Chapter 6
Conclusion and Outlook

Abstract A wide range of ecosystem services is strongly influenced by climate variability over decadal and longer time scales. In this context, our studies focused on an interdisciplinary multi-proxy, multi-archive approach to investigate modern and palaeo-climate and environmental variations during the Holocene on societal-relevant time scales (seasonal to decadal, to modern times with increasingly solution) in the Balkan high mountains. A regional–local research gap was closed. In this summary chapter, the regional landscape history is resumed. Using a suite of palaeo-proxy reconstructions and information from previous studies examining the relationship between climate variability and natural processes, we want to explore how climate anomalies affect the delivery of vital goods and services provided by Pirin National Park and surrounding areas. We discuss the recent trend of regional climate change and possible impacts, assess the applied results and point out further research needs.

Keywords Balkan mountains • Ecosystem services • Landscape history • Multi-proxy approach

Southeastern Europe is a natural mosaic of small mountain ranges, basins and valleys, divided into many nations. Because of this strong segmentation, most regions are in a physical-geographic and political border situation. Thus, there are many transition areas. Particularly, such areas are climatically (moderate-Mediterranean/lowland-highland), hydrologically (water-rich versus dry regions) and socially reflected (orient-occident). In this regard, the Pirin Mountain region is a representative, typical area for southeastern Europe.

High mountains are characterized by high precipitation and permanent low average temperatures. In contrast, the southern and peripheral lowlands and low mountain ranges often experience dryness and heat, as in northern Greece, for example. Climate prognoses for mountain regions are very uncertain. This is due to the spatial and processual variability and heterogeneity. The reliability of meteorological data is also limited because of the region's few operating stations. A systematic, highly technical environmental and climate observation in this region is still under construction.

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The basic knowledge of ecosystem and landscape structures, as well as processes of the northern Pirin Mountains and southwestern Bulgarian region (Mesta watershed), was substantially expanded with the help of modern examination techniques. A range of data was collected, performed, analyzed and assessed. For example, there is a soil map (Section 2.4) and water monitoring (Grunewald et al. 2007). Basic approaches of environmental monitoring system were established in this region that focus on local-climate parameters, glacierets, vegetation of treeline ecotones, soils and waters. Such nature observation is important to sustainable landscape development and planning.

With an innovative archive and method network consisting of dendroecology work in treeline ecotones, physical and chemical investigation of firn and ice layers of a glacieret and its surrounding, and the analyses of climate data, a set of interpretation and coupling approaches were applied and advanced. We were mainly motivated by the fact that despite the high number of high mountain areas in southeastern Europe, the scientific examination of the complex timberline is still limited. Only little is known about their altitude, tree ecology and ecosystem factors (Beug 1975; Willis 1994; Brandes 2007). We realized the glaciological, pedological and dendrological examinations predominantly with regard to climate, particularly in historical time spans.

Important is the coupling of archives and indicators and their inter- and intra-annual variability and sensitivity (see for instance HOLIVAR – Holocene Research 2003, Bigler 2003). Data analysis mainly focuses on recently introduced approaches based on the study of the recurrence structure and multiscaling analysis (Maraun and Kurths 2004, 2005). Dynamic properties and transitions in the features of the palaeo-climate should be studied and compared by applying recurrence quantification analysis to lithological data (from cores, pollen data, isotope records from peat; Marwan et al. 2002).

Since the research design applied to the southwestern Bulgarian Pirin Mountains was very successful and gained acceptance, it will be extended to investigate larger areas of the Balkans, based on the distribution of *Pinus heldreichii*. The objective is the examination of regional differences in environmental conditions and climate characteristics in the Balkan high mountains. The timberline ecotones will also be researched since they play an important regional and local role for climate and landscape changes and consequences. Genetic investigations of *Pinus heldreichii* will be the subject of new studies.

During the past decades, much of the research on postglacial vegetation in the Balkans has focused on solving problems related to patterns of dynamics, vegetation changes, location of tree refuges, migration processes and human impact. Such studies are challenging to palynologists and palaeo-ecologists, as they raise issues important to the understanding of postglacial vegetation history on a European scale. The vegetational history of the Balkans from the end of the last glaciation to the present shows many features reflecting complex processes such as tree immigration from refuges, climatic changes, soil development, forest dynamics, and human impact.

