Suitability of landscape classification systems for quantification of ecosystem services in BIO-SAFE

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Introduction
In the last century, rivers have been heavily regulated to maintain and improve important river functions such as navigation, water supply and biodiversity. These functions are increasingly threatened by climate change and population growth, asking for shifts in river management strategies. The multidisciplinary RiverCare programme was initiated to develop tools and measures for creation of more self-sustaining rivers and reduction of management costs (RiverCare, 2013; Hulscher et al., 2014). Management cost reduction requires tools for evaluation of the effectiveness of riverine management measures.

RiverCare subproject E2 focusses on ecosystem services of river-floodplain systems. The goal is to develop an assessment tool for evaluation of effects of river management measures on the spatiotemporal development of riverine ecosystems and their services (Fig. 1.). Starting point for development of such a tool is BIO-SAFE, a model by which the effects of river management on biodiversity can be assessed (Lenders et al., 2001; De Nooij et al., 2004).

BIO-SAFE is an excel-based model that predicts and valuates biodiversity of a study area. It links landscape ecological units (ecotopes) to (potential) presence of certain target species and can be used for calculation of actual and potential biodiversity values of river-floodplain systems at various spatial scales. The biodiversity values are calculated using criteria that relate to the political and legal conservation status of target species. Management induced changes in surface areas and types of landscape units result in changes of biodiversity values, allowing the evaluation of management measures by comparing before and after values (Lenders et al. 2001; De Nooij et al., 2004).

Incorporating ecosystem services into BIO-SAFE requires linkage of these services to standardized landscape units from a landscape classification system. An extensive literature review was performed to determine the suitability of existing landscape classification systems applicable for linkage to ecosystem services of river systems (green block in Fig. 1.).

The aim of this research was I) to review landscape classification systems that are used across the globe; and II) to determine which landscape classification systems are applicable to rivers and most suited for linking and quantifying spatiotemporal developments of riverine ecosystem services in relation to management measures.

Figure 1. The different steps of RiverCare subproject E2. The place of this review in the project is indicated by the green block: Selecting suitable landscape classification systems (LCSs). (ES = Ecosystem services).
Methods
A search for peer reviewed literature on landscape classification systems and their links to ecosystem services was performed using ISI Web of Knowledge (www.isiknowledge.com) and a set of search terms related to landscape classification, river systems and ecosystem services. All hits were screened for further selection. The landscape classification systems had to comply with our definition: ‘a landscape classification system describes the landscape in multiple classes or features that are distinctive from each other and spatially explicit’. Suitable papers were reviewed and analysed using criteria such as potential for linkage to ecosystem services, applicability to riverine landscapes and suitability for studying spatiotemporal development of landscapes and their ecosystem services.

Results
Out of the 546 hits, we selected 95 papers (that often included multiple case studies) for further analysis. In total, 31 (33%) papers linked ecosystem services to landscape units using either quantitative, semi-quantitative or both types of methods (Fig. 2). Quantitative methods expressed ecosystem services in biophysical or monetary units, while semi-quantitative methods gave scores indicating the potential of landscape units to deliver ecosystem services. The first paper that linked ecosystem services to various landscape units was published in 2002 (Konarska et al., 2002). It took several years before approaches to link ecosystem services to landscapes emerged in other papers. In 2005 a slight increase in publications linking ecosystem services to landscape classifications was visible, followed by a rapid increase after the years 2010 / 2011. Only 25 (26%) of the selected papers applied landscape classifications to rivers.

We found several landscape classification systems that are suitable for incorporation in the new BIO-SAFE ecosystem services tool. Table 1 provides three examples that allow classification on different scales: 1) CORINE covers most of Europe (EEA, 1995), and is applicable to rivers. Several times it has been linked to ecosystem services and it is already incorporated in BIO-SAFE. 2) The Dutch RWES classification (Rijkswateren-Ecotentenset) was specifically designed to classify Dutch river systems (Van der Molen et al., 2000; Willems et al., 2007) and is also incorporated in BIO-SAFE. So far, the RWES classification has not been linked to ecosystem services. 3) The GLC2000 has a global coverage and can also be applied to rivers (Mayaux et al., 2006). It can be incorporated into BIO-SAFE and has been linked to ecosystem services. Furthermore, the GLC2000 was used in the Millennium Ecosystem Assessment of the United Nations (MEA, 2005). Only CORINE has been used to study the effects of landscape changes on ecosystem services performance (Scollozzi et al., 2012), but the RWES and GLC2000 classifications are also considered suitable.

