How to quantify spatiotemporal development of riverine ecosystem services?

Comment quantifier le développement spatio-temporel des services écosystémiques rivulaires ?

K.R. Koopman[1]; D.C.M. Augustijn[2], A.M. Breure[1,3]; H.J.R. Lenders[1]; R.S.E.W. Leuven[1]

[1]Radboud University Nijmegen, Institute for Water and Wetland Research, Department of Environmental Science, P.O. Box 9010, 6500 GL, Nijmegen, The Netherlands (Corresponding author: K.Koopman@science.ru.nl). [2]University of Twente, Twente Water Centre, P.O. Box 217, 7500 AE, Enschede, The Netherlands. [3]National Institute for Public Health and the Environment (RIVM), Centre for Sustainability, Environment and Health, P.O. Box 1, 3720 BA Bilthoven, The Netherlands

RÉSUMÉ

Les cours d'eau sont des écosystèmes complexes, terrains de nombreux processus hydrologiques, géomorphologiques et écologiques en interaction, à l'origine des services écosystémiques rivulaires. Ces services consistent en la fourniture, par les écosystèmes, de biens et de services bénéfiques à la société tels que nourriture, bois et eau potable. Quantifier les services écosystémiques peut permettre d'étayer les études d'impact environnemental ainsi que les analyses scénaristiques pour la gestion des cours d'eau. Une telle quantification requiert de connaître les facteurs déterminants des paysages rivulaires et les liens entre caractéristiques du paysage et services écosystémiques. Une méta-analyse a été conduite pour évaluer l'utilité des systèmes de classification paysagers contemporains pour la quantification des services écosystémiques rivulaires. Nous avons identifié les liens entre unités paysagères et services écosystémiques, afin d'évaluer comment les mesures de gestion affectent la succession de ces services à différentes échelles spatio-temporelles. Certaines classifications paysagères font déjà le lien avec les services écosystémiques; cependant, aucune de ces approches n'inclut la succession de ces services en rapport avec les mesures de gestion. Nous recommandons donc d'orienter la recherche future vers une compréhension mécanistique des facteurs moteurs dans le changement des paysages rivulaires en relation avec le développement spatio-temporel des services écosystémiques.

ABSTRACT

Rivers are complex systems that involve various interacting hydrological, geo-morphological and ecological processes resulting in the provisioning of riverine ecosystem services. The latter are flows of goods and services from ecosystems to society, such as food, timber and drinking water. Quantification of ecosystem services can support environmental impact assessments or scenario analyses for river management. The quantification of ecosystem services requires knowledge of the drivers of riverine landscapes and the linkage of ecosystem services to landscape characteristics. A meta-analysis was performed to evaluate the usefulness of contemporary landscape classification systems for quantification of riverine ecosystem services. We identify how ecosystem services can be linked to landscape units in order to assess how management measures affect their succession at various spatiotemporal scales. Some landscape classification systems are already linked to riverine ecosystem services, however, none of these approaches include succession of ecosystem services in relation to management options. Therefore, we recommend to direct future research on mechanistic understanding of drivers of riverine landscape changes in relation to spatiotemporal development of ecosystem services.

KEYWORDS

Landscape classification systems; River management; Ecosystem services

1 INTRODUCTION

Rivers are highly dynamic systems with complex hydro-morphological and ecological interactions, which need to be taken into account from a management perspective to safeguard river functioning. The increasing pressures of climate change and population growth on important river functions such as navigation and water supply, however, make management measures increasingly difficult. There is a need for more self-sustaining rivers that allow better utilisation of their natural processes in order to reduce management costs, hence the RiverCare program was started in the Netherlands. Part of this multidisciplinary research program is focussed on the use of ecosystem services to evaluate management measures. The ecosystem services concept enables recognition of the contribution of rivers to human wellbeing, during decision making. It allows a comprehensive and holistic evaluation of trade-offs between environmental, economic and social outcomes from current and future river management. According to the Millennium Ecosystem Assessment, ecosystem services can be regarded as '*the benefits people obtain from ecosystems*'. River systems provide several services to man already such as: food (fish, agricultural products), timber (riparian forests), drinking water, and navigation (shipping of goods). Evidently, river management affects provisioning of ecosystem services, both spatially and temporally, for different services in different ways. Understanding how management measures relate to landscape ecological processes is required to determine which ecosystem services are delivered by a river system at various spatial and temporal scales. The riverine landscape can be categorised into different landscape units, each with its own characteristics such as: vegetation type present, ecological processes occurring, ecosystem functions provided and services delivered. One of the RiverCare goals is the development of tools to quantify riverine ecosystem services and implementation of these tools in BIO-SAFE, a model that determines the effect of river management on biodiversity and ecosystems (De Nooij et al., 2004). Developing these tools requires a clear view on what river landscape classification systems are available and how they can be linked to ecosystem services and various management measures.

Therefore, the aim of this study is 1) to analyse and compare different river landscape classification systems that are used worldwide; and 2) to identify which of these systems are most suitable to link and quantify the spatiotemporal development of riverine ecosystem services in relation to river management.

