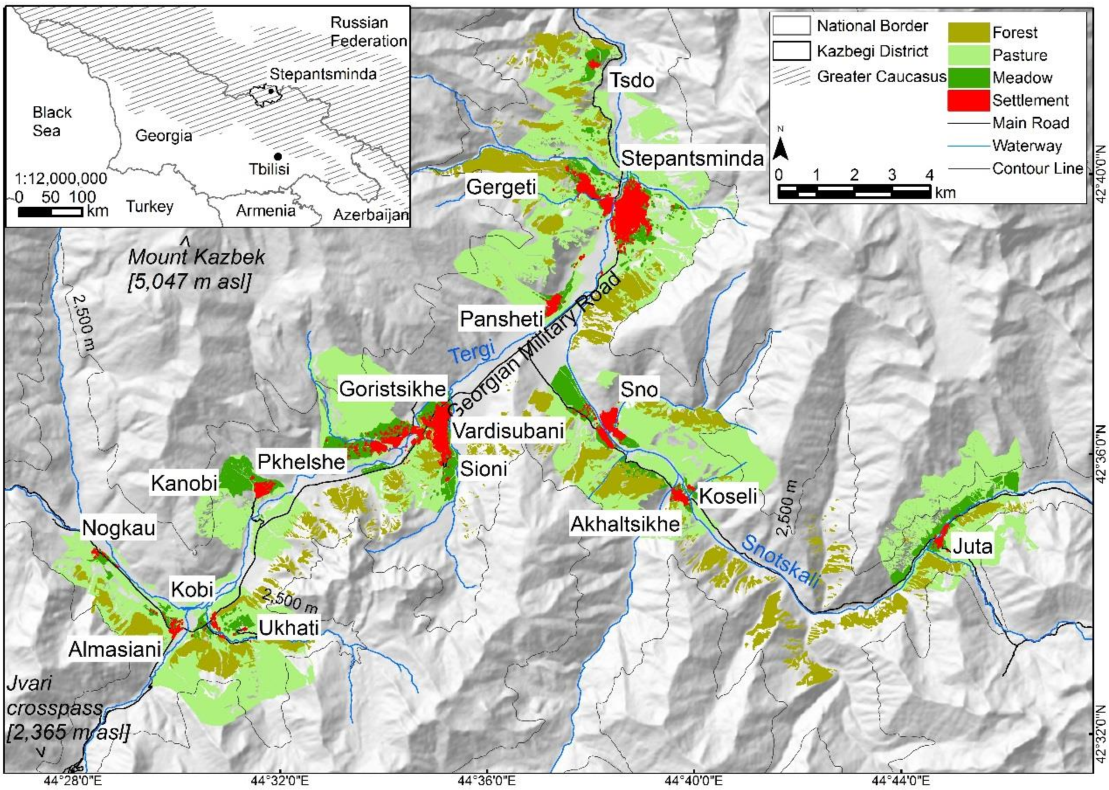

Figure 16: The Kazbegi region in the eastern part of the central Greater Caucasus (Georgia), with Stepantsminda the main settlement. 17 settlements out of 25 mostly populated settlements along the Tergi and Snotskali rivers are the focus of the study. The river Tergi originates in the glacier area of the Mount Kazbek and drains to Russia in the north, in the Caspian Sea.

The geomorphological situation of the study region is diverse and shaped by quaternary fluvial and glacial sediments, tertiary and quaternary volcanic rocks and Jurassic sedimentary rocks (Hanauer et al., 2017). Dominant soils are Leptosols, Cambisols, Gleysols and Histosols (Kirvalidze, 1999). Whereas the productive Cambisols are mainly spread in the lower subalpine zone, the shallow Leptosols primarily occur in the lower subnival belt, which reaches up to approx. 3,200 m asl. Both soils are characterized by acid and weak acid reactions, a high content of humus as well as deep humus penetration (Urushadze and Ghambashidze, 2013).

The climate in the study region is moderately humid and continental. In the subalpine belt (1,700 – 2,400/2,500 m asl), the mean annual temperature is 4.7 °C and the mean annual precipitation is about 800 mm, approx. 70 % thereof falls during the six month growing season (May-October) (Lichtenegger et al., 2006; Nakhutsrishvili et al., 2005). Mean air temperature in July and August, the warmest months, averages to 15 °C (maximum around 30 °C). The daily mean air temperature in January, the coldest month, is -11 °C (with a minimum of -30 °C), and stable snow cover persists from November to May (Akhalkatsi et al., 2006). Besides gorge winds, northerly and southerly winds are typical (Nakhutsrishvili, 2003).

A diverse pattern of land-cover and land-use characterize the study area from the montane belt (< 1,700 m asl) to the alpine belt (2,400/2,500 – 3,050/3,100 m asl). Within the village catchments, pasture (57 % of all catchments), forest and scrubland (12 %), and meadow (8 %) characterize this mosaic. Inside or close to the villages (covering 3 % of the whole study area) we find gardens and orchards (2 %) as well as small-scaled parcels of arable land (1 %). Agriculture and tourism are the main sources of income in the district. The industrial sector has never been important in the region (TJS, 2009).The local agrarian food production is primarily located in the subalpine belt. Under the Soviet Union, agriculture in Kazbegi was dominated by sheep transhumance, a system that has been replaced by semi-stationary and stationary variants with cattle since the independence, mainly for private supply (Didebulidze and Plachter, 2002). Since the middle of the 1990s, the number of cattle has risen because cattle provide meat and milk, the latter of which can be processed into several dairy products (Haerdle and Bontjer, 2010).

The tourism sector has been growing in recent years, with rising participation of the local population in touristic services (Gugushvili et al., 2017; Hüller et al., 2017). The Kazbegi district is a major tourist destination in Georgia, however the tourists are almost exclusively concentrated in the settlements Stepantsminda, Gergeti and Juta (GeoWel Research, 2015). Further touristic infrastructure in the district is incomplete, with shortcomings in regulations and restrictions leading to uncontrolled tourism (Heiny, 2017) – a similar situation as in other regions of Georgia (Oedl-Wieser et al., 2017). Today, the appeal of the region for Georgian (70 % of all visitors in the district) and international tourists mainly originates from nature, sport activities and cultural sites (Heiny et al., 2017). With the rising number of tourists, who spend about two-third of their daily expenditures on food (Bélisle, 1983), the demand for food in the region increases.

7.4 Material and methods

In the selected 17 settlements and their surrounding land within the Kazbegi region, disciplinary and interdisciplinary investigations were carried out to obtain a basic dataset for several land-use scenarios, which take both ecological conditions and economical improvements into account. Field and empirical research in landscape ecology, soil science, vegetation ecology, agrobiodiversity as well as in agronomics and socio-economics built the set of quantitative data. Linkages between agricultural food production and the local tourism sector could be identified by qualitative data form expert interviews, and focus group discussions.

7.4.1 Data set

The study area was digitally mapped on the scale of approx. 1:5,000, based on satellite imagery. In the field the maps were evaluated in 2014 and 2015 to determine spatially explicit landscape patterns and agricultural activities.

Soil quality and suitability were measured using the Muencheberg-Soil Quality Rating (M-SQR) (Mueller et al., 2007). The M-SQR is based on indicators describing the natural yield potential and the evaluation of rooting zone properties for cropping purposes. This soil quality evaluation was applied on selected locations to characterize soil distribution and soil properties in the study area (Hanauer et al., 2017). The indicators cover eight 'basic soil indicators' that describe plant growth criteria, such as texture, rooting depth, wetness and ponding. These basic indicators were measured in the field and were supplemented by laboratory data of soil analyses, like salinity and total nutrient status as well as climatic condition data and topographic indices of the measurement locations (Hanauer et al., 2017). Further, 13 'soil hazard indicators' characterize potential yield-limiting factors, like contamination, acidification and drought. The final M-SQR score calculation is a summation of all indicators multiplied by the most limiting hazard indicator. The score ranges from 0-20 (poorest) to 80-100 (best). Here, the scores are grouped from Very poor (0-20) to Good (60-80). The soil quality rating interpolated and processed in GIS provided a soil map of the study area showing the distribution of the M-SQR-score classes.

For the biomass productivity of the region´s grassland, a spatial explicit grassland yield map was modelled, based on vegetation data, biomass clippings, spatial data and general modelling techniques (Magiera et al., 2017). However, we enlarged the calibration data pool by including 90 vegetation relevés on steep slopes. This considerably expanded the floristic gradient. Mapping of the standing grassland biomass as a proxy for grassland yield was implemented by a two-stage approach. First, all vegetation relevés were subjected to ISOMAP ordination (52 % of the initial distances were transferred to the ordination axes), to reduce the high-dimensional floristic data set to three main gradients. Those were then related to the bands of the satellite image using three random forest models, vegetation indices and topographical variables (R^2 = 42 %, R^2 = 27 % and R^2 = 5.62 % of the variance explained). The resulting modelled ISOMAP/ species composition map scores were then used again in a random forest model to predict biomass. The resulting model explains 43 % of the initial variance with a Root Mean Squared Error of 3.44 t/ha.

Socio-economic conditions of the study settlements´ population and linkages between agri-food producers and tourism service providers were analyzed within the framework of a qualitative study. This study was based on focus group discussions with small-scale farmers and food producing households as well as on expert interviews with retailers, tourism sector representatives, and village heads (Hüller et al., 2017). Moreover, research on the technical efficiency of potato and cheese production provided insights of the agronomic situation in the local farming practices (Shavgulidze et al., 2017). For the scenario development, both research findings identified region-specific challenges and needs in food production and provision.

7.4.2 Scenario development

At present, agriculture in the whole region is dominated by self-sufficiency farming mostly organized in family structures, with 1 – 5 cows per farming household (Heiny et al., 2017). Livestock grazing in the region is locally-driven by each single settlement and the management is restricted by a lack in equipment or suppliers, i.e. lack of machines, pesticides, concentrated feed, and mineral fertilizer (Didebulidze and Plachter, 2002; Shavgulidze et al., 2017). However, many locals stated that the potential of the local dairy production has not yet been fully exploited. Currently, large pasture areas in the region are only used partially. As cattle can make the most of the large pastures, we believe that the best way to develop the agricultural potential in the region is by keeping additional dairy cows and fattening cattle. By supplementing the feed of the cattle with a fodder crop, the dairy farming can be enhanced even with the limited technology available (Shavgulidze et al., 2017).

We thus developed three scenarios, based on additional livestock herding, which differ in cattle density and the dimensions of ecological protection (Fig. 17).

