Climate Change and Land Use Impacts on Ecosystems and Human Well-being in Shatskyi Biosphere Reserve

Situation Analysis for Ecosystem-based Adaptation

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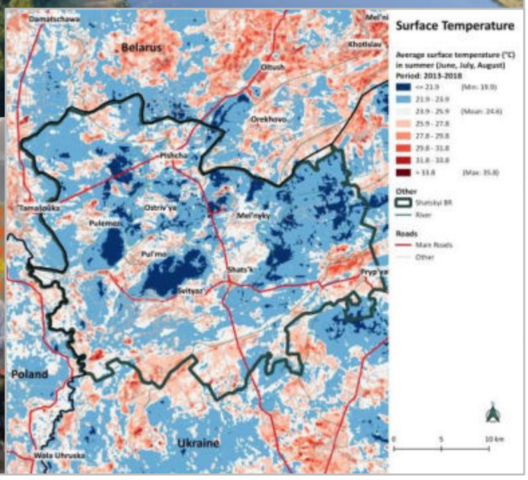

in the frame of the project:

"Ecosystem-based Adaptation to Climate Change and Regional Sustainable Development by Empowerment of Ukrainian Biosphere Reserves"

Implemented by:

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Eberswalde and Greifswald, 2021

International Project:

"Ecosystem-based Adaptation to Climate Change and Regional Sustainable Development by Empowerment of Ukrainian Biosphere Reserves"

https://eba-ukraine.net/

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IKI INTERNATIONAL CLIMATE INITIATIVE

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Contents

1 Introduction

This document provides a summary of the situation analysis and the diagnosis. It is the cumulative result of the findings, discussions, and excursions during a. the citizen workshops[1] b. GIS-based analysis and mapping c. MARISCO (adaptive **MA**nagement of vulnerability and **RIS**k at **CO**nservation sites) expert workshops[2] d. EbA training[3] and recent developments since these events.

The aim is to highlight socio-ecological system components, their functions and services, and their vulnerabilities, especially connected to climate change-related impacts and anthropogenic drivers.

The two coupled and integrated ecosystem-based management approaches of Ecosystem-based Adaptation to climate change (EbA) and the MARISCO method and toolbox are powerful tools to:

1. Analyze the situation, vulnerability, and potentials of the respective socio-ecological-system on a holistic and systemic level, permitting a better understanding and visualization of cause-effect chains, feedback loops and for the identification of leverage points to facilitate the right choice of strategic entry points.

2. Guarantee participation of the local and regional population, stakeholders, land-users, experts, professionals, and decision-makers, thus striving for a holistic approach (diverse sectors and points of view) and understanding of diverse necessities, limitations, and framework conditions. EbA can be successful and applied in the long run if it is structurally rooted in the regional and local administrations, decision-making, and land users' mental models, awareness, and knowledge systems.

Applying an adaptive management approach to climate change adaptation – please note!

Due to the complexity and variability of ecosystem processes and functions, which is even increased by the interaction with social systems and constructs, the here applied approach to Ecosystem-based Adaptation is adaptive by nature.

The approach is itself a learning process, helping to adapt methodologies and practices according to how the relevant systems are being managed and monitored. The aim is to reach workable preliminary conclusions based on the best available and accessible data (which is mostly not peer-reviewed and site-specific). Based on such conclusions the most fitting strategy and implementation programs can be designed, yet in ways to always allow for adjustment to the unexpected, contrary to making rigid assumptions and taking steps based on the false belief of certainties. Such flexibility is also necessary for policymaking and implementation because long-term inflexible decisions are likely to become outdated, inadequate, or even detrimental for the system.

At both spatial and temporal scales climate change impacts, biodiversity loss, and ecosystem malfunctioning become evident to local stakeholders. Irrespective of scale, it is important that people are considered as part of, rather than actors external to the ecosystem. It is crucial to recognize the diversity of social and cultural factors affecting natural resource use. Thus, the concept of a 'socio-ecological *system'* is used throughout the document. It requires considering the specialties and uniqueness of local and traditional knowledge, regional expertise and combining and triangulating these knowledge systems with available scientific studies and research on the local, regional, and wider spatial scales.

Thus, ecosystem management and the here applied approaches, need to be envisioned as a long-term experiment that builds on its results as it progresses, a 'learning-by-doing', a source of information, and a shared gaining of knowledge and progress towards mutually agreed goals.

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[1] The citizen workshops took place in November 2018 and involved a variety of local participants of different age, gender and background.

[2] The MARISCO expert workshops were conducted from 3 to 5 June 2019 in Svitiaz village.

3 The training on Ecosystem-based Adaptation to Climate Change with 28 Ukrainian and German participants took place in December 2019, Eberswalde, Germany.

2 Situation Analysis

One central component of the situation analysis is the MARISCO method. Its output is a comprehensive diagnostic of the area, including ecological stresses diminishing ecosystem functionality and their drivers such as climate change and anthropogenic factors. Both human affectedness and stake in such processes were analyzed and depicted systemically. Besides, a basic portfolio of potential ecosystem-based strategies for adaptation to climate change was developed.

A short introduction to the MARISCO method in frame of the EbA Ukraine project
MARISCO method is an approach and toolbox to adaptive ecosystem-based management. It facilitates the integration of dynamic risk and vulnerability perspectives into the management of conservation projects and sites[4].

To gain knowledge and to analyze the complex socio-ecological system at Shatskyi BR, the project team applies this method, a stepwise process to identify and map both essential and strategically relevant elements of the system. The involvement and active participation of diverse groups of local and regional citizens, professionals, experts, and scientists were ensured to make the model and analysis as site-specific and robust as possible. The findings are being extended and completed by excursions, spatial analyses, and desktop research.

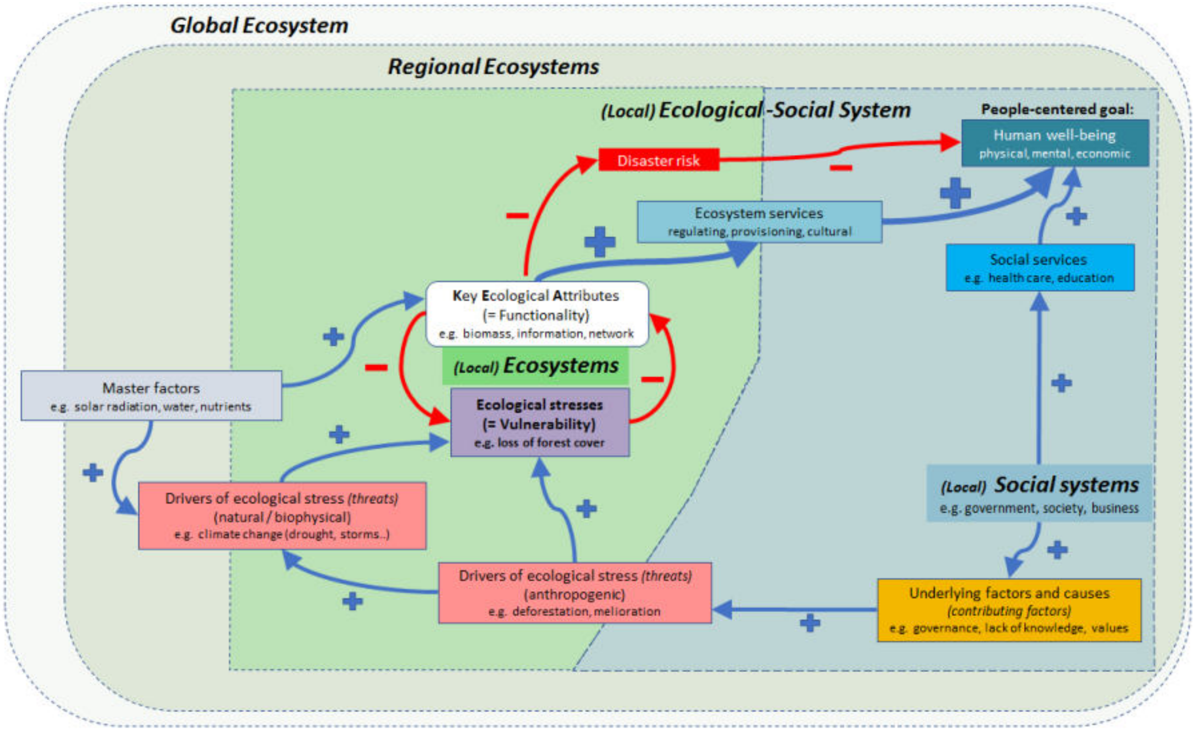

Figure 1 Conceptual model for the MARISCO situation analysis approach; Illustration by K.Mack

This situation analysis comprises the **ecosystems of the Shatskyi BR area**, their respective **key ecological attributes (KEA),** and the **ecosystem services (ES)** they provide to people. A high functionality (availability of KEAs) of the ecosystems secures the quality and quantity of ecosystem services, thus contributing to **human well-being in the Biosphere Reserve and beyond**. The **ecological stresses** (e.g. loss of forest cover) describe degraded or even destroyed KEAs (biomass, information, and network), thus indicating the increased vulnerability of the ecosystems. The **drivers of such ecological stresses** can both be of natural/biophysical (e.g. climate change) and anthropogenic origin (e.g. deforestation, melioration). Nowadays, such drivers of stresses mostly stem from human **underlying factors and causes** (e.g. governance, lack of knowledge, values), which are driven by the government, societal, economic, and other sectors, constituting the **social systems**. The social systems also contribute (or not) to human well-being via the so-called **social services** (e.g. health care, education).

[4] MARISCO (**MA**nagement of vulnerability and **RIS**k at **CO**nservation sites), Source: https://www.marisco.training/

2.1 Ecosystems, their Functions, and Services

Nature is the basis of all life. Ecosystems, i.e. the habitats and organisms inhabiting them, are the natural structures in which the various components interact particularly intensively and perform different services. They consist of complex, dynamically interacting functional units with emergent properties. From a functional point of view, ecosystems are self-organizing bioreactors through the interaction of their living components, in which energy is captured, passed on, converted, stored, and above all, used to perform work.

Thus, ecosystems are complex systems that use energy and perform work in the physical sense. They result from the fact that living organisms interact as system components with each other and with inanimate resources and thereby develop emergent properties, such as temperature regulation. This guarantees or promotes their continued existence.

Main ecosystem classes of the Shatskyi Biosphere Reserve

The following images* show the four general ecosystem classes selected for the Shatskyi BR.

Forest ecosystems

Water ecosystems

Wetland and grassland ecosystems

Cropland and settlement ecosystems

**Images by - Top left: Shatskyi BR / Top right: Shatskyi BR / Bottom left: Shatskyi BR / Bottom right: A. Schick*

Ecosystem map with ecotope classes

The existing functional ecosystem classes in the Shatskyi BR were identified and defined during the MARISCO workshop and in course of the spatial analysis commissioned by the project group.

The map includes data based on landcover classification made within the framework of this project using current sentinel satellite images and manually mapped hydrological and other physiotope conditions, including publicly available data.

The ecosystem map (based on ecotope classes) is **attached to this document series in printed A1 format** and can be accessed online via the project website: https://www.eba-ukraine.net/maps.html

2.1.1 Ecosystem classes and their functions

Results of ecosystems performing work include all physical, chemical, and biological processes and interactions that take place in the various ecosystems. For example, ecosystems produce biomass, filter, and store water, ensure the pollination of plants and thus their survival (also in agriculture), convert and decompose organic and inorganic substances and thus maintain soil fertility. Emergent properties of these systems are for example temperature regulation, which is a precondition for the survival and well-being of many species, including humans. Thus, ecosystems fulfill several important functions and significantly influence many of the life-enabling processes.

Ecosystem Functionality

The functionality of an ecosystem describes a certain state of an ecosystem. It is characterized by inherent structures, ecological functions, and dynamics, the so-called **Key Ecological Attributes** that provide an ecosystem with the following conditions:

- The necessary (energetic, material, and hydric) efficiency
- The flexibility to demonstrate the development of resilience without abrupt changes in system properties and geographical distribution, and to respond flexibly to external change.
- The adaptive capacity to adapt to perturbations and shocks (e.g. caused by climate change)

Thus, the decisive criteria include the nativeness or naturalness of the respective ecosystem, the degree of self-regulation, the amount and type of vegetation or plant biomass, the complexity and diversity, and the proportion of the unsealed area.

The following table introduces the semi-quantitative ranking (levels) of (self-) regulating capacity to reduce climate change vulnerability and risk according to the availability of functional ecological structures and processes.

Level of (self-) regulating capacity based on ecosystem functionality		**Definition**
1	Very high	The ecosystem is **in a (near-) natural state, almost undisturbed** such that **all functional ecological structures and (self-) regulating capacity** are **fully available and maximal**. The conditions are highly beneficial for local and regional climate regulation and buffering.
2	High	The ecosystem is in a **largely natural state** and **negligibly impaired** such that many **functional ecological structures and (self-) regulating capacity** are **available to a high degree**. The conditions are beneficial for local and regional climate regulation and buffering.
3	Rather high	The ecosystem is **partly artificial** and **relevantly impaired** such that **some functional ecological structures and (self-) regulating capacity** are available to **a moderate degree**. The conditions are somewhat beneficial for local and regional climate regulation and buffering.
4	Rather low	The ecosystem is **mostly artificial**, **impaired, and disturbed** such that **functional ecological structures and (self-) regulating capacity are limited**. The conditions are marginally beneficial for local and regional climate regulation and buffering.
5	Low	The ecosystem is **highly artificial**, **significantly impaired, and disturbed** such that **functional ecological structures and (self-) regulating capacity are low**. The conditions are not beneficial or even detrimental for local and regional climate regulation and buffering.
6	Very low	The ecosystem is **completely artificial, heavily impaired, and disturbed** such that **functional ecological structures and (self-) regulating capacity are minimal**. The conditions are harmful to local and regional climate regulation and buffering.

The following tables (2.1.1-2.1.4) describe the ecosystems´ functional classes according to their general site conditions and ranked level of ecological functionality.

2.1.1.1 Forest ecosystems

Forest ecosystem (Functional classes)	Site condition	Description	Approx. Area Size in ha (% of total territory)	Ranked level of functionality (Scale 1: highest – 6: lowest)
Include: Boreal coniferous forests, temperate and sub-polar broadleaf forests, and woodlands				
Broadleaved and Mixed	On low flat watershed surfaces		10.937,05 (14,46%)	
		Natural and near-natural (Conservation and protected forests)		1
		Artificial (Plantations and intensively exploited)		3
Needle-leaf (coniferous)	On low flat watershed surfaces		22.551,28 (29,82%)	
		Natural and near-natural (Conservation and protected forests)		2
		Artificial (Plantations and intensively exploited)		4

Functionality of forest at Shatskyi BR

The area encompasses various forest ecosystems that are differently limited in their functional capacity (Map 11-14: Cooling capacity map as an indicator of the level of regulating functionality). Depending on the degree of use and change, the different forest ecosystems show more or less (self-) regulating capacity.

In the overall forest area, a share of about 67% is dominated by pure and mixed pine stands which form on classical pine relief from dry lichen pine stands to sphagnum wetlands pine forests. The remaining 33% consist of broad-leaved and mixed broad-leaved forests, oak, oak-hornbeam, ash-alder, and fragments of spruce, which are mostly located on loamy soils. In waterlogged areas exist plantations with black alder, birch (Betula pubescens), less often composed with pine, oak, ash, and aspen.

The near-natural broad-leaved and mixed broad-leaved stands with native main tree species, including bog and fen forests, are home to small areas and communities of alder, grey willow, oak, pine, hornbeam, ash-alder. They occur with and without mixed and secondary tree species and have a very high functional capacity. Anthropogenic influence, i.e. ecosystem stresses directly caused by humans, are comparatively low. Due to the high diversity of species and structures and the high proportion of native broad-leaved trees, these stands have sufficient (self-) regulating capacity that climate change impacts are buffered and climate change-induced stresses can occur rarely or only in a weak form.

Mixed pine-broad-leaved stands are usually older stands with scots pine as the main tree species and broad-leaved trees such as Oak (Quercus robur L.), European white birch (betula pendula), Hazel (Corylus avellana L. and late blossoming secondary tree species. Due to the mixture of species and age classes as well as the comparatively high proportion of broad-leaved trees, the functional efficiency can be classified as high, although not very high, since these stands were mostly established or actively influenced by humans.

Pure common pine (Pinus sylvestris L.) stands, mixed pine-needle stands, and other coniferous stands are relatively unnatural forest ecosystems with conifers such as the scots pine, common spruce, or Douglas fir from North America as main tree species is present. Thus, the functional efficiency can be classified as medium to low. Permanent human interventions characterize these ecosystems; self-regulation can hardly take place. Many essential ecosystem structures and processes are missing in these forests, which also makes them vulnerable to climate change impacts in the long term.

Clearcut areas, pioneer forests, and young forests exist due to human activities. These include young afforestations, bare areas, clearings, and patches with overstory on dry sites. Often these areas undergo further maintenance and development interventions such as weeding, planting, and later thinning. However, these highly transformative ecosystems have a high potential to build ecological functioning if allowed to develop in a primarily self-regulated manner in the future. They have intermediate functional capacity.

2.1.1.2 Water ecosystems

Ecosystem types (Functional classes)	**Description**	**Approx. Area Size in ha (% of total territory)**	**Ranked level of functionality (Scale 1: highest – 6: lowest)**
Lakes	Undisturbed and (near-)natural, protected	6.400	1
	Highly frequented and used		2
Springs			1
Ponds (natural)			1
Small (artificial) ponds			3
Wells			4
Rivers			1
Smaller streams			1
Drainage Systems / Melioration channels			6
Other artificially changed water bodies			5

The **hydrography map** (based on ecosystem data) is **attached to this document series in printed A1 format** and can be accessed online via the project website: https://www.eba-ukraine.net/maps.html

Functional classes of water ecosystems

In this classification, water bodies include still waters (e.g. the large Shatskyi lake complex including Lake Svitiaz, puddles, or ponds) as well as continuously above-ground-flowing freshwater bodies and their smaller tributaries. These have grown and developed naturally, but can also be artificially created (e.g. ponds or pools in the settlement area or for agricultural or forestry use). Ponds or pools are not bound to a specific section of the landscape in any characteristic way. Due to their ability to absorb, supply, and evaporate water, they play a significant role in ecosystem-based adaptation to climate change.

In Shatskyi BR, especially the still waters including the regionally large Lake Svitiaz and the partly artificially interconnected lake complexes are dominating the landscape. Furthermore, the area is significantly characterized by drainage ditches, water regulation facilities (small dams). Smaller rivers are present including piped streams and small creeks. Smaller flowing waters are in part strongly influenced by humans. This includes not only the many changes in river courses caused over centuries but more recently also measures of renaturation and revitalization. Locally, these effects manifest themselves in part very differently and are often also spatially displaced. Similar to still waters, streams are central to ecosystem-based adaptation to climate change because of their ability to absorb, store, remove, and evaporate water. Their spatial dispersal and connectivity are particularly important to the networking between different ecosystems.

2.1.1.3 Wetland and Grassland Ecosystems

Ecosystem	Site condition	Functional classes / with … vegetation	Approx. Area Size in ha (% of total territory)	Ranked level of functionality (Scale 1: highest – 6: lowest)
Wetland				
	…in depressions and river floodplains …	Lakeside marshes, oligotrophic bogs, eutrophic fens, mesotrophic (transitional) mires…		1
		…with broadleaved and mixed forest (incl. former drained and fodder-crop land – e.g. birch encroached)	7.859,24 (10,39%)	2
		…with coniferous forest	3.232,65 (4,27%)	3
		…with grassland (boggy grassland, peat grassland)	8.636,46 (11,42%)	3
		…with cropland (incl. fodder crops on drained eutrophic mires (fens))	2.342,36 (3,10%)	5
Grassland	…on low flat watershed surfaces	(e.g. dry heathland)	5.805,66 (7,68%)	3

The presence of especially lakeside marshes, oligotrophic bogs, eutrophic fens, and mesotrophic mires is highly relevant in the Shatskyi BR area. These ecosystems play a significant role as they represent a transitional form between water bodies and terrestrial habitats. The use and alteration of sites where wetlands are present vary greatly, which also has different effects on their functional capacity. Only (semi-)natural swamps, bogs, fens, and marshes have a very high ecological functional capacity. As semi-terrestrial sites, they combine the water storage capacity of water bodies with the ability of terrestrial systems to produce plant biomass that additionally stores and evaporates water. Here, the landscape cooling functions also play a vital role in climate regulation. Farmed and degraded wetlands, on the other hand, tend to match their environment in functional capacity. For example, used bog and fen sites by agriculture and livestock grazing have intermediate to low functional capacity.

