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Agricultural Intensification Reduces the Portfolio of Wetland Ecosystem Services: European Danube River Lowlands as a Global Biodiversity Hotspot

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Abstract: Anthropogenic landscape transformations have promoted the provision of ecosystem services (ES) at the expense of other ES, biodiversity, and human well-being. We analysed the transformation portfolios of ES provisions, the costs of transformation, and the rivalry between ES categories and biodiversity conservation during the pre-communist and communist eras. We also examined EU influences in Romania's Danube River lowlands. The environmental history of social-ecological systems was used to: (1) map transformations of natural environments; (2) analyse the outputs of human modes of production, including crops, fish, timber, and livestock, using economic valuation methods and by appropriating the primary means of production; and (3) describe ideologies and values as drivers of ES transformations. During the communist era, the surface area of the agricultural land increased at the expense of natural ecosystems. This resulted in increased provisions being made for crops and timber at the expense of the fish supply; it also caused a reduction in livestock. The costs of land reclamation, hydrotechnical works, and the use of fertilizers and pesticides, resulted in a net annual loss of EUR 36 million for the entire case study area, disregarding the losses of other ES. Achieving a balanced portfolio of ES requires a discussion about the need for nature restoration, transdisciplinary social-ecological research, and the identification of key leverage points.

Keywords: biodiversity conservation; economic valuation; ecosystem services mapping; environmental history; multifunctional landscapes; land cover transformation; nature restoration; transdisciplinarity

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1. Introduction

Natural wetland ecosystems are among the most productive ecosystems in the world, and they provide a wide range of ecosystem services [1–3]; however, for a long time, socio-economic systems have focused on maximising biological production for the benefit of humans. All over the world, natural wetlands have been regarded as being of low economic importance; they have even been termed as "water sick" or as "wastelands" [4,5]. The drainage and conversion of wetlands into agricultural land supports the development of the industrial agricultural sector. The construction of dikes and dams, forest clearing, and peat extraction, are common anthropogenic drivers of wetland degradation and loss [6,7].

This anthropogenic transformation of wetlands has generally been based on narrow economic considerations, at the expense of regulations, cultural services, and biodiversity conservation [8–11].

The concept of ecosystem services (ES) [12,13] includes a wide range of natural benefits that support human well-being and welfare [11,14]; however, a narrow focus on the provisional category of ES threatens the supply of habitats for species (supporting service), water quality and quantity (regulating service), and leisure activities or activities that relate to the appreciation of aesthetic values (cultural service) in the wetlands [15] (and other land types) [8,16,17]. A key challenge is to determine the effectiveness of different approaches to achieve multifunctional landscapes; such landscapes are able to provide multiple ES that are vital for ecosystem functioning and human well-being. One dichotomy emerges between land sharing and land sparing [18]. Although the former aims to combine the production of wood, feed, fuel, and fibre commodities with biodiversity conservation across entire landscapes, the latter prevents intensive land use in multiple-use areas, and protected area networks provide functional green infrastructure [19,20]. The choice of strategy can be affected by legacies of ideology and approaches to governance.

Human impact creates path dependence effects on landscapes [21] and coping with these effects requires an understanding of systemic interactions; therefore, it is necessary to consider both social and ecological systems when assessing the implementation of sustainable development and sustainability policies [22,23]. Coping with, and learning from, the consequences of ideological and value transitions is enhanced by understanding past trajectories concerning landscapes and regions, especially those with drastic societal shifts [24–26]. In an attempt to learn from the past in order to help deal with today's challenges in landscape management and governance, we may take the following studies into consideration. In 1864, Marsh [27] stressed the need to study how human interactions with the natural environment change. Environmental history, according to Worster [28], parallels the multidimensional concept of landscape [29,30], and thus, it is a relevant analytical framework for studying the dynamic aspects of landscapes—for instance, their role as social-ecological systems—as well as their different components [31].

Countries with transitional economies are facing multiple challenges regarding the reformation of governance and the management of natural resources [32]. Learning from the past requires a comprehensive systematic approach; countries and landscapes in different phases of development, with regard to their social-ecological systems (SES), are thus suitable for such research projects [29,33]. Romania has gone through ideological changes from capitalism to communism, and then back to capitalism [34]. Multiple pressures have had a strong impact on land cover and land use. Romania has a long legacy of being an important agricultural producer in Europe. The Lower Danube River and its wetlands have been particularly affected by agricultural practices, with 80% of those areas being transformed from complex multiple-use wetland systems into simplified agricultural landscapes [35]. Achieving agricultural competitiveness requires the transformation and modernization of the agricultural sector. Consequently, the entire Lower Danube Wetland System has suffered large scale transformation and wetland loss [36]. After World War II, in the early years of the communist regime, agricultural collectivisation took place in the form of the Soviet model. Low agricultural production, overpopulation, and a lack of industry demanded new solutions. Borrowing directly from the Soviet system, agricultural collectivization soon became foundational for Romania's socialist development [37]. Until the collapse of communism in 1989, Romania was one of the main cereal suppliers in the European east bloc. Important ideological changes occurred in 1989 when the authoritarian regime of Ceaușescu ended [38], and Romania transitioned to become a Member State of the European Union. In Romania, the last century can be divided into three distinct time periods: (1) pre-communist period (1900–1945); (2) the communist period (1946 to 1989); and (3) the transition to EU membership from 2007 onwards (1990–2017).

Focusing on these three periods, we used the Brăila Islands Long-Term Socio-Ecological Research (LTSER) platform as a case study in order to do the following: (a) map the transformation of the wetlands regarding its status as a natural environment; (b) assess the provisional services that consider different modes of production that exist under different types of land use and covers; and (c) analyse the ideologies and values underpinning the changes to the wetlands. We also attributed monetary values to both the benefits and investment costs for the provision of ES, and we estimated the net benefits and costs related to the loss of wetlands. Finally, we discussed the trade-offs that emerged between different ES provisions; on the one hand, provisions exist in order to support and regulate ES, and cultural ES exist on the other [39]. We based our analysis on the environmental history approach, and we explored the extent to which transdisciplinary social-ecological research can support collaborative landscape stewardship.

2. Methodology

2.1. Overview of Our Approach

In Figure 1, we present an overview of our comparative multiple methods approach; it is based on comprehensive temporal and spatial quantitative analyses of ecological systems and a qualitative narrative synthesis of ideologies and values in the social system. We applied this approach to a wetland landscape case study in Romania. To address the three aims (Figure 1A), we acknowledged the landscapes' biophysical, anthropogenic, and immaterial dimensions [29,40] and how they change over time. Additionally, we chose Worster's [28] framework for understanding environmental (or landscape) history. We selected a global biodiversity hotspot wetland landscape in the lower Danube as a case study (Figure 1B). Next, (Figure 1C) we focused on three periods of the previous century covering Romania's transition from a communist to a capitalist country, followed by its transition to a EU member state. We also examined its market economy. Moreover, we (1) mapped land use and land cover change; (2) estimated the number of provisional ES using economic valuation and human appropriation of net primary production (HANPP) resources [41]; and (3) we described the ideological dynamics underpinning those changes. Finally, we discussed our conclusions regarding the costs for landscape transformations, and trade-offs between different ES supporting human well-being (Figure 1D). To facilitate learning on environmental history, the transitional periods within that history, and that which affects the portfolio of provisions and other ES, we also discussed and drew conclusions from our transdisciplinary social-ecological research; this research aimed at supporting collaborative landscape stewardship in the Brăila Islands.

2.2. The Brăila Islands LTSER Platform as a Case Study Landscape

The Danube River, which flows through Romania, as well as its floodplains which have fertile wetlands, have contributed to the formation of a region where agricultural expansion has been particularly extensive [9]. We chose the Brăila Islands Long-Term Socio-Ecological Research (LTSER) platform (https://deims.org/d4854af8-9d9f-42a2-af96-f1ed9cb25712, accessed on 1 February 2023) as a case study landscape. It is located in SE Romania (44°57′ N, 28°00′ E), along 78 km of the lower Danube River, between the cities of Hârșova and Brăila (Figure 2).

