BOOK OF ABSTRACTS

I.   SESSION DESCRIPTION

II.   SESSION PROGRAM

III.   ABSTRACTS

I.   SESSION DESCRIPTION

ID: T5

Integrated models and ecosystem services – application in real world case studies

Hosts:

	Title	Name	Organisation	E-mail
Host:	Dr. Ing.	Kremena Burkhard	Leibniz University Hannover, Institute of Environmental Planning	burkhard@umwelt.uni-hannover.de
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Abstract:

The main question of this session is: are integrated ecosystem services models appropriate for different stakeholders and end-user needs? In the 2018 and 2019 ESP sessions we discussed different aspects and dimensions of integrated modelling, including integration in

terms of space and time, multiple ecosystem services, multiple DPSIR aspects and stakeholder participation, as well as how integration affects quantification and propagation of uncertainties. In order to be effective, integrated models should be not only scientifically credible and targeted towards different stakeholder needs but should also be understandable and usable in practice. This session focuses on improving understanding of actual applications of integrated ecosystem service models to real-world case studies, and the lessons that can be learnt from such case studies. This includes co-production of models, good and bad practice examples, barriers and bridges, the importance of transparency in model assumptions and integration components, communication with stakeholders, and evidence of integrated models actually resulting in a policy or management decision. The session will also consider the role of transdisciplinarity and model integration in such real-world applications, and key feedback from stakeholders and policy-makers. We would like to discuss examples of what went well and what didn't, exchange experiences and their implications for researchers interested in further developing and applying integrated ES modelling approaches.

We invite speakers to present advancements in integrated ecosystem service modelling in relation to:

- Application of ecosystem service models in real world case studies with stakeholders;
- Feedback from end-users;
- The balance of scientific credibility, saliency and legitimacy within integrated model development and application;
- Good and bad practices in the co-production of integrated models;
- Evidence on how integrated modelling approaches have informed robust policy-making on ecosystem services and sustainable development.

Goals and objectives of the session:

This session is organized by ESP's Thematic Working Group on Modelling ES (TWG5) and has two main goals:

1. to showcase recent advancements and developments in applications of integrated models by the European ES community;
2. to initiate a discussion on how to proceed in the development of integrated ES models in real world cases.

Planned output / Deliverables:

This session will be used to further develop collaboration and a research agenda within the Thematic Working Group on Modelling ES.

Related to ESP Working Group/National Network:

Thematic Working Group: TWG 5- Modelling ES

II.   SESSION PROGRAM

Date of session: Wednesday, 9 June 2021
Time of session: 13:30 – 17:30

Timetable speakers

Time	First name	Surname	Organization	Title of presentation
13:30 13:40	Kremena	Burkhard	Leibniz University Hannover, Institute of Environmental Planning	Welcoming and update on ESP TWG5 Modelling ES Activities
13:40 13:53	Vilém	Pechanec	Palacky University Olomouc	Integrated modelling and evaluation of the landscape, the state of biodiversity and ecosystem services for the needs of landscaping
13:53 14:06	Paula	Harrison	UK Centre for Ecology & Hydrology	Co-design of an integrated ecosystem service model to inform agricultural and environmental policy in Wales
14:06 14:19	Alba	Marquez-Torres	Basque Centre for Climate Change	How 198 models of pastureland management can be accessible, interoperable and user friendly
14:19 14:32	Benjamin	Black	Swiss Federal Institute of Technology	Ex-ante identification of policy interventions to secure a functioning ecological infrastructure: A participatory Bayesian Network approach in Switzerland
14:32 14:45	Kremena	Burkhard	Technische Universität Braunschweig & Leibniz University Hannover	How can climate change impact modelling and uncertainty analysis actually inform decision-making and support adaptation to change? An example of land use adaptation at the German North Sea coast
14:45 15:00				Discussion
15:30 15:43	Marie Anne Eurie	Forio	Ghent University	Bayesian Belief Network models as trade-off tools of ecosystem services in the Guayas River Basin in Ecuador
15:43 15:56	Adrián	Pascual	Arizona State University	Valuation of land-water ecosystem services and invasive species when using Pareto Frontiers: a showcase in Hawai'i Island, USA

