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Multiple stressors in freshwater ecosystems

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SUMMARY

1. The fundamental importance of freshwater resources, the rapid extinction rate among freshwater species and the pronounced sensitivity of freshwater ecosystems to climate change together signal a pre-eminent need for renewed scientific focus and greater resources. Against this background, the Freshwater Biological Association in 2008 launched a new series of 'summit' Conferences in Aquatic Biology intended to develop and showcase the application of ecological science to major issues in freshwater management.
2. This collection of studies arose from the first summit entitled 'Multiple Stressors in Freshwater Ecosystems'. Although freshwater science and management are replete with mutiple-stressor problems, few studies have been designed explicitly to untangle their effects.
3. The individual case studies that follow reveal the wide array of freshwaters affected by multiple stressors, the spatial and temporal scales involved, the species and ecosystem processes affected, the complex interactions between ecology and socioeconomics that engender such effects, the approaches advocated to address the problems and the challenges of restoring affected systems. The studies also illustrate the extent to which new challenges are emerging (e.g. through climate change), but also they develop a vision of how freshwaters might be managed sustainably to offset multiple stressors in future.
4. More generically, these case studies illustrate (i) how freshwaters might be at particular risk of multiple-stressor effects because of conflicts in water use, and because the hydrological cycle vectors stressor effects so effectively and so extensively; (ii) that dramatic, nonlinear, 'ecological surprises' sometimes emerge as multiple-stressor effects develop and (iii) that good ecology and good ecologists add considerable value to other freshwater disciplines in understanding multiple stressors and managing their effects.

Keywords: climate change, ecosystems, lakes, pollution, streams, wetlands

Introduction

The need to communicate the importance of water as a resource, and as an integral component of all ecosystems, has never been more acute. From a resource perspective, the prospects for billions of people faced with growing water scarcity, and associated food scarcity, are already grim (Falkenmark, 1997). From a conservation perspective, the recognition that freshwater ecosystems contribute disproportionately to global biological richness is being eclipsed by the growing realisation that extinction risks in freshwaters could be among the greatest of all (Revenga *et al.*, 2005; Strayer & Dudgeon 2010). On

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their own, these are already major concerns that illustrate how the exploitation and impairment of freshwaters have outpaced our best attempts at management. Consider further, however, the growing evidence from several continents that freshwaters are also highly sensitive to climate change through effects that will complicate many existing problems (Daufresne *et al.*, 2004; Bêche & Resh, 2007; Chessman, 2009; Durance & Ormerod, 2009). Because the risks of management failure are so large, this combination of factors places freshwater ecosystems second to none among the environmental priorities for science funding.

It was against this background in 2008 that the Freshwater Biological Association (FBA) launched its new series of 'FBA Conferences in Aquatic Biology' to draw together the very best in aquatic biology and its application to environmental management. Essentially 'summits' of the world's foremost leaders in the field, these workshops are intended to act as a forum for the exchange of ideas, developing new concepts, raising the profile of the contribution made by freshwater ecologists and advancing freshwater science at its frontiers. Both the FBA and Wiley-Blackwell have taken a further significant step by ensuring that the studies from this first conference are freely accessible to all as a virtual issue of *Freshwater Biology*. As guest editor (SJO) and convenors of the first conference and its output, we are delighted to bring you the studies presented and discussed at the FBA's Windermere headquarters in September 2008.

