Chapter 10
Impacts of Climate Change on Georgia's Mountain Ecosystems

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10.1 Introduction

Climate change is one of the most important problems for mankind caused by the catastrophic consequences, which could take place if the global climatic system loses its equilibrium. Georgia (as wells as Caucasus), together with other Black Sea countries, is under the impact of climate change. This is because of several environmental problems in Georgia as well as other Black Sea states such as: activation of natural disasters (flooding, avalanches, mudflows, etc.), increase of soil erosion and degradation, deforestation and desertification, a rise in the risk of extinction of relict and endemic species, reduction in biodiversity, landscape fragmentation and degradation, less attention paid towards the sustainable and nature-protection functions, reduction of agricultural productivity (Ozturk et al. 2010a). Therefore, main interest is directed at finding ways that would diminish this danger as much as possible, and avert the effects caused by environmental degradation (Ozturk et al. 1995).

According to Georgia's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC; Elizbarashvili et al. 2000), a number of vulnerable sectors and regions have been identified, and the adaptation of critical systems and economy sectors is a priority for the countries in the Caucasus. One of the most vulnerable to climate change ecosystems in Georgia is the high mountainous zone (Kvemo Svaneti)—which has been identified as a vulnerable area to various degradative forces and disastrous weather events significantly enhanced by global warming (landslides, mud torrents, floods, and snow avalanches),

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intensified land erosions, damaging agricultural losses, and decrease in forests, etc. Mountains are the dominant geographic feature of Georgia. The Caucasian mountain ranges in the country run parallel to the Greater Caucasus range, which are connected by the Likhi range, dividing the country into western (with subtropical humid climate) and eastern (with temperate continental climate) halves. The Southern Georgian Volcanic Highland lies next to the south of Lesser Caucasus Mountains.

One of the most important problems of modern geography is to determine natural potential and trends of the landscapes. This problem needs analysis of many landscape indicators, one of these being landscape and biodiversity. Landscape and biodiversity in Georgia are higher in mountain zones than in the plains. The most diversity is on the low-mountain forest landscapes of East Georgia (located on the southern slopes of Greater Caucasus), which is completely under the influence of natural and anthropogenic factors.

Landscape diversity is high in those landscapes, which are widespread, occupy large hypsometrical zones, and are located between landscapes with different humidities. These are also characterized by different anthropogenic transformations as well as the differences between aspects of slopes.

Against the background of continuous increasing anthropogenic pressures on the natural ecosystems, global climate changes are leading towards the fragmentation of landscapes, deforestation, and desertification; deepening of the uneven distribution of water resources, decrease in productivity of many ecosystems and crops, reduction of the area suitable for agricultural purposes and eventually, to the degradation of the cryosphere and landscape as a whole. It is, therefore, very important to identify the level of responsiveness of landscapes towards the natural and anthropogenic forces.

Glaciers are the best indicators for climate change. Late-twentieth-century changes in glacier extent in the Caucasus Mountains have revealed that average speed of glaciers has retreated during 15 years to 8 m/year; maximum speed of retreat has been 38 m/year (Elizbarashvili et al. 2000). The increase in the number of glaciers is connected with their deviation and partitions, as a result of thawing. The relative uprising of sea level on the eastern coast of the Black Sea has been due to extensive melting of glaciers in the mountainous regions, provoking flooding processes in the lowland territories (Matchavariani et al. 2011).

In view of the facts cited above, the importance of developing scientific methodology to evaluate the sensitivity of the landscapes of Georgia to the climatic changes and trends taking place in the landscapes is very important and one of the urgent problems. It is necessary to plan and realize the measures of both ecological and socioeconomic systems towards their adaptation in the event of more effective climatic changes. The main goal here is to evaluate the impact of the climatic change on the mountain landscapes of Georgia, and identify the landscapes characterized by high sensitivity and facing threats.

10.2 Study Area

Georgia is a country with diverse natural and, also, climatic conditions, which is expressed in the high level of bio- and landscape diversity. The main reasons for this are an interchange of lowlands and mountains. The country is also located on the conjunction of moderate and subtropical climatic belts, characterized by diverse natural and climatic conditions. In this regard, an important role played on the biodiversity are geological factors (distribution of silicate, limestone, and volcanic rocks), and also climatic changes during the Quaternary period, which resulted in a tertiary flora still surviving in the Colchic foothills of West Georgia. Georgia, in general, is characterized by the existence of humid, extra humid, semihumid, semiarid, and arid ecosystems with swamp plants, deciduous and coniferous forests, steppes, thorny plants, subalpine, and alpine meadows, etc. The country has almost every climatic zone, except for savannas, tropical forests, and deserts. These are covered by a plant diversity composed of 300 species belonging to 71 genera on 14 types and 23 subtypes of landscapes (Beruchashvili 1998). So, more than three types of landscapes cover every 10,000 km^2 area. These are distinguished by virgin forests occupying almost 10 % of total territory of the country (Beruchashvili 1995). Georgia is included among those few countries, which are characterized by diversity—having both the natural and anthropogenic diversity (Gobedjishvili and Kotliakov 2006). Latter defines the fragmentation of landscapes, formation of agricultural lands, urban areas, degraded ecosystems, and polluted territories.

There are many studies dedicated to the impact of climate change in Georgia (Lurie 2002; Neidze 2004; Nikolaishvili 2009; Beritashvili et al. 2010; Matchavariani et al. 2011; Nikolaishvili and Demetrashvili 2011); however, not much has been published on the impacts on individual landscapes. No methodological fundamentals explain the mosaic nature of climatic change impacts on the mountain landscapes of Georgia. This is a very important question related to the mountain landscapes. Considering that the network of hydro-meteorological observations is scarce in the mountains, the importance of the problems related to this topic and necessity for its real evaluation fully comes to the forefront.

The impact of the climate change on different landscapes of Georgia has not been studied in depth; as such, no relevant methodology has been developed. A landscape approach allows identifying the mosaic nature in question and reasons for the same. A landscape, like a "mirror," reflects all the properties and trends in the change of the state of environment associated with the climatic change. The main thing is to find out the mechanism allowing identifying the expected trends, particularly the areas at risk, and, most importantly, conditions to avoid or mitigate the threats.

The specificity of this study is associated with two important aspects: First, the information has been accomplished at the level of the landscape species, with basic weather station/post selected individually for each of these. The most important thing is that such an approach has allowed identifying the current changes in the landscape. It is clear that the development of the new methodological basics of the spatial and time model of the climate change and inventory of the landscape ethology need to be based on an approved approach—identification of daily states (geo-states) of the natural-territorial complexes based on the concept of spatial and time analysis and synthesis developed by the earlier workers (Beruchashvili 1986). On the one hand, this means specifying the geo-states and annual dynamics of the natural-territorial complexes based on the basic parameters (daily air temperatures, presence of atmospheric precipitations, and height of the snow cover; approved already); on the other hand, it implies the engagement of the so-called extra parameters (amount of atmospheric precipitations, wind velocity, relative humidity, etc.; duration, reoccurrence, alternation and transition trajectories of geo-states, behavior of the natural-territorial complexes). This means that in order to specify the resistance of the landscape to the climatic change, and its current trends, the geo-states of the natural-territorial complexes should be identified in greater detail. Such an approach will make it possible to fill the gap with the structural aspect of the concept of spatial and time analysis and synthesis of the natural-territorial complexes.

This type of investigation requires 1:1,000,000- and 1:500,000-scale landscape maps form the cartographic basis of the study (Beruchashvili 1998, 2000), with species and type of vertical structure of the natural-territorial complexes as the least landscape classification unit. So we have used here the results of the field and semistationary studies carried out by the scientific research laboratory during 1977–2005 in order to study the environmental aspects, by the Transport studies Unit (Tbilisi State University) aerospace methods, for different time intervals in different landscapes of Georgia. The results of studies carried out for many years, at Martkopi station, were also evaluated. Various reference books (Nikolaishvili and Demetrashvili 2011) on climate studies, giving the climatic features of the weather stations/posts, were also used here.

10.3 Research Methods and Initial Data

10.3.1 Landscape-Forming Oro-Climatic Factors

There are many factors influencing the formation of the landscapes of Georgia, such as (a) location (latitudinal location and elevation of the area), (b) atmospheric circulation and orohydrographic barriers, and (c) nature of the underlying surface.

Georgia is located between 41° North latitude and 43° East longitude, and, as a consequence, the territory of the country receives enough source of solar energy. Its location at the edge of the subtropical and moderate climatic belts results in the diversified landscapes, which is also promoted by the great intervals of the absolute altitude (over 5 km).

Among oro-climatic barriers, Greater Caucasus range—extending approximately about 900-km length in Georgia—plays the most important role in the formation of various climates and different landscapes, separating the north slopes and subtropical climatic belts from the remaining parts. This range blocks the penetration of cold north air masses. However, the cold air masses, sometimes, penetrate the country through some river gorges of the Great Caucasus, but their influence is limited. If no such orographic barrier existed, the climate of Georgia would be colder, being most notable, in the cold season of the year.

