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Anthropogenically forced change in aquatic ecosystems: Reflections on the use of monitoring, archival and palaeolimnological data to inform conservation

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The open collection "Aquatic transitions: Tracking the nature and trajectories of anthropogenically forced change in freshwater and coastal ecosystems" stems from a session of the same name at the ASLO (Association for the Sciences of Limnology and Oceanography) Aquatic Sciences Meeting 2017 in Honolulu, Hawai'i. The five papers gathered here reflect the focus of the special session on long-term ecosystem research and monitoring (LTERM), and collectively make use of monitoring data, palaeolimnology, and historical and documentary records to explore the timing, extent, and causes of human-related impacts on aquatic ecosystems. Collectively, they demonstrate that because timescales of ecological change often extend beyond contemporary monitoring, LTERM plays a crucial role in supporting evidence-based conservation. In this introduction, we reflect on the role that LTERM has had in each of the ecosystems studied, and discuss the opportunities for LTERM work to inform future conservation.

KEYWORDS
aquatic conservation, ecosystem recovery, human impacts, LTERM, monitoring, palaeolimnology

1 | INTRODUCTION

Aquatic ecosystems have become increasingly vulnerable in recent decades due to interactions between climate change and human activity, such as nutrient enrichment, microplastic and organic pollution, extraction, salinisation, and catchment modifications (Carpenter et al., 2011; Dubois et al., 2018). These multiple stressors and their interactions can sometimes cause dramatic ecological changes across all trophic levels (Christensen et al., 2006; Cross et al., 2015; Folke et al., 2004; Jackson et al., 2016). Even where "critical transitions" occur relatively rapidly, they are usually the result of multiple, smaller changes over much longer timescales (Scheffer & Carpenter, 2003). These ecological changes often span decades, yet many records do not extend to these timescales (Sayer et al., 2010). However, if we wish to manage aquatic transitions and restore ecosystems, it is important to understand pre-disturbance conditions (Parr et al., 2003; Sayer et al., 2012), and the mechanisms of ecosystem change (Elosegi et al., 2017). Long-term ecosystem research and monitoring (LTERM) are crucial in evidencing the timing, extent, and causes of human-related impacts on aquatic ecosystems and are key to understanding the complex nature of ecological responses to stressors and related transitions within aquatic ecosystems (Dodds et al., 2012; Johnson et al., 2010; Magurran et al., 2010). Key LTERM approaches include monitoring and modelling, palaeolimnology, and analysis of historical and documentary records. Despite the importance of LTERM, and the wide range of approaches available to researchers, LTERM is often overlooked (Lovett et al., 2007).

The importance of LTERM in identifying, monitoring, and reversing anthropogenically forced changes in aquatic systems was highlighted in the ASLO (Association for the Sciences of Limnology and Oceanography) Aquatic Sciences Meeting 2017 session "Aquatic transitions: Tracking the nature and trajectories of anthropogenically forced change in freshwater and coastal ecosystems." The aim of the session was to explore multidisciplinary approaches to LTERM in aquatic ecosystems. The primary focus was the use of LTERM in determining the timing, extent, and nature of ecological responses to recent anthropogenic stressors. This open collection follows that session, and includes a range of papers that use exclusively, or a combination of, monitoring data, palaeolimnology, and historical and documentary records. In this introduction, we reflect on the contributions of the five papers to the growing body of evidence that supports LTERM, focusing on the lessons that can be drawn from them and applied to aquatic conservation in the future.

2 | WHAT IS THE ROLE OF LTERM IN AQUATIC ECOSYSTEM CONSERVATION?

The papers presented here demonstrate that the effects of anthropogenically driven environmental change are global and enduring. In all of the papers, these environmental effects could not have been elucidated without the use of long-term datasets, and they collectively illustrate the importance of LTERM for evidence-based conservation.

Siver, Marsicano, Lott, Wagener, & Morris (2018) demonstrate the use of long-term monitoring data to study the effects of wind speed on the thermal stratification of lakes. Using a case study of Candlewood Lake, Connecticut, they show a significant relationship between declining wind speed and an increase in thermocline strength, suggesting wind speed as a primary driver of hypolimnion cooling. These findings could help us to understand changes in phytoplankton structure and nutrient distribution in lakes, thereby informing lake management and restoration under future climatic change.

