ENHANCING FINANCIAL SUSTAINABILITY
OF THE PROTECTED AREAS SYSTEM IN GEORGIA

Climate Change Vulnerability Assessment and Preparation of Adaptation Plans for pilot target PAs in Georgia – Tusheti PAs, Kazbegi NP and Pshav-Khevsureti NP

Climate Change Vulnerability Assessment Report

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Acronyms and abbreviations

AP – Adaptation Planning
APA – Agency of Protected Areas
CC – Climate Change
CCVA – Climate Change Vulnerability Assessment
CMIP5 – Coupled Model Intercomparison Project, Phase 5
CMP – Conservation Measures Partnership
GDDP – Global Daily Downscaled Projections
GEF – Global Environment Facility
GLORIA – Global Observation Research Initiative in Alpine environments
IPCC – Inter-governmental Panel on Climate Change
MP – Management Plan
NEA – National Environmental Agency
NEX – NASA Earth Exchange
NP – National Park
PA – Protected Area
PAAP – Protected Areas Adaptation Plan
PL – Protected Landscape
RAC – Regional Advisory Councils
RCPs – Representative Concentration Pathways
SA – Scenario Axis
UNDP – United Nations Development Programme
UNFCCC – Unite Nations Framework Convention on Climate Change
VA – Vulnerability Assessment

Executive Summary

The Central Greater Caucasus at the border of Georgia and the Russian Federation is part of the “Caucasus” Global Biodiversity Hotspot, overlaps with multiple global, pan-European as well as eco-regional conservation priority areas, and harbours a broad range of endemic and globally threatened biodiversity. Georgia’s protected areas (PAs) in this region – Kazbegi National Park, Pshav-Khevsureti Protected Areas, and Tusheti Protected Areas (the target PAs) – therefore are important parts of its national PA system and crucially contribute to meeting national commitments under biodiversity-related multilateral environmental agreements. This requires effective management and protection against all anthropogenic threats.

According to Georgia’s Fourth National Communication to UNFCCC, the country is increasingly, but not uniformly affected by climate change. Because of its location and complex geography, climate change will have different impacts in the various regions of Georgia.

Climate change will also affect the ecosystems and other biodiversity of Georgia’s PAs, as well as the people living around them and the overall operations of PAs. PA management will increasingly need to respond to their vulnerability to the changing climate. So far, this need to adapt to climate change has not been systematically reflected in the management systems of any Georgian PAs. Therefore, the Caucasus Nature Fund has commissioned a climate change vulnerability assessment (CCVA) for the target PAs, along with PA-specific climate change adaptation plans (PAAPs).

To assess the climate change vulnerability of the target PAs, we first summarized their main conservation values and the non-climate change related threats affecting them, as documented in their recent management plans. We then conducted an analysis of available literature and data, as well as online workshops and individual meetings with the PA administrations, local stakeholders and national experts. There we collected information about already observed changes of the climate in the target region and the vulnerability of the non-living nature, ecosystems and biodiversity of the target areas as well as – in general terms – local people.

We then assessed the likely vulnerability of the conservation values of the target PAs to future projected climate change. Locally downscaled climate change projections for the 2021-2040 and 2061-2080 periods – with the 1985-2004 period as a baseline – were used to construct climate change scenarios, which between themselves represent the very likely course of the local climate for these future periods. We used local PA staffs’ and stakeholders’ opinions, expert appraisals, and a review of scientific literature on specific vulnerabilities of relevant ecosystem types and biota elsewhere to interpret these scenarios in terms of the likely vulnerability of ecosystems and other biodiversity of the target PAs to the projected climate change.

The climate of the target area has warmed at a rate comparable to the national and global averages since at least the early 20th Century, with most warming in summer and autumn and not enough data available to discern a clear and consistent altitudinal trend. Data availability for recent observed changes in precipitation was also too limited to allow robust conclusions, although there may have been a reduction of precipitation particularly in the eastern part of the target area.

The target area is undergoing rapid and accelerating de-glaciation in response to warming, Saharan dust deposition events and complex global atmospheric phenomena. This also negatively affects the discharge of glacier-fed streams and rivers, particularly of the Tergi catchment. The scarce and partly inconsistent available data on the frequency and severity of extreme geological events (landslides, mudflows, rockfalls/avalanches) do not prove any trend at a timescale relevant to climate change.

No continuous, consistent broad-scale biodiversity monitoring has been conducted in the target area over the last decades, which coincide with rapid political and socio-economic change and institutional discontinuities. Therefore, our assessment of observed past changes in the status of ecosystems and other biodiversity, which might have been attributed to climate change, relied on a few publications as well as diverse, partly inconsistent and contradictory observations by PA staff and local stakeholders, which typically referred to timescales of only 5-10 years. As a consequence, this analysis revealed few if any clear long-term changes of the state of ecosystems or biota that could be clearly attributed to climate change.

The climate change projections specifically for the target area reveal considerable uncertainty for future trends of both surface air temperature (average warming of only +0.2 dgr. To a considerable +2.5 dgr across seasons) and precipitation (average change -24% to +35% across seasons) for the near (2021-2040) future, and even more uncertainty for the distant future (2061-2080). These uncertainties were qualitatively similar across seasons, possibly reflecting the input variability from the different Representative Concentration Pathways used. We used these projections to construct four cross-seasonal climate change scenarios (“Sirimiri”, “Tropicana”, “Furnace” and “Crisp”).

Broadly in line with prior anecdotal observations and depending on specific scenarios, interpretation of the scenarios revealed multiple likely future climate change vulnerabilities of the ecosystems and biota of the target area. These included upwards shifts of vegetation belts, changes of vegetation (standing crop, productivity, composition and diversity) and habitat suitability for some species (groups), as well as some more specific likely vulnerabilities of mammals and avifauna. Some likely positive impacts of climate change on the viability of conservation values were also identified.

The vulnerability rating according to criteria, thresholds and procedures of the CMP Conservation Standards yielded generally highest direct vulnerabilities for ecosystems/habitats, which also point to high indirect vulnerabilities of the species (groups) depending on them. The vulnerability to climate change impacts tended to rate higher than that to non-climate threats at least for the medium and long term, but management interventions to address either should be prioritized based on a more in-depth assessment of relative vulnerability and cost/benefit ratio of interventions, for the specific conservation values in question.

Our vulnerability assessment method takes into account the existing uncertainty regarding the future climate and at the same time is broader – in terms of the coverage of multiple conservation values, climate change impacts, non-climate threats and climate change scenarios – than most purely academic approaches. This entails a certain level of both uncertainty and generalization in the vulnerability assessment. We nevertheless conclude that the methodology is suitable for informing climate sensitive management of the target PAs and of Georgian PAs in general. Specific adaptation interventions are identified and discussed in the PA-specific adaptation plans, which are a separate output of this assignment.

1 Introduction

1.1 Background

Climate change and human-induced biodiversity loss threaten to jointly degrade the ecological fabric of the planet and to make it increasingly uninhabitable for humans and wildlife alike in the long term. Both threats are linked inextricably – many forests, wetlands and marine ecosystems store carbon which otherwise would contribute to atmospheric greenhouse gases, but at the same time are themselves increasingly compromised by climate change (Korn et al. 2014). Because of the multiple interdependencies between climate change and biodiversity loss, there is a strong agreement that both threats need to be tackled jointly, and in a coordinated manner (see Pörtner et al. 2021 for a summary of the current state of this discucssion).

This agreement is starting to be translated into specific practical steps to meet the full potential of biodiversity and ecosystems for climate change mitigation and adaptation, and to fully take into account climate change impacts in biodiversity conservation practice (e. g. Arneth et al. 2020). With regard to protected areas, a number of approaches and methodologies for climate-sensible or "climate-smart" management have been developed over the last ten years and are being piloted and tested in various parts of the World (Atauri Mezquida et al. 2020, Duffield et al. 2021, Garstecki et al. 2020a, Stein et al. 2014), but to our knowledge not in the South Caucasus.

Georgia is of global importance for biodiversity conservation and increasingly affected by climate change. Climate change impacts on its biodiversity and protected areas have been discussed in the past, but – in spite of the realization that climate change cannot be ignored any longer – no systematic attempts make the management systems of Georgia's protected areas have been made.

The GEF/UNDP project "Enhancing financial sustainability of the Protected Areas (PA) system in Georgia" is a five-year "technical assistance" project financed by the GEF through the United Nations Development Programme (UNDP) in Georgia, with resources allocated from the GEF Operational Program for Biodiversity. The project objective is "To secure long-term financial sustainability and effective management to conserve globally significant biodiversity of target protected areas in Georgia". The ability of Georgian PAs to respond to climate change impacts on their biodiversity, but also ecosystem service provision and human wellbeing, falls within the "effective management" dimension of this objective.

1.2 Goal and objectives

The ultimate goal to which the assignment aims to contribute is that the mitigation and adaptation capacity of the ecosystems in Georgian PAs, as well as the resilience of communities and society directly and indirectly benefiting from ecosystem services provided by natural ecosystems in PAs, are increased.

To contribute to this goal, the Consultants (we) were tasked to develop and pilot – for the first time in Georgia – a participatory, science-based methodology for a PA climate change vulnerability assessment (CCVA) and PA-specific climate change adaptation planning (PAAPs) for three continuous individual PAs in the Central Greater Caucasus – namely Kazbegi National Park, Pshav-Khevsureti Protected Areas and Tusheti Protected Areas (Figure 1).

These shall later inform the integration of climate-informed management actions into the core management system of the target PAs and shall also serve as a first example for this type of assessment and planning for potential broader replication in Georgia and the region.

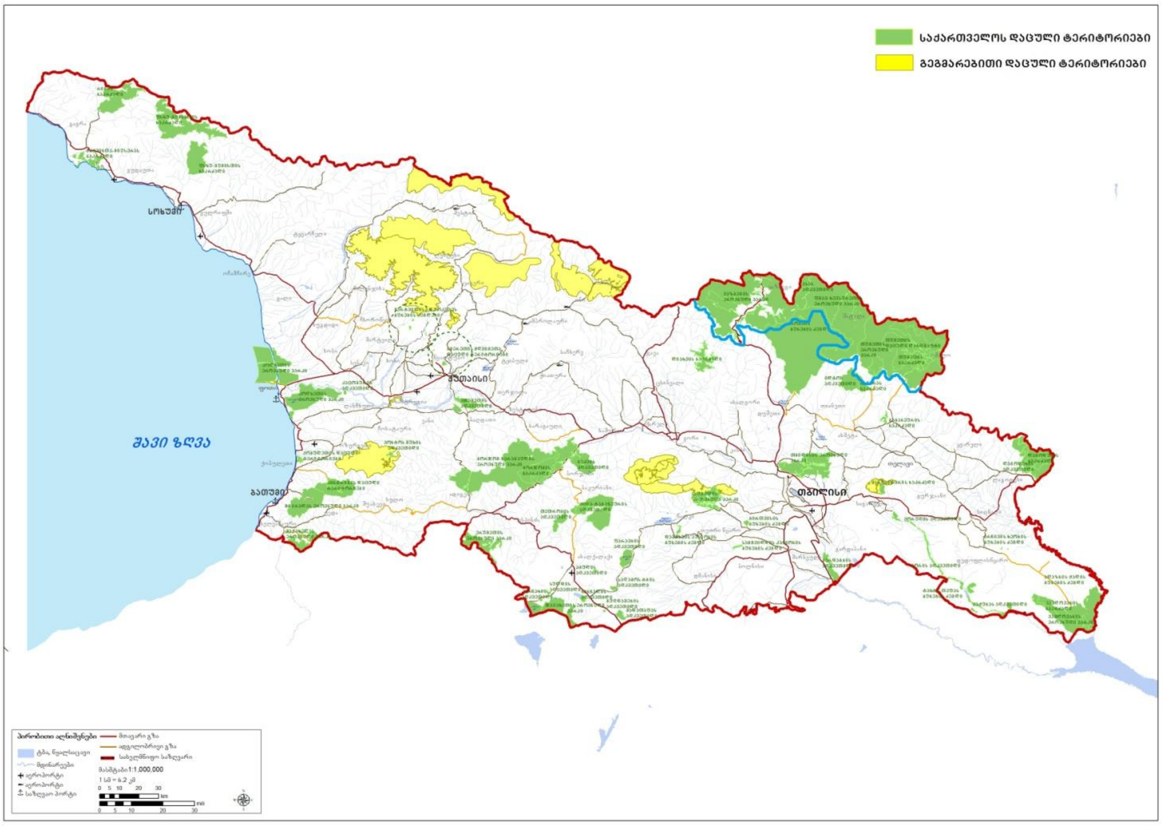


Figure 1. Map of the target area with the three target PAs (Source: APA).

1.3 Vulnerability concept

The concept of "climate change vulnerability" has been discussed intensively over the last 15 years. Our vulnerability assessment follows the more inclusive and broader understanding of "vulnerability" as defined by the Fourth IPCC Assessment report (IPCC 2007), rather than the narrower understanding of the Fifth IPCC Assessment Report (2014). This concept sees vulnerability as the result of exposure (type and magnitude of climate changes), as well as the sensitivity of biodiversity to it and biodiversity's adaptive capacity (Figure 2). These need to be assessed in a vulnerability assessment.

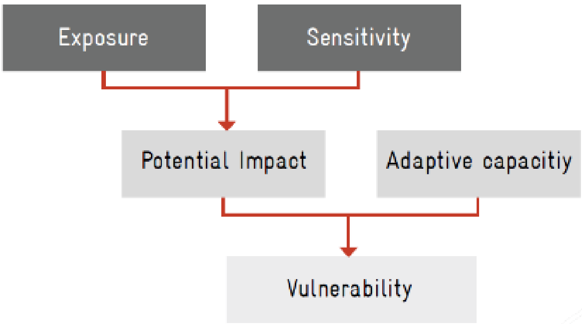


Figure 2. Understanding of "climate change vulnerability" according to the Fourth IPCC Assessment Report (IPCC 2007, see also Garstecki et al. 2020a).

2 Methodology

2.1 Stakeholder analysis and engagement

At the initial stage of the assignment, we tabulated important stakeholders and knowledge holders. We analyzed them in terms of their relevance to the assignment, by filtering recent PA Management Plan (MP) stakeholder analyses. Stakeholders included those represented in the Regional Advisory Councils (RACs) established for Kazbegi NP and Pshav-Khevsureti PAs, as well as Tusheti's local community councils ("Sabjeo"). Stakeholders and experts with specific experience or knowledge related to climate change, as well as general PA stakeholders at national and local level were considered. We presented and discussed the stakeholder engagement plan during the Inception Workshop on 7 October 2021 and incorporated the comments/suggestions received in the final version.

By following the agreed stakeholder engagement plan, we ensured the engagement and involvement of stakeholders and experts in the assessment process. We held individual meetings with various experts, as well as site workshops involving local stakeholders. All relevant stakeholders were involved in the Climate Change Vulnerability Assessment (CCVA) Workshops on 14-15 December 2021 and the Adaptation Planning (AP) Workshop on 24 February 2022.

2.2 Analysis of main conservation values and socio-economic values of the target PAs

The agreed main conservation values – i. e. the landscapes, ecosystems, habitats and populations the target PAs are designated to conserve – were taken from the recent draft MPs (SPPA 2019, SPPA 2020, CNF 2021, CNF 2022) of the four protected areas: Kazbegi NP, Pshav-Khevsureti PAs, Tusheti PAs and Tusheti PL. All four draft MPs define key biodiversity values, as well as attributes of state and current status, subject to available information. Besides the key biodiversity values, the MPs of Tusheti PAs and Tusheti PL identify socio-economic values. Additionally, in the draft MP of Tusheti PL historical-cultural values are identified. The socio-economic values are not defined as key values in the draft MPs of Kazbegi NP and Pshav-Khevsureti PAs, but those were identified as values during the site workshops together with PAs Administration staff, APA and local stakeholders.

2.3 Analysis of vulnerability to non-climate related threats

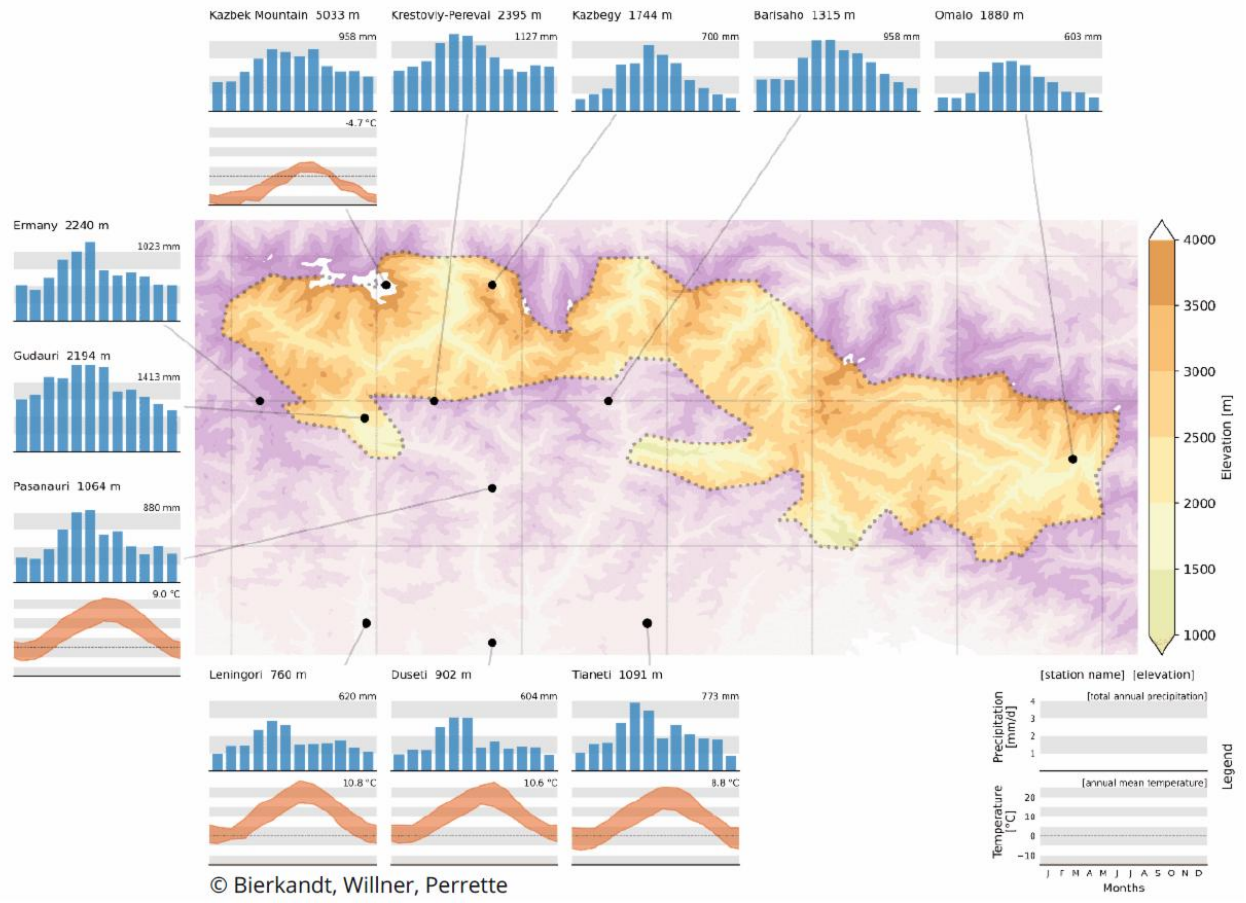
We took the non-climate related threats to the key biodiversity and socio-economic values from recent draft PA MPs. The MPs describe direct threats of the values, as well as their drivers and contributing factors. In case of Tusheti PAs and Tusheti PL, threats are rated, based on the combination of the CMP Conservation Standards and other algorithms.