Other important oro-climatic barriers are Likhi and Arsiani mountains, serving as the watersheds of Black and Caspian Seas, extending from the Greater Caucasus to Lesser Caucasus. The Greater Caucasus also blocks the penetration of western humid air masses, creating two parts in the country: The humid western part, mainly, with forest both on the plain and mountainous areas, and, the relatively dry, eastern part, mainly, with arid woodlands, steppes, semidesert vegetation on the plain, and with forests in the mountains. Its influence makes the difference between the slopes inverted toward the Black Sea and the inner part of country (Beruchashvili 1993). The border between the humid and dry subtropics runs across the crest of Likhi and Arsiani ridges.

West and East Georgia are characterized by, more or less, clearly different physical geographical peculiarities of climate formation, observed in the different circular processes of the atmosphere. As the air masses penetrate the territory of Georgia from the west, the air temperature decreases, the weather is cloudy and wet, and abundant atmospheric precipitation is observed particularly in West Georgia. The same air masses, while moving across Likhi ridge towards East Georgia, lose much of the humidity (CEO 2002).

Thus, humid and semihumid landscapes are mainly represented in the western part of Georgia and semihumid and semiarid distributed between 800 and 2000 m above sea level (asl). The *Javakheti volcanic highland* in the south is dry, where semiarid and arid landscapes are observed, protecting a significant part of Georgia from the penetration of hot and dry south air masses.

Secondary oro-climatic barriers too are important landscape-forming factors, which are responsible for the rain-shadow effect. This effect contributes to both the relative humidity of the windward slopes, and the humidity, which dominates on the opposite side, interior slopes of ranges, and adjacent depressions.

10.3.2 Landscape Diversity of Mountains of Georgia

The landscape spectrum on the territory of Georgia is quite diversified with apparent peculiarities of territorial distribution. Mountain landscapes are found throughout the country within the Great Caucasus and Lesser Caucasus, and, also, within Javakheti volcanic plateau, occupying more than 51,000 km^2 which makes up more than 73 % of the whole territory of Georgia. There are 150 species belonging to 71 genera on 14 types and 21 subtypes of landscapes (Beruchashvili 2000). The mountain landscapes are represented by 8 types, 15 subtypes, and 48 pieces of landscapes (Fig. 10.1).

These landscapes are:

Mountainous subtropical semiarid (type)

- Steppes, "shibliak," open woodlands (subtype)—2 genera

  Mountainous subtropical arid (types)

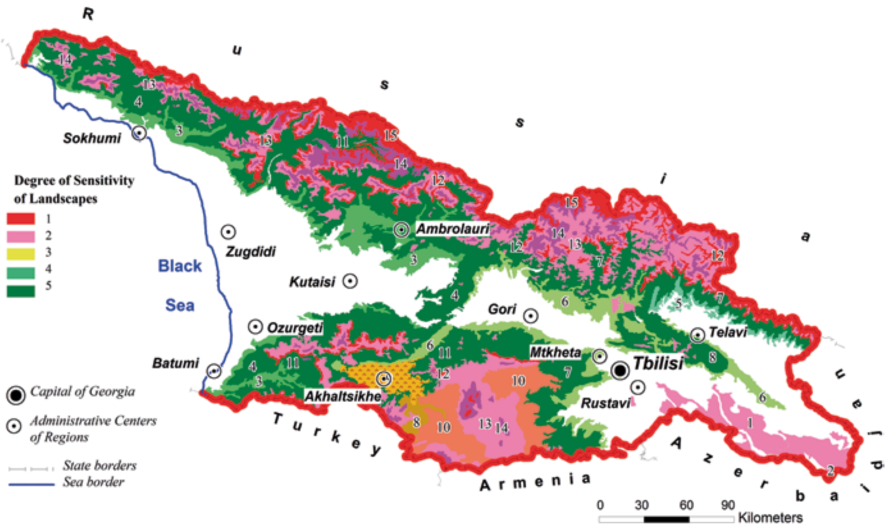

Fig. 10.1 Distribution mountain landscapes of Georgia (explanation in the text)

- Semidesert and Desert (subtype)—1 genera
  Mountainous thermo-moderate humid landscapes (types)
- Low-mountain forests Colchic (subtype)—5 genera
- Middle-mountain Colchic landscapes with beech forests, evergreen understory (subtype)—6 genera
- Low-mountain Iberian Forest (subtype)—1 genera
- Transitional to semihumid low-mountain forests (subtype)—5 genera
- Middle mountain Iberian with prevalence of beech forests (subtype)—3 genera
  Thermo-moderate semihumid landscapes (types)
- Middle-mountain landscapes with meadow–steppes, dry open woodlands (subtype)—1 genera
  Mountainous thermo-moderate semiarid (type)
- Transitional to Thermo-moderate mountainous depression with steppes, meadow-steppes, “frigana” and “shibliak” (subtype)—1 genera
- Highland volcanic plateau landscapes with steppes and meadows-steppes—1 genera
  Mountainous cold-moderate landscapes (types)
- Middle-mountain dark coniferous (spruce, fir tree) forest (subtype)—3 genera
- Upper mountainous pine and birch forest (subtype)—5 genera
  High-mountain meadow landscapes (types)
- High mountain subalpine landscapes with elfin forests, shrubs, and meadows (subtype)—6 genera
- High mountain alpine landscapes with meadows, alpine mats (subtype)—4 genera
- High mountainous subnival landscapes with mosses, lichens, and cliffs (subtype)—2 genera

High-mountain glacial–nival Landscapes (types, subtypes)—1 genera

The most diverse among the landscapes of Georgia are the low-mountain forest landscapes resulting from the natural and anthropogenic factors. These landscapes are located between the piedmont and middle-mountain forest landscapes and as a consequence, have the ecosystems typical to both landscapes. They are modified more than the middle-mountain forest landscapes located at higher hypsometric altitudes. This is the reason why the fragmentation of the low-mountain forest landscapes is greater.

The most diversified are the mountain forest landscapes in the east, spread over the southern Great Caucasus slopes, and northern slopes of the Lesser Caucasus. These landscapes are located between the piedmont semihumid and middle-mountain moderately warm humid landscapes. The result, of the near location of the piedmont semihumid landscapes, is the semihumid ecosystems spread over lower borders, and humid ecosystems spreading at the upper borders, as a result, of the near location of the middle-mountain forest landscapes. The degree of anthropogenic transformation is higher, with the low-mountain landscapes, explaining such a high degree of diversity of the landscapes here.

The middle-mountain forest landscapes are much more uniform than other landscapes. The difference between the landscape species too is clear. In particular, great diversity is observed on the middle-mountain forest landscapes spread over the northern slope of the Lesser Caucasus. The least diversified landscapes are observed along Adjara–Guria section, dominated by beech forest ecosystems with Colchic sub-forest or hemihiles. In the above-described picture of diversity, the exclusion is the lower- and middle-mountain landscapes of Great Caucasus of Kakheti, which are relatively uniform. This is because these landscapes are spread over a narrow strip with less oro-climatic barriers. The exposure difference in the territorial distribution of the natural-territorial complexes is relatively less.

The upper-mountain forest landscapes of West Georgia are more diverse. This must be due relatively to the uneven humidities on these landscapes because of the oro-climatic barriers. A certain part of the territory, of the said landscapes, is subject to the influence of the so-called rain shadows, while the other part is directly influenced by humid air masses. As a result, both, humid and semihumid natural-territorial complexes are observed here.

Most of the landscapes in Georgia are of a humid type, with 86% of the total area of the mountain landscapes belonging to this (Fig. 10.2). It incorporates 37 landscape species, i.e., most of the mountain landscapes are humid, and, as the logic suggests, it must have greater ability to adapt to the climatic change. However, on the background of the diversified natural conditions and anthropogenic impacts, the situation is much more homogenous. The semiarid and semihumid transitional landscapes occupy nearly the same areas (8 100 and 5 400 km^2, respectively) incorporating nine landscape species. As for the semihumid and arid mountain landscapes, each of them incorporate one type of landscape with the total area of only 0.5000 km^2.

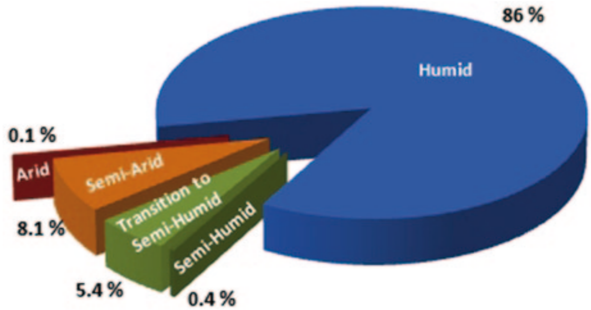

Fig. 10.2 Area of mountainous landscapes of Georgia (on the basis of humidity %)

10.3.3 Territorial Distribution of Mountain Landscapes of Georgia

The borders between the landscape units run at different hypsometric altitudes, and this is well seen not only with large but also with relatively small orographic units. The altitudinal amplitude may reach even several hundred meters. For instance, the borders of middle-mountain forest landscapes mostly run at 800 (1000)–2000 m asl (Fig. 10.3), though, quite often, they go beyond this altitudinal range. The middle-mountain forest landscapes with dominant beech forests in the river Enguri basin, in West Georgia, even go down 700 m asl. The same is true with the upper hypsometric limit of the said landscapes. This is all about the natural borders of the landscapes. On the other hand, the lower limit of the landscapes change with time due to the anthropogenic influences. In particular, the lower border of the middle-mountain forest landscapes has elevated, while their lower border have lowered.

