Fuzzy Maps for Wicked Problems: An Inclusive Systems Approach to Improving Biodiversity Outcomes in the Carpathian Region

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Abstract

Mountains are crucial components of Earth's ecosystem, supporting rich biodiversity and providing essential ecosystem services. As social-ecological systems (SES), mountains are deeply intertwined with human activities, posing unique challenges for sustainability and resilience. This thesis explores the Carpathian Mountain region, focusing on its biodiversity within the context of the Carpathian Convention. Using Fuzzy Cognitive Mapping (FCM) as a participatory method, stakeholders from diverse sectors and countries were engaged to develop a nuanced understanding of the region's SES dynamics. Through interviews and focus groups, stakeholders identified key variables and relationships shaping the Carpathian biodiversity SES. Challenges in quantifying variables and capturing historic influences emerged, highlighting the complexity of mountain SES modeling. Despite divergent perceptions on certain relationships, participants recognized the region's relatively healthy biodiversity while recognizing threats posed by climate change, development, and other factors. Scenario analysis revealed minor impacts of proposed interventions, underscoring the need for more nuanced modeling approaches. Recommendations for advancing FCM methodology include addressing quantitative gaps, reconciling calibration methods, and fostering ongoing stakeholder engagement for informed decision-making.

Executive Summary

Mountains are integral components of Earth's ecosystems, serving as bastions of biodiversity and essential providers of ecosystem services. They play a pivotal role in shaping global regulating processes, including water management, hazard mitigation and biodiversity conservation. However, human-induced global changes, including climate change, land use transformation, and pollution, threaten the delicate balance of mountain ecosystems. These challenges underscore the urgent need for comprehensive strategies to safeguard mountain biodiversity and support communities reliant upon these landscapes.

Mountains are social-ecological systems (SESs), elucidating the interconnectedness between human societies and natural environments. While biophysical boundaries shape mountain SESs, they often transcend political and economic demarcations, complicating governance and management. Nonetheless, four defining characteristics underpin mountain SESs: complexity, marginalization and isolation, natural hazards, and ecosystem services provision, which apply to the Carpathian region.

Firstly, mountain SESs exhibit unparalleled biophysical and cultural complexity, with unique geomorphological settings fostering rich biodiversity. Vertical gradients of climate, hydrology, topography, and population contribute to microhabitat diversity. But as elevation increases, climates become more extreme, leading to reduced species diversity, exacerbating mountains' fragility and vulnerability to global change impacts. Secondly, mountain SESs often experience isolation, hindering connectivity and governance. Evolving in partial isolation, these ecosystems face connectivity challenges, hindering trade, migration, and governance. Despite their remoteness, mountains harbor high levels of endemism and biocultural diversity, underscoring their ecological significance. Thirdly, the geological

contexts and gradients of mountains render them prone to natural hazards, posing risks to human communities and ecosystems. Floods, landslides, earthquakes, and wildfires threaten mountain communities and infrastructure, exacerbating vulnerabilities. Lastly, mountains provide vital ecosystem services on local and global scales, but awareness of these services is limited. Climate change, governance, and economies drive changes in mountain SESs, exacerbating challenges like food and income insecurity, globalization impacts, imbalanced governance, data scarcity, and vulnerability to global changes.

Each of these characteristics interact nonlinearly to present complex, cross-sectoral challenges, otherwise known as wicked problems. This thesis explores such dynamics of mountain SESs, focusing on the Carpathian Mountain region as a case study by drawing insights from diverse stakeholders across the Carpathian region. Nestled in central-eastern Europe, the Carpathians are characterized by its rich biodiversity and traditional land use practices, providing essential ecosystem services to both local communities and beyond. These ecosystems, including expansive mountain forests and biodiverse grasslands, support unique wildlife populations and embody significant cultural heritage.

However, the region faces a myriad of challenges stemming from political, economic, social, and environmental changes, particularly since 1990 following the dissolution of the Soviet Union. During the communist regime, intensive forest exploitation and state-led land nationalization have resulted in vulnerabilities such as large-scale tree mortality and widespread agricultural land abandonment. The transition to market economies post-1989 further altered land management practices, with varied impacts observed across the region. The establishment of the Carpathian Convention in 2003 marked a pivotal moment in coordinating policies and actions among the seven Carpathian countries to protect and sustainably develop the region.

However, the Carpathian landscapes are increasingly threatened by various drivers, including climate change, land-use change, and socioeconomic shifts, posing formidable challenges to their sustainability and resilience, which can be categorized as wicked problems:

Food and Income Insecurity: Many regions within the Carpathians suffer from high unemployment and increasing poverty, contributing to food and income insecurity. Rural depopulation, insufficient job opportunities, and inadequate social infrastructure exacerbate these issues, leading to illegal resource harvesting and agricultural land abandonment.

Globalization Impacts: Globalization poses threats to Carpathian biodiversity through rural depopulation and intensified tourism. Traditional practices are abandoned as younger generations migrate to urban centers, leading to the erosion of local institutions and knowledge. Unsustainable tourism development further exacerbates natural resource use and land degradation.

Imbalanced Governance and Resource Management: Status inequalities and decontextualized legislation, particularly from the European Union (EU), negatively influence the Carpathian SES. Policies designed without considering local contexts often exacerbate existing disparities and fail to address the unique challenges faced by the region.

Data Scarcity: The lack of standardized monitoring data in the Carpathians makes it difficult to assess trends and formulate effective management strategies. Barriers to publishing research in international journals further exacerbate the issue, hindering the dissemination of knowledge and best practices.

Vulnerability to Global Changes: The Carpathian region is highly vulnerable to the impacts of climate change, land-use change, and pollution. Increased temperatures, variable precipitation patterns, and extreme weather events stress ecosystems, making them more susceptible to diseases, invasive species, and natural disturbances.

Understanding and addressing these wicked problems require holistic, interdisciplinary approaches that integrate scientific, local, and traditional knowledge to ensure the sustainability and resilience of mountain ecosystems and the communities dependent upon them. While the challenges facing the Carpathians are complex, they also present opportunities for sustainable transitions. Coordinated actions, informed by a deep understanding of the coupled human-environment interactions shaping the Carpathian SES, are essential for ensuring the long-term resilience of the region.

A cornerstone of this research is the utilization of Fuzzy Cognitive Mapping (FCM) as a participatory methodology to elucidate stakeholders' mental models and perceptions regarding the Carpathian biodiversity SES. FCM facilitates understanding and communication of complex SESs. Through causal reasoning, FCM depicts relationships between key concepts, including feedback loops, to help visualize system dynamics. This effectively creates an external representation of an individual's internal mental model. FCM utilizes fuzzy logic to create weighted cognitive maps. Fuzzy logic allows variables to exist in intermediate states, enhancing its ability to capture the nuances of real-world systems. Stakeholders define relationships between variables qualitatively or quantitatively, assigning strengths on a scale, enabling the modeling of complex interconnections within the system.

FCM serves two primary applications in decision-making: understanding possible system futures and impacts and aligning stakeholders' thinking. It aids in setting policy objectives and management strategies by generating and testing policy scenarios based on stakeholder perceptions, bridging qualitative and quantitative approaches. Additionally, FCM fosters communication and social learning by collecting and comparing perspectives among stakeholders, promoting consensus-building and understanding complex systems. The participatory nature of FCM encourages deliberative processes, challenging stakeholders' mental models and facilitating collective understanding and learning. It creates trust among participants, reflecting stakeholders' needs, beliefs, and values in policy development. However, it is essential to recognize that FCM is not a substitute for statistical methods but serves as a complementary tool in understanding and addressing complex issues.

Through a series of interviews and focus groups, stakeholders representing academia, government, non-profit organizations, protected areas and other sectors engaged in mapping their knowledge of the components making up the biodiversity system in the Carpathians, the challenges that face biodiversity, and the relationships between them. These interactions foster knowledge exchange, promote social learning, and facilitate the co-creation of actionable insights for biodiversity conservation and sustainable development.

However, navigating the complexities of mountain SES proved to be a formidable task, fraught with methodological challenges and epistemic uncertainties. Stakeholders grappled with quantifying variables and delineating causal relationships within the SES framework. Historical legacies, divergent perspectives, and diverse national contexts further complicated the modeling process, underscoring the need for nuanced approaches to capture the multifaceted nature of mountain ecosystems.

Despite these challenges, stakeholders converged on a shared recognition of the region's biodiversity richness and the multifaceted threats it faces. Climate change, land use intensification, and socio-economic drivers emerged as key determinants shaping the trajectory of mountain biodiversity. Through scenario analysis, stakeholders envisioned potential interventions to mitigate these threats, ranging from policy reforms and stakeholder collaboration to community-based conservation initiatives.

However, the efficacy of proposed interventions remains contingent upon the complex interplay of socio-economic, ecological, and governance factors. Scenario simulations revealed nuanced outcomes, with minor variations observed in biodiversity trajectories across different intervention scenarios. This underscores the need for adaptive management strategies that account for uncertainty, feedback dynamics, and stakeholder preferences in shaping policy responses.

In charting a path forward, this thesis offers a set of methodological recommendations to enhance the utility and robustness of FCM as a decision support tool for mountain biodiversity conservation. Addressing quantitative gaps, reconciling calibration methods, and fostering ongoing stakeholder engagement emerge as key priorities for advancing the field of SES modeling. By embracing an inclusive and iterative approach to knowledge generation and decision-making, stakeholders can harness the collective wisdom of diverse perspectives to navigate the complexities of mountain SES and chart a course toward a more sustainable future for the Carpathian region and beyond.

Chapter 1: Introduction

Mountains are essential to Earth's life-support system, harboring rich biological and cultural diversity and providing essential ecosystem services (Schmeller et al., 2022; Thorn et al., 2021; Kato, Rambali & Blanco-Gonzalez, 2021; Brunner & Grêt-Regamey, 2016). They play a crucial role in biodiversity conservation and global regulating processes, including water, food, energy, hazard mitigation and more (Schmeller et al., 2022; Brunner & Grêt-Regamey, 2016; Romeo, Grita, Parisi & Russo, 2020; Bogdan, Pătru-Stupariu & Zaharia, 2016). Mountains are thus deeply integrated with human activities, where social and ecological subsystems mutually impact each other (Melnykvych, Nijnik, Soloviy, Nijnik, Sarkki & Bihun, 2018). In other words, mountains are social-ecological systems (Schmeller et al., 2022; Klein et al., 2019; Thorn et al., 2020).

A social-ecological system (SES) is a complex system that foundationally provides ecosystem services and is composed of multilevel social systems across stakeholder groups, policy, and governance systems (Melnykvych et al., 2018). These subsystems—the resource system, resource units, users, and governance systems—all interact at multiple levels to produce joint outcomes that then feed back into the larger system to affect the subsystems and their components (Ostrom, 2009). Understanding this complex whole requires knowledge of the SES's components and their relationships (Ostrom, 2009). Due to the causality and feedback relationships between ecosystem service provision and human wellbeing, better understanding of their interlinkages is necessary for developing innovative solutions to challenges facing mountain ecosystems and communities (Melnykvych et al., 2018).

Mountain SESs are particularly sensitive to global changes, such as climate change, land use change and pollution, causing concerns over their capacity to cope with trends and disturbances (Brunner & Grêt-Regamey, 2016; Schmeller et al., 2022; Thorn et al., 2020; Bezáková & Bezák, 2022). Human actions are driving the triple planetary crisis of climate change, pollution, and biodiversity loss, threatening the planet's functioning and ability to support life and the future of humanity (UNFCCC, 2022; Grima, Ringhofer, Singh, Smetschka, & Lauk, 2017). Thus, prioritizing mountain biodiversity and supporting mountain communities on the global agenda is crucial for securing healthy ecological systems and meeting the needs of all people within the means of the planet.

This thesis contextualizes this mountain biodiversity SES framework to the Carpathian Mountain region, a mountain range in central-eastern Europe. The Carpathian Mountains are a biodiversity hotspot in Europe, harboring some of its last remaining virgin forests and its largest populations of large carnivores. The region provides essential ecosystem services to millions of people who reside in the area and beyond, contributing to the health of diverse landscapes. A multinational environmental agreement, the Carpathian Convention, unites seven Carpathian countries, and the Secretariat of this convention seeks to mainstream biodiversity across various sectors for protecting the natural and cultural heritage of the area while promoting sustainable development in the Carpathians.

Due to the inherent complexity and vulnerability of mountain landscapes, enhancing their sustainability or resilience is difficult. SES resilience describes the capacity of the system to recover from disturbances, maintaining its integrity (Bamutaze 2015; Brunner & Grêt-Regamey, 2016; Gray et al., 2015). Resilience is needed for managing complex SESs to ensure the sustainable provision and consumption of ecosystem services (Brunner & Grêt-

Regamey, 2016). But pursuing mountain SES resiliency is not easy for at least two reasons: (1) decisions that directly impact mountain SESs are created by and affect many stakeholders divided by geography, political power, interests, and economic realities, and (2) analyzing an entire system is more difficult than partial analysis, which only looks at the effect of one or some policies or components.

To address the first challenge of SES resiliency, the Carpathian Convention provides a forum to harmonize the actions of multiple stakeholders and policies across countries and industries with varying interests. To address the second challenge, typical methods for decision-making rely on two approaches: System I thinking, which involves automatic, intuitive decisions; and System II thinking, which is decision-making that is more conscious and logical (The Decision Lab, n.d.). However, solely relying upon intuition or rational models are insufficient for analyzing mountain SESs, as data for these regions is scarce and creating complex quantitative models is costly. One model that seeks to blend these two approaches is Fuzzy Cognitive Mapping (FCM).

FCM offers a way to analyze the SES behavior and develop simulations for resiliency planning based upon stakeholder perceptions of the SES (Olazabal & Pascual, 2016; Özesmi & Özesmi, 2004; Gray et al., 2015). FCM is a semiquantitative method for visually illustrating the relationships between key concepts of a system, including feedback relationships (Gray et al., 2015; Özesmi & Özesmi, 2004). Applying FCM as a participatory model is suitable for incorporating complexity and diverse stakeholder knowledge, especially in data-scarce contexts (Gray et al., 2015). In this context, FCM can be used for understanding Carpathian mountain biodiversity as a SES by defining its current state, analyzing the structure, running scenarios to analyze its functions, and evaluating how changes in drivers create desirable or undesirable outcomes (Gray et al., 2015).

Understanding the drivers of change in the SES of Carpathian mountain biodiversity can help determine the system's dynamics in affecting human well-being and conservation goals, ultimately influencing resiliency. FCM provides a potential pathway for assessing the Carpathian Mountain biodiversity SES and potential interventions for improving biodiversity outcomes.

This thesis researches how FCM is likely to encourage stakeholders in the Carpathian Convention to adopt a more calibrated, systems approach to decision-making for improving biodiversity outcomes. Supplementary to this research question, it asks whether expected biodiversity outcomes differ based on how FCM is conducted, either via (1) individual interviews, or (2) data generated from group consensus. Such analysis aims to better understand the synergies and trade-offs of integrating biodiversity considerations for the livelihoods of people and nature.

This thesis begins with a closer look at what defines mountain SESs and how those inherent characteristics create inherent challenges for resiliency. It then applies this framework to the Carpathian Mountains in Chapter 3 with a sociopolitical background on the region. Chapter 4 introduces FCM as an emerging method for modeling ecological scenarios. Chapter 5 discusses how this research conducted FCM with Carpathian Convention stakeholders, followed by a discussion of the results. Finally, the thesis concludes with a chapter on recommendations for the Carpathian Convention to consider when taking a systems approach to biodiversity.

Chapter 2: Mountain Social-Ecological System Resilience and Transformation

2.1 Rationale: Why Mountains?

Mountains are repositories of biological and cultural diversity, providing essential ecosystem goods and services to mountain communities and people in the lowlands (Kato, Rambali & Blanco-Gonzalez, 2021; Brunner & Grêt-Regamey, 2016; Schmeller et al., 2022; Thorn et al., 2020; Huber et al., 2013). While only covering about 27 percent of Earth's land surface, excluding Antarctica (Romeo, Grita, Parisi & Russo, 2020), mountains host more than 85 percent of the world's amphibian, bird and mammal species (Kato, Rambali & Blanco-Gonzalez, 2021; Thorn et al., 2020). Mountain ecosystems play a crucial role in global regulating processes, including sequestering carbon, purifying air and water, regulating climate, conserving biodiversity, storing water and regulating floods, and providing energy and biomedical resources. (Brunner & Grêt-Regamey, 2016; Romeo, Grita, Parisi & Russo, 2020; Kato, Rambali & Blanco-Gonzalez, 2021; Schmeller et al., 2022; Bogdan, Pătru-Stupariu & Zaharia, 2016). Over half of humanity relies on these ecosystem goods and services within and beyond mountain areas (Schmeller et al., 2022; Klein et al., 2019; Thorn et al., 2020).

Despite this ecological richness and importance, many of the world's poorest people live in mountain regions, facing food insecurity and less accessibility to infrastructure and services (Thorn et al., 2020). These social concerns are increasing as the ability of mountain landscapes to adapt to disturbances and global change are increasingly compromised (Brunner & Grêt-Regamey, 2016; Huber et al., 2013). The capacity of mountains to provide ecosystem services is declining due to biodiversity loss driven by global change (Schmeller et al., 2022; Thorn et al., 2020; Grima et al., 2017), leading to increased poverty, lower food production, increased health risks and an overall decrease in human wellbeing (Schmeller et al., 2022). Sustaining mountain biodiversity—and therefore enhancing ecosystem services and human livelihoods—requires understanding these interconnected relationships between society and ecosystems as a complex whole.

2.2 Inherent Characteristics cause Inherent Challenges

Mountains are social-ecological systems (SESs) (Schmeller et al., 2022; Klein et al., 2019; Thorn et al., 2020) since they are dynamic, complex, adaptive and uncertain systems with feedback relationships (Bamutaze 2015; Gray et al., 2015). Mountain SESs are shaped by geological forces and human activities (Schmeller et al., 2022) that make them ecologically and economically sensitive to global changes (Brunner & Grêt-Regamey, 2016; Klein et al., 2019; Bezáková & Bezák, 2022). More significantly, the defining characteristics of mountain SESs are the reason for their inherent challenges.

Mountain SES Characteristics

Definitions of mountains and mountain SESs vary, because their boundaries are not only determined geologically, but also based on climate, hydrology, ecosystem patterns, species distributions and human activities (Thorn et al., 2020). Additionally, these biophysical boundaries may not align with political or economic boundaries (Thorn et al., 2020). Nonetheless, four key characteristics define mountain SESs: (1) complexity, (2) marginalization and isolation, (3) natural hazards and (4) ecosystem services provision, which interact nonlinearly to create complicated, cross-sectoral challenges (Klein et al., 2019).

First, mountain SESs are biophysically and culturally complex systems (Klein et al., 2019) due to their geomorphological and geologic settings (Bamutaze, 2015). They are characterized by vertical gradients of climate, hydrology, topography, population and biocultural diversity (Klein et al., 2019) that contribute to a high diversity of microhabitats where a great number of species live in relatively small areas (Schmeller et al., 2022). As elevation increases, climates become more extreme and therefore harbor fewer species and system redundancies (Schmeller et al., 2022). System redundancies, different species with similar functions, provide stability to ecosystems; however, their scarcity in mountain ecosystems contributes to mountains' fragility and vulnerability to global change impacts (Schmeller et al., 2022).

Second, mountain SESs are often biogeographically isolated (Schmeller et al., 2022; Klein et al., 2019) and physically isolated from centers of decision-making power, contributing to their socioeconomic and political marginalization (Klein et al., 2019; Bezáková & Bezák, 2022; Bizikova, Nijnik & Kluvanková-Oravská, 2011). Mountain ecosystems evolved in partial isolation (Schmeller et al., 2022; Klein et al., 2019) and continue to be isolated from other mountain ecosystems like an island amongst lowland surroundings (Klein et al., 2019; Mráz & Ronikier, 2016). Their rugged landscapes create connectivity challenges such as trade and migration and political challenges regarding potentially contested administrative boundaries (Klein et al., 2019). However, an outcome of such remoteness contributes to high levels of endemism and biocultural diversity in mountain SESs (Klein et al., 2019).

Thirdly, the geological contexts and biophysical vertical gradients that characterize mountains make them prone to several natural hazards, more so than non-mountainous regions (Klein et al., 2019; Thorn et al., 2020). These hazards include floods, landslides, erosion, earthquakes, avalanches and wildfires (Klein et al., 2019; Thorn et al., 2020).

Lastly, mountains supply essential ecosystem services and goods on local and global scales (Klein et al., 2019). As described earlier, such goods and services include global regulating processes, natural resource provision such as timber, water and food, hydropower, and more (Brunner & Grêt-Regamey, 2016; Schmeller et al., 2022; Klein et al., 2019; Bezáková & Bezák, 2022). However, people are generally unaware of the services mountain ecosystems provide and the threats that mountain SESs face (Schmeller et al., 2022).

These characteristics of mountain SESs render them complex, dynamic, marginal, diverse, fragile and sensitive to global changes (Bamutaze, 2015; Schmeller et al., 2022); thus, maintaining the delicate equilibrium between resource use and protection (Bamutaze, 2015) necessitates a sustainability approach across sectors and scales (Klein et al., 2019; Bezáková & Bezák, 2022). However, these characteristics interact nonlinearly to create wicked problems: multi-stakeholder problems that are very complex with no easy solutions (Klein et al., 2019; Özesmi & Özesmi, 2004).

Mountain SES Challenges

Globally, climate, governance and economies are key drivers of both gradual and abrupt changes in mountain SESs (Klein et al., 2019). These drivers are embedded within the biophysical, socioeconomic and political characteristics described in the previous section, which interact to produce wicked problems inherent to mountain SESs: (1) food and income insecurity, (2) globalization impacts, (3) imbalanced governance and resource management, (4) data scarcity, (5) vulnerability to global changes from climate change, land use and pollution (Schmeller et al., 2022; Klein et al., 2019).

Firstly, despite mountains being very resource-rich, its inhabitants are often poor; because mountains are very resource-rich, its materials often benefit lowland populations (Klein et al., 2020; Thorn et al., 2020). According to the United Nations, 54 percent of all mountain areas are in developing countries, which includes Africa, Latin America and the Caribbean, most of Asia and most of Oceania (Romeo, Grita, Parisi & Russo, 2020). While 39 percent of all mountain inhabitants in these developing countries are at risk of food insecurity, this number rose to 50 percent for rural mountain inhabitants (Romeo, Grita, Parisi & Russo, 2020). This vulnerability for mountain communities is exacerbated by the reality that many mountain resources like timber, water and minerals are extracted for non-mountain communities or buyers (Klein et al., 2019).

Secondly, globalization trends have accelerated and caused major changes in mountain SESs, consequently compromising their ecological and socio-cultural integrity (Brunner & Grêt-Regamey, 2016). Mountain SESs are experiencing destabilizing demographic fluxes from in- and out-migrations (Klein et al., 2019; Thorn et al., 2020) due to trends like rising connectedness, rural depopulation and urbanization (Brunner & Grêt-Regamey, 2016; Klein et al., 2019; Thorn et al., 2020). Some mountain SESs experience depopulation: people leave mountain areas for education or employment, causing agricultural abandonment, rural depopulation, aging populations and restructured market relationships (Klein et al., 2019; Thorn et al., 2020; Bezáková & Bezák, 2022). Other mountain SESs experience urbanization: climate change brings newly suitable climates at higher elevations for growing crops and the recreational and touristic amenities of mountains attract wealthy individuals (Klein et al., 2019). Such tourism and associated infrastructure compromises mountain biodiversity (Schmeller et al., 2022). Because "globalization often acts as a top-down regulation process that ignores" local knowledge and place-based conditions (Brunner & Grêt-Regamey, 2016, p. 136), it adversely compounds with climate change.

These globalization trends and socioeconomic insecurities of mountain SESs contribute to the third wicked problem of imbalanced governance and resource management. Mountains are both a refuge for marginalized peoples and a destination for wealthy individuals, creating inequities in incomes, investments and interests (Klein et al., 2019). Due to mountain SESs' remoteness, distant decision makers are often the ones who create and manage policies with little understanding of local mountain SES dynamics (Klein et al., 2019). Such top-down and decontextualized policy implementation are often not only ineffective for remote and depopulated rural areas (Bezáková & Bezák, 2022), but may exacerbate scarcities, make mountain communities more dependent on external interventions (Klein et al., 2019), create conflicts between nature conservationists and local farmers, and erode traditional practices and knowledge (Babai, Jánó & Molnár, 2021).

Due to their complexity, managing policies and resources adapted to mountain SESs require interdisciplinary, scientific and local knowledge and fine-scale spatial and temporal data. However, such necessary data for mountain SESs is lacking, because of mountains' remoteness and inaccessibility, political barriers, and inadequate funding (Klein et al., 2019). This fourth wicked problem makes it challenging for making evidence-based policy and resource management decisions suited for mountain SESs.

Lastly, mountains are vulnerable to global changes driven by climate change, land use and pollution, which interact to degrade and destroy mountain ecosystems and biodiversity (Schmeller et al., 2022). Negative impacts on mountain biodiversity threaten ecosystem integrity and functioning, including ecosystem services for local mountain and farther lowland communities and visitors (Schmeller et al., 2022; Thorn et al., 2020).

Mountain SESs are especially vulnerable to climate change impacts because of their biophysical characteristics, and are hindered from adapting to climate change due to their slow restoration and recovery ecosystem processes and sociopolitical marginalization (Schmeller et al., 2022; Kato, Rambali & Blanco-Gonzalez, 2021). Climate change affects mountain biodiversity and ecosystems at a faster rate than other terrestrial ecosystems, including lowland regions (Kato, Rambali & Blanco-Gonzalez, 2021; Schmeller et al., 2022; Thorn et al., 2020), because the rate of warming increases as elevation increases (Thorn et al., 2020). Changes in precipitation, temperature, and frequency of extreme events like droughts and floods affect water availability and predictability (Schmeller et al., 2022). Accelerating warming temperatures increase droughts and extreme precipitation events; droughts increase wildfire likelihoods, which are difficult to extinguish in mountains due to the rugged landscape (Schmeller et al., 2022). These cascading effects jeopardize mountains as “global water towers,” supplying drinking water for billions of people, plants and animals (Schmeller et al., 2022; Thorn et al., 2020). Even lowland populations will experience unpredictable water supplies and destroyed infrastructure due to more frequent and extreme floods and landslides (Schmeller et al., 2022). Climate change also exacerbates the spread of invasive biological species, leading to more biodiversity and economic losses (Schmeller et al., 2022). These rapid climate change impacts combine with the socioeconomic conditions that stress mountain SESs: marginalization, contested boundaries, decontextualized policy decisions and reliance upon outside funding, employment, markets and infrastructure (Schmeller et al., 2022; Klein et al., 2019; Huber et al., 2013). All these threats affect land use (Huber et al., 2013), the second driver of global change for mountain SESs.

Human-nature interactions shape historical and current land use, which determine whether mountain SESs can continue providing ecosystem services (Brunner & Grêt-Regamey, 2016). These social-ecological interactions shape mountain vegetation and soil conditions, influencing carbon sequestration rates and biodiversity (Schmeller et al., 2022). Mountains are used as food and water sources, recreational areas and hydroelectric sources (Schmeller et al., 2022). In most mountains, pastoral activities are not only the major agricultural activity, but the main driver of land use changes (Schmeller et al., 2022). For example, increased clearing, or slash and burn, is associated with rising pastoral pressure (Schmeller et al., 2022). Human activities associated with water extraction or diversion involves land drainage, dredging, dam building, reservoir and canal development, and more (Schmeller et al., 2022). When excessive, these activities dry up aquatic ecosystems and change water levels, stream flows and hydrological connectivity (Schmeller et al., 2022). Overall, this adversely impacts mountain biodiversity structures and functions and jeopardizes endemic and threatened species (Schmeller et al., 2022). Other land use changes involve logging, afforestation, vegetation regrowth in abandoned lands, tourism and non-native plantations (Schmeller et al., 2022). Many of these activities are also pollutant sources, the third driver of global change in mountain SESs.

