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Preface

Tell me the past and I'll see the future.
Confucius

Southeast Europe, the Balkans and not least the southwest Bulgarian Pirin region experienced an eventful natural and cultural history covering a time scale from millenia to the decades of the Younger Past, which has to be decrypted. Information on the Pirin mountains, stored in geo-archives, has been examined using modern methods and with great effort. This monograph seeks to summarize information on landscape and climate development in the region.

For the Holocene period, the last 10,000 years or so, the forest and climate history of the mountain regions was reconstructed using pollen analysis of lake sediments and peat. The extensive work of Bulgarian colleagues was analyzed and supplemented with soil surveys.

Our examination focused on an archive network in the Alpine timberline zone of the northern Pirins. This network provides tree-ring analyses of centuries-old soil and moraine investigations, firn and ice layers of recent glaciers, and cultural-history inquiries, as well as analyses of relatively long-time climate data series. Thus, the climate, including its extremes, can be described in relatively high resolution, for the last 500 years.

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We wish to thank our co-workers and colleagues, namely Sieglinde Gerstenhauer, Alexander Gikov, Bjorn Günther, Dr. Gerhard Helle, Alexander Hennig, Dr. Jürgen König, Dr. Christiana Weber, Thomas Wieloch, Beate Winkler, and students too numerous to be named here, for their assistance with digging and drilling, mapping, sampling and lab analyses.

A German version of the book was published first (www.rhombos.de). We thank Mr. Reiser for helping us with the authorisation chores.

Anne Scheithauer, Laura Grunewald and Silka Halmel: thank you for helping with the English text. Actual developments and findings were incorporated by us, especially regarding glaciers and dendrology.

We would also like to express our gratitude to Margaret Deignan of the Environment Science Unit of Springer for her brilliant publishing support and R. Samuel, project manager at SPi Technologies India Pvt Ltd, who handled the book production and language polishing.

Dresden

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Contents

Chapter 1
Geoarchives – Why View the Past?

Abstract Comprehensive knowledge of climate and landscape dynamics is essential to obtain a basic understanding of the recent geoecological situation and to assess possible future developments. High mountains and their ecosystems offer an outstanding opportunity for studies on the impact of climate change. The Pirin Mountains in Southeast Europe, situated at the transition between temperate and Mediterranean climate, are considered very sensitive to historical and current global changes. To evaluate the current situation, the existing climate proxy data sets need to be amended by precisely dated and highly time-resolved geoarchives spanning past centuries. Thus, the examination aims to reconstruct climate variability on different time scales, allowing us to improve the regional and sub-regional knowledge of facts and ecosystem services due to trends of global climate change.

Keywords Climate and Landscape development • Geoarchives • Methods • Southwest Bulgaria

1.1 Introduction and Objectives

The anthropogenic change of the natural and cultural landscape increasingly affects ecosystems throughout the world on a regional and global scale. Resulting ecological and economic developments need to be recorded and, if possible, sustainably assessed. Therefore a comprehensive understanding of the structure, function and dynamic nature of these ecosystems is essential.

Our working group carried out such investigations in southeastern Europe for several years (Grunewald and Stoilov 1998; Grunewald et al. 1999, 2007; Grunewald and Scheithauer 2008a). The center of interest is the northern Pirin and its flanking basins and valleys. Due to the biodiversity, this area can be regarded as an important refuge (Griffiths et al. 2004). The highest areas are most affected by the pressure of land use and also by climatic alteration. The ecosystem structures,

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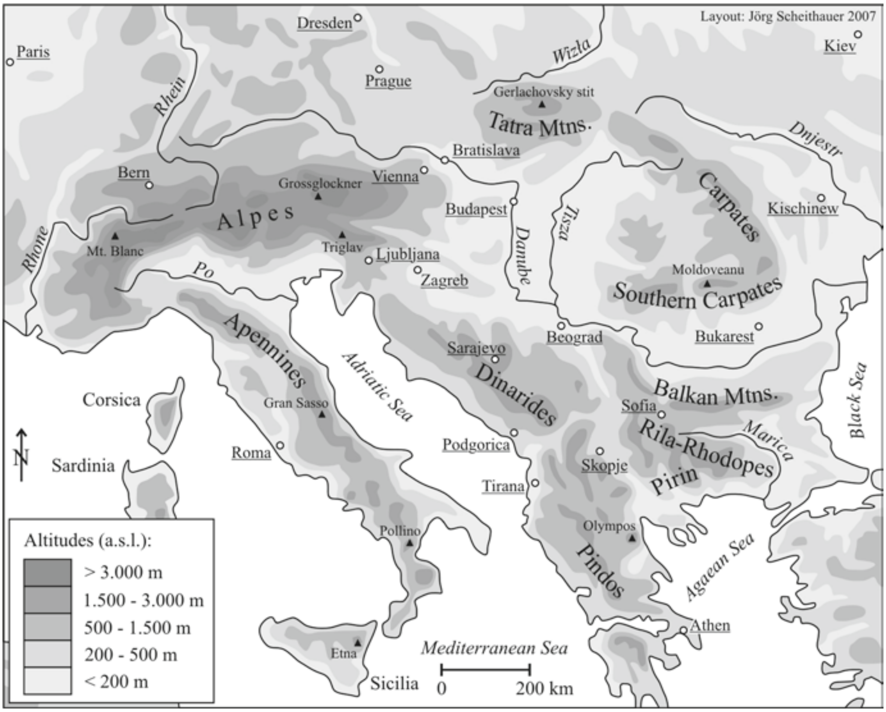

Fig. 1.1 Pirin Mountains as part of the mountain system of southeastern Europe

processes and dynamics of Southwest Bulgaria are representative of the mountain regions of the Balkan Peninsula (Louis 1930; Schönenberger and Neugebauer 1987; Grunewald et al. 1999).

Southeast Europe constitutes a mosaic of several small mountain regions and countries (Fig. 1.1). This strong internal differentiation generates a wide diversity of local physico-geographical and socio-economic situations. On the one hand, high mountain regions such as the Pirin Mountains receive ample precipitation and experience permanently low temperatures. On the other hand, the southern peripheral areas, either highlands or lower areas, are dry and warm (for instance, in northern Greece). Consequently, this strong local geographic diversity offers limited options for extended land use but high potential for nature conservation and recreation areas. However, isolation endured under its eastern bloc political regime, as well as the effects of Balkan historical complexity, have left their mark on the region. Systematic environmental screening is still an exception in this area of Europe (Alitchkov and Kostova 1996; Grunewald and Stoilov 1998; Grunewald et al. 2007). In addition, there is a considerable lack of knowledge regarding the dynamics of weather and climate (time and space), water supply (snow, lakes) and water availability (where and when) at the regional level.

Today, research on long-term past human–environment relationships is of increasing interest. There are efforts to reconstruct prehistoric environmental conditions and their spatiotemporal variability. This information is important, particularly with regard to the expected warming by about 2–4°C by the end of the twenty-first century (IPCC-Report, Solomon et al. 2007).

In historic and prehistoric times of low population density, periods of warm climate have always been advantageous to the population, particularly in mountainous regions such as southeastern Europe (Blümel 2002; Grunewald and Scheithauer 2008b). High mountain regions and their hypsometric zoning are central to the climate change debate because they are sensitive ecosystems and ecological boundaries are exceedingly struck by changes (Pauli et al. 1996, Beniston 1997, 2003; Messerli 2004; Grunewald and Scheithauer 2007; Solomon et al. 2007). Slight temperature variations shift cultivation limits and affect runoff regimes as well as slope stability or other ecosystem services. The mountains, such as Pirin, Rila and Rhodopes, are of extraordinary importance to adjacent semi-humid landscapes such as in North Greece (Grunewald et al. 2007).

The countries in southeastern Europe face challenges from economic and political transition, continuing vulnerability to environmental hazards, and longer term effects of global climate change. The EU-CLAVIER Project aims to help these countries (including Bulgaria) to cope with these challenges (www.clavier-eu.org). For instance, climatic crisis situations can stimulate adaptation strategies and technological innovations, as ancient mass migrations and current efforts to reduce CO_2-emission demonstrate (e.g. Lohmann 2006). Current climate change research in mountains focuses on (cf. Häberli and Beniston 2004):

- The turnover of greenhouse gases
- The expressiveness of long-term instrumental measurements
- The observation of key indicators of environmental change
- Numeric models for analyzing present and future climates in high mountains

The southwestern Bulgarian Pirin Mountains represent an important ecological link between the Mediterranean region and the mid-latitudes. They are the transition between southern European areas where ever taller and thicker trees at the timberline in first line are controlled by the water supply, and the humid high mountains of Europe where the summer temperatures foster tree growing (Grunewald and Scheithauer 2008c). In this transition area, little climate changes have a big effect on environmental conditions and change balances, sometimes, for example, favoring one or the other plant community.

Very different geo-biotopes which are suitable to study the natural landscape and climate dynamics are distributed in the subalpine area of the Pirin Mountains. The altitude of the mountain forest depends on climate-ecological conditions and site characteristics as well as the anthropogenic influences whose examination needs explicit study. Systematic research of the alpine timberline in southeastern Europe's high mountains are not available since Horvat et al. (1974). The endemic tree species *Pinus heldreichii* and *Pinus peuce* show vegetation-historical, climatic, ecological, and local peculiarities (Velchev 1997; Stefanova and Ammann 2003; Grunewald and Scheithauer 2008c).

The main aim of our studies is the reconstruction of climate variability in the high mountains of southeastern Europe, especially in the Pirin Mountains. We analyzed the following temporal dimensions (time scales):

- Scale of millenniums (Holocene, ca. 10,000 years)
- Scale of decades to centuries (modern times, ca. 500 years)
- Scale of days to years (present time)

First, we performed a physico-geographic and environmental mapping of the study area (Grunewald et al. 1999). The main results, which are of fundamental importance for the geoarchives approach, are described in Chapter 2. By characterizing the recent timberline (morphodynamic and soil characteristic, climate parameter, vegetation) we established the basis for analyzing future geodynamic processes.

The research respective to the region's timberline dynamics will be shown. We describe recent timberline ecotones based on selected test plots and sampled sites in the Pirin Mountains. This first implies the analysis and climatical interpretation of the Holocene development of vegetation at higher mountain positions of the Pirin Mountains (Chapter 3). Therefore, we analyzed works of Bulgarian geo-scientists concerning lakes, peats, and vegetation, and we have drawn conclusions based on comparable mountains (the Alps). Drawing on the Pirin Mountains, the southeastern European Holocene climate and landscape development can be well characterized and, through the ups and downs of civilization it can be compared to Southwest Bulgaria (Pirin/Rila Mountains, the valleys of the Struma and Mesta rivers, intra-mountain basins, cf. Chapter 3).

Moreover, relative long climate data series, firn and ice layers of glacierets, soils and moraines, as well as rings of trees several centuries old, were analyzed (Chapter 4). The objective was to reconstruct 500 years of climate development for different time scales (from annual to multi-decadal fluctuations). The results of this palaeo-geoecological method cooperation have a novelty value and close a regional research gap.

The regional peculiarities of climate and landscape history on different time scales are summarized in Chapter 5. Information saved in environmental archives was reliably calibrated and accurately transferred into temperature and precipitation estimation. For that, proxy-data such as tree-ring-width, maximum late wood density, firn density, ions or stable isotopes (^{13}C, ^{18}O) were related to direct climate data sets (temperature, precipitation). Climate "proxies" are sources of climate information from natural archives. The relationship between tree-rings and climate parameters, for example, was determined by calculating correlations and the so-called "response functions" (Cook and Kairiukstis 1992; Oberluber et al. 2008). In addition, the statistical values of the mountain tree-ring chronologies show a proxy for the timberline dynamics because growth-limitated climate conditions should be reflected in stronger or weaker population signals.

1.2 Reasons and Scales for Climate Changes

During Quaternary, with its change of warm and cold periods (interglacial/glacial or warm and ice ages), the high mountains were repeatedly glaciated in Southwest Bulgaria. The multiple climate changes have influenced the ecosystem's basic characteristics seen today, from the relief to flora and fauna, to the water balance, to the soil.

The glacial cycles of the Pleistocene, which included in each case about 100,000 years (Veit 2002), are not considered as they were not the focus of our research. Only the last glacial period, the Würm glaciation, is outlined to analyze the initial landscape development (Chapter 3).

Concrete geo-chronological findings of climate and landscape history are available for the Pirin region since the Late-glacial (period between the end of the Würm glacial maximum and the beginning of the Postglacial/Holocene). The stages and their temporal integration are also discussed in Chapter 3. Thus, the recent interglacial, the Holocene, is a focal point of the presentation (Fig. 1.2). Only the shortest and youngest part of this geological time epoch, the time period since medieval times, can be verified by higher resolution and resilient facts on climate and landscape development. Moreover, this period is the easiest for us to understand.

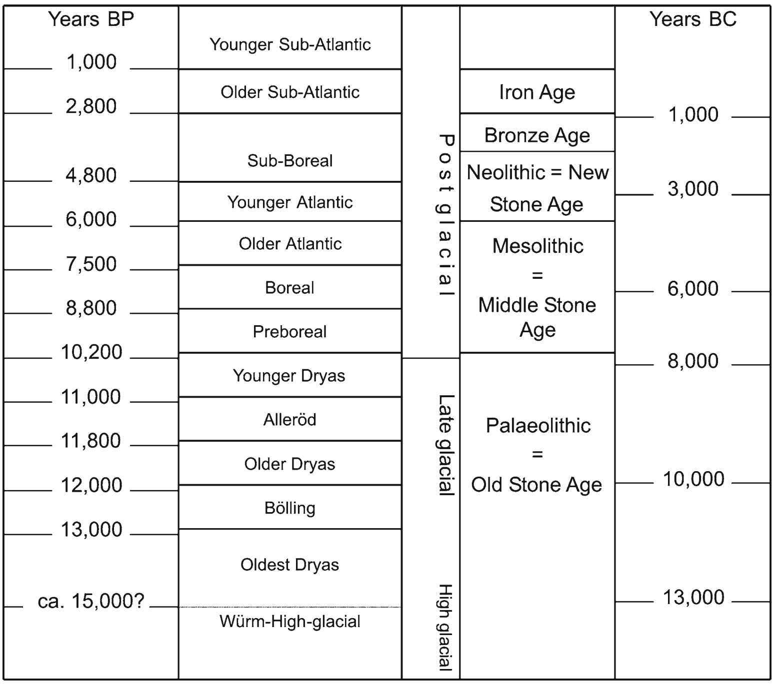

Fig. 1.2 Time-scale and cultural-historic distribution of the Younger Pleistocene (acc. Blümel 2002, modified)

Over millenniums, the climate change is above all determinated by the fluctuation of the earth's orbit parameters (so-called Milankovitch-forcing) as well as changes of the planetary albedo and the composition of the atmosphere (greenhouse gases, aerosols) (Rahmstorf and Schellnhuber 2007; Wanner et al. 2008). Occurrences such as volcanic eruptions, meteorite impacts and self-enforcement effects (positive feedback) considerably influence the effects of the changes. Wanner (2007) compared the correlation of these natural climate-driving factors of the earth's energy balance with the two most important modes of the internal variability system: ENSO – El Niño Southern Oscillation, and NAO – Northern Atlantic Oscillation. He proved that the radiation supply on the northern and southern hemisphere inverted about 5,000 years before present (BP, before AD). Therefore, the summer solarization maximum translocated, which led to a shifting of the circulation and climate belts. Southeastern Europe, our area of study, became moister during the mid Holocene period (circa 6,000 BP). Such a change is singular for the Holocene and is an example of long-term dynamics.

From decades to centuries, the reconstructed data series show quasi-periodicities which, however, are rarely temporal and regionally synchronous (Wanner 2007). Archives have to be examined as precisely as possible with new methods for better understanding, comparing and interpreting the reasons, strengths, regional effectiveness and temporal courses of natural climate changes (Bubenzer and Radtke 2007). Accordingly, a principal aim of our work in the Pirin Mountains was to select and produce data to close regional research gaps.

Since the Stone Age, anthropogenic activities have drawn attention to the climate system (greenhouse gases, land use, aerosols). However, the anthropogenic signal only became clearly visible since the industrial-energetic revolution and its significant increase to the CO_2-concentration of the atmosphere. Hence it is presumed that climate and nature will not remain within the relatively close boundaries of the Holocene in the foreseeable future. The instrumental climate measurements started in the 1930s in the southeastern European mountain areas (Sharov et al. 2000). Thus, only the past 80 years can be verified by direct, well-defined climate data. Data of regional climate stations were investigated, statistically tested, analyzed and interpreted. On this basis, trends, extremes and threshold values of the regional mountain climate were characterized (see Chapter 4).

1.3 Archives and Methods

The application of specific indicators and methods is necessary to value long-term climate and environmental events and dynamics. Soils, lake sediments, trees and geoarchives such as moraines, timberline ecotones and glaciers, are available in high mountains for reconstruction purposes. They are analyzed by means of geoecological fieldwork techniques as well as by biological, physical and chemical laboratory methods (Geyh 2005). In particular, analysis concerns age determination of different temporal resolution samples.

First, research in dendroclimatology, palynology, lichenometry, palaeozoology, sedimentology, loess stratigraphy, tephrochronology, isotope analysis and the analyses of historical documents are established (Röthlisberger 1987). It is important to examine different indicators in different (geo-) archives of one area so that the results supplement, correct and confirm each other, as reconstruction always contains elements of uncertainty. The measured climate data help to verify the examined landscape archives, especially tree-ring widths and the area variance of the glacierets.

The climate signals, which are saved in different geoarchives, do not produce immediate values for temperature or precipitation, but only produce indirect indicators, the so-called proxy data. All data show different accuracies, temporal resolutions and regional significance of former climate and landscape conditions. In the case of climate reconstruction, several methods should be used for validation, i.e. morphogenetic phases known in the cirques should be checked against historical sources and independent physical records such as lichenometry, dendroclimatology and historical climatology. Table 1.1 shows the available geoarchives of the Pirin region, including indications as to whether the archives have already been examined.

The climate archives relevant in the research area are numerous but they supply incomplete and proxy data that do not reach far back in time. Relatively complete climate archives on their own solely represent the polar ice mass and marine or limnic sediments. However, we will attempt to correlate the fragmentary facts with complete and more precise marine and glacier data sets, including regional comparisons with well-examined mountains such as the Alps. Absolute dating methods will be used for the temporal classification of former climate changes (Bradley 1999; Geyh 2005), whereas in the Pirin Mountains, the ^{14}C-radiocarbon method has almost always been applied.

The analyses of the cirque lake sediments and peats constitute an important basis for reconstruction, especially for vegetation historical analyses, because they often show ideal deposit and preservation conditions (Geitner and Becht 2001; Stefanova et al. 2006). Lithology, pollen analysis, macrofossils and radiocarbon

Table 1.1 Geoarchives for the reconstruction of environmental and climate change in Southwest Bulgaria (time period acc. Bradley 1999; Bubenzer and Radtke 2007)

Archive	Minimum ascertainable period of time (years)	Maximum ascertainable period of time (years) (in brackets: analyzed in Pirin Mountains)
Ice/glacier (glacieret)	1	10^6 (10^2)
Limnic sediment (cirque lake)	<1	10^5 (10^4)
Moraine	10^2	10^6 (10^3)
Soils (fossil)	10^2	10^6 (10^4)
Sinter (stalactite)	10^2	10^5 (–)
Fluvial deposits	10^2	10^5 (–)
Tree-rings	<1	10^4 ($10^{2\text{ bis }3}$)
Pollen, Macrofossils	1	10^5 (10^4)
Peat bogs	10^2	10^5 (10^4)

dating of these archives supply good information on vegetation history, climate phases, morphological activity as well as anthropogenic impacts. The spectrum of methods was already developed in northern Europe and the Alps at the beginning of the twentieth century (cf. Gams 1963) and has been further improved and completed since then (e.g. Faegri and Iversen 1989; Beug 2004).

Our working group has already examined a number of soils, which helps solidify our understanding of landscape history since the Mid-Holocene (Chapters 3 and 4). Unfortunately, only one moraine in the "Kasan cirque" could be included in modern geochronological research. Around 70 findings from different laboratories on the radiocarbon dating of pollen, macrofossils, humus sediments and charcoal are available for the Pirin region. The oldest radiocarbon age comes from the sediment of the Kremensko Lake in northeastern Pirin and dates back to 13,526 years BP (15,872–16,285 cal BP, cf. Stefanova et al. 2006).

The concrete research as to the archives of timberline ecotones, glacierets and dendroecology of *Pinus heldreichii*, as well as the applied methods, is considered in Sections 4.2–4.4.

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Chapter 2
The Pirin Mountains as a Model Region

Abstract The northern part of the Pirin Mountains with its distinctive marble peaks and silicate areas constitutes our central area of study. Very differentiated geomorphologic landforms, soil types, micro-habitats and biodiversity are found in the subalpine region and, because there is marginal anthropogenic interference, we can study natural landscape and climate dynamics. To establish a basis, all geophysical features on specific sites and along transects have been documented, and the soil conditions have been mapped. The region's service capacity and conservation strategies are outlined. Hence, this chapter reviews important aspects of the Pirin's remarkable landscape, its natural development (climate, vegetation, soil) and anthropogenic interference (history, current pressure).

Keywords Landscape types • National Park Pirin • Physical-geography • Soil map • Use characteristic

2.1 Location and Ecosystem Characteristics

The mountains in Southwestern Bulgaria are assigned to the Rhodopes Massif (also Rila-Rhodopes Massif or Thracian Massif) and to the Serbo-Macedonian Massif (Fig. 2.1), which occupies swaths of Serbia, southern Bulgaria, Macedonia, Greco-Macedonia and Greco-Thrace (Ager 1980). The highly dissected character of this region is remarkable. The small mountains, which are not exceeding 2,925 m a.s.l. (Peak Musala in Rila), are manifold structured by intramontane basins (e.g. the Basin of Razlog, Simitli Basin) and deep graben valleys (Struma Graben, Mesta Graben) as well as by transverse valleys and rises (e.g. Kresna Rise) (Grunewald et al. 1999). Furthermore, nearly all of these mountains exhibit steep north flanks and comparatively gently inclined south flanks (Schröder and Berkner 1986).

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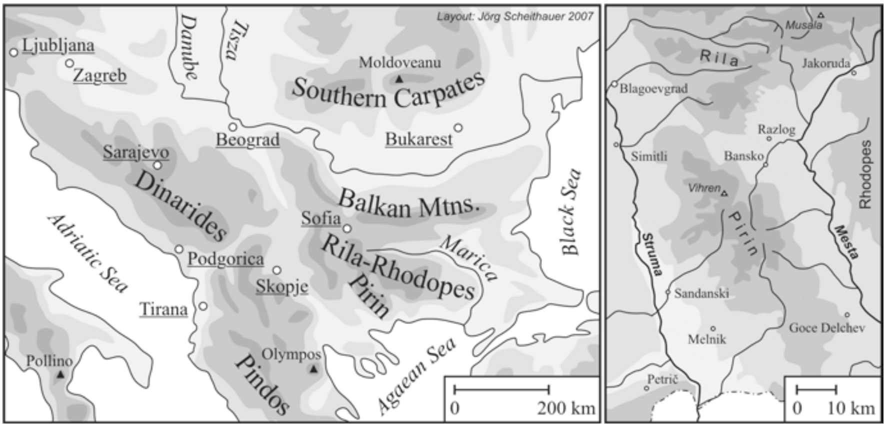

Fig. 2.1 Balkan Peninsula (*left*), Southwest Bulgaria and Pirin Mountains (*right*) – location and structure: mosaic of mountains, basins and valleys

The region is characterized by high seismic activity, numerous thermal springs and post volcanic phenomena (e.g. in Sandanski, Rupite, Sapareva Banya) which indicate tectonic disturbances between the mountains. Pediments and dispersal fans which, due to strong erosion, often emerge as badlands or earth pyramids (around Melnik, Stob, Djerman), are typical at the edges of the intramontane basins as well as partly thick Tertiary and Quaternary accumulations of littoral, estuary, limnic and fluvial genesis in the central parts (Grunewald and Stoilov 1998).

Moraines, cirques, trough valleys and a diversity of periglacial forms with recti-linear slopes and patterned soils prove the Pleistocene glaciations of the Rila and Pirin Mountains (Batakliev 1972; Schröder and Berkner 1986). In the northern Pirin Mountains, small recent glacierets are found (see Chapter 4, Section 4.2).

In the east and the west, the Pirin is seamed by almost parallel disturbances marked by the two main streams, the Struma and Mesta. It impressively overtops its valleys and basins as a single horst. Its main axis has a NW-SE expansion of approximately 70 km and a mean width of 35 km (Fig. 2.1). The northern transition to the Rila Mountains and the southern transition to the Slavyanka Mountains (Paril Pass 1,170 m a.s.l.) are less distinctively formed as saddles. More than 50 peaks within the Pirin Mountains reach altitudes above 2,600 m a.s.l.

The Pirin Mountains can be geologic-morphologically subdivided as follows:

- The high northern part, which extends from Predel Pass to Todor's meadow (Todorova polyana) with characteristically rich dissected alpidic and glacial forms as well as marble peaks (e.g. pyramidal peak Vihren, 2,914 m a.s.l.) and
- The central and southern part with dominant crystalline rocks, rounder forms and maximum altitudes of about 2,000 m a.s.l

An analogy between the spatial distribution of relief-determinate landscape categories and land use types is observed in the study area. Based on the works of Anonymous (1977) and Grunewald et al. (1999), we distinguish following areas of chorological dimension:

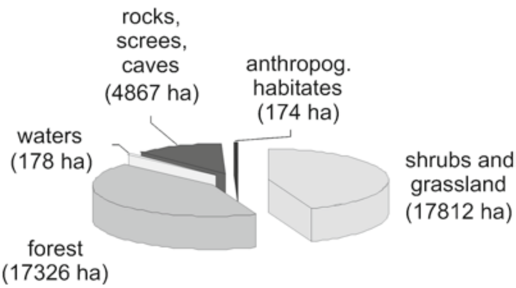

Fig. 2.2 Share of ecosystem types in the Pirin National Park (Anonymous 2003)

1. Mesohemerobe grasslands and steppes of the southern intramontane basins with Quaternary loose sediments, Pliocene sandy-loamy sediments or intrusions of metamorphic rocks
2. Meso to oligohemerobe moderately humid mountain forest landscapes with mixed forests on metamorphic rocks and coniferous forests on intrusive, marble, schist and gneiss
3. Oligo to ahemerobe high mountain landscapes with subalpine meadow-shrub communities, alpine meadows on marble, intrusive, crystalline schist and gneiss and alpine rock and debris landscapes

Due to its unique and beautiful landscapes, and its high biodiversity, a part of the Pirin Mountains is a National Park (NP). The geoecotypes in the NP were mapped following the classification of Palaearctic Habitats (Nature and Environment No. 78/96). Figure 2.2 illustrates the predominance of forests and (above timberline) open areas. Habitats with anthropogenic impact account for 2.2% of the whole area. Hence, the study area is particularly suitable for monitoring natural, mainly climate-driven, changes.

2.2 Geology and Morphodynamic

The Pirin as a horst-blocked highland morphostructure in the western part of the Rila-Rhodopes-Massif was considered a consolidated Precambrian block that separates the alpidic northern mountains (Balkanides) from the southern mountains (Hellenides) as a type of intermediate massif. However, investigations in the 1960s revealed an involvement of the alpidic dynamic for swaths of the Rila-Rhodopes-Massif (Kockel and Walther 1965). The rock mass built up by crystalline rocks is composed of two structural levels. The lower one consists of gneiss and anatexites, whereas the upper one is composed of high metamorphic gneiss, amphibolites and Proterocoic marble.

In the west, the massif is relatively sharp, limited by a disturbance named the Struma-(Strimon-) Line. Here, in the borderland to Macedonia and Serbia, the series of the adjacent Serbo-Macedonian-Massif overthrust the Rila-Rhodopes-Massif.

Due to strong lateral pressure, the Variscan Pirin Mountains and the Basin of Razlog were lifted up like a horst and lowered, respectively. Probably having its climax during Upper Cretaceous, these tectonic processes were accompanied by active volcanism (Burg et al. 1990).

The Pirin itself is characterized by cross faults in metamorphic rocks. The lower part of the mountains is composed of granite, whereas marble and limestone constitute the upper parts. Within the marble part there are embedded granite structures that form three bulges. These structures determine the typical oblong dome-like shape of the massif. Due to erosive processes, the crystalline rocks that were under layers of sediment and marble are exposed on the surface (Georgiev 1991). Consequently, the study area is split into two petrographic parts (Fig. 2.3): marble and silicate, which affect major landforms as well as soil properties, stream

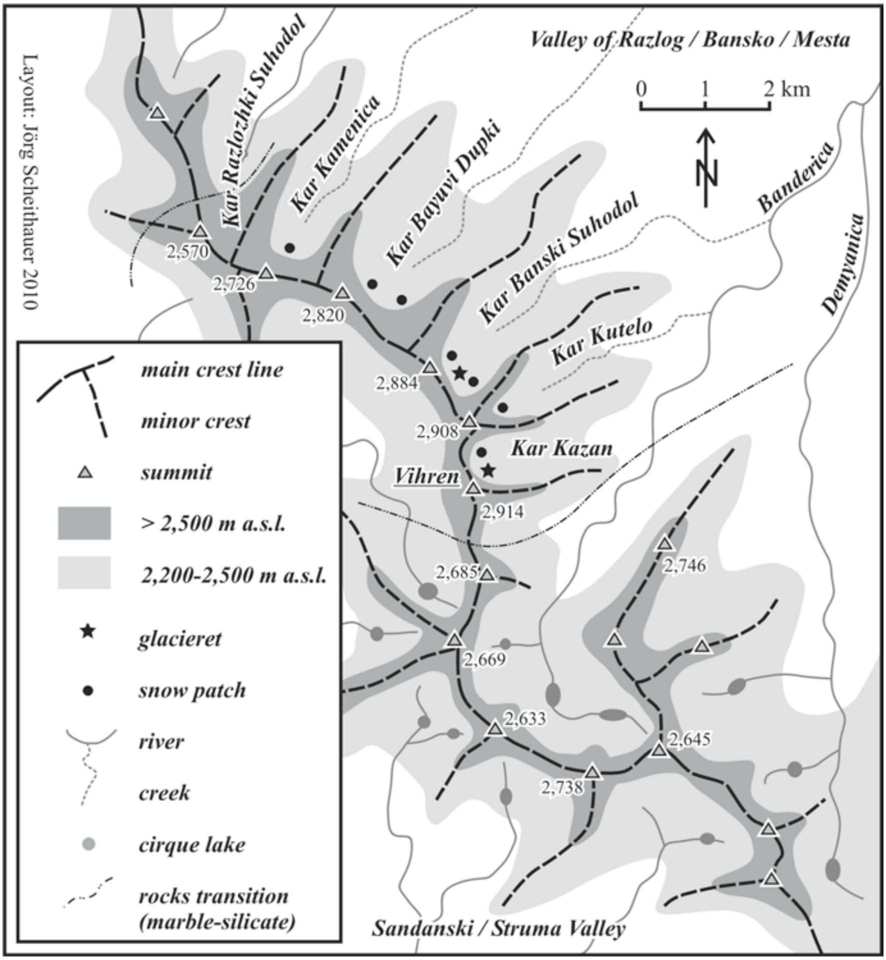

Fig. 2.3 Main crest and cirques of northern Pirin Mountains

networks and vegetation. In terms of area, the dominating rock is granite. Within Pirin National Park, granite accounts for 62% of the area followed by gneiss with 14% and marble with 12%. Schist and glacial rubble account for 5% each (Anonymous 2003).

Traces of the intermittently proceeded Tertiary block movements are found in three levels of denudation, whose erosion surfaces in parts that have recently been covered with meadows (locally called Polyana or Livadi). For instance, located west of the main divide, there are the Golyamo and Malko Spano Pole and the Banderizhka Polyana, which now serve as locations for the Bansko cable car station and a biathlon stadium.

Characteristic of the Pirin Mountains, the northern part in particular, are the large cirques (35 in number, locally known as "circus") and trough valleys (Grunewald et al. 1999). Most cirques are found within the granite parts of the northern Pirin, which is located to the east of the main divide and marked by the headwaters of the Banderica, Demyanica, Bezbozhka Reka, Retize, Kamenica and Tufcha rivers. Many of these cirques bear lakes. One half each of the cirque floors is situated in approximately 2,200 or 2,400 m a.s.l., which argues for two independent glacial stages: Riss and Würm glaciation (Louis 1930, Popov 1962). The snow line at that time is estimated to have been at an altitude of 2,200–2,300 m a.s.l. Within the marble parts, cirques are smaller (areal) but deeper than in silicate parts.

The most profound features of valley glaciation are evident alongside the Demyanica, Banderica, Retize, Vlahinska Reka and Pirinska Bistrica rivers. Remains of moraines are found in the valley of Demyanica down to an altitude of 1,140 m a.s.l., which suggests a valley glacier of 12 km maximum length. The remains in the other valleys merely reach down to 1,570–1,750 m a.s.l. The differences in levels can only be explained by differences in exposition and by the extent of the accumulation area (Schröder and Berkner 1986).

Even though marble usually shows marginal tendencies to karstification, different forms exist. The most common forms are dolines which, in the northern Pirin, mostly have developed as shaft-like small-sized dolines with irregular shapes and fallen blocks covering the floor. Lacking fine sediment, they have a low water-retaining capacity. Even if located in the lower parts of the cirques, they do not bear lakes. Several bear fields of firn periodically or even permanently. Characteristic valleys with karst drainage are called dry valleys in the Pirin Mountains (Banderizhki Suhodol, Razlozhki Suhodol). Karrens, or other karst forms, are only slightly developed. Caves, mostly with vertical orientation, are mainly developed in the contact area between granite and marble (Grunewald et al. 1999; Anonymous 2003).

The absolute altitude difference in the northern Pirin amounts to approximately 1,900 m a.s.l. between Bansko and Vihren Peak, and into Struma Valley near Kresna 1,750 m a.s.l. in turn (air-line distance approximately 15 km). The steep relief in high altitude areas, depending on climatic and geologic premises, results in processes that involve typical morphologic structures for high mountain regions. Of particular mention is the mass-shifting with all its characteristic processes like avalanches, rock slides, mud torrents and floods. Recent erosive processes are marginal on sites with closed forest vegetation. In particular, human interference poses the potential of natural catastrophes. More than 90% of the NP's area features steep (21–30° slope) and highly steep (>30°) relief (Anonymous 2003).

Outlined below are recently developed structures and processes within the study area above the timberline, mapped by Engler (2006). The basic principles for mapping are, among others, the workings of Demek et al. (1976), Lehmkuhl (1989) and Ries (1994). Intensive frost weathering in high altitude areas produces glacial debris, which can be shifted gravitatively, particularly in the crystalline areas. In large part, the debris is scattered extensively over the slopes or accumulated in closed hollows (Fig. 2.4a and b). According to Rathjens (1982), this zone also is called the glacial debris level. This is the belt of free solifluction. By night, frost-weathered material is held together by frozen ice; by daytime, when the sun melts the ice, stones release. Radiation-controlled diurnal temperature variations cause similar effects. Therefore, eastern and southern slopes, in particular, are in danger of falling rock.

While no glacial debris is found on marble crests, there is a special phenomenon of the solifluction belt: rectilinear slopes formed by debris corrosion of soil flow (Fig. 2.4c, cf. Schröder and Berkner 1986). Areal erosion is caused by frequent freezing and thawing of moist soils, accompanied by the development of rectilinear slopes, solifluction lobes, loop bedding soils or the typical patterned ground (Schröder and Berkner 1986, Veit 2002). Extensive erosion forms and rudimental patterned grounds can be found on erosion surfaces. The example illustrated in Fig. 2.4d shows a slump, characterized by the tilt of material alongside a slope parallel line and the disaggregation of the slipping mass into several blocks (Veit 2002). Caused by the rotation of the material, coarse debris from deeper soil layers can be conveyed to the surface. Shell-shaped cracks are typical as well.

Within the belt of free solifluction, on steep slopes, primarily polygonal debris is found, which accumulates to alluvial cones and rock fans, partly obscuring the glacial forms. Often, smaller cirques are completely blocked up (Fig. 2.4b). Rock falls can form rock fall gullies and accumulate the transported material on rock fans (Fig. 2.4e). Such local hollows are predestined for avalanches. The extreme examples are rock falls or mountain creeps. In particular, endangered gullies with rubble slope accumulated are found on hollow slopes with access to open rock.

During winter until early summer, the alpine level of the study area is under nival influence. Snow is likely to accumulate to nivation cirques in hollow moulds and erosive work is performed by meltwater in so-called nivation spouts and rills. In the marble parts of the northern Pirin, the thawing period is characterized by a processes of solution-weathering and karstification. Soils are under the stress of snow erosion, which becomes obvious in so-called blaikens.

If gravity is accompanied by moisture as a slip agent, processes like landslides, filled valleys, soil creeping, mud flow and debris glaciers occur (Ahnert 1999). The belt of impeded solifluction features a closed vegetation cover, which decelerates erosion. The slope-parallel morphologic tendencies manifest in cryoplanation terraces, solifluction folds and loop bedding meadows (Rathjens 1982). Soil creeping processes mainly proceed on rectilinear or expanded concave slopes on marble with

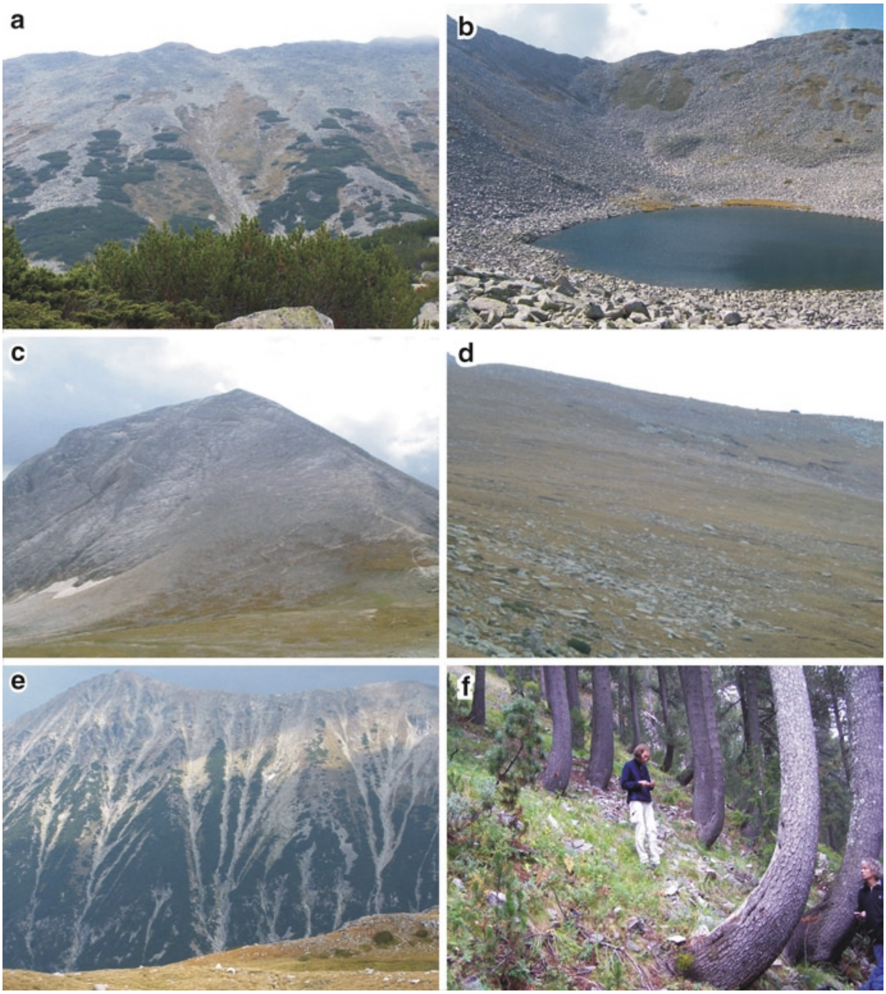

Fig. 2.4 Selected examples of natural morphodynamic in northern Pirin Mountains: (**a**) areal debris, (**b**) accumulated debris in the upper, crystalline Banderica Valley, (**c**) marble rectilinear slopes at the Vihren, (**d**) widespread erosional forms upsite the Spano Pole meadow, (**e**) cutted, elongated steep slope at Todorin peak and (**f**) significant bole sweep

a comparatively strong inclination. Distinctive bole sweeps on trees indicate these processes (Fig. 2.4f). Another fortifying factor for these creeping processes is shallow, imbued, clayey-loamy soils. Snow can further enforce pressure and growth deformation.

