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RESEARCH ARTICLE

Study on the Coupled Human – Natural System in Velingrad municipality, Bulgaria: a resilience perspective

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Abstract

The study presents a new look on the socio-ecological relations in retrospective, focusing on their formation and adaptation over time in Velingrad Municipality, Bulgaria. The dependencies between the main components of the system are outlined and the main disturbances in terms of presses and pulses are examined. Examples of trade-offs and synergies are also offered to better understand the cross-scale dynamics of the studied components. The reaction of the system to pulses in its growth phase of the adaptive cycle is reviewed. In addition, the contemporary state of the main components of the coupled human-natural system is analysed in order to identify the slow and fast variables that determine the trajectory of the system at present. The resilience thinking concept is applied in analyzing the processes within the coupled human-natural system and in identifying the mechanisms that may enhance its capacity to absorb shocks.

Keywords

social-ecological systems, variables, resilience, adaptive cycle

Introduction

Humans have continuously interacted with natural systems, resulting in the formation and development of coupled human and natural systems (CHANS) (Liu et al., 2007). The pathways of change of the coupled human–environment systems are formed by continuous, dynamic interactions among numerous changing factors, social as well as biophysical, which enable and constrain human choices of resource management strategies (Haberl et al., 2016). Using combined social and environmental perspectives to understand how people and wildlife are interlinked, together with the mechanisms that may weaken or strengthen those linkages, is of utmost importance (Carter et al., 2014). CHANS science uses a holistic approach to integrate patterns and processes that connect human and natural systems, as well as within-scale and cross-scale interactions and feedbacks between human and natural components of such systems (Liu e al., 2021)

Drivers of different origin – both endogenous and exogenous affect these interactions, and some scientists consider the exogenous more influential (Bruley et al. 2021). Climate change is the external driver influencing all factors at once and making the ecosystems more vulnerable. Furthermore, conserving wildlife while simultaneously meeting the resource needs of a growing human population is a major sustainability challenge (Carter et al., 2014). Ecosystem services provide regulating, provisioning, supporting, and cultural benefits for human survival, but clarification is needed how the trade-off/synergy relationships can be used to optimize function (Deng et al., 2023). Otherwise, the conjunction of social and environmental events contributes profoundly to the production of trap processes (socio-ecological traps) (Boonstra et al., 2014). Human activity as an agent of change, and thus of the environmental dynamics (Gonzalez et a., 2014). Therefore, a deeper understanding of the correlations of these dynamics and the trade-offs in the ecosystem are needed to support management of ongoing changes and reduce socio-ecological traps.

Liu et al. (2007) distinguishes the interactions within a CHANS, categorizing them into direct and indirect interactions that form a complex web that leads to positive and negative effect in both human and natural systems as well as unique properties not belonging to human or natural systems separately but emerging from the interactions between them. Emergent properties are cornerstones for comprehending human – ecosystem interactions in ways that provide insights for sustainable development (Marten, G., 2001). Untangling complexities, such as reciprocal effects and emergent properties, is essential to developing effective policies for ecological and socio-economic sustainability. The emergent properties within the CHANS suggest that it possesses its own homeostasis and mechanisms for reaching balance, the way the natural ecosystems do (Liu et al. 2007). This resonates with the resilience concept i.e. – the capacity of a system to absorb disturbances and still retain its basic function and structure (Walker and Salt, 2006).

Each society has its own perception of its metabolism with nature (Gonzalez et a., 2014). Hence, looking for answers to these questions in the communities that rely on local resources seems reasonable. Most local communities that have been in one place for long periods of time have developed mechanisms for protection of ecosystem services (McMichael et al. 2005). Apart from that, investigating the way these relationships evolved over time and how the trade-offs behaved under different stressors could be a source of information to build the scenarios. History shows that the human well-being, and indeed the persistence of civilizations, is strongly interlinked to the capacity of the environment to continue deliver ecosystem services at the local and regional scale (McMichael et al. 2005). In Bulgaria these relations have undergone numerous transitions in time. In historical aspect, the country is an example of a strong dependency and relation to the natural resources while periods of overexploitation of such resources (forests in particular) are followed by restoration and management as well (Boev, 2021). In the Rhodope mountains, the importance of material benefits from forests has traditionally been high and are still significant for the development in the region. Forests are crucial to the preservation of the existing potential of landscape functions (Borissova et al. 2015). Therefore, analyzing forest landscapes as socio-ecological systems is of great importance for resilient management (Fisher, 2018) and is considered as fundamental at regional context in present study.

The study deals with the relationships within a CHANS, built on very straightforward and strong connections between society and environment. That makes the correlation easier to follow. This paper focuses on the formation, adaptation and dependencies between the main components of the system in a retrospective. The cross-scale dynamic is examined by looking for examples of trade-offs and synergies that formed over time and the reaction of the CHANS to disturbances in terms of presses and pulses (Collins et al., 2011). The retrospective study allows looking at the system from resilience perspective and following its transformation in the different phases of its adaptive cycle (Salt and Walker, 2006). In addition, the contemporary state of the main components of the coupled human-natural system is analyzed to outline the slow and fast variables that determine the trajectory of the system nowadays. In this regard an analysis of the trends in the basic demographic, economic, social, and ecological parameters is performed covering the period 1985-2023. The main objective of the study is to better understand the processes and interdependencies within the coupled human-natural system and to identify the mechanisms that may enhance its capacity to withstand shocks. With this regard the study reflects on the human-ecosystem relationships that formed over time and the transformation they experience currently by investigating the dynamics of system's key components and their reactions to disturbances in the past.

Materials and methods

The region of investigation is Velingrad municipality, situated in the western Rhodope Mountains in Bulgaria. The study area covers a territory within the altitude range 750 – 2186 m asl. The forests cover 83,46% of the territory of the municipality (National Statistical Institute, 2021) with dominated by *Pinus sylvestris* plantations – 35% (Forest management plan, 2018), managed traditionally since the beginning of the XIX century (Tsanov, 2014). The regional center is town of Velingrad (20031 inhabitants in 2022, National Statistical Institute) with 20 smaller villages (32270 inhabitants in 2022, National Statistical Institute). Velingrad is located in the Chepino basin, which is in the lowland at about 800 m asl, while the villages are mostly scattered in the higher parts of the mountain. The population in the villages has very distinct cul-

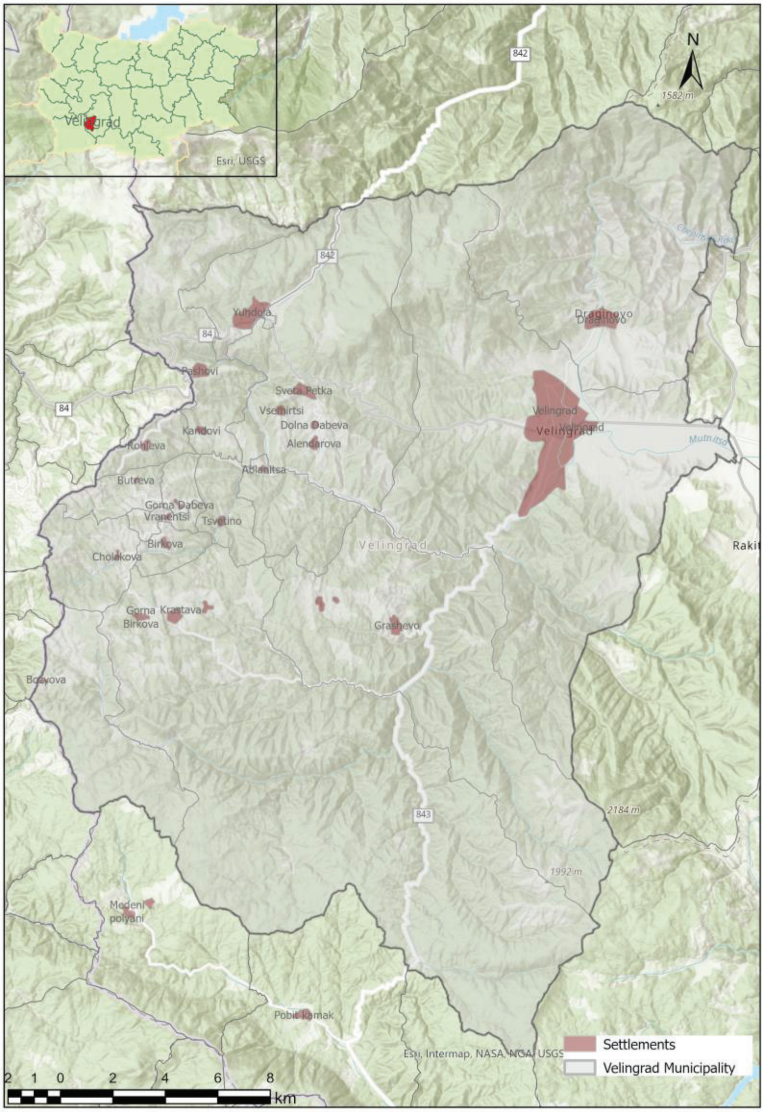

Figure 1. Study object – An overview of Velingrad municipality, Basemap: Google maps

tural specifics – they are predominantly Bulgarian Muslims (Pomak) that were forcefully converted to Islam in the 17th century (Aleksiev et al., 2002). They live in closed communities and have preserved many of the old traditions, typical customs, and close-to-nature way of life, while the town has a mixed population and is a famous spa center. Despite the ways of exploitation of the forests in the past and nowadays, forest management remains the main occupation of the local population (Aleksiev et al., 2002). The natural resources (forests and mineral springs) have to a big extent determined the socio-economic development of the area and are a major factor for its profile today as well.

One of the important factors for the assessment of the vulnerability of modern socio-ecological systems to future human activities and climate change can be greatly improved by knowing the rates and directions of past trajectories in key processes (Petrosillo et al., 2015). In order to outline the cause-effect relationships that formed these processes, a retrospective review of the forestry sector and the economic development was done. Combining demographic, economic, and cultural factors, as well as the land use, the elements linking ecosystem services (ESs) and human well-being at fine scale (Zhang et al., 2021) are considered. Therefore, statistical data on demography, climate parameters and land use is analyzed to complete the analysis of socio-ecological connections. The demographic trends are considered indicative because they form the social aspect of the human-nature system and relate to the economic trends. Land use changes have both environmental and socio-economic impacts (Appelt et al., 2020) and are often a manifestation of socio-ecological changes. Climate fluctuations are also considered since local communities that are strongly dependent on natural resources are considered particularly vulnerable to climate change (Garcia del Amo and Junqueira, 2023).

The investigation was carried out in a series of well-defined, successive stages, each building upon the previous one, following a systematic, step-by-step approach.

A comprehensive survey of the existing literature was undertaken to collate the necessary data for this study. The research started with a literature review that covered sources that trace back the development of the forests (Alexiev et al., 2002; Diviziev, 2007; Tsanov, 2011; Tsanov, 2014; Panayotov et al., 2016). This information was supplemented with data from Forest management plans. Socio-economic information was obtained from local strategic plans and development programs – Plan for development of forests in the territory of Velingrad municipality; Municipal development plan 2007-2013, Integrated development plan of Velingrad municipality 2021-2027, Environmental protection program for the period 2021-2028. To complement the trends and conclusions, available statistical data for past periods was collected for population number and economic parameters –e.g. gross domestic product by sectors, manufactured product incomes, employment (NSI, 2024). All the information was processed and georeferenced. The land use data was gathered from two sources – the Land balance, provided by the National Statistical Institute and the Corine Land Cover data, compared for reference years 1990 and 2018. Data for water and air quality as well as for waste management was collected from recent monitoring reports (EEA, 2024).

The climate data was collected for the period 1975-2022 from statistical climate models (Visual Crossing Weather), including the daily temperature, precipitation and humidity values that were later summarized by pivot tables. The data was gathered for 8 locations, situated in the different parts of the municipality, and covering altitude from 777 m. asl to 1573 m asl. The data was gathered on a daily basis and processed by pivot tables to define the trends of main climate parameters. The mean annual temperatures for the selected locations for the period 1975 – 2022 were georeferenced and

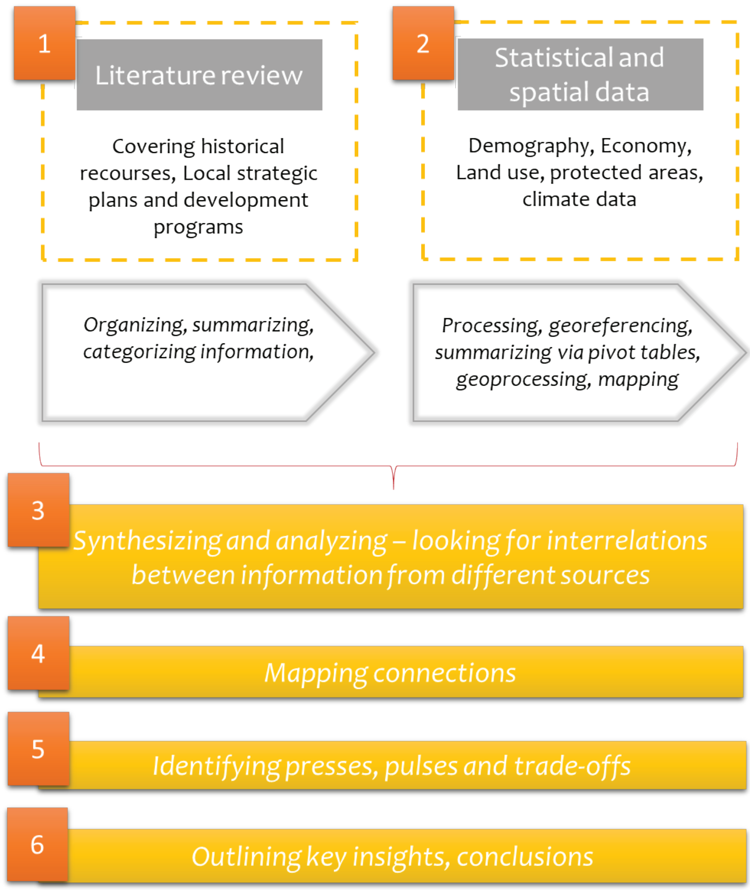

Figure 2. Methodological workflow

interpolated using Inverse Distance Weighted Interpolation to visualize the patterns in the whole study area. The trends were juxtaposed with data from Meteoblue (2024). Anomalies for temperature and precipitation from Meteoblue (2024) were used to complete the results.

The data is very heterogeneous, and the different sources provided data with different resolution and time range. So, when overlaying the data, common trends could be outlined for the period 1985-2022. Nevertheless, the obtained data by components is reviewed in its original time-range in order not to lose any information.

All the data was synthesized and analyzed with focus on finding interrelations between information from different sources. Human well-being has a two-way interaction with ecosystem condition, mediated in one direction through the services that ecosystems provide to people, and in the other by the largely unintended impacts of human activities on ecosystem functioning (McMichael et al. 2005). In the present paper interrelations are identified in the form of linkages that exist in between key components of the CHANS – ecological, economic, demographic, placing in the center forests. To simplify the approach, the presented linkages are unidirectional. The main aim is to identify interdependencies and patterns of behavior and reaction of the socio-ecological system to disturbances. Attempts to identify and assess linkages between human and nature have already been made, using different aspects, and chasing different goals (McMichael et al. 2005, Santos-Martín et al., 2013, Yang et al., 2015). The approach used in the present study is based on two stages – first, breaking down the leading economic sectors of the study area into input natural resources that they rely on, by again preserving the general idea to delineate the needs from the past decades from the contemporary ones and those in the villages from this in the town. Then comes the second stage where the ecosystem services, ecological problems and threats are included in an attempt to put all these key-role actors in one chart and draw the connections that exist and are best manifested by using different colors. The main ecological issues included in the chart are the ones outlined in the analysis of the strategic documents and analyzed statistics, i.e. water pollution, soil damage, air pollution, deforestation, biodiversity loss, solid waste pollution. The leading economic sectors are related both to the ecological issues that they contribute to and the ecosystem services that they rely on. The sectors related to the villages/town and those that are more relevant for the past or present are also indexed. The connections are drawn upon expert opinion. The purpose of the chart is to summarize the socio-ecological connections and to illustrate their complexity without going into further scientific assessment. To sum up all the findings, from the retrospective review, a table summarizing the periods with their main characteristics, environmental consequence and disturbances was prepared. To differentiate the disturbances, the press-pulse dynamic (PPD) framework (Collins et al., 2011) is used – where pulse events are relatively discrete and rapid while press events are sustained and chronic. The table includes also the slow and fast variables within the socio-ecological system that are changing under the influence of the drivers (Walker et al., 2012).

Results

The results presented include historical analysis of the forestry sector, economic changes over time, identified trends by key fields, maps of connections and a summary table of the changes over time.

Forestry sector – retrospection

The coniferous forests in the Western Rhodope Mountains have significant economic value for the country and therefore the forest administration set them on a very specific management regime (Tsanov, 2014). Historical facts from Konstantin Baykushev (end of XIX century) informed that the region was forested mainly with oak forests and oak mixed with pine, very degraded by logging (Panayotov et al., 2016). Since the start of the railway construction in 1868, more than 2 million traverses have been cut from the oak forests. Forests near the railway were strongly degraded, followed by those near the rivers. In 1885, the railway line to Sofia was established, which again increased logging. As the population increased, large areas of forest were destroyed to create more agricultural fields. Most forests are cut down around the villages of Tsvetino, Sveta Petka, Krastava and along the Ablanitsa river. The steep slopes and torrential rains caused this field to turn into gulches and caused severe erosion in more than 8,500 acres of former forest lands (Tsanov, 2014). The first forest management plans in the region were elaborated in 1903 (Tsanov, 2011). During the First and Second World Wars, no afforestation was carried out (Tsanov, 2014), except first afforestation in 1911-1912 with purely decorative purpose. Very active afforestation followed – during the period 1945-1950, an average of 1,500 decares were afforested each year. These afforestation activities were realized with seeds, not saplings and until late spring. The new-formed saplings were not well managed so few of them survived. Erosion processes have been a big problem due to the steep terrains, big slopes and grazing. After 1951, afforestation is initiated with a new technology by making terraces and platforms that cross the path of water runoff during rain and thus cross the erosion process of the entire slope (Tsanov, 2014). From 1950 the average annual afforestation of 3,547 decares started, which reached 8,076 decares in 1960. For comparison, in 2012, 12,041 decares were planted in the whole country (Tsanov, 2014). On May 26, 1961, a strong wind vortex swept away the stands of the most valuable conifer plantations in the area on a territory of 2,800 hectares. In just 7 minutes, over one million cubic meters of wood fell. An active campaign to restore the felled plantations began in 1964. In 1977, the creation of 100,000 decares of new forests was announced. The volume of logging increased continuously during the period 1950-1975, which lead to deterioration of all functions of the forest. Mature and maturing stocks were cut down. These practices did not bear in mind that the renewal processes in the forests take place at different rates and with a different regularity (Tsanov, 2011).

Forestry and felling are changing over time, and currently the new principles for environmentally friendly and sustainable forest management in a mixed and multi-aged forest, composed of adapted local species, whose stock is qualitatively best and optimally high, are recommended (Tsanov, 2011).

Economy

The economic development of this region could be conditionally divided into 4 periods: 1. Ottoman empire – XIV to XIX century; 2. Beginning of the XX century; 3. Planned economy 1944-1989; Market economy 1989 – onwards.

In the first period (Ottoman rule XIV to XIX century) the inhabitants here were weavers, carpenters, and farmers. Later, in the second period, after the road from Pazardzhik field to Chepino was constructed, forestry was strengthened at the expense of the poor weaver business. Forests are the main source of livelihood and sustenance for the local population. The iron and steel crafts, as well as stonework, also took place.

Table 1. Employment by sectors by periods from 1932 to 2019

Employment 1932-1942	Employment 2000 (Municipal development plan 2007-2014 Velingrad municipality)	Employment 2019 (Plan for integrated development Velingrad municipality)
Agriculture – 84%	17,28%	Agriculture – 5.4%
Industry –1.3% Crafts 4.3%	33.51%	Industry – 24.7%
Trade – 4.3%	27,4% (tourism, trade, transport)	Services – 69,9%

Source: Alexiev, 2002, Municipal development plan 2007-2014 Velingrad municipality, Plan for integrated development Velingrad municipality

In the beginning of the XX century, agriculture becomes the main occupation of the locals and main source of income. Agriculture was based on growing rye, barley, corn, oats to potatoes, linen, and fruit. With infrastructural development the importance of forestry was strengthened. After 1949 the agricultural land is nationalized and united, agriculture is strongly developed as a national policy. In the period 1944 -1989 industry is strongly promoted by the political regime and along with agriculture and forestry formed a strong economic base in the region. Forests are the backbone of the economy in this period. In 1948 the woodworking plant „Georgi Dimitrov" (later Yundola-91) started working, processing 110 000 m^3 wood every year. Resin mining was an important industry, and in 1953 the "Crystal" factory was built, which produced balsamic rosin and balsamic turpentine. In 1959 a wooden toys factory is established. It was very successful and exported goods in the country and abroad. In 1960 the first workshop to produce particle boards started working and exporting its production abroad. Furniture production also flourished. The local population was widely occupied in forestry-related sectors either in the plants or as owners of small family workshops. This rapid development of the industry based on timber and timber products stimulated logging and is a prerequisite for exceeding the logging and disturbing the balance in the forests (Divisiev, 2007). Transport is also developed. The population takes an active part in afforestation and forest cultivation, felling, primary processing, and transportation of timber. The traditions in both secondary and higher education in forestry in the region are founded. The economic structure of this region has undergone several great changes. After 1989 agriculture decays – the farms and the processing plants are closed. Agriculture remains the main employment for the villages where single households grow crops and cattle mainly for personal needs. This reflects in land use change– diminishing arable land and increase of the barren lands. Many of the traditional industries such as mining and processing of marble and granite, production of wooden and laminated boards, production of kitchen furniture, metal cutting machines, extraction of aggregates building materials, asphalt production, flax processing, weaving, cultivation of carnations and greenhouse vegetables closed after the transition of the country to a market economy. And these are all productions with negative effects on the environment. Due to the mineral water resources in the region the development of tourism starts. The transition to planned economy led to many structural changes that resulted in total decay of agriculture and industry. The tertiary sector takes precedence – the town economy starts to rely mainly on tourism and supporting trade. Tourism has turned into the dominant economic sector in the region, changing the urban structure of the town, drawing investments, popularizing the whole area and influencing the priorities, policies and funds allocation in the region. For the period 2014-2022 the number of people occupied in forestry and agriculture drops by 15% (NSI, 2024). Unemployment, especially among the young population, appears to be a problem. The villages remain dependent on agriculture, logging, and non-timber products – forestry sector, small-scale livestock breeding and picking forest fruits and mushrooms are the main occupation for the population.

Demography

The demographic analysis is based on the number of inhabitants by settlements, following the trends from 1985 to 2022. The data is derived from the National register of populated places (National Statistical Institute, 2024) that uses both data from census and current statistics. For some of the settlements the number of inhabitants is available since 1934, but since some of them were formed later, or transformed into bigger or smaller settlements, the line of data is straightforward and comparative for the chosen period (1985-2022).

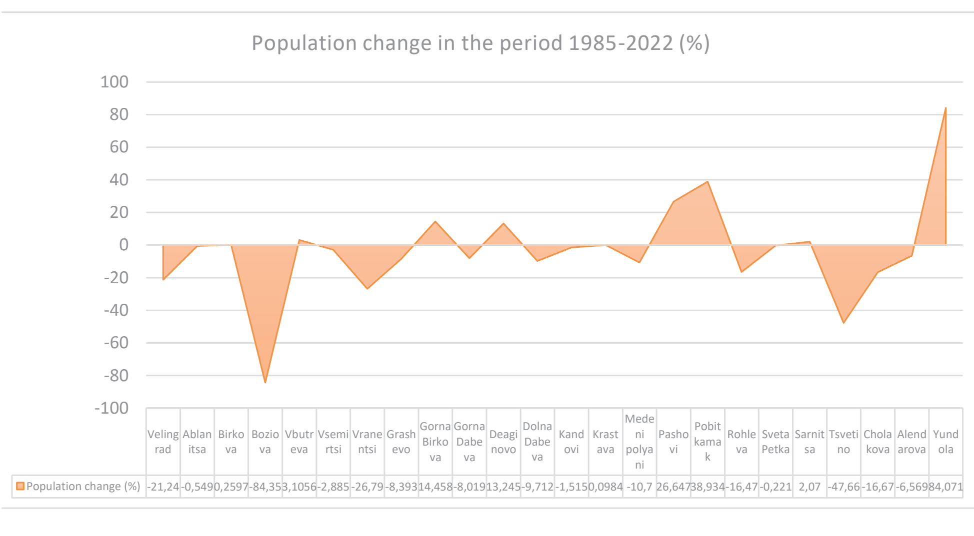

Figure 3. Demographic trends – population numbers for the period 1985-2022, ***S**ource: National Statistical Institute*

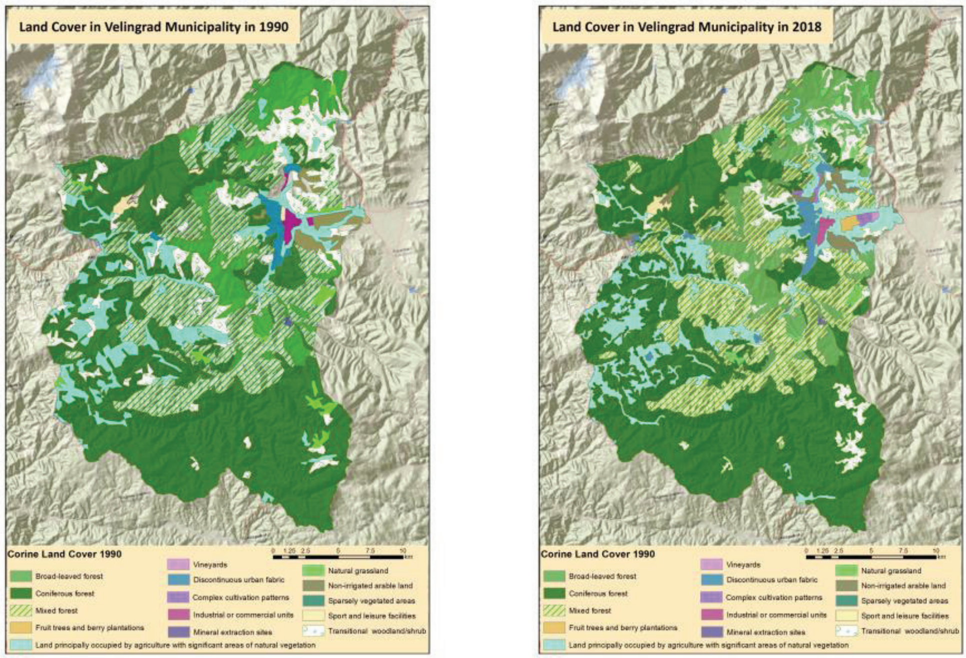

Figure 4. Corine land cover 1990 vs. 2018, *Source: Corine land cover 1990 and Corine land cover 2018*

Table 2. Changes in land use according to Corine land cover 1990 vs. 2018 *Source: Corine land cover 1990 and Corine land cover 2018*

Land Cover	1990 (ha)	2018 (ha)	Difference (%)
Broad-leaved forest	5595.516568	5686.903	1.63321638
Coniferous forest	27897.97999	29043.09	4.10464419
Discontinuous urban fabric	648.85421	789.4571	21.6694047
Fruit trees and berry plantations	26.944649	130.6747	384.974731
Industrial or commercial units	262.925972	158.0244	-39.897771
Land principally occupied by agriculture, with significant areas of natural vegetation	5449.818071	6995.914	28.3696825
Mineral extraction sites	30.280098	26.00884	-14.10582
Mixed forest	13020.96493	12529.19	-3.7768092
Natural grasslands	715.061376	496.4974	-30.565766
Non-irrigated arable land	893.370517	773.1756	-13.454099
Sport and leisure facilities	212.417053	182.1859	-14.232003
Transitional woodland-shrub	5299.023953	3422.262	-35.417121

Land use

According to the data from NSI, the main changes are in the agricultural land – in 2021 decrease with 4% compared to 2000, while only 0.4% decrease of forest territories for the same years. A significant part of the arable land – 20,5%, is not permanently cultivated.

The results from Corine Land Cover show similar results in terms of agricultural land – increase in land principally occupied by agriculture, with significant areas of natural vegetation land and decrease in non-irrigated arable land with more than 13%. The broad-leaved (+1,6%) and coniferous (+4,1%) forests show a slight increase, while the mixed forests decrease (-3,7%).

The allocated grazing areas for domestic animals are not effectively used because of the lack of enough animals. It must be considered that the release of domestic animals into grazing plantations always results in their disruption to a greater or less extent (Tsanov, 2011).

Perennial Climate Regimes

Climate models show a warming trend for the period 1975-2022 (Figure 5).

Variations were observed over the years with lowering and increasing the mean annual temperatures, but a significant raise of the mean annual temperature is observed for that period.

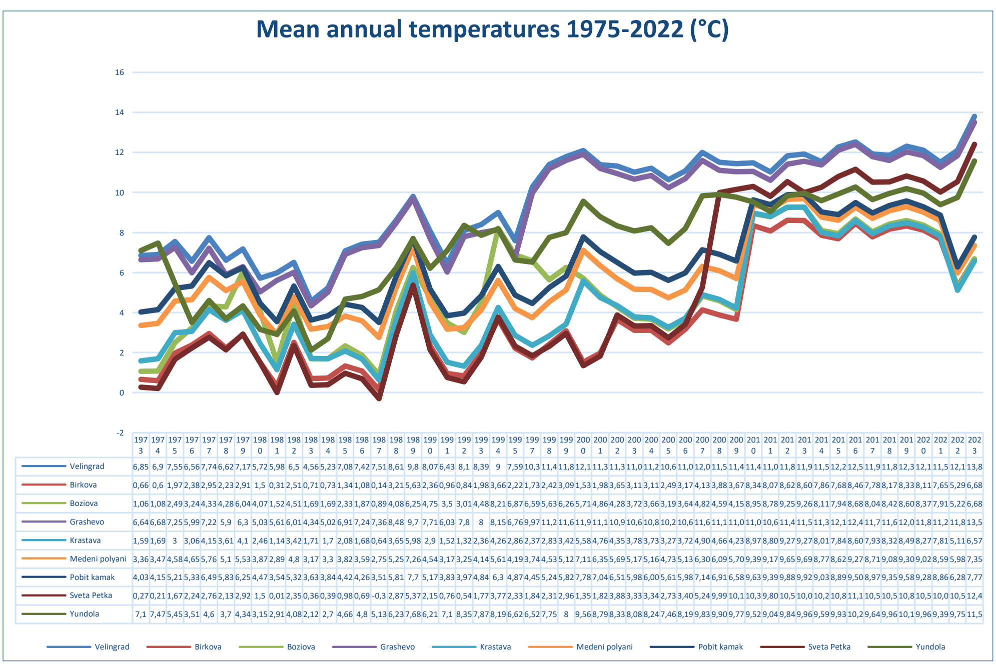

Figure 5. Mean annual temperatures 1975-2022 (°C) in Velingrad Municipality. *Source: Visual Crossing Weather, 2023*

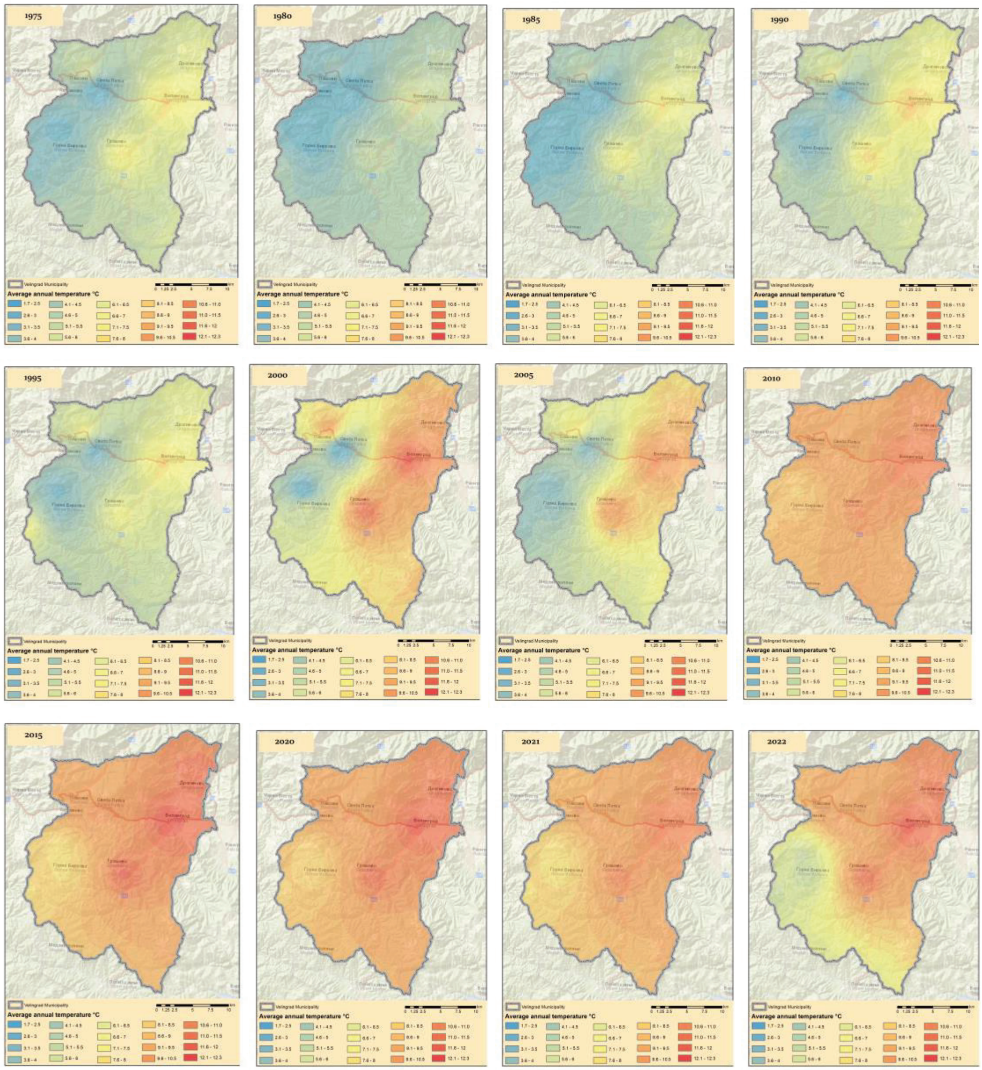

Figure 6. Mean annual temperatures 1975-2022 (°C) in Velingrad Municipality. *Source: Visual Crossing Weather, 2023*

Nevertheless, climate models indicate a warming trend for the period 1975-2022 (Fig. 5 and Fig. 6).