Time	First name	Surname	Organization	Title of presentation
15:56 16:09	Brigite	Botequim	University of Lisbon	Tree species composition and understory coverage as drivers of habitat diversity - An innovative approach for an optimized landscape biodiversity assessment
16:09 16:22	Maria	Felipe-Lucia	German Center for Integrative Biodiversity Research	Incorporating ecosystem services to social-ecological networks: gap or redundancy?
16:22 16:35	Malte	Hinsch	University of Hannover	Influence and dependence on input data for the modelling of pollinator habitat suitability with "ESTIMAP" and "InVEST"
16:35 16:48	E. Seda	Arslan	Süleyman Demirel University	A GIS Based Approach for Predicting Recreational Ecosystem Services Hotspots
16:48 17:01	Thea	Wübbelmann	Climate Service Center Germany, Helmholtz-Zentrum Geesthacht	Urban flood regulation Ecosystem Services under climate change – A modelling approach for heavy precipitation events
17:01 17:14	Lea	Tardieu	TETIS, INRAE	Moving beyond soil sealing evaluation in urban planning with ecosystem services quantification
17:14 17:29				Discussion
17:29 17:30				Close session

III.   ABSTRACTS

Abstracts are ordered based on the session program. The first author is the presenting author unless indicated otherwise.

1. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Integrated modelling and evaluation of the landscape, the state of biodiversity and ecosystem services for the needs of landscaping

First author: Vilém Pechanec

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Biodiversity in the landscape scale is directly reflected in the provision of ecosystem functions and services, as well as in the internal mechanisms of ecological stability and self-regulation. Due to its complexity, it should be conceived comprehensively by an integrated approach and at suitable spatial scale. An integrated approach in our view consists in the analysis and calculation of several indicators in one environment, from the same data sources and at the same time. The integrated tool IMALBES includes the use of 12 specific models with their own knowledge database, working with landscape diversity in habitat detail (scale 1: 10,000). One of the specific case studies of the deployment of the IMALBES integrated tool is the planning of adaptation measures to climate change with a focus on the water regime in the forest-agricultural landscape in the cadaster of the Černovice town (of a total area of 36 km2), located on the border of southern Bohemia and the Bohemian-Moravian Highlands. The tool was used to assess the status and change of water conditions and their impact on biodiversity, the performance of ecosystem functions (production, evapotranspiration, water retention), the provision of ecosystem services, and ecological stability of the urban area. The application of this tool in a real environment has its risks and benefits. Obstacles include the difficult explanation of the principles of individual models to end-users and local residents' distrust of the accuracy and updating of input data. On the contrary, the outputs in the form of digital maps on the basis of textured 3D terrain models and "Swipe images" function met with a positive response. City officials appreciated the scale of the outputs (1: 10,000), which is the basic scale for all spatial planning documentation in the Czech Republic and can be used directly in planning documents.

Keywords: integrated modelling, biodiversity, ecosystem functions/services, water resource stabilization, application for the municipality

2. Type of submission: Abstract

Co-design of an integrated ecosystem service model to inform agricultural and environmental policy in Wales

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Welsh Government is responsible for making and implementing policies and laws in many areas that affect natural resources and how they underpin significant economic sectors including agriculture, forestry, health and well-being. They also recognise that policy effects in one sector may have indirect effects in other sectors. Hence, in order to provide assistance to decision-makers across a wide range of policy portfolios, Welsh Government commissioned the Environment and Rural Affairs Monitoring and Modelling Programme (ERAMMP) and within it the ERAMMP Integrated Modelling Platform (IMP) to enable rapid exploration of the effects of policy and management interventions on farm viability, land use change and ecosystem services in Wales. The IMP takes an integrated approach to allow assessment of potential unintended consequences of policy interventions and appraisal of potential trade-offs and synergies between ecosystem services. To do this, it has been constructed as a chain of specialised models covering agriculture, forestry, land use allocation decisions, water, air, soils, biodiversity, ecosystem services and their valuation. The models pass data between them representing different biophysical and socio-economic interactions between sectors. The IMP is designated as a "business critical" modelling tool with Welsh Government and hence is co-designed with policy teams following HM Treasury's Aqua book guidance for producing quality analysis for government. This attributes roles and responsibilities for ensuring quality assurance, rigour, transparency and appropriate treatment of uncertainty in all stages of the analytical cycle. This presentation will describe the co-design and co-development of the IMP between the research and policy teams, and illustrate how it has been used to support and influence trade negotiations and agricultural policy development in Welsh Government following the UK's exit from the European Union.