2.1.1.4 Cropland and Settlement Ecosystems

Ecosystem	Site condition	Functional classes	Approx. Area Size in ha (% of total territory)	Ranked level of functionality (Scale 1: highest – 6: lowest)
Cropland	On low flat watershed surfaces (e.g. on mineral soils)		3.280,33 (4,34%)	
		Pastures		3
		Hayfields		3
		Cropland (intensively used)		4
Settlements	On low flat watershed surfaces (e.g. on mineral soils)		4.409,71 (5,83%)	
		Cemeteries		4
		Allotment gardens		4
		Settlement (housing) areas		5
		Quarries		6
		Waste polygons		6
		Sewage and waste pits		6
		Roads		6

2.1.2 Ecosystem services

Ecosystems are not only 'nature' out there, beautiful, and simply given. For us humans they are also the indispensable basis of our well-being and economic activity: they provide food, clean water, living space, and a source of income. They also provide recreation and a sense of home. These ecosystem services are essential for human well-being. In addition to these more obvious provisioning and cultural services we receive from ecosystems, they also regulate water balance and water quality, influence air quality, and local climate, protect against soil loss or degrade pollutants. These regulating services are seemingly inexhaustible and free for everyone to use which is why they are often neglected in economic and development considerations.

According to the *Common Classification of Ecosystem Services* (CICES) developed by Haines-Young & Potschin, these services obtained from ecosystems for human benefit can be ordered into the following three classes:

Regulating Ecosystem Services

In current times of accelerating climate change, regulating ecosystem services are coming to the fore. They are the key services when it comes to adaptation to climate change. These include services that result from the fact that the work of ecosystems positively influences the quality of the environment such as air and water purification, pollination, fertile soils, flood prevention (e.g. through soil- and plant water retention), and climate regulation. Further examples are the storage of greenhouse gas carbon dioxide or biological control of pest infestation.

The regulating services can be understood as fundamental services, themselves guaranteeing a sufficient and qualitative provision of material and cultural services.

Provisioning Ecosystem Services

Provisioning ecosystem services are the goods (biomass and genetic materials) that are produced by ecosystems and used by humans. For example, food (such as fish, fruit, and vegetables), drinking water, timber (e.g. as construction material), and fuel materials (firewood, peat) are provided by ecosystems.

Cultural Ecosystem Services

Cultural ecosystem services are of high relevance, especially in modern, technology-oriented societies. Varied and semi-natural landscapes offer high recreational, educational, and adventure value. The typical features and the condition of ecosystems have a complex effect on the human psyche. In this way, they also create an identity and contribute to people feeling connected to their habitat.

On the following page, a non-exhaustive list of ecosystem services of the Shatskyi BR is depicted. They were identified and discussed by a group of local citizens, experts, and stakeholders.

**Images by - Top: Pierre L. Ibisch / Middle: Shatskyi BR / Bottom: Shatskyi BR*

Regulating Ecosystem Services

Regulation of physical, chemical, biological conditions

Regulation of baseline flows and extreme events
- Wind erosion reduction and prevention
- Water runoff regulation
- Hydrological cycle and water flow regulation (Including flood control)
    - Regulation of surface water level and runoff
    - Regulation of groundwater level
- Water accumulation and retention (incl. flood protection)
- Protection from soil erosion
- Reduction of wind speed; wind protection*
- Fire protection*

Lifecycle maintenance, habitat, and gene pool protection
- Pollination*
- Seed dispersal*
- Maintaining nursery populations and habitats*
- Biotic production

Pest and disease control
- Pest control and reduction of the spread of invasive species*
- Prevention and reduction of diseases*

Regulation of soil quality
- Soil formation
- Soil moisture regulation
- Mediation of weathering processes*
- Decomposition and fixing processes*

Regulation of water quality
- Regulation of the chemical and physical quality of freshwater in surface waters (standing and flowing)
    - Water purification (of lakes)
- Regulation of the chemical and physical quality of groundwater

Regulation of air/atmosphere quality and climate regulation
- Microclimate regulation
- Filtration and purification of air
- Air humidity regulation
- Carbon sequestration (reduction of anthropogenic CO2 emissions)
- Oxygen production

Transformation of biochemical or physical inputs

Mediation of wastes or toxic substances of anthropogenic origin
- Bioremediation/cleaning by (micro-) organisms*
- Filtration, accumulation, storage by (micro-) organisms*

Mediation of nuisances of anthropogenic origin
- Smell reduction
- Noise attenuation
- Visual screening

Provisioning Ecosystem Services

Biomass

Nutritional use
- Non-timber forest products (berries, mushrooms, medical herbs)
- Hunting products (not in the core zone)
- Fishery products (both private and business)
- Organic food
- Honey (beekeeping)
- Agricultural produces (crops/grains/vegetables)
- Meat and dairy products by livestock breeding

Materials
- Timber
- Construction wood
- Hay
- Therapeutically used mud and water
- Peat resources

Energetic use
- Fuelwood / Firewood
- Peat

Fundamental goods
- Fresh and clean air
- Fresh and clean water

Genetic material from all types of organisms*
- Seeds, spores, and other plant materials collected for maintaining or establishing a population*
- Individual plants used to breed new strains or varieties*
- Individual genes extracted from plants for the design and construction of new biological entities*
- Animal material collected to maintain or establish a population*
- Wild animals (whole organisms) used to breed new strains or varieties*
- Individual genes extracted from organisms for the design and construction of new biological entities*

Cultural Ecosystem Services

Direct outdoor interactions with living/ecological systems in their natural setting

Physical and intellectual interactions with biota, ecosystems, and landscapes
- Tourism
- Agritourism
- Recreation / sports (swimming etc.)
- Photo hunting
- Health treatment (sanatoriums) – mud
- Ecological education (researching and studying nature)
- Bird/ animal watching

Spiritual, symbolic, and other interactions with biota, ecosystem, and landscapes
- Aesthetic value
- Spiritual, traditional, and cultural value

Table 1: Shatskyi BR Ecosystem Services; Classification based on CICES, Haines-Young & Potschin (2017), contents by workshop participants

*added by the author based on CICES

2.2 Ecosystem Vulnerability, Risks, and Human Affectedness

In the Millennium Ecosystem Assessment, vulnerability is defined as:

> *Exposure to contingencies and stress and the difficulty in coping with them. Three major dimensions of vulnerability are involved: **exposure** to stresses, perturbations, and shocks; the **sensitivity** to the stress or perturbation, including their capacity to anticipate and cope with the stress; and the **resilience** of the exposed ecosystems in terms of their capacity to absorb shocks and perturbations while maintaining function.*[5]

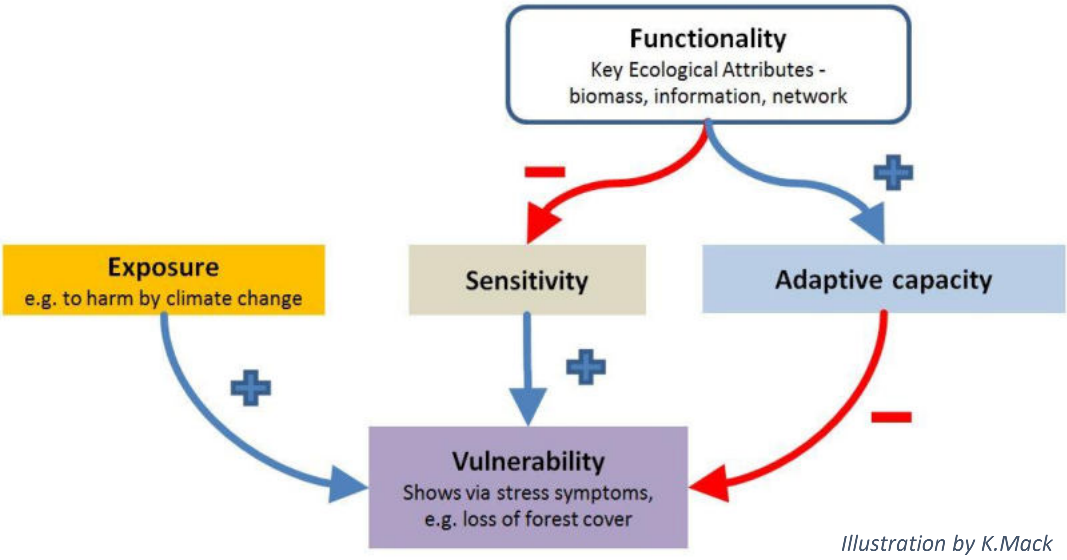

Illustration by K.Mack

Exposure to e.g. climate change causes stress in the ecosystems (e.g. by extreme temperatures or absent precipitation), indicating the increased overall vulnerability.

The **ecological stresses** are the visible symptoms and manifestations of the degradation of key ecological attributes. They indicate how stressed, i.e. vulnerable an ecosystem is. This includes the loss of minimum levels of biomass (e.g. trees, mosses, flowers, fungi, dead matter, etc.), information (gene pool, nutrient uptake, nutrient provision, etc.), and network (e.g. mycorrhizal symbiosis, nutrient exchange, etc.) due to insufficient availability or quality of master factors (e.g. energy input, moisture, temperature, nutrients, etc.)

The result is that, under certain conditions, the ecological attributes begin to degrade, which then impacts the resilience, adaptive capacity, and efficiency of biodiversity elements, such as species or ecosystems. If stress (or a mix of stresses) is sustained, shifts or changes in the ecosystem occur. Ecological stresses are **caused by the "drivers of ecological stress"** (as explained in chapter 2).[6]

The drivers of the ecological stress (also *threats*) can be natural events, for example, droughts and tornados, as well as anthropogenic activities such as deforestation or draining of landscapes. These threats damage and degrade the Key Ecological Attributes, i.e. decrease functionality, and increase vulnerability. The underlying factors and causes (also *contributing factors*) originate both from direct and indirect natural/biophysical processes as well as from anthropogenic origins.

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[5] Adapted from Millennium Ecosystem Assessment (2005), p. 605

[6] Ibisch P. L. and Hobson P. R. (eds.), *MARISCO: Adaptive MAnagement of vulnerability and RISk at COnservation sites: A guidebook for risk-robust, adaptive and ecosystem-based conservation of biodiversity* (Eberswalde: Centre for Econics and Ecosystem Management, 2014).

2.2.1 Exposure to climate change in Shatskyi Biosphere Reserve

Since 1945 regular climate observations within the Shatskyi Biosphere Reserve are conducted at the Svityaz weather station, located adjacent to the region's largest lake – Svityaz. Generally, the local climate is formed by westerlies, which bring most of the annual precipitation from the west. Due to various lakes, the microclimate of the region also features higher air humidity and distinguished impact of breeze winds on general air circulation patterns.

Over the past decades, it is noticed that climate change has increasingly played a role in changing (micro) climatic conditions of the Shatskyi BR territory, promoting a variety of observable and alarming alterations in the ecosystems, and their respective flora and fauna.

Changes in air temperature

During the climatic normal period between 1961 and 1990 (standard reference) the average annual air temperature was about 7.4 °C. It reached a maximum of 9.5 °C and 9.1 °C in 1989 and 1990 respectively. In the last 28 years (1991-2018) the mean annual temperature increased to 8.5 °C, i.e. by 1.1 °C. It has been particularly high since 2014 exceeding each year's value of 9.0 °C with a peak of 9.8 °C in 2015. The mean monthly temperature of the coldest and hottest months (i.e. January and July) in the periods of 1961-1990 and 1991-2018 were -4.6 vs -2.5 °C and 18.1 vs 19.8 °C respectively. This means that the average temperature in January during 1991-2010 has increased by about 2.1 degrees in comparison to 1961-1990, for July - by 1-1.7 degrees.

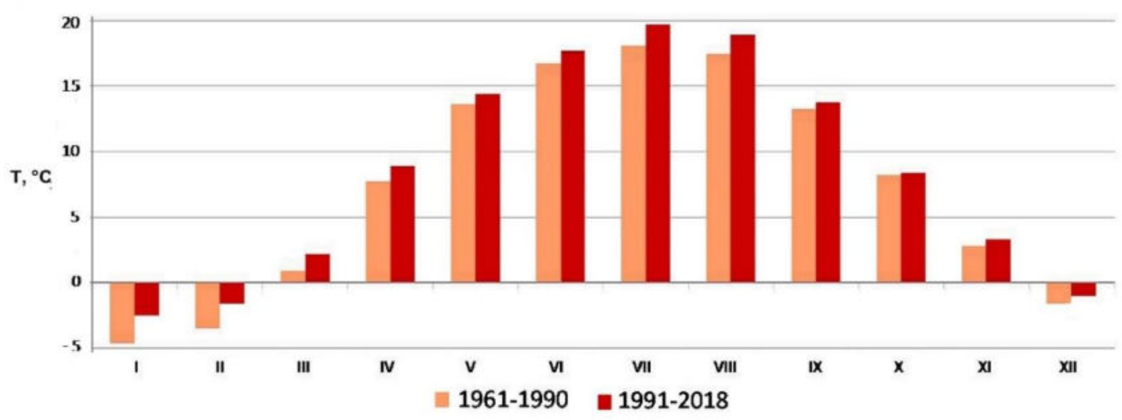


Figure 2 Monthly average temperatures for periods 1961-1990 and 1991-2018; Graph by A. Smaliychuk

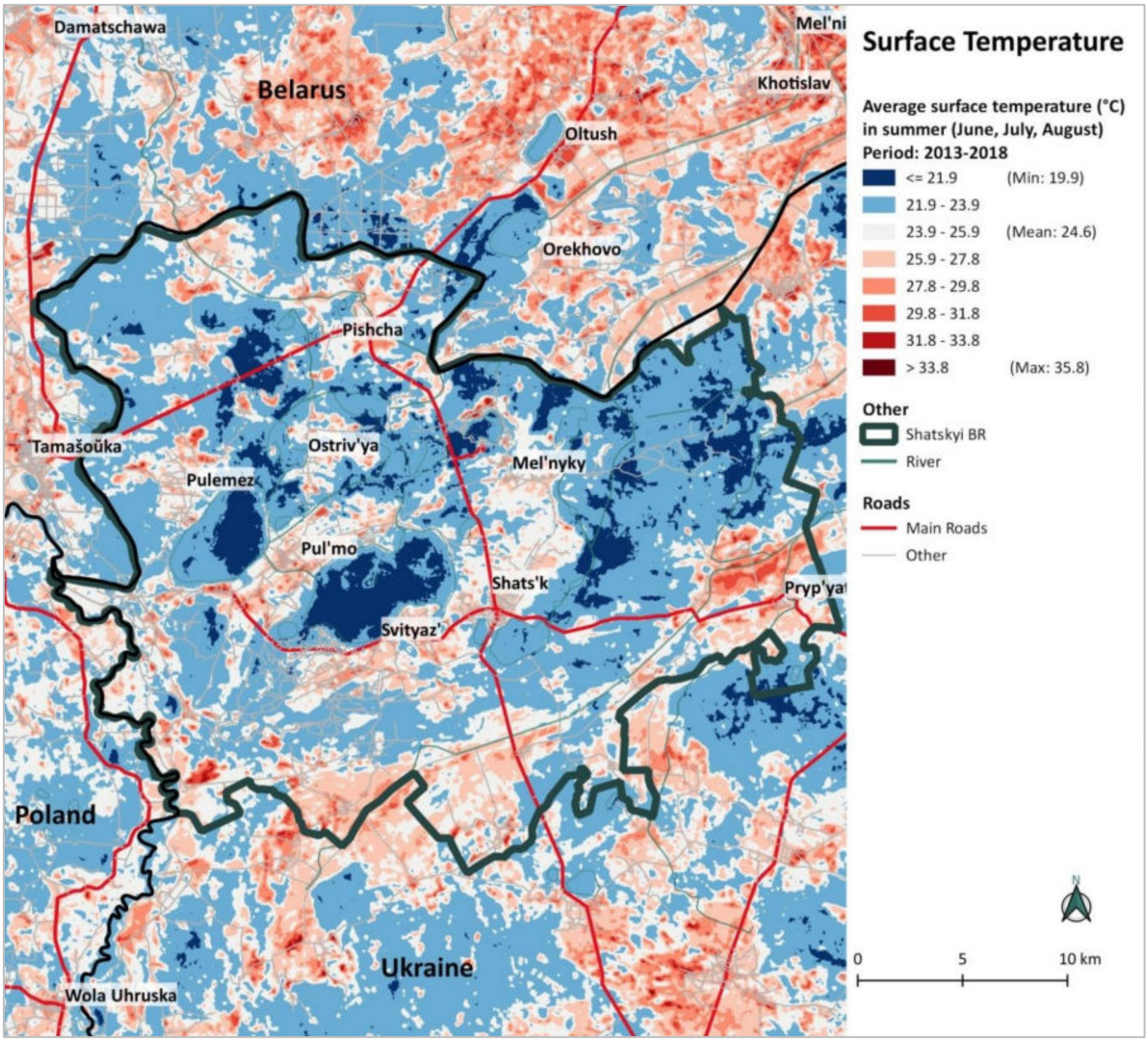
The highest increase in mean monthly temperatures in comparison to the climatic normal was observed for the winter (January & February) and summer months (July & August) (see figure 3). Moreover, this trend has accelerated in the recent five years (2014-2018) when the highest temperature rise was calculated as more than 2.5 °C for February, March, August, and December. It was particularly hot in August 2015 and July of 2014, when the average air temperature reached 21.9 and 21.2 °C respectively due to extreme heat waves during summer seasons. These values correspond to the past long-term average of Central-Eastern Ukraine within the steppe zone.

2018 was a dry and abnormally warm year in Volyn oblast. The air temperature has increased by about two degrees Celsius, and in some months the long-term average temperatures were increased by 3.5 °C. The summer days (maximum daily temperature exceeding 25 °C) were observed from April till September with a total number of 89 days in 2018 compared to 64 days average in 2014-2018. The absolute maximum and minimum recorded temperatures also increased in this timeframe.

Thus, the data and regular observations show a significant, fast-paced increase in average yearly, monthly, and daily temperatures. Seasonal temperature patterns are shifting - winters become abnormally warm and summers are very hot.

This increased number of warm and hot days also causes an incline in surface evaporation, having a significant effect on water bodies and the general hydrological situation of the region, diminishing the cooling capacity through evaporation from lakes, wetlands, forest, and grassland areas.

Satellite-based remote sensing data for the reflection of heat radiation now makes it possible to assess surface temperatures on a global, regional, and local scale. The surface temperature map (see figure 4) shows average surface temperature (°C) patterns in the summer months (June, July, August; day-time) at Shatskyi BR and adjacent regions. They were recorded by the Landsat 8 satellite every two weeks from 2013 till 2018 with a spatial resolution of 30 m. Compared with the ecosystem map on page 6, it appears that settlement and arable land show the warmest (red) areas and the large areas of forest, wetlands, and water bodies the coolest areas (light and dark blue) of the region.



Map 1 Surface temperature map, Landsat 8 OLI & TIRS: US Geological Survey, Roads & settlements: OSM 2019; Data processing and analysis by S. Kriewald (PIK); Map by A. Dichte

Hence, the map also allows interpretations about the work capacity of different ecosystem types, their functional state, and regulating capacity to handle increased incoming energy (solar radiation), buffer and transform it, and thereby cooling themselves and surrounding areas. This (micro-) climate regulating capacity of the different ecosystem types refers to chapter 2.1.1 and is partly included in the rankings of ecosystem functionality.

[7]Rising temperatures are one of the most dangerous consequences of climate change, threatening socio-economic systems (Chen et al. 2020), ecosystem functions (Fisher et al. 2017), and human health (Vicedo-Cabrera et al. 2021, Luber & McGeehin 2008; Mora et al. 2017). These findings increase the importance of regulating ecosystem services, such as mitigating local temperatures and temperature peaks. While the positive influence of forests and wetlands or water bodies on (micro)climate is widely known and acknowledged (e.g. Blumröder et al. 2021, Alkama and Cescatti 2016, Bonan, 2008, Bright et al. 2017, Frenne et al. 2019; Zellweger et al., 2019), their concrete contribution to regional landscape cooling has not been accurately assessed so far. For a study in north-eastern Germany, a satellite-based method was developed to quantify the effect of different land use types on surface temperatures in the landscape (Gohr et al. 2021).