The case study area (2500 km^2) is inhabited by approximately 300,000 people and comprises both modified landscapes (the left and right shores of the Danube River, and the Big Island of Brăila) (ca 2300 km^2), as well as near-natural ecosystems (Small Island of Brăila) (210 km^2).

On the Big Island of Brăila and the surrounding riverbanks, converting the land for intensive agricultural use took place during the communist period; this affected the manner in which ecosystems function downstream in the Danube Delta and the Black Sea [36]. On the Small Island of Brăila, remnants of the formerly abundant, naturally dynamic wetlands are protected as a Natural Park, as a Ramsar site, since 2001 [9]. Moreover, these wetlands are also part of the EU's Natura 2000 network as Sites of Community Importance (SCI) and Special Protection Areas (SPA). This is one of the few areas in Europe that remains under a semi-natural flooding regime and that is preserved on a smaller scale;

the biological diversity, functions, and ES are specific to the Danube floodplain and they remain intact [9,36,42,43].

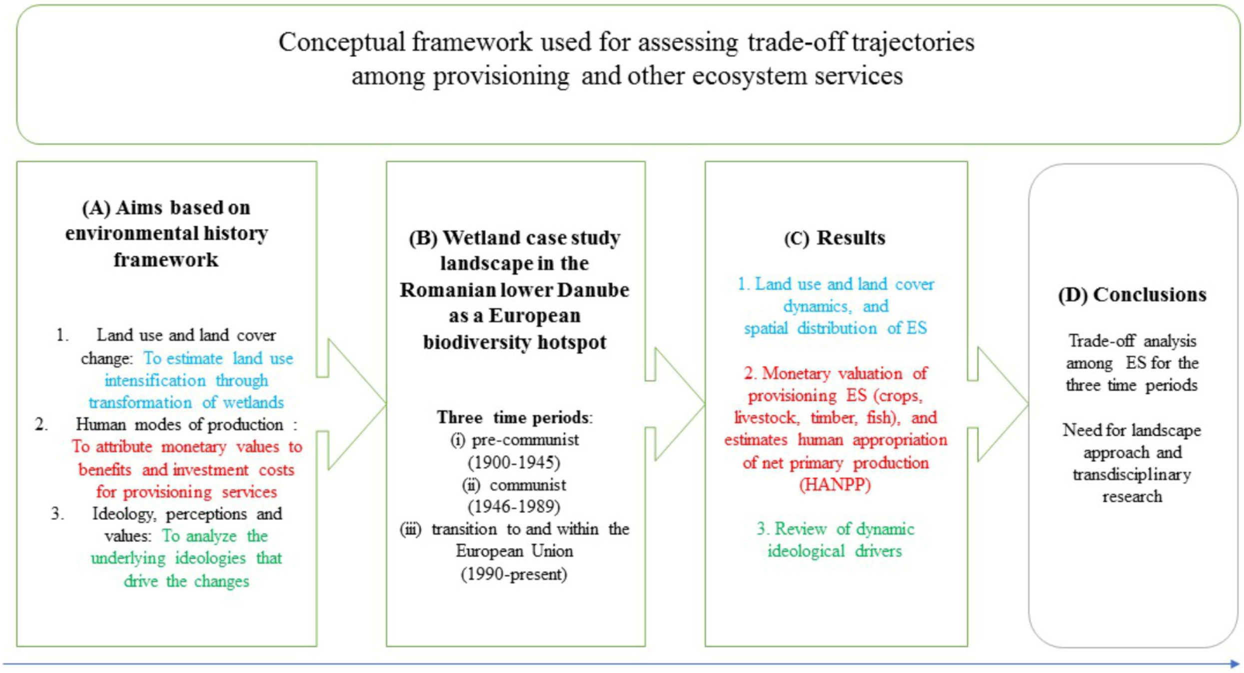

Figure 1. Overview of the research process that aimed to (**A**) analyse the three dimensions of Romania's environmental history, including the transitional periods, by (**B**) selecting a case study landscape in Romania's lower Danube. Beginning in 1900, the time period selected for this study was divided into three. This study (**C**) addresses the three research questions in order to meet the three aims outlined in (**A**). Finally, (**D**) we discuss the trade-offs between provisions and other ES. We also discuss the need for transdisciplinary social-ecological research and landscape approaches which could form the basis for landscape stewardship.

2.3. Theoretical Frameworks for Analysing Landscapes in Time and Space

Of the theoretical frameworks supporting a systems-based perspective on landscapes, wherein landscapes are perceived as human-based and nature-based systems, we chose the social-ecological system (SES) framework [23], and opted to examine the landscape's environmental history [28]. The SES framework is a comprehensive and multi-tiered conceptual framework for examining both the social systems that focus on government interactions at multiple levels, and outcomes in social-ecological systems; in particular, it focuses on the sustainability of these systems, which is measured on multiple scales [44,45]. As a mainstream field of research, the SES concept has evolved into a systematic approach to understand how different SESs can be sustainable for people in places with different resource systems and units, governance systems, and actors [46]. Within these main tiers, it is possible to identify the interactions and outcomes of an SES, with their different socio-economic and political settings, and how they change over time [23].

SESs are dynamic and they exhibit path dependencies [21]. This affects the opportunity to implement policies that aim to sustain the landscapes' supply of ES [47]. This emphasises the need to understand both the historical and contemporary states of the landscapes, in addition to their trajectories, as social-ecological systems. Landscapes are composed of biophysical, anthropogenic, and intangible elements [29,30]. As an interdisciplinary field of research, environmental history [28] is an appropriate analytic framework for studying the dynamics of landscapes as socio-ecological systems, and particularly as a location in space and time. The framework examines the following: (1) biophysical changes in natural environments; (2) human methods of production; and finally, (3) ideologies, perceptions, and values.

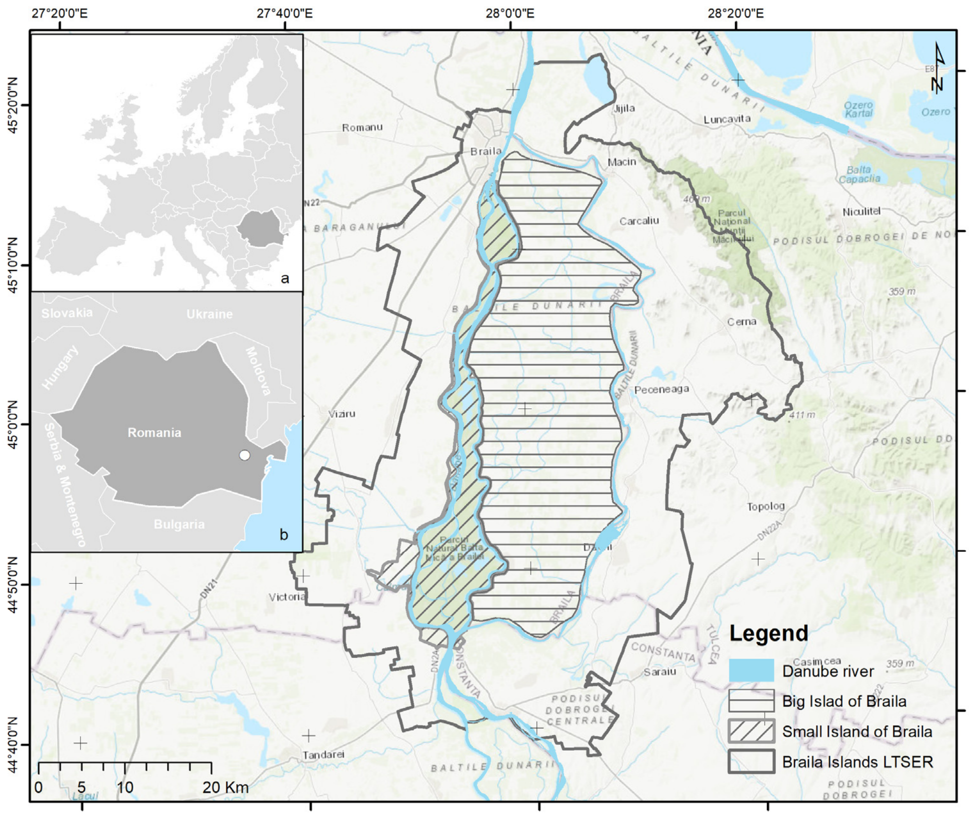

Figure 2. Map of the Brăila Islands LTSER platform. (**a**) European location of the case study area; (**b**) location in the country.