Keywords: integrated model, agriculture, ecosystem services, co-production, policy application

3. Type of submission: Abstract

How 198 models of pastureland management can be accessible, interoperable and user friendly

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Agriculture systems has been incorporating technological advances developed by other industries since the 1950s, increasing production and reducing processing times on a large scale. However, this type of intensive agricultural activities can also compromise the environment, loss of biodiversity, water pollution and soil erosion are some of them. For this reason, a new balanced approach with nature is key. Agriculture has to incorporate new technologies and scientific knowledge such as artificial intelligence, computational capacity of machines or remote sensing to make low-input agriculture more efficient. To this end we have adapted in a Spanish case study a monolithic and cumbersome R model to a set of 198 modular and interconnected models written in k.IM under the k.LAB platform. The set of models simulate vegetation's life cycle (growth, death, senescence and litterfall), livestock grazing (ingestion, digestion, excretion and weight change) and the nitrogen cycle (uptake, soil cycle and leaching). To connect the scientific knowledge generated, we applied the Integrated Modelling approach implementing the FAIR principles. Although the internet and online data repositories have made it easier for both humans and computers (Findable) to retrieve digital resources (Accessible), Interoperability (digital resources are related to the same topic and can interact among themselves) and Reusability (digital resources can be used in other contexts) are still hardly sought-after aspirations. Also, a stakeholders facilities are available through an intuitive web-browser based user interface called k.Explorer. Through Artificial Intelligence (AI), and in particular semantics and machine reasoning, we resolved logical queries based on dependencies declared in each model

component, and their corresponding computational workflow. This technique allows to produce complex analyses by connecting simple self-explanatory and self-contained models. These models can be used in isolation or as components of other, more comprehensive, models. These components can contribute to modelling strategies looking at environmental dynamics as a whole.

Keywords: interoperability, artificial intelligence, semantics, machine reasoning, agricultural management

4. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Ex-ante identification of policy interventions to secure a functioning ecological infrastructure: A participatory Bayesian Network approach in Switzerland

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Assessing Ecological Infrastructure (EI) necessitates value judgements with respect to the importance of different components such as ecosystem services and biodiversity. As such it is crucial that assessments as well as the planning of policies to maintain EI incorporate the participation of relevant stakeholders. However, implementing this can be problematic as the quantification of EI typically involves modelling approaches that are in-transparent to non-experts. Bayesian Networks (BNs) can overcome this by allowing for the integration of knowledge from closed form solutions and machine learning techniques with that from stakeholder elicitation. Furthermore, BNs allow for increased transparency of modelling processes through their representation as directed casual diagrams, with the possibility of spatially visualizing results including attendant uncertainties. These features allow for meaningful stakeholder participation in the simulation of EI thereby fostering increased stewardship. This research

demonstrates this through a prototypical dynamic, spatially explicit, Bayesian Network (BN) incorporating stakeholder participation to simulate future EI in Geneva, Switzerland. First, stakeholder input informs the interactions of actors in the implementation of policies linked to EI conceptualized through Contextual Interaction Theory. This is operationalized alongside historical patterns to model future Land Use Land Cover change (LULCC) which in turn is used to predict future values of ecosystem service supply and biodiversity outcomes. Stakeholders then weight these outcomes into an aggregated measure of EI that reflects their views on the importance of each aspect. This participatory BN is first used in a forecasting capacity to simulate the impact of policy interventions against a business-as-usual scenario. Following this, backwards inference is utilized to identify pathways to securing stakeholder defined visions of a functioning EI. The results of both processes highlight the trade-offs that occur between different prioritizations of EI when attempting to optimize policy interventions to manage natural resources for the future.