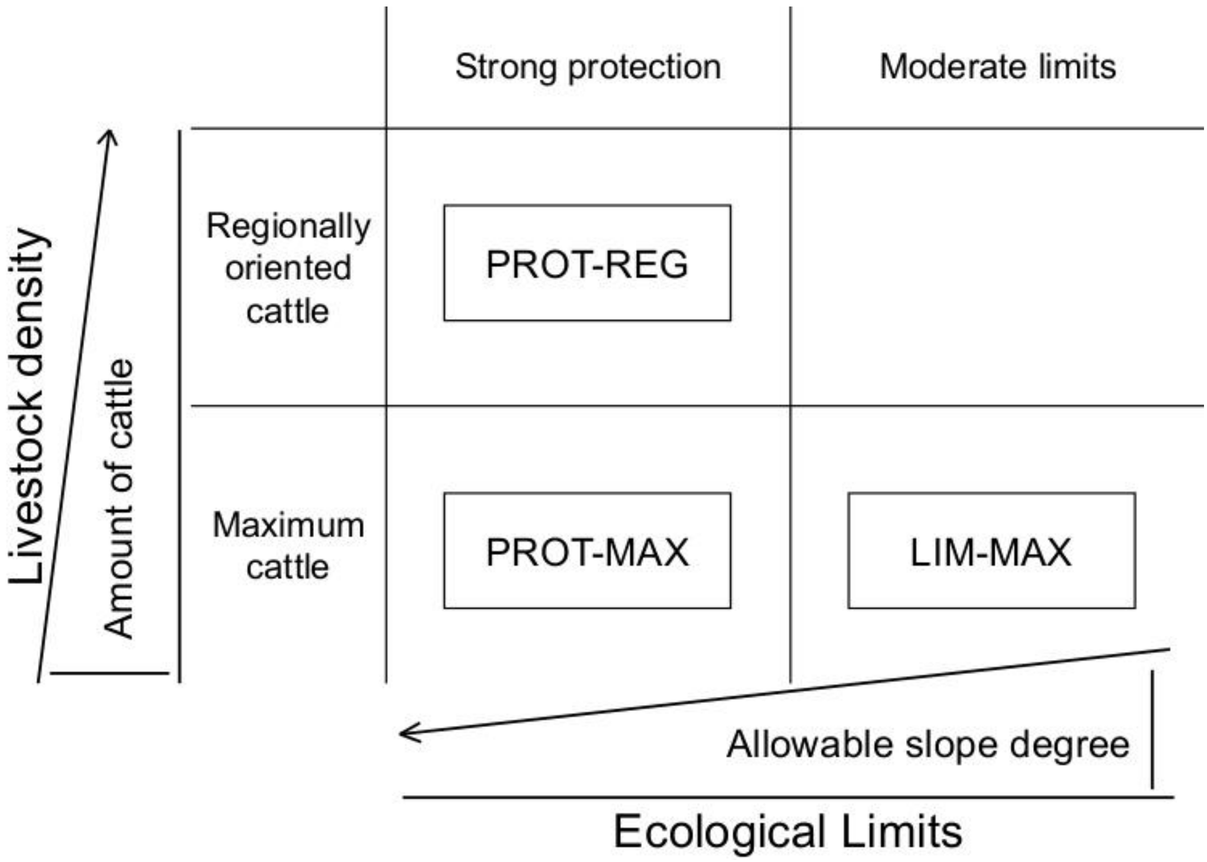

Figure 17: Schematic representation of the scenarios. The 'Ecological Limits' on x-axis describe the level of land-use limitation. In the scenario developments, we considered slope degree as the most important factor for both pasture and crop-cultivation regulation in mountains. We assumed increased intensity of land use on steep slopes would lead to site degradation caused by damaged vegetation cover or loss of soil fertility. Thus, we defined protection thresholds based on inclination accounting for slope positions allowed or excluded for agricultural use, along which the scenarios were set. 'Strong protection' is the conservative threshold (slopes > 30 degrees were excluded), 'Moderate limits' the tolerant one (slopes > 40 degrees were excluded). Further, two levels of cattle amount defined the

livestock density on the y-axis. 'PROT-REG' means Ecological Protection and Regional Orientation, 'PROT-MAX' Ecological Protection and Maximum Cattle, and 'LIM-MAX' Ecological Limits and Maximum Cattle. For further details, see text.

Scenario 'Ecological Protection and Regional Orientation' (PROT-REG)

This scenario assumed strongest protection limitations for the suitability of area use in combination with the 'Regionally Oriented Cattle' numbers assumptions. In this scenario, the threshold set-up was more conservative according to strong ecological protection purposes. Agricultural land use was restricted to protect the region´s biodiversity, soil integrity and slope stability. The land-use system in this scenario encompasses all grassland locations of the study area up to a slope of 30 degrees. The majority was used as pasture. In order to prevent an impairment of the vegetation cover due to the trampling effect of grazing cattle, steep locations (> 30 degrees) were excluded. Hay meadows were included, based on the mapping in 2014/ 2015, but excluded in locations with a SQR value of ≥ 40, which were suitable for fodder crop cultivation. For these potential fodder crop locations, a conservative erosion-control threshold (T 1) defined a limitation that excludes areas steeper than 7 degree, to minimize cultivation-related erosion.

Scenario 'Ecological Protection and Maximum Cattle' (PROT-MAX)

The PROT-MAX scenario assumed the same strong ecological limitations as Scenario PROT-REG, but with 'Maximum Cattle'. Here, the cattle number was extended up to the limit set by winter-feed requirements and pasture yields.

Scenario 'Ecological Limits and Maximum Cattle' (LIM-MAX)

In that scenario, the ecological limits were loosened; a tolerant threshold set-up in combination with 'Maximum Cattle' numbers were used. Land use in this scenario encompasses all locations up to slopes of 40 degrees. In the sense of ecological limitation, it was assumed that a use of steeper locations for intensified agricultural purposes would cause severe vegetation damage, which may initiate downslope mass movements (Wiesmair et al., 2016). Hay meadows were not included and locations with a SQR value of ≥ 20 were assumed to be suitable for fodder crop cultivation in this scenario. Due to erosion protection at these sites, the tolerant slope threshold (T 2) was set at 17 degree, since cultivating steeper locations would lead to erosion, i.e. soil loss. Further assumptions included best management practices and cultivation protection measures, like contour cropping and narrow sowings.

For those three scenarios, the spatial patterns and area sizes of the following land-cover and land-use types were of interest: pasture, meadow and arable land.

General assumptions

Land that was considered as potential arable land was assumed to serve as cropland for the cultivation of alfalfa (Medicago sativa) as a perennial forage crop. For all three scenarios, the yield of the relatively high-protein fodder crop alfalfa was assumed to be used as cattle feed, especially for winter fodder. For crop cultivation, a mean alfalfa yield was set at 3 tons DM (dry mass) * ha-1 * a-1, a conservative value, considering cultivation circumstances in the high-mountains. As a further assumption, the small-scaled arable land, used mainly for potato cultivation in kitchen gardens (Heiny et al., 2017), continues to be utilized this way, i.e. was not used for alfalfa production. Finally, after defining suitable locations for meadow, pasture and arable land, the area sizes and yields were calculated. Based on the compiled biomass model for the region, the biomass yield for the meadow and pasture sites were determined in tons per ha and year. The mapping and calculation were done using ArcGIS 10.2 (ESRI, Redlands, CA, USA).

We assumed that the dairy cows produce about 3,800 kg of milk per year, which is about twice as high as the current yield. We assumed that this process contains the rearing of the calves either for the replacement of old cows or for local slaughtering at a weight of about 300 kg. Furthermore, derived from an idea proposed by local farmers, we included a system of young cattle fattening on the pastures (further referenced as ‘Summer Calves’). We assumed that in spring, young calves could be purchased outside the region and raised on the pastures for fattening purposes only during the summer season, as winter feed and housing are the bottleneck in the area. They were presumed to arrive with an age of 90 days and be sold again with the age of 270 days (for details see Appendix A1).

Based on these data and local resource endowments (feed yields), the amount of cattle of the three scenarios were estimated. The calculated figures were compared to the status quo of heads of cattle in the region. Depending on the estimations of the respective scenarios, a certain amount of milk and meat can be produced. In order to assess the economic potential for marketing and export of meat and dairy products, these production outputs were compared to the estimated needs of the local population (Appendix A1) and the tourists who visit the region (Appendix A1). Potential sales revenues were calculated using milk and meat prices from a survey in the region. Two levels of cattle density were assumed. For the ‘Maximum Cattle’ scenarios, it was assumed that the number of dairy cows is limited by winter feed requirements and maximized according to given feed yields from meadows or alfalfa from arable fields. Additionally, available pasture yields were attributed to additional ‘Summer Calves’. Furthermore, for ‘Regionally Oriented Cattle’ the additional cow numbers that are provided by the calves of the dairy cows were calculated. For this calculation, it was the goal to meet the local demand for meat by the population and the tourists. This leaded to cow numbers 38.6 % less of the ‘Maximum Cattle’ variant. The same share of remaining pasture yield was assumed to be utilized for an uniform extensification level. After deducting the feed need for cattle, cows and related calves, the remainder was attributed to additional 'Summer Calves'.

It was assumed that the additional milk and the additional meat from locally fattened calves as well as the meat from the 'Summer Calves' would be exported from the region.

7.5 Results

7.5.1 Land use and fodder production

The spatially referenced and explicit landscape patterns with different land-use and land-cover types for the situation in 2015 and the three scenarios were depicted in maps (Fig. 18 (Stepantsminda and Gergeti as examples) and Appendix A2 for all study settlements in high resolution, for detailed view).

In the PROT-REG and the PROT-MAX scenarios, the land-use system and thus the biomass outcomes are equal, but with varying numbers in cattle ('Maximum Cattle' in the PROT-MAX scenario). In both scenarios, additional locations for arable land needed for crop fodder production are strongly limited by the availability of suitable soil quality, i.e. soils with SQR values ≥ 40. According to the soil assessment by Mueller (2007), the soils in the Snotskali valley around Sno, Akhaltsikhe, Koseli, and Juta are not suitable for the establishment of further arable land, since the SQR score is below 40. Sufficient soils largely occur on the talus fan of Pkhelshe and Goristsikhe (112 ha) as well as around Kanobi (79 ha) (see Tab. 4). Accordingly, the largest alfalfa production can be expected in Pkhelshe and Goristsikhe (204 tons DM * a-1) and in Kanobi (171 tons DM * a-1). Hay meadows are mainly distributed in Sno, Akhaltsikhe and Koseli (127 ha and 416 tons DM * a-1), as well as in Stepantsminda and Gergeti (106 ha and 336 tons DM * a-1). Pasture sites dominate below the crosspass in the most southern part of the Tergi valley, near the settlements Kobi, Almasiani, Ukhati, and Nogkau, as well as in Stepantsminda and Gergeti. In both sites, the rangeland areas amount to approx. 600 ha, with an aboveground biomass of around 1,700 tons DM per year. Overall, for the PROT-REG scenario and the PROT-MAX scenario, we determined 9,828 tons DM biomass on 35 km² for livestock production.