Last but not least, human interference affects the high mountain morphodynamic. Grazing animals usually move slope-parallel, producing a distinctive cattle trampling relief. Hikers in summer damage vegetation, sparking erosion (Fig. 2.5a, b).

Clearing of forests and krummholz (elfin-tree) woodlands adds up to further destabilization of slopes, which can bring about disastrous erosive events like mud torrents or linear gully erosion. Figure 2.5c and d document such recent events in Pirin NP. Morphology is also controlled indirectly by interferences on surface water (water relocation, discharge adjustment, etc.).

The National Park's management turns its attention to the problem of erosion. It maps processes and damages, and establishes safety measures (Anonymous 2003).

Fig. 2.5 Examples of human-caused morphodynamic in northern Pirin Mountains: (**a**) hiking trail erosion, (**b**) animal trampling relief in Malkya Kazan Cirque, (**c**) linear erosion and (**d**) mud-stream and debris flow as consequences of ski-run buildings

2.3 Water in the Pirin Mountains

Due to the Pirin's abundance of water, it is considered a region of super hydrological importance. Higher precipitation rates and concomitant lower evapotranspiration add up to comparatively high discharges, as the data in Table 2.1 show. Yet, the long-time runoff from the territory of Pirin NP amounts to 356 million m³ per year (Anonymous 2003). The runoff gradient varies between approx. 1,000 mm in higher altitudes and 500 mm in the lower montane belt above the town of Bansko.

Water is of great importance for drinking and industrial use, the production of electric energy and the operation of snow-making equipment for ski slopes. Running off the rivers Mesta and Struma, the water from the mountains is important for ecosystems in northern regions of Greece (Grunewald et al. 2007; Skoulikaris 2008). The water demand increasingly shifts to the winter season, when the amount of runoff and evapotranspiration is marginal.

There are three significant types of subterranean water in the region (cf. Anonymous 1977; Grunewald et al. 1999):

- Flow of groundwater in the shingle of river terraces and floodplains (Struma, Mesta, Istok, Glazne and others)
- Water in crystalline rock ravines of the mountains, and
- Karst water in the northern and southern Pirin Mountains

The Pirin Mountains mark the main water divide, which runs NW–SE according to the main axis of the mountains. The drainage is carried about one half each by Struma and Mesta. The valley and river systems of Banderica and Demyanica are the most important in the northern Pirin.

The Banderica springs from the Banderica Cirque, which bears several lakes. The length of the river amounts to 13 km in an average altitude of 1,900 m a.s.l. The study areas are predominantly situated within the drainage basin, which extends to 37 km² (Hristov and Mitshev 1995). In the upper part, the Banderica flows through a typical trough valley and primarily cuts granites. The marble middle part of its stream course is characterized by a canyon-shaped valley. In the area of the Banderica Polyana (upper station of the cable car), the river partly flows subterraneous. To the southwest of Bansko, the Banderica discharges into Demyanica. Above Bansko the river is tamed, diked and utilized. Numerous streams are drained for irrigation purposes.

From Bansko the river flows in a concreted channel and is called Glazne. To the east of Razlog it joins the Istok, leaves the basin through a meandering narrow valley and finally reaches the Mesta, which springs from the Rila Mountains (Fig. 2.6).

Table 2.1 Water balance of the Pirin Mountains (1936–2000, acc. Anonymous 2003)

	Area (km²)	Mean altitude (m a.s.l.)	Precipitation (mm a^{-1})	Evapotranspiration (mm a^{-1})	Runoff (mm a^{-1})
NP Pirin	404	2,035	1,119	238	881
Pirin Mts.	2,253	1,214	749	360	389
Bulgaria	110,828	506	619	462	157

Fig. 2.6 Map of the Basin of Razlog with river network and flanking mountains

The runoff regime and water supply are regulated by storage in snow and lakes in cold, high altitude areas of the mountains (snow regime). The maximum discharge is in May/June (Anonymous 1977, Grunewald et al. 1999). A high variance of the amounts of precipitation both interannual and within single weather periods is characteristic (see Section 4.1). This can result in relatively long dry periods and in flooding. Smaller water retaining works, mostly between the mountains and basin, ensure a better availability of water. Flood and erosion protection requires improvement.

Field studies conducted between 1998 and 2004 evaluated the water quality of Banderica and Demyanica for saprobity, chemistry and structural values (Grunewald et al. 2007). Generally, the best quality was observed. Only some reaches showed deficits caused by the anthropogenic interference into the stream course and water withdrawal, for example artificial snow making (Banderica), waste water discharges and land use adjacent to the rivers (e.g. areas at the camping ground/kiosk near the Banderica Hut).

In August 2001 (dry weather flow) and June 2002 (humid phase), hydrochemistry and hydrobiology of selected streams in the northern Pirin Mountains were evaluated (Anonymous 2003). The results confirm a very high water quality in the rivers, which almost exclusively can be attributed to the salmonid zone. A continued scientific monitoring on runoff and water constituents has not yet been realized (Grunewald and Schmidt 2001; Anonymous 2003; Grunewald et al. 2007).

Batakliev (1972) counted 160 glacial lakes in the Pirin Mountains (plus 34 intermittent and 110 filled lakes) whereas today there are barely 118 glacial lakes with durable water regime (Anonymous 2003). Approximately one half of the lakes are situated in the cirques within the drainage basins of Demyanica and Banderica in the northeast of the mountains, which were affected the most by the Pleistocene glaciation. This applies to only the parts of the drainage basins in siliceous rock. If there are lakes with episodic water regime, they are in the marble region (cf. Fig. 2.3). In general, the lakes are small and shallow. More than 80% contain a water volume less than 100,000 m^3 (Anonymous 1977). The Popovo Esero is the greatest lake with an area of 12.4 ha and it's also the deepest with a 29.5 m depth.

There are current data on physical-chemical and biological parameters (Anonymous 2003, Bahr 2005) for many of the Pirin lakes. Neutral pH-values (6.5–7.5), electrical conductivity less than 30 $\mu S\ cm^{-1}$ and nearly non-detectable nutritional content are characteristic. The trophic level of the cirque lakes can be classified as oligotrophic and ultra oligotrophic (Anonymous 2003). The sedimentation of the examined lakes show different characteristics (Bahr 2005). For instance, Lake Muratovo and Lake Spanopolsko exhibit indications of biogenic fill-up by peat formation and macrophytes, whereas Lake Bezbog, Lake Ribno and Javorov Lake exclusively fill up with sedimentary material. These processes are natural and partly enforced by anthropogenic interferences (cattle breeding, tourism). Compared to the lakes in the Alps, the Pirin lakes are considered less affected and nutrient-poor (Veit 2002).

Vetter (2003) examined climate-driven changes of Lake Königssee near Berchtesgaden in the Alps from 1975 to 2005. The rise in air temperature by 2°C within this 30-year span also became noticeable aquatically. The lake temperature rose by 0.2°C, the stratification extended by approximately 30 days and the epilimnion shifted deeper by 1 m. The lakes in the Pirin Mountains should respond similarly.

2.4 Soil and Biosphere

In the northern part of the Pirin Mountains, soils, humus forms and vegetation types, as well as their hypsometric variance, were examined. Five toposequences with more than 70 sites were mapped. In addition to the field designation, pH-value, particle size, humus content, C/N ratio, lime and phosphor content, as well as cation exchange capacity, were determined (Grunewald et al. 2005).

Based on a digital terrain model (DTM) of Southwest Bulgaria, a digitized geological region map and statistical methods, the study sites were classified according to soil

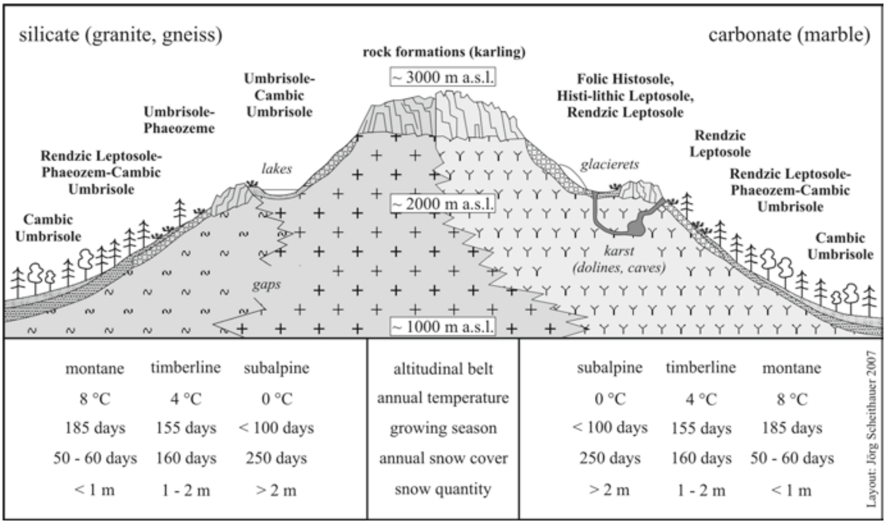

Fig. 2.7 Idealized profile across the northern Pirin Mountains

units (Läßiger 2006). The collected data provided a basis for the compilation of a "map of potential soil groups" by regionalization with the help of GIS (Fig. 2.8).

The distribution of soils is closely related to the geological, geomorphologic and climatic properties of the area (Grunewald et al. 2005). Figure 2.7 illustrates the typical sequence in the northern Pirin with an idealized profile. Läßiger (2006) provides detailed descriptions of the map units. Figure 2.8 shows the compiled soil map. According to AG Boden (1996) and WRB (2006), six different soil communities could be identified. The resulting map exhibits a confidence level of 68% on 74.4% of the covered area (Läßiger et al. 2008). Due to the orographic-determined climate gradient and depending on the petrological specification, different pedologically plausible sequences of soil types are found, which locally experience variations by geomorphologic conditions like exposition and inclination.

On calcareous substrate in higher regions, Skeleton soils and Rendzinas tightly interlock (complexed). At higher levels, alpine Lithosols (Folic Histosols, Histi-lithic Leptosols and Rendzic Leptosols) with occasionally thick humus layers are predominant. Rendzinas (Rendzic Leptosols) are superseded by a combination of Rendzinas, Pararendzinas and Cambisols (Rendzic Leptosols-Phaeozems-Cambic Umbrisols) at decreasing altitudes. On silicatic substrates, pedogenesis is more advanced, such that Regosols in combination with Cambisols (Umbrisols-Cambic Umbrisols) can be found at sites with high radiation exposure, even in alpine regions. Cambisols with increasing thickness and browning of the profiles are found at decreasing altitudes. Other than the enhancement of soil development with decreasing altitude, the hypsometric variance manifest as humus content decreases. The influence of substrates becomes evident in both the enhancement of soil development and in the increase of soil acidity (cf. Blume et al. 2002; Matthews 1992;

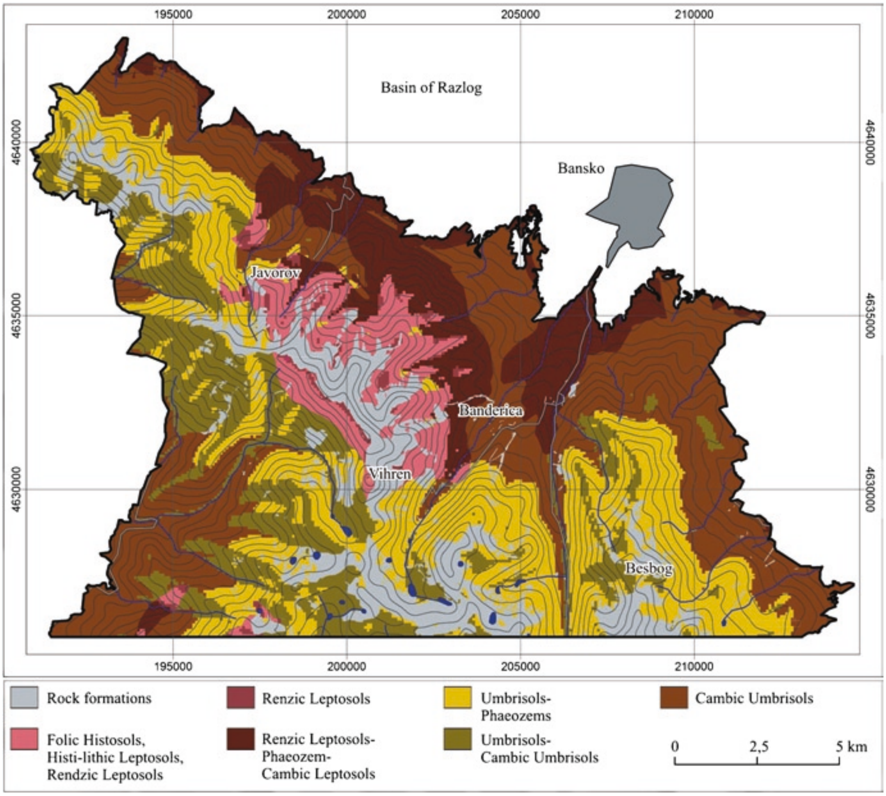

Fig. 2.8 Map of potential soil groups in the northern High Pirin Mountain (Läßiger et al. 2008)

Sjogersten 2003; Stanton et al. 1994; Stottlemeyr et al. 2001; Veit 2002). Humus types are closely related to vegetation. The occurrence of raw humus is related to coniferous trees, while mull and mould are found at sites with larger radiation exposure and under grass and deciduous trees. Within the chemical parameters the humus content exhibits a hypsometric variation. The corresponding slope is 0.8% per 100 m. On calcareous substrates, the soil reaction is slightly acidic or neutral, whereas on silicatic substrates, the pH-level is strongly acidic. The C- and N-content is with 0.77 closely correlated (progressivity of regression 0.053). The C:N ratio exhibits an average value of 18. Subalpine grass areas at the timberline tend to have a higher proportion of nitrogen and therefore a lower C:N ratio than brown vegetation such as dried leaves under forests, particularly on Cambisols (cf. also Section 4.3).

Pirin National Park is on the intersection of the European, Mediterranean and Pontic biogeographical regions. Vegetation zones and altitudinal levels, as well as vegetation-ecological mappings along an altitudinal transect between Bansko and Golemya Kazan Cirque, is compiled in Grunewald et al. (1999). A comprehensive

Table 2.2 Pirin National Park – vegetation communities and representative species (acc. Anonymous 2003)

Community	Representative species
Riparian communities	*Heracleum verticillatu, Cirsium appendiculatum*, *Eriophorum latifolium, Cardamine rivularis, Plantago gentianoides*, *Parnassia palustris*, *Saxi-fraga stellaris*, *Silene pusilla*, *Carex nigra, Carex distans, Trichophorum caespitosum*, *Ranunculus aquatilis*, *Sparganium angustifolium, Isoetes Lacustris*, *Subularia aquatica, Cirsium appendiculatum*, *Heracleum verti-cillatum, Doronicum hungaricum*, *Petasites albus*, *Parnassia palustris, Juncus, Petasites kablickianus*
Shrub communities of the sub-alpine level	*Pinus mugo*, *Vaccinium*, *Sesleria comosa, Nardus stricta, Sesleria coerulans, Agrostis rupestris*, *Carex curvula*, *Juniperus sibirica, Lerchen-feldia flexuosa, Festuca valida*, *Festuca nigrescens, Sesleria comosa*, *Chamaecytisus absinthioides, Agrostis capillaries*, *Bruckenthalia, Dryas*
Grassland communities	*Sesleria comosa, Nardus stricta, Festuca valida, Deschampsia caespitosa, Carex, Festuca nigrescens, Festuca nigrescens, Nardus stricta*, *Agrostis capillaries, Calamagrostis arundinacea*
Forest communities	*Pinus nigra, Pinus sylvestris, Pinus peuce, Pinus heldreichii/ Picea abies, Abies alba, Fagus sylvatica, Populus tremula*
Rock communities	*Saxifraga*, *Thymus perinicus*, *Papaver degenii*, *Arabis ferdinandi-coburgii, Potentilla appenina* ssp. *Stojanovii*, *Dianthus microlepis, Androsace villosa*, *Rhodax alpestris*, *Silene acaulis* u.a.
Secondary communities (anthropogenous)	*Verbascum longifolium* ssp. *Pannosum, Rumex alpinus, Veratrum album*, *Deschamptia caespitosa, Polygonum arenastrum*, *Galeopsis bifida*, *Chenopodium bonus-henricus*

inventory of the flora and fauna in Pirin National Park was carried out in context with the "Pirin Management Plan 2004–2013" (Anonymous 2003). Popov et al. (2005) present a prevailing and well illustrated monograph on the biotic configuration of the Pirin Mountains.

Due to the specific flora, the Pirin constitutes a separate zone of Bulgaria's vegetation units (Bondev 1991). According to Anonymous (2003), a vegetation classification can be carried out considering the groups shown in Table 2.2.

Including the stands of dwarf mountain pines (*Pinus mugo*), forest covers the largest area of the National Park at 57.3%. Pine stands are dominant. Overall, there is 95% of coniferous forest compared with only 5% of deciduous forest (Anonymous 2003). The forest condition is appraised as good. The distribution of tree species becomes apparent in Figure 2.9.

The Pirin flora is comparatively authentic and autochthonous. Lower plants comprise:

- Aquatic plants: 165 species, one very rare and two endemic
- Lichens: 329 species, three protected
- Fungi: 375 species, six with strict protection requirements
- Mosses: 367 species, 25 rare

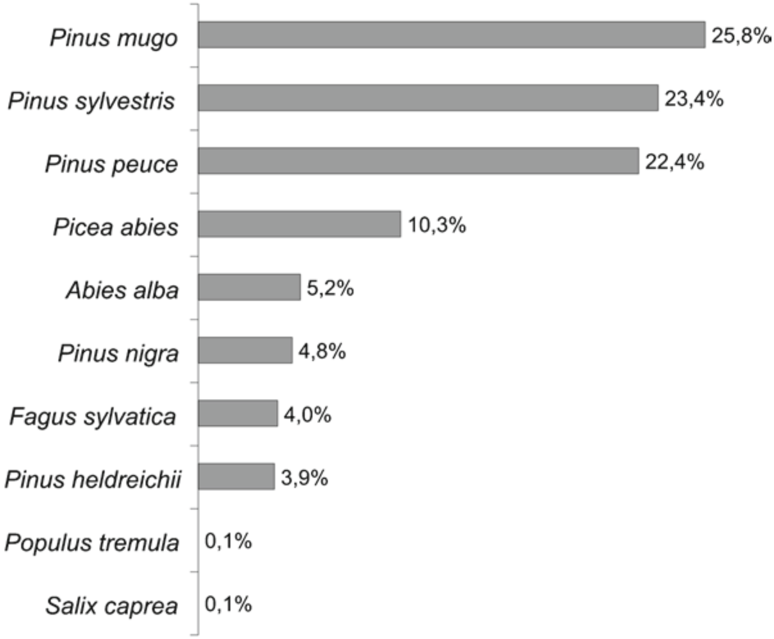

Fig. 2.9 Tree species distribution at the National Park Pirin (Anonymous 2003, p. 46)

In the National Park there are 149 species among the 1,315 higher plant species with special importance placed on nature conservancy matters. One hundred and fourteen of these species are listed in Bulgaria's Red Book of endangered species, 54 species enjoy protection by law and there are 14 Pirin, 17 Bulgarian and 86 Balkan endemics (Popov et al. 2005). Some plants underlie protection requirements according to international conventions, among others the *Pinus peuce* (Macedonian pine). The National Park's Management Plan presents clear protection and use restrictions for flora and fauna (Anonymous 2003).

The invertebrates amount to 2,091 species, 294 of them are rare, 216 endemics and 176 relics. Typical are spiders (*Araneae*), centipedes (*Myriapoda*), mayflies (*Ephemeroptera*), caddis flies (*Trichoptera*), stoneflies (*Plecoptera*), dragonflies (*Odonata*), true bugs (*Heteroptera*), beetles (*Coleoptera*), net-winged insects (*Neuropterida*), membrane-winged insects (*Hymenoptera*), butterflies (*Lepidoptera*) and molluscs.

Six fish species live in the Pirin Mountains. As a glacial relic, the Balkan trout (*Salmo trutta*) is a species of particular interest. Eight amphibians, 11 reptilian species, 159 bird species and 45 vertebrates are counted in the Pirin. Many of them are under a high protection state due to their biological importance and endangerment status (Anonymous 2003). The wild species brown bear (*Ursus arctos*), grey wolf (*Canis lupus*), European pine marten (*Martes martes*) and the Balkan chamois (*Rupicarpa rupicarpa balcanica*) are examples (Anonymous 2003; Popov et al. 2005).

Although many plants in high mountain ecosystems are able to live a long life – some communities more than 1,000 years – they require relatively little space. However, most animals do not grow as old (30 years on average) but require a larger living space (Nagy et al. 2007). Species respond differently to climate changes and anthropogenic interferences (Erschbamer 2007).

2.5 Pirin National Park – Potentials and Anthropogenic Interference

Natural potential determines the pros and cons for human utilization of the landscape and the distribution and intensity of land use, but depends on climate as an ecological control factor (Blümel 2002). In a high mountain region many kinds of land use are limited or impossible. Table 2.3 compiles advantages and disadvantages of the natural setting in Southwest Bulgaria. Basically, they do not differ from other mountainous regions.

In the mountain region Rila-Pirin-Rhodopes forests are predominant, whereas agriculture and settlement areas confine basins and valleys (Grunewald et al. 1999; Grunewald et al. 2007). Due to the resource availability within the northern Pirin study area, four branches became important:

1. The forestry industry: More or less intensive, the timber richness of the montane belt is traditionally used as construction timber and firewood, as well as for furniture construction.
2. Water: Irrigation, drinking water, energy generation and most recently for artificial snow making.
3. Mountain pastures: The Aromanians were residents in the Pirin Mountains; in summer they used the pastures in Pirin and in winter they drove the cattle to the

Table 2.3 Landscape potential of Southwest Bulgaria (Grunewald and Scheithauer 2007)

Favorable factors	Disfavorable factors
Raw material/mining: iron ore, coal, uranium, marble and other	Location: peripheral, near borderlines, migration area
Geothermic/mineral and hot springs	Mountain relief, altitude and climate, impassibility, isolation areas
Water: irrigation, hydroenergy, fish	
Timber, herbs, mushrooms, berries	Mountain soil conditions: shallow, nutrient-poor, stone-rich, dry/wet
Pastures, hunting grounds	Vulnerability: earthquakes, floods, droughts, erosion and other
Fertile soils in basins and valleys; cultivation of special vegetation: tobacco, rice, wine and other	
Fresh mountain air, bracing climate, landscape scenery, uniqueness and beauty	
Biotic refuges	

plains in the Aegean (Kahl 2003). Since the beginning of the twentieth century, the pasture economy has regressed due to border politics and the displacement of the Aromanians.

4. Tourism: Louis (1928) wrote about the increasing influence that tourism had on the most beautiful and most accessible areas of the Pirin Mountains. Today, tourism is still of enormous importance for the region. Bansko emerges as eastern Europe's number one winter sports resort location. Roads and lifts have made the high-elevation sites accessible to everyone (Grunewald and Scheithauer 2008).

Tourism is also the region's motor for socioeconomic development. The traditional mountain agriculture is regressing. Only half of the pastures' capacities are used. Anonymous (2003) estimated the potential for grazing animals in the mountain regions Bayuvi Dupki, Vihren, Bezbog, Sinanica and Kamenica at 2,954 animal units. From 1997 to 2001, the number of grazing animals amounted to between 1,162 and 1,370. One animal unit refers to one cow with 500 kg of weight and a daily consumption of 60 kg of forage, or five sheep or 0.8 horses.

The economic role model of the Alps serves as a guide for mountain regions in southeastern Europe since the fall of the Iron Curtain. It didn't take long to learn that ski and spa tourists bring in significantly more money than hikers and eco-tourists (Grunewald and Scheithauer 2008). The needs of consumers changed rapidly. Recently, a trend to short break, spa and event sports has emerged. The interdependency between tourism, climate change and natural hazards will be much more in focus.

The tourist industry has the biggest strategic significance on Bansko's social-economic development, as it is the most dynamic and the fastest growing branch of the economy. For the period 2001–2006 investments in tourism totalled over 100 million Euros. This led to more than 500 new employment positions in tourist services and several times more than that in the building sector (Anonymous 2008). In recent years (before the global economic crisis), more than 100 hotels were built, from small family hotels to luxurious four-star complexes. Hotel "Kempinski Grand Arena" is the first five-star hotel in the resort area. The bed facilities increased from 2,000 (2002) to 10,000 (2007) with a goal to reach 20,000 (Anonymous 2003, 2008). The clientele are generally wealthy Bulgarians, Greeks, Russians, Germans and most of all British. The latter are the target group for selling flatlets under the slogan, "Why not Bulgaria" (Bulgarian Property Agents 2008).

This development has changed the settlement structure of Bansko rapidly, increasingly interfering in nature and putting growing pressure on resources. The infrastructure is overloaded and negative ecological effects are obvious. Environmental organizations documented that the development of the mountains was not exercised with the required care (e.g. Za Zemiata 2007). Is a healthy coexistence between the dispersing, intensified tourism industry and the concerns of nature conservancy possible?

The area of the Pirin NP, including two UNESCO-MAB Biosphere Reserves, comprises 40,356 ha, which makes up 22% of the whole Pirin Mountains. In comparison, 25% of the Alp's total area are under protection. The biotic and abiotic potential of protection was outlined in the previous sections. Until 1999 it was a "Peoples' Park" (bulg. "Naroden Park") under the administration of the state ministry of forestry (Grunewald and Stoilov 1998). In 1998, Bulgarians reformed nature conservancy law and categories according to international guidelines. The NP is now under the control of the Ministry of Environment and Water. It holds the highest conservancy status in Bulgaria. The NP is integrated in ecological networks as it is member of the EUROPARC Federation, approved by IUCN and included on the UNESCO world heritage list.

The NP's main objectives are set as follows: Preservation of the (sub) natural and worthwhile landscape; preservation of the region's representative landscape types as well as its flora and fauna. Hence, there are following major tasks:

- Execution and coordination of education and recreation as well as science and research in the NP
- Compilation of a nature management plan for maintenance and development
- Coordination, authorization, assistance and control of the planning and execution of all activities concerning the NP

The enacting of the Management Plan for Pirin National Park 2004 to 2013 is a milestone which could be realized with financial help and the assignment of personnel by Switzerland (Anonymous 2003). The plan includes nature conservancy and landscape development, as well as the use of resources and tourism, so as to provide an integrative review. The NP serves as a socioeconomic factor of regional development and constitutes a binding operational instrument. Modelled on "The Alpine Convention" (1991) the management plan became the basis for sustainable development in the mountain region. It is aimed at guaranteed attractive living conditions. This comprises the intermediation in the conflict between the claims of use and conservancy strategies (Grunewald and Scheithauer 2008).

The touristic use of national parks in Europe is not uncommon. They are zoned to separate areas under strict protection (core zones, reserves) from other areas. Figure 2.10 illustrates that only 3.3% of the total area in Pirin National Park is allotted for tourism use. Insofar as the possibility for exemplary cooperation does exist, Bansko and the National Park may act as a model region for modern nature conservancy and the establishment of sustainable tourism on a local, national and international scale. The realization of the objectives established in the management plan requires time, consistency, support and control. If it fails to constrict the further development of the tourism industry, the protective areas of the Pirin are in danger of deterioration.

The international community is watching whether the region can succeed in combining matters of nature conservancy with tourism. Investors, the local population and tourists should be aware of the vulnerability of sensitive high mountain ecosystems and that the World Heritage List approved the UNESCO-MAB reservations as being not untouchable. The Pirin region could be regarded as a role model for upcoming ski resorts in southeast Europe national park areas (e.g. Rila Mountains) and beyond (e.g. Sotchi/Caucasus).

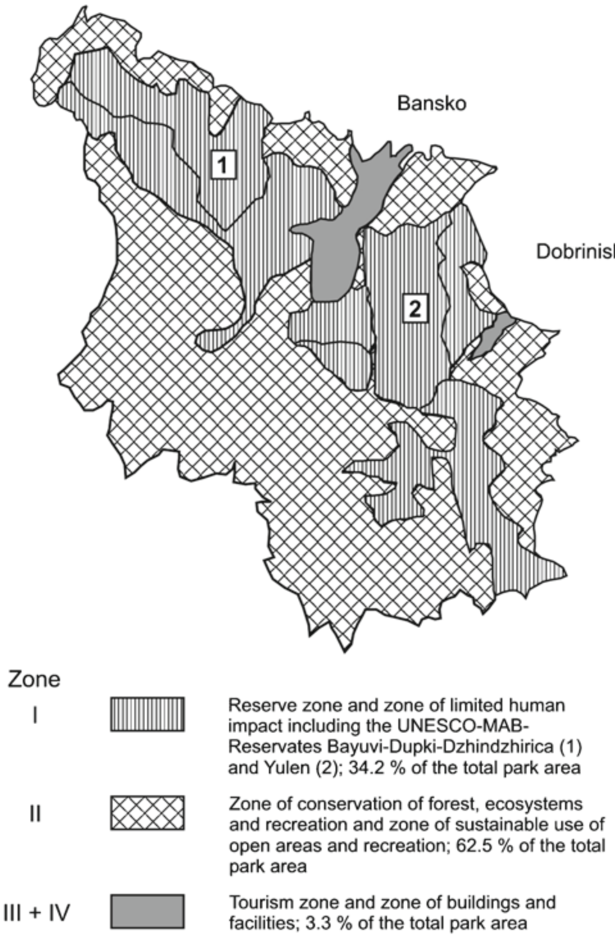

Fig. 2.10 Pirin National Park – zoning of its territory

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Chapter 3
Holocene Climate and Landscape Chronology

Abstract The cyclical ups and downs of historic climate conditions and human effects on our area of study can be detected in pollen profiles of peat, glacier features and soils (stratigraphy, macrofossils, charcoal, ^{14}C-dating). This leads to a chronology on a millennium scale. This chapter uses Southwest Bulgaria to demonstrate the relationship between people and their environment in Southeast Europe. It investigates the connection between climate dynamics and the cultural history of the region. Climate is one of the key regulation factors in this regard. Periods of prosperity and periods of crisis that are linked to the climate were detected for the Balkans and can be shown for Southwest Bulgaria as well. Particularly during the Bronze Age, Iron Age, Roman Age, the "Golden Bulgarian Age" and Little Ice Age, the phases of climatic stagnation and transition correlate with stability (soil formation), activity (erosion), and settlement dynamics (expansion versus abandonment).

Keywords Cultural/vegetation history • Geoarchive • Holocene • Palaeoclimate • Pollen analysis • Radiocarbon • Timberline

3.1 Würm Glaciation and Late-Glacial Development

Glacial and periglacial landforms are manifold in the mountains of Southeast Europe. Hughes et al. (2006) identified three phases of development of Quaternary research in this area:

- First, a pioneer phase characterized by initial descriptive observations of glacial landforms.
- Second, a mapping phase whereby the detailed distribution of glacial landforms and sediments have been depicted on geomorphological maps.
- Third, an advanced phase characterized by detailed understanding of the geochronology of glacial sequences using radiometric dating as well as detailed sedimentological and stratigraphical analyses. There is not much of such updated geomorphological research (third phase) on the Balkan Peninsula and in Bulgaria (Kuhlemann et al. 2008, Milivojevič et al. 2008).

K. Grunewald and J. Scheithauer, *Landscape Development and Climate Change in Southwest Bulgaria (Pirin Mountains)*, DOI 10.1007/978-90-481-9959-4_3,

The evidence for glacial and periglacial activities has been studied (first phase) for the Pirin region most notably by Hochstätter (1870), Cvijić (1898, 1909), Penck (1925), Louis (1928, 1930, 1933), Gellert (1932) and Wilhelmy (1935). Most of the following research is based on this initial observation and description of glacial features in the upland landscape, particularly the work of Louis (1930) for the Pirin Mountains.

The second phase, which began in the second half of the twentieth century, was dominated by Bulgarian geomorphologists. Notable exceptions include the work by Glovnia (1958, 1962, 1968), and Popov (1962), and later by Velchev (1995). These authors used relative dating methods with an emphasis on morphographic analyses. Absolute dating and application of modern palaeochronological techniques are only the beginning of glacial-morphology study in Southwest Bulgaria.

The highest mountains of the region (Rila and Pirin) were glaciated on multiple occasions during the Pleistocene. Glacial traces in both massifs show large contrasts between short steep glaciers exposed to the south and long flat glaciers exposed to the north (Louis 1930, Kuhlemann et al. 2008).

Glacial geomorphological records offer evidence of palaeoclimatic conditions in high mountains during the Quaternary in southern Europe (e.g. Cacho et al. 2002, Garcia-Ruiz et al. 2003, Alberti et al. 2004, Woodward et al. 2004, Kuhlemann et al. 2005). Figure 3.1 shows the estimated glacier fluctuations of the cirque Golemya Kazan in the Pirin Mountains. Most extensive phases of glaciation probably occurred during the Mid-Pleistocene (Kuhlemann et al. 2008, Hughes et al. 2007). In Greece, Italy and Spain the glacial deposits of the Mid-Pleistocene age were specified by radiometric dating (Hughes et al. 2006). The glacial succession in Greece was dated by Hughes and others (2006) who applied U-series methods to date secondary carbonates within Pleistocene tills to develop a new regional geochronology and chrono-stratigraphy. This evidence provided the basis for palaeoclimatic reconstructions of different glaciations. Hughes and others (2007) analyzed the lowest mean summer temperatures during 474,000–427,000 a BP (Mid-Pleistocene), which caused the most extensive glaciations recorded in the Mediterranean region. Later Pleistocene glaciations were characterized by higher summer temperatures and higher annual precipitation, resulting in less glaciation (Vlasian stage and Tymphian stage of the Pindus chrono-stratigraphy; cf. Hughes et al. 2007).

In other regions, detailed sedimentological and pedological analyses of glacial and fluvio-glacial sediments are needed to supplement the numerical dating methods, for example, in other Balkan mountains (Milivojevič et al. 2008, Grunewald and Scheithauer 2010).

The Middle Pleistocene glaciers covered an area of ca. 60 km² of the Pirin Mountains. They formed U-shaped valleys and lower-level cirques (Fig. 3.1a). Cirque barriers of 6 to 140 m height show the dimension of glacial forming (Glovnia 1968). The largest glaciers were situated in the Demyanica and Banderica valleys. As opposed to northern Europe and the Alps, the lowland areas of Southwest Bulgaria were characterized by dry and cold steppe during glaciation times. In the Balkans, this is thought to be responsible for genetic diversity and richness of endemic species (Hewitt 1999, Griffiths et al. 2004).

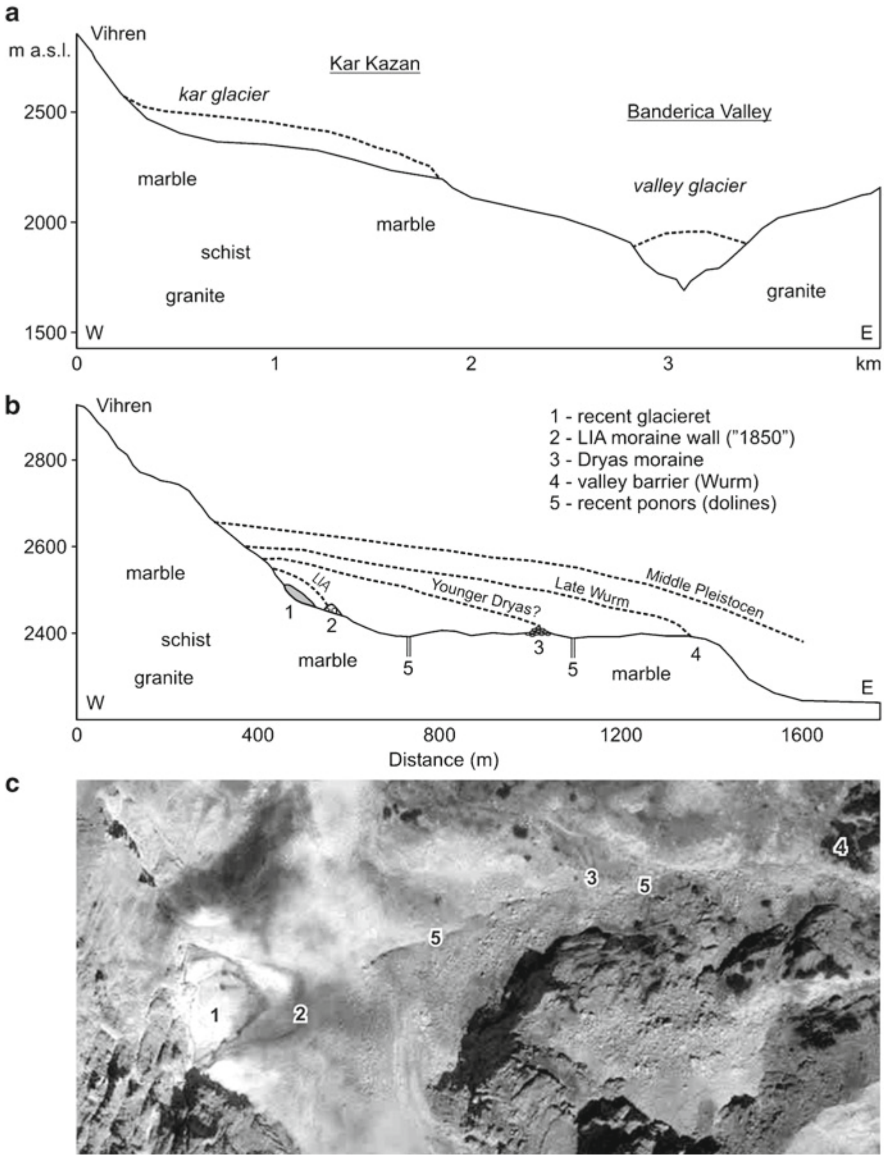

Fig. 3.1 Simplified profile of the glacier positions on a scale of millennia in Golemya Kazan cirque in the northern Pirin Mountains, Bulgaria (**a**) section Vihren – Banderica Valley, (**b**) section of cirque Golemya Kazan, glacier extents estimated according to Popov 1962 and (**c**) satellite imagine of cirque Golemya Kazan with (1) glacieret "Snezhnika" (source: maps.google.de)

The glaciation of the region during the Last Glacial Maximum (LGM ~ 20,000–18,000 ^{14}C BP) reached half of the glacier extension during the Middle Pleistocene (Popov 1962, Kuhlemann et al. 2008). Except for the Pyrenees, the Würm glaciers in southern Europe were limited to a few high altitude cirques (Messerli 1967), which melted relatively quickly. During the late Würm however, fossil, secondary, lobed cirque glaciers and/or rock glaciers must have been situated in cirques such as Golemya Kazan (Fig. 3.1a and b). At lower levels of the northern sides, such as at Malkya Kazan, and at the southern sides, the periglacial solifluidal slope smoothing was the predominating shaping mechanism during Würm Glacial (Höllermann 1983, Schröder and Berkner 1986). Absolute dating has been applied to only one sample from the Rila Mountains, taken in the Musala area from a stadial moraine at 2,390 m a.s.l. (Velchev 1995). The age obtained by thermoluminiscence – 12,000 ± 700 years BP estimates this deposit to probably Younger Dryas depositional age. According to Kuhlemann et al. (2008) the main palaeoclimatic issues unsolved in the Rila and Pirin mountains concern:

- Absolute dating of stadial moraines to follow glacier (and climate) dynamics during the main glacial stages in Late Pleistocene and Early Holocene (Heinrich events, Older Dryas, Younger Dryas, Boreal); and
- Calculation of the equilibrium line altitude (ELA) during the LGM and its patterns within the mountain massif caused by local differences (aspect, location in the mountain) in order to constrain regional atmospheric circulation.