The theme of 'multiple stressors' was intended to epitomise the challenges facing freshwaters while bringing together some of the subject's leading scientific voices. We were aware both that there had been no other major aquatic meeting on this topic, since the American Society of Limnology and Oceanography reported on it in 1999 (e.g. Hughes & Connell, 1999), and that explicit studies of multiple stressors were only thinly distributed in the major freshwater journals. However, this is paradoxical, because freshwater science and management are replete with mutiple-stressor problems. For example, in evolutionary ecology, the fitness of organisms seldom reflects selection pressure from single sources, while the processes linking populations, communities and ecosystems are invariably multivariate. In freshwater management, too, problems almost always involve simultaneous challenges either, because human pressure typically alter more than one environmental factor (e.g. urbanisation affects runoff quantity, water quality, thermal regimes, habitat availability, the dispersal of invasive species…), and because pressures from several sources often coincide. If this were not argument enough to take a fresh look at multiple stressors, climate change is now exacerbating, confounding or complicating many existing problems. Not only are climatically mediated shifts in thermal regime or runoff moving conditions outside those previously experienced by species in their current geographical range, these same factors alter the severity of most other pressures. Human responses to climate change are a further major source of ecological change, for example, via altered patterns of abstraction, water transfer, flood-risk alleviation or catchment use and management (Strayer & Dudgeon 2010).

Under these circumstances, there are major challenges to understand the nature of multiple-stressor effects on species populations, communities and ecosystems, to identify and prioritise the major management issues and to seek the means to identify, diagnose and tackle multiple-stressors effects. The contributions we introduce here are, inevitably, only a small sample of research on multiple stressors in freshwaters taking place around the world. However, they reveal the wide array of freshwaters subject to multiple stressors (e.g. Davis, Sim & Chambers, 2010; Hecky *et al.*, 2010; Tockner *et al.*, 2010), the spatial and temporal scales over which effects arise (Heathwaite, 2010; Smol, 2010) and the species and ecosystem processes affected (Strayer, 2010; Tockner *et al.*, 2010). They also highlight the complex interactions involved (Davis *et al.*, 2010), including those between ecology and socioeconomics (Grantham, Merenlender & Resh, 2010; Hart & Calhoun, 2010). There is a focus, too, on the varying approaches available to unravel multiple-stressor effects, including carefully interpreted surveys of taxonomic (Downes, 2010) or trait composition (Statzner & Bêche, 2010), as well as highly innovative experiments (Fausch, Baxter & Murakami, 2010; Moss, 2010). The contributions reveal the challenge of restoring systems once affected (Davis *et al.*, 2010; Palmer, Menninger & Bernhardt, 2010; Strayer, 2010) and illustrate also the extent to which multiple-stressor problems continue to emerge and develop, for example with respect to invasive species and

climate (Grantham *et al.*, 2010; Strayer, 2010). Most of all, there are hints of a developing vision of how freshwaters might be managed in the wake of multiple stressors in a sustainable future (Bunn *et al.*, 2010; Hart & Calhoun, 2010; Heathwaite, 2010).

The full significance of the generic issues raised by the studies has yet to be realised, but here we draw attention to three key points. First, all of these case studies illustrate how freshwaters appear to be at particular risk of multiple-stressor effects - perhaps because multiple uses of water and the protection of freshwater environments often conflict. The extent and importance of the water cycle also make water such a highly effective vector for the many chemical, physical, climatic and biological effects of stressors: the freshwater networks affected are extensive, particularly through the hydrological linkages between surface waters and catchments that have been highly modified across large areas of the world. Second, several studies highlight how dramatic 'ecological surprises' have sometimes emerged as multiple-stressor effects develop through nonlinear or delayed interactions in systems that were otherwise reasonably well understood (Hecky *et al.*, 2010). This raises an alarming prospect given the extent to which the world's freshwaters are now impacted by a range of simultaneous stressors. Third, all these studies reveal the key role of good ecology, and good ecologists, in understanding multiple-stressor effects and how to manage them. While other areas of science might, hitherto, have been favoured in freshwater funding from governments, ecological science clearly adds very major value to understanding systems whose worth depends in such large measure on ecological processes and functions.

We commend this group of studies to our readership and thank those at the FBA who had the vision to mount what was a fascinating meeting. We also thank our publishers (Wiley-Blackwell) who have supported us so tangibly.

Conflicts of Interest

The authors have declared no conflicts of interest.

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