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Climate impacts on ecohydrological processes in aquatic systems

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ABSTRACT

Since there is no life on earth without water, this opinion paper defines the likely consequences of a changing climate. Rise in global air temperature leads to increase in water temperature. Changes associated with precipitation, extreme events and catchment processes alter the hydrological cycle. Population growth increase water demand while climate warming enhances water scarcity leading to problems with water quantity, availability and water quality. Primary production by planktonic and sessile algae creates the basis for potential ecohydrological problems associated with the predicted changes in inland waters which are then outlined and discussed. Production and growth of algae also affects other trophic levels in the food web. Climate change will also promote non-native species to invade and occupy new previously unsettled ecosystems. To cope with these challenges, various efforts are needed based on ecohydrological principles. Some examples already under way are mentioned and some possible future trends are outlined.

1. Introduction

Human life on earth entirely depends on the availability, quantity and quality of freshwater, in other words on the global water budget and its annual cycle (Trenberth et al., 2007; Lorenz and Kunstmann, 2012). Global climate change is expected to have profound impacts on various aspects of the global hydrological cycle (APCC, 2014; IPCC, 2014) although robust responses of the hydrological cycle to global warming have been reported as well (Held and Soeden, 2006). Warming is likely to lead to more precipitation but also to more evaporation. Since precipitation will increase in some areas and decline in others hydrological patterns will change modifying the water cycle. Regions were the climate becomes drier will react more sensitively to changes in the local hydrology. Regions where evaporation dominates become more saline while regions where precipitation dominates become fresher. Greater precipitation at high-latitude regions will result in more runoff. Extreme precipitation events, well exceeding that of mean precipitation, will increase with warming. Since the evaporative process is largely dependent on radiative and aerodynamic components, wind speed (Vautard et al., 2010) and humidity (Sherwood et al., 2010) must be considered. Recent observations of declining wind speed, referred to as 'stilling', in many regions of the world have been linked to declining evaporative demand (McVicar et al., 2012).

Far reaching consequences are expected for river regimes, flow velocity, hydraulic characteristics, water level, inundation patterns, residence time and connectivity across habitats. Intense rainfalls resulting in flooding could increase loads of suspended sediment associated with soil erosion. Episodic pulse extreme events could influence

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aquatic systems affecting the sensitivity and resilience of ecosystems, habitats or species (Whitehead et al., 2009).

2. Hydrologic changes

Freshwater is distributed unevenly in space and time. Additionally, changes in precipitation, melting snow and ice and evaporation as a consequence of global warming alter the hydrological systems directly affecting both the quantity and quality of water resources. As a result, the characteristic timing of river run-off might change as well as stream discharge. Predictions indicate that the timing and intensity of floods and droughts will change, which can have serious economic and sociological significance (UNEP, 2004).

Processes in the catchment such as variability in precipitation, changes in the duration of the ice and snow season, melting glaciers and permafrost will transform river regimes and discharge. Stilling impacts on actual evapotranspiration from the catchment may increase or reduce streamflow depending on the specific situation (McVicar et al., 2012). Variability in parameters will affect export of nutrients and pollutants from the catchment as well as nutrient transport patterns and processes to inland waters, and hence their physical, chemical and ecological parameters (Jeppesen et al., 2009). Due to the enhanced air temperature and the predicted further increase, water temperature and the number of ice free days will change in almost all inland water types. In lakes, mixing regimes, period and strength of stratification, epi- and hypolimnetic water temperatures will be affected (Dokulil et al., 2006; Dokulil, 2013a,b, 2014a; Shatwell et al., 2013; Nachtnebel et al., 2014). Winter conditions will certainly change as warming reduces or exterminates ice cover, changes winter water temperature and affect biotic components during the winter period. Shallow water bodies will be particularly affected (Dokulil et al., 2014; Jeppesen et al., 2014). Impacts of climate change on European lakes has been summarised by George (2010). A detailed model approach using a 6 °C warming scenario for Denmark, suggests increased plankton biomass and cyanobacterial domination. Warming and the associated increase in nutrient load also affect the food webs within the lakes leading to higher fish control of algal grazing, further reinforcing eutrophication (Trolle et al., 2015).

The biotic interaction associated with these changes will have consequences for water quantity and quality. Water scarcity is already a problem in many regions worldwide often due to water withdrawal and over-exploitation. Quantitative problems are associated also with increasing water-demand due to population growth and economic activities resulting in enormous water stress (Schlosser et al., 2014). This stress will be further magnified by climate warming impacting on water quality enhancing symptoms of eutrophication, algal blooms, potentially toxic, and pollution (Dokulil, 2014b,c; Dokulil and Teubner, 2011). In addition biomagnification of heavy metals, and permanent organic pollutants and pesticides can occur in food chains. All above processes increase the health risk to human populations as indicated by the WHO (2002, 2013).

3. Primary production

The basis for most ecohydrological processes in inland waters linked to climate change is primary productivity. Photosynthetic production and growth of planktonic and sessile algae in the water and on surfaces of lakes, rivers and streams set the level of food available for secondary producers, such as zooplankton and fish (Dokulil, 2013a,b, 2014d). Primary production is largely controlled by a combination of temperature, light and nutrients. When nutrient availability is high, production mainly varies with water temperature and the length of the ice-free period. When nutrient availability is low, overall production is limited by the level of nutrient and is relatively insensitive to changes in temperature (Dokulil et al., 2005). Rates of primary production will be altered by climate change, transforming aquatic ecosystems and the human communities that use them. If food availability at the bottom of the food web is reduced by a decrease in primary production, productivity of fish at the top of the food web will be reduced as well. Excessive increase in primary production can lead to eutrophic conditions, degraded water quality and noxious blue green algal blooms. Global warming may thus lead to climate induced eutrophication (Dokulil and Teubner, 2011; Dokulil, 2014d). The positive effects of increased water temperature can be intensified if aerosols decline or counterbalance by light availability if cloud cover increase as some models predict. Assessment of how light will affect photosynthesis is difficult because scenarios for cloud cover are rather uncertain.

4. Predicted changes in inland waters

Nutrient availability will be crucial for primary production. Longer and warmer summer periods would promote productivity while a general drying of watersheds would reverse production increase. Changes in the dynamics and seasonal pattern of productivity are also consequences of climate change. The timing of the spring peak of phytoplankton, the timing of the clear water phase, the appearance of zooplankton grazers and the timing and extent of the stratification period in lakes influence plankton composition, biomass and productivity (Dokulil et al., 2010; Nõges et al., 2010).

Further consequences of climate change are changes in the species composition and biodiversity of the algal assemblages. In lakes, forward shifts in the spring peak are likely to alter species composition of spring diatoms. Longer periods of summer stratification tend to shift the phytoplankton community to cyanobacteria. If inedible nuisance and potential toxic species dominate algal productivity, or if the timing of algal production is out of synchrony with the food demands of fish, then all upper levels of the food chain will suffer, particularly fish populations (Jeppesen et al., 2012).

5. Non-native species

Aquatic organisms requiring colder temperatures will lose their thermal niche and habitat availability. Warming will favour potentially invasive species which are likely to