2.4 Data compilation on observed climate change

Available information on observed climate trends in the target areas over the last 100 years is incomplete and patchily distributed. The target area has not been covered intensely by the National Environmental Agency, in terms of continuous gathering of weather data from meteorological stations (Box 1). While there are some meteorological data gathered by individual PA administrations, these are not sufficiently systematic and long-term to reveal any relevant trends.

Box 1. Summary of available observed weather data for the study area and its surroundings.

The below is an elevation profile of the project area (Copernicus Digital Elevation Model GLO-90) with climate diagrams of 11 observation stations within and in proximity of the project area for which data are internationally available (Global Historical Climatology Network - Daily (GHCN- Daily) Version 3). Climate diagrams show mean daily precipitation within a month (blue) in mm and the monthly average of daily maximum and minimum temperatures (red) in degree Celcius over a longer observation period (cf. table below). Precipitation values are presented for all 11 stations. Temperature data is very sparse, but values are given for 5 stations. The table below summarizes data availability. The background grid represents the resolution (approx. 25x25km) of the NEX- GDDP dataset, as used for climate scenarios. Meta data of observation data are found in the table below.



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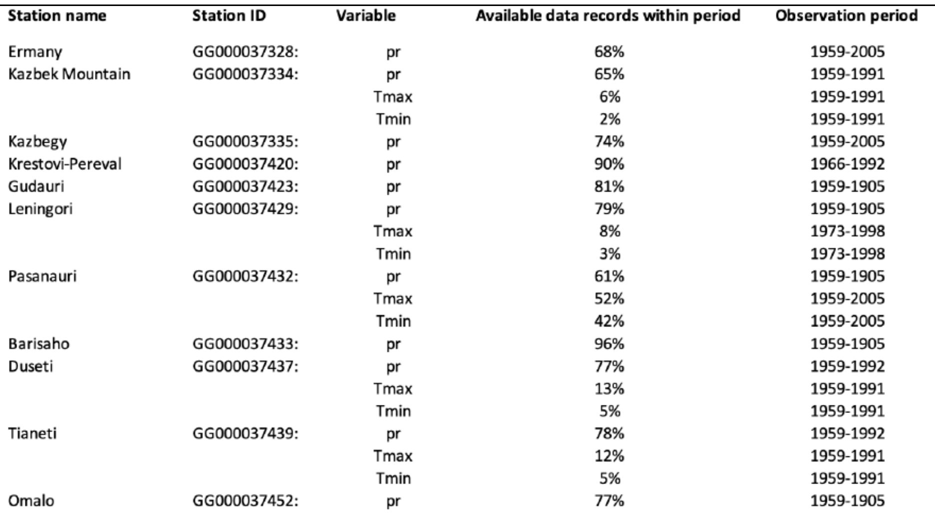


Station name	Station ID	Variable	Available data records within period	Observation period
Ermany	GG000037328:	pr	68%	1959-2005
Kazbek Mountain	GG000037334:	pr	65%	1959-1991
		Tmax	6%	1959-1991
		Tmin	2%	1959-1991
Kazbegy	GG000037335:	pr	74%	1959-2005
Krestovi-Pereval	GG000037420:	pr	90%	1966-1992
Gudauri	GG000037423:	pr	81%	1959-1905
Leningori	GG000037429:	pr	79%	1959-1905
		Tmax	8%	1973-1998
		Tmin	3%	1973-1998
Pasanauri	GG000037432:	pr	61%	1959-1905
		Tmax	52%	1959-2005
		Tmin	42%	1959-2005
Barisaho	GG000037433:	pr	96%	1959-1905
Duseti	GG000037437:	pr	77%	1959-1992
		Tmax	13%	1959-1991
		Tmin	5%	1959-1991
Tianeti	GG000037439:	pr	78%	1959-1992
		Tmax	12%	1959-1991
		Tmin	5%	1959-1991
Omalo	GG000037452:	pr	77%	1959-1905

Data provided by Bierkandt et al. (2021), as a bonus to climate projections. Spelling of place names according to Bierkandt et al.

In the absence of easily available systematic weather data for the target area, we compiled information on observed climate change there from publications (Tielidze 2016, Elizbarashvili et al. 2017). This was combined with a rapid appraisal of the limited (particularly for the recent past) available data from Omalo weather station, which was kindly provided by NEA.

The combination of literature and primary data allowed us to gain a general overview over recent past climate trends in the area of interest, which we consider sufficient for the purpose of this vulnerability assessment. The observed climate change was discussed with the Georgian climate experts, as well as during the stakeholder consultations with PA administrations and local community representatives.

2.5 Climate change projections specifically for target area

PA management planning – including the planning of its adaptation to climate change – is a forward-looking process, which has to inform future responses to future change. Therefore, we tasked a climate scientist to generate climate change projections specifically for the target area, according to the following procedure:

Ranges for changes of climate variables were based on simulations that were conducted from 2010 to 2014 within the framework of the Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Taylor et al. 2012). CMIP5 provides information on past, present and future climate for the 4th Assessment report of the Intergovernmental Panel on Climate Change (IPCC 2014). Considered data has been bias corrected with historical data and downscaled to 0.25 degrees geographic resolution. Here, 21 models were considered, and two different representative concentration pathways (RCPs) for future greenhouse gas emissions were taken into account to assess the range of potential climate change: RCP 4.5 and RCP 8.5 (van Vuuren et al. 2011). Data for the analysis was retrieved from NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) dataset (Thrasher et al. 2012).

The high emission pathway (RCP 8.5) represents a world without effective global climate action policy implementation, while the medium-low emission pathway RCP 4.5 assumes effective global climate action policy implementation. Within RCP 4.5, the global average temperature is expected to stabilize near 2100 at about 2.5 degrees above the pre-industrial temperature. In contrast, within RCP 8.5, the global average temperature is expected to increase by about 5 degrees by 2100 (relative to pre-industrial times) and continues to increase strongly after 2100. Only RCP 2.6, which was not considered in our projections, allows a stabilization below the 2-degree target.

The upper estimate of the range for each climate variable corresponds to the 95th percentile of all model results of the combined two emission pathways. The lower estimate of the range for each climate variable corresponds to the 5th percentile of all model results of the combined 2 emission pathways. The resulting range takes into account the differences between (a) the 2 emission pathways and (b) the model spread among each emission pathway. Under the assumption that (a) there are only 2 emission pathways (RCP 4.5 and RCP 8.5) and (b) that both pathways are equally likely the results correspond to the very likely range of possible future climates as defined by the IPCC (2014).

2.6 Elaboration and interpretation of climate change scenarios

To guide management responses of PAs, it is not sufficient to treat "climate change" in general terms. Rather, it is necessary to understand which specific climate variables of relevance to the biodiversity and socio-economic values of a target area are likely to change, and to what extent. This is the primary purpose of the use of climate change projections as described in Section 2.5 above.

There are cases where all climate change projections, irrespective of specific RCPs and models, all agree on those specific changes in relevant climate variables. More typically – particularly if various RCPs are involved – there is a range of projections for key variables, i.e., uncertainty about specific future climate trends. Where this uncertainty exists, it needs to be accounted for in vulnerability analysis and adaptation planning. This aims at devising interventions that will help adapt PA management in most plausible future climates and at the same time at avoiding maladaptation (i.e. interventions that aggravate rather than reduce climate change vulnerability) in all of them.

To account for the most consequential variability in the local climate projections, we used participatory scenario planning following the methodology of Garstecki et al. (2020b). In short, we plotted the ranges of possible (seasonal and cross-seasonal) trends for temperature and precipitation as produced by the projections (Table 1). We then discussed during the VA workshop which of the uncertainties expressed by these ranges would be most consequential for the management of the various main conservation values of the target PAs. This allowed us to base the prioritization of uncertainties to consider in adaptation planning not only on the projections alone, but also on the understanding of local stakeholders and experts of plausible vulnerabilities of the target systems to these variables.

Table 1. Generation of 12 scenario axes for seasonal climate variables in preparation for elaboration of climate change scenarios (SA.. scenario axis). T_{max} can be interpreted as daytime temperatures whereas T_{min} can be interpreted as night-time temperatures.

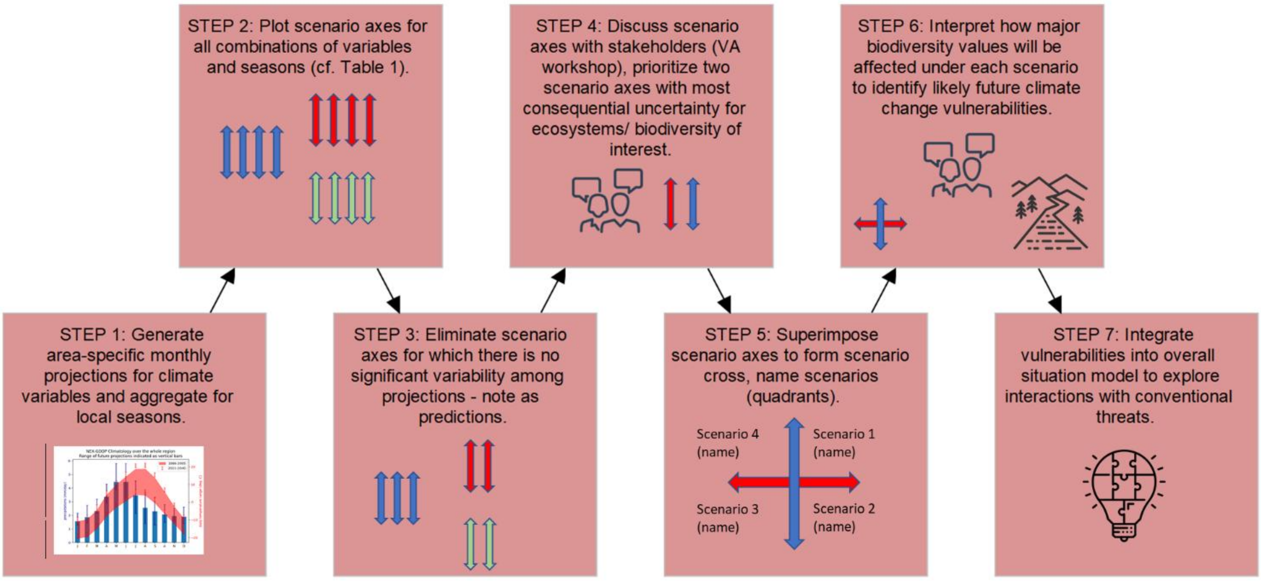
Change in variable/ season	**Spring**	**Summer**	**Autumn**	**Winter**
T_{max} (dgr.)	SA 1	SA 2	SA 3	SA 4
T_{min} (dgr.)	SA 5	SA 6	SA 7	SA 8
Precipitation (%)	SA 9	SA 10	SA 11	SA 12

To keep the number of scenarios to consider in adaptation planning tractable, we identified the two highest-priority variables and used them to construct scenario crosses with four quadrants (qualitative scenarios), also taking note of any trends in variables on which all projections agreed (Figure 1). These scenarios were then considered further in the vulnerability assessment and subsequently the adaptation planning.

To identify future vulnerabilities, we combined each climate scenario with what is known about observed climate change impacts on the main biodiversity values in the planning area and beyond (according to the scientific literature), to identify specific vulnerabilities. These were then described. The checklists of climate impacts, sensitivity factors and adaptive capacity factors from international good practice guidelines[1] were subsequently used to refine this participatory analysis at the vulnerability assessment workshop.

2.7 Prioritization of climate change vulnerabilities

We assessed and prioritized the importance of the identified climate change vulnerabilities based on the criteria of likely exposure (extent in CS terms), sensitivity (severity in CS terms) and adaptive capacity of the biodiversity values concerned, broadly following the approach of Garstecki et al. (2020a). We used the conservation management software Miradi including its thresholds and roll-up algorithms to rate all relevant combinations between impacts/threats and conservation values, and to estimate overall vulnerabilities of values (across threats/climate change impacts) and of threats/impacts (across values). We also compared the relative importance of climate change vulnerabilities to that of the vulnerability to conventional threats, to inform a subsequent discussion of the relative importance of managing climate change vulnerabilities versus conventional threats, at various timescales.



STEP 1: Generate area-specific monthly projections for climate variables and aggregate for local seasons.

STEP 2: Plot scenario axes for all combinations of variables and seasons (cf. Table 1).

STEP 3: Eliminate scenario axes for which there is no significant variability among projections - note as predictions.

STEP 4: Discuss scenario axes with stakeholders (VA workshop), prioritize two scenario axes with most consequential uncertainty for ecosystems/ biodiversity of interest.

STEP 5: Superimpose scenario axes to form scenario cross, name scenarios (quadrants).

STEP 6: Interpret how major biodiversity values will be affected under each scenario to identify likely future climate change vulnerabilities.

STEP 7: Integrate vulnerabilities into overall situation model to explore interactions with conventional threats.

Figure 3. Generation and interpretation of climate change scenarios derived from climate change projections.

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[1] e. g. Belokurov et al. (2016), Tables 6/7, Gross et al. (2016), Avdani (2014)

3 Results

3.1 Conservation values of the target PAs and their status

The main conservation values of the target PAs are defined in the recent draft MPs of four protected areas, i. e., Kazbegi NP, Pshav-Khevsureti PAs, Tusheti PAs and Tusheti PL.

The main natural values of all four PAs can be broadly summarized as (1) forest ecosystems, (2) alpine and subalpine grassland ecosystems, (3) threatened and/or endemic species or species groups (e.g. ungulates, carnivores, raptors, galliforms, herpetofauna) with their habitats, and (4) freshwater ecosystems including mountain bogs. In addition, local agro-biodiversity is of high value in Tusheti, as well as socio-economic values (e.g. Tush nomadic sheep breeding and traditional pasture practices, traditional products). The summarised biodiversity values and socio-economic values (e. g., nomadic sheep breeding and traditional pasture practices, traditional products) of the target PAs are given in the 2. For this assignment the vulnerability of non-living natural monuments of Kazbegi NP as well as historical-cultural values indentified for Tusheti PL were not considered, as this would have required a completely different methodology and the living natural values are likely to be more vulnerable to climate change. Socio-economic values are discussed in chapter 3.2.

The state attributes for each key biodiversity values are defined in the MPs of the corresponding PAs, along with information about the current state to the extent available. We have complemented this with additional updated information from recent studies and documents, e. g. the Forest Management Plan for Pshav-Khevsureti PAs (M3 2019), Pasture Management Plan for Pshav-Khavsureti PAs (Gebhardt 2019), and Biodiversity Monitoring in Selected Protected Areas (NACRES 2020).

All PAs lack data and information about the current status of some of their main biodiversity values. In order to fully understand their status and hence climate change vulnerability, additional research as outlined in their MPs will be necessary in the future.

We noted that some species - raptors in Kazbegi NP, galifforms in Tusheti PL - which might occur in protected areas, are not defined as values of those PAs. The populations of galliforms might not be properly represented within the boundaries of the Tusheti PL, and in case of Kazbegi, the raptors occur in the area, but were not selected as conservation values because of the limited number of values to be identified.

Table 2. Main biodiversity values of target PAs identified in the respective draft MPs.