Research on the biophysical changes in natural environments of the past is a crucial avenue to explore in order to generate knowledge and facilitate learning on how provisional ecosystem services were impacted by changes in decision-making processes and policy actions. By considering and understanding previous land management decisions, future decision-making processes can be improved by taking into account the landscape's capacity to provide ES. Comprehending the biophysical developments of a landscape and its land cover can be achieved by using a time series comprising spatial and statistical data [48]. To understand the consequences of human modes of production and the proximate mechanisms behind biophysical landscape changes, it is important to consider human technologies and ways of organizing the types of benefits produced by land management strategies that have transformed near-natural systems [31]. Finally, ideologies are linked to values and perceptions which influence the political and economic life of society; thus, Bell [49] argued that the role of ideology is not to render reality transparent, but to motivate people to perform, or not perform, certain actions.

2.4. Three Time Periods

We defined three time periods in Romanian history (Table 1) that have shaped the destinies of thousands of people. These time periods comprise the following: pre-communist times (characterised by an agrarian way of living and slow industrialization); communist times (characterised by the strong and forced transition of the political system, mass industrialization, and the relocation of people [50], as well as labour camps); and finally, the transitional period wherein Romania became a EU member state, and beyond, so that the time period wherein Romania is a full EU member state is included (Table 1). The analysis considered multiple elements, including transformative events, power relationships, economic systems, and transitional periods.

Table 1. Defining the three environmental history periods and the implications for the Brăila Islands.

Defining Elements	"Pre-Communist" (ca. 1900–1945)	"Communist" (1946–1989)	"Transitional and EU" (1990–2017)	Sources/Notes
Historiography	Pre-socialist period	Socialist period	Post-socialist period	Dorondel [34]
Path dependency	Pre-productivist	Productivist	Post-productivist	Wilson [21]
Events	Slow industrialization process; the Brăila Islands were naturally flooded; the transformation started during this period.	Change in political system; Soviet influence continued through Ceausescu's administration; transformation into agricultural polders; only a small portion of the area remained naturally flooded.	Revolution against communism in 1989, and Romania was admitted to the EU in 2007; the remaining polders received protected area status due to the Natura 2000 network; the rest of the area remained as agricultural polders.	
Economic system	Capitalism; the local communities were using multiple resources as raw materials, including reeds, fish, cereals, livestock; access to those resources were more or less free; nevertheless, the area was among the poorest in Romania.	Socialism; the local community lost the link to the natural systems; confiscation of private property; planned economic systems in agriculture and forestry.	Capitalism; although the systems changed, the local community did not change how they used the land.	Verdery [51], Murgescu [52]
Land property type	Private landowners and state-owned land; different entities owned land (church, foundations); low productivity.	Owned by cooperatives (state); people were forced to give their land to the state (the process took 20 years 1949–1962); higher productivity.	Private land (transition) and state owned land was partially transferred to their initial owners; (see notes on the "economic system"); some owners received land in the former wetlands, making any future reconstruction processes very difficult or impossible.	Gürel [53]
Power	Democratic form of government (no political monopoly).	Strong authoritarian central government.	Democratic form of government.	
Drivers of change	Economic; debate on the need for land reclamation; the transition started for about 5% of the wetland systems (due to lack of funds).	Political; no debate; the decision was made based on the "need" to transform the natural land to agricultural land (the transition transformed more than 80% of the area into agricultural polders).	Economic; political; climate; the systems did not change from the communist period; the pressures on the systems increased over time; the area provides vital ecosystem services, but little has been done to ensure the restoration of the area; the most successful conservation area is the Ramsar site; Natura 2000.	Kucsicsa, [54]
Societal resilience capacity (defined as social resilience: ability to cope, adapt, and transform)	High (multiple actors involved, multiple ES, strong internal cohesion between social partners).	Lower (power relations with stakeholders; decreased interactions and low internal cohesion between social partners).	Still lower as compared with the pre-communist era (not increasing but stabilised); stakeholders finding their voices; difficult interactions.	Saja et al. [55]

2.5. Methods and Data

2.5.1. Land Use and Land Cover Change

We defined the land cover classes of the "pre-communist" period (Table 1) as the reference conditions for the Brăila Island LTSER ecosystems. As a proxy for this period, data from 1910 were extracted from topographic maps that had detailed information on land covers (Atlas of Central Europe, scale 1:200,000). These maps were georeferenced using spatially fixed control points (i.e., churches, monuments etc.) that can currently be identified on the ground. As a proxy for the "communist" period, the land use and land cover data were based on the 1990 Corine Land Cover data [56]. For the "transitional and EU" period, we used the 2018 Corine Land Cover data [57]. Ecosystem services mapping was completed using ArcMap software.

2.5.2. Human Modes of Production

Ecosystem services assessment and mapping

A wide range of methods and frameworks for ES assessment and mapping have been developed [58,59]. Several approaches for assessing ES involve three different dimensions: economic, biophysical, and socio-cultural [60–62]. Economic valuation methods and concepts, such as direct-use values, replacement cost, avoiding damage costs, and willingness-to-pay, aim to estimate and monetize the benefits that ecosystems provide for society [63]; however, monetary valuation methods have often received criticism due to the fact that economic analyses often concentrate on a small number of ES, and thus, those estimated values remain approximations, depending on the methods used [63,64]. Non-monetary valuation methods, such as the biophysical mapping of ES, human appropriation of net primary production, and social system surveys, have a long-held traditional role in stakeholder engagement and policy making [65]; moreover, different international initiatives, such as MA, TEEB, and IPBES have acknowledged their role in ES assessments [66]. In this study, we adopted a combined biophysical and economic approach for the valuation of selected provisional ES by mapping their supply and quantifying their monetary values.

Using the Common International Classification of Ecosystem Services framework (CICES v 5.1) [13], four provisional ES (agricultural crops, fish, timber, and livestock) were identified as the most relevant ES for our case study area. The first step in the assessment involved conducting a land cover analysis for the pre-communist, communist, and EU periods (Figure 3). The second step involved assessing and mapping the capacity for ES [59] by collecting data concerning the average provisional area per hectare for crops, fishing, timber extraction, and livestock supply (Supplementary Table S1). This was multiplied by the total area of specific land cover in which particular goods were produced. The spatial distribution dynamics of the provisional ES were visualised for each period (Figure 4). The final step of the assessment involved adding a monetary value to the four selected provisional ES. An economic valuation was conducted by linking the obtained values of the selected ES, for all three periods of time; these values were identified using average market prices for the selected ES (2017), which were made available by the National Institute of Statistics. Accounting for the additional energy inputs needed to facilitate the selected ES was achieved by taking the average monetary value of the costs needed for fuel, nutrients, pesticides, seeds, irrigation, and so on, into consideration. These values were obtained from local farmers.

Human Appropriation of Net Primary Production (HANPP)*:*

This is an indicator that measures the extent to which humans interfere with the natural world's processes and functions. HANPP can be used to quantify the extent to which plant biomass is available to different trophic levels after human intervention (e.g., harvesting, land use conversion). This method not only takes harvesting into account, but also the necessary additional energy inputs (mechanization, fertilizers, etc.) required for the delivery of the final ES [41,67].

HANPP is defined as the difference between the potential amount of net primary production available in the ecosystem in the absence of human intervention (NPP0), and the actual amount remaining in the system after harvesting or after land conversion (NPPt). NPPt is calculated as the difference between the actual primary level of productivity available in a given ecosystem (NPPact) and the NPP harvested by the human population (NPPharv) [67]. The NPP0, NPPt, and HANPP data (Supplementary Tables S2–S4) used in this study were obtained using the available literature focusing on urban areas, agricultural land, and semi-natural (pasture) areas; these studies were extrapolated and applied to the Brăila Islands case study. For forest ecosystems, inland marshes, and bodies of water, we obtained data on site specific NPPact using the available literature. NPP0 was calculated based on the assumption that NPPact is approx. 80% of the NPP0 [41]. We calculated the HANPP for wetlands based on the assumption that there is no direct consumption of NPP by the human population/socio-economic sector (NPPharv). The HANPP was estimated as the difference between NPP0 and NPPact.