Besides the warming tendency observed, harmful abiotic impacts on the forests occur due to abnormal climate deviations. This includes extreme temperatures (frost), atmospheric precipitation (snow, frost, hail), atmospheric air movement (strong storms, thunder) (Tsanov, 2014). In the Western Rhodopes an increase in extreme weather events and shifts in climate like a decrease in cold temperature

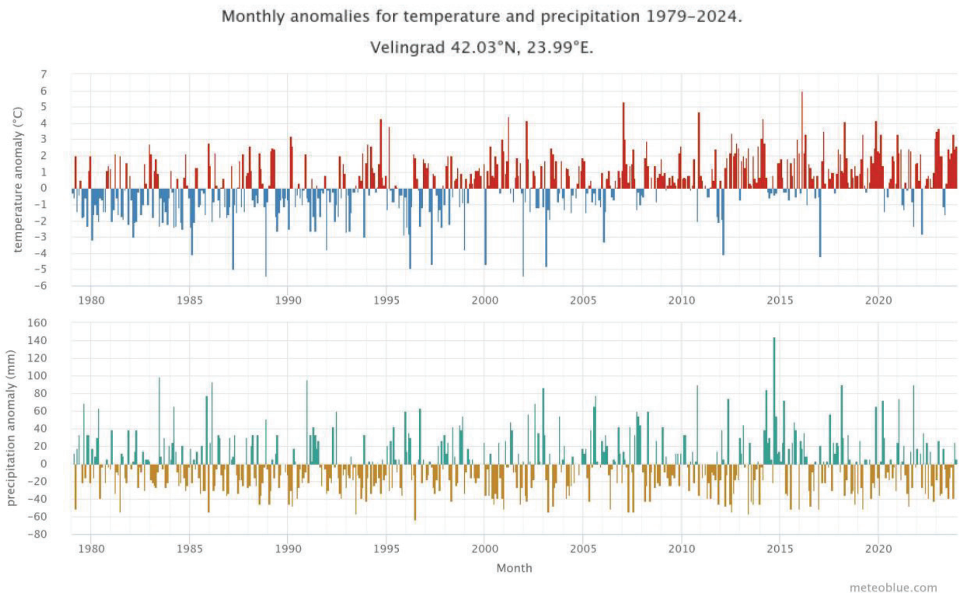

Figure 7. Monthly Anomalies of Temperature and Precipitation – Climate Change Velingrad. *Source: Meteoblue, 2024*

extremes, an increase in warm temperature extremes, an increase in the duration of summer dry periods, and an increase in the number of heavy precipitation events have been observed (Zlatanov et al., 2017). According to climate models, the extremes happen more often and increase their peaks in the last ten years.

This information can contribute to understanding a system's disturbance regime and indicate the need for alternative forest management practices.

Water and air monitoring

Surface waters are monitored at a point for the Chepinska River after the town of Velingrad. According to reports from East Aegean River Basin Directorate, for the period 2014 – 2017, a bad ecological condition was established in terms of biological quality elements – benthic macroinvertebrate fauna. The reason for the bad condition is the discharge of untreated household-fecal wastewater from the settlements. At the Chepinska river point after the town of Velingrad, exceeding the standards for good condition according to Biological oxygen demand (BOD), ammonium nitrogen, nitrate nitrogen, total nitrogen, total phosphorus and orthophosphates are monitored.

There are no sewage treatment plants in the populated areas of the municipality. Industrial wastewater discharges into surface water intakes, about 80% of it is treated in local treatment facilities.

Exceedances of the average nightly norms for the concentration of PM10 in the atmosphere have a highly pronounced seasonal character – they are only during the heating season (Executive environmental Agency, 2024)

Almost all the generated waste is landfilled. No pre-treatment of the waste is carried out. The municipality of Velingrad does not fulfill the goals for recycling household waste. Separate waste collection and construction waste collection systems are not efficient enough (Velingrad municipality, 2020).

Connections

The dependence on local resources in the last two periods (1944-1989 and 1989-now) is investigated, breaking down the dependence on the natural resources of the economic sectors separately for the town and for the villages.

This breakdown is used to build the connections between the economy and local resources. To complete the analysis, the main ecological issues were outlined, using the Programs for environmental protection of forest development of the municipality. The economy sectors are also related to the main ecosystem services and their social meaning. The economic sectors are marked whether they are important for the town or the villages and whether it was developed in the past or is also a leading sector in the present.

In the center of the relations are placed the economic values. The relations are colored according to the ecosystem services that feed them to illustrate the strong dependence on the local resources. The ecological issues are presented in terms of the pressures they experience because of the economy and the external and internal pressures from other origins. Positives are also outlined, again listing both those from the past and those from the present.

Social-ecological systems also undergo change over time. Understanding what is behind these changes—the change drivers—can provide insight into how historical system dynamics have shaped the current focal system and what effects they might have in the future. A historical profile of the system can also reveal changes in system resilience over time, including those that occur in response to specific human interventions, whether intended or not (Resilience Alliance, 2010.).

Table 3. Dependance on the economic sectors on local resources

	Economic sector	**Natural resources**	**Economic sector**	**Natural resources**
	Town		Villages	
1944 -1989	marble and granite, production	Stone resources	agriculture,	Soils, climate, water
	wooden and laminated boards	Forests	collecting herbs, mushrooms	Forests
	production of kitchen furniture	Forests	Logging	Forests
	metal cutting machines,	external raw materials	fodder crops, potatoes,	Soils, climate, water
	extraction of aggregates building materials	Local resources, rivers	sheep breeding, cattle breeding	Soils, climate, water
	asphalt production	external raw materials		
	flax processing	Agriculture (soils, climate, water)		
	chemical industry	external raw materials		
	mechanical engineering	external raw materials		
	cultivation of carnations and greenhouse vegetables	Agriculture (Soils, climate, water)		
	Tourism	Mineral water, Forests		
	Town		Villages	
1989 – present days	Tourism	Mineral water, Forests	agriculture,	Soils, climate, water
	carpentry, woodworking, furniture production	Forests	collecting herbs, mushrooms	Forests
			Logging	Forests
			fodder crops, potatoes,	Soils, climate, water
	bottling of mineral water	Mineral water, forests		
	wood pellet production	Forests		
	food industry	Local and external resources		
	power supply from mini hydroelectric plan	Water		

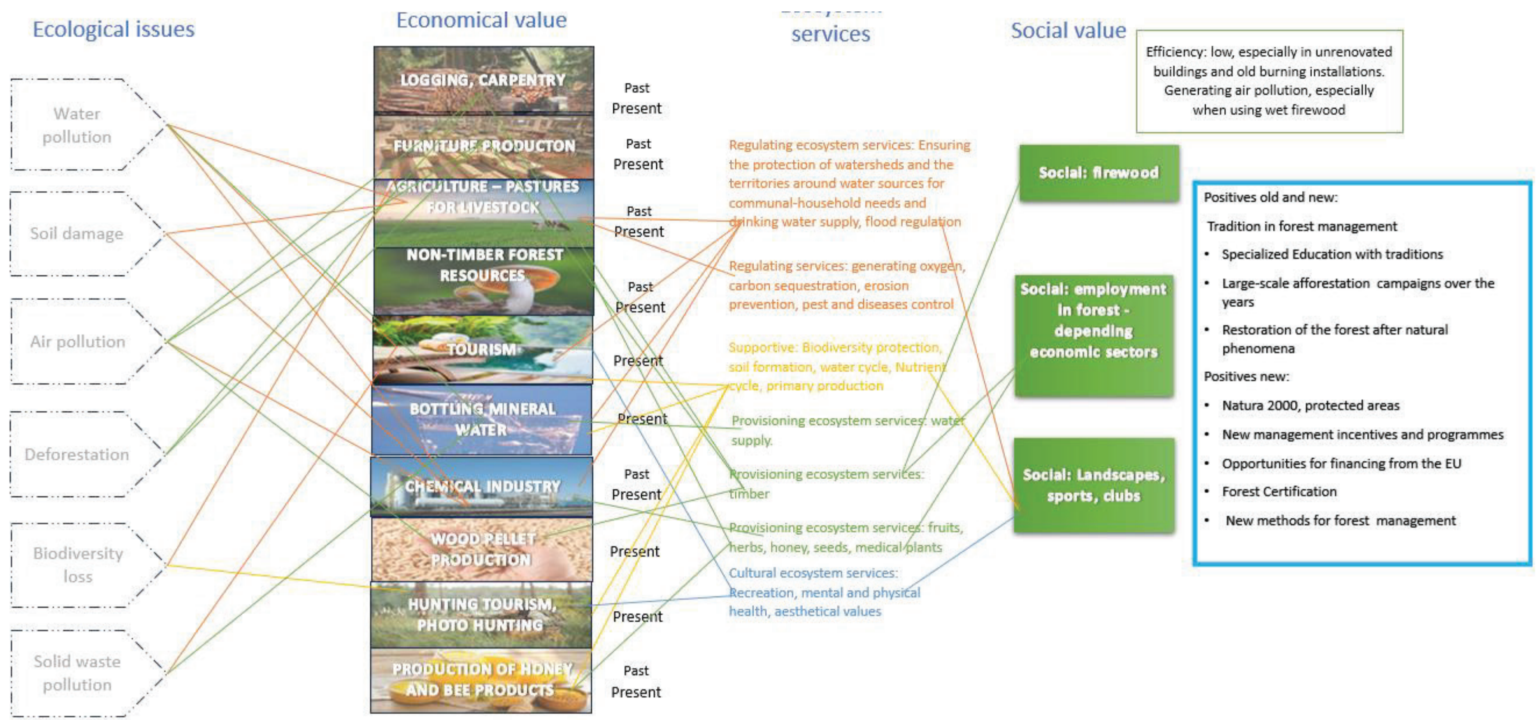

Figure 7. Interrelations between economy, ecosystem services, ecological issues, and social values

Table 4. Summary of the disturbance in CHANS and the changing variables after 1885

Period	Characteristics	Environmental Consequences	Disturbances (Presses and pulses)	Changing variables
Around 1885	Cutting down trees for railroad building	deforestation, biodiversity loss -elimination of the oak forest	Press	Biodiversity Infrastructure – connections improved
Around 1911	Clearing land for agriculture also using forest fires	Deforestation severe landslides on 8,500 acres of lands that were former forests. 9000-acre forests destroyed by forest fires	Pulse, pressure	Land-use change Biodiversity Erosion Agriculture and livestock breeding development Population increase
1950-1977	Forest management	Extensive afforestation – planting with species that are not in their original ecological niche	Change in ecosystem	Land-use change Changing structure and area of the forest Creating valuable coniferous forests
1961	Strong wind	Destroying vast forest area. Many fallen trees, prerequisite for calamities	Pulse	Destroyed forest
1950-1975	Active use of forests for timber	Deforestation	Press	Intensive development of the secondary sector Active forest management Education in forest management Active participation from the local population Grazing
After 1989	Change of economic profile	Illegal logging Calamities Pollution Biodiversity loss	Press (tourism)	Change of forest management practices Climate extremes happen more often Extensive usage of the forest and water resources Pollution – water (solid waste) and air Less people occupied in forestry and agriculture Intensive natural processes of thinning and degradation in the plantations Succession processes towards restoration of autochthonic vegetation

Discussion

Coupled human-natural systems are experiencing unprecedented rapid changes and progressively tighter couplings at multiple scales (Liu et al., 2021). Being aware of critical thresholds between state of the system can potentially provide advances warning of impending change as well as opportunities for preventing undesirable shifts in these states of the system. A broad overview of system change through time can reveal patterns of past disturbances and responses as well as the impacts of cumulative or gradually changing variables (Resilience alliance, 2010). The retrospective analysis of the interactions between forests and people in Velingrad Municipality shows periods of serious disturbances. The uncontrolled logging caused a regime shift from deciduous to coniferous forests. The deforestation caused disruption not only to the ecological system but also had a significant effect on the socio-economic system with the formed landslides which threatened the fields and houses of local people – that is a typical example of a trade-off in the socio-ecological system. Synergies were also formed, for example the community-based afforestation of the region had a tremendous impact on the contemporary landscape, but also formed attitudes towards forest. The massive forest planting marks the growth phase of the adaptive cycle of the socio-ecological system (Walker and Salt, 2006). Proof in this regard is the reaction to pulse disturbances like the strong wind vortex in 1961 which caused great ecological stress. The capacity of the socio-ecological system to absorb that stress was demonstrated with the extremely adequate and well-organized reaction of the forest administration which managed to clean the damaged land to avoid calamities and to afforest for ecosystem recovery. With time, the system's components become more strongly interconnected, its internal state – more strongly regulated. The system moved into its conservation phase. The interconnections of the socio-ecological system strengthened with the strong dependency of the local economy on forests, the specialization of the education system on the forestry sector. The social effect imprinted the way of life of the local population. A good example of these dependencies is the trade-off formed during the economic crisis in the years of transition to a market economy after 1990, when the exploitation of forests in the Velingrad region became the main alternative to the recession and a means of economic and social survival of the region. This leads to certain violations in the balance of the forest territories, as well as to an increase of illegal logging. Illegal logging among the Roma population reached particularly alarming proportions (Alexiev, 2002). This confirms McMichael et al. (2014) suggestion that in places where there are no other social safety nets, diminished human well-being tends to increase the immediate dependence on ecosystem services. Understanding the significance of a system's internal connections, its capacity to respond to disturbances and how these aspects change from phase to phase contributes to resilience thinking (Walker and Salt, 2006). The retrospection helped get a new look on the socio-ecological relations, their formation and adaptation over time. This notion, together with an overview of the contemporary presses and pulses that the system is expereincing support for better understanding the on-going processes and for a proper management of forest resources. Forests are a critical component of the socio-ecological system. They regulate climate, ensure water supply, water balance, water protection and soil protection and have environmental, sanitary, and hygienic functions. Moreover, the forest vegetation in the area is a valuable source of wood, fodder, food products, medicinal plants, etc. (Environmental protection plan, Velingrad)

The pulses and presses with internal origin are tightly related with the population and economy. As populations and consumption levels grow, human-caused disturbances can intensify, with consequences for a system's general resilience (Resiliance Alliance, 2010). Therefore, the general trends for population number and the economic profile are analyzed with regard to possible disturbances. The demographic trend shows a constant population loss and disrupted age structure in town, while the small villages (apart from Boziova) have a very steady population number, some of them even show a slight increase. Nevertheless, we can conclude that the number of people in terms of local population is not a stress factor for the environment.

The economic changes reflected on the CHANS – closing the factories that forced the secondary sector lowered the pressure on the ecosystems, especially reducing the emissions to the atmosphere and water ecosystems, waste generation and resource consumption. Meanwhile the development of tourism has brought new challenges. The number of residents in the town decreases, but the number of people that benefit from the local ecosystem services actually increases because of the increasing number of tourists. This is linked to intensified traffic, more use of water, more load on the sewer system, more generated waste, construction, and urbanization. The lack of efficiency of the use of the resources, the poor infrastructure and the intensifying use of the resources leads to growing ecological issues, mainly in terms of water, air and solid waste pollution. Regarding forests the illegal logging is still a problem. It reduces the quality of forest ecosystems and can lead to disruption of the natural water balance in the entire area and trigger erosion and landslide processes (Plan for development of forests in the territory of Velingrad municipality). These internal pressures are combined with the climate regime fluctuations and the observed climatic extremes. Diamond (2005) includes climate changes as one of 5 main reasons that have contributed to or even led to the collapse of societies in the past. It is a factor that strongly influences each component of the system, no matter if it is anthropogenic or natural. One of the most vulnerable components of the environment is forests. Exceptionally the complex combination of different elements of forest ecosystems, a large part of which live, implies serious uncertainties given how they will be with projected higher temperatures and especially summer droughts over the next century (Panayotov et al., 2023). The extreme temperature strongly influences the condition and growth of the tree species. The late spring colds damage the flowers, leaves and twigs of the more sensitive species and the early autumn colds – the non-woody shoots of the species with longer vegetation period. The high summer temperatures cause dehydration of the cells, burning of the leaves, twigs or the bark of some species (Yurukov and Panayotov, 2015). Norway spruce is a cold-resistant tree species that can withstand low winter temperatures, but often suffers from late spring frosts. In some areas with a large altitude in the central parts of the Western Rhodopes (for example, the area of Beglika) such sharp colds in late spring and early summer are the cause of the death of seedlings and damage to young trees (Panayotov et al., 2016). Currently, most of the coniferous plantations in the Western Rhodope Mountains exceed 40-50 years of age. Due to their low resistance, accelerated processes of deposition and degradation occur in them. Intensive succession processes have begun in the direction of restoration of the natural deciduous vegetation (Popov et al., 2018). The gradual change in climate conditions reduces the resistance of forest stands and makes them susceptible to pest attacks (Georgiev et al., 2022). Given the fact that most of the mature plantations are located at a higher altitude, the rise in temperatures will shift the isotherm lines in height, which will create conditions for insects to affect new forest areas. As a result, the riskiest vertical range will widen, and with it, increased risk can be expected from the occurrence of natural disturbances (Tsvetanov and Karabov, 2020). According to the White paper: Adapting to climate change: Towards a European framework for action, the consequences of climate change for forests are likely to include changes in their condition and productivity, as well as changes in the geographic range of some tree species. Measures have already been taken in this regard as production of saplings of tree species for afforestation that are adapted to the expected climate changes is planned (Plan for development of forests in the territory of Velingrad municipality). However, alternative management practices, tailored to the stands location on the landscape and its management history may be needed (Zlatanov et al., 2017).

The attempt to draw the relationship between the key components within the CHANS supports identifying the direction and magnitude of the influences the components exercise on one another and how the changes and trends reviewed so far influence them. The analysis shows that all key economic sectors rely on local resources. Apart from economic value, they also possess very strong social significance – both satisfying vital needs of the local population and laying in the deep foundation of their customs, traditions, and way of life. These relations are so stable that they have proven themselves over time, including during periods of political and structural change.

The present research makes a quick review of the present and past state of key components of the CHANS without going into in-depth analysis separately. Due to the wide diversity and number of components and interactions the analysis is based on the perception that the systems approach is holistic and focuses on how key components contribute to the dynamics of the whole system (Resilience Alliance, 2010). The component of the CHANS that are considered are not comprehensive enough to reveal the overall complexity of the connections in the system The population number is analyzed but more thorough research is recommended considering the effects of the ethnographic, age and educational structure of the population. The ethnic specifics in the research area are tightly related to natural resources and this is an aspect worthy of investigation. Apart from the rising temperature, the amount of precipitation and the humidity are also important parameters that should also be studied in future research. Another important aspect that influences the socio-ecological system and needs to be more thoroughly considered in the retrospection is the political situation and policy of forestry and related sectors. The time period of the available statistical and literature data for the components do not overlap which hinders the analysis.

Conclusions

Although the structure of the economy has undergone some changes and diversification, the economic and social life in the Velingrad Municipality area is dependent on the local natural resources and has been entirely relying on them now and in the past. The results of the study lead to the conclusion that the local ecosystems are experiencing a hard time due to several exogenous and endogenous threats acting all at once. The additional pressure can damage the capacity of local ecosystems to deliver services, and this capacity can decline to such a degree that the probability of disaster or conflict increases (McMichael et al., 2005). The retrospection showed that the co-existence of humans and nature in the studied area has undergone different stages but has managed to adjust and stabilize itself. The ongoing disturbances nowadays (both pressures and pulses) cause many slow variables to accumulate and generate trade-offs that may lead to traps if not attended on time. The socio-ecological system seems to be in its conservation phase, where components become more strongly interconnected, the system itself becomes more and more rigid and resilience declines (Walker and Salt, 2006). Examples from the past suggest that the CHANS possesses its own homeostasis and demonstrated great resilience after the strong wind vortex from 1961. The dedicated forest management played a crucial role for the ecosystem recovery then. This raises the question, if now, in the next stage of its adaptive cycle, a pulse like that occurred, the system would withstand. The local authorities are already aware of some of these problems the Plan for development of forests in the territory of Velingrad municipality suggests adequate measures in forest management practices. But it also points out many problems that the contemporary forest management experiences, mainly in terms of organization and legislation. The plan is elaborated in 2015 and the problems identified are still relevant today. Degradation of environmental resources on which livelihoods depend is seldom intended as such but is an outcome of the cumulative effect of people's individual behavior (Boonstra et al., 2014). The local administration and population need to be aware of all the problems and threats of the system they are part of and become part of their solution.

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RESEARCH ARTICLE

New parasitoids of *Corythucha arcuata* (Say) (Hemiptera: Tingidae) in Bulgaria

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Abstract

During the period 2019-2020, parasitoids of invasive oak lace bug (*Corythucha arcuata*) were studied in Bulgaria. Biological material (larvae of *C. arcuata*) was collected from European oak (*Quercus robur*) or Austrian oak (*Quercus cerris*) in five localities of the country. Five eulophid specimens (Hymenoptera: Eulophidae) were reared from the host larvae: *Tamarixia pubescens*, *Elasmus* sp., *Minotetrastichus* sp., *Pnigalio* sp. and *Sympiesis* sp. The impact of the parasitoids on the host number was very low (0.1-0.3%). The present records in Bulgaria are the first documented case of adaptation of native parasitoids to the host in the newly occupied areas in Europe and Asia.

Keywords

Oak lace bug, parasitoids, Eulophidae, *Tamarixia pubescens*, Bulgaria

Introduction

The oak lace bug, *Corythucha arcuata* (Say, 1832) (Hemiptera: Tingidae) is widely distributed in North America (eastern part of the USA and southern Canada). In its native range, the species feeds on leaves of different oaks (*Quercus* spp.) and occasionally on *Castanea*, *Acer*, *Pyrus*, *Malus* and *Rosa* (Drake, Ruhoff, 1965; Drew, Arnold, 1977). This invasive species has been first recorded in Italy (2000) (Bernardinelli, Zandigiacomo, 2000), Switzerland (2002) (Forster et al., 2005) and the Asiatic part of Turkey (2002) (Mutun, 2003). In 2012, *C. arcuata* penetrated the Balkan Peninsula in Bulgaria (Dobreva et al., 2013). Recently, it has subsequently spread rapidly and caused damage in oak stands in many European countries (Csóka et al., 2019). Until now, no parasitoids of the host have been established in the expanded range of *C. arcuata* in Europe and Asia.

This note reports *Tamarixia pubescens* (Nees, 1834) (Hymenoptera: Eulophidae) as a new parasitoid of *C. arcuata* in Bulgaria.

Material and methods

The samples (leaves with *C. arcuata* larvae) were collected in 2019 and 2020 from European oak (*Quercus robur* L.) and Austrian oak (*Quercus cerris* L.) in four localities in Bulgaria (Table 1). After collection, the larvae on leaf laminas were placed individually in Petri dishes. They were kept in a laboratory at room temperatures (20-22 °C). The samples were observed weekly.

Table 1. Main characteristics of studied sites and biological material collected

Site	Coordinates	Altitude, m	Host plant	Date of collection	Larval groups, N
Sofia	42°37'41.6"N 23°21'08.8"E	650	*Quercus robur*	19 August 2019	15
Pleven	43°23'17.5"N 24°37'18.5"E	137	*Quercus cerris*	13 June 2020	25
Chirpan	42°12'04.1"N 25°20'08.6"E	197	*Quercus cerris*	28 June 2020	12
Borovan	43°23'31.7"N 23°43'15.5"E	227	*Quercus cerris*	05 Jul 2020	9

The parasitoids that emerged were identified by the keys of Peck et al. (1964), Triapitsyn (1978), Triapitsyn, Kostyukov (1978), Storozheva (1982) and Graham (1987, 1991, 1995).

The specimens were examined under an Olympus SZ51 stereomicroscope and photographed using a Leica EZ4 W stereomicroscope supplied with a WiFi CMOS still camera. All photos were processed by Zerene Stacker and were subsequently edited by manually combining adjusting and cleaning in Adobe Photoshop.

The studied parasitoid specimens are kept in the entomological collection of the University of Plovdiv 'Paisii Hilendarski'.

Results

In this study, five eulophid specimens (Hymenoptera: Eulophidae) were reared as parasitoids from the larvae of *C. arcuata*: *Tamarixia pubescens* (Nees, 1834), *Elasmus* sp., *Minotetrastichus* sp., *Pnigalio* sp. and *Sympiesis* sp. (Table 2, Fig. 1).

Table 2. Emerged parasitoids

Species	Site	Emerged parasitoids	Emergence date	Parasitism, %
Tamarixia pubescens	Sofia	1♀	25 November 2019	0.3
Pnigalio sp.	Sofia	1♂	25 October 2020	0.1
Sympiesis sp.	Pleven	1♀	27 June 2020	0.1
Minotetrastichus sp.	Chirpan	1♀	14 July 2020	0.3
Elasmus sp,	Borovan	1♂	03 August 2020	0.2

Only single parasitoid specimes were established, and the impact of the parasitoids on the host number was very low (0.1-0.3%) (Table 2).

The body length of the reared specimen of *T. pubescens* was 0.88 mm (Fig. 1A).

Discussion

There is insufficient knowledge about specific natural enemies of *C. arcuata* not only in Europe and Asia but also in its native range in North America. Recently, *Erythmelus klopomor* Triapitsyn, 2007 (Hymenoptera: Mymaridae) was described as an egg parasitoid of the host in the region of Missouri in the USA (Triapitsyn et al., 2007; Putler et al., 2014). Latter, *E. klopomor* has been reared from *C. arcuata* and other tingid hosts in Florida, North Carolina, and Maryland: *Corythucha cydoniae* (Fitch), *C. marmorata* (Uhler), *C. pergandei* Heidemann, *C. ciliata* (Say), *Gargaphia solani* Heidemann and *Pseudacysta perseae* (Heidemann) (Triapitsyn et al., 2007; Peña et al., 2009). The representatives of the *Erythmelus* genus are well known as parasitoids of heteropteran hosts, mainly from the Miridae and Tingidae families (Triapitsyn, 2003).

Tamarixia pubescens is a Transpalaearctic species, distributed in many European countries (Bulgaria, Czech Republic, France, Germany, Hungary, Ireland, Italy, Romania, Serbia, Slovakia, Sweden, United Kingdom) and the People's Republic of China (Guangxi Region) (Noyes, 2019). In Bulgaria, it was found in Rila Mt. (Borovets Chalet) and the Western Rhodopes (Rhozen loc.) (Boyadzhiev 1999, 2006). The species is known as a parasitoid of psylids *Trioza remota* Foerster, 1848 and *Trichochermes walker* (Foerster, 1848) (Hemiptera: Triozidae) (Noyes 2019), in which its body size is 1.1-1.3 mm (Graham, 1991). In this study, the smaller size of the *T. pubescens* specimen most probably is an indication of its adaptation to the new host, *C. arcuata*.

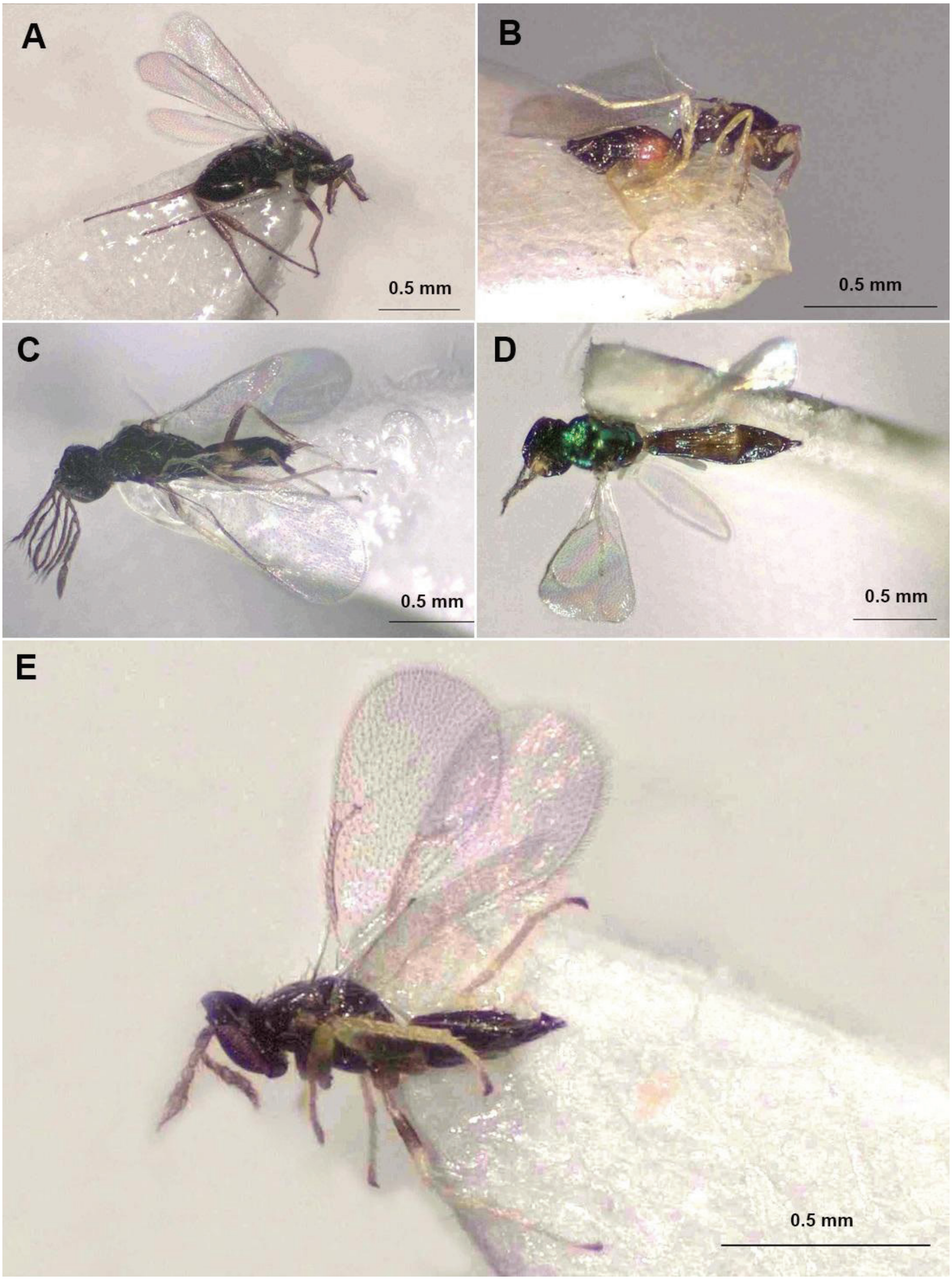

Figure 1. Parasitoids of *Coithucha arcuata*: A – *Elasmus* sp.; B – *Minotetrastichus* sp.; C – *Pnigalio* sp.; D – *Sympiesis* sp.; E – *Tamarixia pubescens*

The species of the genus *Elasmus* are mostly parasitoids or hyperparasitoids of lepidopteran or hymenopteran larvae (Strakhova et al., 2011). Recent data indicate that their hosts belong to the orders Coleoptera, Diptera, Hemiptera, Hymenoptera and Lepidoptera (Noyes, 2019).

The representatives of *Minotetrastichus* genus are known as parasitoids on leaf-mining lepidopteran, coleopteran and hymenopteran hosts (Noyes, 2019).

The species of the *Pnigalio* genus are primary parasitoids of phytophagous coleopteran, dipteran, hymenopteran and lepidopteran hosts, as well as hymenopteran parasitoids (Braconidae and Eulophidae) (Noyes, 2019).

The representatives of the *Sympiesis* genus are associated with phytophagous hosts from the orders Coleoptera, Diptera, Hemiptera (Coccidae), Hymenoptera and Lepidoptera, and parasitoids of the families Tachinidae, Braconidae and Eulophidae (Noyes, 2019).