Biodiversity Conservation Values of PAs			
Kazbegi NP	**Pshav-Khevsureti PAs**	**Tusheti PAs**	**Tusheti PL**
Forest			
1. Birch forests 2. Pine forests	1. Sub-alpine forests and shrubs 2. Mixed, coniferous and deciduous forest 3. Riparian forests	High mountain and sub-alpine forest	High mountain and sub-alpine forest
Alpine and sub-alpine grasslands			

Sub-alpine and alpine meadows	High-mountain meadows and alpine carpets	Sub-alpine and alpine meadows	Sub-alpine and alpine meadows
High mountain ecosystems	**Rock-scree habitats**	-	-
-	**-**	**High mountain Bogs**	**High mountain Bogs**
-	**Rivers and streams**	-	**Fresh water ecosystems**
Glaciers	**-**	-	-
Ungulates			
1. Chamois (*Rupicapra rupicapra*), 2. East Caucasian Tur (*Capra cylindricornis*),	1. Chamois (*Rupicapra rupicapra*), 2. East Caucasian Tur (*Capra cylindricornis*), 3. Bezoar Goat (*Capra aegagrus*) 4. Red Deer (*Cervus elaphus*)	1. Chamois (*Rupicapra rupicapra*) 2. East Caucasian Tur (*Capra cylindricornis*) 3. Bezoar goat (*Carpa aegagrus*) 4. Red deer (*Cervus elaphus)*	1. Bezoar goat (*Capra aegagrus*) 2. Red deer (Cervus elaphus)
Carnivores			
1. Lynx - (*Lynx lynx*) 2. Brown Bear (*Ursus arctos*)	1. Lynx (*Lynx lynx*) 2. Brown Bear (*Ursus arctos*)	1. Lynx (*Lynx lynx*) 2. Leopard *(Panthera pardus)*?	1. Leopard (*Panthera pardus*)?
Raptors			
-	1. Bearded Vulture (*Gypaetus barbatus*) 2. Egyptian Vulture (*Neophron percnopterus*)	1. Bearded Vulture (*Gypaetus barbatus*) 2. Golden Eagle (*Aquila chrysaetos*) 3. Eurasian Griffon Vulture (*Gyps fulvus*) 4. Cinereous Vulture (Eurasian Black Vulture) (*Aegypius monachus*)	1. Bearded Vulture (*Gypaetus barbatus*) 2. Golden Eagle (*Aquila chrysaetos*) 3. Eurasian Griffon Vulture (*Gyps fulvus*) 4. Cinereous Vulture (Eurasian Black Vulture) (*Aegypius monachus*)
Galliforms			
1. Caucasian Black grouse (*Lirurus mlokosiewiczi*)	1. Caucasian Black Grouse (*Lyrurus mlokosiewiczi*) 2. Caucasian Snowcock (*Tetraogallus caucasicus*)	1. Caucasian Black Grouse (*Lyrurus mlokosiewiczi*) 2. Caucasian Snowcock (*Tetraogallus caucasicus*)	-
Herpetofauna			
	1. Dinnick Viper (*Vipera dinniki*), 2. Rock Lizards (*Darevskia caucasica*), 3. Spiny-Tailed Lizard (*Darevskia rudis*), 4. Derjugini’s Lizard (*Darevskia derjugini*)	1. Dinnick Viper (*Vipera dinniki*) 2. Lotievi Viper (*Vipera Lotievi*).	
Local Agro-biodiversity			
			1. Tushetian Horse (*Equus ferus caballus*) 2. Tusehtian sheep (*Ovis aries*)

3.2 Ecosystem services provided by the conservation values and human wellbeing benefits

The ecosystems and other biodiversity of the target PAs provide a wide range of ecosystem services to local inhabitants, the Georgian economy and visitors from all over the World (Figure 4).

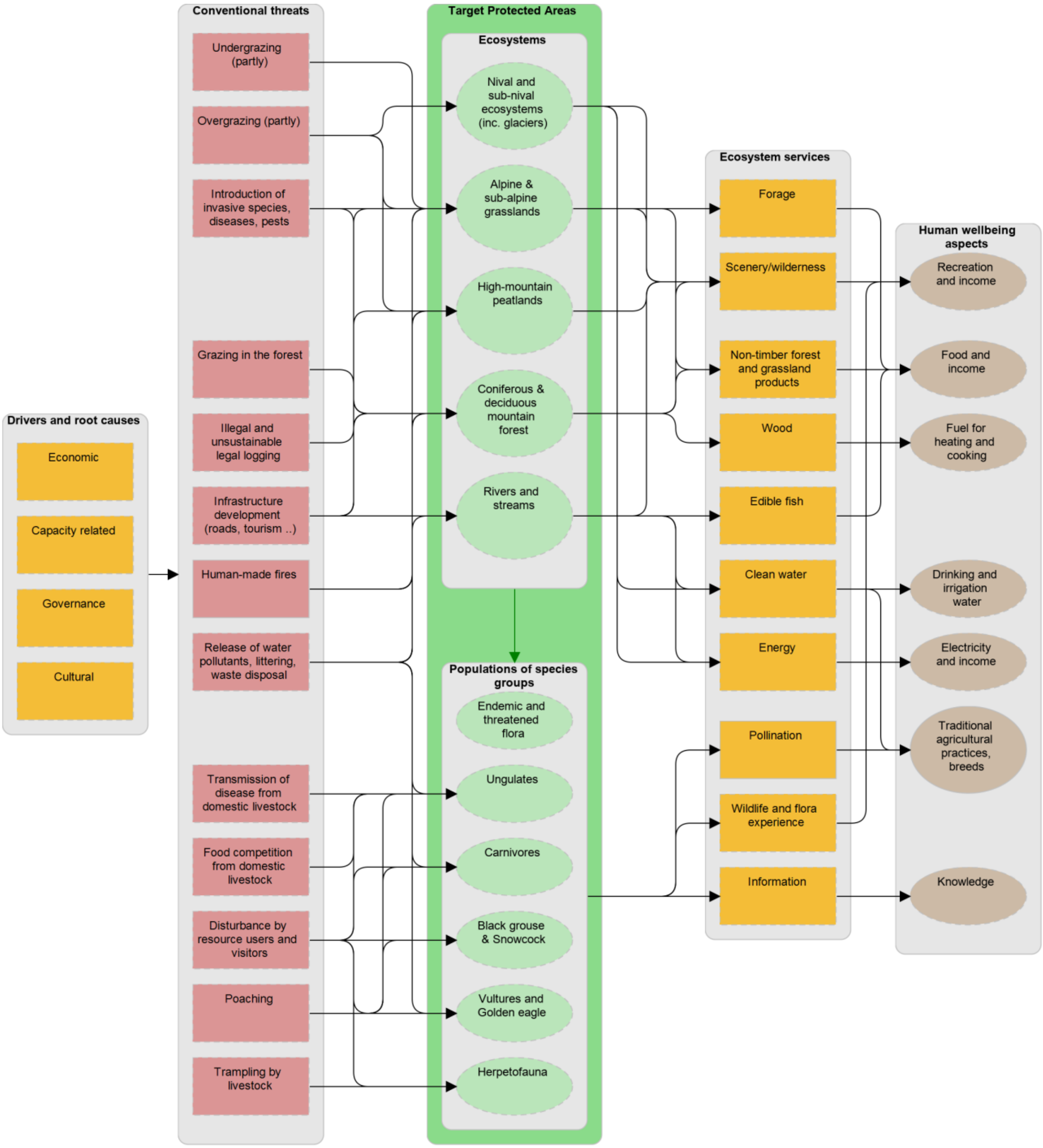


Figure 4. Situation model for the target area. Arrows on the left-hand side of the dark green box show causal relationships between drivers/root causes, direct conventional threats and conservation values. The green arrow inside the dark green box shows dependency of species/populations on the ecosystems where they find their habitats. The arrows on the right-hand side of the situation model show causal relationships between ecosystems, ecosystem services and human wellbeing aspects. See also electronic supplement (Miradi file).

The forests ecosystems offer provisional, regulatory and cultural ecosystem services. They mitigate natural hazards such as erosion and landslides, slow down runoff during the rainy season and release water during the dry season. Firewood, timber (in Tusheti PL), non-timber forest products, and medical plants are essential for the local population, which also benefits from the area in terms of health. Freshwater for drinking, energy generation and irrigation supports the local and national economy as well as downstream populations.

Grassland ecosystems support cattle and sheep breeding and hence the production of dairy products in all target areas. Tush nomadic sheep breeding with traditional pasture practices are defined among the socio-economic values in the MPs of Tusheti PAs and Tusheti PL. Additionally, production of traditional products, traditional practices of grain cultivation and its use, as well as collection of non-timber resources/economically important plant species are also defined as socio-economic values of Tusheti PL. Forest and grassland ecosystems also support honey production. At the same time, the honey bee plays an important role as a pollinator, and hence for maintaining flora diversity and ecosystem function.The educational, aesthetic and spiritual values supported by the nature and cultural values of the target areas attract visitors from Georgia and beyond, which stimulates local eco-tourism businesses and thereby the local economy.

3.3 Vulnerability of conservation values to threats associated with local human activity

The direct and indirect threats from local human activity ("conventional threats") to the conservation values of the target PAs are derived from the threats identified in the recent draft MPs. Only those threats meeting the threat definition of the Conservation Standards were considered for this assessment, in order to provide a solid base for the subsequent adaptation planning. The threats and their relationship to the conservation values are presented in Miradi Situation Model (Figure 4).

The importance of the various non-climate threats was assessed in the MPs of Tusheti PAs and Tusheti PL based on the criteria of severity, spatial extent and reversibility, following the rules of the Conservation Standards (CMP 2020).

In all four MPs, CC is also discussed and considered a very high threat or related indicator factor, but the analysis lacked the necessary detail to serve as a formal climate change vulnerability assessment.

3.4 Observed recent climate change in the target area

According to national data, the air temperature in Georgia – and also in the target area - has increased. As shown in the Fourth National Communication of Georgia (UNDP 2021), the average annual surface air temperature rose throughout the country by 0.25–0.58°C between the 1956-1985 period and the 1986-2015 period, with an average increase of 0.47°C between the two periods (Figure 5). This would theoretically correspond to an average decadal warming rate of ca. 0.16°C between the early 1970s and the turn of the century. Considering that the global average global warming since 1981 has been 0.18°C per decade (NOAA 2021), with an increasing trend, this puts the overall warming estimate for Georgia at a similar level as the global estimate.

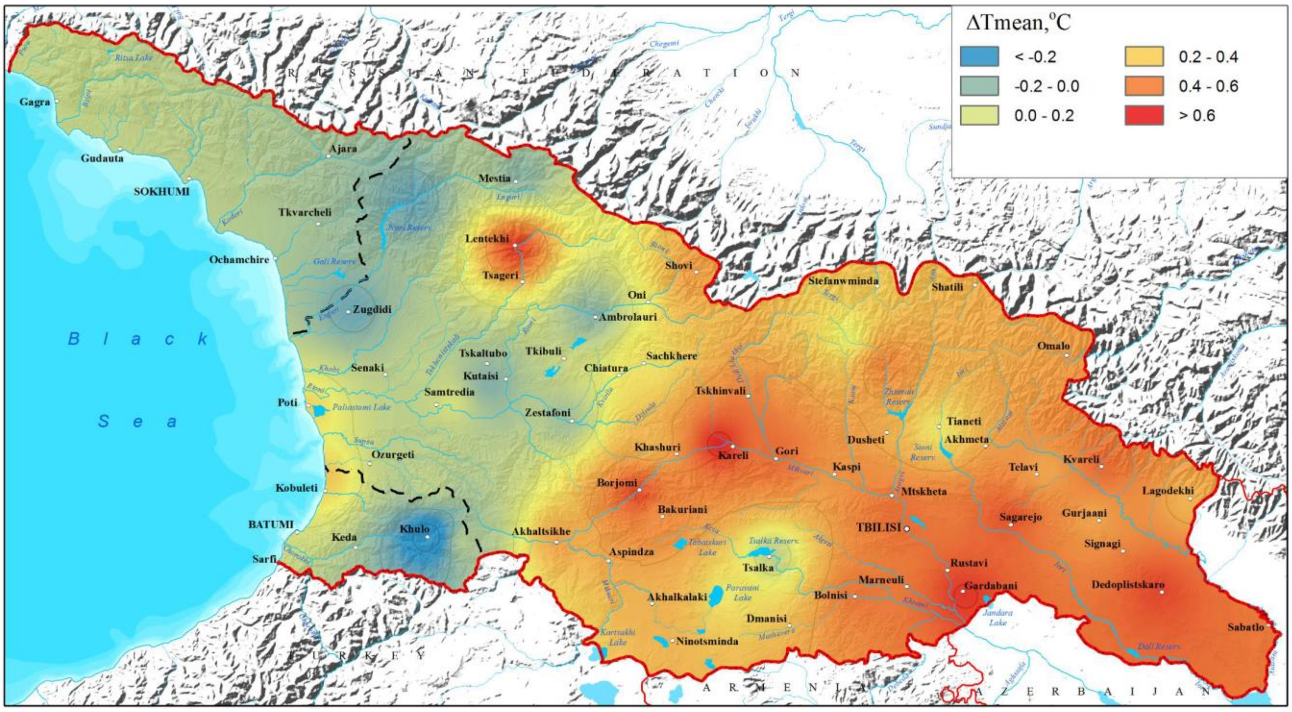


Figure 5. Change in mean air temperature in January between two 30-year periods (1956–1985 and 1986–2015). Source: UNDP 2021.

While not specific for the target region, this general warming trend is confirmed by other sources. For instance, Keggenhoff et al. (2015) compared trends of daily minimum and maximum temperatures between 1981 and 2010, and found a consisting warming trend (Figure 6). This analysis included data from the Pasanauri weather station, but no data from the target area itself.

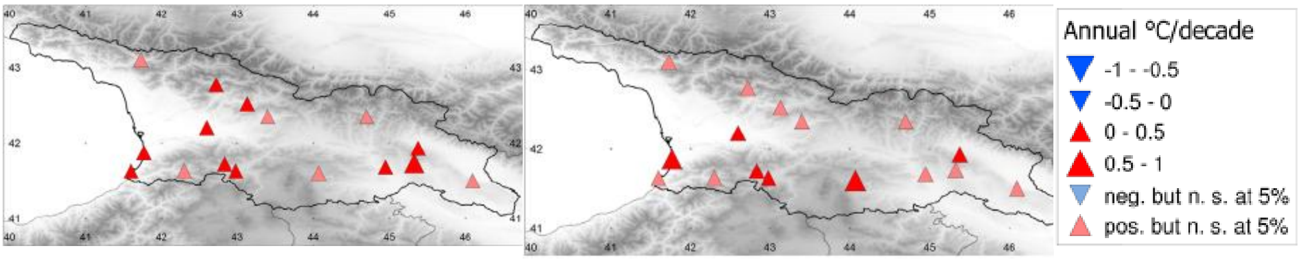
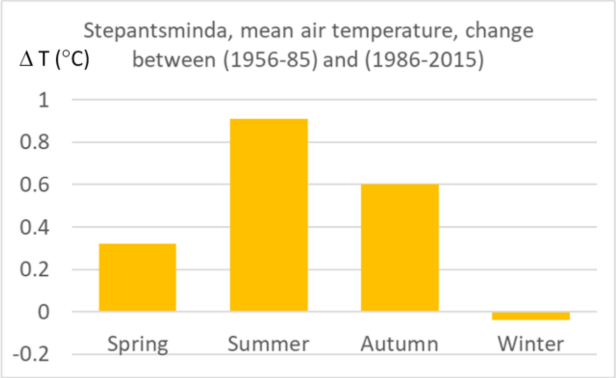


Figure 6. Trends in daily minimum (left) and maximum (right) temperatures at various stations in Georgia during the period 1981–2010. Red triangles indicate warming trends, blue indicate cooling trends. Light blue and red triangles indicate trends not significant at the 5% level. Source: Keggenhoff et al. (2015).

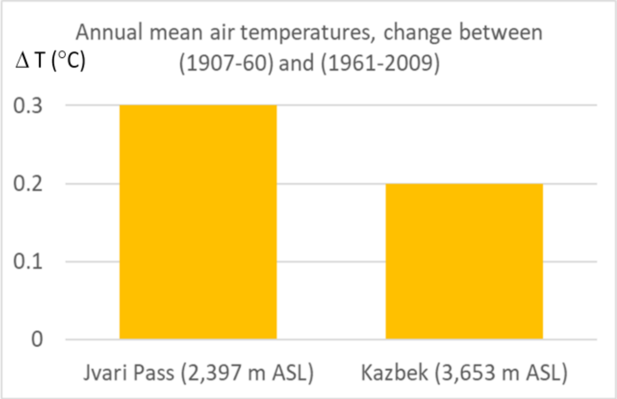
Specific data for the target area are scarce, but broadly support the picture for the entire country. According to data of the Stepantsminda Weather Station (Kazbegi National Park) on main air temperature in 1986–2015 and their change between two 30-year periods (1956–1985 and 1986-2015), there is a clear increase of annual mean air temperature, which is most pronounce in summer (UNDP 2021, Figure 7). A stronger warming trend in summer for the target area was also detected in another analysis of national weather data, along with an increased number of hot summer days (Elizbarashvili et al. 2017).



UNDP (2021)

Figure 7. Stepantsminda, mean air temperature between two 30-year periods (1956–1985 and 1986–2015). Source: Modified from UNDP, 2021.

Annual mean air temperature also increased at Jvari Pass and Mkinvartsveri (Kazbek) Mountain, according to a comparison of the 1907–1960 and 1961-2009 periods (Tielidze 2016, Figure 8). Interesting, the relative increase was more pronounced at the lower altitude Jvari Pass than at Mkinvartsveri (Mount) Kazbek. We do not know if this pattern holds for the entire area of interest.



Tielidze (2016)

Figure 8. Annual mean air temperature at Jvari Pass and Mkinvartsveri (Kazbek) Mountain, change between (1907–1960) and (1961–2009). Source: Tielidze (2016).

In view of the national trend and in the absence of any evidence to the contrary, we tentatively conclude that mean surface air temperature in the target area has increased at about the global average rate since the early 20th Century, with most warming occurring in summer and with unclear altitudinal trends.

Annual precipitation has decreased in most parts of eastern Georgia., with a decadal average decrease of 18% at Tianeti weather station, which is located about 35 km to the South of the Pshavi part of Pshav-Khevsureti PAs (UNDP 2021, Figure 9).

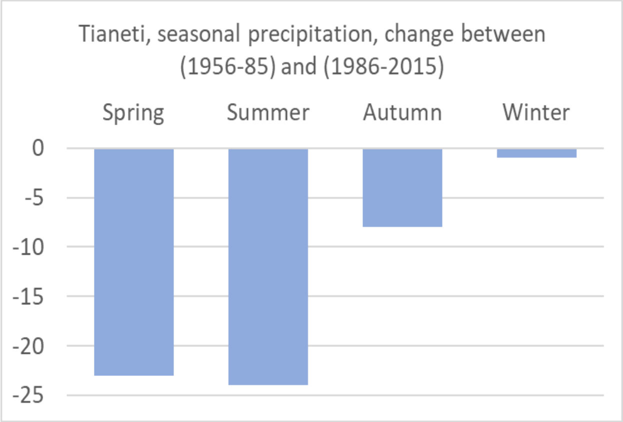


Figure 9. Tianeti, % change in seasonal precipitation between two 30-year periods (1956–1985 and 1986–2015). Source: Modified from UNDP (2021).