Keywords: ecological infrastructure, bayesian networks, participatory modelling, ecosystem services

5. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

How can climate change impact modelling and uncertainty analysis actually inform decision-making and support adaptation to change? An example of land use adaptation at the German North Sea coast

First author: Kremena Burkhard
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The German North Sea coast is characterised by continuous dikes and below sea level elevation of a big share of the terrestrial land, which is drained by a complex system of canals, sluices and pumps. The area is vulnerable to climate change and specifically to increasing sea levels, changes in seasonal precipitation and increased frequency of extreme weather events, which are predicted by recent climate models. The existing drainage and land use system would require adaptation to the afore mentioned pressure in order to sustain the supply of ecosystem services (ES) and the prosper of the area. The inter- and transdisciplinary project RUINS (Risk, Uncertainty and Insurance under Climate Change. Coastal Land Management on the German North Sea) develops a sophisticated ecohydrological modelling system to represent the impacts of climate change predictions on a set of ecosystem services. The inherent uncertainties are systemically analysed and quantified throughout the chain of models. The introduction of diversified landscapes with higher water retention capacity is one of several investigated management scenarios. The adaptation measures inherit large uncertainty. In addition, decisions are impacted by the decision-makers' uncertainty attitude and susceptibility to risk. Through a Bayesian analysis we investigate how the information of climate change impact modelling and uncertainty analysis is conveyed to decision-making. We introduce the examples to highlight the requirement to include uncertainties in the process of impact modelling, ecosystem service assessments and the decision-making process.

Keywords: impact modelling, future scenarios, uncertainties, decision-making support, Bayesian analysis

6. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Bayesian Belief Network models as trade-off tools of ecosystem services

First author: Marie Anne Eurie Forio
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Abstract: Food production often leads to environmental degradation. Consequently, insights into ecosystem functioning in relation to exploitation are needed as a basis for socioeconomically acceptable mitigation of these impacts. A Bayesian Belief Network (BBN) model is developed to link three major ecosystem services (ES), i.e. food production, water provision and ecotourism, and determine the effect of local agricultural practices and management on the ES in the Guayas Basin (Ecuador). Several data sources were integrated into the BBN model, including processed spatial data from primary and secondary sources, sampling and survey data, and expert knowledge. The model suggests that banana and sugar cane generate the highest yield but provide low ecotourism benefits. In contrast, cacao produces the lowest yields but contributes to better water quality. Scenario analyses suggest that environmental gains are possible by optimising the land use (LU) based on the edaphoclimatic requirements of crops. Moreover, the integration of LU optimisation with upscaling and farming intensification can allow for additional advantages in water provision and ecotourism while mitigating productivity losses. The developed model provide insights into the trade-offs between ES.

Keywords: integrated water management, agricultural intensification, land use cover, trade-off tool, land use cover optimization

7. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Valuation of land-water ecosystem services and invasive species when using Pareto Frontiers: a showcase in Hawai'i Island, USA

First author: Adrián Pascual
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Invasive species have altered hydrological processes at watershed scales, with impacts to biodiversity and ecosystem services (ES). This effect is exacerbated by climate change and poor planning of freshwater resources. Using mathematical programming and modeled watershed data, we integrated remote sensing, natural resource economics, climate science and robust mixed integer programming (MIP) optimization to identify resource stewardship maxima. Our goal was to optimize the spatial and temporal arrangement of invasive species treatments, in this case of strawberry guava (SG; Psidium cattlenium) trees, to increase water yields and resulting potential revenues from the management actions. The optimization training area consisted in 904 ~100 ha hydro-units on the windward coast of Hawai'i Island (USA) across which SG varied in density, with high densities across lower reaches exerting a large impact on both native vegetation and land-water dynamics. The hydrological benefit of removing SG, often marginal, was financially quantified. Single- and multi-objective MIP formulations were developed using a 10-year planning horizon. Hydro-unit management costs discounted forest-water revenues to maximize management efficiency. Pareto frontier (PF) approach and corresponding decision-making maps for four different management scenarios are presented. The valuation of land-water natural capital and its temporal dynamics benefits from multi-objective management planning.