The climate variability for the last ~15,000 years can be described with the help of cirque-lake-sediments, peat bog profiles and fossil soil developments/charcoal (Section 3.2). The Pirin Mountains region is well researched in this regard (e.g. Bozilova and Tonkov 2000; Tonkov et al. 2002; Stefanova and Ammann 2003;

Stefanova et al. 2006). It is certain that all smaller southern glaciers melted at the climate optimum of the Atlantic Period. The reconstruction of the alpine timberline implies that the snowline during the Holocene did not change significantly (Grunewald and Scheithauer 2008a). The results confirm a relative climatic stability during the past 10,000 years, however clear changes in the tree population of the timberline were observed as a result of climate modifications and vegetation-historical developments.

The early- and mid-Holocene periods were warmer and wetter so that mesophile deciduous trees spread out to higher altitudes. Since 6,500 BP – due to a change in climate conditions (probably the seasonality) – the endemic pines *Pinus heldreichii* and *Pinus peuce* dominated the alpine treeline of the region. They can best bear summer dryness and warmth and winter coldness and snow, as well as the typical short-term and long-term, cyclic precipitation variabilities.

Investigation of fossil soils and carbon-dating of charcoal indicate climate fluctuations in the late Holocene period. Intensive mass and soil movements took place due to climate-morphological conditions and incipient utilization. Deforestation, slash-and-burn land clearance and overgrazing at the timberline have been recorded since the Neolithic. This, together with climate change, has shifted the alpine timberline downward by ca. 200 m, such as in many European high mountains (cf. Nagy 2006). The timberline ecotone has changed and enlarged in the past. The area between treeline and forest is often thinned, such as in a park. Increasingly, secondary shrub-grass communities substitute for natural vegetation, as in many other mountains.

Climatic improvements and social impulses in Europe were mainly observed for the Atlantic, Sub-Atlantic and Younger Modern History. This can also be shown for southeastern Europe and the Pirin. Optimal conditions for vegetation and soil development, which nowadays lie significantly above the timberline, existed during the Sub-Atlantic and the Early Middle Ages. There is an obvious synchronicity with times of flourishing social development (during the first and second Bulgarian state). So called “climatic pessima” occured during the Subboreal and the “Little Ice Age”. During that time, cultural-historical development in Bulgaria was at a standstill (cf. Section 3.3).

Elevation and physiognomy of the recent timberline are particularly determined by latitude, exposition and topography. The timberline is at ca. 2,100 m a.s.l. on steep and wet northern/northwestern slopes and at about 1,900 m a.s.l. on flatter and drier south-exposed sites in the Pirin Mountains. The soil conditions of the local timberline areas are now relatively well studied. With increasing altitude, the soil depth decreases and the edaphic aridity increases incrementally particularly at marble sites. This limits tree growing.

The tree species at the timberline illustrate the regional transition climate between moderate and Mediterranean mountainous conditions, which is first of all reflected in the summer dryness and the variability of annual precipitation. The consequences are seasonal climate stress situations and contrast-rich, climate-ecological conditions. Thus, the alpine treeline of the Pirin Mountains might be rather dry-limited than temperature-limited, at least on south-exposed carbonate slopes. Toward the south (Greece) this phenomenon increasingly determines the trees’ species at the timberline, as well as their structure, altitude and dynamics (cf. Brandes 2007).

Tree growing at the upper forest line does not solely depend on average temperatures. Temperatures are important indicators but not causal factors. Hence, tree-rings do not appropriately display the temperature rise from the last decades. This phenomenon is called a “divergence problem” of dendrochronology (e.g. D’Arrigo et al. 2008). The key to any form of timberline dynamics is not an increased tree growth but its reproduction (Holtmeier 2003).

Therefore, future investigations will focus on the genetics of *Pinus heldreichii’s* survival capability. We intend to examine the real genetic constitution of existing trees and their present progeny. One aim is to deduce protection strategies for this red book species in order to save the genetic variability and to ensure the existence of the species in their natural habitat. Aspects of regeneration dynamics are especially important due to climate change effects and the genetic constitution of the distributed trees dependent of their age.

