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Mapping and national assessment of ecosystems and their condition in North Macedonia

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Abstract

In 2020, North Macedonia conducted the first national assessment of ecosystem condition. The assessment fully adhered to MAES (Mapping and Assessment of Ecosystems and their Services) working group guidelines and represents the first implementation study in North Macedonia, marking it as the first Southeastern European country outside the EU to conduct such an assessment. National team of 30 experts was established and worked on accomplishment of the first two steps from the MAES operational framework: i) map of the ecosystem types and ii) assessment of their condition. Ecosystem typology corresponds to the MAES Level 2 categories, while the Level 3 categories were modified in order to fit our data.

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Mapping was done by using the available CORINE land cover data, published and unpublished scientific data, however major work was done with analyses of satellite imagery which resulted in a detailed map of country's ecosystems. The ecosystem condition assessment was done for 15 natural and semi-natural ecosystem types. The anthropogenic and agricultural ecosystems were excluded from this assessment. Set of indicators was developed for each of the ecosystem types following MAES guidelines. In total, 16 indicators and 53 parameters were scored from 1 to 5 on specific scales. National and project data bases, as well as GIS tools were the main sources of data for the parameters. The majority of parameters were quantified, although some were evaluated based on their qualitative properties. It was followed by assessment on ecosystem services on national and local scale, accompanied by local scale implementation perspectives.

Keywords: MAES, indicators, classification, ecosystem services

Introduction

Ecosystem condition is defined as an effective capacity of an ecosystem to provide services in relation to its potential capacity (Millenium Assessment 2005). Knowledge of the condition of ecosystems and their services is essential to support decision making for sustainable management of natural resources, climate adaptation, ecosystem restoration and policies on urban sustainability and green infrastructure (Maes et al. 2013). This is especially imperative since ecosystems globally have negative impact from human activities (Newbold et al. 2015). According to the Global Assessment of Biodiversity and Ecosystem Services, natural ecosystems have declined in extent and condition by 47% on average (Brondizio et al. 2019). Assessment and monitoring of their condition can be critical in detecting changes or responses to changed environment.

All countries of the European Union had obligations related to mapping of ecosystems and evaluating their condition on account of Action 5 from the European Biodiversity Strategy (2010-2020). Moreover, methodological guidelines and a common conceptual framework were developed by the MAES (Mapping and Assessment of Ecosystems and their Services) working group (European Commission, Directorate-General for Environment 2013, 2014, 2018). Despite these efforts, the knowledge of ecosystem health, integrity or degree of degradation is far from uniform (Rendon et al. 2019). For Europe, this especially refers to developing countries such as North Macedonia. This gap of knowledge can be accountable for belated actions or policies, as well as unsustainable decisions. To date, Greece and Bulgaria are the most prominent countries in the region of South-Eastern Europe (SEE) in terms of MAES implementation, as well as additional analysis, pilot studies, stakeholder engagement, and contribution to scientific knowledge for ecosystems and their services (Bratanova-Doncheva et al. 2017; Kokkoris et al. 2020; Ivanova 2017; Nedkov et al. 2016). Even when conventions, strategies, and laws pertaining to nature are accepted, other nations within the Balkan region (all non-EU members) are far from the already ambitious targets. According to Rendon et al. (2019) and our current knowledge, there are no published studies regarding ecosystem condition for non-EU countries from the region: Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia and Serbia.

With the internationally increasingly exploited concept of ecosystem services, in 2017 North Macedonia developed national agenda for assessment of ecosystem services starting with the assessment of the ecosystems condition, as recommended by the MAES methodology. It announced the start of implementation of the targets set in the National Biodiversity Strategy and Action Plan (MoEPP, 2018) in regards to ecosystem services assessments. Therefore, a map of ecosystem types and the first national assessment of ecosystem condition was completed in 2020, as part of the Nature Conservation Program funded by the Swiss Agency for Development and Cooperation. As a follow up study within this program an assessment of ecosystem services on national and local scale have been conducted, as well as capacity building plan and training regarding the ecosystem services concept for different national stakeholders. Additionally, payment of ecosystem services (PES) scheme was developed and piloted in one protected area in the country.

Study area

North Macedonia is a landlocked, mountainous country located in the central Balkan Peninsula (Figure 1) with surface area of 25436 km^2. Despite, due to the complexity of geology, climate and relief it boasts exceptionally high diversity of species and habitats (Melovski et al. 2013). In accordance with the regional climate, soil distribution, and vegetation patterns, North Macedonia exhibits eight distinct climate-vegetation-soil zones (Filipovski 1996). These delineated zones encapsulate the diversity of biomes, ranging from pseudomaquis in the lower elevations, progressing through thermophyllous and mesophyllous oak, beech, and coniferous forests, ultimately culminating in alpine tundra-like grassland and dwarf shrub in the high mountain areas. There are three different climate types: modified Mediterranean, moderate continental climate and mountainous climate. Most of the country surface (44.1%) ranges at altitudes between 500–1000 m a.s.l. The country can be

Figure 1. Geographical position of North Macedonia

roughly divided into three regions: the western mountainous region (Šar-Pindus Mountain Range, total of 141 peaks higher than 2,000 m a.s.l.), the central lowland region (mostly the Vardar River Valley, 80–300 m a.s.l., Pelagonia Plain, 650 m a.s.l., Ovche Pole Plain, 350 m a.s.l.), and the eastern mountain (Rhodopean) region (only three peaks above 2,000 m altitude). Large portions in the central part of the country exhibit steppe-like appearance (Melovski et al. 2013).

According to the last country census in 2021, the total human population numbers 1836713 people with average density of 72 people/km^2, majority inhabiting urban areas (61%) (SSO 2021). North Macedonia GDP per capita for 2022 was $6591 (https://www.stat.gov.mk/PrikaziSoopstenie_en.aspx?rbrtxt=32).

Methodology

In 2020, national team of 30 experts conducted the first assessment of ecosystem condition on national level. The team had mainly scientific background (biology, forestry, agronomy, hydrology, GIS), however policy representatives from governmental institutions were also involved. The national team was divided into smaller working groups, each of those assigned to a particular ecosystem type.

The condition assessment was done in line with the common assessment framework from the MAES guidelines (Burkhard et al. 2018b). Yet, due to different reasons (mainly lack of data), several methodological modifications and adaptations were applied. The national assessment of ecosystem condition did not entail collection of new data through fieldwork, but instead relied on existing data. Where possible, this data were improved and updated in GIS.

Ecosystem typology used corresponds to the MAES Level 2 categories (European Commission, Directorate-General for Environment 2013), while the Level 3 categories were modified and adapted. According to the guideline, the classification on Level 3 is a combination of the EUNIS classification and the land cover land use categorization from CORINE. Having this in consideration, for some ecosystem types, the Level 3 categories in North Macedonia are in line with EUNIS (e.g. caves), while others were categorized with combination of EUNIS, CORINE and/or other criteria (e.g. altitude).

All natural and semi-natural ecosystems in North Macedonia were mapped by laborious manual digitalization with visual interpretation from several sources (e.g. ESRI maps, Google Earth, Bing maps etc.). The national land use cadaster (2002-2004), national hydrological network (2002-2004), CORINE land cover (2018) were used as a baseline for the digitalization process. The national cadaster land use database represented a baseline for most of the ecosystems, but it was of secondary priority as the delineation on some of the natural and semi-natural ecosystem types had inconsistent accuracy. Data from the national hydrological network (2002-2004) was used as a baseline for the river ecosystems. Other specific sources of information (reports, personal databases, etc.) were used for some of the most important ecosystems with small surface areas (caves, wetlands, riparian forests etc.). Data from the CORINE land cover database were mainly

