MAPPING ECOSYSTEM SERVICES SUPPLY: CHALLENGES AND OPPORTUNITIES IN THE GEO-SPATIAL ANALYSIS

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Abstract
Ecosystem structure and functions provide significant values to the social well-being and human health. The integration of the ecosystem services concept tailor's multiple challenges and opportunities to the investigation processes simultaneously in the scientific approaches andin the environmental management initiatives. In this paper, the focus is defined by some of the main research questions related to the scale in terms of localization of the service production areas and service benefit areas. The spatial identification and analyses of these units has been delineated by the landscape characteristics in the lower Ogosta (Augusta) River watershed (North-western Bulgaria). The geo-spatial methods allow to model a set of opportunities that arise from the empirical analysis associated to the ecosystem services provision and quantitative assessment. The results support the perspectives for integration of the GIS analysis as decision support and management tool in the context of socio-ecological perspectives when economic valuation is transferred at watershed and/or landscape scale.

Keywords*: ecosystem services, landscape, geo-spatial analysis, mappin, service providing areas*

INTRODUCTION

The integration of the ecosystem services (ES) concept into the scientific and practical domain requires the application of a systematic approach in the landscape investigation. The key importance of the landscape pattern is highlighted by the numerous functions, defining the provision of ecosystem stocks and services for the human wellbeing. The ecosystem functions become services only when there are people who can benefit of (Fisher, Turner, & Morling, 2009; Kenter et al., 2015). The natural capacity for the provision of services depends on the manner the different ecological processes develop, on the structure and on the functions of the ecosystem environment (Burkhard, Kroll, Nedkov, & Müller, 2012; García-Nieto, García-Llorente, Iniesta-Arandia, & Martín-López, 2013; Müller, de Groot, & Willemen, 2010).

In the recent decades, as pressure on natural resources and land increases, the higher becomes the demand of proper organization and management of resource delivery and share between the beneficiaries. This requires better understanding on the spatial and temporal patterns of resources as well as on the spatial and temporal processes governing their availability (Burrough, McDonnell, McDonnell, & Lloyd, 2015). Since the mid-centuries, systematic mapping of the land has been having high values on governmental level where the need of land organization led to the production of cadastral and topographical maps of settlements, regions, and for whole countries. Maps are perceptible product and as such they have significant impact in both scientific and practical contexts to support the decision making process on environmental issues.

The present researche is focused on the complex ecosystem interactions and on the relationship human-environment over time require the use of different geo-spatial tools and models. Whereas there is a constant growth of the possibilities of qualitative data integration (e.g. expert knowledge, demographic surveys, social polls, cost-benefit analysis), the spatial identification and delineation of the unit providing ecosystem services remains still a challenging topic. On the other hand, the opportunities of integration of the GIS analysis to the collaborative landscape planning initiatives necessitates precise physical definition of the service providing units – SPUs. In this context one of the main research questions would be whether the ES supply area matches the ES benefitting area (Burkhard, Kandziora, Hou, & Müller, 2014; Burkhard, Kroll, & Müller, 2009; García-Nieto et al., 2013). Not at the least important, the data availability and visualization of the results remains still challenging where scarce data and unsufficient information meets such investigation criterias.

In this paper, we present a methodological approach for spatial analysis and ecosystem services mapping based on biophysical indicators. Some of the main research questions related to the proper development of that approach appeared during the development of the author's dissertation thesis *"Ecosystem and landscape services in the Danube Plain between rivers Timok and Iskur"*. The goal of this paper is briefly to outline the practical challenges that arise from the different interpretations of the ecosystem services analysis regarding the spatially and temporally explicit settings presented with a case study in the lower Ogosta (Augusta) River watershed in the Danube plain (North-western Bulgaria).