Based on the analysis of the 1:500,000-scale landscape map of Georgia (Beruchashvili 1993), showing the types of the vertical structure of the natural-territorial complexes, the area of each landscape species can be identified. As expected, the mountain landscapes occupy the largest area making 76 % of the total area of Georgia. The landscapes in the mountains—depending on the altitudinal zoning—are distributed as follows: low-mountain landscapes occupy 3 % of the total area of the territory of Georgia, mountain basins occupy 1 %, lower-mountain landscapes 12 %, middle-mountain landscapes 24 %, upper-mountain landscapes 7 %, high-mountain subalpine landscapes 21 %, high-mountain alpine landscapes 6 %, and high-mountain subnival and nival landscapes 1 %.

High-mountain landscapes are widespread both in the West and East Georgia on the northern and southern subcrest slopes of Great Caucasus and Lesser Caucasus, and go up to 1800 (2000)—2700 (3500) m asl. In some places, they descend below this range. The middle-mountain forest and high-mountain subalpine landscapes occupy relatively larger areas in West Georgia, while lower- and upper-mountain landscapes are mostly spread in East Georgia. As for the alpine landscapes, they are almost evenly distributed—western and eastern parts of the country.

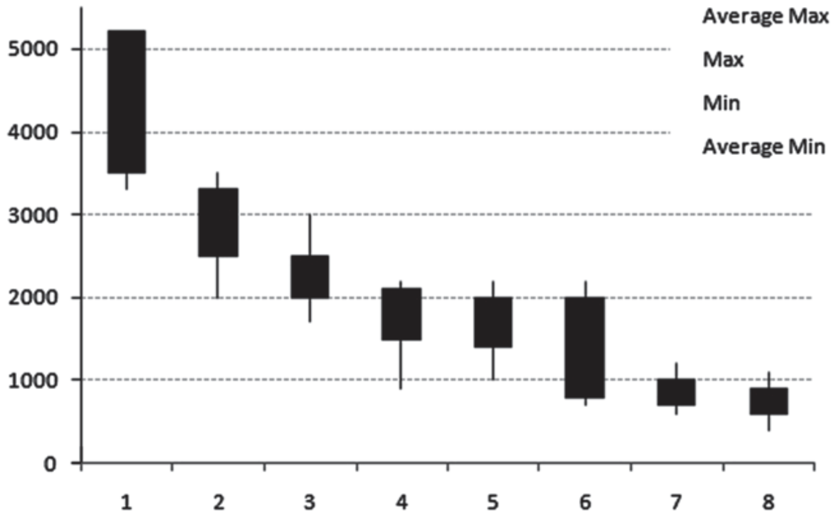

Fig. 10.3 Hypsometrical range of distribution of Georgia's mountain landscapes. *Average Max and Average Min—Average range of distribution; Max and Min—Absolute range of distribution*

10.3.4 Phytomass of Mountain Landscapes of Georgia

The phytomass of the landscapes in Georgia has been investigated by a number of workers, with more than one paper dedicated to the individual aspects of phytomass (Beruchashvili 1993; Nikolashvili 2008), considering the proportions of the total and fractional parts of phytomass, peculiarities of their spatial distribution, their relation to the physical–geographical conditions, and other landscape and geophysical indicators.

The mountain landscapes of Georgia differ much from one another in the amount of phytomass making 230 t/ha. The maximum amount of phytomass (over 500 t/ha) is typical to the middle-mountain beech-and-dark coniferous landscapes, while its minimum amount is found over the semidesert and high-mountain subnival landscapes.

A particularly wide variation in the amount of phytomass is typical on the landscapes with dominant forest natural-territorial complexes (Fig. 10.4). The reason for this is that there are forest-free natural-territorial complexes distributed on the landscapes beyond the forests. As a result, diversified modifications of the landscape transformation are seen, which, in turn, result in their different productivity. In particular, a large amount of phytomass is fixed within the original or slightly transformed natural-territorial complexes. The degraded forest massifs and secondary meadows fall much back. This is the reason why the amount of phytomass within the said landscapes varies widely. However, one thing is clear—the variability is less intense in the relatively untouched environment. For example, a wide range of variation of the amount of phytomass is typical to the lower-mountain and

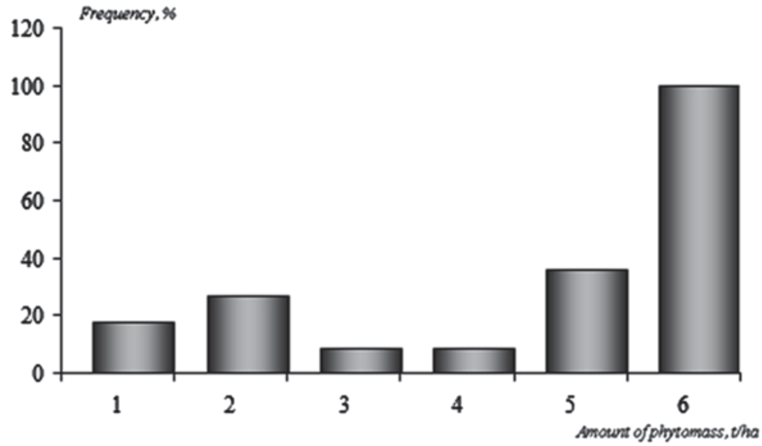

Fig. 10.4 Amount of phytomass in forest landscapes, t/ha

upper-mountain forest landscapes. The lower-mountain forest landscapes contain the natural-territorial complexes with the amount of phytomass varying from less than 50 t/ha to more than 600 t/ha (Table 10.1).

A different range of phytomass amounts is typically observed on the landscapes in West and East Georgia. Comparing the subtypes within the same type of landscape, it is clear that the diversity is more common to East Georgia due to the diversified nature of the ecosystems of East Georgia. In particular, even within the limits of the same subtype of a landscape, there are extra-humid, humid, and semihumid natural-territorial complexes distributed here. We can site middle-mountain forest landscapes distributed over the eastern part of the Lesser Caucasus where there are different types of a vertical structure of the natural-territorial complexes: deciduous shrubs of humid mesophytic macrostructure or grassy cover, deciduous shrubs of semiarid mesophytic macrostructure or grassy cover, grassy cover of a humid micro-mesostructure, grassy cover of a semi-humid or semiarid microstructure, as well as agro-complexes.

A greater amount of the phytomass in the mountain forest landscapes (over 200–300 t/ha) is usually common for the landscapes with annual atmospheric precipitation of more than 750–800 mm. A great amount of phytomass is identified in all forest landscapes of Kolkheti and Greater Caucasus of Kakheti. This is the certain optimal indicator, below which the amount of phytomass starts decreasing sharply. However, among the climatic parameters, it is not the only indicator of phytomass accumulation in the mountain forest landscapes. Two other circumstances also exist: (a) the average amount of phytomass is less at places where the annual atmospheric precipitation is close to the lower optimum, i.e., it is within the range of 700 mm. Such places are found on most of the mountain forest landscapes in East Georgia. The average amount of phytomass in lower mountains is 175–200 t/ha; it is 300 t/ha in middle mountains and 80–90 t/ha in upper mountains, while in West Georgia, the same indicator is 260, 360, and 100 t/ha, respectively, (b) greater amounts of

Table 10.1 Some physical and geographical parameters of mountain landscapes of Georgia. (see legend—Fig. 10.1)

#	Area 100 km^2	Number of landscape genera	Number of NTCs	Forest area, 1000 km^2	Amount of Phytomass, t/ha
1	4.060	3	3	1.39	<1
2	3.920	5	2	1.760	1–5
3	10.780	6	6	10.780	20–125
4	2.040	3	5	0.390	10–35
5	4.710	4	6	4.710	75–180
6	16.243	12	14	15.373	300–500 and more
7	8.110	11	17	6.068	200–300
8	2.360	1	5	2.360	20–50
Total	52.223	45	–	42.8310	–

phytomass are found at places with the maximum amount of atmospheric precipitation (500–600 mm) in the vegetation period (from May through November). This is one of the reasons for more phytomass being typical for the mountain forest landscapes of West Georgia as compared to East Georgia. The only exception is the landscape of the Great Caucasus of Kakheti.

There is a direct proportional relationship between the annual atmospheric precipitations and amount of phytomass. It is gradually leveled, in line, with the growth of these indicators. In fact, it does not matter whether the annual atmospheric precipitation is 1500 or 3000 mm. This fact can be used to explain why, virtually, there is no big difference between the amounts of phytomass over the landscapes with abundant precipitations in the western part of the Lesser Caucasus and other mountain forest landscapes in West Georgia. It is evident that the landscapes of the same subclass, type, or subtype are meant.