The main pollutant sources in mountains are from global atmospheric transport of micropollutants and local human activities like mining, logging, agriculture, pastoralism and tourism (Schmeller et al., 2022). The introduction of new pollutants and changes in pollutant migration from climate change may compromise ecosystem health and increase the vulnerability of species and humans to pathogens, raising health risks (Schmeller et al., 2022).

Mountain SESs' geological, biophysical, political and socioeconomic characteristics render them fragile, diverse, sensitive and complex (Bamutaze 2015) and contribute to their remoteness and political and economic marginalization (Kato, Rambali & Blanco-Gonzalez, 2021). These inherent features make mountains sensitive to global change, but are increasingly made vulnerable due to the effects of globalization and climate change (Bamutaze 2015; Kato, Rambali & Blanco-Gonzalez, 2021; Brunner & Grêt-Regamey, 2016).

The next chapter contextualizes how these mountain SES characteristics and wicked problems manifest in a specific mountain region. The Carpathian Mountains are Europe's richest biogeographical regions (Mráz & Ronikier, 2016), yet are not as well-known as other European mountain ranges, making it even more crucial to further promote the valuable ecological contributions and increasing challenges of this region.

Chapter 3: The Carpathian Mountains and Biodiversity System

The Carpathian Mountains are a mountain range in central-eastern Europe (CEE) that spans seven to eight countries (some literature acknowledges Austria as a country with Carpathian foothills, while other literature does not). It is the second longest mountain ranges in Europe (following the Scandinavian Mountains), extending from the Austrian-Czech Republic border to Serbia in the south, arcing through Slovakia, southern Poland, northern Hungary, western Ukraine, and Romania (Mráz & Ronikier, 2016).

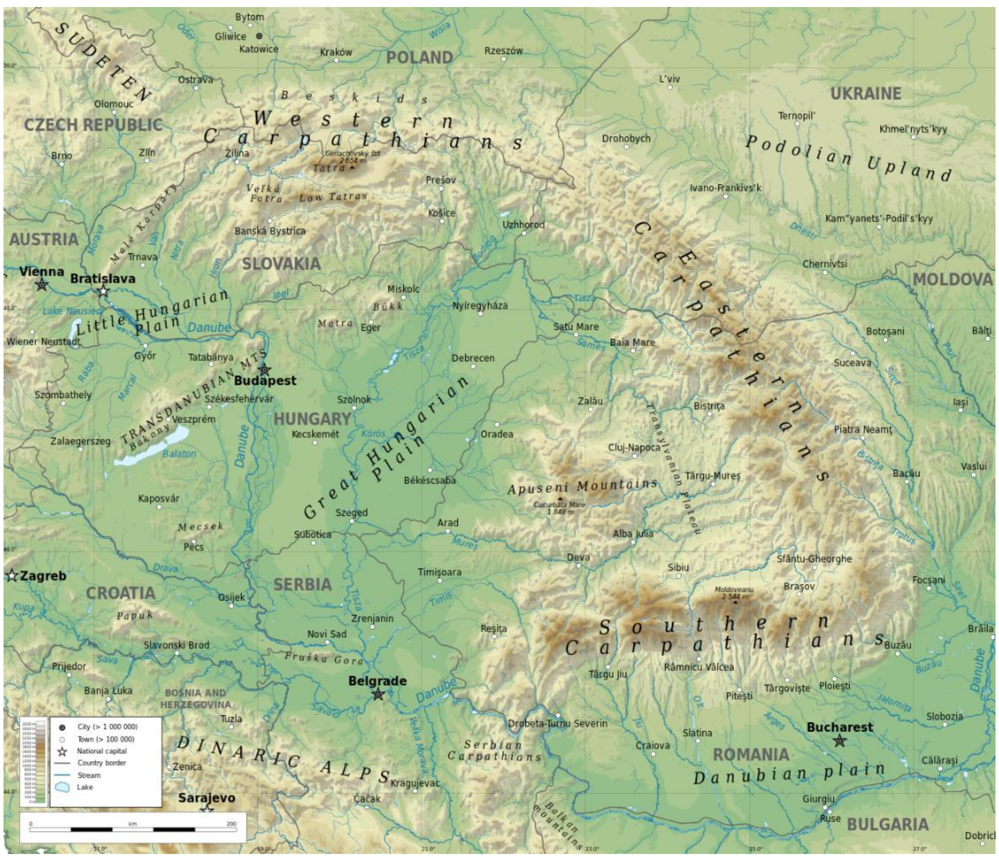

Figure 1: A topographic map of the Carpathian Mountain region. Source: Ikonact; CC BY-SA 4.0 https://commons.wikimedia.org/w/index.php?curid=105539776.

While a European biodiversity hotspot characterized by unique traditional land use systems, it has faced and continues to face major political, economic, social and environmental changes, some of the most drastic changes occurring since 1990 after the fall of the Soviet Union (Pomázi & Szabó, 2010). These historical and ongoing changes threaten biodiversity and traditional management practices, thus also threatening the Carpathian SES.

3.1 The Carpathian SES

The Carpathian region is a biodiversity hotspot in Europe, providing essential ecosystem services to not only the 17 million people living in the region, but other populations beyond (Alberton et al., 2017). It is home to tributaries of four main European watersheds, Europe's largest continuous mountain forests (Alberton et al., 2017; Melnykovych et al., 2018), including the largest unmanaged old growth forests (Björnsen Gurung et al., 2009), and biodiverse-rich semi-natural grasslands (Molnár et al., 2023). These ecosystems are refuge to Europe's largest populations of large carnivores, including brown bears, wolves, and lynxes (Björnsen Gurung et al., 2009). This region is also demonstrative of European mountain cultural landscapes, containing diverse habitat types with majority semi-natural vegetation that hold high cultural and nature conservation values (Babai, Jánó & Molnár, 2021; Molnár et al., 2023).

The cultural landscape is largely characterized by these unique forests and grasslands that perform diverse functions: agricultural production, biodiversity maintenance, and cultural dimensions (Babai, Jánó & Molnár, 2021). 66% of the region is forested (Alberton et al., 2017) and the semi-natural grasslands in the uplands are heavily stewarded through low intensive farming (Babai, Jánó & Molnár, 2021; Molnár et al., 2023). They are not only important for the forestry and agricultural economic sectors, but are highly valuable for tourism, subsistence, spirituality, social cohesion, biodiversity and more (Babai, Jánó &

Molnár, 2021; Melnykovych et al., 2018). However, the integrity of these landscapes is increasingly compromised by social, political, environmental, and economic drivers.

The Carpathian mountain forests ensure local community well-being and reduce vulnerability to climate change (Melnykovych et al., 2018). Rural communities rely on forests for firewood, construction materials, food, livestock forage, and income in logging, tourism and recreation industries (Alberton et al., 2017; Melnykovych et al., 2018). For example, in the Ukrainian Carpathians, forestry and wood processing enterprises are the main local employers (Melnykovych et al., 2018, p.). Due to the long-term interactions between people and nature, forests contribute to local cultural heritage, reflecting local knowledge and practices, such as harboring medicinal herbs and spiritual values (Melnykovych et al., 2018). Forests also provide other ecosystem services like sequestering carbon, maintaining hydrological systems, controlling erosion and conserving biodiversity (Melnykovych et al., 2018).

The Carpathian grasslands, also called hay meadows, are a cultural landscape characterized by traditional land management systems, involving low intensive, small-scale farming systems that conserve and produce diverse semi-natural and cultural landscapes (Bezáková & Bezák, 2022; Soliva et al., 2008; Molnár et al., 2023). While these agricultural systems have low chemical and machinery input, they depend on high human stewardship involving grazing and fodder (e.g. hay) harvesting (Soliva et al., 2008; Molnár et al., 2023). Pastoralism and haymaking provide economic benefits and family subsistence and continue longstanding, generational family traditions (Marcol & Kurcz, 2022; Babai, Jánó & Molnár, 2021). Evidence of herding-related impacts upon the Carpathian landscape dates back to around 5000–2000 BC in some areas (Schumacher, Schier & Schütt, 2016). The commercialization of pastoralist-derived products contributes to both short and long food supply chains (Grădinaru, Triboi, Iojă, & Artmann, 2018). For example, herders in Romania distribute dairy products in the local market, while sheep and meat products are distributed in the international market (Grădinaru, Triboi, Iojă, & Artmann, 2018).

Due to the active management of grazing and traditionally mowing these upland meadows, these ecosystems are incredibly species-rich and critical to cultural heritage (Molnár et al., 2023). Biodiverse-rich habitats build a sense of place and regional identity, representing traditional land use systems and a cultural heritage built upon actively producing food and fiber (Soliva et al., 2008). Some local communities hold a collective identity based on pastoral traditions and foster cultural events and festivals, handicrafts, folk music and other traditions related to pastoralism (Marcol & Kurcz, 2022; Ivașcu & Iuga, 2022). For many communities, these cultural events are tourist attractions (Marcol & Kurcz, 2022).

However, Carpathian forests and grasslands, and the associated traditional land use systems, are impacted directly by climate change and land-use change and indirectly by demographic and other socioeconomic changes (Babai, Jánó & Molnár, 2021). Many of these changes occurred post-World War II, especially after the end of the communist regime in CEE (Soliva et al., 2008).

3.2 Carpathian Brief Political History

The current socioeconomic and environmental processes in the Carpathians are a result of major historical and political changes (Pomázi & Szabó, 2010). Much of this history is outside the scope of this research, but knowing the impacts of the communist regime on the

Carpathian countries is critical to understanding the current state and vulnerabilities of the Carpathian mountain SES.

Because of historical overexploitation of forests and the introduction of non-native tree species, Carpathian forests are now vulnerable to large-scale tree mortality and dieback (Carpathian Convention Secretariat, 2023). Before the communist regime in 1948, intensive production-driven forestry systems led to massive clear cuts (Bogdan, Pătru-Stupariu & Zaharia, 2016). Native beech and mixed species forests were converted to Norway spruce plantations, making them vulnerable to massive tree mortality from disturbances like insects, fungal diseases, drought, windstorms and fires (UNEP, 2023). Climate change amplifies these stresses, limiting the potential resilience of Carpathian forests (UNEP, 2023).

During the communist regime between 1948 and 1989, CEE restructured under command-and-control economies and state monopoly and administrative regulation (Bizikova, Nijnik & Kluvanková-Oravská, 2011). This entailed nationalization of forest and agricultural lands (Babai, Jánó & Molnár, 2021) "under the principles of a planned economy and a heavily subsidized socio-economic system" (Bizikova, Nijnik & Kluvanková-Oravská, 2011, p. 302). All forests were owned and managed almost exclusively by the state (Bogdan, Pătru-Stupariu & Zaharia, 2016) and farmland underwent state-imposed homogenization, intensification and collectivization (Sutcliffe et al., 2015). Collectivization involved the merging of private smallholder farms into industrial farms, often several thousand hectares large (Sutcliffe et al., 2015). At the same time, urban centers offered new job opportunities in industry, so labor migration increased and farming became a secondary activity for many families (Babai, Jánó & Molnár, 2021).

However, this agricultural nationalization process was inefficient or only partially implemented in regions like the Romanian Carpathians (Babai, Jánó & Molnár, 2021), leaving many patches of semi-natural land (Sutcliffe et al., 2015). While forests and pastures were nationalized, hay meadows largely remained privately owned, so their management changed little (Babai, Jánó & Molnár, 2021).

After the fall of the communist regime in 1989 in CEE, mountain landscapes reorganized to adapt to land intensification and the global open market (Bezáková & Bezák, 2022). During the 1990s, the land restitution process began, returning forests and farmland to the original owners before 1948 (Babai, Jánó & Molnár, 2021; Bogdan, Pătru-Stupariu & Zaharia, 2016; Bizikova, Nijnik & Kluvanková-Oravská, 2011). The consequences of this manifested differently in particular regions, as collectivization was not equally applied, and some traditional land management systems in CEE were affected, but not completely eroded, as they were sustained in isolated, hilly and mountains regions (Babai, Jánó & Molnár, 2021).

While smallholder farms reappeared (Babai, Jánó & Molnár, 2021), large areas of cropland and grasslands were abandoned during the 1990s and early 2000s, decreasing overall production (Sutcliffe et al., 2015). Agricultural decline, land abandonment and natural reforestation caused variations in socioeconomic, cultural, aesthetic and environmental consequences (Soliva et al., 2008). Areas like Transylvania, Romania experienced renewed agricultural importance, especially where animal husbandry and extensive management of hay meadows was sustained (Babai, Jánó & Molnár, 2021), but forest-neighboring communities experienced a sharp decline in forestry employment and impoverishment (Bizikova, Nijnik & Kluvanková-Oravská, 2011). The Roma minority, dispersed and marginalized throughout CEE, were most significantly impacted, as the forest sector was the major employment for Roma until 1995 (Bizikova, Nijnik & Kluvanková-Oravská, 2011).

Nonetheless, this fragmentation of land ownership hinders farmland consolidation and agricultural intensification (Sutcliffe et al., 2015). Relative to other parts of Europe, CEE has less agrochemical inputs, mechanization and productivity, and few large industrial farms, consisting mostly of small, subsistence or semi-subsistence farming (Sutcliffe et al., 2015). This supports biodiversity by promoting mixed farming and mosaic structures (Sutcliffe et al., 2015).

The Carpathian Convention

In the wake of these abrupt and drastic changes, the Ukrainian government approached the United Nations Environment Programme in 2001 to facilitate an intergovernmental dialogue among the Carpathian countries to develop a convention for coordinating policies and actions for the Carpathian mountains (Secretariat of the Carpathian Convention, n.d.). In May 2003, the Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention) was adopted and signed by all seven Carpathian countries (Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia, and Ukraine) at the 2003 "Environment for Europe" Fifth Ministerial Conference in Kyiv, Ukraine.

The Carpathian Convention aims to protect the natural and cultural heritage of the area while promoting sustainable development in the Carpathians. It is the only multi-level governance mechanism covering the entire Carpathian region and is the second sub-regional treaty-based regime in the world that focuses on mountain protection and sustainable development, following the Alpine Convention. In 2004, the Czech Republic, Hungary, Poland and Slovakia joined the European Union (EU), Romania joined in 2007 (Pomázi & Szabó, 2010), and Serbia and Ukraine are currently EU candidate countries. Thus, EU agricultural, forestry, and nature conservation regulations profoundly influence land management practices (Babai, Jánó & Molnár, 2021).

3.3 Wicked SES Problems in the Carpathians

Resource-based mountain SESs, like the agropastoral landscape of the Carpathians, have high biocultural diversity and cross-scale ecosystem services (Klein et al., 2019). But these systems face numerous threats and should be prioritized for building resilience and creating transformation (Klein et al., 2019). While the direct drivers of global changes have not irreversibly affected these traditional land management systems in some locales, socioeconomic and political interventions place them under great pressure (Babai, Jánó & Molnár, 2021).

This section incorporates the four defining characteristics of mountain SESs into discussing the five wicked problems inherent to these systems—food and income insecurity; globalization impacts; imbalanced governance and resource management; data scarcity; and vulnerability to global changes from climate change, land use and pollution—contextualized to the Carpathian region.

Firstly, high unemployment and increasing poverty are common features in the Carpathians (Pomázi & Szabó, 2010). Many Carpathian regions are among the poorest in Europe, with a GDP that is less than 50% of the EU average (European Parliamentary Research Service, 2019). Being a largely remote area, these marginalized communities experience depopulation, lack of job opportunities, insufficient social infrastructure and services, and an inability to obtain external funding (Bezáková & Bezák, 2022). Due to these decreased standards of living and remoteness, rural residents turn to illegal logging and harvesting for additional income and subsistence (Melnykovych et al., 2018) and abandon agricultural land (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021). In the Ukrainian Carpathians, this illegal natural resource harvesting decreases forest productivity, thus compromising watershed functions and overall stability of mountain ecosystems (Melnykovych et al., 2018). Agricultural land abandonment is common in remote mountain regions because infrastructure and public services are scarce and inefficient and it is harder to reach markets, thus increasing transportation costs for and reducing the competitiveness of mountain agricultural products (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021). In Hungary, agricultural abandonment is due to remoteness, low population density, socioeconomic factors, and inefficient farm structures: including aging farmers, land-use competition, lack of produce demand and insufficient income (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021).

Secondly, globalization impacts threaten Carpathian biodiversity due to rural depopulation and intensified tourism. Due to uncertain economic prospects in the rural areas, younger generations abandon traditional practices and often move to urban centers (Molnár et al., 2023). This disintegrates formal and informal institutions that govern traditional practices (Molnár et al., 2023). As traditional knowledge holders age (Molnár et al., 2023), they may not be able to continue the intense manual labor of maintaining grasslands, and youth become more disconnected from their local cultural landscape (Molnár et al., 2023). For example, the traditional practices of communal haymaking in Romania, or kaláka, by family-owned farms is almost completely abandoned due to the increased use of mower machines, an adaptation to lack of labor, EU regulations and climate change affecting the growing seasons (Babai, Jánó & Molnár, 2021). After the collapse of the communist regime, tourism development, especially ski resorts, was an important economic strategy in Slovakia, Romania and Ukraine (Alberton et al., 2017). The unsustainable expansion of tourism remains a threat to mountain sustainability (Melnykovych et al., 2018), as such infrastructure intensifies natural resource use and land use of the area.

Thirdly, status inequalities and decontextualized legislation, especially EU regulatory and subsidy systems, have been shown to negatively influence the Carpathian SES context (Babai, Jánó & Molnár, 2021; Molnár et al., 2023). During the 20th century, “progress narratives” sought to spread mechanization and nationalization of landscapes by portraying traditional practices as backward and undesirable, leading to status inequalities between local stakeholder groups (Molnár et al., 2023). These inequalities are exacerbated outside the local community as traditional farming systems are forced into market competition with industrially produced food (Molnár et al., 2023). The EU’s Biodiversity Strategy and Common Agricultural Policy (CAP) also contribute to imbalanced governance and resource management, as they are often based on western European contexts and inputs (Molnár et al., 2023). Many of these policies were developed before the accession of CEE member states to the EU; thus, they are often poorly aligned to CEE agricultural landscapes and ecological practices (Molnár et al., 2023). As mentioned before, kaláka is being abandoned due to CAP’s dictation on mowing time. Mowing grasslands in summer and not spring was found to be beneficial for biodiversity based on western European studies; but when applied to extensively managed meadows like in the Carpathians, postponing mowing decreases sward height diversity (potentially decreasing plant biodiversity, see Wrage, Şahin Demirbağ, Hofmann, & Isselstein, 2012) (Sutcliffe et al., 2015). However, Carpathian farmers comply with the regulations to receive financial support for their small farms, even though social cohesion produced by communal mowing has decreased (Babai, Jánó & Molnár, 2021).

However, it can be favorable that the EU provides payment schemes to marginal farming areas. These schemes compensate farmers that farm despite unfavorable conditions (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021), and a project found that stakeholders in Slovakia wanted increasing agricultural EU support to keep farming profitable and prevent land abandonment (Soliva et al., 2008).

Even if EU and national policies do encourage biodiversity-friendly management and direct funding toward marginal areas, there is often minimal monitoring and local enforcement of regulatory compliance in the Carpathians. For example, in the Ukrainian Carpathians, illegal logging, unregulated development, unsanctioned land acquisition and illegal resource harvesting are not enforced by local authorities (Melnykovych et al., 2018). Such illegal activities are done for multiple reasons, whether fueled by corruption, poverty, or a lack of local government capacities (Melnykovych et al., 2018).

Fourthly, the lack of standardized monitoring data in the Carpathians make general trends hard to measure and data scarcity is further exacerbated by barriers created by scientific journals (Sutcliffe et al., 2015). There is little knowledge on what all is being lost as a result of CAP, for example, and the acceptance rate of submitted journal articles coming out of Eastern Europe has been criticized (Sutcliffe et al., 2015). Journal articles not in English are also hard to gain traction internationally.

Lastly, the Carpathian region faces social and ecological changes because of land use change, pollution, and climate change. Regarding land use change, agricultural land abandonment, agricultural intensification, tourism expansion and logging are commonly described in the literature for the region. Changes to the agricultural landscape reflect the post-war and post-Soviet trends of rural depopulation and decreased competitive advantages of the rural economy (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021) and are continually shaped by CAP (Bezáková & Bezák, 2022). Remote and small-scale grasslands and arable lands steep slopes, at high altitudes or distant from urban areas are disappearing, being left for forest expansion or are rented to large farms (Bezáková & Bezák, 2022). Meanwhile, easily accessible lands are agriculturally intensified: increased mechanization and decreased landscape elements and land use activities are driven by CAP (Bezáková & Bezák, 2022). More intensive farms usually receive higher direct payments per hectare, as CAP favors optimizing farming based on biophysical conditions and efficiency (Bezáková & Bezák, 2022). Thus, grasslands are preferred in “less favored areas,” leading to increased abandonment risk due to poor biophysical conditions (Bezáková & Bezák, 2022), as seen in Polish Carpathians, which are a hotspot for agricultural abandonment (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021).

Ecologically, land abandonment and intensified agriculture result in biodiversity loss, landscape homogenization, increased fire risk, increased soil erosion and degradation, and more pressure on natural resources (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021). Socioeconomically, they are both caused by and cause decreased agricultural-related income, employment, knowledge and cultural heritage, aggravating already weak economic and social structures (Perpiña Castillo, Jacobs-Crisioni, Diogo, & Lavalle, 2021).

Pollution from growing urban and industrial infrastructure impairs forest resilience (Melnykovych et al., 2018) and plastic pollution is a large issue in the Tisza River, which runs through Ukraine, Romania, Hungary, Slovakia and Serbia to join the Danube River. Litter illegally dumped in floodplains are the main cause of severe plastic pollution, and riverine pollution is expected to increase further as a result of the war in Ukraine due to decreased capacities for proper waste management (Hankó et al., 2023).

Carpathian forests are especially vulnerable to climate change effects, exacerbated by forest mismanagement practices described earlier (Carpathian Convention Secretariat, 2023). Increased temperature, particularly during summer and in western portions of the Carpathian region, and increased seasonal precipitation variability stress trees (Carpathian Convention Secretariat, 2023). These stresses make them more vulnerable to diseases and spread of invasive species, and are less likely to recover from extreme climate events like heavy rainfall and floods, heatwaves, drought and wildfires, and altered natural disturbance regimes (Carpathian Convention Secretariat, 2023).

While all these wicked problems—food and income insecurity, globalization, imbalanced governance and resource management, data scarcity, and vulnerability to global changes—compromise the Carpathians' social-ecological integrity and ability to adapt to climate change (Kato, Rambali & Blanco-Gonzalez, 2021) and other disturbances, they also reveal potential opportunities for sustainable transitions (Thorn et al., 2020). Such transitions necessitate that relevant actors coordinate their collaborative efforts to protect mountains (Schmeller et al., 2022) and that human-environment research focuses on these coupled interactions across spatial and temporal scales (Huber et al., 2013).

3.4 Change-Oriented Policy Development for Mountain SESs

There has been an increase in research around decision-making to come up with policies to sustain resilience, especially in vulnerable mountain SESs (Brunner & Grêt-Regamey, 2016). SES resilience is a popular sustainability discourse that seeks to capture the dynamics of human-nature interactions as climate and environmental concerns increasingly threaten human security (Bamutaze 2015). Resilience describes the capacity of a system to experience shocks or disturbances while maintaining its identity, function, structure and feedbacks (Bamutaze 2015; Brunner & Grêt-Regamey, 2016; Gray et al., 2015). The more resilient a system, the better it can cope with disturbances and maintain ecosystem functioning and services (Brunner & Grêt-Regamey, 2016; Schmeller et al., 2022).

When applied to SESs, resiliency provides a frame for understanding the stability and trajectory of a complex whole (Brunner & Grêt-Regamey, 2016; Ostrom, 2009), which requires knowing the specific components of the SES and how they are related (Ostrom, 2009).

From Resilience to Transformation for Mountain SESs

Due to the complex cross-scale interactions of mountain SESs, implementing individual policies are not sufficient against wicked problems: a range of cross-sectoral strategies are necessary to sustain resilience (Brunner & Grêt-Regamey, 2016; Bamutaze, 2015). However, because resilience is about the ability to sustain shocks without significantly changing, a resilient SES may not necessarily be in a desirable state (Olazabal & Pascual, 2015). Maintaining the status quo may not be appropriate, especially in the face of climate change and globalization, which are permanently changing mountain SESs' futures. Thus, mountain

SES resilience requires transformational processes: deliberate, desirable transition from a current undesirable system (Olazabal & Pascual, 2015).

There are two approaches to transformation: a socio-technical perspective and social-ecological perspective (Olazabal & Pascual, 2015). The socio-technical approach emphasizes the ways technologies are embedded in the larger social system and the power dynamics between technology, policy, economics and culture (Olazabal & Pascual, 2015; Betsill & Stevis, 2015). However, such transformation toward a sustainable society requires a process of transition management, or intentional iterative steps for long-term structural change (Olazabal & Pascual, 2015), and disrupting power relations through alliances and discourses (Betsill & Stevis, 2015). The social-ecological approach seeks transformation by combatting rigidity and self-reinforcement in environmental decision making through adaptive and inclusive approaches (Gray et al., 2015). It aims to understand the perceived structure of the SES and identify social values and goals within the SES by incorporating stakeholder beliefs (Gray et al., 2015). Such inclusivity aims to produce policies that "cycle between incremental and transformative actions" to address both immediate and long-term global pressures (Brunner & Grêt-Regamey, 2016, p. 137; Olazabal & Pascual, 2015).

Both approaches to transformation attempt to understand complex systems through continuous processes of collective action, adjusting and learning for producing and reproducing shared visions for the future (Brunner & Grêt-Regamey, 2016; Olazabal & Pascual, 2016; Gray et al., 2015; Betsill & Stevis, 2015; Rodríguez, Reu, Bolívar-Santamaría, Cortés-Aguilar, & Buendía, 2023).

SES Transformation Processes and Challenges in the Carpathians

Pursuing mountain SES transformation is difficult for at least two reasons: (1) decisions that directly impact mountain SESs are created by and affect many stakeholders divided by geography, political power, interests, and economic realities, and (2) analyzing an entire system is challenging, necessitating looking at the effects of several policies or components at once.

<u>Participatory Processes and Challenges in the Carpathians</u>

To meet the first challenge, participatory processes for understanding a system, incorporating complexity, and motivating and engaging stakeholders in pursuing a shared vision for change must be central to transformation management (Olazabal & Pascual, 2016; Gray et al., 2015; Brunner & Grêt-Regamey, 2016; Rodríguez et al., 2023). The Carpathian Convention addresses this challenge by providing a forum for stakeholders to dialogue; a framework for transnational cooperation across sectors; and a platform for developing and implementing transnational strategies, policies, and projects for the protection and sustainable development of the Carpathian region. The Carpathian Convention's general objective is to "pursue a comprehensive policy and cooperate for the protection and sustainable development of the Carpathians with a view to inter alia improving quality of life, strengthening local economies and communities, and conservation of natural values and cultural heritage" (Carpathian Convention, Article 2). Its thematic sectors are outlined in Articles 3 to 13: integrated approach to land resources management; conservation and sustainable use of biological and landscape diversity; spatial planning; sustainable and integrated water/river basin management; sustainable agriculture and forestry; sustainable transport and infrastructure;

sustainable tourism; industry and energy; cultural heritage and traditional knowledge; environmental assessment/information system, monitoring and early warning; climate change; and awareness raising, education and public participation.[1]

Crafting cross-sectoral policies involves repeated stakeholder participation in civic and governance activities (Bizikova, Nijnik & Kluvanková-Oravská, 2011) in order to work towards a common vision for a sustainable, equitable transition (Thorn et al., 2020; Rodríguez et al., 2023). Such repeated stakeholder participation builds trust and reciprocity, increasing their likelihood to participate in decision-making for realizing policies that link both social and environmental spheres (Bizikova, Nijnik & Kluvanková-Oravská, 2011). As knowledge is co-produced between local stakeholders and policymakers, better compromises in management and regulations can increase resilience of local livelihoods (Molnár et al., 2023). This bottom-up cooperation also incorporates complexity and builds local ownership over potential interventions for adaptive transformations (Gray et al., 2015; Klein et al., 2019).