An area of about 11,000 km2 in the northeast German lowlands was chosen for the analyses. The area encompasses a land use gradient that includes the metropolis of Berlin in the south and the Mecklenburg Lake District in the north, thus covering various forest ecosystems of different sizes, water bodies, but also agricultural areas as well as other urban areas in more rural regions.

When considering the hottest days (days with daily maximum temperature ≥ 30 °C in the study period, for the years 2002-2020), temperatures in forests were on average almost 4 °C below temperatures in urban areas and on average about 3 °C below temperatures in agricultural areas. Modeling a theoretical conversion of 10% of the agricultural land in the study area into 'average forest' showed that the average temperature on heat days would be reduced by 0.9 °C.

Furthermore, a clear correlation between the vitality of the vegetation and the cooling effect could be established. The more vital a forest ecosystem is, the more pronounced its cooling capacity, with effective cooling, in turn, helping to mitigate heat stress under extreme summer temperatures, which can thus have a positive effect on vegetation vitality. Thus, climate change effects can be counteracted at the local level. Risks associated with them are reduced.

The study of Gohr et al. (2021) shows that landscape temperature depends on the composition of land use types. The cooling function of forests and water bodies in the landscape on hot days can be explained by their ecohydrological functions, which support the uptake, processing, and storage of water in ecosystems (Ellison et al. 2017). Evaporation, transpiration, and shade (in forests) ensure local cooling during the day (Ellison et al. 2017, Maes et al. 2011, Shen et al. 2020). However, reduced soil moisture due to heat extremes can impair temperature regulation functions (Teuling et al. 2010). In summary, the temperature regulation of forests and water bodies in the landscape depends on different local and regional factors such as evaporation, albedo, and energy conversion, as well as on supra-regional functions such as land use type composition and clouds (Wu et al. 2021, Shen et al. 2020, Bright et al. 2017, Zeng et al. 2017, Bonan 2008, Benayas et al. 2008, Zaitchik et al. 2006, Schneider & Kay, 1994). The thermal effects of forests and water bodies can be understood as a potential for ecosystem-based adaptation to climate change-induced heat stress (e.g. Kupika et al. 2019, Nanfuka et al. 2020). The relevant ecosystem functions need to be integrated into landscape management target systems. Targets and incentives should be created to support these functions (Lusiana et al. 2017). The quantification of landscape cooling with satellite-based surface temperature data can be readily adopted for analyses in temperate landscapes.

For the description of the used datasets and method, please refer to the Toolbox document in frame of this publication series.

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[7] The following paragraphs have been extracted and translated from the document: *Pierre L. Ibisch, Charlotte Gohr, Deepika Mann & Jeanette S. Blumröder (2021). Der Wald in Deutschland auf dem Weg in die Heißzeit. Vitalität, Schädigung und Erwärmung in den Extremsommern 2018-2020. Centre for Econics and Ecosystem Management an der Hochschule für nachhaltige Entwicklung Eberswalde für Greenpeace. Eberswalde* (in German language).

Changes of seasons

A shift in climatic seasons is observable:

- Abnormally hot and dry summers and mild winters without frost and snow become more frequent on the territory of the Biosphere Reserve for several years in a row and especially in 2018-2019.
- The boundaries of the cold and warm periods have changed significantly. Today, September is warm, and almost without frosts, March and April on the contrary are colder and with frosts. Average air temperatures in spring and autumn now drop below 0 degrees 1-6 days earlier. In general terms, the climate is becoming more continental.
- There is no noticeable transition from winter to spring or from autumn to winter, i.e. weather and temperature indicators of each season seem to be shifted by almost a month or a month and a half.

Projections for the future

According to the most probable climate development scenarios for the Shatskyi region (B1 and A2 scenario of IPCC) the mean annual temperature is expected to increase by 2.0 and 4.6 °C respectively by the end of the 21st century in comparison to 2000-2010 average. They also indicate an increasing variability of the amount of precipitation, which might be challenging for the development of sustainable and adapted agriculture and forestry as well as tourism in the region.

Changes in precipitation quantity and patterns

The average annual amount of precipitation in the region of the Shatskyi BR increased by almost 8 % – from 559 to 603 mm compared to the reference period and the last three decades. Moreover, the amount of precipitation in eight out of twelve last years between 2007 and 2018 exceeded 120 % of the long-term average of 1961-1990. Most precipitation still falls during the summer season, but there are some changes in volume throughout the year. Between 1991 and 2018, a substantial increase in the amount of rainwater was recorded for spring months and September-October, while only three months (June, July, and November) featured less precipitation compared to the climatic normal.

During the last five years, the average duration of a dry period was 9 days per month, with the longest consecutive period of 25 days in August 2015. The highest one-day precipitation usually falls in May - July and September - October with an average amount of 15-25 mm over 24 hours. Its absolute monthly maximum was recorded in May 2014 and July 2018 with more than 130 mm, which constituted more than 20 % of annual precipitation those years. Even though the average number of wet days (with snow or rain) in Shatskyi BR is relatively high (ca. 160 days per year), the low water-holding capacity of sandy soils is playing a role for drier conditions. Due to the specific air circulation big, water bodies within Shatskyi BR moderate the adverse consequences of climate change on surrounding ecosystems providing them with cool and wet air flows.

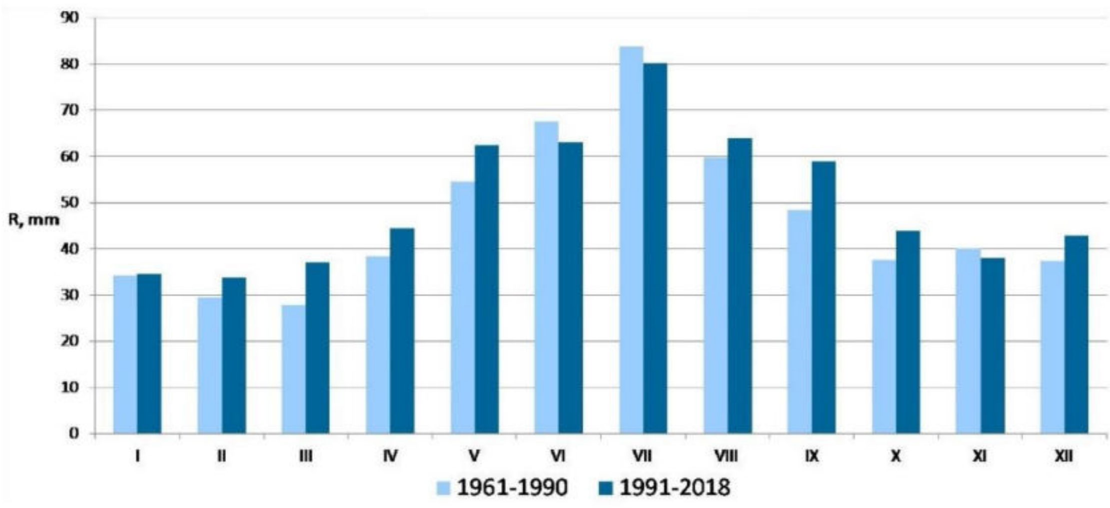


Figure 3 Monthly average sum of precipitation during the periods 1961-1990 and 1991-2018, Graph by A. Smaliychuk

Over the past three years, a drastic seasonal decrease or absence of precipitation over larger timespans was especially observed by the local population in spring and summer. However, according to them it significantly increased in autumn, especially during single, heavy rainfall events when half of or even the whole monthly precipitation amount occurred within just a few hours. As one consequence, water bodies are shallowing as they are not sufficiently refilled with water. This leads to a gradual drying up over consecutive dry years, having lake Svityaz´ - the largest and most frequented lake within the Shatskyi BR - as the most prominent example. Combined with a decrease in groundwater level this is accelerating the worsening sanitary state of forests (insect calamities, disease invasion, and drying) causing the reduction of biodiversity and impacting the communities' well-being.

2.2.2 Climate change-related impacts, disasters, and human risks

The above-described altered temperatures and drought periods, precipitation patterns, and seasonal shifts cause high levels of stress for the ecosystems and make the need for adaptation palpable. For humans, being embedded and forming an active part of these systems, this need for adaptation to climate change becomes drastically visible through the related natural disasters posing direct and indirect risks to human well-being.

The **human well-being in Shatskyi BR** can be defined by a multi-dimensional interrelation of:

- Physical well-being factors such as physical health, sufficient and good nutrition as well as safety from environmental and human harm.
- Mental well-being factors such as mental health, personal fulfillment, sense of belonging, freedom of choice and action, knowledge, spirituality, and social relations.
- Economic well-being, including secured income, and material livelihood.

In the face of climate change, these aspects are threatened, as essential regulating functions and ecosystem services are at stake and might be insufficiently supplied by ecosystems.

Several climate change-related risks affecting the ecosystems´ and human well-being both directly and indirectly have been identified as relevant for Shatskyi BR:

General dehydration and drying of lakes and wetlands

As a consequence of increasing temperatures and more hot days, the evaporation rate is exceeding the water supply via precipitation and soil water saturation. Altered precipitation patterns and less snowfall are having a critical effect on the water balance and water levels of lakes and wetlands. Very recently, less snowfall (e.g., in 2018) or no snow at all (e.g., in 2019) during the winter period was recorded for some areas within the Shatskyi BR. The previous conditions of waterlogging processes have changed to conditions of insufficient water saturation of soils. In warm months, starting in June, the deficit of the climatic water balance is 40-75 millimeters.

Examples:

- Land previously used by the local inhabitants as meadows is now cropland because of drying out.
- The lowlands, which used to be flooded every spring, are now built-up areas even without prior elevation or melioration.
- A lack of water in wells for domestic use is increasingly reported and observed.
- Furthermore, lower groundwater levels paired with drought periods negatively impact crop yields.

For the local population, this leads to increased investments of time and money for growing crops. The shallowing of lakes, ponds, and reservoirs besides lowering groundwater levels make artificial landscaping based on constant watering more difficult and riskier.

Waterbody and wetland shallowing and drying

One of the most noticeable climate change impacts is reflected in the dramatic water level drop of about two dozen lakes. In the summer period of 2019, experts estimated that more than 1 million cubic meters of water evaporated from the Shatskyi lakes. The lakes´ water level cannot recover from the subsequent hot and dry years due to the absence of sufficient precipitation, missing groundwater recharge, and elevated evaporation rates.

The well-known lake Svityaz, the cleanest and the deepest lake in Ukraine recognized as one of the seven Ukrainian natural wonders and a favorite vacation spot for residents of Volyn, is heavily affected.

As the most prominent example, in the autumn of 2019 Lake Svitiaz´s water receded from the shore by a few meters, the reeds were on land and the surface of the lake was cut by numerous sandy spits. A warm, snowless winter, dry spring, and unusually hot early summer with temperatures up to plus 40 °C caused the water level to decrease significantly. The high air temperatures and insufficient precipitation had their effects on the water level of Svityaz, which has no tributaries, and the water supply for the lake depends mainly on precipitation and groundwater sources.

Thus, in June-August of 2019, compared to long-term observations, the water level in Lake Svityaz decreased by 36 cm, and on November 1. the absolute mark was at 162.94 m above sea level, which is 38 cm below the average mark according to the results of hydrological observations over the past 35 years.

Also, the swampy parts around lakes, such as at Luka Bay, have dried up. Black alder trees (*Alnus glutinosa*) began to dry. Ponds that were created from peat extraction in the late 1960s vanished in the summer and began to be overgrown with black alder and downy willow (*Salix lapponum*).

Anthropogenic drivers of stress and underlying factors

Climate change is not the only cause of fluctuations in water levels. Cretaceous mining and depositing in the Malorit district of the Brest region (Republic of Belarus), located 25.8 km from Lake Svitiaz, is ongoing. Scientists from the National Academy of Science predict that the development and operation of this mine in the immediate vicinity of the Biosphere Reserve may lead to a direct or indirect impact on the natural complexes of the territory. Additionally,

- Shatsk district residents make extensive use of groundwater from wells for domestic and touristic use, which is available in almost every household and recreation center.
- On the drained territory of the Upper Pripyat drainage system (Polozhevo village), there is a berry plantation of about 200 hectares, for which irrigation reservoirs are being filled with groundwater (see image 1).

Image 1 American blueberry farm; Source: GoogleEarth (2018-09-30)

The impact of this farm, the domestic and touristic sectors, and the chalk mine on the hydrological regime of Shatskyi BR have not been investigated so far. There are no available studies on the impact of intensification of groundwater use in this region.

Thus, it is difficult to determine the relation of climate change-induced and anthropogenically-caused decrease and fluctuation in the water level.

Changes in flora and fauna

The changing climatic and hydrological conditions lead to an altering composition and decrease in numbers of native plant and animal species, due to a variety of morbidity causes. Meanwhile, the emergence of new invasive species of plants and animals, as well as pests and allergens are noticed. Overall, a reduction in biodiversity is observed which is accelerated by pressure from human land use.

Pests, diseases, and insect calamities

The increasing temperatures, heat, and drought stress besides other relevant anthropogenic drivers are enabling the occurrence and spread of (new kinds of) pests, diseases, and insect calamities. In forests, cropland, and other ecosystems insect calamities and disease invasion are in the advance. Forest ecosystems are increasingly affected by pests and diseases. In the past years, a spread of apical bark beetle in pine plantations of the Shatskyi BR is noticed. This process is facilitated by a variety of factors weakening tree stand as described above.

However, here a **fundamental rethink is necessary**. From an ecosystem perspective, bark beetle infestations also support the “restoration” of a damaged system. The beetle, disease, or plague is a symptom that indicates the level of stress, for example, that a monoculture forest is not healthy and functional. Such a structurally weakened forest is not able to fight the “disease” by its defense mechanisms. To protect the forest from so-called “bark beetle infestations” would necessitate a natural decay and regrowth cycle with as little human influence as possible.

Increasing number of meadow, swamp, and forest fires

Due to the increasingly dry conditions and periodical absence of precipitation, especially in spring, there is an increasing number of fires in meadows and swamp areas being observed and monitored. The risk for forest fires is elevated while the occurrence of such is still low. Usually, the fires are triggered by humans, whose negligence leads to the kindling of fire.

Extreme weather events

The number of weather anomalies and extreme events is increasing, namely:

- **Heat**

A larger number of hot days in the Shatskyi BR are recorded, where the air temperature is exceeding 30 °C. Consequences of increasing heat and heat stress are for example raised levels of mortality of flora and fauna and soil degradation processes. The extinction of certain species may occur at an accelerated pace. Heat also drives elevated evaporation rates leading to faster drying of water bodies and wetlands.

- **Drought** periods causing stress in diverse ecosystems and leading to desiccation of fauna
- Heavy **torrential rains** causing **flooding**
- Increased wind speeds in form of squalls, strong winds, and **heavy storms** atypical for the region causing:
    - Destruction of forests leading to harvest losses.
    - Damage to homes and infrastructure.
    - Wind erosion of the fertile soil layer causing economic losses for farmers.
    - Soil dust storms directly affect human health.
- **Heavy snowfalls** and **snowstorms** causing damage
- **Dense fog events**, reducing visibility and increasing the risk of accidents
- **Heavy hailstorms**, destroying forests, crops, and human infrastructure
- **Heavy ice**, causing damage to tree branches and human infrastructure

All the described climate-change-related contingencies and risks have a significant influence on the diverse ecosystems and the whole network within the Shatskyi BR. Thus, humans are directly and unsparingly affected by these developments.

Affectedness of economic well-being

Diverse economic sectors relevant to the Shatskyi BR region, such as tourism, agriculture, pisciculture, and forestry are facing increasing losses due to climate change impacts. Dropping water levels in touristic relevant lakes, crop failures due to drought, hail, and pests, as well as dying fish because of higher water temperatures are a few examples of the challenges the local economy will be facing.

Shatskyi BR tourism sector

This sector is especially relevant for the region and its many lakes, forests, and recreation sites. It is one of the touristic hotspots of Volyn Oblast and north-western Ukraine. Climate change increases the risk for the region to lose its unique character, being home to lake Svityaz´, one of the seven natural wonders of Ukraine.

The shallowing and drying of lakes can cause a serious decline in touristic attractiveness and thus, activity, employment, and income opportunities for the local population. Forest drying, burning, and dieback caused by insect calamities negatively affect the cultural value of the region and manifest in decreasing attractiveness for visitors and the local population. Tourism will remain a stable income source for many decades to come if approached and developed from a sustainable perspective. (Near-) natural and functional ecosystems are the basis for securing the economic and social dimension of tourism in the long run. Touristic actors should be aware of this and understand EbA as an opportunity.

Forestry Sector

A large area of the Shatskyi Biosphere Reserve features forest plantations, which do not correspond to the composition and age structure of natural forests. Forest plantations growing on these formerly arable lands, due to low humus content, have reduced biological stability and are more vulnerable and susceptible to pests, diseases, and storms.

Such anthropogenically altered forests, plantations and transformed lands increasingly suffer from climate change. It is disrupting the links between the components of forest ecosystems. Forest phytocoenosis is depending on the structure, composition, and shape structure and thus is impacted and reacts differently to critical climatic and anthropogenic factors.

Changes in weather and climatic conditions lead to deterioration of growth conditions, reduction of biological stability of stands, weakening, and death of individual trees and whole stands. For example:

- Excessive drought periods stress forests and lead to the death of artificial pine, common spruce and Douglas fir stands.
- Changes in precipitation amount and patterns, as well as groundwater level decrease, are altering the hydrodynamic regime and water balance.
- Considerable areas of forest are damaged and destroyed by storms recent years.
- Increasing risk of forest fires

- The forests´ resistance to pests and diseases has decreased
- A general decrease in biodiversity is the result of such developments.
    - The number of plant species is decreasing
    - Changes in forest fauna composition are occurring
- Soil degradation and changes in the species composition of soil flora and fauna
- Flooding and waterlogging cause damages to vulnerable stands

The Biosphere Reserve staff observes that in (near-) natural plantations, most consistent with the native forests, outbreaks of pests and diseases occur much less.

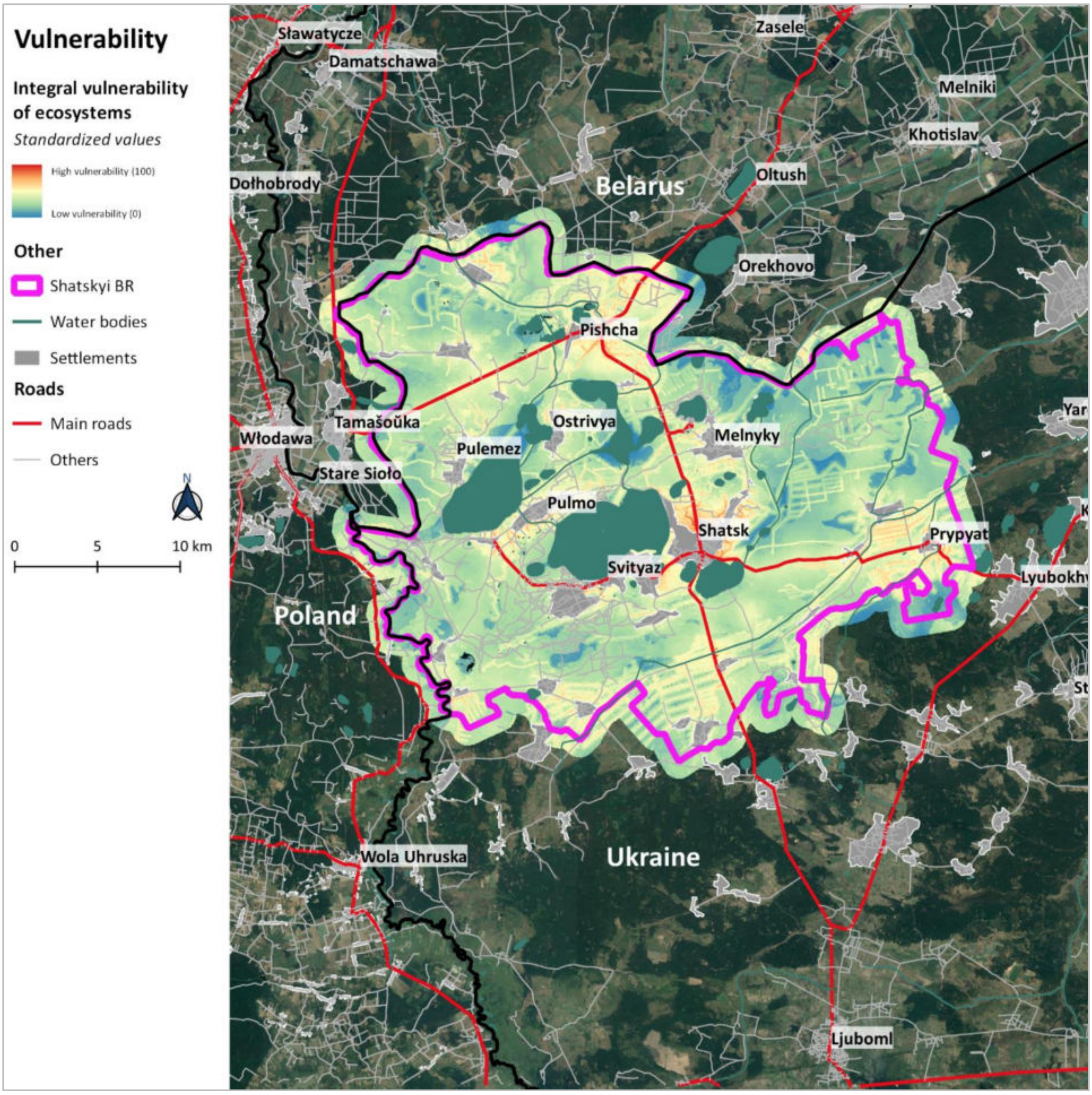
How is EbA related to such impacts and events?