High-mountain landscapes, including alpine meadows and alpine mats (dominated by sedge and fescue), also subalpine rhododendron thickets and rock vegetation, are represented by herbaceous species (grazing, haymaking), which are significant summer pasturelands for sheep, livestock, and, partially, for goats. The dominant species of Mixtoherbosum-meadow and grass-meadow communities are: Brometo Agrostideta (*Bromus variegatus, Agrostida planifolia*), Deschampsiea (*Deschampsia flexuosa*), Hordeeta (*Hordeum violaceuth* and Festuceta (*Festuca ovina, F. varla, F. rupicola, F. supinae*). The dominant species of Mixtoherbosum-meadows communities are: *Betonica grandflora, Polygonum carneum, Inula orientalis*, and others (Gunia 2011; Matchavariani and Lagidze 2012).

Among grassland areas (Nakhutsrishrvili et al. 1980), the highest phytomass is character for *Festuca varia* and *Helictotrichon asiaticus* (more than 60–80 g/m^2 in the beginning of summer), also for *Carex meinshauseniana* (more than 50 g/m^2; Fig. 10.5).

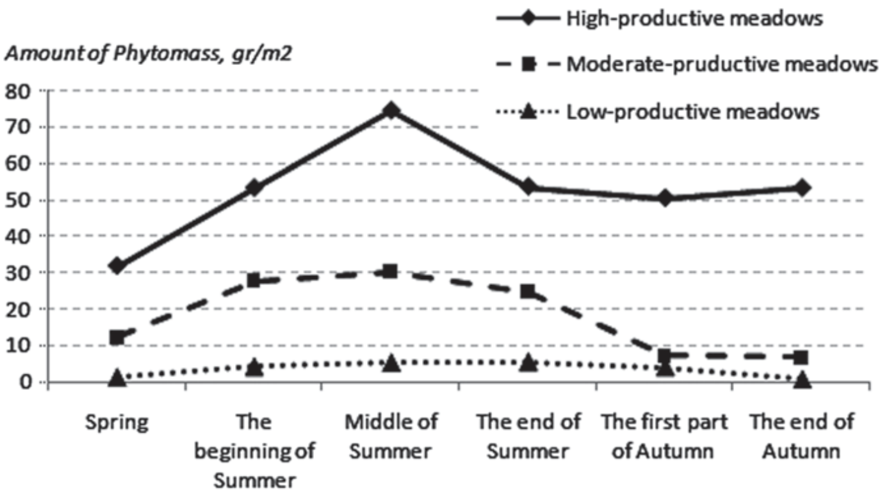

Fig. 10.5 Amount of phytomass in different periods

Overgrazing has resulted in changes in the land cover, increasing soil erosion, and decreasing productivity of soil and vegetation (Ozturk et al. 1995). These processes are determined by both natural and anthropogenic factors. So, avalanches, mudflows, and landslides are common for these landscapes. Caucasian rhododendron thickets mostly are characteristics for northern slopes of Great Caucasus and Lesser Caucasus.

Another dominant vegetation community is subalpine meadows with representatives like *Betula litwinowii, Betula raddeana, Fagus orientalis, Sorbus caucaigena, Salix,* and *Populus*. The vegetation over the cliffs and clastic grounds, much diversified and rich in endemic species, which does not form a single continuous area, but is presented in fragmented and small groups: *Saxifraga juniperifolia, Campanula beldifolia, Driba bryodes, Semecio Sosnowskyi, Nepeta supina, Veronica minuta*.

The typical representatives of the subnival landscape are: *Alopecurus glacialis, Jurinella subacaulis,* and *Delphinium caucasicum*.

The steppe vegetation spreads over high hypsometric steps across Javakheti Plateau in fragments. With its species and floristic content, it is not only similar to the mountain steppe of Southwest Asia but also shows signs of influence of the Mediterranean coastal area (Ozturk et al. 1996a, b) paleoarctic zone and biogeographical zones of Central Asia, and as a result, the relict, endemic, and other floral elements are typical in these mentioned zones.

The analysis of the field and stationary studies and data of different scientific sources (Matchavariani and Lagidze 2012) shows that the change in phyto-productivity depends on the seasons of the year and is less evident in high-mountain subalpine and alpine landscapes, but, nevertheless, it is not uniform. *Festuca varia—Carex meinshauseniana*-mixtoherbosa in the vegetation association where the deviation from the mean value is 22 % (Matchavariani and Lagidze 2012), it is spread across the high-mountain alpine landscapes and forms one of the highly productive high-mountain meadows.

The circumstances associated with the exposure difference are interesting to consider. A multiyear difference in phyto-productivity, both in West and East Georgia, is much less evident over the slopes with southern or southeastern exposure, while it is clearly evident over the slopes with northern or northwestern exposure.

10.3.5 Soil-Edaphic Conditions

Soil humidity has a great influence on the formation of types of natural-territorial complexes and accumulation of phytomass. Our studies of soil humidity are based on the analysis of the field materials, allowing us to consider the said indicator in the annual dynamics. The field materials gathered for one geo-state of the natural-territorial complex reveal that when the phytogenous structure is stabilized, it enables us to compare the different landscapes of Georgia, and identify the optimal soil humidity determining the accumulation of the given amount of phytomass. In general, the increase in the average soil humidity is followed by the increase in the amount of phytomass. It was found that the average soil humidity necessary for the large amounts of phytomass to accumulate over the mountain forest landscapes of Georgia should not be less 25–30 %. As for the landscapes of West Georgia, this indicator must be as high as 30–40 %.

An important indicator to identify the peculiarities in the territorial distribution of phytomass is the distribution of humidity across the whole-soil profile. Usually, large amounts of phytomass are detected at places with the high-soil humidity preserved not only in the upper-soil horizon but also across the soil profile. Most important is to identify the humidity of a 30-cm-thick soil layer (Nikolashvili 2008). The natural-territorial complexes with the phytomass of over 300 t/ha over the middle-mountain forest landscapes of Georgia with dominant beech forests are found at places where a 30 % isoline of soil humidity runs at a depth of 30 cm and a 20 %-soil-humidity isoline runs deeper than 80 cm. In fact, it makes no difference where the 30-cm-soil-humidity isoline runs deeper than 30 cm, as such an environment is mostly characterized by large quantities of phytomass (from 300 to 500 t/ha or more).

A similar situation is observed in the lower-mountain forest landscapes of Georgia. Here too, the degree of accumulation of large amounts of phytomass depends on the depth of a 30 % isoline of soil humidity. If in East Georgia this isoline runs deeper than 30 cm, the average amount of phytomass exceeds 200 t/ha, while it is 250–300 t/ha in West Georgia. The soil humidity exceeding 60–70 % in the 10–15-cm-thick upper-soil layer nearly does not matter.

Different peculiarities were found in the upper-mountain forest landscapes. Large amounts of phytomass are found in the landscapes of the piedmont steppe, where the soil, 30 % isoline, runs at a depth of 15–20 cm. In addition, there is another necessary condition implying that a 40 % isoline of soil humidity must not be located near the surface, but must run deeper than 15 cm minimum. Under such conditions, sparse arid forests or *sibljak* develop, where the average amount of phytomass, in less transformed on natural-territorial complexes amounting to

125–150 t/ha on average. At locations where a 30 % isoline runs at the depth of approximately 15–20 cm from the surface, the amount of phytomass does not exceed 50 t/ha at any location and amounts to only 20–25 t/ha on average.

A large amount of phytomass in the upper-mountain forest landscapes is detected in case of much different values of soil humidity. It is true that here too, a 30 % isoline plays a decisive role, but its location at different depths results in different amounts of phytomass in some or other natural-territorial complexes. As for the forest complexes, such an isoline runs much deeper. A large amount of phytomass is accumulated if this isoline runs deeper than 35–40 cm. In terms of stronger anthropogenic transformation, a 30 % isoline runs nearer the surface, which, in turn, has influence on the amount of phytomass. A relatively larger amount of phytomass in the high-mountain meadow and meadow–shrub natural-territorial complexes is observed at locations where a 30 % isoline runs at a depth of 25–30 cm.

10.3.6 Ecological Functions of Mountain Landscapes

Mountain landscapes play a significant ecological role and influence the human's living environment (Efe et al. 2012; Atalay and Efe 2010). The forest landscapes of Georgia occupy nearly 40 % of the territory of the country and are the most important natural resource. These mountain landscape ecosystems play very important role in the preservation of natural habitats and protection from soil erosion. High-mountain landscapes are very important for collection of medicinal and decorative plants as well as bryophytes and mosses (Gokler and Ozturk 1989; Ozturk et al. 1991, 2010; Uysal et al. 2011). Location of balneological and ski resorts make principle impacts on the sensitive ecosystems.

The ecological function of the said landscapes can be classified into several major categories:

- An environmental protection function is an important ecological function discharged by mountain landscapes. In particular, the mountain landscapes hamper the intensity of such geodynamic processes, as landslides, mudflow currents, and snow avalanches. In this respect, middle-mountain forests as well as high-mountain subalpine and alpine landscapes are of a particular value.
- The water-balance regulation function is also much important to maintain the ecological balance in the environment. Water processes over the plains and valleys are often resulting from the physical–geographical processes taking place in the mountain landscapes, to which their original nature is preserved. In this respect, the role of high-mountain landscapes is particularly important. The impact these landscapes have on the water balance regulation is evident across all vertical landscape spectrum.
- Their function is to maintain the vegetation adapted to narrow environment. The high-mountain landscapes are the areas of such ecosystems, which are adapted to certain ecological conditions only and have low valence of distribution. These ecosystems undertake much important environmental protection function;

therefore, if the conditions of their existence change due to the climate change, they will face a threat of extinction.