Adaptive management dictates that environmental transformation and resilience approaches be flexible and revisable as new information is revealed (Gray et al., 2015). However, the complexity of SESs makes it challenging to account for uncertainties in potential futures of mountain SESs (Thorn et al., 2020)

To affect human well-being and conservation goals, decision makers must first understand the system itself, the drivers that affect it, and local understanding of these effects (Babai, Jánó & Molnár, 2021; Gray et al., 2015). The impact of any one variable depends on the values of the other variables in the SES (Ostrom, 2009); thus, uncertainties in considering

[1] http://www.carpathianconvention.org/convention/framework-convention/

potential futures are highly contingent (Thorn et al., 2020). In every SES, actors must negotiate which factors to sustain, since not every factor in the system can be positively affected in the ideal direction simultaneously (Brunner & Grêt-Regamey, 2016). Policies need to be flexible, adapted to local contexts, cross-sectoral and integrative, and involve multilevel governance systems (Huber et al., 2013). All support the inclusion of local stakeholders in forming and implementing policy (Huber et al., 2013; Bezáková & Bezák, 2022).

However, facilitating stakeholder negotiations is challenging (Brunner & Grêt-Regamey, 2016), especially in countries with a history of command-and-control governance (Bizikova, Nijnik & Kluvanková-Oravská, 2012; Melnykovych et al., 2018). In this region, social capital is mainly based on informal networks and interpersonal relationships, but authoritarian systems weaken social capital (Bizikova, Nijnik & Kluvanková-Oravská, 2012). State monopoly and administrative regulation during the communist regime resulted in distrust in formal institutions; thus, public participation in decision-making eroded (Bizikova, Nijnik & Kluvanková-Oravská, 2012). During the land restitution process, the number of private landowners significantly increased, thus increasing the number of stakeholders who need to be involved in environmental management (Bizikova, Nijnik & Kluvanková-Oravská, 2012). Thus, it is more challenging for institutions to repeatedly collaborate with stakeholders on policy making (Bizikova, Nijnik & Kluvanková-Oravská, 2012). Such repeated stakeholder interactions involve competing interests and high transaction costs, and participants are largely unaware of SES complexity and need capacity building activities for maximizing participation (Brunner & Grêt-Regamey, 2016; Melnykovych et al., 2018). This history helps explain why democratization processes and effective environmental management have been progressing slowly in CEE (Bizikova, Nijnik & Kluvanková-Oravská, 2012).

Policy makers are thus faced with hard questions with great uncertainty regarding how to support biodiversity and rural development with participatory processes (Soliva et al., 2008). To help manage these uncertainties, scenarios can be developed to show several alternatives of the future for analyzing their outcomes (Soliva et al., 2008). Such analytical methods for defining and communicating SES transformation have improved to be constructed with stakeholder input (Gray et al., 2015; Lopes & Videira, 2015).

Systems Analysis Processes and Challenges in the Carpathians

There are two typical approaches for decision-making about systems: System I thinking, which involves automatic, intuitive decisions; and System II thinking, which is decision-making that is more conscious and logical (The Decision Lab, n.d.). However, solely relying upon intuition (System I) is insufficient for analyzing mountain SESs, as the human brain often cannot comprehend or accurately predict outcomes of a complex system; but neither is relying upon rational models (System II), as data for these regions is scarce and creating complex quantitative models is costly.

Scenario development can attempt to blend these two approaches. Cross-sectoral policy development not only requires stakeholder participation, but it must involve planning for potential trajectories of mountain SES changes (Thorn et al., 2020; Rodríguez et al., 2023). In other words, scenarios of potential futures of SESs can be modeled to facilitate planning, discussion, and understanding of an issue and policy impacts and trade-offs (Soliva et al., 2008; Bezáková & Bezák, 2022). This includes jointly considering a range of hypotheses about future changes and a range of policies against these futures in order to realize resiliency: actions that are robust to uncertainties and diverse disturbances (Brunner & Grêt-Regamey, 2016). Identifying and analyzing relationships across multiple levels of a SES at different spatial and temporal scales is central to diagnosing SES sustainability or resiliency (Ostrom, 2009). Due to the uncertainty and spatial and temporal variability of climate change impacts, policy makers would benefit from seeing scenarios of potential futures and expectations in mountain SESs (Huber et al., 2013).

However, human-environment systems are characterized by nonlinearities and thresholds, heterogeneity, trade-offs and feedbacks (Huber et al., 2013), which make operationalization and modeling efforts difficult in mountain SESs (Brunner & Grêt-Regamey, 2016). This led to the development of new modeling and analytical approaches that incorporate surprises and "acknowledge the potential for a system to exist in multiple states" rather than a single equilibrium state (Gray et al., 2015, p. 1).

One scenario-building model that seeks to blend Systems I and II thinking is Fuzzy Cognitive Mapping (FCM). FCM offers a way to analyze the SES behavior and develop simulations for resiliency planning based upon stakeholder perceptions of the SES (Olazabal & Pascual, 2016; Özesmi & Özesmi, 2004; Gray et al., 2015).

Chapter 4: Modeling SESs through Fuzzy Cognitive Mapping

There are four types of difficulties in modeling SESs when trying to model or predict the system's behavior (Özesmi & Özesmi, 2004). The model must (1) account for how human behaviors affect an ecosystem; (2) incorporate local knowledge where scientific data lacks; (3) analyze wicked environmental problems; and (4) incorporate diverse public inputs for ecosystem management and be useful for communicating and gaining their support on policy options (Özesmi & Özesmi, 2004). All these problems require a model for analyzing how people perceive an ecosystem and compare and contrast their diverse perceptions (Özesmi & Özesmi, 2004).

4.1 Cognitive Mapping as a Foundation of SES Modeling

New qualitative and semiquantitative methods for assessing resilience emerged in response to the need for incorporating both complexity and stakeholder knowledge in SES resilience management (Gray et al., 2015). Such methods recognize that human cognitive processes deeply influence decision-making processes, including transformation, and are influenced by values and cultural contexts (Olazabal & Pascual, 2016). Understanding how actors' cognitions affect decision making strengthens understanding of how the system is structured and functions, which is necessary for making policies that avoid undesirable social or environmental impacts (Olazabal & Pascual, 2016). This framework builds upon cognitive mapping, which is a qualitative model that illustrates how a particular system works (Özesmi & Özesmi, 2004).

Cognitive maps reflect mental processing, providing illustrative examples of a shared or individual internal conceptual structure, or parts of a structure, of a particular issue (Gray et al., 2015; Olazabal & Pascual, 2016; Gray, Zanre & Gray, 2013). The map is made up of defined variables, or concepts, that are connected through arrows which show the direction of influence between concepts (Özesmi & Özesmi, 2004; Jetter & Kok; 2014). The person(s) making the map decides which variables are important to the system and defines the directions of the causal relationships (Özesmi & Özesmi, 2004).

Many studies use cognitive mapping to analyze decision making and peoples' perceptions of complex social systems (Özesmi & Özesmi, 2004). It is derived from constructivist psychology, which states that individuals "construct" knowledge by sorting, interpreting and making meaning of their experiences in the world around them in mental systems (Gray et al., 2015; Gray, Zanre & Gray, 2013). These mental model structures facilitate reasoning and exchange understanding (Gray et al., 2015), as they form the foundation of a person's understanding of the world around them (Olazabal & Pascual, 2016; Gray, Zanre & Gray, 2013). Human cognitive processes and mental models involve acquiring knowledge through memory and attention, making causal connections or explanations of their environment, and structuring understanding; this internal process of reasoning is then reflected in the decisions people make (Olazabal & Pascual, 2016; Gray, Zanre & Gray, 2013). Because of how people construct knowledge of systems, this kind of knowledge can be visually or externally represented (Gray et al., 2015; Gray, Zanre & Gray, 2013; Bosma, Glenk & Novo, 2017). Thus, cognitive mapping is a foundational tool for analyzing drivers of change in SESs towards resilience and transformation, because it incorporates complexity and stakeholder knowledge.

Participatory modeling seeks to increase and share understanding of a system and its dynamics, and identify the impacts of solutions to a certain problem (Gray et al., 2015).

While cognitive mapping can be a tool for the first objective, it lacks the ability to meaningfully identify solutions, because it is binary (Özesmi & Özesmi, 2004), where alternative in-between states of a SES cannot easily be modeled. Building upon cognitive mapping to fulfill the goals of participatory modeling for SES resiliency and transformation is Fuzzy Cognitive Mapping (Gray et al., 2015; Olazabal & Pascual, 2016; Blewett, Jacobs & Kok, 2023).

4.2 Rationale for Fuzzy Cognitive Mapping

Fuzzy Cognitive Mapping (FCM) can be used in many disciplines, as it is both a tool for understanding the system of an issue of concern by identifying relationships among variables and a tool for communicating system dynamics (Gray et al., 2015; Mehryar & Surminski, 2022).

Like cognitive mapping, FCM is an external representation of a person's internal understanding or mental model (Gray, Zanre & Gray, 2013) to illustrate the behavior of complex systems through causal reasoning (Olazabal & Pascual, 2016). It graphically or visually shows perceived relationships between key concepts, including feedback relationships, of a system (Gray et al., 2015; Gray, Zanre & Gray, 2013; Verkerk et al., 2017). But FCM builds upon cognitive mapping to better integrate expert, stakeholder, indigenous, and local knowledge "by creating scenarios that bridge the gap between quantitative analysis and qualitative story lines" (Jetter & Kok, 2014, p. 45).

Developed by Kosko (1986) to structure expert knowledge semi-quantitatively and dynamically (Gray et al., 2015), FCM uses fuzzy logic to create a weighted cognitive map (Gray, Zanre & Gray, 2013). Concepts in FCMs are equivalent to neurons and are not binary—they are not defined as being “on” or “off”—but can exist in an in-between state, and are therefore “fuzzy” (Jetter & Kok, 2014). These fuzzy concepts are nonlinear functions (Gray et al., 2015; Jetter & Kok, 2014). As stakeholders identify key variables within the system, they also qualitatively or quantitatively define the relationships between the variables (Gray et al., 2015). For example, a relationship between two variables can be described as weak or strong, and weighted on a scale of [0,1] or [-1,1] (Gray et al., 2015; Jetter & Kok, 2014). Thus, when a neuron fires (when a concept changes its state), “it affects all concepts that are causally dependent upon it” (Jetter & Kok, 2014, p. 46). The affected concepts may consequently also change their state, influencing more concepts connected to them, and because of feedback loops, already-activated concepts may be affected again (Jetter & Kok, 2014). These nonlinear dynamics continue through the FCM network until the system reaches a steady state or when all the values stabilize (Jetter & Kok, 2014).

Because FCM simplifies a complex decision-making environment while integrating actors’ perspectives and expertise semi-quantitatively (Olazabal & Pascual, 2016), it furthers SES understanding as a policy objective development tool, user-friendly tool, and communication and social learning tool

Objectives and Benefits of FCM

There are two potential distinct applications of FCM to support decision-making: (1) understanding possible futures of and impacts to the system if a change were to occur; (2) helping stakeholders align their Systems I and II thinking. These purposes align with the benefits of FCM as a tool for both developing policy objectives and facilitating communication and social learning.

Firstly, FCM is useful for setting and communicating policy and management objectives for SESs, especially in contexts with high uncertainty and complexity (Olazabal & Pascual, 2016). FCM generates and tests policy scenarios (Olazabal & Pascual, 2016) by creating a working holistic model of the SES's components based on stakeholder perceptions that can be used to analyze trade-offs, benefits, and co-benefits of various actions (Mehryar & Surminski, 2022; Gray et al., 2015). The mathematical relationships or weights compute the cumulative strength of the variables' connections to analyze the system holistically and model its potential trajectories (Gray et al., 2015). It illustrates relationships between current and projected equilibrium states of the SES to model desired or undesired outcomes based on the current system and potential interventions (Gray et al., 2015). These scenarios reflect the subjective knowledge of respondents about uncertain drivers of change, bridging qualitative and quantitative scenario approaches (Jetter & Kok, 2014).

Additionally, FCM is a relatively easy tool to use, accommodating data-scarce situations and diverse knowledge types and sources (Olazabal & Pascual, 2016; Özesmi & Özesmi, 2004). Data is costly and hard to obtain, so FCM models social ideas of how a system works by modeling stakeholder perceptions (Özesmi & Özesmi, 2004). FCM allows for the model to be easily changed: relationships can be adjusted and simulations are quick and easy to run (Özesmi & Özesmi, 2004). Thus, it is useful for theory development, hypothesis formation, and data evaluation, and can complement additional quantitative or qualitative tools and methods (Özesmi & Özesmi, 2004; Verkerk et al., 2017).

Secondly, FCM is both a tool for understanding and communicating: an assessment tool for applied research and a tool for promoting social learning about SES dynamics (Gray, Zanre & Gray, 2013; Blewett, Jacobs & Kok, 2023). FCM can collect, compare and negotiate perspectives among different stakeholder groups to overcome barriers for decision making (Mehryar & Surminski, 2022; Christen, Kjeldsen, Dalgaard, & Martin-Ortega, 2015). FCM has been used to collect expert knowledge of a system that is highly complex, uncertain or data scarce, and to gain understanding from non-traditional experts for participatory planning (Gray, Zanre & Gray, 2013). FCM can incorporate as many knowledge sources as desired with diverse types and degrees of expertise; it does not require solely experts or sources who are experts in all aspects of the system, as many sources from different disciplines can be selected to capture the system holistically (Özesmi & Özesmi, 2004; Jetter & Kok, 2014). It standardizes these diverse perceptions and knowledges to analyze key variables in the SES (Gray et al., 2015; Gray, Zanre & Gray, 2013).

Whether the maps are created through group consensus or by aggregating individual maps, FCM produces a visual social cognitive map representative of shared knowledge (Gray et al., 2015; Gray, Zanre & Gray, 2013; Blewett, Jacobs & Kok, 2023; Mehryar & Surminski, 2022). Shared knowledge is useful for understanding complex systems, describing consensus, and defining differences in beliefs or knowledge structures (Gray et al., 2015; Gray, Zanre & Gray, 2013). The process of FCM creation can create trust between participants (Gray et al., 2015). Stakeholder needs, language, beliefs, values, and buy-in are reflected in the policy development of FCM, creating communication and pathways between the stakeholders, researchers and policymakers (Gray et al., 2015; Jetter & Kok, 2014).

FCM is a system thinking exercise that elicits slow-thinking mental models, encouraging more deliberative processes for stakeholder participation, understanding, and learning in decision making (Mehryar & Surminski, 2022). While stakeholders construct the map based on their intuitions, their own mental models and subjective theories are challenged and improved (Jetter & Kok, 2014). FCM can investigate how stakeholders' perceptions align with the resulting scenarios and outcomes of the system and how these results influence their mindset about the problem or SES (Mehryar & Surminski, 2022). This supports decision-makers in collective processes for raising awareness, sharing knowledge, and understanding local perspectives about a common challenge (Mehryar & Surminski, 2022).

When conducted as a participatory process, FCM fulfills these tool functions as an adaptable method for understanding SES transformation. However, they are not substitutes for statistical approaches (Olazabal & Pascaul, 2016; Özesmi & Özesmi, 2004).

FCM versus other Participatory Modeling Methods

For both these reasons, FCM is distinct from other participatory methods for resilience management. Other approaches for capturing how actors' cognitions affect decision making include more qualitative approaches like narrative scenario analysis, discourse analysis, qualitative concept mapping, and more quantitative approaches like multi-criteria evaluation, Bayesian belief networks and systems dynamics models (Olazabal & Pascual, 2016; Gray et al., 2015). Choosing to conduct FCM depends on the need for model complexity and the purpose for the model (Özesmi & Özesmi, 2004).

FCM is a participatory approach where stakeholders are involved in building the model and is most applicable for data-poor situations (Özesmi & Özesmi, 2004). Thus, for models where significant amounts of empirical data is required, such as systems dynamics model or structural equation modeling, FCM is not as appropriate (Özesmi & Özesmi, 2004). FCM also facilitates modeling patterns or changes in the behavior of the system by accommodating feedback loops or complexity (Özesmi & Özesmi, 2004). It does not make predictions, but simulates what may happen to the system given the identified relationships (Özesmi & Özesmi, 2004) and alternatives on how the future may unfold (Olazabal & Pascual, 2016). It is not a dynamic model nor concerned with parameter estimation, which involves finding the best estimators from a measurable sample to extrapolate understanding to a population (Özesmi & Özesmi, 2004).

Weaknesses of FCM

There is little consistent or systematic guidance for conducting FCM to capture, integrate, and analyze diverse stakeholder and expert perspectives (Jetter & Kok, 2014). Several weaknesses of FCM include the inability to model temporal scales, account for nonlinearity or randomness, and provide explanations or absolute values for outputs, and the possibility of encoding misconceptions, inaccuracies, or biases into the model (Olazabal & Pascual, 2016; Gray et al., 2015; Özesmi & Özesmi, 2004).

FCM weakly or does not incorporate temporal scales (Olazabal & Pascual, 2016; Gray et al., 2015; Özesmi & Özesmi, 2004). While the SES can be mapped with a defined spatial and temporal framework by stakeholders, the outputs of the FCM cannot be meaningfully interpreted in temporal units (Gray et al., 2015) as it cannot model transient behavior (Özesmi & Özesmi, 2004). While some literature describes FCM as a dynamic model measuring nonlinearity (Olazabal & Pascual, 2016), this is in fact not true. While FCM accounts for feedbacks, it only measures linear relationships: “the next system state depends on the previous one” (Gray et al., 2015, p. 9). Thus, it does not account for threshold effects (Özesmi & Özesmi, 2004) or randomness often associated with SESs, where the system can change unexpectedly in reality (Gray et al., 2015). The FCM outputs and each variable state can only be qualitatively interpreted in relation to a baseline or based on their relative relationships to other factors in the system (Jetter & Kok, 2014; Olazabal & Pascual, 2016). It does not produce absolute or empirical measurements (Özesmi & Özesmi, 2004; Gray et al., 2015). Additionally, the model cannot determine why a certain outcome occurs, but only simulates possible “what-if” scenarios (Özesmi & Özesmi, 2004). Because FCMs are based on perceived dynamics of the SES, conclusions may not concur with current scientific knowledge (Olazabal & Pascual, 2016). Respondents’ mental models cannot be easily validated against reality, because the FCM does not capture proven theories (Jetter & Kok, 2014) and can encode respondents’ misconceptions or biases (Özesmi & Özesmi, 2004).

Additionally, capturing respondents’ knowledge and process their FCMs can be highly time consuming. While interviews allow respondents to carefully define their mental models, they are often time consuming and require a lot of effort by the modeler (Jetter & Kok, 2014). Post-processing to integrate multiple respondents’ knowledge into one or a few FCM models is difficult and time consuming (Jetter & Kok, 2014). Maps may be very messy and difficult for participants to understand or difficult to communicate (Jetter & Kok, 2014). FCMs may be distorted or insufficiently reflect a respondent’s actual mental model if they provide responses in an attempt to please the interviewer or if the interviewer imposes their own biases into the model (Jetter & Kok, 2014).

Despite these weaknesses, FCM can complement quantitative models and promote social learning (Gray et al., 2015). As elements are later ground-truthed, the FCM can be updated with new data and support more quantitative assessments built on scientific knowledge (Gray et al., 2015). It is also useful in promoting deliberation and understanding among diverse stakeholders (Gray et al., 2015) and assist individual respondents in assessing their own mental models (Jetter & Kok, 2014) and improve their System I thinking (subjective theories) through a System II process (FCM).

4.3 FCM Methodology

Conducting FCM involves (1) sharing or eliciting knowledge to define the SES state, (2) analyzing SES structure, (3) analyzing SES dynamics, and (4) assessing how changes to the structure potentially create desirable or undesirable trajectories (Gray et al., 2015). These four steps are agreed upon in the literature; however, the detailed approaches for completing these steps differ and additional steps may be included (Jetter & Kok, 2014). Jetter and Kok (2014) provide a more detailed six-step approach with explanations of methodological divergences at each step; however, this section will mainly focus on the four described steps.

1. Sharing/Eliciting knowledge to define the SES state

There are three approaches for eliciting knowledge to construct FCMs, where the modeler is either the expert represented in the FCM model, the surveyor of the respondents, or the analyzer of documents (Jetter & Kok, 2014). These approaches, especially the latter two, can be done with individuals or groups through questionnaires, analyzing written texts, mapping data with causal relationships, or interviews (Özesmi & Özesmi, 2004; Jetter & Kok, 2014).

Many studies elicit participant knowledge individually and/or collectively. Previous studies have conducted FCM solely through individual interviews (e.g. Blewett, Jacobs & Kok, 2023); through groups in a workshop setting (e.g. Verkerk et al., 2017); or through both interviews and workshops with separate participants (e.g. Bosma, Glenk & Novo, 2017) or with an overlap in participants (Salberg, Booth, Jahren & Novo, 2022). Because group settings may involve power dynamics, conflict, or other issues that prevent some voices from speaking up and other voices to dominate, some researchers perceive group knowledge that is constructed individually and then aggregated as more equitable (Bosma, Glenk & Novo, 2017).

Regardless, it is important to receive the appropriate sample size and makeup according to the objective of the model and the methodology approach. For example, having too many group participants or too many individual interviews may make the process of creating the FCM too unwieldy (Jetter & Kok, 2014). Having a defined approach to identifying and reaching the appropriate stakeholders is helpful; whether that's through snowball sampling, stakeholder analysis or some other approach (Jetter & Kok, 2014).

When interviewing or surveying participants, approaches also vary. Modelers may have the respondents identify their own variable types and numbers, have them choose from a set list of variables (Mehryar & Surminski, 2022), use a software like FCMapper or MentalModeler, facilitate discussion and workshops, arrange concepts on a work surface in person, or minimize contact between them and the respondents (Gray, Zanre & Gray, 2013; Jetter & Kok, 2014). Depending on the approach, the respondents or modeler identify the most important variables and the relationships between them: the direction of causality, their positive or negative influences, and the degree of strength (Özesmi & Özesmi, 2004; Jetter & Kok, 2014; Gray et al., 2015). Some modelers also ask participants to rank variables from least to most important (Mehryar & Surminski, 2022). Positive values reflect proportional relationships, where an increase (or decrease) in one variable will increase (or decrease) its connected variable (Mehryar & Surminski, 2022). Negative values reflect an inverse relationship between the variables (Mehryar & Surminski, 2022). Modelers may have respondents quantitatively weight the relationship on a scale between [0,1] or [-1,1] (Özesmi & Özesmi, 2004; Jetter & Kok, 2014) or qualitatively, such as high, medium, or low (Gray et al., 2015; Bosma, Glenk & Novo, 2017). Modelers may allow respondents to choose any number on the scale, or choose from three, four, five or seven numbers or levels on the scale (e.g. very weak, 0.2; weak, 0.4; etc.) (Jetter & Kok, 2014). The sequence of how this knowledge is captured differs: variables and quantitative values can be captured at the same time or separately (Jetter & Kok, 2014).

It is important to also capture concept meanings and qualities, especially if maps are to be integrated (Jetter & Kok, 2014; Mehryar & Surminski, 2022). Concepts that can have different qualities should be expressed as adjective + noun (e.g. "sustainable agriculture" not just "agriculture") to avoid confusion about the sign of the causal relationship that respondents identify (Jetter & Kok, 2014).

Modelers may also ask participants about potential interventions to the system and map the associated relationships. Participants may offer their own interventions and/or discuss pre-determined scenarios that modelers would like to test according to stakeholder perceptions (Bosma, Glenk & Novo, 2017).

2. Analyzing SES structure

The static structure between the variables allows the cognitive maps to be translated into an adjacent square matrix (Gray et al., 2015): the same variables are listed on the vertical and horizontal axes in a n x n matrix (Özesmi & Özesmi, 2004). If the modeler has participants qualitatively define relationships, the pre-defined associated quantitative values are added;

for example, a negative weak relationship may be -0.3 or -0.25, while a negative strong relationship may be -0.9 or -0.75 (Verkerk et al., 2017; Bosma, Glenk & Novo, 2017). Each visual map is coded into square adjacency matrices separately (Mehryar & Surminski, 2022). To aid comparisons and/or aggregated between FCMs, concept or variable names and characterizations need to be standardized (Jetter & Kok, 2014; Mehryar & Surminski, 2022). Synonymous variable names should be homogenized, and concepts and dis-concepts (e.g. “forestry quality” and “forestry intensity”) need to be merged, where one concept is converted and its connecting arrows are changed to the opposite direction (positive or negative) (Jetter & Kok, 2014; Salberg, Booth, Jahren & Novo, 2022).

Individual cognitive maps can be augmented or aggregated quantitatively or qualitatively (Özesmi & Özesmi, 2004); however, this process is not standardized in the literature (Blewett, Jacobs & Kok, 2023). Modelers may choose to add all individual (and/or group) FCMs together, aggregate them by stakeholder group (Bosma, Glenk & Novo, 2017), or some other combination. Individual or group maps can also be preserved and not aggregated, if diversity of opinion is important to keep intact (Jetter & Kok, 2014).

Quantitatively, FCMs are aggregated with matrix addition to form a new matrix or social cognitive map (Özesmi & Özesmi, 2004; Jetter & Kok, 2014; Bosma, Glenk & Novo, 2017). Matrices of the same size are added and divided by the total number of matrices (cognitive maps) to average the relationship weights and normalized to maintain the range of causal relationships between [-1,1] (Jetter & Kok, 2014; Özesmi & Özesmi, 2004). Modelers may treat all respondents as equal or assign “credibility weights” to experts to distinguish varying types of knowledge (Jetter & Kok, 2014).

Aggregation is considered a group consensus map, as agreement on a causal relationship reinforces the connection, while opposing connections (where one respondent positively connects two variables, while another negatively connects them) decreases the strength of the relationship (Bosma, Glenk & Novo, 2017). However, quantitatively integrating individual maps is debated, as these variables with opposite causal connections will become 0 and show no causal link, losing the nuance that stakeholders identified a relationship, but did not agree on the type of relationship (Jetter & Kok, 2014). Thus, to better capture the level of consensus of each concept, modelers may also provide information on standard deviation, coefficient of variations and the number of mentions of a relationship (Mehryar & Surminski, 2022). Alternatively, individual maps may better identify divergence in opinions, as group maps result in a consensus based on perceptions, knowledge, personalities, social relationships, and more (Bosma, Glenk & Novo, 2017).

Qualitatively, concepts can be combined by category and represented by a larger encompassing variable (Özesmi & Özesmi, 2004; Misthos, Messaris, Damigos & Menegaki, 2017). Causal connections are drawn in the simplified system to reflect the weight and sign similar to the previous maps (Özesmi & Özesmi, 2004). This allows for analytically comparing cognitive maps to identify areas of agreement and disagreement among different individuals or stakeholder groups (Jetter & Kok, 2014; Özesmi & Özesmi, 2004).

Determining variable types and how they relate to each other in the FCM(s) facilitate understanding of the SES (Özesmi & Özesmi, 2004) by assessing the role and relative importance of each variable (Bosma, Glenk & Novo, 2017). There are three types of variables and three key elements for measuring the SES structure (see Table 1).

Variable type reveals how people think about each factor in the SES and how they act in relation to other variables (Özesmi & Özesmi, 2004). The three variable types are transmitter (also called driver), receiver and ordinary (Özesmi & Özesmi, 2004). Transmitters are variables that only affect other variables, while receivers are only impacted by other variables and do not affect others in the system. Ordinary variables are both affected by and affect other variables.

The three measurements for analyzing the structure of the fuzzy cognitive map are centrality, density and complexity (Bosma, Glenk & Novo, 2017). Centrality measures a variable's relative importance in the SES by defining the strength of its incoming and outgoing relationships relative to other variables' relationships (Gray et al., 2015). As an index of connectivity, density allows for stakeholder comparison to see which groups identified more relationships between variables (Özesmi & Özesmi, 2004). The more connections identified, the more opportunities to change the system; thus, these stakeholder groups could be change-catalysts (Özesmi & Özesmi, 2004) or indicate opportunities for the system to self-organize after a shock due to the presence of more variables (Olazabal & Pascual, 2016). However, increased connectivity could be undesirable in SES transformation, as it often also increases feedbacks and potential futures, making transformation harder to control due to this raised complexity (Olazabal & Pascual, 2016).