The association of dendrochronology and forest-genetic studies can show the relationships of recent individual trees, to identify regeneration periods of the past and to test genetic parameters of survived individuals according to age classes and population. The exact dating of the tree population and dendrological climate reconstruction should indicate whether special regeneration periods occurred that promoted natural regeneration and the establishment of the examined old trees, and whether these time spans were characterized by specific climate conditions. We aim to investigate whether, in comparison to the contemporary climate, the possibilities of natural regeneration of the species improved or deteriorated and how they might be modified under recent climate changes.

Relevant to the survival capability of the Pirin population of *Pinus heldreichii*, compared to other population in the Balkans, is to what extent the in-breeding depression affects the progeny. Comparative genetic analyses should show whether the present abundant young generation differ from its (pre-) parents and whether there is a trend of reduction of the genetic variability of single trees. The clarification of the genetic-relational relations of the existing tree generations is therefore necessary.

The regeneration of pine species in the Pirin Mountains primarily takes place in generative form (Velchev 1997). Seedlings and young plants are very sensitive toward ecological factors and require balanced hydrothermal conditions at the soil surface (Holtmeier 2000). These conditions do not exist in dry years that are partly exacerbated by high insolation with soil temperatures above 50°C, nor in wet and cold cycles. As opposed to the mountains of the Central Balkans (Carpates, Stara Planina) the timberline dynamics of the Pirin Mountains depend more on favorable climate phases without longer drought periods and can even be absent for decades.

The last decades of the twentieth century were especially characterized by low precipitation in Bulgaria (Sharov et al. 2000). Dry conditions during the summer months are also predicted for the twenty-first century (Alexandrov 1999). The timberline formed by *Pinus heldreichii* is likely to be affected relatively late. The treeline potentially advanced when the wintry snow amounts remained about the same, and at the same time frost frequency decreased and winter temperatures rose. Thus, this tree species could be a winner of climate change. The challenge is now to evaluate this thesis for the Balkans.

Meshinev et al. (2000) observed a current upward shifting of the timberline for the Central Balkan Mountains. This is locally, however, the consequence of reduction in use and sparsely documented by climate change. The nomadic pastoralism, primarily operated by the Aromanians, was of regional importance in the broader Pirin area. Since about the fourth–sixth century, this demographic group used with its sheep and goats the alpine pastures in summer and moved the herds to the snow-free pasture grounds in the plains and coastal regions in winter (Kahl 1999). Hence, the climate characteristic of this transition region between moderate and Mediterranean has not significantly changed since early mediaeval times. Settling and pasturing in higher mountain areas was barely possible during winter time. But, mild winters without snow were typical for the southern basins and coastal plains. During summer, the pastures in the lower, hot and southern regions dried up whereas the wetter and cooler mountain pastures were now in use. The Bulgarians also moved their livestock to the mountains but used and irrigated the gardens and pastures more at the periphery of the basins and valleys. The inner-Macedonian and Bulgarian–Greek demarcation in 1912 as a consequence of the Balkan wars stopped the traditional transhumance of the Aromanians (Kahl 2001). Today only few cattle graze on the alpine Pirin pastures. Changes of the timberline areas are caused by tourism, especially by winter sport (Grunewald and Scheithauer 2008b).

The transitional character of the regional climate between the temperate and Mediterranean zone is reflected in its intra-annual distribution of temperature and precipitation. Dry and warm summers are in contrast with cool and wet winters. Short-term as well as long-term amplitudes depend on the position of circulation (Furlan 1977; Maheras and Kolyva-Mahera 1990; Bolle 2003). Depending on the geographical position and the topography, sharp climatic changes are typical for short distances.

High mountains react very sensitively to climate changes. The retreat and loss of glaciers is widely considered as an important signal of recent warming. Climate change can also be observed in the southwestern Bulgarian Pirin Mountains but it is not as severe and the consequences are partly not as visible yet (Section 5.3).

