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Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management

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ABSTRACT

Wetlands are often considered as nature-based solutions that can provide a multitude of services of great social, economic and environmental value to humankind. Changes in land-use, water-use and climate can all impact wetland functions and services. These changes occur at scales extending well beyond the local scale of an individual wetland. However, in practical applications, engineering and management decisions usually focus on individual wetland projects and local site conditions. Here, we systematically investigate if and to what extent research has addressed the large-scale dynamics of landscape systems with multiple wetlands, hereafter referred to as wetlandscapes, which are likely to be relevant for understanding impacts of regional to global change. Although knowledge in many cases is still limited, evidence suggests that the aggregated effects of multiple wetlands in the landscape can differ considerably from the functions observed at individual wetland scales. This applies to provisioning of ecosystem services such as coastal protection, biodiversity support, groundwater level and soil moisture regulation, flood regulation and contaminant retention. We show that parallel and circular flow-paths, through which wetlands are interconnected in the landscape, may largely control such scale-function differences. We suggest ways forward for addressing the mismatch between the scales at which changes take place and the scale at which observations and implementation are currently made. These suggestions can help bridge gaps between researchers and engineers, which is critical for improving wetland function-effect predictability and management.

1. Introduction

Nature-based solutions (NBS) is a newly coined umbrella concept (Albert et al., 2017). It relates to the use of nature for addressing a range of global environmental and social challenges, such as climate change and pollution of water systems (Cohen-Shacham et al., 2016). NBS are determined by the natural functions of ecosystems, which for example includes natural attenuation processes that frequently involve microbial removal of contaminants from groundwater (Scow and Hicks, 2005). Quantitative understanding of the contributions of natural systems towards reaching various targets (e.g. related to water quality) is a prerequisite for scientists,

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managers and policymakers. This is to be able to clarify potential needs for additional technical or ecological engineering solutions (e.g. enhancing contaminant removal) required to reach set targets (e.g. Nesshöver et al., 2017; Mitsch, 2012).

Wetlands are known for their provisioning of ecosystem services and thus have great potential to be used as nature-based solutions to address a variety of environmental, social and economic challenges. Common multi-beneficial ecosystem services from wetlands include carbon sequestration (e.g. Mitsch et al., 2013; Bridgham et al., 2006), water quality protection (e.g. Verhoeven et al., 2006; Mitsch et al., 2001), coastal protection (e.g. Temmerman et al., 2013; Gedan et al., 2011), groundwater level and soil moisture regulation (e.g. Hefting et al., 2004; Xiong et al., 2003), flood regulation (e.g. de Groot et al., 2002; Acreman and Holden, 2013) and biodiversity support (e.g. Gibbs, 2000; Dudgeon et al., 2006). However, despite their potential, there has been a continued and rapid decline in wetland areas globally. Although the absolute number of global wetland loss (both in number and area) are uncertain, and some regions of the world, such as the US and Europe, have slowed down the rate of wetland loss substantially over the last decades, many regions are still experiencing rapid wetland loss (Mitsch and Gosselink, 2015; Davidson, 2014). Nevertheless, the global value of wetland ecosystem services ($26.4 trillion/yr) is still estimated to contribute more than 20% of the total value of ecosystem services globally, exceeding the contributions of terrestrial forests and coral reefs (Costanza et al., 2014). This highlights the need for evaluating how to best use wetlands as cost-efficient and sustainable nature-based solutions to a range of current and future challenges.

Climate change and large-scale land-use changes (Seneviratne et al., 2006), as well as changes in water use and demographic pressures (Destouni et al., 2013), affect large-scale water fluxes and balances. These changes should therefore also be expected to affect wetland functions and associated ecosystem services. Particularly, understanding impacts of regional-global change on wetland functions and associated ecosystem services, and evaluating suitable management practices and engineering solutions for mitigating them, is a major challenge for scientists, engineers and stakeholders. To address this challenge, and support management and engineering solutions, we need to first have a good understanding of how natural wetland systems interact with their surroundings at various scales and how this can be evaluated.