Table 1: Terminology for Analyzing the Fuzzy Cognitive Map(s)

VARIABLE/ ELEMENT	DEFINITION	MEASUREMENT
Transmitter	Variables with only outgoing relationships (Özesmi & Özesmi, 2004).	Row sum of absolute values: cumulative strengths of connections exiting the variable (Özesmi & Özesmi, 2004).
Receiver	Variables with only incoming relationships (Özesmi & Özesmi, 2004).	Column sum of absolute values: cumulative strength of connections entering the variable (Özesmi & Özesmi, 2004).
Ordinary	Variables with both incoming and outgoing relationships (Özesmi & Özesmi, 2004).	
Density	Index of connectivity, showing how connected or sparse the map is (Özesmi & Özesmi, 2004).	$Density = \frac{\#\ of\ connections}{N^2}$ N^2 is the number of all possible connections between N variables (Özesmi & Özesmi, 2004)
Centrality	A variable's relative importance or contribution to the system (Gray et al., 2015; Özesmi & Özesmi, 2004). It is determined by the strength of its incoming and outgoing relationships relative to other variables' relationships (Gray et al., 2015). This measures how connected the variable is to other variables and the cumulative strength of these connections (Özesmi & Özesmi, 2004).	Centrality = summation of its indegree and outdegree (Özesmi & Özesmi, 2004)
Complexity	The total number of receiver variables (Özesmi & Özesmi, 2004).	$Complexity = \frac{\#\ of\ receivers}{\#\ of\ transmitters}$ (Bosma, Glenk & Novo, 2017)

3. Analyzing SES dynamics

The SES dynamics are analyzed by first measuring the baseline scenario of the system and then running "what if" scenarios to compare against the baseline. Dynamic analysis can focus on the transient behavior during the iterative time steps, and/or the equilibrium steady states (Misthos, Messaris, Damigos & Menegaki, 2017).

The baseline scenario is the steady state of the SES, or where the system would go if things continue as they are (Özesmi & Özesmi, 2004). The initial state value of each variable is set equal to 1 (Olazabal & Pascual, 2016), which assumes that all the variables in the system are fully activated (Bosma, Glenk & Novo, 2017). However, in one study, researchers assigned initial state values based on variable type: 1 to drivers expected to increase, -1 to drivers expected to decrease, and 0 to all other variables (Verkerk et al., 2017). To qualitatively compare the causal outputs of the variables, various functions can be performed to transform the results between [0,1] (Özesmi & Özesmi, 2004; Misthos, Messaris, Damigos & Menegaki, 2017). These normalizing functions may be a logistic function (Özesmi & Özesmi, 2004), sigmoid threshold function (Misthos, Messaris, Damigos & Menegaki, 2017), or some other threshold function. The resulting vector (all the initial values of each variable) is then repeatedly multiplied by the matrix (the influence of each factor on the other factors) until the system converges, which usually occurs in less than 30 iterations (Özesmi & Özesmi, 2004; Olazabal & Pascual, 2016; Gray et al., 201). This matrix algebra measures the dynamic interactions between variables, or the baseline scenario (Gray et al., 2015).

After measuring the SES currently defined by stakeholders through the baseline scenario, various "what-if" scenarios can be run to determine what will happen to the system under different conditions (Özesmi & Özesmi, 2004; Gray et al., 2015; Bosma, Glenk & Novo, 2017). These scenarios can involve increasing or decreasing key variables and/or introducing new variables as possible policies to mitigate unwanted outcomes (Gray et al., 2015), showing synergistic interactions (Özesmi & Özesmi, 2004). These key variable(s) in the system are adjusted by fixing their outgoing influence to a continuously high or low value to block all incoming influences (Olazabal & Pascual, 2016; Gray et al., 2015), while the remaining variables are left to change until a (new or similar) steady state is reached (Bosma, Glenk & Novo, 2017). Researchers can "clamp" these variables to 1 (Özesmi & Özesmi,

2004) or very high numbers, between 0.7 to 0.9, or to 0 or very low numbers, between 0 and 0.2, depending on the scenario they want to model (Olazabal & Pascual, 2016).

Other "what if" scenarios can be run by changing the initial state values for the concept(s) under investigation (Misthos, Messaris, Damigos & Menegaki, 2017). By changing the initial value on a range from [0,1], the resulting scenarios represent all possible situations from the concept's "non-existence" to highest possible level (Misthos, Messaris, Damigos & Menegaki, 2017).

4. Assessing how changes to the SES create desirable or undesirable trajectories

This final step can serve two goals: measuring the SES resilience, whether the system's identity persists when faced with disturbances (Gray et al., 2015), and/or testing respondents' own implications of their models to assess their qualitative theories (System I thinking) with the complex system's outcomes (Jetter & Kok, 2014).

The baseline and alternative scenarios are compared together to define the SES's current identity and the scale of disturbance it can endure (Gray et al., 2015). Stakeholders define the preferred state of each variable, whether they want it to increase, decrease, or have no preference, to establish the desirable system outcomes in the face of disturbances (Gray et al., 2015). This provides a qualitative basis for understanding the system's identity to be used in scenario comparisons (Gray et al., 2015). The "what-if" scenario outcomes are compared with the baseline scenario to see how the SES settles into a new equilibrium state and with the preferred conditions of each variable to assess whether the scenario produced a desirable state of the SES (Gray et al., 2015).

The second assessment goal of FCM can help experts and stakeholders reexamine their own thinking of system behaviors based on their own model's outputs. Due to humans' cognitive limitations to predict complex system behaviors, their FCM may accurately represent their mental model, but produce different outcomes than they expected (Jetter & Kok, 2014). This reexamining provokes social learning, which can be useful in modeling potential policies or interventions.

Additional Best Practices for FCM

An additional process to the above four steps includes calibration of the FCM(s). This involves testing and/or adjusting the model for reliability and coherence (Olazabal & Pascual, 2016). Because FCMs do not make predictions nor attempt to make a "true" model of the SES, calibration is not about validating it with quantitative data (Jetter & Kok, 2014; Olazabal & Pascual, 2016). FCMs can be calibrated with a historical scenario to see if it produces results in accordance to observed reality. However, because FCM is often conducted where data is scarce, this may be challenging. Rather, simple FCMs can be calibrated by running the model to see if it produces expected system behavior for simple cases, and then adjusted for any missing connections or inconsistencies (Olazabal & Pascual, 2016; Jetter & Kok, 2014; Christen, Kjeldsen, Dalgaard, & Martin-Ortega, 2015). This process should be done with stakeholder involvement to ensure transparency and understanding of the model (Jetter & Kok, 2014).

Most studies only involve experts and/or stakeholders during the knowledge elicitation portion of building the FCMs (e.g. Gray et al., 2015; Bosma, Glenk & Novo, 2017; Mehryar & Surminski, 2022); very few mention calibration of the models with stakeholder input (e.g. Olazabal & Pascual, 2017); and even fewer studies discuss sharing results and implementation processes with stakeholders (Verkerk et al., 2017). In fact, some research portrays FCM as a "quick and dirty" method for promoting stakeholder social learning (Gray et al., 2015). However, FCM should not be seen as a "quick and dirty" method, as stakeholder participation in policymaking and environmental management should not be quick and dirty in and of itself. Not only should stakeholders be involved in post-processing with calibration, but the scenario outcomes should also be shared with stakeholders for transparency and social learning.

One example of great stakeholder participation is a process conducted by Verkerk et al. (2017) to create river basin management plans adaptive to climate change. They involved local stakeholders in a series of workshops and interviews before, during, and after the actual development of the FCM (Verkerk et al., 2017). They elicited expectations of future water management, developed a model (the FCM), and evaluated desirable interventions for managing the river basins (Verkerk et al., 2017). This resulted in a bottom-up, stakeholder-driven management plan for the river basin (Verkerk et al., 2017). Such a process is time consuming and complex; however, it is an example of what stakeholder participation involves from start to ongoing. Stakeholder participation should not "end," as they should also be involved in implementation and processes of adapting plans.

Chapter 5: Thesis Methodology

To assess how FCM may encourage Carpathian Convention stakeholders to adopt a more calibrated, systems approach to decision-making for improving biodiversity outcomes, two different FCM approaches were conducted: maps were created through both individual interviews and small focus groups. The methodology for this broadly followed the above four steps including some additional processes suggested by Jetter and Kok (2014): (1) defining the FCM objective, (2) identifying methods for knowledge elicitation, (3) sharing or eliciting knowledge to define the SES state, (4) analyzing the SES structure, (5) analyzing the SES dynamics, and (6) assessing how changes to the SES potentially create desirable or undesirable trajectories.

1. Defining the FCM Objective

In order to appropriately elicit fuzzy models of the Carpathian biodiversity system, it was important to frame the request to participants as modeling a problem, rather than a system. This problem focus helps identify relevant elements and stakeholders (Jetter & Kok, 2014). Defining spatial and temporal boundaries were also important; thus, the focus of the research involved modeling current biodiversity challenges in the Carpathian region. Because the Carpathian region is characterized by data scarcity and the Carpathian Convention seeks to increase cross-sectoral cooperation and participation for its processes, conducting FCM as a tool for bridging these gaps was deemed appropriate.

Because the research methodology involves human subjects, I completed the Human Subject Research Training and submitted my proposed methodology to and received approval from the Internal Review Board at Bard College.

2. Identifying methods for knowledge elicitation

To capture cross-sectoral perspectives of biodiversity challenges and potential interventions in the Carpathian region, I identified several stakeholder populations within the Carpathian Convention to reach out to: educators, scientists, policymakers, researchers, protected area employees, and project implementers.

For recruiting focus group participants, I identified three established regional networks that partner closely with the Carpathian Convention: the Science for the Carpathians (S4C) is a network of scientists and researchers conducting work in the region, the Carpathian Education for Sustainable Development (ESD) Expert Network is a network of experts in the field of ESD, and the Carpathian Network of Protected Areas (CNPA) is a network of representatives of Carpathian protected areas. Thus, I planned three focus groups, one for each network, for the FCM process. I emailed members of all three networks asking if they would like to participate in either a focus group or an individual interview.

For recruiting additional individual interviewees, I identified several policymakers, National Focal Points and chairs of Working Groups in the Carpathian Convention, and project implementers, points of contact for recent and ongoing projects being conducted in the Carpathian region.

3. Sharing/Eliciting knowledge to define the SES state

Each interview and focus group were conducted online via video interview so participants could see, interact with, and correct the FCM in real time. The questions and process were the same for both my individual participants and focus group participants. During the interviews/focus groups, I asked what the biggest biodiversity challenges are for the

Carpathian region according to their perspective. As they discussed these initial challenges, I sorted and organized them as individual concepts on MentalModeler. I then shared my screen so they could correct and expand upon the initial concepts. Each concept was formulated with an adjective and noun, such as “Intensity of Tourism Development” or “Rate of Rural Depopulation.” Definitions and explanations for these factors were also captured. Participants were free to name any variable they deemed relevant to the system (i.e. I did not provide a list of options to choose from), with the exception of “Biodiversity Health” being a provided component for each map.

Participants then rated how they perceived the current state of each factor for the Carpathians on a scale of 1 to 10. The scale qualifications varied based on the factor: for example, for “Rate of Rural Depopulation,” 1 would signify that rural depopulation is happening very minimally, while 10 means it is happening very quickly. After capturing these initial states, participants then defined the direction of causality between factors, rated the level of influence on a scale of 0 (very weak) to 1 (very strong), and the sign as positive (reinforcing) or negative (opposite). MentalModeler allows for arrows to be drawn according to the weight and sign, which made it ideal for using it on a digital platform. As I drew the map according to their responses (while still sharing my screen), participants were free to add, change or delete factors and relationships.

After the current state of biodiversity was mapped, I asked what policy or management options would help improve biodiversity for the Carpathian region in the long-term. If this intervention was not already part of the map, I added it to the system and mapped it accordingly, capturing its initial state value and relationships.

4. Analyzing the SES structure

After all the interviews and focus groups were completed, concept names were standardized for ease of interpretation (e.g. "Quality of Local Enforcement" and "Quality of Legislation Implementation" were both renamed to "Quality of Law Enforcement/Implementation" in the respective FCMs). This helped analyze how many times a concept was mentioned across participants, how they related concepts to each other, and where consensus and divergences appeared across the FCMs.

Each individual and focus group FCM was translated into their respective adjacent n x n square matrix in Microsoft Excel. Each adjacency matrix is a translation of the quantified [-1,1] relationships of the map into an n x n square table. It can be mathematically represented as:

$$w_{ij} = \begin{bmatrix} 1 \; if \; i = j, \; otherwise \\ -1 \leq w_{ij} \leq 1 \end{bmatrix}, \text{ where}$$

w_{ij} is the weight of the influence of variable i on variable j. Each concept from the map is listed on both the vertical (i) and horizontal (j) axes in the same order, to be interpreted that the row variable affects the column variable. Where $i = j$, where the variable is the same for the row and column, the value is listed as 1. For example (using random numbers):

	Variable 1	*Variable 2*
Variable 1	1	-0.3
Variable 2	0.7	1

The initial state values that participants identified for each concept were also recorded in Excel as well. These initial state values make up state vector $\vec{A}$. For example:

Variable 1	*Variable 2*
0.5	0.8

5. Analyzing the SES dynamics

For each FCM, I created three matrices in Microsoft Excel: (1) the adjacency matrix, which captured all the fuzzy relationships between concepts as defined by the participants; (2) the standardized matrix, which calculated matrix algebra starting from the initial state values defined by the participants; and (3) the normalized matrix, which normalized the standardized matrix values into the range [0,1]. The latter two matrices are built upon the adjacency matrix and the initial state values that participants defined for each concept, state vector $\vec{A}$.

The dynamics of $\vec{A}$ are calculated by assessing the influence of each concept on all concepts, including itself, over a number of iterations or time steps (k) until the system reaches a steady state or when all the values stabilize. Thus, the baseline scenario of each FCM is calculated based on the following equation:

$$\vec{A}_{k+1} = f(W\vec{A}_k),$$ where f is the logistic density function $f(x) = \frac{e^x}{(1+e^x)^2}$ and W is the adjacency matrix: $w_{ij} = \begin{bmatrix} 1\ if\ i = j,\ otherwise \\ -1 \le w_{ij} \le 1 \end{bmatrix}$

$\vec{A}_{k+1}$ is the value of state vector A at time step $k + 1$. The function f is used to normalize the values at each time step between 0 and 1 for the normalized matrix. This equation states that the initial state vector ($\vec{A}_k$) is multiplied by the entire adjacency matrix W to assess the net effect of all variables on each other, including itself, for that time step including the previous time step, and that product is normalized to fall on a range of 0 to 1. Thus, both the standardized matrix and normalized matrix are created simultaneously. This equation is run repeatedly until the system reaches a steady state, which usually occurs in 20 to 30 time steps.

After this baseline scenario is calculated to show the current projected trajectory of the Carpathian biodiversity system for each FCM, various scenarios were run on each FCM based on participants' proposed interventions.

The same adjacency matrix and methodology were used, but the initial state and outgoing influence of the variable(s) that participants wanted to increase or decrease were changed. In other words, depending on the type of intervention, the initial state value of the variable of interest was changed to 0 or 1 for the $\vec{A}_k$, and its values in the standardized matrix were fixed to 1. This fixed outgoing influence of the variable also blocks all incoming influences upon it to only assess its influence upon the other variables.

6. Assessing how changes to the SES potentially create desirable or undesirable trajectories

Analysis can be done by analyzing scenarios within each FCM, a variable's trajectory behavior, and/or scenarios across FCMs. Firstly, the system dynamics described above lead to a steady state. These steady state values of variables of interest can be compared between the baseline with the "what if" scenarios of each FCM. This can help measure the intended and unintended side effects of various policy interventions upon variables of interest based on stakeholders' perceptions, also providing insight about the alignment of stakeholder perceptions to the outcomes of their own FCM scenarios. Secondly, sometimes the trajectory pattern of a variable's behavior during the iterative time steps of a scenario may be surprising, for example it may initially rise only to completely fall as it reaches a steady state. Lastly, comparisons across FCMs can be made, especially between FCMs with similar concepts to investigate how their trajectories and steady states differed.

Chapter 6: Results and Discussion

Participants in data elicitation ranged from all seven Carpathian countries with a few others from non-Carpathian countries, but whose work focuses on the region. They represented academic and research institutes, law offices, non-profits, state conservation agencies, and state ministries. Most participants were part of the Carpathian ESD Expert Network, S4C network, and CNPA, respectively, with a few policymakers and one additional expert. Some participants belonged to multiple networks or represented various sectors. There were 3 participants in the S4C focus group, 4 participants in the ESD focus group, and 2 participants in the CNPA focus group. In all, 25 individuals participated in the elicitation process: nine of them participated in one of the three focus groups and 16 participated in an individual interview.[2] This resulted in 19 total FCMs.[3]

Table 2: Representation of participants in the interviews and focus groups.

REPRESENTATION OF CARPATHIAN CONVENTION STAKEHOLDER GROUPS

S4C Members	ESD Members	CNPA Members	Policymakers	Other
9	11	6	2	1

REPRESENTATION OF VARIOUS SECTORS

Academia/Research Institute	Law	Non-Profit	State Conservation	State Government
13	1	3	6	2

REPRESENTATION OF CARPATHIAN COUNTRIES BASED ON THEIR WORK

All	Czech Republic	Hungary	Poland	Romania	Serbia	Slovakia	Ukraine
3	3	5	3	3	2	3	3

[2] Due to time constraints, I was only able to work with participants in generating their FCMs. With more time, I would have also run the model in their presence and helped close the gap, if any, between their System I perceptions about system dynamics and the more deliberative outcome of their System II-based FCM.
[3] While it would have been ideal and beneficial to interview local stakeholders such as herders and forest managers, these groups are not as integrated within the Carpathian Convention and thus would be harder to contact. Additionally, the fact that I do not speak any languages spoken in the Carpathian region other than English hindered potential participation from local stakeholders.

Sharing/Eliciting knowledge to define the SES state

Interviews lasted between 45 minutes to 1.75 hours, depending on the participants' availability and willingness to discuss their mental models in depth, and the focus groups lasted between 1.5 to 1.75 hours. For the vast majority of interviews, over half of the time was devoted to listing, defining, and quantifying the initial states of the variables relevant to the Carpathian biodiversity system. This provided a foundation for mutual understanding of the biodiversity SES components according to the participant's perspective, and these conversations were crucial not only for the rest of the conversation, but for post-processing assessment.

Benefits in Building the Map

In both individual interviews and the focus groups, some participants shared how the mapping exercise was helpful in visualizing and thinking through the nature of concepts' interconnections, illustrating FCM's potential for promoting social learning. In the focus groups, some participants learned from the expertise of others, as they came from different sectors or countries, which allowed for more meaningful discussion about variable connections and weights. There were some disagreements in quantifying variable initial states and relationship strengths in the focus groups, but participants came to a consensus, sometimes by taking the average between their proposed numbers.

Challenges in Building the Map

Overall, participants expressed difficulty or discomfort in quantifying variable states and relationships. Some variables were very context dependent, varying greatly by country, time, or circumstance, making FCMs potentially ahistorical and context-dependent. For example, it was hard to model socioeconomic and ecological practices and impacts from the past that have ongoing influences today: such as legacy pollution from industrialization, whether agriculture is more mechanized and intensified as a result of collectivization (which was not implemented in all countries), or the historical forestry practice of planting monocultures, which make forests more vulnerable to large-scale mortality from disturbances. It is hard to capture these historic influences in a dynamic map, because these practices are no longer happening—collectivization is over, the monocultures have already been planted—however, their legacies remain.

It was also difficult for some participants to take a whole-Carpathian view, and they often built their biodiversity SES based on their national context. For example, participants from Ukraine mentioned the detrimental impacts of wind farms being developed; however, this issue was not discussed by representatives from other Carpathian countries. Having focus groups made up of representatives from diverse Carpathian countries and potentially aggregating all the individual FCMs together could help depict a Carpathian-wide biodiversity SES. However, not all Carpathian countries were represented in the focus groups as they were too small, and aggregating the individual maps had its own challenges, which is discussed in the next step.

Analyzing the SES structure

On average, participants identified between nine and 19 individual factors in their maps, including "Biodiversity Health," which remained a required constant across all 19 FCMs. Overall, biodiversity health was perceived to be the most central variable to the system;

however, it was characterized by having very low outdegree influences, implying that stakeholders perceive it as an outcome of the system. Other central variables included quality of local livelihoods, quality of local enforcement, influence of national priorities, amount of private land, quality of forest management, quality of public environmental awareness, provision of ecosystem services, and unsustainable use of natural resources. Variables with the highest outdegree relationships greatly varied across the FCMs with very little overlap: climate change and rate of development each had the highest outdegree relationships in two FCMs. This illustrates that there are many forcing variables that are central to the system according to stakeholders.

After synonymous variable names were standardized across all the maps, around 88 individual variables were identified. It is difficult to identify the total number of individual variables, as some participants described concepts and dis-concepts (e.g. "forestry quality" and "forestry intensity"), which relate to the same idea, but are framed differently. Additionally, some participants merged concepts in a single variable, while others separated concepts (e.g. "Quality of EU Legislation" versus "Quality of EU Agricultural Legislation" and "Quality of EU Forest Legislation").

While the literature offers two potential solutions for merging such concepts—quantitatively converting either the concept or dis-concept, for example (Jetter & Kok, 2014), or qualitatively combining concepts by categories (Özesmi & Özesmi, 2004)—neither approach preserved the integrity of the participants' FCM. Converting a concept (e.g. "forestry quality" to "forestry intensity") and its connecting arrows to the opposite direction changed the steady states of connected variables. This phenomenon is not properly addressed in the literature. Also, because participants determined each factor's initial state value, rather than setting each factor to 1 as in the literature, this value would also have to change in consultation with the participant(s). Regarding qualitatively creating categories with a larger-encompassing variable, it is unclear how to quantify the causal relationships between these categories that have different connections, signs, and weights. Due to these issues and the lack of transparency discussed in the literature, none of the FCMs for this thesis were aggregated together.[4]

Concepts fell broadly in 12 categories, where factors relate to ecosystem and natural resources; land ownership; development issues; disturbances; environmental crime; forest management; wildlife management; grassland & agricultural management; socioeconomic and cultural issues; legislation, incentives, and enforcement; participation and cooperation; and media, economic and political influences. Excluding "Biodiversity Health," the most mentioned concept related to the rate of development, which encompasses transportation, industry, urbanization, and other infrastructure. This concept is represented in 10 individual FCMs and all three focus group FCMs. The second-most mentioned concepts were "Intensity of Unsustainable Tourism Development," which is reflected in nine individual FCMs and two focus group FCMs, and "Frequency and Severity of Climate Change," which is reflected in eight individual FCMs and all three focus group FCMs. See Figure 2 for the most-mentioned concepts: all concepts with at least six mentions in the individual interviews and all concepts with at least two mentions in the focus groups are represented.

[4] Aggregating individual FCMs is still a worthwhile pursuit in generating a median cognitive map of a SES and potentially increasing the predictive validity of FCMs (Blewett, Jacobs & Kok, 2023). For example, Blewett, Jacobs and Kok (2023) found that aggregated models have a higher predictive validity than individual models when they followed up with stakeholders about their system outcomes after three years.

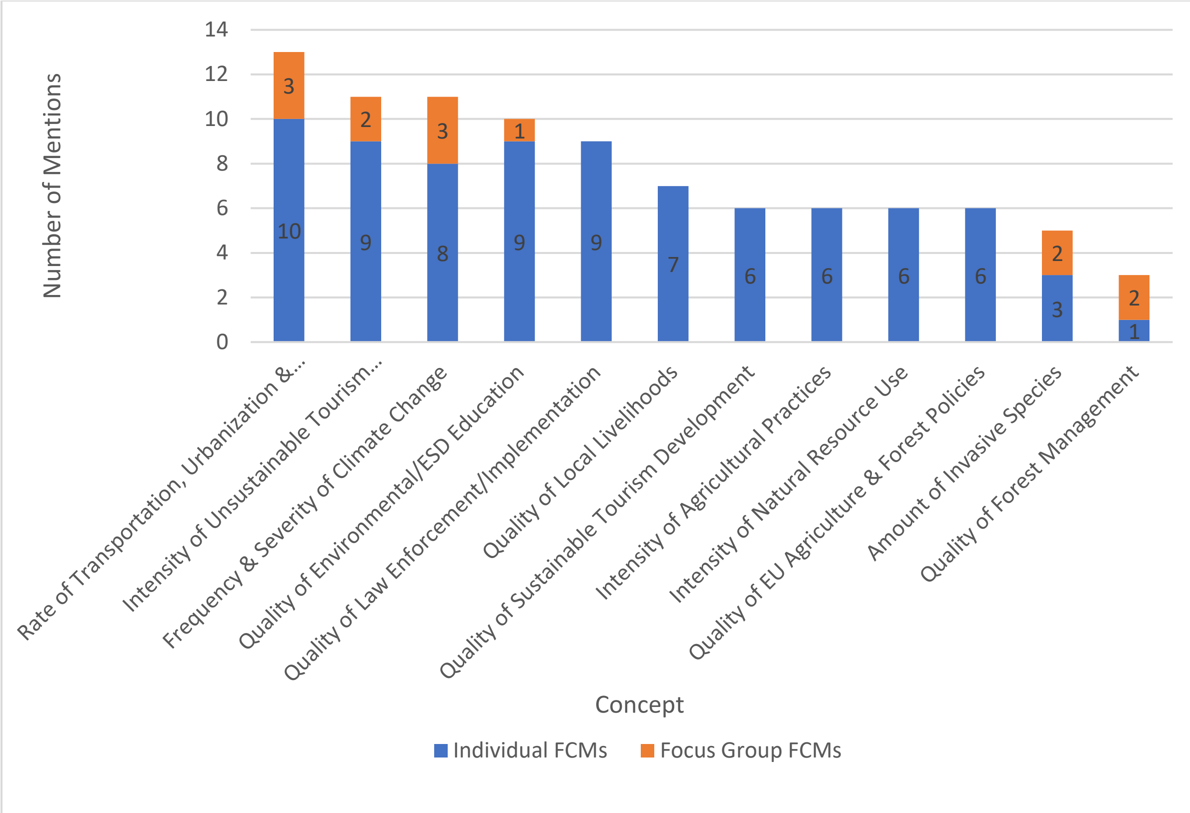

Figure 2: Representation of the concepts with the greatest number of mentions in either the individual interviews or focus groups. Concepts that were mentioned at least 6 times in the individually-generated FCMs are included, as well as concepts that were mentioned at least 2 times in the focus group-generated FCMs.

When participants were asked what potential policies or interventions would help improve biodiversity outcomes, their proposed action(s) thematically related to better multi-stakeholder conservation policies; transnational and policymaker cooperation; subsidy and incentive programs; education and NGO campaigns; enforcement and implementation; policy harmonization and vision; stakeholder cooperation and initiatives; and industry sustainability.

<u>FCM Divergences</u>

Most participants agreed upon the type of causal relationships (positive or negative) between variables; however, there were a few notable divergences involving relationships between local livelihoods, development, climate change, biodiversity, agriculture subsidies, and pastoralism.

There was disagreement between “Quality of Local Livelihoods” and development-related concepts, such as transportation, infrastructure and economic development. Some participants put a two-way positive relationship between the two: as local livelihoods increase in quality, the rate of development also increases and vice versa. However, other participants put a positive relationship from rate of development to quality of local livelihoods, while others qualified this causal relationship as negative. This divergence possibly reflects participants’ worldview around the relationship between development and human well-being.

While the vast majority of participants identified a negative causal relationship from climate change to biodiversity health, there were two exceptions. Both discussed the potential benefits that climate change could bring biodiversity, but diverged in the specifics. One participant put a positive relationship from climate change to biodiversity, describing the potential for warmer temperatures to increase the growing season for high alpine meadows, thus increasing the biodiversity of these hotspots. One focus group also referenced the benefits of climate change bringing a longer growing season, but drew a positive relationship from climate change to pastoral practices. They did not identify a direct connection between climate change and biodiversity because there was some disagreement about whether forest encroachment as a result of warmer temperatures would increase the biodiversity in these higher elevations or decrease biodiversity as a result of a loss of grasslands. They acknowledged that climate change brings more negative impacts upon biodiversity due to increased disturbances and its increasing rate, so they indirectly represented its benefits for biodiversity through pastoralism. But as the warmer temperatures create a more comfortable climate for high alpine meadows, the potential for more diverse plants to grow increases as well as the growing season length. Participants in the focus group discussed whether a longer pastoral season would be more beneficial or difficult for herders' livelihoods: while biomass increases, they may be able to cultivate and sell more agricultural products, but the summer season spent in the mountains is the most difficult time for herders. Spending more time away from their village may make this a less attractive career path.

