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Brian Moss: the wizard of shallow lakes

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This special issue of *Inland Waters* celebrates the contribution of Brian Moss to the science and management of freshwater ecosystems. Brian passed away in 2016 and since then, much has been written about his life and achievements (Carvalho and Johnes 2016; Irvine and Barker 2016; Jeppesen and Johnes 2016). His legacy is wide-ranging: his scientific papers have helped to advance our knowledge on how lakes, especially shallow ones, operate, interact internally and connect to their wider environments; his talks have provoked and entertained; his text books have instructed future generations of freshwater ecologists, and managers have been confronted and challenged by his passion for the environment. The purpose here is not to repeat the 'Life of Brian' but to show-case his scientific legacy in papers written by people who have worked, interacted and been affected by him. The nine papers are truly international, reflecting Brian's global influence, and his commitment to work with, and train, people abroad. Herein, there are contributions from authors from 12 countries: Argentina, Australia, Canada, China, Denmark, Mexico, Mongolia, Spain, Turkey, United Kingdom, United States of America and Uruguay. It is particularly fitting that they are published in this journal since Brian was committed to supporting the International Society for Limnology (SIL) including as its vice-president and its president in two terms between 2007 and 2013.

Below, each of the contributors to this Special Issue have written a personal statement about how Brian affected their outlook, scientific lives and specifically influenced the paper they contributed. These papers cover some of Brian's many interests, ranging from work on nutrient dynamics and trophic state in small shallow lakes (Maberly et al. 2020), use of large scale comparisons (Beklioğlu et al. 2020; Jeppesen et al. 2020), experiments using mesocosms (McGowan et al. 2020), food-web interactions (He et al. 2020; Vidal et al. 2020); training and supporting research in developing countries ((Pavon-Meza et al. 2020; Valencia-Vargas et al. 2020), and how to manage lakes effectively (Søndergaard et al. 2020).

When Brian was appointed as a lecturer at the University of East Anglia, UK, he began working on the nearby Norfolk Broads and their water quality problems, particularly their switch from a historic clear water macrophyte-dominated state to their current turbid water phytoplankton-dominated state (Moss 1977, 1990). After moving to the University of Liverpool he transferred his research attention to another group of small, mainly shallow lakes lying in nutrient-rich agricultural landscapes (Moss 1994; Moss et al. 1997). One topic that Brian studied was the interaction between phytoplankton and other primary producers such as the epiphytes and their host macrophytes (Phillips et al. 1978) and he acted as the examiner of Stephen Maberly's PhD thesis on competition between macrophytes and phytoplankton. The paper by (Maberly et al. 2020) on the influence of N *vs* P limitation of phytoplankton builds on Brian's research on the meres using recent data collected by the Environment Agency and also on Laurence Carvalho's PhD work, supervised by Brian. Laurence Carvalho writes: "Brian threw me in at the deep-end, by telling me a few months before the start of my PhD that he was moving from East Anglia to Liverpool so that the planned research topic on the impacts of pesticides on zooplankton in the Norfolk Broads was no longer viable. Instead, the topic became 'What do we know about the Cheshire-Shropshire meres?'; proper blue-skies research!

Brian's long interest in the ecology of the meres had begun, leading to key insights on how the ecology of small, shallow lakes differs from those of the better-studied large and deep lakes. Our identification of the importance of nitrogen-limitation and co-limitation in these shallow systems reinforces Brian's earlier work on N-limitation (James et al. 2003) that was produced as part of national research initiative (GANE) that also included studies showing N-limitation in upland lakes (Maberly et al. 2002). This has consequences for the management of these systems and whether it is more efficient to target nitrogen or phosphorus in order to bring them to 'good ecological status' in the terms of the European Union Water Framework Directive.

The papers by Beklioğlu et al. (2020) and Jeppesen et al. (2020) exploit national and inter-continental spatial differences among lakes as a device to decipher the environmental factors that control lake structure and function, with a climate change perspective. Erik Jeppesen wrote: Brian and his many papers and books inspired me and our group in Silkeborg tremendously throughout our careers – and will so even after his passing. His idea of combining experimental research with cross-system analyses to study the effects of humans and climate always fascinated us and we learned from it. An example is the cross-European mesocosm study (SWALE) looking at trophic dynamics across a climate gradient (Moss et al. 2004) and cross-system climate gradient analyses led by him (Moss 2010; Moss et al. 2011) He frequently told us that "this Florida-Denmark comparison is really good stuff for understanding climate change effects on lakes- get it published!" It took a while, but now it is done (Jeppesen et al. 2020) and we are very happy to be able to publish it in a special issue celebrating his legacy.