THE CONCEPT OF SPACE, TIME, AND SCALE

The need of identification and quantification of the natural resources brings the ecosystem services concept in the scientific and environmental policy activities. When mapping ecosystem services, it is extremely important to locate them and to delineate their provision area. In this paper we define the landscape unit "level 1" as a service providing unit that could be a subject of analysis and assessment of the natural potential to provide services to the social wellbeing. However, if the capacity of a SPU changes over time, and the social preferences for the particular services stays, it is anticipated that this area will not be able to fulfill anymore the demands for ES provision, i. e. the supply of the service will be affected. We use the following landscape character classification system (Fig. 1) where each taxon defines the importance of the landscape components (Zhelezov & Iliev, 2003) and reveals the spatial liaison and level of subordination between the landscape units, forming the landscape complex (Yaneva & Zhelezov, 2016).

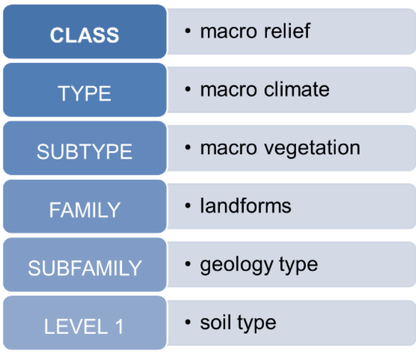

Figure 18 Typology levels and diagnostic criteria

The landscape presents a dynamic system where the provision of ecosystem services could be observed as a variable, defined by different social and physical parameters. The spatial configuration of the landscape elements has a leading role for the application of the ES concept. The Millennium ecosystem services assessment (MEA, 2005) highlights the services and their beneficiaries pinpointing the multifunctional character of the services contributing to the human wellbeing. Despite the widespread recognition of the services as "benefits obtained by nature", in spatial aspect the definition of services within the landscape unit can have better practical application. Environmental management could be efficiently applied to the local and regional planning initiatives by considering space as a structure of homogeneously aggregated zones. In such context the area divided into patches can be analysed and modelled more effectively than administrating a complex system as a whole (Blaschke, 2006). Because of the physically defined limits, the landscape approach asserts its applicability in the environmental practices (Bastian, Grunewald, Syrbe, Walz, & Wende, 2014; Potschin & Haines-Young, 2013).

Concerning the spatial supply and demand aspects, maps represent the temporal dynamics of the services provision depending on naturally or antropogenically driven activities over time. The changes in the land use, land management and conservation may cause disturbances that reflect to the landscape configuration. When dealing with the temporal characteristics it is important to refer them to whether trends can be measured and mapped over time and accurately presented via GIS analysis. Maps can tackle multiple hypothesis and serve as a communication tool enhacing the future understanding of the potential scenarios in the human-environmental dynamics. The commonly used selection criterias for indicators refer to measurability, sensitivity to changes, temporarily and spatially explicit and scalable (Van Oudenhoven, Petz, Alkemade, Hein, & De Groot, 2012). However, some present mapping methods select indicators that are not reliant on multi-dimensional spatial and temporal aspects and the sustainable thresholds to keep the ecosystem functioning (Maes et al., 2012). There are ecosystem services indicators that could be collected from data without any sustainability spatio-temporal resolution criteria for service definition. Such indicators could be the quantitative data based on timber and fibres biomass that do not concider the sustainable potential of the ecosystem to fulfill the maximum of the service delivery.

Scale is used ambiguously in landscape ecology and often brings different aspects of space and time. According to the objectives of the landscape planning an exact use of the terminology and definitions is needed. Lavers & Haines-Young (1993) outline landscape scale as the one that "considers the pattern and interaction between the various mosaic elements of patch, edge and corridor". One of the main challenges when mapping ecosystem services across multiple scales is the data availability for bigger scale. Spatial scale mismatch for a service is a commonly intriguing research question that needs to consider weather the services supply is on local scale and the demand is on regional scale (Blaschke, 2006; García-Nieto et al., 2013). For instance, forest ecosystems have a huge impact on the carbon sequestration, provision of timber, and habitat connectivity, etc. of a region. Extrapolated to a larger scale, the question is whether the ecosystem functioning and landscape configuration have the same effect on global scale. The ecosystem service assessment is based on indicator mapping and leads to spatial representation of the service providing units (SPUs) and the service benefiting areas (SBAs). Models and maps should match not only the scales of the geobiophysical supply origin, flow and demand units but also the scales of administrative units for better integration to the scientific, political and practical domain (Burkhard, Crossman, Nedkov, Petz, & Alkemade, 2013; Burkhard et al., 2014).