- They have a function to maintain the vegetation cover of post-glacial cycles. The high-mountain landscapes are a shelter for psychrophilic plants occurring in such favorable conditions during the post-glacial cycles. If a warming trend follows due to climatic change, these plants will face extinction.
- How can we reverse this process?
- We need to maintain the forest resources.
- The conservation of water and marshy ecosystems is a must. The marshes in Georgia are mostly concentrated over Kolkheti lowland, but they are also found at high-mountain subalpine and alpine landscapes as fragments. Relatively larger and less deep fragments are found at the banks of the lakes over Javakjeti Plateau, in the upper reaches of the river Ktsia-Khrami and at other locations.
- There is a need for the establishment of ecological corridors.

10.3.7 Anthropogenic Transformation of Mountain Landscapes

In some landscapes of Georgia, the reduction of forest cover is considerable, while in some landscapes, the cover has been preserved in their original nature. Georgia is one of the countries where the large masses of pristine landscapes have been preserved fairly well, and this is particularly evident in the mountainous areas. The reduction of forest cover in the history has been significant. Many historical sources refer to great forest areas on the territory of Georgia, which are currently meadows, steppes, shrubs, forest derivatives, or settlements. This fact is proved by the names of many places, fragments of forest, presence of forest soil horizons, etc. The decisive role in the disappearance of significant woodlands in Georgia was played by the change of environmental conditions due to climate change and the anthropogenic impacts.

Identifying the degree of reduction of the forest areas and phytomass reserves in the course of history is rather a difficult task. We used a landscape approach for this purpose and compared two maps: The Map of the rehabilitated vegetation in Georgia (Gunia 2011), showing the distribution of the principal plant communities in the past, i.e., before the times, when man significantly changed the environment of Georgia. We also used the physical map (1:500,000; Beruchashvili 1998), reflecting the modern picture of the distribution and the main types of vertical structures of the natural-territorial complexes. The landscape approach is based on the idea that every plant community on the map of the rehabilitated vegetation of Georgia is to be attributed to a specific type of landscape and certain type of the vertical structure of a natural-territorial complex. This allows comparing the areas of forest landscapes and phytomass reserves in different time intervals and identifying the degree of their reduction with a single methodology.

The studies have shown that the reduction in the forest areas in Georgia has been occurring since the ancient times, and humans have played a significant role (Atlas

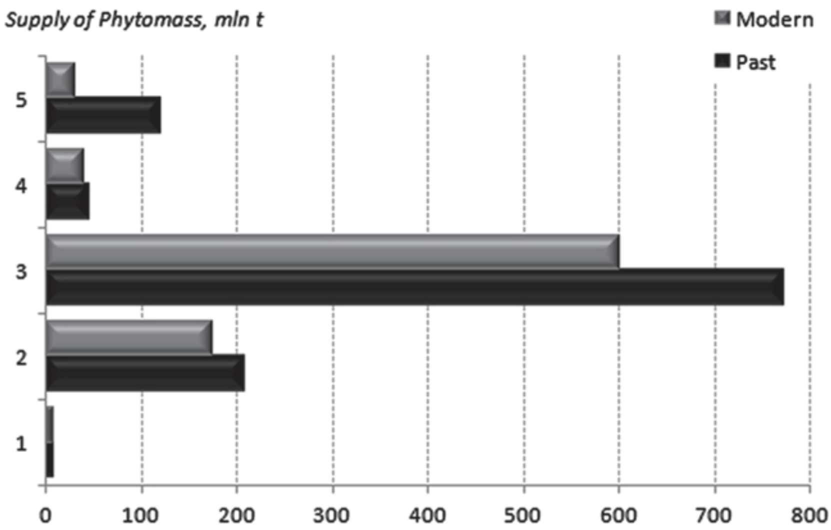

Fig. 10.6 Supply of phytomass in different mountain landscapes of Georgia

of Georgia 2012; Beritashvili et al. 2010). This corresponds to the global trend of deforestation in the same period (Ozturk et al. 1997, 1998). However, for centuries, shrinking of forest areas in Georgia is comparatively less than the same indicator at the global scale. This is quite a high indicator, if comparing this data with the degree of reduction of forest areas over the whole surface of the earth in the last 100,000 years (Georgia 2004; Beritashvili et al. 2010;Tsomaia 2010; Atlas of Georgia 2012).

The mountain landscapes of Georgia occupy large areas (46,000 km^2). They contain the largest amount of phytomass—795,300,000 t (61 % of the total phytomass reserve of Georgia; Fig. 10.6). With this indicator, the middle-forest landscapes are particularly significant, at present having accumulated 608.3 million t of phytomass, with the degree of reduction of only 14 %, while over the plain and higher-mountain landscapes, the same value is 46 and 75 %, respectively. A relatively large stock of phytomass is accumulated in West Georgia, as compared to East Georgia.

From the human historical point of view, the forest areas of Georgia have decreased by almost one third. Nearly 12000 km^2 of forest area has been destroyed. Anthropogenically, the least effected among the landscapes of Georgia are mountain landscapes, with minimum impacts observed in high-mountain subnival and nival landscapes. Similarly, middle-mountain forest landscapes have been subject to relatively less changes, as they are located in complex orographic conditions (over the steep and averagely inclined slopes).

Undisputedly, only some parts of the landscapes are subject to the anthropogenic transformations. In some cases, it occurs at the level of small morphological units, while at other times, they take place at the level of larger classification units. However, we share the view that the largest classification units of the landscapes (classes, subclasses, types, subtypes, varieties) are not subject to the anthropogenic transformation. One can only speak of full or significant transformation of some component of a landscape, for instance, the land cover at the level of the highest classification unit. The important fact of the various anthropogenic factors occurring with different intensity in different regions of Georgia and the natural systems reacting to these effects should be taken into account differently. This is why the differential change in the same landscape can be the case, what makes it difficult to group them in this regard and to fix exactly the taxonomic level, at which the anthropogenic transformation of landscapes of Georgia takes place.

At the level of morphological units, the anthropogenic transformations take place mostly and more intensely in the middle-forest landscapes of Georgia. Such landscapes occupy the largest area (56 %) of the forest's natural-territorial complexes, with 61 % of the total phytomass reserves of Georgia accumulated here. It is these landscapes covered with significant areas of pristine forests. These forest masses have been preserved owing to the complex orographic conditions hindering the expansion of settlements or economic activities, and, for many years, these forests were kept as environmental protection and environmental restoration areas, according to the effective Forest Code. All were assigned to the category I, with the commercial and clear-cutting of forests extremely limited. This Code regulated the questions of use, protection and restoration, and state registration of forest resources and questions of responsibility for violating the forest legislation, and included a clear indication of the most forests of Georgia attributing to the first category, i.e., assigning the forests an environmental protection function. This meant that any commercial cut down of forests was forbidden, and only selective sanitary cut down (of old, withered, or hollow trees) was allowed. Clear-cutting and thinning out the forests over the slopes was totally forbidden, only use was limited, and annual amount of growth of timber never caused any reduction in the forest areas. The area of exploitation of forests was only 10000 ha with the total timber reserve of 1 million m^3 (Beruchashvili 1979). Modern legislative standards envisage the same restrictions and permits. Accordingly, the average mountain forest landscapes, as compared to the high-mountain subalpine or alpine landscapes, have their original appearance preserved better to date.

The situation is quite different with lower-mountain forest landscapes of Georgia. In some cases, the anthropogenic transformation of the phytogenous structure of the landscapes is expressed at the level of morphological units, while other times, it is expressed at the level of the landscape species. The latter is especially evident in the settled mountain basins, in the lower-mountain forest landscapes of the eastern part of the Greater and Lesser Caucasus (with the exception of the Great Caucasus of Kakheti). Here, the natural vegetation consists of hornbeam, oak, hornbeam, oak-oriental hornbeam, oak, and, in particular, beech forests, with their area significantly reduced, while owing to the changed natural-territorial complexes, it accounts for 80–85 % of the total area of these landscapes.

The high-mountain subalpine or alpine landscapes are subject to intense grazing. Particularly negative consequences are observed with the destruction of a grass cover in both the subalpine and alpine landscapes as well as in the steppes of the plains and foothills, which are used as pastures and hayfields. Stopping the use of winter pastures in Dagestan (Kizlyar steppe, Russia) has caused, on the one hand, the decrease of the smalls, and on the other hand, an overload of the pastures on the territory of Georgia, which, in turn, contributed to the acceleration of aridity and resulted in the increased land area subject to desertification, particularly in East Georgia.