According to Elizbarashvili et al. (2017) the precipitation has declined particularly in the eastern part of the study area. According to this analysis, annual precipitation in the wider area around the target PAs has decreased by a considerable 3-5% per decade over the 1936-2012 period (Figure 10). The reduction in precipitation was reported to be stronger in summer, particularly in the eastern part of the Central Greater Caucasus. These data are only partly supported by the results of our own analysis of weather data from Omalo station.

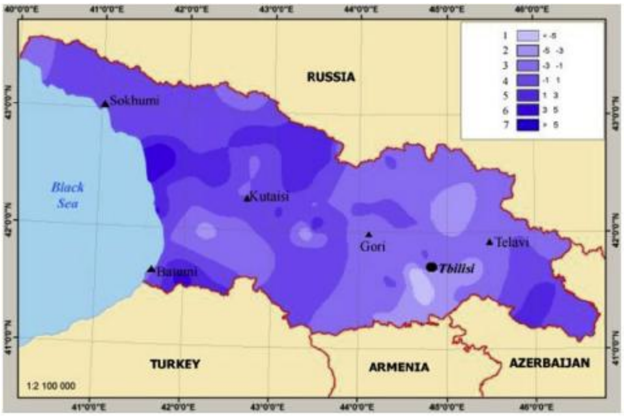


Figure 10. Decadal precipitation trends (%) over the 1936-2012 period for various regions of Georgia. Source: Elizbarashvili et al. (2017).

Nevertheless, we conclude that a trend towards significantly reduced precipitation over the course of the last century is likely, particularly in the eastern part of the target area.

3.5 Projected climate change in the target area

Climate projections for monthly temperature – nightly minima and daily maxima – and precipitation for the 2021-2040 period (near future) and 2061-2080 period (remote future) are summarized in Figures 11 and 12, and Table 3 and 4.

All projections agree that minimum and maximum temperatures in all seasons will increase in the remote future. The projected long-term increase in daytime maxima in comparison to the baseline is least pronounced in winter (0.6 – 4.7°C) and most drastic in summer (1.7 – 7.1°C). The corresponding ranges for nighttime minima are almost as high.

Even in the near future, minimum and maximum temperatures throughout the year will increase in all seasons according to most projections in comparison to the baseline period. Again, the strongest increase of both daytime maxima and nighttime minima is projected for the summer season (0.7 - 3.0°C and 0.4 - 2.8°C, respectively). The projections for winter temperatures range from no change to a 2.3°C increase. Near-future daytime spring temperatures are the only ones for which some projections show a decrease (-0.3°C - 2.7°C).

The projections for seasonal precipitation point to considerable uncertainty about future trends in the target area, both in the near and in the remote future. For the 2021-2040 period, most projections indicate an increase of seasonal precipitation, but there is a very wide range of possible trajectories. Winter precipitation might decrease by up to 22% or increase by up to 42%, whereas as summer precipitation might decrease by up to 35% or increase by up to 34%, in comparison to the baseline period. This uncertainty is even more pronounced in the projections for the remote future.

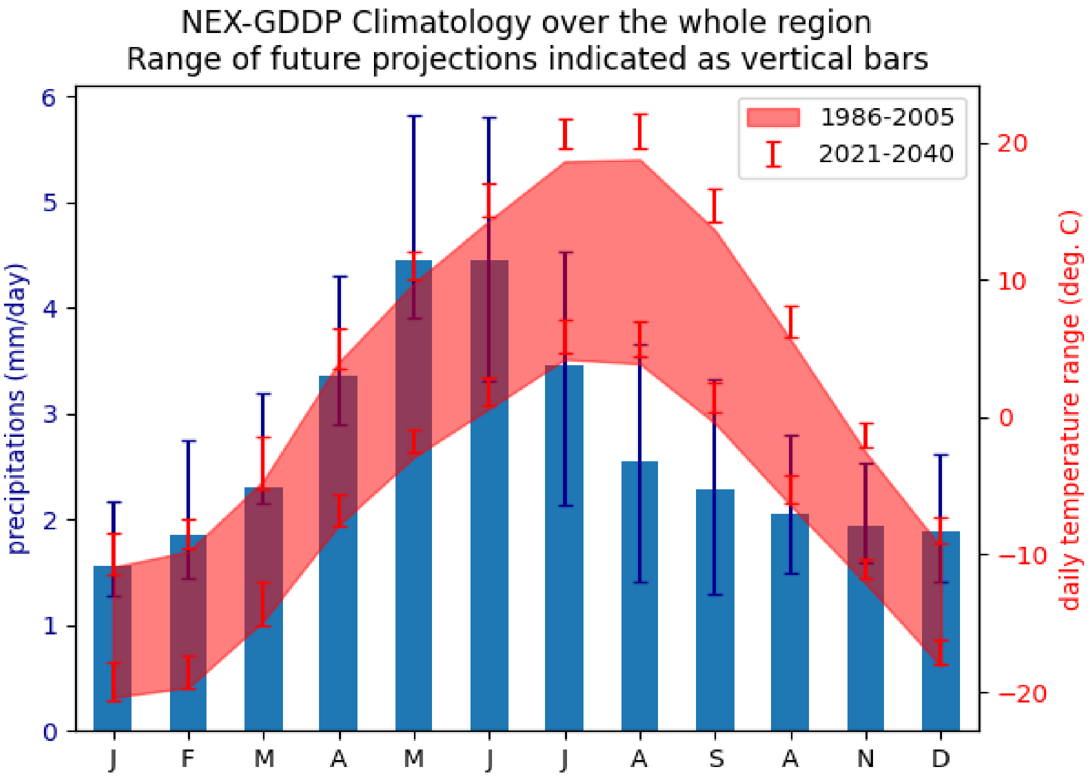


Figure 11. Projected monthly precipitation and temperature for the target area during the 2021-2040 period, in comparison to the 1986-2005 period. The vertical bars (blue for precipitation and red for temperature) show the range of monthly projections, relative to the values during the baseline period. The upper and lower margin of the light red band correspond to average daily minimum and average daily maximum temperatures. See Section 2.5 for further explanation.

Table 3. Ranges of projected seasonal precipitation and temperature for the target area during the 2021-2040 period, relative to the corresponding average values for the 1986-2005 period. See Section 2.5 for further explanation.

		Change of day temperature		Change of night temperature		Change of Precipitation	
Season #	Define Season Name	lower estimate in °C	upper estimate in °C	lower estimate in °C	upper estimate in °C	Precipitation change lower estimate in %	Precipitation change upper estimate in %
1	Winter	0.0	2.3	0.0	2.3	-22%	42%
2	Spring	-0.3	2.7	0.0	2.3	-12%	32%
3	Summer	0.7	3.0	0.4	2.8	-35%	34%
4	Autumn	0.4	2.5	0.5	2.3	-30%	38%

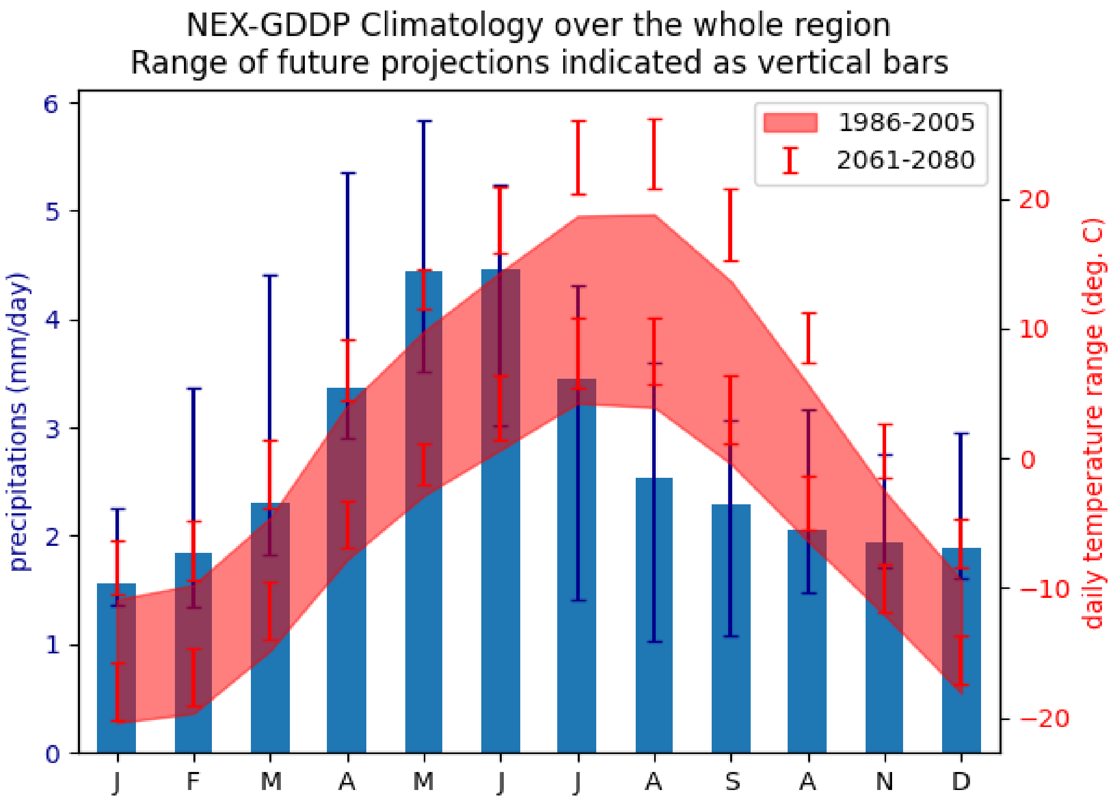


Figure 12. Projected monthly precipitation and temperature for the target area during the 2061-2080 period, in comparison to the 1986-2005 period. The vertical bars (blue for precipitation and red for temperature) show the range of monthly projections, relative to the values during the baseline period. The upper and lower margin of the light red band correspond to average daily minimum and average daily maximum temperatures. See Section 2.5 for further explanation.

Table 4. Ranges of projected seasonal precipitation and temperature for the target area during the 2061-2080 period, relative to the corresponding average values for the 1986-2005 period. See Section 2.5 for further explanation.

		Change of day temperature		Change of night temperature		Change of Precipitation	
Season #	Season Name	lower estimate in °C	upper estimate in °C	lower estimate in °C	upper estimate in °C	Precipitation change lower estimate in %	Precipitation change upper estimate in %
1	Winter	0.6	4.7	0.5	4.7	-18%	61%
2	Spring	0.9	5.3	0.8	4.6	-19%	54%
3	Summer	1.7	7.1	1.2	6.4	-48%	26%
4	Autumn	1.4	6.0	0.9	5.3	-32%	43%

We did not project the frequency of extreme events, such as cold and warm spells, extreme precipitation events, or draught periods. It is generally likely that the frequency and severity of warm spells will increase with average summer temperatures, while the frequency and severity of extreme precipitation events will increase with average seasonal precipitation, particularly in late spring an early summer.

3.6 Observed vulnerability of the non-living environment to climate change

Observed climate change vulnerability of glaciers in the target area

Ecosystems and biodiversity depend on their physical environment. This is why climate change impacts on the physical environment – particularly glaciers, rivers and streams – are important triggers for climate change impacts on the conservation values of the target areas.

The glaciers of the Greater Caucasus have been shrinking dramatically over the last century (Shahgedanova et al. 2014, Tielidze 2016). The rate of glacier loss has further increased over the last 20 years (Tielidze et al. 2021). This is also true for the glaciers of the target area, particularly those of Kazbegi NP. Glacier extent in the main catchments coinciding with the target PAs has declined significantly since 1911 (Figure 13), and this relative loss has been strongest for those areas that had fewer and smaller glaciers to start with, such as the Aragvi, Asa and Arghuni catchments (Figure 14). The trend is likely to be even more pronounced for total glacier volume (Tielidze, in prep.).

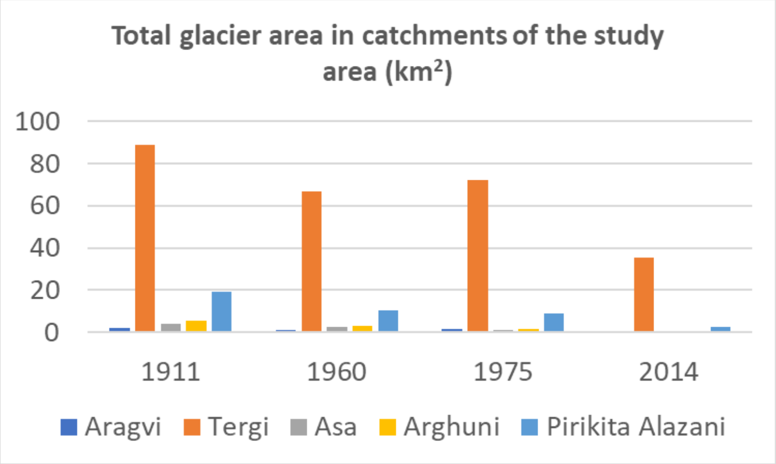


Figure 13. Trends in total glacier area within catchments coinciding with the target PAs between 1911 and 2014 (Data source: Tielidze 2016).

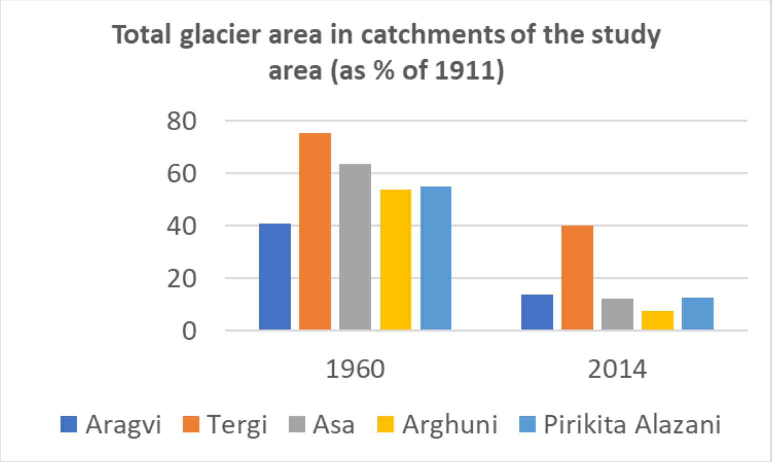


Figure 14. Relative decrease of total glacier area (%) from 1911 for catchments coinciding with the target PAs in 1960 and 2014 (Data source: Tielidze 2016).

The mean annual rate of glacier area loss in Georgia has accelerated from -0.4%/yr during the 1911-2014 interval to -1.19%/yr during the 2000-2020 period, with even higher rates towards the east (-1.82%/yr for the entire eastern Greater Caucasus), where many smaller glaciers are located (Tielidze et al. 2021). It is likely that not only glacier loss per se but also this acceleration is continuing.

Along with the decline in overall area and volume of glaciers, their medium altitude has increased as they have retreated upwards, and glacier number has first increased because of glacier fragmentation, and later decreased because of the disappearance of smaller fragments (Tielidze 2016, Tielidze et al. 2021).

The atmospheric mechanisms driving glacier loss in the central Greater Caucasus are complex and go beyond local warming. Saharan dust pollution events in the recent past may have decreased albedo and thereby contributed to the recent acceleration of glacier loss (Tielidze et al. 2020), and there may also be a trend to decreased cloud cover, owing to more frequent anticyclones in the wider region and shifting large-scale latitudinal atmospheric patterns (cf. Woollings et al. 2018).

Glacier mediated impacts of climate change on rivers and streams

Among the main rivers within the target PAs, only the Tergi receives a significant part (roughly estimated at 18%) of its water from glacial meltwater (UNDP 2021). When the glaciers feeding this river started to retreat following the little ice age (i.e., in the mid-19th Century), discharge first increased as more meltwater was released. General theories about the linkages between glacier loss and river runoff predict that this increase will peak and then decline – ultimately to zero – once glaciers have shrunk so far that they cannot sustain previous meltwater provision rates anymore. The question whether this peak has already been passed in the Greater Caucasus including the Tergi catchment is generally answered affirmatively by large-scale analyses (Hock et al. 2019). This means that the meltwater discharge into the Tergi will decrease in the future. Whether the same will be true for overall discharge depends on future precipitation, which is rather uncertain (cf. Section 3.5 above). In any case, there will be a relative shift in seasonality, with more discharge in spring and less discharge in summer.

We expect a weaker impact of glacier loss on river discharge of the Aragvi, Asa, Arghuni and Pirikita Alazani basins, because of their lower dependency on glacier meltwater.

Climate change impact on the frequency and severity of natural disasters

Extreme natural events such as landslides, mudflows and rockfalls/avalanches are part of the natural dynamics of the mountains and therefore not threats to their conservation per se. At the same time, a strong anthropogenic increase of the frequency and severity of such events can threaten habitats and the populations depending on them to such an extent that they qualify as threats and require a management response.

Systematic and consistent data on the frequency and severity of such events specifically in the target area are scarce. The little information available does not point to a strong increase over the last 40 years (Figure 15). These data do not support anecdotal reports by locals about a medium-term increase in these events. However, the period between 1980 and 2014 coincides with major institutional changes and discontinuities, which may compromise the consistency of these data.

An exception from the notion of extreme geological events as part of the natural dynamics of the mountains (i.e. not a threat) are very large catastrophic events such as the 2002 Kolka/Karmadon rock (ice avalanche (Huggel et al. 2005) and the 2014 Devdoraki Glacier disaster (Tielidze et al. 2019). These caused considerable damage to humans, natural ecosystems and infrastructure. While such events have occurred in the past, it has been hypothesized that their frequency and severity might increase in the future because of glacier instability and the melting of permafrost underneath them. While PA management will not prevent such catastrophic events, it may well include precautions to reduce the exposure of humans, biodiversity values and infrastructure to them in danger areas.