EbA measures have the potential and goal to proactively reduce all the above-described risks by decreasing vulnerability and enhancing (self-) regulating capacity by restoring natural ecological structures and processes. For the EbA measures, please consult the separately printed *EbA measure and activity catalogs* annexed to this document series. The catalogs can also be accessed via the project website (https://www.eba-ukraine.net/Publications.html). The following sections will describe other ecological stresses, their drivers, underlying factors, and causes that were identified during the MARISCO stakeholder and expert workshops.

Map 2 depicts the vulnerability of ecosystems based on the following stress indicators:

Forest ecosystems	**Wetland ecosystems**	**Grassland ecosystems**
a. Management intensity (expressed in structure and species composition) – coniferous/broad-leaved, freshly logged, recently gained + forest change data b. Logging intensity or forest loss intensity (% of logged area) – expressed in a generalized 1 km grid c. Fragmentation by roads and other transport infrastructure, differentiated by impact, expressed in a buffer size d. Patch metric indicators (size, connectivity, edge density, neighbor analysis (e.g., forest-field, forest-wetland) e. Soil parameters (water retention capacity, etc.) – taken from ecosystem map as a site moisture index f. Artificial drainage – continuous buffers along artificial canals g. Human population density – as a chance of human impact on the forest (related to the settlement population and distance)	a. Artificial drainage b. Peat extraction sites c. Human population density d. Fragmentation by roads and other transport infrastructure e. Patch metric indicators (size, connectivity, edge density, neighbor analysis) **Lake ecosystems** a. Buffer around the shoreline to analyze its structure and impact on the lake (incl. patch metrics) b. Population density c. Size (area, form) d. Depth (bathymetry)	a. Patch metric indicators (size, connectivity, edge density, neighbor analysis e.g., wetland-field, forest-wetland) b. Population density c. Fragmentation by roads d. Soil parameters (water retention capacity, etc) e. Artificial drainage **Arable/Cropland ecosystems** (same criteria as grassland) a. Size can indicate management mode (e.g., machinery, chemicals)

The first outcomes were used to make evaluations for separate ecosystem types. Then they were harmonized and weighted with the evaluation results. Only afterward, the neighborhood analysis was applied. For a detailed method description, please consult the Toolbox document, chapter *Spatial Analysis and Mapping – Part I*.



Map 2 Map of ecosystem vulnerability in the region of the Shatskyi Biosphere Reserve (area of the BR + 1 km buffer)
Sources: Data processing and analysis by I. Kruhlov;
Base map: Google Satellite 2016;
Roads, settlements, water bodies: OSM 2020; Produced by A. Dichte

2.2.2.1 Relevant ecological stresses in Shatskyi BR

The rating scale is from 1 (dark green) – low strategic relevance to 4 (red) – high strategic relevance.

Sphere	Ecological stress	Ecosystem affected (direct)				Strategic relevance (based on criticality ratings)
		Forest	Waterbody	Wetlands and Grassland	Cropland and Settlements	
Energy input	Changed solar radiation intensity*	X	X	X	X	?[8]
Atmospheric	Unevenness of precipitation	X	X	X	X	2
	Changed seasonal precipitation patterns	X	X	X	X	?
	Changed (micro-)climatic conditions (e.g. increasing heat)	X	X	X	X	?
	Changed air humidity*	X		X	X	?
Hydrosphere	Disappearance of springs and streams	X	X	X	X	4
	Eutrophication	X	X	X	X	4
	Decreased surface water level	X	X	X	X	3
	Decreased groundwater level	X	X	X	X	3
	Drying of lakes and private ponds	X	X	X	X	3
	Rise of water temperature		X	X		3
	Low water quality (particles and toxins)	X	X	X	X	3
	Sedimentation (silting)		X	X		3
	Negative changes in bogs´ hydrological regime			X		?
Lithosphere	Eroded soils	X		X	X	4
	Decrease of soil fertility	X		X	X	2
	Destruction of peat layer			X		1
	Soil compaction*	X		X	X	?
	Waterlogging				X	?
Matter cycles	…					?
Biomass	Changed tree and flora growth	X		X	X	1
	Less harvest / decreased yield	X			X	1
	Sylvatization (?)			X	X	1
	Loss of forest cover	X				?

[8] The boxes marked with a '**?**' are issues which were not completed, rated, and prioritized by the participants during the situation analysis workshops.
Elements marked with '*****' added by author based on indication outside of MARISCO expert workshop

Sphere	Ecological stress	Ecosystem affected (direct) Forest	Waterbody	Wetlands and Grassland	Cropland and Settlements	Strategic relevance (based on criticality ratings)
	Absence of dead and old wood*	X			X	?
Information	Absence of animals	X	X	X	X	3
	Appearance of alien animal and insect species	X	X	X	X	2
	Appearance of alien plant species	X		X	X	2
	Species extinction	X	X	X	X	2
	Decrease in biodiversity	X	X	X	X	1
	Appearance of adventive species	X		X	X	
Network	Fragmentation of forest areas	X			X	2
	Changed species composition / new species	X				2
	Absence of management (?)				X	2
	Fragmentation of above-ground cover	X		X	X	1
	Changed plant species composition	X		X	X	1
	Internal fragmentation of stands*	X				?
	Canopy gaps*	X				?
	Edge effects*	X	X	X	X	?
	Dissection of mushroom and root plants*	X			X	?
Species-specific factors	Deteriorated sanitary condition of forests	X				3
	Drying of pine trees/forests	X				3
	Destruction of forests	X			X	3
	Second blossoming within one year				X	2
	Windthrow	X			X	2
	Yellowing of needles	X			X	2
	Changed population structure of biota	X	X	X		1
	Crop failure				X	1
Energy, matter and water efficiency	Elevated rate of evapo(transpi)ration*	X	X	X	X	?
Resilience and resistance	?					?

Ecological stresses of forests

Shatskyi BR is home to a relatively large, predominantly contiguous forest area, with a minor proportion of broad-leaved and mixed forest and minor fragmentation. Near-natural and monoculture coniferous plantations dominate the forest ecosystems. Towards the center and southern parts of the biosphere reserve, the forest is more fragmented and replaced by settlement areas, cropland, and agricultural plantations.

The mosaic of different types of use (including settlement areas, traffic routes, energy lines) causes fragmentation and islanding of forest areas that would naturally be contiguous. Resulting forest ecosystem fragments are increasingly separated from each other and limited in their functional capacity. Increased fragmentation leads to downsizing and islanding of populations, genetic impoverishment, and possibly local disappearance of species. Abrupt transitions between forests and other areas without functional forest edges increase edge effects; among other things, it is easier for substances foreign to the ecosystem to enter, e.g., through emissions from road traffic or agriculture.

Due to agricultural use and construction projects, there may be a further loss of forest area. Access roads cause additional internal fragmentation and microclimatic changes. Additional disturbances are caused by the development and operation of forestry areas. Not only the construction and driving of forest roads and trails but also of so-called skid trails for the corresponding machines, result in the loss of areas for tree growth and thus in biomass losses. Linear forest aisles lead to sharp forest edges in the middle of the forest and thus change light and climate conditions.

Stands potentially become thinner, warmer, and drier. Originally non-native species may invade the forest along trails and in disturbed areas, sometimes displacing other species and contributing to further homogenization. Soil is compacted, at least around logging roads; underground, fungal root networks important for water and nutrient uptake (mycorrhizae) may be disrupted. Soil and regrowth vegetation on the skid trails (and beyond) are often damaged during timber harvesting. With heavier logging and lowering of the stocking level, more or less large gaps are created in the canopy. This, together with biomass removal, in turn affects the microclimate. Among other things, biomass in the forest also stores water and cools. Trees that stand more freely are also moved more during storms and may be more susceptible to windthrow. The wind susceptibility of trees is high for a certain period if larger protective trees have previously been removed from a stand.

Particularly problematic in heavily used forests is the poverty of dead and old wood. Deadwood is, for example, a habitat for many species and a substrate for regeneration. It is a nutrient and water reservoir, protects the soil from drying out, and has a favorable effect on soil formation.

The intensive management of coniferous forests and woodlands that are not in their natural state has the effect of severely limiting the age and decay phases, as less old and dead wood is found in these areas. As with all ecosystem uses and any human infrastructural or industrial activities, forestry activities result in the degradation of ecosystems and their ability to function at all stages of operation. Fundamental choices are made when establishing forests and selecting the tree species that will be allowed to grow.

The selection of few species (compared to natural succession) and the cultivation of predominantly even-aged trees results in the severe simplification of stands, loss of biodiversity at all levels, and reduced self-regulation. Among other things, pests can more easily establish themselves and cause economically relevant damage. The risk for windthrow and forest fires may increase. If non-native trees are planted on a larger scale, fewer resources may be available for native species. Certain tree species have an unfavorable effect on the soil in monoculture (e.g., acidification by needle litter, reduction of soil microorganisms, and available nutrients by red oak, for example). Furthermore, in coniferous forests, evaporation is increased even in the recently more frequent mild winters and groundwater recharge is greatly reduced.

Decades and centuries of settlement and use of the former and remaining forest areas, including the loss of predators such as wolves, have increased the population density of, in particular, cloven-hoofed game to such an extent that this disturbs the forest in its development and regeneration.

If the functional capacity of forests is reduced, they become significantly more susceptible to climate change impacts. In heavily modified stands, mainly in those where pine dominates and the understory is very sparse, there is also a changed forest interior climate, which is far from the typical balancing microclimate of a mixed broad-leaved forest. Lower evaporation and stronger or unrestrained solar radiation lead to lower humidity and higher temperatures on hot days. Soils dry out and trees suffer drought and heat stress, which can lead to higher mortality rates. Higher temperatures and less moisture in the forest coupled with highly flammable tree species such as pine also increase the risk of wildfire. Higher winter temperatures also favor the reproduction of insects and other creatures that live in and on wood. Trees are increasingly weakened by pathogens and insect calamities, and mortality rates are increasing. Aisles, sparse stands, and abrupt forest edges promote the effects of wind or storms, which can lead to an individual to areal injury and toppling of trees. The resulting clearings increase edge effects in the forest and provide new targets for storms and strong solar radiation.

2.2.2.2 Relevant natural and anthropogenic drivers of ecological stress in Shatskyi BR ecosystems

Sphere	Drivers of ecological stress	Strategic Relevance (based on criticality ratings)
Climate change and severe weather	Increase of mean annual temperature	?
	Temperature anomalies	?
	Frost in late spring (on peaks)	4
	Hailstorms	?
	Strong winds	?
	Tornados	?
	Drought	?
	Rainfall anomalies	?
	Flooding	?
	Desertification	?
Energy production and mining	Illegal extraction of mineral resources	?
Agriculture and aquaculture	Deforestation	?
	Soil erosion	?
	Lack of agricultural activity	?
Biological resource use	Clear-cutting	?
	Illegal logging	?
	Unlimited harvest of forest resources (mushrooms, berries)	?
	Poaching	?
	Overharvesting of fish resources	?
	Lack of agricultural activity	?
Human intrusions and disturbances	Metamorphization of the chemical composition of water	?
	Trampling of vegetation cover (recreation)	?
Natural system modification	Destruction of hydrological-technical infrastructures	4
	Hydrotechnical melioration (reclamation)	?
	Forest fires	?
	Peat-soil fires	?
Invasive and other problematic species	Alien species	?
	Increase of forest parasites	?
Pollution	Soil pollution	?
	Water pollution	?
Hydro-Geological events	?	?
Residential and commercial development	Uncontrolled residential development	?

Climate change and biological resource use by forestry

Climate conditions currently perceived as "extreme" (Büntgen et al., 2021) could be considered "normal" in the near future (Hari et al., 2020; Scharnweber et al., 2020). It is therefore of great interest to what extent forest management (especially thinning and thinning of forest stands) has the potential to increase the negative effects of heatwaves in forest stands[9].

It has been partly concluded from recent studies that thinning can reduce the impacts of drought (Ameztegui et al. 2017, D'Amato et al. 2013, DelRío et al. 2017, Gebhardt et al. 2014, Giuggiola et al. 2013, 2016, Ma et al. 2010, Primicia et al. 2013, Simonin et al. 2007, Sohn et al. 2016). However, the corresponding findings are by no means as clear-cut as sometimes presented. The benefits of thinning depend on local climatic conditions and cannot be generalized (Ameztegui et al. 2017). It needs to be reflected more critically in times of frequently recurring dry and hot years, namely when rainfall is absent for prolonged droughts. Then, potential advantages of thinning can turn into a disadvantage because higher water losses through evaporation become the decisive stressor in forests exposed to more intense heat. It is also known that forest openings and clearings increase ambient and ground temperatures, which in turn negatively affect water availability, especially during periods of low precipitation (Redding et al. 2003). The larger the canopy openings, the higher the air and soil temperatures (Latif & Blackburn, 2010). At forest edges, soil moisture can be similar to that in open areas (Erdős et al., 2019).

The microclimatic regulation capacity of forests is therefore of central importance. This is mainly a matter of mitigating peak summer temperatures, lowering average temperatures, and buffering temperature fluctuations. An open question was to what extent forest properties that are directly influenced by forest management (e.g., thinning, timber harvesting intensity, and nature conservation) affect microclimatic regulation under extreme climatic conditions in exceptionally hot periods. To this end, a study in northern Germany (Blumröder et al. 2021) investigated temperature indicators in the two extremely hot and dry summers of 2018 and 2019 (see e.g., Buras et al. 2020, Kornhuber et al. 2019, Vogel et al. 2019) in forests of northern Germany. In addition, temperature measurements were collected and analyzed in pine and beech forests along a utilization gradient.

In both years, the highest maximum temperatures were measured near the ground and at a height of 1.3 m in a pine stand with a relatively low supply (177 m3 ha-1). At the same time, maximum temperatures were 9 °C lower in a beech stand with a relatively high stock (>565 m3 ha-1). In 2019, when data on crown closure were also included in the analysis, crown closure was also a significant factor influencing maximum temperature, as was the number of felled trees. Across both study years and all sample plots, the temperature increased by 0.21-0.34 °C near the ground and by 0.09-0.17 °C at 1.3 m per 100 trees per hectare felled in the past. In 2019, when crown closure was also considered in the analysis, it showed a significant influence on maximum temperature (in all datasets studied). Between forest stands differing in crown closure by 10%, there was a difference in maximum temperature of 0.46 °C (including pine and beech stands, measured at 1.3 m) and 0.35 °C (pine stands only, measured at 1.3 m). Near the ground, the maximum temperature was 0.53 °C (pine and beech stands) and 0.41 °C (in pine stands) higher.

The biomass stock also influences the temperature regime. Sample circles with a difference of 100 m^3 less stock per hectare showed a 0.31-0.33 °C and 0.15-0.27 °C higher maximum temperature near the ground at 1.3 m (including all sample plots). In pure pine stands, it was found that the more densely stocked a forest stand, the lower the maximum temperature.

[9] The following paragraphs have been extracted and translated from the document: *Pierre L. Ibisch, Charlotte Gohr, Deepika Mann & Jeanette S. Blumröder (2021). Der Wald in Deutschland auf dem Weg in die Heißzeit. Vitalität, Schädigung und Erwärmung in den Extremsommern 2018-2020. Centre for Econics and Ecosystem Management an der Hochschule für nachhaltige Entwicklung Eberswalde für Greenpeace. Eberswalde* (in German language).

A closed forest has a better cooling capacity (preventing relatively high temperatures) and also greater buffering capacity (reducing temperature fluctuations). Considering all study plots (beech and pine stands), it was found that temperature fluctuations (at 1.3 m) were higher than average when the crown closure was below 65 %.

Forest management has a significant influence on the ability of forests to mitigate temperature peaks, average temperatures, and temperature fluctuations. For the mitigation of maximum temperatures in the forest interior, the openness of the canopy is the decisive factor, but the amount of felled trees is also of great importance, and both variables are directly controlled by forest management (in terms of reducing timber harvesting activities and developing denser, multi-layered forest stands). Other studies also show that a reduction in canopy closure leads to an increase in forest internal temperature (e.g., Thom et al. 2020, Kong et al. 2014).

In the two record heat years of 2018 and 2019, denser and less thinned forests showed better microclimate regulation. Effective forest management aiming at continuous forest cover and more complex structures instead of homogeneous monocultures of the same age thus enables stabilization of microclimatic conditions inside the forest and counteracts extreme macroclimatic conditions that will occur more frequently in the course of climate change. The cooling property of forests contributes to climate regulation in the wider landscape and positively influences water and carbon cycles (Ellison et al. 2017). The regulation of microclimate can therefore mitigate climate change effects (Thom et al. 2020).

Based on the results, it is recommended to minimize warming and evaporation effects in the forest interior by reducing or avoiding the creation of artificial gaps in the canopy through silvicultural measures, including intensive thinning and clear-cutting, as well as the establishment of roads and skid trails. In this context, the fragmentation of forests by roads and infrastructure as well as the opening of the canopy by the construction or maintenance of skid trails and forest roads must be discussed. Regular and regular thinning or timber harvesting in German commercial forests usually takes place every 5 years, with skid trails being cut into the forest at a distance of 20-40 m from each other. The associated opening of the canopy creates internal forest edges and potential edge effects within a forest area, which can reduce microclimatic regulation capacity and increase the risk of heat and drought stress from the edges into the forest interior (Duncan et al. 2019, Reed et al. 1996). Road infrastructure causes higher air and canopy temperatures and saturation deficits (Delgado et al. 2007, Pohlman et al. 2007). Increased tree mortality at forest edges indicates higher stress levels in times of water scarcity and heat (Brun et al. 2020).

Adapting forest management to climate change primarily means reducing the sensitivity of trees to drought events as much as possible. Extremely low precipitation and high temperatures, depleted soil moisture, and increased evaporation were responsible for the recent spring droughts in Central Europe and are likely to persist in the long term due to climate change-induced atmospheric circulation phenomena (Ionita et al. 2020). According to the results of the study (von Blumröder et al. 2021), high stock and dense canopy provide insurance against heat and drought events. This is in contrast to promoting thinning as a management strategy to adapt forests to climate change and reduce the associated impacts of droughts.

Forest microclimate management, with the aim of producing cooler and less variable forest interior temperatures, is a critical element of ecosystem-based adaptation to climate change.

It is recommended to keep the canopy as dense as possible, at least at 80 % cover. This can be achieved through low intervention intensities, intermediate layers (e.g., native deciduous tree species in intermediate and understory), with the aim of creating multi-layered, uneven-aged stands.