In conclusion, the present records in Bulgaria are the first observed cases of parasitism on *C. arcuata* in Europe and Asia. Other cases of adaptation of native parasitoid species to the oak lace bug should be also expected in newly occupied areas.

Acknowledgments

This work has been carried out in the framework of the bilateral project 'Expansion of the invasive insect pest *Corythucha arcuata* (Hemiptera: Tingidae) in the oak forests of Bulgaria and Austria', funded by the Bulgarian National Science Fund, Contract № KP-06-Austria/1/11.08.2021 and Austrian Agency for International Cooperation in Education and Research (Project No. BG 06/2021).

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RESEARCH ARTICLE

Soils after forestry management activities in spruce plantations

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Abstract

The carbon accumulation in forest ecosystems helps to mitigate climate changes, therefore the interest in finding strategies for adapted forest management is a major goal of our time. The artificial plantations of Norway spruce (*Picea abies* Karst) are part of the Bulgarian project to restore the regulatory functions of forest ecosystems. Due to their low resistance, intensive processes of deposition and degradation take place in them, which emphasizes the need to understand the condition of soils and the amount of accumulated carbon in them. This paper reports results from a study on the thinning in even-aged Norway spruce plantations (*Picea abies* Karst) and its effect on some soil properties. The study includes two thinned plots and an untinned control: 1) Control – an unmanaged spruce plantation, without any activities in it through the last 20 years; 2) Thinned – managed with regular felling over the years, the last of which was carried out 10 years ago with 25% intensity; and 3) Ice storm – plantation damaged from an ice storm in 2007 (when it was 33 years old), felling followed by removal of all affected trees – over 95%, and afforestation with spruce saplings. The soil was examined by layers from 10 cm to 30 cm depth. The main soil characteristics connected with the carbon stocks in soil are analyzed - bulk density, skeleton, and carbon content. The results of the experiment show that the performed forestry activities were conducted with abidance of the requirements for habitat protection and the ecosystem's functionality in the studied sites. No significant changes in coarse fraction content and bulk density of soils were found. There is no statistical difference between the plots in the studied depths, but there is a trend of decrease in the organic carbon content in the managed sites. The differences in the soil carbon stocks are significant for the first two soil layers between the control and the managed trough thinning plot.

Keywords

carbon, coniferous, thinning, ice storm

Introduction

Forests constitute about 30% (4–5 billion hectares) of the earth's terrestrial area, providing many essential ecosystem services (Keenan et al. 2015). Soil carbon accumulation is the process of storing carbon in the form of organic matter in the soil. This process can provide various ecosystem services, such as: mitigating climate change by removing carbon dioxide from the atmosphere and reducing greenhouse gas emissions (Yasin et al., 2023); enhancing soil fertility by improving soil structure, water retention, nutrient cycling, and biological activity (Guo et al, 2019); supporting biodiversity by providing habitat and food for soil organisms and plants (Melillo et al., 2017). The multi-functionalities of soils and their role in ecosystem functioning has been an important scientific topic in Bulgaria as well (Todorova and Zhiyanski, 2023).

The major carbon storages in forest ecosystems are biomass and soils (Ciais et al., 2013; Zhiyanski, 2014; Stoeva, 2023). Temperate forests „play a significant role" in the global carbon cycle, considering that more than one-third of the carbon is stored in the vegetation and nearly two-thirds in the soil. The higher proportion (but lower level) in temperate forest soils (compared to tropical forest soils) is because of slower decomposition rates (Gorte, 2009). Many of these forests are managed to produce commercial wood products, and the management practices used in temperate forests can thus have a significant impact on carbon sequestration. Forest management is an activity that has economic importance for society but directly affects carbon stocks in individual carbon sinks. The different types of felling carried out in the forest territories are practices applied in the management of the forest territories (Regulations for the implementation of the forest law, 1999).

Forest thinning is a management practice that selectively removes trees to increase the availability of resources to the remaining trees to improve their growth and productivity (Nazari et al., 2022). Thinning regulates forest structure, reduces the risk of wildfires, enhances timber production, and increases forest resilience to environmental disturbances (Makinen and Isomaki 2004; Wang et al. 2019). Despite these benefits, some silviculture practices or disturbances could affect the soil organic carbon stock if the balance between the carbon inputs (for example from biomass residues or organic amendments) and the carbon losses (due to respiration, mineralization or leaching) is altered (Stoeva and Kirova, 2021). Thinning can lead to decreases in the soil carbon stocks due to reduced litter and root exudate inputs and increased rates of SOM mineralization (Zhang et al. 2018). Specifically, thinning increases the risk of C and nutrient limitations in coarse-textured soils of low fertility (e.g., Podzol) compared to fine-textured fertile soils (Page-Dumroese et al. 2010).

Coniferous plantations in Bulgaria are part of massive afforestation campaigns and are an important part of the Bulgarian work to restore the regulatory functions of forest ecosystems. Currently, most of these crops exceed 40-50 years of age, or they have only recently begun to reach maturity (Markoff et al., 2022). Due to their low resistance, intensive processes of deposition and degradation take place in them. Intensive successional processes have begun in the direction of restoring autochthonous vegetation (Popov et al., 2018). Science and practice should promptly react and anticipate the occurring natural processes, to utilize the accumulated wood mass, without ecological upheavals for the ecosystems. An attempt should be made to direct the natural biological processes in such a way as to obtain a smooth transition to a natural recovery of the most valuable and suitable tree species for the respective habitat (Popov et al., 2018).

Norway spruce (*Picea abies* Karst) is one of the most important species in the forests of the Alps, Carpathians, and the Balkan Mountains (Panayotov et. al, 2011). Apart from their key ecological role, these forests are very important for timber production and, in certain areas, for their protective functions against avalanches, rockfall, and soil erosion (Bebi et al., 2009).

The implementation of various forest management measures can lead to significant changes in the quantity, quality, and redistribution of organic matter in forest ecosystems (Guo & Gifford, 2002; Lorenz & Lal, 2005; Dannenmann et al., 2006). Direct removal of live woody biomass reduces total ecosystem C stocks (Amiro et al., 2006; Davis et al. 2009; Payeur-Poirier et al., 2011). The carbon stock in the living biomass depends to a great extent on the age structure of the plantations and their management (Stoeva, 2023). The management affects also the soil microclimate (Jassal et al. 2007). Logging with different intensities in the above changes the microclimate under the assembly and affects the temperature and humidity regime in the forest floor and soil, and hence indirectly on the resistance to soil processes (Saunders et al., 2012, Vesala et al., 2005, Piirainen et al., 2002). Studies on components of forest ecosystems show that changes in microclimate after logging correlate with increased rates of heterotrophic respiration and lower rates of autotrophic respiration (Ryu et al. 2009), thus CO_2 flux in total soil changes (Selig et al. 2008, Sullivan et al. 2008). It has been found that the change of carbon stocks in soils after thinning depends on the type of soil, climatic conditions, and tree species (Clarke et al., 2015).

The present study aims to determine the changes, or the lack of changes, in basic soil characteristics after forest management activities in spruce plantations from the territory of State Forestry Enterprise Botevgrad.

Materials and methods

Site Description

This study was conducted in 2020 in two forest sections, with a total area of 7.8ha, located in the west part of Stara Planina/Balkan Mountains in Bulgaria, on the territory of State Forestry Enterprise Botevgrad. The research area lies between 23°52′8″ E and 23°52′38″ E longitude and 42°54′18″ N and 42°54′29″ N latitude, at an altitude of 1130–1190 m above sea level. The study area is in the continental climate zone with an average annual rainfall of 51 mm and an average annual temperature of 10.46 °C (https://geotsy.com/bg/b-lgaria/botevgrad-69008/vreme-i-klimat). The soils in the studied fields are brown forest soils (*Cambisols*, WRB 2014). The silvicultural treatment applied in the study area was thinning with intensity between 20-25 % and sanitary felling, where it was needed.

Experimental Design

Three sampling plots have been set in spruce plantations (*Picea abies* Karst): 1) Control – an unmanaged spruce plantation, without any activities in it through the last 20 years; 2) Thinned – with regular felling over the years, the last of which was carried out 10 years ago with 25% intensity; and 3) Ice storm – plantation damaged from an ice storm in 2007 (when it was 33 years old), felling followed by removal of all affected trees – over 95%, reforestation with spruce saplings, and natural regrowth with local species.

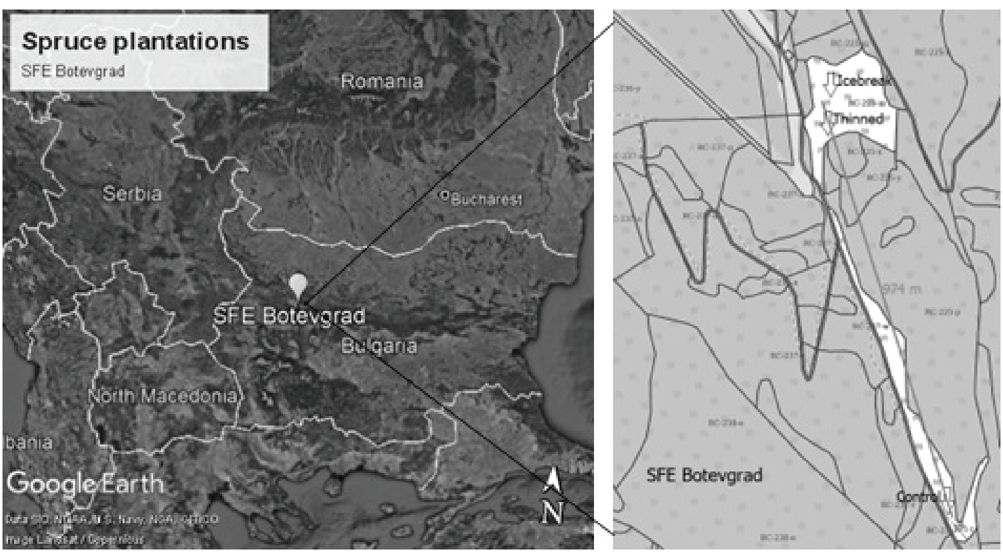

Figure 1. The study area in SFE Botevgrad in West Balkan Mountains, Bulgaria.

The environmental factors that have direct or indirect influence on the main soil characteristics are: the slope (D'Amore and Kane, 2016), the altitude and the aspect of the slope (Borissova et al., 2023). Thus, the three sample areas are chosen to have common characteristics of the habitat, listed in table. 1, and are closely located (Figure 1), which allows comparative analysis of the data obtained.

Table 1. Characteristics of the sampling plots

Sampling site	Soil type WRB 2014	Aspect of the slope	Altitude, m a.s.l.	Mean slope, °	Stand age (yrs)
Control	*Distric Cambisols*	NE	1186	21	45
Thinning		NE	1137	27	45
Ice storm		NE	1137	27	12

Each sampling plot is with a size of 0.1 ha. Soil samples were collected with an auger, covering all variations of the microrelief. The cylinder of the auger has a volume of 502.4 cm^3. The samples were collected in 5 replicates from depths of 0–10, 10–20, and 20-30 cm. They were stored and coded in plastic bags. On the same sampling day, the wet weight of all samples was measured.

Samples of forest floor were taken using a frame with dimensions of 25:25 cm, in five repetitions for all studied sites.

Measurements and Laboratory Analysis

In the laboratory, the soil samples were dried at 105 °C for 24 h to calculate the soil moisture content and dry bulk density. The forest floor samples were dried at 90 °C for 24 h to calculate the moisture content.

The bulk density and soil moisture were calculated using Equation (1) and Equation (2):

$$BD = \frac{WD}{VC} \qquad \text{Equation (1),}$$

where BD is the dry bulk density (g /cm^3), WD is the weight of the dry soil (g), and VC is the volume of the cylinder (cm^3).

$$W = \frac{(WW\text{-}WD)}{WD} * 100 \qquad \text{Equation (2),}$$

where W is the soil moisture (%), WW is the wet weight of the sample (g) and WD is the weight of the dry soil (g). The same equation is used for calculating the moisture content in the forest floor.

Total porosity of the soil was determined by a computational method from the relative and bulk density values (Donov et al., 1973) – Equation 3:

$$P = \frac{(1\text{-}BD)}{RD} * 100 \qquad \text{Equation (3),}$$

where P is the total porosity (%), BD is the bulk density and RD is the relative density.

The content of the coarse fragments was determined by weight method (Donov et al., 1973), which includes the following procedures: 1) a mean sample close to 100 g is taken from the dried soil sample; 2) it is weighted; 3) all the organics and soil is washed; 4) the residue is dried and sieved through 3 mm sieve; 5) all coarse fragments > 3 mm are measured and the content is calculated by Equation (4):

$$Cfr = \frac{WCF}{WMS} * 100 \qquad \text{Equation (4),}$$

where Cfr is a fraction of coarse fragments > 3 mm (%), WMS is the weight of the mean sample (g) and WCF is the weight of the coarse fragments (g).

The mechanical composition of the soil was determined by Kaczynski's pipette method, in which the sample was treated with hydrochloric acid (Donov et al., 1973).

In order to measure the soil's chemical properties, soil particles <2 mm were used for the experiments. The HANNNA pH/ORP Meter (Model HI2211) was used to measure soil pH in a soil:water ratio of 1:5, and 1:4 forest floor:water ratio. The Tjurin method was used to determine the organic carbon (OC) content in percentage in the soil and forest floor samples - oxidation with a bichrome mixture K_2Cr_2O7/H_2SO_4 at a temperature of 160°C for 20 min with a pumice catalyst and silver sulfate Ag_2SO_4. Titrate with a 0.2N solution of Morr's salt $(NH_4)_2SO_4.FeSO_4.6H_2O$, with phenylanthranilic acid as an indicator, The Kjeldahl method was used to measure total N, for the soil and forest floor samples - ISO 11261. The C: N ratio was calculated. Organic carbon and total nitrogen stocks (Cstock and TNstock) were calculated following the GPG-LULUCF from IPCC (IPCC, 2003) and for the total nitrogen stock adapted by Ellert and Bettany (1995):

$$\text{SOC (or TN) Stock} = \text{Con. C or N (\%)} * \text{BD (g/cm}^3) * d\ \text{(cm)} * (1\text{-Cfr}) \qquad \text{Equation (5),}$$

where SOC (or TN) Stock = Soil organic carbon or nitrogen stock (t/ha^1); Con. C or N = Soil organic carbon or total nitrogen (%); BD = bulk density (g /cm^3); *d* = depth or soil layer (cm); and Cfr is a fraction of coarse fragments > 3 mm (%).

The forest floor carbon stock was calculated as the determined organic C content in g/100g multiplied by the dry weight of the sample per unit area (Shulp et al., 2008).

The data obtained from the analysis of the samples were statistically processed. The data are independent with a normal distribution (Shapiro-Wilk test), which allowed to perform t-test - one of the most widely used parametric tests to determine the distribution of probability variables and to draw conclusions about the distribution parameters (Kim, 2015).

Results

Forest floor

The mean forest floor stock is 57.06 t/ha in the control plot, 38.79 t/ha in the thinned plot, and 35.71 t/ha in the managed after ice storm plot (Fig. 2). There is no significant difference, but the trend is for decreasing of the quantities of the forest floor.

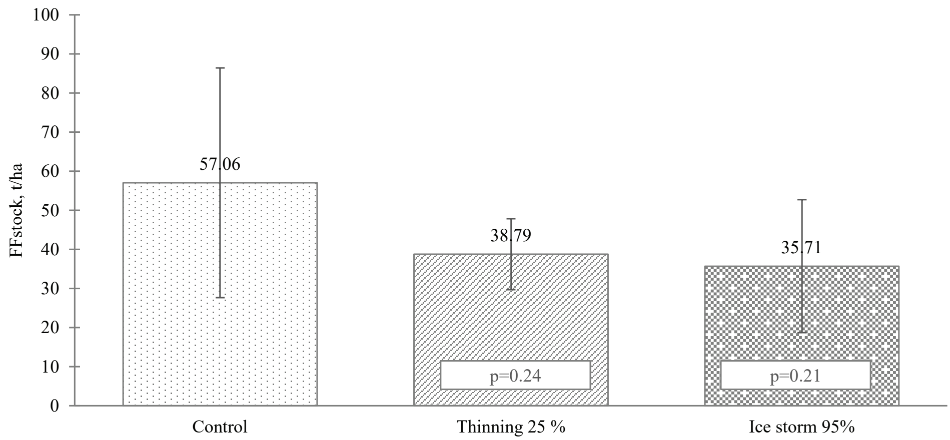

Figure 2. Average forest floor stock ± standard deviation, and p-value between the control and the studied plots

The observed water content in the forest floor layer is 7.88 % in the control plot, 27.10 % in the thinned plot, and 46.09 % in the plot damaged from an ice storm (Fig. 3). The variation has statistical difference and the trend is in increasing of the water content in the forest floor.

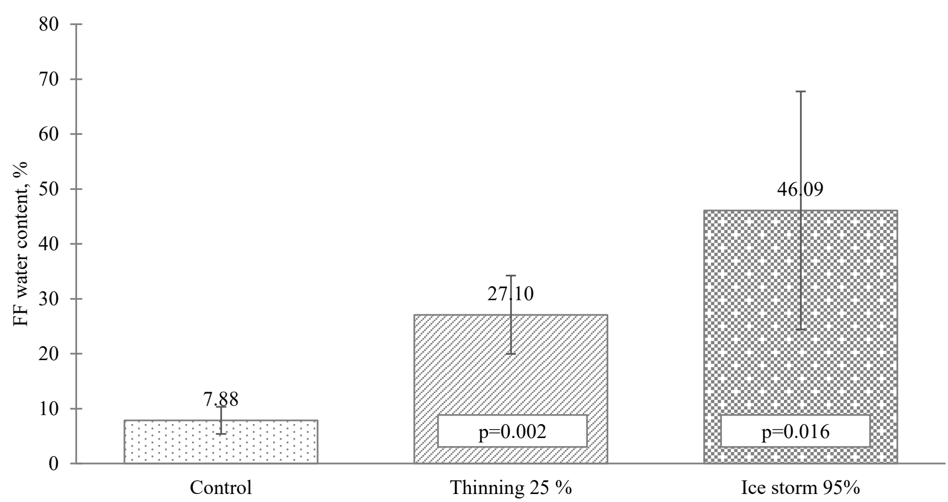

Figure 3. Average forest floor water content ± standard deviation, and p-value between the control and the studied plots

The observed average forest floor's reaction is acid and varies from 4.37 for the control plot, through 4.55 for the damaged from ice storm plot, and to 4.98 for the thinned plot (Fig. 4). The difference is significant between the control and the thinned plots and the reaction is still acid but higher in the managed site.

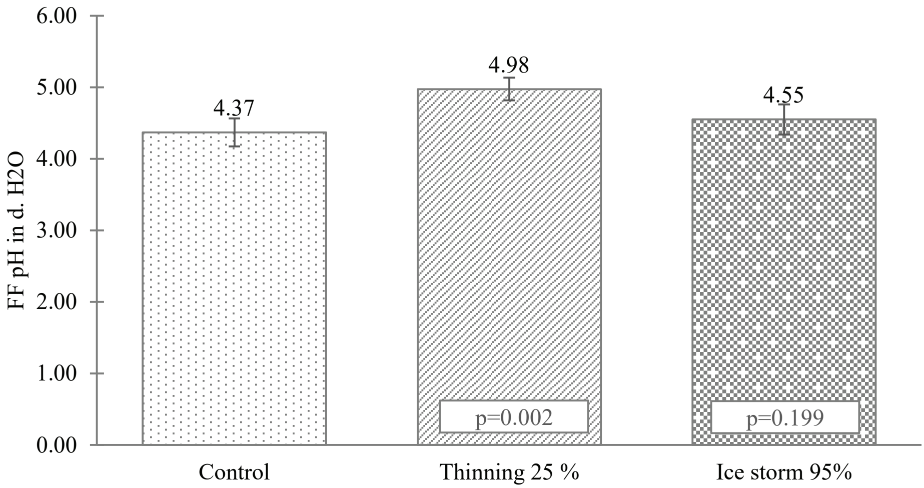

Figure 4. Average forest floor pH ± standard deviation, and p-value between the control and the studied plots

The mean of the measured organic carbon (C, %) in the forest floor for the control plot is 45.58 %, for the thinned plot – 35.54 %, and for the managed after ice storm plot – 44.40 % (Fig. 5). The difference is significant between the control and the thinned plots.

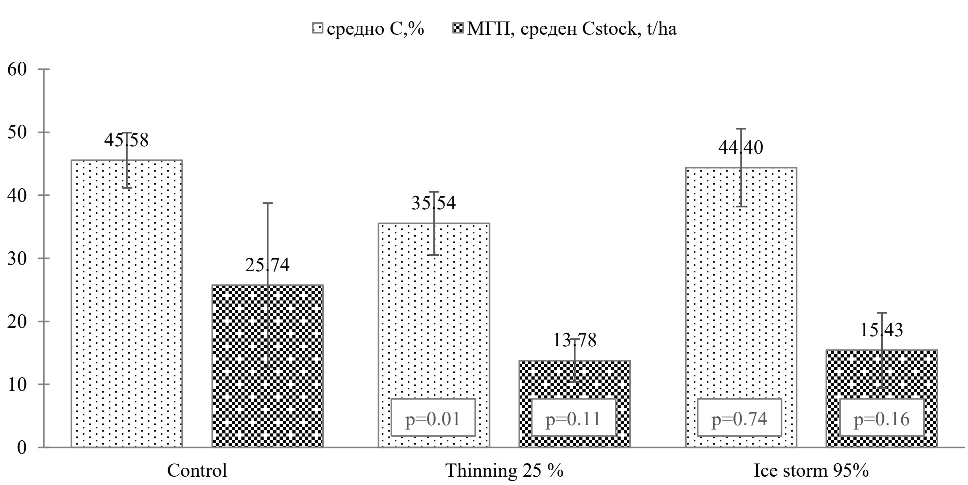

Figure 5. Average carbon content and Cstock in the forest floor ± standard deviation, and p-value between the control and the studied plots

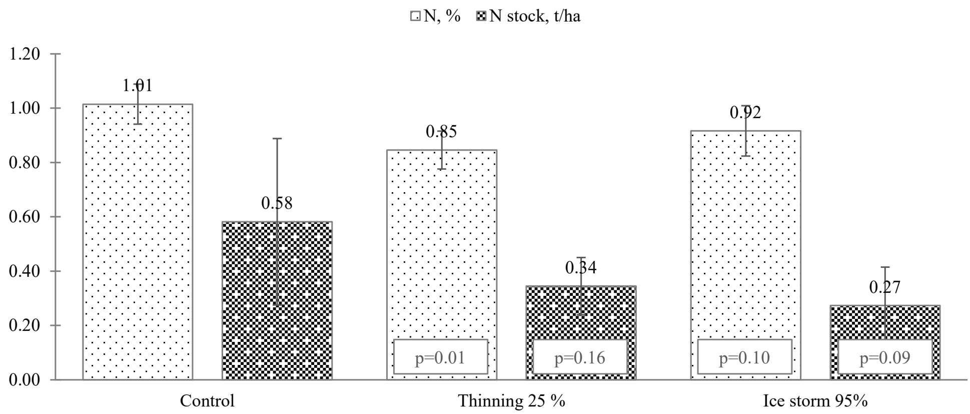

Figure 6. Average total N content (N) and Nstock in the forest floor ± standard deviation and p-values between the control and the studied plots

The average carbon stock (C_{stock}) of the forest floor in the control plot is 25.74 t/ha, in thinned – 13.78 t/ha, and in the damaged from ice storm plot – 15.43 t/ha (Fig. 5). The differences are not significant but there is a trend of decreasing of the carbon stock in the forest floor in the managed sites.

The mean of the measured total nitrogen (N, %) in the forest floor for the control plot is 1.01 %, for the thinned plot – 0.85 %, and for the managed after ice storm plot – 0.92 % (Fig. 6). The difference is significant between the control and the thinned plots.

The average total nitrogen stock (N_{stock}) of the forest floor in the control plot is 0.58 t/ha, in thinned – 0.34 t/ha, and in the damaged from ice storm plot – 0.37 t/ha (Fig. 6). There is significant difference, with p-value under 0.05, between the Nstock in the control and in the thinned plot.

The calculated C/N ratio for the forest floor is 44.90 for the control plot, 41.90 for the thinned and 48.35 for the damaged from ice storm plot. The obtained p-values shows no significant differences, for this parameter, between the control and the managed plots (Table 2).

Table 2. Average C/N ratio for the forest floor with standard deviation and p-values

	C/N	**Standard deviation**	**p-value**	**C/N, %**
Control	44.90	±2.03	-	-
Thinning 25 %	41.90	±3.06	0.111	Control vs Thinned
Ice storm 95%	48.35	±2.97	0.068	Control vs Damaged

Soil

Average soil bulk density on the control plot was measured as minimum 1.06 g/cm^3 to maximum 1.20 g/cm^3 and from 1.00 g/cm^3 to 1.45 g/cm^3 in the managed plots (Fig. 7). Soil compaction increased with the increasing of the depth, but no statistical difference was found between the different plots – p is above the significance level of 0.05.

The determined mechanical composition of the soil in the different layers is medium sandy loam (Table 3) with predominance of the sand fractions. The highest sand content is in the top soil layer in the thinned plot (70.71 %), where the soil mechanical composition type is slightly sandy loam considering Kaczynski's classification.

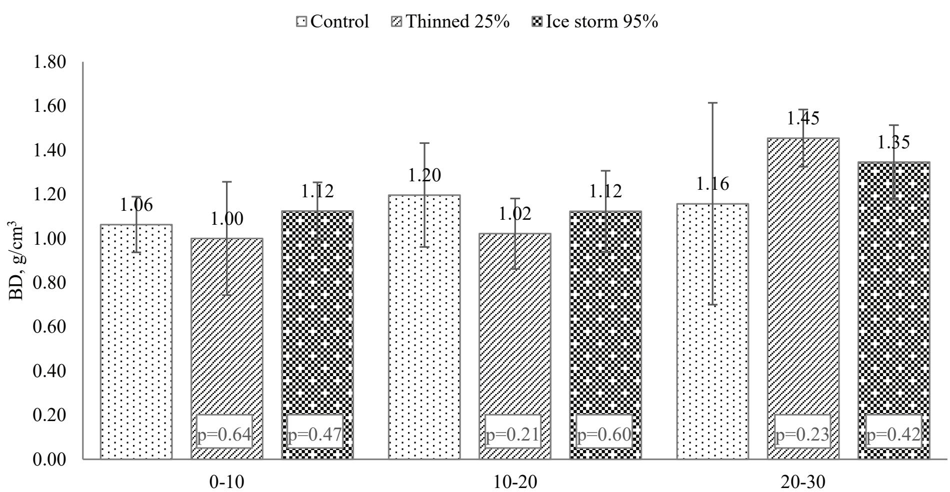

Figure 7. Bulk density/BD – average for the soil layer ± standard deviation, and p-value between the control and the studied plots

Table 3. Mechanical composition for the studied soil layers

Site	Layer, cm	Clay and Silt, %	Sand %	Soil mech. comp. type
Control	0-10	32,98	67,02	medium sandy loam
	10-20	30,95	69,05	
	20-30	36,35	63,65	
Thinned, 25 %	0-10	29,29	70,71	slightly sandy loam.
	10-20	37,81	62,19	medium sandy loam
	20-30	34,16	65,84	medium sandy loam
Ice storm, 95 %	0-10	38,21	61,79	medium sandy loam
	10-20	43,73	56,27	
	20-30	41,63	58,37	

Total soil porosity (P, %) was considerably lower in the damage from the ice storm site (Fig. 8). It increased by 23 % in the topsoil layer with increasing the intensity of the management and decreased by 32 % in the 20-30 cm layer. Porosity is inversely related to bulk density, meaning that a decrease in mean porosity comes with an increase in mean bulk density which is a weak trend in this study.

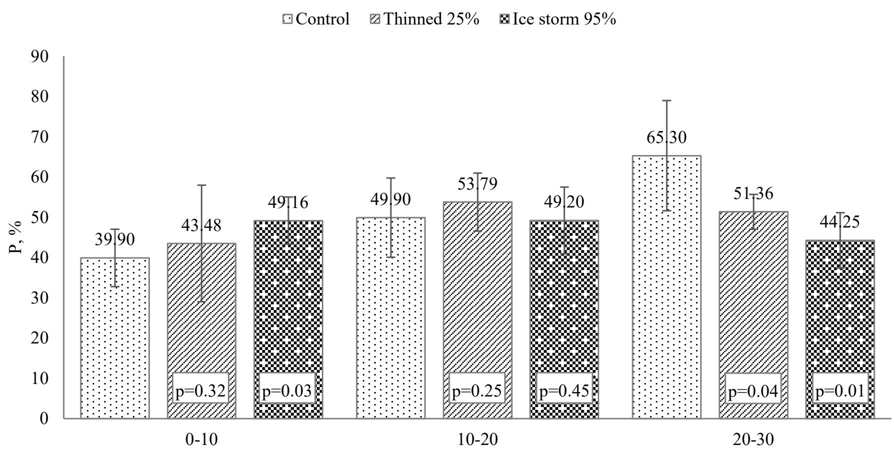

Figure 8. Soil total porosity (P, %) – average for the soil layer ± standard deviation, and p-value between the control and the studied plots

Soil moisture, on average, is from 12.64 % to 13.93 % on the control plot and lower in the managed sites for all studied layers (Fig.9). For the thinned plot observed soil moisture is between 10 % and 11 %, and for the damaged from an ice storm – between 4 % and 6 %. Soil water content was significantly decreased in the 10-20 cm layer, for the thinned plot (p=0.04), and in the managed after the ice storm plot (p=0.01).

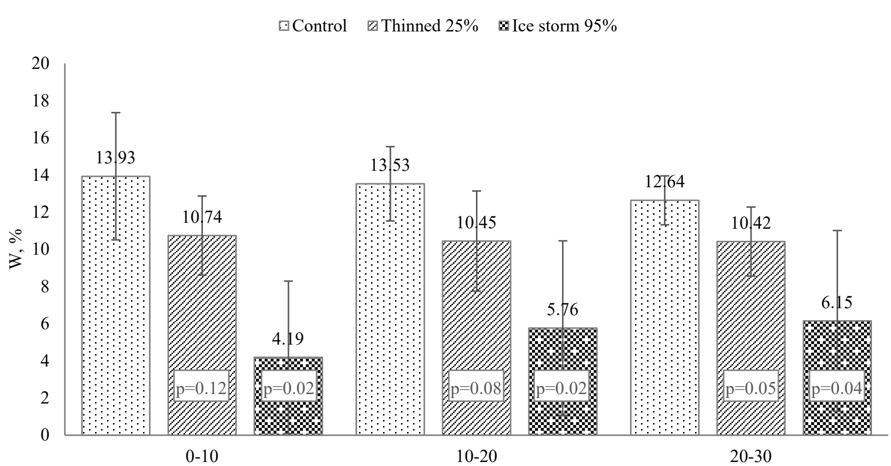

Figure 9. Soil moisture (W, %) – average for the soil layer ± standard deviation, and p-value between the control and the studied plots

Average coarse fraction content has been measured as 44-51 % on the control plot versus 57-65% in the thinned, and 51-60 % in the managed after ice storm plot. The observed skeletal content in the soil layers is highest in the surface 0-10 cm and decreases in depth (Fig. 10), without establishing significant differences between the three sample areas (p>0.05).

The observed soil reaction is acid in all studied plots, on average it varies between 4.49 and 4.80 (Fig. 11). There is no significant difference between studied layers or plots.