Nevertheless, the initial position of landscape development in Late Würm (15,000 BP) for the higher areas of the Pirin Mountains can be summarized as follows:

- Low mean temperatures (ca. 3–5°C lower than today)
- Glacier/block glacier in north-/northwest exposed cirques above ca. 2,300 m a.s.l.
- Periglacial conditions in the subsequent level

In comparison to the Alps and Northern Europe with large-scale Würm glaciation, the small glaciers of Southeast Europe rapidly reacted to the start of warming. Sufficient habitats as refuge for higher plants and animal species probably existed in ice-free areas of lower mountain belts.

After Würm glaciation, the glaciers of Europe melted relatively rapidly, as the saltation of sediment balance of peripheral alpine lakes documented (Veit 2002). The melt water input from many alpine lakes ended from 13,000–12,400 BP. The decrease of ice and snow left slopes with no vegetation in higher mountain regions, which caused heavy erosion and mass movement. Bozilova et al. (2004) and Stefanova et al. (2003) examined the analogous development for the Pirin lakes. Silty-clayey lake sediments with relative high content of sand without fossil pollen indicate vegetation-free conditions that promote erosion during the first phase of the Late-Glacial (Older Dryas, 15,000–13,000 BP).

The geomorpho-dynamics, vegetation succession and 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 (Grunewald and Scheithauer 2008a). The Pirin Mountains region is well researched in this regard (e.g. Bozilova and Tonkov 2000, Stefanova and Ammann 2003, Stefanova et al. 2006, Tonkov et al. 2002). It is certain that all smaller southern glaciers melted at the optimum climate of the Atlantic Period. The reconstruction of the alpine timberline implies

Table 3.1 Review of the geoarchives lake sediment core, peat bog and fossil soil in higher areas of the Pirin Mountains

Site (m a.s.l.), location see Fig. 3.2	Number of ^{14}C datings		Source
	Late-Glacial	Holocene	
(1) Mozgovica peat (1,800)	–	2	Tonkov (2003)
(2) Lake Ribno Breznizhko (1,963)	–	4	Atanassova and Stefanova (2005)
(3) Lake Banderizhko (2,190)	–	6	Tonkov et al. (2002)
(4) Kremensko-5-Lake (2,114)	6	8	Atanassova and Stefanova (2003) and Stefanova et al. (2006)
(5) Lake Muratovo (2,230)	–	9	Bozilova et al. (2004) and own investigation (2002)
(6) Lake Bezbog (2,250)	4	4	Stefanova et al. (2006)
(7) Lake Dalgoto (2,310)	–	9	Stefanova and Ammann (2003)
(8) Moraine at Golemya Kazan cirque (2,430)	–	4	Own investigation (2005–2007)
(9) Soil profile at Malkya Kazan cirque	–	12	Own investigation (2005–2007)
(10) Soils of marble timberline ecotones above the Banderica Hut (1,950–2,200)	–	6	Own investigation (2005–2007)
(11) Soils of granite timberline ecotones between the Vihren Hut and Spano Pole meadow (1,880–2,430)	–	7	Own investigation (2005–2007)

that the snow line during the Holocene did not significantly change (Grunewald and Scheithauer 2008a).

The phases of vegetation development are well examined, documented and dated (Table 3.1, Figs. 3.3 and 3.4). Palynological studies of Lake Kremensko (Atanassova and Stefanova 2003), Lake Dalgoto (Stefanova and Ammann 2003) and Lake Ribno Banderizhka (Tonkov et al. 2002), as well as of lakes and peat bogs in the Rila and Rhodope Mountains (Bozilova and Tonkov 2000, Huttunen et al. 1992) show that the plant communities of the Late-Glacial period had a very similar taxonomic composition at higher elevations in the mountains of Southwest Bulgaria. Pollen zones correlate with the European biostratigraphic subdivisions on the basis of the calibrated ages (Stefanova et al. 2006).

The core of Lake Kremensko-5, one of the cirque lakes in the northern Pirin Mountains (41°43′N/23°32′E, 2,140 m a.s.l.), contains sediments dating back more than 13,500 years. The radiocarbon dates of the bottom sediments of this lake are the oldest of the Bulgarian mountains and have important implications for the chronology and interpretation of vegetational changes during the interstadial/stadial cycles of the Late-Glacial. Lake Kremensko-5 has more than a meter of Late-Glacial sediments (Atanassova and Stefanova 2003).

The Late-Glacial chronology can be divided into four pollen zones (Atanassova and Stefanova 2003, Stefanova et al. 2006):

1. The initial step in vegetation development began before 13,500 years BP. Cold-resistant species were present. The found pollen herbs suggest the ground covers composition immediately after ice retreat. Wide distributions of open herb communities were dominated by *Artemisia* and *Chenopodiaceae*.
2. Zone 2, dated with 13,350–12,360 BP, also suggests open herb communities of mountain steppe. Increased values of *Ephedera distachiya* type and *E. fragilis* type in the pollen spectra imply drier conditions than during zone 1.
3. After 12,360 BP, the increase of *Pinus diploxylon* indicate warmer conditions leading to the enlargement of coniferous trees in the higher mountain regions. It probably shows the beginning of the Bölling-/Alleröd-Interstadial stage. A distinct change in the type of sediments from grey-green silt to brown silty gyttja was also observed, which suggests increasing productivity in the lake or on the land.
4. In pollen zone 4, the dominance of *Artemisia* and *Chenopodiaceae,* and the occurrence of the *Juniperus-Ephedra* assemblage, indicate increasing aridity and a colder period (Younger Dryas). Mountain steppe species again dominate the areas in 2,000 m a.s.l. elevation, and trees are rare. But the persistence of high levels of *Poaceae* implies that climatic conditions were less severe than before 12,360 years BP.

It is possible to draw the following main conclusions concerning this Late-Glacial environmental and palaeovegetational reconstruction: First, in comparison to the Late-Würm, it became warmer and drier (Oldest Dryas, 15,000–13,000 BP). *Artemisia* and *Chenopodiaceae* predominate, indicating the presence of mountain steppe pioneer vegetation soon after the ice retreat. The morphologic activity increased (erosion, fluvio-glacial debris movement).

From 13,000 BP (or even earlier) temperatures increased once again and humidity probably also rose. An initial increase of organic matter in lake sediments was measured as well (Bozilova und Tonkov 2000, Stefanova et al. 2006, Tonkov et al. 2006). This phase marks the Bölling-/Alleröd-Interstadial, whereas a depression of temperature cannot be explicitly documented for the Older Dryas in the Pirin region. Re-forestation started with migration from the refugial areas in lower elevations. The pollen spectra of investigated cirques were characterized by *Pinus diploxylon* types and macrofossils of *Pinus peuce* and *Juniperus*. Other wind-drifted tree pollen increased (*Quercus, Alnus, Ulmus* and other).

During Younger Dryas (ca. 11,000–10,200 BP) trees again shifted to lower altitudes because of colder conditions. There was a mountain steppe with grass heather and individual dwarf shrubs (*Ephedra, Juniperus*) in altitudes around 2,000 m a.s.l. Palaeolimnological studies of Lake Dalgoto (Stefanova et al. 2003) ensure the described regional climate conditions of Younger Dryas: low water temperature, long ice covering, low productivity and diversity of Diatom. However, the cirque

Dalgoto (ca. 2,300 m a.s.l.) was free of ice during the Younger Dryas period, whereas small debris that covered glaciers and rock glaciers probably existed in a few exposed cirques in high altitudes (ca. 2,400 m a.s.l.) of the northern Pirin (e.g. cirques Golemya Kazan and Banski Suhodol), indicated by moraines of retreat stages, as Fig. 3.1b and c show.

3.2 Climate and Vegetation During the Holocene

Unlike the unknowns in the characteristics of the Late-Glacial period, the Holocene vegetative development in southern Bulgaria's high mountains is comparatively well known and supported by consistent radiocarbon chronologies, as Fig. 3.2 and Table 3.1 show. Lithology and stratigraphy, pollen and plant macrofossil analysis, as well as radiocarbon dating performed on profiles from subalpine lake sediments and peat in the northern Pirin Mountains, enable the reconstruction of vegetation

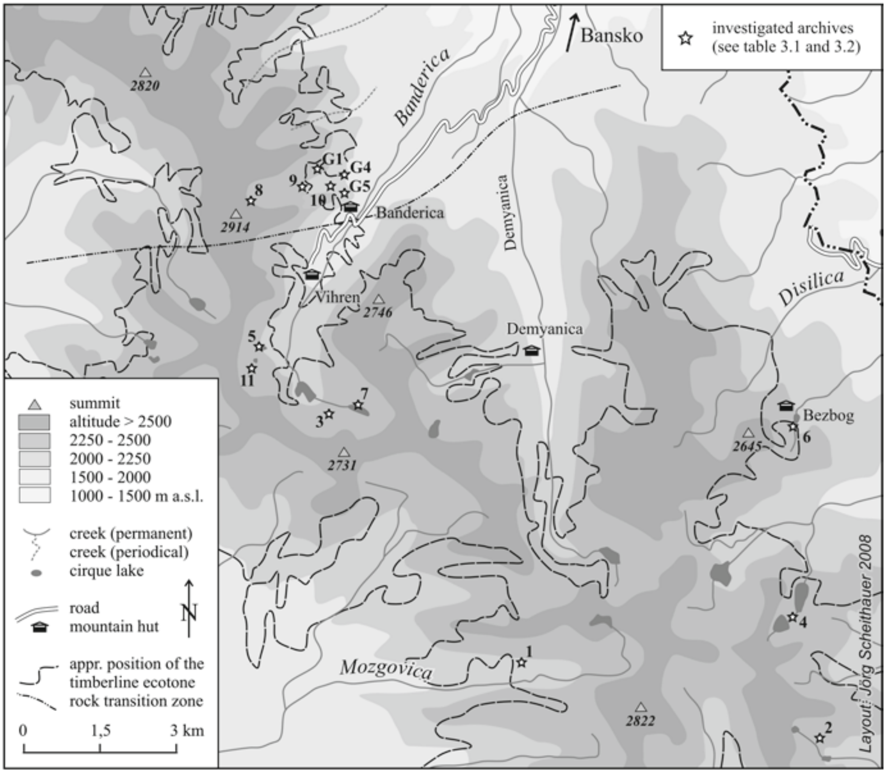

Fig. 3.2 Location of examined georchives in the Pirin Mountains (cf. also Table 3.1)

history, climate phases, morphologic dynamics and human pressures (e.g. Stefanova et al. 2006, Tonkov et al. 2006).

The investigation of fossil soils and younger moraines help improve our knowledge of the Holocene landscape history (Grunewald and Scheithauer 2008c). Stratigraphic and dating examination was performed at the moraine of the Vihren glacieret (Grunewald and Scheithauer 2010), at two sites in the cirque Malkya Kazan, at nine sites on marble below the Malkya Kazan cirque barrier and at five sites on granite rocks in the upper Banderica valley. Figure 3.2 shows the location.

In addition to mapping the geomorphological and vegetational properties, the sites were recorded and samples were collected from different horizons. The air-dried fine soil (<2 mm) was investigated with respect to its particle size (sieving), pH-level (electrometric in KCl solution), nitrogen content (N_{org}, acc. to Springer/Klee with Büchi instrument), phosphorous (P_t, photometric acc. Kjeldahl), organic carbon content (C_{org}, wet combustion acc. to Springer/Klee), the elements Fe, Al, Mn and Ca (HNO/HF-extraction, measured by atomic absorption spectrometry), pedogenic iron (Fe(p,) extracted with Dithionit-Citrat acc. Mehra & Jackson, measured by atomic absorption spectrometry), and lime content ($CaCO_3$, with Scheibler). The corresponding methods are described in Barsch et al. (2000) and Schlichting et al. (1995).

Björn Günther, Institute of Forest Use, University of Technologies Dresden, was able to determine existing wood types of sampled available charchoal. More than 70 radiocarbon datings of pollen, macrofossils, charcoal and fine humic sediments/soils, analyzed by different approved-AMS laboratories are available today, as Table 3.1 lists.

Figure 3.3 shows the approximate distribution of forests and how the major trees adapted to ecological conditions at mountain levels. Birch trees quickly reached an altitude of about 1,900 m a.s.l. during the Early Holocene. The so-called Holocene Climatic Optimum was marked by the *Pinus peuce* expansion. The *Pinus peuce* distributed up to 2,300 m a.s.l. during the 7,000–4,000 years BP period. This corresponds well with the maximum rise of the timberline in the Alps and the maximum northern shifting of the polar timberline in Fennoscandia. The Holocene has been a period of

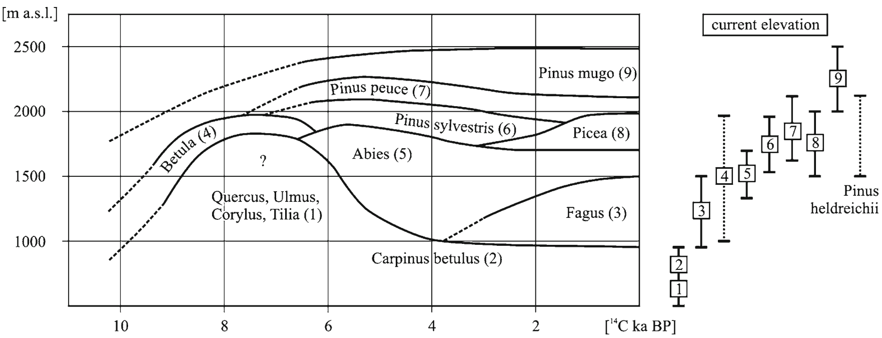

Fig. 3.3 Distribution and elevation gradient of main tree species in the Pirin Mountains during Holocene (according to Stefanova and Ammann 2003, p. 104, modified)

remarkable climatic stability in Europe. During the Holocene, the temperatures varied within a small range of ±2°C (Veit 2002, Solomon et al. 2007).

Climate-ecological changes, different distances to the glacial refuges and long migration times of the species probably caused the expansion of deciduous forests and the late widespreading of *Abies* and especially *Picea* (Grunewald and Scheithauer 2008a). Warm and wet conditions during the early and mid Holocene may have favored the rise of the upper limit of the deciduous tree taxa.

On the millennium timescale, changes in the earth's movements (variations in eccentricity, axial tilt, and precession of the earth's orbit) determined climatic patterns on earth, known as Milankovitch forcing. The distribution of total solar irradiance substantially changed over the course of the last 6,000 years due to changes in the orbital parameters. The largest changes occurred during boreal summer and autumn, when the solar irradiance was progressively reduced in the Northern Hemisphere and enhanced in the Southern Hemisphere. Therefore, the Intertropical Convergence Zone (ITCZ) and the monsoon systems moved south (Wanner et al. 2008). This trend started from ca. 5,500 years BP and was abrupt in some regions, especially in Southeast Europe and the Mediterranean. It is a main reason for the changing dominating tree species in the Pirin Mountains during this time period (Fig. 3.3).

3.2.1 Early Holocene (Preboreal, Boreal)

The Holocene starts with a sharp increase in the tree pollen of *Betula, Quercus*-types, *Corylus, Alnus, Ulmus, Tilia* and *Pinus Diploxylon*-types such as *Pinus peuce,* as Figs. 3.3 and 3.4 show. Accordingly, the amount of cold-resistant, non tree pollen types (*Ephedra, Artemisia, Chenopodiaceae, Poaceae, Achillea, Rumex, Aster*, etc.) decreased (Bozilova and Tonkov 2000). But the diversity of herb types, as seen in the Late-Glacial, continued in the Early Holocene in higher altitudes. Pedogenesis slowly began and vegetation became denser. The lithology of lakes shows increasing proportions of organic matter and algae, whereas minerogenic incorporation into lakes decreased (Stefanova et al. 2003).

The initial stage of afforestation began with the spread of birch (*Betula pendula*) in open forests at middle and higher altitudes. Individual groups of pines (*Pinus mugo, Pinus sylvestris, Pinus peuce*), alder (*Alnus viridis*) and willows (*Salix* ssp.) established themselves (Bozilova und Tonkov 2000). The upper treeline was formed by *Betula pendula* at about 1,900 m a.s.l. during the Early Holocene (Preboreal and Boreal) in the northern Pirin Mountains. An expansion of mesophylous deciduous trees (*Quercus, Tilia, Ulmus, Fraxinus excelsior, Carpinus, Acer* and others) was observed in lower altitudes (Stefanova and Ammann 2003).

Minor but steady quantities of pollen from *Abies*-, *Fagus*- and *Picea*-types indicate that these mesophylous, moisture-demanding trees survived in environmentally favourable habitats such as deep mountain valleys (Tonkov et al. 2002).

The Preboreal upward expansion of birches and the establishment of new taxa is a response to warmer and more humid climatic and edaphic conditions. The summers

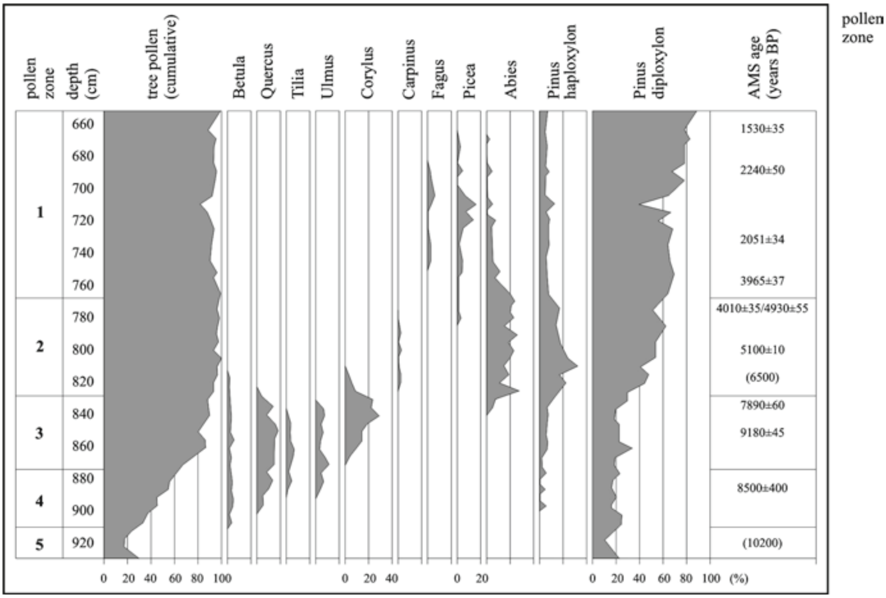

Fig. 3.4 Pollen spectrum of major tree species of the Lake Dalgoto, pollen percentage according to Stefanova and Ammann (2003), cf. Fig. 3.3

became warmer and drier because of high summer insolation (Kutzbach et al. 1993). However, the landscape character of mountain steppe was preserved in higher mountain regions.

The Early Holocene transition between Preboreal and Boreal was marked by a continuing increase of mesophylous deciduous trees. The *Betula* and *Juniperus* distribution decreased (Bozilova and Tonkov 2000, Stefanova and Ammann 2003). Yet only Stefanova et al. (2003) reported clear climatic and biostratigraphic changes regarding the approximate 8,500 years BP period. They detected a clay-gyttja change to Gyttja, increases of *Corylus* pollen and decreases of *Juniperus*, as well as changes in algae and zooplankton in Lake Dalgoto.

3.2.2 Mid Holocene (Atlantic)

At the transition between Subboreal – older Atlantic, the change to conifers began in higher regions of the Pirin Mountains (Fig. 3.3). Since 6,500 years BP, a sharp increase of *Pinus Diploxylon* pollen (esp. *Pinus mugo*), *Pinus peuce* and *Abies* pollen was observed in the lake sediments and peats (Stefanova et al. 2006). Conifers superseded birch and other pioneer species, and deciduous trees were forced to grow at lower altitudes. Macrofossils of *Pinus peuce*, *Pinus* ssp. and *Abies* *alba* in 1,900–2,200 m a.s.l. indicate a high level of the alpine timberline and a climatic optimum (Stefanova and Oeggl 1993, Tonkov et al. 2002).

Herbaceous types decreased to about modern values. Mixed oak deciduous forests dominated the belt up to 1,900 m, significantly higher than today. Aquatic conditions also changed after 6,500 BP. The expansion of *Pinus mugo* coincides with signs of natural eutrophication as recorded by an increase of planktonic diatoms (Stefanova et al. 2003). This period was characterized by climate-morphological stability and mountain pedogenesis up to an altitude of 2,300 m a.s.l. in the northern Pirin. Findings of oldest radiocarbon ages of subalpine soils suggest the described environmental conditions, as Fig. 5.3 in Chapter 5 shows.

About 5,000 BP, *Pinus peuce* was established as the dominant tree in the upper part of the coniferous belt and rose above 2,200 m a.s.l. Since 5,000 BP, the abundance of *Pinus peuce* decreased. *Abies* also had its maximum vertical range of distribution between 6,500 and 4,800 BP (Stefanova und Oeggl 1993). These facts indicate a climate-ecological change during the Atlantic epoch. The reason probably was a change of climate seasonality. Cooler summers and warmer winters, characterized by a rise in humidity and precipitation, stimulated this development (Cheddadi et al. 1997, Tonkov et al. 2006). A shift in wind systems and general weather situations could have caused a change of wind-driven pollen and the profile spectra, too.

3.2.3 Late Holocene (Subboreal, Subatlantic)

The late Holocene reconstruction of vegetation and environmental history becomes more detailed because pollen profiles of lake sediments, peat bogs and other archives supply more information.

From 4,000 BP, pollen and macrofossils of *Picea* and *Fagus* increased. The pollen profile of Lake Dalgoto reveals tree and forest development (Fig. 3.4). Spruce (*Picea abies*) started to colonize areas that were dominated by *Abies alba* during the Subboreal – Subatlantic transition at ca. 3,000 BP (Bozilova and Tonkov 2000). *Fagus sylvatica* established itself in lower altitudes. *Picea* and *Pinus peuce* formed the upper treeline, whereas the dwarf pine (*Pinus mugo*) distributed above the treeline (Stefanova and Ammann 2003). According to Tonkov (2003), this development was caused by decreasing average temperatures and increasing precipitation.

Pinus heldreichii dominated at marble sites in higher altitudes. Figure 3.3 does not show the Holocene development of this tree species because its pollen is summarized under the subgenera *Pinus Diploxylon* types (hard pines), and the differentiation from other species of this subgenus is ambiguous (cf. Little and Critchfield 1969). Lakes are almost exclusively located in the silicate area, and macrofossils of Pinus heldreichii were not found in this area.

Anthropogenic activities in the mountain region of Southwest Bulgaria, as well as at the timberline, have increasingly affected changes in the vegetation since 3,000 BP (the end of the Neolithic). Palynogical investigations of human impact in

Southwest Bulgaria have revealed three distinctive periods when anthropogenic activities increased (Bozilova and Tonkov 2000): the Late Eneolithic, the greater part of the Bronze Age and the Iron Age onward. Tonkov (2003), for instance, reported an artificial lowering of the upper treeline and new pasture land in the mountains of Southwest Bulgaria. The occurrence of charcoal particles in profiles correlates well with a rise in the pollen curve of *Juniperus* and other anthropophytes, suggesting the presence of human impact. The native population's basic means of livelihood was animal husbandry, including livestock-grazing in high-mountain pastures.

Since 2,300 ^{14}C years BP charcoal findings in soils increased (see Fig. 5.3 in Chapter 5). This indicates increasing geomorphological activities caused by fires and deforestation. Thus, in connection with climate development, a depression (downward shifting) of the alpine timberline occurred (Fig. 3.3).

Further dating (^{14}C dating of humus and charcoal) of the Vihren glacier moraine (2,430 m a.s.l.) and soil sediments at the cirque Malkya Kazan in the northern Pirin Mountains verifies the soil development intervals and climate-morphological conditions (Grunewald and Scheithauer 2008b).

A moraine at the Sneshnika Glacieret was sampled and examined in September 2005 (Grunewald and Scheithauer 2008c). Dark humus, soil-like components were found in 60 to 240 cm depth in the moraine wall (Fig. 3.5). On the one hand, this is evidence for soil development at this altitude, while on the other hand it shows relocation because such thickness could not be developed in-situ. A *protalus rampart* can be ruled out due to 2 m thick humus material in the moraine. The steepness of the outer wall and two-layered stratification of the front slope is

Layer depth in cm	^{14}C age (AD) clay (%) pH (KCl)	C_{org} (%) N_{org} (%) C/N-ratio	Fe (g kg^{-1}) Mn (g kg^{-1}) Al (g kg^{-1})	Ca (g kg^{-1}) Mg (g kg^{-1}) Na (g kg^{-1})
I 0 60	debris, rocks of marble			
II 60 120	1147-1263 5.5 7.5	1.91 0.07 27.3	10.4 129.5 24.1	272.1 32.9 5.5
III 120 150	332-537 1.8 7.6	2.31 0.18 12.8	9.0 115.8 23.4	277.1 29.4 4.8
IV 150 180	1152-1273 3.4 7.8	2.02 0.06 36.7	6.4 72.7 17.8	313.2 25.1 5.8
V 180 240	428-611 1.6 7.6	2.73 0.14 20.2	7.2 87.1 20.1	291.8 30.4 5.6

Fig. 3.5 Debris-covered moraine of the Snezhnika Glacieret (2,430 m a.s.l., lab-No. of datings: Erl-8743-8746)

characteristic for a rock glacier (rocks on top, finer material underneath; Barsch 1993). The debris underneath the glacieret gravitated in a frozen, ice-rich state towards the wall. The results clearly confirm a moraine because it contains coarse, ungraded, strangled material. The moraine probably marks the size of the glacier at LIA maximum at ~1850 AD in cirque Golemya Kazan (e.g. Grove 2004).

The ^{14}C datings of the humus layers showed two soil-genetic phases of surprisingly younger ages (calibrated ages: 330–610 and 1150–1270 AD). A younger pressure on the wall can be assumed because the four analyzed layers are stored in alternating ages. The chemical-physical results verify the dating of two different age layers (Fig. 3.5). The soil ages determined at the AMS Laboratory in Erlangen refer to the soil organic matter (SOM) of the samples. The SOM should be generated *inter alia* by root material and to a lesser extent by decomposed litter at this altitude. According to Trumbore and Zheng (1996), the SOM age is slightly greater than the ^{14}C age. Although the composition of the SOM was not investigated and the age has to be carefully interpreted, the finding is an indicator of changing climatic conditions.

Warmer periods during Roman times and in early Medieval times might have enabled geomorphological stability and development of plants and soils at ice-free conditions in the range of the present glacieret. When subjected to regular frost, soil genesis stagnates (Eitel 1999) and cryogenic processes dominate. Consequently, the moraine development probably took place under colder conditions between 1270 and ~1850 AD.

The soil profile at the cirque Malkya Kazan is characterized by many humic-boggy layers over melt water-sands (Fig. 3.6). Pasture, deforestation, fires and abundant water events might be the reasons for soil movement and layering. The ^{14}C dating of humus and charcoal at cirque Malkya Kazan support the climate-morphologic determinating soil development intervals.

Basic chemical-physical results of the moraine and soil profile are shown in Figs. 3.5 and 3.6. Particularly the pedogenesis processes of decarbonation, acidification, release of pedogenic oxides and enrichment of phosphates give age indications depending on the altitude (Matthews 1992).

The moraine profile is characterized by a slight alkali soil reaction, a very high content of calcium carbonate, humic contents between 3% and 5% and silty to clayey particle sizes (fraction less 2 mm). The older layers 3 and 5 show nitrogen contents that are twice to three times higher than those of layers 2 and 4. Phosphorous was measured with ca. 250 mg kg^{-1}, clearly under the values that were detected in soil layers of the cirque Malkya Kazan. The element contents also show the relatively small pedogenesis or pedochemical dynamics respectively. High calcium values and low potassium, manganese, zinc and aluminium contents in all examined layers suggest this.

The genesis of pedogenic iron hydro-oxides was obstructed under the climate-morphological conditions at ca. 2,400 m a.s.l. (Fig. 3.5). The values of the cirque soil in 2,200 m a.s.l. (Fig. 3.6) as well as the timberline ecotones soils (Table 4.13) clearly show advanced pedogenesis.

depht (cm)	clay (%)	pH (KCl)	$CaCO_3$ (%)	C_{org} (%)	N_{org} (%)	P_t (mg/kg)	Fe(p) (g/kg)	Ca (g/kg)	Mn (g/kg)	Al (g/kg)	^{14}C BP
0-30	5.7	5.5	5.2	7.3	0.6	---	17.7	15	1164	83	5206
45-50	2.4	7.0	17.2	6.2	0.5	1812	16.6	49	645	48	613
69-77	2.9	7.0	13.6	6.4	0.5	---	14.2	45	854	73	1122
83-87	14.1	7.1	40.6	3.3	0.3	---	14.9	103	589	57	1161
87-107	2.7	7.0	6.8	9.7	0.8	1927	16.6	31	967	75	1132
107-116	2.2	6.9	11.0	9.2	0.7	---	16.1	34	1032	82	1155
116-127	1.6	6.9	4.5	8.2	0.7	---	15.8	34	1052	81	1471
127-142	3.1	7.0	5.2	7.0	0.6	2326	16.4	16	421	90	1276
158-240	0.5	7.6	46.0	---	---	250	1.0	143	42	12	---

Fig. 3.6 Soil profile at the cirque Malkya Kazan with charcoal in many layers (2,200 m a.s.l.); lab-number of dating Erl-8736-8742; not all layers represented in the table; – not examined)

The moraine of the cirque Golemya Kazan in 2,400 m a.s.l. did not contain any charcoal. This indicates treeless conditions. The layers were full of charcoal a cirque step lower in 2,200 m a.s.l. The timber was analyzed. Thin sections for light microscope and recordings of charcoal by scanning electron microscope were performed. By means of anatomical features, the tree species *Pinus mugo* was solely detected. So far there has been no indication as to other trees of the timberline such as *Pinus heldreichii*.

Below the Malkya Kazan cirque, charcoal of shallow humus rich skeleton soils were sampled and dated (Table 3.2). Convex areas are characterized by debris areal, rocks or older moraines. Wet depressions with big humic accumulations are found in concave areas. The ^{14}C age dating shows two building periods: an older one between 2,000 and 3,000 years BP and a younger one at 80–320 BP.

Table 3.2 Characterization of the investigated sites on marble (Oe1–Oe8, timberline ecotones below the cirque Malkya Kazan) and on silicatic substrates (Boe1 to Boe3 and Spa1/Do1, location see Fig. 3.2 No. 10 and 11)

	^{14}C Dating		Short characteristic
Site (elevation m a.s.l.)	Lab-No.	Age BP	(Dating material: CC = charcoal, OM = organic matter, depth)
Oe1 (2,206)	Erl-10444	2,318 ± 52	Small and wet hollow, 10°-inclination, slope, mountain pine, grass, NE-exposition (CC, 10–40 cm)
Oe2 (2207)	Erl-10445	79 ± 44	dry, east-exposed slope with mountain pines and debris of marble (CC, 10–25 cm)
Oe3 (2,194)	Erl-10446	2,973 ± 51	SE-exposure, trampling relief, shallow soil (CC, 10–20 cm)
Oe4 (2,166)	Erl-10447	190 ± 44	Upper steep area of a gully/block debris, garland soils, little charcoal, skeleton-humus-soils, 15°-inclination, SE-exposure (CC, 5–40 cm)
Oe5 (2,124)	Erl-10448	317 ± 45	Rock debris, humus rich, 8–10°-inclination, timber founds (CC, 30–45 cm)
Oe8 (1,950)	Erl-10449	2,028 ± 50	Below of an avalanche talus, juniper-raspberry-meadow, wet, at the foot of opposite slope, N-exposure, 6°-inclination, (CC, 50–65 cm)
Spa1 (2,428)	Erl-11625	3,245 ± 47	Skeleton-humus-soil, subalpine grassland, garland soils, no charcoal (OM, 30–40 cm)
Do1 (2,325)	a-Erl-11626 b-Erl-11627	2,597 ± 45 1,645 ± 44	Layered sands at the siltation area of “Dual Lake”, little charcoal (a-CC 20–50 cm; b-OM 40–60 cm)
Boe1 (2,250)	a-Erl-10440 b-Erl-10441	4,385 ± 54 4,340 ± 54	Slope moved humic material with charcoal on culm granite, below the end moraine at the Lake Ribno, individual mountain pines, animal faecal (horse, cow) (a-CC 20–50 cm; b-CC 50–60 cm)
Boe2 (1,980)	Erl-10442	6,013 ± 58	Boggy site with charcoal on culm granite above the Vihren-hut, grasses, mountain pines (CC 40–50 cm)
Boe3 (1,880)	Erl-10443	2,225 ± 51	Shallow soil on the sidelines of the Block debris talus on granite, below the Vihren-hut, dry grasses, mountain pines (CC 0–40 cm)

Five sites on silicate substrates were examined at the upper, relatively strong anthropogenic-affected Banderica Valley. Table 3.2 summarizes the site characteristic. In comparison to the soils on marble rocks, the locations were wetter as well as richer in humus and clay. The soil reaction was acidic and the C/N-ratio some wider. Ages of charcoal or SOM are notably older than in profiles of marble sites. These findings give important indications, but the derivation of geomorphological phases of stability and activity, or climate conditions, is more or less unsure.

3.3 Outline of Cultural-Historical Dynamics

3.3.1 Würm Glaciation

At the climax of Würm Drift, approx. 20,000 years ago, the snow limit was located between 2,000 and 2,300 m a.s.l., and high mountains were characterized by impressive valley glaciers (Louis 1930). Cirques and cirque lakes, U-shaped valleys and moraines are evidence of these glacial activities. Due to increasing warming, glaciers melted and shaped characteristic landscapes such as glacial-fluvial talus fans at the bottom of the mountains as well as sediments along the runoff paths.

The amount and extent of the material indicate tremendous forces and the dimension of deglaciation processes. Despite the initial warming, conditions in the mountainous regions were still inhospitable. Tundra vegetation was predominating as well as cold snaps and geomorphologic instability. Late-Glacial hunting cultures appeared not before the Younger Dryas (11,000–10,200 BP) and adapted to the new environmental conditions. A global warm period followed the Late-Glacial cold snap almost immediately. Approximately 10,200 BP the last cold stage was definitely over and the so-called postglacial climatical optimum followed (Blümel 2002).

3.3.2 Boreal and Atlantikum (10,200–4,800 BP)

A rather long and stable period during the Boreal and Atlantikum marked the beginning of essential cultural-historical developments. Temperatures were 2°C warmer than today (Blümel 2002). Forests spread out and psychrophil species were displaced as glacial relics into higher mountain regions.

Humans became sedentary in basins and valleys. Southwest Bulgaria is situated near the Fertile Crescent (Palestine, Lebanon, Syria, Mesopotamia, Turkey, Persia), where the Neolithic Revolution took place approx. 7,000 BC. A culture of nomadic hunter-gatherers turned into a society based on agriculture and animal breeding. This way of living also spread to ecologically favored regions in Southeast Europe due to immigration or expansive diffusion. The climate during the Atlantikum was mild with warm summers and reliable atmospheric conditions, and hence, was a main factor in high agricultural output and the development of neolithic cultures in Europe. Areas with fertile soils had an advantage. This applied only to the basin and valley areas in Southwest Bulgaria.

In the Thracian plain (Marica Valley) and elsewhere, settlements were established around 6,000 BC (Renfrew 1980). Grave and settlement mounds, as well as evidence that farmers (probably Thracians) led a stable life (wheat and barley cultivation, storage in clay pots, baking ovens), indicate a high level of development

(Marinova et al. 2002). Since 5000 BC, metals such as copper and gold could be melted. In this regard, the archaeological excavations are ongoing and should reveal more information (Williams 2007).

3.3.3 Bronze Age and Ice Age

Climate conditions in Europe deteriorated again during the Bronze Age (3,000–2,600 BP), as, for instance, revealed by studies on the death of the glacier body "Ötzi" 3,000 years ago. The annual mean temperature was between 1°C and 2°C lower than today. Consequently, we can assume that cultural-historical development stagnated in many parts of Europe (Blümel 2002).

The following Ice Age is considered a period of change and transition for Southeast Europe. Thracian tribes probably evolved their culture. They cultivated wine, which indicates a favorable climate. There is also evidence for settlement formations (Belov 2005).

The Thracians as feared warriors were involved in the Trojan War against Greece (1,200 BC) and in the campaigns of Alexander the Great in the fourth century BC (Williams 2007). Heredot described the Thracians as a grand nation of people having a large and strong physique (Dimitrov 1966, Weithmann 2000). Such a description implies that they had a good diet.

The further trend of climate development was characterized by a cyclical rise and fall of temperature over several hundred years, without extreme amplitudes.

3.3.4 Roman Empire (2,300–1,600 BP)

The spread of the Roman Empire can be partly explained by a favorable climate. Mean temperatures in Europe during the Older Subatlantikum were 1–1.5°C warmer than today. Therefore, various mountain passes remained accessible in winter (e.g. the Imperator Trayan's Balkans passage over the Troyan-Pass, Härtel and Schönfeld 1998). As during the Neolithic period, the basins and river valleys were the preferred settlement areas (Fig. 3.7a).