Depending on the degree of anthropogenic transformation, the landscapes of Georgia are grouped in six categories (Nikolashvili 2008), with no categories of strongly or significantly transformed landscapes found in the mountains. *Moderately altered landscapes* with low population density (50–100 people/km^2), 20–40 % of the agricultural plots of fields of the total landscape area and a small number of industrial enterprises mostly occupy lower-mountain forest landscapes. *Slightly altered landscapes* with very low population density (less than 50 people/km^2), less than 20 % of the total agricultural plots of field of the total landscape area and small number of industrial enterprises incorporate semiarid and arid landscapes of east Georgia, as well as middle-forest and higher-mountain forest landscapes of Georgia. This category also incorporates much of the high-mountainous subalpine and alpine landscapes. *Virtually unchanged landscapes* occupy only 6 % of the total area of the territory of Georgia. These include high-mountain subnival and nival landscapes.

10.3.8 Dynamics of Air Temperature

The analysis of many-year data has evidenced significant changes in air temperature expressed differently in different landscapes of Georgia, including high-mountain ecosystems. Such a difference occurs depending on average multi-year air temperature, maximum temperature, duration of cold and warm periods, and other parameters. It should be mentioned that trend of change of annual average air temperature is very complex and diverse especially in high-mountain ecosystems. These differences are determined by inequalities of high-mountain ecosystems of western and eastern parts of Great Caucasus and Lesser Caucasus, also Javakheti Volcanic Plateau.

It should be noted that the change in air temperature is not a one-sided trend. The multiyear analysis of the data shows that the average multiyear air temperature grow or reduce at different times, but the general trend is anyway clear. In particular, this parameter grew by 0.2 °C during the years 1990–2006.

The mountain landscapes are characterized by cold and continuous winter and cool, humid, and short summer. The annual average temperature is −8 to −10 °C and less. During the period from 1955 to 2008, in Georgia, the annual average air temperature increased by 0.2–0.6 °C (Elizbarashvili et al. 2000). Obviously, the increasing trend is evident in both East and West Georgia. Due to the various trends in different landscapes, the real situation must be characterized in detail. Data analysis shows a relatively increasing trend in mountainous, subtropical, semiarid, and arid landscapes extending up to a height of 900–1000 m asl in extreme southeast part of Georgia with open woodland, steppe, and poly-desert vegetation. This is a characteristic found mostly during the cold period of the year. On the contrary, in the warm period of the year, there is either a slight decrease in the temperature or no change at all. So, it can be mentioned that the climate becomes more continental in mountainous, subtropical, semiarid, and arid landscapes.

To some extent, a different situation is observed in mountainous landscapes of West Georgia. Here, the abovementioned trend is less expressed, but not unimportant. In recent years, here, the average annual temperature has increased by 0.2–0.3 °C.

In high-mountain landscapes with alpine and subalpine thickets, shrubs, and meadows, at altitudes above 2000–2500 m, we come across temperate and humid climate with cool summer and cold winter. In July, the average temperature is about 16.7 °C, with an absolute minimum between −30 and −35 °C. In recent years, the average annual air temperature in these landscapes has increased by 0.4 °C. The duration of plant vegetation continues from the beginning of April to the end of September. The lowest average temperate is fixed in December and January (−3, −5 °C), absolute temperature is −25 or −28 °C.

In mountainous thermo-moderate, semihumid, and semiarid landscapes of South Georgia, in fact, the average air temperature in mountainous thermo-moderate, semihumid, and semiarid landscapes of South Georgia has not changed, but decreased slightly in recent decades. This is a clear indication of the minor outcome of the impact of the climate change on the temperature regime over the given landscapes.

10.3.9 Dynamics of Precipitation

It is considered that the change of atmospheric precipitations will be more important than that of air temperature in Georgia. Therefore, in this respect, the evaluation of this indicator is particularly important. In almost every landscape of Georgia, the annual precipitation is varying according to different natural conditions. The differences are not connected to the distance from the sea, but the increase in altitude, getting some territory under a rain shadow, local peculiarities of landforms, etc. Besides some exceptions, the gradual decrease of atmospheric precipitations and humidity takes place from west to east, in compliance with the distances from the Black Sea. So, depending on the altitude and remoteness from the Black Sea, three district/subdistrict of climate are represented. The mountainous landscapes of West Georgia belong to the humid subtropical climatic district, while the mountainous landscapes of East Georgia are a part of moderate humid subtropical climatic district. In accordance with the annual precipitations, landscape area of West Georgia accounts for more than 1600 mm. The exceptions are the mountainous depressions, situated under the rain shadow, with amount of precipitation less than 900–1000 mm. The annual precipitation of mountainous landscapes of East Georgia is rather low and is less than 1200–1400 mm (with some exceptions). The mountainous landscapes of South Georgia enter in the composition of moderate humid subtropical climatic district as a transitional subdistrict to the dry subtropical climate. Here, annual precipitation is fluctuating between 450–700 mm (Atlas of Georgia 2012).

In the low-mountain and middle-mountain forest landscapes of West Georgia, a slight increase in atmospheric precipitation takes place, which is far less than in the Colchic valley. As for the low-mountain and middle-mountain forest landscapes of East Georgia, mostly a decreasing trend in the precipitation is characteristic.

Unlike air temperature, the impact of the climate change on the landscapes in South Georgia is much stronger. The period from 1970–1980s to 2006 was marked with the trend of reducing atmospheric precipitations making annual 8 mm on average. Since 1990, this trend has remained unchanged, but the winter precipitations have increased, while the precipitations in other seasons have reduced (Beritashvili et al. 2010). This evidences that the trend of reduction of atmospheric precipitations in the vegetation period will have a much negative impact on the bio-productivity of the plants.

There are evident differences according to separate monthly average indicators. In particular, the identical trends of precipitation are not a characteristic of every month of the year. Besides, the amount of days with short and abundant precipitations has increased. This regime takes place in both East and West Georgia and makes good preconditions for formation of natural catastrophes such as floods, flash floods, mudflows, and landslides.

10.3.10 Dynamics of Droughts

One of the expressive parameter of climate change is duration and intensity of drought. But it is especially a character for the plain landscapes of East Georgia with negative influence on the productivity of vegetation, agriculture and pastures, amount of water resources, and soil productivity. Due to intensive anthropogenic pressure, timber logging, and overgrazing, as in other parts of the Black Sea region (Ozturk et al. 1997, 1998, 2010), certain places of these landscapes are degraded. This phenomenon is less characteristic for mountainous landscapes of Georgia, but it cannot be excluded. In recent years, the droughts have occurred in mountainous thermo-moderate, semihumid, and semiarid landscapes with open woodlands, shrubs, steppe and semidesert vegetation, which is stretched in southeastern part of Georgia. During 1952–2011, the duration of droughts has increased. In comparison to 1969–75 and 1998–2011,we can see that the amount of drought days has almost doubled, making a serious problem for summer pastures.

It is assumed that a drought period of less than 20 days in east Georgia (with the atmospheric precipitations not exceeding 5 mm, maximum air temperature of 28 °C and average daily humidity of 50 %; Elizbarashvili et al. 2000) has no destructive impact on agricultural crops. Therefore, the conditions of more than 20 days were analyzed, and the analysis of the meteorological data evidences evaluated. The number of such days has grown both generally and with almost all landscapes considered above.

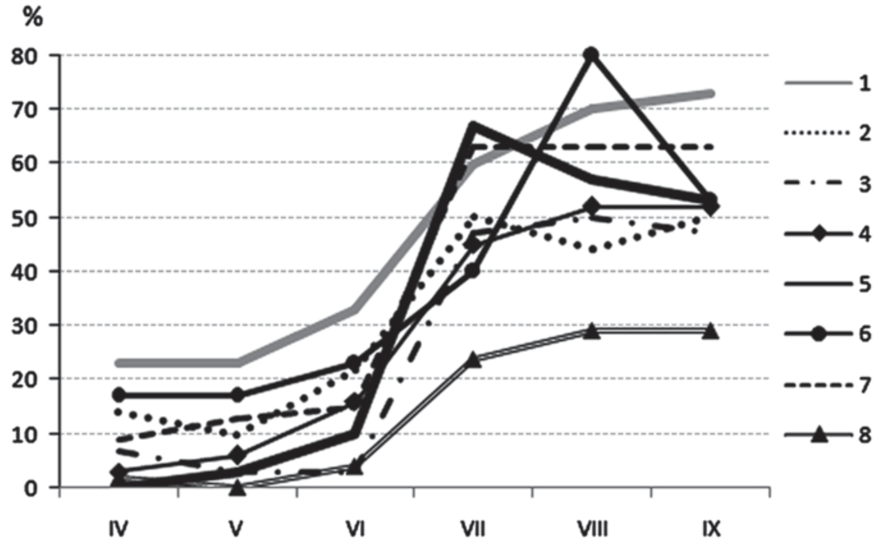

Fig. 10.7 Repetition of droughts according to months. *Landscapes genera*: *1* Low mountain arid-denudational landscapes with "shibliak," partially steppes and "phrygana" (extreme southeast part of Georgia); *2* Low-mountain erosional–denudational landscapes with hornbeam-oak, partially with chestnut forest (Kakhetian Great Caucasus); *3* Low-mountain erosional–denudational landscapes wich oak and hornbeam-oak forest (Lesser Caucasus); *4* Low-mountain erosional–denudational landscape with hornbeam-oak (*Carpinus orientalis*) and oak forests and "shibliak" (Great Caucasus); *5* Low-mountain erosional–accumulativr landscapes with hornbeam-oak (*Quercus iberica*), oak-pine and pine (*Pinus caucasica*), partially with "shibliak" (Bordjomi valley); *6* Middle-mountain erozional-denudational landscapes with beech, partially pine (*Pinus caucasica*) forest; *7* Mountainous depression denudational–erosional landscapes with steppes, "frigana," "shibliak," partially mountainous semidesert vegetation (Akhaltsikhe depression); *8* Highland volcanic plateau landscapes with steppes and meadows–steppes (Javakheti volcanic plateau).