Keywords: decision support models, combinatorial optimization, natural resource economics, watersheds management, payment ecosystem services

8. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Tree species composition and understory coverage as drivers of habitat diversity – An innovative approach for an optimized landscape biodiversity assessment

First author: Brigite Botequim
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Sustainable forest management needs to address biodiversity conservation concerns. One of the major challenges today is how to balance the increasing demand for species diversification, whilst targeting increased supply of other ecosystem services (ES) to ensure profitability for forest owners? Indeed, forest managers need models and indicators that may help assess the impact of management options on biodiversity under the uncertainty of climate change. In this research we address the critical problem of managing forest landscapes for conflicting objectives, such as the provision of biodiversity, wood production and wildfire vulnerability, which are the utmost importance for improving the decision-making processes of stakeholders in the Northwestern of Portugal. For this purpose, a landscape-level Resource Capability Model (RMC) along with an optimization method based on linear programming (LP) has been extended to integrate a biodiversity-oriented forest management indicator in the face of two local-climate conditions to measure the quantitative impact of forest management models on the potential biodiversity landscape provision. In this sense, our approach integrates (i) indicators of tree species composition, stand age and understory vegetation as effective biodiversity proxies; (ii) and explores the application of a LP model to guide forest actors in considering optimal practices to safeguard future biodiversity, while other ES commitments are reached for an application encompassing 14,765 ha in long-term forest management (planning horizon 90-years). The results highlight the potential of the approach to help assess the impact of both stand and landscape-level forest management models on biodiversity conservation goals. We emphasize that the implementation of alternative forest management models (native species) in practice appears to be a real chance to provide a promising path to support the provision of various ES while contributing to mitigate climate change. The set of long-term optimized solutions emphasize a multifunctional forest where a desirable biodiversity can be delivered with levels of sustainable wood production and reduced socio-ecological risk.

Keywords: climate change, biodiversity indicator, ecosystem services, mathematical programming, landscape-level planning, silvicultural practices

9. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Incorporating ecosystem services to social-ecological networks: gap or redundancy?

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Social-ecological networks (SEN) represent complex relationships within and between components of the ecosystems that provide societies with critical life-supporting services. The practical application of SEN to ecosystem services, however, has been hindered by a lack of clarity how to employ SEN approach and the challenge that ecosystem services can be represented in multiple ways, i.e. as nodes, links, attributes and emergent properties of networks. To untap the potential of SEN for ecosystem services research, we present a typology for the beneficial incorporation of ecosystem services in SEN, and also identify limitations and challenges. By showcasing the benefits of applying SEN approaches for a key set of ecosystem services questions and challenges, our examples demonstrate how and when social-ecological networks can improve our ability to solve multiple challenges in ecosystem services research.

Keywords: social-ecological research, multilayer network, multilevel network, multiplex network, complex systems, social-ecological interactions, ecosystem services

10. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Influence and dependence on input data for the modelling of pollinator habitat suitability with "ESTIMAP" and "InVEST"

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The presence of pollinators is an important factor for biodiversity and crop-based ecosystem services. For example, most flowering plants, including wild plants, rely on pollination ecosystem services for reproduction. Suitable nesting sites and accessible floral food resources are crucial to the abundance of pollinators. Therefore, the habitat suitability for pollinators and the pollination service itself are influenced by the type of land use, the composition of the land cover and structures in the landscape. One way to estimate the habitat suitability is to use models such as ESTIMAP and InVEST. Both models calculate the potential relative habitat suitability for pollinators based on spatial land use data and the suitability as nesting and feeding habitats. Many different land use data sets are available, such as CORINE Land Cover, CORINE Urban Atlas, ATKIS (for Germany), City Structure data or Open Street Map. All these data sets contain different resolutions and different structural elements, which are important for modelling with ESTIMAP and InVEST. Besides the decision for a certain model, the selection of a spatial data set also has important effects on the modelling. Both models are applied on the basis of two different spatial data sets, which are provide a different amount of landscape structures. In our approach, the biophysical properties required for modelling with ESTIMAP and InVEST are determined by literature research and an interview with a wild bee expert. The differences between the results based on two different spatial data sets and the differences between the models are determined. The comparison of the results based on both data sets and both models shows that the proportion of near-natural structures in the landscape is a decisive factor for modelling. The comparison of the models shows that ESTIMAP estimates the influence of small structures in the landscape to be higher than InVEST and thus generally calculates a higher habitat suitability than InVEST.