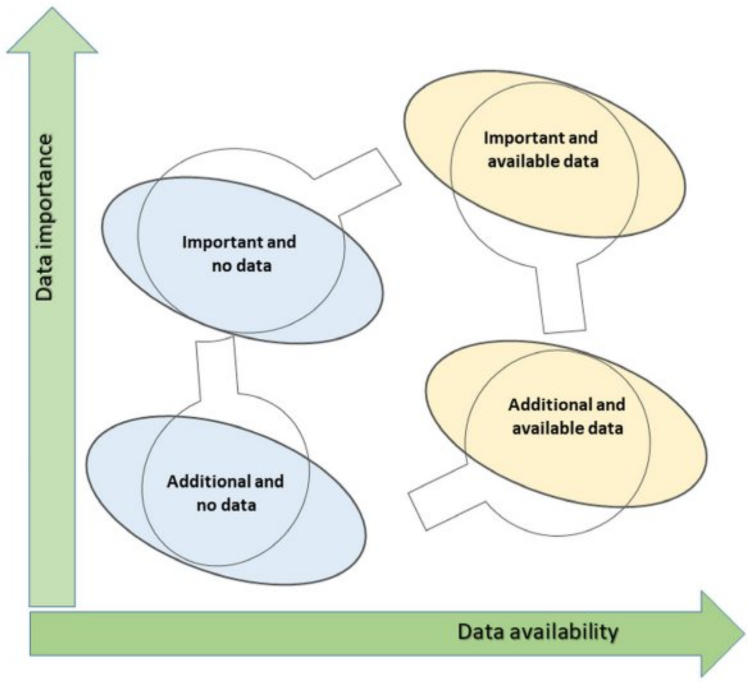

Figure 2. Axis for structural arrangement of identified indicators

used for quality control, especially for ecosystems that have larger occupancy (e.g. pastures, shrublands, heathlands). Caves are the only ecosystem type that was mapped as point data, while all other ecosystem types were mapped as polygons. Anthropogenic habitats were generally mapped based on the national land use cadaster.

A team of national experts selected a set of potential indicators and parameters for the assessment of ecosystem condition for each of the 15 ecosystem subtypes (the five anthropogenic and two cropland ecosystem subtypes were not assessed). The indicators belong to the following groups: biotic, abiotic, energy, matter and water balance. Each indicator meets at least one of the requirements for the MAES indicator framework for ecosystem condition (European Commission, Directorate-General for Environment 2018). The final selection process involved arrangement of all indicators on a feasibility axis (Figure 2). Only indicators with considerable data availability and importance were selected.

Selected indicators were valued on a basis of one or more parameters. Each parameter was scored on a scale 1 to 5 (reflecting poor to excellent condition of the ecosystem). One has to bear in mind that the scoring was relative (each scale was defined for particular ecosystem type and presents the range of ecosystem conditions from poor to excellent) and refers only to the ecosystems in North Macedonia. Scoring was supported by qualitative (limited number of parameters) or quantitative data (majority of parameters) provided by the team of experts, mainly consisted of the authors of this paper. Qualitative scoring was performed on a basis of predefined scales (1-5) for all of the UTM 10x10km grid cells on national level.

Quantitative scoring was based on available spatial data for parameters. In case that an ecosystem was represented by several polygons in a UTM grid cell, the scores for the parameter were calculated as the average of the scores of the individual polygons, using their surface as a weighting factor. For this purpose, before calculating the parameter values, an analysis of the ecosystem and the UTM cell was carried out using the "intersect" function in ArcGIS. To calculate the average score for a given parameter of a given ecosystem subtype, the following formula was used:

$$G' = (\sum_{k=1}^{n}(Ak * Gk^1))/(\sum_{k=1}^{n} Ak),$$

G' = weighted index for the parameter within the given UTM cell, expressed as an integral number (1-5).

n = number of ecosystem's polygons within the given UTM grid cell;

Ak = surface (ha or m^2) of the polygon within the given UTM cell;

Gk = score of the parameter for the ecosystem polygon within the given UTM cell, based on the quantitative data;

It is important to note that many parameters actually represent more complex indices, some of which are already available (e.g. NDVI or Normalized Difference Vegetation Index) and some created for the

Table 1 Classification of ecosystem types in North Macedonia

Level 1 Main ecosystem categories	Level 2 Ecosystem types	Level 3 Ecosystem subtypes	Data utilization and corresponding equivalents to Level 3 Ecosystem subtypes categories
Terrestrial	Heathlands and shrubs	Mountain heathlands and shrubs	Corresponds to the category 'bushes' from the National Land Use Cadaster which was used for cross-referencing with CORINE. Major improvements were done by manual mapping
		Lowland heathlands and shrubs	Further division by altitude was done (mountain heathlands and shrubs >1200 m; lowland heathlands and shrubs <1200 m).
	Grasslands	Mountain grasslands	Corresponds to the category 'meadows' from the National Land Use Cadaster which was used for cross-referencing with CORINE. Major improvements were done by manual mapping. Corresponds to EUNIS Classification groups E1 – E4. Further division by altitude was done (mountain grasslands >1200 m; lowland grasslands <1200 m).
		Lowland grasslands	
	Inland wetlands	Mountain wetlands	Corresponds to the categories 'Bogs and peat bogs' and 'Swamps' from the National Land Use Cadaster which was only used for cross-referencing with CORINE. This ecosystem type was mainly mapped by manual vectorization. Corresponds to EUNIS Classification group D: Mires, bogs and fens. Aligns with CORINE class 4.1 Inland wetlands
		Lowland wetlands	Further division by altitude was done (mountain wetlands >1200 m; lowland wetlands <1200 m).
	Sparsely vegetated land	Rocks and sparsely vegetated ecosystems	Corresponds to the category 'rocks' from the National Land Use Cadaster which was used only for cross-referencing with CORINE. Major improvements were done by manual vectorization Aligns with EUNIS Classification groups H2, H3 & H5 Aligns with CORINE classes 3.3.2 & 3.3.3
		Caves	Fully manually digitalised; Aligns with EUNIS Classification group H1
	Woodland and forests	Deciduous forests	Four categories from the National Land Use Cadaster merged ('forest plantation', 'broadleaf forest', 'coniferous forest', 'mixed forest'), then split in the 3 ecosystem categories using manual Deciduous forests aligns with EUNIS Classification groups G1.6 to G1.9. Coniferous forests aligns with EUNIS Classification group G3. Lowland riparian forests aligns with EUNIS Classification groups G1.1, G1.2, G1.3 & G1.B. All three ecosystem subtypes align with CORINE class 3.1
		Coniferous forests	
		Lowland riparian forests	
	Anthropogenic	Urban ecosystems	Used directly from the following Cadaster categories: 'bus station', 'railway station', 'medical facility', 'public facilities', 'park', 'school', 'construction site (high buildings)', 'construction site (low buildings)', 'archaeological sites', 'historical sites', 'religious sites', 'supplies', 'state institution', 'marketplace', 'border pass', 'aqueduct', and then split in 2 ecosystem categories according to existing data for city/town borders, with minimal corrections and updates Aligns with CORINE 1.1
		Rural ecosystems	
		Industrial and mining ecosystems	Used directly from the following Cadaster categories: 'airport', 'industrial zone', 'dump site', 'quarry and mine' with significant manual improvements. Aligns with CORINE 1.2 & 1.3
		Fisheries	Used directly with significant updates from the 'fishery' category from the National Land Use Cadaster Aligns with CORINE class 5.1.2
		Artificial water bodies	Manual digitalization; Aligns with EUNIS Classification group J5 & refers to standing water bodies with artificial substrate
	Cropland	Agroecosystems	Corresponds to three categories from the National Land Use Cadaster: 'acres', 'orchards' and 'rice fields' which were directly used, with minimal corrections and updates. Aligns with CORINE classes 2.1 & 2.2
		Vineyards	Used directly with minimal corrections and updates from the category 'vineyards' from the National Land Use Cadaster. Aligns with FB.4 from the EUNIS Classification. Aligns with CORINE class 2.2.1
Freshwater	Rivers and lakes	Big rivers	Used directly with significant updates from the category 'river' from the National Land Use Cadaster. Aligns with CORINE class 5.1.1
		Tectonic lakes	North Macedonia has three tectonic lakes: Prespa Lake, Ohrid Lake and Dojran Lake.
		Glacial lakes	Mainly manual digitalization; Aligns with CORINE class 5.1.2
		Accumulations	Used directly with significant updates from the category 'lake' from the National Land Use Cadaster, excluding three tectonic lakes. Aligns with EUNIS Classification group J5.3. Aligns with CORINE class 5.1.2

