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Towards threshold-based management of freshwater ecosystems in the context of climate change

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ABSTRACT

Climate change is an increasing threat to freshwater ecosystem goods and services. We review recent research regarding the direct and indirect impacts of climate change on freshwater ecosystems and the severity of their undesirable effects on ecosystem processes and services. Appropriate management strategies are needed to mitigate the long-term or irreversible losses of ecosystem services caused by climate change. To address this, this review puts forward a threshold-based management framework as a potential platform for scientists, decision makers and stakeholders of freshwater ecosystems to work together in reducing risks from climate change. In this framework, the susceptibility of local freshwater ecosystems to change beyond thresholds is continuously investigated and updated by scientists, used to design policy targets by decision makers, and used to establish mitigation measures by local stakeholders.

1. Introduction

Freshwater ecosystems, defined as aquatic systems with average salinities less than 0.5 parts per thousand (Moss, 2009), provide a diverse range of essential services such as food products, clear water, waste recycling, nutrient cycling, carbon storage, as well as cultural and recreational amenities. However, freshwater ecosystems are changing rapidly due to factors like urbanization and climate change. Over the past 50 years, economic and population growth have resulted in more rapid changes in the structure and function of freshwater ecosystems than in any other comparable time period of human history (MEA, 2005). Populations of freshwater species in North America, Europe, Australia, and New Zealand are estimated to have declined on an average by 50% between 1970 and 2000 (MEA, 2005). Freshwater ecosystems in urban areas are among the most affected (Kozlowski and Bondallaz, 2013), in that urbanization has led to dramatic changes in freshwater ecosystems throughout the globe (Alberti et al., 2007; Kozlowski and Bondallaz, 2013).

Adding to the ongoing burdens of intensive agriculture, industrialization and urbanization, climate change is an additional serious threat to freshwater ecosystems and biodiversity worldwide. Climate change can alter freshwater ecosystems via various direct and indirect mechanisms (Chu et al., 2005; Vörösmarty et al., 2010). Rising temperature and changing precipitation directly influence shifts in habitats and seasons, and also the physiological adaptation and phenology of freshwater species, thereby altering food web structure and ecosystem dynamics (Doak and Morris, 2010; Walther et al., 2002). Climate change can also indirectly affect freshwater ecosystems via geomorphological alterations of lake and river systems, changes in nutrient and ionic loads (leading towards alteration of photosynthetic rates, eutrophication, acidification, salinization) as well as enhancing the impacts of prevalent diseases, chemical pollutants, biological invasions, and changes in predation and competition among species (IPCC, 2007). There have been a large number of discussions on the challenges and solutions facing human interventions to freshwater ecosystems (e.g., Chen et al., 2014), considering experimental and theoretical ecological thresholds (e.g., Horan et al., 2011), and how to best implement

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[1] Junguo Liu and Giri Kattel have equal contributions to the conceptual framework; Giri Kattel prepared the first draft, and Junguo Liu followed up to the paper preparation; Giri Kattel, Hans Peter H. Arp and Junguo Liu created all figures; all the authors contributed to Table 1; Hong Yang, Hans Peter and Junguo Liu contributed to Table 2; all the authors synthesized the results and wrote the paper.

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risk management of aquatic ecosystems (e.g., Chen et al., 2011, 2013). However, it remains rare to explicitly discuss the freshwater ecological thresholds associated with climate change. There is an urgent need for integrating the scientific understanding of the diverse, complex and interrelated impacts of climate change on the thresholds of freshwater ecosystems. Here we review freshwater ecosystem thresholds in the context of climate change, and suggest the need for collaborative efforts across scientists, decision makers and stakeholders at all levels.

2. What are ecological thresholds?

There are several definitions for the term "ecological threshold". Most of these definitions commonly emphasize the non-linearity of ecological or biological responses to pressures caused by human interventions or natural processes. As defined by Groffman et al. (2006), an ecological threshold is the point, or "tipping point", at which there is an abrupt change in an ecosystem quality, property or phenomenon, or where small changes in environmental drivers can lead to dramatic changes to an ecosystem. Thresholds and their associated stability towards different environmental drivers can be conceptualized within a coupled socioeconomic–ecological system (Horan et al., 2011). Any restoration of losses in ecosystem services after a threshold is crossed could be difficult or costly (Groffman et al., 2006).

Identifying ecological thresholds related to climate change is complex, as various climate-change control variables (e.g., atmospheric and surface water temperature) can be related differently to changes in the ecosystem service responses (e.g., fish supply, volume of potable water) (Rockström et al., 2009).