The trade-off between sufficient light availability for tree regeneration growth, which is necessary for the forest to develop into a more resilient ecosystem, and the need to maintain protective shade is increasingly evident under climate change conditions, especially in extremely hot and dry years. Of key importance is the risk that extreme heat, soil dryness, or even direct sunlight (which can lead to sunburn in exposed beech trees) can jeopardize the success of forest development.

The regulation of micro-and mesoclimate by forest ecosystems is an important function and service, which in turn influences other ecosystem services (Tuff et al. 2016). The socio-economic importance of forests goes far beyond timber production and is also highly relevant for human health and recreation. Therefore, forest management should assume greater responsibility for regulating the microclimate in order not to further exacerbate the negative impacts of the macroclimatic climate crisis, but to counteract it.

2.2.2.3 Relevant underlying factors and causes

Sphere	Underlying factor and cause	Strategic Relevance (based on criticality ratings)
Biophysical factors	Global climate change[10]	?
	CO_2 emissions	?
Institutional factors	Lack of financing of melioration system*	?
Governance-related factors	Absence of financial resources for road reconstruction*	?
	Insufficient supervision of construction	?
	Uncontrolled market (buying and selling of land)	?
	Absence of legal regulation of land consolidation	?
	Lack of control of natural resource use	?
Socio-economic factors	Tourism*	?
	Low economic development (only forestry and agriculture)	?
	… ?	
Socio-demographic factors	Seasonal migration (labor and touristic)	?
	…?	
Infrastructure-related factors	… ?	?
Socio-cultural factors	Not following of legislative norms	?
	Low level/absence of ecological knowledge	?
Spatial factors	Non-even (spotted) recreational overpressure	?
	… ?	
Natural resource-use related factors	Monocultures	?
	… ?	

*** ? - To be determined/assessed**

[10] Itself natural and biophysical processes but today mostly driven by anthropogenic activities

2.3 Diagnosis

Shatskyi Biosphere Reserve, its nature, and humans are already suffering a regime of climatic and anthropogenic pressure. It is mostly driven by increasing temperatures, uneven precipitation patterns, and shifts in seasons causing increased exposure to extreme events and stress.

The direct and indirect effects of climate change for ecosystems and human beings are perceptible and visible: droughts in summer, heat stress for flora and fauna, decreasing surface and groundwater levels as well as drying of lakes, ponds, and wetlands. Furthermore, there is an increasing occurrence of extreme weather events such as strong winds and storms, torrential rains, and flooding that destroy forests, lead to crop failures, damage homes, and put human health at risk.

Anthropogenic activities and unsustainable land use (draining of wetlands. monocultures, clear-cut areas, sealed surfaces, compacted and intensively used soil, etc.) degrade key ecological attributes, making the ecosystems vulnerable and less resilient to exposure to climate change impacts. This in turn raises the risks of direct climate change effects on human well-being, including physical, mental, and economic spheres.

Thus, the Shatskyi BR has an urgent need to protect and restore (self-) regulating, functional ecosystems, while limiting harmful and destructive land use and behavior to a minimum extent. Only then there is a chance that human well-being and a qualitative and quantitative provision of ecosystem services can be guaranteed in the long term. This is also a vital requirement for sustainable regional development of the Shatskyi BR, which is mainly based on natural resources and tourism (attracted by natural beauty and functionality).

The objectives to counter climate change and its negative impacts are based on the findings of the situation analysis and the necessity to protect and restore (near-)natural ecosystems.

These goals shall safeguard that the ecosystems of the Shatskyi Biosphere Reserve:

- **maintain their ecological functionality** even under the influence of climate change including long-term local climatic changes and an increase in extreme weather events.
- can **buffer and reduce the effects of climate change on themselves** as much as possible.
- **continue to provide the ecosystem services needed for human well-being**, including most importantly the regulating services (e.g., local climate and water balance) mitigating negative effects of extreme events on humans, the provisioning services (e.g., food and energy), and the cultural services (such as recreation and cultural identity).
- **reduce climate change-related disaster risks to human well-being**.

Thus, the overarching aim is to **reduce Shatskyi BR´s vulnerability to climate change**. Since vulnerability is caused at different levels (cf. chapter 2.2), these different levels must also be addressed to reduce vulnerability holistically.

For Shatskyi BR, the following four climate change relevant and both ecosystem and human well-being centered goal-dimensions can be reached by EbA:

A. Temperature buffering and cooling
B. Water retention, stabilization of hydrological regime, and moisturizing
C. Water regime and flood regulation
D. Natural hazard reduction (fires, storms, pests)

EbA measures have the potential and goal to proactively reduce the above-described risks by decreasing vulnerability and enhancing (self-) regulating capacity by restoring natural ecological structures and processes. For the EbA measures, please consult the separately printed *EbA measure and activity catalogs* annexed to this document series. The catalogs can also be accessed via the project website (https://www.eba-ukraine.net/Publications.html). The map “Priority Areas for Ecosystem-based Adaptation” provides a spatially explicit orientation of where what kind of action is primarily needed.

2.4 Spatial Analysis and Maps

In preparation for the local citizens' workshops and the MARISCO workshops, GIS experts carried out spatial analyses of the Biosphere Reserves Desnianskyi, Roztochya, and Shatskyi as well as their surroundings. Innovative maps were produced that take the ecosystem-based approach into account and incorporated first information on climate change impacts as well as land use.

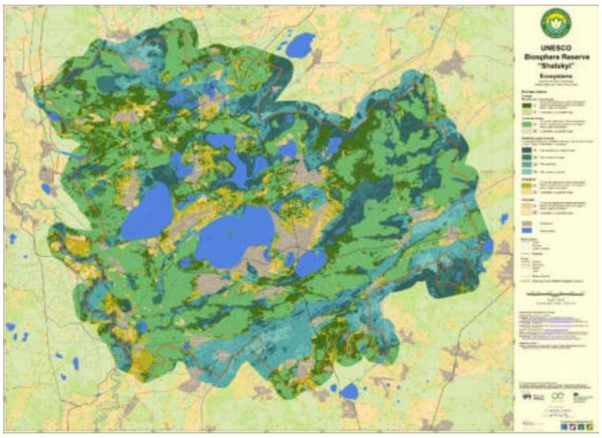
The spatial analysis enables statements to be made on the distribution and condition of relevant ecosystems and their services. Through citizen participation and stakeholder workshops, existing knowledge of the participants and their wishes and ideas are incorporated into the situation and target maps. They help to prioritize areas of conservation value and to localize EbA measures.

2.4.1 Situation Maps

The situation maps included: Ecosystems, Hydrography, Threats, Vulnerability, and Thermo

For more information on the method and geodatasets used to produce these maps, please refer to the Toolbox document and project website.

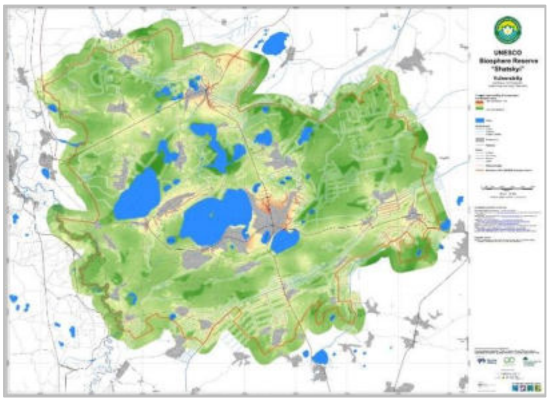
Ecosystems - Based on current satellite imagery, a land cover classification was developed, which depicts the ecosystem complexes of the region. In addition, information on topography, soil, and drainage was added manually (only inside the borders + 5 km buffer of the Biosphere Reserve areas).



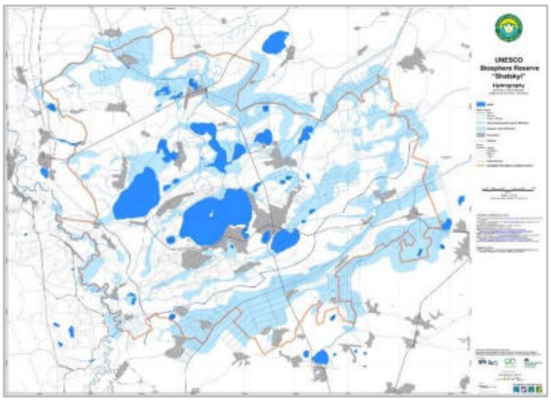
Map 3 Ecosystem map of the Shatskyi BR

The ecosystem maps represent relatively small and homogeneous ecosystems of a local geographical scale – ecotopes. An ecotope can be viewed as a combination of the two sets of ecological components: (1) a physiotope encompassing abiotic characteristics such as local landform, climate, hydrologic regime, and soil; (2) a biotope as a plant community with microorganisms and animals (biocenosis) within defined geographic boundaries.

The Hydrography maps focus on the representation of the hydrological regime including watersheds, surface waters, and wetlands. The Vulnerability maps show the spatial distribution of stress impacts in the ecosystems, based on an assessment of stress indicators carried out beforehand.



Map 5 Vulnerability map for the Shatskyi BR



Map 4 Hydrography map of the Shatskyi BR

The plotted maps were already handed out to the biosphere reserve administration and staff in the course of the MARISCO expert workshops in May and June 2019. All maps are included as A1 printouts to this document series and will be also downloadable from the project website.

2.4.2 Demand and Target Maps

Map types:

1) Deviation from Mean Surface Temperature
2) Ecosystem Cooling Capacity for the summer months 2002-2018

In the *mean surface temperature deviation maps*, geospatial distribution of temperature (T) deviations from mean for different weather conditions were calculated and visualized. In the *ecosystem cooling capacity maps,* zonal statistics were used to describe each ecotope class surface T values for the four weather conditions. Both sets of maps are annexed at the end of this document.

The method and steps for the creation of these maps are explained in more detail in the *Toolbox document*, chapter "Spatial Analysis and Mapping" – part II.

The four weather conditions cover:

1) Mean T for June-August

2) Mean T for cozy days (with max air T of 20 – 25 deg. C)

3) Mean T for summer days (with max air T of 25 – 30 deg. C)

4) Mean T for heat days (with max air T over 30 deg. C)

These four different conditions show one significant pattern over the entire study period (2002-2018). Water bodies with intact riparian zones, wetlands and the areas covered with forest as well as forest-shrub transition stages are the coldest areas in the study area. They sharply contrast with warmer agriculturally managed areas as well as urban and industrial areas. Sealed settlement or urban areas such as Shatsk and Svityaz, and the direct surroundings show the warmest areas. The difference in average surface temperatures between the coolest and forested areas and the warmest urban areas is over 10°C.

For example, on hot summer days with maximal air T > 30°C, the more functional and natural ecosystems, such as near-natural wetlands and lake systems, as well as mixed and mostly unmanaged forest constitute the coolest areas with down to -5,2°C from the mean (cf. map 10). Their cooling potential (cf. map 14) is thus significantly higher than that of intensively managed or altered ecosystems such as agricultural and settlement (up to +11,5°C)

It becomes evident that different ecosystems and land use areas which are, for example, heavily modified, biomass-poor, drained, and sealed by humans, feature a significantly higher positive deviation from the mean temperature. Thus, temperatures differ significantly between the different ecosystems and land use classes.

2.4.3 Maps of Priority Areas for Ecosystem-based Adaptation Action

The project also aimed at indicating spatially explicit *Priority Areas for Ecosystem-based Adaptation Action.*

To support targeted, urgent action and efforts to prevent and reduce climate change and its impacts, ecosystem degradation, and biodiversity loss, a map was elaborated with the following color gradient indicating:

1. Green - Conservation (mainly in (near) natural, i.e., rather functional, less stressed, and damaged ecosystems)
2. Yellow - Reduction of human influence/pressure (modified and (intensively) used and stressed ecosystems)
3. Red - Restoration (destroyed, heavily used, damaged, and stressed ecosystems)

It is important to note that the transitions of the three lines of action (conservation, reduction of human drivers of stress/pressure, restoration) are fluid, meaning that in areas of restoration (e.g., rewetting drained wetlands) also reduction of human influence (e.g., peat extraction, agricultural use) needs to be pursued, while conservation efforts are still relevant (e.g., preserving individual trees or tree communities that remained as functional structures). This applies to both directions of the gradient and is very site-specific. At this level of analysis, available data, and area section, the maps cannot provide further detail. Ground truthing and further research and monitoring are needed to clearly define the area, and which actions are most needed and efficient. For the selection of more concrete action, the EbA measure and activity catalogs can provide first guidance. They are attached to the document series and can be downloaded via the website.

For this map, thermal datasets standardized on the scale 0-100 were merged with integral vulnerability datasets for each BR, which also contain standardized values 0-100. The method is explained in more detail in the toolbox.

The maps are attached to this document in the annex (cf. maps 7-15) and part of the printed materials within the series of documents.

3 Conclusions and Outlook

Shatskyi Biosphere Reserve, its ecosystem, and social system complexes have been and increasingly will **face significant climatic changes** causing alterations in their physical, chemical, and biological conditions. This especially concerns the increase of air temperature, changes in precipitation patterns, and seasonal shifts, affecting all ecosystems and humans alike. These climatic developments cause **changes in the hydrological regime**, including a decrease in surface and groundwater levels leading to shallowing, drying, and transformation of lakes, forests, swamps, meadows, and wells. Meanwhile, the risk and number of meadow-, peat bog-, and forest fires are increasing. Climate change also prompts alterations in flora and fauna and drives the spread of pests and diseases.

A higher number of and **exposure to extreme and hazardous** weather events are observed, including short-term heavy, torrential rainfalls that lead to flooding, crop damage, erosion, and contribute to processes of waterlogging. Warmer winters with less precipitation and summer heatwaves paired with longer and more frequent droughts cause dehydration of lakes and other ecosystems, raise the risk and number of forest and wetland fires and stress both flora and fauna in manifold ways. Storms are causing windthrow in forests, erosion of topsoil, and damage to human infrastructure. Hailstorms, sandstorms, and spring frosts produce damage and disruption in ecological processes. Human well-being, including physical, mental, and economic spheres, is almost always directly and indirectly affected by such extreme events. Increasing pests and diseases affect flora and fauna.

To **buffer and adapt to** these **climate change developments and impacts**, the **self-regulating and self-organizing functions of ecosystems**, and thus the guaranteeing of regulating ecosystem services, are fundamental. Degraded Key Ecological Attributes make the ecosystems more vulnerable and less resilient and resistant to exposure to climate change impacts. However, they are impaired, reduced, or partly lost due to a **variety of harmful anthropogenic activities**. Foremost, these include land-use practices, having their origins both in the past (e.g. land reclamation via draining of wetlands for grass- and cropland, monoculture forestry), and continue in the present (deforestation by clear-cutting, monocultures, surface sealing, artificial water abstraction, compacted and intensively used soil, and the like).

Ecosystem-based Adaptation to climate change aims at:

- **Protection, maintenance, and restoration of ecological functionality** even under the influence of climate change.
- Maximal capacity of ecosystems to **buffer and reduce** climate change **effects on themselves.**
- **Continued provision of ecosystem services** needed for human well-being.
- **Reduction of climate change-related disaster risks** for humans.

For Shatskyi BR, four climate adaptation goal dimensions are proposed:

1. Temperature buffering and cooling
2. Water retention, stabilization of hydrological regime and moisturizing
3. Water regime and flood regulation
4. Natural hazard reduction (fires, storms, pests)

To achieve this, the EbA approach proposes four lines of action to increase ecosystem functionality and decrease vulnerability through heightened self-regulating and -organizing capacity. This will enable ecosystems to cope with the challenges and climatic uncertainties ahead:

I. **Conservation** of existing functional ecological structures and (self-) regulating capacity
II. **Reduction of human-made stresses and factors** that limit and disturb (self-) regulating capacity
III. **Restoration and targeted support** of (self-) regulating capacity
IV. **Development of enabling factors** supporting lines of action I – III

Outlook

The strategy development process played a central role in the continuation of the EbA and MARISCO approaches. The discussion of existing and additional strategies for each ecosystem complex and the ecosystem network of the Shatskyi Biosphere Reserve led to the elaboration of five concrete work and monitoring plans. Both the spatial and temporal dimensions were addressed and considered in this process. These complementary strategies aim at filling strategic gaps and include relevant information for operationalization and implementation of the most viable EbA measures and actions. Based on these results of the strategy development process, the strategies are included in the upcoming annual planning and discussed with regional and national decision-makers.

4 Annex

4.1 Workshop Series at Shatskyi BR and Training in Eberswalde

Since the project started in August 2018, the team and partnering biosphere reserve staff conducted two multi-day workshops and excursions at each biosphere reserve. These workshops form part of the MARISCO adaptive management approach, described in the previous section.

The first visit during November 2018 was aimed at familiarizing the German project team with the biosphere reserves, meeting with administration staff, local actors, and land users. With the involvement of the local population the question of “in which nature do we want to live?” was addressed. These so-called *citizen workshops* were designed to get a first-hand insight into the residents' relationship to their natural surroundings and allowed for the first assessment of Ecosystem Services.

The second journey to the Biosphere Reserves took place from May-June 2019 and aimed at a situation analysis based on the inputs of local and regional experts as well as excursions in the region. Furthermore, the insights of the citizen workshops were introduced and integrated into the considerations and systemic model.

Due to the COVID-19 pandemic, the third workshop trip to the Biosphere Reserves had to be canceled. Instead, a web-based process was developed and conducted to elaborate Ecosystem-based Adaptation strategies, measures, and activity catalogs, as well as working and monitoring plans.

4.1.1 Citizen Workshops

The citizen workshops included a series of three workshops within the area of each biosphere reserves, involving diverse actors from school children to foresters, land-users to administration staff. The participants exchanged knowledge and discussed views on the local ecosystems and their services.

Process

Firstly**,** the biosphere reserve introduces itself to the participants and gives some general insights into both work and purpose. Like this, the workshop also provides a platform to familiarize the audience with the biosphere reserve, its activities and to raise awareness.

The project staff introduces the citizen workshop. The “why” and “how” are explained to the audience. Smaller working groups of 4-6 people are formed.

Session 1: Nature and humans

The previously formed groups work on a set of simple questions and write the answers on moderation cards. The concept of Ecosystem Services and ecosystem classification is explained. Afterward, they are presented by the groups and directly clustered into the scheme shown below. The guiding questions were:

- **How does nature contribute to your well-being?**
- **How do you use nature in the biosphere reserve, where?**

Services of nature (ecosystems)	**Forests** (Natural and managed)	**Water bodies and wetlands** (Lakes /rivers/mires etc.)	**Open land** (Agricultural land/ grassland etc.)	**Settlements and urban green areas**
Provisioning				
Regulating				
Cultural				

Session 2: Nature & (Climate) Change

What kind of changes and threats in nature do you perceive in the biosphere reserve?

- ➢ General changes are written down
- ➢ The group discusses for about 10 min.

Is climate change occurring?
The group adds more observed features of climate changes

If so, how is climate change affecting nature?

- ➢ Locate visible effects on the map
- ➢ Create small result ordered by the affected type of nature

Session 3: View to the future

How can nature and people be better prepared to deal with climatic changes?

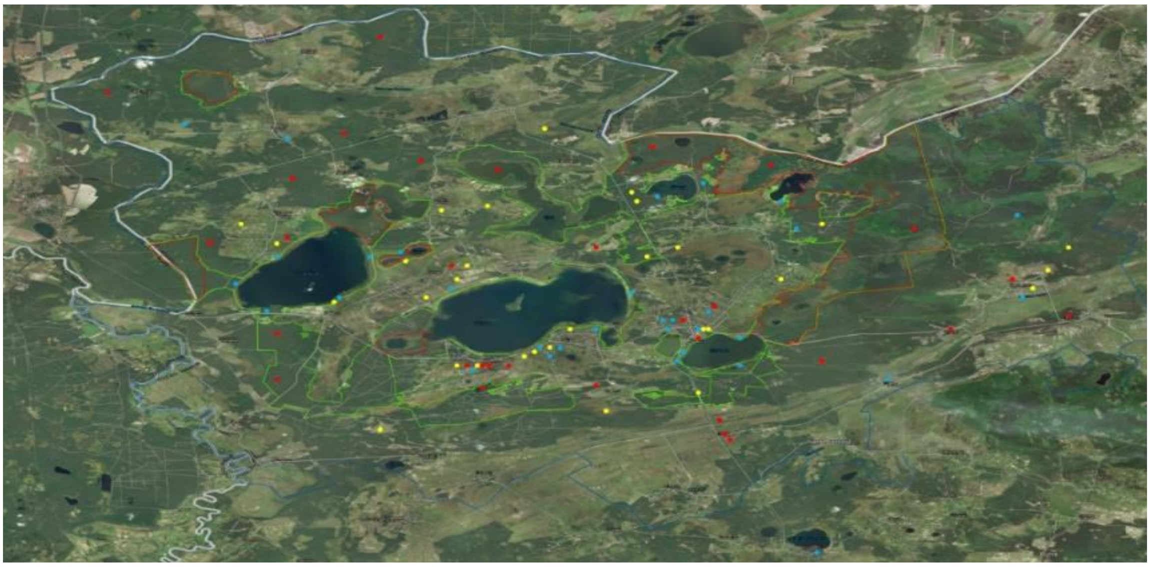
- ➢ 3 main ideas are noted down

How do you wish that the future landscape and its use in the biosphere reserve will look like? What should be changed where?