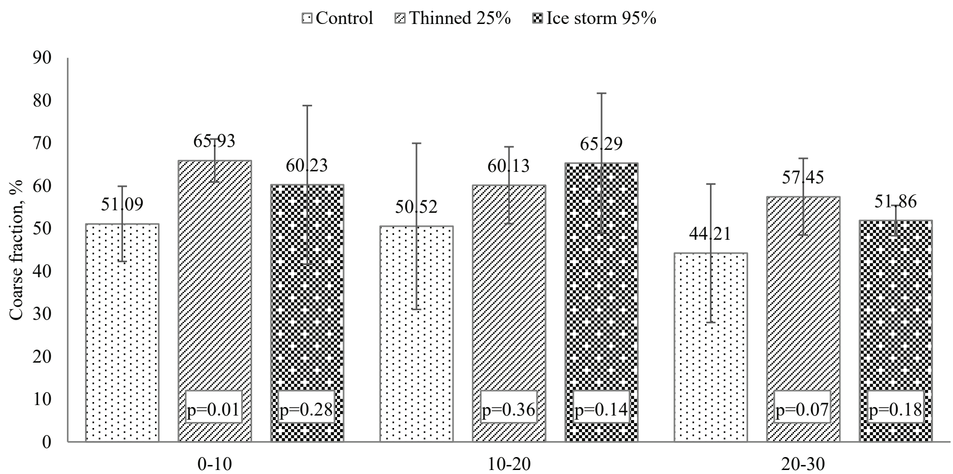

Figure 10. Coarse fraction content, % - average for the soil layer ± standard deviation, and p-value between the control and the studied plots

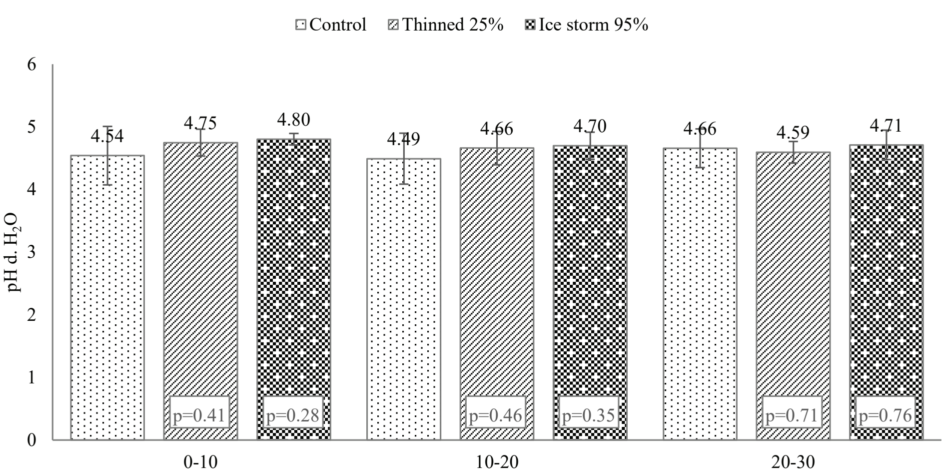

Figure 11. pH in distilled H2O – average for the soil layer ± standard deviation and p-value between the control and the studied plots

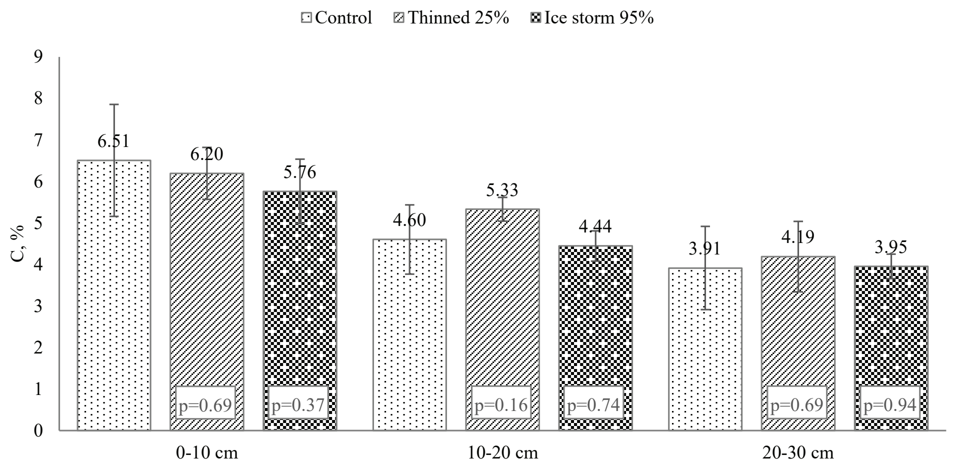

Figure 12. Average C content (C, %) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

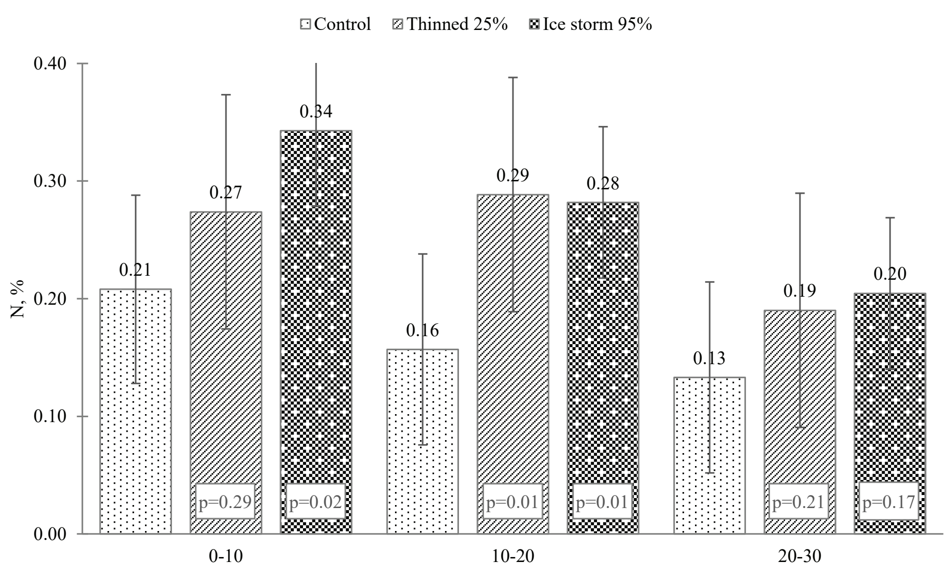

Figure 13. Average total nitrogen content (N, %) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

Soil total nitrogen content was highest in the top soil layer for all studied plots, slightly decreasing in depth for the control – from 0.21 % in 0-10 cm to 0.13 % in 20-30 cm. For the thinned plot the content of total nitrogen is similar for the first two layers (0.27 and 0.29 %), and decreases in the last studied soil layer (20-30 cm –

0.19). In the damaged from ice storm plot, total nitrogen content is highest between the studied plots for all layers, starting from 0.34 % in the top soil, trough 0.28 % for 10-20 cm, and dropping to 0.20 % on the 20-30 cm layer (Figure 13). The results from the conducted t-test indicate that the difference between the control and the damaged plot is significant for the soil layers from 0 to 20 cm. The total nitrogen content in the thinned with intensity of 25 % plot differs significant from the control plot in the 10-20 cm layer.

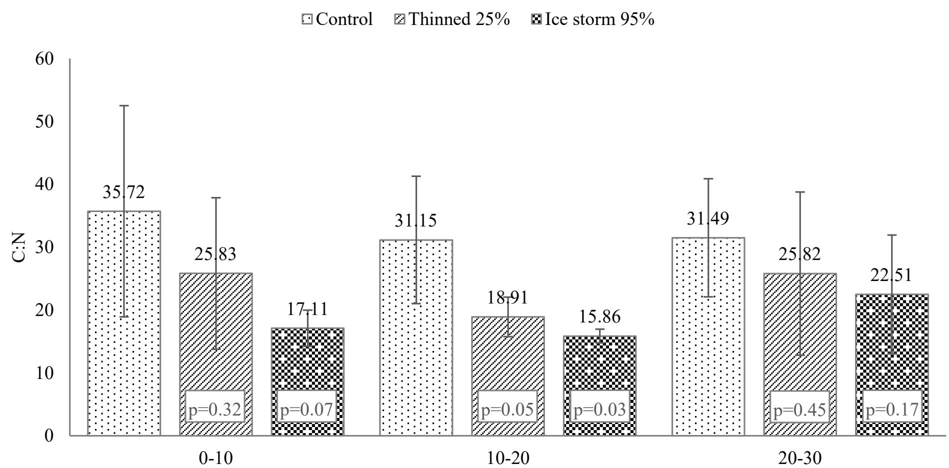

Figure 14. Average C/N ratio (C/N) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

The calculated average C/N ratio for the studied soil layers varies between 31 and 35 for the control plot, from 18 to 26 for thinned plot, and between 15-23 for the damaged from ice storm plot (Figure 14). The p-values, obtained from the t-test, indicate significant difference in the 10-20 cm soil layer between the control and the damaged plot.

The average total nitrogen stocks calculated for the studied layers do not fluctuate in wide ranges between the plots. In the control Nstocks are 0.86 t/ha for the 20-30 cm and 10-20 cm layers, and it goes to 1.06 t/ha in the top soil layer (Figure 15). For the thinned plot the calculated mean Nstocks are 1.00 t/ha for the 0-10 cm, 1.16 t/ha for 10-20 cm, and 1.20 t/ha for 20-30 cm layer. The damaged from ice storm plot has the highest total nitrogen stocks – respectively 1.46 t/ha (0-10 cm), 1.11 t/ha (10-20 cm), and 1.34 t/ha (20-30 cm). There is no statistical difference, considering the obtained p-values.

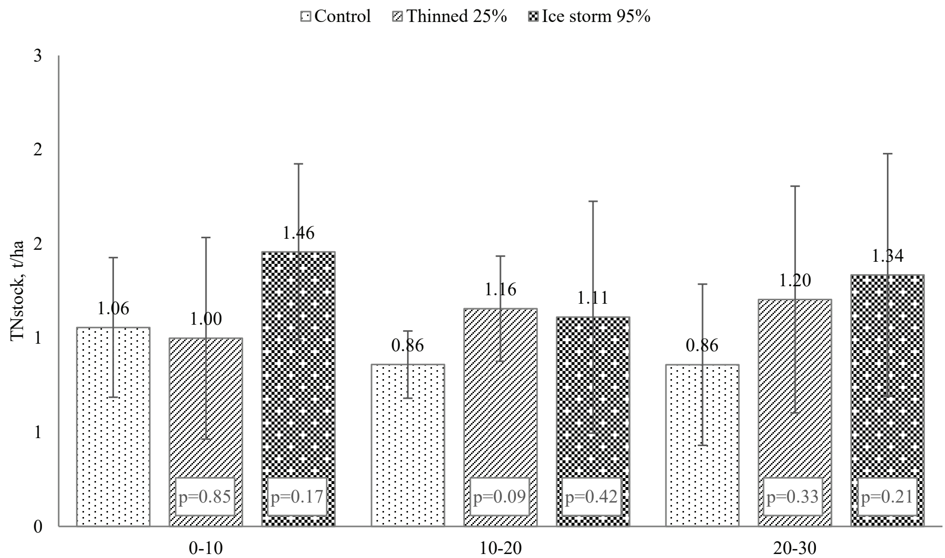

Figure 15. Average total nitrogen stock (N, t/ha) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

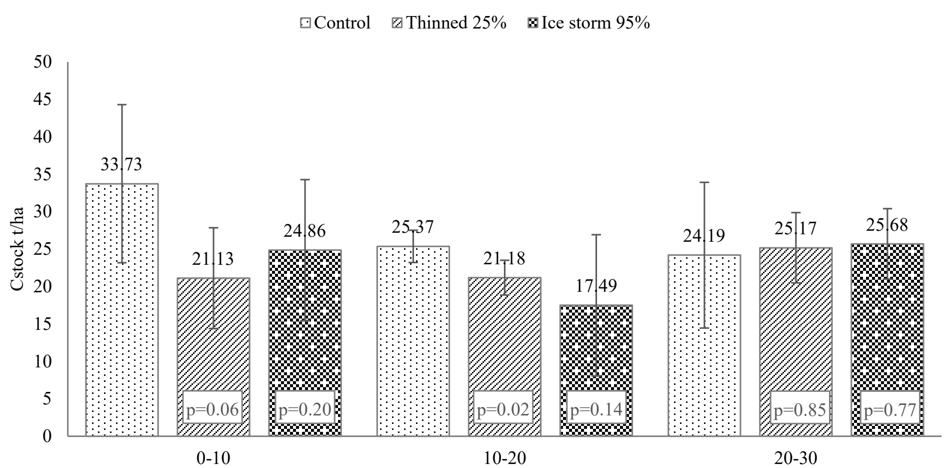

Figure 16. Average organic carbon stock (C, t/ha) in the studied soil layers ± standard deviation and p-value between the control and the studied plots

The average soil carbon stock (Cstock) in the top soil layer varies between the tree studied plots from 21.13 t/ha in the thinned plot, through 24.86 t/ha in the managed after ice storm, to 33.73 t/ha in the control plot. For the second studied layer 10-20 cm the variation is from 17.49 t/ha in the damaged from ice storm plot, through 21.18 t/ha in thinned plot, to 25.37 t/ha in the control plot (Fig. 16).

Discussion

Forest floor

Mountain ecosystems are highly sensitive and vulnerable to environmental changes and different impacts (Glushkova et al., 2020). The forest floor was considered to be easily influenced by thinning intensity (Vesterdal,1995). A thinning operation is followed by a change in forest floor microclimate towards reduced evapotranspiration and increased solar and. thermal radiation (Bala et al., 2006). These changes provide more favorable moisture and temperature regimes for decomposing microorganisms and increase the mineralization rate (Vesterdal,1995). Furthermore, reduced competition between the remaining trees might increase the amount of available nutrients per tree without actually increasing the nutrient capital of the site and result in a more nutrient-rich and easily decomposable litter (Yingrui et al., 2023). However, after a few years canopy closure and root development will suspend the effects of thinning (Vesterdal,1995). Consequently, the effect of thinning in a long-term perspective must depend on both frequency and intensity of the individual thinning operations. The thinning operations which have been repeatedly performed in the investigated plots may thus be expected to have created different conditions for mineralization over many years. A tendency towards more favorable conditions for mineralization, i.e. higher pH and lower C/N was found in the thinned plot. This indicates that the accumulation in the thinned plot might be more influenced by the microclimate than by a possible nutritional effect of thinning, since pH and C/N ratio were only little affected. At the same time, we can assume that in the plot damaged by the natural disturbances, followed by reforestation with spruce coppice and natural regrowth of local species, the microclimate conditions don't differ significant anymore – 10 years after the ice storm, and the canopy is closed. There is no significant difference in the quantities of the forest floor on the studied plots, but the water content is statistically higher in the managed plots, comparing to the control. This may be due to the increased ambience of broadleaved local species, for the damaged from ice storm plot as reported in other studies (Shinohara and Otsuki, 2015). Overall, the carbon stock in the forest floor doesn't differ between the studied plots. The calculation of the carbon stock of the forest floor depends on its quantities which doesn't differ significant in the studied plots. Thus, we may conclude that the observed difference in the carbon content is not significant for the ecosystem carbon stocks, it is more related to the availability of the nutrients, and the mineralization rates.

Soil

Research on the impact of thinning over the soil bulk density, in spruce forests, has shown mixed results. In some studies, it was found that thinning increased soil bulk density (He et al., 2018), while other – that thinning influenced tree characteristics and growth, but did not specifically address changes in soil bulk density (Pfister et al., 2007; Misson et al., 2005). Silvicultural thinning in spruce forests can have significant impacts on soil properties, including bulk density. However, the effects of thinning on soil bulk density may vary depending on the specific thinning method and intensity. In the current study there is a trend of compaction of the soil in depth, which is typical for the studied *Cambisols* (Koinov et al., 1998). Between the control and the managed plots there is no significant diference in the bulk density which can let us to assume that the soil porosity has not been affected too, as a result of the anthropogenic intervention in the managed areas (Shaheb et al, 2021).

The observed increase in the water content of the forest floor can lead to a reduction in soil moisture, particularly during the growing season (Kellomäki et al., 1996), which is observed in the present study for the damaged from ice storm plot. In moisture soil, the use of heavy machinery in forest operations can reduce soil porosity (D'Acqui et al., 2020). The forestry activities in the studied plots were not conducted with heavy machinery which preserved this soil indicator. In spruce crops, given the specificity of the morphology of the root system of this species, a tendency of gradual reduction of fine roots in depth is noticed (Dimitrova et al., 2015), which also leads to a decrease in soil moisture (Messenger, 1980). Considering the management in the thinned and after-ice storm plots which lead to a decrease in the density of the trees and their roots, it is acceptable to conclude that the management has its effect for the observed soil moisture reduction.

The content of coarse fractions in forests is a critical factor in estimating soil pool of carbon (Poeplau et al., 2016). Therefore, understanding the distribution and content of coarse fractions in spruce forests is essential for accurate estimation of soil nutrient pools and for effective forest management. In some studies, an inverse relationship between skeletal content and bulk density has been found (Guidi et al., 2014), which is also confirmed by the data obtained in this study.

Spruce contributes to increasing soil acidity (Kostić et al. 2012). Stand age has also been proven to affect soil pH in spruce plantations, with lower pH values in the soil of older stands (from 37 to 150 yrs) in comparison to younger spruce plantations – under 20 yrs (Smal and Olszewska, 2008). The results of this study suggest otherwise. There is no significant difference in the pH between the studied plots, which could be due to the obstacles connected with the land-use history of the plots, soil type, maturity rock etc., and additional studies are needed.

Thinning can have complex and varied effects on soil carbon content in spruce forests. Some studies observed decrease in soil respiration rates immediately after thinning, followed by a gradual increase of soil carbon content (Pang et al., 2016). In other it was found that with increasing thinning intensity soil carbon content decreases (He et al., 2018). It was also noted a site-specific response, with a slight decrease in forest floor carbon but an increase in mineral soil carbon under thinning treatments (Kim et al., 2019). When felling is carried out, in which the preservation of the good condition of the plantation and the habitat is observed, a weak or no effect on the content of org. C in the soil and the reduction in the amount of fresh fall applied is compensated by the fallow left (Lal, 2005). These findings suggest that the impact of thinning on soil carbon content in spruce forests is influenced by a range of factors, including forest type, environmental conditions, and the specific management practices used. This study contributes to the findings that the thinning practices conducted low intensity, and with attention for maintaining the habitat, leads to no significant changes in the soil carbon content. For the damaged from ice storm plot we could note that although the conducted heavy thinning – over 95 %, reduced more plant photosynthetic biomass, decomposition of dead roots, litterfall, and woody debris can only offset the decrease in soil organic carbon, within a certain time scale after thinning and thus led to no significant changes in soil carbon content in heavy thinned plot.

There is a positive correlation between the organic carbon content and the total nitrogen content in the soil (Xue and An, 2018). In the present study while the organic carbon content does not differ between the studied plots, the total nitrogen is significantly higher in the managed sites. Low intensity thinning in spruce forests can

lead to an increase in soil total nitrogen (Wang et al., 2010). On the long-term, the removal of tree biomass in form of stems, branches, and leaves and the associated decreased litter fall and discontinuation of a steady input of N-containing biomass can reduce total N contents in the soil (Olsson et al., 1996). Depending on the further development of understory vegetation, this loss of N input into the soil can partly be diminished by the reduced N plant uptake after high intensity thinning (Siebers and Kruse, 2019), which can also affect the C/N ratio. The C/N ratio is barely affected in the damaged from ice storm plot, in the 10-20 cm soil layer, in positive direction. The lack of change in this parameter is actually a good result, because it indicates that the decomposition rate and the quality of the compost are good. The optimal carbon-nitrogen ratio for composting is between 25-30 to 12.

Management practices may affect C dynamics (Yang et al. 2011) and alter C storage in forest ecosystems (Powers et al. 2011). Thinning improves the growth conditions of remaining trees (Balboa-Murias et al. 2006), affects stand conditions and soil environmental factors such as soil moisture and temperature (Kim et al. 2009), and thus influences forest C storage, dynamics and cycling (Nilsen and Strand 2008). Overall, the studied soils in the control, thinned with 25 % intensity, and cleared after ice storm with over 95 % of the biomass, plots did not occur with significant differences in the studied properties, which could lead to decrease in the carbon stocks.

Conclusions

Forest floor characteristics undergo changes, which we observed ten years after thinning activities and natural disturbances, can be related more to the availability of the nutrients, and the mineralization rates, than to its carbon stocks.

Soil pH depends on many factors, and the present study results contribute to the idea that the vegetation type is not the leading factor for soil acidity. The rich variety of soil types, and other conditions, in Bulgaria provoke the conclusion that more studies, connected with the changes in this parameter, are needed.

The results of the experiment show that the forest management carried out in compliance with the requirements for the protection of the habitat and the functionality of the ecosystem in the studied sites did not lead to negative changes in the studied soil properties.

Taking soil carbon accumulation into consideration we can conclude, that light thinning (thinning intensity < 33%) is recommended for silvicultural practice, but when needed the clear cuttings and afterall activities can be conducted with preservation of the soil function to accumulate carbon and nitrogen. We can also suggest that having more long-term field experiments to study soil carbon stocks and dynamics under different thinning intensities is need to fulfill the knowledge and understanding the processes of accumulating organic carbon and total nitrogen in the soil.

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RESEARCH ARTICLE

Impact of maintenance regimes on species richness in newly established perennial wildflower meadows

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Abstract

Perennial wildflower meadows contribute to the enhancement of the quality of urban green spaces, offering benefits for both people and wildlife. Significant impact is attributed to management in fostering species-diverse plant communities. However, there are not enough studies exploring the influence of early maintenance regimes on plant diversity. A three-year experiment was conducted to investigate the impact of maintenance regimes on newly established perennial wildflower meadows and the influence of sowing mix on species richness. Three types of perennial wildflower seed mixes were sown on arable land and managed differently during the initial year. Results indicate statistical significance for each main effect, including maintenance type and sowing mix, with no significant interaction between these factors. Mowing during the early growth stage is shown to increase species richness, while no significant difference is observed between weeded and unmanaged plots. The dry meadow sowing mix demonstrates the highest diversity index (Shannon-Weaver, 1963). Maintenance regimes exhibit a significant influence on species richness independently of the sowing mix used. Furthermore, mowing during the early growth stage is found to enhance species diversity in the long term. These findings provide beneficial insights for the more efficient management and establishment of species-rich wildflower perennial meadows in both urban and suburban environments, particularly in areas with a significant soil weed seed bank.

Keywords

biodiversity, urban meadows, wild flowers, maintenance, mowing

Introduction

Urban development increasingly disturbs natural habitats. This is the reason for creating more diverse urban green spaces. Flowering meadows provide a rich diversity of perennials, both forbs and grasses. They have a positive impact on citizens with their ornamental effect (Wood et al., 2018). Using native perennial seed mixes improves the quality of urban greenery (Norton et al., 2019) and conserves biodiversity (Bretzel et al., 2016). An essential requirement for using native seeds is that they originate from the same biogeographic zone (Mainz & Wieden, 2019). There is evidence for the positive effect of a lower sowing rate on species richness, especially when seeds are sown in unproductive soils, weed-free mulches, or when the initial fast effect of rapid forb development is not required (Jiang & Hitchmough, 2022).

Maintenance plays a significant role in preserving species richness. Mowing frequency is an important factor for the number of species in the meadows. Decreasing mowing times to twice per growing season in existing grass areas increases the number of plant species in the long term (Chollet et al., 2018; Sehrt et al., 2020; Wastian et al., 2016). There is one more advantage to the variety of plant species: Species richness is associated with flower diversity and abundance, which provide food for more wild species like pollinator insects (Lindemann-Matthies and Bose, 2007; Wastian et al., 2016). There is an opportunity for providing habitat and food for wildlife animals by leaving unmown parts or by gradually mowing some parts, leaving others (Johansen et al., 2019).

The mowing regime manages the flowering period and duration. The appropriate mowing regime increases flowering. Establishing optimal mowing frequencies throughout the year influences the preservation of dicotyledon diversity. This is particularly important in fertile soils, as they create a competitive environment that favors the growth of monocotyledonous grass species, especially in phosphorus-rich soils (Piqueray et al., 2019). Mowing in combination with collecting hay decreases nitrogen and iron in the soil and plays a key role in increasing plant diversity (Chollet et al., 2018; Manninen et al., 2010). Mowing is a significant factor in maintaining species quantity in the long term.

There are seven significant factors related to future meadow establishments based on stakeholder manager perceptions: “aesthetics and public reaction, spatial context, human resources and economic sustainability, local politics, communication, biodiversity and habitat value, and physical factors affecting establishment and maintenance” (Hoyle et al., 2017). The first three factors are described as the most influential. Cities could introduce perennial meadows to boost biodiversity and enhance the aesthetic appeal of urban green spaces. There is a challenge for local authorities from an economic point of view, such as removing and composting of meadow arising. There is a need of more detailed economic research on cutting frequency and species that produce less biomass. Frequent cutting could be cheaper because it involves dispersing the removal over the site, in contrast with cutting once a year, which requires collecting and composting the removed biomass. Using shorter plant species or species from unproductive soil habitats could decrease plant biomass and the cost of disposal. From this perspective, selecting the right seed mix is crucial. It is appropriate to use plants from less productive habitats, which produce less biomass.

There is much evidence for the positive effect of mowing to preserve and increase species richness, but there is not enough research on different types of maintenance in initial plant growth to create species-rich flowering meadows. The aim of this research is to examine the impact of various maintenance practices on the initial growth of meadows, utilizing three distinct regimes and three different perennial wildflower mixes, and to assess their effects on species richness.

Material and methods

Experiment establishment and field studies

In Bulgaria, there are no native perennial seed mix producers. This was the reason for using wildflower species from Hilzingen, Germany, which is in the same biogeographic zone as Sofia, Bulgaria. (*Europe's Biodiversity - Biogeographical Regions and Seas — European Environment Agency*, 2002). Flowering meadows were established using three distinct types of wildflower perennial seed mixes, each sourced from nursery-raised wildflower plants. These mixes include: Mix 02 - Wet meadow seed mix, Mix 06 - Universal meadow seed mix, and Mix 06a - Dry meadow seed mix. Table 1. presents the plant species contained within various seed mixes. With the exception of Buphthalmum salicifolium L. and Rhinanthus alectorolophus (Scop.) Pollich, all species are native to the Bulgarian flora. The plots are situated in the Vrazhdebna Training and Experimental Field Centre, Sofia, Bulgaria. The soil in the area is alluvial-meadow, slightly gravelly. The latest soil analysis data from Megatron (2022) shows an average level of organic matter (3–6%), a low level of ammonium (NH_4-N =02-04kg/ha) and nitrogen (NO_3-N = 10-30kg/ha). The soil has high quantities of phosphorus (P > 45 mg/kg (ppm)), low quantities of potassium (K = 60-120 mg/kg (ppm)), and neutral acidity (pH = 6.3-7.0). The soil structure is mostly sandy (40–60%) with low quantities of loam (10–20%) and average silty content (20-40%). Plant available water value is low (50-65% of field capacity).

The climate is European continental. The average annual precipitation is 650 mm and 380 mm of it is during the growing season. The driest months are December, January, and February; with the highest precipitations being May, June, and July (Koleva, 1990).

The soil preparation includes applying a rotary tiller to the top soil and removing all plant parts, roots, and others; levelling with a rake; and removing large parts from the surface. Every seed mix has four samples. Each of them is 10 m². Seeds were spread in the middle of April 2021, raked shallow (1-2 cm), and compacted with a plank. During the germination period, they were irrigated in extremely dry periods with quantities that enrich the top 2 cm of soil with an approximate amount of water. Three types of maintenance were applied at the end of May in the first year: weeding, mowing, and control, which were left without any interventions. There are two mowed plots, one weeded and one control, for every seed mix.

Table 1. Plant species in seed mixes

№	Species	Seed mixes		
		02	**06**	**06a**
1	*Achillea millefolium* L.	+	+	+
2	*Agrimonia eupatoria* L.		+	
3	*Anthemis tinctoria* L.		+	+
4	*Anthoxanthum odoratum* L.		+	+
5	*Anthriscus sylvestris* (Hoffm.) Link	+		
6	*Anthyllis vulneraria* L.		+	+
7	*Arrhenatherum elatius* (L.) P.Beauv.	+		
8	*Bellis perennis* L.	+		
9	*Briza media* L.			+
10	*Bromus erectus* Huds.			+
11	*Buphthalmum salicifolium* L.		+	+
12	*Campanula patula* L.	+	+	+
13	*Campanula rotundifolia* L.			+
14	*Carum carvi* L.		+	
15	*Centaurea jacea* L.	+	+	+
16	*Centaurea scabiosa* L.		+	+
17	*Cichorium intybus* L.		+	
18	*Crepis biennis* L.	+	+	
19	*Cynosurus cristatus* L.	+	+	+
20	*Daucus carota* L.	+	+	+
21	*Dianthus carthusianorum* L.		+	+
22	*Echium vulgare* L.		+	
23	*Festuca ovina* L.			+
24	*Festuca rubra* var. trichophylla (Vill.) Gaudin			+
25	*Galium mollugo* L.	+	+	
26	*Galium verum* L.		+	+
27	*Geranium pratense* L.		+	
28	*Heracleum sphondylium* L.	+		
29	*Hypericum perforatum* L.		+	+
30	*Knautia arvensis* (L.) Coulter	+	+	+
31	*Leontodon hispidus* L.	+		+
32	*Leucanthemum vulgare* (Vaill.) Lam.	+	+	+
33	*Lotus corniculatus* L.		+	+
34	*Malva moschata* L.		+	+
35	*Medicago lupulina* L.		+	+
36	*Onobrychis viciifolia* Scop.	+	+	+
37	*Picris hieracioides* L.	+		
38	*Pimpinella saxifraga* L.		+	+
39	*Plantago lanceolata* L.	+	+	
40	*Potentilla recta* L.		+	
41	*Prunella grandiflora* (L.) Scholler	+	+	+
42	*Prunella vulgaris* L.	+	+	
43	*Ranunculus acris* L.	+		
44	*Ranunculus bulbosus* L.	+		+
45	*Rhinanthus alectorolophus* (Scop.) Pollich		+	+
46	*Rumex acetosa* L.	+		
47	*Salvia pratensis* L.	+	+	+
48	*Salvia verticillata* L.		+	
49	*Sanguisorba minor* Scop.	+	+	+
50	*Scabiosa columbaria* L.			+
51	*Silene nutans* L.		+	
52	*Silene vulgaris* (Moench) Garcke	+	+	+
53	*Thymus pulegioides* L.			+
54	*Tragopogon orientalis* L.		+	+
55	*Trisetum flavescens* (L.) Beauv.	+	+	
56	*Veronica teucrium* Crantz			+

Legend: 02 – Wet meadow seed mix, 06 – Universal meadow seed mix, 06a – Dry meadow seed mix

On 27 Jul. 2021, all experimental plots were cut down. After that, they were irrigated two times per week in dry weather until the middle of September 2021. The annual weeds were removed in November 2021. In the second year, all plots were cut down on 8 Aug. 2022, and on 27 Jul. 2023.

Data collection took place in the third year (2023), where information regarding the percentage range of species cover abundance and the Braun-Blanquet scale (Barkman et al., 1986; van der Maarel, 1979) was recorded two times in June. Each sample area of 10 m^2 was evaluated and reported accordingly. Number of plant species in each sample were recorded twice (in May and June) or once (in July and September) per month from May to September 2023. The plant species were identified according Delipavlov (2011), Yordanov (1963) and Fetovadzhieva (1973). Non-native for Bulgaria species were identified according to seed mix specifications.

Data analysis

The dependent variable, species richness, was determined by the total number of observed plant species recorded between May and September 2023. Two independent variables were considered: maintenance regime and seed mix. To assess the impact of initial maintenance type and seed mixes on species richness, a two-way analysis of variance (ANOVA) was performed using SPSS Statistics 28.0.0. A comparison between various maintenance regimes and seed mixes was conducted using the Tukey`s Honestly Significant Difference (HSD) test.

The species diversity index H` (Shannon-Weaver, 1963) and index of species evenness E (Pielou, 1966) were calculated for each sample based on species abundance.

Formula (1) for determining the species diversity index (H`) (Shannon-Weaver, 1963):

$H` = - \Sigma (C).\ln (C)$

Where: C = the relative abundance of the species.

Formula (2) for determining index of species evenness (E) (Pielou, 1966):

$E = H`/\ln (S)$

Where: H` = Shannon-Weaver index; S = number of species in the sample.

Results

Rapid weed emergence commenced in mid-May during the first growing season. Weeds such as: *Amaranthus retroflexus, Agropyron repens, Alopecurus myosuroides, Anthemis arvensis, Capsella bursa-pastoris, Chenopodium album, Convolvulus arvensis, Cynodon dactylon, Galinsoga parviflora, Lithospermum arvense, Lolium temulentum, Panicum sanguinale, Plantago major, Polygonum lapathifolium, and Setaria viridis*. The coverage of each plot reached 80% at the end of May, when the first maintenance had been applied (Figure 1.). The majority of the plants were *Amaranthus retroflexus, Polygonum lapathifolium,* and *Panicum sanguinale.*

Figure 1. Different types of maintenance regimes in the first year: weeded (left), mowed (middle), control (right)

Table 2. The means and standard deviations of species richness under different maintenance regimes.

Seed mix**	Maintenance*	M	SD
Wet meadow	**Control**	8,00	1,41
	Mowed	9,50	1,84
	Weeded	8,80	1,92
Universal meadow	Control	13,00	5,43
	Mowed	17,80	6,86
	Weeded	14,00	4,85
Dry meadow	Control	10,80	3,27
	Mowed	14,90	3,11
	Weeded	13,20	2,49

Legend: 02 – Wet meadow seed mix, 06 – Universal meadow seed mix, 06a – Dry meadow seed mix

After the interventions, the vegetative cover started to recover. The rapidest growth was observed in the mown plots, and on the 10th day, the cover had reached 55–70%. In weeded plots, vegetation appeared more slowly and reached coverage between 10–15%. In control plots, coverage was between 85 and 90%. The first detected species from the sown seed mixes were *Bellis perennis, Silene vulgaris* and *Daucus carota.* After mowing all the plots at the end of July, annual weeds had disappeared and the rosettes of seeded perennial plants had shown. After the irrigation started, Setaria viridis had become the most common species. At the end of the first growing season, *Dianthus carthusianorum*, *Tragopogon orientalis*, *Centaurea jacea,* and *Leontodon autumnalis* were blooming. There were rosettes of *Echium vulgare, Anthyllis vulneraria, Malva moschata, Achillea millefolium, Plantago lanceolata, Leucanthemum vulgare*, and *Knautia arvensis*. *Campanula patula* appeared in the second year but disappeared thereafter. Most of the seeded plant species were observed. There were no individuals in the experimental plots from *Pimpinella saxifraga, Anthoxanthum odoratum, Carum carvi, Agrimonia eupatoria, Anthriscus sylvestris, Campanula rotundifolia, Geranium pratense, Heracleum sphondylium*, or *Rhinanthus alectorolophus*. Some native species, like *Viscaria vulgaris, Lychnis flos-cuculi, Centaurea cyanus, Holcus lanatus, Trifolium incarnatum*, and *Coronilla varia*, were noticed in the third year.