2.5.3. Ideology, Perceptions, and Values

To replicate the approach by Naumov et al. (2016) [31], we employed the left–right differentiation that is used in politics to distinguish between different ideologies. Ideology is often linked to particular approaches to natural resource usage. For example, planned economic systems for agriculture and forestry are supported by the communist (far left) ideology. With the adoption of such a left-wing ideology, the state attempts to overcome inequalities in society by becoming more actively involved in the lives of citizens, thus prompting the adoption of more regulations; conversely, right-wing ideologies understand inequalities as innate social phenomena. On the one hand, liberalism promotes freedom of the individual, individualism, and rationalism; on the other, communism stresses community, equality, and collective ownership [68]. By examining three different time periods, this study explored a range of ideologies, from more liberal (right) ideologies, to communist (left) ideologies.

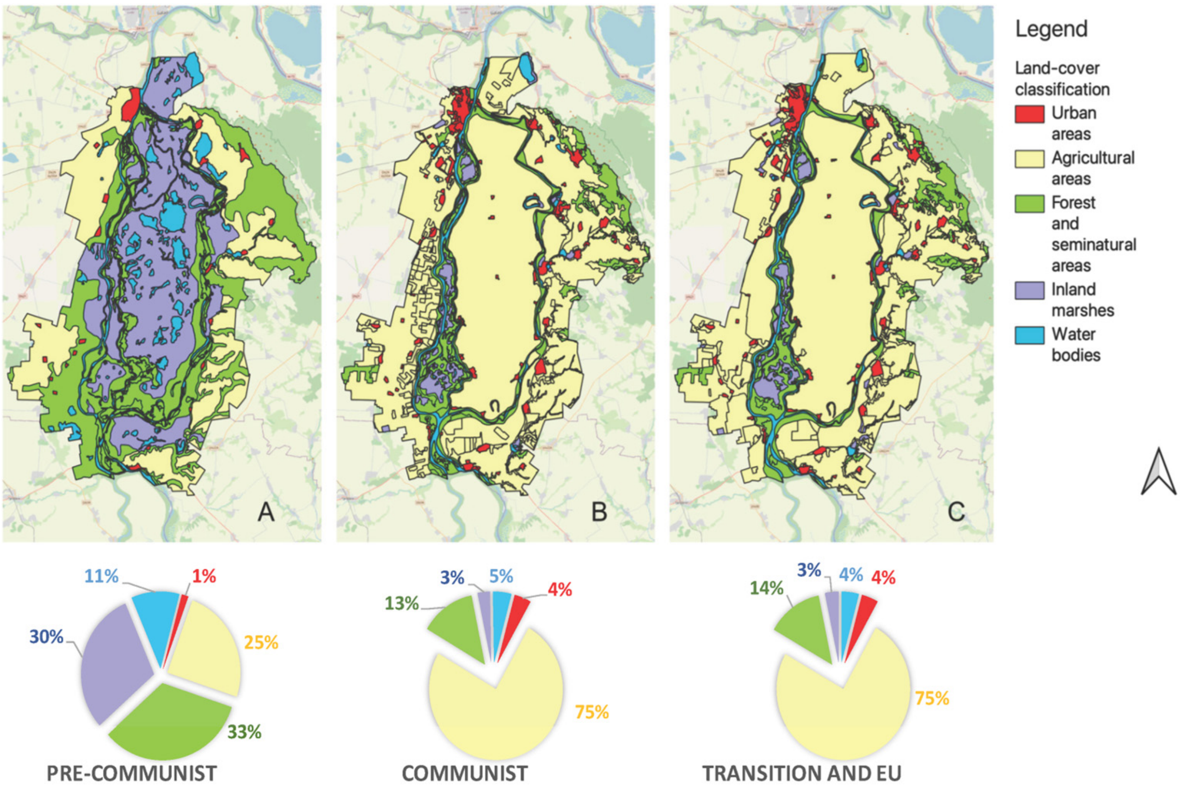

Figure 3. Land cover distribution dynamics in the Brăila Island case study area for the pre-communist (**A**), communist (**B**), and transitional and EU periods (**C**).

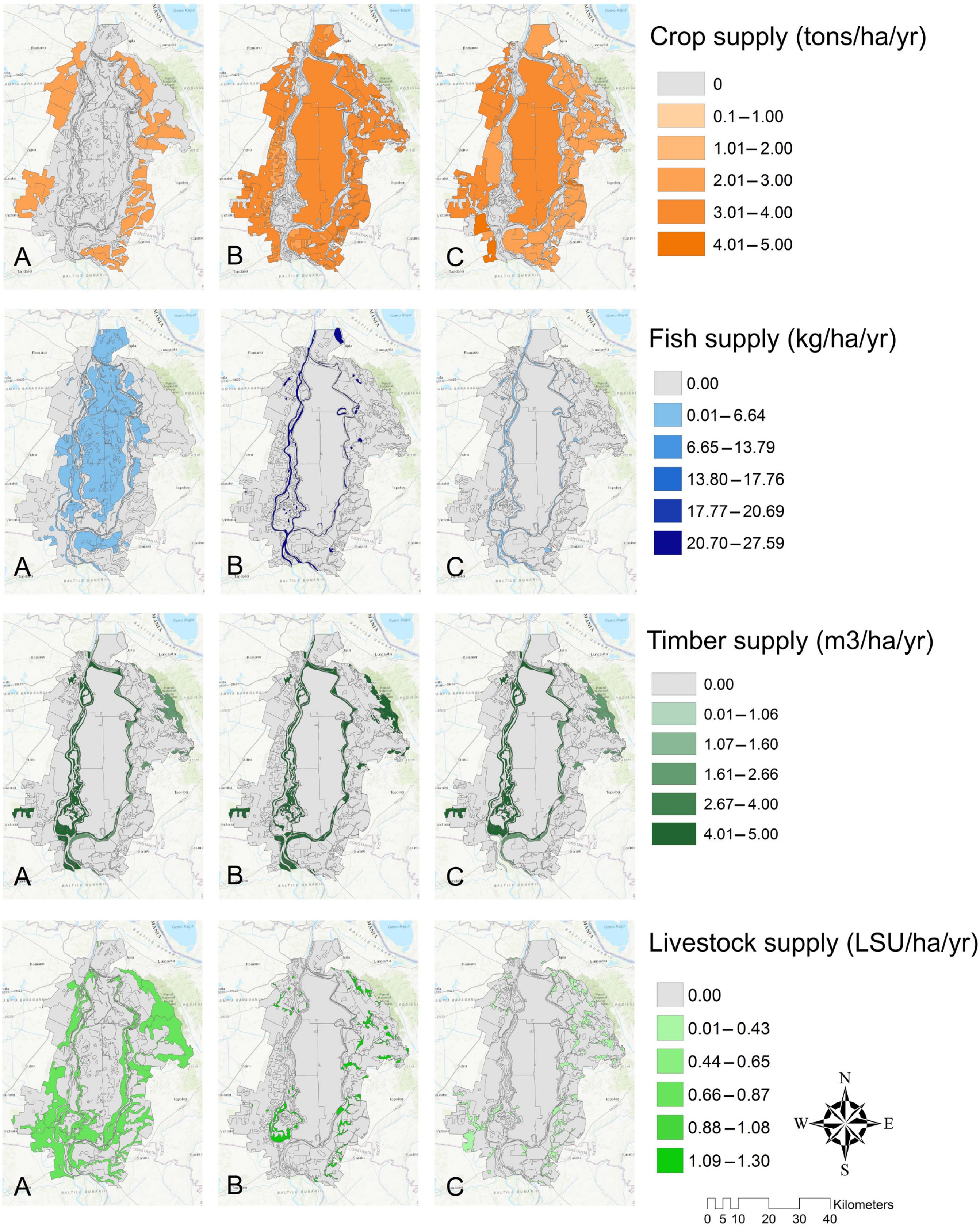

Figure 4. Spatial distribution of the provisional ES for the pre-communist (**A**), communist (**B**), and transitional and EU periods (**C**).