MATERALS AND METHODS

Study area and selection of services

The study area covers the lower Ogosta River watershed located in the Danube plain, North-western Bulgaria (Fig. 2). The investigated territory encompasses part of the Danube floodplain - an area exposed to high natural and technological hazards (Dobrev et al., 2013; Kotcev et al., 2013, Nikolova & Nedkov, 2013). In demographic terms the study area is characterized by rapid depopulation rates and the regional GDP per inhabitant is calculated to 30% for 2014 (EUROSTAT[4]).

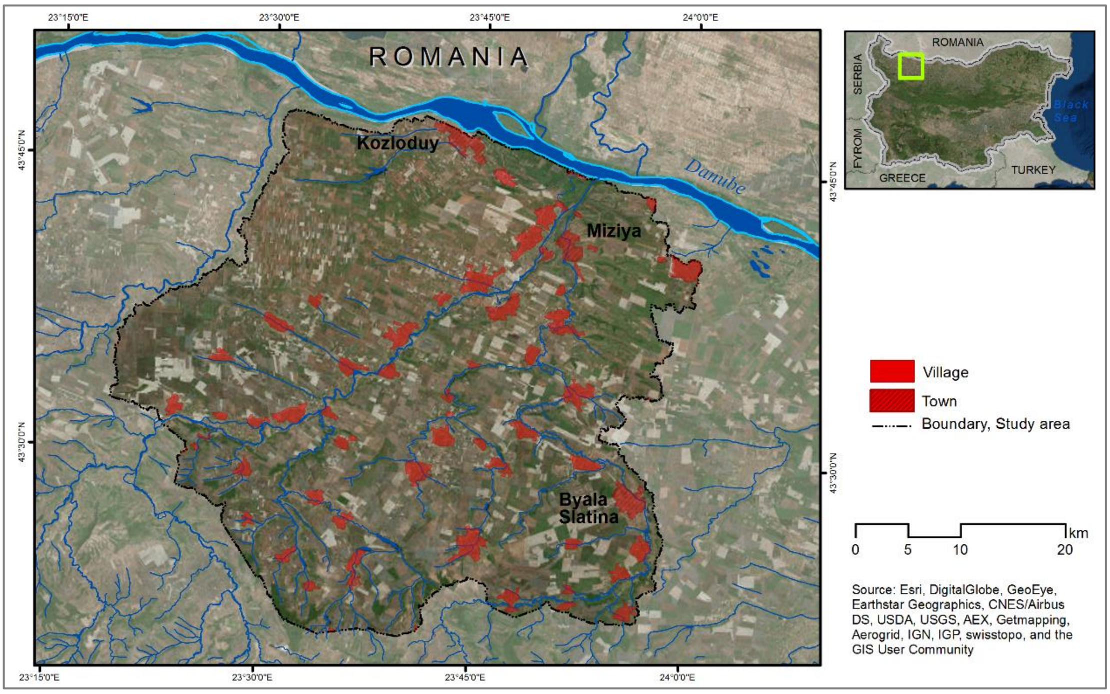

Figure 19 Map of the lower Ogosta watershed, North-Western Bulgaria

In the recent decades, the industrialization of the region and the intense agricultural activities have assimilated most of the natural vegetation. Nowadays major part of the watershed territory is covered by croplands and non-irrigated arable land and remnant patches of natural flora are predominantly dispersed throughout the river valleys. Deforestation processes reflect directly to transformations in the biophysical and ecological properties that highlight the vegetation as an important resource and main factor for the ecosystem functioning processes.