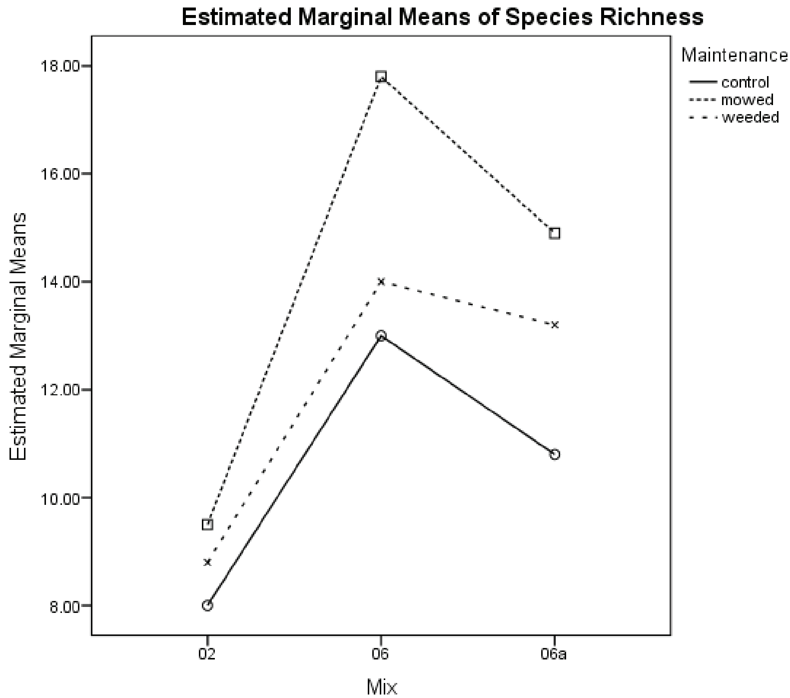

Figure 2. Effects of maintenance regimes and seed mixes on species richness

Silene nutans, *Veronica teucrium, Lotus corniculatus, Anthemis tinctoria, Ranunculus acris, Potentilla recta*, and *Trisetum flavescens* were self-seeded in other plots. *Briza media* was found only in the weeded plot of the dry meadow mix, and *Malva moschata* was found in the mown plot of the universal meadow mix.

Maintenance regime

The results of the two-way analysis of variance (ANOVA) for the number of germinated species under different maintenance regimes are presented in Table 2. There is a significant main effect for maintenance, $F\ (2, 51) = 3.916$, $p = 0.026$; a significant main effect for seed mixes, $F\ (2, 51) = 10.80$, $p < 0.001$; and no significant interaction between maintenance type and seed mix, $F\ (4, 51) = 0.446$, $p = 0.774$.

On Figure 2. it is presented that there is no interaction between the main effects. Estimated marginal means are highest in weed plots and lowest in control plots.

A post hoc comparison using Tukey`s HSD test indicated that the mean score for mowed plots ($M = 14.07$, $SD = 5.56$) was significantly different ($p = 0.009$) than the controls ($M = 10.60$, $SD = 4.07$). However, the weeded ($M = 12.00$, $SD = 3.89$) did not significantly differ from the mowed and controls. Taken together, these results suggest that early mowing in the first year does have a positive effect on species richness. Weeding does not appear to be a significant maintenance factor for species richness.

Figure 3. below shows that the mowed plots have more established sown species in comparison with others.

The Shannon-Weaver diversity index (Shannon-Weaver, 1963) (Figure 4.) shows that mown plots have the highest diversity in comparison with weeded and control plots. However, mown plots have the lowest index of evenness (Pielou, 1966), in contrast with weeded and control plots, which are equal. It means that some species in mown plots had started to dominate.

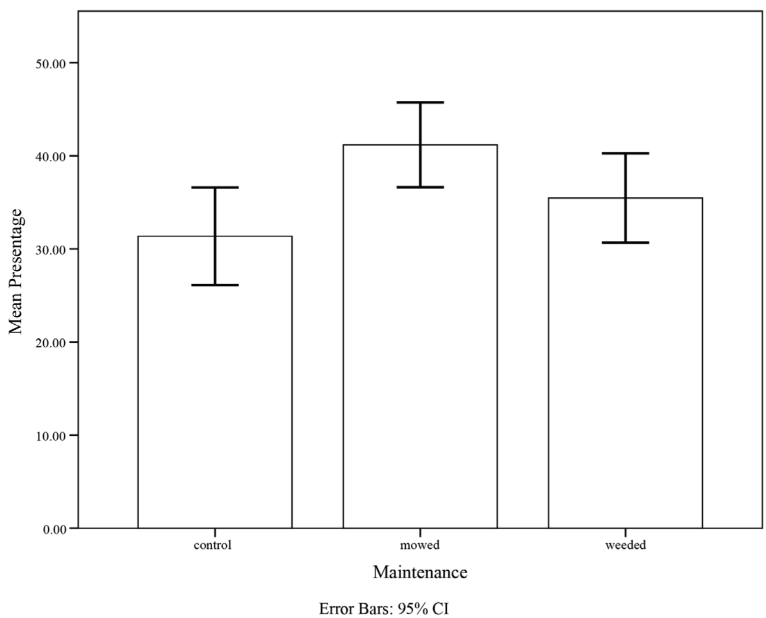

Figure 3. The mean percentage ratio between the established species from the seed mixes and the total number of species for all seed mixes under various maintenance regimes.

Seed mix

A post hoc comparison using the Tukey`s HSD test for seed mixes indicated that the mean score for the wet meadow mix 02 (M = 8.95, SD = 1.79) was significantly different ($p<0.05$) than the universal meadow mix 06 (M = 15.65, SD = 6.02) and dry meadow mix 06*a* (M = 13.45, SD = 3.33). The universal meadow mix 06 (M = 15.65, SD = 6.02) did not significantly differ from the dry meadow mix 06a (M = 13.45, SD = 3.33). Consequentially, there is no significant difference between dry meadow and universal seed mix species richness.

The species diversity index (H`) (Shannon-Weaver, 1963) (Figure 5.) indicate that the plots with the highest index of diversity are those with a dry meadow seed mix. The plots with the highest index of species evenness (E) (Pielou, 1966) are those with a wet meadow seed mix. The plots with the lowest diversity and evenness index are those with a universal meadow mix.

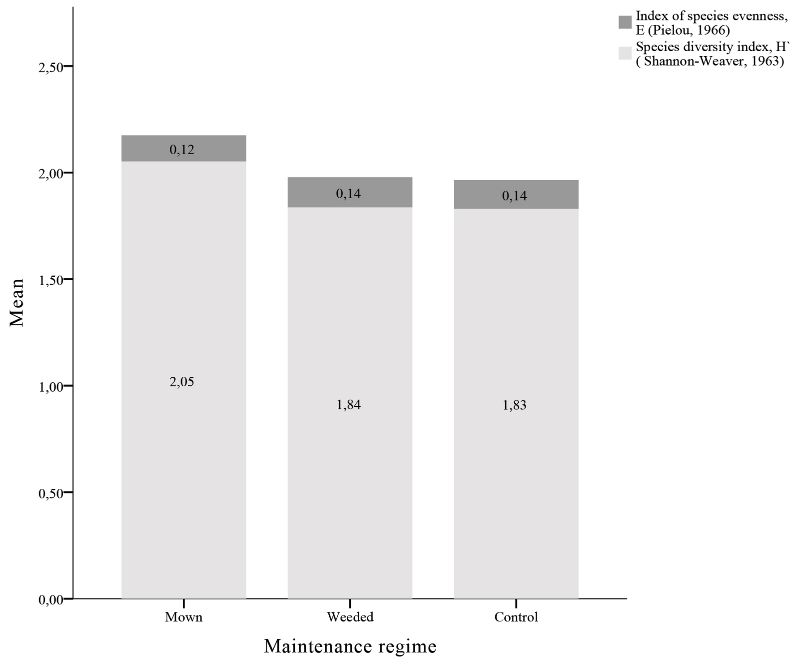

Figure 4. Alpha diversity for different maintenance regimes (species diversity index H` (Shannon-Weaver, 1963), index of species evenness E (Pielou, 1966))

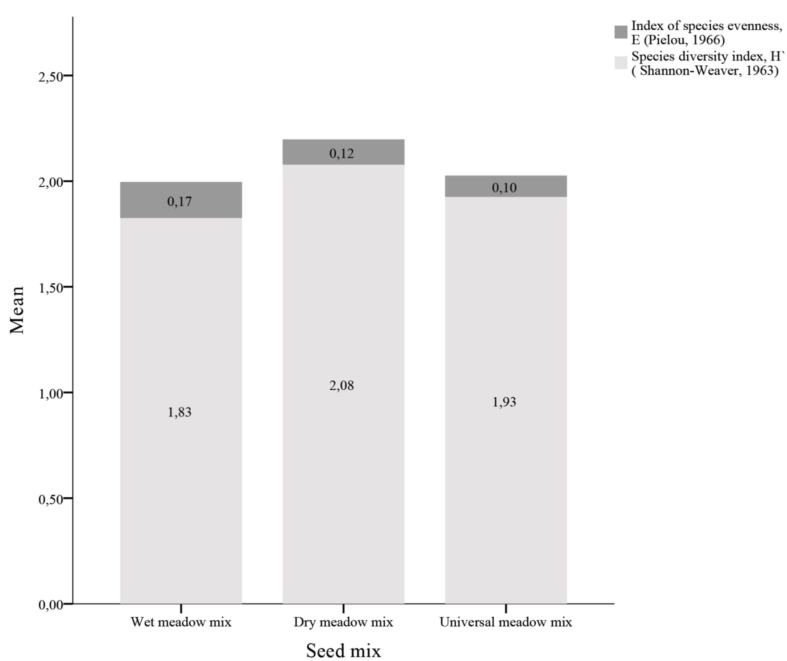

Figure 5. Alpha diversity for different seed mixes (species diversity index H` (Shannon-Weaver, 1963), index of species evenness E (Pielou, 1966))

Figure 6. The beginning of the flowering season in the third year (2023)

Figure 7. Blooming in the middle of May 2023 (third year). Mix 02 (left), mix 06 (middle), mix 06a (right)

Figures 6. and 7. show flowering at the beginning of the third vegetative season. There are *Tragopogon orientalis*, *Onobrichis viciifolia*, *Leucanthemum vulgare*, *Salvia pratensis*, and *Dianthus carthusianorum* blooming.

Discussion

The maintenance regime in the first year is a significant factor for species richness in the establishment and development of newly established wildflower meadows in the long term. Early mowing has a positive effect on removing annual weeds. The cutting allows more light to enter the soil surface for wildflower species germination. Mowing increases the diversity index (Shannon-Weaver, 1963) but leads to lower evenness index (Pielou, 1966). Some species are not adapted to mowing or require more frequent mowing to decrease dominant species abundance. A further research about this effect is needed.

Weeding has no significant impact. In some cases, weeding could lead to less diverse communities because of a human factor. Some plants from the sown seeds might be inadvertently removed during the weeding process. The other reason for the lower diversity of weeding plots might be the microclimate. However, there were species with individuals only in mowed or weeded plots. The microclimate of mowed communities differs from that of weeded communities. Weeds create partial shade on the ground. Removing them allows direct sunlight to reach the ground, increasing the amount of sunlight on the soil surface. However, this also leads to a rise in temperature and faster water evaporation. Shading the ground retains moisture in the soil for longer and provides better conditions for germination (Bringmann et al., 2006).

Mowed and control plots have a significant difference in plant species richness. Leaving plots without any intervention in the first months is the worst scenario for species richness. Weeds suppress the germination of perennial plants. However, annual weeds are pioneer species, and their quantity decreases with time at the expense of perennial flowers (Kirmer, 2014). Like pioneer species, weeds play the role of plant community edificators and may provide more suitable conditions for perennial seed germination. Though, if they completely cover the surface, they become a barrier that prevents light from reaching the ground.

As previous findings these results support that cuttings and removing the aboveground biomass once or twice per year increase species richness (see Chollet et al., 2018; Piqueray et al., 2019; Sehrt et al., 2020; Wastian et al., 2016). However, mowing and leaving the aboveground biomass could lead to poor diversity in contrast with setting-aside plots (Hyvönen et al., 2021).

In the seed mix specifications, there was no information about the proportion of seeds from different species. Additionally, it was noted that certain species, such as *Bellis perennis* and *Stachys recta*, were found in the plots despite not being included in the seed mix. This was particularly evident in the dry meadow mix.

Future studies could consider conducting experiments using wild regional seeds, examining their field seed germination rates, and evaluating their proportion in the seed mix. Additionally, it would be interesting to explore the reasons for the lower evenness index (Pielou, 1966) observed in mown plots.

This research could benefit urban and suburban greening projects devoted biodiversity enrichment by creating perennial wildflower meadows and to improve the quality and aesthetic of urban environments. The findings would be helpful in the establishment of perennial wildflower seeds, especially in soils with a significant weed seed bank.

Conclusions

Early mowing proves to be a successful method for weed suppression during the initial phase of flowering meadow establishment, especially in phosphorus-rich soils. Implementing a mowing regime with two cuttings for the first year, followed by annual cutting thereafter, provides advantage to many perennial species and results in greater plant species diversity in flower meadows. Weeding is not appropriate in the initial growing stage. Species richness is influenced by the maintenance regime, irrespective of the type of seed mix used. Nevertheless, sowing seed mixes designed for dry habitats creates more diverse flowering meadows.

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RESEARCH ARTICLE

Influence of erosion control afforestation on some soil parameters in two watersheds in Southwest Bulgaria

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Abstract

Soil is limited resource with vital role in maintenance of variety ecosystems. One of the greatest treat for soils is soil erosion. This natural hazard is widely spread in the terrestrial world, and the territory of Bulgaria is also affected.

Important role for soil protection has a forest vegetation and afforestation is widely used for erosion control activity. The main benefits of afforestation are reduction of water runoff, erosion and sedimentation year-round, which is important for the areas located around the reservoirs and their basins. They also decrease the migration of vital substances for soils and sedimentation yield.

The main goal of the study is to establish the influence of erosion control afforestation to the main soil characteristics in the territory of two watershed situated in Southwest Bulgaria. Soil samples and dead leaf cover were analyzed as well as some characteristics of afforestation and topographic characteristics.

It was established high water resistance of the soil aggregates under the planted forests and low resistance in the controls. The amounts of content of org. carbon and total nitrogen varying with slope and exposure.

The differences between parameters of soils under afforestation and in control samples is established which shows an important influence of forest to the soil characteristics.

Keywords

Soil erosion, forest vegetation, Dzherman river

Introduction

Afforestation activities have been found to be one of the most successful erosion control practices (Pavlova-Traykova et al., 2021). Tree vegetation has a positive effect on decrease degradation processes, by reducing solid runoff, as well as on improving soil characteristics (Angelov, Bachvarov, 1963; Marinov, 2011).

Planted forests takes about 21% from forest territories in Bulgaria. They were created mainly in the middle of the 20th century with an erosion control purpose and for the restoration of degraded forests (Appendix No. 1.4). The tree species that are mainly used are white pine *(Pinus sylvestris* L.) with 48% and black pine (*Pinus nigra* Arn.) with 41%. The main reason for this is their ecological characteristics like relatively easily grow on different soils, including eroded ones (Panayotov et al., 2016).

A large part of the planted forests are in good health and showed high productivity, but there are with deteriorated health and suffer from various damages and disturbances.

One of their problems though have been staked since their inception (Popov et al., 2018). Planted forests was carried out at high densities over 10,000 number per hectare, and in one period it is forested even several in one hole, which is far away from recommended by Regulation on the terms and conditions for afforestation (Regulation 2, 2013) 2500-3000 number per hectare. The aim was to quickly form a forest environment and restoration of the ecological functions of the forest, provision of maximum protective effect, elimination of erosion processes, increase in productivity and accelerated production of large-scale construction wood from coniferous species (Popov et al., 2018).

Although serious problems are looming in forested areas and it is necessary to take a number of decisions regarding the management of these forests, they have fulfilled their function and strengthened the terrain, reduced erosion processes and improved soil conditions.

The article presents the results for soil characteristics and their connection with afforestation. Different relationships were established based on topographic features and tree species.

Materials and Methods

The study area is situated in Southwest Bulgaria on the watersheds of Bistritsa and Dzhubrena (fig 1.). Bistritsa river is one of the left tributaries of the Dzherman River. The area of the watershed is 56.90km^2 from which 24.13 km^2 are forest territories. The average slope gradient of the watershed is 21° and the average altitude is 1577 m a.s.l (Pavlova-Traykova, 2019).

Dzhubrena river is right tributary of Dzherman river. The area of the watershed is 112.2km^2 of them 41.53km^2 are forest territories (fig 1). The average altitude of the watershed is 1016 m and average slope gradient 11° m a.s.l. (Pavlova-Traykova, Marinov, 2018)

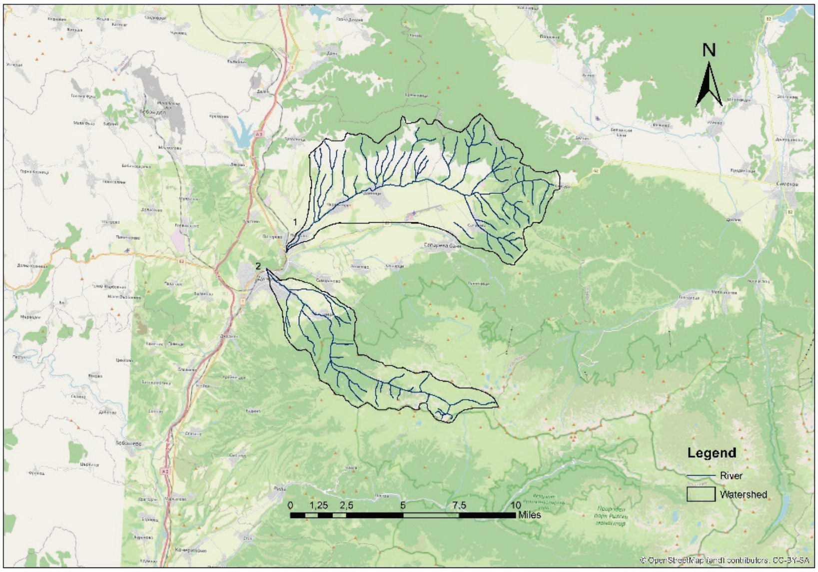

Figure 1. Location of watersheds 1. Dzhubrena and 2 Bistritsa

In the watersheds 17 soil profiles were analyzed. The profiles are 13 formed under the influence of two type of tree species and 4 control samples. In the sample areas (SA), detailed measurements of silvicultural indicators were made, the average height was measured and their afforestation scheme was determined. Soil samples were taken from the surface layers (0-5 and 5-20 cm). The indicators that have been studied are bulk density, relative density, porosity, water resistance of soil aggregates, mechanical composition, active reaction (Ph H_2O) of soils, content of org. carbon (C, %) and total nitrogen (N, %), for the study of which generally accepted methods were used (Donov et al., 1974).

For dead leaf cover were determined the reaction (Ph), the content of carbon (C, %), total nitrogen (N, %) and holding capacity. The water holding capacity was determined for 12 and 24 hours. Each result obtained for the forest litter is the average of three separate measurements.

Results and discussion

The main tree species used for afforestation in the Bistritsa river watershed are white pine and black pine. In the higher parts of the watershed there are also planted forests of fir (*Abies alba* Miller). In this watershed, 5 sample areas were established, four of them in white pine and one in black pine, samples were also taken from two controls on meadow, situated on apparently undisturbed terrain. The characteristics of the areas are presented in table 1.

Table 1. Characteristics of sample areas in Bistritsa watershed

Type of forest	Altitude, m	Slope, °	Exposition	Age,y	Height, m	Afforestation scheme	№ Sample area
White pine	1000	32	Southwest	50	17	1.5x1.5	SA 1
White pine	1100	39	Northwest	60	16	1.5x1	SA 2
White pine	750	23	North	70	19	1.5x1.5	SA 3
White pine	750	18	North	55	20	1.5x1	SA 4
Black pine	700	18	North	55	20	1x1	SA 5
Meadow	800	9	Northwest	-	-	-	Control 1
Meadow	750	8	North	-	-	-	Control 2

The selected afforestation are located at an altitude of 700 to 1000 meters, mainly on shady slopes. All selected SA have a dense afforestation scheme, which is due to the goals of their creation.

The established soils characteristics for this watershed are presented in the table 2. In the analyzed samples, the amount of total nitrogen in the surface horizons is in the range of 0.04 to 0.16, which is lower than in some other investigated watershed with common characteristics (Pavlova-Traykova et al., 2018) and shows that the soils are poorly stocked with nitrogen. In this catchment, a high water resistance of the soil aggregates under the afforestation is established, and in the controls resistance of aggregates are low. Due to the intense erosion processes in the past in this catchment, the controls from the surface layer 5-20 cm are mainly composed of different sized hard rock particles, which made it impossible to apply a soil analysis for this layer.

The carbon content (C, %) varies from 0.93% to 4.86%, decreasing in depth. In SA 1, the results in the mechanical composition differ from the general trend. Such a distribution of the mechanical composition with little or no silt is characteristic of soils with the presence of erosion processes (Erzsebet, Gergely, 2001). The slope as the main factor of the erosion process can be determined as the reason for this difference. The slope in this SA is steep (32°), but in SA 2 is steeper (39°) and the mechanical composition resembles the trend in this watershed. For that reason, these results may be related to the different exposure and, accordingly, the different conditions in which all processes take place.

All analyzed soils have an acidic reaction (pH 5.09-5.56), which is characteristic of soils under coniferous. According to skeleton results, the soil samples from SA 2 and SA 3 are highly skeletal, and in the remaining soil samples the soils are low skeletal. From the obtained results for the bulk density, the soils in the watershed of the Bistrica River can be classified as light soils, which defines them as more vulnerable to soil-

Table 2. Soil characteristics

Sample area(SA)/ forest type	Depth, cm	pH (H_2O)	C, %	N, %	Soil skeleton , %	Q, g/sm³	D…	Porosity, %	Water resistance of soil aggregates, %	Mechanical composition, %		
										Sand	Clay	Silt
SA1/ White pine	0-5	5.24	0.93	0.11	23.04	1.60	1.3	30.43	100	86.99	13.01	-
	5-20	5.17	0.27	0.06	85.24	-	2.4	-	100	88.65	11.35	-
SA 2/ White pine	0-5	5.56	3.12	0.14	87.28	0.91	1.3	30	98	80.17	19.83	8.26
	5-20	5.60	2.91	0.13	71.38	-	2.3	-	99	81.29	18.71	4.16
SA 3/ White pine	0-5	5.36	4.86	0.16	71.33	1.29	2.2	41.36	100	86.73	13.27	4.09
	5-20	5.09	0.27	0.04	68.14	-	2.4	-	99	87.09	12.91	4.07
SA 4/ White pine	0-5	5.46	4.26	0.19	25.13	0.85	2.7	68.52	100	74.38	25.62	8.23
	5-20	5.11	1.64	0.11	26.83	-	2.2	-	97	70.4	29.6	12.51
SA 5/ Black pine	0-5	5.24	3.76	0.14	26.54	1.09	2.6	58.08	97.5	78.57	21.43	4.1
	5-20	5.33	0.87	0.08	41.36	-	1.1	-	97	78.49	21.51	12.17
Control 1	0-5	5.25	0.49	0.06	34.72	1.19	1.4	15	65.5	65.54	34.46	8.11
	5-20	-	-	-	-	-	-	-		-	-	-
Control 2	0-5	2.24	3.82	0.22	30.77	0.71	2.3	69.13	68	66.77	33.23	8.1
	5-20	-	-	-	-	-	-	-		-	-	-

destroying processes. The porosity of the soil samples is „very poor" to „unsatisfactory" for the soil samples from test areas 1, 2 and 3 and „very good" in the soil samples from test areas 4 and 5. Porosity mainly depends on the organic matter content. With „unsatisfactory" porosity, the soils are poorly permeable, precipitation cannot pass into the soil horizons, and this is a prerequisite for the formation of a large amount of surface water runoff.

Based on the data on the amount of water that the dead leaf cover retains, it was established that a litter of 400 cm^2 is able to retain an amount of water that is more than its own weight (table 3). At SA 1, it is three times the weight of the dead leaf cover in a dry state. A high water-holding capacity of the forest litter was also found at Badinska river (Pavlova-Traykova et al., 2018). In studies of other watersheds, Kitin (1984) and Marinov (1995) also found such a trend. In SA1 the content of carbon and nitrogen are the highest. All forest litter in the sample areas has an acidic reaction (pH - 5.4-5.68). The content of (C, %) in the analyzed samples (table 3) varies from 10.72 % in SA 5 to 25.21 % in SA 1. Nitrogen (N, %) varies within the range from 0.83% to 1.11%.

Table 3. Characteristics of dead leaf cover in Bistritsa watershed

Sample area/type of forest	pH, (H_2O)	C, %	N, %	Dry sample, g	After 12h,g	After 24h,g
SA 1/ White pine	5.05	25.21	1.11	691.95	2166.4	2352.99
SA 2/ White pine	5.17	22.69	1.06	611.67	1159.2	1178.6
SA 3/ White pine	5.4	13.99	0.83	457.97	1101.05	1219.21
SA 4/ White pine	5.68	16.81	0.88	679.39	1323.97	1347.53
SA 5/ Black pine	5.42	10.72	0.73	476.82	957.57	1015.22

In the watershed of the Dzhubrena River, the main tree species that are used for afforestation are white pine, black pine and acacia. In the watershed, 9 SA have been established (table 4), of which 4 are planted with white pine and 4 with black pine. Two controls under meadow are also studied.

The porosity in the surface 5 cm of the soils in the Dzhubrena River can be defined as „good" to „very good", and in SA 7 it is „unsatisfactory" (table 5). The good porosity indicates the high ability of the studied soils to fully absorb the fallen precipitation, thus reducing the surface water runoff. A high water resistance of the soil aggregates was found in all soil samples, while it was lower in the controls (from 70 to 79%), which shows the impact of forest vegetation on the soils. The content of physical clay is from 8.17% to 65.25%, of silt from 4.0% to 32.22%, and in the SA 4 there is no silt in the 0-5 cm layer. The absence of silt indicates weaker connectivity of soil aggregates, which is an indicator of less resistance to erosion processes in this SA. The content of clay, silt and organic matter are high in most of the samples, which helps to stabilize the soil aggregates and increase the resistance of the soil to the erosive force of water.

Table 4. Characteristics of sample areas in Dzhubrena watershed

Type of forest	Altitude, m	Slope, ˚	Exposition	Age, y	Height, m	Afforestation scheme	№ Sample area
White pine	750	7	Southeast	45	16	1x2.5	SA 1
White pine	800	6	Southeast	45	20	1x2.5	SA 2
White pine	750	14	Southeast	18	5	0.5x1	SA 3
White pine	950	23	Northeast	25	26	2.5x2.5	SA 4
Black pine	850	24	Northeast	60	23	0.5x2	SA 5
Black pine	900	16	Southwest	65	24	2x2.5	SA 6
Black pine	900	21	West	75	25	2x2	SA 7
Black pine	850	27	Northeast	60	24	2x2	SA 8
Meadow	850	12	Southwest	-	-	-	Control 1
Meadow	850	11	South	-	-	-	Control 2

Table 5. Soil characteristics

SA/Type of forest	Depth, cm	pH (H_2O)	C, %	N, %	Sceletion, %	Q, g/sm^3	D	Porosity, %	Water resistance of soil aggregate, %	Mechanical composition, %		
										Sand	Clay	Silt
SA 1/ White pine	0-5	5.21	3.54	0.12	21.54	1.15	2.3	50	98	57.22	42.78	26.23
	5-20	4.95	1.87	0.06	71.62	-	2.4	-	99	54.11	45.89	32.22
SA 2/ White pine	0-5	5.13	4.49	0.14	43.61	1.12	2.7	58.52	100	75.42	24.58	8.16
	5-20	5.49	0.99	0.02	42.75	-	2.6	-	100	49.96	50.04	8.34
SA 3/ White pine	0-5	5.36	2.76	0.08	35.21	1.26	2.3	45.22	100	74.23	25.77	16.3
	5-20	5.40	2.74	0.08	44.08	-	2.3	-	100	66.30	33.70	16.44
SA 4/ White pine	0-5	4.51	1.45	0.05	26.3	1.6	2.7	40.74	99.5	83.71	16.29	-
	5-20	4.28	1.20	0.04	41.84	-	2,5	-	100	91.83	8.17	4.09
SA 5/ White pine	0-5	4.91	5.76	0.14	38.2	1.21	2.2	45	98	83.74	16.26	8.23
	5-20	4.80	2.25	0.07	50.24	-	2.3	-	100	83.46	16.54	12.4
SA 6/ Black pine	0-5	4.97	3.97	0.14	21.5	1.13	2.6	56.54	100	83.09	16.01	4
	5-20	4.94	1.71	0.06	21.1	-	2.6	-	98,5	83.68	16.32	8.16
SA 7/ Black pine	0-5	4.78	4.2	0.14	20.32	1.23	2.4	48.75	99	83.91	16.19	8.1
	5-20	4.78	0.95	0.03	31.38	-	2.2	-	100	83.79	16.21	12.15
SA 8/ Black pine	0-5	4.56	1.24	0.04	26.37	1.27	1.9	32.80	97	83.59	16.41	4.09
	5-20	4.45	0.48	0.02	45.72	-	2.2	-	94	87.54	12.46	4.15
Control 1	0-5	6.23	3.75	0.13	27.42	0.89	1.1	19.09	70.5	63.46	36.54	28.62
	5-20	6.02	3.23	0.08	23.15	-	2.0	-	73	67.32	32.68	4.56
Control 2	0-5	5.38	2.27	0.07	26.6	1.37	2.5	46.4	79	75.11	24.89	12.24
	5-20	5.41	2.08	0.566	22.15	-	2.3	-	73.5	60.93	39.07	12.51

All dead leaf cover has an acidic reaction, with pH values ranging from 4.48 to 6.24. The carbon content (C, %) varies from 13.92% to 33.55% (Table 6). Nitrogen (N, %) in litter varies from 0.36% to 0.98%. From the results obtained for the amount of water retained for 12 and 24 hours, it was found that the best water holding capacity was found in the forest litter in the pine afforestation.

Table 6. Characteristics of dead leaf cover in Dzhubrena watershed

SA/Type of forest	pH, (H_2O)	C, %	N, %	C:N	Dry sample, g	After 12h,g	After 24h,g
SA 1/ White pine	4.85	13.92	0.52	15.64	381.36	1384.23	1476.7
SA 2/ White pine	4.48	29.21	0.49	34.33	902.98	2387.6	2443.11
SA 3/ White pine	4.77	15.55	0.36	25.30	490. 78	994.2	1037.46
SA 4/ White pine	4.83	33.55	0.98	19.87	227.46	827.45	874.2
SA 5/ Black pine	5.02	31.33	0.82	22.20	568.53	1269.94	1314.5
SA 6/ Black pine	5.07	22.91	0.53	25.15	413.21	1380.18	1429.27
SA 7/ Black pine	4.91	21.10	0.47	25.85	387.24	735.99	767.25
SA 8/ Black pine	5.2	26.38	0.54	28.34	529.46	1713.81	1760.21

Conclusion

Positive effect of the created coniferous afforestation was established. In both watersheds a high water resistance of the soil aggregates under the planted forests is established, and in the controls resistance of aggregates is low. The obtained results for the organic C and total N showed that with lower altitude the content being higher. All SA have an acidic reaction.

In the Bistritsa river mechanical composition of the controls and the content mainly of different sized hard rock particles in the lower layers are indicative of the strong erosion processes in the past.

The presence of a high content of C and N in the dead leaf cover and, at the same time, their lowest content in the soil samples, shows that the processes of decomposition and soil formation proceed very slowly, and despite the high accumulation of nutrients in the forest litter, they do not have reached the soil layers. It is established a high water-holding capacity of the afforestation, especially in white pine crops.

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RESEARCH ARTICLE

Morus sp. cultivation in Natura 2000 sites: environmental constraints and considerations

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Abstract

Morus sp. is a versatile resource with diverse benefits; however, its cultivation may entail negative environmental impacts. Environmental legislation imposes constraints to mitigate these effects. The current study presents a three-tier classification approach to assess the severity of constraints imposed by environmental legislation on *Morus* sp. cultivation. The approach is tested in a case study area located in BG0000254 Besaparski vazvishenita, Bratsigovo Municipality, Bulgaria. Approximately 23.6% of this area is under strict protection, thereby prohibiting cultivation. In about 21.3% of the area, *Morus* sp. cultivation is feasible but most probably an Appropriate Assessment procedure will be required to ensure nonsignificant negative impact. In the remaining 56.4% of the area, notification/screening is necessary, with the likelihood of not requiring a full Appropriate Assessment procedure. Thus, despite a significant portion being under strict protection, there remains potential for *Morus* sp. cultivation within the study area, albeit with varying procedural complexities.