Frequency of droughts differs much in different areas of Georgia. Dry months last from 1 to 6 months. The duration of dry months varies greatly in different regions of Georgia (Varazanashvili and Elizbarashvili 2008; Begalishvili et al. 2009).

Despite the differences, one common peculiarity comes to the forefront during the observations in 1965–2005. In particular, the reoccurrence of droughts increases in the second half of the vegetation period, from the second half of June (Fig. 10.7). The least reoccurrence of droughts is fixed over Javakheti Volcanic Plateaus, while the highest indicator is fixed with semihumid and semiarid landscapes of extreme southwestern part of East Georgia. So, likelihood of droughts is mostly expected from July to September and continues during 3 months.

Droughts are rarer, but, nevertheless, must be considered in the mountain basins of West Georgia. In terms of little atmospheric precipitations, the droughts reduce the bio-productivity of agricultural crops and cause certain problems for intensely cultivated agricultural lands and agriculture generally.

10.3.11 Dynamics of Winds

The wind intensity and direction on the territory of Georgia is associated with the impact of the western branch of Siberian anticyclone resulting in high frequency of strong eastern winds in West Georgia and dominating northwestern winds in East Georgia in terms of the Black Sea high pressure. The average wind velocity reaches its maximum in subnival and nival belts of the high-mountainous zone, across Likhi Ridge, in the crest zone of Samsari and Javakheti ridges.

Many-year studies evidence that in the cold period, the frequency of the impact of arctic anticyclone has decreased by 25–33 % in the twentieth century, a deviation from its mean value what must have been followed by intensified west processes (Beritashvili et al. 2010).

10.3.12 Dynamics of Geo-Conditions

The studies on the natural-territorial complexes is much important in predicting their dynamics. If a change in the physical–geographic parameters, including landscape–geophysical parameters in different time intervals is fixed, one can consider the expected trends developing in the natural-territorial complexes, and their reaction to some or other natural or anthropogenic impacts.

The study of the dynamics of the natural-territorial complexes is based on the analysis of many-year average data of meteorological parameters, with average daily air temperature, amount of atmospheric precipitations, strength of a snow cover, etc., being the most important ones. Based on these parameters, the changes in the vertical structure (phytogenic, nival) of the natural-territorial complexes are identified. In order to study the dynamics of the states of all landscapes of Georgia, first of all, it is necessary to link the weather stations and posts to the landscapes. This can be easily done based on the geoinformation systems.

During the said study, it is important to fix not only the average many-year dynamics of the states of the natural-territorial complexes but also their dynamics in different years. This would allow identifying the trends developed in the natural-territorial complexes and answer all the questions having constructive importance—the activation of which natural or natural-anthropogenic processes (climate warming, desertification) does it evidence? In which landscapes are these processes most clear and which landscapes face the threat of basic changes? How much close are the recent dynamics of the states of the natural-territorial complexes to the average many-year dynamics, or how much do they deviate from it? As a result (based on the concepts method), the kinds of expected changes, depending on the landscape–geophysical properties (amount of geo-masses, strength and complexity of a vertical structure), can be identified. This, in the final run, will allow identifying the trends of changes of the resource potential of the landscapes and making forecasts.

The landscapes of Georgia differ with their set of geo-states and frequency of their reoccurrence. There are approximately 25 types of geo-states of landscapes in the country, with 13 of them considered as dominant, as they occur annually in most of the landscapes. The longest is the stabilization of the winter structure, followed by the geo-states of stabilization of summer phytogenous structure.

As the geo-states change, the soil productive moisture and consequently, the process of accumulation of phyto-resources of the plants changes. The interval of change of soil productive moisture is quite long depending on the landscapes, and such a change is observed even in the period of establishment of the same geo-state. This is associated with the duration of the current geo-state, or to be more exact, how long it has been from its establishment. If humid geo-states last for several days (in the first case) or several weeks (in the second case), the productive moisture is quite high. This means that there are conditions established favorable for developing phyto-resources. As the coincidence of pluvial geo-states grows, the indicator of productive geo-states grows and reaches high values in the upper-soil layer. As for the geo-state of the winter nival structure, during it the amount of soil productive humidity is low.

The amount of phytomass in the area with the meadow–steppes, steppes, and sparse arid forests of East Georgia (over the inclined slopes) varies in quite large limits: In terms of humid microthermal geo-states, its average amount is 20–120 g/m^2, while in case of humid geo-state of complication of a phytogenous structure, it is 120–160 g/m^2. It is in terms of the two geo-states when the high value of bio-productivity is fixed. If the trend of reduction of the duration of these geo-states is observed at the expense of semiarid or arid growth, then we must assume that this process will be less intense. Consequently, the trend of reduction of bio-productivity is expected in the mentioned landscapes. If considering that a large area of the said landscapes is occupied by agricultural plots with plant growing (grain growing, fruit growing, vine growing) as a dominant branch, it will become clear how much it may hamper the economic development of the country.

A similar trend is observed in the high-mountain subalpine landscapes of East Georgia with meadow vegetation. This trend is particularly evident over the slopes of a southern exposition and in terms of significant anthropogenic impact. In particular, phytomasses originate and stabilize as the humid geo-states (nine types of them). Maximum phytomass (450–550 g/cm^2) is observed during the geo-states of summer phytogenous stabilization with their duration characterized by slightly expressed increasing dynamics. At a single glance, this must be the evidence of the conditions favorable for phyto-formation; however, if considering that the duration of simplification of humid phytogenous structure is increased and duration of pluvial states is reduced, it becomes clear that the process of phyto-origination in these landscapes will be relatively "hampered."

10.3.13 Evaluation of Landscape Sensitivity to Climate Change and Classification

A certain part of Georgia occupies an arid or semiarid zone. If considering the landscapes of Georgia on the background of the Caucasus, we will see that aridity is the least common feature of our country. However, this does not mean that there are no

Table 10.2 Classification of landscapes according to sensitivity to climate change

Degree of sensitivity	Number of landscapes genera	Number of types of NTCs	Area (1000 km^2)	Supply of phytomas (million tons)
Very high sensitive	8	16	6.740	8.1
High sensitive	17	22	21.513	72.3
Moderate sensitive	5	12	3.248	40.4
Low sensitive	5	13	4.872	166.9
Very low sensitive	13	14	15.850	323.9
Total	48	–	51.223	3526.7

problems of droughts or aridization in Georgia. As the scientists think, the natural factors promoting aridization on the background of global warming are intensified, and, as a result, the natural aridity in the Caucasus (including Georgia) has increased. This is particularly obvious in the arid and semiarid zones of the country. However, the literary sources mention the appearance of different xerophilous plant species at the locations with no such species in the past (over the cliffy massifs in Ajara and Abkhazia, in a dune zone). As far back as in the 1940s, O. Yaroshenko, a researcher of the flora in the Caucasus, talked about the increased continentality of the climate over the Lesser Caucasus and Armenian Plateau, and its influence on the vegetation cover. Such areas can be considered particularly sensitive to the climate change. This is evidenced by frequent droughts taking place in recent years on the territory of Georgia.

The landscapes of Georgia can be divided into five categories: much vulnerable, vulnerable, moderately vulnerable, slightly vulnerable, and insignificantly vulnerable (Table 10.2).

The much vulnerable mountain landscapes incorporate high-mountain subnival and nival, as well as a part of the upper-mountain forest and high-mountain alpine landscapes of East Georgia. The total area of the given category is 6700 km^2 making 9.6 % of the total territory of Georgia.

The impact of the climate change on water resources is seen in many aspects; first, there is a drawback in glaciers, change in the regime of atmospheric precipitations, and change of the water balance in watercourses. The drawback of glaciers is most important. The comparison of many-year climatic indicators and topographic maps of different years has revealed the facts of drawbacks of many glaciers across the Great Caucasus.

High-mountain nival and subnival landscapes must be considered as the most sensitive to climate change. A number of scientific works (Beritashvili et al. 2010; GNC 1999; Ketskhoveli 1959) mention the fact of drawback of glaciers (Fig. 10.8). As it becomes clear, until the 1980s, a reducing trend was observed with most of the glaciers of Georgia; however, in some cases, advancement was fixed as well.