In the LIM-MAX scenario, the ecological limits are loosened in combination with 'Maximum Cattle' numbers, allowing grazing on steep slopes (< 40 Degree). The lower soil quality value for potential arable land (SQR ≥ 20) resulted in more alfalfa production in every settlement. Notably, the potential area for arable land in Stepantsminda and Gergeti increased from 21 ha in the first two scenarios to 265 ha in the LIM-MAX scenario. In general, the more intensive land-use system with a tolerant threshold set-up resulted in an agricultural area increase of almost 40 % (22 km²) compared to the first two scenarios, to a total area of 57 km². This means, here we expect approx. 16,600 tons DM biomass in total.

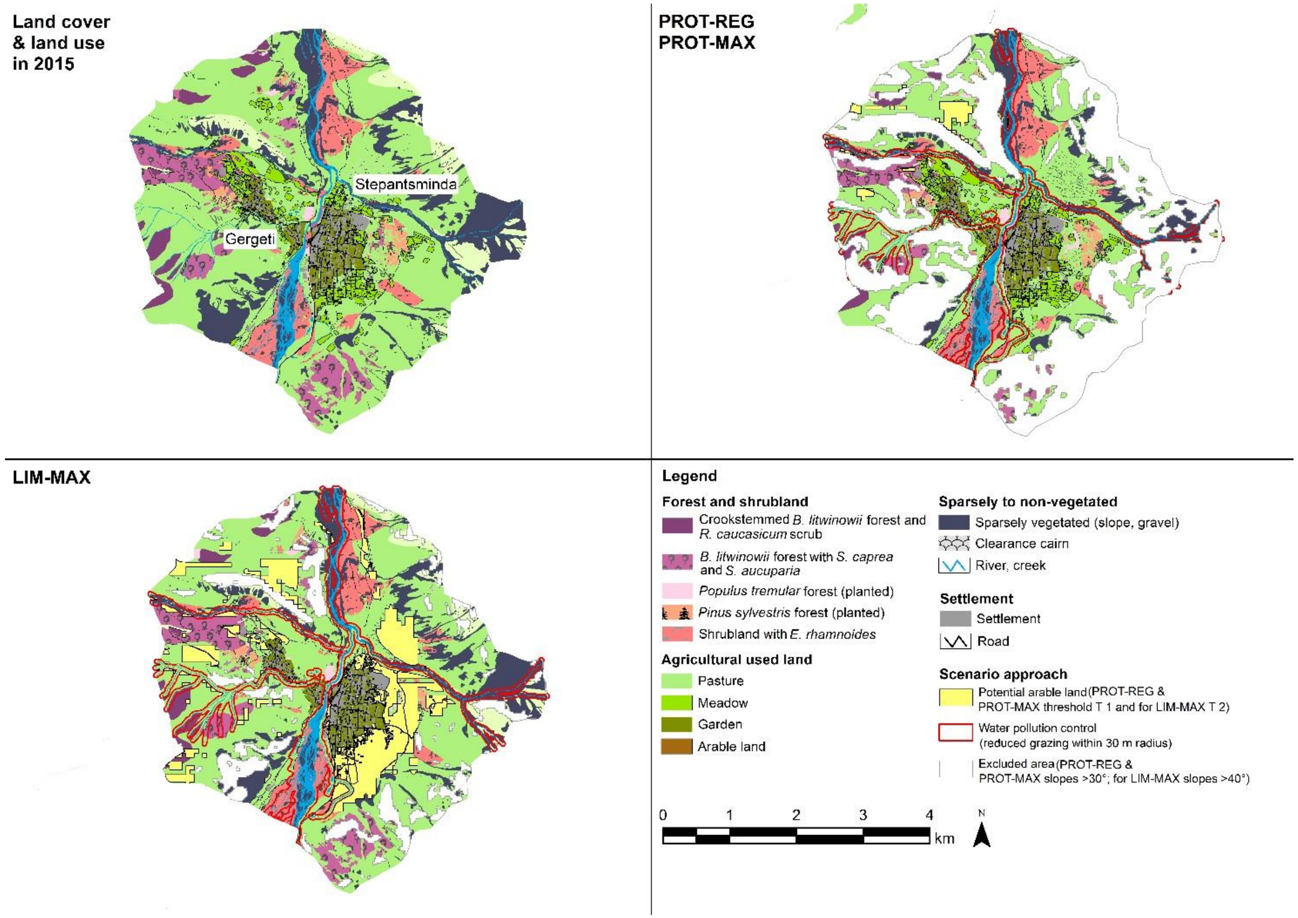

Figure 18: Land cover and land use (LCLU) in Stepantsminda in 2015 and for the scenarios PROT-REG, PROT-MAX and LIM-MAX. The LCLU map for 2015 is based on satellite imagery-mapping and two fieldtrips in the region for validation (2014 and 2015). The 2015 maps of the 17 study settlements served as a geo-spatial database for the scenario developments. The resulting scenario maps are spatial-explicit representations for the rule-based LCLU distribution, according to the scenario assumptions. Potential arable land is selected according to the soil quality rating method by Mueller (2007), and by defining scenario-adapted ranges of suitable SQR-values as well as applying two thresholds for erosion protection (T 1 and T 2). Water pollution control defines reduced grazing along waterways within a 30 m radius to minimize pollution through increased livestock husbandry. In the scenarios PROT-REG and PROT-MAX, slopes above 30 degrees inclination are excluded from the land-use system, in the LIM-MAX scenario we excluded slopes above 40 degrees.

*Table 4: Area (ha) and DM biomass (t * a-1) for different land-cover and land-use (LCLU) types in 2015 and for scenarios PROT-REG, PROT-MAX and LIM-MAX, for the 17 study settlements. The area calculation was based on the LCLU pattern and the defined scenario maps. The biomass yield calculation for meadow and pasture were derived from the biomass model. Suitable additional arable land in the scenarios was defined by selected SQR value ranges (SQR ≥ 40 and SQR ≥ 20), based on the soil quality rating method by Mueller (2007) and two erosion protection thresholds (T 1 and T 2). The alfalfa biomass was calculated based on an assumed crop yield (3t * ha-1 * a-1). It is a conservative mean value, according to cultivation circumstances in the high mountains. For the alfalfa fodder crop production, we omitted the small-scaled gardens.*

	Land cover & land use		Gergeti, Stepantsminda	Pansheti	Koseli, Sno, Akhaltsikhe	Tsdo	Sioni, Vardisubani	Pkhelshe, Goristsikhe	Kanobi	Kobi†, Almasiani†, Nogkau†, Ukhati‡	Juta	**Total**
		Altitude [m a.s.l.]	1,765	1,770	1,770	1,780	1,875	1,900	1,985	2,010†; 2,190‡	2,160	
Condition 2015	**Area [ha]**											
		Forest & shrubland	371	2	239	80	43	16	8	262	128	1149
		Arable land	10	1	4	1	4	5	4	18	1	48
		Orchard	48	10	31	2	49	17	4	7	4	172
		Meadow	114	20	138	31	91	113	92	69	103	771
		Pasture	1214	348	955	172	187	414	302	1064	719	5375
		Sparsely to non vegetated	400	132	408	33	60	102	82	183	73	1473
		Settlement	117	12	42	2	58	28	6	12	6	284
		Road	34	3	18	4	15	3	9	20	3	109
		Total	**2308**	**528**	**1835**	**325**	**507**	**698**	**507**	**1635**	**1037**	**9381**
		Soil with SQR-score < 40	2241	516	1835	297	463	586	428	1573	1037	8976
		Soil with SQR-score > 40	67	12	0	28	44	112	79	62	0	404
Scenarios PROT-REG & PROT-MAX	**Area [ha]**	Alfalfa (SQR ≥ 40, ≤ 7°)	21	0	0	9	17	68	57	12	0	184
		Meadow (< 30°)	106	20	127	24	89	54	77	56	46	599
		Pasture (< 30°)	614	178	379	118	127	223	123	643	308	2713
		Total	**741**	**198**	**506**	**151**	**233**	**345**	**257**	**711**	**354**	**3496**
	Biomass [t DM * a^{-1}]	Alfalfa (3t)	63	0	0	27	51	204	171	36	0	552
		Meadow	336	75	416	102	280	200	271	145	142	1967
		Pasture	1661	437	1041	385	315	576	299	1721	874	7309
		Total	**2060**	**512**	**1457**	**514**	**646**	**980**	**741**	**1902**	**1016**	**9828**
Scenario LIM-MAX	**Area [ha]**	Alfalfa (SQR ≥ 20, ≤ 17°)	265	31	40	25	121	137	119	67	41	846
		Pasture (< 40°)	960	328	965	170	160	358	257	958	688	4844
		Total	**1225**	**359**	**1005**	**195**	**281**	**495**	**376**	**1025**	**729**	**5690**
	Biomass [t DM * a^{-1}]	Alfalfa (3t)	795	93	120	75	363	411	357	201	123	2538
		Pasture	2904	861	2837	567	442	972	792	2749	1932	14056
		Total	**3699**	**954**	**2957**	**642**	**805**	**1383**	**1149**	**2950**	**2055**	**16594**

7.5.2 Additional dairy cows and summer fattening cattle

The available feed allows for additional dairy cows and summer fattening cattle (Fig. 19). Winter-feed (and for the PROT-REG scenario the potential need for dairy products) is limiting dairy cattle, since not all grassland can be used to produce winter feed. Only meadows and arable land with sufficient soil quality rather close to the villages allow producing high quality feed that is worth to be conserved for the winter period either as hay or as silage. Based on the assumed limits, the amount of dairy cattle increased to 300 heads (PROT-REG), 595 heads (PROT-MAX) and 939 heads (LIM-MAX) and their respective calves. As the 'Summer Calves' are assumed to be in the region only for one summer period, they are not depending on winter feed and solely make use of extensive pasture areas. This allows for very high additional cattle numbers: 1,887 (PROT-REG), 3,718 (PROT-MAX), and 8,952 (LIM-MAX).