3. Results

3.1. Land Use and Land Cover Change

Pre-communist period (1900–1945): The land cover analysis for the pre-communist period revealed five distinct classes: inland marshes (30%), bodies of water (11%), forests and semi-natural areas (33%), agricultural land (25%), and urban areas (1%). During this period, major parts of the area mostly comprised natural, unmanaged, near-natural ecosystems (marshes, bodies of water and forests). Under a natural flooding regime, and as the area lacked anthropogenic intervention, these ecosystems were capable of providing a wide range of highly valuable ES in terms of their natural productivity levels (e.g., biomass, drinking water, fish, timber, game, and genetic resources); thus, they supported biodiversity in terms of natural processes, facilitating the existence of a large number of habitats and species [9] (Figure 3A).

Communist period (1946–1989): During the 1960s, the case study area was subject to a large-scale land expansion that increased the agricultural area from 640 km^2 to 1950 km^2 (Big Island of Brăila), and now, this represents 75% of the total case study area. This expansion took place at the expense of the survival of natural areas, including inland marshes (3%), bodies of water (5%), and forests and semi-natural areas (13%), which were dramatically reduced in size. Compared with the pre-communist period, the area occupied by the urban system increased from 37 km^2 to 104 km^2, and currently, it accounts for 4% of the total area of the case study (Figure 3B).

Transitional and EU period (1990–2017): The land cover analysis for the transitional and EU period revealed no major changes in terms of land cover classes (Figure 3C).

3.2. Human Modes of Production

Pre-communist period (1900–1945): During this period, the area was still naturally flooding, and the main provisional ES were cereal crops (2.04 t/ha), fish (0.95 kg/ha), timber (2.66 m^3/ha), and livestock (0.8 Livestock Units (LSU)/ha) (Table 2). The average values per hectare were used to map the spatial distribution of the amount of selected ES (Figure 4A). The economic value for the four selected provisional services was estimated to be 60.7 $\times$ 10^6 EUR/yr (Table 3).

Despite the fact that in the past, the study area produced impressive quantities of agricultural products (see Table 2), this incurred almost no associated costs because all the nutrients and the water were supplied by the Danube River after natural flooding occurred. The average NPPact values in the pre-communist period were 430 gC/m^2/yr in urban areas, 458 gC/m^2/yr in agricultural systems, and 187.5 gC/m^2/yr in forests and semi-natural areas. This translated into HANPP values of 242 gC/m^2/yr for agriculture, 227 gC/m^2/yr for urban areas, and 180 gC/m^2/yr for pastures (Figure 5A).

Table 2. Average values of the provisional ecological services for the Brăila Islands case study area during three periods of environmental history (n—number of samples, see Supplementary Table S1 for data source references).

Average Amount of Provisional ES	"Pre-Communist" (1900–1945) Mean ± SD	"Communist" (1946–1989) Mean ± SD	"Transitional and EU" (1990–2017) Mean ± SD
Crop (tons/ha)	2.04 ± 0.33 (n = 10)	3.68 ± 1.30 (n = 20)	4.46 ± 1.24 (n = 11)
Fish (kg/ha)	0.95 ± 1.86 (n = 5)	27.58 ± 0.99 (n = 17)	3.69 ± 1.42 (n = 6)
Timber (m^3/ha)	2.66 (estimated from literature)	4.23 ± 0.65 (n = 11)	2.77 ± 0.40 (n = 11)
Livestock (no/ha)	2.26 ± 7.52 (n = 11)	1.30 ± 0.44 (n = 19)	0.14 ± 0.03 (n = 11)

Table 3. Economic values of the selected four provisional ES in the case study area, including investment costs, for the three periods of environmental history.

	Pre-Communist (1900–1945)	Communist Period (1946–1989) (Diking Cost Accounted for)	Transitional and EU Period (1990–2017) (Diking Cost Accounted for)
Crop supply (Euro/yr)	14.8×10^6	41.0×10^6	32.0×10^6
Fish supply(Euro/yr)	0.50×10^6	1.80×10^6	0.20×10^6
Timber supply (Euro/yr)	0.80×10^6	3.20×10^6	2.00×10^6
Livestock supply (Euro/yr)	44.0×10^6	9.90×10^6	1.60×10^6
Total (Euro/yr)	60.7×10^6	55.9×10^6	35.8×10^6

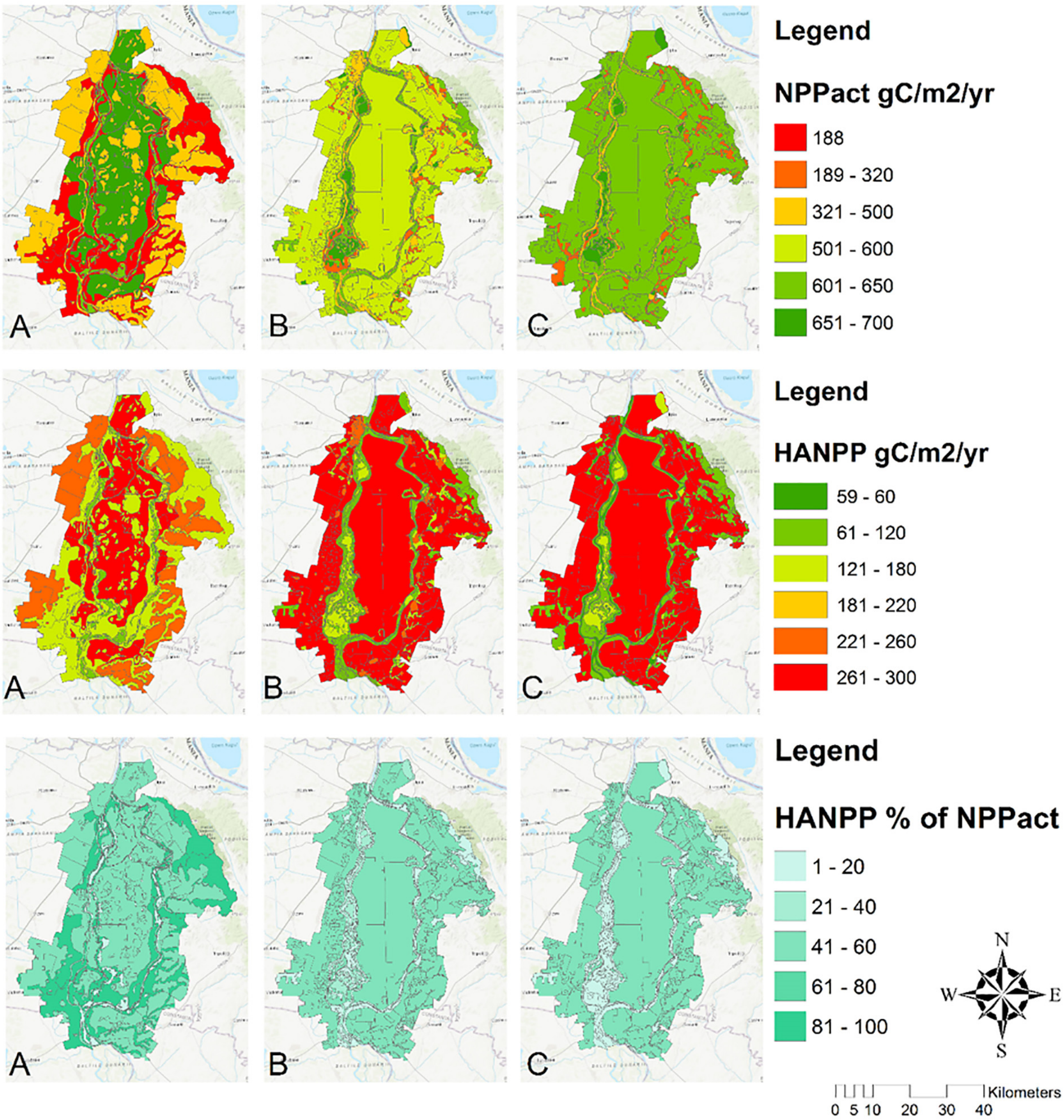

Figure 5. Spatial distribution of the HANPP indicators for the pre-communist (**A**), communist (**B**), and transitional and EU (**C**) periods.