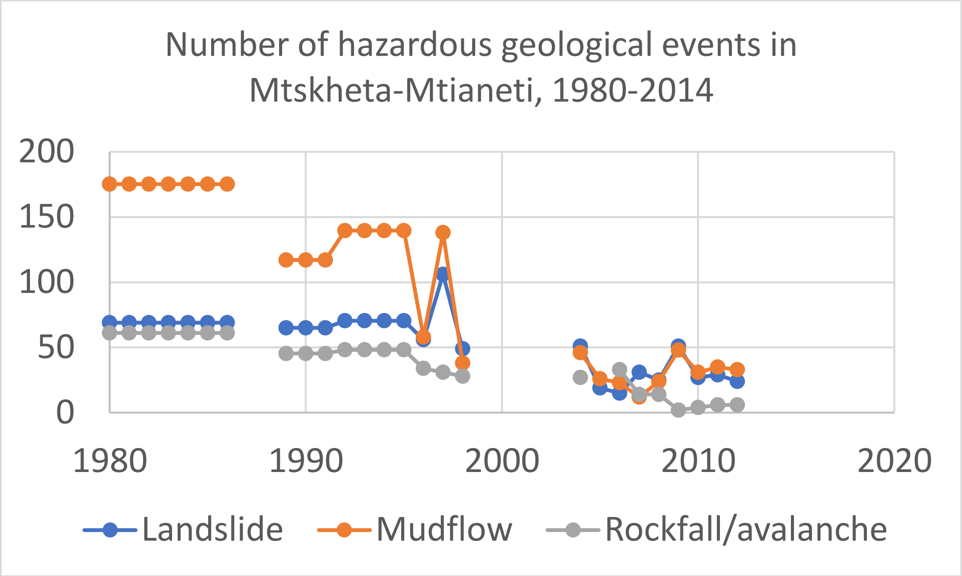


Figure 15. Number of hazardous geological events in Mtskheta-Mtianeti, where Kazbegi NP is situated (Source: Keller et al. 2013).

3.7 Observed impacts of climate change on the conservation values of the target PAs

Globally, the high mountains of temperate zones are considered to be among the most sensitive biomes to climate change. There is already ample evidence that it affects alpine grassland vegetation (GLORIA 2022). However, according to studies carried out in Kazbegi Region within the framework of the GLORIA project since 2001, no distinctive impacts of climate change on alpine grassland flora and vegetation have been detected there so far (Gigauri 2021). No direct evidence of an upward shift of the treeline was identified on sample plots in the Kazbegi region (Abdaladze 2021, pers. comm.). This is in contrast to observations in other comparable mountain areas (GLORIA 2022).

The increase in alpine grassland species richness during recent decades, recorded in various studies worldwide, was closely correlated with rising temperatures (GLORIA 2022). A study in the sub-alpine zone of the Central Greater Caucasus, which also took into account soil moisture, found that species richness increased there as well (over 30 years) but concluded that this observed increase was not induced by climate change, but rather by declining land-use intensity (Tephnadze -Hoernchen 2021).There seems to be a trend towards increased forest coverage at high altitude in Kazbegi region, but it is not clear if this can be attributed to climate change. In 2018-2019, the Centre for Biodiversity Conservation and Research "NACRES" carried out the project "Assessment of Carbon Accumulation Potential in Truso Gorge", which evaluated the foresting processes on natural grasslands in Kazbegi Region. While primarily concerned with the carbon sequestration potential of mountain forests, this research showed that in Truso Gorge, the area covered by forests had grown by 9.4% over the previous 20 years. Forest had occupied former hay meadows there, and spread up to 2,500 meters ASL. Birch (*Betula* spp.) dominated (91.8%) the composition of the newly formed forest (UNDP 2021). Similar results were observed in other regions of the target area (Khevsureti, Tusheti) and elsewhere in Georgia (e.g. Racha, Svaneti) (UNDP 2021). However, this study and other referred to in the 4th National Communication of Georgia to UNFCCC did not explicitly study forest extension in former grassland areas as a response to climate change, but simply observed this in the context of other studies. Therefore, this does not clarify whether any observed increase of forest cover in the target area has been in response to climate change, or to other factors such as reduced grazing pressure.

We did not find additional studies on climate change impacts on forests or other ecosystems especially in the target area, nor for individual species or species groups. The recent national communications of Georgia to UNFCCC also did not reference any such studies (UNDP 2021, UNDP 2015, UNDP 2009, UNDP 1999).

In the absence of published information, we discussed observed changes with the four PA administrations and other local stakeholders during workshops in October 2021. The participants mentioned a number of changes observed, which they attributed to a changing climate. The most important perceived changes mentioned by stakeholders related to ecosystems, species, pests/diseases etc. are as follows:

- Vegetation:
    - Upward shift of the treeline in all three regions (e.g. Makratela mountain range in Tusheti PAs, rhododendron-birch in Truso valley, Kabarjina, Kazbegi forest, Sno-Garbani forest in Kazbegi NP).
    - Increase of forest coverage in Kazbegi (e. g. grove of birch in Gaiboteni area) and increase of rhododendron (*Rhododendron caucasicum*) coverage in Pshav-Khavsureti PAs and Kazbegi NP. However, it was also mentioned that such changes might be caused by decrease of grazing since the 1990s.
    - Decrease in the number of grass species – reduced number (by 1/3) of *Iris sibirica* on Omalo Plateau; *Symphytum* spp. and some other taxa on bogged areas, as well as the plant used by locals for tea (e.g. *Thymus nummularius*), in Tusheti PAs.
- Predators:
    - Appearance of Grey Jackal (*Canis aureus*) in Kazbegi and also in Pshav-Khavsureti (Arkhoti) over the last 5-6 years. According to locals, the reason of its appearance at higher elevation (up to Jvari pass - 2,379 m a.s.l.) might be a shortage of food in the lower areas and/or a now more benign climate higher up.
    - Significant increase of bear (*Ursus arctos*) numbers in Kazbegi NP. The locals considered milder weather suitable for bear overwintering in Kazbegi areas, which was not the case earlier. However, this explanation would not be consistent with published studies on the relationship between winter temperatures and reproductive success of Brown Bears (see below).
    - Increased numbers of a rodent species, which have reportedly damaged agricultural lands and grasslands in Khevsureti and Tusheti PAs over the last ten years. The species responsible are likely to be *Prometheomys schaposchnikovi* and other field vole species present in the area (Bukhnikashvili 2021, pers. comm.).
- Ungulates:
    - Appearance of Red Deer (*Cervus elaphus*) in Kazbegi, Truso valley, where it was never observed before. In Tusheti PAs it re-appeared in 2010 and its number is increasing.

- Birds:
    - Decreased number of Caucasian Black Grouse (*Lyrurus mlokosiewiczi*) in Arkhoti, Pshav-Khevsureti. The number of snowcock (*Tetraogallus caucasicus*) and partridges (*Perdix perdix*) reportedly remained the same. Local stakeholders thought that the cause might be the occurrence of Golden Jackal in the area.
    - Records of Corncrake (*Crex crex*) in the target PAs since the late 1990s. Now their numbers have reportedly decreased in Tusheti PAs.
- Pests/Diseases
    - Pests observed on pine-trees in all three areas (outbreak in Tusheti in 2013 (*Tomicus piniperda, Tomicus minor Hart*)).
    - Pests and pathogens on deciduous trees (localized areas), Tusheti PAs.
    - Pests (*Stephantis rhododendri*) on Rhododendron in Pshav-Khevsureti PAs, considered to be linked with warmer winters.

Some of these observations were not shared by all stakeholders consulted In many cases the attribution to the CC was not very clear. Most of the changes reported were at a much shorter timescale than the one on which climate change impacts are usually measured, and therefore cannot be attributed to it directly. However, all these observations can be used to derive hypotheses about ***potential*** climate change impacts and vulnerabilities, and considered during the design of future monitoring and research programmes.

3.8 Vulnerability of the conservation values of the target PAs to projected future climate change

As shown in Section 3.7 above, publications and reports do not contain sufficient information about the vulnerability specifically of the natural values of the target area to observed climate changes – to the extent that those have been clearly documented – to inform a robust vulnerability assessment. Likewise, many of the local PA managers and stakeholders whom we interviewed reported various anecdotal observations of perceived changes in the ecosystems and biota of the area – sometimes attributed to climate change – but these perceptions and particularly climate change as the main driver were often contested. Many referred to timescales of only a few years.

In any case, even if observed climate change vulnerabilities of conservation values there would be certain, it would be problematic to extrapolate them into the future because we cannot assume that the local climate will continue changing in the same way and at the same rate as previously. Since PA management planning is concerned with the future, effective PA adaptation planning must rely on information on the possible future climate, including its uncertainty. Therefore we used participatory scenario planning and interpretation to better understand future climate vulnerability (cf. Section 2.6).

Inspection of scenario axes and construction of climate change scenarios

Our localized climate change projections (cf. Section 3.5) revealed considerable uncertainty regarding trends in future temperature and precipitation for both the 2021-2040 and the 2061-2080 periods, as compared to the reference period (1986-2005). During the vulnerability assessment workshop on 26 November 2021, participants agreed to consider primarily the near-future projections during the vulnerability assessment, as these are more relevant to adaptation planning now. The remote-future projections were also considered, but only to check conclusions from the near-future projections and to develop a joint understanding of the potential severity of long-term trends.

As a result of the discussion during the vulnerability assessment workshop and subsequent discussions with the climate change scientist, we made the following observations:

- The projected ranges of both temperature trends and precipitation trends are qualitatively rather similar across seasons,
- The projected ranges particularly for temperature but also for precipitation for the various seasons are likely to be highly interdependent,
- There was no agreement about the most critical seasons across the various conservation values of the area, and hence no common ground for prioritizing any specific seasons.

In order to reflect this and also to keep the vulnerability assessment to a tractable level of complexity (i. e. only one general set of scenarios, not specific ones for each conservation value), we constructed a set of cross-seasonal climate scenarios for further analysis (Figure 16). “Cross-seasonal” here means that we looked at projected trends not for individual seasons but rather for all seasons together.

The quadrants of the scenario cross constructed in this way resulted in four scenarios (descriptions of possible alternative climate futures):

- ***Sirimiri:*** Considerable wetter but only slightly warmer[2],
- ***Tropicana:*** Considerably wetter and much warmer,
- ***Furnace:*** Considerable drier and much warmer,
- ***Crisp:*** Considerably drier but only slightly warmer.

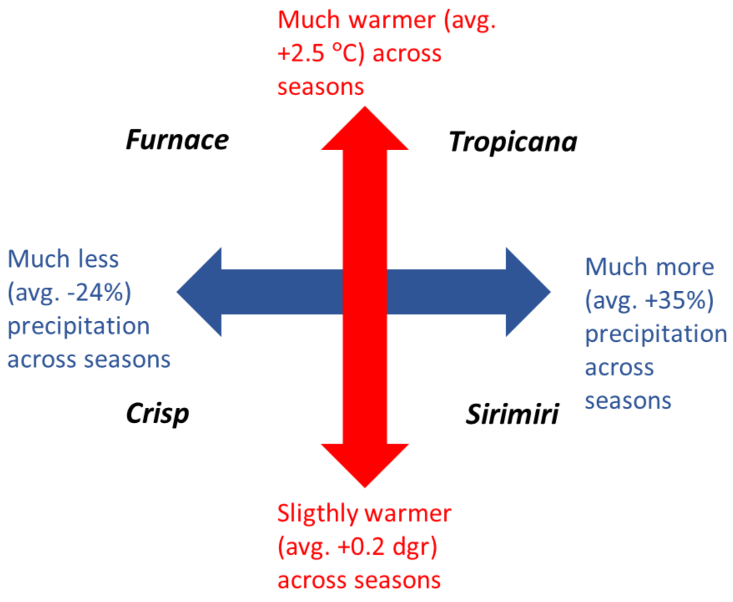


Figure 16. Cross-seasonal axes of uncertainty and resulting climate change scenarios for the target area, for the 2021-2040 period.

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[2] Named after the cool drizzle typical of the spring and autumn in the Basque Country.

It is important that – according to the projections – these four scenarios are not the only possible climate future, but rather represent the outer envelope of possible climate futures for the target area. For instance, according to the climate projections it is possible that the 2021-2040 period will have the same average precipitation as the reference period, or that average cross-seasonal warming will be somewhere between the values shown in Figure 16. Considering the outer envelope of possibilities is useful to cover their entire range, and to prevent maladaptation when it comes to designing interventions for adaptation.

Analysis of scenario-specific climate change vulnerabilities of biodiversity values

We used the experience of local PA managers with short-term weather variability – as expressed during the vulnerability assessment workshop – to hypothesize possible climate change impacts on the ecosystems and other biodiversity of the target PAs. In addition, we queried the available scientific literature not only from the Central Greater Caucasus, but also from comparable high-mountain regions elsewhere, where more research into climate change vulnerability of ecosystems and other biodiversity has been conducted, to conclude on likely climate change impacts under the four scenarios on the conservation values of the target PAs (Table 2). This we then used as a basis for further assessing their vulnerability (Table 5).

Many projected climate change impacts tended to be more or less severe in the various scenarios, but it was usually impossible to define clear quantitative thresholds. In these cases, we qualitatively described the differences between the scenarios to convey at least a conceptual understanding (Table 5).

Table 5. Plausible climate change impacts on the main conservation values of the target PAs under the main climate change scenarios (2021-2040 period in comparison to 1985-2004 period). To identify these plausible impacts, we interpreted four climate change scenarios representing the main uncertainties of localized climate change projections for this period – slight temperature increase to strong temperature increase across seasons, and strong precipitation decrease to strong precipitation increase across seasons – in the light of literature information and expert communications about weather and climate change impacts on the main conservation values of the target PAs.

Scenario/value	**Sirimiri**	**Tropicana**	**Furnace**	**Crisp**
Scenario description	Slight warming, much more precipitation	Strong warming, much more precipitation	Strong warming, much less precipitation	Slight warming, much less precipitation
Ecosystems				
(Sub-)nival (incl. glaciers)	- Continued glacier loss and loss of near-glacier habitats with their highly adapted vegetation (UNDP 2021)	- Further accelerated glacier loss and loss of near-glacier habitats with their highly adapted vegetation (UNDP 2021)	- Further accelerated glacier loss and loss of near-glacier habitats with their highly adapted vegetation (UNDP 2021)	- Continued glacier loss and loss of near-glacier habitats with their highly adapted vegetation (UNDP 2021)
(Sub-)alpine grasslands	- Upwards shift of (sub-)alpine grassland belt (Vitasse et al. 2021), contraction from below because of upward moving forest belt (Cazolla Gatti et al. 2019) - Earlier onset of spring	- Strong upwards shift of (sub-)alpine grassland belt (Vitasse et al. 2021), strong contraction from below because of upward moving forest belt (Cazolla Gatti et al. 2019)	- Upwards shift of (sub-)alpine grassland belt (Vitasse et al. 2021), possibly contraction from below because of upward moving forest belt (Cazolla Gatti et al. 2019) - Earlier onset of spring	- Upwards shift of (sub-)alpine grassland belt (Vitasse et al. 2021), contraction from below because of upward moving forest belt (Cazolla Gatti et al. 2019) - Earlier onset of spring

	in (sub-)alpine grasslands (Vitasse et al. 2021) - Increase of vegetation cover throughout (sub-)alpine vegetation belt (Rogora et al. 2018) - Shift in species composition towards more thermophilic (Steinbauer et al. 2018) and less cold-adapted species (Rumpf 2018) Enhanced erosion through more surface run-off (Neale et al. 2014)	- Significantly earlier onset of spring in (sub-)alpine grasslands (Vitasse et al. 2021) - Strong increase of vegetation cover throughout (sub-)alpine vegetation belt (Rogora et al. 2018) - Strong shift in species composition towards more thermophilic (Steinbauer et al. 2018) and less cold-adapted species (Rumpf 2018) Enhanced erosion through more surface run-off (Neale et al. 2014)	in (sub-)alpine grasslands (Vitasse et al. 2021) - Shift to vegetation like that of dry gorges of the rocky main ridge of the Greater Caucasus (10-15 km N of Kazbegi region) (Abdaladze et al. 2015); - Shift in species composition towards more thermophilic (Steinbauer et al. 2018), less cold-adapted (Rumpf 2018) and more drought-adapted species (Lamprecht et al. 2018)	in (sub-)alpine grasslands (Vitasse et al. 2021) - Shift in species composition towards more thermophilic (Steinbauer et al. 2018) and less cold-adapted species (Rumpf 2017) - Shift in species composition towards more thermophilic (Steinbauer et al. 2018), less cold-adapted (Rumpf 2018) and more drought-adapted species (Lamprecht et al. 2018)
Alpine peatlands	-	- Raising treeline may lead to overgrowth of subalpine and alpine peatlands (Parish et al. 2008)	- Strong desiccation and degradation due to reduced water input (Zhao-Jun Bu et al. 2011) - Rapid replacement by highly specialized peatland flora – including *Sphagnum* spp. by more generalist vascular species (Zhao-Jun Bu et al. 2011)	- Desiccation and degradation due to reduced water input, particularly for ombrogenic mires (Zhao-Jun Bu et al. 2011) - Replacement by highly specialized peatland flora – including *Sphagnum* spp. by more generalist vascular species (Zhao-Jun Bu et al. 2011)
Mountain forest	Upward shift of all forest classes (Zazanashvili et al. 2011) Increased risk of colonization by invasive alien species, if there is also habitat/soil disturbance (Slodowicz et al. 2018) Increased risk of outbreaks of some insect forest pests and forest diseases (Pureswaran et al. 2018, Sturrock et al. 2011)	Contraction of sub-alpine pine forest (*Pinus kochiana)*. Other forest classes (particularly those dominated by deciduous forest) could shift up (Zazanashvili et al. 2011) Strongly increased risk of colonization by invasive alien species, if there is also habitat/soil disturbance (Slodowicz et al. 2018) Strongly increased risk of outbreaks of some insect forest pests and forest diseases (Pureswaran et al. 2018, Sturrock et al. 2011)	Contraction of sub-alpine pine forest (*Pinus kochiana)*. Other forest classes (particularly those dominated by deciduous forest) could shift up (Zazanashvili et al. 2011) Increased risk of colonization by invasive alien species, if there is also habitat/soil disturbance (Slodowicz et al. 2018) Strongly increased fire risk (stakeholders) Increased risk of outbreaks of some insect forest pests and forest diseases (Pureswaran et al. 2018, Sturrock et al. 2011)	Upward shift of all forest classes (Zazanashvili et al. 2011) Slightly increased risk of colonization by invasive alien species, if there is also habitat/soil disturbance (Slodowicz et al. 2018) Increased fire risk (stakeholders) Increased risk of outbreaks of some insect forest pests and forest diseases (Pureswaran et al. 2018, Sturrock et al. 2011)