Meryem Beklioğlu wrote: as a young MSc graduate awarded a PhD scholarship from the Turkish government, I was searching for a supervisor to carry out my PhD on freshwater ecology but had no background and no idea who to study with. I did a lot of searching in the library (without the internet) and accidently stumbled upon Brian's Norfolk Broadland papers and started to read a few. Though I did not understand the details, I felt that Brain would be the one to teach me. So, I wrote to him saying: "I have no background in freshwater ecology but I am eager to learn if you give me a chance". I was so lucky and privileged that Brian gave me a chance, which changed my life and I am certain that all his students share my opinion of his excellent supervision. I did my PhD with him on the functioning of shallow lakes looking at nutrients and top-down effects of fish as major drivers. We combined the mesocosms experiments, for which Brian was a pioneer, with monitoring and small lab experiments. He supported and encouraged my crazy ideas (e.g. running two large mesocosms experiments at the same time (>50 mesocosms)) and never complained of the hardship of turning my Turkish-English (Turenglish) chapters of my thesis or manuscripts into proper English. We kept close contact afterwards and he supported me when needed, especially through the difficult stage of establishing myself in science, and I never stopped being inspired by him. The data used in Beklioğlu et al. (2020), dedicated to Brian, were collected as part of a large project that combined cross-system analysis of Turkish shallow lakes covering large latitudinal and altitudinal gradients in western part of the country. We were especially inspired by Moss et al., (2004), Jeppesen et al. (2010) and Moss et al. (2011).

The paper by McGowan et al. (2020) uses the mesocosm tanks system set up by Brian at the Ness Botanical Gardens in Liverpool in 1994, now officially called “The Brian Moss Aquatic Mesocosm Facility”. Brian was at the leading edge in developing such experimental facilities, which were uncommon at that time. The facility was originally set up to conduct research connected with ‘alternative stable states’ (Jones et al. 2002), and was used for warming-related experiments (McKee et al. 2010) including those looking at interactions with eutrophication (Feuchtmayr et al. 2009). Other experimental work in the tanks reflects Brian’s interest in the effects of nitrogen on lake ecosystems, and especially its role in plant diversity (Barker, Hatton, O'Connor, Connor, Moss 2008). Brian’s work on the West Midland Meres, which identified a rare example of nitrogen-limited temperate lakes (Moss et al. 1994; Kilinc and Moss 2002; James et al. 2003; Moss et al. 2005) asked questions about the role of nitrogen in eutrophication which are still being debated (Schindler et al. 2008; Hayes et al. 2019). For the paper in this special issue, Brian wanted to understand the interactive effects of nitrogen pollution and salinization, as observed in some of the larger Norfolk Broads (Bales et al. 1993; Barker, Hatton, O'Connor, Connor, Bagnell, et al. 2008). The paper uses chlorophyll and carotenoid pigments from phytoplankton as biomarkers for phytoplankton phototrophs. This biomonitoring technique formed the basis for Suzanne McGowan’s PhD, co-supervised by Brian, Liz Haworth and George Britton, a carotenoid biochemistry expert (McGowan et al. 1999). These techniques have since become routinely used for aquatic monitoring, and the ongoing experiment provided a chance for a renewed collaboration to address the question of how nitrogen and salinity enrichment influence phytoplankton community composition.

Brian was skilled at seeing the ‘big picture’, and took an ecosystem-based view of freshwater ecology. He promoted the idea of interactions among trophic levels as being a key mechanism controlling how these systems operated. Two papers touch on these issues, those of He et al. (2020) and Vidal et al. (2020). Hu He wrote: I met Brian Moss for the first time at the SIL 2009 symposium in Nanjing, China and was impressed by his talk. When I later started my PhD focusing on the effects of climate change on subtropical shallow lakes, I therefore consulted his papers and they inspired me a lot. He liked to cite an old adage or allusion at the beginning of scientific papers (e.g. (Moss, McKee, et al. 2003; Moss et al. 2011)) which also fascinated me. When I visited Silkeborg in 2019 to work on zooplankton in brackish lakes, I recognized his strong synthesis paper “Brackish and freshwater shallow lakes - different systems or variations on the same theme?” (Moss 1994) and the many related and interesting outdoor experimental studies of high quality on saline systems, such as (Bales et al. 1993; Barker, Hatton, O'Connor, Connor, Bagnell, et al. 2008) and (McGowan et al. 2020) and references therein. These studies have been a major sources of inspiration for the paper (He et al. 2020) that we present to honour him in this special issue.