Macedonia became a Roman province (Eastern Province) around 148 BC, although a Greek influence remained (Weithmann 2000). The infrastructural advances by the Romans (especially land transport infrastructure, bases and fortresses) were noteworthy, and facilitated transport, trade and migration. Southwest Bulgaria's ancient cultural landscape with Thracian, Greek, Macedonian and Roman influences strove to its peak. However, Thracian and Macedonian slaves were transported to Rome. The Thracian Spartacus from the region of Sandanski organized the slave revolt in Rome 73/71 BC.

City foundations are evidence of efficient agriculture and trade. Many ancient sites in Southwest Bulgaria, for example, those, near Melnik, Sandanski, Razlog

Fig. 3.7 Selected evidence of the cultural-historic development in Southwest Bulgaria: (**a**) remains of the roman town Nikopolis ad Nestrum (106 AD) near Gotse Delchev, (**b**) view from the early-medieval fortress Momina Kula to the Mesta valley, (**c**) the church of Dobarsko, probably eleventh century – one of the oldest preserved churches of the region, (**d**) evidence of the structural recovery during nineteenth century in Bansko, (**e**) steppization, devastation and erosion problems as a result of non-sustainable usage and (**f**) the new sewage treatment plant in the foreground and behind it the old paper factory "Pirin-hart" from the socialist era in the Basin of Razlog

and Gotse Delchev, show that the valleys in the mountainous regions of Southeast Europe were included in this development. In Roman times, the territories of present Bulgaria were also considered Rome's sanatorium because of the numerous mineral springs (Teodossieva 2004, Grunewald and Scheithauer 2007).

3.3.5 The Migration Period (Fourth–Sixth Century)

Between the fourth and sixth century, climate conditions worsened again in many parts of Europe. It became colder and more unsettled. In the mountains, glaciers expanded and the timberline shifted downwards (Veit 2002). Willows supplied less food and there were crop shortfalls in the agricultural areas. There are reports of droughts during 300–400 AD (Blümel 2002). All of these conditions led to hunger and economic-social insecurity. The Roman road became dilapidated and trade was partially disrupted. Displacement of people and migration were intimately connected with climate. Germanics, Sarmatians, Goths, Eurasian Avars and other tribes crossed the territory of the present Bulgaria. They destroyed the ancient cultures and therefore brought the antiquity to an end. Particularly, Slavs and so-called Old Bulgarians became sedentary. They held their ground in the forests and swamplands as they were skilled hunters, fishermen, beekeepers and artisans (Grunewald and Stoilov 1998). “People displacement” and “migration benefit” are attributed to the described changing climate conditions in Bulgaria.

According to Härtel and Schönfeld (1998), the religious beliefs of the Slavs at that time were characterized by a kind of monotheism. The hurling lightning Perun was considered the chief god (godfather of the Pirin Mountains). Mountains, forests, rivers and lakes were inhabited by the spirits of nature. In many places, these traditions live on today. They show the people’s dependence on, and awe of, the forces of nature. Changing climate conditions and land use through deforestation can be shown by using, for example, geomorphological and soil formation intervals (e.g. Grunewald and Scheithauer 2007).

3.3.6 The Golden Bulgarian Period (Seventh–Eleventh Century)

The First Bulgarian Empire was founded in 681 and was mainly feudalistic (Paskalevski 2006). Its borders ranged from the Black Sea to the Aegean, from the Adriatic to the Tisza and the Carpathians in the ninth–tenth century. The Slavic language and script were developed, laws were enacted, Christianity manifested itself and a Bulgarian church structure evolved, especially in the ninth century (Döpmann 2006). Starting in the eighth century, a symbiosis of Slavic (language), Greek Orthodox (church, tradition) and Thracian elements emerged (Weithmann 1995).

During this time, the expansion of the pre-industrial cultural landscape - forests, meadows, fields, villages, roads and mining - was completed. This development could only occur under warm, stable climate conditions. It does not mean that there were no regressions and periods of crisis, characterized by wars, changing rulers, natural disasters and famine.

Building activity (residential buildings, palaces, fortresses, churches, bridges), visual arts and literature experienced a boom (Döpmann 1973). Vegetation was more and more degraded near the settlement areas (logging, deforestation); herdsmen with sheep and goats were seen over a long distance. People began to keep the cattle in stables throughout the year and the stocks were increased. As a result, more fertilizer was available and the grain yields increased. The open land considerably increased in Southwest Bulgaria, especially in the basin regions. The erosion caused major problems (see Fig. 3.7e). The forests were characterized by strong multiple use: pasture, firewood and timber extraction, collections of leaf litter, poll (German: Schneiteln), charcoal etc. The wet depressions and suitable mountain sites were reserved to meadows and pastures (Grunewald and Stoilov 1998).

3.3.7 Medieval Warmth Optimum (1000–1230) – Also in Bulgaria?

European temperatures increased in the early Middle Ages. This led to a cultural boom, which Bulgaria had experienced a few centuries prior. In central and western Europe, the borders grew 200 m higher, the forest was greatly reduced (in Germany to below 20%, see Bork et al. 1998); accordingly cropland and pastures increased. Agricultural production could supply a growing population, so a surplus was obtained. Trade and industry flourished. Settlements were established everywhere and construction began. Architecture and art from the period reflect the population's vitality, creativity and productivity. But the high goal of the western and central European guilds to build, for example, beautiful "cathedrals into the sky" was not achieved in Southeast Europe. Bulgaria came under Byzantine rule from 1018 to 1185 – a peaceless time with numerous ravages (Härtel and Schönfeld 1998). However, basic life conditions did not change. The property of churches and monasteries even expanded. The Athos monasteries got control over the fertile valleys of the Struma and the Vardar. Some nobles increased their estates; they enjoyed immunity rights and built fortresses. At the end of the twelfth century, principalities emerged in Bulgaria that were de facto independent from the central government (Döpmann 1973).

Regional Bulgarian rulers installed a "Second Bulgarian Empire" from 1187 to 1396 that became, again, a determining power in the Balkans. However, the country did not rest. Feudal feuds, separatist tendencies of the boyars, tax burdens, wars, natural disasters, famine and epidemics, and perhaps climatic amplitudes all weakened rulers and people. Unrest, riots and gangs of robbers were characteristic. Free farmers who wanted to escape bondage and serfdom fled into the mountains (Härtel and Schönfeld 1998).

However, there was a second heyday in early Medieval Bulgaria. Feudal structures were further expanded. Taxes, the introduction of money, duties and compulsory labor reflect this. Little of the architectural and cultural achievements of this period have been preserved. Turkish power, wars, earthquakes and fires have destroyed most of it.

This era is relatively well documented in Southwest Bulgaria. The famous Rila Monastery was founded and gained high spiritual and temporal influence. Twenty villages belonged to the Rila Monastery in the thirteenth–fourteenth centuries (Döpmann 1973). Church buildings from this period are preserved in Dobarsko in the basin of Razlog (Fig. 3.7c) or in fragments in Melnik. Construction and settlement activity is known to have occurred in Mechomya (now Razlog), Bansko, Nevrokop (now Gotse Delchev) and Melnik. Typical were early medieval fortifications at strategic points, often in a location that was difficult to reach. Zvetkov (1981) has documented those for the valleys of the Struma and Mesta. Melnik's prime in the twefth–thirteenth centuries is an example. The despot Alexej Slaw, a nobleman, governed from Melnik to the Rhodope Mountains. From the income, he developed Melnik to an important regional center with fortresses, churches, the Rose Monastery, art and culture (Zvetkov 1979, Härtel and Schönfeld 1998).

The mountain agriculture was as follows:

- Grain could obtain only marginal importance due to the physical-geographical situation.
- Technical crops such as flax, cannabis, cotton, poppy, sesame, and later sunflower, peanuts, lavender and tobacco grew in basins and valleys.
- Fruit (apples, pears, plums, cherries, nuts, figs, peaches, almonds, pomegranates) and vegetables (onions, garlic, tomatoes, cucumbers, Chile peppers, red peppers, potatoes, cabbage, lentils, pumpkins, zucchini, beetroot etc.) were cultivated in gardens. Immigrants introduced many fruits and vegetables.
- Most families kept animals such as horses, donkeys, oxen, cows, chickens, sheep and goats (Hadzinikolov et al. 1980).

Nomadic pastoralism in Southeast Europe was operated by the Aromanians. In particular, the Aromanians moved their sheep and goat herds to high mountain pastures in summer and moved them to snow-free pastures in the plains and coastal regions in winter (Kahl 1999). Since the early Middle Ages, the region's climatic characteristics in the transition zone – from temperate to Mediterranean – has been maintained. The mountain areas were hardly inhabited or grazed in winter. In the southern basins and coastal plains, mild winters without snow were typical. Pastures withered in lower southern locations in summer, while the wetter and cooler mountain pastures were used. The Bulgarians also moved their cattle to the mountains but used and irrigated their pastures and gardens at the sides of basins and valleys.

We can conclude that the period from the first until the end of the second Bulgarian Empire (Seventh–fourteenth century) was a time of complex living with conditions equal to the West (Härtel and Schönfeld 1998). This period abruptly ended with when the Ottomans took over the Balkans.

3.3.8 Contemporary Climate Pessimum (1330; Particularly 1550–1850): The "Little Ice Age"

With the beginning of the fourteenth century, Europe's climate became cold and unsettled. There was considerable glacial expansion and the timberline lowered in the high mountains. This had several implications for Bulgaria. A united army of Poland, Hungary and Transylvania did not come over the Balkans in October 1443 because of harsh winter conditions (Stara Planina, Härtel and Schönfeld 1998). There are reports of "thick snow and long winters" at the beginning of the nineteenth century in Meyers Lexicon of 1871 (cited in Comati and Vlahova-Ruykova 2003, p. 156) and in Kanitz (Volume I/p. 80 and Volume II, p. 119, Kanitz 1882) who reported snow patches in summer in the Stara Planina. According to historical records, the Danube froze more often in the Bulgarian-Romanian part (Weithmann 2000, Comati and Vlahova-Ruykova 2003).

This temperature trend has been overshadowed by more extreme events:

- Floods: In Central Europe especially in 1313, 1319 and 1342, whereas the latter flood reached torrential proportions and caused half of the erosion damage of the last 2,000 years (Bork et al. 1998). Flooding along the Danube is known to have occurred in 1342, 1490, 1501, 1572, 1595, 1598, 1670, 1682 and 1787 (Weithmann 2000).
- Volcanic eruptions with global-regional consequences: for instance, the eruption of the Tambora in April 1815, which was deemed responsible for the following "year without a summer" in many parts of the world (De Boer and Sanders 2004).
- Epidemics: the plague in Sofia in 1340–1342 (Kanitz 1882, Volume II/p. 207), in different parts of the region in 1348, 1416 and 1447 (Weithmann 2000) and in Gotse Delchev in 1834 (Penkov and Dojkov 1998).

The deteriorating environmental conditions had an impact on the vitality of the population, which shrunk by 40% (Blümel 2002, Weithmann 2000). In many places, a regression of civilization evidenced by superstition and witchcraft persecution was observed. Crop failure due to cold and wet summers and extreme season peculiarities became more frequent. Grain badly ripened, harvest rotted and mildew or fungus affected the harvest. Agricultural crises led to deserted villages in central Europe (Bork et al. 1998). Blümel (2002) marks the height of unfavorable weather conditions as between 1680 and 1700. However, there were also some very warm years, revealing wide climate variability, which posed a great production risk.

Many researchers postulate that the described conditions weakened the Bulgarian and Byzantine powers in Southeast Europe and facilitated the Ottoman invasion. The 500-year-long Turkish domination strongly influenced Bulgaria, but the country never lost its identity.

What was the cultural development of the region between the fourteenth and twentieth century, during the Modern Times Era the Turkish feudal system replaced the Bulgarian feudal system. People who were ruled by the Ottomans were considered sojourners, a status that meant extensive freedom of religion (partly toleration for money) and some preservation of cultural identity (Matuz 2005). The power and strength of the Ottoman Empire were based on two pillars: a centralized administration and strict military order. The Ottoman organization initially showed signs of being a caring welfare state (Weithmann 1995). The system worked relatively well until the end of the sixteenth century. Islamization campaigns occurred later. For example, the population of several villages in the Rhodopes, in the Mesta Valley, had to convert to Islam in 1657 (Papadimitriou 2003). The Islamized Bulgarians, the so-called Pomaks, still live in great numbers there.

At that time, however, the disadvantages of orthodox-Islamic ideologies that inhibited the development of productive forces were already evident. There was a shortage of engineers and architects. Art and science could hardly develop. The urban settlements were more spacious than before and their character was determined by mosques and minarets. There was no municipal law. Settlement development, trade, infrastructure and the like lagged that of Western Europe. Forts and roads decayed. Education was frowned upon and remained reserved for the Bulgarian monastery cells. Experiences, skills and knowledge were rarely passed on as there were no textbooks and illustrations were not allowed (Matuz 2005).

Southeast Europe missed the “connection to progress” as there was no individuality or enlightenment (Wagner 2003). An urban or bourgeois class had not emerged among the Balkan nations, with the exception of Greece. Agriculture stagnated. People usually grew only what they needed for survival (Weithmann 1995).

It was a time of strong demographic change: On the one hand, there was a superimposition by the Turks and other nationalities. On the other hand, the population was decimated by plague and other epidemics, and refugee movements from village to city or into mountainous regions were reported. Remote mountain villages in Southwest Bulgaria often remained Bulgarian. These villages became refuges of ethnic and cultural traditions and “hearths” of resistance (Hadzinikolov et al. 1980). There was freedom but life was difficult.

The Ottoman Empire declined in the seventeenth–eighteenth century and the central government weakened (“the sick man at the Bospurus”). The influence from Western and Central Europe increased. There were changes in ownership of land (sales) and various reforms were adopted. In the 1830s, the fief was abolished so that taxes had to be paid directly to the state (Hadzinikolov et al. 1980). Church reforms and the land law of 1867 followed. Christian churches could be built again in Bulgaria in the nineteenth century (there were five churches in and near Razlog), massive houses were built and urban life was stimulated (for example, in Bansko, see Fig. 3.7d, Gotse Delchev and Melnik). The time of the “National Renaissance of Bulgaria” was heralded (Weithmann 1995).

3.3.9 Contemporary Thermal Optimum (Since 1850)

A warmer period is recorded starting around 1850. In almost all the high mountains, moraine walls mark the “peak of the Little Ice Age” at ca. 1850 and thus the start of the younger, naturally caused climate fluctuation (Blümel 2002, see also Sections 3.2 and 4.2). For the twentieth century Sharov et al. (2000) differentiated cold periods in the first decade, in 1940–1944 and 1968–1985 and warm periods in 1910–1940, 1944–1968 and since the mid-1980s. The years 1990–1994 were characterized by unusually warm summers and dry winters.

The temperature and precipitation levels have been cyclic in Bulgaria in the last century (see Section 4.1). Since the 1990s, the so-called man-made greenhouse effect becomes more apparent, i.e. rapid temperature increase and climate change due to burning of fossil fuels (carbon dioxide emissions), deforestation, industrialisation, population increases, and so on.

The years 1877–1878 are of historical importance for Bulgaria because the country achieved its liberation with the help of Russian troops and established an independent principality. Southwest Bulgaria was part of Eastern Rumelia and merged with the Principality of Bulgaria in 1885. The Turkish influence, however, remained until the beginning of the twentieth century. New migration movements were recorded and there was a redistribution of land ownership. Bulgaria became a country of small farmers. An economic boom began. First factories were built, a national currency was introduced in 1880, the administration was established and infrastructural measures could be taken (Härtel and Schönfeld 1998).

The inner-Macedonian and Bulgarian-Greek borderline in 1912, instituted after the Balkan wars, led to the decline of the traditional transhumance (seasonal movement) and the Aromanians (Kahl 2001). Today, the pastures in the Pirin Mountains and other mountains are hardly used by livestock. Many border towns in Southwest Bulgaria suffered a huge loss of importance and population (Melnik and Gotse Delchev). The towns of Blagoevgrad, Sandanski, Melnik, Petrich, Gotse Delchev, Razlog and Bansko received official city status in 1912. Settlements with rural character such as Simitli, Kresna, Jakoruda and Hadzhidimovo were also awarded city status in the second half of the twentieth century (Penkov and Dojkov 1998). From 1920 to 1975, the population nearly doubled. Noteworthy is Melnik, which has about 200 inhabitants, the smallest city in Bulgaria; 12,000 people lived there in 1912. Causes for this decline are non-sustainable land management, erosion and climate impacts as well as political forces.

The capitalist period was very short in Bulgaria (1912–1944); in many mountain areas it did not arrive. Many of these places reflect original, partly medieval conditions. Socialism was established according to the Soviet model after World War II. Towns such as Blagoevgrad or Razlog were “systematically” developed and selectively industrialized (Fig. 3.7f). Agriculture and forestry were collectivized and mechanized as far as possible in the mountainous regions and among the ethnic groups (Grunewald and Stoilov 1998). In the Struma valley, for example, vegetable growing developed. In the Basin of Razlog and in the Mesta valley the cultivation of tobacco dominated, as did wine near Melnik (Anonymous 1977).

Since 1990, a difficult transition to a market economy has been taking place (Ermann and Ilieva 2006). The economic conditions in industry and agriculture in the mountainous regions of Southeast Europe offer only a few jobs. The connection to Western standards still seems far off although Bulgaria has been a member of the EU since 2007. Borders to neighboring countries have gradually become more porous. Gotse Delchev already benefits from its proximity to Greece. In some places, such as Bansko, winter tourism has recently started booming (see Section 2.5).

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Chapter 4
Climate Data and Geo-Archives of the Recent Past

Abstract Historical climate records gathered in our study 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. There is objective evidence for an increasing annual mean temperature, longer vegetative periods and local droughts in spring and autumn. The research suggests that these climate changes could have long-term effects on the region's eco-systems.

Glacierets and their surroundings, used as archives in eastern and southeastern Europe, provide instructive information about climatic and environmental properties of the past. Ice cores from the glacieret Snezhnika in the Pirin Mountains – currently the southernmost in Europe – have been drilled. Small glacier features such as this respond quickly to climatic extremes. However, despite the trend toward warmer years since the late 1970s, some glacier patches still survive – even after some of the hottest summers on record.

Coniferous trees at the subalpine forest and timberline are excellent archives for climate proxies. The results on dendroclimatology and dendroecology provide an initial insight into the potential of the *Pinus heldreichii* and its high mountains chronology in the northern Pirin Mountains.

Keywords Climate change • Climate trend analyses • Dendroecology • Europe's southernmost glacieret • Ice core • *Pinus heldreichii* • Treeline

4.1 Characterization of Contemporary Local Climate Change

4.1.1 Introduction

Spatial factors, such as the geographical latitude or the landmass, continentality influence a region's climate. Further, mountain ranges mark and regulate regional climate processes. The Rhodope massif along with the Pirin and Rila Mountains constitute a

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disruptive element in the atmospheric circulation over Southeast Europe. The climate of these high mountains differs significantly from the climate of the surrounding plains, basins and valleys due to the vertical gradient of the atmospheric parameters. Mountains intensify spatial climate contrasts from valleys to valleys and the disparity of climate temporal regimes (Böhm 2004). They can be seen as a vertical stack of horizontal climate zones. In Bulgaria, for instance, a distance of only 100 km separates the coldest place (Musala Peak in the Rila Mountains) from the warmest place (Sandanski in the Pirin Mountains). Thus, polar and subtropical-Mediterranean climate characteristics can be found very close to each other in the area of study.

Southeast Europe is a mosaic of several small mountain regions and countries (Figs. 1.1 and 2.1). This strong internal differentiation generates a wide diversity of local physic-geographical and socio-economic situations (see Chapter 2). On the one hand, high mountain regions such as the Rila Mountains receive ample precipitation and experience permanently low temperatures. On the other hand, the southern peripheral areas, either highlands or lower areas, are dry and warm (for instance in northern Greece). In general, there is a considerable lack of knowledge regarding the dynamics of weather and climate (time and space), the water supply (snow, lakes), and water availability (where and when) at the regional level.

Climate predictions for mountain regions are uncertain because of regional variability and heterogeneity, as well as because they are monitored by an insufficient number of weather stations. This chapter analyzes available meteorological data series for southwestern Bulgaria and then discusses the possible climate trends for this mountainous region. These results are relevant to ecological and environmental issues linked to the sustainable development of forestry and agriculture in the area as well as that of tourism and health care. Furthermore, the data set is useful for cross-checking geo-archive results, for instance tree-ring-width to climate data correlation (see Section 4.4).

4.1.2 Analysis of Meteorological Observations

Climate data have been kept on southwestern Bulgaria since the beginning of the twentieth century. Monthly temperature and precipitation measurements have been available from the stations at Musala Peak (Rila Mountains) and Bansko (northern Pirin Mountains foothills) since 1931. Petkova et al. (2004) reconstructed snow cover trends for the Bulgarian mountains over the same period. Several other stations located in the Bulgarian lowlands started measuring and recording climate data around 1900 (Alexandrov and Genev 2003). Thus, compared to similar time series available for the Alps (Böhm 2004), climatological measurement started in Bulgaria some 100–170 years later (Sharov et al. 2000).

Table 4.1 shows the vertical distribution of the 25 weather and climate stations available in the Pirin Mountains and adjacent areas. They extend over the 6.500 km² of Blagoevgrad district, which means that on the average there is one station per 260 km².

Table 4.1 Vertical distribution of climate stations in southwestern Bulgaria

Geographical unit	Altitude (m a.s.l.)	Share of units in the district Blagoevgrad (%)	Number of stations
Lowland	<200	4.8	3
Basins/hilly	200–600	18.4	4
Lower mountain zone	600–1,000	26.8	7
Middle mountain zone	1,000–1,600	36.3	4
Upper mountain zone	1,600–2,200	10.3	4
Alpine zone	> 2,200	3.4	3

Although the measuring network seems well distributed both spatially and vertically, its technology is outdated and data quality, such as that of precipitation measurements, is uncertain. Many stations have been used temporary only, and some have been neglected since the political change that occurred in 1990. It is only at Musala Peak that a modern monitoring station has been established, thanks to help from France (Stamenov et al. 2001). The stations of Musala Peak, Bansko, Vihren Hut and Sandanski supply well-populated time-series. However, other stations often provide data based on monthly mean values, which are sometimes based on historical series of measurements (1930–1970, Anonymous 1977).

Climate data administration in Bulgaria is under the responsibility of both the Bulgarian Academy of Sciences (BAN) and the National Institute of Meteorology and Hydrology (NIMH) in Sofia. However, since data pricing often exceeds usual research projects budgets, other sources, such as reports, statistics and the open-access data on the Internet, are used as well. We have used most of these alternate sources for our study.

Climate variability assessment must be based on carefully examined and standardized instrumental time series (Auer et al. 2001). In our case, monthly mean temperature and precipitation values were submitted to significance tests and t-tests statistical screening, and stations were also compared to each other (Schönwiese 2000).

It is common knowledge that measurements of precipitation in high mountain regions generally include high discrepancies due to relief effect, velocity of wind and high snow rates. According to Veit (2002), the error rate is about 15% for rain and as high as 50% for snow. These error rates are often underestimated, and may increase with altitude and bias annual values. Therefore, precipitation statistics gathered in the Pirin Mountains should be used with caution as the small number of available stations is not sufficient to capture the full precipitation's spatial and temporal heterogeneity.

4.1.3 Regional Climate Aspects

Due to its latitude, most parts of Bulgaria are influenced by the Azores anticyclones. According to the Lauer/Frankenberg classification, a warm temperate, continental, semi-humid climate dominates, which is classified as C*fb* following W. Köppen (Weischet 2002).

The climatic regimes have a transitional character due to the continental influences coming from Europe, West Asia and to some extent North Africa, and the maritime influences of the Atlantic Ocean, Black Sea and Mediterranean Sea. At a local level, orographic factors from the main mountains' relief (Stara Planina, Dinarides, Rhodopes) determine climate characteristics. Recent suspected shifts in global pressure systems and wind belts also bring subtropic influences, which are noticeable in South Bulgaria (Velev 1990, Grunewald and Stoilov 1998).

Our area of interest in Southwest Bulgaria covers two typical climatic regions: the Mediterranean transitional climate and the mountainous climate (Dimitrov 1996). The former region is under the influence of warm air coming from the Aegean Sea region, which mostly affects the southern valleys of the Struma and Mesta rivers (Fig. 2.1). The beech-fir-forest belt (above 900–1,400 m of altitude in Southwest Bulgaria) marks the transition to the mountainous climate. Vertical layering of temperature and local relief influence the climate and often lead to thermal inversion sites. Therefore, the climate in the Pirin Mountains and adjacent areas shows a strong differentiation driven by a variety of influences: air stream, solar radiation, lee- and windward effect, mountain wind, vertical distribution of temperature and precipitation.

Temperature

Figure 4.1 displays the mean monthly temperatures of selected stations and gives an overview of the regional temperature range and the spread of annual mean temperature. At alpine altitude, the mean temperature values were below 0°C during

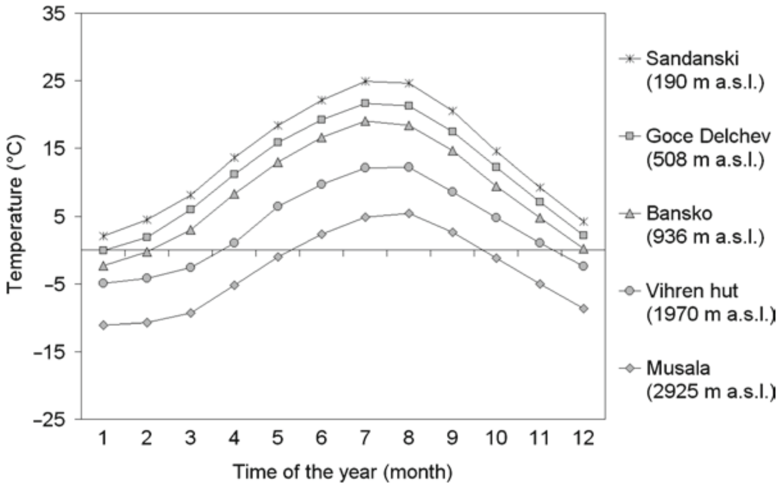

Fig. 4.1 Mean monthly temperatures in southwestern Bulgaria from 1931 to 1970 (data base: Anonymous 1977; Musala Peak added)

the twentieth century. The values vary according to altitude and are modified by the N-S-location. Temperature decrease with altitude is more pronounced in summer and this may be the reason for smaller annual temperature amplitudes compared to what happens in nearby valleys (Koleva 2003). January is the coldest month, evidenced by the average temperature difference between the highest northern station (Musala Peak with −11.1°C) and the lowest southern station (Sandanski with +2.1°C) is 13°C. This difference is even higher at about 20°C during the warmest months of July and August. Rashev and Dinkov (2003) classified the area near Sandanski as a Mediterranean climate with cold winters.

Threshold values have been calculated using the measured daily temperatures at Musala Peak station (2,925 m) from 1973 until 2006, which amounts to about 12,000 single measurements. These values were extrapolated to the areas of the timberline and the cirques in the nearby northern Pirin Mountains (Kar Golemya Kazan, 2,500 m, Kar Malkya Kazan, 2,200 m and Vihren Hut, 1,970 m) as well as for the town of Bansko (936 m). Tables 4.2–4.4 summarize the results and clearly show the influence of altitude.

Most days in the upper mountainous region can be considered as “cold days” (above 1,970 m) while “summer days” are very rare (Table 4.4). However, the number of days with frost varies strongly from year to year. The limits of tree-growth depend heavily on temperature (100 days of higher than 5°C) and hence the timberline is situated between 2,000 and 2,400 m. The vegetative period characterized by temperatures of more than 5°C can help categorize the stations as follows (cf. Anonymous 1977 and 2003):

- lower and middle altitude: from mid-April until the beginning of November (180–215 days)
- upper altitude: from the beginning of May until October (120–160 days)
- highest altitudes, summits: less than 100 days

A specific characteristic in mountainous regions is the frost change climate. A “frost change day” is a day on which one or more movements through 0°C occur (Geiger et al. 2003). The number of frost changes occurring on a *frost change day* is an indicator of thawing-freezing-cycles. The average number of frost change days per year ranges from 89 to 92 days at the timberline in the study area (Table 4.4) and is lower in the summit areas and in the lower mountain zone (77 days at Musala Peak, 62 days in Bansko) where lengths of ice days or warm days are more important.

The number of frost change days per month in Bansko shows only one maximum in winter while days with frost change do not occur in the summer (Fig. 4.2). For higher stations situated near the timberline, such as the Vihren Hut and the cirque Malkya Kazan, there are maxima in April as well as during winter in November and December. However, frost change days are rare at this altitude from June until September. For the summit station of Musala Peak, two maxima (May and October) and two minima (winter and summer) are observed. This behavior is close to the one observed in the Eastern Alps (Veit 2002).

Koleva (2003) provides data on solar radiation and of sunshine duration for the National Park of Pirin. The mean radiation is 13–15 MJ/m² per year. Maximum

Table 4.2 Statistic of daily temperatures in the period 1973–2006

	Musala			Golemya Kazan			Malkya Kazan			Vihren Hut			Bansko		
	$T_{ø}$	T_{max}	T_{min}	$T_{ø}$	T_{max}	T_{min}	$T_{ø}$	T_{max}	T_{min}	$T_{ø}$	T_{max}	T_{min}	$T_{ø}$	T_{max}	T_{min}
Mean	–2.8	0.2	–5.4	–0.6	2.5	–3.2	1.0	4.1	–1.6	2.9	6.0	0.3	8.4	11.4	5.8
Max.	15.3	25.0	12.5	17.5	27.2	14.7	19.1	28.8	16.3	21.0	30.7	18.2	28.3	38.0	25.5
Min.	–29.6	–26.4	–31.6	–27.5	–24.3	–29.5	–26.0	16.3	–28.0	–24.1	–20.9	23.0	–19.2	–15.7	–22.6

Table 4.3 Threshold values of temperature based on daily averages (mean number of days per year in the period 1973–2006)

Station	Altitude (m a.s.l.)	<–5°C	>–5°C to < 0°C	>0°C to <5°C	>5°C to <10°C	>10°C
Musala	2,925	137	89	86	46	5
Golemya Kazan	2,500	96	90	88	71	18
Malkya Kazan	2,200	70	88	86	83	35
Vihren Hut	1,970	47	77	88	88	64
Bansko	930	20	37	70	67	168

Table 4.4 Threshold values based on daily minimum and maximum temperatures (mean number of days per year in the period 1973–2006)

Station	Frost changing days (T_{min} < 0° C/T_{max} > 0°C)	Frost days (T_{min} < 0°C)	Ice days (T_{max} < 0°C)	Cold days (T_{max} < 10°C)	Summer days (T_{max} > 25°C)
Musala	77	261	175	325	0
Golemya Kazan	89	222	133	300	0
Malkya Kazan	91	199	108	279	0
Vihren Hut	92	166	74	247	0
Bansko	62	94	32	155	15

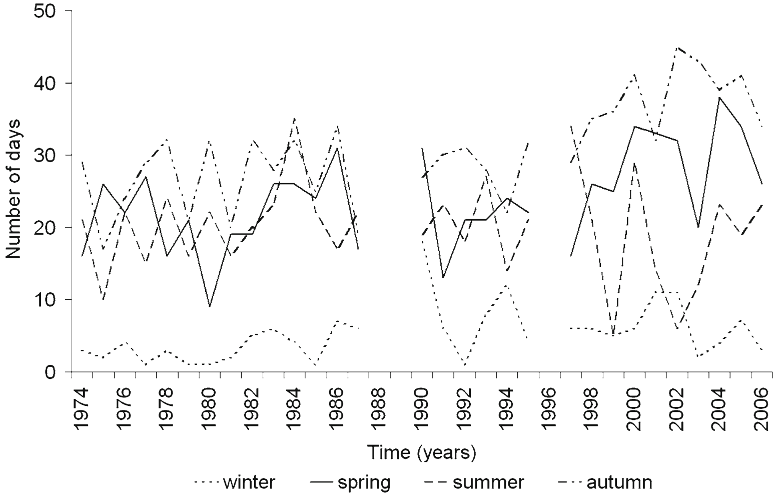

Fig. 4.2 Average number of frost change days per season from 1974 to 2006 (Musala Peak)

values are observed in July with a value of about 18–20 MJ/m² at altitudes above 2,000 m. This is three times more than the solar radiation measured in January. Obviously the intensity of sun radiation in relief areas depends on the local exposition. The accumulated sunshine hours per year ranges from 1,900 to 2,100. The maximum monthly sunshine duration is within 210–240 h observed in July and August. Overall, the regional thermal level is quite high.

Precipitation

Precipitation patterns are strongly determined by relief (altitude, lee-/windward effects), atmospheric circulation, and the humidity of circulating air masses. In the upper mountain regions of southwestern Bulgaria, the average annual precipitation ranges from 1,000 mm per year up to 1,300 mm per year in isolated areas (on north-facing slopes and/or summits). In the lower and middle mountain regions (Anonymous 1977) it lowers to 700–1,000 mm per year. Some intra-mountainous basins, and particularly the southern valleys, are relatively dry with an annual precipitation between 400 and 700 mm and high evapotranspiration.

Figure 4.3 compares the distribution of annual precipitation values for the stations of Bansko and Musala Peak during years 1973–2005. In the town of Bansko, precipitation rates range between 500 and 700 mm during two thirds of the observed period. The variation spread is higher for Musala Peak where precipitation rates vary between 600 and 1,000 mm per year. At this high altitude, the monthly precipitation rate is often over 50 mm. In general, monthly precipitation in mountain regions display a high inter- and intra-annual variability. At Musala Peak for instance, a high of 304 mm was observed in April 1997 while precipitation dropped as low as 6 mm in July 2000.

Figure 4.4 displays the annual variation of average monthly precipitation at selected stations. In Bansko and at Musala Peak, most precipitation occurs between March and June, which can be explained by the fact that W-NW-weather conditions are typical, particularly in spring (Koleva 2003), which leads to orographic rainfalls in the Rila and Pirin Mountains. The lowest amount of precipitation occurs in February and from August until November. Therefore, a humid surplus in spring and a deficit in late summer can be expected.

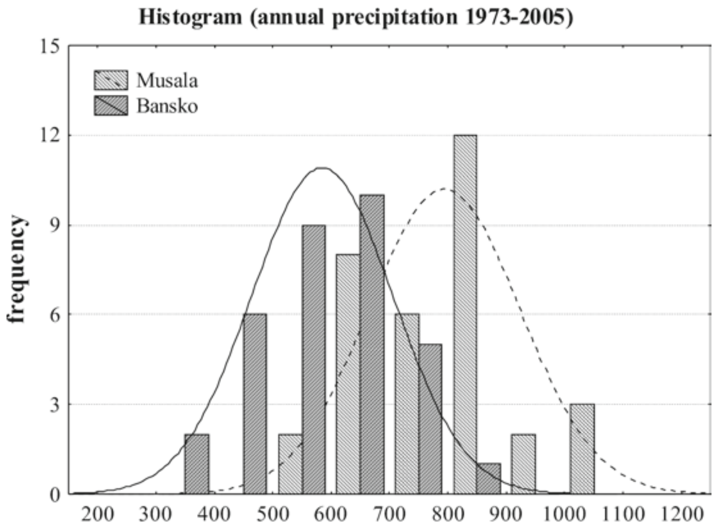

Fig. 4.3 Histograms of the annual precipitation in Bansko and at Musala Peak (mm)

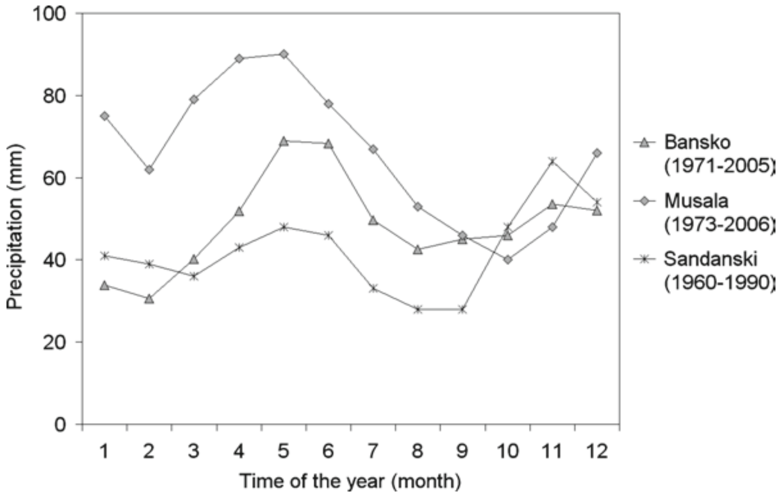

Fig. 4.4 Distribution of the average (mean) monthly precipitation

Table 4.5 Characteristics of snow cover for southwestern Bulgaria (Anonymous 1977 and Vekilska 1995)

Altitude (m a.s.l.)	Days with snow cover	Mean max. of snow depth in winter (cm)
<1,000 (southern basins)	15–20	3–5
1,000	50–60	80–90
2,000	ca. 160	100–200
>2,400	ca. 250	>200

The southern valley station of Sandanski shows a distinctive November-December precipitation maximum due to the impact of cyclonic systems coming from the Mediterranean area. Sandanski is further characterized by another maximum in spring. As the Pirin Mountains are situated between Bansko and Sandanski, they probably experience an intermediate pattern for the annual distribution of precipitation.

Mountains are also known as "water towers" due to the high amount of precipitation that they receive and their retention of water as snow. The release of water during the thawing period is vital to their environment and to the people living in the downstream plains (Andreeva et al. 2003, Grunewald et al. 2007). The observations clearly show that solid precipitation (snow, frost, fog) amounts from 70% to 90% of the total precipitation received by both the Pirin and the Rila Mountains. These massifs are covered by snow during more than half of the year. Table 4.5 presents the snow average thickness and the duration of snow cover for southwestern Bulgaria. The maximal snow thickness ranges between 3.6 m and 4.7 m in the Rila and Pirin Mountains while an overall maximum of 4.72 m was measured at the Vihren Hut on the 5th April 1963 (Nikolova and Jordanova 1997). Wind, avalanches, solar radiation and exposition also affect locally the depth and duration of snow cover.

Table 4.6 Descriptive statistic and trend analysis of number of days with snowfall at Musala Peak (1973–2006)

	n	Mw	Median	Min	Max	uQ	oQ	SD	Variance	QA	Trend
Year	33	126	122	87	169	114	139	19	348	25	–0.45*
Winter	31	47	48	30	66	39	54	9	84	15	–0.18
Spring	32	50	50	36	72	44	55	9	88	11	–0.31
Summer	31	7	7	0	15	4	11	4	14	7	–0.47*
Autumn	33	23	23	13	35	19	25	6	39	6	–0.35*

* $p<0.05$; significant trend (rR)

Another evaluator of precipitation is the number of days with snowfall. While at Musala for the period from 1973 to 2006, solid precipitation was recorded on more than 120 days per annum (Table 4.6), in Sandanski only 10 days with snowfall occurred, however the recordings here refer to the period from 1961 to 1990 (Rashev and Dinkov 2003).