Fig. 1 presents a general schematic diagram on how to view the interactions between climate change control variables and

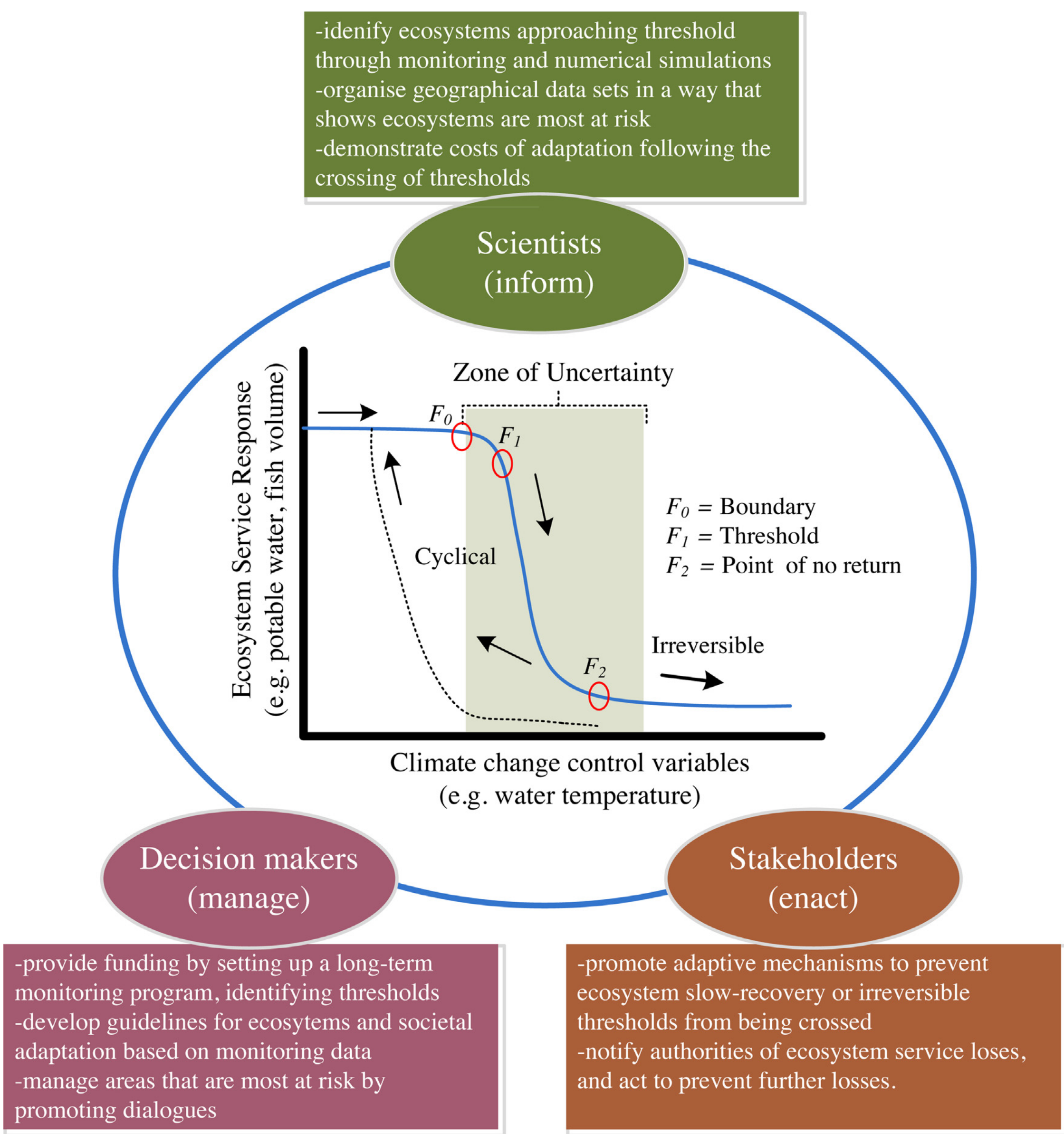

Fig. 1. Conceptualization of threshold-based ecosystem change. Climate change control variables are on the *x*-axis and the response variables on ecosystem services are on the *y*-axis. The climate change variables could be one or any combination of parameters that are directly or indirectly affected by climate change (such as temperature, number of invasive species, nutrient concentration). The ecosystem service could refer to any required by the local population (such as potable water, fish population). Conceptualizing ecosystem change in this way could serve as a basis for communication in ecosystem management, where scientists inform of susceptibility to threshold changes, decision makers manage appropriately, and stakeholders get involved through enacting mitigation measures to prevent loss of services.