Nicolas Vidal and Mariana Meerhoff wrote: *“There are men who struggle for a day and they are good. There are men who struggle for a year and they are better. There are men who struggle many years, and they are better still. But there are those who struggle all their lives: these are the indispensable ones*”. With these lines from Bertolt Brecht we celebrate Brian as being indispensable to the limnological community and particularly to his many academic offspring. I (Nicolas Vidal) met Brian in person during the 2008 in the Shallow Lake conference held in Uruguay; at this time I did not

know exactly who this grandpa was. Six years later, in the Shallow Lake conference held in 2014 in Turkey, I shared a round table with him and several other colleagues about nutrients and algae interaction which inspired me deeply - besides the influence it had on my PhD topic that focused on the impacts of climate change and other stressors on food webs including the paper in this special issue (Vidal et al. 2020). Reading Moss et al. (2011), Moss et al. (2003) and his reflexions in Moss (2010) profoundly influenced my PhD and subsequent work. I would like to have interacted more with the person behind the scientist. Brian is, and will surely always be, a strong influence on my research, mentoring and science communication ethics. Mariana Meerhoff wrote: I was so fortunate to have him as my MSc thesis supervisor in Liverpool, 2000. Since then, he taught me the need to understand that the complexity of nature is not separate from the complexity of society, as he constantly shared in conversations and demonstrated in his books and wonderful public talks. His generosity, warmth and loud laughter are also indivisible from his scientific legacy.

Brian was passionate about providing training to scientists in developing countries, especially in Africa, but also elsewhere as here in Mexico. S. Nandini and S.S.S. Sarma wrote: We met Brian Moss for the first time during the PEG meeting in Mexico in 2012. We met again at the Shallow Lakes meeting in Turkey (2014) after which he and Joyce visited Mexico in January 2015 to check out sites for the 2017 Shallow Lakes Meeting. After visiting a couple of places, he chose Merida, Yucatan as a "safe spot for people to interact freely". During these visits he gave excellent talks and interacted with the students (and our children!), helping them with their project proposals and resolving their doubts. We only wish we had met him earlier in our careers. Brian was one of the best orators on limnology in modern times. During his visits to our university, he gave us several tips on effective written and oral communication. He suggested using simple language to convey our views and illustrated this using an example of an abstract from an article in the *Journal of Animal Ecology*. The summary written by him was far clearer than the original! He always felt the necessity of conducting experiments based on field observed phenomenon. The two contributions appearing in this special issue (Pavon-Meza et al. 2020; Valencia-Vargas et al. 2020) are a result of discussions held with Brian on inter specific and intra-specific zooplankton interactions.

Brian had forthright views on how lakes should be managed and was concerned about the implementation of the European Union Water Framework Directive. Maberly et al. (2020), described above, address some of the issue about how best to manage nutrient loads, while the paper of Martin Søndergaard et al. (2020) addresses the underlying issue of defining a lake typology. Martin Søndergaard wrote: I do not remember exactly when I first met Brian. It might have been at the shallow lake conference in Silkeborg, Denmark in 1992. As was often the case at the countless numbers of meetings that Brian attended, he gave one of his memorable speeches where he managed to put everything into a broader perspective. As always, he did this in a humorous style with a touch of poetry (which was not always completely understood by the non-native English speaking audience). Later, I had the honour to write a chapter with him on the impact of submerged macrophytes on phytoplankton (Søndergaard and Moss 1998). Here, he was a perfect mentor. For example, he warned me of undocumented statements, as he said: "It will haunt you for the rest of your life". Brian was also involved in the management of lakes and in 2002 he and many others wrote

a paper on how the European Water Framework Directive could be implemented (Moss, Stephen, et al. 2003). It challenged the 'One out –all out' principle as mentioned in the Directive, but also provided guidance on how to define the ecological status of shallow lakes. This paper was a huge inspiration to me and many other European colleagues for years to come as we struggled to translate this directive into management action. In this way, the early paper by Moss et al. (Moss, Stephen, et al. 2003) has also been an important background and inspiration for the paper on Danish lake types presented in this volume of Inland Waters.

Brian Moss has been one of the most influential lake ecologists in the world over the last three decades, and was undoubtedly the world's leading scientist, and inspiring initiator of studies on shallow lake ecology. He was the first to identify a number of important concepts: the alternative states in shallow lakes; the role of macrophytes as a refuge for zooplankton against fish predation; the importance of nitrogen for the loss of submerged plants, and thereby, indirectly on the trophic dynamics in shallow lakes; the effects of climate on the ecology of shallow lakes; and the first to study the role of salinity for trophic structure and dynamics in shallow brackish lakes. More than that, Brian was a Renaissance Man and in the book resulting from his Excellence in Ecology Prize 'Liberation Ecology: The Reconciliation of Natural and Human Cultures' (Moss 2012) he used parallels from religion, art and music to convey complex ecological and environmental issues. In addition to primary research, Brian also had a huge influence on freshwater ecologist, students and 'old-hands', in his series of synthesis text books, the final fifth edition of which 'Ecology of Freshwaters: Earth's Bloodstream' was published posthumously (Moss 2018) with help from his beloved wife, Joyce Moss. The subtitle demonstrates Brian's belief that freshwaters are of central importance for life on Earth, while the papers in this Special Issue, published in his honour, demonstrate the strong influence and legacy he left to the freshwater science community, especially those studying shallow lakes.

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Photo for front cover.

Brian Moss sorting plants from a mesocosm experiment at Ness Gardens, Liverpool September 2005. Photo courtesy of Tom Barker.