Keywords: ESTIMAP, InVEST, pollinator habitat suitability, modelling

11. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

A GIS Based Approach for Predicting Recreational Ecosystem Services Hotspots

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This study will be used social media photographs for spatial analysis of recreational ecosystem services (RES) in the city of Antalya (Turkey). 7980 geo-tagged photos (commercial use & mods allowed) from the Flickr photo-sharing platform will be used for determining RES values. The species distribution model will be used for modelling hot spot areas for RES. Natural and cultural landscape values of the study area will be used as environmental variables and point data from the geo-tagged photos as presence-only data for the predicting model. MaxEnt and QGIS software will be use integrally for modelling process. Hotspots for RES will be identified and all environmental variables will be analyzed in terms of their significance degree to the model. This research is thought to contribute landscape planning and management process in terms of protecting hotspot areas with their vital characteristics. On the other hand, this study will be presented a novel method for analyzing and mapping intangible ecosystem values.

Keywords: recreational ecosystem services, species distribution model, MaxEnt

12. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Urban flood regulation Ecosystem Services under climate change – A modelling approach for heavy precipitation events

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Heavy precipitation is a common cause of pluvial flooding in urban areas resulting in damages and associated high damage costs. Regional climate projections show an increase in frequency and intensity of heavy precipitation events in many regions of Germany for the future. Therefore, flood regulation is one key regulation ecosystem service (ES) under the pressure of climate change. To use ES as a component for sustainable and climate-adapted city development, it is important to analyze its functionality under changing climatic conditions. By combining the hydrological setting, socio-economic aspects and climate information, two points are investigated: 1) Potential flood regulation ES with respect to heavy precipitation events and 2) Future pluvial flooding regulation functionality under climate change. A modelling approach to estimate the heavy precipitation regulation ES in urban ecosystem areas using regional climate change information will be presented. The research area is located in the city of Rostock (northeastern Germany). For the hydrological small-scale simulations, we use the modular python-based toolbox CMF (Catchment Modelling Framework). The local flood regulation ES are assessed under current and future climate conditions to test the functionality. The model delivers hydrological parameters for intercepted volume, soil water volume, and surface water volume. This information is classified and transferred into ES. The comparison of current and future functionalities can be used to develop adaptation options to support the regulation functions. With this work, an approach for small-scale heavy precipitation regulation ES assessments is presented based on the linkage of the outcomes of the hydrological model CMF with regulation ES. The additional quantification of future heavy precipitation regulation ES is an important tool for future disaster risk reduction of urban areas. Strategies and adaptation measures to reduce damage and increase the climate resilience can be developed and tested with respect to potential urban flooding in the future.

Keywords: pluvial flooding, hydrological modelling, Catchment Modelling Framework (CMF), flood regulation ecosystem service supply, future functionality

13. Type of submission: Abstract

T. Thematic Working Group sessions: T5 – Integrated models and ecosystem services – application in real world case studies

Moving beyond soil sealing evaluation in urban planning with ecosystem services quantification

First author: Lea Tardieu

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Despite increasing evidence that ecosystem services (ES) enhance the quality of life, ES information is still underused in urban planning. Simpler indicators such as soil sealing—the conversion of natural areas to artificial land—are preferred in environmental impact assessment of urban plans, although these do not capture the multiple social and environmental impacts of land use change. In this paper, we present a modelling exercise conducted with stakeholders of the Paris metropolitan area, in France, the most artificialized country in Europe in proportion to its population, which aimed to co-produce ES information relevant to current planning regulations and practices. After identifying the type of ES information that could best support urban planning decisions, we used geospatial models to quantify the evolution of eight ES over the last 35 years. For some ES, spatial and temporal trends followed trends in soil sealing, while others showed stark differences. The temporal mismatch was explained by different driving forces influencing ES, particularly land management practices for agricultural areas and building densification, which are not captured by measures of soil sealing. The spatial mismatch was explained by the spatial dependency of ecological functions, implying that ecosystem degradation in one place may impact services in another place. Our results show how integrating ES indicators in urban planning provides more nuanced information on environmental and social impacts, confirming the need to move beyond a simplistic vision of "artificial versus natural areas". Because our analyses are based on publicly available spatial data and open-source models, they can be easily reproduced for the Paris metropolitan area and other cities to inform future master plans.

Keywords: stakeholders involvment, soil sealing, historical evolution, inVEST, urban planning