Discussion
We reviewed landscape classification systems that are used worldwide for a wide range of purposes and different types of landscapes. About 26% of these landscape classification systems were applied to riverine landscapes. Most of these systems classify both the terrestrial and aquatic part of the river system. However, some only focussed on either the aquatic or terrestrial part of the river system. Only six of these river-applicable landscape classification systems were linked to ecosystem services.

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The number of papers linking ecosystem services to landscape
classification systems increased significantly after the publications of major international ecosystem services works such as: the Millennium Ecosystem Assessment in 2005 (MEA, 2005), the TEEB reports in 2010 (TEEB, 2010) and the CICES classification in 2011 (Haines-Young and Potschin, 2011) (Fig. 2). Initial linking was only quantitative using monetary units. The publication of these major works provided new approaches and methods that were picked up by the scientific community. Especially the semi-quantitative approach was used often in recent studies (Fig. 2). In this approach, expert judgement was used to determine the landscapes’ capacity to deliver ecosystem services. The use of this method offers a relatively ‘quick and easy’ approach to identify the ecosystem services of a given study area. Furthermore, it allows for comparing the delivery of different ecosystem services among each other. However, the method also possesses a level of subjectivity which, on the other hand, might also be useful when the experts involved are also stakeholders in the area. It thus enables the incorporation of different stakeholders’ views in the ecosystem services assessment. The number of papers describing biophysical quantification of ecosystem services through indicators was very limited.

We found several landscape classification systems that are suitable for the development of an ecosystem services tool in BIO-SAFE, e.g. the systems listed in Table 1. More suitable classification systems exist and are described extensively in Koopman et al. (in prep.) The main advantage of using CORINE and the RWES classification is that they are incorporated already in BIO-SAFE. Both systems are applicable to rivers. CORINE has already proven to be suitable for biophysical quantification of ecosystem services (Burkhard et al., 2009). Furthermore, CORINE is applicable across Europe to multiple scales (continental, national and regional) allowing the ecosystem services tool to be applied at an international level. However, since CORINE’s resolution might be rather coarse for application on regional scales, it is an option to use the RWES classification for this level of scale. Preliminary results indicate that it is feasible to link the ecological landscape units of the RWES classification to indicators for various ecological functions and the state of ecosystem services. Since, the RWES classification was designed to classify Dutch river-floodplain systems, direct application in other countries might prove difficult due to, for instance, missing specific landscape types (e.g. braided rivers or mountainous headwaters). However, it should be achievable to extend the RWES classification by incorporating additional ecotope types. The GLC2000 might be useful for assessment of ecosystem services at larger scales or in other biogeographical regions than Europe. This landscape classification system is suitable for ecosystem services linking and is also applicable to rivers. It has not been incorporated in BIO-SAFE yet, but considering its landscape classes, there are ample possibilities to do this. For application on national levels, however, the resolution of the GLC2000 might be too coarse (Schulp and Alkemade, 2011). So far, only CORINE has been used to determine effects of landscape changes on ecosystem services (Scollozi et al., 2012). However, it is expected that all three classification systems can take spatiotemporal development of ecosystem services into account using transition matrices.

Although we found several landscape classification systems that are potentially suitable for the development of an ecosystem services tool in BIO-SAFE, knowledge on indicators for biophysical quantification is still very limited and scattered across the literature. Furthermore, we did not find any approaches or case studies that assessed spatiotemporal development of ecosystem services in relation to river management measures.

Future work
Future work will focus on development of biophysical indicators for quantification of ecosystem services and studying how these indicators may be coupled to ecosystem quality and develop spatiotemporally in relation to various types of river management measures (Fig. 1).

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