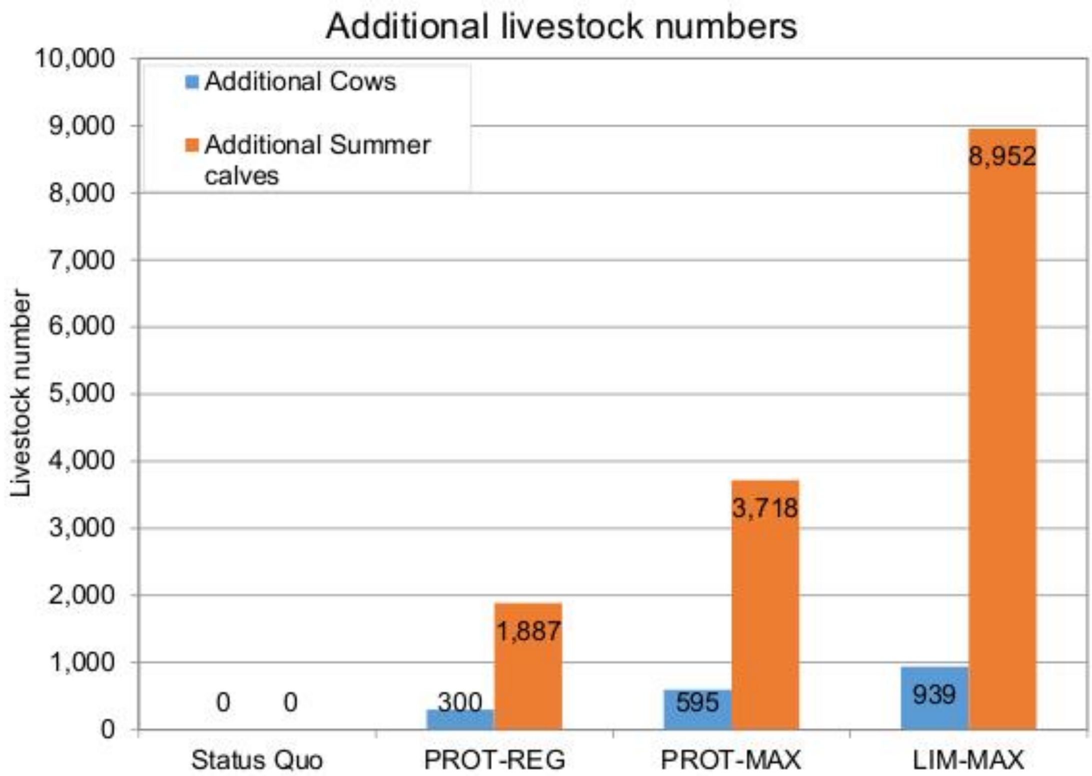

Figure 19: Additional dairy cow and summer calve numbers of the status quo in 2015 and the scenarios. For further details in assumptions and calculation, see appendix A1.

Based on the increased amount of cattle, we calculated the yields of selected food items in the Kazbegi region with regional balances (Fig. 20). This calculation showed that available grassland and arable yields offer a lot more agricultural production potential than the actual food need of the region (Appendix A1), even taking tourists into account. Although the local population and tourists might partly consume the additional food, all scenarios showed possible exports, that exceed the local need.

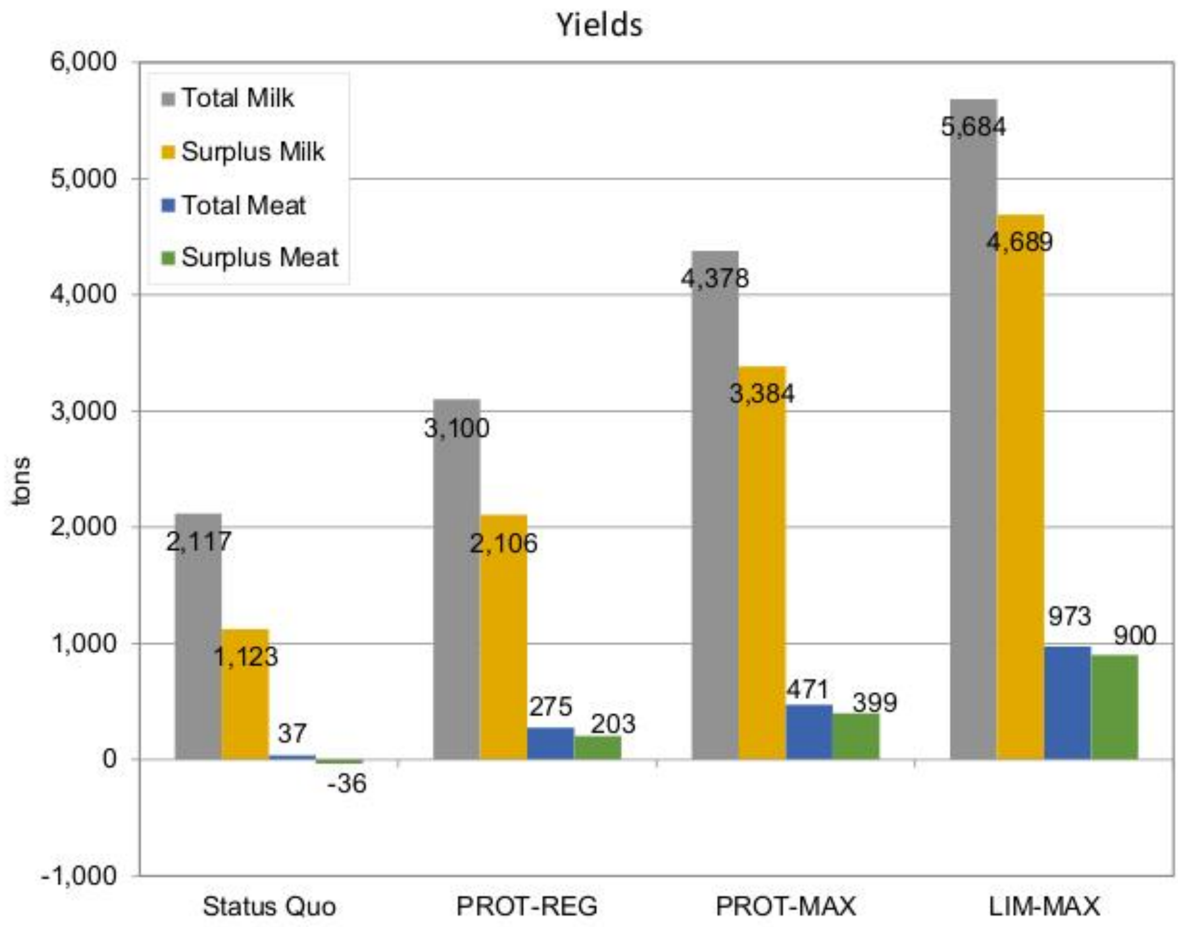

Figure 20: Milk and meat yields of the status quo and the scenarios. For further details in assumptions and calculation, see appendix A1 and Shavgulidze et al. (2017)

A comparison of the scenarios´ revenue generation revealed that the LIM-MAX scenario provides the best opportunity, i.e. the most generated revenue for farmers in the Kazbegi Region, followed by PROT-MAX scenario and PROT-REG scenario in a descending order. Based on this estimation, in the LIM-MAX scenario the total revenue generated by farmers in the region should be GEL (Georgian currency = Georgian lari) 12.7 million, in the PROT-MAX scenario GEL 6.7 million, and for the PROT-REG scenario GEL 3.7 million (Fig. 21). In scenario PROT-REG, meat sales contribute with 55 % of total revenue, while the share is 60 % and 71 % for PROT-MAX and LIM-MAX scenarios, respectively.

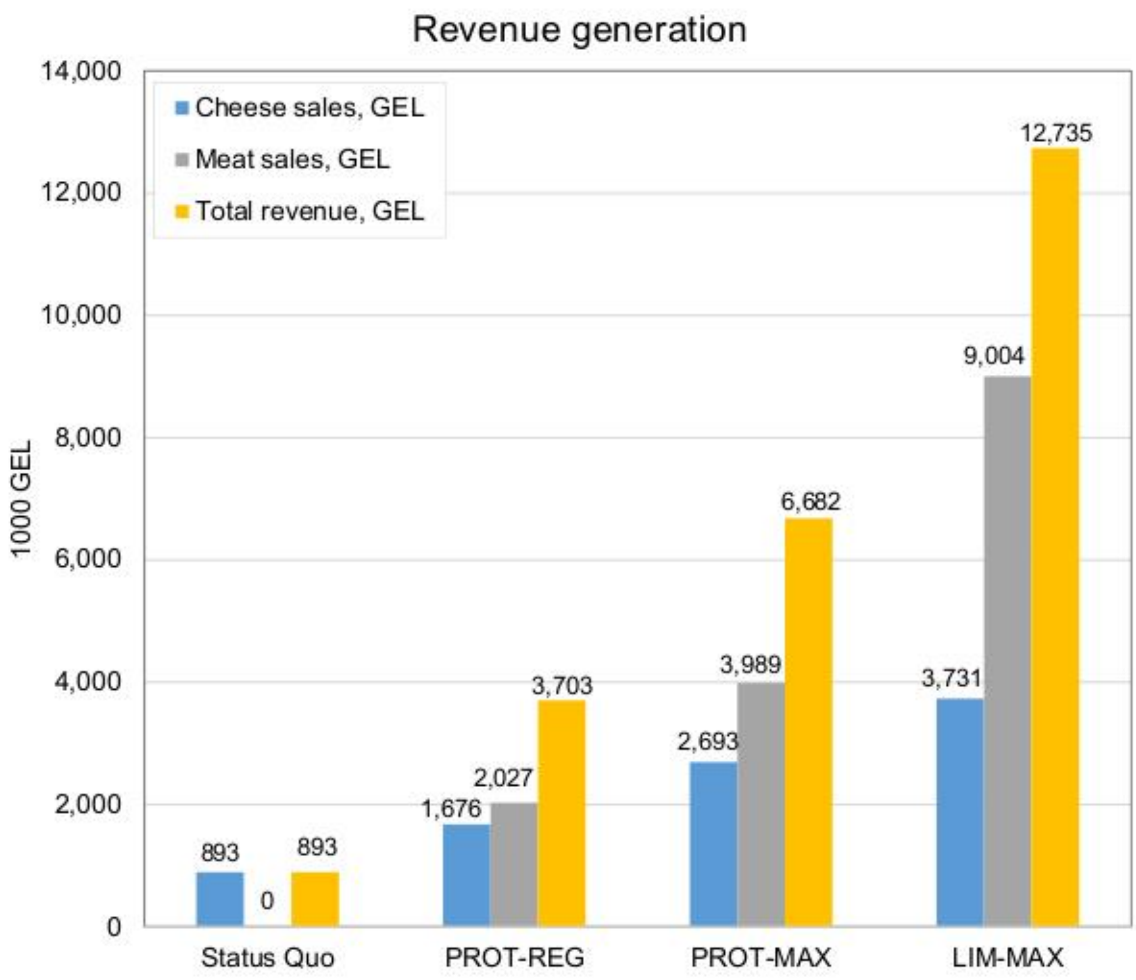

Figure 21: Regional revenue generation from export sales of milk and meat.

7.6 Discussion

7.6.1 Scenario outcome

The disciplinary and interdisciplinary investigations revealed detailed insights into the ecological, agronomic and socio-economic relationships within the study region.