[4] Regional gross domestic product (PPS per inhabitant in % of the EU28 average) by NUTS 2 regions: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&pcode=tgs00006&language=en

The ecosystem services delivered by the natural vegetation within the watershed have been recognized in relation to the biomass production and mediation by biota in forest areas. The selected indicators, corresponding to the services definition, are derived by biophysical data collected through field work analysis. These indicators refer to the final ecosystem services in the *Common International Classification of Ecosystem Services* (CICES V 4.3[5]) where "final" denotes the directly enjoyed, consumed or used components of nature (Boyd & Banzhaf, 2007). The selected services that will be mapped are timber for direct use or processing, bio-remediation by plants, and filtration/sequestration/storage/accumulation by plants (Tabl. 1).

Table 2 Ecosystem services identified by the selected indicators in CICES V 4.3

SECTION	DIVISION	GROUP	CLASS
PROVISIONING	MATERIALS	BIOMASS	Timber for direct use or processing
REGULATION & MAINTENANCE	MEDIATION OF WASTE, TOXICS AND OTHER NUISANCES	MEDIATION BY BIOTA	Bio-remediation by plants
			Filtration/sequestration/storage/accumulation by plants

Mapping the supply of ecosystem services

The EU Habitats Directive[6] and the EU Water Framework Directive[7] both integrate the space-time characteristics of the natural systems regarding the environmental management and conservation efforts. The emphasis is placed on the ecosystem services flows through different landscape types and on the spatial distribution of the services to the final beneficiaries (Fig. 3). Fisher et al. (2009) suggests a classification scheme that should include the following categories:

- In-situ – where the place of services provision and the benefits are realized at the same location
- Omni-directional — where the services are provided in one location, but benefit the surrounding landscape
- Directional — where the service provision benefits a specific location due to the flow direction.

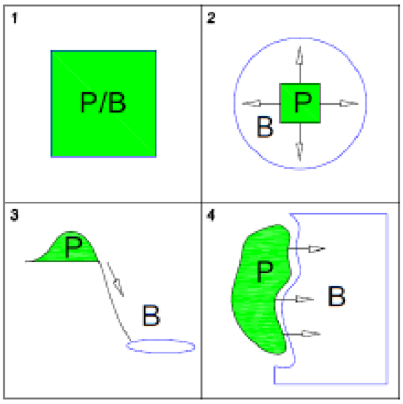

Figure 20 Possible spatial relationships between service production areas (P) and service benefit areas (B). In panel 1 the service provision and benefit occur at the same location. In panel 2 the service is distributed to the beneficiaries at different locations in the surrounding landscape. Panels 3 and 4, the generated services have specific directional benefits (by Fisher et al., 2009).

Mapping and modelling of the ecosystem functions gives the opportunity to reveal the spatial heterogeneity in the quantity and quality of the provides ecosystem services. Empirical analysis on landscape functions and landscape properties can be used as spatial indicator selection and quantification method (de Groot, Alkemade, Braat, Hein, & Willemen, 2010). The selection of quantitative indicators and their integration in the mapping process uncovers the actual ecosystem service supply and the biodiversity status (Burkhard et al., 2013). Each system is characterized with a

[5] Common International Classification of Ecosystem Services V 4.3: http://cices.eu/
[6] The Habitats Directive: http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm
[7] The EU Water Framework Directive: http://ec.europa.eu/environment/water/water-framework/index_en.html

specific potential to deliver services according to its functioning. The naturally defined supply of and the socially defined demand for these services are the factors which turn them into “benefits for the human well-being”. The concept of the sustainable landscape management brings to the front long term stability/resilience and the achievement of a stable equilibrium by slowly varying biophysical parameters and fast changing anthropogenic-driven disturbances (Blaschke, 2006; Botequilha Leitão & Ahern, 2002; Walker, Holling, Carpenter, & Kinzig, 2004).