Communist period (1946–1989): The case study area was not subject to large structural changes until the late 1960s, when it was decided that the area would be transformed into intensive agricultural and forestry systems. As a result, the amount of fish and livestock, the main provisional services in the pre-communist period, significantly declined, and thus, the provisional services provided by the Brăila Islands shifted towards crop production (Figure 6B). Agricultural intensification was based on huge investments, estimated at about EUR 900 $\times$ 10^6 for all of the Danube floodplains. Within the communist period, due to agricultural intensification and urban sprawl, the average NPPact values for urban areas, agricultural fields, and pastures were increased to 468, 503, and 291 gC/m^2/yr, respectively. This resulted in higher values of HANPP for urban areas, agricultural fields, and pastures at 242, 261, and 151 gC/m^2/yr (Figure 5A), respectively. The biggest difference was associated with the transformation from a wetland that provided multiple ecosystem services to agricultural land.

Figure 6. Quantitative assessment of the selected provisional ecosystem services and their supply dynamics.

Transitional and EU period (1990–2017): The collapse of the communist regime in 1989 led to a decrease in the average values reported for fish, timber, and livestock; however, agricultural activities produced a higher value per hectare in this third period compared with the communist period. Estimates show that compared with the pre-communist period, crop provisions increased by 5.7 times, from approximately 129 $\times$ 10^3 tons to 741 $\times$ 10^3 tons of cereals, with an average price of EUR 150/t and a calculated value of about EUR 234/ha.

During the same period, the number of fish and livestock declined significantly. The amount of fish caught decreased from 96.3 tons in the pre-communist period to 37.1 tons in the transitional and EU period. A similar trend was also observed for livestock, which decreased by 63 $\times$ 10^3 to 1.9 $\times$ 10^3 LSU per total land area, with an average price of EUR 352.2/LSU. Timber extraction increased by 2.5 times from approx. 32 $\times$ 10^3 cubic meters during the communist period, to 82.7 $\times$ 10^3 cubic meters, priced at EUR 27.78/m^3, during the transitional period. Using the data collected from national statistics, the average values of timber per hectare of land cover were calculated (Table 2). Long-term data analysis shows that provisional services underwent a transition at the Brăila Islands site (Figures 5C and 6).

The land cover composition during the current transitional and EU period is associated with the highest average values of NPPact in urban and cropland areas (632 and 626 gC/m^2/yr, respectively) compared with the previous two periods. The HANPP index for pastures decreased to gC/m^2/yr (Figure 7).

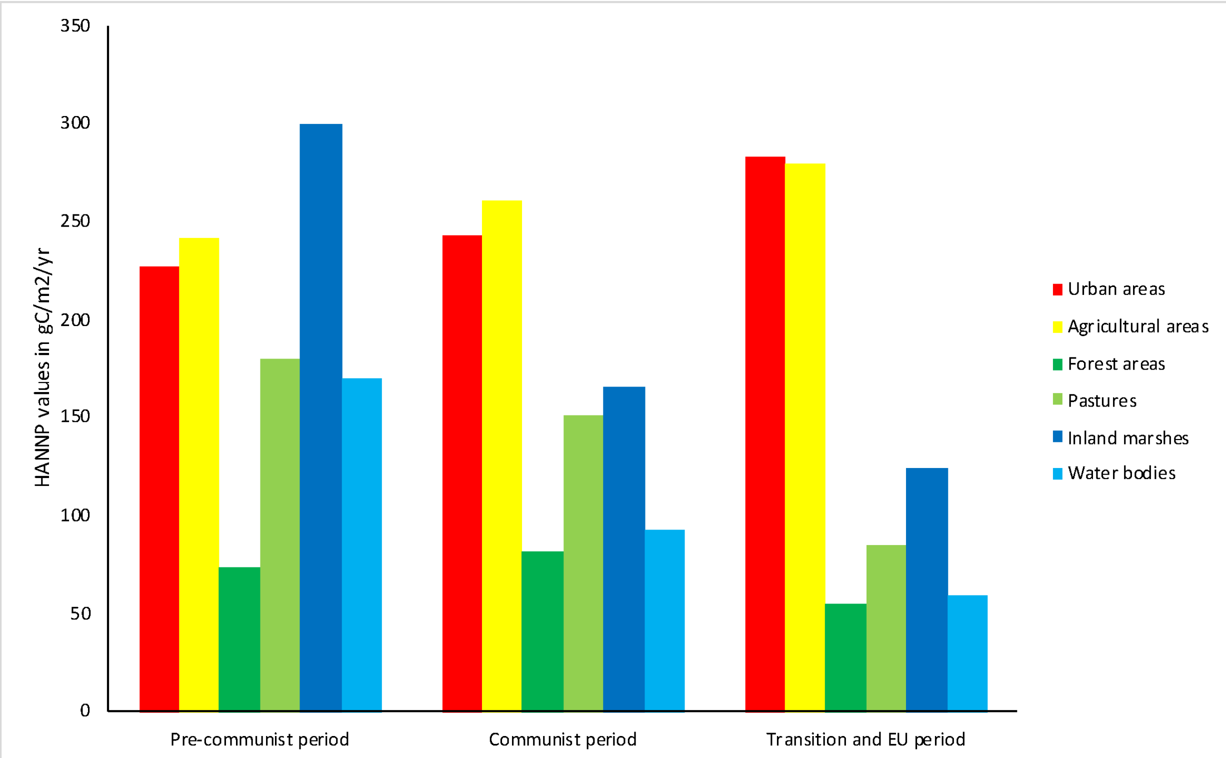

Figure 7. The HANPP values of each of the land cover classes.

By contrast, the natural forest ecosystem values of NPPact remained constant throughout the three time periods, and was estimated to be 621 gC/m^2/yr. Despite this, the HANPP values increased from 75 gC/m^2/yr in the pre-communist period to 110 gC/m^2/yr in the communist period, and they remained relatively constant moving into the transitional and EU period.

In the natural marshes of the pre-communist period, the HANPP values were estimated to be 300 gC/m^2/yr. This was followed by a reduction of almost 50% during the communist regime, at a mean value of 165 gC/m^2/yr, which reached 124 gC/m^2/yr in the current transitional and EU period. The HANPP values for bodies of water in the area ranged from 169 gC/m^2/yr in the pre-communist period, to 94 gC/m^2/yr during the communist period, to 60 gC/m^2/yr during the transitional and EU period (Figure 7).

3.3. Ideology, Perceptions, and Values

Pre-communist period (1900–1945): During this period, the comprehensive analyses of livelihoods [69] demonstrate that the provisional ES offered by the landscape structure of the Brăila Islands (fish, livestock, crops) could be directly accessed by local people [42]; thus, access to food and natural resources was decentralised. In 1921, Romania implemented one of the most important agricultural reforms; it was aimed at expropriating the larger landowners' holdings (>500 ha) so that agricultural land could be redistributed to peasants [70]. Nevertheless, the measures taken failed to increase agricultural productivity on a national level. This was due to land ownership fragmentation, the peasants' failure to form associations, a lack of investments in inventory and machinery, and the fact that the policy was more socially-oriented than monetarily-targeted [71,72]. The same problem applied to the case study area, wherein the newly implemented land reform failed to produce a modern, productive, agricultural sector.

Communist period (1946–1989): The new agricultural reform of 1949, the implementation of which had been planned from 1945 by the Communist Party, also aimed to expropriate land and distribute it to peasants for propaganda purposes while preparing for long-term mass land collectivization. From 1946, communism emerged, and Romania fell under the economic control of the USSR until the late 1950s. During this period, natural resources were exploited by mixed Soviet–Romanian companies (SovRoms) that were set up for utilitarian purposes. After the Soviet period, which can be mostly characterized by the export of goods to the USSR, came the Romanian communist era with a management regime that was mainly focused on maximizing agricultural production, in addition to other goods and services. Consequently, during the 1960s, the natural wetland ecosystems of the Lower Danube River System were subject to intensive hydrotechnical works, and most of the land was converted into agricultural land, forests, or intensive fish farms were introduced [36]. The area was transformed by the communist regime without any public consultation, and by using political detainees kept in labour camps [73].