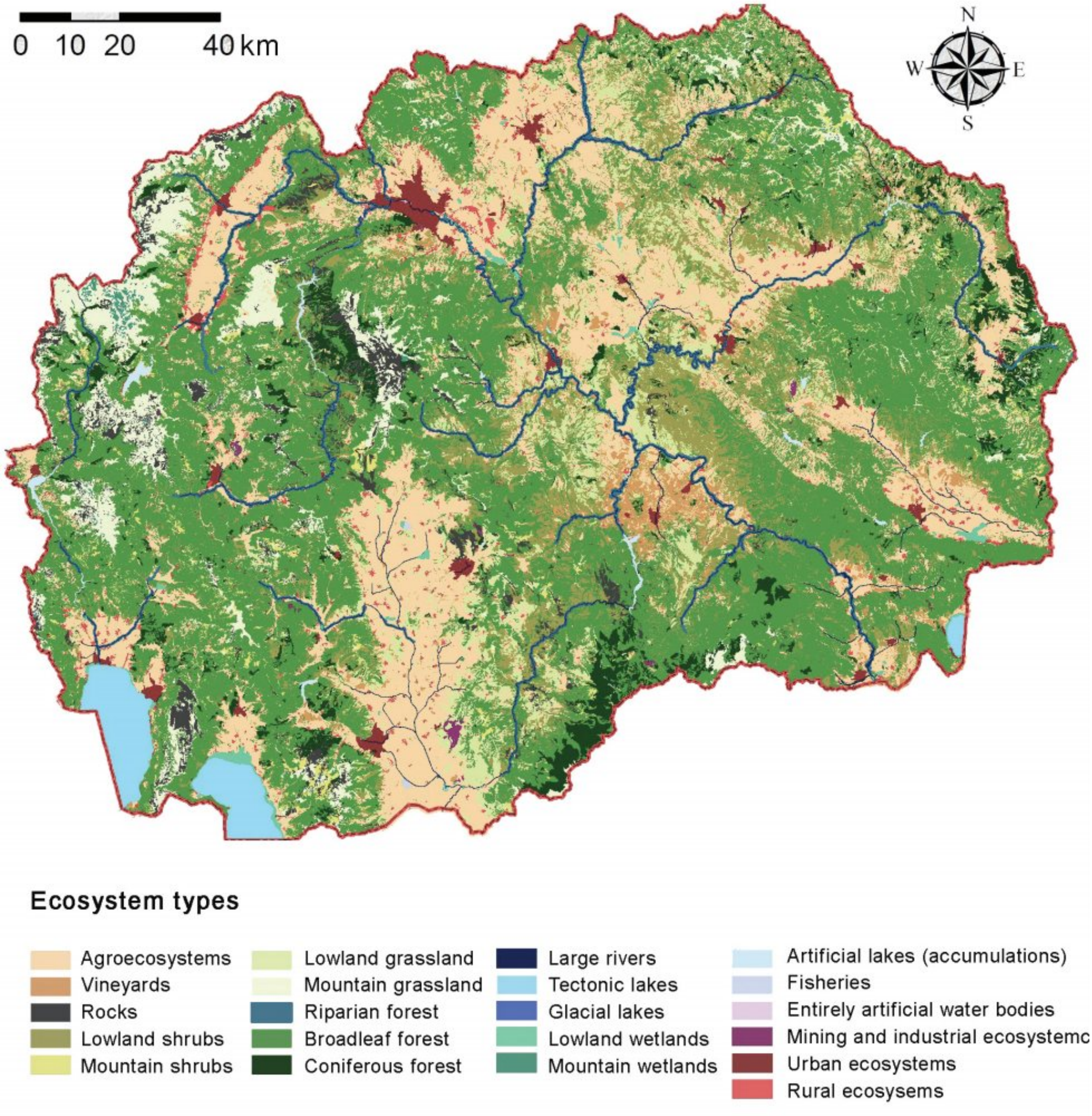

Figure 3. National map of ecosystem types in North Macedonia (without caves)

needs of this assessment (specific measures for diversity, fragmentation indices, erosion intensity, etc.)

Each indicator was calculated as an average value of the scores from the containing parameters, rounded to an integral number (1-5). The final score for the ecosystem condition within the given UTM grid cell was calculated as an average value of the scores for all indicators.

In the context of visual depiction, the ultimate score of the ecosystem condition within a designated UTM grid cell involved the summation of individual scores corresponding to all indicators. The final ranking was contingent upon the statistical dispersion of the scores, employing diverse representation rankings (linear, quadratic, and logarithmic).

Results

As a first step, identification, classification and mapping of ecosystem types was conducted.

Classification and mapping of ecosystem types

The ecosystem types were classified in three levels which contain eight main ecosystem types and 22 subtypes (Table 1). Therefore, we consider that the following level 3 ecosystem types can be grouped into anthropogenic ecosystems: Urban, Rural, Industrial and mining, Fisheries, Artificial water bodies, Agroecosystems and Vineyards. All of the other 15 ecosystem types were considered as natural or semi natural ecosystems. Shrublands, grasslands and inland wetland ecosystems were categorized by altitude (lowland >1500 a.s.l.; mountain <1500 a.s.l.) which corresponds to their ecology and habitats. The sparsely vegetated ecosystems were divided into two categories: sparsely vegetated rocky landscapes and caves. The forest ecosystems were categorized as coniferous, deciduous and lowland riparian forests (along the big lowland rivers). The urban ecosystems have the most categories: cities, rural settlements, industrial and mining areas, fish ponds and artificial water bodies with completely man-made substrate. These categories are in line with the CORINE land cover. In the category of agroecosystems, beside arable land (agroecosystems), vineyards present a separate category due to their larger areas of occupancy. Lastly, the rivers and lakes ecosystems were categorized as: large rivers, tectonic lakes, glacial lakes and artificial accumulations (with natural substrate). We have to emphasize that the type of glacial lakes also includes some permanent water bodies in the high mountain zones and even the artificial ponds in Galichica National Park. Smaller rivers, especially mountain rivers and streams were not taken into consideration due to the lack of special data.

All identified ecosystem types were mapped and the first comprehensive map of ecosystem types in North Macedonia was produced (Figure 3). The highest accuracy is found in ecosystem types that were manually digitized. Caves were mapped as point data but they are not presented in the map.

The most dominant ecosystem type in North Macedonia is the deciduous forests with surface of 9933 km^2 (or 39.1 %) followed by agroecosystems (21 %). Lowland grasslands are present in the lowlands, complementing the agricultural areas. Most of the high mountains especially in the west parts of the country have significant presence of mountain grasslands (pastures) as well as mountain shrublands. Riparian forests are tightly connected to the distribution of large rivers in the lowlands. There are three tectonic lakes and more glacial lakes in the mountains (especially Shar Planina, Pelister, Jablanica). Ecosystems such as inland wetlands and lowland shrublands are less visible on the map due to their small sizes.

Ecosystem condition

The identified natural and semi-natural ecosystem types were assessed for their condition (six ecosystem types out of eight on level 2). Artificial water bodies with natural substrate were also included in the assessment. In total, 16 indicators and 53 parameters were used. The following list in Table 2 presents the summary of the indicators and parameters used for different ecosystem types. The complete set of national indicators and parameters applied for each of the assessed ecosystem types is presented in Supplementary material (Annexes I-VI).

The condition was assessed of all Level 3 ecosystem types (subtypes) and it is presented on 15 separate maps (Figures 4-18). In addition, summary of the assessment for each ecosystem subtype is presented.

Heathlands and shrubs

Heathlands and shrubs were categorized into two Level 3 categories: *mountain heathlands and shrubs* and *lowland heathlands and shrubs*. Heathland and shrubland ecosystems have very important ecological functions (for example: hydrological cycle, pedogenesis, erosion control, carbon cycling etc.), although these have been insufficiently studied in North Macedonia.

The assessment shows that the lowland shrubs in the central parts of the country, i.e. in the valley of the Vardar River including its main tributaries (Bregalnica, Crna Reka, Kriva Lakavica and Pčinja), have the best condition. This is also the case for some low mountain massifs (Serta, Selečka Planina, Babuna, Plaush, Dub, etc.) (Figure 4). This is to be expected considering the natural conditions in this area represented by the dominance of the sub-Mediterranean climate-vegetation-soil zone with long historical alterations of natural forests (Filipovski 1996). In the western parts, the lowland shrubland ecosystems of Galichica, Bistra, the basin of the Radika River, low parts of Shar Planina, Suva Gora, etc. are present in good condition. Potentially, this area may be characterized with high, and more importantly, unique biological diversity. Unfortunately, there is little data on the biological diversity to support this assumption at the moment. However, the data on the presence of shrubland communities of Krivolak (Matevski et al. 2008), as well as the diversity of ornitofauna, herpetofauna and some insect groups (Velevski et al. 2010; Sterijovski et al. 2014; Hristovski and Gueorguiev 2015) points to high biological values.