As a referent spatial base for the ES mapping an extract from the *Landscape character map of the Danube Plain between rivers Timok and Iskur*, developed in the author’s dissertation thesis has been used (Fig. 4). The values of the biomass quantities have been associated to the landscape unit “level 1” and later aggregated to 6-point Likert scale (0-5). This classification method is based on the assumption that the interval between the values is expected to be equal and each interval has values. The maps visualize the landscape units with high and low supply capacity of the ecosystem services in the case study. In addition, the GIS analysis provides a spatial database of information that could support the decision making processes and could present a high level of integration and achievement.

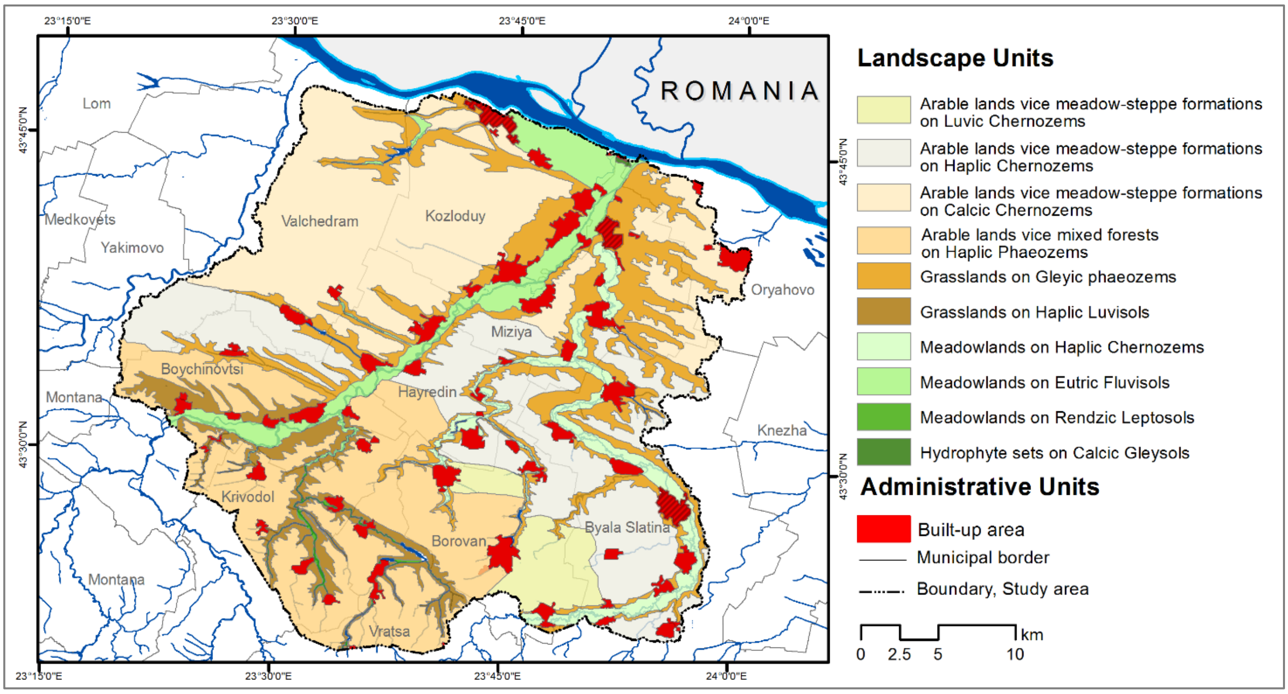

Figure 21 Landscape character map of the lower Ogosta watershed, North-western Bulgaria

RESULTS

As discussed above, landscape heterogrnity changes over space and time. Based on the structure and processes, the ecosystems functions have different capacity to supply particular ecosystem service. The generated maps reveal the high capacities of the more natural landscape patterns. The more human induced the landscape is, the lower is the supply of the service and the capacity to support ecological integrity. By linking the biophysical information to 0-5 values in GIS, estimates of ecosystem services supply can be mapped in spatially explicit unis (Burkhard et al., 2012). The values of the indicators for the selected ecosystem services in the study area are shown in Tabl. 2.