Direct technical climate measurements still constitute an exception in the Balkan mountain regions. There is a data deficit, especially for altitudes above 1,000 m a.s.l. (Böhm 2004; Brandes 2007). Local meteorological case studies with modern equipment at the timberlines are also lacking. These factors restrict scientifically climatological and hydrological statements. Hence, there is also a lack of applied information about evaporation values, flood dangers, weather forecasts for tourists and so on. We helped to improve the situation by establishing an automatic weather station, a gauging station, and data logger at the timberline in the northern Pirin Mountains.

Existing historical climate records gathered in the area have been researched, checked and statistically examined. The mountainous climate has been characterized and trends in the evolution of temperature and precipitation since 1931 have been outlined. Climate and weather were subject to significant changes in the last decades, possibly in response to global influences (Sections 4.1 and 5.3). A seasonal temperature increase, longer vegetative periods, and shorter, warmer winters with less snow were observed in mountainous regions of the Balkans, particularly in the Rila-Pirin region (Sharov et al. 2000; Alexandrov und Genev 2003; Andreeva et al. 2003; Koleva-Lizama and Rivas 2003; Grunewald et al. 2009). Furthermore, the intra-annual variability of precipitation has shifted. There is also a decreasing trend of the snow–rain ratio.

Glaciological archives react very sensitively to the current climatic changes. As a consequence, they indicate changes early. Because of the low altitude and southern location, most of the Balkan Mountains are not recently glaciated terrains. Whether there are adequate objects to observe and reconstruct climatic and environmental changes are little known since they have been rarely investigated or published. Only 100 years ago, glaciers were much more extensive than at present in the high mountain areas of the Balkans. In many of these areas, the glaciers have completely disappeared. New research activities on this field are recorded in younger time (Grunewald and Scheithauer 2010).

Analysis of three ice cores drilled on Snezhnika glacieret in the Pirin Mountainsa in September 2006 revealed possibilities and limits to the study of these small glaciers (Section 4.2). Core drilling with the Ruefli-driller was technically very successful. Plausible depth profiles of ~11 m could be obtained. The ion concentrations of the glacierets were relatively high, and dating of material from the base indicated an ice age of 50–100 years. However, annual long-term climate information was not obtainable because of intermittent layers or percolating melt water, which modifies the climate signals (Grunewald and Scheithauer 2010).

The investigations were supplemented and substantiated by studies in the glacier's surroundings. Thick humus developments in the moraines around the glacierets indicate changing climatic conditions. Warmer periods with vegetation and soil development must have alternated with cooler, periglacial conditions. In the Pirin Mountains, these warmer phases during which glacierets and firn patches barely existed were probably at ~300–600 and 1100–1300 AD. The moraine features around the glacieret represent the maximum of the LIA glaciation in the area (Section 3.2).

Regional comparison of glaciers of Atlantic-Mediterranean characteristics (Iberian Peninsula) to those of Pontic-Mediterranean characteristics (Balkan Peninsula) shows many similarities concerning glacier types and geo-factors, as well as climate-glacier phases. Climate change appears to take place with a similar intensity at the scale from millennia to centuries in the investigated regions, even though the characteristics of single years and seasons are regionally differentiated. New results from glacier environments in the Balkans closely correlate with these climatic changes (Grunewald and Scheithauer 2010).

During the course of the twentieth century, a temperature increase of up to 1°C was observed in many places, such as in Bulgaria. The glaciers have responded to the significant warming; some of the southernmost glaciers such as the Corral del Veleta in Spain quickly disappeared. The pace of the retreat is a function of initial size (LIA maximum), local climate and geo-factors (i.e. slope, aspect, topography). The annual snow/firn balance particularly depends on the amount of accumulated winter precipitation and avalanche/snow blown catchment as well as on summer temperatures and warm summer rainfall (Ohmura et al. 1992; Grunewald et al. 2006; Hughes 2008).

Between phases of glacier retreat, glaciers temporarily stabilized. These periods of stabilization correspond with colder phases that were observed in Spain and Bulgaria and correlate with the Alpine glacier re-advances in the 1890s, 1920s, and from 1970 to 1980 (Patzelt 1985; Chueca et al. 2007; Zemp et al. 2007; Grunewald et al. 2009).