Soil productivity is an ecological landscape function and plays a key role for agriculture; its conservation is particularly important for sustainable land use in mountain areas (Körner, 2000). In general, with increasing altitude the growing season shortens (Nagy and Grabherr, 2009). Besides the climate, the topography (slope steepness) is the most limiting factor for suitable agricultural production in the high-mountain Kazbegi region (Hanauer et al., 2017). Furthermore, grazing on slopes includes the risk of surface runoff with related soil loss, considering impropriate grazing practices (Leitinger et al., 2010). Productive soils, with SQR-scores ≥ 40, here mostly Cambisols and Cambic Umbrisols, are located in the study area on sediment fans and volcanic plateaus, for example around the villages of Ukhati, Kanobi as well as Pkhelshe and Goristsikhe (Hanauer et al., 2017).

Grassland productivity is closely linked to the soil types and the topographic factors as well (eastness, altitude). For the European Alps, the dependency of the vegetation structure on human impact and topography as well as edaphic and climatic factors are well described (Lüth et al., 2011; Marini et al., 2007). It is further described for the Kazbegi region that the grassland near settlements is used as meadow on former arable land, and only fertilized by the feces of grazing cattle and horses in early spring (Lichtenegger et al., 2006; Magiera et al., 2017, 2013; Seifriz, 1931). These are the most productive grassland sites in the study area (Lichtenegger et al., 2006; Magiera et al., 2017; Tephnadze et al., 2014).

A significant part of the natural production potential in the region is yet unused. Especially dairy cattle farming and cattle fattening seem to be well-adapted sectors as they are based on the widespread grassland resources of the region. Furthermore, we focused on livestock farming because the potential of an increase in production is high for this sector with regard to technical efficiency in the Kazbegi region (Shavgulidze et al., 2017). The scenarios´ outcomes show, that even without reaching the ecological limits, additional production could be achieved. However, meadows should be mown earlier than August to gain higher energy and protein contents in the fodder which would increase the milk yields per cow. While locals and the increasing number of tourists could consume some of the additional food, a large share of the additional products are possible exports. Such exports as well as the sale of own produce provide the opportunity to improve the income situation of the local people by marketing or exporting dairy products, meat or living animals by up to 12.8 mio GEL per year (Fig. 21) but less the production costs. The growing number of tourists is another favorable aspect. However, with regard to the concept of sustainability (compare e.g. World Commission on Environment and Development, 1987), the tourism in the region should be managed in a nature-compatible form (Newsome et al., 2012), for example with guidelines for activities related to sustainable tourism development.

To answer the study questions: the productivity in milk and meat production can be extended in all scenarios compared to the status quo. As we assume a linear relationship between input and output, with increased cattle number and farmland, the regional agricultural production and the calculated revenues will benefit. However, these benefits decrease with increasing ecological limitations and regional oriented cattle numbers.

Compared to the status quo, the landscape heterogeneity will increase in the PROT-REG and the PROT-MAX scenarios with increasing land-use diversity, i.e. with cultivated arable land, hay meadows, open pastures and expanding forests. Grazing in combination with other land-use practices can affect key cultural services, like the aesthetic value and can possibly enhance recreation and tourism functions of landscapes (Bernués et al., 2016; Cooper et al., 2009). Further, increased reforestation on steep slopes can have positive effects on regulating services, such as carbon storage, water quality and hazard protection (Schirpke et al., 2017). However, as Egarter Vigl et al. (2017) found that for the Alps, the functionality depends on regional ecological and socio-economic conditions. Moreover, the perceptions and valuations of such a spatial pattern can vary; in consequence, there are uncertainties in defining benefits of ecosystem services (Brunner et al., 2017). Additionally, the increased area of arable land and the expanding forest might affect the plant species richness and the vegetation composition of the open grassland (Magiera et al., 2016; Marini et al., 2008; Rudmann-Maurer et al., 2008). This is especially true for the LIM-MAX scenario, where meadow cultivation is excluded, transformed to either alfalfa cultivation or pasture. The agricultural production is most intensive in this scenario, with the highest outputs but the strongest impact on the high-mountain landscape, due to livestock carrying capacity and the extend of fodder crop cultivation. The strong focus on agricultural production here, even though within ecological limitations, might affect the biodiversity of the region, as mentioned above, as well as the landscape structure. The change to a more homogenous cultural landscape can have adverse impacts on soil and water quality and can lead to alterations in habitat mosaics and landscape character (Cooper et al., 2009).

7.6.2 Normative land-use scenarios – weakness and possibilities of the study approach

Our scenario approach is oriented towards measurable production output. Therefore, we mapped the land use and calculated the cattle numbers on the local level for each study settlement. We combined this local-level information to gain the region level, although not all settlements could be considered. Thus, the calculated scenario outputs are not reaching all actual agricultural activities in the region. Further, this region level is harmonized by compensations between the settlements. Some settlements produce a surplus in winter fodder others do not produce fodder at all, because of less productive soils there. It is questionable if a trade in resources would take place in the way assumed. Finally, as we focused on specific functions of landscape, namely the cattle production and touristic potential function, we ignored further activities, like for example honey and herb production, which on the one hand influence the farmers´ income and on the other hand are affected by visiting tourists, as they are potentially capable to stimulate agricultural diversification in favor of market-oriented agricultural products (Khardzeishvili, 2009).

Nevertheless, besides the export of agricultural products, establishing local linkages between agriculture and tourism, like marketing of local agri-food products to hotels and guesthouses in the region, might contribute to improving family income and thus potentially enhance the livelihood of the local population (Gugushvili et al., 2017; Hüller et al., 2017). The currently developing tourism sector might also provide an opportunity for the farmers regarding the commercialization of regional products, if food-processing infrastructure is available to meet food safety standards. This could lead to a positive synergy effect between the tourism and agricultural sector (Gugushvili et al., 2017; Hüller et al., 2017).

7.6.3 Goals of land-use concepts – sustainability in rural areas

Land-use options to improve the livelihood of the local population are at the center of this study. We developed normative scenarios based on a synthesis of the interdisciplinary results and based on the outcome of a transdisciplinary exchange with experts. With the consideration of ecological limits and societal objectives, like food security, livelihood, and cultural heritage, we focused on the economic potential of agriculture for a sustainable land use in the marginal Kazbegi region. To evaluate the sustainability of land-use options, a holistic and interdisciplinary evaluation is essential. Scenario development is an applicable tool for such an interdisciplinary evaluation of future land use (Lindborg et al., 2009; Soliva et al., 2008). In our scenario modelling, we want to picture a potential future land use that mostly relies on grassland management. Sustainable grassland management considers the carrying capacity of the landscape for domestic livestock. For this reason, we consider the biomass potentials of the pasture-grounds and the soil stability on slopes for the scenario development. We further try to face the increasing touristic activity in the region and include touristic demand in the scenario calculations. The scenario outcomes emphasize promising linkages between agriculture and tourism in the region and indicate tourism as an important issue for the farmers, similar to a situation in the Alps as Kohler et al. (2017) pointed out. Here, in the Stubai Valley of the Central Alps, however the economic perspective of agriculture is of low importance (Kohler et al., 2017). In contrast, our scenarios outcomes show possibilities to increase the profitability of livestock farming in the study area compared to the status quo. Our land-use concepts can promote inclusive and sustainable economic growth as well as sustainable production and consumption, as stated in the Sustainable Development Goals 8 and 12 (United Nations 2015). Further, to reach SDG 15 our approach showed possibilities of a prevention of land degradation and biodiversity loss.

7.7 Conclusion

Normative land-use scenarios help to determine profitable land-use concepts in marginal agricultural regions. These concepts provide guidelines for land users, landscape architects and development planners in terms of agricultural structure strategies. A concept development that integrates different disciplines from social and natural sciences is capable of highlighting interdependencies between society and the environment. Land-use concepts based on local research investigations are suitable and specified for the studied region. In our approach, we exclude external effects like dependencies on national or international market prizes or the effects of global warming on specific landscape functions. To reach land-use concepts based on such a broader perspective, further investigations are needed. In our viewpoint, however, the developed scenarios on regional level are constitute possibilities to capitalize on social and economic opportunities that may arise in the future within a framework of environment and landscape protection. Nevertheless, the study is focused more on the methodical approach than on implementation, i.e. contemplating integrated land use in a possible future, rather than on the realization of a scenario as precise as possible.

7.8 Acknowledgements

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8. Main results and discussion

8.1. Traditional Caucasian High-mountain Farming

In the 2010s, the Caucasian high-mountain landscapes of the study areas are characterized by traditionally shaped land use in agriculture, forestry, and agroforestry. Large unused areas on steep slopes with rocky outcrops, sparsely vegetation cover, or natural forest are further typical features and structural shapes in these montane and alpine belts of the Greater and Lesser Caucasus. As the maps demonstrate, both landscapes consist of a small-scale and diverse mosaic of land uses starting from single settlements. Horticultural land use with gardens, orchards and small parcels of arable land are located within and near the settlements. Grassland management with meadows, pastureland and forest dominate in farer distances. Nearly the whole grassland that is accessible, i.e. not fenced and not too steep is grazed by freely grazing livestock. This reflects the vital elements of subsistence agriculture, which is attributed to traditional Caucasian high-mountain farming. Subsistence farming is still important for rural households today and was essential after the demise of the USSR, especially in the years of 1993 and 1994 with a total collapse of law and order in Georgia (Kegel, 2003). Against the background of long-running adaptions to changing conditions within a post-socialist transition country and general problems in high-mountain agricultural production, large parts of the populations of Kazbegi and Bakuriani are facing severe existential challenges. Subsistence agriculture provides the basis for the household´s food security and for the sale and trade of products, especially fruits, vegetables, milk, yoghurt and cheese; the latter being the main marketable commodity (Kötschau et al., 2009; Shavgulidze et al., 2017). Still, the land ownership structures in the study regions are small-scaled and fragmented; the supply of machinery and technology is insufficient. Both, the fragmented structure and the low supply of production resources are leading to a low agricultural productivity (Oedl-Wieser et al., 2017). This agricultural system combines the maximum use of natural productivity with minimum input, creating a labor-intensive production without financial benefit (Haerdle and Bontjer, 2010a). For both regions, this low intensity agriculture is characterized by arable cultivation without plant protection products and mineral fertilizer, a pasture management below the carrying capacity (low stocking densities) and meadows manually cut once a year using scythes.

On the other hand, the low yielding cultivation (often followed by aftermath grazing) maintain soil fertility and organic content (Bignal and McCracken, 1996) of these arable fields. Moreover, low intensity grazing systems that remove only the annual growth increment positively affect biodiversity (Bontjer and Plachter, 2002; Cooper et al., 2009). And, the mountain meadows which are traditionally used with one, late-summer cut are characterized by a high species richness with an extraordinary biodiversity (Chemini and Rizzoli, 2003; Fischer and Wipf, 2002; Marini et al., 2008; Rudmann-Maurer et al., 2008). This described Caucasian agricultural system has a strong positive effect on the biodiversity at the levels of ecosystems and landscapes (Didebulidze and Plachter, 2002).