Finally, the participants received a certificate of participation.

Results

During the citizen workshops, the participants considered a variety of ecosystem functions and services contributing to their wellbeing and livelihood. Ecological stresses, drivers of stress, and climate change impacts in the area were listed and indicated spatially explicitly on printed versions of the area´s satellite image provided during the workshops.



Map 6 Climate change-related events in the Shatskyi BR indicated by the workshop participants, Credit: CEEM

During the citizen workshop, a broad array of climate change-related impacts and threats was mentioned by the participants, including:

- Increase of mean annual temperature
- Temperature anomalies (e.g., extremely low temperatures in spring with frost)
- Seasonal changes of precipitation patterns
- Rainfall anomalies (torrential rain in short periods)
- Flooding
- Hailstorms
- Strong winds, storms, and tornados
- Drought
- Desertification
- Forest fires
- Peat-soil fires
- Soil erosion
- Increase of forest parasites

The full list of the situation analysis results can be found in chapter 2.2.2.1

4.1.2 MARISCO I - Stakeholder and Expert Workshops

In June 2019, the expert and land user workshops were held in Svityaz. Here, the MARISCO method was applied to elaborate a first comprehensive diagnostic of the area. Both challenges to ecosystem functionality as imposed by climate change, as well as the first inventory of potential Ecosystem-based Adaptation strategies, were gathered. Results of the previous workshops were considered and further developed.

Shatskyi Biosphere Reserve

03.06.2019 - The workshop started with the excursion day for an insight into the biosphere reserve, its ecosystems, people, and visible climate change challenges.

Image 3 Excursion to Lake Ecosystem at Shatskyi BR; Credit: A. Schick

Image 2 Group working on the conceptual model; Credit: A. Schick

On 04.06.2019, the participants started working on the situation analysis and followed the stepwise approach described in the Toolbox document (MARISCO method section). The following elements of the conceptual model were elaborated:

1. Ecosystems
2. Key Ecological Attributes (KEAs)
3. Ecological Stresses
4. Introduction of drivers of ecological stress (threats). Here, the findings from *Citizen Workshops* were included
5. Introduction of underlying factors and causes
6. Ecosystem Services
7. Human well-being

On the third day, the participants revised and added cards to the drivers of ecological stress, underlying factors, and ecosystem services. A focus was then put on regulating ecosystem services. The strategies module was introduced, and the first Ecosystem-based strategies and measures were elaborated and integrated into the conceptual model.

Image 4 Participants in front of the conceptual model; Credit: CEEM

Assessing the vulnerability and risk for the ecosystem and human population of the Shatskyi BR has contributed to a better understanding of the systemic interrelation of diverse factors.

The results of the workshop as well as the conceptual model can be found in chapter 2.2.2.

Feedback of workshop participants:
Pro:

- Gaining of and systemization of knowledge concerning the region, climate change, and adaptation
- Effective group brainstorming method for complex issues
- Good for understanding problems, threats, and driving factors
- Sharing of ideas and awareness-raising
- Productive and interesting system of information collection and processing for the development of the climate change adaptation strategy.
- The methodology of the seminar is very good as for the interdisciplinary approach.
- The thoughts of various specialists and scientists on one particular territory and being in one place is very important and good for the results.

Cons:

- Very theoretical, challenge to move to concrete implementation steps
- Complex approach – not enough time to proceed and discuss the complicated elements and problems sufficiently.
- Method (at this stage) neglects or underestimates resistance or obstacles of stakeholder or lobby groups when strategies come to an implementation level.
- The speed of the group work situations might lead to misunderstanding and overruling of crucial and essential impulses if they are not strongly promoted in due time
- Establish a closer link of elaborated strategies to ecosystem classes and maps
- Involve more local people knowing the region
- The applied approach for information gathering is quite subjective. It is hard to interpret and evaluate stresses, if they are mentioned by other teams (misinterpretation possible)

Results and conclusion:

- **The participants gained more clarity of what kind of role, functions, and services ecosystems play in climate change.**
- **Understand systemically, where the problems and challenges lie, how human activity contributes to them, and how they can be overcome.**
- An important goal was to **harvest the first appropriate strategies for the region**, which form a good base for the elaboration of strategies of Ecosystem-based Adaptation to climate change.

The participation of the biosphere reserve representatives was valuable, as this allowed for networking and learning together about climate change and adaptation options. Like this, the areas can inspire each other and share their solutions.

The project team expresses gratitude to all the workshop participants. The conceptual model represents walls full of "knowledge" and regional insight. The idea contest, as well as the implementation phase of the project, shall provide an opportunity for action on the local scale, to move from theory to practice, and implement parts of the Ecosystem-based Adaptation strategies and measures. It is very important to not only produce paper stacks but implement something, thereby inspiring people and making a change.
Biosphere Reserves are the right places for experimenting with such "revolutionary" new strategies and measures. The mission of BRs is to inquire, implement and monitor such people-centered and ecosystem-based approaches to changes in management, land use, and education. In this aspect, they can be the drivers of change and serve as role models.

4.1.3 Training and dialog in Eberswalde: Ecosystem-based Adaptation in Biosphere Reserves

From December 09-13, 2019, 15 representatives of 5 Ukrainian UNESCO Biosphere Reserves met in Eberswalde and initiated a dialog to mutually support the understanding of Ecosystem-based Adaptation to climate change. The training was organized and conducted by the Centre for Econics and Ecosystem Management with the support of the Michael Succow Foundation.

Image 5 Group photo at Lower Oder Valley National Park, Credit: EbA Ukraine

The participants and organizers set out to mutually explore, discuss, and understand practical options for the implementation of corresponding measures.

Image 6 Workshop session at Eberswalde University for Sustainable Development, Credit: K. Mack

The training week comprised diverse formats – from lectures and excursions to workshop-like group work, the elaboration of a common statement paper, and the co-creation of own criteria for effective ecosystem-based measures in biosphere reserves.

Image 8 Guided excursion at Treuenbrietzen forest fire site; Credit: A. Dichte

Image 7 Guided excursion at Sernitz valley spring fen, Credit: K. Mack

December 9, 2019

Lecture day

After a welcome by the organizers, participating biosphere reserves, and a Ministry representative, presentations covered the topics of:

- The Biosphere Reserves Concept
- Adaptive Management under the Ecosystem Approach
- Participation and governance
- Climate change and developments in Ukraine
- Ecosystem-based Adaptation and Mitigation: Climate management with forest ecosystems
- Regional sustainable development and justice

Image 9 Uli Gräbener, head of the Biosphere Reserves Institute presenting the functional zonation concept; Credit: K. Mack

December 10, 2019

Forest ecosystems day

Excursion 1:

Glassy Forest Project,
Schorfheide-Chorin Biosphere Reserve
Gollin, Reiersdorf, Brandenburg

- Visiting the project site with a best practice approach from an EbA perspective
- Examples of measures positively affecting and securing regulating, provisioning, and cultural ecosystem services

Image 10 Dietrich Mehl (Brandenburg State Forestry Service), Pierre Ibisch, and Jeanette Blumröder (both Centre for Econics) guiding the excursion at Reiersdorf forest, Schorfheide-Chorin Biosphere Reserve; Credit: A. Dichte

Excursion 2:

CleverForest Project,
(**CL**imate-adaptive, **E**cosystem-based, **VE**rsatile and **R**esilient Forest)
Treuenbrietzen, Brandenburg

- Recent forest fire site
- Research on vulnerability and climate change impacts
- Project area with a new management approach
- Self-regulated and natural regeneration of the area

Image 11 Jeanette Blumröder and Pierre Ibisch (both CEEM/HNEE) guiding the excursion to the post-fire excursion site at Treuenbrietzen, Germany

December 11, 2019

Open land and settlement ecosystems day

Excursion 1:
Bernau – Project Bernau.Pro.Klima

Vulnerability and climate change impacts in semi-urban ecosystems and surrounding ecosystems

- Participatory adaptation approach for Bernau
- EbA best practice and management approaches including the topics of renaturation of a small river, urban greening, and surface unsealing

Image 12 Excursion to small river renaturation site - Panke, Bernau, Brandenburg; Credit: K. Mack

Excursion 2:
Ökodorf Brodowin, Schorfheide-Chorin BR
Ecological/Organic (Demeter certified) agriculture as an example of best practice approaches in agriculture and livestock breeding.

- Support of species and structural diversity
- Extensive forms of livestock breeding and agricultural production

Image 13 Ludolf v. Maltzan, CEO of the Ökodorf Brodowin explaining the concept, challenges, and benefits of organic farming; Credit: A. Dichte

December 12, 2019

Water and wetland ecosystems day

Excursion 1: **Lower Odra Valley National Park**

- Vulnerability and climate change impacts on river and floodplain landscape
- EbA best practice approaches: Renaturation of Odra river meanders
- Support of structural landscape diversity
- Protection of biodiversity

Image 14 Dr Michael Tautenhahn, deputy director, guiding the excursion in the national park; Credit: A. Dichte

Excursion 2: **Sernitz marshland**

Schorfheide-Chorin Biosphere Reserve
Project: Revitalization of one of Northern Germany's largest spring bogs

- Options of Ecosystem-based Adaptation in land-use of wetlands (Paludiculture)
- Wetland nature protection activities
- Preservation and restoration of wildlife habitat

Image 15 Dr Benjamin Herold (Schorfheide-Chorin BR) and Andreas Haberl (Succow Foundation) guiding the excursion at Sernitz marshland; Credit: A. Dichte

December 13, 2019

Strategy and EbA criteria day

Elaboration of a **statement paper** concerning Ecosystem-based Adaptation and biosphere reserves.

Identification and selection of **criteria for Ecosystem-based Adaptation measures**

- for the planned idea contest
- for project proposals

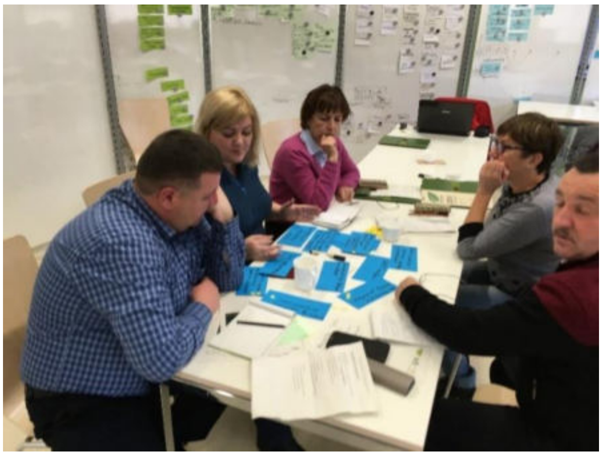


Image 16 Group work for the elaboration of the statement paper and criteria for EbA measures/projects. Credit: K. Mack

Results of the training:

- Improved understanding of the **concept and measures of Ecosystem-based Adaptation**
- **Networking** and **strengthening of the cooperation** between Ukrainian Biosphere Reserves and German partners.
- **Criteria** for the selection of EbA measures and projects
- Elaboration of a **statement paper** regarding Ecosystem-based Adaptation and biosphere reserves aimed at regional and state decision-makers.

4.1.4 MARISCO II – Strategy Development Process

The process consisted of different working steps, covering the identification of strategies, measures, and actions (SMA) relevant for restoring, increasing, and protecting ecosystem functions such as water retention and storage, filtration of solar radiation, and soil formation. These functions generate indispensable services urgently needed by humans to reduce climate-change-related threats like heat, drought, floodings, storms, forest- and wetland fires, etc. It furthermore provided an opportunity to assess and discuss the effectiveness and viability of strategies together with stakeholders to support the selection of key strategies for each of the BRs' upcoming work and monitoring plan development.

MARISCO and adaptive management expert Axel Schick guided through the process and, together with the whole project team and partners, took on the challenge to moderate all sessions via video-conferencing from Lima, Peru. Thus, the project operated on a global level, in different time zones, progressing amidst the challenges due to Covid-19-related travel and meeting restrictions. Positive side-effects were lower Greenhouse gas emissions, reduced travel time, and material use. The flipside of the adapted method was the missing possibility to further elaborate on and work with the conceptual model within the original group, the valuable in-person discussions, and the informal gatherings which used to complete the long working sessions in past on-site meetings in both Ukraine and Germany.

Part I: EbA Strategy identification and gap analysis

In Block A, the strategy identification was conducted for each biosphere reserve. Here, the task was to look through all existing strategies elaborated in the SMA catalog as well as in the available management plans of the BRs. Additionally, strategic gaps were identified based both on the participants´ expertise as well as the MARISCO conceptual model.

Table 1 Online sessions conducted for strategy identification and gap analysis

Date	Biosphere Reserve	Ecosystem considered
13.07.2020	Opening session / ceremony – 46 participants	
14.07.	Roztochya	Open land and settlement
16.07.	Shatskyi	Open land and settlement
17.07.	Roztochya	Forest
20.07.	Desnianskyi	Open land and settlement
21.07.	Roztochya	Grassland
22.07	Shatskyi	Forest
24.07	Roztochya	Water-& Wetland
28.07.	Desnianskyi	Forest
29.07.	Shatskyi	Wet-& Grassland
10.08.	Desnianskyi	Wetland
11.08.	Shatskyi	Waterbody
14.08.	Desnianskyi	Waterbody
26.08.	General summary and presentation of results	

The strategy process was met with great interest from a variety of participants. On 13.07.2020 up to 46 persons participated during the session ranging from biosphere reserves, local land users, universities, NGOs, to ministry representatives.

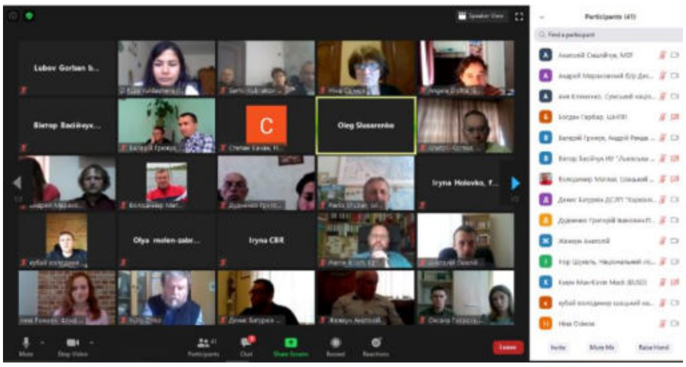


Image 17 Participants at the web-based opening session of the Strategy Development Process on 13.07.2020

As a result of the sessions shown in Table *6, from **July to September 2020***, experts and staff of the three partner Biosphere Reserves together with the project team **developed an extensive Ecosystem-based Adaptation strategy portfolio.**

Part II: EbA Strategy evaluation, rating, and prioritization

03.09.2020

- Integration of existing strategies
- Removal of some strategies which were not viable and unfit.
- Some stakeholders participated in the workshop.

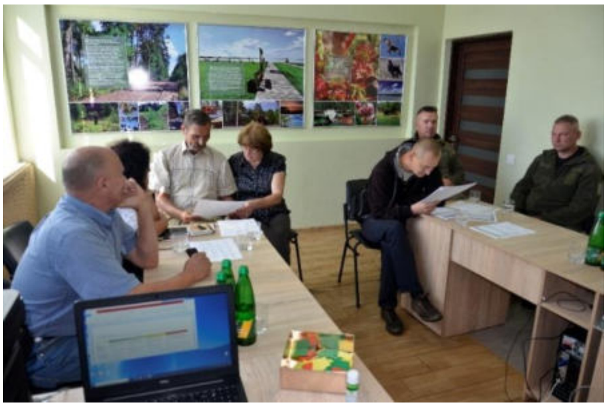


Image 18 Strategy rating and prioritization session at Shatskyi BR on 03.09.2020, Credit: Shatskyi BR

10.09.2020

Presentation and discussion of the ranking results as well as of the final strategy selection by the Shatskyi BR.

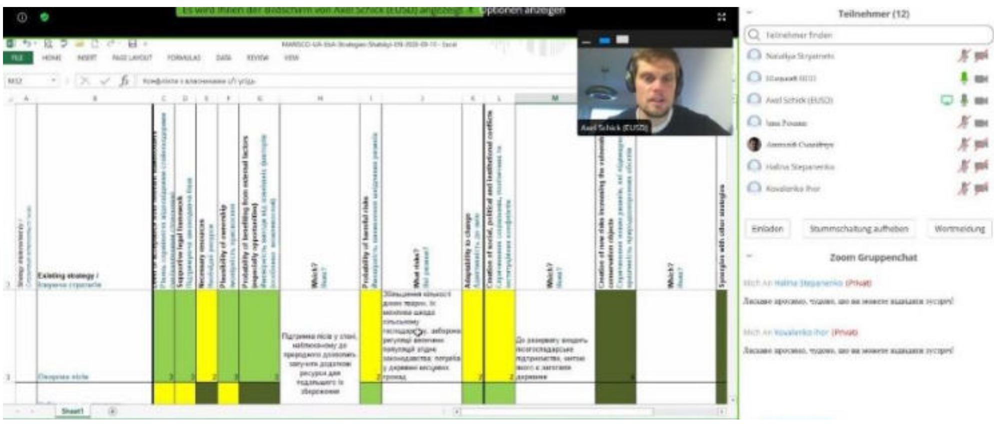


Image 19 Axel Schick (CEEM) discussing results in the revision/discussion session on 10.09.2020, Credit: K. Mack (CEEM)

15.09.2020

In the general summary and closing session, all biosphere reserves and the project team got together.

This didn´t mark the end of the whole process, but a milestone of having finished the SMA workshops for each ecosystem cluster, the offline workshops, and strategy ratings.