The proposed constraints classification approach can inform land use planning, facilitating informed decision-making in site selection not only for *Morus* sp. but for all types of permanent crops.

Keywords

constraints, cultivation, *Morus* sp., Natura 2000

Introduction

Morus sp., commonly known as mulberry, encompasses species with diverse biological, chemical, and horticultural characteristics. The genus has a wide geographical distribution, high morphological variability, long history of domestication and high rate of natural hybridization among the species (Vijayan et al., 2011).

The rich phytochemical composition, beneficial effects on human health, fast growth, adaptability and different applications in agriculture and urban planning make *Morus* sp. a valuable resource for addressing various societal needs. *Morus* sp. are widely distributed in various regions, suggesting their adaptability and potential for cultivation in different climates suggesting their potential for cultivation and resilience in the face of climate change (Temviriyanukul et al., 2020). The genus is not native to Bulgaria. Alexandrov, Dobrev (2011) have assessed the services and values of *M. alba* and *M. nigra* in the country, including drought, salt and smoke resistance, soil and water conservation (including watershed management), soil fertility and aesthetic values.

Despite the proven benefits of *Morus* sp. cultivation, growing mulberries can have negative effects on the environment and biodiversity. Monoculture plantations may lead to the loss of natural habitats, habitats of species, plant and animal diversity, as well as damage to water resources. A potential risk of planting non-native species is the uncontrolled dispersion, including in natural habitats. Species of genus *Morus* are considered invasive in North America, South America and Southern Africa (Richardson, Rejmánek (2011); GISD (2024)). The genus is not considered invasive in Bulgaria (EEA (2024); Petrova et al. (2013)). Blitek et al. (2022) surveyed the distribution of *Morus alba* in Wrocław (Poland) and found low number of seedlings reaching maturity. This led to the conclusion that the species does not show signs of expansion. However, depending on the region, the period between the introduction of a species and its excessive expansion can vary considerably, and the invasive influence of trees and shrubs is difficult to assess on the basis of distribution alone. The authors recommend *Morus alba* for planting, but with a continuous monitoring of its current and future development.

Additional issues may arise from use of pesticides and chemicals used in agriculture to control diseases and pests. To prevent such negative impacts, the cultivation of *Morus* sp. needs to adhere to certain constraints, including legal ones. A number of constraints are related to the protection of natural ecosystems and biodiversity. In Bulgaria, potential constraints to *Morus* sp. cultivation, triggered by biodiversity protection, may arise if activities are planned in sites from the National Ecological Network (NEN). This network is developed in accordance with the Biodiversity Low (2002) and consists of sites that are part of the European ecological network Natura 2000, and protected territories designated in accordance with the Protected Territories Low (1998). Priority is given to including CORINE sites, Ramsar sites, important plant areas, and ornithologically important areas in the network. According to Biodiversity Low (2002), the objectives of NEN are long-term conservation of biological, geological and landscape diversity; provision of sufficient of size and quality areas for breeding, feeding and resting, including migration, moulting and wintering wildlife; creation of conditions for genetic exchange between separate populations and species; participation of Bulgaria in European and global environmental networks; limitation of the negative anthropogenic impact on protected areas.

According to the Protected Territories Low (1998), protected territories fall into six categories: reserves, national parks, natural monuments, managed nature reserves, nature parks, and protected sites. By the end of 2021, the number of protected territories in Bulgaria is 1025, covering a total area of 583625.9 ha, or 5.27% of the country's territory. The restrictions vary depending on the category of the protected territory and are described in each one's regimes. By the end of 2021, the Bulgarian Council of Ministers had adopted 353 Natura 2000 sites within the Natura 2000 ecological network, covering a total of 34.9% of the country's territory. Sites are designated via Order of Designation, containing information about the site, its subject, objectives, and the prohibitions within it. For each site, a Standard Data Form (SDF) is issued containing information about the site and its subject to protection. With the exception of the prohibitions listed in the Order of Designation, activities within Natura 2000 sites are not prohibited, but an Appropriate Assessment procedure must be followed in accordance with the Biodiversity Low (2002) and the Ordinance on the conditions and procedures for conducting appropriate assessment of plans, programs, projects, and investment proposals with the subject and aims of conservation of protected sites (AA Ordinance) (2007), to demonstrate the lack of significant negative impacts. According to the Biodiversity Low (2002), plans, programs, projects, and investment proposals that are not directly related to, or necessary for the management of Natura 2000 sites, and that individually or in interaction with other plans, programs, projects, or investment proposals may have a significant negative impact on the Natura 2000 sites are subject to an Appropriate Assessment procedure. According to the AA Ordinance (2007), plans, programs, investment proposals, or their modifications or expansions, entirely or partially falling within the boundaries of protected sites and related to a change in the purpose and/or manner of permanent land use, are subject to an Appropriate Assessment.

Other nature conservation restrictions stem from the necessity to preserve permanently grassed areas. According to Ordinance No 105 (2006), the Ministry of Agriculture and Food creates a specialized layer "Permanently Grassed Areas" in the System for Identification of Agricultural Parcels. The "Permanently Grassed Areas" layer is normatively defined in the Law on Support for Agricultural Producers (1998), which introduces a prohibition on the conversion and plowing up by farmers of permanently grassed areas included in the layer. The Minister of Agriculture and Food may, by exception, authorize, by order, the conversion into another type of agricultural land or the plowing up of permanently grassed areas outside the scope of Natura 2000 sites, provided that another area on the same farm is converted into permanently grassed areas accordingly. Areas within Natura 2000 are not subject to such substitution.

Restrictions to activities in forest areas arise from the Forestry Low (1997), which regulates the management, reproduction, use, and conservation of forests in Bulgaria. Waterbodies also represent restrictions to the cultivation of *Morus* sp. All the described restrictions are added to existing ones arising from urbanization, infrastructure, cultural heritage, land use, etc. The identification and compliance with the various existing constraints is a crucial step in the planning of *Morus* sp. cultivation.

The aim of this article is to develop a classification approach for ranking the severity of constraints imposed by environmental legislation to *Morus* sp. cultivation within Natura 2000 sites, facilitating informed decision-making and land use planning, and test it in a selected case study area.

The selected case study area falls within Bratsigovo Municipality. The municipality is located in the western part of Bulgaria, within the administrative region of Pazardzhik. The territory of the municipality covers 229 km^2. The largest proportion of its territory is occupied by forested areas, covering 120203 ha (52.28% compared to the national average of 35%). Agricultural land comes second, covering 99067 ha (43.09% compared to the national average of 58%). Populated areas account for 2.45% or 5.64 ha. Water bodies occupy 1.75% of the municipality's territory, while areas for transportation and infrastructure cover 0.43% (General Development Plan of Bratsigovo Municipality (GDP), 2017). Plant cultivation in the municipality is limited due to soil and climatic conditions and the mountainous to semi-mountainous terrain. However, there are opportunities for the cultivation of perennial crops and vineyards, as well as the traditional cultivation of potatoes in the region (GDP, 2017). As part of its implementation program for the Integrated Regional Operational Program of Bratsigovo Municipality (2021), under Priority 1 – Strengthening the municipality's competitive position, fostering sustainable, innovative, intelligent economic growth based on local resources, improving the business environment, and stimulating entrepreneurship, is outlined Measure 1.3 Development of modern, sustainable, and diversified agriculture. One of the activities under this measure is the increase of perennial plantations in the municipality.

According to the Information system for protected sites from the ecological network Natura 2000 (MOEW), within the municipality's territory partially fall two Natura 2000 sites designated for the conservation of wild birds (BG0002057 Besaparski ridove and BG0002063 Zapadni Rodopi), and two Natura 2000 sites designated for the conservation of natural habitats and wild flora and fauna (BG0000254 Besaparski vazvisheniya and BG0001030 Rodopi – Zapadni). Furthermore, 8 protected territories under Protected Territories Low (1998) fall within the municipality (either wholly or partially). As a case study area for identification and assessment of the constraints is selected the part of BG0000254 Besaparski vazvisheniya, falling withing the borders of Bratsigovo Municipality.

Materials and methods

Case study area

The case study area covers the part of BG0000254 Besaparski vazvisheniya falling within the boundaries of Bratsigovo Municipality. The site has a total area of 6743.06 ha. Within the municipality of Bratsigovo, 2753.25 ha fall under this designation. This area represents 40.8% of the site's territory and 12% of the territory of the municipality (Figure 1).

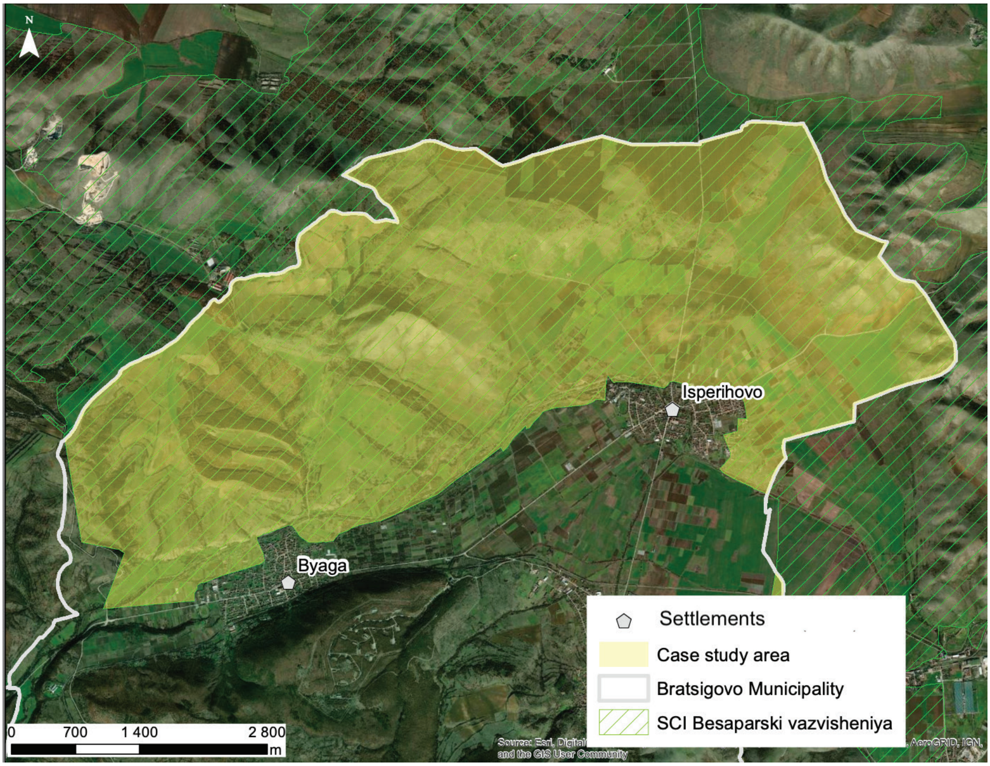

Figure 1. Case study area

Methods

The analysis of the constraints triggered by environmental legislation to the cultivation of *Morus* sp. in the case study area is made within a GIS environment, using the ArcGIS 10 software.

The datasets used to delineate the constraints are listed in Table 1.

Based on the analysis of the relevant constraints, a three-tier classification approach was developed and employed to rank the case study area according to existing constraints related to environmental legislation.

Tier 1: Major constraints - Cultivation of *Morus* sp. is not possible due to significant constraints, including:

- Protected territories designated in accordance with the Protected Territories Low (1998);
- Restricted areas according to the Order of Designation of a Natura 2000 sites;
- Permanent grasslands within Natura 2000 sites;
- Forested areas;
- Water bodies.

Table 1. GIS data used for the delineation of the constraints

Data used for the determination of the geometry
• Borders of the Natura 2000 sites, available at the Information system for protected areas from the ecological network Natura 2000 https://natura2000.egov.bg/EsriBg.Natura.Public.Web.App/Home/Documents • Borders of the protected territories (designated in accordance with Protected Territories Low (1998)), available at the website of the EEA https://eea.government.bg/zpo/bg/index_download.jsp • GIS database of the project: "Mapping and determination of the conservation status of natural habitats and species - Phase I", Ministry of Environment and Water (MOEW, 2013), available at the Information system for protected areas from the ecological network Natura 2000 https://natura2000.egov.bg/EsriBg.Natura.Public.Web.App/Home/Documents • GIS Database from Japan International Cooperation Agency (JICA), (JICA 2006); • General development plan of Bratsigovo Municipality (GDP) (2017) https://drive.google.com/drive/folders/1YqPyYNLSOK5op2GslwiljOBZAS-ck_F4 • GIS layer "Permanently Grassed Areas" available in the System for Identification of Agricultural Parcels https://www.mzh.government.bg/bg/politiki-i-programi/programi-za-finansirane/direktni-plashaniya/identifikaciya-na-zemedelski-parceli/

Tier 2: Major Constraints - Cultivation of *Morus* sp. is potentially possible in these areas under specific conditions and only after a justification for nonsignificant negative impact (via full Appropriate Assessment procedure). These areas encompass:

- Natural habitats protected within Natura 2000 sites;
- Habitats of plant species subject to protection in Natura 2000 sites;
- Habitats of animal species subject to protection in Natura 2000 sites (important / optimal).

Tier 3: Minor Constraints - Cultivation of *Morus* sp. is likely possible in these areas, however nonsignificant negative impact justification via Appropriate Assessment procedure is required. In these cases, it is likely that a full procedure will be not necessary, only notification/screening phase. These areas include:

- Areas within Natura 2000 sites that are not natural habitats or habitats of species, subject to protection;
- Areas within Natura 2000 sites that are habitats of species, subject to protection, but the cultivation of *Morus* sp. does not have the potential to significantly affect them;
- Suboptimal habitats of protected species within Natura 2000 sites.

The habitats of species subject to protection are assessed case by case. They may trigger Tier 1, 2 or 3, depending on the specifics of the site and the species.

Results and discussion

Subject to protection within BG0000254 Besaparski vazvisheniya are seven types of natural habitats (SDF, 2021; Order of Designation, 2021):

- 5210 Shrubs with Juniperus spp.;
- 6110* Rupicolous calcareous or basophilic grasslands of the Alysso-Sedion albi;
- 6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (* important orchid sites);
- 6220* Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea;
- 62A0 Eastern sub-mediteranean dry grasslands (Scorzoneratalia villosae);
- 91AA* Eastern pubescent oak woods;
- 91M0 Pannonian-Balkanic turkey oak –sessile oak forests.

In the site's SDF (2021), 29 species are included as conservation subjects, 8 of which have a population assessment "D". In the Order of Designation (2021), 6 species of mammals, 4 species of reptiles, 3 species of amphibians, 2 species of fish, 6 species of invertebrates, and one plant are included. In this analysis, the species from the Order of Designation (2021) are considered, as the species with an assessment "D" are not evaluated in the Appropriate Assessment procedure, and therefore their habitats do not trigger constraints to *Morus* sp. cultivation. The species from the Order of Declaration (2021) are:

- Mammals: marbled polecat (*Vormela peregusna*), Eurasian otter (*Lutra lutra*), european souslik (*Spermophilus citellus*), greater horseshoe bat (*Rhinolophus ferrumequinum*), lesser horseshoe bat (*Rhinolophus hipposideros*), long-fingered bat (*Myotis capaccinii*);
- Amphibians and reptiles – European fire-bellied toad (*Bombina bombina*), yellow-bellied toad (*Bombina variegata*), southern crested newt (*Triturus karelinii*), blotched snake (*Elaphe sauromates*), European pond turtle (*Emys orbicularis*), Hermann's tortoise (*Testudo hermanni*), Greek tortoise (*Testudo graeca*);
- Fish – spined loach (*Cobitis taenia*), Thracian barbel (*Barbus cyclolepis*);
- Invertebrates – stag beetle (*Lucanus cervus*), great capricorn beetle (*Cerambyx cerdo*), long-horned beetle (*Morimus funereus*), wrinkled darkling beetle (*Probaticus subrugosus*), large copper (*Lycaena dispar*), jersey tiger moth (*Euplagia* (*Callimorpha*) *quadripunctaria*);
- Plants –*Himantoglossum caprinum*.

Two of the prohibitions of the Order of Designation (2021), trigger constraints to the cultivation of *Morus* sp. These are:

Prohibition 8.4. Changing the permanent use, destruction, afforestation, and conversion into permanent plantations of meadows, pastures, and marshes when using agricultural lands as such is prohibited.

Prohibition 8.5. Clearing and afforestation of glades, clearings, and other non-afforested forest areas within the boundaries of non-forest natural habitats subject to conservation are prohibited except in cases of proven necessity for protection against erosion and torrents, as well as in cases of implementation of permissible plans, programs, projects, or investment proposals approved under the environmental legislation.

The main water artery passing through the municipality is the Stara reka River. This river and several of its tributaries traverse the territory of BG0000254 Besaparski vazvisheniya. Within the case study area, there are 5 micro-dams and two lakes, with a total area of 15.45 ha. These areas trigger Tier 1 constraints, and the cultivation of *Morus* sp. is not possible.

In the case study area, there are 250.18 ha of forested areas (GDP, 2017). They also trigger Tier 1 constraints. The forests under the GDP (2017) largely overlap with forest habitats subject to protection (MOEW, 2013), but about 39 ha of forest habitats, subject to protection, are not included in this area (about 4 ha of 91M0 and 35 ha of 91AA).

The area of meadows and pastures in the case study area (triggering Tier 1 constraints due to the restrictions of the site's Order of Designation (2021)) is 309.27 ha. They are almost entirely overlapped by permanently grassed areas, which trigger Tier 1 constraints, however permanently grassed areas trigger an additional 8 ha of Tier 1 constraints. Taking into account the overlap, the total area affected by Tier 1 constraints triggered by grasslands is 317.27 ha.

One of the protected territories in Bratsigovo Municipality falls within the boundaries of BG0000254 Besaparski vazvisheniya. This is Protected Locality (PL) Nahodishte na atinska merendera, Isperihovo, with an area of 37.48 ha. In the PL are prohibited changing the land use and permanent land use methods (which is pastures and meadows) and importation of non-native species. The PL triggers Tier 1 constraints and cultivation of *Morus* sp. in its territory is not possible. It completely overlaps with permanently grassed areas and it is covered with pastures and meadows, so its presence does not increase the area of Tier 1 constraints.

The analysis of Tier 1 constraints, triggered by forests, pastures and meadows, permanently grassed areas, waterbodies and protected territories (taking into account the overlapping) showed that, these constraints cover a total of 612.9 ha in the case study area, or about 22.3% of it (Figure 2).

Non-forest habitats, subject to protection in BG0000254 Besaparski vazvisheniya are 5210, 6110, 6210 and 62A0. They trigger Tier 2 constraints, as activities on their territory are not strictly forbidden but an Appropriate Assessment procedure may be needed to justify the lack of significant negative impact. Part of the areas covered with these habitat types are triggering Tier 1 constraints due to the presence of pastures, permanent grasslands, forest lands or protected territories. The total area of habitats, subject to protection triggering Tier 2 constraints that do not overlap with Tier 1 territories is 581.8 ha, including habitat 5210 – 1.3 ha, 6110 – 22 ha, 6210 – 255.17 ha, and 62A0 – 303.3 ha (Figure 3).

Habitats of species cover nearly the entire area of the site in Bratsigovo Municipality. The constraints triggered by each species depend on its ecological specifics and habitat preferences.

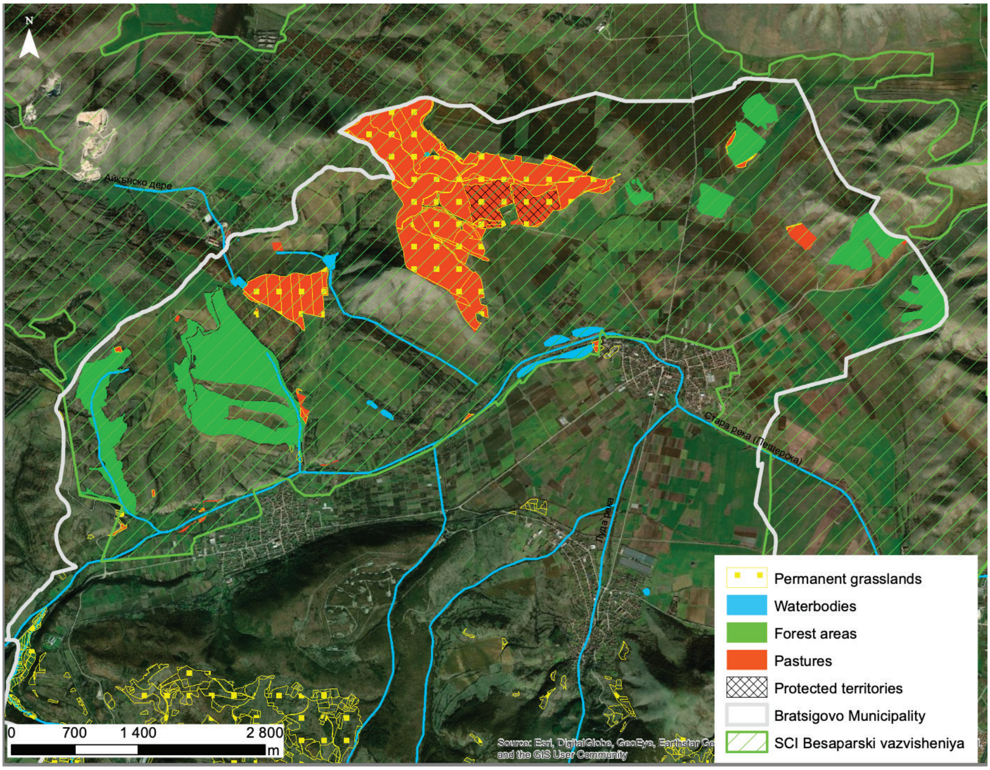

Figure 2. Land cover, triggering Tier 1 constraints

Vormela peregusna: The species inhabits open habitats such as meadows, pastures, steppes, semi-deserts, rocky terrains, fallow lands, including river valleys, dry valleys, and canyons. Preferred sites include those with large colonial rodents (Spasov, Spiridonov, 2011). These habitats generally trigger Tier 1 constraints as they include pastures and meadows. The species is also found in cultivated areas, orchards, outskirts of settlements (Gorsuch, Lariviere 2005), so the cultivation of *Morus* sp. will not result in complete loss of habitat. Habitats of the species outside of Tier 1 sites (triggered by permanently grassed areas, pastures and meadows) are considered Tier 3.

Lutra lutra: Habitats of the species in the site consist of flowing and standing water bodies and their adjacent riparian zones. The species favours wooded banks (Georgiev, 2008). Water bodies and forest vegetation in the case study area are considered Tier 1 constraints, meaning this species does not trigger additional constraints.

Spermophilus citellus: The optimal habitat of the species are grasslands and meadows, assessed as triggering Tier 1 constraint due to permanently grassed areas and the prohibitions from the site's Order of Designation (2011). The species does not inhabit cultivated areas, although it enters them for feeding (Red Data Book, 2011). The habitats of the species outside of the Tier 1 sites are considered Tier 3.

Rhinolophus ferrumequinum, Rhinolophus hipposideros, Myotis capaccinii: The cultivation of *Morus* sp. does not have the potential to damage old-growth forests

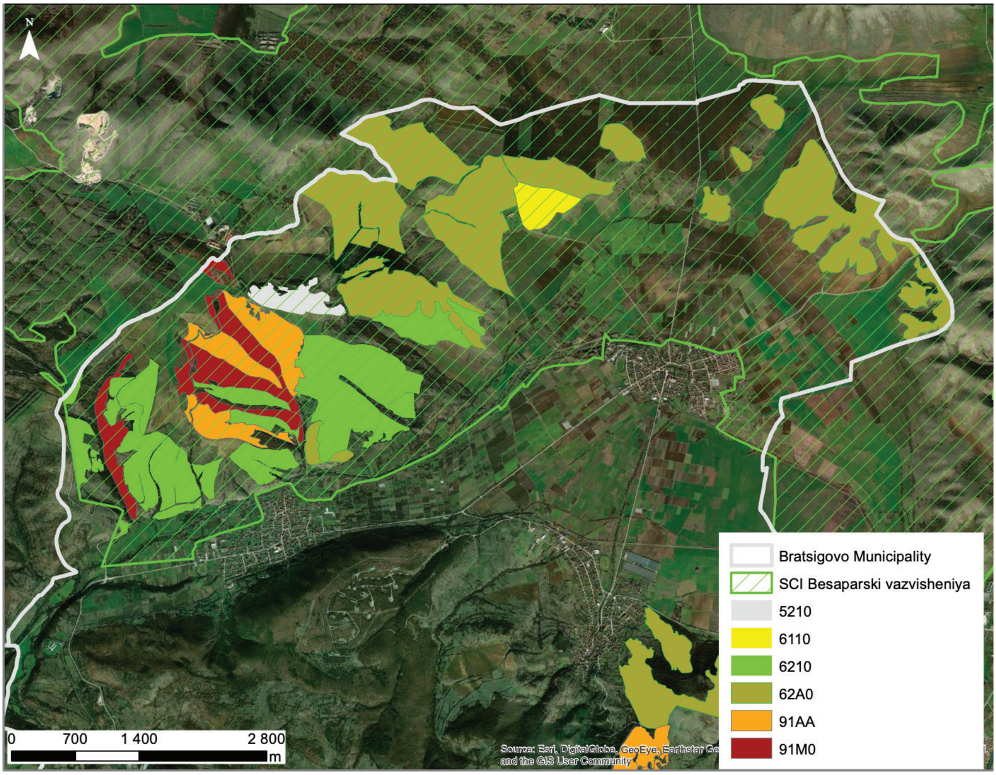

Figure 3. Habitats, subject to protection

with hollow trees or underground/synanthropic shelters, hence it does not have the potential to cause significant negative impact on the populations and habitats of bats. The constraints triggered by feeding habitats of bats are assessed as Tier 3.

Bombina bombina: There are no potential habitats in the case study area (MOEW, 2013)

Bombina variegata: The species inhabits natural and artificial lakes, rivers, ditches, canals, temporary ponds, and flooded tracks. It prefers ponds with abundant vegetation (Biserkov, 2007). Constraints in the species' habitats are assessed as Tier 3, as the cultivation of *Morus* sp. does not have the potential to damage water bodies, hence it does not have the potential to cause significant negative impact.

Triturus karelinii: The species reproduces and hibernates in stagnant water basins such as lakes, marshes, reservoirs, etc. (Beshkov, Nanev, 2002; Tzankov et al., 2014). During the terrestrial phase, it inhabits areas around the aquatic habitat but can also be found at a distance from water basins (Stojanov et al. 2011). Constraints in the species' habitats (outside those already identified as Tier 1) are assessed as Tier 3, as the cultivation of *Morus* sp. does not have the potential to damage water bodies, hence it does not have the potential to cause significant negative impact.

*Elaphe sau*romates: The species inhabits open spaces covered with grass vegetation, pastures, scrubland areas, scattered broad-leaved forests, and sometimes wet-lands along rivers, marshes, and water bodies (Biserkov, 2007). Outside of the areas designated as Tier 1 habitats, the habitats of the species are suboptimal. Areas where *Morus* sp. is cultivated also provide a suboptimal habitat for the species. The habitats of the species outside of the Tier 1 sites are considered Tier 3.

Tortoises: *Testudo graeca* is found in various types of habitats but prefers open areas with grass and shrub vegetation, forest edges, clearings, scattered broad-leaved forests (especially oak). *Testudo hermanni* inhabits hilly areas with shrubs and low-statured forests. It is more closely associated with the forest compared to *Testudo graeca* (Bekchiev et al., 2017). Outside of the areas designated as Tier 1 habitats, the habitats of both species are suboptimal. The cultivation of *Morus* sp. will also provide a suboptimal habitat for the species. The habitats of both species outside of the Tier 1 sites are considered Tier 3.

Emys orbicularis: Habitats of the species in the case study area are the rivers, assessed as Tier 1 constraint, so this species does not trigger additional constraints.

Cobitis taenia, Barbus cyclolepis: Habitats of the fish in the site are the rivers (for both species), and stagnant waterbodies (for *Cobitis taenia*), assessed as Tier 1 constraint, so the fish do not trigger additional constraints.

Lucanus cervus, Cerambyx cerdo, Morimus funereus: These species inhabit forests with specific characteristics (species composition, age, availability of dead trees) (Zingstra et al., 2009). Forests are assessed as Tier 1 constraint, so these species do not trigger additional constraints.

Probaticus subrugosus: Inhabits steppe and sub-Mediterranean grassland communities, often mixed with shrubs, and less frequently, derivative steppe and meadow vegetation (Bekchiev et al., 2018). Those habitats are assessed as triggering Tier 1 constraint due to permanently grassed areas and the prohibitions from the site's Order of Designation (2011). The habitats of the species outside of the Tier 1 sites are considered Tier 3.

Lycaena dispar: Species, associated with wetland habitats (e.g., wet meadows, riparian zones, around streams and lakes) where the larval host plants are present (Beshkov, 2011; 2014). These habitats are assessed as triggering Tier 1 constraints due to the presence of water bodies, permanently grassed areas, and prohibitions from the designation order. The habitats of the species outside of the Tier 1 sites are considered Tier 3.

Euplagia quadripunctaria: This species is associated with broad-leaved forests, although in Bulgaria it can be found in various habitats where the larval host plants are present (Bekchiev et al., 2017). Forests trigger Tier 1 constraints, and the remaining territories, which according to MOEW's database, are potential habitat of the species, trigger Tier 3 constraints as they are suboptimal.

Himantoglossum caprinum: Occurs in open, sunny areas, on lightly used pastures, among shrubs, and in forest clearings within light broad-leaved forests. It is one of the orchid species in habitats 6210* and 91AA*. In the case study area, the potential habitat of the species does not coincide with the natural habitats subject to protection or with other areas triggering constraints. The habitat of the species (5.7 ha) is considered to trigger Tier 2 constraints.

The analysis of the habitat preferences of the species, subject to protection in the SCI, and the available GIS data of their distribution (MOEW, 2013) showed that most of the species trigger constraints in areas, where constraints are already identified due to the presence of permanently grassed areas, habitats, subject to protection, forests, water bodies. Only the distribution of *Himantoglossum caprinum* does not overlap with the identified constraints and triggers additional 5.7 ha Tier 2 constraints.

At 1552.85 ha, or 56,4% of the case study area, none of the analysed Tier 1 and Tier 2 constraints were identified (Figure 4). The area is, however, part of a Natura 2000 site, which triggers Tier 3 constraints. If *Morus* sp. cultivation is planned in this area, notification/screening as per the AA Ordinance will be necessary, but it is likely that no entire Appropriate Assessment procedure will be needed to justify the lack of significant negative impact.

Conclusion

Despite the recognized ecological benefits of cultivating *Morus* sp., it may lead to potential adverse impacts on biodiversity, necessitating careful consideration. Environmental constraints, stemming from legislation are related to the protection of permanently grassed areas, Natura 2000, protected territories, and forests. Some constraints render certain areas unsuitable for *Morus* sp. cultivation, while others necessitate adherence to specific procedures to demonstrate lack of significant impact.

The analysis reveals that the entire case study area (BG0000254 Besaparski vazvisheniya, located in Bratsigovo Municipality) is subject to constraints dictated by environmental legislation. However, these constraints vary in their stringency. Tier 1 constraints, triggered by forests, pastures and meadows, permanently grassed areas, waterbodies and protected territories (taking into account the overlapping) cover a total of 612.9 ha in the case study area, or about 23.6% of it. This area is under strict protection, precluding cultivation. The total area of Tier 2 constraints, triggered by non-forest habitats, subject to protection and habitats of *Himantoglossum caprinum* outside of the areas triggering Tier 1 constraints is 587.5 ha, or about 21.3% of the case study area. If cultivation of *Morus* sp. is planned in these areas it will most likely require an Appropriate Assessment procedure to ensure the lack of significant negative impacts. The remaining 1552.85 ha (56.4%) of the area (suboptimal habitats of species, subject to protection) trigger Tier 3 constraints. In these areas notification/screening as per the AA Ordinance will be necessary, but it is likely that no entire Appropriate Assessment procedure will be needed to justify the lack of significant negative impact. Thus, despite a considerable portion being under strict protection, there is still potential for *Morus* sp. cultivation within the study area, albeit with differing levels of procedural complexity.