Concerning this biodiversity value, the Bakuriani study region in the Lesser Caucasus, which is lower situated and thus majorly in the forest belt, is a focal point because here the pastures and meadows are deeply embedded in the richly forested landscape, as wooded pastures and wooded meadows. These ecotones are floristically and faunistically rich biotopes with a long history, rarely found in Europe today (Buttler et al., 2014; Hartel et al., 2013).

With regard to rural development that support livelihoods and economies of mountain citizens, the challenge is to overcome subsistence farming without losing the positive effect on biodiversity of low intensity agriculture. Sustainable land-use concepts that consider site-based potentials, which vary strongly in topographical diverse mountain areas, try to tackle such a big task.

8.2. Landscape Pattern in Bakuriani – How Natural are the Forests?

In the Lesser Caucasus Bakuriani region, the situation is quite similar like it is in the Kazbegi region: the main settlements, here Bakuriani and Tsikhisjvari, are equipped with intact infrastructure, the population is mainly active in the local tourism sector, in combination with small-scaled agriculture. In the peripheral settlements, which are less populated, agriculture is the main income. Obviously, the landscape structure is shaped by abandoned agricultural land use, too, as the land-use map reveals. Along all altitudinal belts shrubs and woody vegetation were spreading. However, in some settlements, like in Tsikhisjvari, agriculture was a vital element within the settlement and in the surrounding landscape, with clearly separated types of land use and less fragmentation. Overall, the amount of wooded grassland is very high in this Lesser Caucasus region – a characteristic and remarkable feature of this mountainous cultural landscape.

Forests – and especially mountain forests – are important multifunctional ecosystems with productive, protective as well as cultural and amenity functions (Gratzer and Keeton, 2017; Schickhoff, 2014). As the study revealed, the forests in the Bakuriani region are closely related to the European map of the potential natural vegetation by Bohn et al. (2004). This means the forests are in a near-natural condition with a near-natural distribution pattern. Maps of natural vegetation are future extrapolations characterizing final (climax) stages of successive plant community developments on geographical and ecological defined locations (Wascher, 2005). The question about naturalness or vice versa the question about the degree of anthropogenic influence – hemeroby, a reciprocal factor to naturalness – is important for the evaluation of the endangerment of natural habitats and landscape areas (Pott, 1996). In the concept of hemeroby, where mostly floristic and vegetation indicators have been applied, the evaluation of the naturalness of the current vegetation leads to the value of hemeroby (Rühs, 2001). Grabherr et al. (1995), for example, proceeded in such an approach for the forest ecosystems of the Austrian Alps. Along a history of definitions and research on the hemeroby concept, Pott (1996) defined four levels of hemeroby: hemeroby level 1, natural and near-natural vegetation types; hemeroby level 2, semi-natural vegetation types; hemeroby level 3, not natural vegetation types; and hemeroby level 4, artificial vegetation types. For the Kazbegi region, Nakhutsrishvili and Abdaladze (2017a) classified the holy forests, which are unused and pristine, in level 1 of Pott´s hierarchy. In addition, Zazanashvili (2005) identified less than 12 percent of the whole Caucasian Ecoregion´s natural habitats in their original state. With the help of the level of naturalness of the current vegetation, conclusions can be drawn on the ecological state, ecosystem stability/ resilience and biotic regeneration (Schlüter, 2005). The resilience or the stability of an ecosystem can be seen as natural science explanations of ecosystem health based on the 'One Health' concept, noted in chapter 1. This is linked by the understanding of human activity, ecological change, disturbance, equilibrium, or the transfer between both latter. Health in this context can be seen as the availability of freshwater, food, pollination, etc. in an ecosystem (Lerner and Berg, 2015). The comparison of the current state of an ecosystem/ a habitat with the Vegetation Map of Europe allows to visualize alternative future landscapes and manage ecological processes (Rodwell, 2005) an approach that appears to be closely related to the concept of sustainability (Pott, 1996; Wascher, 2005). In the context of nature protection, the potential vegetation map offers the opportunity, especially for the Caucasus Ecoregion as a biodiversity hotspot, to plan and implement nature conservation, agri-environmental measures as well as the sufficiency of a protected area network (Zazanashvili, 2005).

Another important ecosystem, which is not taken into account in the sense of the potential natural vegetation but is of importance in the context of mountain biodiversity (and nature conservation), is the mountainous cultural grassland in the montane and subalpine belts below the tree line. The biodiversity in the montane and alpine belts of the Caucasus that evolved throughout traditional land use is extraordinary high and is of ecological, conservation and economic value (Millennium Ecosystem Assessment, 2005). The extensive, low-input land use, in this respect, is of value-giving significance: the abandonment of these habitats can lead to scrub encroachment with forest development, and an intensification can promote common species. In both cases, valuable plant and animal species that are dependent on low-input and traditional agriculture can be displaced. The connection between biodiversity and land use in a cultural landscape is also well known for the Alps, where especially a high number of different types of use are responsible for high biodiversity (Maurer et al., 2006; Stöcklin et al., 2007).

Finally, the mountainous landscape In the Bakuriani study area is characterized by near-natural forests, natural open grassland, cultural open grassland, and wooded grasslands. These habitat types are closely linked, as most of them evolved through extensive, often small-scale farming use, especially sheep and cattle grazing or once a year mowing. These habitat types are of Europe-wide importance, especially in the context of the EU´s habitat directive. To evaluate an endangerment of the mentioned habitat types and their biodiversity in the context of the Bakuriani study, the mountainous landscape in 2012 was mostly characterized by receding agricultural use, as described above. Moreover, the forests were subjected by irregular and uncontrolled forestry, driven by mostly individual and private interests. In accordance with the land-use map and the fieldtrip in 2012, the tourism sector, in Bakuriani especially the winter tourism, seemed to be a large factor in shaping and using the landscape besides agriculture.

8.3. Land-use and Land-cover Mapping to Classify Kazbegi´s High-mountain Landscape – Spatial Analysis in GIS

To map local land use and land cover in both study regions, to analyze correlations between patterns of LULC and land-use decisions or societal developments, a map-classification key was developed. This key was solely defined to identify and sample the Georgian-Caucasian land-use system. The focus is on agricultural land use, forest types and shrubbery. The classification should clearly and spatial-explicit characterize the land-use and land-cover patterns of both cultural and natural landscapes. Crucial for the development of the key was the quality of the aerial and satellite images. The key tries to meet the maximum detail in land-use and land-cover identification, and, at the same time, the minimum in generalization and inaccuracy in order to map clear distinctive classes (Eriksen et al., 2019). The problem of such an approach in the present synthesis was that most of the land-cover and land-use classes were not clearly delimitable either in the aerial images nor on the ground, as the field evaluations showed. Partly, a distinctive classification was proved difficult because of recent changes in land use or abandonment of use. Moreover, transition zones between two classes that were subjects of secondary succession, for example from pasture to forest, were difficult to identify exactly because of such transformation processes in vegetation composition.

Nevertheless, the advantage of a distinctive, accurate classification is a more or less clearly defined pattern of land use and land cover, which can be useful as a basis for reasoning and decision-making in landscape planning. Eriksen et al. (2019) support that assumption because they conclude that aggregated land-use and land-cover types reduce the rational conclusion on ecological processes running in landscapes and ecosystems.

8.4. Land-use and Land-cover Change in Kazbegi – Past and 2015 Landscape Patterns

Consistently using the same classification key offers the opportunity to compare different locations or time periods. In the case of Kazbegi, land use and landscape structure in 1987 and in 2015 were compared based on the digitized maps for both periods. The comparison showed that the investigated Kazbegi settlements and the corresponding agricultural land differ in their land-use development. It was concluded that the main reason for such different trends is the location of a single settlement. Settlements down in the valley are well connected, regional and supraregional, because they are located directly at main infrastructure. Others are located at the mountainside, and thus more peripheral and difficult to reach. The level of connectivity and mobility concerns structural aspects of a single settlement like economic activity, supply with goods and services and touristic potential. Initially unaffected from connectivity is the agricultural potential of a settlement because the related natural productivity is mainly determined by topographic and climatic conditions and soil fertility.

However, the results show that across all investigated settlements the productive and settlement-near sites were mostly affected by change in land use, like from meadow to arable land. These locations are well and intensive managed due to their fertility (caused by intensive cultivation with relatively regular nutrient input and output) and in moderately sloped positions. By contrast, locations far off and steep were mostly affected by abandonment of use, like pasture to forest or pasture to shrub. This pattern of change was true for most of the investigated settlements. However, even when the land-use development trend seems similar – hence independent from the level of connectivity and independent from the agricultural potential too – under a differentiated lens, there are slight but fundamental differences in the development trends. The study showed that peripheral settlements were more severely affected by abandonment, caused by a stronger population outmigration tendency, and thus by a loss of cultural grassland and an increase of forest and woody vegetation. However, for those lasting population the agricultural potential of the settlement bears the main activity or even the last opportunity. The well-connected and valley bottom settlements experienced stronger transformations of land use: besides meadow to arable land, garden land and urban area increased on former hay meadows, i.e. a tendency of low-level 'urbanization'. This tendency was also expressed by increased touristic activity in the region (GeoWel Research, 2015) and an economic change towards a stronger involvement in tourism services than in agriculture by the locals (Heiny et al., 2017; Hüller et al., 2017).

There have been different driving forces of land-use change in the Kazbegi region, although they are all affected by the political upheavals and economic transitions the republic experienced after the independence. First, the mentioned agricultural restructuring after 1989, from export-oriented production with large collective and state farms to subsequent smallholder production for self-supply (Kegel, 2003; Salukvadze, 1999). Second, the low state support for rural agriculture and mountain communities (Ministry of Agriculture, 2016). Third, from the 1990ies until the mid-2010, the population in the Kazbegi region, as in all rural Georgia, decreased constantly (National Statistics Office of Georgia, 2016a). This rural outmigration, especially by the youth (that simultaneously induce a rural population aging) was and still is an essential reason for backward rural development in Kazbegi that was caused by poor general infrastructure conditions, the absence of social comfort, weak economic diversification and unemployment (T. Kohler et al., 2017; Nakhutsrishvili et al., 2009).