4.1.4 Climate Change and Climate Trend

According to the Intergovernmental Panel on Climate Change (IPCC) our world is experiencing global warming: the global average annual temperature has increased by 0.74 °C since 1990. The last decade was the hottest since worldwide temperature measurement began in the nineteenth century. Further global warming ranging between 1.4 °C and 5.8 °C is expected by the end of the twenty-first century (Solomon et al. 2007). This could also lead to an increase in temperature extremes as well as the frequency of heavy rainfall and droughts.

Through existing meteorological records it is worth studying how these global climate trends reflect locally in Bulgaria and particularly in the mountains of its southwestern region. Anonymous (1997), Sharov et al. (2000), Alexandrov and Genev (2003) and Topliiski (2004) have already presented comprehensive studies on climate change in Bulgaria. They describe the main evolution of climate in the twentieth century as follows:

- Three periods with minimal annual air temperature (1905–1914, 1941–1945, 1972–1981) and three with higher temperatures than normal (1922–1931, 1945–1954, 1984–1993)
- A temperature decrease in the 1970s and a temperature increase in the 1990s
- A cyclic evolution of precipitation: 1897–1901: humid; 1902–1909: dry; 1910–1934: normal to dry; 1935–1944: humid; 1945–1953: dry; 1954–1984: humid; 1985–1994: dry

The data analyses need to be further refined when dealing with the Pirin, Rila and Rhodope Mountains due to the scarcity of existing stations in these zones, the dominance of orographic influences and the close vicinity of the Mediterranean Sea. Through existing dedicated analyses of the area by Bulgarian scientists, the main climate evolution compared to what it was at the beginning of the twentieth century is a decrease of precipitation by 5–10% and a small increase in temperature (Sharov et al. 2000, Alexandrov and Genev 2003, Andreeva et al. 2003, Zlatunova and Slaveykov 2005).

These climate changes can be better scrutinized by analyzing the meteorological data series available for the stations of Bansko and Musala Peak between 1931 and 2006. On the basis of mean decade values, the monthly and annual averages at Musala Peak from the 1930s until the 1980s show that temperature deviates by only ±0.2°C from the long-term average (−3.0°C). An increase in temperature is, however, observed in the 1990s (2.7°C) and since 2001 (2.5°C).

In Bansko, mean decade periods 1931–1970 and 1981–1990 experience an average annual temperature of 8.3–8.5°C, which can be considered normal. In comparison, the 1970s were relatively colder (average 8.1°C), and temperature has distinctly increased since 1990 (1991–2000: 9.1°C; and since 2001: 9.6°C). Colder years with an average temperature below 8.0°C have occurred periodically between 1931 and 1980, but there was only one such cold year since 1981. Between 1998 and 2001, average temperatures were above 10.0°C, so these years are considered as the warmest of the observed period. A trend toward temperature increase in Southwest Bulgaria since the 1990s can also be verified when looking at the temperature time series from Bansko and Musala Peak (Fig. 4.5). It would tend to indicate an evolution in the temperature regime, particularly for the period 1998–2002.

Although a fairly good linear correlation does exist between the annual temperature series of Musala Peak and Bansko ($r_R = 0.72$), a significant linear warming

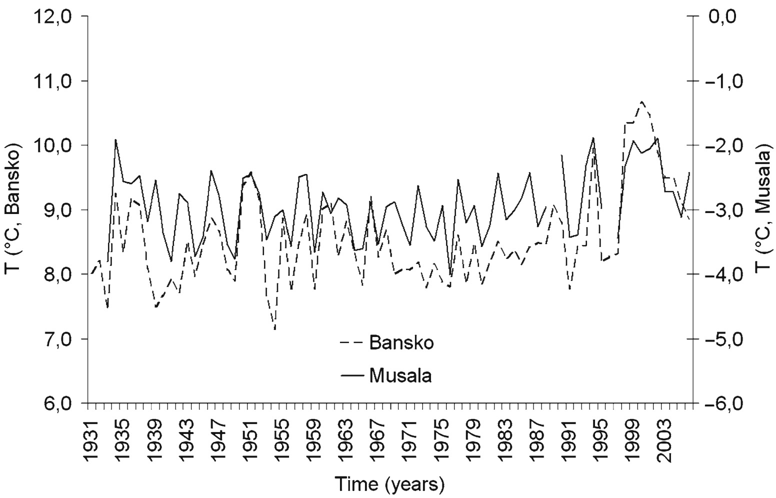

Fig. 4.5 Evolution of annual mean air temperature in Bansko and at Musala Peak from 1931 to 2006

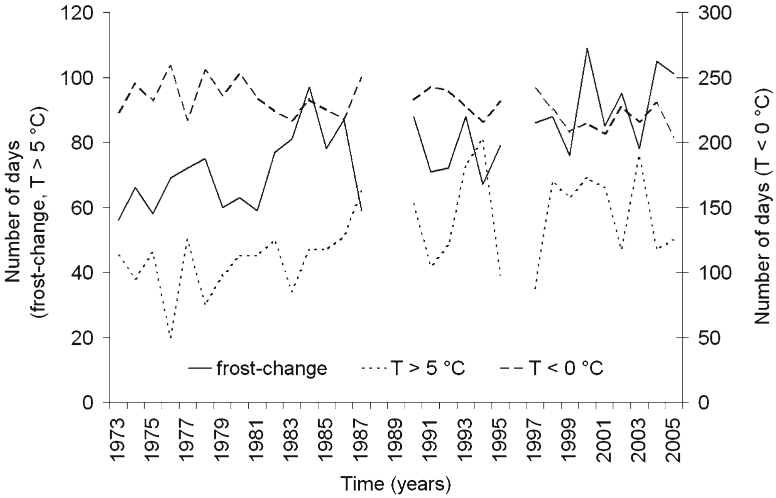

Fig. 4.6 Change in temperature threshold values at the Musala Peak

trend could be detected only for Bansko over the 1931–2006 period. A seasonal analysis has also been conducted using average monthly temperature values of predetermined periods (winter: December of the previous year – February; spring: March – May; summer: June – August; autumn: September – November). A little increase in warming trends can be observed for Bansko's summer temperatures. However, restricting the analysis to the last 30 years, a significant modification of temperature regimes at the summit level and in the basins can be characterized through the study of typical threshold values (frost change or vegetative periods) and extremes. If one considers the station of Musala Peak over the 1973–2006 period, (Fig. 4.6), the main features are:

- a significant shift from cold to warm days
- an increase of days with frost change, especially in April and September/October
- a general decrease of days with temperatures below 0°C
- a significant longer vegetative period (>5°C)
- a tendency to shorter winters and longer summers

These changes should affect the morphological stability of this alpine area, the development of soils, micro-organisms, vegetation and species composition, as well as the water retention capacity and snow cover period suitable for winter tourism (e.g. Veit 2002, Koleva-Lizama and Rivas 2003).

When looking at precipitation measurements, a long-term trend could not be detected. Humid and dry years alternate on a relatively frequent basis. Year periods 1990–1995 and 1998–2002 were characterized by high temperatures and low precipitation.

The analysis of monthly precipitation reveals possible trends for June (a decrease during the first vegetation period) and September (increase), but statistical significance of these trends is fairly low.

The statistical evaluation of Bansko's precipitation data resulted in significant trends from 1955 to 1995. A decrease of annual precipitation was observed ($r_R = -0{,}50$), which, with the exception of summer, is reflected seasonally. On a monthly basis, only September had a significant decline.

Petkova et al. (2004) investigated the change in snow cover duration over the Bulgarian mountains from 1931 to 2000 using 15 mountain weather stations. However, they could not characterize a variation in the beginning of the spring thawing period nor could they find significant evidence of the recent global warming. For the lack of consistent data, we could not clarify whether these insufficiently significant changes in snow cover regime in the beginning of the thawing period, presented in Petkova et al. (2004), are mostly caused by an increase of solid precipitation totals during the observed winter seasons.

A global correlation between winter precipitation variability in the Alps and the Northern Atlantic Oscillation (NAO) has been recently documented (Beniston 1997, Petkova et al. 2004). This would cause a later start of the snow period in the mid-mountain region between 1,000 and 1,500 m, and would lead to a shorter annual snow cover period. This type of hypothesis has been tested by analyzing the number of days with/without snowfall at Musala Peak station during the 1973–2006 period. It showed that the annual number of days with snowfall decreases over time as well as for the summer and autumn periods (Table 4.6). Comparatively, rainfall and temperature have significantly increased (Fig. 4.7).

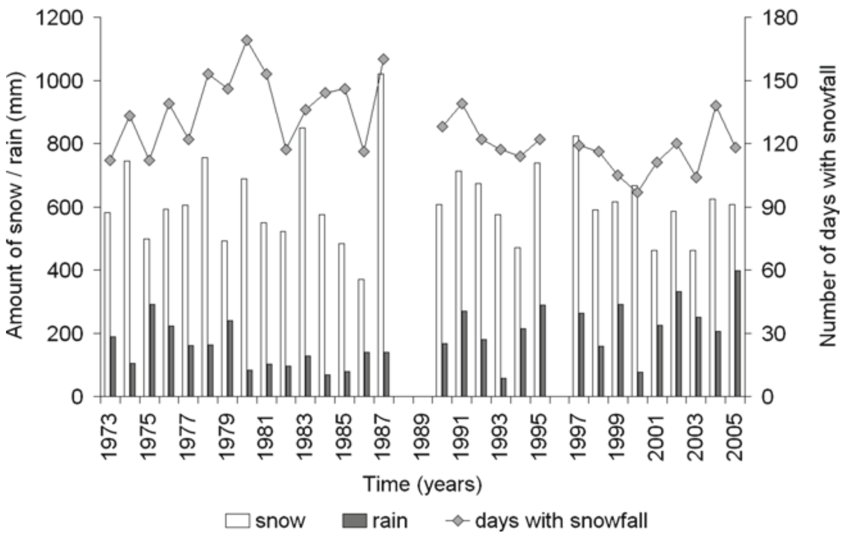

Fig. 4.7 Days with snowfall and snow-rain-balance at the Musala Peak

4.2 Pirin's Glacier Features as a Climate Indicator

4.2.1 Introduction

Numerous mountain ranges in the Mediterranean and Balkans were covered by glaciers during the Pleistocene. In a classic work, Messerli (1967) documented evidence of glaciation across the Mediterranean mountains and used this evidence to reconstruct the glacial snow line across the region: ~ 1,000 m lower than the modern snowline in many areas. This was based on Messerli's own field observations and also the works of renowned glacial morphologists such as Louis (1933), Büdel (1949) and Paschinger (1955).

The Calderone Glacier in Italy is often cited as the southernmost glacier in Europe. This claim was preceded by the Corral del Veleta in the Spanish Sierra Nevada, but this glacier melted at the beginning of the twentieth century. The Calderone Glacier also seems likely to disappear in the near future (Pecci et al. 2001, Meier et al. 2003, Citterio et al. 2007). In 2009, it was divided into two small glacier patches (glacierets). A review of the current status of Europe's southernmost glaciers and the regional and local climatic and topographic factors controlling their development is given by Grunewald and Scheithauer (2010).

Glaciers also exist at similar latitude in the Balkans (Grunewald et al. 2006, Hughes 2007, 2008, 2009, Milivojevič et al. 2008). However, until recently, little was known about the small glacier forms of this region. In the Prokletije Mountains on the Montenegro-Albania border, Roth von Telegd (1923) reported several ice and snow features at the beginning of twentieth century, including Firnmasse, which was over 1 km long. Today in this area, there are still several glaciers, which cover areas of up to 0.05 km^2 (Milivojevič et al. 2008, Hughes 2009). These are all situated just north of 42° latitude and well below the climatic snow line. They survive as a result of avalanching and wind drift snow and shading. Our first aim is to review the current status of Europe's southernmost glaciers as well as the climatic and topographic factors controlling their development.

To understand the response of southern European glaciers (particularly Balkan glaciers and Pirin Mountain glacierets) to recent climate change we have studied the Snezhnika Glacieret in Bulgaria during the past few years (Grunewald et al. 2006, Grunewald and Scheithauer 2008d, 2010). Snezhnika is the remains of the Vihren Glacier in the Pirin Mountains. This glacier patch covers an area of nearly 0.01 km^2 and is currently Europe's southernmost glacieret (41° 46′ N). The Snezhnika Glacieret is exceptional, persisting despite a relatively high (and recently increasing) annual mean temperature and low precipitation. To examine the special conditions pertaining to this glacier-feature in southeastern Europe we

- mapped cirques with snow and glacier-patches in the northern Pirin Mountains,
- assessed the local topographic and climatic factors contributing to glacier activity,
- reconstructed the firn area of the younger past, and
- carried out an ice core drilling project on the Snezhnika glacieret.

4.2.2 The Recent Glaciation of High Mountains in Southeastern Europe

At the beginning of the third millennium, there are only a few small glaciers in southern Europe (Fig. 4.8). The southernmost of these are situated close to 42° N. Photographs of selected examples are presented in Fig. 4.9. The Caucasus area is excluded from our investigations although there is a European part of the Caucasus at approximately 42° N where large glaciers appear.

Messerli (1967) described the southern European glaciers as "Pyrenean type" with these characteristics:

(1) a location at the foot of a wall or in a hollow in N- to E-orientation,
(2) an underdeveloped tongue and
(3) a small area, width often larger than length.

Grunewald et al. (2006) used the German term "Mikrogletscher" to describe small dynamic snow and ice features in Bulgaria. Here, we use the term "glacieret" or "glacier-patch" (Maisch et al. 1999b). They form from either drifted or avalanched snow and/or heavy accumulation in certain years (WGMS 2008, p. 99). These glacierets, according to Grunewald et al. (2006), are characterized by:

(1) quasi-permanency (relatively reliable for the past few decades back to 1850 AD),
(2) firn and ice (density > 0.600 g cm^{-3}, at the bottom ~ 0.800 g cm^{-3}),
(3) perennial firn layers and
(4) an area of at least 10,000 m^2 and thickness of several meters.

Moraines on the front or side are typical (Fig. 4.9), with crevasses often present in the firn, indicating motion (normally rotary motions, Grunewald and Scheithauer 2008d). At the Debeli Namet Glacier in Montenegro, Hughes (2007) observed evidence of

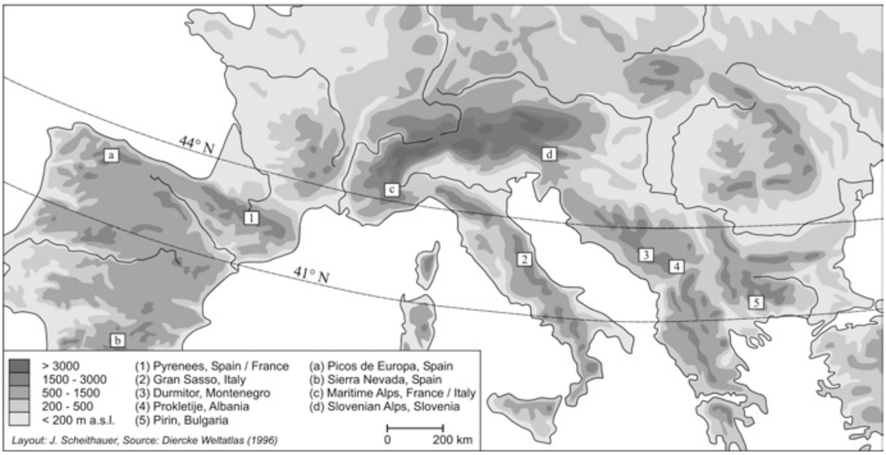

Fig. 4.8 Location of the southernmost glaciers in Europe (Grunewald and Scheithauer 2010)

Fig. 4.9 Photographs of glacier features in the Pirin Mountains: the Snezhnika glacieret at the Vihren wall in (**a**) September 1959 (photo: Popov), (**b**) September 2004, (**c**) May 2005, and (**d**) September 1994 as well as (**e**) the glacieret and snow patches in the cirque Banski Suhodol in September 2004 (photos: K. Grunewald)

deformed banding on the glacier surface, suggesting dynamic glacier ice. However, unlike larger glaciers, these are either in the accumulation or in the ablation zone at the end of the melt season. In fact, in some years, the entire glacier surface can experience negative mass balance, while in high precipitation years the entire glacier surface can experience positive net balance. This fickle mass balance behavior means that defining the equilibrium line altitude (ELA) is often problematic (Hughes 2008).

In addition to small glaciers and glacierets, perennial ice, firn and snow patches are also present in southern Europe. They are often accumulations of avalanche and windblown snow and outlast one or more summers on protected sites of the periglacial altitude level (Stahr and Hartmann 1999). The transition between ice, firn and snow patches, glacierets and glaciers is not always clear, although for to define a glacieret or glacier, there must be evidence that the ice mass is actively deforming and the ice is moving rather than static (UNESCO/IAHS 1970, Maisch et al. 1999a). An example of problems in defining these features is illustrated in the Tatra Mountains of Poland and in Slovakia. Here, Jania (1997) calls them snow patches, whereas Gadek and Kotyrba (2003) refer to glacierets.

Modern Glacier Features of the Balkans

Glaciers formed in all Balkan high mountains during the Pleistocene (Hughes et al. 2006). However, recent research has also revealed new evidence of small modern glaciers in the Balkans (Grunewald et al. 2006, Hughes 2007, 2008, 2009, Milivojevič et al. 2008, Grunewald and Scheithauer 2008d).

Modern glaciers are not present in Greece since the permanent snowline is situated well above most of the highest peaks. The snowline was above 3,000 m a.s.l. in the Pindus Mountains of northern Greece and above 3,500 m across Crete during the middle of the twentieth century (Messerli 1980) but has risen in the past few decades.

Further north in the Bulgarian Pirin Mountains, we mapped two glacierets and several firn patches between 1996 and 2004 (Table 4.7). The Snezhnika Glacieret (41° 46′ N, 23° 40′ E) at the foot of the north-wall of the peak Vihren (2,914 m a.s.l.), is currently the southernmost glacial mass in Europe (Table 4.8, Fig. 4.8). Beside the Snezhnika glacieret exist a nameless glacieret under the Koncheto ridge (cirque Banski Suhodol) with a firn area of ca. 1.5 ha (2009). The adjacent Rila Mountains to the north are free of ice due to silicate rock although the highest summit of the Balkan Peninsula (Musala, 2,925 m a.s.l.) is found here.

Further north and west, there are glaciers of areas of up to 0.05 km^2 in Albania and Montenegro. In the central part of Mt. Prokletije (Albanian Alps, 2,694 m a.s.l.), Milivojevič et al. (2008) detected three glaciers with moraines and two rock glaciers in cirques around 2,000 m a.s.l., which are situated within ridges more than 400 m high. The Debeli Namet Glacier is further north, in the Montenegrin Durmitor Massif (Table 4.8, Fig. 4.8). The glaciers of Albania and Montenegro

Table 4.7 Current glacierets and snow patches in cirques of the northern Pirin Mountains

	Type			
Cirque	Glacieret	Calderon-type snow-patch	Wall-niche type snow-patch	Explanation
Golemya Kazan	1	–	x	At the wall bottom and on flanks, heavy avalanche filling and shadowing
Kutelo	–	2	–	Exposition in depth contours of the cirque, strong avalanche filling, no shadowing by cirque walls
Banski Suhodol	1	several	x	At the wall base and in deep holes, heavy avalanche filling and shadowing
Bayuvi Dupki	–	–	x	At the wall bottom and in depth contours of the cirque, strong avalanche filling, moderate shadowing by cirque walls
Kamenica	–	–	x	At the wall bottom and in depth contours of the cirque on the shady side of the very small cirque, few avalanche filling

Table 4.8 Characteristics of southern European glaciers (representative selection <44°N, for location see Fig. 4.8)

Glacier name	**Maladeta**	**Calderone**	**Debeli Namet**	**Maja e Kolacit**	**Snezhnika**
Exposition	NE	NNE	N	N	NE
Max.-min. height (m a.s.l.)	2,870–3,210	2,680	2,080–2,290	1,980–2,100	2,430–2,480
Length (m) (year)	810 (2007)	300 (2007)	360 (2007)	410 (2007)	80 (2007)
Country	Spain	Italy	Montenegro	Albania	Bulgaria
Mountain (Fig. 4.8)	Pyrenees (1)	Apennines (2)	Durmitor Massif (3)	Prokletije (4)	Pirin (5)
Coordinates	42°65'N, 0°63'E	42°28'N, 12°27'E	43°06'N, 19°04'E	42°30'N, 19°55'E	41°46'N, 23°40'E
Highest peak (m a.s.l.)	Maladeta 3,308	Corno Grande 2,912	Šljeme 2,455	Maja e Jezerces 2,694	Vihren 2,914
Estimated climate data near the glacier					
Precipitation (mm a^{-1})	2,500	>2,000	2,500–3,000	2,500–3,000	1,000
Mean temperature (°C)	0,7	1	0,9	0,9	0
Area (km^2) (year) (measurement: ground/field topography, GPS, tape, photogrammetric, aerial + ground control)	1.52 (1820) 0.55 (2000) 0.45 (2007)	0.104 (1794) 0.091 (1884) 0.070 (1916) 0.060 (1934) 0.053 (1990) 0.033 (2006)	0.018 (2003) 0.041 (2005) 0.050 (2006) 0.037 (2007)	0.054 (2007)	0.013 (1959) 0.004 (1994) 0.008 (1996) 0.007 (2000) 0.010 (2006) 0.007 (2008)
Max. thickness (m) (year) (measured by drilling or calculated, using an empirical volume-area relationship; Chen and Ohmura 1990)	?	25 (1990)	16 (2006)	? (average ~ 10 m)	12 (2006)
Volume (m^3) (year) (estimated from average area and thickness)	?	361,000 (1990)	122,250 (2003) 373,500 (2005) 489,000 (2006) 325,000 (2007)	542,880 (2007)	30,000 (2006)
References	Chueca et al. 2007	D'Orefice et al. 2000; D'Alessandro et al. 2001; Pecci et al. 2001; Di Paola 2007	Hughes 2007, 2008	Hughes 2009	Popov 1964; Grunewald et al. 2006; Grunewald and Scheithauer 2008c

represent some of the lowest altitude glaciers (around 2,000 m) at this latitude (42–44° N) in the northern hemisphere (Hughes 2008, 2009).

In the northern Balkans, two glacierets are present in the mountains of Slovenia. On Mount Triglav (2,864 m a.s.l.) in the Julian Alps of Slovenia, the former Zeleni Sneg Glacier is situated on the northern slopes between ~2,550 and 2,400 m a.s.l. By 1995, the glacier covered an area of only 0.0303 km² (Gabrovec 1998). Increases in summer temperatures and maximum daily temperatures from May to September between 1954 and 1994 are closely correlated with the retreat of the glacier front and a reduction in ice thickness (Gams 1994). In addition, a small glacieret is present at the foot of the 700 m high Skuta north face in the Steiner Alps, at ~ 1,700 m a.s.l. – considerably lower than the regional snow line (Pavšek 2004).

Synthesis: Factors and Regionalization

The small number of glaciers and glacierets in southern and southeastern Europe indicates that the recent regional climatological ELA is above the altitude of the summits (e.g. Messerli 1967, González Trueba et al. 2008, Hughes and Woodward 2009).

Figure 4.10 illustrates the factors that influence the formation and dynamics of small glaciers and glacier-patches in the mountains of southern Europe. Europe's southernmost glaciers are currently found at altitudes between 2,000–3,000 m a.s.l. and at latitudes between 41° and 44° N (Fig. 4.8, Table 4.8). The size of the glaciers varies from ~ 800 m length and 0.1–1.0 km² in the Pyrenees (González Trueba et al. 2008), up to 300–400 m length and 0.03–0.05 km² in the western Balkans, and to almost 100 m length and 0.005–0.015 km² (glacier patches) in the Pirin Mountains (eastern Balkans).

All regions show a relatively warm and wet mountain climate with oceanic, Mediterranean or continental moderate conditions (west to east). The annual mean temperature in the glacier areas is estimated at 0 to +1°C (Table 4.8), which is normally much too warm for glacier persistence. The fact that conditions are warm at the glacier sites in southern Europe means that there must be large amounts of accumulation to offset melting (Ohmura et al. 1992, Kaser 2001).

The topography and exposure of the southern European glacier sites are very similar. They all survive in north/northeast facing locations within very steep cirque

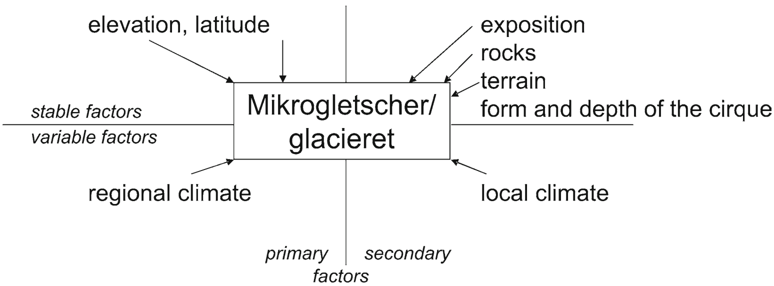

Fig. 4.10 Basic formation factors of small glacier features (cf. Grunewald et al. 2006)

walls below the highest summits. This applies especially to the Calderone, Debeli Namet and Snezhnika glaciers (Fig. 4.9). They are thereby protected against perpetual, intensive and direct summer radiation. The glaciers persist below the ELA because of substantial inputs from avalanches and windblown snow. Hughes (2008) showed, for example, that the annual accumulation required to balance melting at the Debeli Namet Glacier in Montenegro was 5,000–6,000 mm snow water equivalent but the precipitation in the high mountain area is only 2,500–3,000 mm (Table 4.8). Thus, local sources of snow input must effectively double the accumulation to preserve the glacier.

The underlying lithology is also relevant. Limestone and marble rock form small and deep cirques, promoted by the occupation and excavation of pre-existing dolines (Grunewald et al. 2006, Hughes and Woodward 2009). These light-colored carbonate rock types also typically exhibit high albedo (Popov 1964). Furthermore, due to karstification, melt water is quickly trickled away. For example, no cirque lakes persist as thermal storage systems.

4.2.3 Investigation Methods and Application to Snezhnika Glacieret

The same methods used to examine bigger glaciers can be utilized for the investigations of small glaciers (e.g. Stauffer and Schotterer 1985, Kuhn 1993, 1995, Weiler et al. 2005, Hagg 2006, Grunewald and Scheithauer 2008d). These methods include surveying the size and mass balance and their changes using photographic-historic, photogrammetric and geophysical investigations as well as firn drilling. Field and laboratory analyses of firn characteristics, as well as investigations in the glacieret's environment (rock, soils, moraines, and caves), are essential.

Georadar measurements (Ground Penetrating Radar – GPR) are extremely suitable to illuminate the inner structure and stratification of small glaciers without taking samples. The Georadar measurements at the remains of the Triglav glacier (Vrebič and Gabrovec 2002), at the Calderone glacier (Pecci et al. 2001) or at the Mieguszowiecki glacieret in the Polish High Tatra (Gadek and Kotyrba 2003) are described in full detail.

Changes of the glacierets' area and surface can be understood by simply measuring the objects in situ using GPS, measuring tape, a declinometer, a compass (highest and lowest elevation, inclination, form, etc.) or more elaborate photogrammetric measurements. Location, time and quality of the records essentially decide the result. Direct volume and mass balances require density measurements (Gams 1994, Litwin 1997, Gabrovec 1998, Triglav et al. 2000, D'Alessandro et al. 2001, López-Moreno et al. 2006).

The glacier thickness (ice component) can also be estimated by using glacier surface slope (Hughes 2008), rearranging the equation: $\tau_b = r\ g\ h\ \sin_\alpha$ to isolate h (where τ_b is basal shear stress (kPa, Paterson 1994) and r is the density of ice (0.9 g cm^{-3} or 900 kg m^{-3}), g is gravitational acceleration (9.81 m s^{-2}), h is ice thickness (in meters) and α is the surface slope of the ice). Glacier volume can be estimated using an empirical volume-area relationship that is widely applied in glacier inventory and water resources estimation. Based on data from 63 mountain glaciers, Chen and Ohmura (1990) found that: $V = 28.5\ S^{1.357}$ (where V is glacier volume – 10^6 m^3 – and S is glacier surface area – 10^6 m^2). The ratio between the drainage area leading directly onto the glacier surface and the total glacier area can provide an indication of the possible contribution of windblown and avalanching snow (Hughes 2008).

All of these methods were applied to the Balkan glaciers and glacierets in the last few years. The basic step is the mapping of the glacier cirque and the description of the glacier surrounding.

The physical-geographical conditions of the Golemya Kazan cirque are described in Table 4.9. The cirque is ellipsoidal, belted by the northeast wall of peak Vihren (2,914 m) and the south wall of peak Kutelo (2,907 m) and ca. 1.2 km² large (Grunewald et al. 1999). To the east exists a narrow pass with a moraine-covered cirque barrier to the down-valley cirque Malkya Kazan (see Fig. 3.1). The morphologic properties were laid out apparently during the end-stadium of the Würm glaciation (Popov 1962).

The firn-size of the Snezhnika glacieret is retraceable through photographs taken up until the middle of the twentieth century. A Bulgarian climbing guide from 1956 shows the upper part of the glacieret. September is the best month for observation because it has the most snow ablation and the least firn-size. The Photo of Popov (1964) from September 1959 (Fig. 4.9) is good starting material. Since September 1994 we have routinely performed our own measurements and documentations.

Table 4.9 Geo-factors of the cirque Golemya Kazan

Geo-factor	Characteristics
Rock	Light-colored marble rock (high Albedo: 25–30%)
Morphology	Bowl form (three-sided framing of the NNE/NE-exposed cirques); detailed map in Grunewald et al. 1999)
Soils	Skeleton soils with humus layers (pH 5–7; relative close C/N-ratio; high humus-, C_{org} and N_t-values, cf. Grunewald et al. 2005)
Vegetation	Alpine rock and scree communities, individual grass communities, insular shrubs (list of species in Grunewald et al. 1999)
Hydrology	Due to karstification, meltwater is quickly trickled away
Climate (acc. to Popov 1964 on the base of measurements during the period 1957–1961)	– Wind and radiation protected – Mean annual air temperature ca. 0°C, annual amplitude value ca. 16°C only – Coldest months January to March (mean: −6.1°C) – Warmest months June to August (mean: 7.2°C) – Precipitation ca. 1,000 mm per year, relative evenly distributed – Snow cover from November to May/June typically; up to 2 m depth of the snow (with snow drifts and avalanches even more)

Further photos in recent years (1962, 1975, 1979, 1984 as well as 1987–1993) attest to the persistence of the glacieret over the last 60 years. But these records can't be used for quantification of firn-size because the moment, point or detail of photography. High resolution satellite imaging was available August 2007 (see Fig. 3.1).

In comparison to 1959, the firn area extension of the Snezhnika glacieret was barely half what it was in the 1990s and at the beginning of the twentieth century (Table 4.10). We observed the following cycle: 1985–1994 slowly de-icing; then fast growing in the mid-1990s, then slowly thawing up to 2003 and then an increase of firn-masses from 2004 to 2006. There has been a stabilization phase up to the present.

Grunewald et al. (2006) showed, that the sum of melting temperatures is not directly correlated with yearly firn-size. The reason is the delayed reaction of firn to increasing temperature. But the snow-precipitation-relation is correlated with the firn-size of a year ($r=0.7$; Grunewald et al. 2006).

Three drillings were carried out in September 2006 at the Snezhnika Glacieret (Grunewald and Scheithauer 2008d) using a Ruefli-driller provided by the Alfred Wegener Institute, Potsdam. The drill is equipped with:

(1) a circular cutter with three knives that cut a ring into the ice leaving the core (70–100 cm length, 10 cm diameter) in the center,
(2) glass fiber leverage up to 16 m (13 individual extensions) + additional equipment (tools, scale, spare parts) and
(3) hand crank, motor cap, fuel, transport and cooler boxes (all together ~ 60 kg wt.).

Figure 4.11 shows the position of the drill holes, each vertical and to the bottom of the ice. Depths of 7.8 m (site BOA), 10.9 m (BOB) and 11 m (BOC) were reached. BOD marks the position of the investigation at the cleft in 2004, described by Grunewald et al. (2006). Processing in the field consisted of core description (stratification, characteristics), photographs, core physical and

Table 4.10 Climate data (Musala peak) and firn-size variability of the Snezhnika glacieret (climate data: difference of the year to the mean of the period 1973–2006; winter: Nov.–April; summer: June–Aug.; n.d. = no data)

Year	ΔT-Winter (°C)	Δ P-Winter (mm)	ΔT-Summer (°C)	Δ P-Summer (mm)	Firn-size in Sept. (ha)	Firn-size relative to 1959 (%)
1959	+0.3	+109	−1.4	+124	1.3	100
1994	+1.3	−60	+0.5	−9	0.4	31
1995	+0.4	+36	−0.9	−22	n.d.	n.d.
1996	−0.6	−42	−0.1	−74	0.8	62
1997	−0.1	+260	−0.7	+68	n.d.	n.d.
1998	+0.6	−33	+1.5	−62	0.7	54
1999	−0.5	−37	+1.4	+10	0.6	46
2000	−0.3	+201	+1.6	−160	0.7	54
2001	+2.1	−117	+1.0	+21	0.6	46
2002	+0.1	−63	+0.7	+93	0.5	38
2003	−1.0	−15	+1.5	−33	0.5	38
2004	+0.2	−79	+0.1	−45	0.8	62
2005	−0.5	+125	+0.2	+72	0.9	69
2006	+2.6	−9	+0.3	+4	1.0	77

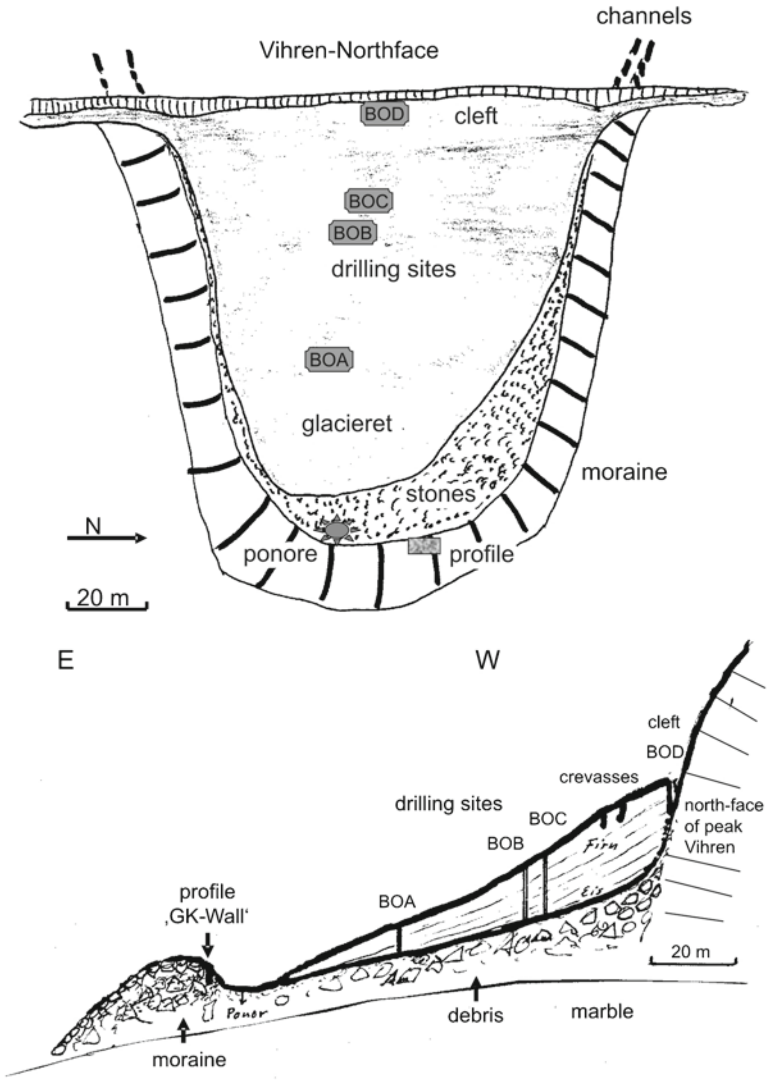

Fig. 4.11 Profile of the Snezhnika glacieret showing the position of the core drilling sites

chemistry measurements, borehole temperature, weighting and core packing. Core density, ion content and isotope ratio were measured in the laboratory to reconstruct climate and environmental indicators.

Numerous boundary layers could be identified in the cores (Fig. 4.12). However, to a large extent these boundary layers do not separate homogenous layers of a mass balance year but several, alternating soft and hard layers. The layers represent larger precipitation or avalanche events in the upper zone; further down they are compressed. A sloping stratification of ~ 30–45,° analogous to the gradient of the bedrock and the surface of the glacieret, was determined. Characteristic features

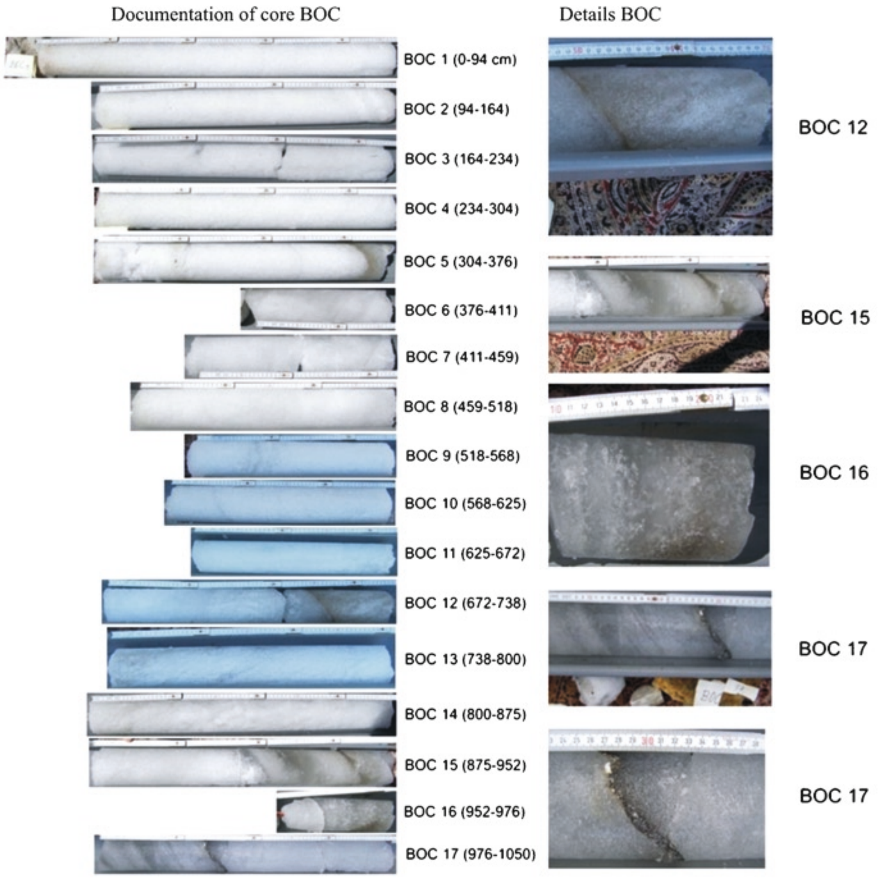

Fig. 4.12 Documentation of the ice core BOC and selected detailed views

included layers with a reddish coloration in snow, firn and ice (probably due to Sahara dust) and ice-lamellae due to surface melting or rock layers (culm) of up to 2 cm thickness close to the bottom. One hundred and twenty five layers were sampled in total (BOA: 44, BOB: 47, BOC: 34). The layers were divided into categories: 1-old snow, 2-firn, 3-firn ice or 4-ice, based on color, consistency and particle size and verified the density measurements. To analyze the relation between parameters, Spearman's rank correlations were determined. Several significant relationships between individual parameters were identified (Grunewald and Scheithauer 2008d). Cluster analyses of the data according to the Ward-method confirmed the element combination. We found logical relations between:

(1) the depth profiles and density,
(2) the pH-value, Ca^{2+} and conductivity (ion dominance of the calcium, probably because of the close position to the marble wall and therefore alkalinity with depth), and

(3) nitrate, sulphate and $\delta^{18}O$. The depth pattern may be the result of a common atmogenic origin and similar translocation processes in the glacier (molecular size and integration in firn/ice crystals).