There was also disagreement between FCMs regarding the influence of agricultural subsidies. Some participants saw these programs as benefiting pastoralism and traditional agriculture, thus enhancing the quality of grasslands for increased biodiversity. However, others described agriculture subsidies as incentives for intensifying non-traditional agriculture, which reduces biodiversity.

FCM Comparisons with the Carpathian SES Literature

All the drivers and outcomes of the five SES wicked problems in the Carpathians described in Chapter 3 were reflected in the FCMs and conversations.

Several participants referenced income insecurity being a driver for illegal logging, unsustainable natural resource use and agricultural land abandonment. Globalization was referenced in the FCMs through rural depopulation, unsustainable tourism, rising connectedness (such as urbanization or transportation), and traditional agricultural abandonment. Infrastructure development and unsustainable tourism were the most frequently cited factors in the FCMs. Several FCMs included national environmental legislation and EU legislation, with even more including enforcement of legislation as being a key component of the biodiversity SES. Participants were more critical of national legislation, where this varies in quality across the countries. For example, the Slovakian government has taken measures to curtail civil society organizations and increase logging in protected areas. The contested benefits of EU agricultural subsidies as described above were included the FCMs, reflecting this complexity. Some participants described the lack of standardized monitoring data, especially regarding wildlife and large carnivores, being an issue. Climate change was tied as the second-most mentioned factor; land use change was reflected in all the FCMs as infrastructure development, land abandonment, ecosystem succession, agricultural activities, tourism expansion and logging; and pollution was specifically referenced in three FCMs.

There were two points of divergence from the wicked SES problems in the Carpathians. First, some participants discussed the potential positive impacts of climate change upon grassland biodiversity and pastoral practices (described above). Secondly, all participants were favorable of EU policies. They acknowledged that while these environmental legislations and schemes could be more cross-sectoral and participatory, many individuals stated that environmental conservation would be much worse if it were not for the EU. However, they were more critical of national legislation quality and most concerned with the actual (lack of) enforcement of environmental legislation.

Analyzing the SES dynamics

All participants perceived that biodiversity in the Carpathians to be relatively healthy, especially in relation to Western Europe. On the 0 to 1 scale, they all rated its initial state value above 0.5, with the average being 0.72. However, they argued that it is increasingly threatened by the various challenges they listed. Such endangerment would presumably be reflected in the baseline scenario of each FCM, where biodiversity health should be seen as decreasing. However, only seven FCM baseline trajectories showed biodiversity health decreasing relative to its initial state after reaching a steady state.

As discussed in the previous chapter, the literature sets all initial state values to 1 as an "activation" value. However, having each stakeholder set their own initial state values proved fruitful to the discussion and helped provide a clearer qualitative storyline of how each participant perceives their own mental model. After running the models, whether the initial state values were all set to 1 or were their unique values, the steady state remained the same. The values for variables differed in the first few time steps, but the end steady state was the same regardless of the initial state value.

Because proposed policy interventions for modeling alternative scenarios need to be part of the adjacency matrix—its relationships defined and weighted—I did not add my own interventions to stakeholders' FCMs.

Assessing how changes to the SES potentially create desirable or undesirable trajectories

Another finding of the model was that scenarios yield very minor differences to variables' trajectories in the system when the policy or intervention variable(s) already exists in the baseline scenario. Simply fixing the policy or intervention variable to 1 in the standardized matrix does not have large impacts than it otherwise would if it were excluded from the baseline scenario and then introduced in an alternative scenario. However, excluding these policy variables from the baseline scenario was not relevant to stakeholders' mental models, as their current perspectives of the biodiversity system includes these policies; they just proposed improving their implementation and/or quality. This finding of "what if" scenarios producing minor differences relative to the baseline scenario is not uncommon in other studies, though, and many of these studies did not express concern for this in their results interpretation (Falcone & De Rosa, 2020; Bosma, Glenk & Novo, 2017; Salberg, Booth, Jahren & Novo, 2022).

Because this research yielded minor changes to variables' steady states, it is worth exploring whether low changes are due to low levels of outdegree relationships and connectedness (Bosma, Glenk & Novo, 2017). Other studies have explored raising thresholds for concepts and relationships, and normalized outputs after performing dynamic analysis, rather than during (Blewett, Jacobs & Kok, 2023).

Nonetheless, one FCM's policy intervention yielded no changes to biodiversity health relative to its baseline steady state, 11 FCM's policy interventions yielded positive effects on biodiversity, and six FCM's policy interventions yielded negative effects on biodiversity. However, it is unclear whether the policy interventions that decrease biodiversity health are a result of the system's dynamics or the logistic density function.

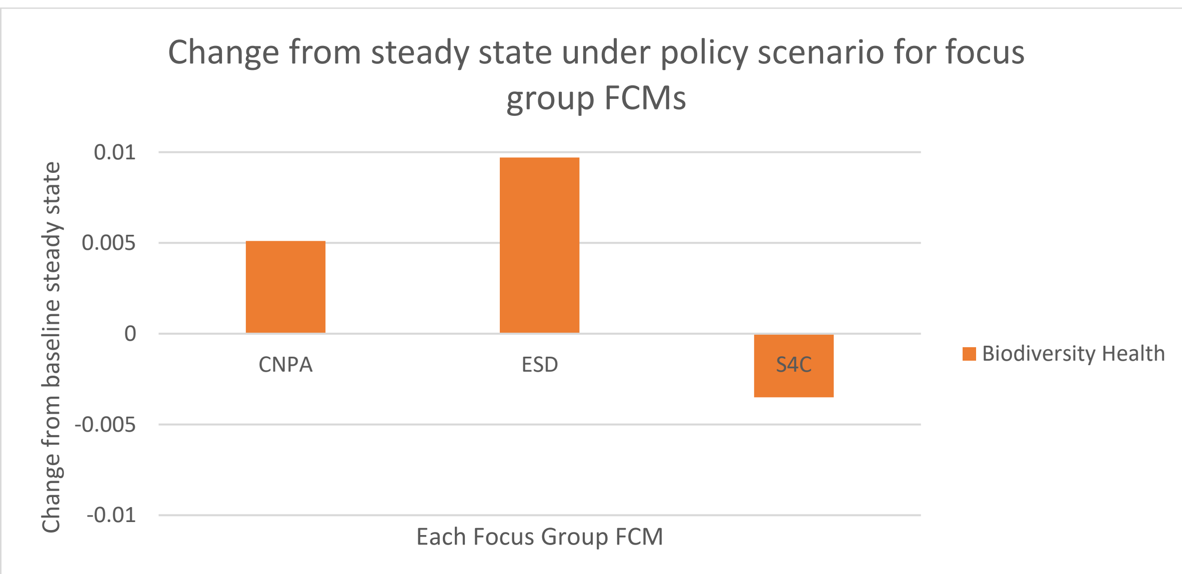

Figure 3: Change in biodiversity health in the three focus group FCMs according to their proposed policy intervention. See Appendix B for more information.

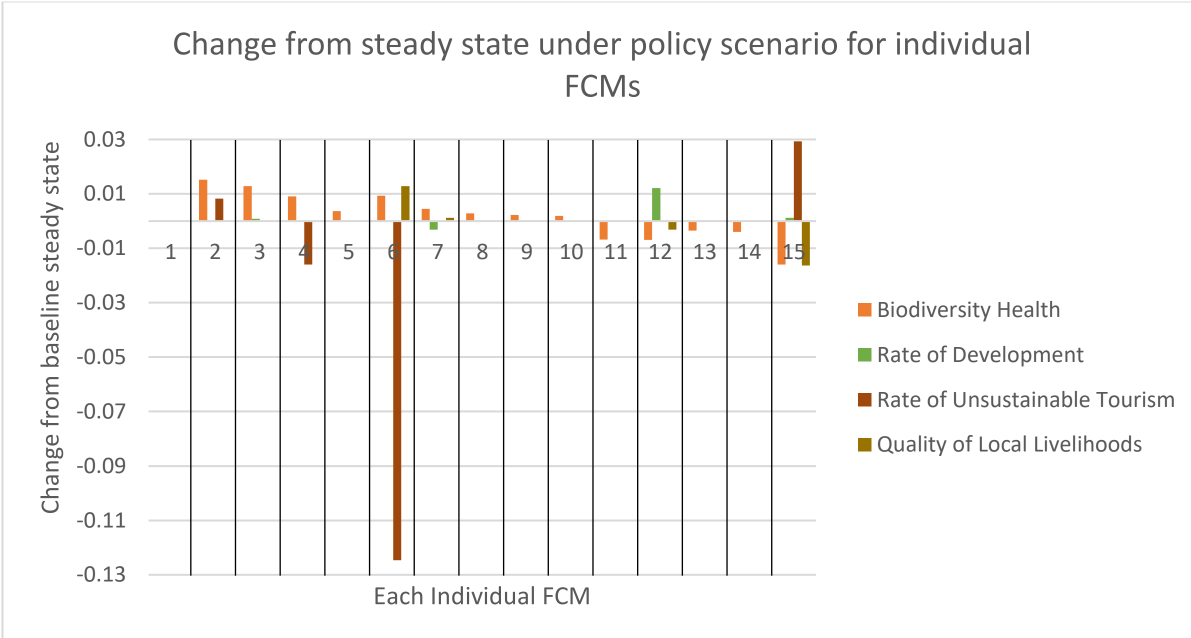

Figure 4: Change in biodiversity health and other variables of interest in each individual FCM according to their proposed policy intervention. See Appendix A for more information.

Because values in the standardized matrix can extend beyond the bounds of [-1,1], some of the policy intervention variables' values were greater than 1 in some of these matrices for the baseline scenario. Thus, when its value is fixed to 1 in the alternative scenario, its value decreased relative to its baseline value, thus decreasing its overall impact upon biodiversity health. From brief experiments, it was found that the type of normalizing function greatly impacts the final steady states and trajectories of each variable. This sensitivity illustrates the need for more comparison analysis on how different functions affect scenario outcomes. However, due to time constraints, I did not have time to test this, nor conduct calibration.

Chapter 7: Conclusions and Recommendations

To my knowledge, this thesis is the first attempt of applying FCM to the Carpathian region. Overall, there were no meaningful differences between the focus group-generated FCMs and the individually-generated FCMs in terms of the FCM structure and dynamics. While the implications for social learning and knowledge representation differed, the system components and dynamics between the two approaches were very similar. This is probably because the individual maps were not aggregated together, where it is assumed that the FCM structure would include many more variables and thus potentially create different outcomes.

FCM can be an iterative step and tangible pathway for incorporating more local stakeholders and expert knowledge into higher-level Convention processes. While improvements to the methodology should be made, FCM should not replace more robust scientific research and predictive modeling techniques, as it not only reflects individuals' perceptions, but it only reflects the perceptions of those in the room. Thus, broader stakeholder inclusion is necessary for making meaningful connections and filling in knowledge gaps. Additionally, more research is needed in further developing the FCM methodology to better understand the potential synergies and trade-offs of integrating biodiversity considerations.

7.1 FCM Methodology and Policy Recommendations

Based on these results, I provide two sets of recommendations. The first set of methodological recommendations apply to researchers and practitioners for developing FCM further as a useful participatory approach for decision-making about general SES problems. These include addressing issues and gaps in the quantitative methodology, reconciling the two uses of calibration, and properly incorporating stakeholder participation at all stages of

FCM. The second set of policy recommendations apply to Carpathian Convention policymakers and project implementers for leveraging FCM and the results of this thesis to engage more local stakeholders and authorities and prioritize key issues and interventions.

Researchers and practitioners should carefully and transparently deliberate their quantitative approaches to FCM development and processing.

The choice of normalizing function, effects of density, and quantitative and qualitative aggregation methods greatly impacted the system dynamics and steady states. Additionally, methods for FCM aggregation are still largely unclear and unstandardized: whether and/or how to cull concepts that are outliers, how to accurately change dis-concepts, and how to qualitatively merge similar concepts while preserving their unique relationships. Clarifying these methods will assist in better understanding the differences and trade-offs between individually and collectively developed maps for balancing divergence in opinions, power dynamics and more (Bosma, Glenk & Novo, 2017). Therefore, I recommend further researching these effects and approaches so the appropriate function and aggregation methods are chosen according to the research purpose.

Researchers and practitioners should calibrate each individual FCM with stakeholders to ensure the accuracy or authenticity of the model.

FCMs can be calibrated with a historical scenario to see if it produces results in accordance to observed reality, or by running the model to see if it produces expected system behavior for simple cases (Olazabal & Pascual, 2016; Jetter & Kok, 2014; Christen, Kjeldsen, Dalgaard, & Martin-Ortega, 2015). However, this process is not often discussed in the literature. I recommend that stakeholders be involved in the calibration process to ensure transparency and understanding of the model (Jetter & Kok, 2014).

Researchers and practitioners should engage stakeholders throughout all processes of FCM: deliberation, creation, calibration, and results sharing.

While all the FCM literature acknowledges and promotes FCM as a participatory approach for integrating complex stakeholder and expert knowledge, some studies—including this thesis—neglect to follow through with stakeholder participation past building the maps. While the process of building the FCM promotes deliberation and understanding among diverse stakeholders (Gray et al., 2015), neglecting to calibrate and share results with the participants prevents the process of bridging System I and II thinking. Therefore, I recommend that stakeholders be involved throughout the entire process of FCM for maintaining its approach as a transparent method for including stakeholders in crafting potential policy or management actions.

Researchers and practitioners should emphasize the careful and time-consuming nature of FCM development and processing.

A thoughtful FCM elicitation process should require several hours for explaining the process to participants, listing and defining variables, reconciling differences, running system dynamics, and assessing participants' intuitive projections with the system outputs. I recommend transparently disclosing this process and using skilled facilitators to avoid workshop fatigue among participants.

Carpathian project implementers should conduct FCM for incorporating stakeholder engagement and present the results to the Carpathian Convention.

Organizations that are implementing relevant regional projects often create policy-relevant documents, such as Strategic Action Plans for/with the Carpathian Convention Secretariat for their input and endorsement to the countries' national ministries. Thus, I recommend that these project partners utilize FCM in their project processes to elicit stakeholder knowledge, divergences, and recommendations to then present in their action plans for the Secretariat to consider and disseminate.

While it was not feasible for this thesis, including more local stakeholders throughout the entire FCM process might have resulted in more concrete gaps and recommendations for biodiversity. The Secretariat can leverage FCM to expand its networks through project implementers. Because project partners involve local and regional organizations, they may be in direct contact with stakeholders such as herders and forest managers and can conduct the FCM process in local languages. This would better integrate these groups within the Carpathian Convention, which are currently underrepresented in the Convention and this thesis. This would facilitate more cooperation for bridging civil society with policymakers and potentially begin building local ownership over potential interventions.

Carpathian policymakers should prioritize infrastructure development and (un)sustainable tourism issues.

These two issues were the most frequently cited factors in the FCMs and in the literature as wicked globalization problems. While there are/have been Carpathian projects focused on such, it is apparent that these are still relevant cross-sectoral issues for Carpathian biodiversity and rural development. Thus, I recommend that FCM and other participatory methods be utilized for identifying the current trajectory of these topics and what barriers exist for implementing best practices as outlined in previous projects.

Carpathian policymakers should prioritize legislative enforcement and education as potential interventions for safeguarding biodiversity.

These two factors were also among the most cited across the FCMs and were the most mentioned policy interventions. I recommend that the Carpathian Convention better engage with local authorities and administrations to understand why local enforcement of environmental policies is poor (according to participants' perceptions) and which educational pathways would be most effective for catalyzing mountain SES transformation.

Carpathian policymakers should actively engage with FCM researchers and practitioners during Convention events for co-developing scenarios and sharing results

Policymakers may benefit from visualizing scenarios of potential futures of SESs to identify future priority areas, such as when the Carpathian Convention decided to develop an assessment on climate change's effects on Carpathian forests.[5] FCM could be leveraged to facilitate planning, discussion and filling in knowledge gaps (such as the impacts of CAP as described in Chapter 3) to overcome data scarcity. I recommend that policymakers support

[5] http://www.carpathianconvention.org/topics/sustainable-forest-management-2/

participatory exchange by integrating FCM workshops into the Convention's meetings, conferences, and other events, and that they participate in such co-creation opportunities.

Carpathian policymakers should provide more fora for the three networks (CNPA, ESD Expert Network and S4C Network) to exchange and provide input on projects and policy decisions.

The FCMs across these three networks show substantial overlap and that many members from each of these networks already consider the biodiversity system a cross-sectoral issue, given the many socioeconomic, development, political, natural resource and landscape factors they cited. Thus, it may be more efficient to build upon their collective knowledge and work with the three networks together on policy and project proposals, rather than engage with them separately. The Carpathian Convention can leverage this foundation for identifying concrete interventions for biodiversity protection and improving local livelihoods that are not generalized frameworks.

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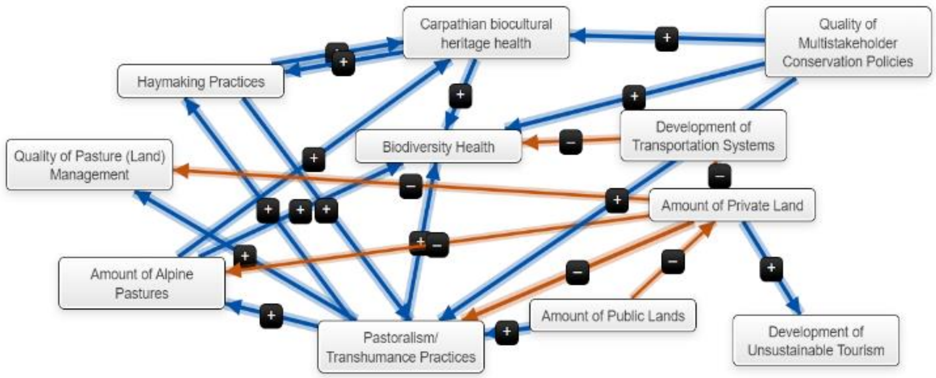
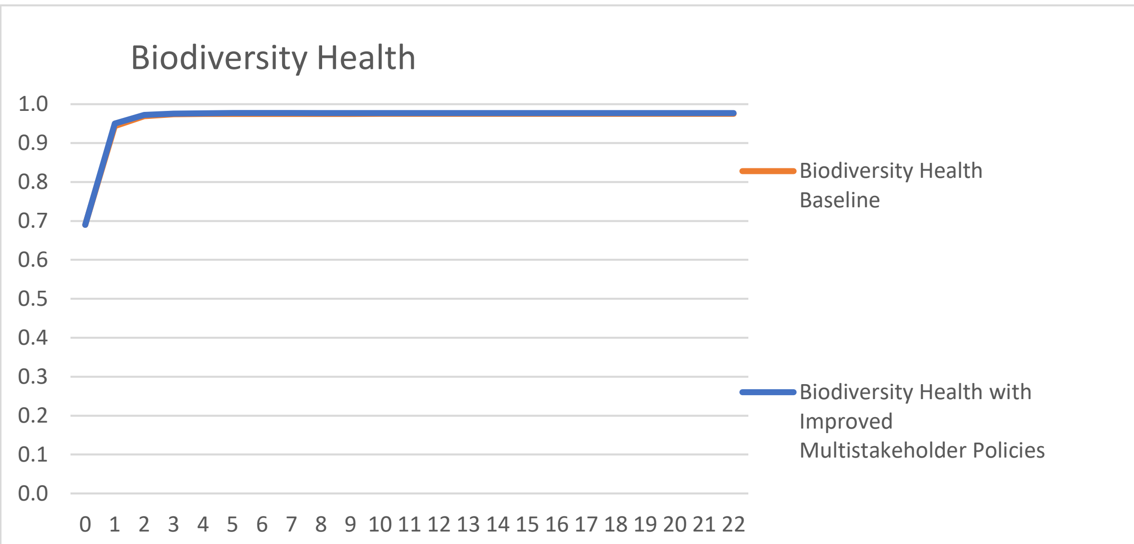
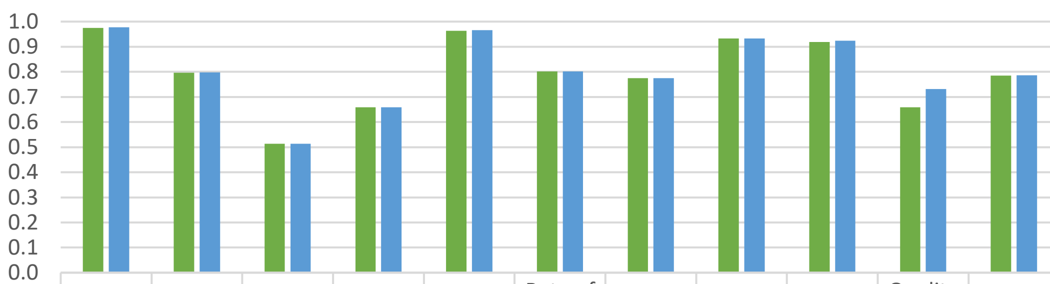
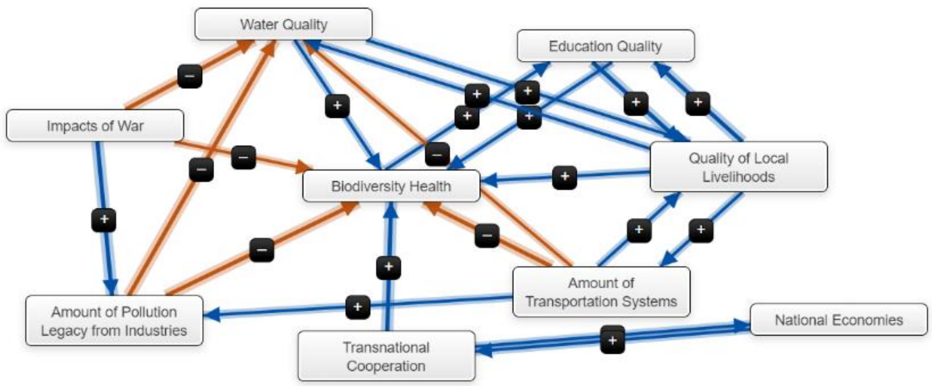
Appendix A: Individual Maps and Scenario Results

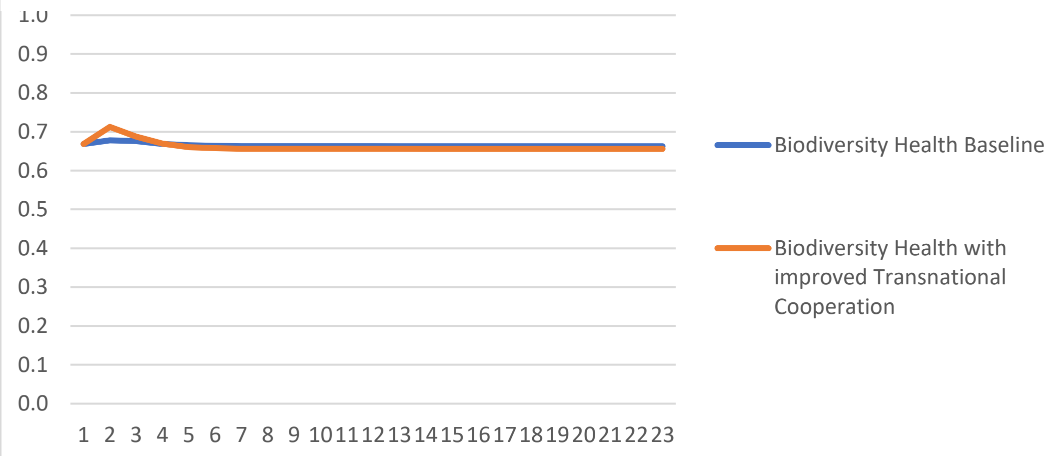


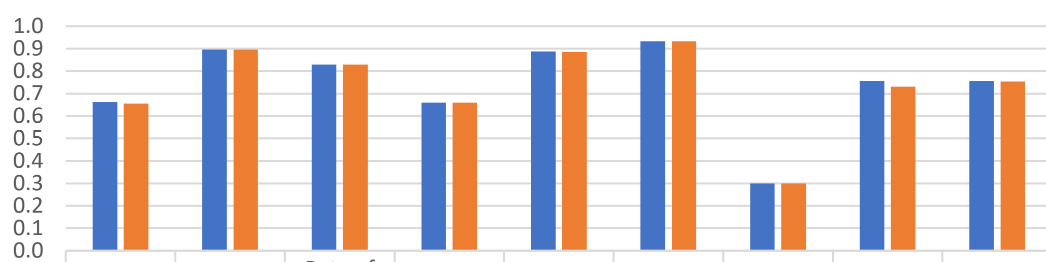




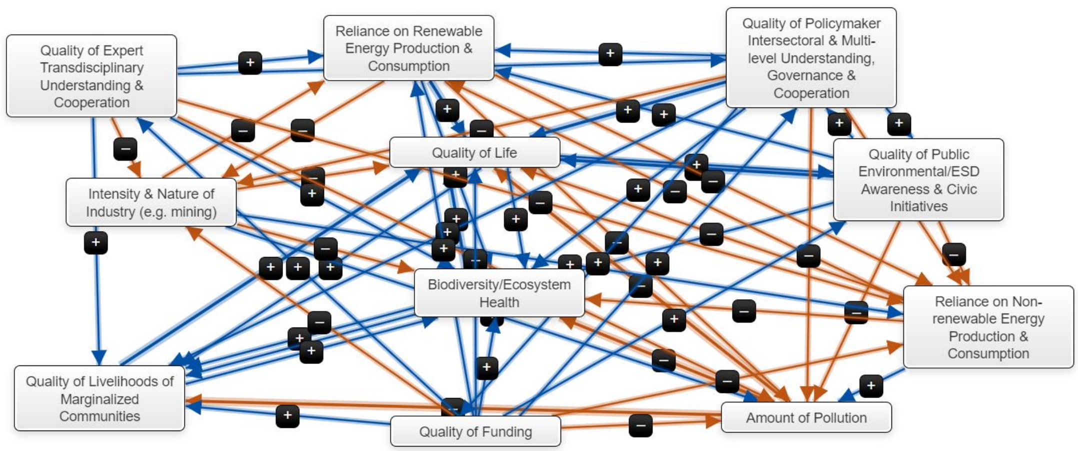
	Biodiversity Health	Amount of Alpine Pastures	Amount of Private Land	Amount of Public Lands	Carpathian Biocultural Heritage Health	Rate of Transportation, Industry, Urbanization & Infrastructure...	Intensity of Unsustainable Tourism Development	Quality of Haymaking Practices	Pastoralism/Transhumance Practices	Quality of Conservation Policies (Multistakeholder/Intersector...	Quality of Grassland/Pasture Management
Baseline	0.9752	0.7970	0.5129	0.6590	0.9635	0.8013	0.7750	0.9326	0.9192	0.6590	0.7848
With Policy	0.9771	0.7979	0.5129	0.6590	0.9660	0.8013	0.7750	0.9330	0.9243	0.7311	0.7858