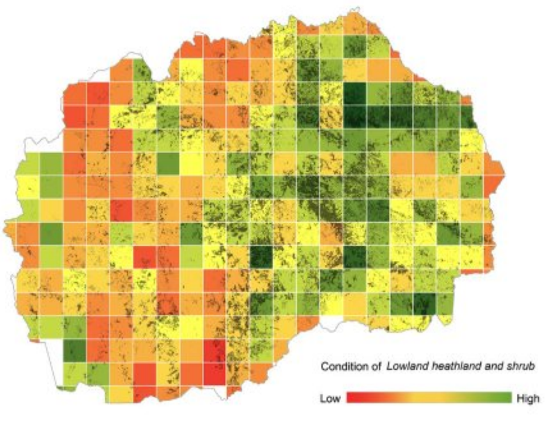

Figure 4. Map of assessed condition of ecosystems of Lowland heathlands and shrubs

Table 2. List of indicators and their parameters used in the assessment of ecosystem condition in North Macedonia

Indicators	Parameters
Anthropogenic pressure	Agricultural surface area Distance of the analyzed ecosystem to the nearest highways, regional roads or railways Distance of the analyzed ecosystem to the nearest mining and industrial ecosystem Distance of the analyzed ecosystem to the nearest mining, industrial areas or landfills Landfills and dumpsites Mine, quarry and separation areas Relative surface area of agricultural ecosystems Surface representation of mine, quarry and separation areas
Biogeochemical cycle	Biochemical oxygen demand (BOD) Dissolved oxygen (O_2) Total phosphorous (P)
Conservation status	National legal protection or international valorization
Disturbances	Erosion intensity Fragmentation Length of irrigation channels
Ecological integrity	Average Score Per Taxon (ASPT) index
Energy flow/Matter storage	Biomass accumulation Wood biomass
Fauna diversity	Number of amphibian and reptile species Presence of Anostracans (Branchiopoda: Anostraca) Number of Aquatic snail species Number of bird species Number of dragonfly species Number of endemic aquatic snail species Abundance of Naididae worms (Tubificidae - Oligochaeta) Size of bats population Species richness of cave invertebrate fauna
Flora diversity	Number of Diatom species Number of important diatom species Number of important wetland habitats Plant species richness Number of rare and important plant species Number of wetland habitats
Hydro-energetic capacity	Annual capacity
Morphology of caves	Length of the cave's channels Presence of speleothems and their integrity Type of cave
Usage	Purpose/use of the accumulation
Size of the ecosystem	Absolute ecosystem surface area Basin area Relative ecosystem surface area Wetland polygons
Soil heterogeneity	Humus quantity in the soil Soil types represented in the analyzed ecosystem type
Structure of the riparian belt	Connectivity of the riparian belt Riparian belt width
Threats	Expected changes in annual temperatures by 2050 Expected changes in the amount of annual precipitation by 2050 Invasive aquatic invertebrate species
Water balance	Annual water flow Average annual volume Hydrology function Rainfall

Regarding the mountain heathland and shrub ecosystems it can be noted that higher scores prevail in the western parts of the country (Figure 5). The best condition for the mountain shrubland ecosystems was recorded for the mountain massifs in the western part of the country, especially Korab, Bistra, Jablanica, Galichica and Pelister and for some mountains in the eastern part: Osogovo and Plachkovica. Some of the mountain shrub ecosystems have commercial importance (collection of blueberries, junipers). However, this importance has not been validated on a national level, but only on certain massifs (Stefkov et al. 2014; Todorov et al. 2022). There is a lack of data regarding the biological values of these ecosystems thus of the diversity of different groups of animals that can be potentially used as indicator group for this type of ecosystems. Mountain heathland and shrubland ecosystems are included in some of the existing protected areas in the country. However, they have not been the direct subject of protection and conservation measures, which is especially true for lowland shrub ecosystems.

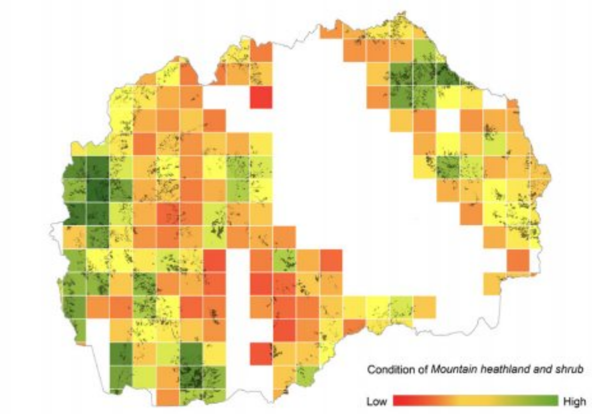

Figure 5. Map of assessed condition of ecosystems of Mountain heathlands and shrubs

Grasslands

Grasslands were categorized into two Level 3 categories: *mountain grasslands* and *lowland grasslands*. Lowland grasslands (mainly hill pastures) are secondary vegetation formations, which have been formed by gradual and prolonged degradation or clear-cut of lowland forests up to about 1200 m. Mountain grasslands (mainly pastures are) mostly distributed above the forest belt although some patches can be found within the forested landscapes, above 1200 m a.s.l.

The map for the condition of lowland grassland ecosystems shows scattered distribution of positively scored quadrants (Figure 6). The reason for this can be the low anthropogenic influence in those regions. Additionally, lowland grasslands that are far from populated areas and on a limestone substrate are highly scored. Plant diversity is also assessed as highest in these quadrants. The large number of highly evaluated quadrants is also due to the fact that the dependence of the plant diversity on the altitude is inversely proportional (Stevens 1992).

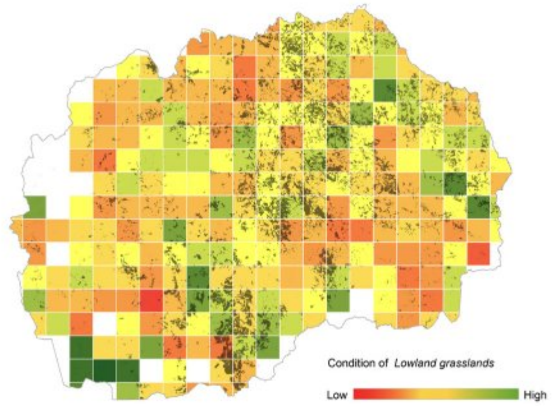

Figure 6. Map of assessed condition of Lowland grassland ecosystems

Good condition of the mountain grasslands prevail in the western part of the country (Figure 7). A concentration of highly scored grid cells cover the mountains of Shar Planina, Korab, Bistra, Jakupica, Jablanica, Galichica, Pelister in the west, Osogovo in the east, as well as Nidze in the south. This result is mostly a results of the indicator of flora diversity which is connected to the substrate. It is the number of different plant species on limestone substrates is greater in relation to silicate substrates (Michalet et al. 2002). Having in consideration that limestone is more common in the western part of the country (Milevski 2015), the obtained results are expected. Additionally, the scores for the parameter *Number of rare and important plant species* in the ecosystem, per quadrant, complement areas that are protected, where rare and endemic species are found, as well as species that have national and international importance, threatened status, species listed in conventions, etc.