The high densities in the firn profiles, which increase from top to bottom as well as from site BOA to site BOC (Figs. 4.11, 4.13a), i.e. toward the marble-wall, characterize the important role that the freeze-thaw cycle plays in determining the structure of the Snezhnika Glacieret. Such densities (> 0.815 g cm^{-3}) generally occur at depths between 50 and 100 m in polar regions where the snow metamorphose is influenced only to a small extent (if at all) by melt or water precipitation (Leuenberger 2005). Temperature measurements, using a probe that was inserted into the core immediately after core extraction, produced values between 0.0 and −0.4°C. The precipitation contains isotopes of oxygen and hydrogen that are correlated with air temperature at the time of deposition (Johnsen et al. 1997). Aerosol concentrations allow *inter alia* conclusions as to previous environmental conditions and the possibility of a chronological classification. However, during the summer period, ablation processes occur that can considerably damage the deposition record. It is almost certain that there are translocation processes due to percolating water during the melting process (Eichler et al. 2001). During the course of the rearrangement of ions at snow metamorphosis, the substances that are less efficient wash out and undergo integration into the ice grid during grain growth.

As indicated by the conductivity measurements (Fig. 4.13c), the total ion concentration generally increases with depth (conductivity <10 μS cm^{-1} in the old snow/firn; 10–20 μS cm^{-1} in the deeper firn/ice layers). This increase indicates relative matter enrichment (relative to volume, mass or bulk density; enrichment processes: translocation, evaporation, compaction). Individual layers near the base show conductivity peaks of more than 60 μS cm^{-1}. pH values (Fig. 4.13b) of 6.0–6.5 are found in the uppermost 3 m. Below this, they decrease slightly, then increase with depth to values between 6.5 and 7.0.

At Snezhnika glacieret, calcium dominates as a rock-determined ion (marble), whereas sulphate exhibits the highest concentration in firn and glacier features in siliceous areas (Eichler et al. 2001, Veit 2002, Pohjola et al. 2005). Quantitatively, magnesium is usually at the end of the ion series. Compared with anions, cations quantitatively dominate in the Pirin Mountains (Table 4.12), and the total ion contents are considerably higher than in larger glaciers. The calcium ion concentration fluctuates by 1 mg L^{-1} to a depth of almost 10 m and increases at the base. However, the sulphate ion concentration decreases with increasing depth in the BOC core. For most other ions, there are no clear trends, while single layers in different depths stand out because of peaks. Whether the latter could constitute marker-horizons for dating purposes is yet to be clarified.

Isotope investigation of ice cores allows us to estimate the past climate. The $\delta^{18}O$ analyses of the sampled layers of the Snezhnika glacieret, however, are suitable to only a limited degree in this regard because complete annual layers over time scales greater than one year are likely to be deficient. There is a decreasing trend with increasing depth of the isotope values in our cores (Fig. 4.13d). The lower $\delta^{18}O$

values at the base may indicate cooler deposition conditions and older ice (Moser and Rauert 1980).

Material from the BOC core near the base (9.75 m depth) was ^{14}C-dated. Pollen was analyzed, however age could not be calibrated at the AMS Laboratory, Erlangen. Apparently the sample contained a mixture of material from before and after the 1955 bomb peak. This ice could therefore be ~ 50 years (± 20 years) old. Organic material from 10.03 m deep in the BOC core was also dated. This sample

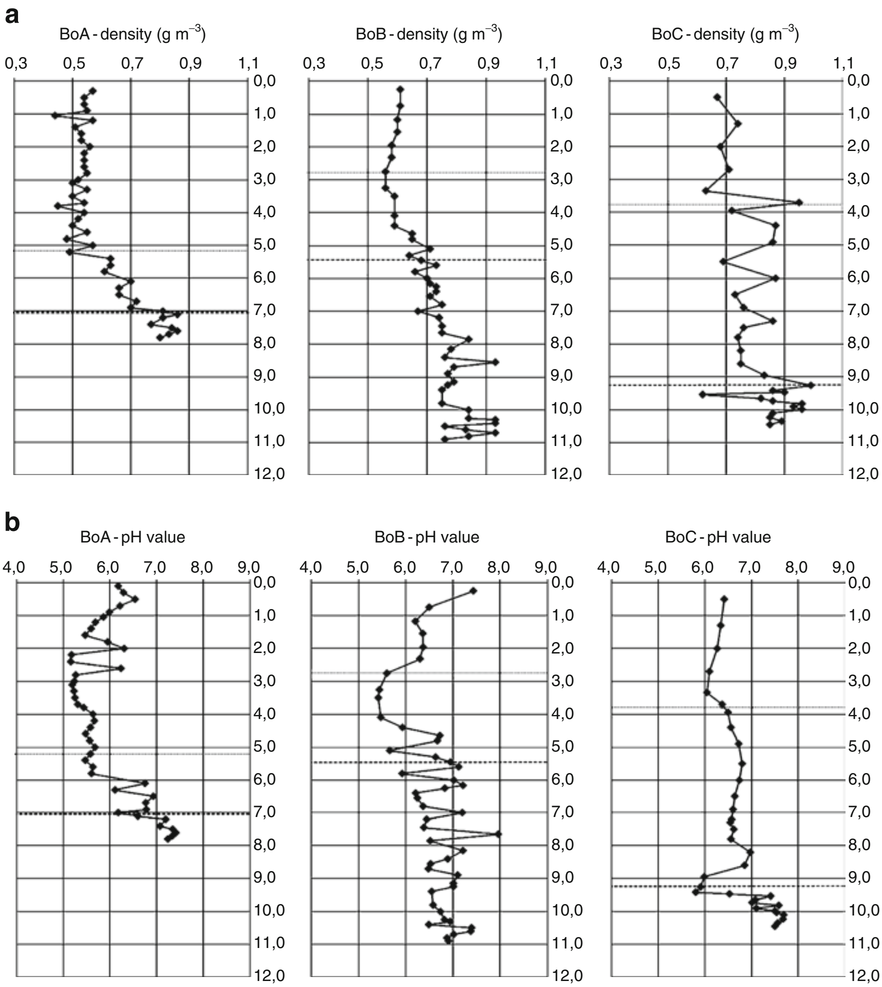

Fig. 4.13 Plots against depth of (**a**) density, (**b**) pH value, (**c**) conductivity and (**d**) stable isotope ratio for each of the three cores, BOC, BOB and BOA. The dotted horizontal lines indicate the transition depth between old snow and firn. The dashed horizontal lines indicate the transition depth from firn to ice

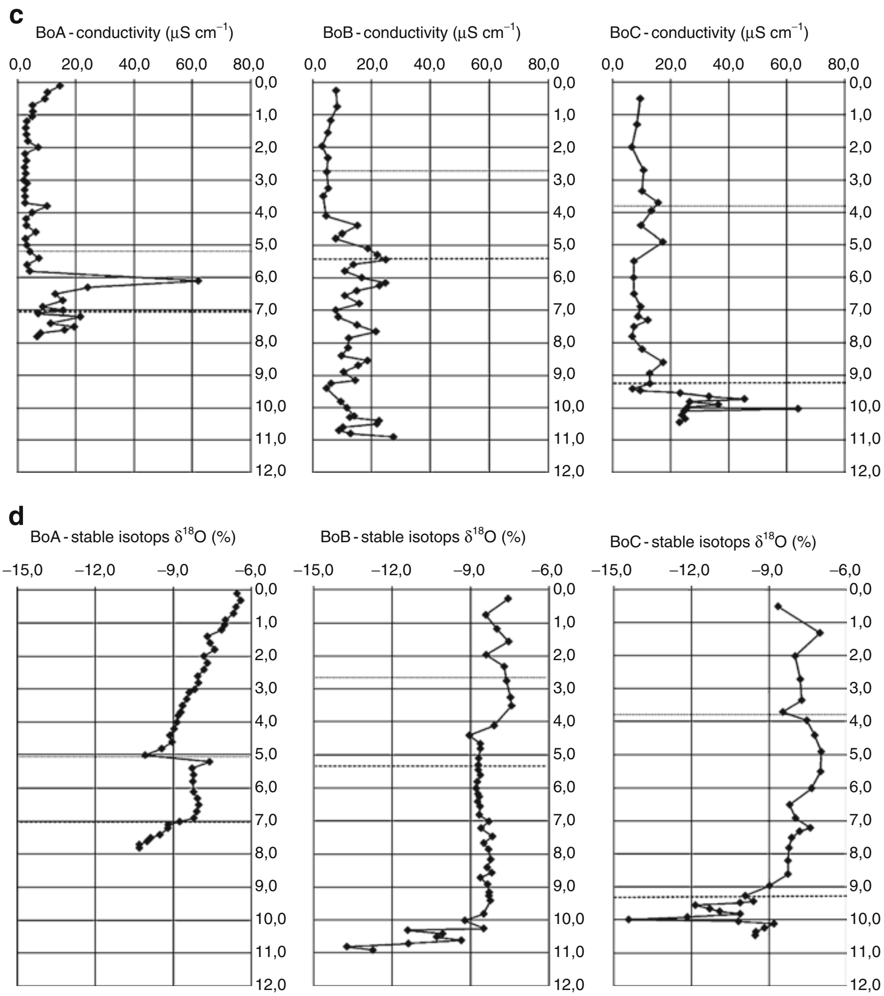

Fig. 4.13 (continued)

was measured at a calibrated age of 1810–1924 AD, but the result allows statements on the development period of the organic substance only.

In the case of all climate reconstructions based on former glacier variations, several methods should be used for validation, i.e. morphogenetic phases known in the cirques should be checked against historical sources and independent physical records such as lichenometry, dendroclimatology and historical climatology.

The moraines around the glaciers are characteristic of cirque moraines and provide interesting data on the former behavior of the glaciers. Their dating gives important indications as to glacier advances. The moraine at the Snezhnika glacieret was dug up and examined in September 2005. Chapter 3 discussed the results.

Table 4.11 Means and medians of core physics and chemistry measurements

	Density (g cm^{-3})	pH	Cond. (μS cm^{-1})	$\delta^{18}O$ (‰)	F^- (mg L^{-1})	Cl^- (mg L^{-1})	NO_3^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	Na^+ (mg L^{-1})	NH_4^+ (mg L^{-1})	K^+ (mg L^{-1})	Mg^{2+} (mg L^{-1})	Ca^{2+} (mg L^{-1})
Median													
Total	0.72	6.53	9.80	−8.41	0.11	0.42	0.09	0.26	0.33	0.06	0.15	0.02	1.04
BOA	0.55	5.78	5.05	−8.22	0.10	0.28	0.05	0.11	0.27	0.05	0.11	0.00	0.28
BOB	0.73	6.63	11.60	−8.59	0.10	0.43	0.12	0.38	0.34	0.06	0.16	0.02	1.46
BOC	0.84	6.63	12.40	−8.37	0.11	0.54	0.09	0.49	0.33	0.06	0.20	0.02	1.24
Mean													Ca^{2+}
Total	0.71	6.45	12.45	−8.68	0.14	0.67	0.12	0.39	0.51	0.06	0.23	0.02	1.40
BOA	0.61	6.03	8.52	−8.33	0.17	0.75	0.08	0.23	0.62	0.05	0.23	0.01	0.65
BOB	0.72	6.62	12.59	−8.81	0.13	0.64	0.16	0.39	0.48	0.06	0.23	0.02	1.51
BOC	0.81	6.77	17.33	−8.96	0.12	0.61	0.11	0.58	0.41	0.08	0.22	0.04	2.22

Table 4.12 Spearmans Rang-correlation r_R of the data-set (in bold: significant from $p < 0.05$)

Total	Depth	Density	pH	Cond.	F^-	Cl^-	NO_3^-	SO_4^{2-}	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	$\delta^{18}O$
Density	**0.79**	.	.	.	.	.	.	.	.	.	.	.	.	.
pH	**0.65**	**0.68**	.	.	.	.	.	.	.	.	.	.	.	.
Cond.	**0.59**	**0.67**	**0.68**	.	.	.	.	.	.	.	.	.	.	.
F^-	–0.10	0.05	0.10	**0.43**	.	.	.	.	.	.	.	.	.	.
Cl^-	0.03	**0.20**	**0.21**	**0.53**	**0.89**	.	.	.	.	.	.	.	.	.
NO_3^-	0.17	**0.18**	**0.25**	**0.25**	0.13	**0.22**	.	.	.	.	.	.	.	.
SO_4^{2-}	–0.06	0.16	0.14	**0.25**	0.15	**0.26**	0.10	.	.	.	.	.	.	.
Na^+	–0.06	0.06	0.11	**0.44**	**0.88**	**0.90**	**0.18**	0.10	.	.	.	.	.	.
NH_4^+	–0.02	0.13	0.02	**0.25**	**0.38**	**0.47**	0.17	0.14	**0.42**	.	.	.	.	.
K^+	0.02	**0.19**	**0.22**	**0.51**	**0.83**	**0.88**	**0.20**	0.17	**0.88**	**0.40**	.	.	.	.
Mg^{2+}	**0.52**	**0.57**	**0.57**	**0.69**	**0.23**	**0.38**	**0.35**	0.14	**0.32**	**0.25**	**0.32**	.	.	.
Ca^{2+}	**0.71**	**0.74**	**0.76**	**0.94**	**0.23**	**0.36**	**0.27**	**0.24**	**0.27**	0.17	**0.35**	**0.72**	.	.
$\delta^{18}O$	**–0.67**	**–0.46**	**–0.40**	**–0.43**	0.05	0.03	–0.07	**0.18**	0.05	0.09	0.02	**–0.35**	**–0.52**	.
Category	**0.88**	**0.82**	**0.62**	**0.61**	–0.05	0.15	0.17	0.15	0.03	0.16	0.13	**0.52**	**0.71**	**–0.44**

Hughes (2007) examined front moraines using lichenometric methods (*Aspicilia calcerea agg*.) at the Debeli Namet glacier in Montenegro. The dating produced three ages: 1878 AD, 1904 AD and a more recent activity (1994-2005). Hughes (2007) deduced periods with cooler summers between 1875 and 1925, which correspond well with the proxy data for the Alps (Wilson et al. 2005) and the Mediterranean (Repapis and Philandras 1988). However, precipitation could also be an important factor. According to Katsoulis and Kambezidis (1989), precipitation was particularly high in the southern Balkans during the decade 1875–1884. But, the period between 1850 and 1870 was, at least in the Alps, extremely dry (Böhm et al. 2006).

4.2.4 The Response to Climate Change

The southern European mountains have received scant attention in the literature. However, numerous small glaciers, glacierets and perennial snow/firn patches exist in several mountain areas, such as in Spain, southern France, Italy, Montenegro, and Bulgaria – the focus of this study. There has recently been interest in these small glaciers – the southernmost glaciers in Europe, excluding those of the Caucasus.

The smaller southern glaciers respond quickly and in whole to extreme weather phases. Measurements at the Snezhnika glacieret show evidence of accumulation and melt behavior. Below the Vichren summit is a plateau area, and snow accumulations from this plateau are carried onto the glacier at the bottom of the cirque cliffs, contributing significant amounts of snow to the glacier mass balance. Whereas typical snow depths constitute ~ 2 m on the cirque in April (measured with stakes in April, 2001, 2003 and 2005), they reach more than 10 m at the Snezhnika glacieret (estimated at the face above). Popov (1964) determined loss rates of 104 cm (1.4 cm d^{-1}) between September 16–30, 1957. We determined melt rates of up to 7 cm d^{-1} in the lower part of the glacieret between August 6 and September 9, 2004, measured using five stakes (Grunewald et al. 2006).

If warm summers follow winters with few snow falls over several years, the glaciers and glacierets shrink until they reach a new equilibrium mass balance or melt completely. This conclusion was drawn for the Balkans Peninsula (also High Tatra) for example in 1994 (Litwin 1997, Nadbath 1999, Grunewald et al. 2006, Hughes 2007). Glaciers survived single heat summers, such as those in 2003 and 2007, although they experienced significant retreat. Phases with above-average winter precipitation and cooler summers are often sufficient to stabilize small glaciers or even produce re-advance. At the Debeli Namet glacier, for example, a new moraine developed between 1994 and 2003, and between 2004 and 2006, due to small glacier advances (Hughes 2007, 2008). Debris for moraine formation is likely to be enhanced by the large area of debris-supplying rock walls, and this may explain the production of very large late nineteenth/early twentieth century moraines yet small glacier size (Maisch et al. 1999a, Zemp et al. 2005, Hughes 2008).

Chueca et al. (2007) examined the recent evolution (1981–2005) of the Maladeta glaciers in Spain and their relation to climatic factors. Precipitation during the accumulation period decreased significantly, reducing the snowfall contribution to mean balance in February and March. In addition, an increase in temperature during the ablation season, in particular the maximum temperature, was observed. That is the main reason for surface and volumetric shrinkage registered on all glaciers. There are no reports of stabilization phases in the recent past in the Iberian region.

Overall, we can say that during the recent final step of glacial degradation in southern Europe, the relative influence of climatic factors decreases as the influence of topographic and other geo-factors (Fig. 4.10) increases (López-Moreno et al. 2006, Zemp et al. 2006).

The firn area of the glacieret at Vichren wall can be reconstructed for the last 50 years. Furthermore, analysis of three ice cores drilled on Snezhnika glacieret in the Pirin Mountains in September 2006 revealed possibilities and limits to the study of these small glaciers. 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 to 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 2008d).

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 (cf. Chapter 3 and Section 5.3).

Regional comparisons of glaciers with Atlantic-Mediterranean characteristics (Iberian Peninsula) to those with Pontic-Mediterranean characteristics (Balkan Peninsula) show many similarities concerning glacier types and geo-factors, as well as climate-glacier phases (Grunewald and Scheithauer 2010). 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.

There has been a temperature increase of ~ 1°C since the LIA in many investigated areas (e.g. Pirin Mountains, Grunewald and Scheithauer 2008c, Pyrenees; González Trueba et al. 2008) and for this reason, southern European glaciers have retreated. This tendency for climate warming has intensified in recent years. However, small glaciers appear to survive such warming – largely because of local topo-climatic influences. 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 of course a threshold is reached when local climate controls are unable to sustain glacier survival.

A further temperature increase by 1.1 to 6.4°C in the twenty-first century, as predicted by IPCC (Solomon et al. 2007), anticipates the following scenario estimation for all southern glaciers in Europe (<44° N): 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. Glacier retreat will result in opportunities for pioneer plant and soil development over the former glacier sites, and permafrost is likely to become rarer. 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 Pyrenees and in the Balkans.

4.3 The Timberline Ecotones as Key

4.3.1 Introduction

The transition between forest and treeless vegetation in mountains fluently or abruptly leads from a closed forest via insular forests groves, shrinking single trees, bush and cripple forms to a treeless vegetation of the alpine level with increasing altitude. Seen from a small-scale view, the borders form a relatively sharp line. Seen in detail there are, however, gradual and different transition areas. Sharp borders usually indicate an anthropoid-zoogenic influence (Burga et al. 2004).

Ecotone is defined as a transition area between two adjacent ecosystems, such as forest and grassland. In this context, the passage between the treeline and species barrier, also called the "struggle for existence zone" ("Kampfwaldzone") is regarded (see Fig. 4.14). For historical climate problems, the alpine timberline is of particular interest because it is mainly temperature-determined. The timberline does not constitute a "simple thermometer" (Nagy 2006, p. 339) because its altitude

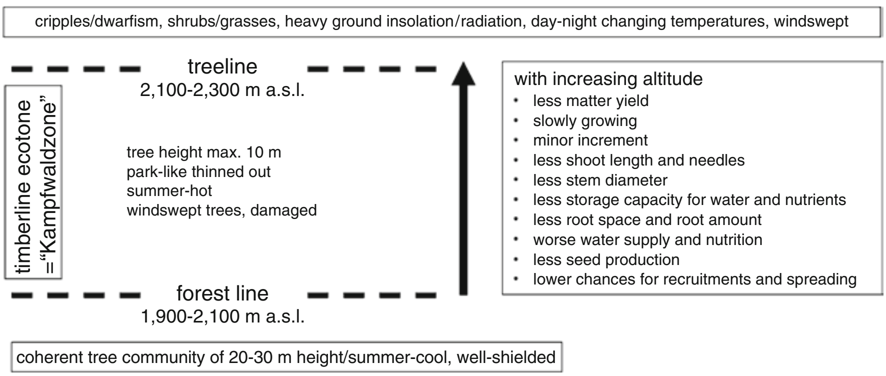

Fig. 4.14 Terms and tree physiology at the timberline in the Pirin Mountains (Grunewald and Scheithauer 2008b)

secondarily depends on variables such as precipitation quantity and distribution, wind (exposition timberline) and soil property (edaphic timberline), as well as human influences (Eggenberg 2002, Körner 2002, Holtmeier 2003, Burga et al. 2004, Holtmeier and Broll 2007, Wieser and Tausz 2007).

The climate-ecological limited timberline, or rather the upper border of tree life in the study area, is especially influenced by these stress and disturbance factors (cf. Körner 1998, Brandes 2007):

- frost and dryness, frost and water shortage depending on substrate properties and radiation climate
- wind exposition, ice blowing, snow breaking and avalanches, as well as herbivores and pathogenic germs
- constrained pollen formation, seed development, seed distribution, sprout or seed development caused by unfavorable hydro-thermical conditions

Trees in mountains often cannot exceed a defined altitude because they wither. The water piping capillaries in the xylem collapse, and air bubbles, which cut the water transport, develop within the embolisms. After research by Mayr and Charra-Vaskou (2007) these embolisms, which often appear in winter, are only observed directly in the "struggle for existence zone". Due to the low temperatures, the water in the ground is frozen and cannot be transported into the needles where water continuously evaporates, which causes low-pressures up to 40 bar. The water becomes gaseous and the lethal embolisms develop. Tree size may play a determining role in winter humidity conditions as trees profit from water stored in the stem and in crown parts below the snow cover (Mayr and Charra-Vaskou 2007).

Second fundamental limiting factors are freeze-thaw events (freezing by night, melting by day). This has an effect not only on vegetation but also on the geomorphological and soil forming processes (solifluction, rock fall etc.).

Regionally, the timberline characteristics (tree species, altitude and spread, physiognomy, dynamics) as well as the complex of timberline factors are of interest (cf. Holtmeier 2003, Brandes 2007). The latter comprises topography, soil- and substrate properties, macro- and micro climate, snow, frost, wind and aridity, biotical characteristics and influences (like soil vegetation, pest), fire and human effects.

As the timberline is not only sensitive to climate, it also includes the investigated geoarchives tree-rings, cirque lakes, fossil soils, moraines, and glacierets. It is the key for the reconstruction of the landscape history of the Pirin Mountains. The approximated location of the timberline and the examined archives is shown in Fig. 3.2, in Chapter 3. The Holocene development of the treeline level and predominate tree species was discussed in Section 3.2. Our own examination of current treeline dynamics, especially on a test plot, are the focus of the following remarks. The inventory of the timberline and the timberline ecotone includes soils and vegetation, morphodynamics, local climate, physiognomy, regeneration, and anthropogenic changes and causal interrelations. The description of the main current timberline pines of the northern Pirin is the aim of the dendroecological studies (Section 4.4).

4.3.2 Timberline Characteristics of the Northern Pirin Study Area

Climate, Geomorphology and Soils

The detailed climate conditions of Southwest Bulgaria and the Pirin Mountains were discussed in Section 4.1. Whereas the 0° isotherm presently is located in approximately 2,400 m a.s.l., the 5° isotherm is located in 1,600 m a.s.l. Important parameters and threshold values were calculated for the timberline area (Table 4.5). Thus the middle number of frost-changing days per year varies from 83 to 85 days. In autumn of 2008, 14 temperature loggers, which hourly register air temperature and moisture in a height of 2 m and in soil temperature in a depth of 10 cm, were installed at representative sites below, in and above the timberline ecotone. First data are available but are not yet consistent or old enough.

In the montane forest areas, the vegetation causes a relative morphological stability, unless it is not very steep or avalanche-damaged. Above the timber and forest line, the dynamic clearly increases. In particular, due to the climatic conditions, solifluction is observed, as the upper timberline is likewise the lower limit of the recent periglacial level (see Section 2.2 and Fig. 2.4).

The spatial variability of soils is closely interrelated to the geological, geomorphological and climatic conditions. Table 4.13 lists representative location characteristics in the timberline ecotone of the northern Pirin. On carbonated substrates, a combination of skeleton humus and rendzina soils is typical, however on silicates mostly regosol in the sub-alpine belt are found (Section 2.4). The formation of thick organic layers is characteristic. Due to slight bioturbation, the humus horizons are partly well subdivided. The thickness of the organic layers is 0 to 15 cm on granite and up to 70 cm on marble. As the soil parameters of the examined sites show (Table 4.13), the pH-values are in the neutral band (carbonate sites). Test-plot G1 shows the closest C/N-ratio and the highest nutrient contents (P_t, N_{org}).

Vegetation

The zone between the upper treeline and timberline (timberline ecotone), in northern Pirin predominantly situated in 1,900 and 2,250 m a.s.l., is characterized by two subendemic tree species: *Pinus peuce* and *Pinus heldreichii*. Mapping the vegetation in the study areas showed a petrographically effective dualism at the timberline: *Pinus peuce* as well as numerous occurrences of *Pinus mugo* and typical acid indicators like blueberries on silicate rock, *Pinus heldreichii* and only some specimen of the Macedonian pine on marble (Grunewald et al. 1999). Sub-alpine krummholz-shrubes reach up to approximately 2,200–2,500 m a.s.l. in the northern Pirin. They are dominated by *Pinus mugo*, *Juniperus sibirica* and *Vaccinium* on dry locations and accompanied by the green alder (*Alnus viridis*) on moist shady slopes and in hollows with thicker soil substrates. These woods are adapted to the short vegetation period, wind velocities and the weight of snow load.

Table 4.13 Relief, soil parameter and tree characteristics of three test-plots of the timberline in the Pirin Mountains (marble rock region, location see Fig. 3.2)

Level	Below the forest line (G3)	Timberline (G5)	Treeline (G1)
Spectrum of tree species	*Pinus sylvestris* (*Pinus nigra*, *Pinus peuce*, *Picea abies*)	*Pinus heldreichii* (*Pinus peuce*, *Pinus mugo*)	*Pinus heldreichii* (*Pinus mugo*)
Relief	1,640–1,720	2,100–2,120	2,100–2,235
Height (m a.s.l.)			
Exposition	E	NNE-N	ESE-SSW
Slope inclination (°)	≈35	≈20	≈45
Soil (no. of study sites)	4 sites	3 sites	4 sites
Soil type[a]	RRn/Rendzic Leptosol	RRn/Rendzic Leptosol	FSn-OLn/Folic Histosol, Histi-Lithic Leptosol
Rock share (%)	10	0	60
pH (KCl)[b]	7.2 (7.1–7.3)	7.0 (6.9–7.2)	6.9 (6.7–7.1)
P_t (mg kg^{-1})[b]	404 (176–503)	654 (609–716)	1015 (763–1,288)
C_{org} (%)[b]	14.9 (3.3–42.7)	22.6 (16.6–32.3)	15.3 (13.2–17.1)
N_{org} (%)[b]	0.4 (0.2–0.8)	0.8 (0.7–0.9)	1.1 (1.0–1.2)
C/N-ratio[b]	30 (22–53)	29 (21–42)	14 (14–16)
$CaCO_3$ (%)[b]	58 (12–77)	26 (19–36)	14 (2–25)
Trees (analyzed number)	9 *P. sylvestris*, 1 *P. heldreichii*	20 *Pinus heldreichii*	18 *Pinus heldreichii*
Height (m)[b]	22 (17–26)	15 (10–16)	10 (7–14)
Diameter (m)[b, d]	0.6 (0.3–1.0)	0.5 (0.4–0.7)	0.8 (0.5–1.0)
Vitality[c]	0.7	0.9	0.6
Bole sweep[c]	0.2	0.2	0.1
Competition[c]	0.6	0.6	0.2
Rock fall[c]	0.3	0.0	0.4
Protzen, forks[c]	0.3	0.5	0.5
Age (estimated)	250 years	400 years	900 years
Tree-rings (drilled)	1790–2003	1693–2005	1285–2006
Tree-ring-width (mm)[b]	2.1 (0.7–4.5)	0.9 (0.08–4.0)	0.6 (0.06–2.8)

[a]According AG Boden (1996)/WRB (2006)
[b]Mean (minimum–maximum)
[c]Subjective determined parameter, ranged from low to high or poor to strong, factor 0 … 1
[d]Diameter in breast height

The Pirin National Park administration has recently observed an altitudinal upward shifting of *Pinus mugo*. This is probably caused from both an increase in warm and long growing seasons as well as less grazing or human disturbances.

Typical grazing land areas are the open land on plateaus, on flat inclined slopes and in small valleys, as well as in the zone above the timberline. The *Nardetum strictae* for example has arisen despite human influences. It is found both on silicate and carbon rocks (Tidow 2002). The *Nardetum strictae* community often is accompanied by *Seslerion variae* and *Carex curvula*.

A peculiarity in the Balkan Mountains is the endemic pine forest (*Pinetum peucis*) in the high montane and subalpine region. In particular, the five-needled Macedonian

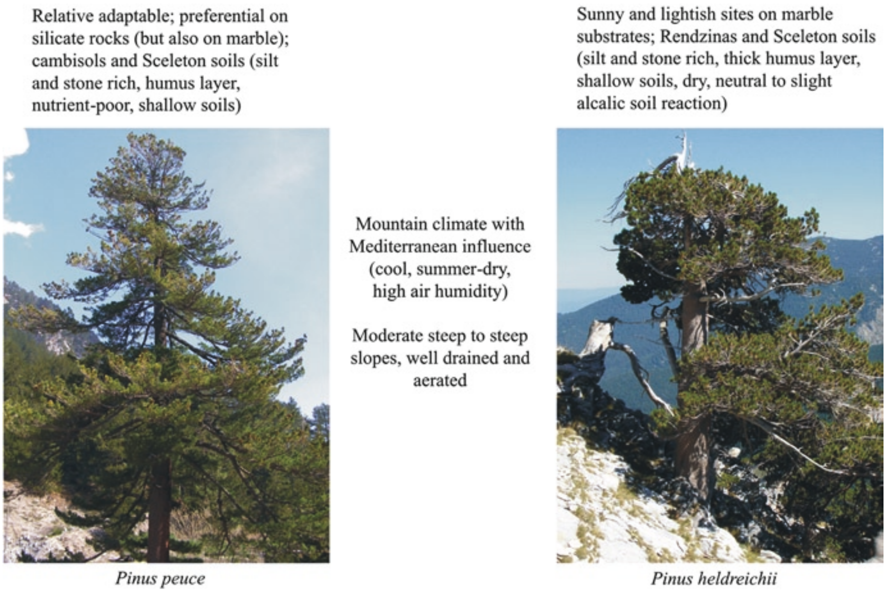

Fig. 4.15 Site requirements of *Pinus heldreichii* and *Pinus peuce* in the Pirin Mountains (Grunewald and Scheithauer 2008b)

pine (*Pinus peuce*), which is considered a tertiary relic, and the two-needled Bosnian pine (*Pinus heldreichii*, also *Pinus leucodermis*) are found. Figure 4.15 outlines the site requirements of both tree species.

Pinus peuce has its optimum in the coniferous forest belt in a range of 1,450 to 2,000/2,100 m a.s.l. Velchev and Rusakova (1991) examined its altitude maximum with 2,200 to 2,500 m a.s.l. at the subalpine level and its minimum at 1,200 m a.s.l. (individual specimen in the beech wood belt). Only in the small range between 1,800/1,900 and 2,000/2,100 m a.s.l. the tree species is crop building. The discrepancy between the current relative restricted distribution and the ecological optimum of the species verifies that the forests were repressed and degraded anthropogenic.

The forestry exploited the *Pinus peuce*. It was used among other things for buildings, furniture and barrels. The populations fell victim to both natural and anthropogenic fires. Other negative influences occur through forest grazing (erosion by livestock tread), tourism, air pollution and water engineering in the high mountains (Velchev and Rusakova 1991). Hence *Pinus peuce* was often replaced by timbers like *Pinus sylvestris*, also *Betula pendula, Populus tremula* and *Fagus sylvatica*. During very heavy anthropogenic influences, woods were substituted by bush and meadow populations. A lot of populations are destroyed or changed in composition and degraded in structure. On many sites the *Pinus peuce* sub-belt is discontinuous. The last stage of the degradation of high mountain woods is the replacement of *Pinus peuce* by *Pinus Montana* or *Chamaecytisus absinthoides* and anthropogenic populations like *Rumex alpines* and *Verbascum pannosum,* especially if soil is absent, which affects the timberline region.

Pinus heldreichii (respectively *Pinus leucodermis*) occurs in some mountains of Bosnia, Bulgaria, Macedonian, Kosovo, Montenegro, northern Greece and south Italy, and often constitutes the timberline (Nagy 2006). The species was first described as *Pinus heldreichii* by the Swiss botanist H. Christ in 1863 from specimens collected on Mount Olympus in Greece, and then described a second time as *P. leucodermis* by the Austrian botanist F. Antoine who found it on Orjen above the Bay of Kotor in 1864 (Christ 1867, Antoine 1864). Some minor morphological differences have been claimed between the two descriptions (leading to the maintenance of both as separate taxa by a few botanists), but this is not supported by modern studies of the species, which show that both names refer to the same taxon. Molecular genetic analysis with isoenzymes, chloroplasts-micro satellites (cpSSR) and DNA (cpDNA) markers did not find sufficiently genetic differences in the two (Morgante and Vendramin 1990). Altogether, the species is popular for its high adaptability to extreme climates but it occurs in really small, partly relic-like existences, which are witnesses of former, clearable wide-spread distribution.

We use primarily the term *Pinus heldreichii*, because also the English name "Bosnian Pine" is unwelcome in Balkan countries outside of Bosnia.

The optimum range is in an altitude of 1,500 to 2,100/2,200 m a.s.l. in the northern Pirin (maximum 2,270 m; minimum 950 m a.s.l., single specimen). The winter-resistant pine has a high adaptability to extreme ecological conditions (Schütt et al. 1994). Characteristic are the thick, scale-like bark pads and the twisted trunk growth. Spiral grain is very common in members of the *Pinaceae* growing in stressful environments. *Pinus heldreichii* is able to settle on steep, erosion-endangered slopes with extremely thin soils. It assumes the pioneer function. A pronounced taproot system gives the necessary stability. The tree is growing as high as 15 to 20 m; some species reach a height of 25 to 30 m. On marginal sites, cripple growth and bush forms are observed.

Pinus heldreichii grows extremely slowly at timberlines and can live an astounding 1,000 years. Verifiably, the *Pinus heldreichii* was broadly exploited in the past (Velchev and Vassilev 1987). In Bansko, the timber industry predominantly processed this pine-timber till 1944: as ornamental wood in churches and houses, for fences, doors, stairs, tables, chairs, barrels, as parapet, deal boards, water-wheels, for drains, water pipes and so on. In Macedonia *Pinus heldreichii* has been used to make roof shingles. Trees near the alpine timberline have been of economic interest. There the *Pinus heldreichii* has a highly resinous wood, mainly in the core, so the wood is long and durable without impregnation or treatment. The woodworm avoids it. Hence in Bansko the beams of the old houses (seventeenth to twentieth century) mostly are made of the *Pinus heldreichii* of higher sites in the mountains of the northern Pirin. But the exact extent of the wood harvest is disputed and with it the amount of anthropogenic impact on the *Pinus heldreichii* populations. Today the crops are under protection. The *Pinus heldreichii* was added to the "red list of endangered species" of the IUCN in 2007 (Conifer Specialist Group 1998).

The taxonomic position of *P. heldreichii* remains uncertain, and it has seldom been studied at the molecular level (Boscherini et al. 1994). Wang et al. (1999) found that in the clade comprising the Mediterranean pines, *Pinus heldreichii* was a sister species to the remaining members and is regarded as more closely related to *Pinus nigra, Pinus sylvestris,* and other Asian hard pines than to the true Mediterranean pines.

The Bulgarian population could unambiguously be distinguished genetically by means of its cpSSR and its terpene composition (Naydenov et al. 2005). A danger for the species is the genetic constriction, which is fundamentally caused by high self-fertilization rates of the old trees and the consequential inbreeding depression and selection against genetically impoverished descendants (Morgante et al. 1991, 1993, 1994). There are two preconditions for long-term survivability of the geographically strong isolated populations of *Pinus heldreichii* that almost exclusively occurs in timberline ecotones: processes of natural regeneration of the population and a minimum of genetic variability. Secondary to direct anthropogenic influences like hill pasture or non-sustainable use of wood, climate change, which increasingly will affect the timberline ecotones, entails further threats.

In addition to the natural regeneration of *Pinus heldreichii,* we also know that it becomes fertile very early (blooming at age 15 to 20 years), it often has fattening years (each second to third year) and it produces a huge seed quantity (Morgante and Vendramin 1990). Nevertheless, in the Italian populations of *Pinus heldreichii* subsp. *leucodermis* a regeneration gap of approximately 200 years is verifiable, which can be attributed to anthropogenic pressure and also to the climate change in the second half of the twentieth century (Todaro et al. 2007). The dynamics of natural regeneration - which comprises blooming and fattening years, and accordingly the germination of the seeds and survival of the young generation - depends on favorable development of micro climatic conditions. All sub-processes of regeneration, that means bloom, seed development, germination and juvenile growth phase of the trees, require the coincidence of favorable micro climatic conditions like a sufficient water supply from precipitation. Because of the strong genetic influences like flowering and other phenological qualities of tree species (Ingvarsson et al. 2006, Savolainen et al. 2004) rapid climate changes, for example, can lead to improper temperatures for flowering and seed formation.

So far, no serious threats from climate change could be determined for the Italian tree populations (Todaro et al. 2007). This is due to the high conformity of the old trees to the dryness of southern Europe, as well as to the altitude-related winter cold. Hence, the use for reforestation measures in the Apennines (Morgante and Vendramin 1990) or even as urban tree in Germany (Roloff et al. 2008) under the conditions of a changing climate is judged positively.