A fundamental question that arises in the face of the issues outlined above is: what are the relevant scales to study wetland functions? We will here argue for the need to consider the large-scale functioning of the hydrologically coupled system of multiple wetlands and their total hydrological catchment, hereafter referred to as a wetlandscape (see Fig. 1 and further motivated in Section 2). More specifically, we investigate to which extent large-scale wetlandscape functions, services and impacts may differ from those of individual wetlands. Also, can they even be predictable from the behavior of individual wetlands? If not, what are collective results of evaluations about expected large-scale change impacts on the functioning of whole wetlandscapes? These questions have not, to the best of our knowledge, previously been systematically investigated.

2. Problem statement

A call for conducting wetland research at the landscape scale was made almost 30 years ago when Preston and Bedford (1988) stated that "*the scale must be enlarged from the individual wetland project to include the broader landscape. Only this broader view can provide the context within which decision-makers can evaluate the potential cumulative effects of individual mitigation decisions on broad-scale patterns of wetland diversity*". While it is clear that studies on individual wetlands have been crucial for enhancing our understanding of fundamental wetland functions (e.g. Perry et al., 2004; Drexler and Bedford, 2002), evidence is now mounting that critical ecosystem services indeed emerge from the aggregated effects of individual wetland interacting with their surrounding landscape (e.g. Cohen et al., 2016).

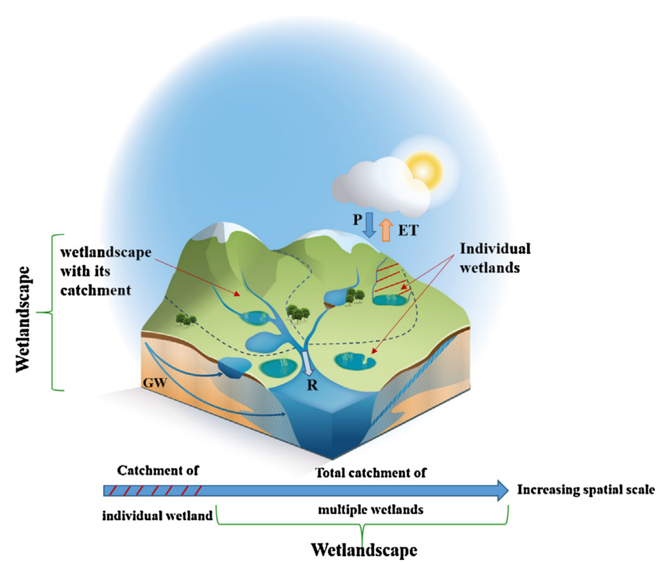

Fig. 1. Conceptual sketch of a wetlandscape. A wetlandscape consists of multiple wetlands that are hydrologically connected within an associated larger hydrological catchment than that of an individual wetland. The associated large-scale water fluxes precipitation (P), evapotranspiration (ET), runoff (R) and groundwater (GW) flows are represented by arrows in the landscape. A wetlandscape and its associated total catchment is not a static unit but will be defined at and represent various spatial scales (exemplified by dashed lines).

Even today though, mitigation decisions are typically made at the level of individual wetland projects, and engineering solutions as well as management and policy decisions are often based on understanding isolated parts of the water system, such as treating groundwater and surface water as separate components (Destouni et al., 2015; Borer et al., 2014). This fragmented approach could lead to the risk of implementing costly solutions that may be inefficient due to overlooking many dynamic effects that emerge at larger scales of wetlandscapes. This may adversely affect wetland management and global wetland loss.

We see two main reasons why the consideration of wetlandscapes may substantially improve wetland science, management and policy efforts. The first is process-oriented and relates to the inherent water flux interactions between wetlands and the hydrological system. This includes groundwater and evapotranspiration exchanges (McLaughlin and Cohen, 2013), which are naturally limited by the borders of entire interconnected hydrological catchments (Destouni et al., 2015). Additionally, large-scale water balances in a landscape can change considerably as a result of cross-scale changes in climate, land-use and water-use, with emerging patterns at integrated scales of whole drainage basins (Jaramillo and Destouni, 2015, 2014). By definition, such large-scale water-balance dynamics and changes will, in a basin with multiple connected wetlands, influence and interact with the whole wetlandscape.

The second reason is model-dependent and relates to the constraints of climate and Earth System models that are used to assess future climate change and its impacts. These models all have spatial resolutions that are clearly coarser than the size of most individual wetlands. Thus, predictions regarding specific wetlands will most likely be highly uncertain, whereas regional predictions have much