In a coastal environment, Roberts et al. (2019) demonstrate the use of chemical and biological monitoring, and documentary and archival records from a range of sources, to extend our understanding of centennial-scale lake ecosystem change and recovery from increasing salinity. The authors consolidate records from the Thurne Broads in the Broads National Park, UK as a test-bed for using historical records as a low cost and effective method to determine pre-anthropogenic reference conditions for the European Union Water Framework Directive, and to inform the future management of sites. They highlight the potential limitations of long-term monitoring in multi-stressor environments and suggest a combined historical record and palaeolimnological study for more robust reconstructions.

This combined approach was undertaken by Bishop, Bennion, Sayer, Patmore, & Yang, (2019), who merged contemporary ecological and chemical monitoring with paleoecology to investigate the decline of the rare aquatic plant *Najas flexilis*. In doing so, they challenge two assumptions that had previously been made about *Najas flexilis* based on monitoring data alone: that the plant had previously been abundant at Loch of Craiglush, Scotland; and that ecological recovery from eutrophication at Esthwaite Water, UK made the lake a favourable site for *N. flexilis* reintroduction. In both cases paleoecological data revealed that the ecological history of *N. flexilis* was not adequately represented by the contemporary data alone, with implications for future conservation efforts of the species.

Despite the effectiveness of LTERM to inform management of sites and species, monitoring data prior to anthropogenic impact is lacking globally. Furthermore, historical and current monitoring efforts and methods are globally varied (Pereira & Cooper, 2006; UNEP, 2016). The papers by Adams, Peng, Rose, Shchetnikov, & Mackay (2019) and Briddon et al. (In press) underline the critical role of palaeolimnology to assess the effect of multiple human-induced stressors and natural climate variability in locations where monitoring data are limited. At the study site of Adams et al. (2019) – a large freshwater lake in southern Siberia – human activities have occurred since the 19th century without the existence of environmental monitoring. Diatom assemblage records along with reconstructed records of human activity (e.g., spheroidal carbonaceous particles and trace metals) indicate increased local and regional development beginning c. 1920, with more profound ecological effects occurring since the early 20th century as a response to increased nutrient influx, aquaculture, and power plant wastewater discharge into the lake. Briddon et al. (In press) reconstruct ecological changes in diatom communities in a large freshwater lake in Malaysia, and relate them to declines in rainfall between 1937 and 1995 and consequent decreases in water level, combined with an increased input of pollutants from oil palm plantations and mining in the basin since 1995.

3 | WHAT ARE THE FUTURE CHALLENGES AND OPPORTUNITIES FOR LTERM?

The papers in this open collection span freshwater and coastal ecosystems across the globe in Europe, North America, and Asia, demonstrating the extent of anthropogenic effects on aquatic ecosystems. They also demonstrate that insights from long-term datasets can provide an evidence base to support conservation in both freshwater and saline environments across the world. Continued environmental monitoring is clearly incredibly valuable. Datasets that span multiple decades/centuries using consistent methodologies are ideal (Beard et al., 1999), but as Roberts et al. (2019) discuss, the effective use of these data are often hampered by improvements to data quality over time. Despite this, it is still of great importance to continue to establish and build upon these datasets (Parr et al., 2003). The reporting requirements of international legislations, such as the Water Framework Directive in the EU, are resource intensive and require a shift in the methodologies used to monitor change and set baselines for restoration (Bennion, Battarbee, Sayer, Simpson, & Davidson, 2011). The UN Sustainable Development Goals require all UN member states to regularly report on the state of freshwater environments, yet many of them do not currently produce any monitoring data (United Nations, 2018). The papers presented here illustrate that LTERM offers the potential to assist both by providing baseline data and by informing conservation in resource-poor regions where conventional monitoring is absent (e.g., Adams et al., 2019; Briddon et al., In press).

To fulfil regulatory reporting requirements, government agencies and conservation organisations are increasingly looking to amass data from a diverse range of sources, including in situ sensors, remote sensing, citizen science, and more traditional monitoring inputs (Hering et al., 2016; UNEP, 2018). This will require the integration of multiple data streams (Parr et al., 2003). Within this integrated approach, we have the opportunity to include long-term palaeolimnological and historical datasets; indeed, the papers by Roberts et al. and Bishop et al. in this collection illustrate that such integration is not only possible, but can be highly effective. In many circumstances contemporary monitoring programmes only began once a pressure on an ecosystem was evident. The inclusion of historical or long-term datasets would allow conservation targets to be defined by pre-disturbance data, rather than around the date at which contemporary monitoring began (e.g., Kittinger et al., 2013; McClenachan et al., 2012). This would be a significant move towards evidence-based conservation (Sutherland et al., 2004), and all of the papers included in this open collection constitute proof that this approach is both possible and effective.

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