2 METHODS

A search for relevant (peer) reviewed literature on landscape ecological and ecosystem services classification systems was performed, using Web of Science, Scopus, Google Scholar and Google. Next, these classification systems were evaluated on multiple criteria: scale, coverage (e.g. global to river reach), data availability, data requirements, definitions of landscape units and their links with ecosystem services classification systems, and feasibility to identify landscape units using remote sensing. Lastly, we also determined whether landscape classification systems included quality characteristics (e.g. species richness or types of vegetation) and if links with ecosystem services were correlative or mechanistic by nature.

3 RESULTS AND DISCUSSION

At present multiple (river) landscape ecological classification systems exist, like CORINE, LANMAP, EUNIS and RWES. Comparing these classification systems reveal differences in scale, complexity, reach and definitions of landscape units. The scale directly affects the complexity since smaller scales allow more distinction in landscape units than larger scales do. For instance RWES (scale 1:10,000) has more unit types than CORINE (scale 1:100,000). On the other hand, CORINE covers the whole of Europe, while RWES only focuses on riverscapes in the Netherlands.

The classification and definition of ecosystem services is still inconclusive since multiple approaches exist and are used in science and management. Three commonly used classification systems are: The Millennium Ecosystem Assessment (MA), The Economics of Ecosystems and Biodiversity (TEEB) and The Common International Classification of Ecosystem Services (CISES). These systems have similar categories regarding provisioning and cultural services, but differ in the categorisation of regulating and supporting services. Furthermore, the number of ecosystem services recognized and thus the level of complexity to

link them to landscape units and management measures increases across the MA, TEEB and CICES classification systems.

Studies on the linkage of ecosystem services to landscape characteristics and the quantification of these services are emerging. Van Wijnen et al. (2012) explored the linkage between the Dutch landscape and soil ecosystem service: natural attenuation of pollutants, which is the capacity of the soil to keep itself clean (Table 1). Large and Gilvaer (2014) developed a method for semi-quantitative scoring of provisioning of eight ecosystem services per river reach (Table 1). Both methods already allow quantification of ecosystem services through linkage with landscape classification systems. However, these methods are either not available for rivers yet (approach of Van Wijnen et al., 2012) or are not able to quantify ecosystem services biophysically (method by Large and Gilvaer, 2014), which allows making cost-benefit analyses. Furthermore, these methods only focus on (some) spatial components of ecosystem services. The temporal aspect, however, is also of great importance for assessing impact of management measures on succession of riverine landscapes and the ecosystem services they provide. Understanding how these processes are linked to the landscape and how they develop through time is necessary for the temporal quantification of ecosystem services.

Table 1: Example of the evaluation of studies that link ecosystem services to landscape characteristics

Approach	Methods	Output
Spatial quantification of soil ecosystem service: natural attenuation of pollutants (Van Wijnen et al., 2012)	Assigning (a)biotic proxy indicators (best professional judgement) Assessing deviation of proxy indicators compared to 'reference situation', determines condition of the soil Generalized Linear Regression models link six proxy indicators to land use, soil type and abiotic characteristics	Maps showing performance and potential for improvement per proxy indicator, across the Netherlands Map combining proxy indicator maps, to show relative performance value (0 to 1) of natural attenuation
Modelling riverine ecosystem service performance (Large and Gilvaer, 2014)	18 Riverscape features + land cover types linked to ecosystem processes and delivery of 8 ecosystem services. Extraction of riverscape features from remote sensing data (Google Earth) Riverscape features + land cover types assigned to individual ecosystem services with semi-quantitative scores for potential ecosystem services provisioning.	2D river-model, showing Individual Ecosystem Services Scores per river reach Score (0-3 / absent-optimal) per ecosystem service category (Supporting, Regulating or Provisioning) and Total Ecosystem Services Score per river reach

We conclude that multiple landscape ecological classification systems are available, with various scales and definitions. Some methods already link ecosystem services and landscape classification systems (Van Wijnen et al., 2012; Large and Gilvaer, 2014). However, there is no sound approach for the quantification of impacts of river management on biophysical riverine landscape processes and spatiotemporal development of ecosystem services. Therefore, we propose directing further research on the interaction of river management, riverscape and succession of ecosystem services.

4 ACKNOWLEDGEMENTS

This study was conducted as part of the RiverCare program funded by STW, project number: 13519

LIST OF REFERENCES

Large, A.R.G. and Gilvear, D.J. (2014). Using Google Earth, A virtual-globe imaging platform, for ecosystem services-based river management. *River. Res. Appl.*, DOI: 10.1002/rra.2798

De Nooij, R.J.W., Lenders, H.J.R., Leuven, R.S.E.W., De Blust, G., Geilen, N., Goldschmidt, B., Muller, S., Poudevigne, I. and Nienhuis, P.H. (2004). BIO-SAFE: Assessing the impact of physical reconstruction on protected and endangered species. *River. Res. Appl.*, 20: 299-313

Van Wijnen, H.J., Rugters, M., Schouten, A.J., Mulder, C., De Zwart, D. and Breure, A.M. (2012). How to calculate the spatial distribution of ecosystem services – Natural attenuation as example from the Netherlands. *Sci. Total Environ.*, 415: 49-55