The proposed and tested classification approach for ranking the severity of constraints imposed by environmental legislation to *Morus* sp. cultivation within Natura

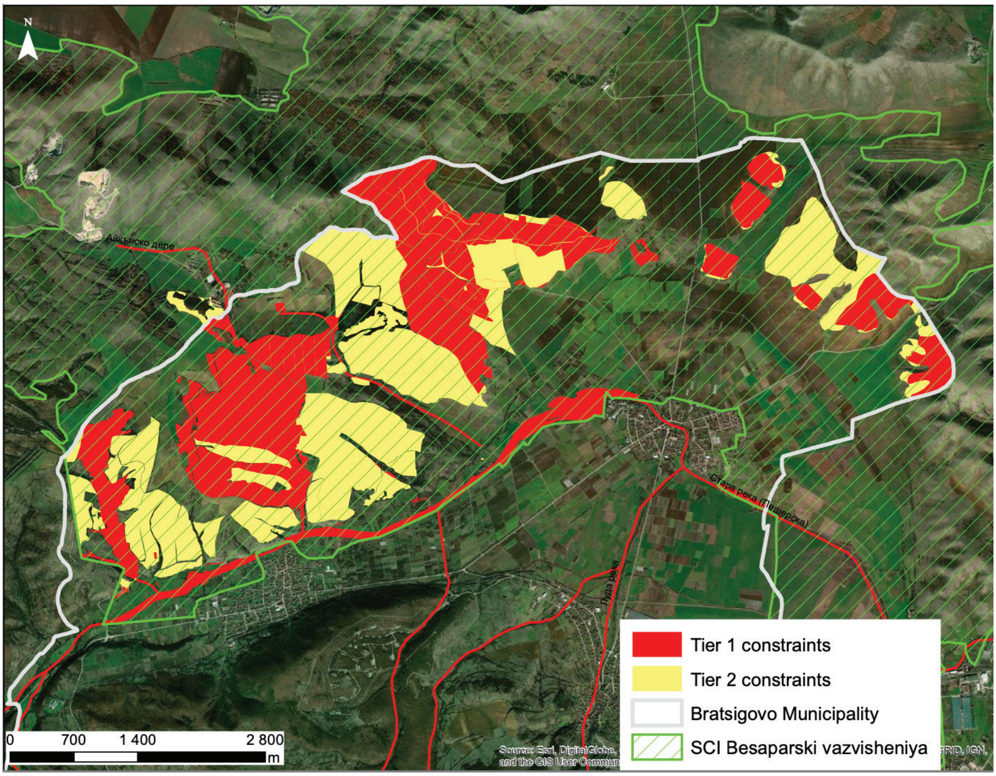

Figure 4. Tier 1 and Tier 2 constraints

2000 sites can be used in land use planning, to facilitate informed decision-making in selection of sites for cultivation not only for *Morus* sp., but for all types of permanent crops.

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RESEARCH ARTICLE

Changes in erosion susceptibility of a Chromic Haplustert pasture soil by some polymers under simulated rainfall

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Abstract
Due to the climate change that has become evident especially in the last ten years, ecosystems such as forests and pastures in the Mediterranean climate zone have become even more vulnerable to degradation. High erosive precipitation increases the amount of erosion in these soils with increasing their erodibility. The aim of this study was to determine to what extent some polymers, such as polyacrylamide and polyvinylalcohol, can prevent runoff and soil loss from erosion pans where a pasture soil was placed. For this purpose, aggregates of soil samples <8 mm from the A horizon of a Chromic Haplustert were used. Polyacrylamide and polyvinylalcohol solutions at different doses (0, 3.5, 7.0 and 14.0 kg ha^{-1}) were applied to the aggregates by spraying. Erosion pans with slopes of 9% and 15% were exposed to simulated rainfall produced by a drop former rainfall simulator for one hour. The simulation trial was planned as 2 replications according to the randomized plots trial design. During simulated rainfall, runoff water and sediment from pans were collected at 10-minute intervals. Transported soils were expressed as dry weight, and runoff waters were expressed as volumetric. According to the results obtained, the highest runoff occurred from a 15% inclined soil pan (11.06 mm) without polymer applied (control). After one hour of simulated rainfall, runoff did not occur from some pans with high-doses of applied polymer. The amount of soil transported from the control pan by runoff and by splashing to the sides is 362 and 4241 kg ha^{-1}, respectively. The pan, in which the least soil is carried by splashing, was the one with a 9% slope and the highest dose of polyacrylamide (97 kg ha^{-1}). Statistical results show that polyvinylalcohol was

more successful than polyacrylamide in reducing soil and water losses especially on 15% slope. These results indicate that the application of polymer to pasture soils can be a valid way to combat erosion, but the treatments should be carried out by choosing the right dose, taking into account factors such as the slope of the land, the erodibility of the soil and the erosivity of rainfall.

Key words
polyacrylamide, polyvinylalcohol, rainfall erosivity, soil erodibility, soil management

Introduction

Land and soil degradation is one of the biggest problems threatening the balance of ecosystems and sustainable agricultural activity. Sustainable agricultural production is required to meet the increasing demand for food. The increase in food demand in parallel with population growth and the needs of the developing industry increase the demand for land. In order to meet these demands, it is necessary to increase the yield obtained from the unit area and to ensure the sustainability of existing soil resources. For this purpose, it is necessary to take protection measures against factors that cause soil degradation and reduce yields or cause soils to disappear. Accelerated soil erosion, especially in areas with a sloping land structure or poor cover, is triggered by use and damages the economies of countries by reducing soil productivity (Evin et al. 2004). As in the rest of the world, erosion is one of the most important ecological problems threatening the natural resources of Türkiye (Doğan et al. 2000).

In order to take effective measures against erosion, it is necessary to know the factors that prepare it and accelerate or slow it down by affecting it in different degrees, to determine their functions and to determine the methods of minimizing the negative effects or contributions of these factors. The phenomenon of erosion is related to the erosion-forming power of climate and the erodibility of soil. Other factors (topography, vegetation and human impacts) affect the extent and direction of erosion. Rainfall is the main component of climate that directly affects water erosion. Rainfall-induced water erosion is mechanistically classified into four categories: (1) raindrop fragmentation and transport by raindrop splashing, (2) raindrop fragmentation and transport by raindrop splashing of surface runoff water, (3) raindrop fragmentation and transport by surface runoff, and (4) surface runoff fragmentation and transport by surface runoff (Kinnell, 2005).

Measuring surface runoff under natural conditions is time consuming and expensive. Therefore, there is a need for methods that can provide results in a short time. To this end, researchers have focused on rainfall simulators that can be successfully used in soil conservation studies (Köse and Taysun, 2000; Şahin and Alagöz, 2000). Operability under controllable conditions and repeatability of experiments in short time periods are the most important benefits. The use of sprinklers provides numerous conveniences and possibilities in data acquisition and therefore different aspects of erosion can be investigated rapidly. Especially since the 1980s, raindrop studies have improved the understanding of the mechanisms of soil splash erosion (Nearing et al. 1986; Erpul and Çanga, 2001) and have largely characterized the intrinsic resistance of soil to erosion (Sharma et al. 1991). These studies reveal the inevitability and necessity of using rainfall simulators in erosion studies.

For many years, many studies on soil erosion have been conducted and are still being conducted. Researchers have tried many ways to increase the structural strength of soils. For this purpose, the use of polymers as soil conditioners is popular. These conditioners, which are high molecular weight organic polymers or inorganic salts, have hydrophilic or hydrophobic properties according to their water solubility (Yolcu, 2001). Polyvinylalcohol (PVA) and polyacrylamide (PAM) are two of the synthetic stabilizers that can be used as soil conditioners (Aksakal and Öztaş, 2004a). Many researchers (Sojka et al. 1998; Green et al. 2000; Aksakal and Öztaş, 2004b) have investigated the effect of PVA and PAM on the physical properties of soils and reported that these synthetic polymers provide high infiltration rates during rainfall, reduce surface runoff, improve soil physical properties and thus increase soil resistance to erosion.

The aim of this study was to investigate the effects of PVA and PAM applied at different doses to a Vertisol pasture soil on runoff and soil losses using simulated rainfalls under laboratory conditions.

Material and method

Soil and land properties

The soils used in the polymer application trial were taken from the Golet Basin within the borders of Samsun province. This soil is located in the Vertisol taxonomic order due to the fact that the amount of clays with swelling-shrinkage properties is very high throughout the profile, it has deep and wide cracks in the summer season, especially in August, and slickensides (ss) are observed between 19-65 cm, in the Ustrert sub-order and Haplustert large group due to its moisture regime, and in the Chromic Haplustrert sub-group due to its chroma 3. General land and profile views are given in Figure 1. The potential distribution of the studied soil class is widespread for the pastures of this catchment. Some chemical and physical analysis results of the soil are given in Table 1.

Most of the uplands in the basin of the pond were formed from the Eocene of Time III and the lands on the slope foothills were formed from the Upper Cretaceous phyllite of Time II (Kara et al. 1993). Most of the natural vegetation of the basin consists of oak trees. The remaining part of the land consists of natural pastures and meadows. Shrub vegetation is also common. In addition, tree and shrub species such as plane tree, willow, poplar, tamarisk are observed in the basin. In the agricultural areas where shrub vegetation has been destroyed and previously cultivated but now abandoned, meadow vegetation is dominant (Özen, 1988). The annual precipitation in the pond basin is 670.2 mm, the maximum precipitation falls

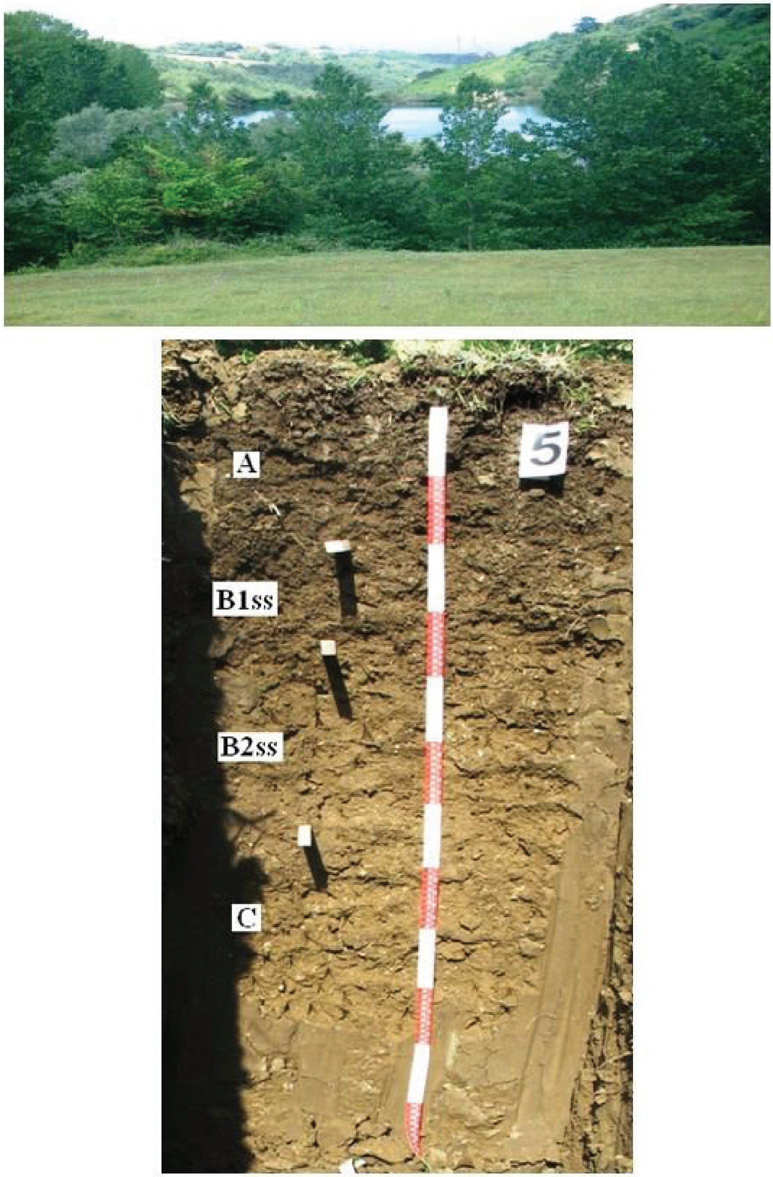

Figure 1. General land and profile views of the Chromic Haplustert

in October with 87.4 mm and the minimum precipitation falls in July with 31.3 mm. The hottest months are July and August (23.2 °C) and the coldest month is February (6.6 °C). The climate of the pond basin has Eastern Black Sea climate characteristics. Summers are hot and partially rainy, while winters are cool and rainy. The soil temperature regime of the research area was defined as Mesic and soil moisture regime as Ustic (Yakupoglu, 2010).

Table 1. Some chemical and physical properties of the Chromic Haplustert

Horizon	**Depth (cm)**	**pH***	**EC* ($dS\ m^{-1}$)**	**Salt (%)**	**$CaCO_3$ (%)**	**SOM (%)**	**Colour (dry, wet)**
A	0-19	7.66	0.691	0.032	8.78	2.72	2.5 Y 4/3 2.5 Y 3/2
B1ss	19-39	7.95	0.581	0.026	12.58	1.18	2.5 Y 4/2 2.5 Y 3/2
B2ss	39-65	7.94	0.523	0.024	10.73	0.62	2.5 Y 5/3 2.5 Y 4/3
C	65+	8.0	0.571	0.026	11.75	0.56	2.5 Y 5/4 2.5 Y 4/4
Horizon	Sand	Silt	Clay	Textural class	HC ($cm\ h^{-1}$)	FC (%)	PWP (%)
A	10.93	16.16	72.91	C	2.44	44.0	28.8
B1ss	11.07	18.41	70.52	C	1.71	41.7	26.5
B2ss	11.78	16.10	72.12	C	2.48	43.5	24.9
C	14.15	18.14	67.71	C	2.30	43.3	26.2

*pH and EC values were measured in saturation paste. EC: electrical conductivity, SOM: soil organic matter content, HC: hydraulic conductivity, FC: field capacity, PWP: permanent wilting point

Polymers

Polyvinyl alcohol (PAM) and polyacrylamide (PVA) were used as soil conditioners. Among the synthetic polymers used, PAM ($(-CH_2CHCONH_2-)_n$) is a linearly bonded, water-soluble acrylamide sodium acrylate copolymer and PVA ($(-CH2OHOH-)_n$) is a cross-linked venylalcohol-acrylic acid that is hydrophobic up to a certain solvent temperature. These two soil conditioners are widely used in agricultural studies (Aslan, 2004). The molecular weights of PAM and PVA applied to the soils under investigation were 200000 g and 72000 g, respectively.

Experimental

Disturbed surface (0-15 cm) soil samples were taken from the to represent the Chromic Haplustert. These soil samples were dried under atmospheric conditions and then pounded with a wooden mallet and passed through an 8 mm sieve to be placed in soil pans. Sea sand was placed in the first 10 cm of the pans with dimensions of 30 x 29.5 x 15 cm (length-width-depth) and the drainage holes in the bottom were covered with coarse filter paper. After the surface of the sand was carefully leveled, a cheesecloth was laid over it and the remaining 5 cm of the pan was leveled by placing samples sieved through an 8 mm sieve, taking into account the runoff initiation level. It was determined that the volume weights of the soils stacked in the erosion pans ranged between 1.09-1.18 $g\ cm^{-3}$ (±0.046). Approximately 4.9 kilos of soil was packed into each pan.

PAM and PVA were applied to the prepared erosion pans in 500 ml solutions at four different doses (0, 3.5, 7.0 and 14.0 kg ha^{-1}) including control. The pans were prepared 1 night before sprinkling. During the 60-min rainfall simulation period, rainfall with an intensity of 70 ± 5 mm h^{-1} and a kinetic energy of approximately 27.95 J m^{-2}-mm with a C_V value of 0.87 was rained on the pans. A laboratory-type simulator, modified from Erpul and Çanga (2001), was used to generate simulated rainfall. This simulator is technically described in another paper (Yakupoglu et al. 2018). With the start of runoff, sediment and water samples were taken at 10 minute intervals with aluminum containers placed under the discharge opening of the soil pan. The aluminum containers in which the runoff and sediments were collected were left for 1 night for settling and when the runoff water became clear, it was transferred to a glass tape measure by siphoning. To determine the amount of soil moving by side splash, splash-boards were placed on both sides of the soil pan at a distance of 6 cm from the pan. These splash-boards, which have dimensions of 140 x 120 cm and are made of metal material, have a sloping groove at the bottom. Soil particles on the splash-boards were washed into the gutter every 10 minutes from the beginning of the rainfall and samples were collected with plastic containers placed at the mouth of the gutter. The material in these plastic collectors was then transferred to aluminum containers. Twice the amount of material collected by the splash plates was considered as the total amount of soil splashed (Moore and Singer, 1990). After the runoff amount was determined, the soils in the aluminum containers were dried at 105°C, weighed and recorded to calculate the amount of soil lost through runoff and splashing (Yönter and Geren, 2006). Some views from the rainfall simulation experiment were given in Figure 2.

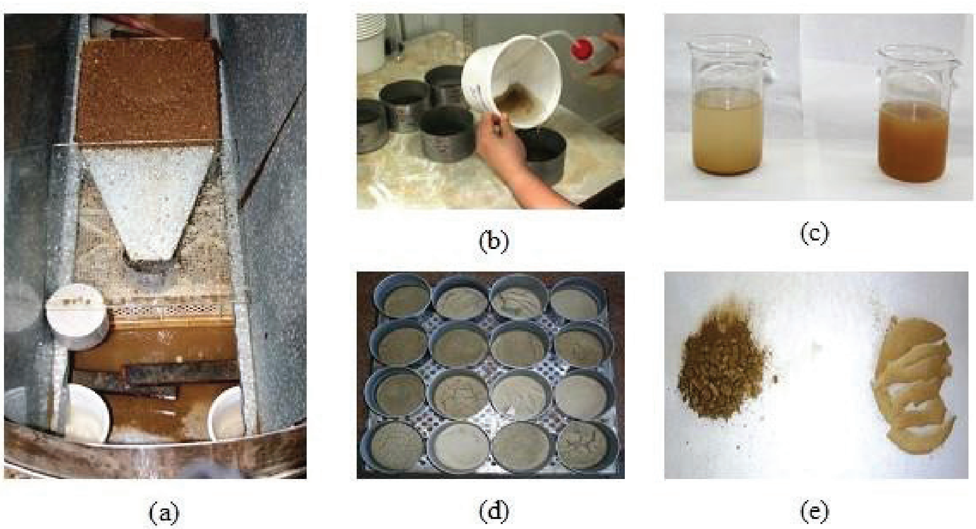

Figure 2. Views from the rainfall simulation experiment (a: view of the soil pan during simulated rainfall application; b: transfer of soil carried by splashing to aluminum containers; c: view of different runoff water carrying sediment; d: pictures of dry soil in the oven; e: oven-dry view of soil transported by splashing (in the left) and suspended by runoff (in the right).

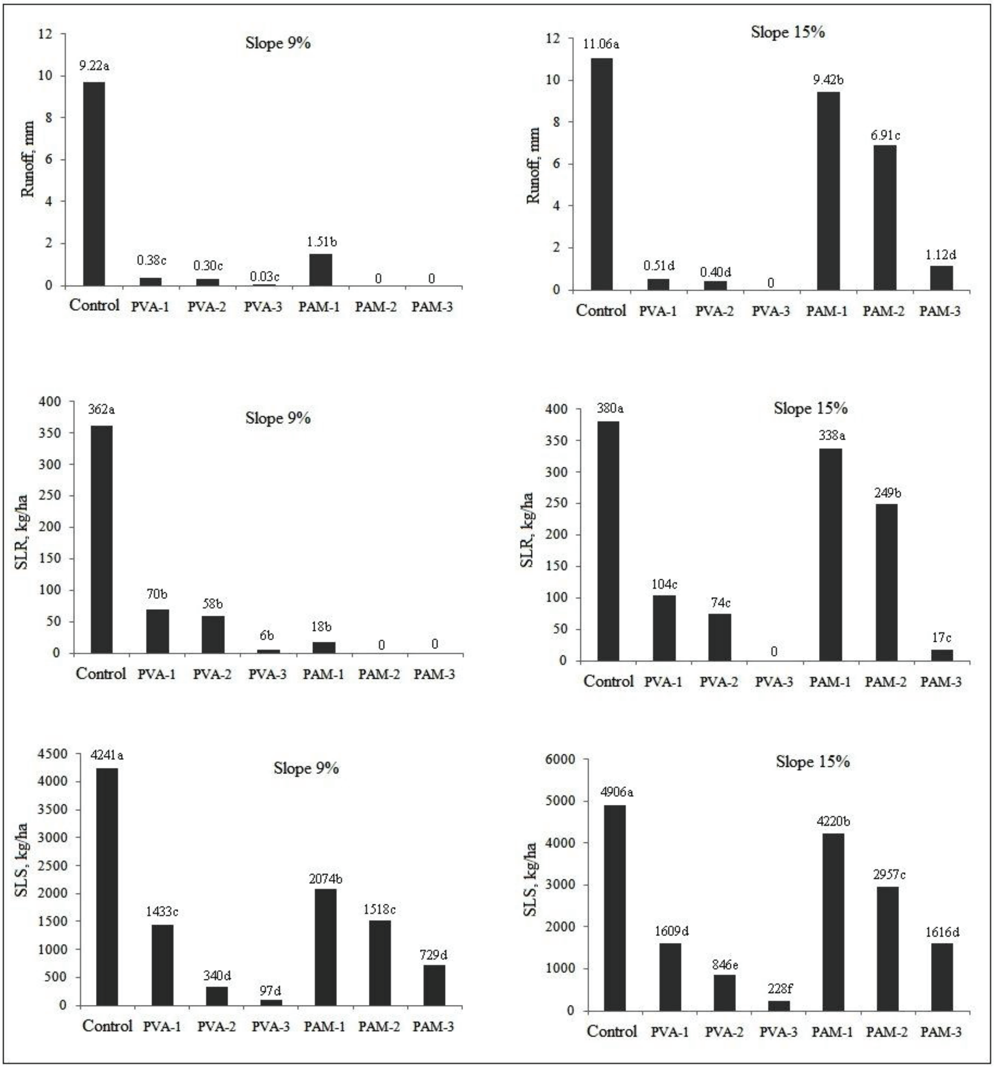

Figure 3. Changes in soil and water losses in two slope angles (SLR: soil loss by runoff, SLS: soil loss by splash)

Results

The comparison of the effects of treatments on runoff, soil loss by runoff (SLR) and soil loss by splash (SLS) values of Chromic Haplustert soil is given in Figure 3. According to Figure 3, the highest runoff occurred from the control pan (9.22a) in Vertisol soil at 9% slope, followed by PAM1 (1.51b) treatment. There was no statistical difference between the PVA application doses in terms of their effects on runoff, on the other hand, no runoff occurred after 1 hour of simulated rainfall in the pans with high PAM doses. Among the pans at 15% slope, the highest runoff occurred in the control pan (11.06a), followed by PAM1 (9.42b) and PAM2 (6.91c) treatments. It was also concluded that no runoff occurred from the pan treated with PVA3 and the lowest runoff values were obtained with PVA1 (0.51d), PVA2 (0.40d) and PAM3 (1.12d) treatments, which were not statistically different.

According to Figure 3, it was observed that the highest SLR occurred in the control pan (362a) at 9% slope. At this slope, the effect of all PVA treatments and PAM1 treatment on SLR was statistically the same. No surface runoff occurred at the end of 1 hour of simulated rainfall in the pans where PAM2 and PAM3 treatments were applied. When the data for the pans with 15% slope are examined, it is seen that the highest SLR occurred in the control (380a) and PAM1-treated pan (338a), which are statistically similar. If the pan with PVA3 treatment, which did not have SLR at the end of the raining period, is excluded, the least SLR occurred in the pans with PAM3 (17c), PVA1 (104c) and PVA2 (74c) treatments, which were statistically similar.

When the bar graphs of the comparison of SLS data at 9% slope are examined (Figure 3), it is seen that the highest SLS was formed from the control pan (4241a). PVA1 (1433c) and PAM2 (1518c) treatments did not show statistical difference in terms of their effects on SLS. The lowest SLS values were recorded for the statistically identical PVA3 (97d), PVA2 (340d) and PAM3 (729d) treatment pans. In Chromic Haplustert soil on a high slope, the highest SLS occurred in the control pan (4906a), followed by the pans with lower PAM doses. The effects of the highest PAM dose and the lowest PVA dose on SLS were the same in Vertisol soil at 15% slope. The lowest SLS occurred in the PVA3 treatment pan (228f).

Discussion

When the total soil-water losses occurring at different slopes from Chromic Haplustert are compared, it is noteworthy that the losses occurring at 15% slope are numerically larger than the losses occurring at 9% slope. This may be due to the increase in runoff velocity and erosion power with increasing slope grade. The increased runoff velocity may have also increased the flow rate of the runoff, thus increasing the total amount of runoff generated in a 1-hour period. Brown et al. (1989) explained that an increase in runoff flow rate increases rill erosion. On the other hand, increasing slope angle increases the kinetic energy of the runoff. As the kinetic energy of the runoff increases, it gains the power to drag larger particles and erodes more soil, thus creating more material to be transported in suspension. Runoff velocity, flow rate and kinetic energy are runoff components that directly affect the amount of soil transported (Özdemir, 2002) and they are always evaluated as main or sub-factors in the developed water erosion prediction models.

According to the findings of the experiment, the total soil loss by runoff at 9% slope is a fraction of the loss by splash at the same slope. Similarly, the soil loss by splash at 15% slope is many times more than the amount of soil transported in suspension by runoff. This result is most likely due to the fact that the energy of a raindrop is about 260 times that of runoff (Hudson, 1995) and that splash transport begins immediately upon contact with bare soil surfaces. In a study (Karaoğlu and Çanga, 2002) conducted by utilizing simulated rainfall under laboratory conditions, it was stated that a soil may give different values of surface runoff and soil loss at different slope levels. Changes in the degree of slope cause the infiltration properties of soils to be different and this situation can strongly affect the properties of the runoff that will occur on the surface of the soils. Differences in the characteristics of surface runoff also change the amount of soil transported.

Soil aggregates are stabilized by both macroscopic and microscopic forces. Macroscopic forces include biotic components such as plant roots and fungal hyphae, cementing agents such as $CaCO_3$ and sesquioxides, and organic polyelectrolytes. Microscopic forces are electrostatic attractions and Van Der Waals bonds (Greenland, 1979). Considering the 73% clay content in the surface horizon of the Vertisol subject to this study, it can be said that it has durable aggregates in terms of macro-micro forces. The effectiveness of the polymers may have been complicated because the precipitation with an intensity of 70 ± 5 mm h^{-1} and a kinetic energy of approximately 27.95 J m^{-2}-mm, which was rained for one hour, was probably not strong enough to break down the aggregates of the polymer-treated Vertisol soil. If the duration or intensity of the rainfall had been extended or increased, perhaps the effect of the high molecular weight PAM polymer would have been seen more clearly. On the other hand, in some high dose polymer applications in Chromic Haplustert soil, surface runoff and soil loss values at the end of the rainfall period could not be recorded and were used as "zero" in the calculations. This may have resulted in the complexity of the effect of the polymers in this soil.

The protective effect of soil-applied polymers on the durability of the structural structure depends on their adsorption on the outer surfaces of the aggregates as well as on the amount of clay fraction and type of clay mineral. In Vertisol soil with 73% clay content, the effects of PAM and PVA may have been complicated because the application doses were high. In other words, since both of the polymers used in this study are anionic, the effect of polymers on soil water losses in Vertisol, which is rich in clay fraction, which is already a source of anionic charge, may have been complex. It may be a more appropriate way to investigate the effects of polymers in this soil with lower dose applications. Many researchers (Miller et al. 1998; Peterson et al. 2002; Kukal et al. 2007) have concluded that polymers can reduce the total soil-water losses under simulated rainfall using various polymers.

Conclusions

It is known that anionic polymers have positive effects on soil physical properties. They decrease soil and water losses by preserving the aggregate stability property of soils. Otherwise, their effectiveness changes depending on application dose, landscape elements (slope etc.) and soil physicochemical and morphological properties. Key findings of this study are: (i) as a result of high dose polymer applications in this Vertisol, runoff and associated soil loss did not occur at the end of the rainfall simulation period, (ii) considering the total runoff and soil losses occurring at different slopes, it was determined that the losses occurring at a 15% slope were higher than the losses occurring at a 9% slope, (iii) in general, PVA is more effective than PAM in terms of decreasing soil/water losses, (iv) with increasing dosage applications of polymers, the start time of runoff was delayed during rainfall simulation period, and at the end of the rain total soil/water losses decreased, (v) for decreasing soil and water losses, the most effective dose is PVA-3 treatment (14 kg ha^{-1}). Also PVA-2 (7 kg ha^{-1}) and PVA-1 (3.5 kg ha-1) can be selected by considering economical conditions. But, high dosage PAM should be preferred because, especially on the high slopes, its low dosage doesn't work. For more meaningful results, management practices that integrate polymer applications should be improved. Polymers should be subjected to trials in soils under different uses, for example, forest, agriculture, burnt forest, etc.

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RESEARCH ARTICLE

Valuation of the Water Protection Function of Forest Territories and Income Allocation: a Case Study of Bulgaria

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Abstract

The owners of forests with water protection functions in Bulgaria do not receive compensation for their limited right to use wood and non-wood forest products from the forest areas they own. At the same time, the contribution derived from forests with water protection functions is received by water users and water consumers, whereas the costs of managing the forests are borne by their owners. The problem thus defined is not a forestry one, but an economic one, and the purpose of this paper ensues therefrom, namely to propose and test a methodology for valuating the production function of forest areas with water protection function in Bulgaria, allowing a fair distribution of income between the forest owner and the user of forest ecosystem services. The methodology is based on the form of forest management and the analytical expression of the economic relationship between a forest owner and a user of forest ecosystem services, constructed using Schenrock's formula. It has been tested with actual data from forest areas with water protection functions falling within the administrative and territorial scope of Velingrad municipality. The obtained results are as follows: as regards the forest territories falling into Sanitary protection zone (SPZ) I of the forests with water protection functions, the economic gains from the property should be 100% realized from water consumption and the owner should receive about EUR 49.83 /ha per year; in SPZ II of the forests with water protection functions, the economic gains from the property should be realized by prioritizing the water protection over the wood production function in a 75:25 ratio, i.e. the owner should receive about EUR 37.37 /ha/year; in SPZ III of the forests with water protection functions, the economic gains from the property should be realized equally in a 50:50 ratio through both production functions, i.e. about EUR 12.22 /ha/year.

Keywords

forest ecosystem services, rental income, wood production function of forests, water protection and regulation function of forests.

Introduction

The forests with water protection functions in Bulgaria occupy an area of 576,117 ha, which accounts for 7.8% of the country's forest areas. Of these, 72.64% are state owned, 11.41% - municipality owned, 9.89% - privately owned, and 6.06% under other ownership. The forests with water protection functions accumulate, annually, between 1-1.5 billion m^3 of water. These forests, by nature, serve as multi-annual equalizers, generating a steady flow of clean water all year round, which reaches water consumers and water users through the water-supplying infrastructure (Ministry of Environment and Water, https://eea.government.bg/bg/soer/2020/forest/gorskite-resursi-i-tehniya-prinos-kam-globalnite-tsikli-na-vaglerod-1; Ministry of Agriculture, 2022, 53 (project)).

In order to obtain this product, forest owners are obliged to manage them under a special regime. Under the water protection regime, the goal is not to obtain wood from the forest, but to manage it in such a way as to maintain and even increase the natural water protection and regulation properties of forest ecosystems. Forest owners would choose to manage their forests as water protection ones as long as they have the opportunity to generate income from this property. However, this type of management is only possible if the water protection properties of forest ecosystems acquire a production function for the forest owner. The funds advanced for the realization of this production function must be protected by institutions in such a way as to allow each forest owner to generate their future income along the water use and water consumption chain. These problems are not forestry, but economic in nature, where the main question associated with every production function should be answered – the question of production efficiency and how the income should be distributed between the owners of the factors of production. In other words, what fair income the forest owner should receive from the water protection function, calculated as a portion of the gross value added created for the country's water sector. The current tying of their income to wood production and wood processing transfers the contributions generated by these forests to the account of water users and water consumers, and the costs associated with these forests remain at the expense of forest owners and organizations that manage them. In relation to the problem thus defined, this study argues that water protection forests should be recognized as capital, and their owners should have the right to generate income from them by recognizing the water protection properties of forests as having a production function. This is precisely what this study aims to address, namely: to propose and test a methodology for valuating the production function of forest areas with water protection functions in Bulgaria, allowing a rational distribution of income between the forest owner and the user of forest ecosystem services.

In specialized literature there is enough research concerning economic valuation of the water protection function of forests based on different approaches. M. Krey, D. Adams and F. Escobedo (2014) assessed the economic value of conserving forests for water quality protection by means of a meta-analysis of willingness-to pay for fully preserved water resources. At the same time, the authors verified a multiple regression model with regressors, which predetermine the dependent variable – willingness to pay (Kreye et al., 2014). The willingness-to-pay for restoration of out of the country forested watersheds was valuated by E. Obeng and F. Aguilar. Using the bivariate probit model, the scholars estimated the drivers influencing the willingness to pay (Obeng et al., 2021). To some extent the willingness-to-pay approach is not so precise for the economic valuation of the water protection function of forests. A more accurate method is applied by Z. Mashayekhi, M. Panahi, M. Karami, S. Khalighu and A. Malekian (2010). The scientific team assessed the water storage function of Zagros forests in Iran using Replacement Cost Method and four simulation models. On these grounds the authors established that the water retention value of each hectare of Zagros forests amounts to 43 USD (Mashayekhi et al., 2010). Similar research has been done by A. Keogh and W. Vasquez (2019), M. Islam, R. Akter and M. Haider (2022), C. Wilson et al. (2020) and T. Kim et al. (2021) (Islam et al., 2022; Keogh et al., 2020; Kim et al., 2021; Wilson et al., 2021). An original approach for the economic valuation of the water supplying function of a mountain-forest in Turkey has been proposed by G. Uzel, S. Gurluk and F. Karaer (2020). Based on the Faustman and Hartman approaches the scholars integrated the natural resources economic valuation with the forest rotation system. On this ground they have developed three models for valuation of the water protection function of the forests in Uladag National Park. According to the first and second models, the forests must be subjected to rotation at intervals of 44 years and their net value is 956 USD/year per hectare and 976 USD/year per hectare respectively. At the same time, in the third model the water quality increases by 10%, the rotation age is 107 years and the stand value per hectare is 1,470 USD (Uzel et al., 2020). Interesting approaches for water protection function valuation of forests have been studied by P. Golos (2009) who compared results from the Contingent Valuation Method (CVM) and the Relative Utility Method (RUM). As of 2009 the water protection function of forests estimated by both methods amounts to 109.5 PLN/ha/year and 805 PLN/ha/year respectively. The variation in the results is due to differences in the theoretical assumptions of the methods. For example, the CVM creates a quasi-market to evaluate the water protection function of forests while the RUM relies on the base function which is the timber production function, which is assessed based on the timber sales income per hectare for a year (Golos et al., 2009).