Monitoring Approach to Timberline Dynamics

In September 2008 a monitoring of climate, soil conditions, tree-physiology and dendrochronology parameters was started between the timberline and treeline, not far from the Banderica Hut and the cirque Malkya Kazan. Examined was a 400 m long and only 10 m wide transect, which was divided into eight 50-meter-sections (VIA – VIH), subdivided into five 10-meter-segments (A – E). The considered slope is exposed from southeast to east and reaches from 1,975 m to 2,175 m a.s.l. The transect runs next to a depression or avalanche track and is predominantly characterized by a stretched slope, which is only partly slightly convex. Whereas in lower areas, thick soil layers (Rendzinas) are characteristic, shallow soils and bar rock areas are determining from the moddle to the higher areas of the slope (alpine Lithosols, cf. Section 2.4). After each section (50 m) soil profiles were mapped. The soil type and humus layer type was examined. Soil samples were taken for chemical-trophic characteristics (pH-value, humus content, C/N-ratio) of the sites.

The structure of population respectively the treeline ecotone changes from a closed *Pinus heldreichii* forest (VIA – VIC) to a park-like character with seedlings and natural regeneration (VID – VIE). Above this belt, the trees and shrubs reflect the increasing harsh conditions near the treeline: they are windswept, wind and ice scoured, have partly dead crowns, torn trunks and a spiral grain with traces of rock and soil moving and even lightning strikes. This elevation is dominated by low and crippled growing *Pinus heldreichii* (VIF – VIH), which finally are replaced by *Pinus mugo* and grass communities.

Prevailingly, *Pinus heldreichii,* as well as some individuals of *Pinus peuce*, Norway spruce, silver fir and mountain pine are joining over the whole transect. In altitudes of 1,975 m (VIA), 2,050 m (VID, VIE) and 2,175 m a.s.l. (VIH) loggers for continuous measurement and recording of air and soil temperature and moisture were installed to monitor the treeline.

Almost 400 trees were measured and mapped on a scale of 1:2,000 in the segments. Furthermore, the tree height was estimated and the diameter in breast height of taller individuals and at the basis of seedlings and smaller trees (up to 1 m) was determined. Growth characteristics were valuated (bole sweep, cripple growth etc.), detailed photos were taken as were samples for a herbarium. Drilling cores could be taken from individual specimens with different diameter and growth to determinate the yearly accrescence and age. For the latter, it was necessary to drill the pith. Samples of drives and branches should be used for genetic analysis.

Conclusions on the ability for natural regeneration in the timberline ecotone in different altitudes and crop structures along the transect are drawn from the simplified tree-physiological site analysis. The first results of mapping could be summarized as follows:

- Half of the 160 registered trees with less than 1 m height (Fig. 4.16a) are smaller than 0.5 m. The high proportion of young trees indicates good ability for regeneration.
- In context with the tree height, small trunk diameters are dominating (Fig. 4.16b). Approximately one out of four of the individual trees has stems thinner than 2 cm. Some trees can reach a height of more than one meter breast height diameter (amongst others a dendroecological examined individual in VIG, compare Section 4.4).
- With increasing altitude in the transect, the relation between tree size and stem diameter is getting closer, mostly connected with compact, crippled growth and bush-like tree groups (Figure 4.16c).

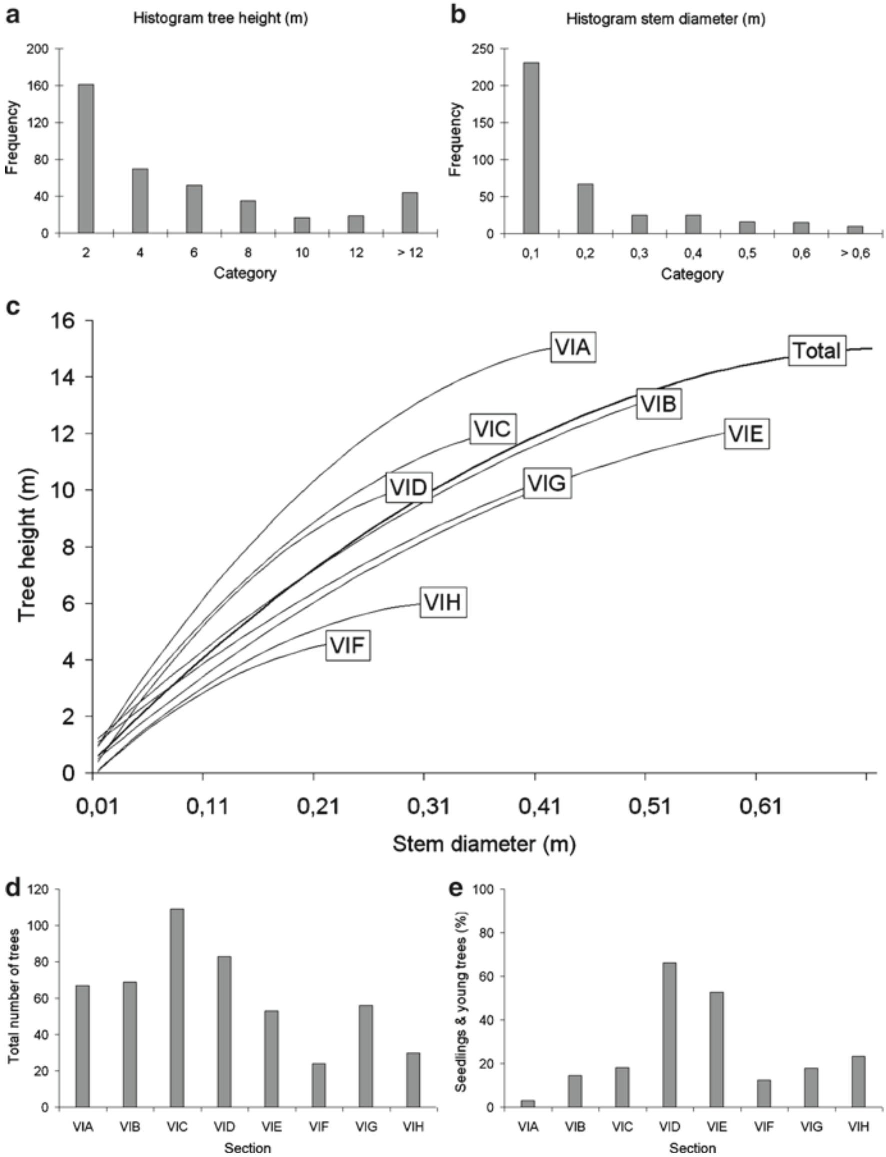

Fig. 4.16 Histograms of distribution of (**a**) tree height, (**b**) stem diameter, (**c**) hypsometric change of the relation between tree height and diameter, (**d**) whole number of mapped trees, (**e**) percentage amount of seedlings and young trees

- The number of trees increases from closed stock (VIA) to a park-like character (VID). Above a decrease is recorded, with the exception of tree isles at VIG (Figure 4.16d).
- The seedling- and young tree proportion (Figure 4.16e) shows a maximum in the area between the tree- and timberline with 55 individuals (VID) and a minimum of two species in the Section VIA.

4.4 Dendroecology of *Pinus heldreichii*

4.4.1 Conifers as Geoarchives

The reconstruction of the modern landscape development in the Bulgarian Pirin Mountains is an important contribution to the understanding of the current climate dynamics in Southeast Europe. Located at the transition zone from temperate to Mediterranean latitudes, the high mountain ranges of the Pirin are very sensitive to climatic changes (Beniston 2003).

Tree-rings of conifers in extreme locations are valuable archives of climate signals, particularly if the measurement of temperature and precipitation is lacking or is limited in time and space. Moreover, ancient trees allow a climatic review into the distant past. Several pine species are often used as a climate archive. On the one hand, they are often in the Mediterranean region at the upper timberline. On the other hand, they are among the dryness-sensitive species (Brandes 2007, Martin-Benito et al. 2008, Oberhuber et al. 2008). Our dendroecological investigations in the northern Pirin Mountains focus on the *Pinus heldreichii*. There exist up to 1,000-year-old conifers of this species at the timberline on marble, which previously were subject to only marginal dendroecological interest (Lyubenova et al. 2004). Extensive studies of climate-growth relationships of *Pinus leucodermis* are so far known only from southern Italy (Todaro et al. 2007).

Inter-annual and intra-annual information on climatic conditions and site situations are continuously saved in the tree-rings (Schweingruber 1993, see Fig. 4.17). An important role is played by the positioning of the trees. Timberline ecotones are extreme locations and are therefore regarded as particularly suitable for the dendroecological reconstruction (Hansen-Bristow et al. 1988, Schweingruber 1993, Briffa and Osborn 1999, Meyer and Schweingruber 2000, Nicolussi et al. 2001, Hughes and Funkhouser 2003). In addition to the late wood density annual ring width and stable isotopes of carbon, oxygen and hydrogen (δC, δO and δH) are used as indicators. The carbon is taken from the atmospheric CO_2 and passed through the stomata into the leaf (Rebetez et al. 2003, Esper et al. 2004, Helle and Schleser 2004, Treydte et al. 2004). The uptake of oxygen and hydrogen isotopes is realized via the root, directly and in the short term from precipitation and from groundwater or stagnant water in the long term. The maximum late wood density is characterized primarily by the temperature signal at the upper timberline. Global, climate-events such as the major volcanic eruptions of Pinatubo, Tambora and others are archived within the growth rings and can support the dating (Briffa et al. 1998). Astronomical occurrences (such as the Maunder Minimum of sunspot activity) are also included in tree-ring series (USGS 2000, Creer 2001, Burckle and Grissino-Mayer 2003).

For the statistical analysis of tree-ring series, the growth depending/declining trend ("biological noise", Esper et al. 2004) has to be involved as well as the response to temperature variations, depending on tree species (Lloyd and Fastie 2002, Laroque and Smith 2003). For this purpose, deterministic and stochastic methods are used, taking into account the elimination of actual long-term trends (Cook and Kairiukstis 1992, Schweingruber 1993).

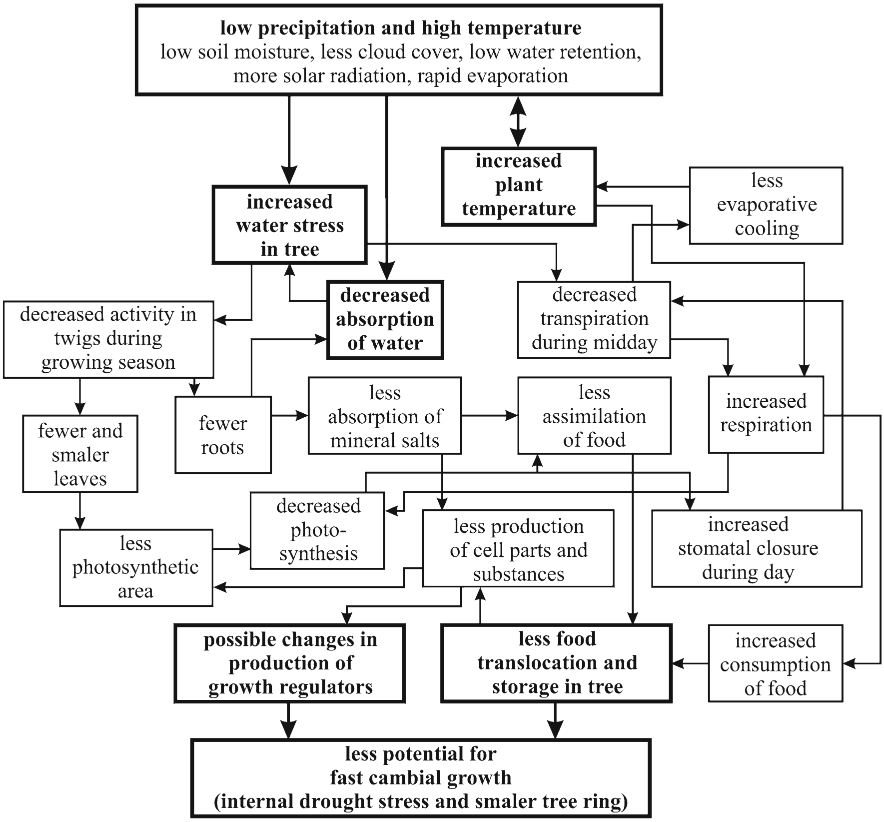

Fig. 4.17 Effects of increased temperature and precipitation deficit on the tree physiology (schema according to Fritts in Schweingruber 1993, modified)

Embedded in the geo-archive methods compound the dendroecological studies are an essential component for reconstructing the modern climate and landscape history. The following objectives will be persued:

- Compilation of robust chronologies of the *Pinus heldreichii*, including various methods for the trend adjustment
- Statistical identification of the chronologies and comparison with series from other (neighboring) regions
- Climate-growth analysis to identify similarities and differences of site-specific and especially climatic parameters that determine the growth of the *Pinus heldreichii*
- Clarification of the temperature and/or moisture limitation (ring width growth as the result of the climate-growth analysis)
- Comparison of the results with other dendroecological and climatological studies
- Preparation and application of approaches to climate reconstruction for the last 500 years (Section. 5.2)

4.4.2 Methodological Approach

For dendroecological investigations of the *Pinus heldreichii*, we selected six test plots (G1 to G6) in the marble part of northern Pirin, where the basic site conditions were recorded and a detailed description and sampling of trees proceeded (location Fig. 3.2, features of G1, G3 and G5 in Table 4.13).

Of interest to the chronology quality and climate-growth relationship are the three adjacent test areas G1, G4 and G5. The other test areas were not suitable due to their location and stand characteristics, or due to outstanding laboratory work at this stage. G1 represents a rock flank with ancient and stocky individual trees (see Fig. 4.18). G5 is characterized by a closed stand, more or less of the same age. The site G4 differs partly due to the low altitude (2,005–2,055 m above sea level) and its eastern and east-northeastern exposition. But, the stand has rendzina – pararendzina on block debris at a slope angle of 25°. In the *Pinus heldreichii* stock, several *Pinus peuce* appear as well. It is composed of individuals of different ages.

The elevation from 2,005 to 2,235 m corresponds to the transition from montane to subalpine zones, and thus marks the area of forest and treeline, which can also be referred to as the timberline ecotone (see Section 4.3). With a local north-south exchange and exposure and different morphological and geo-ecological processes being effective in the high mountains (landslides, impact of wind and snow), a wide range of site conditions is covered to finally interpret the response of the *Pinus heldreichii* on climate impact. *Pinus heldreichii* is particularly adaptable to extreme site conditions, in both the summer drought of the Mediterranean and the harsh climate of high altitudes, as well as to the rocky and erosion-prone terrain (Morgante

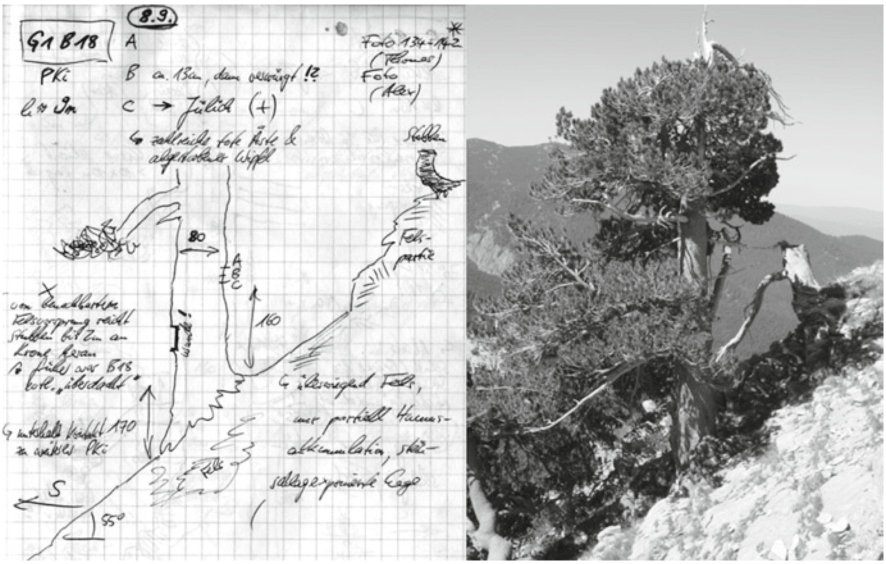

Fig. 4.18 Sketch from the field notebook and photo of the individual G1B18

and Vendramin 1998). In all test areas detailed morpho-pedological studies were realized using the pedological mapping instruction (AG Boden 1996). The spatial relationships between the individual trees were mapped (effects of communication, competition or isolation) and a description, sketch and photo for each individual and each site was prepared (vitality, height, growth habit, diameter at breast height, features such as rock falls and bole sweep). Figure 4.18 gives an example of tree G1B18s field recording.

The collection of wood samples could be realized in two ways. Basal stem discs were cut with a chainsaw from stumps of dead individuals (sample length up to about 0.5 m), whose tree-ring series should go back to the Middle Ages, and living specimens were sampled using an increment borer (core diameter 1.2 mm, length up to about 25 cm, sampled two to three cores) at chest level and outside the compression wood. The dull edge facilitates the dating. The relief and the slope in particular only allowed an extraction of cores on the hang-facing side. Several trees could not be reached due to their extreme position (especially on steep rock slopes).

Measurements of 116 samples from 58 trees build the chronologies of G1, G4 and G5 (103 cores, 13 segments from stem discs). The samples were stored until analysis at approximately 20° C and a relative humidity of 65%. First, the annual ring width was measured in a conventional manner using LINTAB (RinnTech) and TSAPWin version 0.55 (Rinn 2005) with an accuracy of 1/100 mm. With the help of the analysis program TRA TreeRingAnalyser (König et al. 2005) and with TSAPWin it was possible to synchronize various tree-ring sequences according to established criteria based on multivariate statistical cross-correlation analysis, whereby common t-values and date indexes as well as similarity values and corresponding significance levels in the form of the Multivariate Dating Index (MDI) were ranged after the numerical size. In this way, the actual age of dead trees (stumps) could be detected.

The individual ring-width series were examined with the statistical quality control software Cofecha (Holmes 1983, Grissino-Mayer 2001). With this software, missing or false tree-rings, and hence segments with flawed cross-dating, could be identified. The descriptive statistics finally reflect the quality of the individual series and of the sampling group. The chronology development itself was realized with the help of the Arstan software (Cook 1985), which is a program for standardization and tendency adjustment of the individual tree-ring series as well as for the development of a standard chronology and residual chronologies (without autocorrelation). A negative exponential function was used for the first detrending of the raw series, removing the low frequency non-climatic growth trend. For a second detrending, a cubic smoothing spline function (66 years) was applied to amplify the high frequency climatic signal. The quality of the chronology was tested by calculating the Rbar (average correlation between all series) and the EPS (expressed population signal). The EPS parameter quantifies the variability within all ring width series at the sampled site as a proportion of common variance of trees and total variance (signal + noise), and should be > 0.85 (Wigley et al. 1984). The software program Corina developed by the Cornell Tree-Ring Laboratory was used for continual statistical tests to help correct flawed segments and to calculate pointer years (Brandes 2007). Pointer years are characterized by simultaneous positive or negative tree-ring growth compared to the previous year, reflected in at least 75% of all investigated trees.

Two climate stations - Bansko and Musala - were considered (Fig. 2.1 and Section 4.1). At both stations, monthly temperature data were taken from 1936 to 2006, and precipitation data from 1955 to 2005. Bansko station lies about 12 km away from the study area in the town of Bansko and hence at the foot of the Pirin Mountains (936 m a.s.l.). The second station is located about 45 km linear distance at peak Musala in the neighboring Rila mountain range. With 2,925 m a.s.l. the Musala is the highest mountain in the Balkan Peninsula. To determine a climate-growth relationship of Pinus heldreichii, the standard ring width chronology was regressed against the monthly parameters of temperature and precipitation using the software package DENDROCLIM2002 (Biondi and Waikul 2004). Pearson correlations and response functions were calculated by applying principle components analysis. Bootstrapped confidence intervals were calculated to assess the significance of both. To study changes in monthly climate response between October of the previous year and September of the current growth year, moving interval correlation was established with a base length of 24 years according to the available time periods of climate parameters and stations.

Possible monthly parameters for humidity or dryness were also the standardized precipitation index (SPI) using the software SPI_SL_6 (Giddings et al. 2005) and the Walter index using the modified formula (N/2.1) – T (N – Rainfall in mm, 2.1 – factor, T – temperature, changed after Kempes et al. 2008). Negative values indicate dryness ($SPI < -1$), positive values indicate humidity and precipitation surplus ($SPI > 1$, Loukas and Vasiliades 2004, Touchan et al. 2005).

The climate reconstruction is based on the findings from the climate-growth analysis. These are usually the indices of the standardized tree-ring chronology transfer models converted to climatic factors (cf. Büntgen et al. 2008, Wilson et al. 2005). Simple and straightforward applicable models are linear regressions (r^2). Within a defined period, the curve or rather the relationship between the measured climate values and the climate proxies is calibrated and verified within another period inversely. In the absence of a long series of measurements for the Pirin Mountains, difficulties and uncertainties with respect to a sufficiently long period of calibration and verification are possible.

4.4.3 Development of Chronologies

The tree-ring series were verified with Cofecha separately for each of the sampled sites and finally chronologies were generated with Arstan (Fig. 4.19). The *Pinus heldreichii* ring width chronology that goes back 722 years could be established at site G1 (Grunewald and Scheithauer 2008b). The age trend was successfully eliminated by detrending in which the high frequent interannual climate signal was intensified.

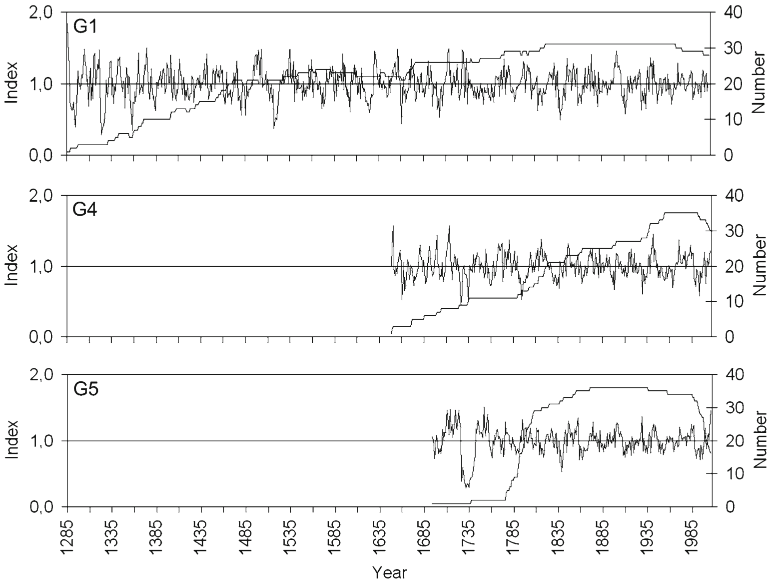

Fig. 4.19 Site chronologies and configurations for G1, G4 and G5

The chronologies for G4 and G5 are shorter. Here the drillings often reached the pith. Moreover, in the G5-series, it becomes obvious that a local event (e.g. fire) destroyed nearly the whole stand. Possibly due to the stand dynamic, numerous A-flags are significant (indicates the calculated correlation for segments fell below the 99% confidence level). Nevertheless, the Cofecha quality parameters, as well as the Arstan parameters, show the chronology's robustness (Table 4.14). These differences in the mean ring width are less a result of site conditions as they are the result of average tree age per test area. The majority of younger individuals in G4 and G5 are reflected by age in wider tree-rings.

Beyond the partial characterization of the chronologies (Table 4.14), statistical comparisons among each other were carried out. Considering the total length of the series, the correlation between the chronologies is rather weak (r=0.39 … 0.51). Close relations were observed (r = 0.67 … 0.87) for the period, during which the climate-growth-analyses were realized (1936–2005).

Whereas regarding the pointer years of the period that is relevant for the climate data, differences between the sites were observed (Fig. 4.20). The G4-series show a total of 33 (18 positive and 15 negative) and therefore the most pointer years between 1936 and 2005. For G1, a total of 26 (13 positive and 13 negative) and for G5, only 20 pointer years could be determined (11 positive and 9 negative). In addition, there are statistically significant correlations between the occurrence of pointer years and the established chronologies, especially after eliminating the autocorrelation (e.g. positive pointer year and positive index in the residual chronology).

Table 4.14 Average descriptive statistics from all ring width series (Cofecha: No. of dated series … mean length of series, Arstan: means, in brackets minimum and maximum values from 50 years moving intervals)

Parameter	G1	G4	G5
No. of dated series	45	35	36
Time span of master dating series	1285–2006	1648–2005	1693–2005
Series intercorrelation	0.67	0.64	0.51
Sensitivity	0.23	0.19	0.21
Segments, possible problems	3	9	36
Average series length (years)	352.6	193.4	200.4
Average, min and max ring width (mm)	0.6 (0.06–2.8)	1.1 (0.05–4.9)	0.9 (0.08–4.0)
Rbar	0.48 (0.38–0.60)	0.31 (0.21–0.52)	0.30 (0.24–0.41)
EPS	0.95 (0.89–0.97)	0.83 (0.73–0.92)	0.94 (0.92–0.96)
Standard deviation	0.18 (0.11–0.24)	0.24 (0.15–0.30)	0.20 (0.17–0.24)

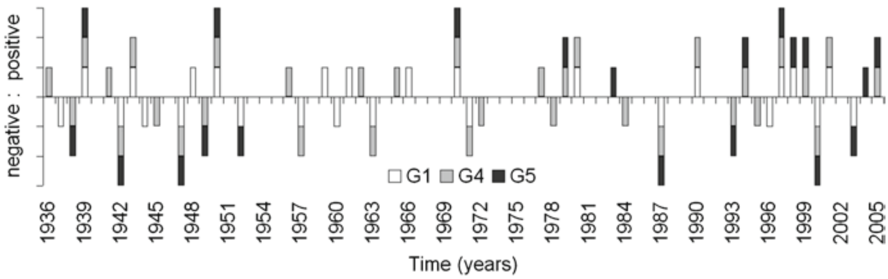

Fig. 4.20 Pointer years in the tree-ring growth series of G1, G4 and G5 from 1936 to 2005 (conform to the climate period)

Basically positive or negative pointer years simultaneously occurred at all three sites in several years only. This fact indicates the storage of different climate signals depending on site and stand conditions.

Perennial increasing or stagnating accrescence, as well as differences in the analyzed interval of the quality testing, suggest that variability and sensitivity of the samples at the timberline ecotone are related to local and regional effects, in particular climate or anthropogenic influences as well as to spatially confined site conditions or events like rock falls and landslides due to increased morphological activity. These events do not necessarily relate to all individuals and therefore they cause a high level of divergence of the single series. Such influences can only be derived partly from the presented ring-width series, since it involves some specific disorders that may not be covered with a single core (for example rockfall). This requires special sampling and analysis strategies that make callus tissue apparent entirely (Stoffel and Bollschweiler 2008).

However, at present, first correlations can already be established between tree-ring width and influencing (exogenous) factors. Perennial ring-width growth increases or decreases at the timberline ecotone correlating with local site conditions and events as well as with local to regional, particularly climate effects or anthropogenic impacts. Beside in situ natural processes (rockfall, land slides), anthropogenic factors (slash-and-burn for grazing, wood cutting) can be responsible for the divergence between several trees and ring width series respectively at the sampled sites. For instance, it is known that the Aromuns, nomadic and half-nomadic shepherds and goatherds, also used the Pirin Mountains in summer for long-distance grazing over many centuries. In addition, the wood of the *Pinus heldreichii* in the range of the investigated timberline was manufactured in considerable amounts in the Bansko saw mill until 1944.

In addition to site influences, extremely cold or dry, or very mild and wet years, late frost events and insects calamities become locally effective and are reflected in the entire sampling group as pointer years (Schweingruber 1993). Touchan et al. (2005) could deduce periods with water deficiency or water surplus from Turkish *Juniperus excelsa*-chronologies. Significant positive or negative changes in growth can be determined accordingly in the ring-width series of the Bulgarian *Pinus heldreichii* (dry years 1608, 1675, 1907: negative pointer years, wet events in 1428, 1503, 1629/30, 1914: positive pointer years). A similar reference can be established for individual pointer years and the drought-limited growth of the *Pinus nigra* in the Greek Taygetos Mountains (Brandes 2007) and for most positive pointer years between 1881 and 1959 for the Aegean (Hughes et al. 2001).

In this context, even the chronology of *Pinus leucodermis* from northern Greece (Olympos Oros, WSL Dendro Database, Switzerland. www.wsl.ch/dendro) closely correlates to the Pirin Mountains series (correlation with master 0.64). In addition, a chronology of Schweingruber exists for the Pirin National Park (1721–1981). While the implementation with Cofecha showed no relationship to Mt Pollino and Katara Pass, the series of northern Pirin, and in particular of the Olympos, are closely related to our own ring-width series (correlation $r=0.59$ and 0.64). The variability of the analyzed segments is largely synchronous (no B flags in Cofecha, indicates higher correlations within segments −10/+10 years). Due to this fact, a huge potential of the built-up dendroclimatological *Pinus heldreichii* standard chronologies may be expected.

4.4.4 Climate Growth Relation

Based on the chronologies comparison, it is stated with regard to *Pinus heldreichii's* growth characteristics that the climate-growth-relation varies according to site conditions (sunny or shady slope) or that either temperature or precipitation should have a limiting effect. Therefore, the ring-width growth at the north-exposed location G5 should be temperature-limited, whereas on the southern flank, G1 humidity should be the limiting factor.

The statistical investigations lead to different findings with regard to temperature's impact. On the one hand, there are differences between the data series from Bansko and the Musala despite a close correlation of the annual values (rR = 0.72, see above). Whereas the temperature variability between April and July in Bansko is in negative relation to the ring-width growth at G1 (Fig. 4.21 a), high temperatures during the vegetation period entail a thin tree-ring and rather mild winters at Musala promote growth (Fig. 4.21 b). This would mean that the tree-ring traces the temperatures at the peak as climate signals of the winter months, whereas the more warm and dry-influenced Bansko is characterized by a kind of heat limitation.

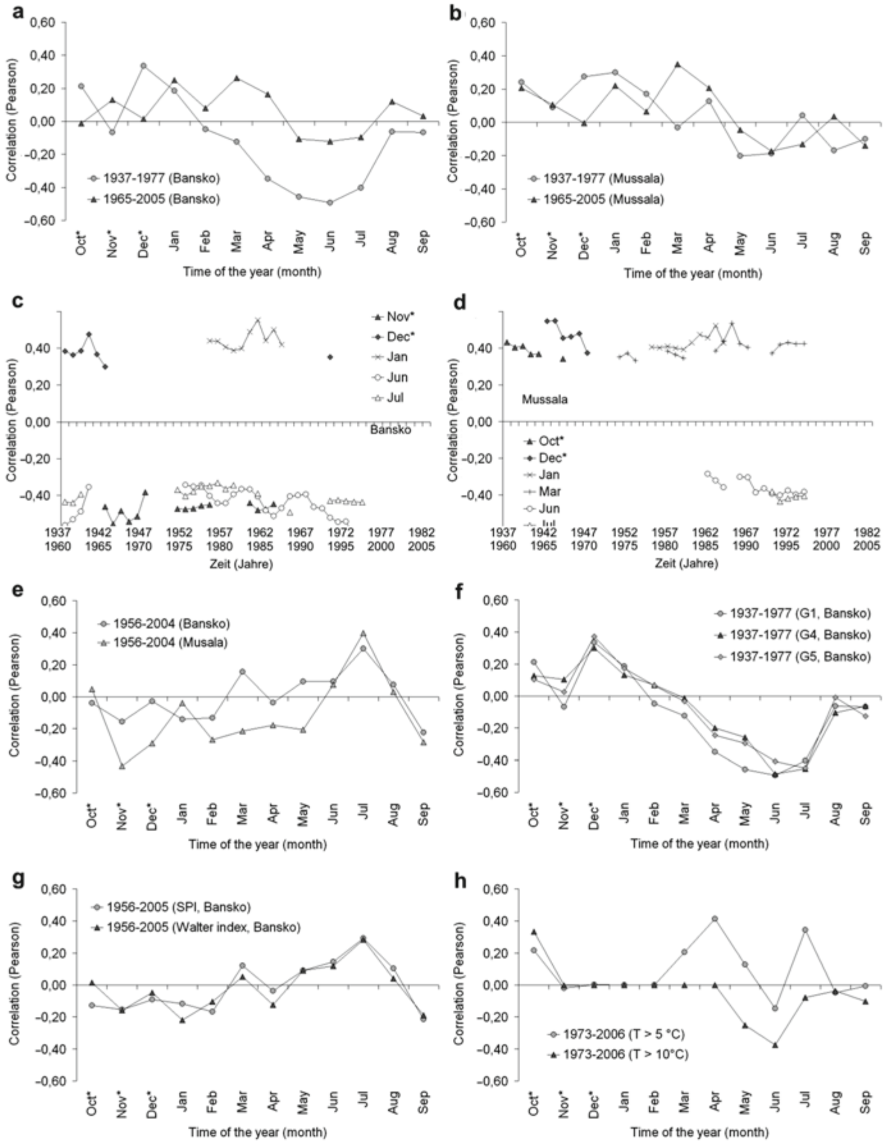

Fig. 4.21 Climate-growth relationship of the *Pinus heldreichii*: G1 and temperature (**a** – Bansko, **b** – Musala); Moving intervals: G1 and temperature (**c** – Bansko, **d** – Musala); G1 and precipitation (**e**); G1, G4, G5 and temperature (**f**); G1 and SPI, Walter index (**g**); G1 and days with T > 5 °C, T > 10 °C (**h**, according to Musala)

On the other hand, the summer temperatures could barely act growth-resistant at the theoretically thermal-determined timberline and treeline.

Furthermore, the temperature series from 1937 to 2005 show comparatively weak correlations with the ring width. In contrast, the periods 1937–1977 and 1965–2005 are more closely correlated, however in different months. A comparison with the last 40 years of the series showed few relationships within the 0.05-significance level. Instead, the growth of the tree-ring-width is closely related to summer temperatures in the years 1937–1977. If one considers the analyzed moving intervals for the total series length (base length 24 years), a change in the response of the climate-growth relationship becomes apparent. For Musala, this means a shift from a positive last year's impact to a winter and spring-time impact as well as a negative June and July temperature impact. Referring to Bansko, the summer, and partly last year's November, had an almost limiting effect during the entire observation period (Fig. 4.21 c – Bansko, Fig. 4.21 d – Musala).

Koutavas (2008) found, that the sensitivity of growth to moisture was substantially greater in the early and middle 20th century but effectively disappeared in the late 20th century. Why the change? The working hypothesis is that trees are now growing more favorably because of excess CO_2 in the air. This causes two things: (1) the average rate of growth is increasing and (2) the sensitivity to moisture stress is decreasing. Both of these effects are predicted from a CO_2 effect on water-use efficiency via stomatal conductance. Whereas the tree-ring-widths are negative related to the summer temperatures, they are positively correlated with precipitation, in particular in July (Panayotov et al. 2010, Fig. 4.21 e). This indicates heat and, accordingly, drought stress. These significant interrelations are valid for monthly average temperatures in the measurement period from 1937 to 1977 and for the precipitation sums from 1956 to 2004. The statements correspond with the results of Brandes (2007) and his discussion on a climate-ecological timberline in the Greek high mountains.

Interestingly, the *Pinus heldreichii* behaves similarly - with regard to the Bansko climate data - at the three investigated sites. The expected temperature limitation in summer at the G5-north slope was not observed. The number of months with statistically significant impact on the ring growth simply declines from G1 toward G5 (Fig. 4.21 f). Nevertheless, as a result, moisture-limited growth should be found at G1.

The standardized precipitation index (SPI) and the Walter index as a temperature-controlled humidity signal was calculated. Both are climatic parameters, which are also closely related to the ring-width growth (Fig. 4.21 g). Like in Touchan et al. (2005) the precipitation amount during the growth period (water plus or drought stress) is essential, however for *Pinus heldreichii* in Pirin, it is significant during July only. Furthermore, the previous summer has a growth-promoting or inhibiting influence (significant for August-SPI: $r=0.31$). "Dry" combined with "hot" during summer would then be a stress factor. Similarly, the role of thresholds, such as growth-days per month with temperatures above 5 °C and 10 °C are interpreted. On the south-exposed site, days in July and especially in April with $T>5$ °C appear to have a positive impact on growth, whereas with an increasing number of days with $T>10$ °C, a negative link to the growth-ring width develops (Fig. 4.21 h).

The tree-ring width, as well as the occurrence of pointer years and the annual number of trees with a conform growth tendency respectively correlate to climate parameters. There were negative pointer years in winters (December, January) with low temperatures and early summers (May, June) with high temperatures. Interestingly, this impact is similarly stored in all chronologies. In addition, negative pointer years are in a statistically significant relationship to low precipitation in July and thus also reflect the humidity limitation of *Pinus heldreichii* growth.

The statements on the climate-growth relationship are based on the chronologies detrended with a negative exponential function and a 66-year moving average. In these standard curves, the long-term trends are eliminated (Fig. 4.19). The temperature rise of recent decades will not be reflected accordingly (see Section 4.1).

The summer temperatures over the period 1965–2005 are correlated consistently weak or not significant, which is surprising, because further analysis with the simple detrended G1 series (linear regression, Fig. 4.22, left) have resulted in other interrelations. Here, a shift toward a positive influence of August is observed ($r=0.44$). Moreover, the chronology of the non-standard series (mean raw data series, see Fig. 4.22, right) for the past decade shows close and highly significant correlations with the temperatures of the months from June to August ($r = 0.58$), indicating a loss of information due to the trend adjustment. The use of this average raw data series for the climate-growth analysis, however, is only legitimate if single years up to decades of youthful growth are excluded, which is secured for the period of climate measurement.

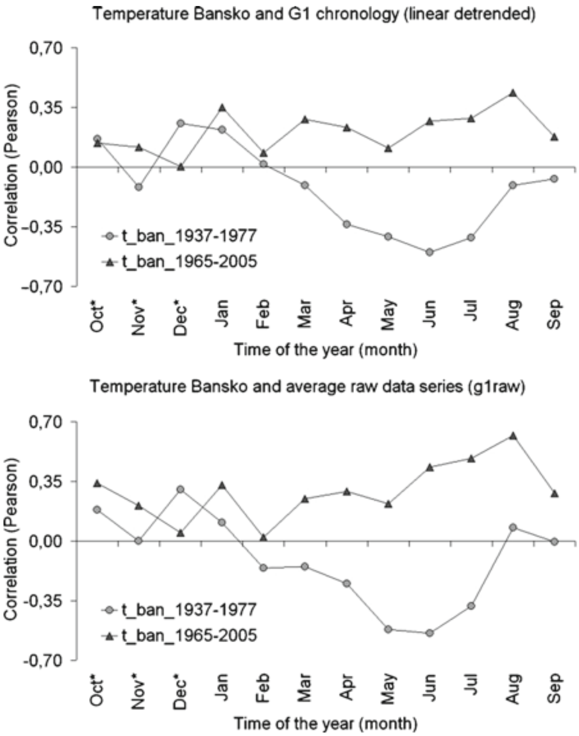

Fig. 4.22 Continuative climate-growth relationship for G1: correlation after linear trend adjustment (*left*) and for the average tree-ring width series (*right*)

Finally, the ecological plausibility of the described relationships should be evaluated (see Scheithauer et al. 2009). For a better understanding of the limiting and supporting factors it is reasonable to reconstruct annual growth of *Pinus heldreichii* after the example of the series of Yellow Cedar in Laroque and Smith (2003). An adjustment with the months that have an abrupt change in correlation, for example, allows an approximation of the beginning and the end of the annual growth.