The process continued with the focus on the most viable and necessary goals, SMAs, and the development of concrete operational and monitoring plans

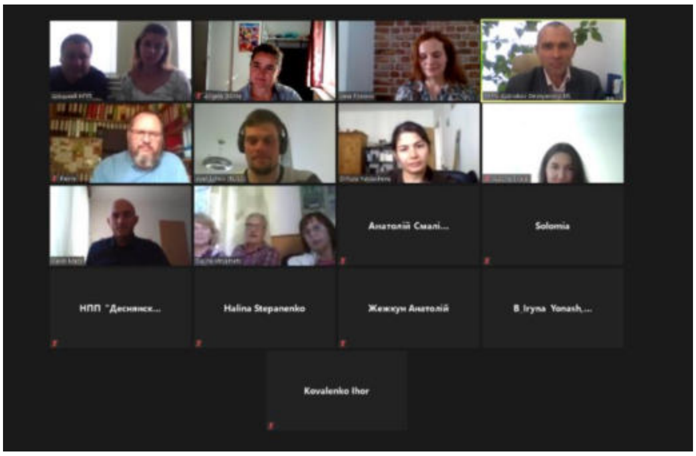


Image 20 Participants at the closing session on 15.09.2020, Credit: K. Mack

Conclusions and necessities:

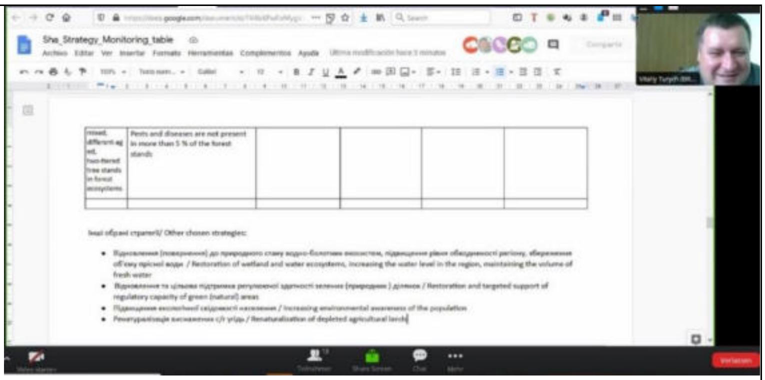
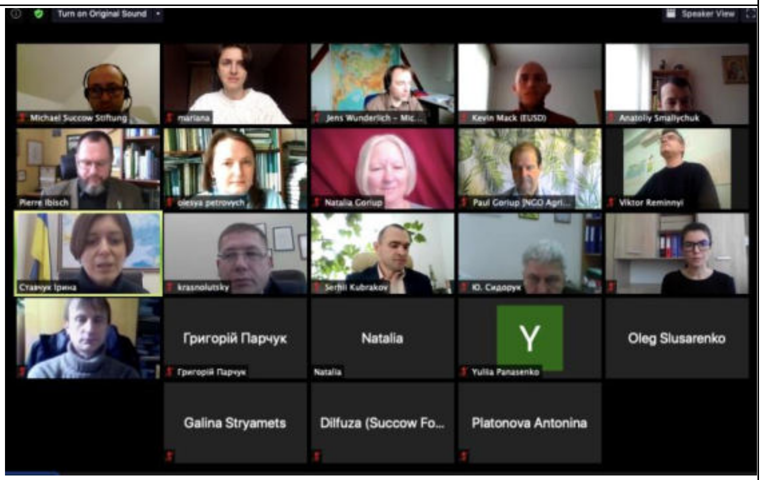
- It is important to develop an Ecosystem-based Adaptation strategy on the national level.
- The 3 Biosphere Reserves are working at the forefront, doing groundbreaking work on these topics. So far, the BRs in general (also globally) haven´t stood up in favor of Ecosystem-based Adaptation.
- The development of a shared vision on EbA in biosphere reserves is both a big challenge and a chance for finding workable ways and answers to climate change.

Part III: Elaboration of Work- and Monitoring Plans for 5 Key Strategies

From ***October to December 2020,*** **detailed work and monitoring plans for strategies (five per BR) of Ecosystem-based Adaptation to climate change were prepared**. The strategies were developed during months of cooperation and 22 online workshops and meetings as well as regularly discussed, independent work on behalf of the Biosphere Reserves.

After the introduction session, the BRs were invited to elaborate in total 5 strategies which the BR will work on after the session:

The tasks for the BRs encompassed the following:
1. Define goals for each ecosystem (-cluster)
2. Select strategies most likely to achieve these goals
3. Take strategies & start to divide them into concrete tasks & actions
    a. Who is going to implement each task
    b. Define concrete timeline
    c. Define what resources are needed for implementation
4. Make use of the conceptual model to evaluate and conduct a plausibility check
    a. Do we achieve the change we want in the system?
5. Write concise work and monitoring plans
	Further filtering and priority setting are required to advance to strategies that allow for adequate action. Here, two criteria are especially relevant:
	• Effectiveness (will the measure contribute to the goal?)
	• Feasibility (Will such a measure be accepted by the stakeholders?)
	    • Socio-economically
	    • Culturally appropriate
	    • Financially viable (is there money to implement?)
	Further criteria had to be defined by the biosphere reserves and other participants

24.09.2020	*1st revision session for the working and monitoring plans*	 *Image 21 Shatskyi BR´s Vitaliy Turych discussing the EbA work and monitoring plan - online session on 24.09.2020; Credit: K. Mack*
08.10.	*Goals and strategy revision*	
21.10	*2nd revision session for the working and monitoring plans*	
16.12.	*Closing event*	
02.03.2021	*Web-based presentation of updated results for the steering committee and Ministry of Environmental Protection and Natural Resources of Ukraine*	 *Image 22 Participants during the results presentation session Credit: K. Mack*

Based on the elaboration and collection of EbA strategies and measures (five catalogs per BR for the main ecosystem complexes), a criteria-based selection of 5 'key EbA-strategies' per region was completed. The work and monitoring plans for the strategies are ready for implementation. The results have already been presented to the project steering committee with the participation of Ukrainian ministry representatives and various documents have been distributed among the participants.

Results of the Strategy Development Process

1) An extensive portfolio of EbA measures and actions for the present ecosystem clusters of the biosphere reserves and regions was developed (cf. attached catalogs in this documents series or via the project website: https://www.eba-ukraine.net/Publications.html).
2) Strategy evaluation and rating schemes were elaborated during offline work sessions by the BRs and partners by which the prioritization of strategies and final selection process was informed: The final selection of strategies was the following:

Shatskyi BR (5 out of 17 strategies):

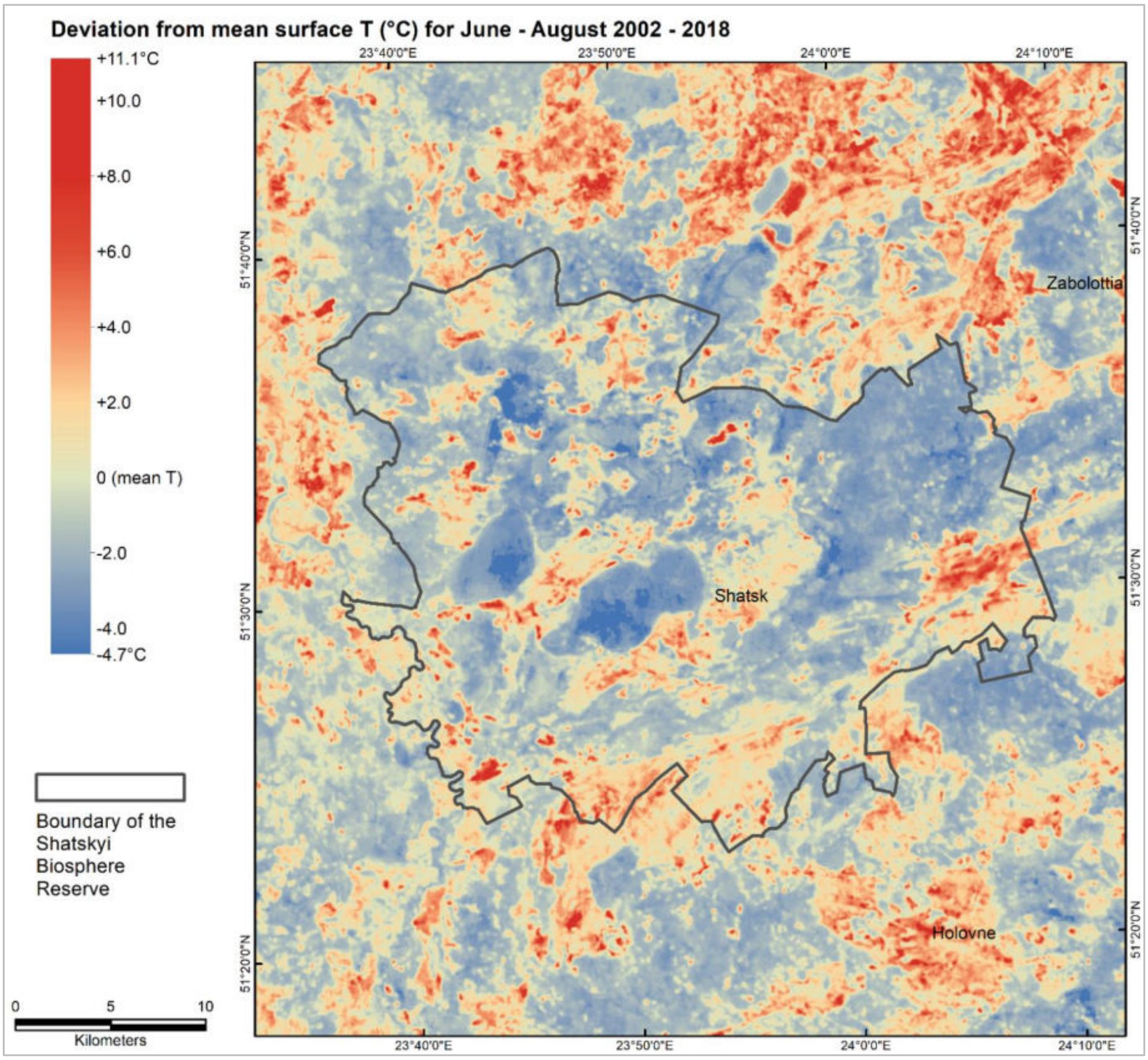
- Ecosystem-based forestry
- Restoration of the natural state of wetland and water ecosystems (increasing the water level in the region)
- Increasing environmental awareness of the population
- Ecological management of urban green spaces and targeted support of regulating the capacity of green (natural) areas
- Renaturation of depleted abandoned agricultural lands

This process showed that Ecosystem-based Adaptation needs to address different levels of management:

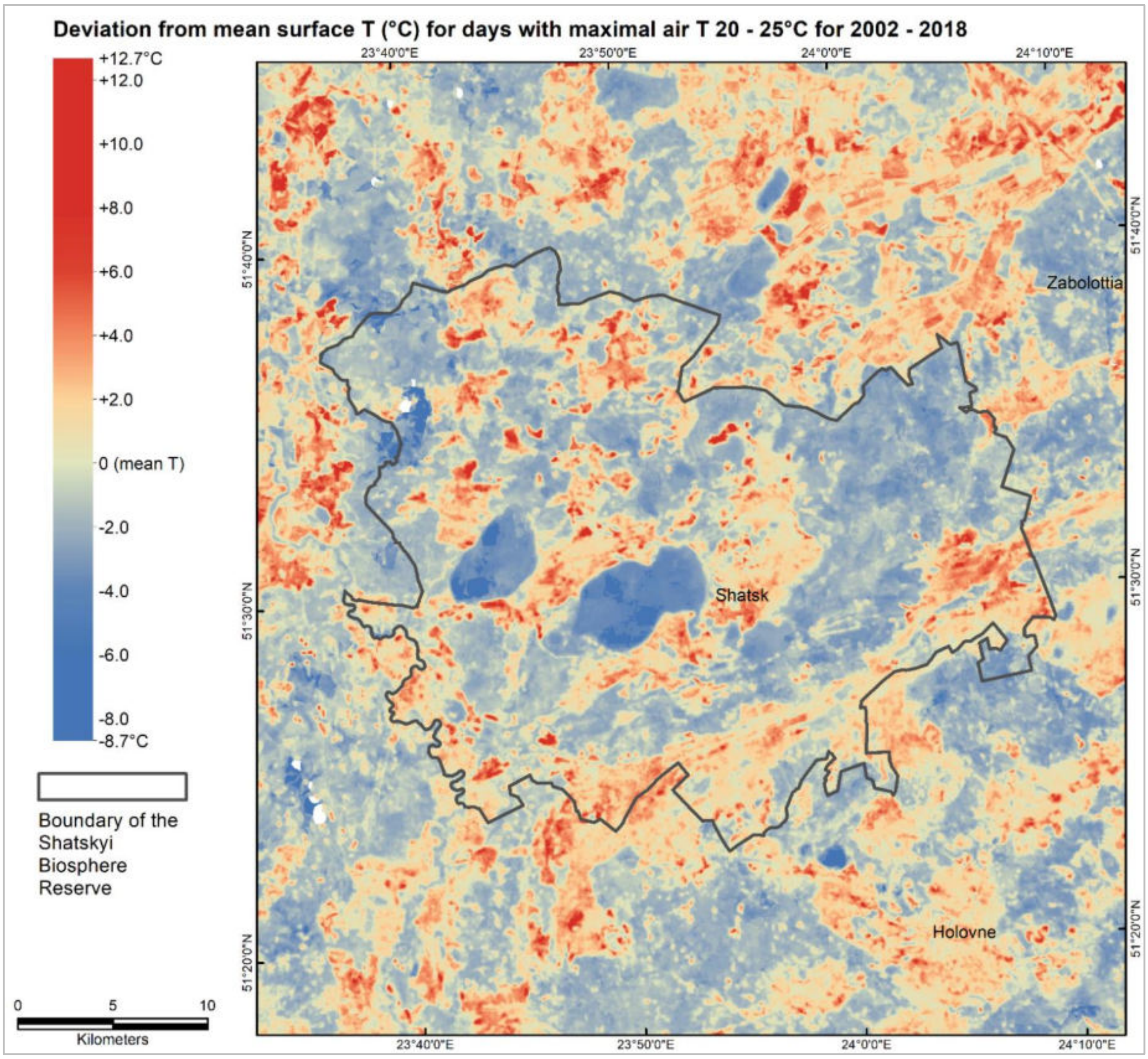
- Direct protection and renaturation activities by the BR staff.
- Land-use changes with stakeholders in all zones of the biosphere reserves and beyond.
- Influence on regional and national strategies, policies, and laws.

Showing presence and highlighting the importance of the UNESCO MAB program nationally and internationally.

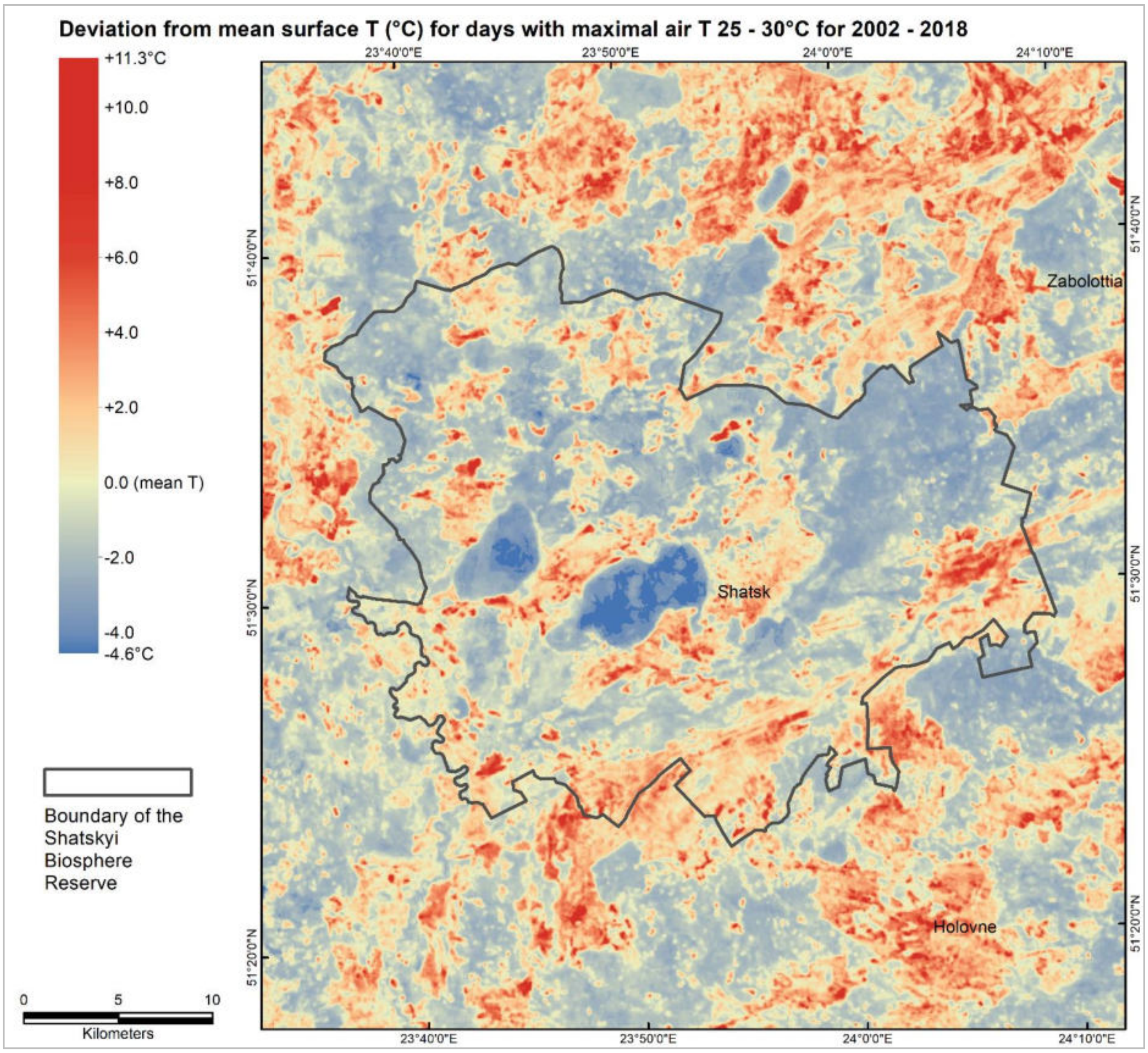
4.2 Maps: Deviation from Mean Surface Temperature - Summer Months 2002-2018



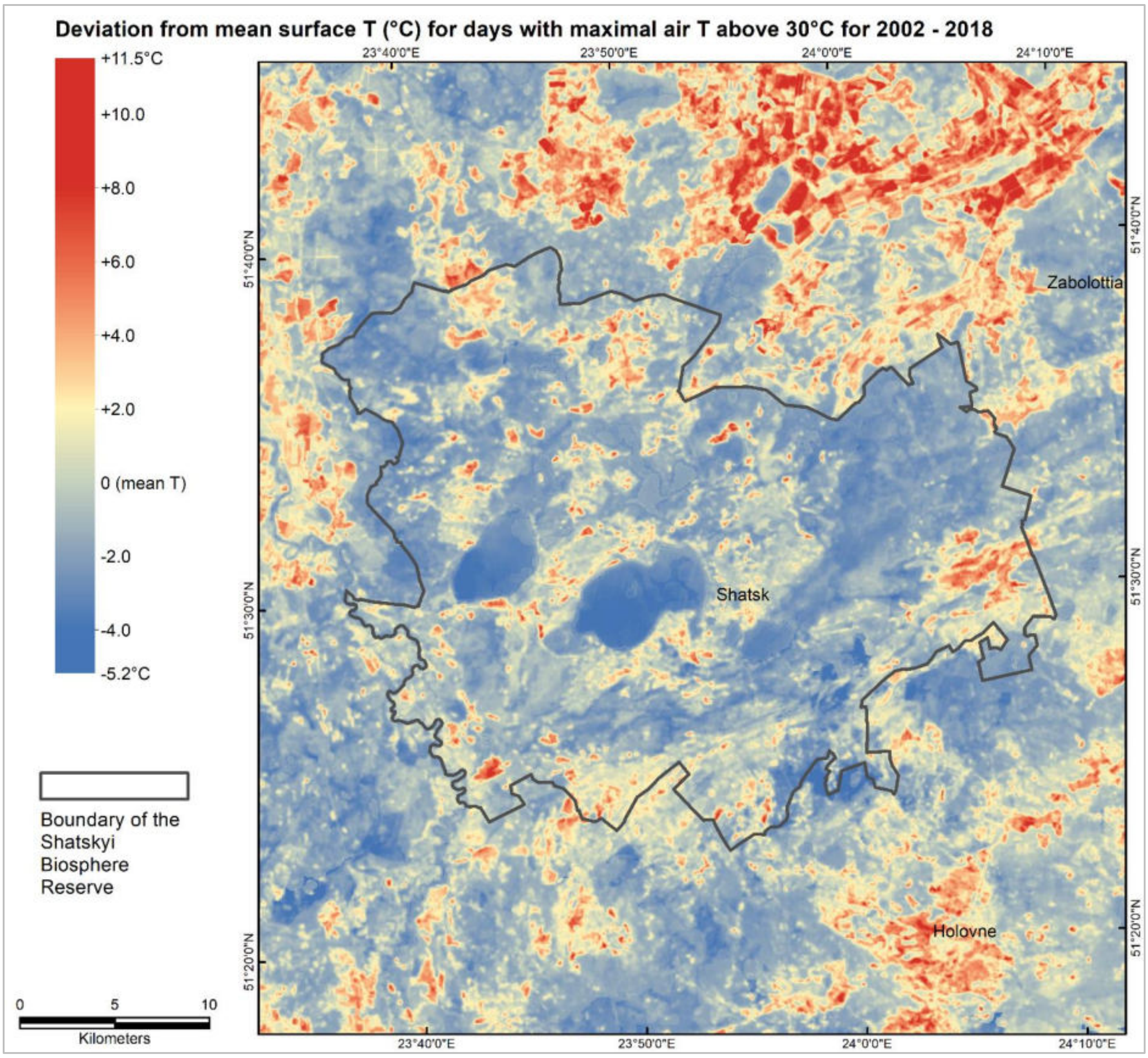
Map 7 Deviation from mean surface T (°C) for June-August (2002-2018)