Forest investments are usually analyzed using the Faustmann model (Faustmann 1849, Samuelson 1976). This method was mainly discussed by Conrad and Clark (1987) and Comolli (1981), and later revised by Yin and Newman (1997) (Comolli, 1981; Conrad et al., 1987; Faustmann, 1995; Samuelson, 1976; Yin et al., 1997).

In Bulgaria, the issue of forest valuation has also been considered. Prof. Temelko Ivanchev (1940) was the first to lay the theoretical and methodological foundations of forest valuation. For this purpose, he used German textbooks on the subject, published at the beginning of the 20th century (1912, 1919, 1921) (Ivanchev, 1940).

I. Yovkov, I. Paligorov and Y. Poryazov, using the theory of contribution, developed a solution to the economic problem of optimal duration of the cutting cycle in order to achieve the maximum financial contribution from the use of the clear-cutting form of forest management (Yovkov et al., 1992). I. Yovkov, I. Paligorov and I. Dobrichov (1992) undertook the task to determine the optimal volume at which the maximum financial contribution would be achieved from the use of the cutting form of forest management (Yovkov et al., 1992).

Georgieva (2005) perfected the approach for economic valuation of selectively cut forests in structural balance by using net present value in perpetuity. She proposed an approach for choosing the optimal target diameter of selectively cut forests under conditions of uncertainty by means of the marginal analysis method (Georgieva, 2005).

It should be noted that the Bulgarian authors listed so far have succeeded in valuating forests with timber production functions. However, both the theory and practice is not enough for an economic valuation of the other functions (Andréassian, 2004; Tsoklinova et al., 2019; Kolev et al., 2020). On the other hand, the methods and valuations turn to the ecological functions of forests (Boggs et al., 2015; Clément et al., 2017; Duan, 2018; Ellison et al., 2017; Oishi, 2018).

Despite having a significant contribution to the management of forest ecosystems, the silvicultural ecological approach in Bulgaria leaves a certain gap in the theory and practice of forest management. The water protection functions of forests, their recreational and tourist functions, their field protective functions, etc., remain undervalued. The main commodity produced by forests with such functions is not wood, but water, tourist products and services, agricultural products, etc. In the present study, it is therefore justified to make a valuation of the water protection function. Its economic aspect is missing both in the economic theory of forestry and in the well-established practical market approach to forest management. The reason for this is that forests in general, including water protection forests, are still viewed as a fund and not as capital. If forests are viewed as capital, then they constitute an investment and should be valued as such. This is precisely what is missing in the existing research in Bulgaria Unlike us, a scientific team led by Constanza et al. (1997) estimated that the value of the world's ecosystem services and natural capital was in the range of 16 to 54 trillion USD per year (Constanza et al., 1997).

Materials and Methods

Study Area

The methodology for valuating the water protection function of forest areas in Bulgaria has been tested using actual data on the forest areas with water protection functions falling within the scope of Velingrad municipality, taken from the forest management plans of the territorial division of State forestry unit (SFU) "Alabak" and the territorial division of State hunting unit (SHU) "Chepino". It should be specified that according to the legislation in force in Bulgaria, sanitary protection zones (SPZ) are designed around water sources and facilities for drinking and domestic water supply from surface and underground water. Each SPZ has 3 belts, which are outlined according to an accepted methodology. In belt I of the water sources and facilities for drinking and domestic water supply from surface and spring waters, the permitted activities include anti-erosion, afforestation and thinning activities. In belt II, cutting activities are limited to thinning, and in belt III, these activities are restricted if proven necessary (Sirakov, 1982). The area distribution of sanitary protection zones by forest type on the territory of Velingrad municipality is presented in Table 1. It shows that the area of coniferous forests falling within the three sanitary protection zones on the territory of Velingrad municipality is 89.28% of the total area of the municipality's water protection forest territories. Therefore, the valuation of the water protection function in this paper focuses on the coniferous forests falling within the first, second and third belts of SPZs in Velingrad municipality. The wooded area of the coniferous water protection forests is 98% of their total area, their tree species composition consists of 70% spruce and 30% white pine, and their total timber volume amounts to 951,527 m^3 or 346 m^3/ha with an average increment per hectare of 4.60 m^3/ ha (Forest management plans of the territorial division of SFU "Alabak", 2018; Forest management plan of the territorial division of SFU "Rakitovo", 2019).

Methodology for valuating the productive function of forests with water protection functions

The silvicultural systems that are currently used in Bulgaria are mainly even-aged forest management systems. These systems employ regenerative cutting methods, which result in even-aged, and uniform in structure and density stands over large areas. For this reason, the methodology for economic valuation of the water protection function of forest territories is limited to this type of cutting, and its silvicultural technical characteristics have been briefly presented.

The size of the cutting area in shelterwood cutting is up to 2 ha, and the period of regeneration is a minimum of 15 years and a maximum of 20 years. Cutting is carried out evenly over the cutting area in 3 or 4 phases (preparatory, seeding, secondary and final). Each phase is characterized by a different cutting intensity and canopy density. In the preparatory phase, canopy density is reduced to 0.7 - 0.8, and the cutting intensity is up to 25%. This phase can be skipped if regular thinning has been carried out. The seeding phase is carried out no earlier than 5 years after the preparatory phase, where the cutting intensity is up to 30%, and the canopy density is reduced to 0.5 - 0.6. During the secondary phase, the cutting intensity is up to 30%, and the canopy density is reduced to 0.3 - 0.4. It is carried out no sooner than 5 years after the seeding phase. Finally, when the canopy density of tree stands in the cutting area is not greater than 0.4 and more than 80% of the area is covered with undergrowth, the final cutting phase is carried out (Kostov et al., 1996).

In accordance with the silvicultural and technical characteristics of the shelterwood cutting presented above, the methodology for valuating the water protection functions of even-aged forests is based on the following algorithm:

Table 1. Distribution of area of sanitary protection zones on the territory of Velingrad municipality by forest type and age classes, ha

Age classes, years	**0-10**	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**	**81-90**	**91-100**	**101-110**	**111-120**	**121-130**	**131-140**	**141-150**	**151-160**	**TOTAL**
Area of SPZ, ha	36.9	33.9	127.8	280.8	553.2	555.3	91.8	145.8	182.9	310.7	451.7	266.2	61.8	3.8	16.1		3118.8
Belt I of SPZ , ha			0.4	0.3	0.4	0.1			0.4	2.2	0.2	0.3	0.1	0.2			4.6
Coniferous, ha			0.4	0.1	0.4	0.1			0.1	1.8	0.1	0.3	0.0	0.2			3.6
Broadleaved High stem, ha			0.0	0.1					0.3	0.4	0.1	0.0	0.0				1.0
Belt II of SPZ , ha	5.2	22.7	94.4	177.2	290.7	309.1	64.5	120.7	126.7	284.2	224.6	154.8	61.0	0.7			1936.4
Coniferous, ha	4.9	21.5	88.3	164.7	264.2	302.3	58.3	107.9	74.1	191.0	193.3	132.1	50.4	0.7			1653.6
Coppice, ha	0.2		0.2	4.0	1.1	1.8	0.8	0.3									8.5
Broadleaved High stem, ha	0.2	1.2	6.0	8.4	25.3	4.9	5.5	12.4	52.7	93.2	31.3	22.7	10.6				274.3
Belt III of SPZ , ha	31.7	11.2	32.9	103.4	262.1	246.1	27.3	25.1	55.8	24.3	227.0	111.1	0.7	3.0	16.1		1177.8
Coniferous, ha	31.3	10.5	30.7	101.4	261.0	244.4	23.6	25.1	43.0	22.3	210.2	105.4	0.7	3.0	14.8		1127.4
Coppice, ha	0.4	0.7	2.2	0.9	0.2	1.5	3.3										9.3
Broadleaved High stem, ha			0.0	1.1	0.9	0.2	0.5		12.8	2.0	16.7	5.7			1.3		41.2

Source: Forest management plan of the territorial division of SFU "Alabak" and forest management plan of the territorial division of SHU "Chepino"

Determining the volume of standing timber(V)

The **volume of standing timber** - It depends on the natural conditions of growth and development of the plantation and on the economic activity carried out in them. The volume (V) of the **standing timber** is calculated using several methods: the mean sample stem method, mensuration methods by girth and class, and mensuration table methods.

Determining the monetary value of wood from shelterwood cutting

Based on the silvicultural technical characteristics of shelterwood cutting described above, it is clear that income from regenerative cutting (W_u) does not come all at once, but at different times during the regeneration period. In this case, a certain year is chosen, which is taken as the u cutting age. This year or age is the year in which the final phase of regenerative cutting occurs. It is clear that a portion of the income from regenerative cutting (W_u) is received in the u year of final cutting. Another part of this income (W_{u-m}) from preparatory cutting is received before reaching the u age, for example in year m, and therefore this income is extended for the period from its receipt to year u, equal to (u - m) years (Kolev, 2018).

Capitalized monetary value of wood from the preparatory, seeding and secondary phases of cutting:

$$W_{u-m} = \sum_{i=1}^{4} Q_i \cdot P_i \cdot (1+r)^{u-m}, \quad (1)$$

where W_{u-m} is the capitalized value of wood from the preparatory, seeding and secondary phases of cutting;

Q_i – volume of wood from the ith category, m^3;

P_i – the warehouse price of $1m^3$ of wood from the ith category EUR/m^3, where m is the year of cutting;

r – the rate of return on alternative investments for the period, percentage expressed as a fraction of 1.0.

The current methodology has adopted the use of the so-called forest interest rate r = 4% [30].

Monetary value of wood from the final phase of cutting (W_u):

$$W_u = \sum_{i=1}^{4} Q_i \cdot P_i, \quad (2)$$

Finally, the monetary value of wood from regenerative cutting (W_{reg}) is determined using the formula (3):

$$W_{reg} = W_{u-m} + W_u, \quad (3)$$

Determining the present monetary value of wood from thinning (W_{clear})

When calculating income from thinning, first of all, it should be examined and determined whether such income can be actually generated or not. Oftentimes such revenues cannot be generated either due to the limited market conditions for the sale of wood harvested from thinning, or due to a lack of convenient and cost-effective freight transport. It is clear that given these unfavorable conditions, this intermittent income should be left out of the calculations.

There are also cases when, due to inefficient management, thinnings are not carried out, but they are perfectly possible, and then the income generated from them will have to be determined and included in the calculations. Data on the amount, receipt, etc. of the income from thinnings can be obtained from other neighboring state forestry offices working under approximately the same conditions, which carry out regular thinning activities and receive a corresponding income generated from them.

It goes without saying that, if thinning activities are carried out properly, in addition to being of great silvicultural importance, they are also sources of significant income for state forestry offices.

The monetary value of wood from thinning activities in year a (W_a) is calculated using the following formula:

$$W_a = \sum_{i=1}^{4} Q_i . P_i, \tag{4}$$

In order to add the income from thinning to the income from regenerative cutting, the former must be expressed in a comparable form, i.e. should receive a present value at the end of each plantation age.

The cash income from intermittent cutting must be capitalized in year u when the income from the regenerative cutting is received.

The total revenue from all thinning activities (W_{clear}) is calculated as follows:

$$W_{clear} = W_a(1+r)^{u-a} + W_b(1+r)^{u-b} + \dots + W_q(1+r)^{u-q}, \tag{5}$$

where W_a, W_b,... and W_q are the monetary values of wood from thinning, EUR;
a, b... and q are the years in which thinning activities are carried out in the plantation.

Determining the costs of creating woodland and their future value at plantation age (FV_c)

The costs of establishing a forest plantation include the costs incurred until the establishment of the plantation: clearing the cutting area, soil preparation, delivery of planting material, tree planting, fertilization, replacement, cultivation, fencing. The costs of establishing the plantation depend on the tree species, its origin and the difficulty of the terrain during planting. This investment is one-off and is capitalized for the entire period of the adopted cutting cycle.

The costs incurred initially to establish the forest plantation and capitalized at plantation age are calculated using the formula (6):

$$FV_c = c.(1+r)^u, \tag{6}$$

where FV_c is the future value of the costs of establishing the forest plantation at plantation age, EUR;

c – the costs of establishing the forest plantation, EUR.

Determining the fixed costs and their future value at plantation age (FV_v)

During the life of the plantation, usually every year until its regenerative cutting, fixed costs amounting to EUR v are incurred (Kim et al., 2021). These costs have the characteristics of an annuity, whose future value is calculated using the formula (7) (Clément et al., 2017):

$$FV_v = v.\frac{(1+r)^u - 1}{r}, \tag{7}$$

where FV_v is the present value of fixed costs, EUR.

v – average annual fixed costs, EUR;

Determining the net financial contribution at different plantation ages (NFC_u)

The net financial contribution (NFC_u) is calculated as the difference between the total updated income generated from thinning activities (W_{clear}) and regenerative cutting (W_{reg}) and the total present costs of establishing the forest plantation (F_{vc}) and the average annual administrative costs (FV_v).

Based on the above formulas for calculating the income and costs, the net financial contribution at the end of year u will equal (Kim et al., 2021; Kostov et al., 1996):

$$NFC_u = W_u + W_a(1+r)^{u-a} + W_b(1+r)^{u-b} + \cdots + W_q(1+r)^{u-q} - FV_c - FV_v, \tag{8}$$

The above formula (8) gives us the net financial contribution of the plantation over its lifetime of u years. With its help, the production possibility frontier can be defined. At the same time, the economic choice is limited to alternative options. The criterion for this choice is the value of use (max NFC_u) of forest ecosystems for different target functions or a combination of several functions.

Determining the forest rent and the distribution of the income between the forest owner and the user of forest ecosystem services

The resulting net financial contribution (NFC) has to serve the interests of the owners of the three types of capital: forestry, labor and entrepreneurial capital, i.e. the individual owners of the factors of production must obtain an economic benefit from their property. The factor of production – timber fund (standing timber) – has the characteristics of a natural resource. The economic benefit from any natural resource is the rent. Forest rent is an income generated from the property rights over forest resources. This income is acquired by the owners by means of two mechanisms. The first involves leasing the right of use, where the so-called "natural fruits"[1] are acquired by the "user of the forest ecosystem services", and the "civil fruits"[2] by the "forest owners". Historically, the institutional environment has been created in such a way as to support forest owners, protect their property rights (the forest) and improve the forest for future generations. A resource to help carry out this function is the rent (R). It is the economic benefit of ownership of forest territories. The user of the forest ecosystem services is the bearer of the property rights on the capital advanced for the forest business. The user is the entity that has a monopoly on the management of forest territories. The economic benefit from their property is the profit. The mechanism that reflects the nature of the transactions between the two entities and by means of which they acquire the rights to the property is expressed by Schenrock's formula (Glushkov et al., 2006; Kolev, 2008; Kolev, 2021; Markov, 2021; Sirakov, 1982):

$$R = \frac{P}{1+g} - (e + d), \tag{9}$$

where: R is the forest rent (income from the right of use of forest property) for forest owners, EUR/m^3, EUR/kg, etc.;

P – the market price per forest product, EUR /m^3, EUR/kg, etc.;

g – profitability based on production costs per user of forest ecosystem services, as a fraction of 1.0;

e – costs for harvesting forest products, EUR/m^3, EUR/kg, etc.;

d – costs for transporting forest products EXW to the nearest location where the user of forest ecosystem services can receive them, EUR/m^3, EUR/kg, etc.

The transactions under this mechanism are of such a nature that the two entities, guided by their interests and protecting them in the negotiation process, receive a fair value of the income from the invested capital. The meaning of fair here extends to the degree in which the institutions set up to regulate the market equally protect both types of property – that of forest owners and that of the user of forest ecosystem services. Under this mechanism, if the forest ecosystem has a wood production function, the rent (R) as an income for the forest owner will be generated based on the market price reached by wood resources.

According to this mechanism, the profit generated by a user of forest ecosystem services is the result of the amount of wood resources used and the rate of profit (g) of the market price per unit of wood resource. This norm reflects the following exchange relation: the price that the respective buyer has agreed to pay and the seller has agreed to accept under the circumstances existing at the time of each transaction. Therefore, it is fair insofar as the institutions provide conditions for the protection of the prop-

[1] Natural fruits – movable things that are periodically separated from forests as natural ecosystems without affecting their integrity (Yovkov et al., 2007).

[2] Civil fruits - the income that the forest owner receives from its forest estate through transfer of property rights to another person on the grounds of contracts between them (Yovkov et al., 2007).

erty rights of a user of forest ecosystem services. Finally, the operating costs (e+d) incurred by a user of forest ecosystem services will obviously depend on the price of the factors of production. These factors are territorially differentiated and obviously have an impact on the final income – rent and profit.

Now, we can ask the question: What should the owner of forests with water protection functions receive if the nature of the transactions is of the type reflected in formula (9) in the case of an even-aged forest (under a clear cutting form of forest management)? According to economic logic, this would be the opportunity cost of the loss of rental income from unrealized gains from timber use rights. These unrealized gains can be:

Full – when the forests are used only for their water protection function and the income from wood is zero. Here the loss from unrealized gains from forest use rights is 100% and should be 100% covered along the water consumption or wood production pricing chain;

Partially limited – when forests are used equally for both wood production and water protection. The fair allocation here requires that 50% of the income be at the expense of wood production, and the other 50% - at the expense of the water protection and water regulation function;

Limited – when the wood production function is given priority over the water protection function or vice versa. Here, it is reasonable that 75% of the income should be covered by the wood production function and 25% - by the water protection and regulation function or vice versa.

The second question that arises is what income the forest owner loses from unrealized gains from timber use rights over even-aged forests?

When a forest owner grants the timber use rights to a user of forest ecosystem services, their net financial contribution (NFC) will obviously acquire the characteristics of a rent. In order for it to be determined, the economic balance between the forest owner and the user of forest ecosystem services must also take into account the current costs of the user of forest ecosystem services. In this case, formula (9) calculating this balance takes the form of an annual balance between the two entities, i.e.:

$$R_{year} = \frac{NFC_{year}}{1+q} - (e+d).Q_{year}, \qquad (10)$$

where R_{year} is the annual forest rent, EUR/ha/year;

NFC_{year} – mean annual contribution per 1 year, EUR/ha/year. It is calculated using formula (11):

$$NFC_{year} = \frac{NFC}{u}, \qquad (11)$$

Q_{year} – the average volume of wood harvested per 1 year from thinning and regenerative cutting under a clear cutting form of forest management, m^3/ha/year.

Table 2. Economic valuation of the net financial contribution from 1 ha even-aged coniferous forest from SPZ1

Age classes, years	**0-10**	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**	**81-90**
1.Volume of standing timber (m^3/ha) (V)	22	92	204	310	419	512	481	515	511
2. Monetary value of $1m^3$ of round timber, (W_{vumean}), EUR/m^3	14.11	14.11	16.36	16.36	21.21	41.5	21.21	21.21	21.21
3. Monetary value of wood harvested from regenerative cutting, BGN/ha (W_{reg})	-	1 298	3 338	5 073	8 886	21 238	10 201	10 922	10 838
4. Future (present) value of income from regenerative cutting at cutting age in year **u** (W_{reg}), EUR/ha		127	499	1 066	2 214	8 068	7 146	11 659	18 361
5. Present value of all income (W_{reg} + W_{clear}), EUR/ha	-	1425	3 837	6 138	11 100	29 306	17 347	22 581	29 198
6. Future (present) value of costs at cutting age in year u (FVc), EUR/ha	498	737	1090	1614	2389	6917	5235	7749	11 470
7. Future (present) value at cutting age in year **u** (FV_v), EUR/ha	364	551	827	1236	1842	5379	4065	6029	8937
8. Net financial contribution (NFC) for the whole economic life, BGN/ha	-861	138	1920	3288	6870	17 010	8047	8804	8792
9. Net financial contribution (NFC) for 1 year, BGN/ha	-172	9	77	94	153	309	124	117	103

Source: Forest management plans of the territorial division of SFU "Alabak" and the territorial division of SHU "Chepino" and authors' own calculations

Table 3. Economic valuation of the net financial contribution from 1 ha of even-aged coniferous forest from SPZ2

Age classes, years	**0-10**	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**	**81-90**
1.Volume of standing timber (m^3/ha) (V)	27	101	206	308	415	509	486	523	514
2. Monetary value of $1m^3$ of round timber, (W_{vumean}), EUR/m^3	14.11	14.11	16.36	21.21	21.21	21.21	21.21	21.21	21.21
3. Monetary value of wood harvested from regenerative cutting, BGN/ha (W_{reg})	-	1 428	3 374	5 045	8 083	10 791	10 310	11 083	10 897
4. Future (present) value of income from regenerative cutting at cutting age in year **u** (W_{reg}), EUR/ha	-	141	520	1 097	2 259	4 172	7 236	11 792	18 558
5. Present value of all income (W_{reg} + W_{clear}), EUR/ha	-	1 570	3 894	6 141	11 062	14 963	17 545	22 875	29 455
6. Future (present) value of costs at cutting age in year u (FVc), EUR/ha	498	737	1090	1614	2389	3536	5235	7749	11 470
7. Future (present) value at cutting age in year **u** (FV_v), EUR/ha	364	551	827	1236	1842	2738	4065	6029	8937
8. Net financial contribution (NFC) for the whole economic life, BGN/ha	-861	282	1977	3291	6832	8688	8246	9097	9048
9. Net financial contribution (NFC) for 1 year, BGN/ha	-172	19	79	94	152	158	127	121	106

Source: Forest management plans of the territorial division of SFU "Alabak" and the territorial division of SHU "Chepino" and authors' own calculations

Historically, in Bulgaria, a profit margin of g=20”%” has been found to ensure a relatively good distribution of income between entities (Glushkov et al., 2006; Markov, 2021). This balance again places the two entities on an equal footing, each of them having the right to receive income from the property they own. This income must be used by them to satisfy their needs, as well as to improve this property for future generations.

Results and discussion

Prices from 2020 were used for the economic valuation of the coniferous forests with water protection functions on the territory of Velingrad municipality, and the main results of the application of the methodology described in section 2 of this paper have been summarized in Table 2, Table 3 and Table 4 for SPZ 1, SPZ 2 and SPZ 3, respectively.

The general trend observed for coniferous forests with water protection functions in each SPZ is that the net financial contribution (NFC) increases with age, reaches a maximum value and then starts to decline. It is most economically advantageous to maintain plantations at an age when the financial contribution is the highest (Yovkov, 1994). This age is between 50 and 60 years for the coniferous forests with water protection functions in all three sanitary protection zones on the territory of Velingrad municipality. The average age of the coniferous forests with water protection functions is 51 years, which means that they have reached their most economically advantageous age. Concerning the latter, similar results have been obtained by G. Uzel, S. Gurluk and F. Karaer (2020). According to some of their models to maintain the water supplying function of the forests in Uladag National Park, the forests must be subjected to rotation at intervals of 44 years (Uzel et al., 2020). As seen in Table 2, Table 3 and Table 4, the maximum net financial contribution for 1 year from 1 ha of coniferous forests with water protection functions on the territory of Velingrad for SPZ 1, SPZ 2 and SPZ 3 is EUR 158 /ha/year, EUR 158 /ha/year, and EUR 128 /ha/year, respectively. This income is for the forest owner, which they receive as an economic gain from the property if they use the wood themselves.

If the forest is used by a user of forest ecosystem services, the economic balance between the forest owner and the user of forest ecosystem services, where the current costs of a user of forest ecosystem services are also taken into account, is calculated using formula (9).

The profit margin of a user of forest ecosystem services (r), as already stated in the methodology, is 20%. At the same time, the average costs associated with cutting, primary processing and transportation to the nearest forest inspection post (e+d) for Velingrad municipality are EUR 10.23 20/m^3, and the average annual quantity of wood harvested from thinning and regenerative cutting for 1 year from 1 ha is about 7–8 m^3/ha/year (Forest management plans of the territorial division of SFU “Alabak”, 2018, Forest management plan of the territorial division of SFU “Rakitovo”, 2019).

Table 4. Economic valuation of the net financial contribution from 1 ha even-aged coniferous forest from SPZ3

Age classes, years	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90
1.Volume of standing timber (m^3/ha) (V)	25	97	201	293	378	472	455	499	499
2. Monetary value of $1m^3$ of round timber, (W_{vumean}), EUR/m^3	14.11	14.11	16.36	16.36	21.21	21.21	21.21	21.21	21.21
3. Monetary value of wood harvested from regenerative cutting, BGN/ha (W_{reg})	-	1 369	3 288	4 794	8 017	10 018	9 647	10 575	10 591
4. Future (present) value of income from regenerative cutting at cutting age in year **u** (W_{reg}), EUR/ha	-	127	278	1 730	1 730	3 282	5 813	9 665	15 388
5. Present value of all income (W_{reg} + W_{clear}), EUR/ha	-	1 496	3 566	6 524	9 747	13 301	15 460	20 240	25 979
6. Future (present) value of costs at cutting age in year u (FVc), EUR/ha	498	737	1090	1614	2389	3536	5235	7749	11470
7. Future (present) value at cutting age in year **u** (FV_v), EUR/ha	364	551	827	1236	1842	2738	4065	6029	8937
8. Net financial contribution (NFC) for the whole economic life, BGN/ha	-861	209	1648	3674	5516	7026	6161	6462	5573
9. Net financial contribution (NFC) for 1 year, BGN/ha	-172	14	66	105	123	128	95	86	66

Source: Forest management plans of the territorial division of SFU "Alabak" and the territorial division of SHU "Chepino" and authors' own calculations

Under these conditions, the annual forest rent (R) from forests with water protection functions is:

for SPZ 1:

$$R_{year} = \frac{158}{1+0.2} - 10.23x8 = 49.83 \text{ EUR/ha/year}$$

for SPZ 2:

$$R_{year} = \frac{158}{1+0.2} - 10.23x8 = 49.83 \text{ EUR/ha/year}$$

for SPZ 3:

$$R_{year} = \frac{128}{1+0.2} - 10.23x8 = 24.65 \text{ EUR/ha/year}$$

Table 5 provides information on the income that must be received by the forest owner and the user of forest ecosystem services under different rights of use of the forests with water protection functions on the territory of Velingrad municipality.

In relation to the forest territories falling into Sanitary protection zone (SPZ) I of the forests with water protection functions, the economic gains from the property

Table 5. Distribution of income from water protection forests, even-aged plantations

	Income distribution EUR/ha		Area of SPZ ha	Distribution of income from the whole area EUR/year	
	Forest owner	Forest user		Forest owner	Forest user
Belt I of SPZ (100:0)	49.83	0.00	3.6	179.39	0.00
Belt II of SPZ (75:25)	37.37	12.46	1,653.6	61,799.17	20,599.72
Belt III of SPZ (50:50)	12.33	12.33	1,127.4	13,896.64	13,896.64

Source: Authors' own calculations

should be 100% realized from water consumption and the owner should receive about EUR 49.83 ./ha per year. In SPZ II of the forests with water protection functions, the economic gains from the property should be realized by prioritizing the water protection over the wood production function in a 75:25 ratio, i.e. the owner should receive about EUR 37.37 ./ha/year. Finally, in SPZ III of the forests with water protection functions, the economic gains from the property should be realized equally in a 50:50 ratio through both production functions, i.e. about EUR 12.22 /ha/year. The results of Golos (2009), who evaluated the water protection function through the application of CVM, do not differ significantly from those obtained in the present study and amount to EUR 23.98/ha/year (Golos, 2009). The obtained results confirm our main scientific hypothesis, namely that forests with water protection functions should be recognized as capital, and their owners should have the right to gain income from them by attributing production functions to the water protection properties of forests. In this regard, by means of the Forest Act and the Water Act and the relevant institutional departments and officials, a system of rules (Behera et al., 2006) working in favor of the owners of forests with water protection functions should be constituted. This protection itself is aimed at providing opportunities to generate income from the ownership of forest ecosystems (Asquith et al., 2008), including in cases where they are only used for water protection purposes. Since every forest ecosystem has both a wood production and a water protection function, all future actions should obviously be directed at including forests in transactions not as a fund (accumulation), but as capital, whose profitability is functionally dependent on the relative prices of the commodities along the respective pricing chains.

Only by clarifying and recognizing the production function of forests through market mechanisms along all pricing chains will they acquire capital value as a multifunctional resource. This right in relation to their water protection function is currently not being realized. In addition, there are no direct economic gains from the ownership of forests with recreational and tourist functions, field protection functions, anti-erosion functions, etc. (FAO, IUFRO, USDA, 2021). The main reason for this is the lack of an economic approach to the valuation of the multipurpose production functions of forests in general and of forests with water protection functions in particular. Here it should be underlined that the different valuation methods used generate different results, which raises some doubts. Because of that, the implementation of the methods for assessment of the water protection function of forests has to be done with prudence at national level as a political decision (Golos, 2009).

The tasks associated with the economic approach to the problem of the economic valuation of forests with water protection functions boil down to an alternative choice. The criterion for this choice is the value of using forest ecosystems for different target functions or a combination of several functions. The alternative to the wood production function, which has become dominant in the course of the historical development of the country's forestry sector and as a result of the market mechanism for generating more than 95% of the forest income through wood production, is the economic valuation of the water protection function. This is necessary because the wood production function of forests is no longer able to generate sufficient income (Yovkov et al., 1992). There is a conflict of interest between those who manage the forests for free in compliance with environmental criteria (Martynova et al., 2021) and those who generate income along the water use and water consumption pricing chain.

Overcoming this conflict obviously requires a new institutional environment that would grant forest owners and forest management organizations the right to generate income from the water protection function of forests. This income, as an alternative to the income generated from the wood production function, can also be awarded in the form of a rent. In relation to the wood production function, under the current model of forest management, the rent as an economic gain from the ownership of forest ecosystems is ensured by any single transaction according to formula (9). In relation to the water protection function, the alternative to this rental income will obviously be of equal value, but this value will already have been created along the water consumption pricing chain. This will of course be valid if the forest ecosystem fully participates as an agent of production along this pricing chain. In this case, this value shall be equal to the loss that the forest owner would make from income foregone resulting from the unrealized wood production function, which is the same as if the forest ecosystem was established solely with water protection functions.

Conclusions

Forests with water protection functions must be recognized as capital, and their owners must have the right to derive income from them by attributing production functions to the water protection properties of forests. Consequently, the following question arises: How much should the owner of forests with water protection functions receive if the economic relations between the two main entities – the forest owner and the user of forest ecosystem services – are expressed in analytic form using Schenrock's formula (see formula (9))? Economic logic shows that this will be the opportunity cost of the loss of rental income from unrealized timber use rights, which currently accounts for 95% of the revenues generated from forests in Bulgaria. The fair distribution of the contribution of forest ecosystems between the two main economic entities requires that the Forest Act and the Water Act, which set the rules for the protection of property rights over forests and their functional purpose, should allow for the following alternatives: forests with 100% wood production functions should generate 100% of the economic gains from forest ownership through the use of wood; forest territories falling into the first SPZ belt should generate 100% of their economic gains from the property through water consumption; forest territories falling into the second SPZ belt should generate their economic gains from the property by prioritizing the water protection function over the wood production function in a 75:25 ratio; forest territories falling into the third SPZ belt should generate their economic gains from the property equally in a 50:50 ratio through the two production functions; all forest territories in the country, which are managed by prioritizing the wood production function over the water protection function, should generate their economic gains from the property in a 75:25 ratio, taking this prioritization into account.

The alternatives described above are essentially forms of economic realization of the real contribution of forest ecosystems in the process of their multifunctional management (wood production and water protection functions). The owner of the forest ecosystem has the right to this contribution and they must be protected by the relevant legal instruments. This right, of course, can be economically realized only if the natural water protection and water regulation properties of the forests acquire a production function for forest owners. This new production function is at present as socially significant as wood production and requires institutional protection by means of the mechanisms for natural resource management. In this regard it should be pointed out that the Forest Act (2011) (chapter 17 'Public ecosystem benefits from forest areas') already provides a legal basis for forest owners to derive income not only from timber production, but also from other beneficial characteristics of forests (Forest Act, 2011). The problem is that at the present moment there is not an accepted methodology for the economic valuation of the non-timber production functions of forests. Due to this, our future research should be directed towards the development of reliable methodologies for the assessment of different functions of forests. The results from these methodologies are crucial for the development of national ecosystem accounts and for assessing the costs and benefits associated with national and regional strategies and plans.

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