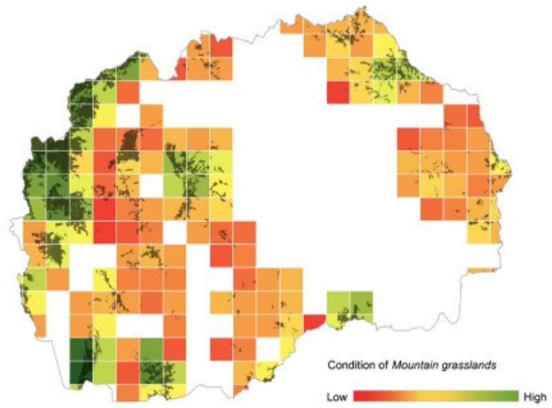

Figure 7. Map of assessed condition of Mountain grassland ecosystems

Inland wetlands

We consider "inland wetlands" (MAES Level 2 category) as natural vegetation types, with a water table for at least part of the year, dominated by herbaceous and/or peat forming vegetation. Water bodies, waterlogged habitats dominated by trees or large shrubs and rock structure of springs are excluded from this ecosystem type. Even though EUNIS Level 3 classification refers to concrete wetland habitat types, we simply divided wetlands in North Macedonia according to altitude. Those up to 1200m a.s.l. were classified as *lowland* and those above 1200 m a.s.l. as *mountain wetlands*.

Lowland wetlands are distributed throughout the country with significantly smaller areas than in the past (Markoski 2019). The results of the assessment (Figure 8) reflect the expected situation, which to great extent present unfavorable condition of the lowland wetlands. Good condition was obtained in the southwestern part of the country, for the wetlands along Prespa and Ohrid Lakes (including Belchishko Blato and Studenchishta). These wetlands have a large number of important wetland habitats, which significantly increases their value. The high scores do not mean that there is no anthropogenic pressure on these ecosystems, but at the moment, compared to all the others, they are in a better condition in terms of providing ecosystem services. On the other hand, our largest lowland wetland - Monospitovo, has a relatively lower overall score, which is mostly due to the intensive land transformation and pressure from agriculture (Melovski et al. 2010). The highest pressures on these ecosystems are intensive agriculture, waste disposal, urbanization, infrastructure development, fires, drainage, pollution and climate change.

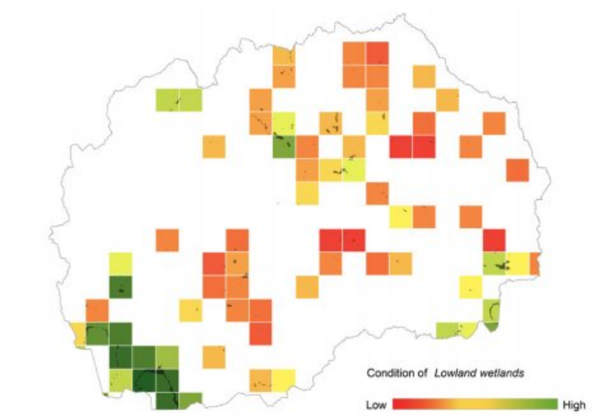

Figure 8. Map of assessed condition of Lowland wetland ecosystems.

Mountain wetlands in North Macedonia are mostly small ecosystems that are fragmented and scattered (Figure 9).

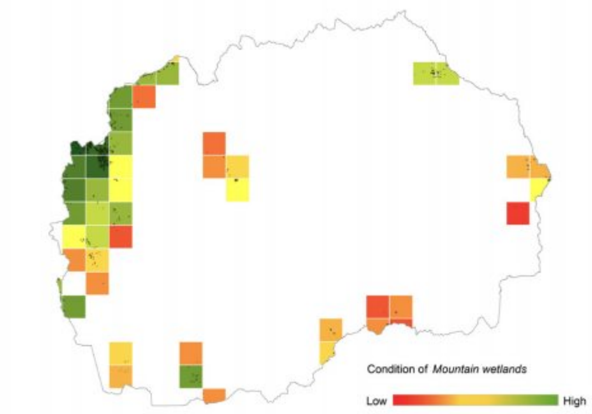

Figure 9. Map of assessed condition of Mountain wetland ecosystems

According to the map, they are mainly distributed in the western parts of the country, but it should be noted that they require additional attention in the future, for improvement of the map. Despite their small areas, mountain wetlands support a variety of plant species that increase the local and regional species diversity. Also, noteworthy are the larger high-mountain wetlands in the alpine belts of the mountains, which are often connected to large glacial lakes. The most represented mountain wetlands, largest and most numerous are on the Shar Planina - Korab mountain range where they are in very good condition. It is important to point out that these ecosystems are understudied in North Macedonia due to which many suitable indicators were not applied. However, the overall picture is in line with the experts' expectations.

Sparsely vegetated land

The sparsely vegetated land was categorized into two Level 3 categories: *rocky and sparsely vegetated ecosystems* and *caves*.

The favourable, good condition of the rocky and sparsely vegetated ecosystems correlates to the spatial abundance data, which can be observed from the obtained map (Figure 10).

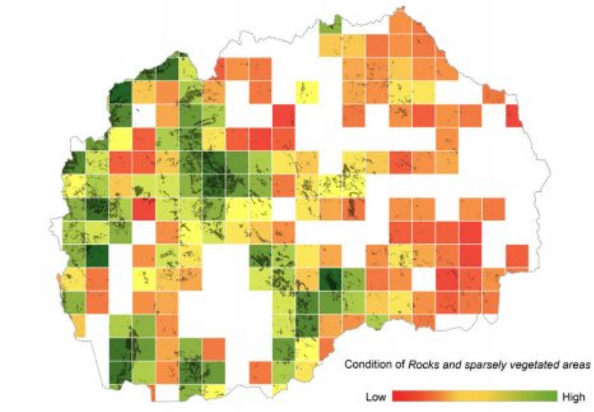

Figure 10. Map of assessed condition of ecosystems of Rocky and sparsely vegetated areas

This is mainly due to the influence of the large complexes of rocks and stones as a positive factor in assessing the condition. These are primarily areas where the substrate is limestone, with presence of karst (Shar Planina, Korab, Bistra, Stogovo, Jablanica, Galichica, Zheden, Jakupica, Babuna, Orle and Galčin, as well as other smaller fragments) or granite (parts of mountains of Babuna, Pelister and Kumanovski Kozjak as well as the region of Mariovo). The condition also corresponds to the better degree of biodiversity research in some of these areas in relation to others, but this factor does not significantly affect the overall assessment of the condition. For example, data of the well-studied Demir Kapija gorge and the gorges of the Babuna and Topolka rivers do not compensate for the relatively small area of these sites. Additionally, so called "negative indicators" (such as presence/distance of quarries) are also assessed which also balance out the final score. The inclusion of more biological indicators and parameters in the future may change this picture to some extent, but it will be more significant only when it comes to smaller complexes and more detailed scope.

Caves are the only ecosystem that is mapped as point data. A total of 166 speleological objects (caves and sinkholes) were mapped and assessed. They are distributed throughout the entire territory of the country, in areas that are predominantly built of carbonate rocks (limestone, dolomite, marble and their varieties) of different ages (Figure 11).

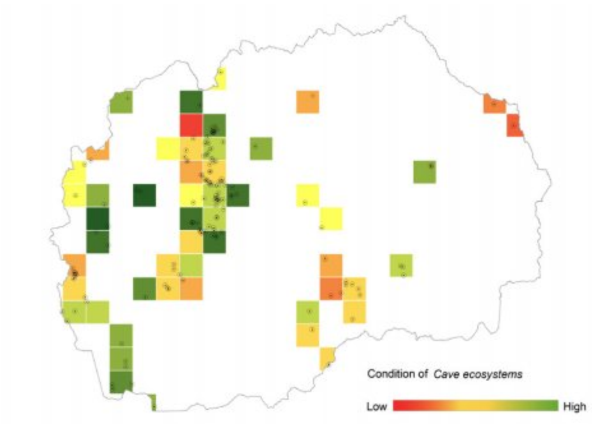

Figure 11. Map of assessed condition of Cave ecosystems

Cave ecosystems differ according to the agents that influenced their formation, according to morphometric characteristics, the presence of water bodies, the richness and variety of cave decorations, the preservation of cave decorations, etc. The caves' condition map presents highest scores in the western and central parts of the country. This area truly supports the largest cave systems, rich in hydrological phenomena. This is understandable since the massiveness of the karst, i.e. the geological substrate in this area is evident. The caves on Bistra (Alilica, Kalina Dupka, Sharkova Dupka, etc.), Galichica (Samoska Dupka, Vojla, Leskoechka Peshtera, etc.), Bukovik (Gjonovica cave), Karaorman (Mlechnik cave) and Jakupica (large number of important caves) are particularly noteworthy. In the vicinity of Skopje, there are many important cave systems with high scores for their condition, such as the caves in the Matka canyon (Vrelo, Ubava, Krštalna), the Dona Duka cave on Zheden, etc. Smaller and isolated cave systems with poorly studied fauna can be found in the Vardar river valley. Exceptions are some of the caves in Demir Kapija gorge, in which a rich and specific fauna has been recorded, as well as presence of bats. The cave systems around Tikvesh reservoir are undoubtedly rich, but there is scarce information apart from some data on morphology of the caves and their genesis. In-depth research can change the results regarding the condition of the cave ecosystems in this region. The caves in the eastern parts of the country are small and isolated systems, which is the result of the small patches of carbonates found in this area. The exception are the caves on Plackovica Mt. (Turtel), which represent ecosystems with a higher potential for ecosystem services. In contrast, the caves in the far eastern parts (Delčevo region) are small and have poor cave fauna, but are also poorly explored. This assessment of the cave condition should only be considered regarding their capacity to provide ecosystem service, but does not present an assessment of their natural values. All caves in North Macedonia deserve special attention, especially for their effective conservation and protection (formal and informal).