Map 8 Deviation from mean surface T (°C) for June-August (2002-2018) - max air T 20-25°C

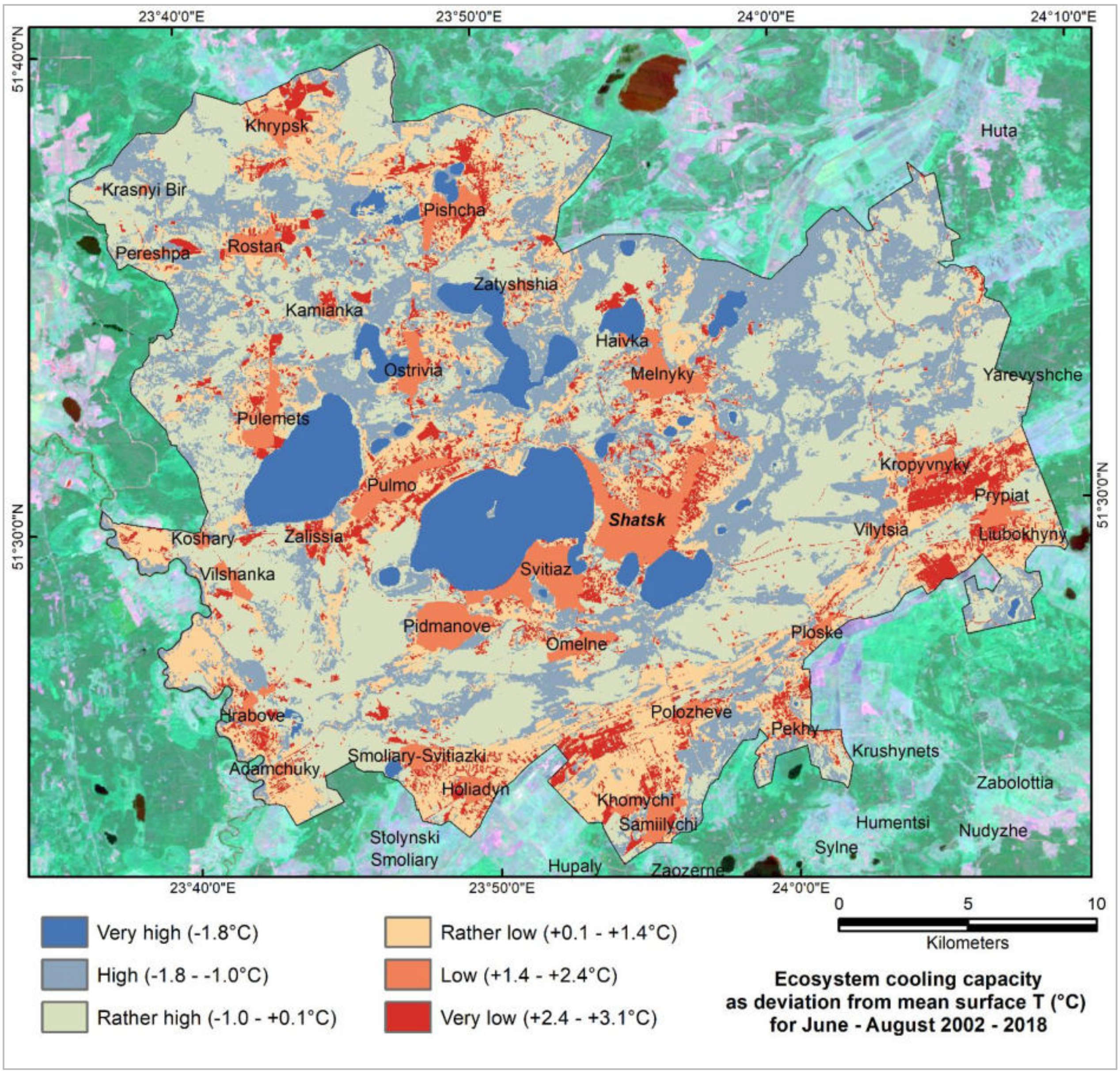


Map 9 Deviation from mean surface T (°C) for June-August (2002-2018) - max air T 25-30°C

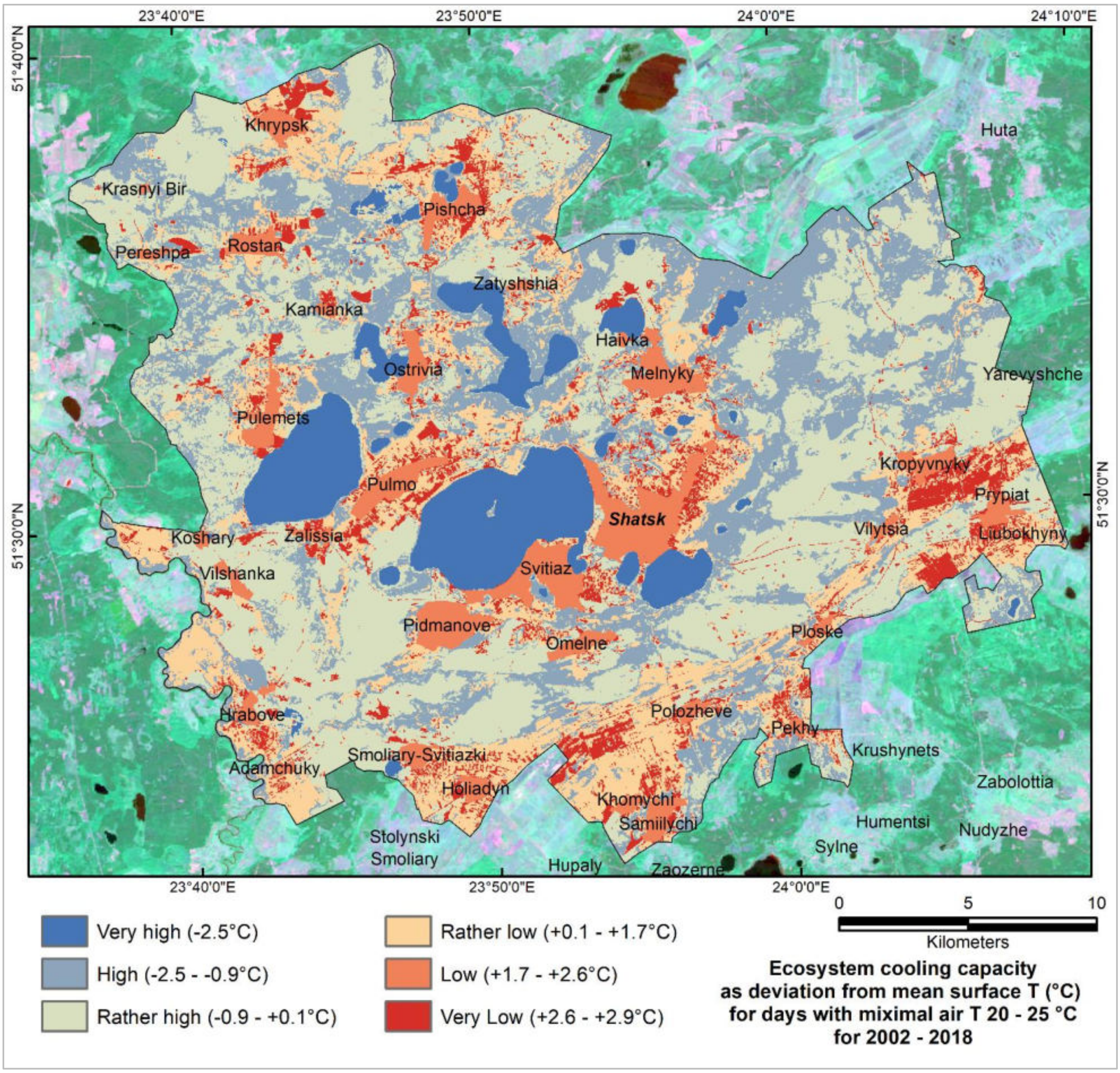


Map 10 Deviation from mean surface T (°C) for June-August (2002-2018) - max air T > 30°C

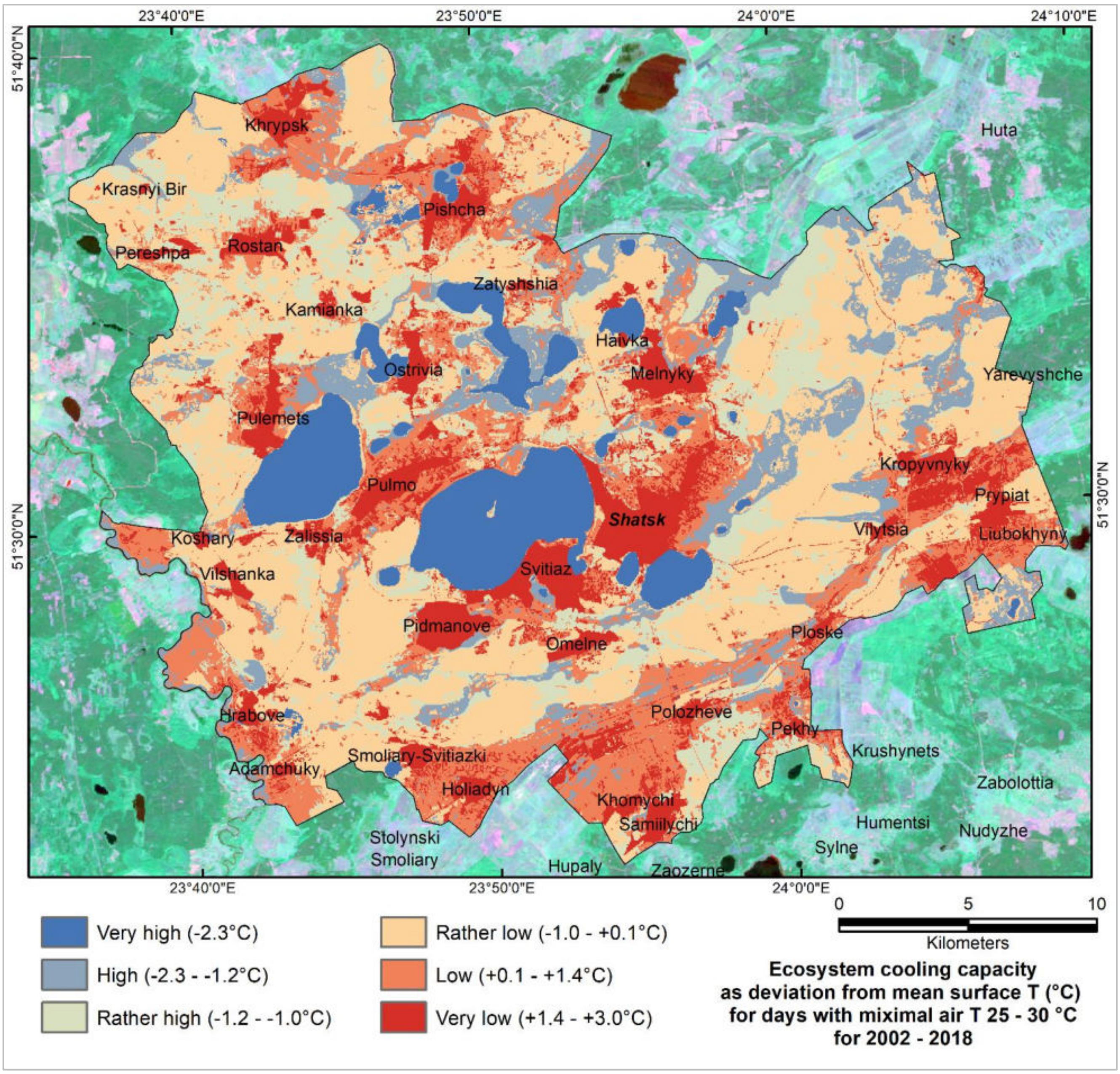
4.3 Maps: Ecosystem Cooling Capacity – Summer Months 2002-2018



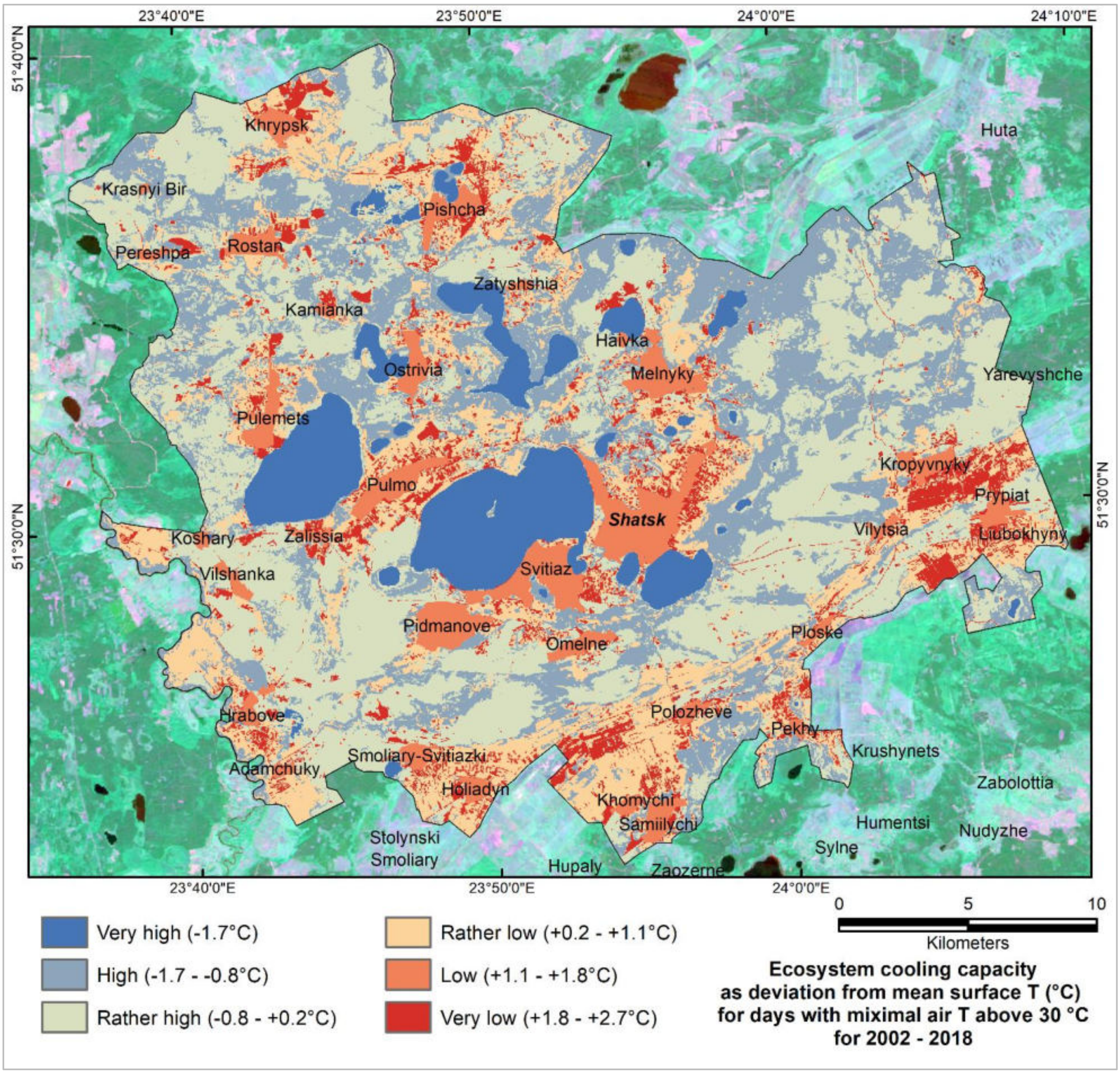
Map 11 Ecosystem Cooling Capacity – based on deviation from mean surface T (°C) June-August (2002-2018)



Map 12 Ecosystem Cooling Capacity – based on deviation from mean surface T (°C) June-August (2002-2018) for max T 20-25°C

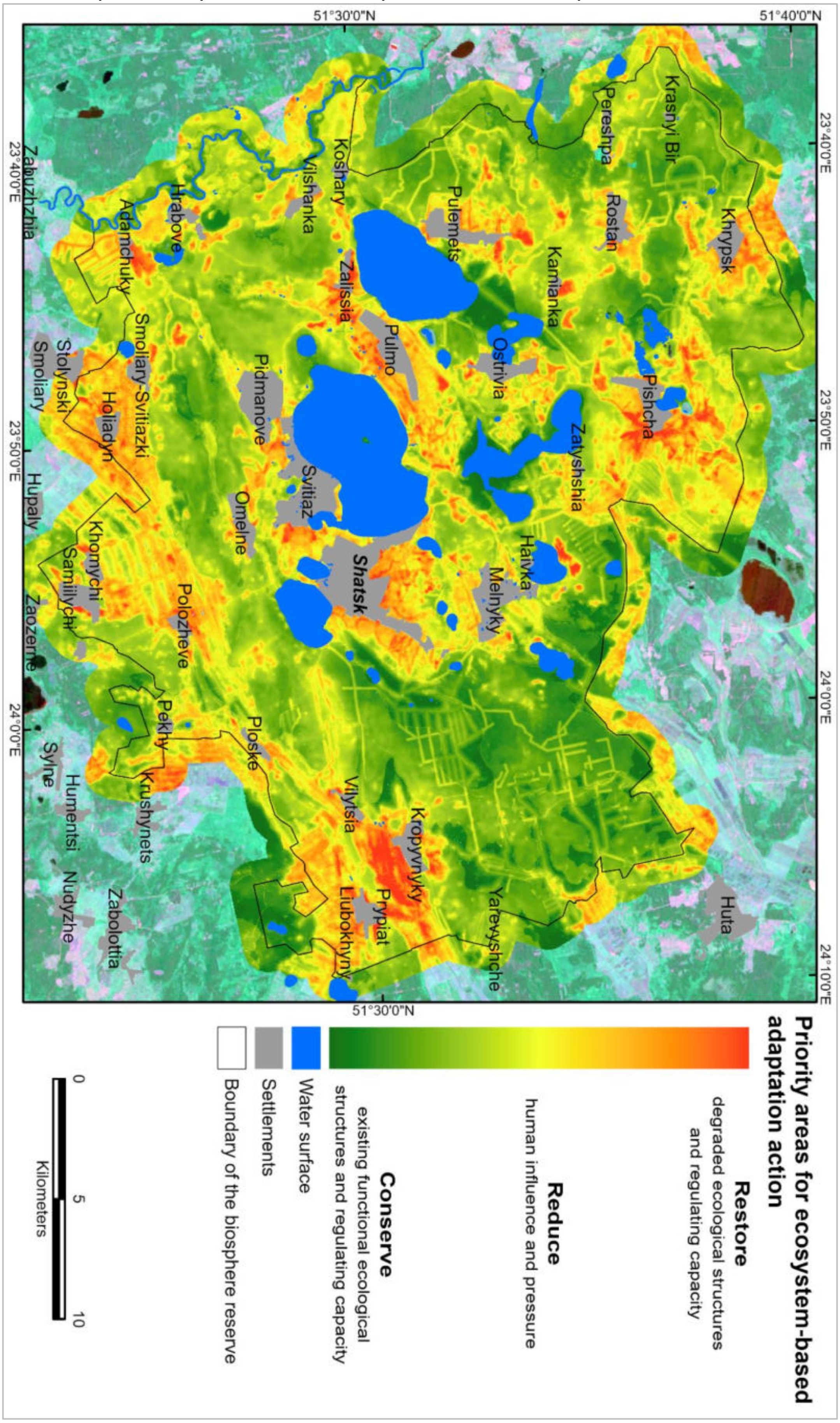


Map 13 Ecosystem Cooling Capacity – based on deviation from mean surface T (°C) June-August (2002-2018) for max T 25-30°C



Map 14 Ecosystem Cooling Capacity – based on deviation from mean surface T (°C) June-August (2002-2018) for max T >30°C

4.4 Map: Priority Areas for Ecosystem-based Adaptation Action



Map 15 Priority Areas for Ecosystem-based Adaptation Action - Restore, Reduce, Conserve

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