Nevertheless, overall glacier retreat was characteristic of the last ~150 years. Europe's southernmost glaciers have lost relatively moderate surface area but significantly more in volume. For example, the Calderone glacier in Italy lost half of its surface between 1794 and 1990 but 92% of its volume (D'Alessandro et al. 2001). The Pyrenean glaciers lost 84% of their extension between 1894 and 2001. The Alpine glaciers lost half of their surface between 1850 and 2000, and two-thirds of their volume (Zemp et al. 2007). In a northern European region like Jotunheimen (Norway) the glacier recession since LIA was only one-third (Andreassen et al. 2008).

Since the 1980s, a significant temperature increase has been observed in all study regions in southern Europe, for example the Alps, and record temperatures have repeatedly been reported in the last two decades (i.e. Böhm et al. 2006; Chueca et al. 2007; Citterio et al. 2007; Grunewald et al. 2009). For instance, 2003 was the hottest year of the last 500 in Europe (Luterbacher et al. 2004); in Montenegro 2007 was even warmer (Hughes 2008). We reported a "new temperature level" in the south-western Bulgarian mountains at the end of the 1990s (Section 4.1).

Despite climate warming having intensified in recent years, some small glaciers appear to survive such warming – largely because of local topo-climatic influences. The monitored Snezhnika glacieret in the Pirin Mountains is a representative example. The dominance of local climate effects on accumulation and ablation, such as avalanching and shading, is likely to insulate them from the effects of the regional climate. Thus, even at higher temperatures, these glaciers are likely to persist, until a threshold is reached when local climate controls are unable to sustain glacier survival.

A further temperature increase by 1.1–6.4°C in the twenty-first century, as predicted by IPCC (Solomon et al. 2007), anticipates the following scenario for the two Pirin glacierets: they will melt and disaggregate in situ. The old ice relics of the LIA at the base of these glaciers will also disappear. Thus, the environmental information stored in this ice will be lost. In the future, however, increasing winter precipitation is likely to result in greater snow accumulation. In the short term, this snow accumulation may exceed snow mass lost by summer ablation so that, in protected sites, snow/firn patches may dominate in the Balkans (Grunewald and Scheithauer 2010).

Most of our present knowledge about climate variability over the last millennium is based on tree-ring studies using tree-ring width and maximum late wood density. Data of both, ring-width and maximum late wood density are standardized to minimize non-climatic variances originating from tree aging, changing light conditions in the canopy and changes in the supply of soil nutrients. Usually, transfer functions are developed by applying linear regression models using relationships between standardized data series and measured climatic quantities. These transfer functions enable the reconstruction of climate quantities from proxy data series after they have been verified against climate data from a training set. Many articles have been written that describe the methods used by classical dendroclimatology. But about the endemic species at the alpine timberline in the Balkans (*Pinus heldreichii* and *Pinus peuce*) there is a lack of knowledge. Dendroecological research on *Pinus heldreichii* offers a secured reconstruction possibility of climate and landscape development, and requires geoarchives with a high temporal resolution (Section 4.4).

In this study we compared *Pinus heldreichii* from ecologically different sites located close to each other in the Bulgarian Pirin Mountains. This tree is a conifer, growing up to 1,000 years. Generally, this species only occurs on the Balkan Peninsula and in the southern part of Italy. The spectrum of parameters comprises tree-ring-width (total, early and late wood), wood density (minimum and mean early wood density, mean and maximum late wood density) as well as stable isotopes ($\delta^{13}C$, $\delta^{18}O$). The different parameter chronologies were correlated with time series of various climate quantities from local stations as well as CRU 2.1 grid point data. The objective was to find relevant relationships and test their stability over time.

Pinus heldreichii demonstrates a mixed climate signal, influenced by both high summer temperatures and periods with low precipitation. Mild winters have a positive growth effect. So it is possible to obtain precise data for the past periods with both extremely dry or cold years. The series of tree-ring-widths correlate with individual climate parameters and indicate colder climate conditions at the timberline ecotone between the fifteenth and mid-nineteenth century. Afterwards, the growth of conifers increased again. Several events are archived in more than 700 years such as the Maunder Minimum of sun spot activity in 1672–1704 and volcanic eruptions.