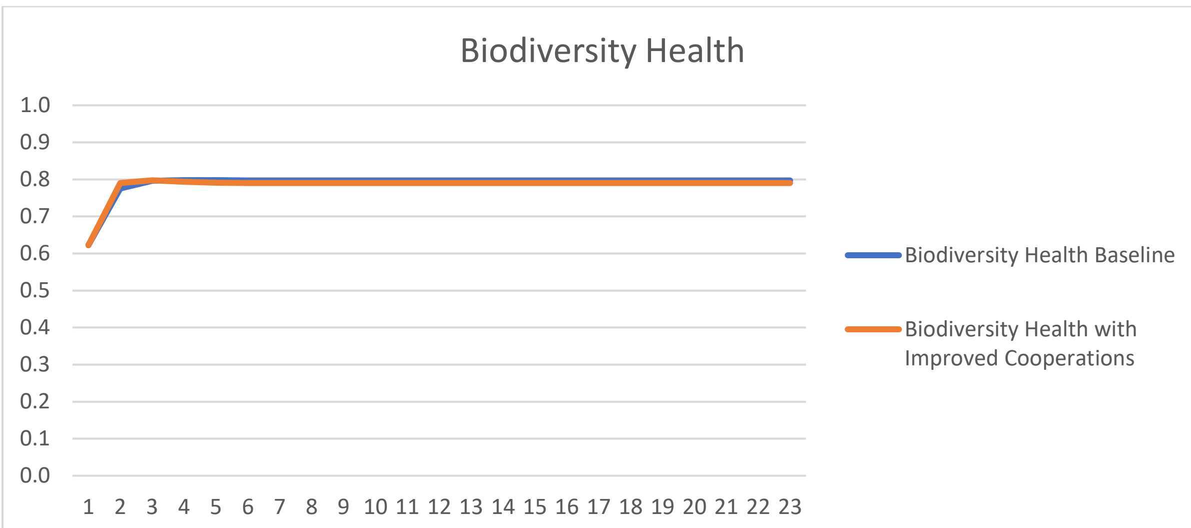


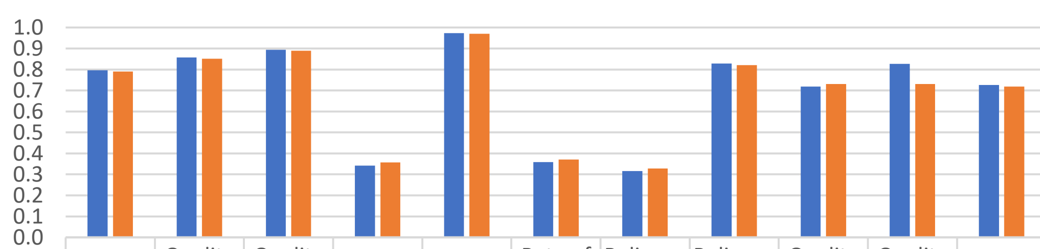




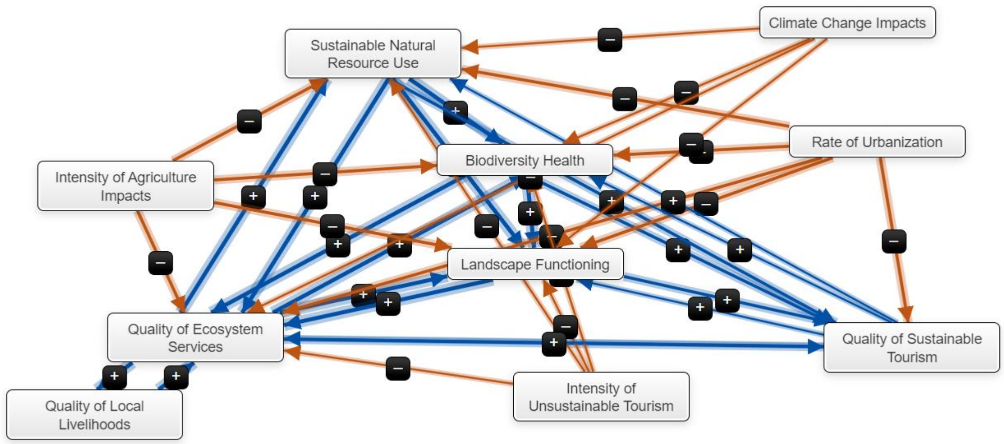
	Biodiversity Health	Amount of Pollution Legacy from Industries	Rate of Transportation, Industry, Urbanization & Infrastructure Development	Environmental Impacts of War	Quality of Public Environmental/ESD Education & Civic Initiatives	Quality of Local Livelihoods	Water Conditions (Quantity & Quality)	Transnational Cooperation	Quality of National Economies
Baseline	0.6626	0.8958	0.8285	0.6590	0.8867	0.9330	0.2993	0.7568	0.7568
With Policy	0.6558	0.8958	0.8285	0.6590	0.8863	0.9329	0.2993	0.7311	0.7539

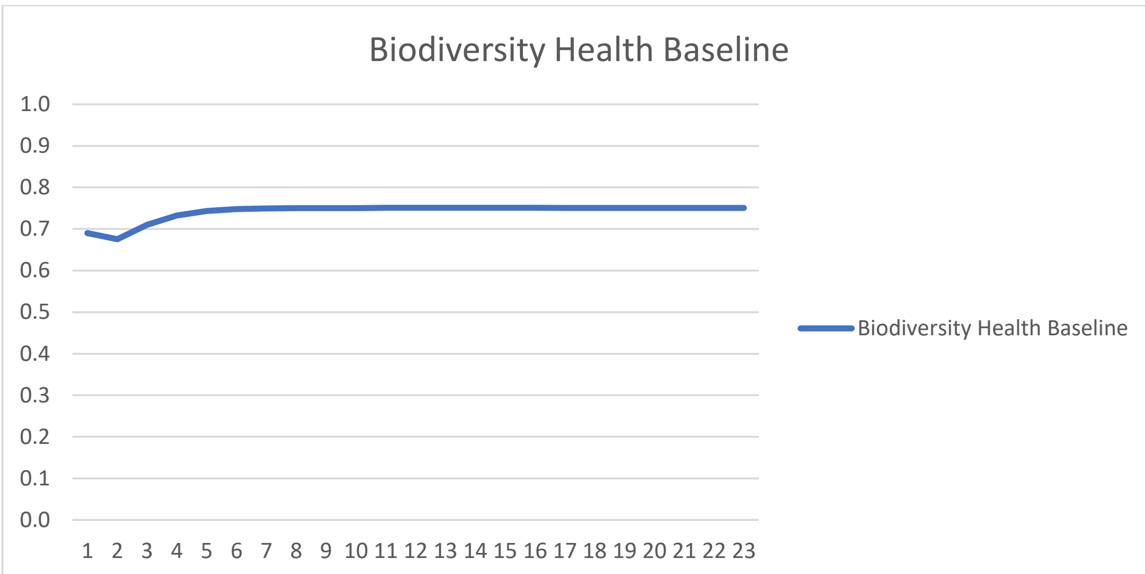




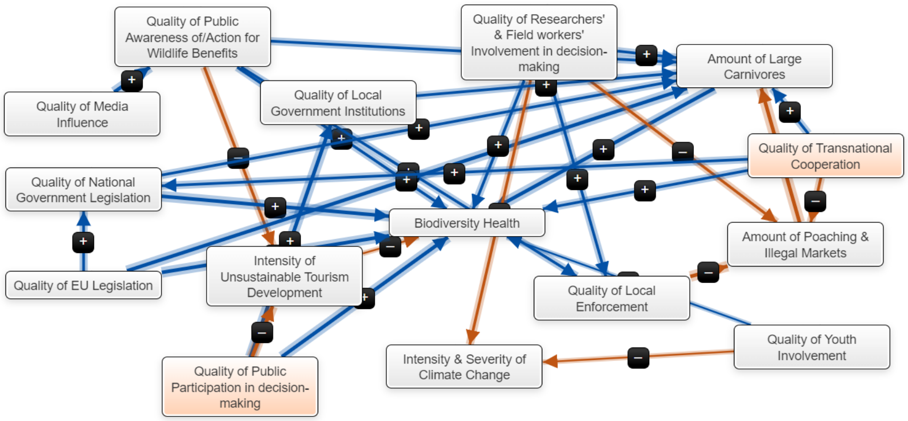


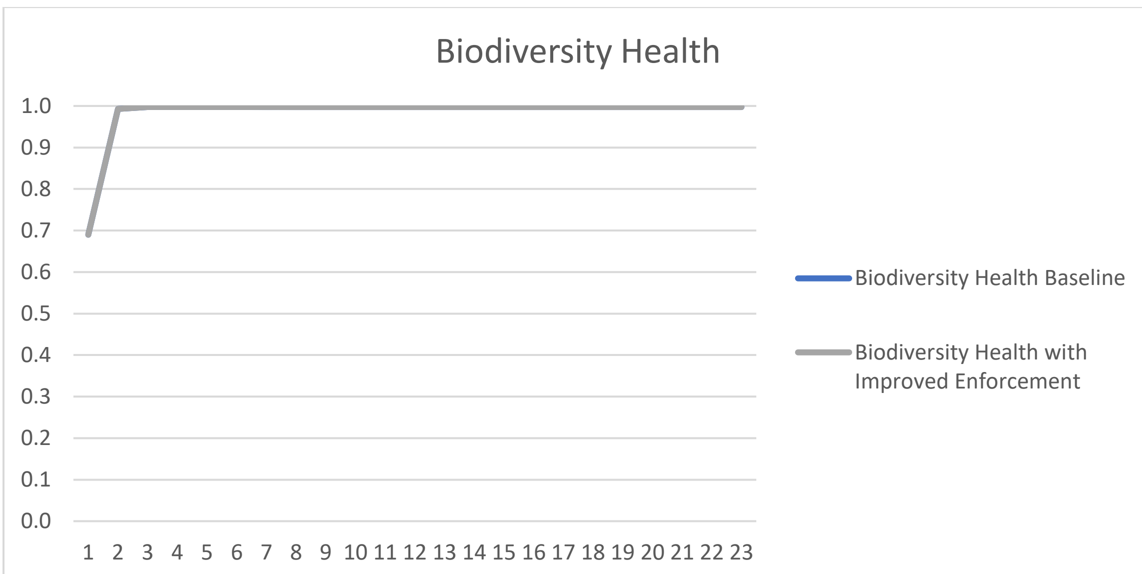
	Biodiversity Health	Quality of Public Environmental/ ESD Education &…	Quality of Livelihoods of Marginalized Communities	Amount of Pollution	Quality of Local Livelihoods	Rate of Transportation, Industry, Urbanization & Infrast…	Reliance on Non-renewable Energy Production & Consu…	Reliance on Renewable Energy Production & Consu…	Quality of Expert Transdisciplinary Understanding &…	Quality of Policymaker Cooperation (Intersectoral/…	Quality of Funding
Baseline	0.7969	0.8576	0.8932	0.3420	0.9733	0.3583	0.3153	0.8287	0.7183	0.8275	0.7260
With Policy	0.7900	0.8517	0.8886	0.3567	0.9701	0.3705	0.3281	0.8207	0.7311	0.7311	0.7187

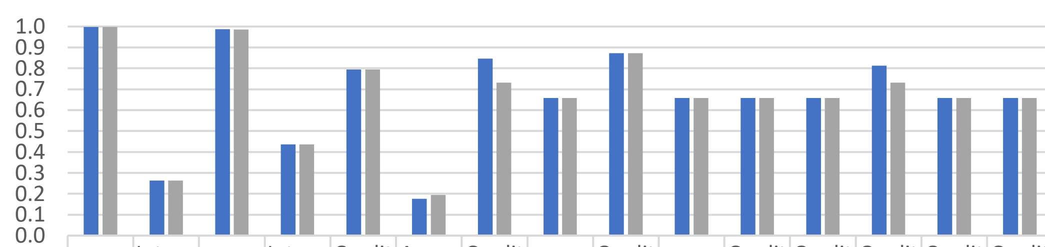




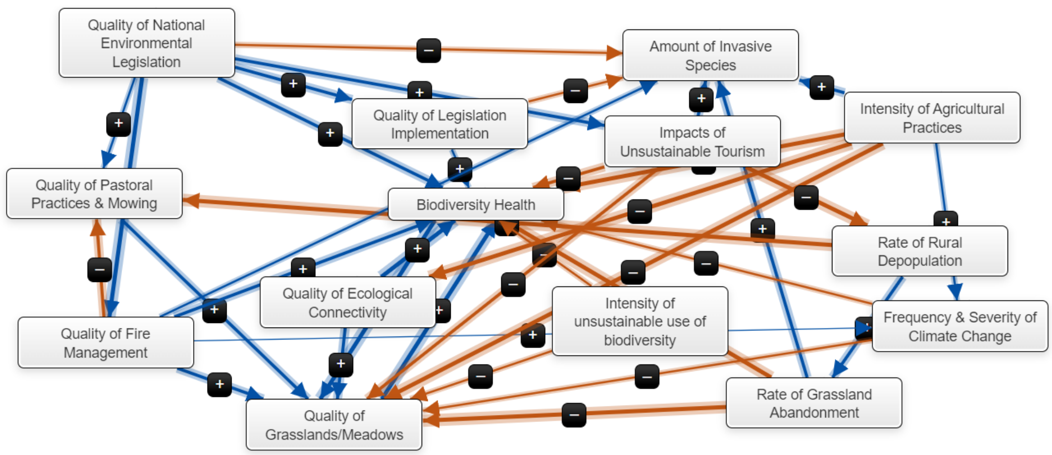
*participant did not propose any policy interventions due to time constraints

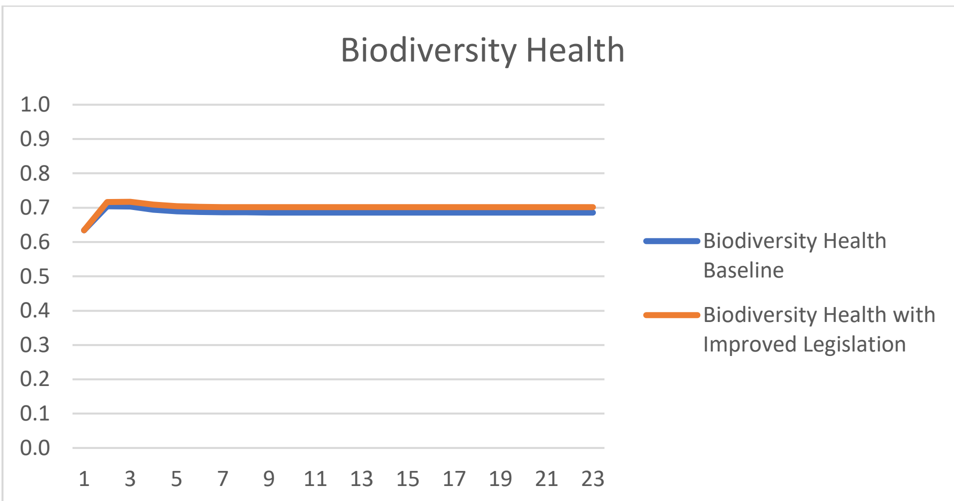


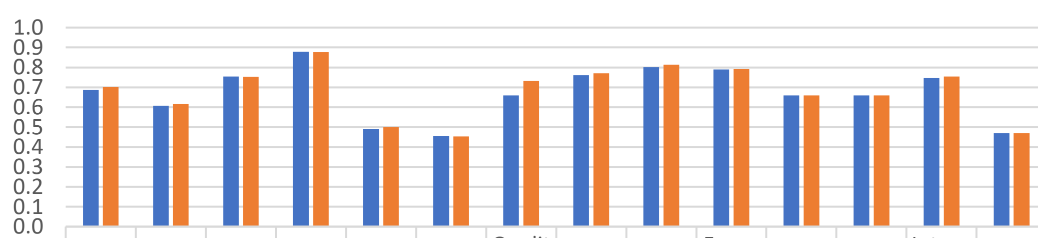




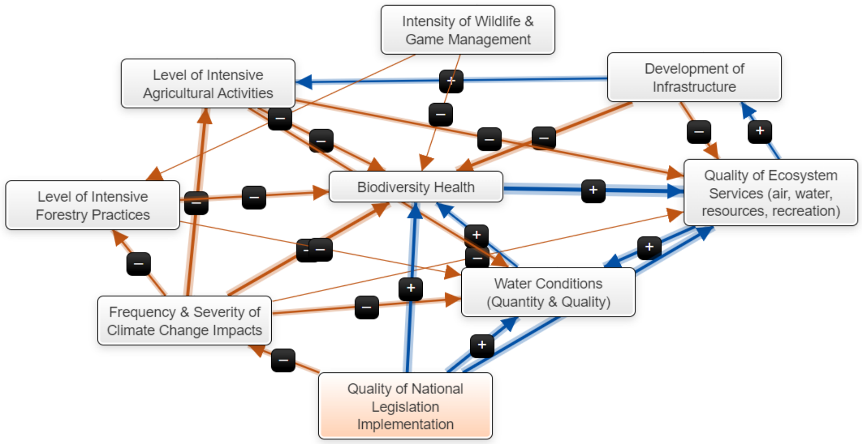
	Biodiversity Health	Intensity of Unsustainable Tourism Dev…	Amount of Large Carnivores	Intensity & Severity of Climate Change	Quality of Public Awareness of/Action for…	Amount of Wildlife Crime & Illegal Mar…	Quality of Law Enforcement/Implementat…	Quality of Youth Involvement	Quality of National Environmental Legi…	Quality of EU Legislation	Quality of Expert Cooperation & Part…	Quality & Amount of Media Influence	Quality of Local Government Institutions	Quality of Public participation in decision-…	Quality of Transnational Cooperation
Baseline	0.9974	0.2626	0.9872	0.4365	0.7950	0.1763	0.8472	0.6590	0.8730	0.6590	0.6590	0.6590	0.8134	0.6590	0.6590
With Enforcement	0.9974	0.2626	0.9861	0.4365	0.7950	0.1949	0.7311	0.6590	0.8730	0.6590	0.6590	0.6590	0.7311	0.6590	0.6590

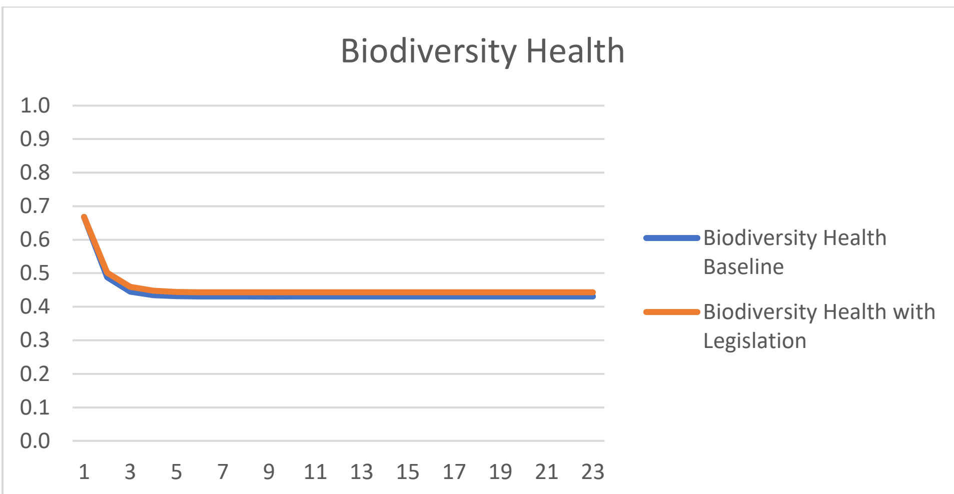


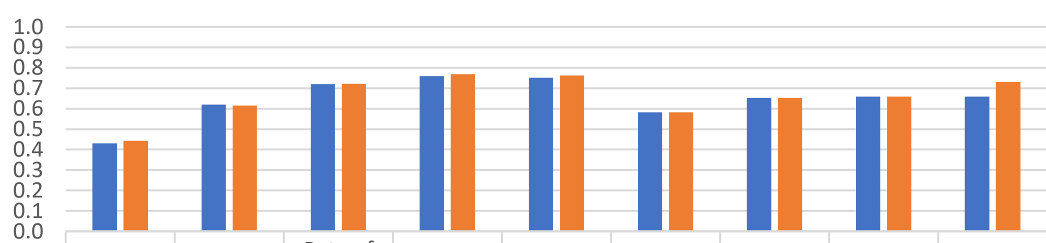




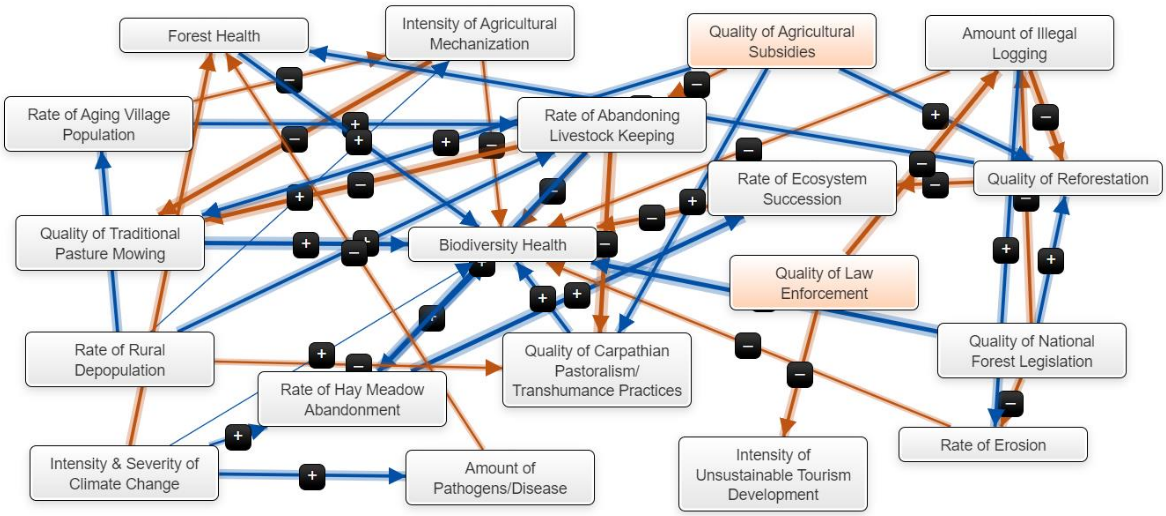
	Biodiversity Health	Quality of Grasslands/ Pastures	Rate of Grassland Abandonment	Amount of Invasive Species	Quality of Pastoral Practices & Mowing	Rate of Rural Depopulation	Quality of National Environment al Legislation	Quality of Legislation Implementation	Quality of Fire Management	Frequency & Severity of Climate Change	Intensity of Natural Resource Use	Intensity of Agricultural Practices	Intensity of Unsustainable Tourism Developm...	Quality of Ecological Connectivity
Baseline	0.6862	0.6076	0.7536	0.8789	0.4919	0.4556	0.6590	0.7606	0.8013	0.7895	0.6590	0.6590	0.7456	0.4690
With Policy	0.7014	0.6152	0.7532	0.8768	0.5002	0.4533	0.7311	0.7701	0.8132	0.7907	0.6590	0.6590	0.7539	0.4690

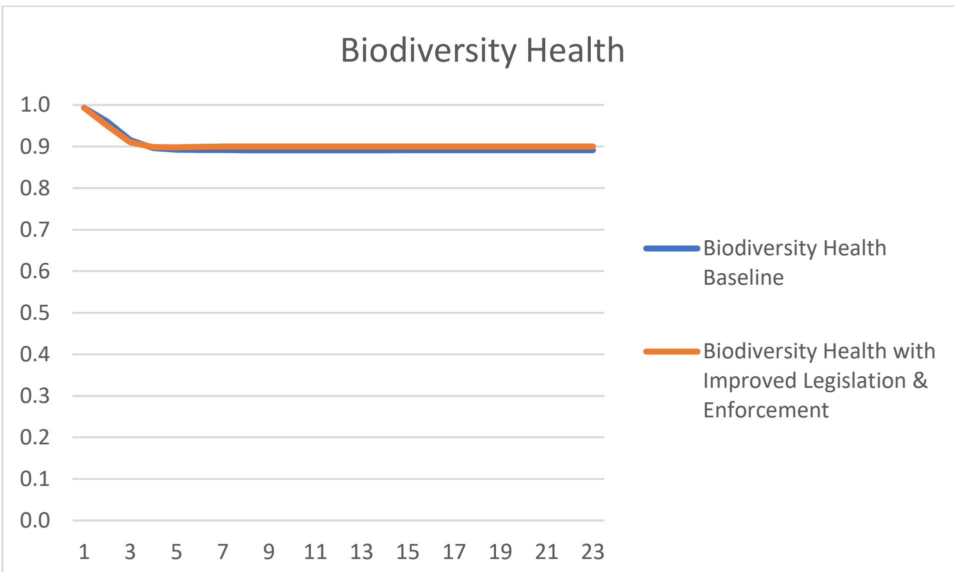


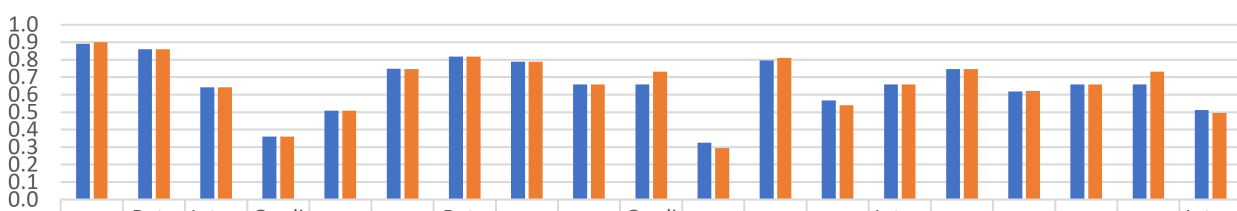




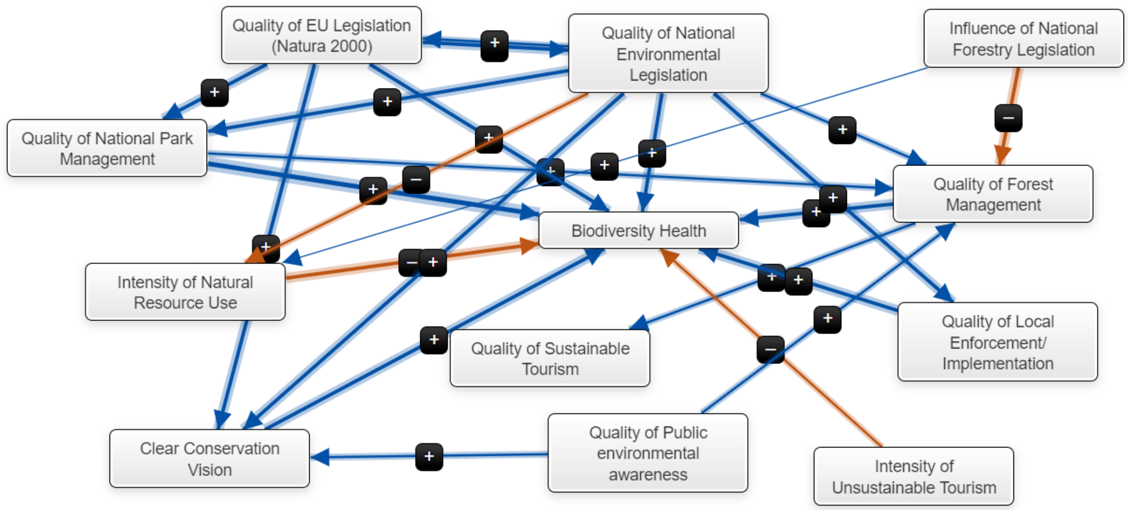
	Biodiversity Health	Frequency & Severity of Climate Change	Rate of Transportation, Industry, Urbanization & Infrastructure Develop...	Water Conditions (Quantity & Quality)	Quality of Ecosystem Services	Intensity of Forestry Practices	Intensity of Agricultural Practices	Intensity of Wildlife & Game Management	Quality of National Legislation Implementation
Baseline	0.4304	0.6196	0.7202	0.7599	0.7506	0.5818	0.6527	0.6590	0.6590
With Policy	0.4432	0.6151	0.7210	0.7692	0.7617	0.5822	0.6535	0.6590	0.7311