Rivers/streams	- Possibly increase in discharge - Possibly earlier discharge maxima, mainly Tergi catchment (cf. Hock et al. 2019)	- Changes in discharge impossible to project because of likely interactions between warming and wetter conditions - Earlier discharge maxima, mainly Tergi catchment (cf. Hock et al. 2019) - Upstream shift of distribution of Brown Trout (*Salmo trutta*) (Borgwardt et al. 2020) - Higher incidence of disease in Brown Trout (Borgwardt et al. 2020, Bruneaux et al. 2016)	-Strong reduction in discharge - Markedly earlier discharge maxima, mainly Tergi catchment (cf. Hock et al. 2019) - Upstream shift of distribution of Brown Trout (*Salmo trutta*) (Borgwardt et al. 2020) - Higher incidence of disease in Brown Trout (Borgwardt et al. 2020, Bruneaux et al. 2016)	- Reduction in discharge - Possibly earlier discharge maxima, mainly Tergi catchment (cf. Hock et al. 2019)
Species (groups)				
Endemic and threatened flora	- Loss of specialist, cold- and wet-adapted high-mountain endemic flora, first in (sub-)nival zone and subsequently in alpine and subalpine zones (Pauli et al. 2012, Cazolla Gatti et al. 2019)	- Rapid loss of specialized, cold adapted endemic flora, first in (sub-)nival zone and subsequently in alpine and subalpine zones (cf. Pauli et al. 2012, Cazolla Gatti et al. 2019);	- Rapid loss of specialized, cold- and wet-adapted flora, first in (sub-)nival zone and subsequently in alpine and subalpine zones (Pauli et al. 2012 , Cazolla Gatti et al. 2019)	- Loss of specialist, cold- and wet-adapted high-mountain endemic flora, first in (sub-)nival zone and subsequently in alpine and subalpine zones (Pauli et al. 2012 , Cazolla Gatti et al. 2019)
Ungulates	Indirect impacts (habitat availability) through impacts on (sub-)alpine grasslands and partly forests			
	- Potentially some loss of habitat (sub-)alpine grasslands	- Loss of habitat (sub-)alpine grasslands - Increased competition with domestic livestock on shrinking (sub-)alpine grasslands - Higher risk of infection with disease because of closer contact to domestic livestock on shrinking (sub-)alpine grasslands - Eastern Tur: potentially reduced fitness because of sub-optimal physiological performance and/or higher parasite stress at higher night temperature (cf. Gavashelishvili et al. 2018)	- Loss of habitat (sub-)alpine grasslands - Increased competition with domestic livestock on shrinking (sub-)alpine grasslands - Higher risk of infection with disease because of closer contact to domestic livestock on shrinking (sub-)alpine grasslands - Eastern Tur: potentially reduced fitness because of sub-optimal physiological performance and/or higher parasite stress at higher night temperature (cf. Gavashelishvili et al. 2018)	- Potentially some loss of habitat (sub-)alpine grasslands

Carnivorous mammals	Indirect impacts (food availability) through impacts on prey species – mainly ungulates as listed above			
	- Potentially increased food competition from colonizing Golden Jackal	- Potentially improved conditions for Persian Leopard because of reduced snow cover (cf. Gavashelishvili & Lukarevsky 2008) - Brown Bear: Potentially reduced fitness due to compromised hibernation period (cf. Albrecht et al. 2017) - Potentially increased food competition from colonizing Golden Jackal	- Potentially improved conditions for Persian Leopard because of reduced snow cover (cf. Gavashelishvili & Lukarevsky 2008) - Brown Bear: Potentially reduced fitness due to compromised hibernation period (cf. Albrecht et al. 2017) - Potentially increased food competition from colonizing Golden Jackal	- Potentially improved conditions for Persian Leopard because of reduced snow cover (cf. Gavashelishvili & Lukarevsky 2008) - Potentially increased food competition from colonizing Golden Jackal
Black Grouse and Caucasian Snowcock	Indirect impacts (habitat availability) through impacts on (sub-)alpine grasslands and partly forests			
		- Strong contraction of climatic niche and distribution range (Hof & Allen 2018)	- Strong contraction of climatic niche and distribution range (Hof & Allen 2018)	
Vultures and Golden Eagle	?			
Herpetofauna	Indirect impacts (habitat availability) through impacts on (sub-)alpine grasslands and partly forests, and the inability of habitats and species to move upwards quickly enough to keep up with climate changes (Auf der Maur 2021)			
		- Precipitation-independent upwards habitat shift (Christy & McCain 2010) - Earlier start of spring activities (Auf der Maur 2021, Vitasse et al. 2021)	- Precipitation-independent upwards habitat shift (Christy & McCain 2010) - Earlier start of spring activities (Auf der Maur 2021, Vitasse et al. 2021)	

The following plausible future climate change impacts on the ecosystems and other biodiversity of the target area can be derived from Table 5 and Figure 17:

Glaciers and (sub-)nival ecosystems

The glaciers of the target area will continue to shrink under all scenarios, but at varying rates. A further acceleration of glacier loss beyond the rates reported by Tielidze et al. (2021) appears possible, particularly under the Furnace and Tropicana scenarios.

This will also lead to a varying negative impact on the extent of the highly specialized peri-glacial, sub-nival flora and vegetation. A replacement of this flora and vegetation with more generalist alpine species and plant communities is likely in the long term, but not during the near-future projection period. Since there will be "no-where to move up to" for the sub-nival and nival belt, the biota associated with it may be the first to experience irreversible loss of habitat.

Decreasing glacial runoff particularly from the glaciers of Kazbegi National Park will lead to decreased discharge and an earlier seasonal discharge maximum, particularly in the Tergi catchment.

Since prospective de-glaciation of the area will be accompanied by thawing and destabilization of permafrost in the nival zone, there may theoretically be an increasing risk of large-scale geological disasters like the 2002 Kolka-Karmadon and 2014 Devdoraki disasters.

(Sub-)alpine grasslands

Considering what is being observed in other high-mountain environments, the (sub-)alpine grassland belt of the target PAs will apparently move upwards under most scenarios, particularly under Tropicana and Furnace. This apparent upward movement will be a result of colonization of previously sub-nival and nival areas at the upper distribution edge and at the same time of overgrowth by shrub and forests at the lower distribution edge. This may lead to an overall loss of (sub-)alpine grassland area, as the same vertical shift of environmental conditions will decrease grassland area more along the lower distribution limit than increasing it along the upper distribution limit.

Grassland phenology will also change, with earlier springs and an overall longer vegetation season. Vegetation cover, productivity and standing crop are likely to increase, and species composition is likely to shift away from the – often rare and/or endemic – cold adapted to more thermophilic and – at least for the Furnace and Crisp scenarios – drought-adapted species. This means that while local (“alpha”) grassland diversity is likely to increase in the target area, landscape and biome scale (“gamma”) diversity are likely to decrease.

(Sub-)alpine peatlands

With their high dependency on precipitation and moisture conditions, the alpine peatlands of the target area are likely to suffer desiccation and degradation particularly in the Furnace scenario, and to a lesser extent in the Crisp scenario. Their characteristic *Sphagnum* vegetation may get replaced by more generalist vascular plant species, thereby changing ecosystem function and carbon retention in affected areas. It is also possible that upward shifts of the treeline will lead to replacement of (sub-)alpine peatlands by forest.

Mountain forests

The likely changes in forest composition and extent differ considerably between scenarios: In the Sirimiri and Crisp scenarios, there would be an upward shift of all forest types, whereas in those scenarios with more pronounced warming (Tropicana and Furnace), available information points towards a contraction of alpine pine forest and a relative upward extension of deciduous forest types.

Invasive alien forest species are likely to become more of a threat, particularly if there is also soil disturbance – e. g. connected to infrastructure development – that creates new pioneer habitats. This risk is particularly high for the Tropicana scenario.

Climate change impacts on the incidence and severity of insect pests and forest diseases strongly depend on the lifecycle traits of the specific pests or diseases in question and cannot be fully predicted in general terms: *“For example, under a (…) scenario of warmer and drier future conditions, we predict that diseases caused by pathogens directly affected by climate (e.g. Dothistroma needle blight) will have a reduced or unchanged impact on their hosts, but an increased impact under a scenario of warmer and wetter conditions. For diseases caused by pathogens indirectly affected by climate (e. g. Armillaria root disease) and for decline diseases, in general, we predict an increased impact on hosts under a climate-change scenario of warmer and drier future conditions and a reduced or unchanged impact under warmer and* *wetter future conditions"* (Sturrock et al. 2011). Conditions can become more favourable for a second generation of some insect pests (e.g., *Ips typographus*) (Bentz et al. 2019). Nevertheless, abiotic stress to forest tree species will generally increase their susceptibility to diseases – the more the more rapid the abiotic stress is.

Rivers and streams

In addition to deglaciation impacts, the four scenarios describe a range of water balances for the target area, ranging from an overall wetter (Sirimiri) to a significantly drier and hotter situation (Furnace). The corresponding effects on discharge range from possibly an increase in discharge under Sirimiri to a strong reduction in discharge. These effects will be overlain by decreasing glacial runoff and earlier seasonal discharge maxima, particularly in the Tergi catchment.

We found only limited sources on indirect impacts on stream and river biota. The distribution range of Trout is going to move upwards, and the species will be increasingly vulnerable to disease outbreaks.

Endemic and threatened flora

Corresponding to the findings on vegetation above, projected climate change will particularly negatively affect (sub-)nival and (sub-)alpine species, and particularly cold-adapted, high-mountain endemics. This will be particularly pronounced in the Tropicana and Furnace scenarios.

Ungulates

The ungulates of the target area comprise various species and climate change will affect them differently. Those species (i. e. Eastern Tur *Capra cylindricornis*, Chamois *Rubicapra rubicapra* and to a lesser extent Bezoar Goat *Capra aegagrus*) that spend a large part of their life cycle on (sub-)alpine grasslands will be particularly vulnerable to any decline in the extent of this habitat. Reduced availability of these grasslands in the medium term will also increase competition with domestic livestock, and transmission of diseases from domestic livestock to these wild ungulates.

In contrast, forest ungulates such as Red Deer will experience increased habitat availability and less harsh conditions, particularly in the Tropicana scenario. Their populations might actually benefit from climate change unless improved habitat availability is not outweighed by negative direct heat effects (see below) or by competition with domestic livestock

Apart from these habitat-triggered impacts, there may also be more direct vulnerability to warming – and potentially changes in precipitation – of the fitness of ungulates. Gavashelishvili et al. (2018) observed a preference of Eastern Tur populations in the Greater Caucasus for colder areas during the night (with other factors being equal), which may reflect eco-physiological mechanisms or differences in the activity of parasites. A negative effect of heat stress on calf growth rate and fitness was observed for Red Deer (Pérez-Barbería et al. 2020). It is entirely possible that similar effects exist in other species, but they have not been studied to our knowledge.

Carnivorous mammals

Similar to the ungulates, "carnivorous mammals" is a generic term that includes several different species with different ecological requirements. In addition to climate change impacts on the autochthonous carnivores of the target areas that are triggered by changes in habitat availability and food supply (see above), several additional impacts appear likely: The observed progressive colonization of the area by the Golden Jackal (*Canis aureus*), which is observed not only in the target area but also throughout northern

Eurasia, will likely continue – particularly under the Tropicana and Furnace scenarios, and lead to increased foot competition with other species.

The Brown Bear (*Ursus arctos*) is a rather generalist species with a considerable altitude range, but it has been reported vulnerable to increased winter temperature, which lowered reproductive rate, in a pan-European modelling study (Albrecht et al. 2017).

The Persian Leopard (*Panthera pardus saxicolor*) appears to have no reproductive population in the Central Greater Caucasus anymore, but occasional sightings in Tusheti PAs and nearby over the last years identify the target area as a potential re-colonization area. Past modelling studies have shown a negative correlation between snow cover in winter and habitat suitability for leopards (e. g. Gavashelishvili & Lukarevsky 2007). Reduced snow cover at medium-high altitude, which is implied by the Furnace and to a lesser degree the Crisp scenarios, would therefore improve habitat suitability for leopards in this area. At the same time, such a positive impact might well be overridden by negative impacts such as reduced habitat and food availability.

Avifauna

Among the avifauna of the target area, groups of particular conservation importance include two endemic species of galliforms (Caucasus Black Grouse *Lyrurus mlokosiewiczi* and Caucasian Snowcock *Tetraogallus caucasicus*) and nesting raptors (e. g. Bearded Vulture *Gypaetus barbatus* and Golden Eagle *Aquila chrysaetos*). We did not find any literature or other hints on the climate change vulnerability of the latter. A modelling study on the range of the grouse and snowcock predicted a strong contraction of the niche of suitable climate and consequently of the distribution range of both species in response to climate change (Hof & Allen 2018). This study referred only to RCP 8.5, i. e. a relatively pessimistic projection of greenhouse gas emissions. This would broadly correspond to our Tropicana and Furnace scenarios.

Herpetofauna

For mountain herpetofauna, literature from other areas indicates upward range shifts and changes in seasonality. In the Alps, it was observed that their habitats did not shift up quickly enough to allow these species to stay within their optimal temperature range (Auf der Maur 2021). This type of lag effect and resulting mismatch between abiotic conditions and habitat availability might also increase the climate change vulnerability of other groups.

3.9 Prioritization of vulnerabilities of the conservation values to climate change

The results of the rating of climate change vulnerabilities according to likely exposure (extent in CS terms), sensitivity (severity in CS terms) and adaptive capacity of the biodiversity values concerned are summarized in Table 6. The vulnerability rating for non-climate threats according to exposure, sensitivity and irreversibility (the standard third rating criterion of the Conservation Standards for non-climate threats is also included).

In comparison of the overall vulnerability of the various conservation values of the target area (to both non-climate threats and climate change impacts combined), the summary shows that ecosystems were rated higher on average than species (groups), reflecting the number of threats/impacts affecting them, and their inability to conduct adaptive movements. However, species/populations indirectly depend on these and therefore will have a higher “indirect” vulnerability.

For the sake of simplicity, the table presents coniferous and deciduous mountain forests together, although threats to coniferous forests are particularly high.The endemic mountain galliforms (Caucasian Black Grouse and Caucasian Snowcock) received the highest overall vulnerability rating of all species groups. This is in line with the strong niche contraction projected by other authors for the entire range of both species (Hof & Allen 2018). However, we need to take into account that all species groups are aggregates containing several species with diverse ecologies, which introduces a degree of fuzziness into the aggregate ratings used in this assessment.

Comparing the vulnerabilities of the biodiversity values of the target area to non-climate related threats and climate change impacts, the rating shows that the latter tend to have higher ratings, mainly because of the very high exposure (large geographic scope) of the climate change impacts, and the often limited adaptive potential of the biodiversity values at least at the scale of the target region.

An important and at the same time difficult question in this regard is timing: While it appears plausible that climate change impacts will become relatively more important in the long term, it is not clear when exactly the future vulnerabilities identified through scenario analysis will fully manifest themselves, and hence will require a full management response supported by prioritized resources.

On a more general level, the vulnerability rating also points to a fundamental and practically important difference between the non-climate threats that PA staff usually deal with on the one hand, and climate change vulnerabilities that they will increasingly have to deal with on the other hand: While the former are usually relatively severe, but localized and with sometimes reversible impacts, the latter may appear milder, but at the same time affect a much broader area and are usually irreversible, also given the inertness of the global climate system. This difference might be compared to that between ripples caused by throwing a stone into a lake (or many), and a ground swell.