Cambial activity and cell growth commence mid May at Mt. Pollino (Todaro et al. 2007). Our own observations in the northern Pirin Mountains show that the snow is completely melted on the investigated, south-exposed rock flank by the end of April/beginning of May. This corresponds with the amount of days with temperatures >5°C in April, which are positively correlated with the growth. In contrast, days with temperatures >10°C in May already have a limiting effect.

Furthermore, the July-SPI is significantly positive in the current growth year, however the August-SPI is weakly correlated. Hence, the latter does not play any role in the summer tree-ring growth. There is instead a close relationship between the SPI in last year's August and the tree-ring-width. As a result, cambial activity and cell growth should be completed by the end of July or beginning of August of each year and thereafter under wet conditions. It should start with the accumulation of reserves for the following year (applicable for the analyzed period 1956–2005). In turn, these assumptions correspond with the results of Todaro et al. (2007) in South Italy, where cambial activity is done at the end of July and cell growth is done during the first half of August.

Thus, dry conditions in summer have basically a limiting effect, analogous to a cold winter and a cool spring with few days with temperatures >5°C. The currently discussed divergence problem between climate and tree-ring parameters (D'Arrigo et al. 2008) insofar gains an interesting component as far as *Pinus heldreichii* is concerned, as the mean growth has increased over the last 50 years despite increasingly drier and warmer conditions in southwestern Bulgaria. Although the *Pinus heldreichii* forms thinner tree-rings in dry years in comparison with wet years, it tolerates sparse conditions relatively well. It is assumed that there will not be any competition for the *Pinus heldreichii* by tree species of the upper montane level zone during the course of hypsometric shifting of vegetation zones toward the summit.

Next, other climate parameters, such as – the Palmer drought severity index (PDSI) and climate data of the Royal Netherlands Meteorological Institute (KNMI) – were implemented on the one hand (grid data, Climate Explorer). On the other hand, series of the earlywood and latewood density, as well as the stable isotopes, were also measured ($\delta^{18}O$, $\delta^{13}C$), which show a more robust climate proxy than the tree-ring-width (Helle and Schleser 2004). They have been analyzed but have to yet be compared with other studies on *Pinus heldreichii* and on climate change in the Mediterranean area (Touchan et al. 2005; Brandes 2007; Todaro et al. 2007).

In conclusion, we have shown that in terms of reconstructing and monitoring current and historical climatic and environmental changes, there is a wide spectrum of regional archives in the upper zone of the Pirin Mountains: artefacts of soil genesis, sediment and peat layers from silting areas of glacial lakes, ecotones of the timberline, glacierets or geomorphological forms (moraines), and so on. Archives need to be examined properly for a better understanding, comparing and interpreting of causes, strengths, spatial effects and chronological progression of climate change's natural processes.

Reconstructions always include uncertainties. Therefore it is important to survey different indicators in different geo-archives of an area and deliver results that complement, correct and affirm one another. The climate data serves as verification for the surveyed landscape archives, especially the growth ring width of the trees and the varying size of the glacierets.

The illustrated change could have a long-term effect on the ecosystems in the Pirin Mountains. Warming leads to a change in the vertical distribution of the vegetation's altitudinal zones. This can be the case of the Mountain Pine (*Pinus mugo*), which presently spreads out vertically.

The increase in the number of days with frost could also increase the erosion processes in high mountain parts. Generally, it is expected that under such climate modifications the stability of mountain ecosystems could change, as it is already happening in the Alps (Beniston et al. 1997; Anonymous 2002; Beniston 2003). These climate evolutions have been confirmed in the Pirin Mountains by the examination of a glacieret and by the record of growth rings from coniferous trees that are centuries-old (Sections 4.2 and 4.4). This type of climate change could also have socio-economic consequences, such as the reliability of snow cover in the Bulgarian ski resorts and the sustainability of the water supply in the currently booming Bansko ski resort, situated at the foot of the northern Pirin Mountains. Being a regional "water tower", a significant modification in the southwestern Bulgarian mountains' water resources would also have a far-reaching impact on the water reservoirs and the irrigated agriculture in northern Greece.

Analyses, monitoring, and planning for the development of complex ecosystem structures, processes and functions that can handle ecosystem goods and services and human well-being during climate change will be a great challenge for the upcoming years, especially for Balkan countries.

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