A similar structural change was undergone in the Alps, too. Since the beginning of the 20th century, especially the central-located, well-connected urban centers in the valley bottoms experienced a strong urbanization, whereas peripheral, higher elevated regions with mostly sparsely populated communities were characterized by decreasing population (Baetzing et al., 1996). This urbanization and the differentiation between place of residence and place of work (commuter) resulted in the fact that 57 % of the population of the Alps lived in urban regions in 1990 (Veit, 2002). The Swiss Alps in the 1950s, to give a further example, were characterized by agricultural settlements, whereas in the 1980s many of these smallholders stopped farming (Stöcklin et al., 2007). Overall, in the context of such structural changes, types of traditional mountainous land use that are directly linked to environment, history and culture vanished or were replaced by modern types, which are often characterized by a single function (Baetzing et al., 1996; Veit, 2002).

Besides regional land-use concepts and against the background of rural development in the Kazbegi region, an appropriate policy response is needed that also reach and support the peripheral, mountainside settlements to create or restore quality of live that counteracts ongoing population outmigration. Nationwide policies are called to ensure resources and services for mountain communities. The enactment of the *Law on the Development of High Mountainous Regions* in 2015 (Ministry of Agriculture, 2016) is a step in the right direction. Another strategy with the focus on agriculture is financial support for applied implementation measures to landscape protection, like contractual nature conservation or in the context of the implementation of the EU Habitats and Species Directive as it is practiced in EU countries.

8.5 Agricultural Potentials in Kazbegi Based on Land-use Scenario Planning

Land-use scenarios can function as concepts for sustainable land-use development. Scenarios are 'an account of a plausible future', a possibility how the future might unfold (Peterson et al., 2003; Sarkki et al., 2017), and their development is a common tool in science since decades, with several approaches differentiated by the goal, the process, the design or the content, using different scales (Sarkki et al., 2017; van Notten et al., 2003).

The goal of the developed scenarios for the Kazegi region was to increase profitable agricultural land use for rural development and quality of life. This goal is based on the current agricultural situation in the region, which depends on livestock breeding and vegetable cultivation by smallholders for self-supply. At the same time, the scenarios aim to consider the protection and conservation of the high-mountain cultural landscape and mountain ecosystems focusing on the prevention of negative effects by increased land use on valuable and vulnerable mountain ecosystems and important ecological landscape functions, like soil productivity and species richness. To unite both goals, the three normative scenarios are facing selected SDG's (8, 12 and 15) formulated by the United Nations (2015).

In contrast to participatory approaches, which can include citizen ideas and values, the scenario process designs are normative and place-based (Nassauer and Corry, 2004; Santelmann et al., 2004; Waldhardt et al., 2010). Normative rules, in forms of thresholds, measures and specific agricultural practices, define future land-use scenarios that are based on locational potentials. For each scenario, a set of assumptions and thresholds define a spatially explicit pattern of arable land, pasture, and meadow. The designs of the three scenarios are the same but they vary in the assumptions and thresholds, thus in the consequential patterns. The designs are solely based on expert knowledge by the participating scientists and are thus not a local people participatory or transdisciplinary scenario design (like, for example, by Hanspach et al., 2014; M. Kohler et al., 2017; Oteros-Rozas et al., 2015).

Empirical and interdisciplinary research investigations in the study area, both quantitative and qualitative, form the scenario contents. The single disciplines of landscape ecology, soil science, vegetation ecology as well as social and agronomic science participate in the development. However, in an interdisciplinary context, the scenarios aim to fully exploit the potential of optimized livestock production in Kazbegi´s high-mountain farming system and thus focus on dairy cow keeping and cattle fattening. Main obstacles that still limit further agricultural developments are localized in the high level of inefficiency and the lack of modern technologies on farm level (Shavgulidze et al., 2017). As the disciplinary investigations found out, there is a great potential to further optimize the livestock production to support regional economic activities and increase household´s incomes. Besides the production potential, the scenarios focus on the increased tourism activity in the region (GeoWel Research, 2015). Linkages between agricultural food production and rural tourism offer the opportunity for smallholders to market local agri-food products (Hüller et al., 2017). With regard to product marketing, the aim of the scenarios is to tap the potential of rural diversification (European Commission, 2006), because diversified economies are seen as a practicable possibility and can further maintain a decentralized settlement patterns (Mountain Agenda and Center for Development and Environment, 2002), which can help to counteract outmigration.

The Kazbegi scenario development is a strict regional approach. Further political and economic conditions and decision-making that indeed would influence the scenarios were deliberately excluded. Nevertheless, decisions of local farmers are compulsively influenced by subsidies or incentives to support rural development and agricultural productivity as well as by national and foreign investments. However, to include such critical factors further research by corresponding disciplines is necessary. This regional approach promotes rural initiatives to capitalize on regional social and economic opportunities that may arise in the future, within a framework of environment and landscape protection. However, transferability of the scenarios to other regions may be limited because in other regions landscape patterns, land-use practices as well as landscape potentials may differ from the study regions (Lindborg et al., 2009).

8.6. The Effect of Tourism and Global Change on the Study Landscapes

This closing chapter will give a brief outline about the local tourism in both study regions – a topic that was shortly mentioned above but is of increasing significance for the economic situation in both regions. On the one hand, tourism had a profound positive impact on the regional income. On the other hand, tourism may negatively affect the regional environment, with impacts on, for example, the agricultural used land and the landscape structure (see chapter 3.3). Compared with Kazbegi, the tourism sector is more important in Bakuriani and the population is more engaged in tourism services (Heiny, 2017). The touristic infrastructure is further expanded.

The tourism sector of the Kazbegi and Bakuriani regions serves as an important additional source of income as the number of visitors increase (GeoWel Research, 2015; MRDI, 2013). Globally, tourism is one of the leading industries and therefore a major factor of globalization for mountain areas that is attributive of a high percentage of regional incomes (Sonesson and Messerli, 2002). The tourism sector, which largely comprises the local population offering guesthouses and tourism services, benefits from the unique landscape characteristic maintained by local farmers. However, the risk of increased tourism with adverse effects on the local environment are on the rise. Tourism generate jobs, livelihoods, and tax revenues, but threatens the biological and cultural diversity of regions, particularly from the construction of new facilities as well as increased traffic and communication networks (European Environment Agency, 2002; Price et al., 2004). Therefore, tourism in both regions should be managed in a sustainable way, incorporating an awareness of the environmental impacts associated with infrastructural expansion and other activities corresponding to tourism. This can be implemented, for example, with guidelines for activities encouraging sustainable tourism development, especially since winter and summer tourism are co-responsible for severe human impacts on the environment that caused widespread soil erosion in Kazbegi (Nakhutsrishvili and Abdaladze, 2017a). In comparison, in the northern Alps, tourism and leisure activities become a major threat factor on alpine habitat types beside climate change, as the German Red list of Threatened Habitat Types highlighted (Heinze et al., 2019).

Georgian politicians often struggled with political democratization and economic liberalization, have become aware of the tasks of rural development and the protection of natural resources. Lately, several strategies and action plans facing these tasks are formulated by the republic´s government (e.g. the Social-economic Development Strategy of Georgia - "Georgia 2020", 2016), and by single ministries (Rural Development Strategy of Georgia 2017-2020, Ministry of Agriculture, 2016). In order to tackle the special challenges of highland development, the Law on the Development of High Mountainous Regions, as mentioned above, have been adopted in 2015 (Ministry of Agriculture, 2016). These political actions can also be seen as the consequence of the legal implementations of international conventions and agreements Georgia joined, like, for example, the Convention for the Protection of the World Cultural and Natural Heritage, 1972, the Convention on Biological Diversity, 1992, and the Association Agreement between Georgia and the EU, 2014 ("Georgia 2020", 2016; Krever et al., 2001).

8.7 Conclusions

The main question of this synthesis was how both land use and topography of the Caucasian high-mountains influence the landscape structure, i.e. the patterns of land-use and land-cover types, in this outstanding biogeographical region, with mountain range-specific habitat types and their associated typical and endemic flora and fauna species. Based on the results of the first and second studies landscape analyses, it can be concluded that first, topography and land use strongly influence the structural diversity, especially a small-scaled interconnectedness of open land- and forest biotope and habitat types mainly developed by focused land-use distributions of pastures, hay meadows, arable land and woodlands. The pronounced topography, which determines the locational micro and macro climate with temperature and precipitation patterns, is a main factor for vegetation distribution in the landscape, i.e. the pattern of land cover types structuring the land. Land use, in both study regions mainly agriculture and forestry, obviously affects the structure as well, as the land users are responsible for the patterns of open land and forest ecosystems through the cultivation of land. In both regions land use clearly structured the landscape starting from single settlements: settlement near locations were most used/ cultivated and most anthropogenically modified. With further distance and increasing altitude the landscape was less influenced by human activity, and thus less transformed and near natural. However, and secondly, it is evident that land use is not independent from topography. Especially in the high mountains with changing locational conditions within a small distance, agricultural favorite and unfavorable locations are usually dependent on topography, as a location for cultivation can be characterized by sunshine hours, steepness and altitude-related precipitation and temperature. Especially the strong altitudinal gradient determines land-use possibilities.

This synthesis could reveal the impact and the importance of agriculture and forestry on the Caucasian landscapes with several high mountain ecosystems, the basis of an extraordinary biological diversity. Cultivating the high-mountains, that means an ongoing agricultural use of the landscape, is important for the conservation of the Caucasian natural heritage: for the local communities as a source of income and livelihood on the one hand, and for biodiversity preservation on the other. In terms of biodiversity the species-rich hay meadows that are unfertilized and traditionally used once a year are invaluable habitats for several rare and endemic species. However, as valuable the high mountain landscapes are, the more vulnerable they are to land-use change. Both, land-use intensification with fertilization to increase the productivity and land-use abandonment with spreading shrubs and woodlands are the reasons for vanishing habitats and decreasing species richness. This means, land use should be adapted to the local ecological conditions to avoid adverse developments in the landscape´s energy and material fluxes, with critical consequences, like one-sided species composition development, destroyed vegetation cover, soil loss or landslides. These considerations were tackled in the third study, with normative rules of land use and restrictions to push landscape conservation and to achieve significant UN´s sustainable development goals for the Kazbegi study region. In order to develop sustainable agricultural options, the focus was set on the human-environmental interface, i.e. ecological and socio-economic research was combined.

This practical and place-based approach of scenario development was a concept to achieve economic needs in agriculture plus the integration of landscape and biodiversity conservation. Besides such locational approaches, there is a need for nation-wide support of nature conservation. On the one hand, this can be reached by designations of protected areas, to strictly avoid any adverse human impact on valuable and delimited natural resources (land sparing principle). However, in terms of cultural landscapes in central- and western Europe, this principle includes costs for measures that preserve a valuable biodiversity that is related on-going land-use practices. Here, and on the other hand, the land sharing principle that combines an agricultural or forestry use with nature conservation seems to be more appropriate. In this case, the land user/ owner is compensated, and financial incentives are created for a cultivation in a non-profit-maximize way, with less resources use but for nature conservation. However, for now the situation is quite different in Georgia´s Caucasus regions because the agricultural and forestry infrastructure is less developed. This means the non-intensive mountain subsistence farming by small holders is a result of limited capabilities and with low state support. Thus, the high biodiversity is mainly a result of limited or restricted development opportunities in agriculture and forestry. The above described system of nature conservation is widespread in central- and western Europe and measures are strongly financial subsidized by the EU. In Georgia the first important step is to help and support mountain communities to overcome subsistence farming, to allow an acceptable quality of life with individual economic development. In this situation concepts are needed that guarantee a sustainable development that preserve Georgia´s natural heritage. The UN´s sustainable development goals can function as a guideline for this goal.

