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Towards a global model for wetlands ecosystem services

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Wetlands play an important role in the provision of important ecosystem services like the provision of clean water to the world, adaptation to climate change, and support for biodiversity; although they are sometimes also associated with adverse climate effects. Wetlands are, however, currently grossly underrepresented in global environmental models. In this paper, we explore the required functionality of a generic model of the effects of climate and land-use changes on wetlands ecosystem services worldwide. We briefly review existing models to identify elements which can be combined to compile a generic wetland model.The proposed global wetland model should be integrated into and receive data from existing hydrology and climate models. Wetland delineation can be based on local hydrological and topographical conditions and verified with global wetland databases. We conclude that an integrated approach combining hydrology, biogeochemistry and vegetation for wetlands is not available yet, however, useful building blocks exist that can be combined.

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Introduction

The Sustainable Development Goals [1] require the sustainable use of the world's water and land resources to ensure food and water security, biodiversity and resilience to climate change. Wetlands are important for delivering these ecosystem services because of their regulating functions in the global water cycle, high productivity and biodiversity [2,3•,4] and their estimated value is proportionally much higher than their current modest 5–6% share of global land-use [5]. Forested watersheds and wetlands supply three-quarters of the world's freshwater for humans and nature [6]. Conversion of these natural lands into farmland during the last century has increased global annual river discharge by about 5%, according to a global model study [7]. Wetlands generally increase resilience to climate change by buffering against droughts and floods (although with exceptions) [8], storing carbon and, if untouched, cooling the climate in the long-term [9•,10]). On the other hand, wetlands may be associated with processes that are adverse to human well-being ('disservices') like methane emissions and water-borne diseases [9•,3•]. In the past decade, an ecosystem approach to land and water management has been advocated, for instance by utilizing more 'green water' for agriculture and reducing the pressure on 'blue water' resources [11,7,6].

Despite their ecological and economic values, about two-thirds of the world's natural wetlands have disappeared since 1900, based on existing data [12]. This loss is continuing, mostly for agricultural and urban development [13,14]. Remaining wetlands are threatened by hydrological change and nutrient enrichment, driven by population growth, economic development and climate change [15,3•].

Policymakers recognize the importance of healthy wetlands for achieving the SDGs and are concerned about their loss. At the global level, this has been emphasized by the conventions concerned with sustainability (Ramsar, UNFCCC, UNCCD and UNCBD), and by UN organizations such as FAO and UN-Water. The Ramsar Convention list of wetlands of international importance covers 13–18% of the world's wetlands [16•] but not all 170 signatory countries are successful in implementing the convention [17]. This raises strategic questions about the current Ramsar sites: if well-managed, would they be sufficient for providing critical ecosystem services worldwide? Does the current list include the most crucial wetland areas for resilience to climate change? And how should 'sustainable use' be defined (e.g. [18])?

Global earth surface models, dynamic vegetation models and integrated assessment models have contributed significantly to policy making by evaluating the impact of land use change on climate, food security and biodiversity [19•,20,21]. However, wetlands and their ecosystem services are mostly neglected in the current global models. When included, the focus is on disservices like potential methane emissions of wetlands [22] or on their beneficial carbon sequestration function [23]. Although several modelling studies of specific wetland types or regions have been helpful for land-use planning or management, a global framework that integrates hydrological, biogeochemical and vegetation processes of wetlands is currently lacking. The need for a global framework has been inspired by the increasing global problems of climate change and land use, while recognizing that the existing regional wetland models do not provide adequate global coverage. The model should however acknowledge the great diversity that exists between wetland types. This paper is a plea to develop such a model, in order to explore the contributions of wetlands to solving global food and water problems more effectively. The model could be used for periodic assessments of wetland extent, it could help prioritize wetlands for protection and would evaluate synergies and trade-offs in ecosystem services (e.g. water provision) and disservices (e.g. GHG emissions) resulting from alternative policies or management scenarios. Prospective users of the model are policy and decision makers from international conventions and organizations, regional and national governments, NGOs and the private sector.

The overall goal of this paper is to explore the outlines of a generic, process-based global wetland model that can be used to evaluate the effects of climate and land-use change on the areal extent and key ecosystem services of wetlands worldwide and to assess synergies and trade-offs. First, we delineate the model based on the required functionality. Then we review existing wetland models, and finally propose the elements needed for a global wetland model.

Functionality and delineation of a global wetland model

Definition of wetlands covered by the model

At this stage, we confine ourselves to inland wetlands; coastal wetlands are excluded. Wetlands are defined as permanent or seasonal (inundation occurring every year) water bodies dominated by emergent vegetation and/or areas with a permanently water-logged soil. We consider only natural wetlands, which may however be used seasonally for agriculture or livestock grazing. Artificial wetlands, used for permanent agriculture (like rice-fields) or water treatment are not included. We also exclude stratified lakes, as we focus on ecosystems dominated by emergent vegetation, noting that the boundary with shallow lakes is not fixed. We strive for coherence and possibly linking with global-scale modelling efforts for lakes [24]. Our definition comprises more or less the water types 4, 5, 8 and 10 and a part of type 1 of the Global Lakes and Wetland Database [25]: floodplain wetlands, swamp forests and mineral marshes, peatlands (bogs and fens) and shallow lakes, together now covering about 5–6% of the world's continental surface. While this classification is mainly GIS-based, for modelling it needs to be linked to hydrological, hydrogeomorphic and chemical features. Major criteria for wetland classification are the proportion of atmospheric, groundwater and surface water as water source, the water renewal time and landscape type (upland, slope, valley, depressions, flat lowland) [26•]. It seems appropriate for the global model to use a classification based on these criteria. Based on increasing water renewal rate, some major classes will be defined within the continuum from peatlands (bogs and fens) to river floodplain wetlands, which may be further subdivided if needed.

Required functionality: ecosystem functions and services

The global wetland model should allow the quantification of ecosystem services in relation to environmental change and anthropogenic pressure [27]. Five elements of wetlands, that is areal extent, water budget, water level fluctuation (i.e. intermittent or permanently inundated fractions), nutrient fluxes, and vegetation, determine the hydrology, biogeochemistry and ecosystem characteristics or ecosystem functions [28] underpinning the ecosystem services specified in Figure 1 that contribute to achieving the SDGs [29]. This set-up will allow evaluation of the influence of pressures such as land use change, pollution and climate change on wetland size and ecosystem services and disservices. By linking the ecosystem services to the corresponding SDG indicators, the model will also show the impact of these pressures on human well-being. Biodiversity indicators can be linked to these elements, either directly or through empirical 'add-on' models (e.g. [30]). Other wetland benefits that are related to wetland area and functioning, such as recreation and contribution to pollination and biological pest control can be expressed in semi-quantitative terms.

Key elements

To achieve the objectives outlined above, a global model needs to comprise at least the following functional components, in a dynamic way: area, volume (water depth), water retention time, nutrient pools (N, P, C) and retention in water and soil, and emergent and floating vegetation (Table 1 and Figure 2). On the input side, the wetland model should be easily linked with (spatially