Table 3 Ecosystem services and estimated values of the service indicators

ECOSYSTEM SERVICES	***Timber for direct use or processing***	***Bio-remediation by plants***	***Filtration/sequestration/storage/accumulation by plants***
class	**t/ha**	**t/ha**	**t/ha**
0	0 – 2.68	0 – 2.72	0 – 2.72
1	2.69 – 5.37	2.73 – 5.45	2.73 – 5.45
2	5.37 – 8.06	5.46 – 8. 18	5.46 – 8. 18

3	8.06 – 10.74	8.19 – 10.91	8.19 – 10.91
4	10.75 – 13.43	10.91 – 13.25	10.91 – 13.25
5	13.43 – 16.12	14.53 – 16.37	14.53 – 16.37

For the provision of the service *timber for direct use or processing* (Fig. 5) landscapes of flat meadow-steppe, steppe, and forest formations present the highest supply capacity. Because of its topography and hydrological peculiarities, these landscapes do not provide favorable conditions for development of agricultural activities and forest areas are developed following the increase of the elevation to the periphery of the Danube plain. Indicators fot the ecosystem service is the predominant vegetation type of *Quercus cerris* (oak tree) and the estimated quantity of dry matter [t/ha]. The estimated quantities are arranged in the scale 0-5 and linked to the landscape units. As mentioned in the previous sections, this service is not conditional on the spatio-temporal resolution criteria and both the service provision and benefit area share the same location.