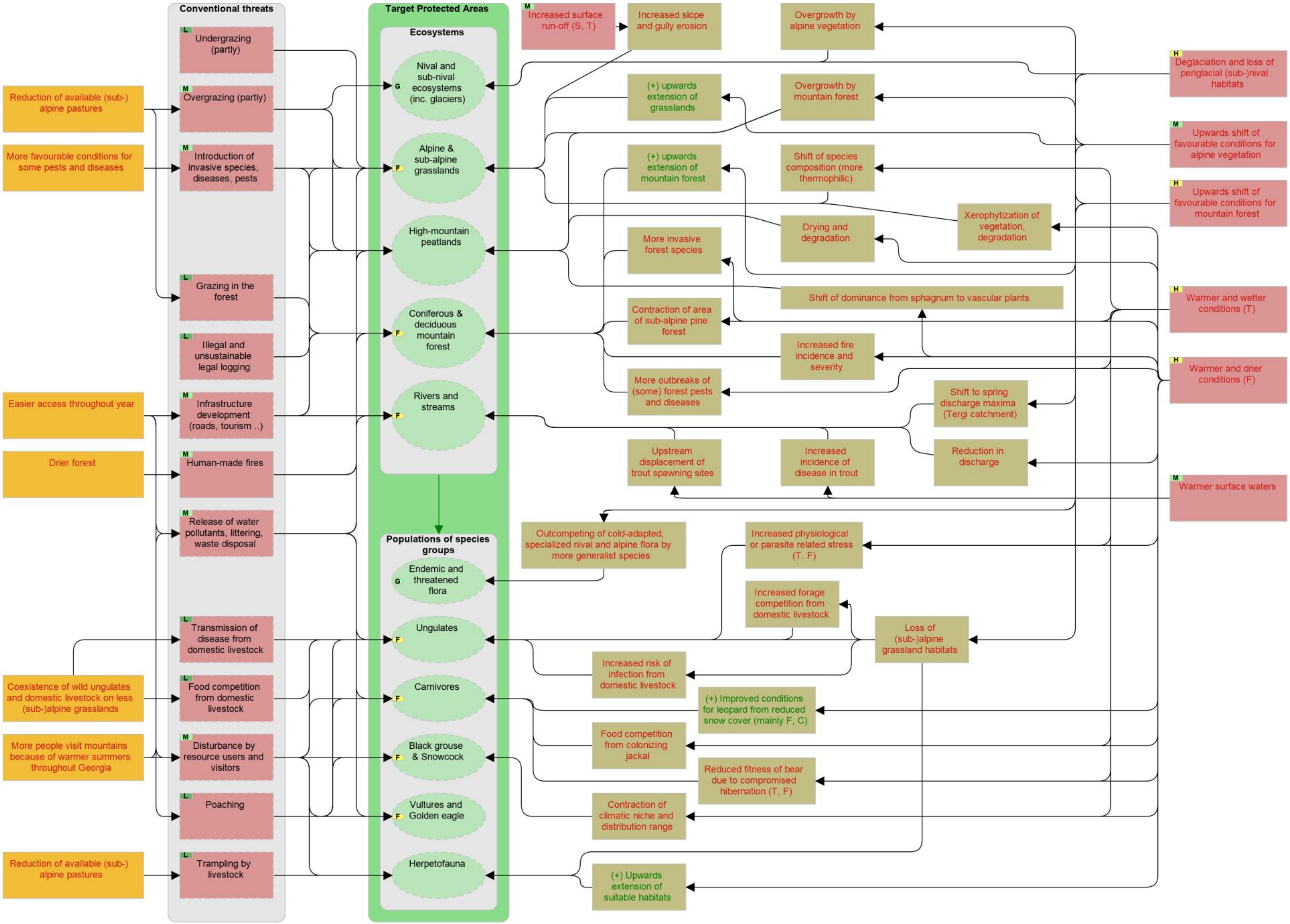
Conventional threats
Target Protected Areas
Ecosystems
L Undergrazing (partly)
M Overgrazing (partly)
M Introduction of invasive species, diseases, pests
L Grazing in the forest
L Illegal and unsustainable legal logging
M Infrastructure development (roads, tourism ..)
M Human-made fires
M Release of water pollutants, littering, waste disposal
L Transmission of disease from domestic livestock
L Food competition from domestic livestock
M Disturbance by resource users and visitors
L Poaching
L Trampling by livestock
Reduction of available (sub-) alpine pastures
More favourable conditions for some pests and diseases
Easier access throughout year
Drier forest
Coexistence of wild ungulates and domestic livestock on less (sub-)alpine grasslands
More people visit mountains because of warmer summers throughout Georgia
Reduction of available (sub-) alpine pastures
G Nival and sub-nival ecosystems (inc. glaciers)
F Alpine & sub-alpine grasslands
High-mountain peatlands
F Coniferous & deciduous mountain forest
F Rivers and streams
Populations of species groups
G Endemic and threatened flora
F Ungulates
F Carnivores
F Black grouse & Snowcock
F Vultures and Golden eagle
Herpetofauna
M Increased surface run-off (S, T)
Increased slope and gully erosion
Overgrowth by alpine vegetation
(+) upwards extension of grasslands
Overgrowth by mountain forest
(+) upwards extension of mountain forest
Shift of species composition (more thermophilic)
Xerophytization of vegetation, degradation
More invasive forest species
Drying and degradation
Shift of dominance from sphagnum to vascular plants
Contraction of area of sub-alpine pine forest
Increased fire incidence and severity
More outbreaks of (some) forest pests and diseases
Shift to spring discharge maxima (Tergi catchment)
Upstream displacement of trout spawning sites
Increased incidence of disease in trout
Reduction in discharge
Outcompeting of cold-adapted, specialized nival and alpine flora by more generalist species
Increased physiological or parasite related stress (T. F)
Increased forage competition from domestic livestock
Loss of (sub-)alpine grassland habitats
Increased risk of infection from domestic livestock
(+) Improved conditions for leopard from reduced snow cover (mainly F, C)
Food competition from colonizing jackal
Reduced fitness of bear due to compromised hibernation (T, F)
Contraction of climatic niche and distribution range
(+) Upwards extension of suitable habitats
H Deglaciation and loss of periglacial (sub-)nival habitats
M Upwards shift of favourable conditions for alpine vegetation
H Upwards shift of favourable conditions for mountain forest
H Warmer and wetter conditions (T)
H Warmer and drier conditions (F)
M Warmer surface waters

Figure 17. Situation model with climate change vulnerabilities added. The ecosystem services and human wellbeing aspects have been removed from the situation model and the scenario-derived climate change vulnerabilities have been introduced instead. The brown boxes represent biophysical factors, i. e. factors in the causal chain linking climate change impacts (pink boxes on right-hand side) and the conservation values. Biophysical factors with green script show positive climate change impacts on values. The small rectangles inside the threat/impact windows show the threat rating results (**L**ow, **M**edium or **H**igh). The small circles inside the ovals representing conservation values show the results of a rapid viability appraisal for each value (**F**air or **G**ood - except values where this was deemed impossible). Scenario-specifc climate change impacts are identified by capital letters in brackets (**S**irimiri, **T**ropicana, **F**urnace, **C**risp). The situation model also shows where climate change is likely to interact or aggravate existing non-climate related threats (orange boxes, left-hand side). Note that aggregate threat ratings for species (groups) took included threats to their habitats. See Appendix 1 for a version of this situation model that has been broken down by conservation values, for easier readability.

Table 6. Rating of climate change vulnerabilities according to the criteria of likely exposure (extent in CS terms), sensitivity (severity in CS terms) and adaptive capacity of the biodiversity values concerned, broadly following the approach of Garstecki et al. (2020a). Scenario-specifc climate change impacts are identified by capital letters in brackets (Sirimiri, Tropicana, Furnace, Crisp). For non-climate related threats, the rating was done based on exposure, sensitivity and irreversibility, in line with CMP (2021). We used the conservation management software Miradi including its criteria, thresholds and roll-up algorithms to rate all relevant combinations between impacts/threats and conservation values, and to estimate overall vulnerabilities of values (across threats/climate change impacts) and of threats/impacts (across values).

Threats \ Targets	**Rivers and streams**	**Alpine & sub-alpine grasslands**	**Ungulates**	**Carnivores**	**Black grouse & Snowcock**	**Vultures and Golden eagle**	**Nival and sub-nival ecosystems (inc. glaciers)**	**Herpetofauna**	**Coniferous & deciduous mountain forest**	**Endemic and threatened flora**	**High-mountain peatlands**	**Summary Threat Rating**
Poaching	–	–	Low	Medium	Low	Low	–	–	–	–	–	Low
Illegal and unsustainable legal logging	–	–	Low	Low	Low	–	–	Low	Low	Low	–	Low
Infrastructure development (roads,	Low	Low	Medium	Medium	Low	–	–	Low	Medium	Low	Medium	Medium

Threats \ Targets	**Rivers and streams**	**Alpine & sub-alpine grasslands**	**Ungulates**	**Carnivores**	**Black grouse & Snowcock**	**Vultures and Golden eagle**	**Nival and sub-nival ecosystems (inc. glaciers)**	**Herpetofauna**	**Coniferous & deciduous mountain forest**	**Endemic and threatened flora**	**High-mountain peatlands**	**Summary Threat Rating**
tourism ..)												
Disturbance by resource users and visitors	–	–	Medium	Medium	Low	Low	–	Low	–	–	–	Medium
Grazing in theforest	–	–	Low	Low	Medium	–	–	Low	Low	Low	–	Low
Release of water pollutants, littering, waste disposal	High	Low	–	Low	–	Low	–	Low	Low	–	Low	Medium
Introduction of invasive species, diseases, pests	–	Low	–	–	–	–	–	–	Medium	–	Medium	Medium
Overgrazing (partly)	–	Medium	Medium	–	–	–	Low	–	–	–	–	Medium
Undergrazing (partly)	–	Low	–	–	–	–	–	–	–	–	–	Low
Transmission of disease from domestic livestock	–	–	Medium	–	–	–	–	–	–	–	–	Low
Food competition from domestic livestock	–	–	Low	–	–	–	–	–	–	–	–	Low
Trampling by livestock	–	–	–	–	–	–	–	Low	–	–	–	Low

Threats \ Targets	**Rivers and streams**	**Alpine & sub-alpine grasslands**	**Ungulates**	**Carnivores**	**Black grouse & Snowcock**	**Vultures and Golden eagle**	**Nival and sub-nival ecosystems (inc. glaciers)**	**Herpetofauna**	**Coniferous & deciduous mountain forest**	**Endemic and threatened flora**	**High-mountain peatlands**	**Summary Threat Rating**
Human-made fires		Low	Low	Low	Low	–	–	Low	Medium	Low	Low	Medium
Deglaciation and loss of periglacial (sub-)nival habitats	High	–	Low	Low	Low	–	High	–	–	High	–	High
Upwards shift of favourable conditions for alpine vegetation	–	–	–	–	–	–	High	–	–	Medium	–	Medium
Upwards shift of favourable conditions for mountain forest	–	High	Low	Low	High	–	–	–	–	Medium	High	High
Warmer and wetter conditions (T)	–	Medium	Medium	Medium	Medium	–	–	–	High	Medium	–	High
Warmer and drier conditions (F)	High	High	Medium	Medium	High		–		High	Medium	High	High
Increased surface run-off (S, T)	–	High	Low	Low	–	–	–	Low	–	Low	–	Medium
Warmer surface waters	High	–	–	–	–	–	–	–	–	–	–	Medium
	High	High	Medium	Medium	High	Low	High	Low	High	Medium	High	

3.10 Vulnerability of ecosystem service provision and human wellbeing to climate change

This vulnerability assessment is primarily focused on the climate change vulnerability of the ecosystems and other biodiversity of the target PAs. It also addresses indirect climate change vulnerability of people living around these areas and using them, but only to the extent that these are triggered by the direct climate change impacts on ecosystems and biodiversity that form its main focus. Assessing the overall climate change vulnerability of the communities surrounding these PAs would be technically possible, but is beyond the scope of this assignment.

Observed vulnerabilities of human wellbeing

During the site workshops and vulnerability workshop, the representatives of PA administrations and other local stakeholders provided some observations related to perceived climate change impacts on ecosystem services, including the following:

- Increased water scarcity in all three PAs
- Disasters risk – increased risk of landslides on roads to and inside Tusheti (also close to the villages)
- Decrease of economically used grassland plants – i. e. local plants used for making tea, in Tusheti (attributed by locals to reduced precipitation)
- Perceived climate change impacts on economically used grasslands and livestock:
    - A decrease in hay productivity in Tusheti by 50% in 2021 (mainly in Pirikita and Shenako gorges, and too short-term to be really attributed to climate change).
    - Increased incidence of diseases of cattle/sheep in all three areas. More effort for immunization needed (several times per seasons), which was not necessary in the past, in Khevsureti (not in Pshavi). In Kazbegi, one climate-independent cause might be that sheep/cattle there come from different regions now, whereas in the past there was much less exchange of livestock with other regions.
- Perceived climate change impacts on orchards:
    - Changed phenology: Now apples ripen in Khevsureti, whereas in the past only plums ripened (not in Pshavi).
    - Increased incidence of pests and diseases on fruit trees observed for the last 5-10 years in Kazbegi.
    - Pests on tomato in Kazbegi observed for the last 7-8 years; similarly in Shatili and Mighmakhevi, in Khevsureti (not in Pshavi).
- Increased accessibility of Kazbegi NP (Stepantsminda area) in winter and consequently increased number of winter tourists there. The same might happen in the other target PAs in the future, particularly under the Tropicana and Furnace scenarios.
- Weather affecting health:
    - Unpleasantly warm summer nights in Kazbegi causing discomfort, which was not the case in the past.
    - Decreased weather predictability in Pshav-Khevsureti: In the past, the predictions of locals regarding short-term weather trends were true and could be relied on for the planning of livelihood activities, but now this is reportedly no longer possible.

Future human vulnerability under the climate change scenarios

The projected climate change vulnerability of the principal ecosystems of the target PAs (Table 5) implies an increased projected vulnerability of ecosystem-dependent human livelihoods. Without conducting a full community vulnerability assessment, the main triggering factors for this increased vulnerability can be summarized as follows:

- Warming, deglaciation and decreased precipitation (particularly under the Furnace and Crisp scenarios) leading to reduced water availability for drinking, energy production, irrigation etc.
- Contraction of (sub-)alpine grasslands leading to reduced availability of pastures and meadows.
- Increased incidence and severity of extreme natural events as a result of warming, deglaciation and increased precipitation (particularly under the Tropicana and Sirimiri scenarios) disrupting infrastructure, posing health risks and impairing the tourism sector/

These plausible climate change vulnerabilities of humans are important to the community in their own right, but they are also important for PA management because the way in which people try to adapt to them might add additional stress onto the main conservation values of the area. These potential feedbacks are summarized in the next section.

3.11 Vulnerability of conservation values to human maladaptation to climate change

The most foreseeable and significant potential maladaptation mechanisms with feedbacks on the conservation values of the target PAs are related to water use, (sub-)alpine grassland use and access:

- Significantly reduced precipitation is projected under the Crisp and Furnace scenarios, under the latter also combined with increased evapotranspiration due to higher temperatures. Together with reduced glacial runoff, this may exacerbate the already perceived water shortages in parts of the target area. One potential human reaction to this may be more efficient water abstraction from streams and rivers, which would aggravate drought stress on natural ecosystems.
- According to the Climate Change National Adaptation Plan for Georgia's Agriculture Sector (MEPA 2017), the potential productivity of natural grasslands may become unstable in the Kazbegi region if increased air temperature and decreased precipitation will result in the xerophytization of plant live in the mountains' alpine and subalpine zones. This would correspond to the Furnace scenario of our vulnerability assessment. If pastoralists try to maintain their livestock numbers under these conditions, this will lead to more intense pasture use, increased erosion, increased competition and contact of domestic livestock with wild ungulates, and potentially increased transmission of diseases between domestic and wild animals.
- Reduced snow cover and milder weather year-round may improve accessibility of the more remote areas of the target PAs for touristic and other uses, leading to increased disturbance of wildlife. If infrastructure is established to make use of this improved access, additional indirect effects may include habitat conversion or degradation, soil disturbance and creation of colonization opportunities for invasive species, as well as increased pressures on natural resources.
- If temperatures throughout Georgia raise in line with the Tropicana and Furnace scenarios, it is likely that many more people will visit the target area in summer, to seek the relative cool of the mountains. This may lead to increased visitor pressure including disturbance, waste and sewage emissions, and tourism infrastructure development.

It is possible that additional feedback mechanisms that cannot be foreseen currently will add further stress to the natural values of the target PAs.

3.12 Vulnerability of PA infrastructure and operations to climate change

This CCVA primarily focuses on the vulnerability of the biodiversity protected in the target PAs to climate change and indirect vulnerabilities of people depending on this biodiversity. It is not intended as a CCVA for the local infrastructure around the PAs. At the same time, the likely increased frequency and severity of extreme weather and other natural events (rain, flooding, landslides and mudflows, etc.) may also disrupt infrastructure such as access roads to the target PAs, shelters and communications equipment. While much of the infrastructure needed for access to the PAs is within the mandate of organizations other than APA, transport, ranger and visitor infrastructure within the areas is APA' responsibility.

This may compromise the ability of the PA administrations to conduct not only the climate change adaptation interventions identified in response to the vulnerabilities described in this assessment, but also general PA management and visitor access to the areas.

4 Discussion

4.1 Availability of climate data and information

Information on observed climate trends over the last 100+ years in the target areas is incomplete and fragmented. There are no continuous weather data from existing meteorological stations within the target area. Some meteorological data are available at individual PA administrations, but being not sufficiently systematic and long-term they do not give reliable information about any relevant trends. In order to get the necessary information, data from neighbouring weather stations were also analysed and the vulnerability assessments were based on them, and on climate projections.

For future analyses, the availability of continuous weather data will be increasingly important. Therefore, the set-up of the meteorological stations in the target areas is critically important. Whether these should be run by the PA administrations or by the hydrometeorological service of the NEA needs to be discussed among national stakeholders and is also addressed in the PA adaptation plans.

4.2 Reliability of hypotheses on climate change vulnerability

Section 3.7 summarizes available information about observed vulnerabilities of the main conservation values of the target area to recent climate change. It shows that even this information is very limited, because systematic ecological monitoring has been largely absent from the target PAs until very recently (and in part still is). If even past climate change vulnerabilities are not clearly understood, this means that future vulnerabilities will be even more difficult to discern.

In this assessment, we constructed – in a participatory manner – climate change scenarios from locally specific climate change projections and used information from the peer-reviewed international scientific literature about functional relationships between climate change, ecosystems and their biota to work out hypotheses about specific vulnerabilities of the major conservation values of the Central Greater Caucasus. We stress that these **(1)** are hypotheses, which will need systematic testing through targeted ecological monitoring and scientific studies, and that at the same time **(2)** these hypotheses are nevertheless useful to inform future conservation management in the target PAs.

There are two sources of uncertainty involved in hypothesizing climate change impacts from scenarios and stakeholder experience or published studies (for the target area or from other locations) about functional linkages between climate change and the viability of conservation values:

- **Uncertainty of climate change projections:** This uncertainty is taken into account during the scenario planning step, as the real climate in the target area is very likely going to be within the envelope defined by the four scenarios together.
- **Completeness, correctness, and relevance of identified functional linkages:** It is possible that not all relevant functional linkages between the projected climate changes in the target area and the viability of their biota have been identified by local stakeholders previously or are represented in the literature. At the same time, some – by far not all – functional linkages reported in the literature may be incorrect or not apply in our target area.

Even with the remaining uncertainty, the vulnerabilities hypothesized as a result of this analysis are useful because, depending on the degree of confidence in functional linkages, they can be used to define precautionary management interventions and to guide the development of targeted monitoring programmes aimed at providing an early warning in case the ecosystems and other biodiversity of the area are indeed affected by climate change in the hypothesized way.

4.3 Relative importance of climate change related threats to PA management

Like in many countries, PA management effectiveness in Georgia continues to be resource limited, i.e. higher management effectiveness then observed could be achieved if more financial resources could be invested into human resources and their training, infrastructure and equipment. Some actions prescribed by Georgian PA management plans are not being implemented because of this. In such a resource limited situation, PA authorities need to decide into which management areas to invest their scarce resources.

This leads to the question whether the overall conservation goals of the target PAs will be pursued more effectively by investing into climate change adaptation – i. e. into interventions to reduce the climate change vulnerability of the main biodiversity values – or into reducing their vulnerability to conventional, non-climate related threats. This question can not be answered in general terms, because it depends on the relative magnitude of conventional threats versus climate change vulnerabilities in each area. It is also likely that the relative importance of these changes over time. For instance, hypothetically it might be more important to address a current high threat from poaching in the short term, to invest into climate change adaptation later.