Transitional and EU period (1990–2017): One of the main characteristics of the former communist regime was state ownership of land; however, after the collapse of communism, and during the EU's accession period, the Romanian agricultural industry transitioned so that it could participate in a free-market economy. This led to the massive restitution of land to former owners, and land was transferred from state ownership to private ownership through sales and privatization [74]. A direct consequence of this was agricultural land fragmentation; indeed, there were a large number of small farms (<5 ha) and most of them were not economically viable. After becoming a EU Member State, and after aligning with the Common Agricultural Policy (CAP), there was an increase in the number of large-scale farms emerging either through sale or lease. This new approach led to the creation of large agricultural holdings that are largely dependent on EU agricultural policy. After the collapse of communism in 1989, and during the transitional period until EU membership in 2007, biodiversity conservation became a point of concern for the academic community, the general public, and political institutions. The characteristics of each of these three periods are presented in greater detail in Table 1.

4. Discussion

4.1. Environmental History as a Form of System Analysis

4.1.1. Land Cover Change

This study clearly shows that during these three periods of environmental history, the transformation of the wetlands led to an increase in agricultural land (up to 75%), and forests and semi-natural areas, whereas marshes and bodies of water decreased dramatically (from 30% to 3%) (Figure 3). The land use changes in the Brăila Islands case study area occurred during the communist period (1960–1989), under both Soviet and Romanian authoritarian leadership. This pattern of land use intensification is spread out widely across the globe [33,75,76].

During the third time period, there was an increase in the adoption of novel land and water management policies and practices [77,78]. Since 1990, some of the factors promoting land cover change have therefore been transformed in order to prioritize biodiversity conservation; indeed, there has been a shift toward immaterial landscape values with the emergence of eco-tourism as a new industrial sector [79]. This is supported by research activities that use a transdisciplinary approach, and which encourage stakeholders to increase their involvement in biodiversity conservation.

4.1.2. Human Methods of Production Led to Net Economic Losses

Dynamic natural ecosystems and landscapes are life supporting systems that provide a wide range of regulating, cultural, and provisional services. Additionally, they maintain the ability of socio-ecological systems to develop and secure their adaptive and evolutionary potential [36]. In other words, conserving natural ecosystems, while reducing anthropogenic impact, by adopting fewer impactful human methods of production, can help increase the resilience of coupled socio-ecological systems. Biodiversity loss caused by the transformation of wetlands into agricultural systems can have a huge impact on the number of ES [80]. During the pre-communist period, the wetland areas of the Brăila Islands case study provided a wide range of goods and services that are characteristic of natural ecosystems; for instance, primary levels of productivity were accessible at higher trophic levels, thus increasing the number of genetic resources, game and wild animals, fish, the amount of freshwater, wood for use as fuel, and species diversity. In the pre-communist period, the land covers supported the provision of resources that were mainly based on natural productivity levels; these resources were "taken for granted" by decision makers and local rural communities. Fishing and animal husbandry were the main provisional services, and thus, they comprised the livelihoods and main sources of income for local communities as people were able to monetize their harvests [81]. During this period, while still in a natural ecosystem state, the case study area had the ability to conserve biodiversity and habitat quality, and it was more likely to deliver ES to the human population as a consequence of the high rate of natural processes.

A consequence of the subsequent land use intensification during the communist period was that crop production services reached a maximum value, estimated at EUR 41×10^6. This was followed by a small decline in the transitional and EU period to EUR 32×10^6 (Table 3). By supporting the development of intensive commercial fishing in the area, the communist regime caused a threefold increase in the economic value of fish, from approx. EUR 0.56×10^6 to EUR 1.7×10^6; however, the benefits of this were capitalized upon by the state, which had also replaced the sustainable fishing practices employed by local communities. Similarly, to crop production and fishing, timber extraction estimations reached the highest value during the communist regime, ranging from approx. EUR 0.90×10^6 to EUR 3.2×10^6 in the communist period, and EUR 2.3×10^6 in the transitional and EU period, respectively. In contrast, livestock provisions faced an accelerated decline, from EUR 44×10^6 to EUR 9.3×10^6 during the communist period to EUR 1.6×10^6 during the transitional and EU period with the current configuration of the ecosystem (Table 3).

Intensified land use does increase the number of agricultural and forestry-base provisional ES, but this is also dependent on additional energy inputs (fertilizers, pesticides). Heavy mechanization for crop harvesting translates into high auxiliary costs in terms of production. The total investment cost of the dykes surrounding the Big Island of Brăila covers a total length of about 175 km, and their maintenance, accounting for inflation, cost approximately EUR 889×10^6. Dividing this figure by the 47 years that passed between 1970 (when the river embankment was finished) and 2017 resulted in an average cost estimate of 18.9×10^6 EUR/yr for the dykes. Additionally, there is evidence of a direct trade-off occurring between agricultural intensification and an increase in provisional ES on the one hand, and the full range of other ES (regulations, cultural ES, and ES that supported habitats), including natural or semi-natural landscapes, on the other. Regarding the Brăila Islands case study, the landscape changes increased agricultural outputs, but at the expense of regulations and cultural ES. The existing data in the literature [9] suggest that the value of regulatory services provided by the Brăila Islands is approximately EUR 1140/hectare, whereas cultural services (recreation, fishing-based tourism) were estimated as having a value of EUR 104/hectare.

As a result, the highest total monetary value of the Brăila Islands' complex ecosystem (approx. 60.7×10^6 EUR/yr) (Table 3) was recorded during the pre-communist period. In contrast, due to the fact that increased crop production is associated with high costs for river embankments, dyke maintenance, fertilizers, machinery, renting land, purchasing seeds, and salary costs, the total economic value of the provisional services in the transitional and EU period was estimated at EUR 35.8×10^6. This means that despite huge investments and intensive land use changes, the area lost almost 41% of its value as compared with the pre-communist era.

4.1.3. Ideology, Perceptions, and Values

Politically, economically, and culturally, Romania is typical of Eastern Europe, and it is a fledgling democracy that joined the European Union in 2007. For many decades, Romania has been a country locked in a transitional state as it moved from capitalism to communism, and then back to capitalism [51]. It nevertheless retained its communist roots, which were associated with changes in social, political, and economic conditions [82], and had important consequences for the state of natural ecosystems. The trajectories of land cover change and ES portfolios are clearly related to the ideologies of the three environmental history periods studied. The transformation of the Danube Delta and the Danube floodplains is a striking example [9].

During the first pre-communist period covered in this study, we focused on how humans enhanced the natural benefits of the wetlands by building so-called "submerged dykes" that allowed the river to flood the area, but with reduced frequency [39]. Consequently, the floodplains could also be used for agriculture and animal husbandry, and they could function as flooding areas that supported natural processes such as sedimentation, nutrient retention, and carbon sequestration. With the transition to communism, however, the situation changed, and important decisions were taken that focused on industrialisation in general [83]; thus, both the Danube floodplain and the Danube Delta were completely transformed into more productive systems for agriculture, forestry, and fishing. Ceaușescu's regime (1965–1989) represented an important driver for continued intense industrial development. After the 1989 revolution, Romania began the transition towards democracy and becoming a capitalist market economy; it became a EU member in 2007.

The transition of provisional services and their associated dynamics from natural ecological productivity during the pre-communist period to market-oriented provisional services is easily explained by changes in ideology, which translated into different management regimes. Even though land was returned to its former owners from the pre-communist period, land fragmentation and abandonment occurred due to unsustainable management programs that favoured large-scale exploitation; thus, local communities found it difficult to understand and financially benefit from the value of the ES provided. Indeed, as with all European countries under Soviet influence, Romania transitioned from a capitalistic incipient market system towards communism, and then, after the changes that occurred in 1990, it slowly transitioned again towards a neoclassical economic model.