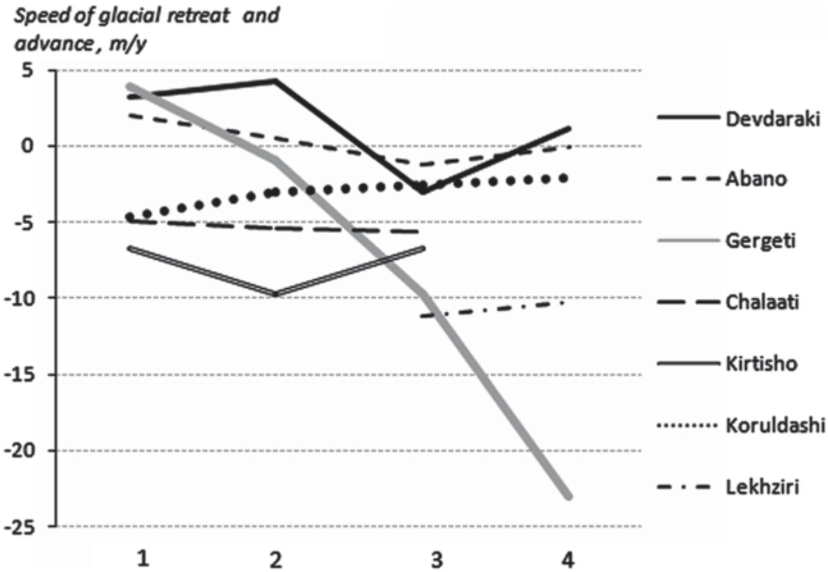

Fig. 10.8 Dynamics of glaciers of Georgia during 1965–1990. Periods: 1—1965/1966–1972/1973; 2—1973–1977/1979; 3—1977/1978–1983/1985; 1983/1985–1990

Even the advancement of Devdarak glacier has changed for drawback since 2000. Particularly, high drawback indicator was fixed with Gergeti glacier in 1985–1990 amounting to 23 m annually (Beritashvili et al. 2010).

The dynamics of nine selected glaciers at the central part of Great Caucasus during 1964–1980 has shown a retreat and advance episodes with mean rates correspondingly 6.1 and 3.4 m/year. But in the following years the absolute majority of glaciers exhibited only the retreat at the average rate of 11 m/year. Eventually, the satellite imagery data of 1985–2000 period shows that the mean retreat rate of glaciers in this region equals to about 8 m/year at the background of an annual increase of air temperature by 0.1 °C in the ablation season temperature (Beritashvili et al. 2010).

During 1965–1980, the reduction of the area of glaciers on the territory of Georgia was 17 % (from 616 to 511 km^2). Based on the analysis of the data of 1890 and 1965, the scientists assumed that the annual loss of the glaciers on the Great Caucasus was equivalent to an area of 7.5 km^2 (Neidze 2004). This process continued further. In 1900–1970, the average speed of drawback of the absolute majority of the glaciers of the Great Caucasus was 11.8 m annually (Ketskhoveli 1959; GNC 1999).

The drawback of the glaciers was much influenced by the reduced amount of winter precipitations and increased liquid precipitations. Owing to such circumstances, the glacier pulsation is activated, and mudflow currents fall down. The drawback of glaciers is followed by the origination of glacial lakes and increased areas of morena talus which, in turn, is the precondition for the origin of new areas of vegetation groups.

As for the ecosystems of subnival landscapes, their high sensitivity to the climate change is associated with very low projection coverage of the vegetation cover making 20–40 % on average, and even 5–10 % at some locations. It is known that the ecosystems of great strength and diversity are particularly resistant to the natural and anthropogenic impacts, with subalpine landscapes hard to attribute to such a category. Therefore, one can talk about the low resistance of the latter to the expected changes.

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Highly sensitive landscapes are also semihumid and semiarid landscapes spread in the extreme southeastern part of East Georgia. A significant part of these landscapes is occupied by pastures with degraded steppe vegetation due to overgrazing. The degradation of the steppe vegetation growing in the pastures is followed by the dominance of the less productive semidesert vegetation. The effective measures to mitigate the vulnerability of pastures in these regions to the climate change are the irrigation of pastures and windbreak belts preventing the soil from drying out and protecting the ground against wind erosion. As is the case with forests, the mass ploughing of pastures without arranging the windbreak belts or irrigation system will significantly boost the vulnerability of these areas to the climate change.

Due to a number of natural peculiarities (high solar radiation, abundant atmospheric precipitations, high, though not very high air temperature, duration of the vegetation period, long-lasting humid state, large amount of humus), bio-productivity of *the high-mountain subalpine and alpine landscapes* meadows is high making 5–15 t/ha on average, with the annual growth of 3–4 t/ha. However, on the background of high anthropogenic transformation and climate change, they, are the most vulnerable landscapes, and at a very high risk. This impact may be less on the northern slopes and slightly inclined slopes with the northern exposition or in terms of minor anthropogenic transformation. In this respect, the maximum impact is expected on the moderately inclined slopes with a southern or southeastern exposition, where the bio-productivity is already low.

The *vulnerable mountain landscapes* incorporate 17 landscape species occupying a vast area (21.513 000 km^2) constituting the largest part of the territory of the country (72.3 %).

Dry periods are mainly common for the landscapes located in “rain shadows” in the high-mountain zone of West Georgia. Here, as compared to other landscapes of West Georgia, the amount of annual atmospheric precipitations is less (900 mm and less), when compared to 1956–1972, the period since 1991 has been marked by the trend of increased duration and frequency of droughts. One can assume that these landscapes are highly vulnerable which will presumably reduce the phyto-resources.

These two categories of landscapes form a special group of risk, and due to moisture deficit, reoccurrence of frequent and strong winds, increased intensity of erosion, anthropogenic load, and other factors, (with some exceptions) are prone to aridization, it will have a negative impact on the bio-productivity of the natural vegetation and agricultural crops. Their high sensitivity is evidenced by the duration of daily arid and semiarid states of the natural-territorial complexes making 20 % of a calendar year (Nikolaishvili 2009).

Moderately vulnerable mountain landscapes incorporate five species occupying quite a large area (3.248 000 km^2), but making only 4.7 % of the total area of the country.

Slightly vulnerable mountain landscapes incorporate five species only, while *insignificantly vulnerable mountain landscapes* incorporate 13 species only (7430 km^2). Out of mountain landscapes, the middle-mountain forest landscapes of West Georgia are found here (except for a karstic landscape, where limestone substrate, due to greater infiltration of moisture and loss, is more vulnerable). This is caused by many factors, in particular, abundant atmospheric precipitations, strong vegetation cover, high values of phytomass (300–500 t/ha and more), well-preserved original nature, and low degree of anthropogenic transformation of the area. The set of the said factors result in a relatively better resistance of the landscapes to the climate change. It is true that the given landscapes have complex orographic conditions, but the factors mentioned above play a limiting role in this respect. However, it should be mentioned that in terms of a strong anthropogenic impact, the existing degree of vulnerability will decrease, and some individual sites may turn to one of the most vulnerable landscapes. Therefore, protection and conservation of the middle-mountain forest landscapes and maintaining their environmental protection function is a much important task.

10.4 Conclusion

Out of the mountain landscapes, the *middle-mountain forest landscapes with beech and beech-dark coniferous forests* are distinguished for their highest resistance to the climate change, in West Georgia particularly.

The reality cannot be judged in a one-sided manner only, as there are two opposing trends to be considered: First, the decline in the number of population and formation of post-residential areas, what, in its turn, reduces the anthropogenic load on the landscapes, and second, the deterioration of the socioeconomic situation in the country since the 1900s, having boosted the impact on the forest landscapes by the population. In the final run, the climate change may cause changes in the structure and functioning of the landscapes of Georgia. Since the forest massifs are particularly well preserved, it is in the middle-mountain forest landscapes of Georgia, where the population receives the real profit from these forest resources. Therefore, these forests, now, and in terms of the same situation in the future, are subject to a high anthropogenic pressure apparently to be the case in the future. Given the fact that the middle-mountain forest landscapes are less resistant to the anthropogenic impacts, we must assume that some of their areas may face a great risk to develop geodynamic processes. Anyway, these changes will be observed only at the level of facies or tracts, the proportion of which (of the modified morphological units) will gradually increase. Since it is difficult to "localize" even small-scale destructions of geosystems and they can spread to great distances from the source of impact, the situation is quite alarming and the management of forest resources requires special attention.

In addition, the signs of the changing forest structure and, consequently, changing functioning of the forest is expected in some forest areas. This is particularly true with the forest massifs growing over the slopes of a southern exposition, particularly when they border semihumid ecosystems. Such ecosystems will face a particular hazard at the expense of the increased air temperature and decreased atmospheric precipitations.

The natural factors promoting aridization have intensified on the background of the climate change resulting in the increased natural aridity of individual landscapes of Georgia. This is particularly obvious in the arid and semiarid zones of the country. The landscapes of Georgia are under various impacts due to the global climatic change. The landscapes in semihumid, semiarid, or arid climatic conditions face the greatest risk. As the analysis of the landscape map of Georgia evidences, they occupy 15300 km^2, making 21.9 % of the total area of the country. It is clear that most of these landscapes are located in the lowland zone of east Georgia, and they occupy 11.1 % of the total area of the country. On the other hand, certain parts of the mountain landscapes also face hazards due to the scarce and incomplete data, the study of this problem is of particular importance.

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