Woodland and forests

This ecosystem type was classified and mapped into three categories (subtypes): lowland riparian forests along the big rivers, broadleaf and coniferous forests. The same parameters and range of scores were used for the condition assessment of coniferous and deciduous forests, while lowland riparian forests were analyzed separately.

Coniferous forests have slightly higher scores for the wood biomass than deciduous forests. This is primarily due to their spatial distribution, which is mainly in the higher mountainous areas, where the climate conditions for the development of forest vegetation are more favorable. It should also be noted that their distribution is most prevalent precisely in the more difficult-to-access mountainous areas, so consequently they preserve their structure and ecological integrity. There is also a clear correlation between the distribution and condition of coniferous and deciduous forests with the climatic-vegetation-soil zones of the country (Filipovski 1996).

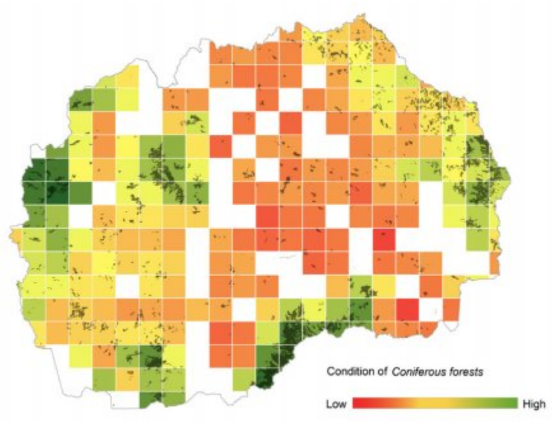

Figure 12. Map of assessed condition of Coniferous forest ecosystems

In general, coniferous forests were assessed with high scores (Figure 12). The highest scores are distributed in areas that are protected or proposed for protection. The lowest scores are distributed in areas with strong anthropogenic pressures or areas where there is an evident process of land use change. For the most part, these forests were artificially planted during the period of intensive afforestation with black pine and cypress in the last century, as part of the erosion protection programs. On the other hand, very good scores are most common for deciduous forests (Figure 13). The highest scores are distributed in areas with long-term successful management practices, in protected areas or in such proposed for protection. The lowest scores, are distributed in areas where thermophilic forest communities of the oak belts spread, especially the part of the forests in Povardarie region (along river Vardar), as well as in areas with strong anthropogenic pressures or where there is an evident process of land use change.

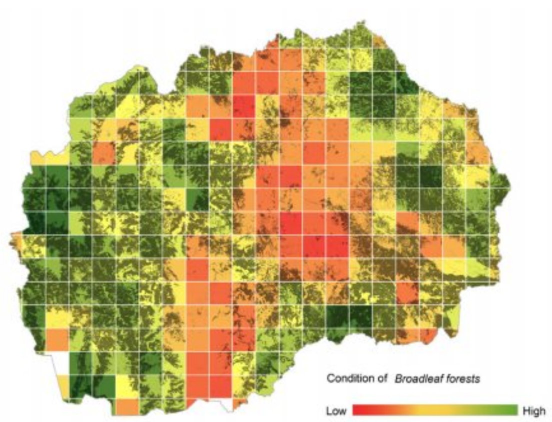

Figure 13. Map of assessed condition of Broadleaf forest ecosystems

The riparian ecosystem type is widespread in North Macedonia. It is mainly distributed in the lowlands along the larger rivers and lakes and with smaller areas around smaller lowland and mountain watercourses. The most strongly developed belts of riparian forests from the analyzed data are evident in the plain regions, along the courses of the big rivers: Vardar, Bregalnica, Pchinja, Kriva Reka, Crna Reka, etc. However, it is also evident that in the plain parts, this type of ecosystem is under the greatest anthropogenic pressure, mainly from agricultural activities, mining, sand extraction, various industrial facilities, smaller landfills and dumps, etc. According to the results, it can be noted that riparian forests have the highest scores where Bregalnica, Pchinja, Babuna and Topolka rivers flow into Vardar, as well as in the upper course of Bregalnica River (Figure 14).

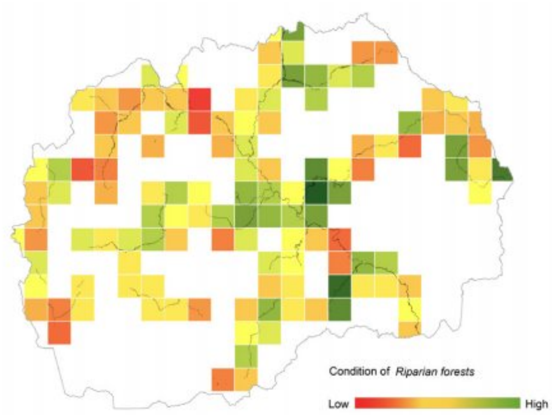

Figure 14. Map of assessed condition of Riparian forest ecosystems

Rivers and lakes

According to the EUNIS classification, freshwater ecosystems have two types on Level 2: lakes and rivers. *Lakes* included tectonic, glacial and artificial lakes, while *rivers* included streams, permanent and intermittent streams. For the purposes of the assessment, we evaluated condition of the big rivers, tectonic, glacial and artificial lakes.

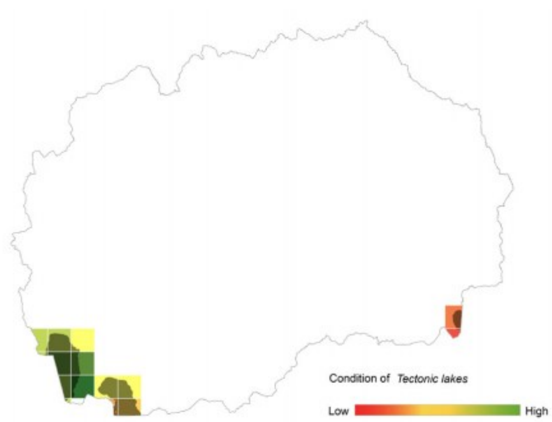

Figure 15. Map of assessed condition of Tectonic lakes

The condition of the tectonic lakes resulted in highest scores for Lake Ohrid, which shows excellent condition of the ecosystem (Figure 15). This lake has unique biological diversity represented by a large number of species of aquatic species (snails), among which a large number are endemic. In contrast to Ohrid Lake, the condition of Dojran Lake is significantly poorer. Although the lake itself, with its specific diversity, represents a special and no less important ecosystem, the evaluation based on the selected parameters resulted in relatively low scores for the ecosystem condition. The Prespa Lake has intermediate condition from the three tectonic lakes. It is important to note that the assessment of the condition of the tectonic lakes should be taken only as a function of their capacity to provide ecosystem services and not as an assessment of their value and significance as natural and cultural heritage. All three tectonic lakes in North Macedonia deserve special attention and active engagement for their conservation.

The assessment of the condition of glacial lakes highlighted the scarcity of data regarding biological indicators. From the map on the condition of glacial lakes (Figure 16) it can be noted that the highest scores prevail to the ones located in the southwestern parts (Shar Planina, Korab, Jablanica, Pelister).