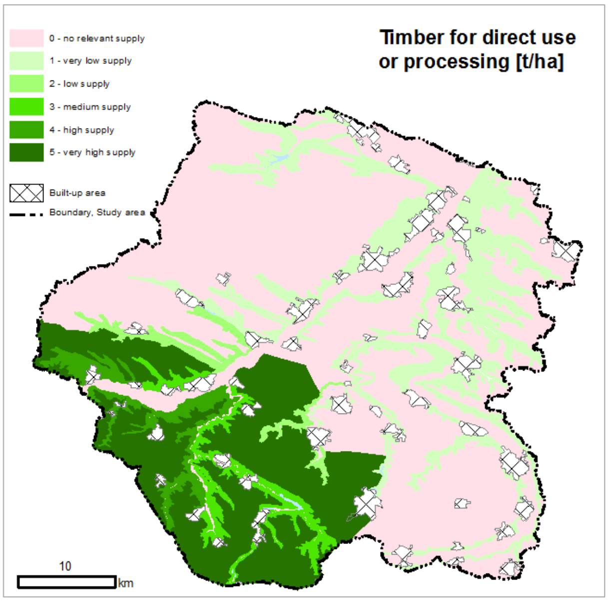

Figure 22 Supply map of timber for direct use or processing

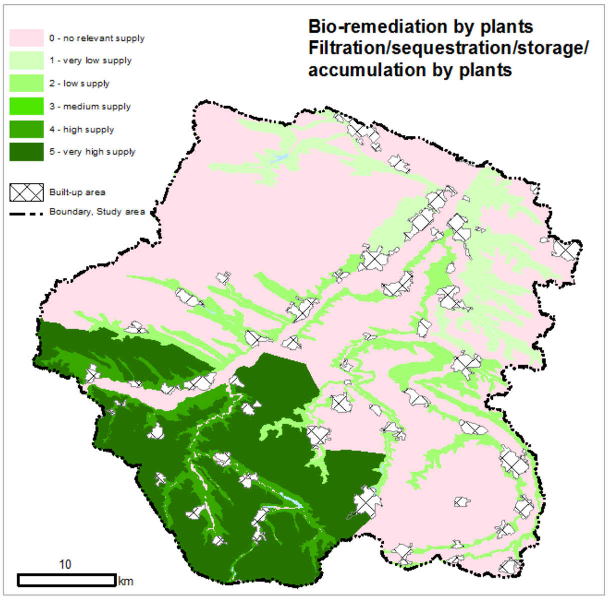

Figure 23 Supply map of Bio-remediation by plants and Filtration/sequestration/storage/accumulation by plants

The regulating ecosystem services *bio-remediation by plants* and *filtration/sequestration/storage/accumulation by plants* are defined according to the total biomass quantity of the vegetation. The provision of both of the services is characterized by the same indicators therefore the values in Tabl. 2 are the same. The map on Fig. 6 illustrates the higher supply capacity of the SPUs on territories with lacking or less intensively developed agricultural activities. There is an omni-directional relationship between service production areas and service benefit areas. The units with hydrophyte meadow and forest formations demonstrate the highest potential to supply the particular ecosystem services. Major part of the landscapes within the study area are intensively antropogenic modified and the land cover is presented by non-irrigated arable lands. Therefore, these areas are not a subject of study and are not concerned during the field work analysis.

DISCUSSIONS

As the investigation and knowledge about the human-environmental relationship goes further, the need of interdisciplinary analysis and better geo-spatial interpretation of the results grows. Nevertheless, the challenges facing the analysis of ecosystem services remain. Van Oudenhoven et al. (2012) summarize them in: (1) the identication of comprehensive indicators to measure the capacity of ecosystems to provide services; (2) the dealing the complex dynamics between land management and ecosystem services provision; (3) the quantification and modelling of the provision of ecosystem services by linking ecological processes with ecosystem services; and (4) the accounting for the multiple spatial and temporal scales of ecological processes and ecosystem services provision. The spatial synthesis of the landscape characteristics allows the delineation of landscape units at the smallest scale on taxonomy “level 1”. At this spatially explicit landscape base the capacity of each unit to supply ecosystem services has been defined and the ecosystem services have been quantified by biophysical parameters.

In the context of natural and anthropogenic systems the integration of social component to the geo-spatial analysis affects the productivity capacity of the landscape unit, since ecosystem functions are directly dependent on land cover and land use. Associated statistical data can also improve the interpretation of the maps. The proximity of the users of these services to the place of their generation has prominent importance for the ecosystem flows of services. Their differentiation reveals the spatial relationship between the locations of services generation and the places where services are consumed by humans. Ecosystem functions are assessed via quantitative parameters and are displayed in maps presenting the supply capacity of each landscape unit to provide ecosystem services. In addition, the created maps could contribute to the spatial representation of the relationship between possible actions for environmental management and the supply/demand aspects for ecosystem services depending on the scale of planning.

CONCLUSION

The achievement of better results and fostering the recognition of the potential of the ecosystem services approach for environmental management needs an integrated approach. It is crucially important to select suitable indicators, appropriate temporal and spatial scales and physically defined system borders. Regarding the vegetation component, for the lower Ogosta watershed intensive agricultural activities and vast croplands have negative impact on the regulating ecosystem services in terms of mediation by the biota. Maps illustrate the temporal dynamics of the spatial supply distributions in the case study area using the example of *timber for direct use or processing*, *bio-remediation by plants* and *filtration/sequestration/storage/accumulation by plants* ecosystem services. The mapping approach and the geo-spatial analysis could help to represent quantitatively and qualitatively the interactions between landscape management, ecological processes and the provision of ecosystem services. Therefore, a better understanding of the opportunities and the challenges in the geo-spatial analysis in the evaluation processes of ecosystem services could further develop the communication platform and implementation of the concept to the environmental management.

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