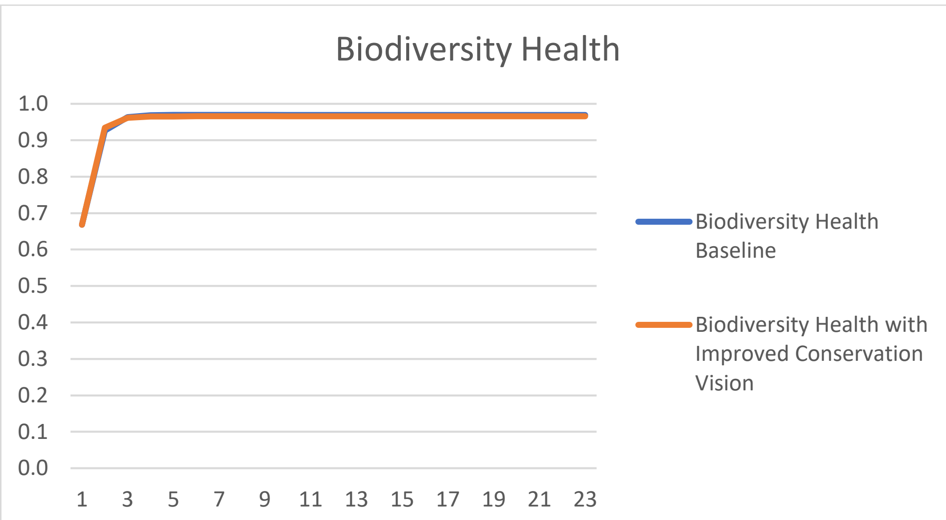


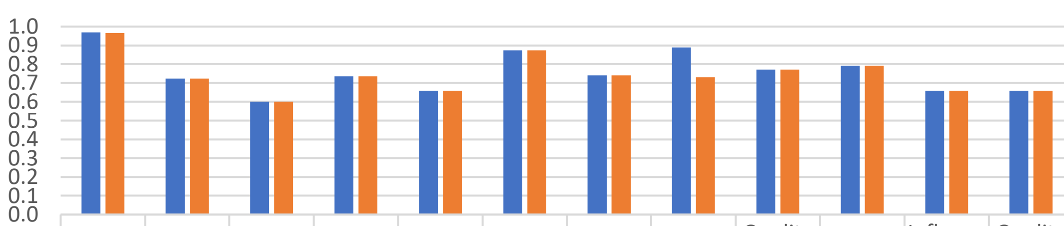




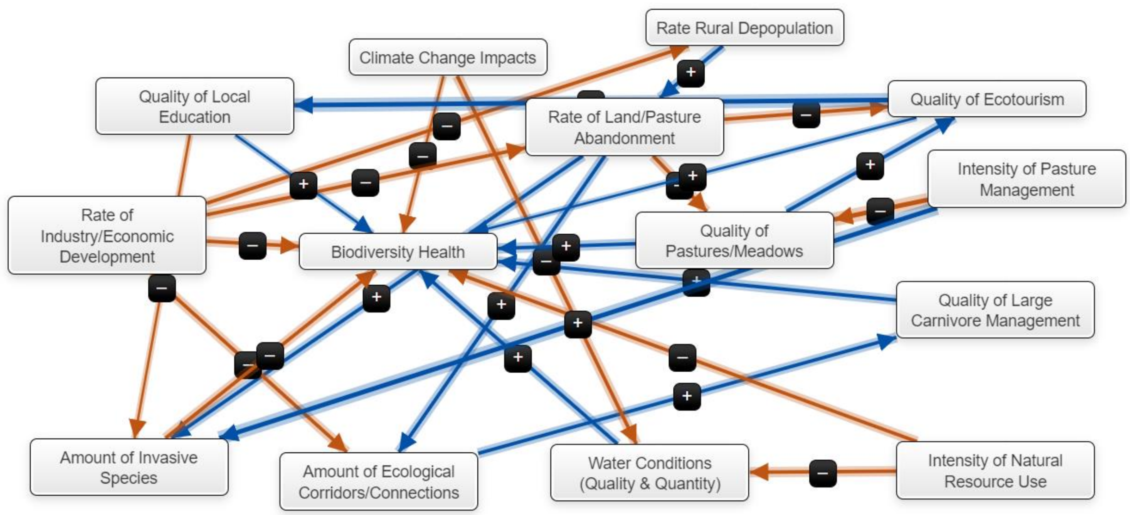
	Biodiversity Health	Rate of Hay Meadow Abandonment	Intensity of Agriculture (Mechanization)	Quality of Traditional Pasture Mowing	Quality of Pastoral Practices	Rate of Ecosystem Succession	Rate of Abandoning Livestock Kee...	Rate of Aging Village Population	Rate of Rural Depopulation	Quality of National Forest Legislation	Amount of Illegal Logging	Quality of Reforestation	Rate of Erosion	Intensity & Severity of Climate Change	Amount of Pathogens/Disease	Forest Health	Quality of Agricultural Subsidies	Quality of Law Enforcement	Intensity of Unsustainable Tourism...
Baseline	0.891	0.859	0.641	0.360	0.509	0.748	0.817	0.788	0.659	0.659	0.325	0.795	0.566	0.659	0.745	0.618	0.659	0.659	0.512
With Policy	0.900	0.859	0.641	0.360	0.509	0.746	0.817	0.788	0.659	0.731	0.294	0.811	0.540	0.659	0.745	0.621	0.659	0.731	0.496

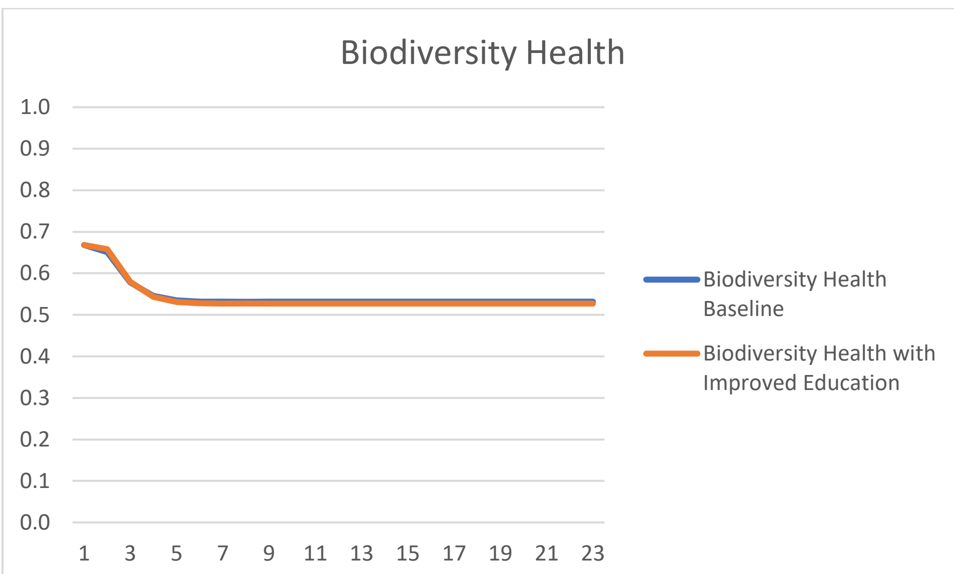


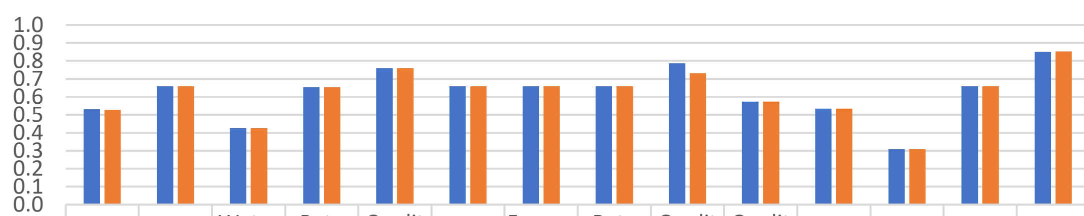




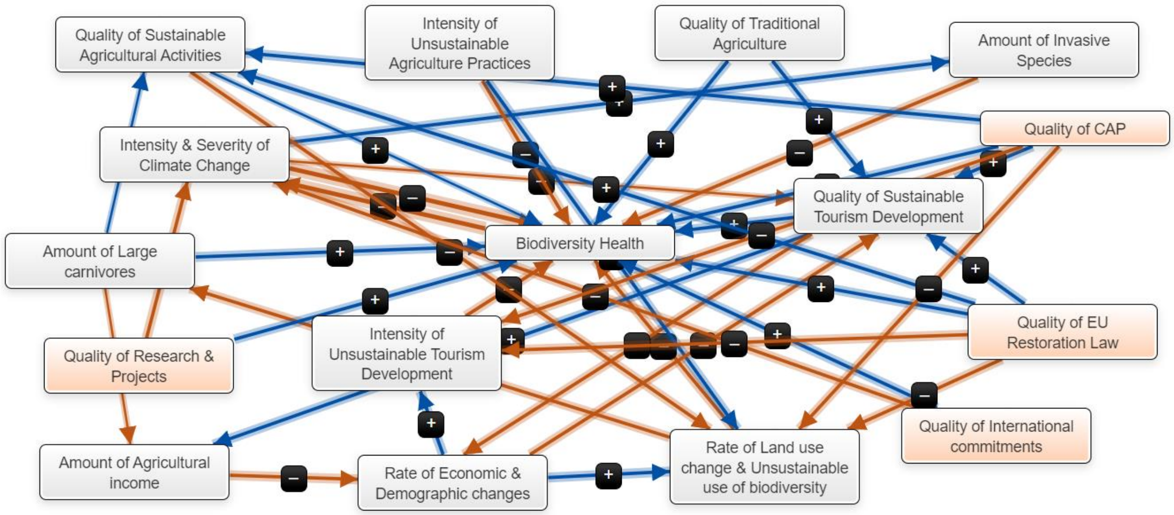
	Biodiversity Health	Quality of Forest Management	Intensity of Natural Resource Use	Quality of Sustainable Tourism	Intensity of Unsustainable Tourism	Quality of National Park Management	Quality of EU Legislation	Quality of Conservation Vision	Quality of National Environmental Legislation	Quality of Law Enforcement/Implementation	Influence of National Forestry Legislation	Quality of Public Environmental/ESD Education &...
Baseline	0.9694	0.7239	0.6008	0.7361	0.6590	0.8734	0.7406	0.8883	0.7713	0.7910	0.6590	0.6590
With Policy	0.9659	0.7239	0.6008	0.7361	0.6590	0.8734	0.7406	0.7311	0.7713	0.7910	0.6590	0.6590

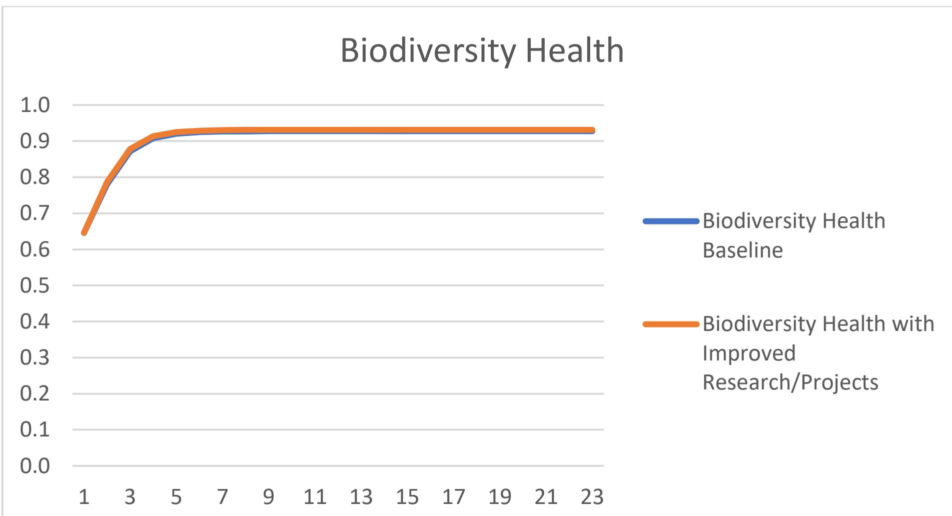


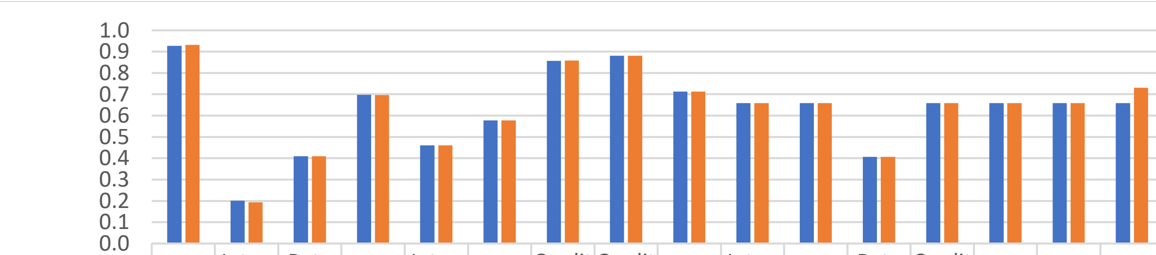




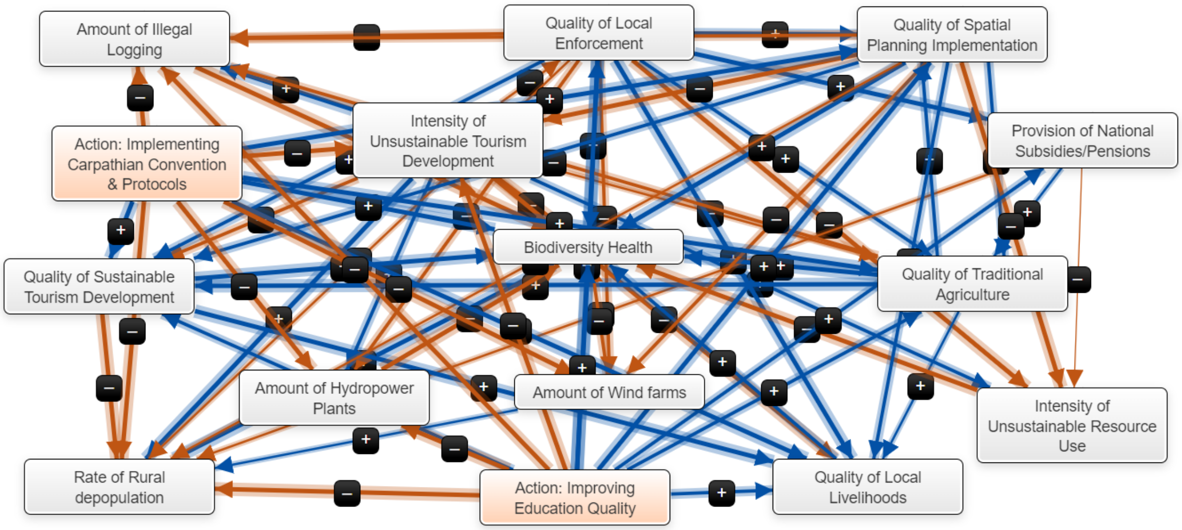
	Biodiversity Health	Quality of Ecological Connectivity	Water Conditions (Quantity & Quality)	Rate of Grassland/Pasture Abandonm...	Quality of Large Carnivore Management	Intensity of Natural Resource Use	Frequency & Severity of Climate Chan...	Rate of Transportation, Industry,...	Quality of Public Environmental/ESD Educ...	Quality of Sustainable Tourism Deve...	Rate of Rural Depopulation	Quality of Grasslands/Pastures	Intensity of Pasture Management	Amount of Invasive Species
Baseline	0.5315	0.6580	0.4258	0.6529	0.7605	0.6590	0.6590	0.6590	0.7863	0.5741	0.5348	0.3085	0.6590	0.8512
With Policy	0.5275	0.6580	0.4258	0.6529	0.7605	0.6590	0.6590	0.6590	0.7311	0.5741	0.5348	0.3085	0.6590	0.8528

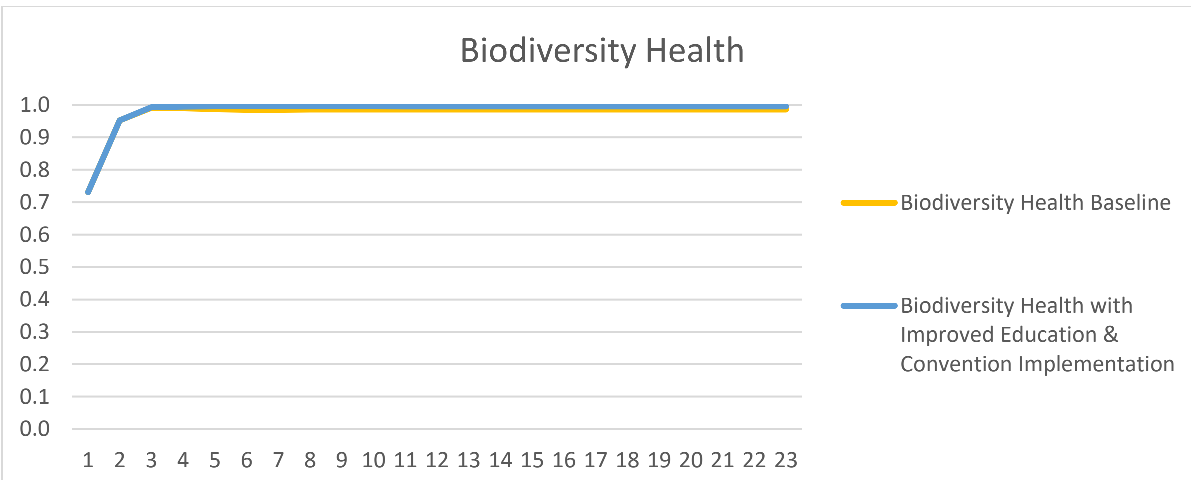


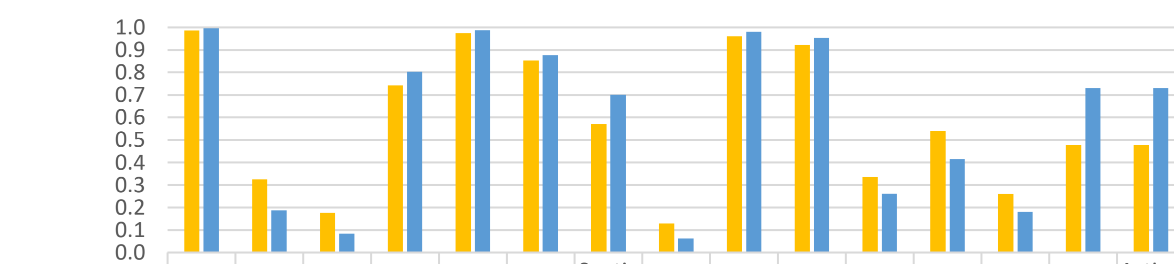




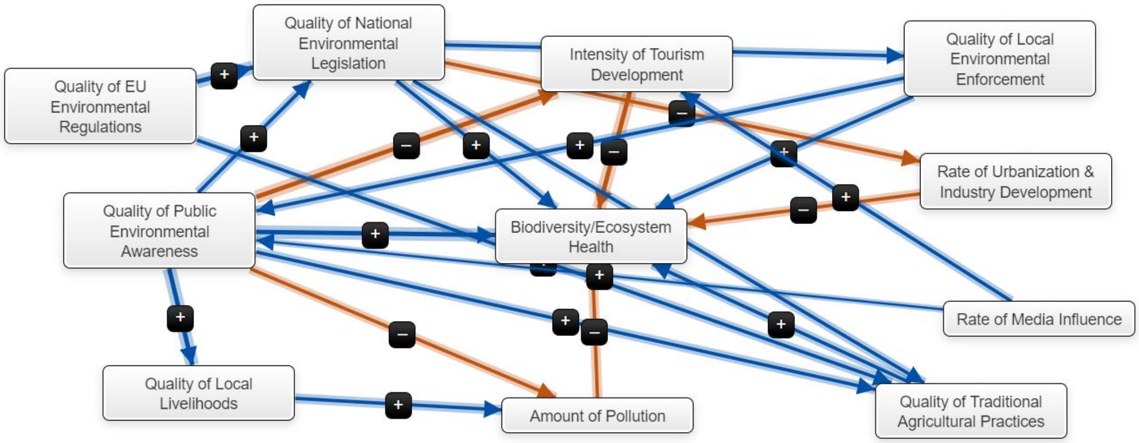
	Biodiversity Health	Intensity & Severity of Climate Change	Rate of Land Use Change & Unsustain…	Amount of Invasive Species	Intensity of Unsustainable Tourism Dev…	Amount of Large Carnivores	Quality of Sustainable Tourism Develop…	Quality of Sustainable Agricultural Acti…	Amount of Agricultural Income	Intensity of Unsustainable Agricultural I…	Quality of Traditional Agriculture	Rate of Economic & Demographic…	Quality of International Commitments	Quality of EU Restoration Law	Quality of CAP	Quality of Research & Projects
Baseline	0.927	0.201	0.409	0.698	0.459	0.577	0.857	0.881	0.713	0.659	0.659	0.406	0.659	0.659	0.659	0.659
With Policy	0.931	0.192	0.409	0.696	0.459	0.577	0.857	0.881	0.713	0.659	0.659	0.406	0.659	0.659	0.659	0.731

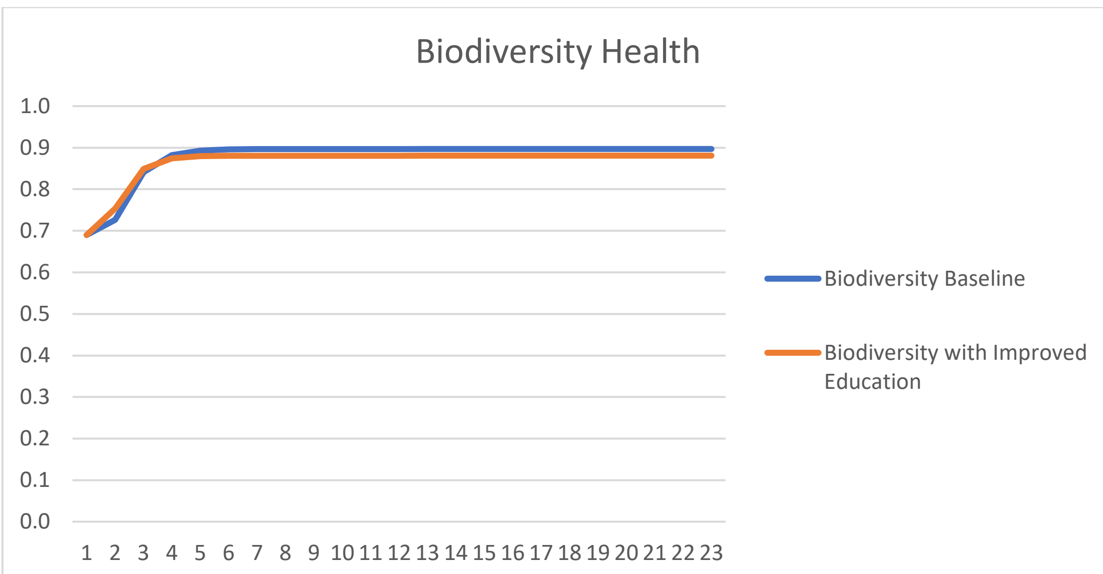


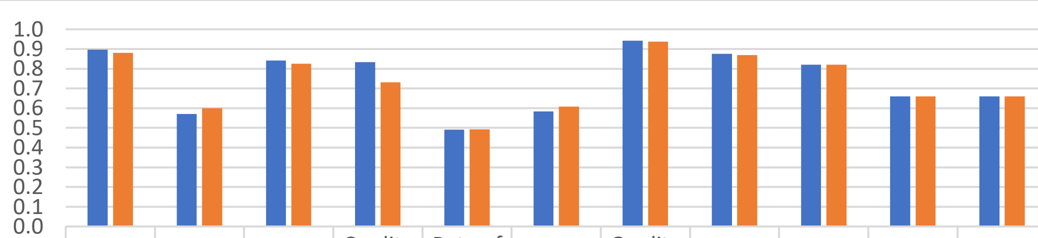




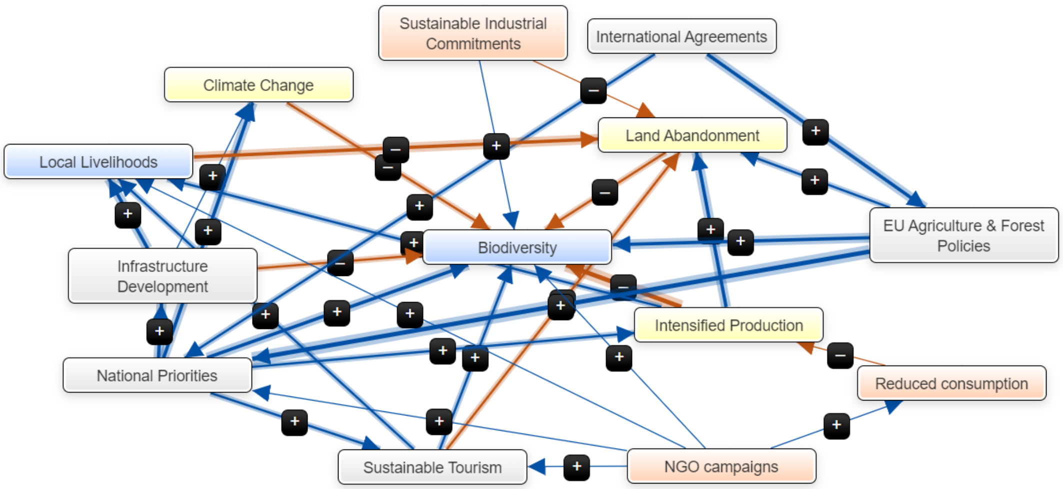
	Biodiversity Health	Hydropower Plant Amount	Illegal Logging (Amount)	Local Enforcement Quality	Local Livelihood Quality	National Subsidies/Pensions Provision	Spatial Planning Implementation Quality	Rural Depopulation Rate	Sustainable Tourism (Amount)	Traditional Agriculture Quality	Unsustainable Resource Use (Amount)	Unsustainable Tourism (Amount)	Wind Farm Amount	Action: Education Quality	Action: Convention Protocols Implementation
Baseline	0.9864	0.3248	0.1762	0.7423	0.9755	0.8532	0.5711	0.1297	0.9602	0.9224	0.3347	0.5387	0.2601	0.4774	0.4774
With Policies	0.9957	0.1869	0.0844	0.8039	0.9884	0.8772	0.7011	0.0621	0.9801	0.9539	0.2608	0.4141	0.1804	0.7311	0.7311