Todaro et al. (2007) describe the start of the cambial activity and cell growth of the *Pinus heldreichii* at Mt. Pollino for mid-May. In the north Pirin the beginning is likely to be earlier, because after our own observations in late April or early May the snow is completely melted at south-exposed rock flank. This coincides with the number of days with temperatures > 5 °C in April, which are significantly and positively correlated with the growth. However, in May, days with temperatures > 10 °C already contribute limiting in relation to the standard chronology.

Warm-dry conditions in summer, therefore, continue to have an effect up into the 1970s, usually limiting. Analogue effect has a cold winter and a cool spring with just a few days with temperatures > 5 °C. The period after that behaved predominantly inverse (see Fig. 4.23). Regarding the divergence problem in dendroclimatological issues (D'Arrigo et al. 2008) the *Pinus heldreichii* is interesting because despite drier and warmer conditions in southwestern Bulgaria during the last 50 years, it showed an increasing average accrescense. Although in dry years compared to wet years, it develops narrow growth-rings, it endures the harsh conditions quite well. Competition with species of the montane level as a consequence of a hypsometric shift of vegetation levels toward the summit should be unlikely. So *Pinus heldreichii* is a winner of climatic changes.

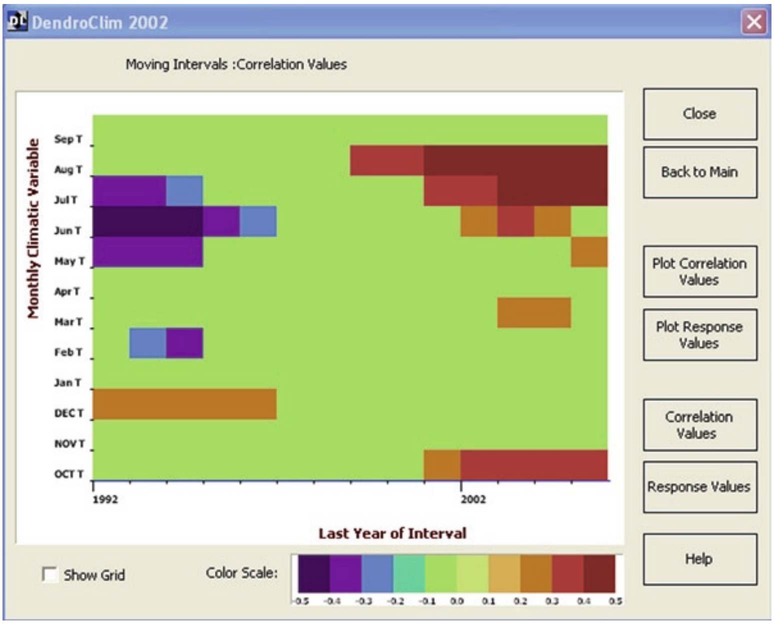

Fig. 4.23 Screenshot of the climate-growth analysis with DENDROCLIM2000 (temperature in Bansko 1937–2005 and average G1 raw data series, moving intervals, 56 years)

Furthermore, in the current year of growth the July-SPI is significantly positive, however the August-SPI is only weakly correlated. Thus the latter plays only a marginal role for the summer tree-ring growth with regard to the humidity. Instead, there is a close relationship between the SPI of the previous year's August and the annual ring width. As a result, cambial activity and cell growth should be completed around the end of July or early August and afterwards under humid conditions, the formation of reserves for the following year starts (true for the analyzed period 1956–2005). Although these assumptions are consistent with the results of Todaro et al. (2007) in southern Italy where the cambial activity is completed at the end of July and cell growth in the first half of August, the relationship between summer temperature in the Pirin (in Bansko) and ring width in recent decades does not fit. Here mainly August is positively correlated ($r=0.62$), which contradicts the theory of the end of cell growth.

The current situation of increasing temperatures with a trend to wider tree-rings must be regarded in the context of the past centuries. The described dualism of the climate-growth relationship requires a careful review of both the used ring-width chronologies as well as the appropriate time interval for the calibration to reconstruct single climate parameters (Fig. 4.24). Verification of both regression models was

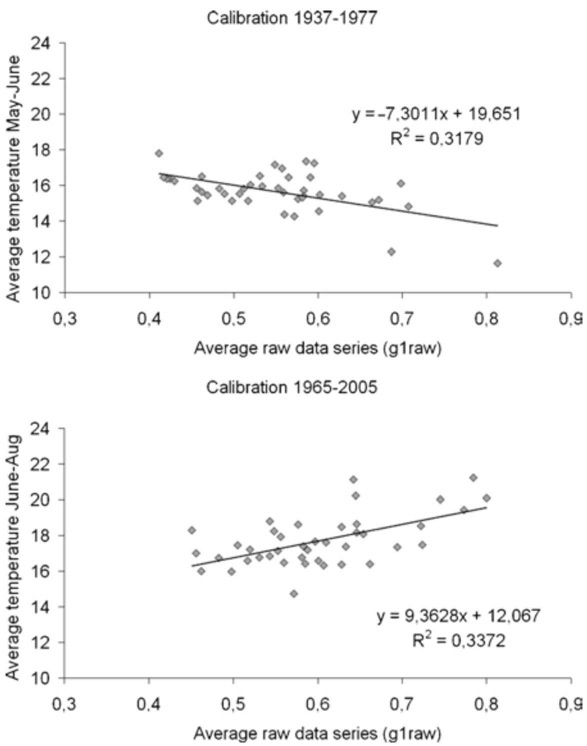

Fig. 4.24 Comparison of both calibration approaches: tree-ring width and negative relationship to May and June temperatures 1937–1977 (*left*) and positive correlation to June to August temperature 1965–2005 (*right*)

not possible due to the short series of measurement and the inverse relationships. In this respect, the first reconstruction of the June to August temperatures during the past 500 years (Section 5.2), which, based on the positive correlation to the mean raw data series (1965–2005) in Section 4.1, shall be considered as preliminary.

Next, the series of the earlywood and latewood density, as well as the stable isotopes (δ18O, δ13C) will be used, which shows a more robust climate proxy than the tree-ring width (Helle and Schleser 2004). They are currently analyzed and have yet to be compared with other studies on *Pinus heldreichii* and on climate change in the Mediterranean area. Furthermore the phenomenon of increasing ring width during the last decades will be ensured with climate data and other proxies. Having carried out additional statistical analyses and applied adjusted methods (Cook and Kairiukstis 1992, Naurzbaev et al. 2004, Esper et al. 2008), the climate reconstruction for the Pirin Mountains will be improved.

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Chapter 5
Specifics of the Regional Climate and Landscape History

Abstract The last 10,000 years, the Holocene warm period, were characterized by relatively stable temperature conditions in southwestern Bulgaria, which is documented in the altitude range of the alpine timberline and the variability of glaciers and moraines of the high mountains. The climate of the Modern Time Era (including the Little Ice Age period) can be described in higher resolution by means of the geoarchive *Pinus heldreichii*. The 500-year dendrology-based reconstruction of the temperature and precipitation course gives indications, although compared to other proxy-data it certainly needs further improvement and crosschecking. The present trends of global warming are clearly detectable in the Pirin region. But the climate change in the twentieth century was not as distinct as in other European regions nor considered global.

Keywords Climate variation • Little Ice Age • Regional warming • Timescale

5.1 Changes on the Millennial Timescale

Much research has shown that rapid shifts and transitions have occurred in regional climates (e.g. Allen et al. 1999; Hu et al. 1999; Haug et al. 2003; Mayewsky et al. 2004). This is evident in palaeo-climate data. Since the beginning of Quaternary the course and reasons of shorter climate cycles have been well registered (Bubenzer and Radtke 2007). First of all, they are influenced by fluctuations of the earth's orbit around the sun, which lead to changes in the irradiated energy quantity as well as in their regional distribution (Rahmstorf and Schellnhuber 2007; Wanner et al. 2008).

Consequences are the warm and cold stages (interglacial and glacial), which especially characterize the Pleistocene. In addition, rapid climate changes are known; more than 20 are verifiable for the Würm glacial alone. These changes are well-founded with rapidity changes of large-scale thermohaline circulation of the oceans (Rahmstorf and Schellnhuber 2007). The cold snap and radical changes in the Younger Dryas, for instance, is believed to have been caused by the depletion of a huge proglacial lake (Bubenzer and Radtke 2007).

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Based on pollen sections and macro-fossil findings in lake sediments, peats and soils as well as appropriate carbon-datings, the climate and landscape history is assessable on the scale of centuries in southwestern Bulgaria (cf. Section 3.1). However, high precision and higher temporal resolution cannot be achieved by proxy-data for the Holocene because the lakes do not record varves and real glacier archives do not regionally exist.

Silty-clayey lake sediments with a relatively high content of sand without fossil pollen indicate vegetation-free, erosion-favorable conditions in the high elevation belts of the Pirin during the Older Dryas (15,000–13,000 BP, cf. Stefanova and Bozilova 1995; Stefanova et al. 2003). Since 13,000 BP, the temperature further increased and the reforestation of the montane zones started by migration from the glacial refuges. For this period *Pinus Diploxylon* pollen and macro fossils of *Pinus peuce* and *Juniperus* are found in the pollen spectrums of the examined cirque lakes. During the Younger Dryas (11,000–10,200 BP) a temperature depression happened again. However, the transition of Pleistocene to Holocene was probably relatively dry in southeastern Europe (Wanner 2007). Glacier peripheral locations should document this epoch in the northern Pirin (Fig. 3.1). The climate conditions are corroborated by the results at Lake Dalgoto during the Younger Dryas (lower water temperature, long ice-covering, minor productivity and species diversity of the diatom, cf. Stefanova et al. 2003).

The last ca. 10,000 years (Holocene) are a climatically astonishing stable period, which means that the boundary conditions of the global climate system did not dramatically change (in comparison to larger glacial-interglacial changes). Figure 5.1 describes the proxy-based reconstruction of the global temperature over the last ten millenniums. The temperature probably varied only in the narrow corridor of between 14° and 16°. This quasi-constancy is also documented in the chemistry of glaciers or at sea level (Wanner et al. 2008). The slight short-term natural climate changes are especially seen in connection with fluctuations of the insolation or volcanic eruptions during that time (Rahmstorf and Schellnhuber 2007).

Figure 5.2 attempts to assess the Holocene climate fluctuation in the study region. In the Pirin Mountains, tree pollen rapidly increased at the beginning of the

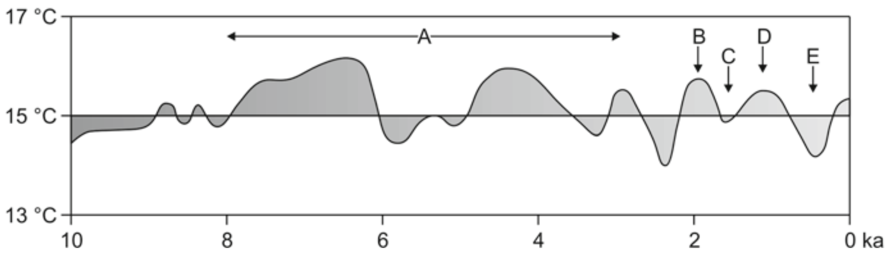

Fig. 5.1 Reconstructions of Northern Hemisphere air temperatures for the past 10,000 years: Optimum during Holocene (**A**), Roman era (**B**) and in Medieval period (**D**), Pessimum of Migration period (Völkerwanderung) (**C**) and LIA (**E**) (Source www.klimaentwicklung.de)

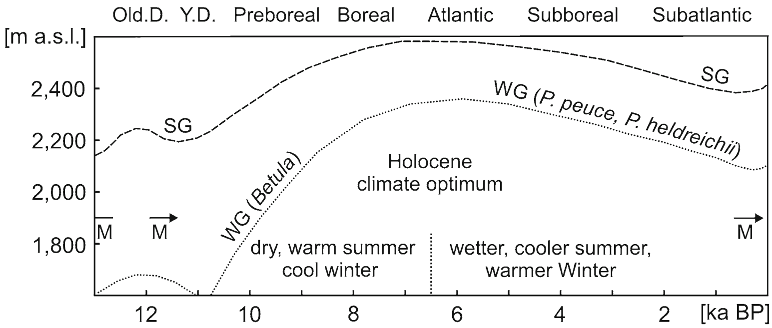

Fig. 5.2 Estimation of the Holocene climate conditions in higher elevations of the Pirin Mountains (M – glacier advances/moraine development, WG – approximate altitude of the alpine timberline, SG – approx. altitude of the climatic snow line)

Holocene. *Betula*, *Quercus*-types, *Corylus*, *Alnus*, *Ulmus*, *Tilia* as well as *Pinus Diploxylon*-species such as *Pinus peuce* are found in the lake sediments (Bozilova and Tonkov 2000). Birch determined the upper treeline during the Early Holocene (Fig. 5.2). Mesophilic trees (*Quercus*, *Tiliai Ulmus*, *Fraxinus excelsior*, *Carpinus*, *Acer*, etc.) spread out in the lower regions (Section 3.2). The shifting toward a *Betula-Quercetum mixtum* is ascribed to warmer conditions caused by high insolation. Consequently, the global trend of the Holocene temperature optimum in the Atlantic period can also be identified in southeastern Europe.

From the Middle Holocene at ca. 6,500 BP the endemic pines *Pinus peuce* and *Pinus heldreichii* dominated the treeline of the high mountains of the region (Fig. 5.2). They both bear best the dryness and warmth in summer as well as the coldness and snow in winter and finally the typical short-term and long-term cyclic precipitation variability, too (Grunewald and Scheithauer 2008b). According to Wanner (2007), the change at ca. 6,500 BP was caused by the alteration of the Milankovitch cycle – for example, the decrease of the earth's orbit caused insolation, which probably led to a change of seasonality of the climate in southeastern Europe. The global temperature trend reversed (Fig. 5.1) and as a regional consequence, the alpine treeline was slightly pushed downwards (Fig. 5.2).

Since the Middle Holocene, hunters and gatherers settled down and the development into a modern society took place (Section 3.3). People have been active in that region since the Neolithic. Hence, the alpine treeline was influenced, and therefore soil conditions and morphologic processes of this belt were changed. However, it only marginally modified the climate. Since the nineteenth century, human activities increasingly have affected the climate system in a regional-global dimension as a consequence of the industrial-energy revolution.

Stratigraphic examination of soils and carbon-dating in the sub-alpine zone verify the climate fluctuations during the Late-Holocene (Fig. 5.3). Intensive mass and soil movements took place because of climate morphologic conditions and incipient exploitation. However, these movements cannot be clearly linked to a specific cause except for the moraine of the Vihren glacier (cf. Section 3.1).

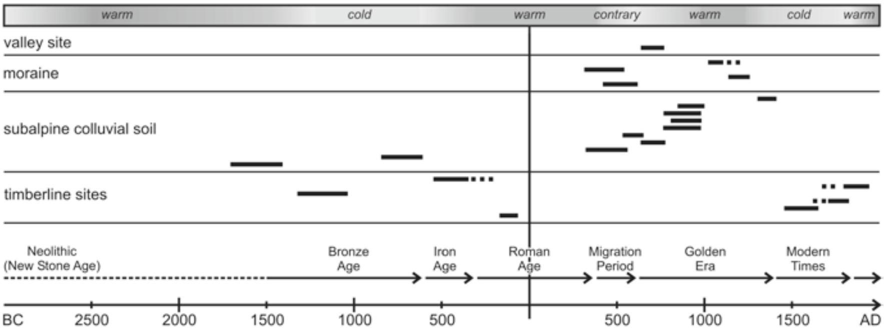

Fig. 5.3 Cultural stages, climate history and analyzed radiocarbon age of geoarchives in the Pirin Mountains (black lines: ^{14}C age range BC or AD)

Climatic improvements and social impulses in Europe were mainly observed for the Atlantic and Subatlantic in recent modern history. This can also be shown for southeastern Europe and the Pirin. Optimal conditions for vegetation and soil development existed during the Subatlantic and the Early Middle Ages, which nowadays significantly lie above the timberline. There is an obvious synchronicity with periods in which social development flourished (during the first and second Bulgarian state). Climatic pessima occurred during the Subboreal and the "Little Ice Age". During those times, cultural-historical development in Bulgaria was at a standstill. Temperature variations during the Post-glacial were, however, within a small range of ±2°C. Figure 5.3 provides a preliminary synthesis regarding the correlations between climate and cultural history during the Holocene, as indicated by our own findings and data.

5.2 Climate Development of the Region During Younger Modern History

An important aim of climate reconstruction is to reach a high temporal resolution. In the ideal case, this would be annual and seasonal information. In the study area, only the dendroclimatology of old pines is relevant in this regard. The tree-rings of *Pinus heldreichii* cover the last 500 years, partly even beyond and hence the so-called Modern Age (cf. Section 4.4). All other geoarchives (glaciers, lake sediments, peat bogs, soils etc.) provide only fragmentary, reduced or low-resolution data. "Real" archives, such as written notes or visual presentations, exist in only rudimentary form because of the social historical developments in southwestern Bulgaria, which were mentioned in Section 3.3. Instrumental climate measurements started in only the 1930s and so they cover a very short period of time (Section 4.1). It implies that dendrological investigations of *Pinus heldreichii* can provide comprehensive environmental information for the Younger Modern History, but this information can be verified only to a limited extent by other geoarchives or data in the region. Glacieret deposits, for instance, solely trace the main climate phases when ice advanced or stabilized (Sections 3.1 and 4.2).

The climate-growth-analysis has shown (see Section 4.4) that the examined climate parameters in the seasonal cycle have a highly different, sometimes reverse, influence on the tree-ring width. The (summer) temperature can have a limiting effect (May–July) as well as a supporting effect (June–August) but certainly in strong dependency of the distinguished calibration phase of the temperature-tree-ring-model. In this regard, precipitation probably plays a crucial role during the growth period (see precipitation and SPI in July, Section 4.4). Therefore, a warm and humid summer would entail wider tree-rings. If the summer period is extremely dry, then temperature has minor influence. Growth generally seems to be moisture-limited in this case. Moreover, the temperature regime in winter and spring, as well as wintry precipitation, have an inhibiting or supporting effect (Section 4.4). Table 5.1 summarizes the interactions between climate and tree-ring width for the northern Pirin.

Nevertheless, according to Körner et al. (2005), Laroque and Smith (2003) as well as Todaro et al. (2007) a temperature and precipitation-determined growth cycle of *Pinus heldreichii* can be estimated in the northern Pirin (see Section 4.4 and Fig. 5.4). The beginning and ending of cell growth and cambial activity vary depending on the characteristics of both climate factors (spring: warm vs. cold, summer: warm and humid vs. dry).

Regarding climate reconstruction, the dualism of temperature influence entails the problem that no clear distinction can be made and should not be made as to temperature and humid limitations. More complex parameters such as the drought index PDSI (Palmer Drought Severity Index) have to be calculated since it considers temperature, precipitation and evaporation. The SPI and Walter Index used so far implement in a rather simple way “only” precipitation and/or temperature. The continuing multiple regressions or the forecast equation of the tree-ring width in dependency of temperature and precipitation in summer (June–August) for the comparison period 1965–2006 comprises as follows:

$$\text{Tree} - \text{ring width}\,(\text{G1}) = -0,25 + 0,04 * T + 0,66 * N$$

Based on this relation, about two-thirds of the average tree-ring fluctuations can be explained in the analyzed period for G1, whereas temperature has the stronger influence (Beta = 0.71). In this respect, climate reconstruction is realized by means

Table 5.1 Influence of different climate parameters on the growth of tree-rings of *Pinus heldreichii* (cf. Section 4.4)

Wider tree-rings	Narrower tree-rings
High June–August temperature	High May–July temperature
Many days with T > 5°C in April	Many days with T>10°C in May and July
A lot of rainfall in July	SPI in July <−1 (dryness)
High precipitation sum during summer	High precipitation sum during winter

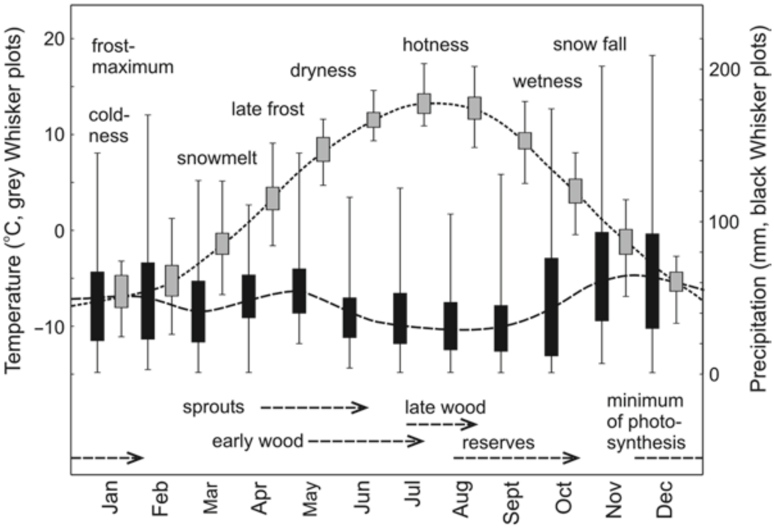

Fig. 5.4 Simplified growing cycle of *Pinus heldreichii* (following Körner et al. 2005; Laroque and Smith 2003; Todaro et al. 2007) and seasonal course of temperature and precipitation in the northern Pirin Mountains (cf. Section 4.1)

of the summer temperature until further tree-ring parameters, such as late wood density and stable isotopes, are utilized. In this case, the positive relation between tree-ring width and summer temperatures (June–August) have to be favored because they are correlated more closely than the negative influence of summer and better explain the course of the Modern Age.

The local standard chronology already reflects the climate situation very well during the last 500 years by deriving phases of above and below average growing conditions, which correspond with tree-ring width evidence outside the quartiles (Fig. 5.5a). The dynamics within the quartile can be considered as a normal fluctuation zone. There is also the long-term trend with the modelled summer temperature (Fig. 5.5b).

Validation and interpretation of both graphs are based on the regional and transregional comparison with information from other archives despite the earlier mentioned weaknesses (cf. Sections 3.2, 3.3 and 4.1 as well as Schweingruber 1993; Blümel 2002; Veit 2002; Böhm 2004; Wilson et al. 2005; Hughes 2007). The following preliminary conclusions can be drawn with regard to modern climate dynamics in the Pirin region.

During the LIA (beginning 1300–1550 AD, end 1850–1860 AD) the glaciers of southeastern Europe reformed or advanced and this interval was a significant climatic event for geomorphology and culture in this region (Grove 2001; Grunewald and Scheithauer 2008a, 2010). Young, loosely bedded moraines are the definite result of glacier advances (Fig. 3.6) and the current glaciers of the Balkan Peninsula are relics of this cold Holocene era.

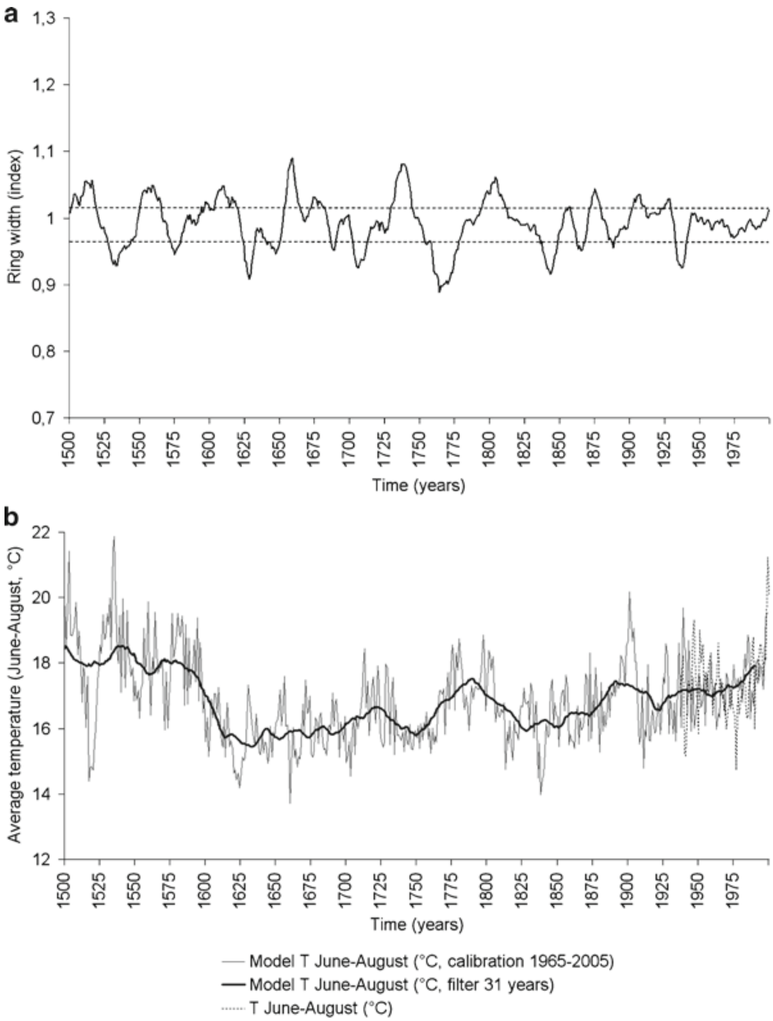

Fig. 5.5 (**a**) G1sStandard chronology, smoothed with a 31-year filter (*dotted lines: upper and lower quartile*), and (**b**) reconstruction of the June–August temperature of Bansko for the period 1500–1999 AD

The glacier–climate relation of the LIA has been examined with high resolution for the Alps (Fagan 2000) and the main stages also apply to the Spanish mountains (Chueca et al. 2007; González Trueba et al. 2008). In Figure 5.6, the four main phases of Iberia are opposed to the dynamics of the Alpine glaciers and furthermore the reconstructed temperatures in southeastern Europe (Pirin Mountains) are listed (Grunewald and Scheithauer 2008c). The synchronism of cold and warm phases is astonishing (Fig. 5.6). There was a sharp temperature decline at 1600 AD, which implies the beginning of the main phase of the LIA. The climate of the following

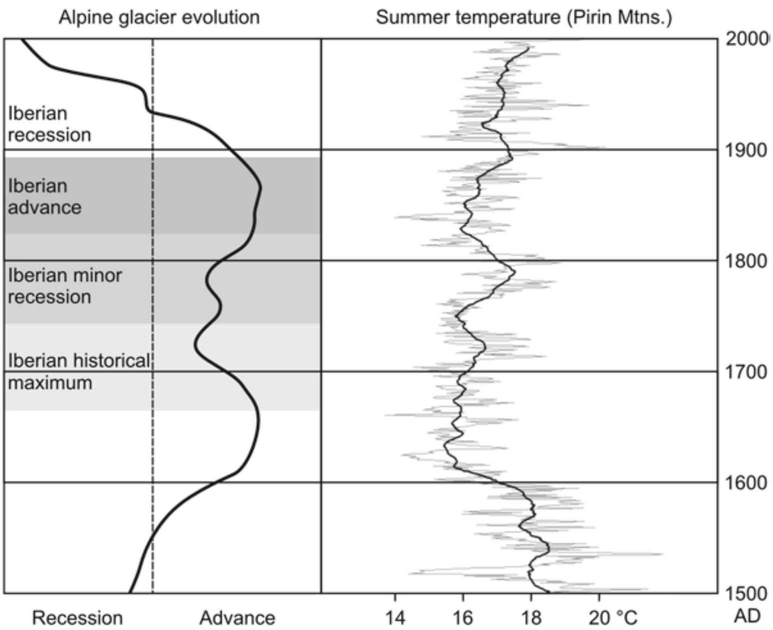

Fig. 5.6 Alpine glacier evolution (after Fagan 2000), Iberian LIA-stages (González Trueba et al. 2008) and reconstructed temperatures of the Pirin Mountains during the LIA (dendrochronology of *Pinus heldreichii*; Grunewald and Scheithauer 2008c)

period was determined by mean summer temperatures, which are nearly 2–3°C lower. Soil genesis processes, which were observed in the subalpine sites of the Pirin Mountains, came to a halt, along with a descended climatic snow line, a shorter vegetation period and a longer snow cover (Grunewald and Scheithauer 2008c).

Smaller southern glaciers probably existed for the first time during the early seventeenth century. Charcoal findings in soils in many, partly overlapped layers at the subalpine timberline in the Pirin Mountains (Grunewald and Scheithauer 2008a) mark the beginning of a morphologically more active phase with evidence of an increased occurrence of weather extremes. The overall relatively cold period was repeatedly interrupted by milder phases, such as in 1718–1729 or 1775–1800; these phases are known as favorable years (Veit 2002).

After 1800 AD, the second temperature decrease period began and lasted about 50 years (Fig. 5.6). The Vihren-glacier probably reached its maximum extension during the LIA (cool period from 1835 until 1845). In addition, epidemics appeared in the region such as occurred in Goce Delchev in 1834. The Ottoman Empire began to disintegrate. Since the second half of the nineteenth century, the climate became warmer, more consistent and possibly more humid. Probably both the ending of the Turkish supremacy and the increase of temperature had a favorable effect on the region's social development. The so-called "years without summer" that followed great volcanic eruptions, such as that of the Tambora in 1815, are not contained in the tree-ring-based reconstructed temperature of June–August (Fig. 5.5).

This phase from the second half of the nineteenth century until the beginning of the twentieth century partly shows contradictions to the climate monitoring and reconstructions in the Alps and in some high mountains of the Balkan Peninsula, and that is why it needs to be made further plausible. After the turn of the century the modelled temperature dropped again. Since the 1930s, climate values have been available, which are discussed in the following section.

5.3 The Recent Climate Change

It is generally known that the earth is warming up. Figure 5.7a shows the global temperature trend for the twentieth century. The warming began between 1910 and the 1940s. After that, temperatures stagnated until the 1970s, and since then it has been clearly increasing. Most recent measurements reached positive temperature record values. The warming has been about 1°C within the past 100 years. The strong increase of the global air temperature, especially from 1975 until 2005, can hardly be reduced to natural causes. Anthropogenic influences are mainly responsible.

Because of the higher air temperatures, the atmosphere is able to absorb more steam, so more water evaporates above land and water. Hence, precipitation has increased during the last 100 years. Above terrestrial areas, it increased by 11 mm (Gerstengarbe and Werner 2007).

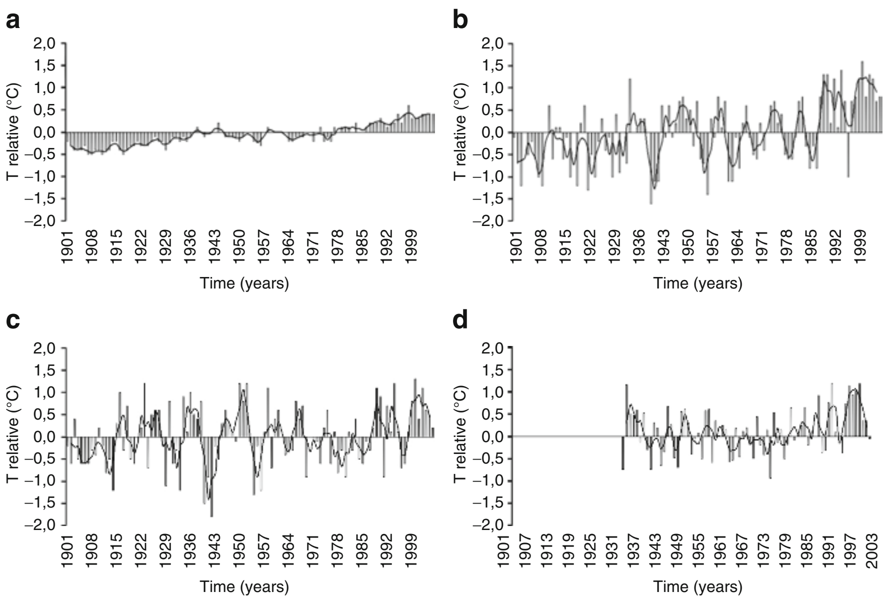

Fig. 5.7 Annual mean air temperature (**a**) global, (**b**) Germany, (**c**) Bulgaria and (**d**) Musala peak; Abnormities for the period 1901–2005 related to the average 1961–1990 (cf. Gerstengarbe and Werner 2007; NIMH 2008; Grunewald et al. 2009)

However, regional climate trends can more or less differ from the global trend. In Figure 5.7, temperature anomalies in Bulgaria and Germany are in contrast to global trends. From 1933 on, mountain climates in southwestern Bulgaria have been classified based on the data from the Musala peak station (2,925 m a.s.l.). Compared to the global temperature anomaly, regional diagrams show a more instable structure and a larger fluctuation. However, the basic course is very similar (Fig. 5.7b–d). On an annual basis, the variance of the temperature amplitude of the Musala peak station is smaller than the average of regional measurements.

All statistical series show a positive trend and significantly correlate with the global trends as well as among one another. The warming trend in the period 1901–2005 is uneven. The global trend is most evident with $r = 0.86$, and Germany warmed up relatively strong too ($r = 0.45$). However, the temperature increase in Bulgaria ($r = 0.19$) and at Musala peak ($r = 0.20$) is not significant, meaning that the warming (of the air temperature) was regionally lower than in other parts of Europe in the twentieth century.

If one considers only the last decades, the temperature increase becomes even clearer. This seems to be particularly evident in the Pirin Mountains (Table 5.2, Fig. 5.7). With all due caution regarding the measurement data of the mountainous region of southwestern Bulgaria, a warming, and hence a recent climate change, is detectable based on the annual temperature.

Alexandrov and Genev (2003) examined the changes in precipitation between 1900 and 2000 in Bulgaria, and the precipitation was slightly negative ($r = -0.20$). However, there was no significant long-term trend but a large natural variability (Fig. 5.8). This result is analogous to our analysis of the precipitation in the Rila-Pirin Mountains (see Section 4.1) and empirical data from other European areas, especially the Alps, show that no long-term trend in precipitation exists (Casty et al. 2005).

If we consider only the climatically normal period from 1961 until 1990, we will find a relative strong negative trend for the precipitation in Bulgaria. The higher air temperatures in Bulgaria are not generally associated with higher precipitation as they are on a global scale. On the contrary, the positive temperature anomalies are significantly correlated with the negative precipitation values ($r = -0.50$ for Bulgaria).

This is confirmed by the snow conditions in the mountains of Bulgaria. Petkova et al. (2004) examined the variability of snow in the period from 1931 until 2000 and concluded that the duration of the snow cover, the maximum snow thickness, as well as winter precipitation did not show significant trends. But for the highest

Table 5.2 Trends and correlations of annual mean air temperature for the period 1973–2005

	Year	Global	Germany	Bulgaria	Musala peak
Global	0.88*				
Germany	0.53*	0.53*			
Bulgaria	0.44*	0.40*	0.86*		
Musala peak	0.50*	0.41*	0.52*	0.63*	
Bansko	0.70*	0.64*	0.65*	0.70*	0.79*

*Trends and correlations (rR) significant from $p < 0.05$.

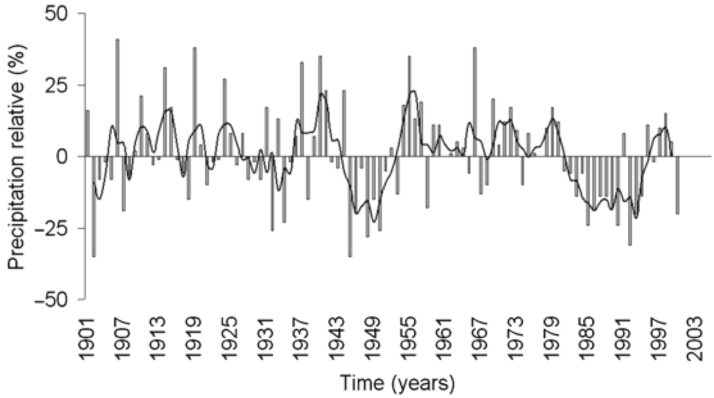

Fig. 5.8 Annual mean precipitation in Bulgaria, abnormities for the period 1901–2000 related to the average 1961–1990 (according Alexandrov and Genev 2003)

mountain regions, a significant decline in winter precipitation since 1970 was confirmed.

Our analysis of climate data of Bansko and Musala peak showed a temperature increase in winter, as well as in the other three seasons, especially during the last years. However, the trend was not statistically significant.

Conspicuous periods have been filtered. The years 1982–1994 were characterized by very little snow cover. The glacieret at the Vihren showed a minimum in 1994 (Section 4.2). Winter precipitation decreased from 1940–1955 and 1982–1995, and at the same time temperature increased during both periods (Brown and Petkova 2007).

This means that temperature and/or precipitation have a limiting effect on the development of glacierets and snow patches, on the regeneration or location of the timberline, as well as on the tree growth in higher areas of the Pirin, which also confirms the transition character of Mediterranean-summer dry and moderate-humid mountains. A shifting to warmer and dryer conditions in the mountains of southeastern Europe – as it seems to happen – entails changes in geo-factors, using potential and ecosystem services.

Prognoses regarding the climate change in Bulgaria have been developed by the EU-project CLAVIER (www.clavier-eu.org). According to that project, winters become warmer and summers hotter. This goes along with an increase of winter precipitation by almost 10% but summers become dryer, whereas the total annual precipitation changes little. In addition, more thunderstorms, flood events and other extreme natural phenomena are expected.

By means of climatic threshold values it was verified in Chapter 4 that climate change is already taking place in southwestern Bulgaria. It can also be “felt”. According to the population, there was no snow for the first time in Bansko in the winter of 2006/2007. For the ski resorts, it is not a problem yet as temporary snow deficits in recent years have been equalized by massive investments in snowmaking technologies.

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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 south-eastern 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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Abbreviations

AD	(Anno Domini)
AMS	(Accelerator Mass Spectrometry)
a.s.l.	(above sea level)
BAN	(Bulgarian Academy of Sciences)
BC	(Before Christ)
BP	(Before Present)
CRU	(Climate Research Unit, University of East Anglia)
DBH	(Diameter at Breast Hight)
ELA	(Equilibrium Line Altitude)
ENSO	(El Niño and the Southern Oscillation)
EPS	(Expressed Population Signal)
GCM	(General Circulation Model)
GIS	(Geographical Information System)
GPR	(Ground Penetrating Radar)
GPS	(Global Positioning System)
IPCC	(Intergovernmental Panel on Climate Change)
ITCZ	(Intertropical Convergence Zone)
IUCN	(International Union for Conservation of Nature)
LGM	(Last Glacier Maximum)
LIA	(Little Ice Age)
MDI	(Multivariate Dating Index)
NAO	(North Atlantic Oscillation)
NIMH	(National Institute of Meteorology and Hydrology)
NP	(National Park)
PDSI	(Palmer Drought Severity Index)
Rbar	(Interseries Correlation)
SD	(Standard Deviation)
SOM	(Soil Organic Matter)
SPI	(Standardized Precipitation Index)
TRA	(Tree-Ring Analyser)
TRW	(Tree-Ring-Width)
WGMS	(World Glacier Monitoring Service)

Geographical Features

Latin Plant and Animal Names

Time Period

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