These ideological transitions had a huge impact on decision-making processes, and on the ways in which benefits were distributed to local communities. Trade-offs between 'winners and losers'—in terms of benefits—changed over time among the local population, which included prominent landowners prior to the reform of 1921, and the "people in general". This term was used during the communist period when land belonged to the state, and when only a few people who leased land from the state could receive benefits from that land. The leasing system allowed the new "owners" to benefit from very good economic conditions and keep the profits from the agricultural land to themselves; they did not have to share their profits with the local communities. Thus, local people benefited most from the harvested NPP in the pre-communist period, mainly because the distribution of the HANPP benefited local communities. Later, during the communist, transitional, and EU periods, the HANPP was no longer available to local communities; rather, it was kept and distributed by large state owned or private companies.

The emergence of intensive agriculture thus had severe consequences for the social-ecological system [9]. This included fewer benefits, a concentration of power and money in the hands of certain people, and poverty, despite huge available resources. For example, traditional fisheries are small, and have few economic opportunities and low capital intensity; nevertheless, they are vital to the Danube Delta's remaining human population [84]. Intensification also affected biodiversity through changes in land use, a reduction in wetland areas, its impact on species and communities, and in general, the system became less able to adapt to future changes [9].

Land reclamation and hydrotechnical works conducted in the Brăila Islands represent the main drivers of change that occurred in the 1960s [9]. Transformations occurred with the intention of converting the land use in order to increase the provision of goods, disregarding the ecological costs and consequences. The drainage and conversion of wetlands to highly valued agricultural and industrial areas during the communist era, as well as the transitional and EU periods, thus had direct consequences on ecosystems. The eutrophication of aquatic ecosystems, as well as erosion, hydrology alterations, biodiversity loss, a decrease in ecosystem regulating capacity, and a decrease in cultural services, occurred in both local level ecosystems, and in remote natural ecosystems downstream (Danube Delta and northwestern Black Sea coast) [85].

4.2. Social-Ecological Research Can Support Landscape Stewardship

Achieving sustainable development requires an inclusive societal process, and it could result in a sustainable and resilient relationship between human societies and the natural environment with regard to real-world landscapes; however, this process is fraught with issues [39]. The intensification of both agriculture and forestry, while disregarding biodiversity conservation in terms of maintaining ecosystem processes, habitats, and the species that inhabit them, is a good example of such an issue. Moreover, such issues are well documented in the Brăila Islands case study. River wetlands offer a particularly wide variety of benefits to society, ranging from fertile soils, freshwater resources, and biodiversity; however, they have been transformed by human interventions, are increasingly affected by the consequences of climate change, and require restoration. Addressing these issues requires knowledge of both social and ecological systems; however, usually, only one aspect of the system is examined. For example, despite a comprehensive investigation of the dynamics of the ecosystem services of the Danube wetland landscape, Gómez-Baggethun et al. [35] did not mention terms such as landscape, governance, or stewardship. Conversely, in their studies concerning the co-management of a wetland Biosphere Reserve in southern Sweden, Olsson et al. [5,86] focused on achievements in the social system, but they did not monitor the negative consequences on local wetland species [87]. Living in the anthropocene thus emphasises the need to integrate socio-economic and ecosystem research, and it needs to include both academic and non-academic participants [79] for the development of a regionally-adapted landscape stewardship that includes relevant stakeholder groups [88]. At the same time, different levels of governance call for evidence-based knowledge [89] that will facilitate the transition towards multi-functional landscapes. To encourage necessary transdisciplinary knowledge production and learning, an integrated place-based landscape approach towards research and innovation that can maintain representative ecosystems and their biodiversity (species, habitats, and processes) is urgently needed. A landscape approach should focus on both social processes and nature-based solutions using functional green infrastructures, including spatial planning, that involve key players and sectors from multiple levels of society, and scientists from all relevant disciplines [30]. Coping with trade-offs between beneficiaries is challenging, and thus, it requires locally- and regionally-adapted solutions.

The Brăila Islands form a "living laboratory" wherein transdisciplinary research has been applied to provide the necessary results for developing sustainable strategies at the local level, and to provide arguments for developing such strategies at regional levels. A network of place-based transdisciplinary clusters for knowledge production and learning can be helpful. The Brăila Islands case study is part of such a network, namely, the Long-Term Socio-Ecological Research (LTSER) platform [30,90–92]; however, Holzer et al. [79] observed that management, interdisciplinary integration, and stakeholder collaboration on LTSER platforms have proven to be challenging. Moreover, Holzer et al. [79] found that despite having all the components of transdisciplinary SES research, regarding the Brăila Island LTSER platform, there was "… *no overarching strategy to link long-term planning and funding, knowledge integration, and priority-setting with stakeholders to ensure the relevance of research for policy and practice*."

Ensuring collaborative knowledge production and learning, and the production of a landscape stewardship that acknowledges multi-functional landscapes with a broad portfolio of ecosystem services, is not made easier by the fact that the ideological legacies of previous decision-makers ignore the needs of the local population [93]. Romania is a post-communist society; authoritarianism is still strongly related to support for communism, and both authoritarianism and traditional forms of religiosity are key characteristics of the Romanian ideology [82]. Industrialization was viewed as the only way to achieve emancipation from underdevelopment and subjection to Western powers [83]. This process was also based on biased scientific knowledge; only the production capacity of the ecosystems was taken into consideration, and other ES were neglected. This means that there is no precedent for public consultations, nor dialogues with poorly empowered local communities [9]. Van Assche et al. [93] argued that unless other institutions are worked upon, direct participation by citizens would not solve the observed problems, but rather, it would reinforce unwanted informal institutions.

We propose that there are two ways in which to cope with these challenges. First, it is important to understand what the composition, structure, and function of the once multi-functional landscapes were like, it is important to secure a societal memory of such landscapes, and it is necessary to learn how to maintain them. Another avenue is to identify leverage points for sustainability (https://leveragepoints.org, accessed on 1 February 2023). Abson et al. (2017) [94] proposed three realms of leverage, which include re-connecting people with nature, re-structuring institutions, and re-thinking how knowledge is produced. A key challenge, however, is that ingrained systemic characteristics such as power, mindset, and rule-setting in SES constrain the types of interventions possible when weaker forms of leverage are used, such as mechanistic aspects of landscapes which are typically targeted by policy makers.

5. Conclusions

Prior to the communist period, the Brăila Islands' natural wetlands provided a wide range of ES, including a primary production level that enables access to higher trophic levels, genetic resources, game and wild animals, fish, and wood. Subsequent ideologically driven wetland transformations, and hydrotechnical works carried out in the Brăila Islands case study area, comprised the main cause of the transformation of the socio-ecological system in this area. These steps were taken with the intention of converting the land use in order to increase the provisional services obtained from the area, disregarding (or not being aware of) the ecological costs and the impact of socio-economic consequences on the livelihoods of local communities. The increasing level of pressure from highly anthropogenic and energy dependent systems led to a reduction in other ES, such as the support for biodiversity, regulating capacities, and cultural values.

Taking into account the wetland drainage costs and annual maintenance costs, the final estimated total economic value of the Brăila Islands case study area was significantly lower in its current configuration, as compared with its natural ecosystem state. Additionally, accounting for both the benefits of provisional services, and the significant costs of land reclamation, hydro-technical works, and high additional inputs for agriculture (fertilizers, pesticides), the value of the area resulted in a net loss.

The transformation from a complex wetland landscape that provided multiple ecosystem services, and which had numerous habitats and species, into agricultural land was realised by a particular group of people with a specific ideology, but without a deep understanding of the wetland ecosystem and traditional knowledge of the area. The Brăila Islands case study illustrates the mechanisms that made this transformation possible. Powerful societal structures did not rely on evidence-based knowledge, but on ideologies and beliefs; thus, management, interdisciplinary integration, and stakeholder collaboration in a landscape approach initiative such as the Brăila Islands LTSER platform is challenging. Environmental history can improve our understanding of the types of knowledge, institutions, and processes needed to enhance the resilience of socio-ecological systems.

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