As mentioned above, several nation-wide policies, like strategies and action plans have lately been formulated by Georgian politics to achieve SDGs. Mountain communities and their societal development are often out of the political focus and thus of secondary interest, which often resulted in disadvantage economic and livelihood conditions in the past. However, the mountain population is the focal point for the mountain cultural landscape, for a regional identity and the cultural diversity of a country. Further research is needed to explore different ways of how to support their livelihood, how to engage their interests and needs in countrywide decisions and allowing positive societal developments in remote regions. For such tasks, international co-operations can be beneficial and should be a focal point. In order to get aware of concepts and approaches that combine sustainable development in mountain communities with nature conservation, a knowledge transfer with neighbor states, further countries with alpine regions are very valuable. External knowledge and experience in smart infrastructural expansion, economic opportunities, location adapted mountain farming; overall, in ways of fostering sustainable mountain development can be beneficial for Caucasian remote regions. This cross-border co-operation should not be carried out exclusively by politics, as also the private business sector and science communities can benefit throughout international joint ventures.

Especially the Kazbegi and the Bakuriani region are focus regions for scientific investigations, both with a long history in (international) research activities. Within the framework of this landscape ecology synthesis and in order to evaluate further research in both regions, it seems to be appropriate to focus on geo-botanic investigations, for example to study and evaluate species and habitat types distributions and conditions, also in the framework of climate change, which got a more pronounced impact on mountain ecosystems than on others. For this thesis, many LULC maps were created. This data pool can function as a sound base for further research, for instance in population ecology and ecosystem research. As mountain areas are valuable by both their natural design and cultural uniqueness, further research should also focus on the mountain cultural landscape, to uncover hidden or complex interrelationships.

9. Summary

In two Georgian high-mountain landscapes, Kazbegi in the Greater and Bakuriani in the Lesser Caucasus, the land use and the structural diversity of the cultural landscape have been investigated in three studies. Along steep altitudinal gradients a variety of mountain biotopes and habitats of open lands and forests are located in these landscapes. Land use and landscape structure is substantially influenced by local small-scaled subsistence farming with low number of cattle and small parcels of cultivated land for vegetable cultivation and haymaking. In both regions, agriculture is practiced on low-yielding marginal locations due to climate conditions in the high mountains. The large number of heated glasshouses for vegetable cultivation in the Kazbgei region is an example to tackle the difficult high-mountain farming conditions in an energy-intensive way. Both study regions are also subject to consequences of the countrywide political and economic restructuring since Georgian independence in 1991. On the one hand, urban regions are suffering by outmigration of the population, especially by the youth, with adverse consequences for the agriculturally used land and therefore for the landscape structure and biodiversity. On the other hand, since the 2010ies the tourism begins to flourish in both regions, with increasing employment possibilities for the population in the tourism sector.

In the field of tension between the two opposing developments, the synthesis´ investigations focus on three different focal points. However, the land-use pattern and the structural diversity of high-mountain cultural landscapes are always the heart and the linkage of research and evaluation. First, for the Bakuriani region in the Lesser Caucasus the land-use pattern and forest structure have been investigated. In this Lesser Caucasus study area forest is the dominating land cover. Considering this, the naturalness of the diverse mountain forest types were analyzed along altitudinal belts. These forests were characterized by a high degree of naturalness and a traditional silvo-cultural land-use system of forest pastures and forest meadows. Second, for the Kazbegi region in the Greater Caucasus the land-use change from 1987 to 2015 have been analyzed and quantified in consideration of societal and structural development. In this study, changes in land use and land cover have been quantified spatially explicit in relation to the distinctive high mountain topography at settlement level. Third, interdisciplinary and sustainable land-use concepts have been developed for the Kazbegi region to promote the profitability of agricultural production while respecting the ecology of the mountain landscape. With ecological and socio-economic parameters and indicators three normative land-use scenarios have been developed to meet sustainable development goals of the UN. These scenarios can help optimizing farm management and the use of inputs in the local agriculture.

According to the described studies and in comparison to various scientific concepts like the multifunctionality of landscapes, ecosystem services, the concept of hemeroby, and ‘One Health’, the landscape structure and the pattern of land use in both regions were studied and evaluated. Landscape structure today is still characterized by traditional agricultural land use adapted to high-mountain conditions. However, in both study regions the retreat of agriculture is evident, indicated by increasing shrubification and reforestation. Non-intensive high-mountain farming that is adapted to the diverse topography with a small-scaled pattern of various climatic conditions shall be decisive, i.e. beneficial and preserving, for an exceptional high mountain biodiversity. The agricultural cultivation of the mountain landscape is a formative factor for biodiversity and species protection in both regions. Additionally, it also shapes the landscape in the sense that it is currently gaining in national and international tourist appeal. The importance of the two core issues mentioned above, high mountain biodiversity and tourism, has been recognised by politicians in the recent past and various protection measures and support actions have been formulated and established.

10. Zusammenfassung

Im Zuge dreier Studien sind die Hochgebirgslandschaftsstrukturen im Großen und Kleinen Kaukasus Georgiens untersucht worden. Maßgebenden Einfluss auf die Landschaftsstruktur, mit einer Vielzahl an verschiedenen Offenland- und Wald-Biotopen und Lebensräumen entlang eines steilen Höhengradienten, übt die kleinstrukturierte, in Familienbetrieben organisierte Landwirtschaft aus, die mit geringen Viehstückzahlen und Anbauflächen pro Betrieb überwiegend für den Eigenbedarf ausgeübt wird. In beiden Hochgebirgsregionen findet Landwirtschaft auf Grund der Höhenlage und der damit verbundenen klimatischen Bedingungen auf ertragsarmen Grenzstandorten statt. Die große Zahl an Gewächshäusern in der Untersuchungsregion des Großen Kaukasus sind ein Beispiel für Maßnahmen, um diesen schwierigen Anbaubedingungen im Hochgebirge zu begegnen. Beide Untersuchungsregionen (Kazbegi im Großen Kaukasus und Bakuriani im Kleinen Kaukasus) unterliegen zudem den Folgen der landesweiten politischen und wirtschaftlichen Umstrukturierung seit der georgischen Unabhängigkeit von 1991. Einerseits leiden die abgeschiedenen Bergregionen unter den Abwanderungen vor allem der jungen Bevölkerung und damit Verbunden einem Rückzug der landwirtschaftlichen Nutzung, mit Folgen für die Landschaftsstruktur und die Biodiversität. Andererseits, und diesem Trend entgegenstehend, begann zum Ende der 2010er Jahre der Tourismus in beiden Bergregionen zu florieren, mit steigenden Möglichkeiten für die lokale Bevölkerung in der Tourismusbranche Beschäftigungen zu finden.

Im Spannungsfeld beider gegenläufigen Entwicklungen zielen die Studien dieser vorliegenden Dissertation auf drei unterschiedliche Schwerpunkte, in denen aber jeweils die Struktur der Hochgebirgslandschaft den Kern der Forschung und der Bewertung ausmacht. Erstens ist für die Bakuriani Region die Landnutzung und die Waldtypenverteilung erfasst und untersucht worden. In der Untersuchungsregion des Kleinen Kaukasus, die wesentlich von Wald geprägt ist, sind die Waldtypen und deren Struktur bezüglich ihrer Natürlichkeit, bzw. Hemerobie erforscht worden. Der Bakuriani-Wald ist geprägt von einer hohen Natürlichkeit sowie von einer traditionellen und über mehrere Höhenstufen hinweg verbreiteten Wald-Wiesen- bzw. Wald-Weiden-Nutzung. Zweitens ist für die Kazbegi Region der Landnutzungswandel von 1987 bis 2015 unter Berücksichtigung von Gesellschaftsveränderungen quantifiziert und analysiert worden. In dieser Studie sind flächenscharfe Veränderungen der Landschaftsnutzung und -struktur in Bezug zur ausgeprägten Hochgebirgstopografie auf Siedlungsebene erforscht worden. Drittens sind für die Kazbegi Region interdisziplinäre und nachhaltige Landnutzungskonzepte erarbeitet worden, die zum Ziel haben die Rentabilität in der landwirtschaftlichen Produktion unter Berücksichtigung der Ökologie der Gebirgslandschaft zu fördern. Hierbei sind drei normative Landnutzungsszenarien anhand ökologischen und sozio-ökonomischen Parametern und Indikatoren erstellt worden, die ausgewählte nachhaltige Entwicklungsziele der Vereinten Nationen erfüllen. Die entwickelten Landnutzungskonzepte können als Grundlage dienen, das Betriebsmanagement und den Betriebsmitteleinsatz in der örtlichen Landwirtschaft zu optimieren.

Im Zuge der beschriebenen Studien und im Vergleich mit verschiedenen wissenschaftlichen Konzepten, wie der Multifunktionalität der Landschaft, den Ökosystemleistungen, dem Hemerobiekonzept oder dem One-Health-Ansatz, ist die Landschaftsstruktur und die Landschaftsnutzung beider Regionen untersucht und bewertet worden. Die Landschaftsstruktur ist teilweise auch heute noch geprägt von einer traditionellen, dem Hochgebirge angepassten Nutzung. Beide Regionen sind aber auch gekennzeichnet durch Nutzungsaufgabe, mit sich ausbreitender Verbuschung und Wiederbewaldung. Eine extensive Nutzung, die angepasst ist an eine ausgeprägte Topografie, mit vielfältigen und kleinräumlich wechselnden klimatischen Bedingungen, ist maßgebend, d.h. förderlich und erhaltend, für eine außergewöhnliche Hochgebirgs-Biodiversität. Die landwirtschaftliche Kultivierung der Berglandschaft ist prägender Faktor für die Biodiversität bzw. den Artenschutz in beiden Regionen. Ferner prägt sie die Landschaft in dem Sinne, in dem sie gerade an nationaler und internationaler touristischer Attraktivität gewinnt.

Die Wichtigkeit beider genannten Kernpunkte, Hochgebirgs-Biodiversität und Tourismus, sind gerade in junger Vergangenheit von der Politik erkannt und verschiedene Schutz- und Fördermaßnahmen formuliert und festgeschrieben worden.

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13. Appendix