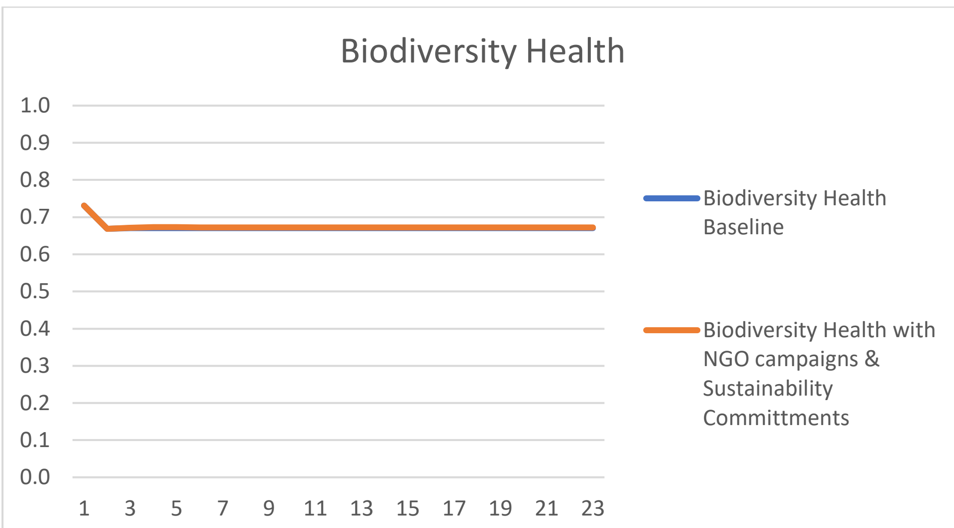


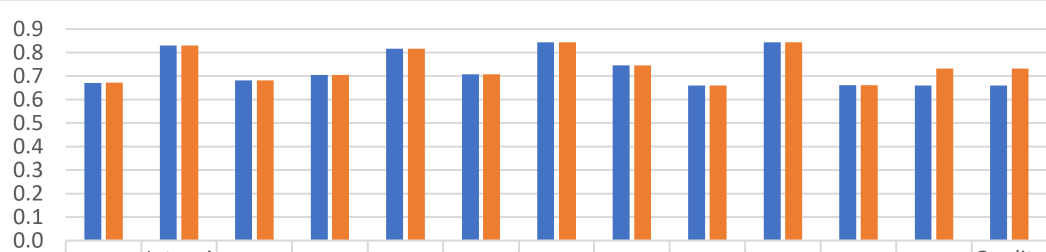




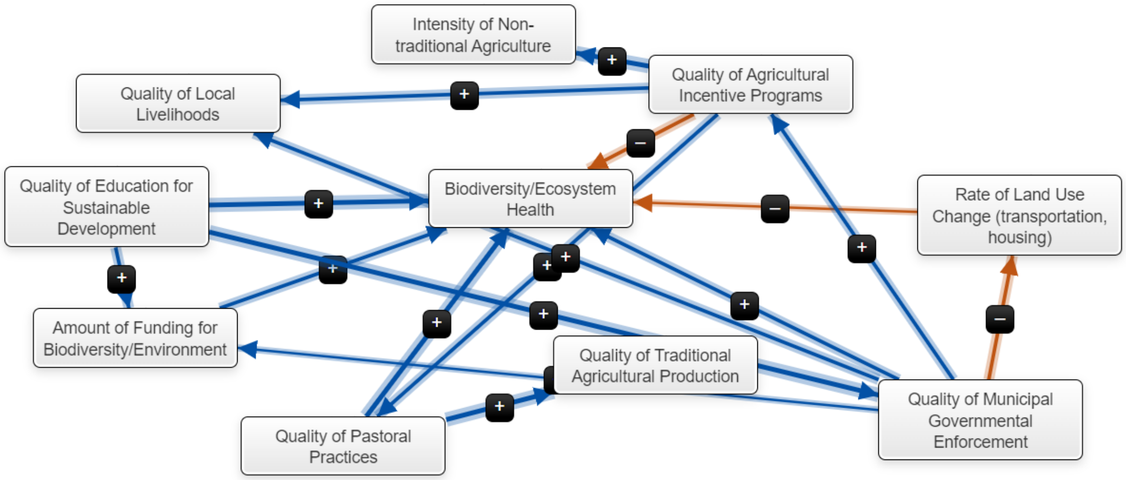
	Biodiversity Health	Intensity of Unsustainable Tourism Development	Quality of Local Livelihoods	Quality of Public Environmental/ ESD Education &…	Rate of Transportation, Industry, Urbanization & Infrast…	Amount of Pollution	Quality of Traditional Agricultural Practices	Quality of National Environmental Legislation	Quality of Law Enforcement/Implementation	Quality of EU Environmental Regulations	Quality & Amount of Media Influence
Baseline	0.8969	0.5700	0.8422	0.8327	0.4916	0.5839	0.9429	0.8755	0.8207	0.6590	0.6590
With Policy	0.8809	0.5993	0.8259	0.7311	0.4928	0.6071	0.9377	0.8692	0.8198	0.6590	0.6590

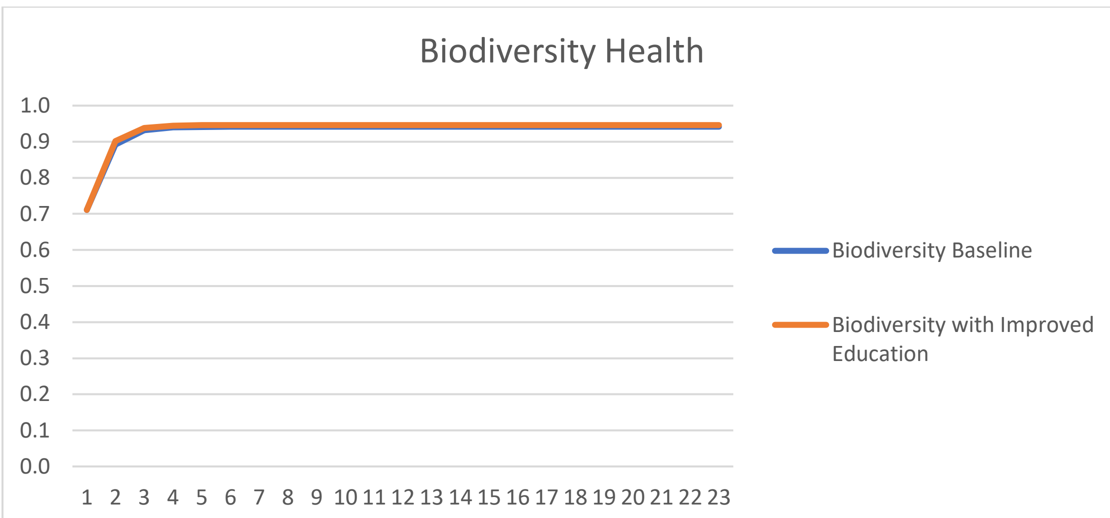


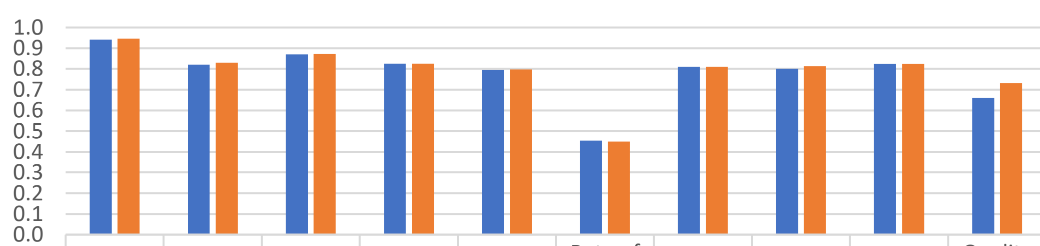




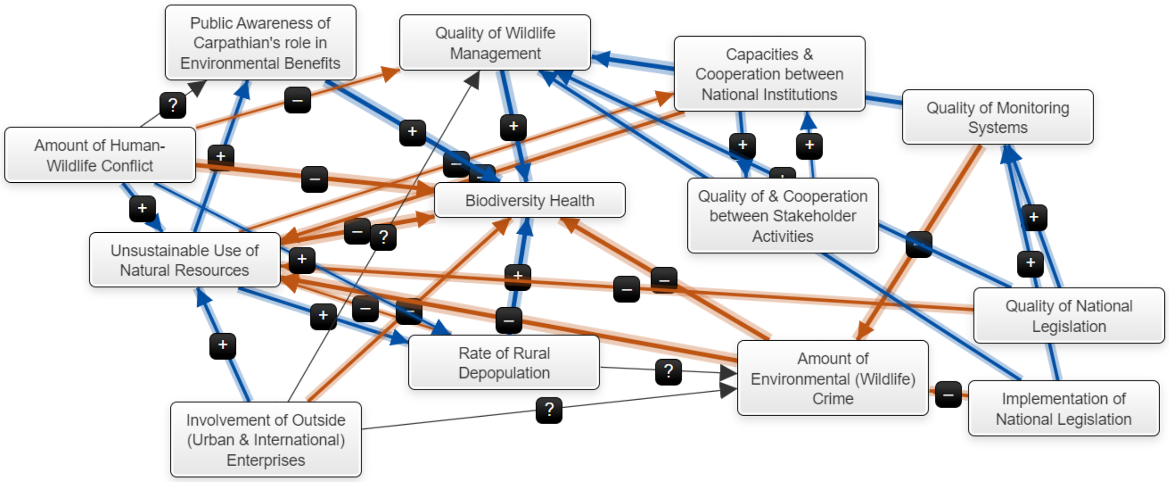
	Biodiversity Health	Intensity & Severity of Climate Change	Rate of Land Abandonment	Rate of Intensified Production	Rate of Infrastructure Development	Quality of Sustainable Tourism	Quality of National Priorities	Quality of EU Agriculture & Forest Policies	Quality of International Agreements	Quality of Local Livelihoods	Amount of Reduced Consumption	Quality of NGO Campaigns	Quality of Sustainable Industrial Commitments
Baseline	0.6702	0.8301	0.6819	0.7039	0.8162	0.7074	0.8430	0.7456	0.6590	0.8430	0.6610	0.6590	0.6590
With Policy	0.6725	0.8301	0.6817	0.7039	0.8162	0.7075	0.8432	0.7456	0.6590	0.8432	0.6612	0.7311	0.7311

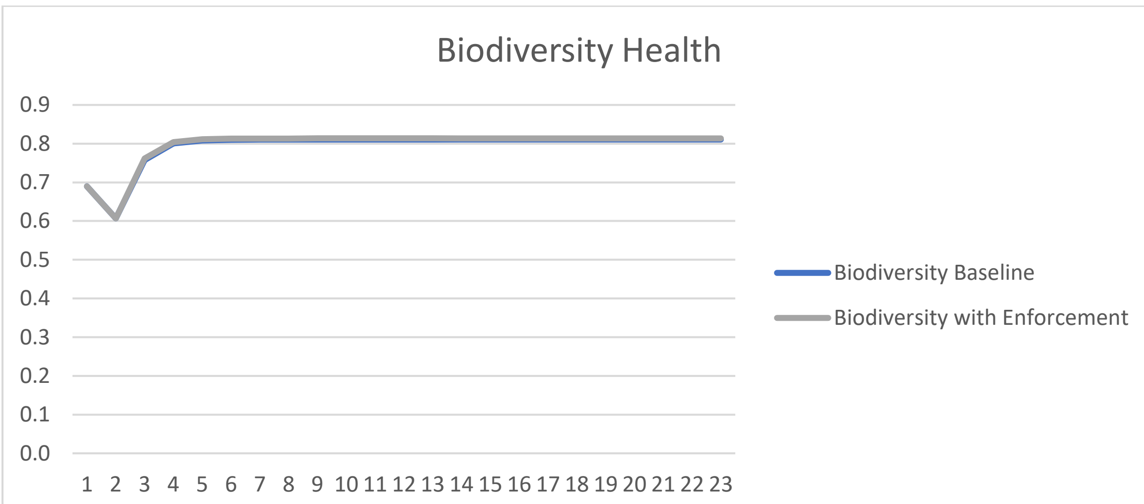


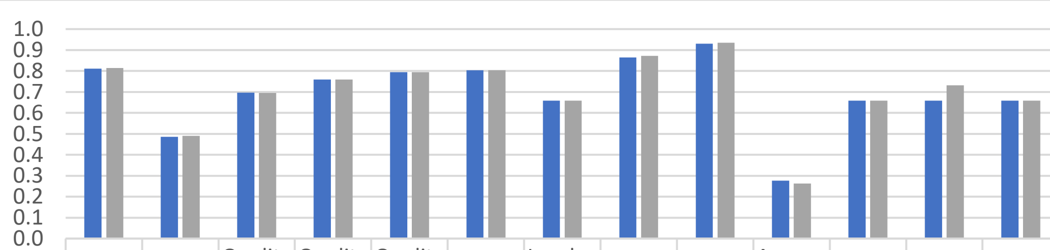




	Biodiversity Health	Quality & Amount of Funding	Quality of Local Livelihoods	Quality of Traditional Agricultural Practices	Quality of Agricultural Subsidies/Incentives	Rate of Transportation, Industry, Urbanization & Infrastructure…	Quality of Pastoral Practices	Quality of Law Enforcement/Implementation	Intensity of Agricultural Practices	Quality of Public Environmental/ESD Education & Civic Initiativ…
Baseline	0.9416	0.8209	0.8709	0.8255	0.7951	0.4532	0.8093	0.8013	0.8233	0.6590
With Policy	0.9461	0.8300	0.8721	0.8255	0.7967	0.4500	0.8095	0.8132	0.8236	0.7311



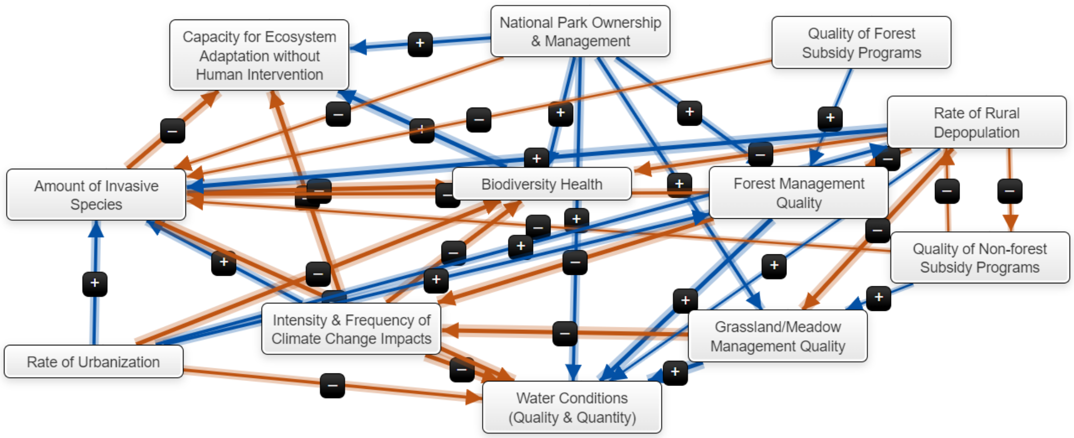


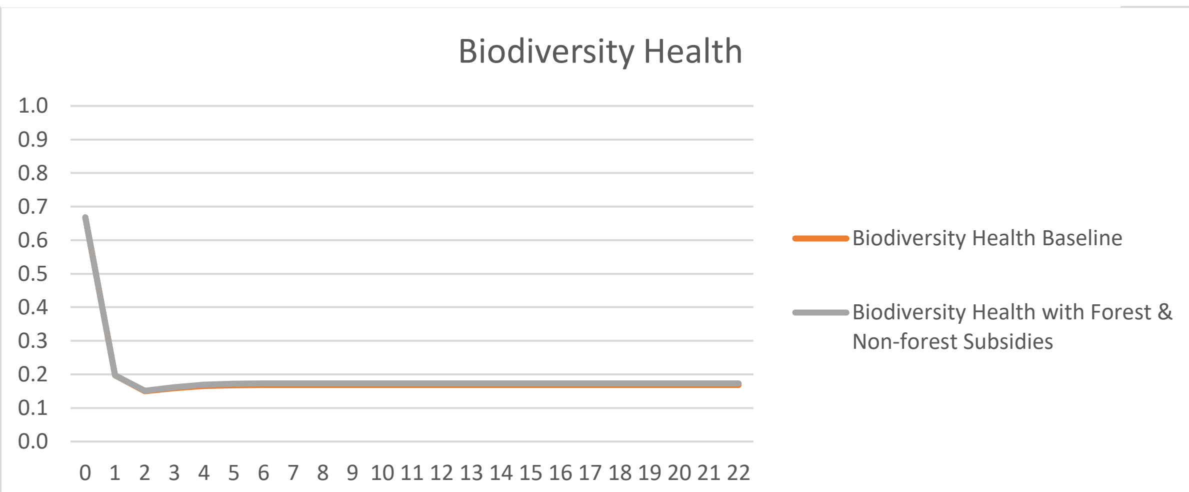


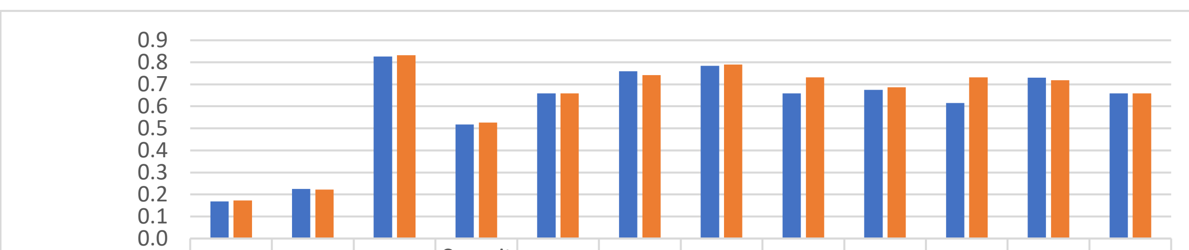
	Biodiversity Health	Intensity of Natural Resource Use	Quality of Policymaker Cooperation (Intersectoral/Mul...	Quality of Public Environmental/ESD Education & Civic...	Quality & Cooperation between Stakeholder Activi...	Rate of Rural Depopulation	Involvement of Outside Enterprises (Urban &...	Quality of Monitoring Systems	Quality of Wildlife Management	Amount of Wildlife Crime & Illegal Markets	Quality of National Legislation	Quality of Law Enforcement/Implementation	Amount of Human-Wildlife Conflict
Baseline	0.8107	0.4856	0.6960	0.7591	0.7943	0.8033	0.6590	0.8645	0.9299	0.2763	0.6590	0.6590	0.6590
With Policy	0.8135	0.4903	0.6956	0.7599	0.7943	0.8039	0.6590	0.8719	0.9343	0.2623	0.6590	0.7311	0.6590

Appendix B: Focus Group Maps and Scenario Results

CNPA Map

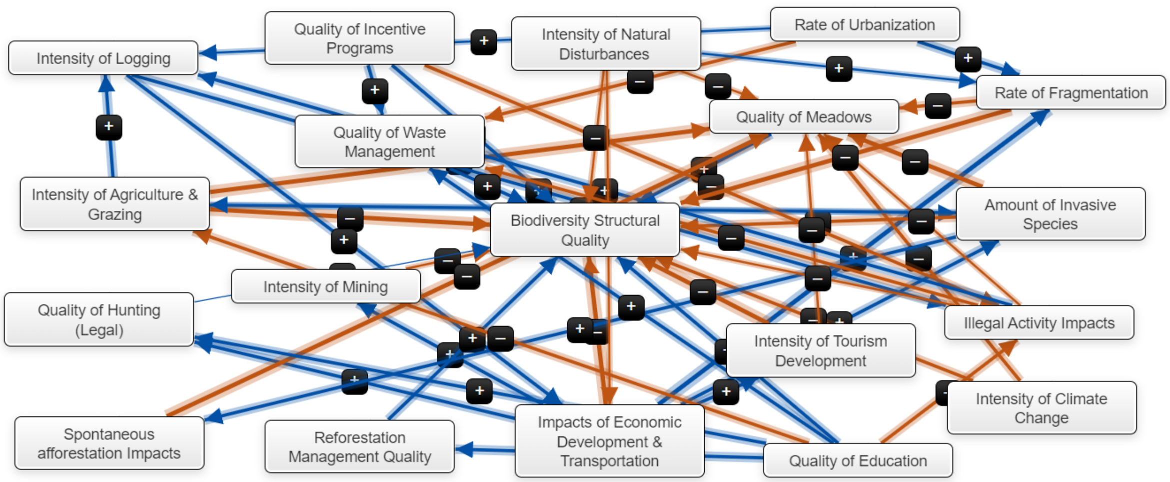


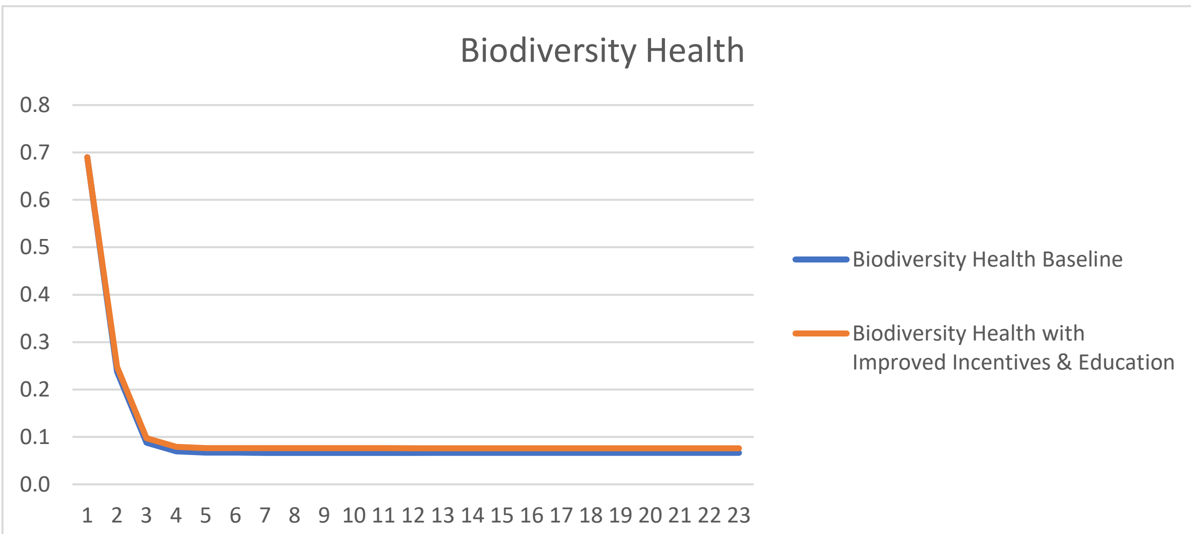


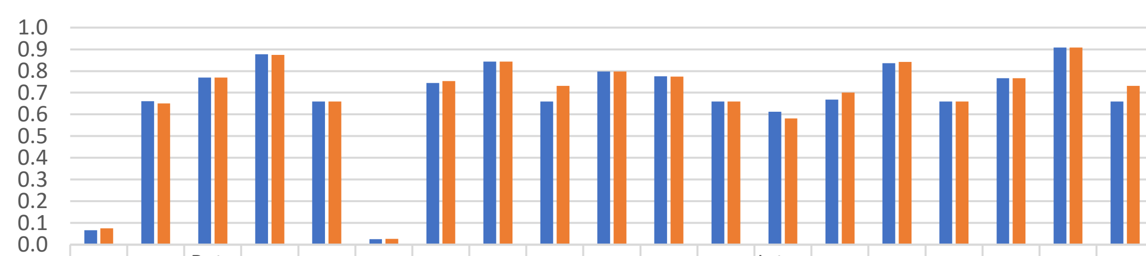


	Biodiversity Health	Intensity & Frequency of Climate Change Impacts	Water Conditions (Quality & Quantity)	Capacity for Ecosystem Adaptation without Huma...	National Park Ownership & Management Quality	Amount of Invasive Species	Forest Management Quality	Quality of Forest Subsidy Programs	Grassland/Meadow Management Quality	Quality of Non-forest Subsidy Programs	Rate of Rural Depopulation	Rate of Urbanization
Baseline	0.1681	0.2258	0.8260	0.5178	0.6590	0.7591	0.7835	0.6590	0.6745	0.6151	0.7308	0.6590
With Policy	0.1732	0.2217	0.8320	0.5264	0.6590	0.7417	0.7905	0.7311	0.6870	0.7311	0.7193	0.6590

ESD Map

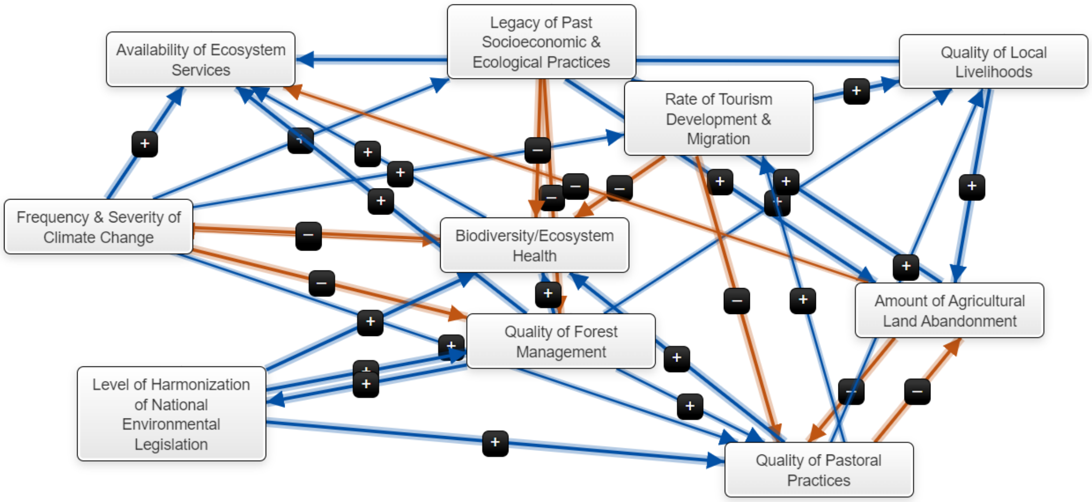


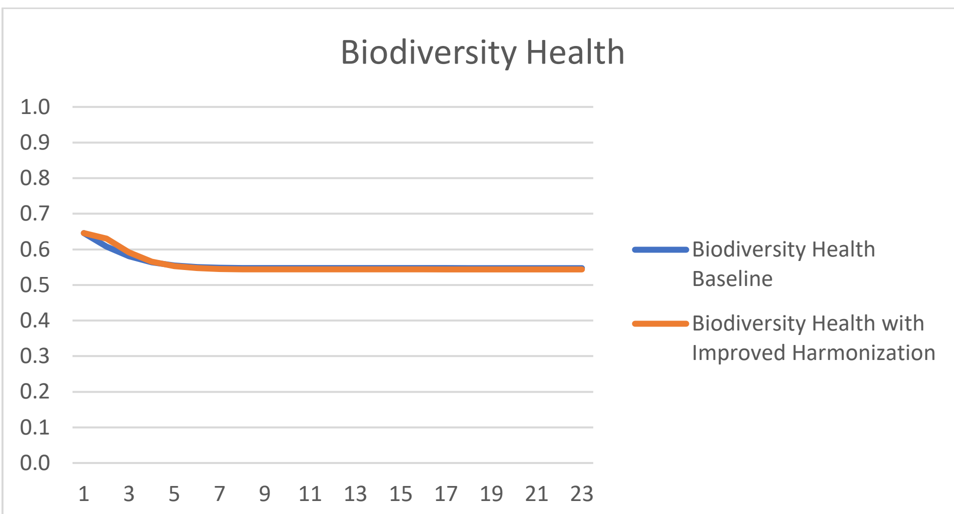


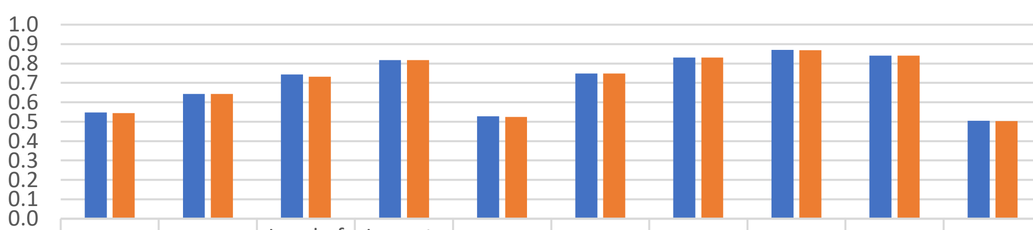


	Biodiversity Health	Intensity of Agriculture & Grazing	Rate of Economic & Transportation De...	Intensity of Logging	Intensity of Climate Change	Quality of Meadows	Reforestation Management Quality	Amount of Invasive Species	Quality of Incentive Programs	Intensity of Tourism Development	Intensity of Mining	Rate of Urbanization	Intensity of Illegal Activity Impacts	Quality of Waste Mnagement	Quality of Hunting (Legal)	Intensity of Natural Disturbances	Rate of Spontaneous Afforestation	Rate of Fragmentation	Quality of Education
Baseline	0.066	0.661	0.770	0.877	0.659	0.025	0.745	0.843	0.659	0.798	0.775	0.659	0.612	0.668	0.835	0.659	0.766	0.908	0.659
With Policy	0.076	0.650	0.769	0.873	0.659	0.026	0.753	0.842	0.731	0.798	0.775	0.659	0.581	0.700	0.841	0.659	0.766	0.908	0.731

S4C Map







	Biodiversity Health	Frequency & Severity of Climate Change	Level of National Environmental Legislation Harmo…	Impacts of Past Socioeconomic & Ecological Practices	Quality of Forest Management	Rate of Tourism Development & Migration	Quality of Local Livelihoods	Availability of Ecosystem Services	Amount of Agricultural Land Abandonment	Quality of Pastoral Practices
Baseline	0.5472	0.6430	0.7425	0.8166	0.5273	0.7490	0.8303	0.8695	0.8396	0.5051
With Policy	0.5437	0.6431	0.7311	0.8166	0.5245	0.7489	0.8300	0.8691	0.8398	0.5028