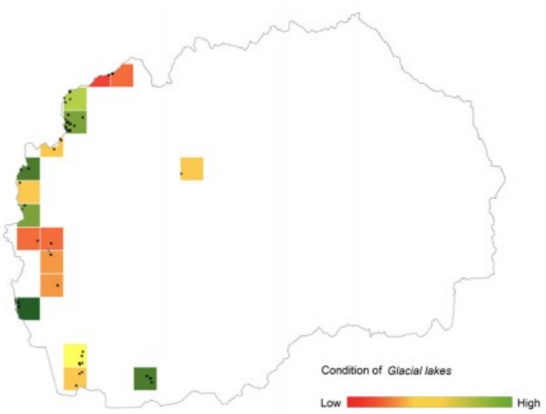

Figure 16. Map of assessed condition of Glacial lakes

Significant lack of available information was also noticed for artificial lakes which limited the number of indicators. To assess the state of this subtype ecosystem, the available data were used, as well as personal knowledge about the ecological potential (abundance of Tubificidae), total area of the reservoir, area of the watershed, annual capacity, annual inflow of water, mean annual volume, number of uses, etc. The distributed scores for all these parameters showed that the artificial lakes in the western and southern parts of North Macedonia are characterized by a significantly better condition than those in the central and eastern parts of the country (Figure 17). Such results are primarily due to the greater water inflow compared to the pressures on the one hand, as well as the availability of data on the selected parameters on the other hand.

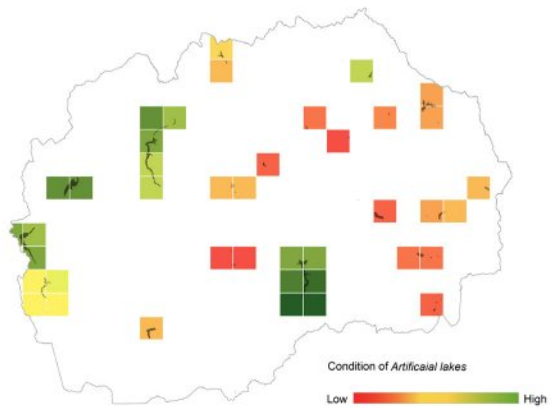

Figure 17. Map of assessed condition of Artificial lakes (accumulations)

According to the summary of scores of all evaluated parameters related to large rivers, it can be concluded that good scores prevail (Figure 18). It is evident that the highest scores are assigned to the Radika River, the source of Crn Drim, Crna Reka before the confluence with Tikvesh reservoir, Treska River from the Kozjak Dam to Kozjak 2 reservoir and Pchinja River at the border with Serbia. The condition is significantly poorer for rivers and their parts that pass through larger cities such as Bregalnica, Strumica, Vardar, Kriva Reka, the upper and middle reaches of Crna Reka, as well as Crn Drim from Lake Ohrid to the border with Albania. The unsatisfactory ecological status of these parts of the rivers is clearly confirmed by the low values of the selected indicators and parameters. It is clear that settlements, especially cities without wastewater treatment infrastructure, the presence of industry in urban areas, as well as intensive agriculture in rural areas influence to the condition of the river ecosystems in these parts of the hydrographic network.

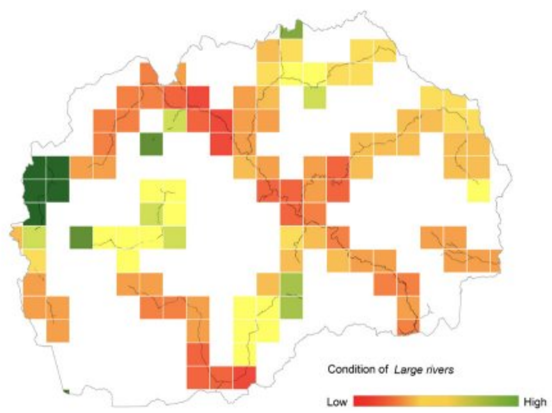

Figure 18. Map of assessed condition of River ecosystems

Discussion

The spatial depiction of various ecosystem types and the evaluation of their condition constitute the initial endeavor at a national scale to implement the MAES framework in North Macedonia. This undertaking reflects the country's commitment to integrating the ecosystem services concept, aligning with stipulations outlined in national biodiversity and nature conservation strategies. The assessments of ecosystem type and condition assume significance as they ascertain the capacity of ecosystems to supply ecosystem services. Our study's findings exhibit a noteworthy correlation with the attainment of the national goal 16 from the Biodiversity Strategy (2018), which aims to enhance the condition of significant ecosystems in terms of delivering ecosystem services.

As a country aspiring the European Union integration, North Macedonia aligns its national legislation with European laws. Consequently, the national strategies are formulated based on the country's adherence to international strategies, such as the European biodiversity strategy and, more recently, the European Green Deal articulated through the Green Agenda.

A crucial facet arising from the national assessments is the identification of challenges and gained insights (Vári et al. 2024). Noteworthy among the challenges encountered were issues related to data availability, data gaps, and time constraints. Nevertheless, of particular emphasis are two principal aspects: firstly, the deficiency in national capacities, encompassing an understanding of the ecosystem services concept and its methodologies. In this regard, the MAES working group has provided assistance to EU member countries, enhancing a European multidisciplinary community of practice that shares a common understanding of key MAES concepts (European Commission 2019). Consequently, our study serves a dual purpose by not only contributing to capacity building among national experts and policymakers, but also addressing the lack of expertise in the application of the ecosystem services concept. Conversely, the inadequacy of capacities or general progress concerning the application of the ecosystem services concept is evident in the limited networking with other European countries. Major collaborative projects such as ESMERALDA (Burkhard et al. 2018a) or the ongoing SELINA (https://project-selina.eu/about), excluding non-EU member countries from SEE, hinder progress and diminish opportunities for future collaboration. Lack of collaboration opportunities limit knowledge exchange and can act as a significant impediment to the national assessments in the Western Balkans countries. Initiating the initial steps is imperative, as future integration into national accounting workflows becomes increasingly challenging without this foundational groundwork.

Conducting condition assessments that rely on quantitative and qualitative parameters associated with the polygons digitized on an ecosystem type map, requires an establishment of a dependable ecosystem type map. Moreover, a national ecosystem type map is of paramount importance in supporting environmental policy and conservation management (Tanács et al. 2022b). Another challenge pertained to the outdated nature of many national datasets, with information dating back 15 years or more. As a result, certain anthropogenic changes were not always evident. Furthermore, mapping priorities had to be judiciously determined, taking into account project deadlines and time limitations. While CORINE Land Cover is the recommended base map for ecosystem types (Erhard et al. 2017), our mapping experience revealed that its accuracy inadequately represented, or in some cases completely omitted, certain ecosystem types. This discrepancy is particularly noteworthy for ecosystems with smaller areas, such as wetlands, a pattern also observed in neighboring countries (Petkova et al. 2022). For smaller countries like North Macedonia, a thorough analysis is imperative before utilizing the CORINE dataset to ensure more precise ecosystem mapping. Consequently, a substantial spatial data gap needed to be addressed. The latter was done by using available mapping sources, but mostly, manual digitalization. On the other hand, it is noteworthy that there is no established Natura 2000 network, which often serves as a foundational reference for studies in other countries (for e.g. Kokkoris et al. 2019). Others on the other hand exclude Natura 2000 sites in order to fulfill knowledge gaps outside protected areas (for e.g. Sopotlieva et al. 2018).

In terms of classification, the map allows connection with other European maps and databases at least to MAES level 2 categories. Our experience showed that lower levels of classification such as Level 3 require reliable data in order to provide higher accuracy of the categories. Thus, the uncertainties with lower classification levels can be high in small sized countries. On the other hand, there was a common conclusion that the MAES Level 2 categories do not reflect the true heterogeneity of all ecosystem types in the country. Having in consideration that there was no previously established national typology, we had to define Level 3 categories that were more detailed than MAES Level 2, but more flexible than EUNIS Level 3. Therefore, all Level 3 categories were defined by the national experts for each main Level 2 category. Consequently, this map serves as a robust spatial baseline for future ecosystem type classification and mapping at Level 3. Adaptations in different ways have been done in other studies as well, depending on the available data and methods (Tanács et al. 2022b).