To weight these factors, it is important to appraise the relative magnitude of conventional threats versus climate change impacts. For the target area, this appraisal (Table 6) leads to the conclusion that climate change impacts will become a higher priority for PA management even for the near future (2021-2040 projection period) and definitely for the remote future (2061-2080). Therefore it is timely to start routinely integrating climate change adaptation measures into the management systems of the target protected areas. The relative priority of addressing non-climate threats versus climate change vulnerabilities for specific conservation values can also be discussed more specifically, based on the respective threat ratings and a cost/benefit analysis of management options.

4.4 Trade-offs between width versus depth of analyses of climate change vulnerability

Discerning and weighting the already observed and likely future impacts of climate change on even a single species or ecosystem is a difficult and laborious task. During the literature analysis, we found entire scientific articles and in some cases even series of articles dedicated to observed or modelled linkages between specific aspects of climate change and individual species/ecosystems. This academic approach can be characterized as “deep”, because individual specific linkages are studied and evaluated into detail.

In contrast, we broadly assessed the vulnerabilities of ***all*** identified main conservation values (ecosystems and species) of the target PAs to ***all*** observed and plausible projected climate change impacts, taking into account ***several*** climate change scenarios. As a result, the width of our assessment vastly exceeds that of academic assessments as discussed above. This also means that not the same amount of resources could be invested into the depth of the analysis. While the result is unlikely to meet the standards of a specialized academic study, it is nevertheless relevant to PA management and therefore justified.

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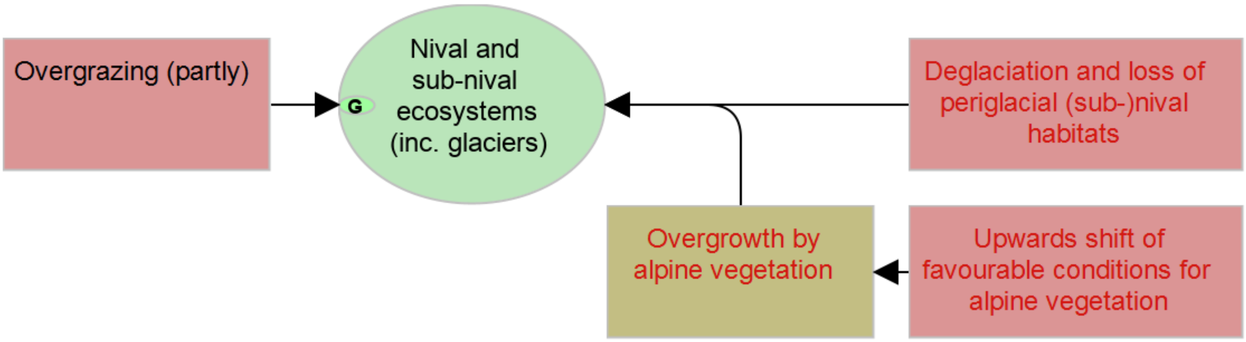
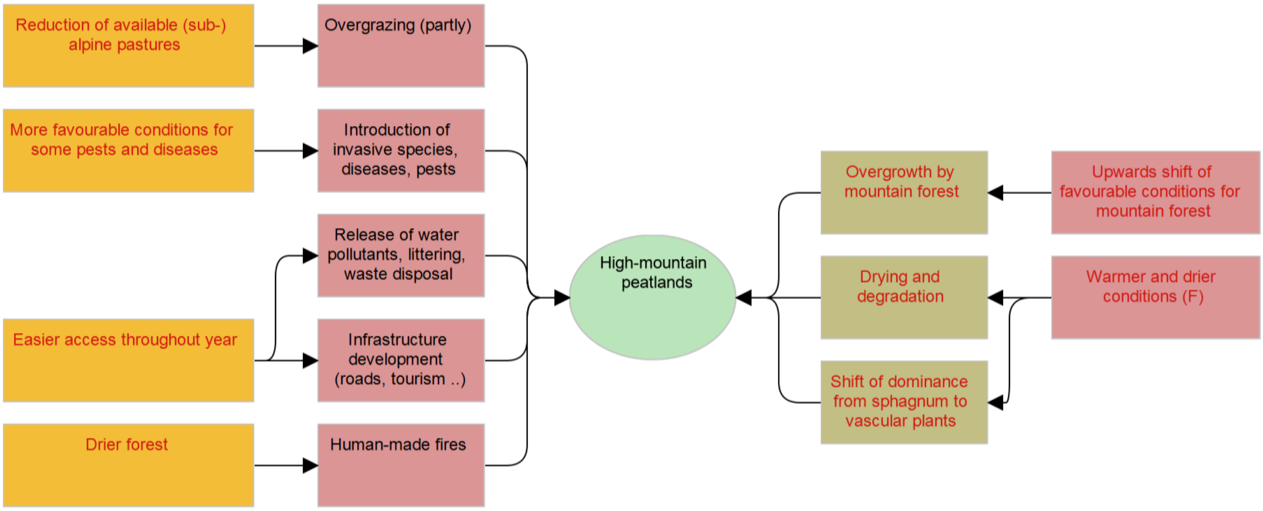
6 Appendix

Situation model with climate change vulnerabilities for individual conservation values (see Table 6 for vulnerability ratings):

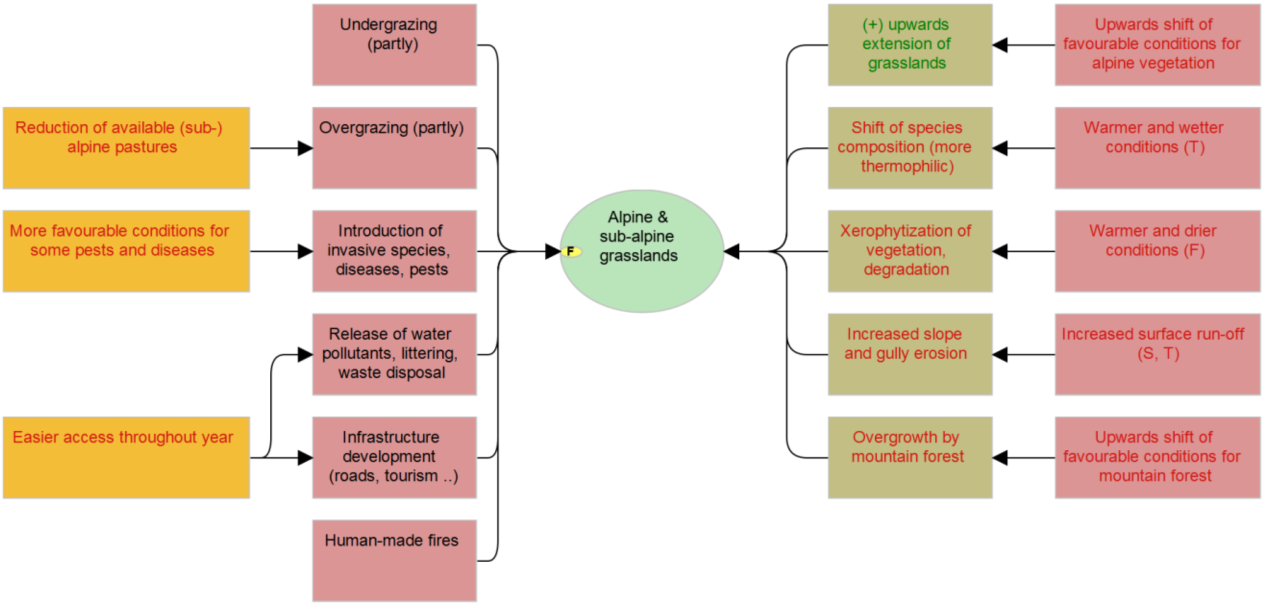
a) *Situation model for Nival and Sub-Nival Ecosystem (inc. Glaciers).*



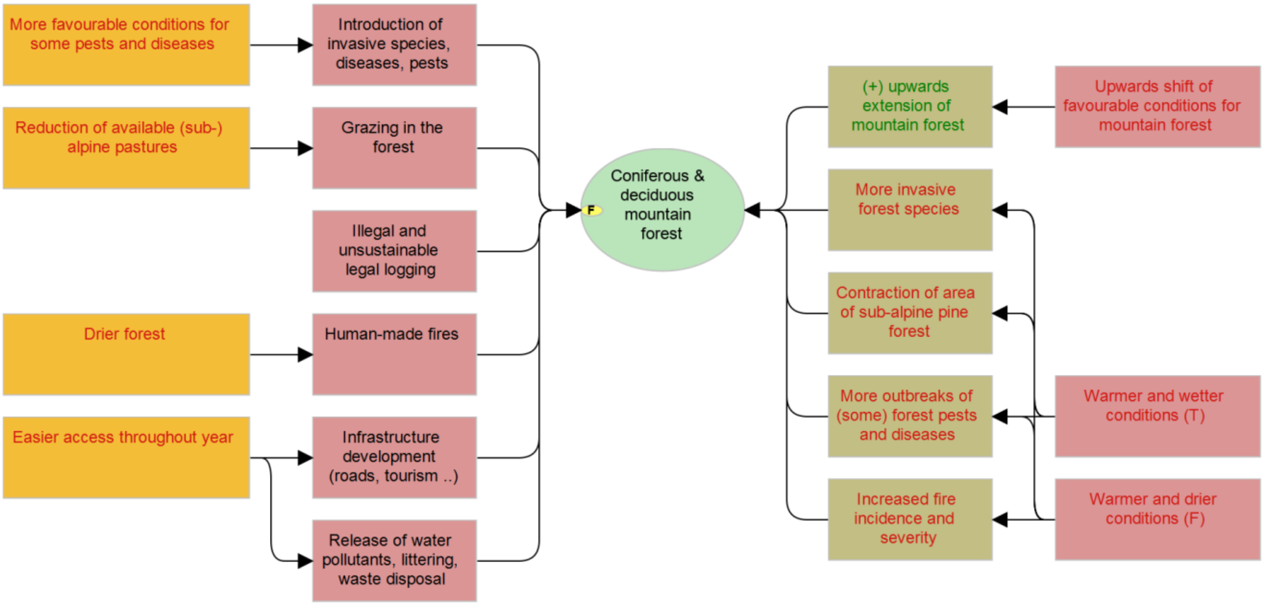
b) *Situation model for High-Mountain Peatlands.*



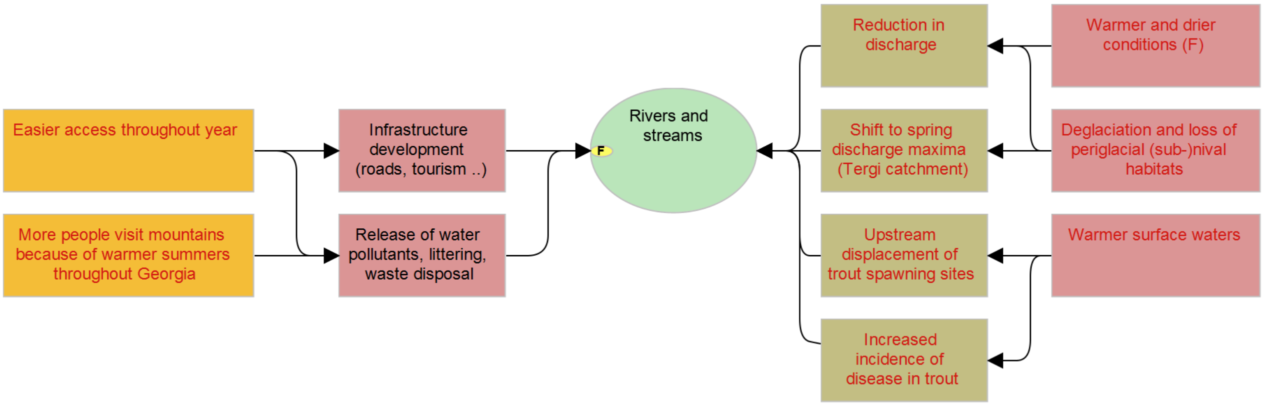
c) Situation model for Apline and Sub-Apline Grasslands.



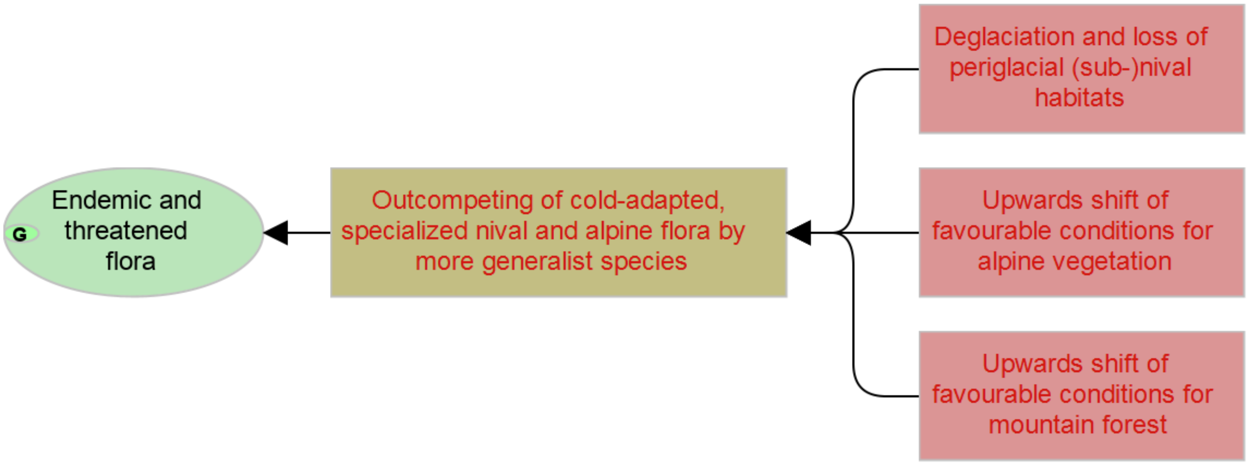
d) Situation model for Apline and Sub-Apline Grasslands.



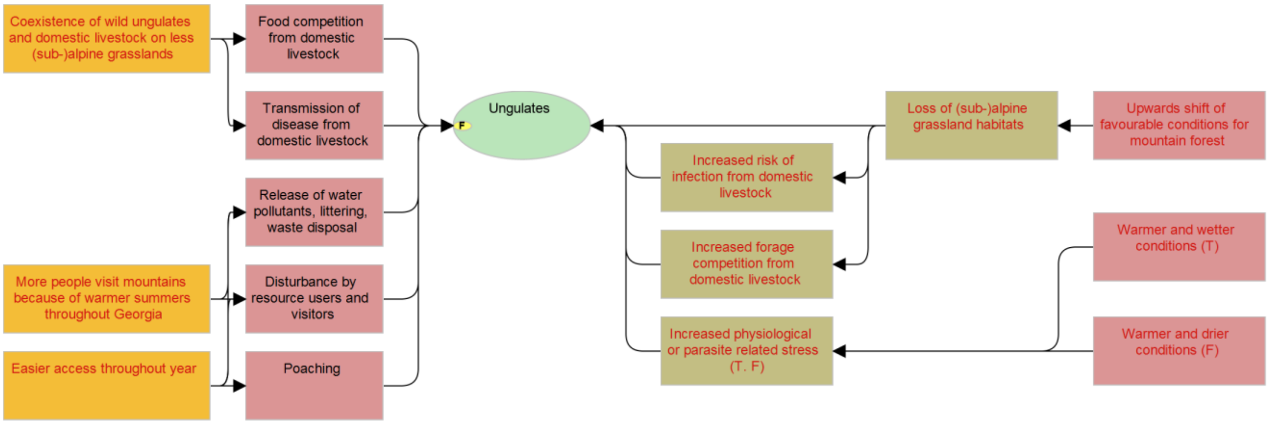
e) Situation model for Rivers and Streams.



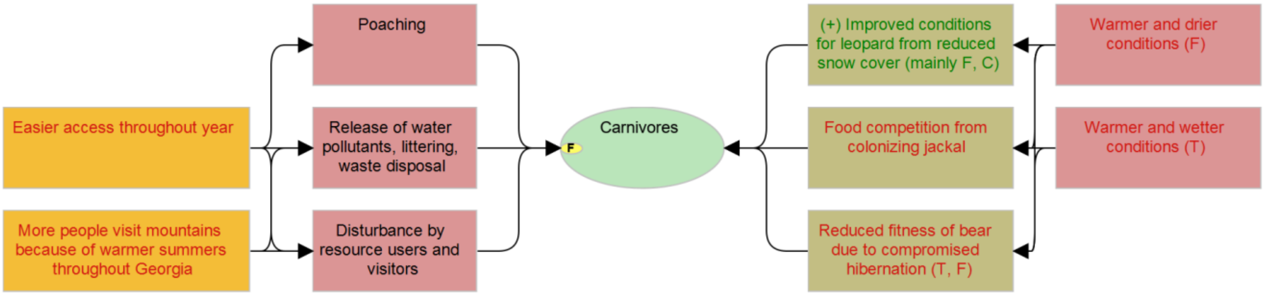
f) Situation model for Endemic and Threatened Flora.



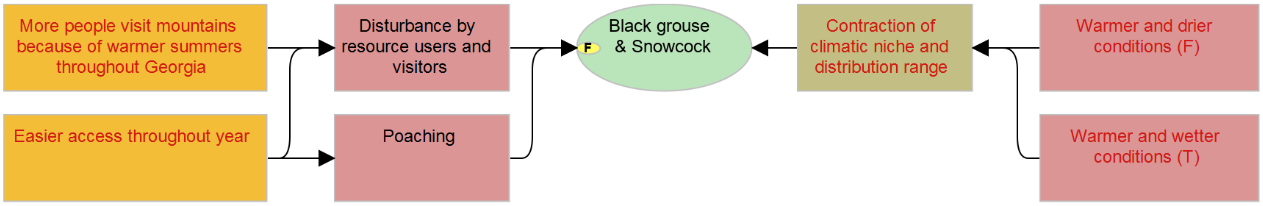
g) Situation model for Ungulates.



h) Situation model for Carnivores



i) Situation model for Galliforms



j) Situation model for Herpetofauna