According to the common assessment framework (European Commission, Directorate-General for Environment 2014), the condition assessment follows after the creation of the map of ecosystem types. In this order, it should serve as the foundation for the subsequent stage involving ecosystem services assessment since the underlying concept is that the capacity of an ecosystem to provide ecosystem services is contingent upon its condition. Even so, knowledge gap concerning the interconnections between ecosystem condition and ecosystem services still prevail (Vári et al. 2024). This gap may be associated with the selection of general indicators for assessing the integrity of the ecosystem, which are less straightforward than the service-specific indicators. Even though condition inherently embodies a form of ecosystem integrity linked to human use of nature (Roche and Campagne 2017), yet it is still challenging to establish a direct link with the supply of ecosystem services (Tanács et al. 2022a). In the case of North Macedonia, the set of applied indicators and parameters was mainly limited due to the scarce spatial information available. The general approach required uniform measurable assets throughout the country, which was very challengeable due to the lack of scientific data. Therefore, selection and valuation of indicators had to bridge from theoretical significance and feasibility criteria to practical application (Tanács et al. 2022a). More information was available for several protected areas, the eastern part of the country (Bregalnica watershed) and smaller areas where recent conservation projects have been conducted. However, many potentially suitable indicators were not selected due to lack of data for the whole country. Therefore, it is important to note that the selection and valuation of the indicators was challenging and lengthy process for which even with guidance, adaptation to context was necessary. Having in consideration that this assessment also introduced a whole new concept in North Macedonia, this adaptation was demanding and quite often back and forward process. Gathering data for additional indicators can always improve new condition assessments in the future, as well as help in creating a comprehensive national set of indicators.

Ecosystem services concepts have become increasingly influential in shaping policy instruments, particularly in terms of nature conservation (Fisher and Brown 2015). North Macedonia has acknowledged the significance of this concept as an important tool for enhancing nature management in alignment with international policy objectives. Developing countries, constrained by limited capacities and funding, necessitate innovative approaches to overcome multifaceted challenges at various levels. However, the acceptance of new concepts is contingent upon the potential impact of national assessments on policymaking, hinging on attributes such as relevance, credibility, and legitimacy (Wilson et al. 2014). In terms of legitimacy, the national assessment in North Macedonia has been conducted by a diverse group of national experts with pertinent experience. Moreover, the outcomes serve as a foundational framework for subsequent diverse analyses, paving the way for new avenues in scientific research. These studies may encompass assessments related to connectivity/fragmentation, the formulation of a national set of indicators and associated protocols, identification of vulnerable ecosystem types, and their prioritization for conservation, among other aspects. The attribute of relevance has been fortified through the integration of results into mainstream initiatives, ensuring applicability to various stakeholders via a capacity-building program conducted under the Nature Conservation Program (http://www.bregalnica-ncp.mk/?lang=en). The obtained results are particularly valuable to practitioners in protected areas, offering a methodological guide that can be seamlessly integrated into their monitoring plans. However, the incorporation of these assessment methods into management plans necessitates political will for policy change. The endorsement of this national assessment by policy and decision-makers, coupled with their active engagement, has played a pivotal role in conferring high legitimacy. In terms of policy integration, the data derived from this national assessment can propel a more detailed IPBES national assessment (IPBES 2018), clarifying policy priorities (Díaz et al. 2015). Even though there is increasing utilization of the results, especially of the ecosystem type map in various projects already (for e.g. creation a national habitat map), at national level, the potential application of results is also seen in the incorporation of the condition assessment into spatial plans, as ecosystem distribution and their condition should be recognized as key factors in the spatial planning process. We believe that this approach can enhance the representation of nature in strategic planning. Additionally, these results could inform future nature conservation strategies and restoration activities. Beyond national boundaries, these findings provide a robust foundation for the much needed regional assessments.

Conclusions

Ecosystems of North Macedonia were classified in 22 ecosystem types at level 3 according to the MAES guidelines (Mapping and Assessment of Ecosystems and their Services). Ecosystems were classified in two types at level 1: Terrestrial and Freshwater ecosystems. Terrestrial ecosystems were classified in seven level 2 types: Heathlands and shrubs (with two level 3 types: Mountain heathlands and shrubs and Lowland heathlands and shrubs), Grasslands (with two level 3 types: Mountain grasslands and Lowland grasslands), Inland wetlands (with two level 3 types: Mountain wetlands and Lowland wetlands), Sparsely vegetated land (with two level 3 types: Rocks and sparsely vegetated ecosystems and Caves), Woodland and forests (with three level 3 types: Deciduous forests, Coniferous forests and Lowland riparian forests), Anthropogenic (with five level 3 types: Urban, Rural, Industrial and mining, Fisheries and Artificial water bodies) and Cropland ecosystems (with two level 3 types: Agroecosystems and Vineyards). Freshwater ecosystems contained only one type at level 2 (Rivers and lakes) which contains four level 3 types: Big rivers, Tectonic lakes, Glacial lakes and Accumulations). The most dominant ecosystem type in North Macedonia is the deciduous forests with surface of 9933 km^2 followed by agroecosystems with extent of 5327 km^2. All of the 22 ecosystems were mapped and the first national ecosystem map of North Macedonia was elaborated.

Based on the comprehensive assessment of various ecosystem types in North Macedonia, it is evident that the country boasts a diverse array of natural and semi-natural landscapes, each with its unique set of characteristics, ecological functions, and conservation needs. Through the meticulous evaluation of 16 indicators and 53 parameters, the condition of six out of eight identified ecosystem types at Level 2 was thoroughly analyzed, alongside artificial water bodies with natural substrate. The findings underscore the importance of these ecosystems for biodiversity conservation, hydrological regulation, carbon sequestration, and other vital ecosystem services. Moreover, they shed light on the anthropogenic pressures and natural disturbances affecting these ecosystems, highlighting areas of concern and opportunities for targeted conservation efforts.

Heathlands and shrubs, distributed across lowland and mountainous regions, exhibit varying degrees of condition, with the best-preserved areas found in central and western parts of the country. While lowland shrublands in the Vardar River valley and surrounding mountain massifs demonstrate relatively good condition, challenges such as land transformation and agricultural pressure threaten the ecological integrity of these ecosystems. Grasslands, both lowland and mountainous, display favorable conditions, particularly in limestone-rich areas where plant diversity thrives. However, anthropogenic influences and land use changes pose risks to these valuable habitats, emphasizing the need for sustainable management practices. Inland wetlands, crucial for water filtration, flood control, and habitat provision, face significant anthropogenic pressures, particularly in lowland regions. While wetlands along Prespa and Ohrid Lakes showcase relatively better conditions, intensive agriculture, urbanization, and pollution threaten their long-term sustainability. Sparsely vegetated lands, including rocky ecosystems and caves, play vital roles in supporting unique flora and fauna. While areas with limestone and karst formations exhibit favorable conditions, concerns arise over the impacts of quarrying and habitat fragmentation on these sensitive ecosystems. Woodlands and forests, encompassing riparian habitats, coniferous, and deciduous forests, demonstrate varied conditions influenced by management practices and anthropogenic activities. Protected areas and successful conservation initiatives contribute to the preservation of high-scoring forest ecosystems, while riparian forests face challenges from agricultural expansion and urban development. Rivers and lakes, vital freshwater ecosystems, exhibit diverse conditions across tectonic, glacial, and artificial lakes, as well as river systems. While some water bodies like Lake Ohrid and certain rivers show excellent conditions, others face threats from pollution, urbanization, and inadequate wastewater treatment.

Overall, the assessment provides valuable insights into the condition of North Macedonia's ecosystems, guiding policymakers, conservationists, and stakeholders towards informed decision-making and targeted conservation strategies. By addressing key challenges such as habitat degradation, pollution, and unsustainable land use practices, the country can safeguard its rich biodiversity and ensure the long-term health and resilience of its natural landscapes for future generations. Additionally, this assessment establishes a methodology that can guide future, similar assessments, especially within protected areas, as a useful tool for definition of targeted management actions within their management plans. Trends in ecosystem condition can be followed by time, as well as links between the condition and ecosystem services supply. From an introductory and methodological point of view, the whole process presents knowledge base and it strengthened the national capacities regarding the ecosystem services concept, in general. All results have been communicated with a variety of national stakeholders in the direction of potential integration within their plans, strategies and policies.

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